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Report of Abstracts
The role of the sigma meson in thermal models
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The by now well-established scalar-isoscalar resonance $f_0(500)$ (the $\sigma$ meson) seems potentially relevant in evaluation of thermodynamic quantities of a hadronic gas, since its mass is low. In this talk, based on the recent work of Ref. [1], we show that its contribution to isospin-averaged observables is, to a surprising accuracy, canceled by the repulsion from the pion-pion scalar-isotensor channel. As a result, in practice one should not incorporate $f_0(500)$ in standard hadronic resonance-gas models for studies of isospin averaged quantities. In our analysis we use the formalism of the virial expansion, which allows one to calculate the thermal properties of an interacting hadron gas in terms of derivatives of the scattering phase shifts, hence in a model-independent way directly from experimentally accessible quantities. A similar cancellation mechanism occurs for the scalar kaonic interactions between $I=1/2$ channel (containing the alleged $K^*(800)$ or the $\kappa$ meson) and the $I=3/2$ channel.


The Quark Gluon Plasma as a Dynamical Quasi-Particle Medium

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The thermodynamic properties of the quark gluon plasma (QGP) - as produced in relativistic nucleus-nucleus collisions – is well determined within lattice QCD calculations at vanishing quark chemical potential [1]. However, the QGP equation of state needs to be interpreted in terms of effective degrees of freedom (d.o.f). Considering the QGP as a dynamical quasi-particle medium of massive off-shell particles (as described by the dynamical quasi-particles model “DQPM” [2]), we reproduce the lQCD results at finite temperature and chemical potential including the speed of sound. Moreover, we simultaneously describe the quark number density and susceptibility. Within our study, we determine the momentum, temperature and chemical potential dependencies of the QGP d.o.f. within the dynamical quasi-particle model [3]. In the same approach, we compute the transport properties (shear and bulk viscosities, electric and heat conductivities, etc) of the QGP at finite temperature and chemical potential. The cross sections at finite temperature and chemical potential, used in our study, are evaluated for these dynamical quasi-particles using the leading order Born diagrams [4]. We, furthermore, provide a comprehensive comparison between perturbative and non-perturbative QCD based models on the determination of the QGP transport coefficients [5].

3 H. Berrehrah, W. Cassing, E. Bratkovskaya, Th. Steinert, to be submitted.

On behalf of collaboration:

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**Poster Session** - Board: 0005 / 461

**Broad eta Range Survey of 1/N dNch/deta at the LHC**

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We present the charged particle pseudo-rapidity density in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with an extended centrality dependence, and in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV over a broader pseudo-rapidity range. In the forward regions where the signal is dominated by secondary particles produced in surrounding material, we use a data-driven correction to extract the charged primary particle density. We compare our results to predictions of various models, and show that none of these models capture all of the aspects of the full distribution. This talk extends the previous results reported by ALICE into more peripheral collisions and with higher granularity for Pb-Pb and broader range in pseudo-rapidity for both p-Pb and Pb-Pb.

On behalf of collaboration:

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**Poster Session** - Board: 0006 / 231

**Deconfinement and chiral crossover with Dirac-mode expansion in QCD**

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We discuss the relation between confinement and chiral symmetry breaking using Dirac-mode expansion in finite-temperature lattice QCD.

The ratios of the real, imaginary and modulus of the Polyakov loop fluctuations are sensitive probes for quark deconfinement even in the presence of dynamical quarks [1].

We focus on the correlations of these Polyakov loop fluctuations with eigenmodes of the lattice Dirac operator. Their analytic relations are rigorously derived on the temporally odd-number size lattice with a non-twisted periodic boundary condition for the link-variables [2,3].

We show that the low-lying Dirac modes, which are essential for chiral symmetry breaking, yield negligible contributions to the Polyakov loop fluctuations. This property is confirmed in confined and deconfined phases by numerical simulations in quenched QCD. Our results indicate that there is no direct, one-to-one correspondence between confinement and chiral symmetry breaking in the context of different properties of the Polyakov loop fluctuations and their ratios.
On behalf of collaboration:

**Poster Session** - Board: 0007 / 48

"QCD equation of state at finite density and finite magnetic field"

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The Polyakov linear-sigma model (PLSM) and Hadron Resonance Gas (HRG) model are considered to study the hadronic and partonic equation(s) of state for the case of nonzero external magnetic fields. Thermodynamic quantities including the pressure, interaction rate, entropy density, magnetization and the speed of sound are presented as function of the temperature and the magnetic field and compared with recent lattice QCD calculations. Positive magnetization indicates paramagnetic properties. Direct and inverse catalysis depends on increasing and decreasing critical temperature with the magnetic field. Confronting PLSM and HRG to lattice QCD gives an indirect estimation for the effective degrees of freedom, coupling, etc.

On behalf of collaboration:

**Poster Session** - Board: 0008 / 175

Universality of particle production and energy balance in hadronic and nuclear collisions

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A study of the universality of multihadron production in nucleus-nucleus and pp/p ¯p collisions is performed using the dependencies of the midrapidity pseudorapidity and transverse energy densities and of the mean multiplicity on the collision energy and on the number of nucleon participants, or centrality, in the energy range from a few GeV to a few TeV. The approach in which the multiparticle production is driven by the dissipating centrality-dependent effective energy of participants is introduced exploiting the earlier proposed consideration that combines the constituent quark picture with Landau hydrodynamics. Within this approach, the data on the energy dependence of the global variables studied and the pseudorapidity spectra from the most central nuclear collisions are well reproduced. The centrality dependence of the midrapidity pseudorapidity and transverse energy densities of charged particles are well described pointing to a similarity in the most central collisions and centrality data. The study of the mean multiplicity centrality dependence reveals a new scaling between the measured and calculated pseudorapidity spectra. Using this scaling, called the energy balanced limiting fragmentation scaling, one reproduces the pseudorapidity spectra at all centralities. The obtained scaling clarifies on the differences in the multiplicity centrality dependence from RHIC and LHC as well as on the dependence of the midrapidity pseudorapidity density vs. multiplicity at RHIC. A complementarity in the multiplicity energy dependence in the most central collisions and centrality data is obtained. A new regime in heavy-ion collisions is pointed out to occur at ∼ 1 TeV. The pseudorapidity spectra of photons are also well reproduced within the proposed approach in the entire collision energy range and an explanation of their
centrality independence is given. Predictions are made for the forthcoming higher-energy measurements in pp and heavy-ion collisions at the LHC.

On behalf of collaboration:

Poster Session - Board: 0009 / 44

Matrix Models for Deconfinement and Their Perturbative Corrections
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Matrix models for the deconfining phase transition in SU(N) gauge theories have been developed in recent years. With a few parameters, these models are able to reproduce the lattice results of the thermodynamic quantities in the semi-quark gluon plasma (QGP) region. They are also used to compute the behavior of the 't Hooft loop and study the exceptional group G(2). In this talk, I review the basic ideas of the construction of these models and propose a new form of the non-ideal corrections in the matrix model. In the semi-QGP region, the new model is in good agreement with the lattice simulations as the previous ones, while in higher temperature region, it reproduces the upward trend of the rescaled trace anomaly as found in lattice which, however, can not be obtained from the previous models. In addition, I discuss the perturbative corrections to the thermal effective potential which could be used to systematically improve the matrix models at high temperatures. In particular, I provide, for the first time, an analytical proof of the relation between the one- and two-loop effective potential: two-loop correction is proportional to the one-loop result, independent of the eigenvalues of the Polyakov loop. This is a very general result, I prove it for all classic groups, including SU(N), SO(2N+1), SO(2N) and Sp(2N).

On behalf of collaboration:

Poster Session - Board: 0011 / 209

Chemical potential dependence of the critical quark mass with Many flavor approach

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We discuss the QCD critical point at finite density through the study of many-flavor QCD, in which two light flavors and Nf massive flavors exist. Performing simulations of QCD with 2 flavors of improved Wilson fermions, we calculate probability distribution functions in many-flavor QCD at finite temperature and density, where the reweighting technique is used to add the dynamical effect of massive flavors and the chemical potential. From the shape of the distribution functions, we determine the critical surface separating the first order transition and crossover regions in the space spanned by the light and massive quark masses and the chemical potentials. It is found that the critical massive quark mass becomes larger as the chemical potential increases in (2+Nf)-flavor QCD. The indication to the (2+1)-flavor QCD is then discussed.

On behalf of collaboration:
Renormalization and temperature dependence of dimension 6 gluon operators

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Understanding the temperature dependence of the gluon condensate in the purged gauge theory offers a useful picture on the nature of the QCD phase transition. In a recent work[1], we identified the independent dim 6 twist 4 gluon operators $O_1 = D_\beta G^a_{\alpha\mu} D_\alpha G^{a}_{\mu
u}$, $O_2 = D_\mu G^a_{\alpha\nu} D_\nu G^{a}_{\alpha\mu}$, $O_3 = D_\beta G^a_{\alpha\mu} D_\nu G^a_{\mu\nu}$ and calculated their renormalization to one loop order in the pure gauge theory. We found the scale invariant operators are given as follows:

$\phi_1 = \alpha_s^{-9/11} \langle O_1 \rangle$, $\phi_{2,3} = \alpha_s^{-(15 \mp \sqrt{17})/44} \left\langle \frac{-653 \pm 21\sqrt{17}}{424} O_1 \pm O_2 + O_3 \right\rangle$.

Together with the dim 6 scalar operators whose renormalization has been worked out before[2], our result completes the calculation of renormalization of all the dim 6 gluon operators, hence is a first step toward identifying their mixing and thus a systematic analysis in the operator product expansion (OPE) of heavy quark correlation functions up to dimension 6. After using the equation of motion in the purged gauge theory, only $O_1$ remains nonzero.

As an application, we rewrite the dim 6 scalar and twist 4 operators as $f^{abc} B_a \cdot (B_b \times B_c)$ and $f^{abc} B_a \cdot (E_b \times E_c)$ and estimate their temperature dependence using inputs of dim 4 electric and magnetic condensate extracted from lattice gauge theory. We then improve the previous QCD sum rules for $J/\psi$ mass near the $T_c$ based on dim 4 operators, by including the contribution of the dim 6 operators to the OPE. We find an enhanced stability in the sum rule and confirm that the $\psi$ will undergo an abrupt change in the property across $T_c$.


On behalf of collaboration:

Poster Session - Board: 0012 / 178

Lattice Two-Color QCD with nonzero chiral density

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The phase diagram of two-color QCD with non-zero chiral chemical potential is studied by means of lattice simulation. We focus on the influence of a chiral chemical potential on the confinement/deconfinement phase transition and the breaking/restoration of chiral symmetry. The simulation is carried out with dynamical staggered fermions without rooting. The dependencies of the Polyakov loop, the chiral condensate and the corresponding susceptibilities on the chiral chemical potential and the temperature are presented. The critical temperature is observed to increase with increasing chiral chemical potential.

On behalf of collaboration:
**Poster Session** - Board: 0014 / 31

**Charged \( \rho \) meson in a magnetic field at finite temperature and chemical potential**

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The charged vector \( \rho \) mesons in the presence of external magnetic fields at finite temperature \( T \) and chemical potential \( \mu \) have been investigated in the framework of the Nambu–Jona-Lasinio model. We compute the masses of charged \( \rho \) mesons numerically as a function of the magnetic field for different values of \( T \) and \( \mu \). The self-energy of the \( \rho \) meson contains the quark-loop contribution, i.e. the leading order contribution in \( 1/N_c \) expansion. It is found that the charged \( \rho \) meson mass decreases as the magnetic field increases and drops to zero at a critical magnetic field \( eB_c \). The charged vector meson condensation, i.e. the electromagnetic superconductor can be induced above the critical magnetic field. We find that at zero density, in the temperature range \( 200 \) – \( 500 \) MeV, the critical magnetic field for charged \( \rho \) condensation is in the range of \( 0.2 \) – \( 0.6 \) GeV\(^2\), which indicates that high temperature superconductor could be created at LHC.

On behalf of collaboration:

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**Poster Session** - Board: 0016 / 147

**Holographic calculation of the QCD crossover temperature in a magnetic field**

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Lattice data for the QCD equation of state and the magnetic susceptibility computed near the crossover phase transition (at zero magnetic field) are used to determine the input parameters of a five dimensional Einstein-Maxwell-Dilaton holographic model. Once the model parameters are fixed at zero magnetic field, one can use this holographic construction to study the effects of a magnetic field on the equilibrium and transport properties of the quark-gluon plasma. In this talk we use this model to study the dependence of the crossover temperature with an external magnetic field. Remarkably, our results for the pressure of the plasma and the crossover temperature [1] are in quantitative agreement with current lattice data for values of the magnetic field \( 0 < eB < 0.3 \) GeV\(^2\), which is the relevant range for ultrarelativistic heavy ion collision applications.

Reference:

On behalf of collaboration:

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**Poster Session** - Board: 0017 / 676

**Thermodynamics of an exactly solvable confining quark model**

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In the last years, some works have explored the thermodynamic properties of softly BRST broken pure gauge theories, as the ones that take into account the effect of Gribov ambiguities in the deep infrared regime. The results obtained display clear nonperturbative aspects and indicate that this may be a new pathway for QCD model building.

In this talk, we explore thermodynamic properties of a model of quarks with soft BRST breaking for arbitrary temperatures and quark chemical potentials. This model is expected to describe the infrared properties of confined quarks, while keeping compatibility with ultraviolet QCD properties. Indeed, the analytical propagator of the model displays positivity violation and fits well the available lattice data. The model has been also proven to be renormalizable, reducing to perturbative quarks in the ultraviolet regime. Our goal here is to show not only that confinement in the form of positivity violation in the quark sector implies a well-defined macroscopic behaviour, but also that the tree level model is capable of predicting nontrivial features, being in general qualitatively compatible with the effect of nonperturbative interactions as observed in lattice data.

On behalf of collaboration:

Poster Session - Board: 0019 / 601

Taking the ratio between shear viscosity and electric conductivity of QGP
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The transport coefficients of strongly interacting matter are currently subject of intense studies due to their relevance for the characterization of the Quark-Gluon Plasma produced in ultra-relativistic heavy-ion collisions. One of the main results of heavy ions collision at relativistic energy experiments is the very small shear viscosity to entropy density ratio of the Quark-Gluon Plasma, close to the conjectured lower bound \( \eta/s = 1/4\pi \) for systems in the infinite coupling limit. Another key transport coefficient, but less studied than shear viscosity, is the electric conductivity that represents the response of a system to an applied external electric field. In heavy Ion Collisions very high electromagnetic fields are expected to be generated with a decay time depending on the value of the electric conductivity and their impact on pressure isotropization depending on the \( \eta/s \) of the plasma.

We discuss the connection between shear viscosity and electric conductivity and explain why the ratio \( \langle \eta/s \rangle / (\sigma_{el}/T) \) supplies a measure of the quark to gluon scattering rates whose knowledge would allow to significantly advance in the understanding of the QGP phase. We also predict that the ratio should increase near the critical temperature contrary to the flat behaviour predicted by a conformal theory. We show that \( \langle \eta/s \rangle / (\sigma_{el}/T) \), independently on the running coupling \( \alpha_s(T) \), should increase up to about \( \sim 20 \) for \( T \rightarrow T_c \), while it goes down to a nearly flat behavior around \( \sim 4 \) for \( T \geq 4T_c \). Therefore we in general predict a stronger \( T \) dependence of \( \sigma_{el}/T \) with respect to \( \eta/s \) as \( T \rightarrow T_c \).


On behalf of collaboration:

Poster Session - Board: 0020 / 247

SU(3) Dual QCD Formulation and Phase Transition at Finite Temperature
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Based on the well known topological properties of non-abelian gauge theories, a dual QCD gauge theory is constructed in terms of magnetic symmetry, which manifest the topological structure of the symmetry group in a non-trivial way. The topological magnetic charges associated with monopoles have been brought into the dynamics by the possible homotopy \( \Pi_2[{SU(3)/U(1) \otimes U'(1)}] \). The dynamical breaking of the magnetic symmetry has been shown to impart the dual superconducting properties to the magnetically condensed QCD vacuum which ultimately leads to a unique flux tube configuration in QCD vacuum responsible for enforcing the color confinement. The color singlet physical spectrum in accordance with the color confinement has been achieved through the requirement of the color reflection invariance which provides two magnetic glueballs as the collective excitations of the magnetically condensed dual superconducting QCD vacuum which in turn, are intimately connected to the flux confining parameters (penetration length and coherence length) of the superconducting vacuum. Furthermore, in view of the relevance of the phase transitions at finite temperatures, utilizing the path-integral formalism, dual QCD theory has also been extended to the thermal domain to examine the deconfinement phase transition. The effective potential at finite temperature has, thus, been derived to compute the critical temperature for phase transition which has been shown to be in good agreement with the lattice results. A large reduction of color monopole condensate and glueball masses near the critical temperature has been shown to lead to a first order deconfinement phase transition and the complete evaporation of color monopole condensate in the high temperature domain reveals to the restoration of magnetic symmetry.

On behalf of collaboration:

Poster Session - Board: 0021 / 329

Complex heavy quark potential at high temperature from lattice QCD and its consequences for phenomenology.

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We measured recently the complex heavy quark potential at high temperature in lattice simulations [1]. After reviewing shortly the method used, I will discuss the results obtained, explain how to understand them in terms of in-medium screening and show that this potential can be used to obtain a gauge invariant definition of the Debye screening mass [2]. This finite temperature potential also enables a description of quarkonium in a thermal medium with a Schrödinger equation, similar to what is done for the spectroscopy at zero temperature. I will show how these physical spectra inform us about the phenomenology of quarkonium melting and recombination [3] in heavy ion collision. In particular I will show first estimates for the \( \Psi' \) to \( J/\Psi \) ratio in nucleus-nucleus collision at RHIC and LHC, assuming production at the phase boundary and discuss the disappearance of excited states of bottomonium at the LHC.


On behalf of collaboration:
The q-statistics and QCD thermodynamics at LHC

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Tsallis non-extensive thermodynamics has been successfully used in describing the transverse momentum distributions from RHIC to LHC energies. In this work, we present a simplified and thermodynamically consistent Tsallis distribution by using Taylor series expansion in \((q-1)\). It helps us to study the degree of deviation of Tsallis distribution from a thermalized Boltzmann distribution, for proton-proton collisions at LHC energies. We provide analytical results for the Tsallis distribution in the presence of collective flow up to the first order in \((q-1)\) and observe that the pion \(p_T\) spectrum for Pb+Pb collisions at center of mass energy of 2.76 TeV at LHC, could be well described by Tsallis q-statistics with inclusion of a constant radial flow. We study the degree of deviation of the thermodynamic observables like, the number density, pressure and energy density, from a Boltzmann type of distribution, in the ambient of Tsallis q-statistics, for different physically acceptable values of the q-parameter. Further, we extend the q-statistics for the Hagedorn resonance gas to examine the basic thermodynamical quantities for systems having different 'q' parameters. The speed of sound and thus the equation of state in a Hagedorn resonance gas is also studied in the framework of non-extensive statistics.

On behalf of collaboration:

The QCD equation of state at nonzero temperature and density from lattice QCD

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We present results from a calculation of the QCD equation of state to next-to-leading order \((O(\mu_4^4))\) in the baryon, strangeness and electric charge chemical potentials [1,2]. We approximate the conditions met in heavy ion collision by enforcing strangeness neutrality and a constant baryon number to electric charge ratio. We show that the fourth-order equation of state is suitable for the modeling of dense matter created in heavy ion collisions with center-of-mass energies down to \(\sqrt{s_{NN}} \sim 20\) GeV. Sixth-order results for Taylor expansion coefficients are used to estimate truncation errors of the fourth-order expansion. We will further discuss lines of constant pressure and energy density in comparison to the freeze-out and chiral critical lines.

The presented results will be close to final, i.e., many of the quantities will be continuum extrapolated, based on lattice calculations performed with the Highly Improved Staggered Quark action (HISQ) in the temperature range 140 MeV < \(T\) < 330 MeV, with lattice sizes \(24^3 \times 6, 32^3 \times 8\) and \(48^3 \times 12\). The strange quark mass is tuned to its physical value and we use a strange to light quark mass ratio \(m_s/m_l = 20\), which in the continuum limit corresponds to a pion mass of about 160 MeV.

References


On behalf of collaboration:
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Poster Session - Board: 0024 / 139

Quark susceptibility calculation under one loop correction in the mean-field potential

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We calculate quark susceptibility and thermodynamic parameters with one loop correction in mean field potential. The calculation shows the susceptibility up to the range of temperatures $T = 0.6$ GeV. The susceptibility lies in the range of lattice results. Moreover the thermodynamic properties like entropy and specific heat also shows similar outputs with the recent calculations and agree with the lattice results.

On behalf of collaboration:

Poster Session - Board: 0025 / 166

QCD inspired determination of NJL-parameters

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Studies of the QCD phase diagram at finite temperature and quark chemical potential are currently one of the most discussed topics in theoretical physics and are of great importance to better our understanding of heavy-ion collision experiments. However, there is considerable uncertainty about the detailed structure of the QCD phase diagram at high baryon densities. Models provide some insight into the phase structure but usually rely on various parameters and therefore require validation from the point of view of the fundamental theory. We propose to apply nonperturbative functional Renormalization Group methods (FRG) to QCD in order to determine constraints on the parameters used in low-energy QCD models. In particular, this includes a determination of the dependence of these parameters on temperature and quark chemical potential. We present first results and argue that our findings can be used to improve the predictive power of model calculations.

On behalf of collaboration:

Poster Session - Board: 0026 / 261

Calculation of high-order cumulant with canonical ensemble method in lattice QCD

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Confinement/deconfinement phase transition is one of the most interesting subjects in finite density QCD. For example, high-order cumulant of net quark number that has been observed in experiments shows a specific behavior around the phase transition line. However, sign problem caused by complex action makes it difficult to numerical calculation of it. In this study we realize the calculation of high-order cumulant with a combination of “canonical ensemble method” and hopping parameter expansion in heavy quark region. Also, we study a finite density phase transition from the specific behavior of high-order cumulants and its volume dependence.

On behalf of collaboration:

**Poster Session** - Board: 0027 / 198

**Long-range correlations in the deconfined phase of QCD**

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Experimental evidence indicates that the quark-gluon plasma created in heavy-ion collisions at RHIC and LHC behaves like a strongly coupled liquid. These features are intimately related to the infrared (IR) behavior of QCD at finite temperature and present a challenge for conventional perturbative approaches. A way to tackle this obstacle is to improve the description of soft non-Abelian gauge degrees of freedom (DoF) using Gribov’s quantization. In consequence, a physical scale, which at high temperature corresponds to the (chromo)magnetic scale, is induced in the system. We discuss how this novel framework affects the relevant quark collective DoF’s. Strikingly, we uncover a previously unknown massless mode which is protected by a novel non-Abelian magnetic scaling. As a result, the quark spectral function violates positivity, a well-known feature of confinement. This sheds new light on the interplay of quasi-particle DoF’s and genuine long-range modes in the deconfined phase of QCD. Within the same framework, we also discuss the impact of the modified IR dynamics on the jet quenching parameter. We calculate its temperature dependence and find a strong enhancement near the phase transition that is in line with the expectation of a strongly coupled QGP.


On behalf of collaboration:

**Poster Session** - Board: 0028 / 21

**Future prospects for heavy ion physics with LHCb**

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After the successful participation of LHCb in the 2013 lead-proton run, the experiment is planning to further expand its scope toward heavy ion physics. Simulation studies show that up to semi-central lead-lead collisions can be analyzed. Furthermore, the SMOG system for the injection of small amounts of gas into the LHCb collision area, which was developed for luminosity calibration by beam-gas imaging, allows fixed target physics with proton and lead beams. The physics reach of the experiment as well as first results from exploratory studies with fixed target interactions will be discussed.

Entanglement Entropy of Several Bosonic Quantum Field Theories

We investigate how entanglement entropy behaves in general non-conformal quantum field theories which describe kinds of physical systems. The scalar field in $O(N)$ $\sigma$–model and non-Abelian $SU(N)$ gauge field on lattice are concerned as two typical bosonic models in our study. By virtue of divergency structure of entanglement entropy, we distinguish different phases of $O(N)$ $\sigma$–model, symmetric phase with positive mass square and symmetry-breaking phase with negative one. The ultra-violet divergences in entanglement entropy of field theories, further more, are demonstrated to be cancelled by counter-terms induced on the interface between two subregions entangling to each other. It is consistent with that topological entanglement entropy as non-divergent part of entanglement entropy is renormalizable quantity which is understood as cosmological constant living on interface. In non-Abelian $SU(N)$ gauge field theories, at the same time, interface cosmological constant becomes more important because it is able to clarify ambiguity emerging from different choices of boundary conditions on the interface in gauge field theories simultaneously. In order to extract physical quantity from the disputed issue, we continue to calculate finite temperature dependence, susceptivity to size of subsystem and mutual information which are related to physical parts of entanglement and as well irrelevant to interface counter-terms.

(Non-)Critical fluctuation signals and their fate in heavy-ion collisions

A major goal of ongoing experiments in heavy-ion physics is the exploration of the QCD phase diagram with the potential discovery of the QCD critical point. Here, fluctuation observables are considered to be promising quantities for achieving this goal. Present experimental
results alone are however inconclusive and need to be accompanied by advanced theoretical calculations which capture the relevant aspects of heavy-ion collisions.

In this talk we address two main topics in this context: the dynamical modelling of fluctuations within fluid dynamics and the impact of late stage effects on the (non-)critical signals in the fluctuation observables. In the first part we report on the inclusion of fluctuations into the fluid dynamical evolution equations. We show that (thermal) noise can be consistently incorporated in fluid dynamics and check our results against known equilibrium fluctuations and analytical results for Bjorken flow. This framework also allows one to study the evolution of critical fluctuations, for example by applying transport coefficients with critical behavior or by coupling the sigma-field to a fluid dynamical background. In the second part we assume that critical fluctuations have formed in the collision dynamics according to universality arguments and parametrizations of the correlation length. We study how resonance decay and regeneration as well as the distance of the system’s trajectory and the chemical freeze-out from the critical point alter the signals that are expected to be seen in net-proton and net-charge fluctuations.

On behalf of collaboration:

Poster Session - Board: 0103 / 219

Search for critical parton density fluctuations through baryon clustering

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Phase transitions and/or critical phenomena are known to lead to local density fluctuations in the nuclear matter created in high-energy heavy-ion collisions. In the quark coalescence picture of particle production, the baryon formation probability can be influenced by these local parton density fluctuations that lead to clustering and voids in the distribution of hadrons in the phase space. We propose to use the normalized distribution of produced particles in coarse azimuthal angular bins to study the fluctuations. The shape of the normalized distribution is expected to be sensitive to clustering in the phase space. We use Poisson and Binomial distributions to generate reference comparisons. Clustering of particles is introduced empirically in the Monte Carlo to investigate the sensitivity of various moments of the normalized distribution. We compare our Monte Carlo results with the STAR Beam Energy Scan data to demonstrate deviations from Poisson/Binomial distributions and the sensitivity of our approach to possible clustering and parton density fluctuations in heavy-ion collisions.

On behalf of collaboration:

Poster Session - Board: 0104 / 530

Equation of state in two-, three-, and four-color QCD at nonzero temperature and density

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We calculate the equation of state at nonzero temperature and density from first principles in two-, three-, and four-color QCD with two fermion flavors in the fundamental and two-index, antisymmetric representation. By matching low-energy results (from a “hadron resonance gas”) to high-energy results from (resummed) perturbative QCD, we obtain results for the pressure and trace anomaly that are in quantitative agreement with full lattice-QCD studies for three colors at zero chemical potential. Our results for nonzero chemical potential at zero
temperature constitute predictions for the equation of state in QCD-like theories that can be tested by traditional lattice studies for two-color QCD with two fundamental fermions and four-color QCD with two two-index, antisymmetric fermions. We find that the speed of sound squared at zero temperature can exceed 1/3, which may be relevant for the phenomenology of high-mass neutron stars.

On behalf of collaboration:

Poster Session - Board: 0105 / 278

Production of light nuclei, coalescence parameter and Blast-wave model comparison in heavy-ion collisions at RHIC.

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A strongly interacting medium, namely Quark Gluon Plasma (QGP), is formed in high-energy heavy-ion collisions at RHIC. Light nuclei (anti-nuclei) can be produced in such heavy-ion collisions by the recombination of produced nucleons (anti-nucleons) or stopped nucleons. This formation process is called final-state coalescence. The production of light nuclei is dependent on the baryon density and the correlation (freeze-out) volume. Therefore, by studying the yield and azimuthal anisotropy of light nuclei (anti-nuclei) and comparing them with that of proton (anti-proton) we can gain insight in the particle production mechanism via coalescence and physical properties of the expanding system at the thermal freeze-out. Unlike the quark coalescence phenomena of identified hadrons, nucleonic coalescence is directly measurable as both the light nuclei and nucleons (proton and anti-proton) are measured by the detectors in a given experiment. In this poster, we will show the invariant yields of $d$ and $\bar{d}$ for Au+Au collisions at $\sqrt{s_{NN}} = 7.7, 11.5, 19.6, 27$ and $39$ GeV from the STAR experiment at RHIC. Light nuclei are identified using the Time Projection Chamber (TPC) and Time-of-Flight (ToF) detector of the STAR experiment. The ToF detector enhances the identification of the light nuclei and extends the $p_T$ reach of light nuclei beyond 1 GeV/c. The $p_T$ spectra of nuclei will be compared with $p$ ($\bar{p}$) to obtain the nuclei to nucleon ratio and $B_2$ parameter to understand the light nuclei production mechanism in heavy-ion collisions. Light nuclei spectra will also be compared with the prediction from Blast-wave model, using the fit parameters obtained from Blast-wave fit of $\pi$, $K$, $p$ spectra.

On behalf of collaboration:

15

Poster Session - Board: 0106 / 635

The curvature of the chiral phase transition line at small values of the quark chemical potentials

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One of the goals of the ongoing Beam Energy Scan program at RHIC is to look for evidence of the conjectured QCD Critical Point. The feasibility of detecting the critical point however depends on how close the QCD chiral phase transition line is to the freeze-out curve. In the two-flavor chiral limit, this transition is expected to be second-order at zero and small values of $\mu$, the quark chemical potential. The critical temperature $T_c$ however, tends to decrease as $\mu$ is increased; this shift is characterized, for small values of $\mu$, by the curvature of the transition line $\kappa$.

While the current lattice QCD results [1-5] on the curvature are significantly smaller than the phenomenological parametrization of the freeze-out line given by Cleymans and Redlich [6], it
must be noted that they differ by more than a factor of two among themselves. In this talk, we will present an upper bound for the light and strange curvatures $\kappa_q$ through extrapolation to the chiral limit. We work in 2+1-flavor QCD and with five different pion masses between 80 MeV $\leq m_\pi \leq 160$ MeV. Our new results improve on our earlier result [1], both by working at a smaller lattice spacing and through the use of the HISQ action, which has considerably smaller cutoff effects than the actions that were previously used.

References


On behalf of collaboration:

Poster Session - Board: 0107 / 124

Nuclear Symmetry Energy in QCD degree of freedom

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Nuclear symmetry energy is an important ingredient in understanding asymmetric nuclear configuration starting from rare isotopes at nuclear matter density to the core of neutron star at extremely high density. The symmetry energy in continuous matter can be defined as \begin{equation} \bar{E}_{\text{sym}}(\rho_N)I^2 + \cdots, \end{equation} where $\rho_N$ is the nuclear medium density and $I = (\rho_n - \rho_p)/(\rho_n + \rho_p)$ the asymmetric parameter. Our goal is to understand the iso-spin asymmetric nature of the nuclear matter using the QCD degree of freedom.

For the hadronic phase, by taking the difference between the neutron and proton self-energies calculated in the QCD sum rules, we obtained the symmetry energy in terms of local operators [1]. We find that the scalar (vector) part gives a negative (positive) contribution to the nuclear symmetry energy, which is consistent with the results from relativistic mean field theories.

For the quark phase, we used hard dense loop (HDL) resummation for the normal phase and considered BCS pairing in 2-color superconductor (2SC) phase [2]. In the normal phase, the effect of gluonic interaction to the symmetry energy, obtained from the HDL resumed free energy, was found to be small. In the 2SC phase, the BCS pairing gives enhanced symmetry energy as the gapped states are forced to be in the common Fermi sea reducing iso-spin asymmetrizable states. Also, in the 2SC phase, the gluonic contribution to the symmetry energy is expected to be minimal as only the unimportant Meissner mass has iso-spin dependence. The different symmetry energy in each phase will affect the iso-spin density of the dense matter and subsequently lead to different prediction for the particle yields in HIC experiment.


On behalf of collaboration:
**Poster Session** - Board: 0108 / 37

**Dissipative properties of hot and dense hadronic matter in excluded volume hadron resonance gas model**

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We estimate dissipative properties viz: shear and bulk viscosities of hadronic matter using relativistic Boltzmann equation in relaxation time approximation within ambit of excluded volume hadron resonance gas (EHRG) model. We find that at zero baryon chemical potential the shear viscosity to entropy ratio (\(\eta/s\)) decreases with temperature and reaches very close to Kovtun-Son-Starinets (KSS) bound. At sufficiently large baryon chemical potential this ratio shows same behavior as a function of temperature but goes below KSS bound. We further find that along chemical freezeout line \(\eta/s\) increases monotonically while the bulk viscosity to entropy ratio (\(\zeta/s\)) decreases monotonically.

On behalf of collaboration:

**Poster Session** - Board: 0109 / 584

**Phonons, Pions and Quasi-Long-Range Order in Spatially Modulated Chiral Condensates**

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We investigate low-energy fluctuations in the real kink crystal phase of dense quark matter within the Nambu–Jona-Lasinio model. The modulated chiral condensate breaks both the translational symmetry and chiral symmetry spontaneously, which leads to the appearance of phonons and pions that are dominant degrees of freedom in the infrared. Using the Ginzburg-Landau expansion near the Lifshitz point, we derive elastic free energies for phonons and pions in dependence on the temperature and chemical potential. We show that the one-dimensional modulation is destroyed by thermal fluctuations of phonons at nonzero temperature, and compute the exponent that characterizes the anisotropic algebraic decay of quasicondensate correlations at long distance. We also estimate finite-volume effects on the stability of the real kink crystal and briefly discuss the possibility of its existence in neutron stars.

On behalf of collaboration:

**Poster Session** - Board: 0110 / 615

**Crossover Equation of State Compared to Lattice QCD and to Baryon Fluctuations in the RHIC Beam Energy Scan**

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We match hadronic equations of state at low energy densities to a perturbatively computed equation of state of quarks and gluons at high energy densities. The hadronic equations of
state include all known hadrons; repulsive interactions are taken into account via two versions of the excluded volume approximation. A switching function is employed to make the crossover transition from one phase to another without introducing a thermodynamic phase transition. A fit to accurate lattice calculations of the pressure and trace anomaly, with temperature $100 < T < 1000$ MeV and $\mu = 0$, determines the parameters. These parameters quantify the behavior of the QCD running gauge coupling and the hard core radius of the nucleon. With no new parameters, the pressure and trace anomaly from lattice calculations for $\mu = 400$ MeV are equally well reproduced, as is the speed of sound. We then compute the skewness and kurtosis and compare to measurements of the fluctuations of the proton number distribution in central Au-Au collisions as measured by the STAR collaboration in a beam energy scan at RHIC. The crossover equations of state can reproduce the data if the fluctuations are frozen at a temperature significantly lower than the average chemical freeze-out.

On behalf of collaboration:

**Poster Session - Board: 0111 / 638**

**Fluctuation-induced effects in inhomogeneous chiral phases**

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We discuss the effect of fluctuations for the inhomogeneous chiral phase in the thermodynamics of QCD. Inhomogeneous chiral phase is characterized by the spatially modulated chiral condensate, $M(z) = -2G(\langle \bar{q}q \rangle + i\langle \bar{q}i\gamma_5\tau_3q \rangle) = m(z)e^{i\theta(z)}$. There are two typical types of condensates. One is called real kink crystal (RKC), which is modulated only in the amplitude; $M(z) = m(z)$[1]. The other one is called dual chiral density wave (DCDW), which is modulated only in the phase; $M(z) = me^{i\theta(z)}[2]$. Here, we concentrate on the analysis for sinusoidal condensate. Within the mean field approximation, it is known that there appears the inhomogeneous phase between the homogeneously broken and the normal phases in QCD phase diagram. Both RKC and DCDW have characteristic behavior: there is the second order phase transition line between inhomogeneous and chiral restored phases. If we consider the fluctuation effects, this behavior is remarkably changed. Brazovskiï has shown that the thermal fluctuation effect changes the order of phase transition between the inhomogeneous and normal phases [3]. Dyugaev has also shown that the quantum fluctuation induces similar effect [4]. Here, we develop these works and apply to the inhomogeneous chiral condensate: we consider both the thermal and quantum fluctuations. As a result, we show the effects of the quantum and thermal fluctuations change the order of the phase transition. Also we show that these effects disfavor the inhomogeneous condensate, the region of the inhomogeneous phase in QCD phase diagram is decreased.

Reference

On behalf of collaboration:

**Poster Session - Board: 0112 / 420**
Inhomogeneous chiral condensates and nonanalyticity under external magnetic field

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We investigate inhomogeneous chiral condensates such as the dual chiral density wave in QCD under an external magnetic field at finite real and imaginary chemical potentials. In a model-independent manner, we find a non-analyticity at zero chemical potential induced by the inhomogeneous chiral condensates and then the analytic continuation is no longer possible at the singular point. We discuss consequences from the existence of the nonanalyticity to the Taylor expansion, reweighting, canonical and analytic continuation methods which are widely used in the lattice QCD simulation. We also discuss an exceptional case which does not have the nonanalyticity at zero chemical potential.

On behalf of collaboration:

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**Poster Session - Board: 0113 / 204**

**Event-by-event extraction of kinetic and chemical freeze-out properties in the CBM experiment**

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The future CBM experiment at FAIR is designed to study properties of strongly interacting matter produced in heavy-ion collisions at high baryon densities. It will employ high intensity beams and large acceptance detectors. One important task is to extract the thermal parameters of matter at stages of kinetic and chemical freeze-out from the observed data. The extraction of thermal parameters is implemented as a package within the CBMROOT framework. The kinetic freeze-out temperature and the inverse slope of charged pions, kaons and protons are extracted from their measured momentum spectra with appropriate correction on acceptance and reconstruction efficiency. The longitudinal flow is taken into account in the framework of a Blast Wave model. The parameters of the chemical freeze-out are extracted by fitting the measured particle ratios in the framework of Hadron Resonance Gas model. The described procedures can be performed both online and offline, on events selected with arbitrary criteria. The analysis can be done on event-by-event as well as on the inclusive spectra level.

On behalf of collaboration:

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**Poster Session - Board: 0114 / 388**

**Inhomogeneous chiral condensed phases with an algebraic long-range order**

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In recent theoretical studies of QCD at finite temperature and density, there is a growing consensus that spatially inhomogeneous chiral condensed phases appear in the region where a first-order chiral phase transition would occur. We present a study on the stability of a Fulde-Ferrell type inhomogeneous chiral condensed phase, the so-called dual chiral density wave (DCDW) phase, of dense quark matter against low energy fluctuations about a spatially modulated order parameter [1]. We find that the DCDW phase exhibits a flavor-translation locking symmetry from the symmetry point of view. We also show that the Nambu-Goldstone modes, whose dispersion relations are spatially anisotropic and soft in the directions transverse to the modulation, wash out the long-range order at non-zero temperatures, but sustain quasi-long-range correlations (algebraically decaying long-range correlations), starting with a Landau-Ginzburg-Wilson effective Lagrangian. Consequently, at finite temperatures the DCDW phase is found to be a quasi-one-dimensional ordered phase as in smectic phases of liquid crystals. [1] T.-G. Lee, E. Nakano, Y. Tsue, T. Tatsumi, and B. Friman, arXiv:1504.03185 [hep-ph].

On behalf of collaboration:

**Poster Session** - Board: 0115 / 155

**Baryon number fluctuations around an expanding Bjorken background**

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Baryon number density perturbations could provide a possibility to access baryon number susceptibilities and the heat conductivity of a quark gluon plasma. We use a background-fluctuation splitting and a Bessel-Fourier decomposition for the fluctuating part of the fluid dynamical fields with respect to the azimuthal angle, the radius in the transverse plane and rapidity. We examine how the time evolution of linear perturbations depends on the equation of state as well as on shear viscosity, bulk viscosity and heat conductivity for modes with different azimuthal, radial and rapidity wave numbers. Finally we discuss how this information is accessible to experiments in terms of the transverse and rapidity dependence of the net baryon number correlation function (baryon minus anti-baryon) in high energy nuclear collisions.

On behalf of collaboration:

**Poster Session** - Board: 0116 / 288

**STAR Au + Au Fixed Target Results**

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The RHIC Beam Energy Scan (BES) program was proposed to look for the turn-off of signatures of the quark gluon plasma (QGP), search for a possible QCD critical point, and study the nature of the phase transition between hadronic and partonic matter. The results from the NA49 experiment at CERN have been used to claim that the onset of deconfinement
occurs at a collision energy around a center-of-mass energy of 7 GeV, the low end of the BES range [1]. Data from lower energies are needed to test if this onset occurs. The goal of the STAR Fixed-Target Program is to extend the collision energy range in BES II with the same detector to energies that are likely below the onset of deconfinement. Currently, STAR has inserted a gold target into the beam pipe and conducted test runs at center-of-mass energies 3.9 and 4.5 GeV. Tests have been done with both Au and Al beams. First physics results from a Coulomb analysis of Au + Au fixed-target collisions, which are found to be consistent with previous experiments, will be presented. These results demonstrate that STAR has good particle identification capabilities in this novel detector setup. Furthermore, the Coulomb potential, which is sensitive to the Z of the projectile and degree of baryonic stopping, will be compared with published results from the AGS. Additional results and comparisons will be presented if available.


Poster Session - Board: 0117 / 176

Yang-Lee Zeros and Phase Boundary From Net-Baryon Number Multiplicity Distribution

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Fluctuations of conserved charges provide us information on the state of matter at freeze-out temperature $T$ and baryon chemical potential $\mu$. Since the underlying multiplicity distribution of the net-baryon number is related to the canonical partition function $Z(T,V,N)$, one can construct the partition function $Z(T,V,\mu)$ as a series of fugacity [1], $Z(T,V,\mu) = \sum_{N=-N^*}^{N^*} Z(T,V,N)e^{\mu N/T}$, where $N^*$ is maximum baryon number the system can possess. While one may be able to obtain thermodynamic quantities and fluctuations from the partition function in this way, this also enables us to study Yang-Lee zeros, which is the zeros of the partition functions in complex chemical potential and provides information on the phase boundary.

In this work, we show that the information on the phase boundary extracted from Yang-Lee zeros of the truncated partition function is stable under the truncation up to some orders, by making use of a chiral random matrix model [2]. We compare the zeros from the exact solution of the model with those from truncated partition function and from the corresponding Skellam partition function. We also show that the behavior of the zeros in the model against the truncation has a significant difference compared to those from the Skellam partition function. We also discuss statistics necessary for obtain such zeros in heavy ion experiments.


Poster Session - Board: 0118 / 442

Lattice simulation of two-color QCD with $N_f = 2$ at non-zero baryon density
At the present time study of the QCD phase diagram in the \((T, \mu)\) plane from LQCD calculations is very difficult due to the sign problem. On the other hand, QC\(_2\)D has no sign problem, thus providing an opportunity to investigate properties of QGP from the first principles. In this talk we present the results of lattice simulation of QC\(_2\)D with two flavors of staggered fermions and non-zero quark chemical potential. Dependencies of the Polyakov loop, chiral condensate and baryon number density on \(\mu_q\) were studied. We found, that raising of the baryon chemical potential leads to the chiral symmetry restoration. At small \(\mu_q\) our results for the baryon density agree with ChPT predictions.

On behalf of collaboration:

Poster Session - Board: 0119 / 167

**Crystalline chiral condensates in an external magnetic field**

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We study the QCD phase diagram by the Nambu-Jona-Lasinio (NJL) model within the mean-field approach, taking into account both of the magnetic field and inhomogeneity of the chiral condensates. For the analysis of the chiral inhomogeneous phase, the generalized chiral condensate \(\Delta := -2G \left[ \langle \bar{\psi}\psi \rangle + i \langle \bar{\psi}i\gamma^5\tau^3\psi \rangle \right] \) is used. The dual chiral density wave (DCDW) and the real kink crystal (RKC) have been commonly used as typical form of the chiral condensate: DCDW is a plane wave configuration, \(\Delta(x) = me^{iqx}\), and RKC is a multi-soliton configuration, \(\Delta(x) = 2m\nu \frac{1 + \sqrt{\nu}}{1 + \sqrt{\nu}} sn \left( \frac{2mz}{1 + \sqrt{\nu}}, \nu \right) e^{iqz}\). The thermodynamic properties of the DCDW phase in the magnetic field has been studied by Frolov et al., and it has been shown that the DCDW phase develops in the wide density region in the presence of the magnetic field. However, they have only considered DCDW, while it has been suggested that the RKC phase may be favored without the external magnetic field. Here we figure out the properties of the chiral inhomogeneous condensate in the presence of external magnetic field, taking into account the possibility of the RKC phase. We introduce a hybrid configuration (HCC) which has the feature of both DCDW and RKC, \(\Delta(x) = 2m\nu \frac{1 + \sqrt{\nu}}{1 + \sqrt{\nu}} sn \left( \frac{2mz}{1 + \sqrt{\nu}}, \nu \right) e^{iqz}\), to this end. Note that it smoothly connects both configurations by changing modulus \(\nu\). There never appears the pure RKC phase, and DCDW and RKC coexist as HCC in the weak magnetic field at moderate density. Eventually DCDW becomes most favorable in the strong magnetic field. It is also shown that there is a first order phase transition between inhomogeneous phases in the presence of magnetic field.

On behalf of collaboration:

**Poster Session - Board: 0120 / 597**

**Strangeness production in Au+Au collision at \(\sqrt{s} = 2.4\) A GeV**
HADES COLLABORATION, -¹

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Particle production in collisions of heavy ions at energies in the few AGeV energy regime is still a matter of theoretical controversy. Is the assumption of statistical emission from a thermalized system sufficient, or is there evidence for sequential freeze-out? Is there a consistent picture of chemical and thermal freeze-out? Or can particle production at these energies be only understood in a fully dynamical description like e.g. microscopic transport? HADES has recently measured 7 billion central (40%) Au+Au collisions at a beam energy of 1.23 AGeV. For the first time at such low energies it has been possible to reconstruct the dominant particles carrying strangeness like K⁺, K⁻, K⁰ and Λ as well as the hidden-strange φ. After development of an improved reconstruction method the particles can now be reconstructed with high purity and with a large phase space coverage. The respective phase space distributions are analyzed with regard to the above phrased questions. In particular the conjecture of a possibly uniform freeze-out configuration is assessed as well as its location on the QCD phase diagram. Preliminary studies of flow and e-by-e observables will also be presented.

On behalf of collaboration:

Poster Session - Board: 0121 / 208

Study of high density phase transition in lattice QCD with canonical approach

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The canonical partition function is related to the grand canonical one through the fugacity expansion. In this talk we perform the fugacity expansion by a method of the hopping parameter expansion in temporal direction. The canonical partition function is evaluated for Nf=2 QCD upto baryon numbers of nB=30 in a wide range of temperature. After derivation of the canonical partition function we study the chemical potential dependences of hadronic observables like chiral condensate, quark number density and its susceptibility. In this talk we report a phase transition found at real chemical potential and its dependence on the quark mass and the volume.

On behalf of collaboration:

Poster Session - Board: 0122 / 555

Lifshitz point for the inhomogeneous chiral phase transition in the magnetic field

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The possible existence of the inhomogeneous chiral phase in the QCD phase diagram has recently received enhanced attention. We elucidate some peculiar features of the inhomogeneous chiral phase in the magnetic field. Taking the dual chiral density wave (DCDW) [1], we have found that the energy spectrum of the Dirac operator exhibits the spectral asymmetry in the lowest Landau level, which is closely related to chiral anomaly [2]. It is a topological effect due to the phase of the chiral condensate inherent in the DCDW phase and gives rise to some interesting consequences such as a novel Lifshitz point [2], spontaneous magnetization [3] or appearance of the hybrid chiral condensate [4]. A new term appears in the generalized Ginzburg-Landau (gGL) expansion and the Lifshitz point appears on $\mu = 0$ in the chiral limit. Such point should be directly explored by the lattice QCD simulations [2]. We can further pursue the Lifshitz point in a realistic situation, where quark mass is finite. Within the gGL theory the thermodynamic potential should include an additional term proportional to the quark mass and disfavor DCDW: DCDW is greatly modified around the Lifshitz point by the mass term, and it is shifted to larger $\mu$. As a result one may expect a shift of the Lifshitz point from $\mu \sim 0$. On the other hand, it is well known that this term changes the usual chiral transition to be cross over at high temperature but small $\mu$. Note that the inhomogeneous to homogeneous phases should exhibit a clear phase transition due to the difference of symmetry between them. We discuss how the finite mass effect modifies our earlier findings and some implications on the lattice QCD simulations.


On behalf of collaboration:

Poster Session - Board: 0123 / 234

Charge Asymmetry Correlations to Search for the Chiral Magnetic Effect from Beam Energy Scan by STAR

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STAR has reported the measurement of charge asymmetry correlations with respect to the event plane in search for the Chiral Magnetic Effect [1]. The charge separation parameter $\Delta$ after model-independent subtraction of elliptic flow ($v_2$) background, was measured to be $1.3\pm1.4$ (stat.)$^{+4}_{-1.0}$ (syst.)$\times10^{-5}$ for 20 – 40% Au+Au collisions at 200GeV, consistent with zero. In this talk we report results obtained with higher statistics data. A statistically significant finite signal is observed. The improved statistical precision allows systematic studies of the charge separation and investigation of possible further physics background. It is found that the charge separation parameter $\Delta$ increases with decreasing centrality, but shows a weak beam-energy dependence.

We also report the application of a multi-particle correlation method [2] for the measurement of charge separation with model-independent background subtraction by the mixed-event technique. By comparing correlation functions along and perpendicular to the event plane, potential upper limits are set on the charge separation parameter in the high statistics 200 GeV Au+Au data.

These results will be discussed in terms of the possible Chiral Magnetic Effect and/or physics background.


On behalf of collaboration:
Poster Session - Board: 0124 / 187

Mott-Hagedorn resonance gas and lattice QCD thermodynamics
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We construct a combined effective model reproducing the equation of state of strongly interacting matter as obtained in recent lattice QCD simulations. The model reproduces basic physical characteristics of the hadronic resonance gas at low temperatures and embodies the crucial effect of hadron dissociation. The quark and gluon degrees of freedom are described within an effective mean-field theory, the Polyakov-loop improved Nambu, Jona-Lasinio (PNJL) model. The hadron dissociation is obtained by the Mott effect within a generalized Beth-Uhlenbeck approach. The lowering of the thresholds for the two- and three-quark scattering state continuous spectrum triggers the transformation of hadronic bound states to resonances in the scattering continuum. We postulate a generic temperature dependent behavior of the scattering phase shifts in these channels. The in-medium phase shift model is in accordance with the Levinson theorem. This results in the vanishing of hadronic contributions to the thermodynamics at high temperatures. The crucial in-medium effect responsible for the hadron-to-quark matter phase transition is the lowering of the quark masses in the chiral restoration transition which itself is a result of the behavior of the chiral condensate. We aim at a selfconsistent solution of the model. The used PNJL model is improved over its standard versions by adding perturbative corrections in \(0(\alpha_s)\) for the high-momentum region above the three-momentum cutoff. This leads to the broadening of the quarks, while the quark selfenergy is calculated from the same kind of diagrams as hadronic selfenergy. This is an extension of former results obtained in arxiv:1501.00485 (Phys. Part. Nucl. 46 (2015) in press)

On behalf of collaboration:

Poster Session - Board: 0125 / 54

Critical exponents of chiral and isospin phase transitions
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We investigate chiral and isospin symmetries of QCD matter at finite temperature and density in the frame of functional renormalization group. The critical exponents and universality class are explored by analyzing the fixed points of scale transformation and RG flow around them. The dimension of the system near the phase transition is found to be temperature-dependent, resulting in continuous change of pion superfluid from 4d O(2) universality class at zero temperature to 3d O(2) at high temperature. Moreover, the critical dimension of chiral critical end point is determined, the critical exponents and universality class of chiral CEP are entirely described by symmetry and critical dimension, even though its location in phase diagram is model-dependent. This sheds light to further seeking of CEP location and critical phenomenon in QCD phase diagram.

On behalf of collaboration:
Poster Session - Board: 0126 / 574

Chiral mirror-baryon-meson model and nuclear matter beyond mean-field

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We describe the liquid-gas transition of nuclear matter together with chiral symmetry restoration in the high baryon-density phase considering a chiral baryon-meson model for nucleons and their parity partners in mirror assignment interacting with pions, sigma and omega mesons. The model is known to provide a phenomenologically successful description of nuclear matter properties within the mean-field approximation. Here, we go beyond this approximation and include mesonic fluctuations by means of the functional renormalization group. We concentrate on cold nuclear matter in the vicinity of the nuclear-matter transition but also consider finite temperatures to study the full phase diagram of the model. While including beyond mean-field fluctuations does not lead to major qualitative changes in the phase diagram of the model, in the vacuum one is no longer free to adjust the parameters so as to reproduce the binding energy per nucleon, the nuclear saturation density, and the nucleon sigma term all at the same time. However, the prediction of a clear first-order chiral transition at low temperatures inside the high baryon-density phase appears to be robust. Moreover, combining an extended mean-field approximation for the grand potential in the vacuum with thermal fluctuations at finite density provides a promising approach to explore the phenomenological consequences of the chiral transition of this model inside the high baryon-density phase for an equation of state of neutron matter and the mass-radius relation of neutron stars.

On behalf of collaboration:

Poster Session - Board: 0127 / 252

Energy Dependence of Moments of Net-Kaon Multiplicity Distributions at STAR

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One of the main goals of the RHIC Beam Energy Scan (BES) program is to study the QCD phase structure, including the search for the critical point, over a wide range of the collision energy. Theoretical calculations predict that fluctuations of conserved quantities, such as baryon number (B), charge (C), and strangeness (S), are sensitive to the correlation length [1] of the dynamical system. Experimentally, higher moments of multiplicity distributions have been utilized to search for the QCD critical point and extract freeze-out conditions [2] in heavy-ion collisions.

The STAR Collaboration has published moments of net-proton and net-charge multiplicity distributions [3]. In this talk, we will report recent efficiency corrected cumulants and higher moments of the net-kaon multiplicity distributions at mid-rapidity (|y| < 0.5) in Au+Au collisions at $\sqrt{s_{NN}} = 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4, \text{ and } 200$ GeV obtained from the first phase of the RHIC BES program. The collision energy and centrality dependence of cumulants up to the fourth order, as well as their ratios, will be shown. Furthermore, we will also present
studies of their rapidity and pT dependence. The comparisons with baseline calculations (Poisson, NBD) and non-critical point models (UrQMD, AMPT) will also be discussed.


QCD Kondo effect in quark matter with heavy flavor impurities

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The Kondo effect has been known as a phenomenon in electron systems with heavy mass impurities having finite spins. This phenomena is caused by imperfect cancelation of the infrared divergences of particle and hole excitations and is realized by a combination of the following ingredients; (0) heavy mass of impurity, (i) existence of Fermi surface, (ii) quantum loop effects, (iii) non-Abelian nature of interaction (e.g. the spin-spin interaction). These are indeed identified in a (light) quark matter with small number of heavy flavor quarks as impurities. In the quark matter, the non-Abelian properties of the interaction is given by the color exchange by gluons (S. Yasui and K. Sudoh, Phys. Rev. C88, 015201 (2013)). This is called the QCD Kondo effect, which modifies the transport properties of the quark matter with heavy flavor impurities, and can be relevant to experiments in the relativistic heavy-ion collisions.

In this presentation, we discuss how the effective coupling strength, between a heavy flavor impurity and a light quark, evolves in the low energy effective theory near the Fermi surface (K. Hattori, K. Itakura, S. Ozaki and S. Yasui, arXiv:1504.07619 [hep-ph]). We investigate the renormalization group flow at the leading log accuracy on the basis of the high-density QCD where the gluon propagator has the static screening mass and the dynamical screening effect for the electric and magnetic components, respectively, and show that the effective coupling becomes divergently large at a certain infrared scale near the Fermi surface, which is called the Kondo scale. This indicates the presence of a strongly coupled regime in the dynamics of the quark matter containing heavy flavor impurities. We find that, while the dynamical magnetic screening provides the dominant effect in the color superconductivity, it is sub-dominant compared to the static electric screening in the QCD Kondo effect.

Spectral function analysis of the hydrodynamical mode around the QCD critical point with use of functional renormalization group

Author(s): YOKOTA, Takeru
One of the unique points of QCD phase diagram is the existence of QCD critical point (CP), which is the end point of the phase boundary of the first-order chiral transition at low temperature. It is noteworthy that the phase transition turns to a second order at the CP, where fluctuations of some physical quantities should be divergent in the system with infinite degrees of freedom. People are thus interested in identifying such physical quantities which divergent behavior can be nicely detectable in experiment. It has been suggested that the soft modes at the QCD CP are hydrodynamical modes such as the baryon density fluctuation (particle-hole excitation) and entropy fluctuation, using RPA analysis of Nambu-Jona-Lasinio model and time-dependent Ginzburg-Landau theory [1, 2]. A notable point is that these modes are coupled to the scalar mode or the fluctuating mode of the chiral order parameter at finite chemical potential off the chiral limit. We examine whether this suggestion remain valid even when the thermodynamic fluctuations are fully taken into account. For this purpose, we calculate the spectral function of the collective modes coupled to the scalar mode using functional renormalization group. We employ the quark-meson model and set spatial momentum finite to investigate particle-hole excitations. On the basis of the numerical calculation of the spectral function around the QCD CP, we explore possible development and softening of the collective modes in the space-like as well as the time-like region.


Beam energy dependence of d and dbar productions in Au+Au collisions at RHIC
Dr. YU, Ning

The production of light nuclei with small binding energy such as deuterons, can be used to study the freeze-out properties and local baryon density in high-energy nuclear collisions. The azimuthal anisotropic results of protons and deuterons have shown that the coalescence is the dominant process for the light nuclei production at later stage of the evolution. In this talk we present a systematic study of colliding energy, centrality, and transverse momentum dependence of mid-rapidity deuteron and anti-deuteron production, measured by the STAR experiment, from Au+Au collisions at RHIC at $\sqrt{s_{NN}} = 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4$ and 200 GeV. Deuterons, protons and their anti-particles are identified using the time projection chamber (TPC) and time-of-flight detector (TOF). Proton and anti-proton yields are corrected from Lambda and anti-Lambda decays, respectively. The $B_2$ parameters, defined as $(N(d)/N^2(p))$, which measure the phase space density for nucleons show a difference between $B_2(d)$ and $B_2(\bar{d})$ and the difference becomes stronger at lower collision energy or higher baryon density region. These observations may imply that baryon and anti-baryon freeze-out at different densities. These new results will be discussed in light of data collected from AGS to LHC energies. In addition, the results will also be compared with transport model calculations.

On behalf of collaboration:
**Poster Session - Board: 0131 / 446**

**Dual condensates at finite isospin chemical potential**

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The dual observables as order parameters for center symmetry are tested at finite isospin chemical potential $\mu_I$ in a Polyakov-loop enhanced chiral model of QCD. As a counterpart of the dressed Polyakov-loop, the first Fourier moment of pion condensate is introduced for $\mu_I > m_\pi/2$ under the temporal twisted boundary conditions for quarks. We confirm this dual condensate exhibits the similar temperature dependence as the conventional Polyakov-loop. We demonstrate that its rapid increase with $T$ is driven by the evaporating of pion condensation. On the other hand, the dressed Polyakov-loop shows abnormal thermal behavior, which even decreases with $T$ at low temperatures due to the influence of pion condensate. We thus argue that in QCD the critical temperature extracting from a dual observable may have nothing to do with the quark confinement-deconfinement transition if the quark mass is very small.

On behalf of collaboration:

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**Poster Session - Board: 0201 / 146**

**Collective medium in small collision systems with percolation color sources**

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We analyze high multiplicity proton-proton ($p-p$) collision events data in the framework of the String Percolation Model (SPM) that has been successful in describing several phenomena of multiparticle production, including the signatures of recent discovery of strongly interacting partonic matter. Our study shows predicted signature of change of phase, and the predictions for the coming 13 TeV $p-p$ collisions data generated by the high color string density created in small systems.

On behalf of collaboration:

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**Poster Session - Board: 0202 / 582**

**Colour reconnections in the DIPSY Monte Carlo**

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We present results from the DIPSY Monte Carlo, a new BFKL based generator for $pp$ minimum bias, $pA$ and $AA$ collisions. We emphasise the inclusion of colour reconnection effects. Instead of superimposing a medium, the color reconnection model in DIPSY builds up collective effects dynamically, based on local fluctuations in individual events. These models have previously provided explanations for medium-like effects observed in high multiplicity proton collisions. We show to what extent the inclusion of color reconnections in $AA$ collisions introduces effects similar to those normally attributed to a thermalized medium.
Analysis methods to extract possible flow and ridge signal in small systems and application to high multiplicity events in 510 GeV p+p collisions at RHIC PHENIX experiment

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Elliptic flow and ridge-like correlation have been observed in heavy-ion collision and they are considered as important probes for understanding the hydrodynamic properties of Quark Gluon Plasma. The ridge and \( v_2 \) are also measured in \( d + Au \) and \( ^3He + Au \) collisions at RHIC, and in \( p + p \) and \( p + Pb \) collisions at LHC, therefore these observation have raised a great interest whether a similar hot and dense matter observed in heavy ion collision is also formed in small systems or not. 510 GeV p+p collisions were operated at RHIC in 2013. So far in p+p collisions at 200 GeV, ridge-like signal have not been found yet. However, there is significant difference in the multiplicity between 510 GeV and 200 GeV, so comparison of the two energies could provide an important insight on multiplicity and collision energy dependent studies with small collision systems.

In this poster, we report current status of flow and long-range correlation studies in high-multiplicity \( p + p \) collisions at \( \sqrt{s_{NN}} = 510 \) GeV with various analysis methods including (1) 2-particle correlation, (2) event plane as well as (3) reference fitting methods, and possibly to compare with \( p + p \) collisions at \( \sqrt{s_{NN}} = 200 \) GeV and other small collision systems, such as \( p + A, d + A \) and \( ^3He + A \) collisions at RHIC energies in PHENIX experiment.

"NA61/SHINE results on spectra and yields in p+p and Be+Be collisions at CERN SPS energies"

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The signatures of the onset of deconfinement were reported by the NA49 experiment in the energy scan of central Pb+Pb collisions. This motivated the strong interactions program of the NA61/SHINE experiment, where possible evidences of the energy threshold for deconfinement will be searched in proton+proton, proton+nucleus, and nucleus+nucleus interactions. In this contribution intriguing results will be presented based on NA61/SHINE spectra and yields of identified hadrons obtained in inelastic p+p interactions and centrality selected Be+Be collisions at CERN SPS energies. The NA61/SHINE results will be compared with NA49 ones as well as with model predictions.
Collective flow in high-multiplicity proton-proton collisions

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We present an evidence of strong radial flow in high-multiplicity pp collisions. We analyze the CMS data on the inclusive spectra of the charged pions, kaons and protons in the LHC $\sqrt{s} = 7$ TeV collisions. For $\langle N_{\text{tracks}} \rangle \geq 75$ we demonstrate the consistency of the hydrodynamic description with the (idealized) Gubser flow. Using a one parameter fit of the model to experimental data, we obtain the initial fireball size to be of the order of 1 fm. At smaller multiplicities, the fit cannot be performed which shows a limitation of the hydrodynamic approach and provides us with falsifiability of our theory.

On behalf of collaboration:

Collective flow in small systems from an integrated dynamical model

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Whether hydrodynamic flow is generated in small systems such as p+Pb collisions at LHC and d+Au collisions at RHIC is hotly debated open problem. We analyze these systems by employing a fully 3-dimensional integrated dynamical model [1] in which an initial model with various kinds of fluctuations, hydrodynamic QGP evolution and hadronic transports are incorporated. For this purpose, we develop a novel type of hydrodynamic initialization model by combining an event generator, PYTHIA [2], Brodsky-Gunion-Kuhn type initial nuclear effects [3] and MC-Glauber model. In addition to the fluctuation of transverse profile having been discussed frequently so far, this newly developed model enables us to demonstrate multiplicity fluctuation, longitudinal fluctuations and highly asymmetric longitudinal profile, which have not been available in the conventional MC-Glauber model. Since the size of the system is small and, in turn, the lifetime of the QGP fluid is short, the hadronic afterburner must play a major role in the whole dynamical evolution. So we investigate this by switching on/off the hadronic rescatterings in the integrated dynamical model so that we can quantify how much the hydrodynamic evolution of the QGP is attributed for the observed collective-flow-like behaviors in the experimental data.


On behalf of collaboration:

Poster Session - Board: 0206 / 448

pQCD short path length corrections to (D)GLV energy loss in the QGP
We show the way in which energy is dissipated in the QGP created in high-multiplicity pp and pA collisions by calculating, in pQCD, the short path length corrections to the now well-known DGLV energy loss formulae for massive quarks. Previously neglected terms, exponentially suppressed for large paths, are derived and included in the radiative energy loss formula for the first time; thus our generalization matches onto the usual DGLV formula for large paths but includes additional contributions for small paths. We compute the corrections to $R_{AA}$ at LHC using an energy loss model including the full radiative energy loss formula convolved with collisional energy loss, and we give a first prediction for $R_{pA}$ including final state energy loss.

On behalf of collaboration:

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**Poster Session - Board: 0208 / 250**

**Charged hadron production and two-particle correlations in $^3$He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV measured with PHENIX detector**

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The high $p_T$ hadron suppression caused by the energy loss of partons traversing the hot and dense matter is found to be one of the evidences of Quark-Gluon-Plasma (QGP) formation in high-energy heavy-ion collisions. Measurements in p+A and d+A collision systems have been considered as a control-experiment to study cold nuclear matter effects without QGP formation. However, recent measurements of hydrodynamic flow behavior and long-range angular correlations in p+A, d+A, and high multiplicity p+p collisions have indicated that small but high-density systems could be produced in such collisions, although the minimum bias $R_{AA}$ is about unity. $^3$He+Au collisions have been delivered at RHIC in 2014 in order to perform a systematic study of small systems from p+p and d+Au to $^3$He+Au having different spacial anisotropy of initial states.

In this poster presentation, we report the current status of charged hadron production and two-particle correlation measurements in $^3$He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Obtained results are compared between different collision systems.

On behalf of collaboration:

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**Poster Session - Board: 0209 / 47**

**Scaling Properties of Particle Production, Azimuthal Anisotropy and Two-pion Emission Source Radii in p+p, p+A, d+A and A+A Collisions**

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A crucial open question is whether a fundamental change occurs in the reaction dynamics and the particle production mechanism, when the collision system-size is reduced from the values
produced in central and mid-central A+A collisions, to those obtained in p+p, p+A d+A, and peripheral A+A collisions. This question can be addressed via detailed complementary validation tests for similarities in the reaction dynamics and particle production mechanism in p+p, p+A, d+A and A+A Collisions. The results from complementary scaling tests of particle production, azimuthal anisotropy and two-pion emission source radii in these systems, will be presented and discussed.

On behalf of collaboration:

Poster Session - Board: 0210 / 39

Interacting Ensemble of the Instanton-dyons and Deconfinement Phase Transition in the SU(2) Gauge Theory

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Instanton-dyons, also known as instanton-monopoles or instanton-quarks, are topological constituents of the instantons at nonzero temperature and holonomy. Numerical simulations of the ensemble of interacting dyons has been performed for SU(2) pure gauge theory. The focus is the back reaction on the holonomy and the issue of confinement. The free energy has been calculated as a function of the holonomy and the dyon densities, using standard Metropolis Monte Carlo and integration over parameter methods. It is observed that as the temperature decreases and the dyon density grows, the minimum of the free energy indeed moves from small holonomy to the value corresponding to confinement.

On behalf of collaboration:

Poster Session - Board: 0211 / 723

First measurements of long-range near-side angular correlations in $\sqrt{s_{NN}} = 5$ TeV proton-lead collisions in the forward region

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Two-particle angular correlations are studied in proton-lead collisions at a nucleon-nucleon centre-of-mass energy of $\sqrt{s_{NN}} = 5$ TeV, collected with the LHCb detector at the LHC. The analysis is based on data recorded in two opposing beam configurations, in which either the direction of the proton or that of the lead remnant is analysed. The correlations are measured as a function of relative pseudorapidity, $\Delta \eta$, and relative azimuthal angle, $\Delta \phi$, for events in different classes of event activity and for different bins of particle transverse momentum. In high-activity events a long-range correlation on the near side is observed in the pseudorapidity range $2.0 < \eta < 4.9$. This is the first measurement of a long-range correlation on the near side in proton-lead collisions in the forward region and extends previous observations in the central region. The correlation increases with growing event activity and is found to be more pronounced in the direction of the lead beam. When comparing the proton and lead hemispheres for the same absolute activity the correlation strengths are compatible with each other.

On behalf of collaboration:
The ridges in pp, pPb and PbPb at CMS
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Long-range near-side dihadron correlations have been extensively studied at RHIC and LHC over the past decade in heavy ion collisions. The ridge revealed the collective behavior of particles produced in such collisions. This behavior mainly comes from hydrodynamic properties of the hot medium created, the so-called Quark and Gluon Plasma. Surprisingly, a few years ago, similar features were discovered in high multiplicity events in a small system such as p-p and p-A. Even if the latter one has already revealed its collective properties, the nature of the ridge in p-p collisions remains unknown. Studying the Ridge in small systems is also a good probe to improve our knowledge of initial conditions and its fluctuations. A deeper look into 7 TeV p-p data using CMS detector allowed us to have a better idea about the possible origin of long-range correlations. Furthermore, in light of 13 TeV p-p data this year, we will provide more constraints on potential hydrodynamic properties in small systems. In this poster, results on long-range near-side dihadron correlations are shown at different energies and for different colliding systems using CMS detector. The potential origin of the Ridge in p-p collisions will be discussed.

On behalf of collaboration:

Poster Session - Board: 0213 / 193

The PHENIX MPC-EX pre-shower detector
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The Muon Piston Calorimeter Detector Extension (MPC-EX) is a silicon strip preshower detector recently installed at PHENIX. The MPC-EX detector comprises two arms of eight layers each, which in turn are composed of 2 mm of tungsten and 0.5 mm of Silicon with a pitch of 2 x 15 mm$^2$. Due to its granularity, forward acceptance and complementarity to the MPC calorimeter, it will allow for precise $\pi^0$ and direct photons spectra measurements, jet reconstruction and the quantification of flow observables. Last year, the MPC-EX and MPC detectors’ particle separation power and energy resolution were tested with a monochromatic testbeam of 9 and 12 GeV/c electrons at SLAC. This year, both detectors has succesfully taken data during both p-p and p-Au runs from where we have obtained first results of the performance of the detector in both systems. The MPC-EX detector performance in the testbeam and Run15 is presented here.

On behalf of collaboration:

Poster Session - Board: 0214 / 701

Multiplicity dependence of $\Xi$ production in pp, pPb and PbPb at CMS
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Identified strange and multi-strange particle production has long been considered as an important probe of thermalization and chemical equilibration of the strongly interacting system created in relativistic heavy ion collision. Recently, observations of long-range two-particle correlations in high-multiplicity pp and pPb collisions opened new opportunities for exploring QCD dynamics in small collision systems. These results pose the fundamental question of how small a system can exhibit thermalized behavior. Important parameters that could be varied in these studies are the mass of the particles, their baryon number, and their strangeness content. Multi-strange baryons provide unique probes to test baryon/meson dynamics and strangeness equilibration. The transverse momentum spectra of $\Xi^-$ and $\Xi^+$ at mid-rapidity are studied over a wide range of multiplicity in pp, pPb and PbPb systems using the CMS detector at LHC. The results are compared to the production of other strange mesons and baryons to study the baryon/meson differences and strangeness equilibration as a function of the multiplicity of final-state particles in different collision systems.

On behalf of collaboration:
obtained from multi-particle cumulant analysis is reported. A comparison between p+Pb and Pb+Pb results at matching event activity is performed, showing similarities of the two collision systems.

On behalf of collaboration:

**Poster Session** - Board: 0217 / 616

**Covariant (D)GLV energy loss in proton-lead collisions at the LHC**

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With the assumption that QGP is produced, as well as that its evolution can be modeled by hydrodynamics, we calculate jet radiative energy loss in p+Pb interactions at LHC, using a frame-independent formulation of the (Djordjevic-)Gyulassy-Levai-Vitev approach. In A+A reactions we have shown that covariance matters because compared to the “vanilla” (D)GLV energy loss model it gives about 50% higher \(v_2\) for pions, and also D and B mesons, due to an interplay between jet propagation direction and collective flow of the medium. I will now present results on the nuclear modification factor (R\(_{AA}\)) and harmonic flow (\(v_n\)) in p+Pb collisions at LHC energies. This is especially interesting because hydrodynamics requires high opacities which should then be visible in energy loss. I will discuss whether hydrodynamics in p+A reactions can be reconciled with (D)GLV energy loss and experiments, especially in view of measurements finding R\(_{AA}\) close to unity but with significant \(v_2\) at modestly high \(p_T\).

On behalf of collaboration:

**Poster Session** - Board: 0218 / 213

**Search for long range angular correlations in high-multiplicity p+p collisions at \(\sqrt{s} = 200\) GeV from PHENIX**

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Long range angular correlations have been found in \(d + Au\) and \(^{3}He + Au\) collisions at RHIC energies, and in \(p + p\) and \(p + A\) collisions at LHC energies. To have a better understanding of whether quark-gluon plasma could be formed and collective behavior could arise in small systems motivates this study to see if such correlations also exist in \(p + p\) collisions at RHIC energies. With the implementation of a high-multiplicity trigger using the forward silicon detector (FVTX), the PHENIX collaboration has taken several hundred million high multiplicity events for \(p + p\) collisions at \(\sqrt{s} = 200\) GeV. The correlation results will be shown as a function of transverse momentum and charged particle multiplicity. This poster presents first results on two-particle angular correlations for charged particles emitted in \(p + p\) collisions at center-of-mass energy of 200 GeV.

On behalf of collaboration:

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Flow and correlation measurement in d+Au collisions at √s_{NN} = 200 GeV at PHENIX experiment

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The small collision systems have been considered too small to create hot and dense matter. However, this assumption has been challenged with the recent measurements of elliptic flow and long-range angular correlation in d+Au and p+Pb collisions at RHIC and LHC. In order to understand whether hot and dense matter can be created in small collision systems or not, we have done more detailed measurements of flow and long-range angular correlation. In this poster, we report the measurements of azimuthal correlation between rapidity separated hadrons, and elliptic flow coefficient v₂ for charged hadrons using three methods: event plane method, two particle correlation method and reference fitting method in d+Au collisions at √s_{NN} = 200 GeV. The analysis utilizes PHENIX central arm spectrometers plus various forward detectors with focus on rapidity and rapidity-gap dependence of the extracted elliptic flow coefficients.

On behalf of collaboration:

Poster Session - Board: 0220 / 236

Investigation of collective behaviors in pp and p+Pb collisions at the LHC energies

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Flow measurements in p+Pb collisions at √s_{NN}=5.02 TeV have indicated the development of collective flow in the small systems created at the LHC. Using the ultrarelativistic quantum molecular dynamics (UrQMD) model, we investigate the azimuthal correlations in p+Pb collisions at √s_{NN}=5.02 TeV with two- and four-particle cumulants. Our calculations indicate that pure hadronic interactions can not generate the collective flow as measured in experiments, additional effects from initial state and/or from the QGP are needed to reproduce the flow data[1]. Using the same flow analysis method, we predict the collective flow in pp collisions at √s = 13 TeV with three different baseline calculations, including: 1. UrQMD hadronic cascade simulations with the assumption that high energy pp collisions only create pure hadronic systems, 2. VISHNU hybrid model simulations that connect viscous hydrodynamics for the QGP expansion and UrQMD for the hadron resonance gas evolution, using smooth initial conditions, 3. VISHNU simulations with fluctuating initial conditions. We find that triangular flow (if observed) is one of the unique observable directly associated with the domain structures in the created small pp systems.


On behalf of collaboration:

Poster Session - Board: 0301 / 244

From high-energy collisions to hydrodynamics in strongly coupled non-conformal theories
We use gauge/string duality to model a heavy ion collision in a non-conformal gauge theory. We focus on new physics (as compared to the conformal case) such as the non-trivial equation of state and the presence of a non-zero bulk viscosity. We study the effect of this non-conformality on the hydrodynamization of the system. The gravity model consists of solving numerically the collision of shock-waves with a non-trivial scalar field. We adjust the scalar field potential such that the bulk space-time coincides with AdS in the infrared and in the ultraviolet with different AdS radius. This introduces a non-trivial running of the dual gauge theory coupling constant which we choose at our convenience.

On behalf of collaboration:

Poster Session - Board: 0302 / 128

An Application of the Non-extensive Phenomena: Soft + Hard Model at Various Energies

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Hadron spectra measured in high-energy collisions present distributions which can be derived from the non-extensive statistical and thermodynamical phenomena. Based on earlier theoretical developments, it seems, the methods are very applicable for jets hadronization processes in electron-positron, proton-proton, and even in heavy-ion collisions. Here, we present what can was learnt from the recent theoretical and phenomenological developments: transverse momentum spectra and azimuthal anisotropy (v2) of charge averaged pions, kaons and protons stemming from high-energy collisions form RHIC to LHC energies, which are described analytically in a ‘soft + hard’ model. In this model, we propose that hadron yields produced in heavy-ion collisions are simply the sum of yields stemming from jets (hard yields) in addition to the yields originating from the Quark-Gluon Plasma (soft yields). The hadron spectra in both types of yields are approximated by the Tsallis – Pareto like distribution.

On behalf of collaboration:

Poster Session - Board: 0303 / 162

Collective flow in event-by-event partonic transport plus hydrodynamics hybrid approach

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Complete evolution of the strongly interacting matter formed in ultra-relativistic heavy-ion collisions is studied within a coupled Boltzmann and relativistic viscous hydrodynamics approach [1]. For the initial non-equilibrium evolution phase, we employ a MultiPhase Transport model that explicitly includes event-by-event fluctuations in the number and positions of the participating nucleons as well as of the produced partons with subsequent parton transport. The ensuing near-equilibrium evolution of quark-gluon and hadronic matter is modeled within the (2+1)D relativistic viscous hydrodynamics. (1) We probe the role of parton dynamics in generating and maintaining the spatial anisotropy in the pre-equilibrium phase. Substantial spatial eccentricities $\varepsilon_n$ are found to be generated in the process of parton production from initial NN collisions. (2) For ultra-central heavy-ion collisions, the model is able to explain qualitatively the unexpected hierarchy of the flow coefficients $v_n(p_T)$ ($n = 2 - 6$) observed at LHC. (3) We find that the results for $v_n(p_T)$ are rather insensitive to the variation (within a range) of the time of switchover from AMPT parton transport to hydrodynamic evolution. (4) The usual Grad and the recently proposed Chapman-Enskog-like single-particle distribution functions are found to give very similar results for $v_n(p_T)$ ($n = 2 - 4$). (5) The model describes well both the RHIC and LHC data for $v_n(p_T)$ at various centralities, with a constant shear viscosity to entropy density ratio 0.08 and 0.12, respectively. (6) The event-by-event distributions of $v_{2,3}$ are in good agreement with the LHC data for mid-central collisions. The linear response relation $v_n = k_n \varepsilon_n$ is found to be true for $n = 2, 3$, except at large values of $\varepsilon_n$, where a larger value of $k_n$ is required, suggesting a small admixture of positive nonlinear response even for $n = 2, 3$.


On behalf of collaboration:

Poster Session - Board: 0304 / 549

Probing Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV using spectator neutrons

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The primary goal in heavy ion collision (HIC) experiments is to characterise the properties of the hot and dense strongly interacting matter produced after the collision. A precise comparison between theoretical predictions and experimental data helps to select one theoretical model over another. However, one of the significant challenges in such endeavors is the ignorance of the initial condition at the time of collision. The nuclei being extended objects, there are event by event geometric fluctuations in addition to quantum fluctuations of the nuclear wave function. The standard method of analyzing the collisions in bins of centrality is only able to select events with the initial condition averaged over many possible initial states. In this work, we perform an additional binning in terms of total spectator neutrons in an event. A Multi Phase Transport (AMPT) model has been used in our analysis. We have used the left (L) going and right (R) going spectator neutrons to form the observable $L + R$ that can be measured in experiments using Zero Degree Calorimeters (ZDC). The spectator binning helps us to analyse rarer events whose property usually get masked in the standard analysis with centrality bins. We find that in a given centrality bin, events with different ellipticity can be selected with $L + R$ binning. This serves as a complementary technique to $q_2$-binning to analyse initial event shape. The advantage in using spectators is that they are never part of the fireball produced and hence are pristine carriers of the initial state information. We find that the scaling relation between $v_2/\varepsilon_2$ and $(1/S) dN_{ch}/d\eta$ obeyed by different centrality bins.
is broken by the $L + R$ bins, instead the hydrodynamic response for both centrality as well as $L + R$ bins exhibit scaling with the initial transverse dimension.

On behalf of collaboration:

Poster Session - Board: 0306 / 151

Early quark production and approach to chemical equilib-rium

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We explore how quarks are produced in QCD starting from initial conditions relevant for the early pre-equilibrium phases of heavy-ion collisions. The purpose of our investigation is to determine the overall scale of quark production and to get an insight into spectral properties of non-equilibrium quark distributions. Furthermore, we compare different initial scenarios concerning their influence on the quark sector. Varying the number of light quark flavours we determine the impact of fermionic fluctuations on gluon dynamics in the strongly coupled regime, allowing an insight into parameter region otherwise inaccessible with classical-statistical lattice simulations.

Poster Session - Board: 0307 / 712

LHC and RHIC as Glueball Factories - Pure Gauge 1. Order Phase Transition in pp, pA and AA and direct GlueBall-Hagedorn hadronization

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pp, pA and AA collisions at RHIC, LHC, FCC and in cosmic rays show according to QCD transport theory (Blaizot et al, Biro et al, Alam et al, Shuryak et al, Xu et al, Senzel et al) fast (over)saturation and chemical equilibration of gluons, $t_g \sim 1$ fm/c. In stark contrast, soft light quarks are according to these calculations created much more slowly (saturation times $t_q \approx 3$ fm/c).

Hence, a change of paradigm seems appropriate for describing the initial states of collisions at collider energies:

• the system evolves from a CGC through the Glasma state (McLerran and Venugopalan) -into a saturated pure gauge Yang Mills quarkless gluon plasm.

• This ‘pure’ glue plasma expands until it reaches the 1. Order Phase Transition FOPT with a critical temperature $T_c \approx 270$ MeV to the GlueBall fluid as predicted by pure gauge theory (Svetitsky&Yaffe, Brown et al, Meyer, Borsanyi et al). As expansion continues at $T_c$, the heavy Hagedorn glueballs undergo a sequential two body decay chain directly into the final hadrons, with hadron yield ratios and slopes as observed in pp and AA collisions.
On behalf of collaboration:

**Poster Session** - Board: 0309 / 212

**Thermalization, Isotropization, and Bose-Einstein Condensation in Overpopulated Massive Boson Systems**

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We study the kinetic evolution in dense systems of bosons with overpopulated initial conditions. Two important examples of such systems include (1) the dense gluon system at the early stage of heavy ion collisions and (2) the scalar field system shortly after inflation in the early universe. Common to both systems are the high overpopulation and possible dynamical formation of Bose-Einstein Condensation during the course of thermalization. We perform detailed investigation of both systems by numerically solving the pertinent Boltzmann equations, with elastic scatterings, both before and after the onset of condensation. We report our results and compare the two systems in a number of key aspects: the approach to BEC onset and the critical scaling behavior; the final course of thermalization and the corresponding time scales; the isotropization with anisotropic initial conditions; the isotropization in the longitudinally expanding case; as well as the comparison between classical limit and full quantum treatment of the Boltzmann equations. Finally we discuss the implications of our findings for the thermalization process in heavy ion collisions.

On behalf of collaboration:

**Poster Session** - Board: 0310 / 89

**A Study of Nuclear effects in Drell-Yan and Charmonia Productions in p-A collisions at Fermilab E906/SeaQuest Experiment**

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Strong suppressions of charmonia have been observed in heavy ion collisions at RHIC and LHC. The suppressions exhibit strong nucleus A and also kinematic dependences, especially with Feynman-x (or rapidity) and transverse momentum pT. Such suppression in heavy ion collisions is predicted to be an important signature for the formation of quark-gluon plasma (QGP) due to color screening, however, there are also other non-QGP effects, such as initial state parton energy loss, parton shadowing and final state breakup, that affect the formation of charmonia. It is important to quantify the contributions from the cold nuclear matter, and it could be achieved through studying charmonia and Drell-Yan productions in proton-nucleus collisions where no significant QGP is expected. E906/SeaQuest is a fixed-target dimuon experiment at Fermilab using the 120 GeV proton beam from the Main Injector. E906 has been taking high statistic data samples of p+p, p+d, p+C, p+Fe and p+W collisions since 2014 and will continue data taking until the summer of 2016. E906 measures J/\Psi, \Psi' and Drell-Yan productions in the dimuon channel in p+p and p+A collisions over a wide range of kinematic coverage, that is optimal for the study of the cold nuclear matter effects. Recently, we released the first preliminary measurements of Drell-Yan production in p+A collisions from the 2014 Run-II data. Analyses of J/\Psi and \Psi' productions are underway. In this talk, the latest status of the analyses and preliminary results will be presented.
Anisotropic hydrodynamics for a mixture of quark and gluon fluids

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Relativistic hydrodynamics has been a fundamental tool to understand the evolution of matter in heavy-ion experiments at RICH and LHC. Despite the success of second order viscous hydrodynamics in reproducing collective behavior and particle spectra, there are still theoretical shortcomings that may question the validity of the approach in heavy-ion experiments conditions. Large gradients and fast longitudinal expansion produce very large pressure corrections, in contrast to the founding hypothesis of small deviation from local equilibrium and the perturbative treatment viscous corrections. One way to address this problem is anisotropic hydrodynamics. Most of the theoretical investigations about hydrodynamics started from a kinetic underlying substrate of a single species of particles. Unfortunately the striking agreement of anisotropic hydrodynamics with the exact solution of the Boltzmann equation was not preserved in the case of a mixtures of quarks and gluons. We recently extended the anisotropic hydrodynamics prescription for massless particles in 1+1-dimensions to the case of mixtures of fluids, largely improving the agreement with the exact solutions compared to previous works [1-3]. We allow quarks and gluons to have different momentum scales during the evolution and a non vanishing baryon chemical potential. We take the dynamical equations from the zeroth, the first and the second moment of the Boltzmann equation [4]. We performed a test of the new formulation, comparing the results of anisotropic hydrodynamics with the exact solution of the Boltzmann equation for a mixture of fluid in the Bjorken flow limit, finding a very good agreement [5]. [1] W.Florkowski, R.Maj, R.Ryblewski, M.Strickland, Phys.Rev.C87 (2013) 3, 034914. [2] W.Florkowski, R.Maj, Acta Phys.Polon.B44 (2013) 10, 2003-2017.[3] W.Florkowski, O.Madetko, Acta Phys.Polon.B45 (2014) 1103. [4] L.Tinti, W.Florkowski, Phys.Rev.C89 (2014) 3, 034907. [5] W.Florkowski, E.Maksymiuk, in progress

Radiative 3<->2 transport and thermalization

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The mechanism of rapid thermalization in heavy-ion reaction is still an open problem. While 2<->2 perturbative QCD rates do not thermalize sufficiently fast (e.g., Molnar & Gyulassy anno 2000), it has been claimed a decade ago by Xu & Greiner using their BAMPS code that perturbative 3<->2 rates shorten thermalization time-scales in A+A at RHIC and LHC energies to 1 fm/c or smaller. Later it has been argued, however, (e.g., Deng et al) that
the BAMPS calculation may have missed the rates by a factor of 3!=6. We investigate the thermalization question using the transport code MPC/Grid, which algorithmically is quite similar to BAMPS (it has scatterings implemented via sampling test particles in small spatial cells in discrete timesteps). The new code has been verified against every analytic test we could think of, and in 2->2 mode also against earlier A+A results from the geometric MPC/Cascade code. On one hand, we do find that the inclusion of 3<->2 rates speeds up thermalization very significantly, however, the rates are still not as high as those published from BAMPS. The difference in 3<->2 rates, however, is not simply a factor of 6 even when we try to reproduce their calculation exactly. On the other hand, we do find that the 3<->2 rates are very sensitive to how screening and the LPM effect are implemented. Results from MPC/Grid for collective flow in A+A reactions will also be discussed.

On behalf of collaboration:

Poster Session - Board: 0313 / 405

New parameteric model for entropy deposition in ultrarelativistic nuclear collisions

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Hybrid models based on hydrodynamics and Boltzmann transport provide a powerful tool to extract properties of the strongly coupled quark-gluon plasma produced in the first fm/c of ultrarelativistic nuclear collisions. The largest source of uncertainty in these model-to-data extractions is the choice of theoretical initial conditions used to model the distribution of entropy (energy) at the hydrodynamic thermalization time. In this work we adopt a data driven approach and introduce a new parametric initial condition model that is constrained by systematic model-to-data comparison [1412.4708]. Starting from a participant nucleon model, we eschew binary collision scaling and parameterize the mapping from participant nucleon density to entropy deposition using a family of functions known as generalized means. These functions — described by a single continuous parameter — interpolate between the minimum and maximum of the local participant thickness functions and reduce to well known harmonic, geometric and arithmetic means for certain special cases. We demonstrate that this new ansatz is flexible and can be used to emulate a broad class of initial condition models which are not described by a two-component wounded nucleon and binary collision parameterization. The model is then embedded in a state of the art hybrid simulation, and Bayesian model-to-data comparison is used to constrain initial state and medium properties simultaneously [1502.00339]. We compare results to measured flows, spectra and charged particle multiplicities and discuss implications for first principle initial condition calculations.

On behalf of collaboration:

Poster Session - Board: 0314 / 148

Analytical solution of the nonlinear relativistic Boltzmann equation in the early universe and the thermalization of expanding systems

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In this talk we present a general method for computing exactly the nonlinear collision term of the relativistic Boltzmann equation for a homogeneous and isotropic system [1]. This is used to find the first full analytical solution of the nonlinear Boltzmann equation for an expanding system corresponding to the primordial matter in the early universe. This solution is used to investigate (in an analytical manner) how thermalization is reached in rapidly expanding kinetic systems. We also determine whether this expanding system displays a nontrivial scaling solution corresponding to a nonthermal fixed point.

Reference:

Quark production in heavy ion collisions
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In this work we study the production of quarks and antiquarks in the early stages of heavy ion collisions, in the Color Glass Condensate framework. To this effect, we express the single inclusive quark spectrum in terms of a basis of mode functions of the Dirac equation in the presence of a classical color background field. In order to fully exploit the longitudinal boost invariance of this problem, we use a basis in which the mode functions are labelled by the Fourier conjugate $\nu$ of the spatial rapidity. This choice has also the virtue of being suitable for a lattice implementation in which the rapidity $\eta$ is used as longitudinal coordinate. We have derived analytic expressions for the initial value (at $Q_s \tau_0 \ll 1$) of these mode functions, and based on them we will present preliminary results for the spectrum of produced quarks in the CGC.


On behalf of collaboration:

Poster Session - Board: 0317 / 541

Quark Pair Production from Expanding Electromagnetic Flux Tube

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Just after a collision of ultra-relativistic heavy ions, there appear strong color electromagnetic flux tubes. It is commonly believed that the electromagnetic flux tubes decay into a huge number of particles to form the quark-gluon plasma, however, its physical mechanics is not well understood.

We discuss the quark production from an expanding electromagnetic flux tube based on the Schwinger mechanism. Emphasis is put on the effects of the expanding geometry and/or the existence of magnetic fields in addition to electric fields. In the first part of this presentation, we analytically compute the time evolution of the produced quarks by ignoring their backreaction to the electromagnetic flux tube, and show that (i) the quark distribution is consistent with the Schwinger formula for small transverse mass $m_T$, but it has a power-dependence $m_T^{-4}$ for large transverse mass $m_T$; (ii) the higher Landau level contributions are not exponentially suppressed. In the second part of this presentation, we take into account the backreaction effects by using numerical and/or model calculations, and discuss their phenomenological consequences in the formation of the quark-gluon plasma.

On behalf of collaboration:

Poster Session - Board: 0318 / 295

Low Vector meson production in p+p collisions at $\sqrt{s} = 510$ GeV in PHENIX and dependence of $\phi$ production cross section from RHIC to LHC energies

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Low mass vector mesons ($\rho, \omega$ and $\phi$ ) provide important information on the hot and dense state of strongly interacting matter produced in heavy ion collisions. Among them, strangeness enhancement, a phenomenon associated with soft particles in the bulk matter, can be accessed
through the measurement of the ratio $\phi/(\rho + \omega)$. Low mass vector meson production in p+p collisions provides a reference for this study. In addition, vector meson production in p+p collisions is an important tool to study QCD, providing data to tune soft phenomenological QCD models and to compare to hard pQCD calculations.

The PHENIX experiment at RHIC is capable of studying low-mass vector meson production with two muon spectrometers covering the rapidity range $1.2 < |y| < 2.2$, offering a complementary measurement to the one done at mid-rapidity.

In this poster we report the latest PHENIX results on the measurement of differential cross sections, $p_T$ and rapidity dependencies of $(\rho + \omega)$ and $\phi$ mesons production in p+p collisions at $\sqrt{s} = 510$ GeV based on the data sample collected in 2013. Forward rapidity $\phi$ production cross section was measured in p+p collisions at RHIC and LHC energies. The status of the comparison study of those experimental results to model calculation is presented.

On behalf of collaboration:

Poster Session - Board: 0319 / 2

Initial state elliptic flow from instabilities of saturation dynamics

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We argue that heavy ion data, taken as a whole, presents scaling patterns (the scaling of $v_2$ between large and small systems, the scaling of $v_2$ with multiplicity across energies, the near energy-independence of $v_2(p_T)$, the presence of photon $v_2$) which look too simple to be described by a non-linear multi-parameter theory such as hydrodynamics.

In particular, we remark that such scaling behavior resembles the approximate Bjorken scaling of parton distribution functions, and could be naturally explained if “somehow”, parton distribution functions acquired an angular dependence.

We speculate on how this could occur, focusing on the stability structure of the GLR (Gribov-Levin Ryskin equation) when its full 2+1 dimensional structure is considered. Via a linearized solution, we isolate a regime in which azimuthal perturbations grow with $\ln(1/x)$.

On behalf of collaboration:

Poster Session - Board: 0320 / 160

Entropy production in the early stage of relativistic heavy ion collisions

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The problem of early thermalization is a theoretical challenge in relativistic heavy ion collisions. There are many proposals for pinning down the underlying mechanics for it. Immediately after a collision, which is a crucial stage of the problem, strong gluon field is dominant and quantum fluctuations on the top of the classical configurations (glasma) induce instabilities. It may trigger the chaotic behavior of the gauge field and eventually give rise to entropy production.
production. In this work, we investigate thermalization of glasma by using the Husimi-Wehrl (H-W) entropy defined by Husimi function which is a coarse-grained quantum distribution function. We calculate the semi-classical time evolution of the Husimi function and the H-W entropy in Yang-Mills field theory with two numerical methods based on Monte-Carlo method, and also discuss the time scale of the entropy growth.

On behalf of collaboration:

Poster Session - Board: 0321 / 334

Parametric instabilities in nonexpanding and expanding geometries

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We investigate parametric instabilities of classical gluon fields in nonexpanding and expanding geometries. Plasma instabilities play an important role in thermalization. Since the glasma initial condition consists of longitudinally polarized color-flux tubes, possible instabilities should reflect this background. Recently, classical gluon fields in a nonexpanding geometry are found to show parametric instability under a longitudinally polarized background with homogeneous intensity [1]. The growth rates of low momentum modes are large enough compared with other instabilities proposed so far. The rapid growth is caused by the spin-magnetic field interaction. Surprisingly, parametric instability survives even in an expanding geometry [2]. We introduce the conformal coordinates which enable us to map an expanding problem into a nonexpanding problem. We find that fluctuations with finite longitudinal momentum can grow exponentially due to the suppression of effective momenta coming from the longitudinal expansion. We also discuss the relevance of the parametric instability to the early stage dynamics.


On behalf of collaboration:

Poster Session - Board: 0322 / 518

Baryon Number Fluctuations and Quark Correlations in the CGC Framework

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We calculate the two particle correlation function for the net baryon number fluctuations using the saturation/Color Glass Condensate (CGC) framework in proton-nucleus and heavy-light ion collisions. We show that the main contribution to the net baryon number fluctuations at mid-rapidity comes from $q\bar{q}$ pair production in the transverse plane. There are three intrinsic length scales associated with this process: the transverse size of the baryon fluctuation $r_\perp$, the inverse of the saturation scale $Q_s^{-1}$ and the inverse of the mass $M^{-1}$ for heavy massive quarks. We identify two regimes determined by the dominant scale $R_{\text{max}} = \max(Q_s^{-1}, M^{-1})$ and discuss in detail the properties of each regime as one varies the transverse scale of the baryon fluctuation $r_\perp$. In proton-nucleus collisions the net baryon correlation function is
suppressed when \( r_\perp > R_{\text{max}} \), while for heavy-light ion collisions this correlation extends up to the typical transverse size of the nucleus. These baryon number fluctuations generate non-trivial correlations which may propagate into the subsequent hydrodynamical evolution of the expanding fireball.

On behalf of collaboration:

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**Poster Session - Board: 0323 / 30**

**A critical reassessment of cold nuclear matter effects in proton-nucleus collisions at RHIC and LHC**

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Recent results from the p+Pb run at the LHC on light hadron, heavy flavor, and jet production reveal highly non-trivial nuclear cross section modifications, when compared to p+p collisions. These discoveries complement similar earlier findings from d+Au reactions at RHIC. In this talk we present recent calculations and theoretical interpretation for two such examples - the nuclear enhancement for heavy meson production in the backward rapidity region and single inclusive jet production in both d+Au and p+Pb collisions. We demonstrate that the incoherent multiple parton scattering can describe rather well the observed Cronin-like nuclear enhancement in the intermediate \( p_T \) region of heavy meson production at RHIC and the LHC [1,2]. On the other hand, we show that initial-state inelastic parton processes in p+A collisions lead to attenuation of the jet production cross section, which is amplified at very high \( p_T \) and forward rapidity. We demonstrate quantitatively to what extent parton energy loss effects in cold nuclear matter can explain the attenuation of the recently observed jet production yields in p(d)+A reactions at RHIC and the LHC [3]. We further show the consistency between the observed scaling behavior of the nuclear modification factor as a function of the jet energy and the initial-state parton energy loss picture.


On behalf of collaboration:

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**Poster Session - Board: 0324 / 233**

**Implementing the exact kinematical constraint in the saturation formalism**

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It is fairly well established by now that the single inclusive \( pA \rightarrow h + X \) cross section, when calculated in the saturation model up to next-to-leading order, becomes negative at high \( p_\perp \). We improve this calculation by incorporating the exact kinematical constraint in the dipole splitting functions, obtaining two additional terms which help offset the negativity. In doing
so, we are able to extend the applicability of the saturation formalism to higher \( p_T \), where it can be more accurately matched with the collinear factorization result. Furthermore, with an enhanced numerical implementation, we are able to present a comparison to single inclusive hadron production measurements from both RHIC and, for the first time, the LHC. We find excellent agreement with the data throughout the range of validity of our calculation.

On behalf of collaboration:

**Poster Session** - Board: 0402 / 165

**Breaking the degeneracy of hard+soft modelling**

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Current freedom to adjust competing effects of the jet-medium coupling, the jet-path length, eccentricities, and fluctuations make it difficult to decide between pQCD tomographic or AdS holographic paradigms. We test jet tomographic and holographic models in a broad range of state-of-the-art event-by-event fluctuating bulk sQGP background evolutions and compare predictions of leading-hadron fragment and reconstructed jet-nuclear modifications factors as well as high-\(p_T\) azimuthal harmonics. New measures of other jet correlation observables will be suggested to help break the current degeneracy of hard+soft modelling.

On behalf of collaboration:

**Poster Session** - Board: 0403 / 531

**High \( p_T \) Charged Hadron Spectrum in Au+Au Collisions at 200 GeV as Measured by PHENIX**

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The suppression of single hadrons still provides one of the strongest constraints on energy loss mechanisms in the Quark-Gluon Plasma. At RHIC, neutral pions have provided the best measurement of single particle suppression to date. Charged hadrons have independent sources of systematic uncertainty and can thus provide additional constraints. At PHENIX, the measurement of charged hadrons has been limited to \( p_T < 10 \) GeV/c by off-vertex background from photon conversions and weak decays mimicking high \( p_T \) particles. The silicon vertex tracker upgrade (VTX) will be used to reject this background allowing the measurement of the charged hadron spectrum out to a significantly higher momentum. The VTX is capable of performing precision tracking measurements of the distance of closest approach of a track to the primary vertex (DCA). Off-vertex photon conversions and weak decays are vetoed with the VTX by rejecting tracks with large DCA. The status of high-\(p_T\) charged tracking and associated high-\(p_T\) charged hadron spectrum will be reported.

On behalf of collaboration:

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**Poster Session** - Board: 0404 / 264

**Full jet evolution in quark-gluon plasma and nuclear modification of jet structure in Pb+Pb collisions at the LHC**

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We study the evolution of full jets in quark-gluon plasma (QGP) via solving a set of coupled differential transport equations for the three-dimensional momentum distributions of quarks and gluons contained in the full jet shower. In our jet evolution equations, we include all partonic splitting processes in the dense nuclear medium. We also include the collisional energy loss and transverse momentum broadening for both leading and radiated partons of the full jets due to elastic collisions with the medium constituents. We keep track of both the energies and the transverse momenta of all partons within the full jet shower, thus the modification of both jet energy and jet structure due to jet-medium interaction can be studied straightforwardly. Combining with realistic (2+1)-dimensional viscous hydrodynamic calculation for the space-time profile of the hot and dense nuclear medium produced in Pb+Pb collisions, we apply our formalism to calculate the nuclear modification of single inclusive jet spectra, and the momentum imbalance of photon-jet and dijet pairs at the LHC. The jet shape function and jet fragmentation function (at the partonic level) are also studied for the quenched/modified jets in Pb+Pb collisions at the LHC. We further present the detailed studies on the roles of various jet-medium interaction mechanisms on the modification of jet structure.

On behalf of collaboration:

Poster Session - Board: 0405 / 50

Towards a Unified Picture of Jet Modifications in the QGP Using Soft-Collinear Effective Theory

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Theoretical investigations and experimental measurements of jet substructure modifications in heavy ion collisions allow us to disentangle cold nuclear matter effects and jet-medium interactions in the quark-gluon plasma, providing a direct probe of the QGP properties. Precision calculations of jet substructure observables will thus become the key to extracting the medium properties. Jet shapes and jet fragmentation functions give the transverse and longitudinal energy profiles inside jets and are sensitive to the jet formation mechanism in the medium. In this talk we will demonstrate the resummation of jet shapes at next-to-leading logarithmic accuracy using Soft-Collinear Effective Theory. This is the first time phase space logarithms in this observable are resummed using renormalization group techniques. We will then present the calculation of jet shape modification in heavy ion collisions caused by Glauber gluon interactions in the background QGP medium. The study of jet shape modification is closely related to the calculation of jet energy loss. Taken together, these observables provide a comprehensive description of the energy distribution of the in-medium parton shower. We will show first results for the modifications of jets beyond the soft gluon emission limit for 2.76 TeV Pb+Pb collisions at the LHC and present predictions for the 5.1 TeV Pb+Pb run.


On behalf of collaboration:

Poster Session - Board: 0406 / 240

Medium-induced jet energy loss and flavor conversion in e+A

Author(s): Dr. CHANG, Ning-Bo ¹
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The jet produced in QCD medium will suffer multiple scatterings and induced parton splitting process. This process lead to not only energy loss of leading partons but also convert its flavor to others due to induced gluon and quark pair production. As a consequence, beside the suppression of leading hadron spectra, the flavor compositions of a jet should be modified. Through a numerical study of the medium-modified QCD evolution, the leading K^+ strange meson spectra are found to be particularly sensitive to the induced flavor conversion in e+A collisions. This conversion can lead to increased number of gluons and sea quarks in a jet and enhance the K^+ spectra to counter the effect of energy loss with large momentum fractions x_B where the struck quarks are mostly valence quarks of the nucleus.

On behalf of collaboration:

**Poster Session - Board: 0408 / 129**

**Unravelling Medium Effects in Heavy Ion Collisions with Zeal**

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Strong medium effects seen in the suppression of R_{CP} in RHIC data are also visible in the recent LHC data. Constructing jets explicitely in heavy ion collisions, similar ratios for jets have also been constructed, and display suppression as well. The latter are theoretically more appealing for studies of jet quenching. However, the corresponding results appear to depend on cone radius, and perhaps background subtraction. We propose a new observable, called zeal, to characterize jets for analysis in heavy ion collisions. Zeal measures how the thermal medium affects the multiplicity and distribution of energetic particles in a jet, and is designed to be minimally dependent on cone radii or the underlying background. Toy models are used to illustrate these properties.

On behalf of collaboration:

**Poster Session - Board: 0409 / 453**

**Transverse momentum distribution of charged particles in pp collisions at \( \sqrt{s} = 13 \, TeV \) with ALICE at the LHC**

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A measurement of the transverse momentum distribution of charged particles in pp collisions at \( \sqrt{s} = 13 \, TeV \) was performed using the ALICE detector at the LHC. Charged particles were reconstructed in a pseudorapidity range \( |\eta| < 0.8 \) and with transverse momenta down to \( p_T = 150 \, MeV/c \). The results are compared to the previous ALICE measurements at lower collision energies, as well as to model calculations.

On behalf of collaboration:
**Poster Session** - Board: 0410 / 267

**Direct-photon hadron correlations in d+Au with PHENIX**

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Measurements of direct photon tagged jets, in the form of photon-hadron correlations, are unique as an experimental tool for gaining access to the initial parton kinematics in a hard scattering. Once produced, these photons will not interact strongly with the medium produced in heavy-ion collisions, providing a calibrated measure of the pre-energy loss properties of the opposing parton and giving unique insight into how jets interact with the quark-gluon plasma (QGP). To understand the observed modification to jets opposite a direct photon, it is necessary to make similar base-line measurements within a reference system. Previously this was done using p+p collisions, however cold nuclear matter effects may also play a role, making similar baseline measurements in d(p)+A important. Additionally, recent results from d+Au and p+Pb suggest that there may be medium-like effects present, making clean measurements of the initial parton energy in a hard scattering crucial. We present the most recent results for direct photon-hadron correlations in d+Au from PHENIX.

On behalf of collaboration:

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**Poster Session** - Board: 0411 / 241

**Linear Boltzmann Transport for Jet Propagation in the Quark-Gluon Plasma: Medium-induced Gluon Radiations and Medium Recoil**

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A Linear Boltzmann Transport model within perturbative QCD is developed for the study of parton propagation inside the quark-gluon plasma. Our previous work has shown that thermal recoil partons have significant influences on jet shape, fragmentation functions and angular distribution of reconstructed jets [Nucl. Phys. A931 (2014) 460-464; Nucl. Phys. A932 (2014) 99-104; Phys. Rev. C91 (2015) 054908]. In this study, we implement the medium-induced gluon radiation processes and find the radiative contribution dominates over the elastic one. For both situations, we investigate parton energy loss, transverse momentum broadening and their nontrivial energy and length dependence. All partons, including leading partons, thermal recoil partons and the radiated gluons, are tracked so that one can also study jet-induced medium excitations. We further investigate medium modifications of the jet shape and fragmentation functions of reconstructed jets.

On behalf of collaboration:

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**Poster Session** - Board: 0412 / 291
Characterizing the away-side jet, devoid of flow background, via two-particle and three-particle correlations in \( \text{Au}+\text{Au} \) collisions at \( \sqrt{s_{NN}} = 200 \) GeV in STAR

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Jets are modified in relativistic heavy-ion collisions due to jet-medium interactions. Measurements of jet medium modifications have so far been obscure because of the large underlying anisotropic flow background. In this analysis we devise a novel method to subtract the flow background using data themselves. We select events with a large recoil momentum \( (P_x) \) within a pseudorapidity \( (\eta) \) window of \( 0.5 < \eta < 1 \) \( (-1 < \eta < -0.5) \) from a high-\( p_T \) trigger particle to enhance the away-side jet population. Di-hadron azimuthal correlations are analyzed with associated particles in two \( \eta \) ranges \( (-0.5 < \eta < 0 \) and \( 0 < \eta < 0.5 \) ) symmetric about midrapidity, one (close-region) close to and the other (far-region) far away from the \( P_x \) selection \( \eta \) window. The away-side jet contributes to the “close-region” but not as much to the “far-region” due to the large \( \eta \) gap, while the flow contributions are equal. Assuming the \( \Delta \phi \) shape of jet-like correlations does not depend on \( \Delta \eta \), the correlation difference measures the away-side jet shape where the anisotropic flow background is cleanly subtracted.

The away-side jet correlation width is studied as a function of centrality and associated particle \( p_T \). The width is found to increase with centrality at modest to high associated particle \( p_T \). The increase can arise from jet-medium modifications, event averaging of away-side jets deflected by medium flow, and/or simply nuclear \( k_T \) broadening. To further discriminate various physics mechanisms, a three-particle correlation analysis is conducted with robust flow background subtraction also using data themselves. Based on this analysis we discuss possible physics mechanisms of away-side broadening of jet-like correlations.

On behalf of collaboration:

Heavy flavored jet modification in CMS

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The energy loss of jets in heavy-ion collisions is expected to depend on the flavor of the fragmenting parton. Thus, measurements of jet quenching as a function of flavor place powerful constraints on the thermodynamical and transport properties of the hot and dense medium. Measurements of the nuclear modification factors of the heavy-flavor-tagged jets (from charm and bottom quarks) in both PbPb and pPb collisions can quantify such energy loss effects. Specifically, pPb measurements provide crucial insights into the behavior of the cold nuclear matter effect, which is required to fully understand the hot and dense medium effects on jets in PbPb collisions. In this talk, we present the heavy flavor jet spectra and measurements of the nuclear modification factors in both PbPb and pPb as a function of transverse momentum and pseudorapidity, using the high statistics pp, pPb and PbPb data taken in 2011 and 2013. Finally, we also will present a proposal for c-jet tagging methodology to be used for the upcoming high-statistics heavy-ion run in late 2015 at the LHC.

On behalf of collaboration:

Mechanisms of jet quenching in PbPb collisions at the LHC
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The LHC data on various high transverse momentum hadron and jet observables (nuclear modification factors for inclusive hadrons and jets, jet fragmentation function and jet shapes, D-meson and b-jet spectra) in PbPb collisions at center-of-mass energy 2.76 TeV per nucleon pair are analyzed and interpreted within PYQUEN jet quenching model. Selfconsistent jet quenching pattern is obtained with PYQUEN simulations taking into account wide-angle radiative and collisional partonic energy loss. The contribution of radiative and collisional energy loss mechanisms to the medium-modified jet characteristics is dicussed.

On behalf of collaboration:

Poster Session - Board: 0415 / 708

A Spacetime description of Hard Parton evolution in the QGP

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Typical energy loss calculations in AdS/CFT simulations use an initial condition of off-shell pairs of quarks placed back-to-back in the QGP, but a precise and theoretically motivated description of this does not exist.

Quark virtuality can have noticeable effects on the rate of energy loss so a first principals calculation is needed for the early time behaviour of virtual particles soon after production. We use the Schwinger Keldysh formalism to calculate a perturbative expression for the Energy Momentum Tensor of hard partons created before the formation of the Quark Gluon Plasma. We propose this as a foundational model to use in jet energy loss.

On behalf of collaboration:

Poster Session - Board: 0416 / 636

Light flavor jets in strongly coupled plasma

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We present the first, and so far only, fully strongly coupled prediction for jet suppression at LHC and show that our result is in qualitative agreement with preliminary CMS and published ATLAS data. Along with the famous AdS/CFT results for the bulk properties of quark-gluon plasma, for example the 1/4\pi viscosity to entropy density ratio, and the recent next-to-leading order strong-coupling heavy flavor energy loss calculations, we claim that strong coupling provides a coherent, self-consistent model for the dynamics of the sQGP created in heavy ion collisions.

In our investigations into strong coupling light flavor energy loss, we found that the results are extremely sensitive to the initial conditions of the string in AdS space. We thus refine
our calculation by creating a hybrid strong/weak model in which the initial conditions for the AdS/CFT equations of motion are constrained by early time pQCD jet physics.

On behalf of collaboration:

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Poster Session - Board: 0417 / 451

$K^*(892)^0$ production at high transverse momentum in pp and Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

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The ALICE experiment has unique particle-identification capabilities allowing one to identify pions, kaons and protons over a wide momentum range through the measurements of their specific energy loss in the Time Projection Chamber (TPC) and of their velocity in the Time-Of-Flight (TOF) detector. Hadronic resonances can therefore be successfully reconstructed via invariant mass analysis of the daughter particles in the hadronic decay channels. The measurement of the production of the $K^*(892)^0$ resonance in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and pp collisions at $\sqrt{s} = 2.76$ TeV is reported. The yield of $K^*(892)^0$ at high $p_T$ is observed to be suppressed in Pb-Pb relative to pp collisions due to the effect of parton energy loss in the hot and dense medium created in nuclear collisions. This has been studied via the measurement of the $K^*(892)^0$ nuclear modification factor ($R_{AA}$). Further understanding on the particle production mechanism can be provided by the measurement of the particle ratios $K^*/K$ and $\phi/K$ over a wide transverse momentum ($p_T$) range.

On behalf of collaboration:

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Poster Session - Board: 0418 / 194

Azimuthal anisotropies of reconstructed jets in Pb + Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in a multiphase transport model

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Azimuthal anisotropies of reconstructed jets $[v_n^{\text{jet}}(n = 2, 3)]$ have been investigated in Pb + Pb collisions at the center of mass energy $\sqrt{s_{NN}} = 2.76$ TeV within a framework of a multiphase transport (AMPT) model. The $v_2^{\text{jet}}$ is in good agreement with the recent ATLAS data. However, the $v_3^{\text{jet}}$ shows a smaller magnitude than $v_2^{\text{jet}}$, and approaches zero at a larger transverse momentum. It is attributed to the path-length dependence in which the jet energy loss fraction depends on the azimuthal angles with respect to different orders of event planes. The ratio $v_n^{\text{jet}}/e_n$ increases from peripheral to noncentral collisions, and $v_n^{\text{jet}}$ increases with the initial spatial asymmetry ($e_n$) for a given centrality bin. These behaviors indicate that the $v_n^{\text{jet}}$ is produced by the strong interactions between jet and the partonic medium with different initial geometry shapes. Therefore, azimuthal anisotropies of reconstructed jet are proposed as a good probe to study the initial spatial fluctuations, which are expected to provide constraints on the path-length dependence of jet quenching models.

On behalf of collaboration:
Measurement of neutral pions in $p$-$Pb$ collisions at $\sqrt{s_{NN}} = 5.02$ TeV in ALICE at LHC

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Strong suppression of high $p_T$ particles has been observed in heavy-ion collisions at LHC energies, which can be interpreted by various processes involving transport properties of the QCD medium and the initial state effect. Proton-nucleus ($p$-$A$) collisions are intermediate between proton-proton ($pp$) and nucleus-nucleus ($A$-$A$) collisions in terms of system size and number of produced particles. Comparing particle production in $pp$, $p$-$A$, $A$-$A$ reactions has frequently been used to separate initial state effects of colliding nuclei from final state effects in quark matter created by the collisions. We have measured neutral pions emitted in $p$-$Pb$ collisions at $\sqrt{s_{NN}} = 5.02$ TeV with PHOS at the ALICE experiment. The PHOS is a unique and precise photon spectrometer composed of lead-tungstate crystals. With its outstanding performances of fine granularity and high energy resolution, neutral pions can be identified via two photon decays at an excellent mass resolution $\sigma_m/m = 3\%$. Raw yields of pions out of a 90 million minimum-bias event sample were counted in invariant mass spectra. We will present the current status and results of the analysis.

On behalf of collaboration:

The new C++ based HIJING event generator: HIJING++

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The popular HIJING event generator is redesigned to match the compatibility with ALIROOT and is rewritten to C++. We review here the design of the C++ interface and the connections to the PYTHIA 8 event generator. Furthermore, with the development new physics is also introduced, like the inclusion of new particle distribution functions, the DGLAP evolution of the shadowing effect, different jet-quenching models.

On behalf of collaboration:

Violations of geometric scaling in the production of high-$p_T$ jets in 200 GeV d+Au collisions with the PHENIX detector

PEREPELITSA, Dennis Vadimovich$^5$
Recent measurements of high-$p_T$ jet and dijet production in centrality-selected proton–lead collisions at the LHC are observed to grossly violate geometric models of the relationship between jet production at mid-rapidity and soft particle production in the nuclear fragmentation region. These modifications have been, variously, attributed to the suppression of soft gluons in proton configurations with a high Bjorken-$x$, taken as a direct observation of proton color fluctuations, or interpreted as the result of a rapidity-separated energy conservation between soft and hard processes. This poster reports the measurement of high-$p_T$ jet production in 200 GeV deuteron–gold and proton–proton collisions by the PHENIX experiment at RHIC. Fully corrected invariant yields and spectra are presented for jets at mid-rapidity covering the wide kinematic range $12 \text{ GeV/}c < p_T < 50 \text{ GeV/}c$. The nuclear modification factor $R_{dAu}$ for minimum bias collisions is consistent with unity. However, the centrality-selected $R_{dAu}$ shows substantial deviations from unity, with a qualitative pattern similar that observed at the LHC albeit at a smaller $p_T$. These measurements provide crucial new information for understanding the anomalous relationship between hard and soft processes in $p/d+A$ systems.

On behalf of collaboration:

**Poster Session** - Board: 0422 / 142

**Forward di-jet production in dilute-dense collisions**

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We propose a factorization formula for the cross section for forward di-jet production in dilute-dense collisions. The new formula is applicable for an arbitrary value of the momentum imbalance of the two jets, $k_t$. This generalizes the transverse momentum dependent (TMD) factorization formula that has been derived before by Dominguez et al. Their formula is valid only for small values of the transverse momentum of the small-$x$ gluon from the target; it has TMD gluon distributions, but on-shell hard matrix elements. We extend their formula to all ranges of $k_t$ by including off-shell matrix elements. We also add finite $N_c$ corrections. The derivation is done with a standard Feynman diagram technique, and, independently, with a color ordered amplitudes method. The new formula encompasses both, the TMD factorization for small $k_t$ on the order of the saturation scale, and the High Energy Factorization (HEF) for large $k_t$ on the order of the momentum of the jets. The TMD and HEF factorizations can be derived from the Color Glass Condensate (CGC) formula for forward di-jet production in the appropriate limits. We show explicitly the equivalence of HEF and CGC in the dilute target approximation.

On behalf of collaboration:

**Poster Session** - Board: 0423 / 702

**Mesurement of Heavy flavored jet modification and heavy flavor jet tagging in CMS**

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The energy loss of jets in heavy-ion collisions is expected to depend on the flavor of the fragmenting parton. Thus, measurements of jet quenching as a function of flavor place powerful constraints on the thermodynamical and transport properties of the hot and dense medium. Measurements of the nuclear modification factors of the heavy-flavor-tagged jets (both from charm and bottom quarks) in both PbPb and pPb collisions can quantify such energy loss effects. Specifically, pPb measurements provide crucial insights into the behavior of the cold nuclear matter effect, which is required to fully understand the hot and dense...
medium effects on jets in PbPb collisions. In this talk, we present the b-jet spectra and measurements of the nuclear modification factors in both PbPb and pPb as a function of transverse momentum and pseudorapidity, using the high statistics pp, pPb and PbPb data taken in 2011 and 2013. Finally, we also will present a proposal for c-jet tagging methodology to be used for the upcoming high-statistics heavy-ion run in late 2015 at the LHC.

On behalf of collaboration:

Poster Session - Board: 0424 / 125

Nuclear modification of jet structure in proton-lead collisions at the LHC

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The collective anisotropic flows observed in high-multiplicity proton-lead collisions at the LHC and the agreement with hydrodynamic calculations strongly support that a hot and dense QGP may be formed in such small collisions systems. However, the current experimental measurement showed no indication of nuclear modification on the production of large transverse momentum hadrons and jets in minimum-bias proton-lead collisions. As is well known, jet quenching has been one of the most important evidences for the formation of QGP in relativistic nucleus-nucleus collisions at RHIC and the LHC. Thus, the search for the signature of jet modification is essential to our understanding of high-multiplicity proton-lead collisions at the LHC.

We study the nuclear modification of full jets and their structure in proton-lead collisions at the LHC. The evolution of full jet shower in dense QCD matter is simulated via a pQCD-based Monte-Carlo transport model which includes the medium effects from both radiative and collisional processes. The space-time evolution of the hot and dense nuclear matter produced in proton-lead collisions at the LHC is simulated utilizing a (3+1)-dimensional ideal hydrodynamics with fluctuating initial conditions as obtained from a Monte-Carlo Glauber-based energy deposition model, from which we calculate the anisotropic flows and compare to the experimental data. We are particularly interested in the multiplicity dependence and the rapidity dependence for the nuclear modification of the inner structure of single inclusive jets and photon-triggered jets in proton-lead collisions. Comparing to the single inclusive hadron or jet spectra, the modification of full jet structure is more sensitive to the details of jet-medium interaction. We argue that the multiplicity and rapidity dependences for the nuclear modification of full jet structure, once observed, should clearly signal the formation of QGP in high-multiplicity proton-lead collisions at the LHC.

On behalf of collaboration:

Poster Session - Board: 0425 / 640

Color Coherence, Mass and Quenching Weights

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We study the role of mass in color coherence effects of radiating antennas inside a QCD medium. Comparison between the massless and massive cases is made through their quenching weights. Special focus is put on the heavy-\(q\bar{q}\) pair, since it can behave as a massive gluon.
NLO correction to the radiative energy loss using MHV calculation

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We want to compute the momentum distribution of a multiple Bremsstrahlung gluon emission from QCD processes in order to improve the Poisson approximation. We present a new technique using the MHV method with the BCFW, Britto Cachazo Feng and Witten, recursion to deal with multiple gluons amplitudes. Instead of summing over 15 diagrams using Feynmann technique, we use the recursion to compute the NLO radiation or two soft gluons correction to a quark in a medium and we show how the splitting function from the collinear limit emerge as one of the BCFW term.

Nuclear Modification of Jet Fragmentation in Au+Au Collisions

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The characterization of energy in the quark gluon plasma is facilitated by measurements of modifications to the observed jet fragmentation. A favorable channel of study relies on direct photons created in the initial parton interactions of heavy ion collisions. Such a photon traverses the created medium unscathed and grants us a proxy for the transverse momentum of an away side jet. PHENIX Au+Au data recorded at $\sqrt{s_{NN}} = 200$ GeV during RHIC run 14 benefit from the background rejection capability of the silicon vertex detector, enabling the extraction of a higher purity hadron signal. This advantage, combined with a larger integrated luminosity, allows previous PHENIX measurements of fragmentation functions to be extended to greater jet energies. This poster will describe the status of the analysis of direct photon hadron correlations with the new data set.

Quenching and Broadening of Holographic "Jets"

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I will describe the results of an exploration currently in progress of how to use holographic calculations of an ensemble of energetic light quarks to describe the energy loss and broadening in angle of jets in heavy ion collisions. We construct an ensemble of energetic light quarks in $\mathcal{N} = 4$ SYM theory, with a distribution of the “jet” angular extent for a given “jet” energy based upon what is known about real jets in pp collisions. We then see how this distribution changes after the “jets” propagate through a slab of strongly coupled plasma, which degrades their energies and expands their angular extent.

On behalf of collaboration:

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Poster Session - Board: 0429 / 459

Nuclear Modification of Light-Flavor Hadron Production at the ALICE Experiment

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Relativistic heavy-ion collisions produce a hot and dense state of strongly interacting matter, the quark-gluon plasma. The presence of the quark-gluon plasma has been observed to affect the yields of final state particles. High-$p_T$ partons may lose energy while traversing the medium, resulting in the suppression of hadrons at high $p_T$ with respect to the reference values obtained from binary-collision scaled proton-proton measurements. This modification is quantified as the nuclear modification factor $R_{AA}$. Possible initial state effects due to the nuclear nature of the collision system are quantified in the absence of a quark-gluon plasma with p-Pb collisions. The ALICE Collaboration reports the nuclear modification factors $R_{AA}$ and $R_{pPb}$ of several light-flavor hadrons and compares these results to measurements from lower energies and to theoretical models.

On behalf of collaboration:

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Poster Session - Board: 0430 / 301

Measurement of neutral pions in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the PHOS detector at ALICE

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A state of deconfined quarks and gluons, called quark-gluon plasma (QGP), is created in high-energy heavy-ion collisions. The ALICE experiment is mainly devoted to the study of heavy-ion collisions produced at the LHC to investigate such the new state of matter. Neutral mesons such as $\pi^0$ and $\eta$ that decay into two photons are suitable to study parton energy loss in the QGP, since they can be identified, using a fine-segmented electromagnetic calorimeter, in a wide transverse momentum range. The Photon Spectrometer (PHOS) in the ALICE is an electromagnetic calorimeter, located at 4.6 m from the interaction point, consisted of 10,752 segments with a $2.2 \times 2.2 \times 18 \text{ cm}^3$ PbWO$_4$ crystal read out by an APD. This fine granularity allows us to distinguish two photons decayed in a small opening angle from a parent particle at a high transverse momentum. I am analyzing the Pb-Pb data at $\sqrt{s_{NN}} = 2.76$ TeV recorded in 2011 with an integrated luminosity $100^{-1}$ $\text{b}^{-1}$ and detected with centrality triggers. Clear $\pi^0$ peak was extracted in a wide $p_T$ range and each centrality class via di-photon channel with the PHOS detector in ALICE. I will report the current status of my analysis, namely event selections, acceptances, efficiencies and invariant mass spectra with two photons up to 40 GeV/c.
Measurement of azimuthal anisotropy for high pT charged hadrons in Au+Au collisions at 200 GeV at RHIC-PHENIX

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The azimuthal anisotropy on the particle emission is expected as a method to approach the characteristics of the deconfined quarks and gluons state (QGP) generation in the high-energy heavy-ions collisions. The azimuthal anisotropy is sensitive to the early stage and, is the observable that is affected by QGP properties. The behavior of anisotropy is consistent with the hydro-dynamical model for $p_T$ lower than 2 GeV/c, but not for higher $p_T$. When there is QGP, parton lose their energy (jet quenching) and its energy loss is related to the pass length in the dense matter. In non-central collisions, this jet quenching makes an azimuthal anisotropy in the high $p_T$ region where the hard process is dominant. In this poster, we will present the status of detailed study for $p_T$ and centrality dependence of the azimuthal anisotropy for high $p_T$ (up to 8–10 GeV) charged hadrons in 200 GeV Au+Au collisions with RHIC-PHENIX. The relation of the pass length to the azimuthal anisotropy will be discussed.

Jet fragmentation measurements in p+Pb collisions with ATLAS

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Proton-nucleus collisions have been studied to provide baseline measurements for hard processes in heavy ion collisions. The rates of such processes can be modified compared to the expectation from binary scaled pp reference through nuclear modifications of the parton distribution functions. The measurements of jets in minimum bias p+Pb collisions at $\sqrt{s_{NN}}=5.02$ TeV show small deviations from the binary scaling, in line with expectations based on nuclear parton distribution functions tuned to existing data. Measurement of charged particles at high $p_T$ (above 30 GeV) show an increase in yields with respect to the expectation from binary scaling which is larger than any deviations seen in the jet measurements. Since particles at these $p_T$ arise from jet production, these measurements could be an evidence for modification of the jet fragmentation in p+Pb collisions compared to pp collisions. Measurements of the jet internal structure in p+Pb collisions spanning the jet $p_T$ from 45 GeV to 260 GeV are presented. The fragmentation functions measured in $\sqrt{s}=2.76$ TeV pp collisions were extrapolated to $\sqrt{s}=5.02$ TeV in order to provide a comparison for the p+Pb fragmentation functions.

Jet fragmentation measurements in Pb+Pb collisions with ATLAS

On behalf of collaboration::

Page 60
A broad program of measurements using heavy ion collisions is underway in ATLAS, with the aim of studying the properties of QCD matter at high temperatures and densities and its interaction with hard probes. ATLAS has measured the distributions of charged particle transverse momentum and longitudinal momentum fraction in Pb+Pb collisions at \( \sqrt{s_{NN}} = 2.76 \) TeV and in pp collisions at the same center-of-mass energy. A detailed study of the jet fragmentation as a function of jet pseudorapidity and transverse momentum in heavy ion collisions is presented, using the jet fragmentation measured in pp collisions as a reference. The dependence of the measured modifications on the distance from the jet axis as well as the magnitude of the soft enhancement will be quantified. These detailed measurements are expected to provide an insight into the mechanism of the modification of parton showering by the QCD medium.

On behalf of collaboration::

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**Poster Session - Board: 0434 / 512**

**Measurement of the dependence of transverse energy production at large pseudorapidity on the hard scattering kinematics of proton–proton collisions at \( \sqrt{s} = 2.76 \) TeV with ATLAS**

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A new control measurement of the relationship between hard scattering kinematics and the soft underlying event at negative pseudorapidity in 4.0/pb of pp collisions at 2.76 TeV is presented with the ATLAS detector at the LHC. These results are needed interpret the strong modifications in the rates of jet and dijet production in centrality-selected p+Pb collisions observed by ATLAS and CMS. The mean value of the transverse energy in the acceptance of the ATLAS forward calorimeter, where the centrality in p+Pb collisions is characterized, is reported in pp events with a dijet in the central region. This quantity is presented as a function of the average pseudorapidity and transverse momentum of the dijet, and also as a function of the scaled longitudinal momenta \( x_{\text{proj}} \) and \( x_{\text{targ}} \), estimated event-by-event from the dijet kinematics, of the hard-scattered partons in the protons headed away from and towards, respectively, the region of transverse energy production. The transverse energy is observed to decrease strongly with increasing \( x_{\text{targ}} \), which in the analogy with p+Pb collisions represents one of the nucleons in the Pb nucleus. On the other hand, the transverse energy depends only weakly on \( x_{\text{proj}} \), which represents the proton in p+Pb collisions. These results provide counter-evidence to claims that the observed modifications in the jet production in p+Pb collisions arise from a correlation between hard scattering kinematics and soft particle production in the individual NN collisions.

On behalf of collaboration::

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**Poster Session - Board: 0435 / 514**

**Inclusive charged hadron production in lead-lead collisions with the ATLAS detector**

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The ATLAS experiment at the Large Hadron Collider measures charged hadron spectra obtained in 2010 and 2011 lead-lead LHC data taking periods with total integrated statistics of 0.15/nb. The results are compared to the pp spectra of charged hadrons at the same centre-
of-mass energy, accumulated by ATLAS in 2013 with the integrated luminosity of 4/pb. This allows for a detailed comparison of the two collision systems in a wide transverse momentum (0.5<pT<150GeV) and pseudorapidity (|η|<2) ranges in different centrality intervals of Pb+Pb collision. The nuclear modification factors RAA and RCP are presented as a function of centrality, pT and ƞ. They show a distinct pT-dependence with a pronounced minimum at about 7 GeV. Above 60 GeV, RAA is consistent with a flat, centrality-dependent, value within the uncertainties. The value is 0.55±0.01(stat.)±0.04(syst.) in the most central collisions. The RAA is observed to be independent of pseudorapidity over the whole transverse momentum range in all centrality classes.

On behalf of collaboration:

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**Poster Session** - Board: 0436 / 13

**Interpreting single jet measurements in heavy ion collisions**

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Recent measurements of jet and charged particle suppression and single jet fragmentation in heavy ion collisions at the LHC provide important experimental information on the quenching of high-energy jets in the quark-gluon plasma. Important features such as the variation of jet \(R_{AA}\) with \(p_T\), the pattern of modification of the jet fragmentation functions and the evolution of the charged particle \(R_{AA}\) with \(p_T\), taken together, should provide insight on the physics mechanism responsible for the quenching. While a proper understanding of the data requires a detailed theoretical model of jet quenching in a dynamically evolving medium, we argue that multiple features of the data including those listed above arise from a common origin. Using a phenomenological model with minimal assumptions on the parametric behavior of the parton energy loss, we can reproduce most of the features of the single-jet data. Results of our analysis will be presented and used to argue that there are important features of the underlying jet production that may need particular attention in jet quenching models.

On behalf of collaboration:

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**Poster Session** - Board: 0437 / 383

**HBT measurements with respect to event plane and jet axis in Pb-Pb 2.76 TeV collisions from ALICE**

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The study of nucleus-nucleus collisions at ultra-relativistic energies aims to characterize the properties of hot and dense matter, the so called Quark-Gluon Plasma (QGP). Jet quenching has been observed at RHIC and the LHC, and it has been extensively studied at both colliders. Recently a new aspect of jet physics has been revealed at RHIC and the LHC. The jet energy deposition in the medium (jet-quenching effect) was found to result in an increased production of low \(p_T\) particles at large angles opposite to the survived jet or triggered gamma direction. However, there are still remaining open questions how the quenched jet energy is re-distributed in geometrical space, and how the QGP medium responds to it.
The HBT correlations using quantum interferometry of identical particles provide a unique tool to measure the source size at kinetic freeze-out. In particular, azimuthally sensitive HBT with respect to the event plane ($\Psi_2$) offers the detailed analysis of freeze-out source shape. In order to obtain more detailed information on the jet modification effect in geometrical space, the HBT technique can be extended and applied relative to jet axis. In this poster, we present the first measurement of HBT radii with respect to the jet axis and second order event plane with $\phi_{jet}-\Psi_2$ angle selection in Pb-Pb $\sqrt{s_{NN}} = 2.76$ TeV collisions at the ALICE experiment.

On behalf of collaboration:

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Poster Session - Board: 0438 / 239

Status of Jet Reconstruction in Cu+Au collisions at 200 GeV from PHENIX

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Jet reconstruction in heavy ion collisions is a vital tool to explore medium effects, including energy loss and modification of parton fragmentation functions. In 2012, the PHENIX experiment collected a large sample of minimum bias Cu+Au collision data at $\sqrt{s_{NN}} = 200$ GeV. Asymmetric heavy ion collisions offer unique geometrical configurations and studying reconstructed jets in such systems provides the opportunity to understand the interplay between collision geometry and initial and final state effects. Energy densities in Cu+Au collisions are similar to those in Au+Au collisions at 200 GeV but without the low-density ‘corona’ region. In the most central Cu+Au collisions, the smaller Cu nucleus is completely buried in the larger Au nucleus. The comparison of Cu+Au and Au+Au collisions as a function of centrality can help disentangle the ‘core’ of the collision region, characterized by a large energy density, and the outer ‘corona’ region.

We will present the status of jet reconstruction in Cu+Au and baseline p+p collisions at 200 GeV using the anti-kT algorithm with a resolution parameter of $R = 0.2$.

On behalf of collaboration:

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Poster Session - Board: 0439 / 381

Jet azimuthal distributions with high $p_T$ neutral pion triggers in pp 7 TeV and Pb-Pb 2.76 TeV collisions from ALICE at the LHC

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Jet measurements play a critical role for probing the hot and high energy density matter created in heavy-ion collisions through parton energy loss, and to observe possible modifications of the hot and dense matter itself by the deposited energy. According to the quenching model, hadron-jet correlation measurements allow us to maximize the medium path length of the parton which produces the jet, by selecting high transverse momentum hadrons as a trigger that mainly come from the surface of the medium. In this poster, we report jet azimuthal distributions relative to neutral pion triggers in pp 7 TeV and Pb-Pb 2.76 TeV from ALICE at the LHC. For neutral pion identification, an electro-magnetic calorimeter (EMCal) is used. Jets are reconstructed from charged particles measured by a Time-Projection Chamber (TPC)
and Inner-Tracking System (ITS). The high $p_T$ neutral pion sample is enhanced by using the EMCal gamma trigger in combination with a shower shape analysis to identify neutral pions. We report ratios of per-trigger yields ($I_{AA}$) and Gaussian widths of both near and away-side correlation peaks as a function of neutral pion trigger $p_T$ and jet $p_T$.

On behalf of collaboration:

Poster Session - Board: 0440 / 305

Neutral mesons production in $pp$ collisions at LHC energies

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The ALICE experiment at LHC is designed to study very wide $p_T$ range neutral mesons in all collision systems and energies provided by LHC, what is useful to test QCD theory predictions. ALICE covers the measurement of neutral pions with the photon conversion method (low and intermediate $p_T$) making use of the ALICE-ITS and TPC, and the electromagnetic calorimeters PHOS and EMCAL (intermediate and high $p_T$). High $p_T$ can be reached thanks to the triggering capabilities of the calorimeters. We will discuss the neutral mesons production at LHC energies. The xT scaling will be shown containing LHC and RHIC results.

On behalf of collaboration:

Poster Session - Board: 0441 / 440

Eta meson production of high-energy nuclear collisions at NLO

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The transverse momentum spectrum of $\eta$ meson in relativistic heavy-ion collisions is studied at the next-to-leading-order (NLO) within the perturbative QCD, where the jet quenching effect in the QGP is incorporated with the effective medium-modified $\eta$ fragmentation functions using the higher-twist approach. We show that the theoretical simulations could give nice descriptions of PHENIX data on $\eta$ meson in both $p + p$ and central Au + Au at the RHIC, and also provide numerical predictions of $\eta$ spectra in central Pb + Pb collisions with $\sqrt{s_{NN}} = 2.76$ TeV at the LHC. The ratios of $\eta/\pi^0$ in $p + p$ and in central Au + Au collisions at 200 GeV are found to overlap in a wide $p_T$ region, which matches well the measured ratio $\eta/\pi^0$ by PHENIX. We demonstrate that, at the asymptotic region when $p_T \to \infty$ the ratios of $\eta/\pi^0$ in both Au + Au and $p + p$ are almost determined only by quark jets fragmentation and thus approach to the one in $e^+e^-$ scattering; in addition, the almost identical gluon (quark) contribution fractions to $\eta$ and to $\pi$ result in a rather moderate variation of $\eta/\pi^0$ distribution at intermediate and high $p_T$ region in A + A relative to that in $p + p$; while a slight higher $\eta/\pi^0$ at small $p_T$ in Au + Au can be observed due to larger suppression of gluon contribution fraction to $\pi^0$ as compared to the one to $\eta$. The theoretical prediction for $\eta/\pi^0$ at the LHC has also been presented.

On behalf of collaboration:
**Measurement of high $p_T$ neutral pions at $\sqrt{s_{NN}}=2.76$ and 7 TeV with ALICE-EMCal at the LHC**

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The measurements of neutral meson spectra in $pp$ collisions at LHC energies present important data for perturbative QCD calculations such as gluon fragmentation function, and provide reference to study scaling properties of hadron production at LHC energies, such as the nuclear modification factor $R_{AA}$. The existing ALICE data of the $\pi^0$ production in central Pb-Pb collisions at $\sqrt{s_{NN}}=2.76$ TeV already showed a clear pattern of strong suppression in a hot QCD medium with respect to $pp$ collisions, at low- to intermediate-$p_T$ range.

In this presentation, we will show the new $\pi^0$ measurement at mid-rapidity region in $pp$ collisions at $\sqrt{s_{NN}}=2.76$ and 7 TeV. Much higher $p_T$ range, up to 50 GeV/$c$, is reached via merged cluster splitting method at the ALICE electromagnetic calorimeters called EMCal. Unlike the traditional invariant mass method of two separate clusters, this merged cluster method focuses on high energy $\pi^0$s, whose decay photon pairs fall into a single large and elongated cluster in EMCal. In order to identify such clusters, several selection criteria are applied including the shower shape of the cluster, the energy balance between the two sub-clusters, and the invariant mass of the two sub-clusters. We will present the current status of this analysis technique in this poster.

On behalf of collaboration:

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**Production of $K_S^0$ and $\Lambda$ in charged jets and underlying event in proton–proton $\sqrt{s}=8$TeV collisions with ALICE experiment**

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It has been found that the baryon to meson ratio at intermediate transverse momentum ($p_T \sim 3$ GeV/$c$) is up to a factor three larger in the systems such as Pb–Pb but also p–Pb collisions than that in proton–proton collisions. This effect has been discussed in terms of collective flow, which could be present in small systems like pp collisions, and/or parton recombination. To discriminate between hard and soft processes contributing to the baryon and meson production, ALICE is studying particle production in reconstructed jets and the underlying event.

In this contribution, we present the $p_T$ distributions of reconstructed $K_S^0$ and $\Lambda$ associated with a charged jet and in the underlying event in $pp$ collisions at the LHC. The hard scatterings are selected on an event-by-event basis by anti-$k_T$ jets with resolution parameter $R = 0.4$ (or $R = 0.2$) reconstructed from charged particles with a minimum $p_T$ of 8 GeV/$c$. To investigate the effects of hadronization, we will compare the resulting baryon-to-meson ratio inside and outside jets to PYTHIA 8 simulations with different color reconnection models.

On behalf of collaboration:

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Production of strange hadrons in charged jets in p–Pb and Pb–Pb collisions measured with ALICE at the LHC

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Studies of jet production can provide information about the properties of the hot and dense strongly interacting matter created in ultra-relativistic heavy-ion collisions. Specifically, measurements of strange hadrons in jets may clarify the role of fragmentation processes in the anomalous baryon to meson ratio at intermediate particle $p_T$, that firstly was observed in A-A collisions at RHIC and later confirmed in lead-lead (Pb–Pb) collisions at the LHC. Furthermore also measurements in proton-lead (p–Pb) collisions at the LHC showed this anomaly, but to a lesser extent. In this contribution, measurements are presented of the $p_T$ spectra of $\Lambda$($\bar{\Lambda}$) baryons and $K^0_S$ mesons produced in association with charged jets in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The analysis is based on data recorded by ALICE at the LHC, exploiting its excellent particle identification capabilities. The baryon/meson ratios of strange particles associated with jets are studied as a function of the event activity in p-Pb collisions and are restricted to central events in Pb-Pb collisions. A comparison is shown to the ratios obtained for inclusive particle production and for particles stemming from the underlying event as well as to PYTHIA proton-proton (pp) simulations.

On behalf of collaboration:

Poster Session - Board: 0502 / 595

Is heavy quark diffusion applicable? – A new time scale introduced by decoherence

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Interaction of heavy quarks with particles in the quark-gluon plasma (QGP) results in the heavy quark energy loss. In the nonrelativistic regime, the effective theory for this process is the Langevin equation, a classic example in the nonequilibrium physics. In the heavy-ion collisions, several studies have applied the Langevin dynamics to phenomenology and tried to interpret the experimental data of nuclear modification factor ($R_{AA}$) and elliptic flow ($v_2$) of charm quarks.

In this talk, I would like to introduce a new aspect to the Langevin dynamics, namely the dynamics of heavy quark color charge [1]. In the perturbative picture, each scattering rotates heavy quark color into a new color state and causes a macroscopic superposition state (Schrödinger’s cat state) of the momentum. To derive classical descriptions of the Langevin dynamics, the quantum interference of the superposition must be destroyed by decoherence. I estimated this time scale to be $\sqrt{M/\gamma}$, where $\gamma$ is the momentum diffusion constant of heavy quarks. This time scale should be the lower limit of the discretization of the Langevin equation. Interestingly, this is estimated to be about 3-5 fm for charm and bottom quarks, which is not small enough compared to the QGP lifetime so that the naïve application of Langevin equation to heavy-ion physics might be questioned.


On behalf of collaboration:

Poster Session - Board: 0503 / 186
Heavy flavor electron $R_{AA}$ and $v_2$ in event-by-event relativistic hydrodynamics

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In this work we investigate how event-by-event hydrodynamic fluctuations affect the nuclear suppression factor and elliptic flow of heavy flavor mesons and non-photonic electrons. Local temperature and flow profiles are computed using a 2D+1 Lagrangian ideal hydrodynamic code [1] on an event-by-event basis. We use a strong coupling inspired energy loss parametrization [2] on top of the evolving space-time energy density distributions to propagate the heavy quarks inside the medium until the freeze-out temperature is reached and hadronization (modeled using PYTHIA) takes place. The resulting $D^0$ and non-photonic electron yield, computed event by event [6], is compared with recent experimental data for $R_{AA}$ and $v_2$ from the STAR and PHENIX collaborations [3-5]. We also present predictions for the higher order Fourier harmonic coefficients $v_3(p_T)$ and $v_4(p_T)$ of non-photonic electrons at RHIC’s $\sqrt{s} = 200$ GeV/n collisions.

**REFERENCES:**


**On behalf of collaboration:**

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**Poster Session - Board: 0504 / 279**

Measurement of the Distance of Closest Approach of electrons from heavy flavor hadron decays at PHENIX

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The production of heavy quarks (charm and bottom) is a good tool for investigating the hot and dense partonic medium created in RHIC. Due to their large masses, the production process of heavy quarks is essentially restricted to primordial nucleon-nucleon collisions. Thus, heavy quarks are clean probes to study the hot and dense matter because they carry information about the entire time-evolution of the medium. The Silicon Vertex Tracker (VTX) was installed in the RHIC-PHENIX detector in year 2011. The VTX was designed to give precise tracking reconstructions of the distance of closest approach (DCA) to the collision vertex in order to distinguish prompt particles from in-flight decays. In this way, we will be able to statistically separate electrons from semi-leptonic decay of heavy flavor hadrons. In order to extract the heavy flavor contributions from DCA distribution, understanding of background and its subtraction from the DCA distribution play crucial roles. This poster will present detailed analysis of background in the DCA distribution of electrons measured in Au+Au collision at $\sqrt{s_{NN}} = 200$ GeV.

**On behalf of collaboration:**
**Poster Session - Board: 0505 / 269**

Measurements of electrons from semileptonic decays of open heavy flavor hadrons in p+p and Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV

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Heavy flavor quarks have been suggested as excellent probes to study the properties of the hot and dense nuclear matter created in high-energy heavy-ion collisions. In this regard, high precision measurements of heavy flavor production in p+p collisions are also important as they provide a reference to study the medium effects in heavy-ion collisions. In this poster, we will present the latest results on electrons produced from semileptonic decays of open heavy flavor hadrons in p+p and Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV. The p+p results are extracted from data taken by the STAR experiment at the Relativistic Heavy Ion Collider in the year 2012, which have a highly improved precision than previous results over a wider range of transverse momentum, $0.2 < p_T<12$ GeV/c. With this new p+p baseline, improved nuclear modification factors $R_{AA}$ in Au+Au collisions are also obtained and compared with theoretical model calculations.

On behalf of collaboration:

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**Poster Session - Board: 0506 / 404**

Measurement of open-charm production as a function of charged-particle multiplicity in pp collisions at $\sqrt{s} = 7$ TeV with ALICE at the LHC

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The ALICE detector was designed for the study of the high energy-density QCD matter produced in high-energy heavy-ion collisions. Heavy quarks (charm and beauty) are important probes of this matter, as they are produced in initial hard scattering processes and they experience all the stages of the medium evolution. Therefore measurements of heavy-flavour hadron production provide important information on the early stage of the collision and the parton-medium interaction. Open heavy-flavour production measurements in pp collisions provide the necessary baseline to understand the results in Pb-Pb collisions and a test of pQCD (perturbative quantum chromodynamics) calculations. Furthermore, the study of open heavy-flavour production in pp collisions as a function of charged-particle multiplicity allows us to investigate the interplay between hard and soft mechanisms in particle production. In particular, it could give insight into the role of multi-parton interactions (MPI), i.e. several hard partonic interactions occurring in a single collision at high centre-of-mass energies.

In this contribution, the measurement of open heavy-flavour per-event yields as a function of charged-particle multiplicity in pp collisions at $\sqrt{s} =7$ TeV recorded with the ALICE detector will be presented. D⁰, D⁺ and D⁺⁺ mesons are reconstructed from their hadronic decay channels in the central rapidity region, and their yields are measured in different multiplicity and $p_T$ intervals. These yields will be compared to the results obtained for inclusive and non-prompt J/ψ. Finally, comparisons with model calculations will be reported.

On behalf of collaboration:
**Poster Session** - Board: 0508 / 401

### D$^+$-meson nuclear modification factor in Pb–Pb collisions with ALICE

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Heavy quarks (charm and beauty) can be used to study the properties of the strongly-interacting matter that is created in central Pb–Pb collisions at ultrarelativistic energies. They are produced in parton scattering processes with high-momentum transfer in the initial stages of the collisions. Therefore, the heavy quarks experience all the phases of the system evolution losing energy in the medium via gluon radiation and elastic collisions. The measurement of the D-meson nuclear modification factor ($R_{AA}$) is sensitive to the in-medium energy loss of charm quarks.

The D-meson production has been studied by ALICE in pp, p–Pb and Pb–Pb collisions. In particular, the measurement of the D$^+$-meson nuclear modification factor in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, collected in 2011, will be presented. The dependence of the D$^+$-meson $R_{AA}$ on its transverse momentum and on the centrality of the collisions will be reported.

On behalf of collaboration::

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**Poster Session** - Board: 0509 / 718

### Elliptic flow of heavy flavour decay muons at relativistic heavy ion collisions

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Heavy quarks are produced at the initial fusion of ultrarelativistic heavy-ion collisions. After their production, they propagate through the quark gluon plasma and lose energy by colliding with quarks and gluons and by radiating gluons. After their production, they may also get fragmented into heavy mesons by picking up light quarks/antiquarks and in turn may decay through leptonic channels. These leptons would carry information of the initial stage of heavy ion collisions and also the evolution of the plasma. In this work, we calculate the elliptic flow of muons from heavy flavours decay at forward rapidities in Pb+Pb collision. The transverse momentum distribution of heavy quarks produced from the initial fusion of partons, is calculated by FONLL (Fixed Order Next-to-Leading Logarithms) approach. We consider both radiative and collisional energy loss along with a boost-invariant expansion of the plasma for the calculation of elliptic flow. The fragmentation of heavy quarks into mesons is governed by Peterson fragmentation function. We compare our result at 2.76 ATeV with the ALICE Preliminary data. References: 1. R. Abir et al., Phys. Lett. B 715, 183 (2012). 2. M. Cacciari, M. Greco and P. Nason, J. High Energy Phys.9805, 007 (1998). 3. M. Cacciari, S. Frixione and P. Nason, J. High Energy Phys.0103, 006 (2001). 4. C. Peterson, D.

On behalf of collaboration:

Poster Session - Board: 0511 / 76

**Tomography of the Quark-Gluon-Plasma by Charm Quarks**

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The charm production in ultra-relativistic heavy-ion collisions is studied based on the Parton-Hadron-String Dynamics (PHSD) transport approach. The initial charm quarks are produced by the Pythia event generator tuned to fit the transverse momentum spectrum and rapidity distribution of charm quarks from Fixed-Order Next-to-Leading Logarithm (FONLL) calculations. The shadowing effect is accounted for the nuclei collisions. The produced charm quarks scatter in the quark-gluon plasma (QGP) with the off-shell partons whose masses and widths are given by the Dynamical Quasi-Particle Model (DQPM), which reproduces the lattice QCD equation-of-state in thermal equilibrium. The relevant cross sections are calculated in a consistent way by employing the effective propagators and couplings from the DQPM. Close to the critical energy density of the phase transition, the charm quarks are hadronized into $D$ mesons through coalescence and fragmentation. The hadronized $D$ mesons then interact with the various hadrons in the hadronic phase with cross sections calculated in an effective lagrangian approach with heavy-quark spin symmetry. The nuclear modification factor $R_{AA}$ and the elliptic flow $v_2$ of $D^0$ mesons from PHSD are compared with the experimental data from the STAR Collaboration for Au+Au collisions at $\sqrt{s_{NN}} =200$ GeV and to the ALICE data for Pb+Pb collisions at $\sqrt{s_{NN}} =2.76$ TeV. We find that in the PHSD the energy loss of $D$ mesons at high $p_T$ can be dominantly attributed to partonic scattering while the actual shape of $R_{AA}$ versus $p_T$ reflects the heavy-quark hadronization scenario, i.e. coalescence versus fragmentation. Also the hadronic rescattering is important for the $R_{AA}$ at low $p_T$ and enhances the $D$-meson elliptic flow $v_2$.


On behalf of collaboration:

Poster Session - Board: 0512 / 649

**Variation in the K* meson abundance during the hadronic stage in heavy ion collisions**

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We investigate the variation of the $K^*$ meson abundance in heavy ion collisions by focusing on the hadronic effects on the $K^*$ meson abundance. We evaluate the absorption cross section of the $K^*$ meson as well as that of kaon in the hadronic matter, and further investigate the variation in the meson abundances for both particles during the hadronic stage of heavy ion collisions.
collisions. We show that the interplay between the interaction of the $K^*$ meson with light mesons in the hadronic medium and that of the kaon determines the final yield difference of the statistical hadronization model to the experimental measurements. For the central Au+Au collision at $\sqrt{s_{NN}} = 200$ GeV, we find that the $K^*/K$ yield ratio at chemical freeze-out decreases by 32% during the expansion of the hadronic matter, resulting in the final ratio comparable to STAR measurements of 0.23 ±0.05.

On behalf of collaboration:

**Poster Session** - Board: 0513 / 441

**Strangeness production in pp collisions at $\sqrt{s} = 13$ TeV measured with ALICE**

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The study of strangeness production in both pp and Pb–Pb collisions is of particular interest since the strange quark is the lightest and most abundantly produced among the higher generation quarks. Measuring the relative production of strange and multi-strange particles in different colliding systems enables a systematic investigation of possible dependence of strangeness production mechanism with system size and energy density. Making use of its tracking and particle identification capabilities, ALICE is able to reconstruct the weakly decaying strange hadrons by detecting their daughter tracks and mapping their decay topology. In this contribution, the recent measurement of strange hadrons and the corresponding antiparticles performed by ALICE in pp collisions at the new record center-of-mass energy of 13 TeV will be presented. Results will be compared to predictions from QCD inspired models as well as to measurements performed at lower energies.

On behalf of collaboration:

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**Poster Session** - Board: 0514 / 399

**Simulation studies of beauty-jet tagging in p–Pb collisions at the LHC with ALICE**

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Heavy quarks (charm and beauty) are predominantly produced via initial hard parton scatterings in the early stages of hadronic collisions. Thus, they are ideal probes of the QCD matter since they lose energy by means of elastic scatterings and radiative processes while propagating through the strongly-interacting medium created in high-energy heavy-ion collisions. According to theoretical models, the parton energy loss is colour charge and parton mass dependent. In particular, it is expected that beauty quarks lose less energy than charm and light quarks. These dependencies can be studied by comparing the nuclear modification factor of beauty jets with that of charm or light-parton jets. The measurement of beauty-jet production in p–Pb collisions is needed to quantify cold nuclear matter effects, a fundamental step for the interpretation of Pb–Pb results.

In this poster we present Monte Carlo based performance studies of beauty-jet tagging via displaced secondary vertex reconstruction, obtained with ALICE for p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The tagging technique, its performance in terms of efficiency and beauty jet selection purity, and the corrections required for measuring the cross section of beauty-jet production will be described. Finally, prospects for measurements in LHC Run 2, will also be presented.
On behalf of collaboration:

Poster Session - Board: 0515 / 216

Charm and bottom nuclear modification in Cu+Au collisions at $\sqrt{s_{NN}}=200$ GeV
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Forward and backward rapidity measurements in heavy ion asymmetric collisions offer the opportunity to study the nuclear modification of particle yields versus path length, time inside the medium, particle densities and different mixtures of cold nuclear matter and quark-gluon plasma effects in the same collision. The PHENIX Experiment collected data from a large sample of Cu+Au collisions at $\sqrt{s_{NN}}=200$ GeV and, for the first time, with forward vertex detectors (FVTX) which enabled the study of displaced vertex muon decays from heavy flavor at backward and forward rapidities. Charm and bottom yields can be separated in inclusive single muon yields and bottom yield can also be obtained from $J/\psi$ vertex displacements. The status of this analysis will be presented.

On behalf of collaboration:

Poster Session - Board: 0516 / 660

Charm decay leptons in pA collisions within the CGC framework
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We compute electron and muon productions from the charm semileptonic decays in proton-lead collisions at the LHC within the Color Glass Condensate framework. At the LHC energies, open heavy flavor and quarkonium productions are expected to have an access to the small-$x$ region of hadronic wavefunctions, where the nonlinear character of the dense gluon system becomes manifest. Leptonic channels of heavy flavor decays are important observables, but the information on the small-$x$ gluons are relatively indirect there. In this presentation, we will show electron and muon spectra of heavy-flavor decays at low-$P_T$ and their two-particle correlations. We will discuss in which kinematical region the saturation effects are well reflected in the lepton distributions.

On behalf of collaboration:

Poster Session - Board: 0517 / 232

Electrons from open heavy flavor decays in central U+U collisions at STAR
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Properties of a hot and dense strongly interacting form of matter called the Quark-Gluon Plasma (QGP) are being studied in ultrarelativistic heavy-ion collisions at the Relativistic Heavy Ion Collider (RHIC). Heavy quarks are created during early stages of heavy-ion collisions in hard processes before the QGP is formed. Their identities are not lost during the evolution of the QGP and subsequent phases, which makes them a good probe for the study of the properties of the QGP. Non-Photonic Electrons (NPE) that originate from semileptonic decays of $D$ and $B$ hadrons can serve as a good proxy for heavy flavor quarks. The nuclear modification factor $R_{AA}$ of NPE is sensitive to the interaction of heavy quarks with the QGP and thus the QGP properties.

Measurements of NPE $R_{AA}$ have revealed a strong suppression at high $p_T$ in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at the Relativistic Heavy Ion Collider. In the year 2012 STAR collected data in U+U collisions at $\sqrt{s_{NN}} = 193$ GeV. In the most central U+U collisions a higher energy density can be achieved than that in Au+Au collisions, which is expected to enhance the suppression of NPE. In this poster the preliminary results on NPE $R_{AA}$ with $1.2 < p_T < 6.0$ GeV/$c$ in 0-5% most central U+U collisions will be presented and compared to those in Au+Au collisions.

On behalf of collaboration:

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Poster Session - Board: 0518 / 498

Heavy Quark dynamics in the Quark-Gluon Plasma and the puzzling relation between $R_{AA}$ and $v_2$

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We review the basic concepts related with the study of the dynamics of the heavy quarks in the quark-gluon plasma created in ultra-relativistic heavy-ion collisions. We challenge the assumption of brownian motion for charm quarks comparing the dynamical evolution of charm and bottom quarks in a Fokker-Planck approach and in a Transport Boltzmann one [1] as well as investigating the uncertainties inherent to the different realization of the Fluctuation Dissipation Theorem (FDT) [2]. We show that while for bottom the motion appears quite close to a Brownian one, this does not seems to be the case for charms quarks. We address the difficulties of the present theoretical approaches to have a self-consistent description of the experimental data at both RHIC and LHC. In particular a puzzling relation between the nuclear modification factor $R_{AA}(p_T)$ and the elliptic flow $v_2(p_T)$ related to heavy quark has been observed which challenged existing models. We discuss how the temperature dependence of the heavy quark drag coefficient can account for a large part of such a puzzle. We point out that for the same $R_{AA}(p_T)$ one can generate 2-3 times more $v_2$ depending on the temperature dependence of the heavy quark drag coefficient [3]. A non-decreasing drag coefficient as $T\rightarrow T_c$, as in liquids and not in gas, is a major ingredient for a simultaneous description of $R_{AA}(p_T)$ and $v_2(p_T)$ along with hadronization by coalescence.

References

On behalf of collaboration:
Non-prompt J/$\psi$ measurement with the PHENIX VTX detector at RHIC

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The bottom quark is a powerful probe to study the characteristics of hot dense medium created in high energy heavy ion collisions. A strong suppression of hadrons containing heavy quarks was observed through the measurement of single electrons semi-leptonic decays. To further understand phenomenon of heavy quark suppression, the bottom and charm production needs to be measured separately. The non-prompt J/$\psi$ from B decay ($B \to J/\psi + X$) is a direct measurement of the bottom production. The silicon vertex detector (VTX) enables us to identify the $B \to J/\psi$ through electron pairs ($J/\psi \to e^+ + e^-$) by measuring a secondary vertex position of the B decays. In this poster, we will report the current status of the analysis measuring the secondary vertex of electron pairs from non-prompt J/$\psi$ decays in 200 GeV p+p and Au+Au collisions.

Dielectron measurement from charm and bottom quark decays in p-Pb collisions with the ALICE detector

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Electron-positron pairs (dielectrons) are excellent probes for studying the properties of the medium created in high energy heavy-ion collisions. For dielectron invariant masses above 1 GeV/$c^2$, the semi-leptonic decays of open heavy flavor hadrons are the main contributions to the spectrum. The invariant mass and pair $p_T$ distributions are expected to be modified from the pp reference due to the energy loss of heavy quarks in the medium and the excess of thermal radiation. A correct understanding of heavy-ion results requires, in addition, an evaluation of initial state nuclear effects, through the study of p-Pb collisions. To access the intermediate and high mass regions, abundant high $p_T$ electron samples are needed. In the ALICE experiment, the Transition Radiation Detector (TRD) is used for electron identification at momenta above $p > 1$ GeV/$c$. The TRD also provides an electron trigger to enrich the data samples for the study of charmonium and open heavy flavor production. We will show the status of the TRD triggered data analysis in p-Pb collisions at $\sqrt{s_{NN}}=5.02$ TeV.

Measurement of $D^0$ meson elliptic anisotropy in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV from STAR using the two-particle correlation method

HE, Liang
The observed azimuthal anisotropies of light flavor hadrons suggest large partonic collectivity in the hot and dense medium created in relativistic heavy-ion collisions. Since heavy quark interactions with the medium may be different from light quark interactions, the measurements of heavy quark elliptic anisotropy is complementary to those of light quarks and can provide new insight in understanding the path length dependence of heavy quark energy loss in the medium and the degree of thermalization.

In this poster, we present the STAR measurement of elliptic anisotropy ($v_2$) of $D^0$ in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV using the two-particle correlation method. The data were taken in the first year of physics running with the new STAR Heavy Flavor Tracker detector, which greatly improves open heavy flavor hadron measurements by the topological reconstruction of secondary decay vertices. The results will be compared with measurements of other heavy flavor and light flavor particles, as well as measurements from other experiments.

Non-perturbative Approach to Open Heavy Flavor in Relativistic Heavy Ion Collisions

We evaluate open heavy-flavor (HF) transport in relativistic heavy-ion collisions utilizing a strong-coupling treatment for both macro- and micro-dynamics of the problem [1]. The former is realized through a hydrodynamic evolution quantitatively constrained by bulk-hadron spectra and elliptic flow. The HF transport is based on non-perturbative $T$-matrix calculations of heavy-light parton scattering in the Quark-Gluon Plasma (QGP) [2], yielding a diffusion coefficient consistent with lattice QCD, and on effective interactions of $D$-mesons with light hadrons in hadronic matter [3]. The $T$-matrix interactions in the QGP lead to resonance formation close to $T_c$ which are implemented as a hadronization (recombination) mechanism on a hydrodynamic hypersurface, providing a seamless treatment of HF interactions throughout the bulk-medium evolution. We deploy this framework for a comprehensive study of open HF observables from 62-2760 GeV [4,5,6]. A fair description of current experimental data for the nuclear modification factor and elliptic flow of $D$, $D_s$, $B$ mesons and HF leptons emerges at low and intermediate transverse momenta $p_T$. Discrepancies arise toward high $p_T$, which allows us to determine the onset of radiative energy loss processes.

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We show that our strong-coupling heavy flavor energy loss model based on a rigorous treatment of drag and diffusion from AdS/CFT describes all current non-photonic electron, D meson, and non-prompt J/psi suppression measurements at RHIC and LHC. Taken with the recent success of our strong-coupling light flavor jet energy loss model, we claim that AdS/CFT provides a self-consistent theoretical description of the QGP at all experimentally accessible energy scales.

We allow for further testing of the strong-coupling description of QGP by presenting for the first time falsifiably different predictions for heavy flavor correlations from AdS/CFT and from pQCD. Finally we gain additional insight into the AdS/CFT description of heavy quarks by examining the energy loss of strings with finite endpoint momentum.

On behalf of collaboration:

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Poster Session - Board: 0524 / 661

Multi-strange hyperon production at FAIR energies

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Nuclear collisions with beam energies between 5 and 40 A GeV are predicted to produce net-baryon densities which are ≈ 5-6 times higher than normal nuclear matter density. At such high densities, it is expected that baryons start to melt into their constituents, the quarks and gluons, forming a mixed of even deconfined phase. Such collisions will be explored at the upcoming Facility for the Antiproton and Ion Research (FAIR). Multi-strange hadrons will play a major role as diagnostic probes of the of the dense QCD matter. The yields of (anti)hyperons and their relative enhancement with respect to pions have been investigated in heavy-ion collisions at beam energies between 5 and 90 A GeV using the hadronic-string model (UrQMD), hadronic and partonic modes of the transport model (AMPT) and a statistical hadronization model (Therminator). It is found that the yields of multi-strange (anti)hyperons are sensitive to the partonic medium. At beam energies around 10 A GeV - which is the top energy of the FAIR start version - the partonic contribution to the production yield increases strongly with increasing number of (anti-)strange quarks.

On behalf of collaboration:

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Poster Session - Board: 0525 / 421

High $p_T$ heavy-flavour decay electron measurements in p–Pb collisions with the TPC and EMCal of ALICE

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Measurements of heavy-flavour (charm and beauty) production in high-energy heavy-ion collisions allows us to study the Quark-Gluon Plasma (QGP). The QGP is a high energy-density state of strongly-interacting matter in which partons are deconfined. Due to their large masses, heavy quarks are produced in the early stages of the collision and experience the whole evolution of the system. The ALICE collaboration has measured electrons from heavy-flavour hadron decays in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at mid-rapidity. A
strong suppression of the yield of heavy-flavour decay electrons in the transverse momentum interval $3 < p_T < 18 \text{ GeV}/c$ is observed in the 0-10% most central collisions, when compared to binary-scaled pp measurements. Measurements of heavy-flavour decay electrons in the same $p_T$ range in p–Pb collisions are crucial to disentangle cold nuclear matter effects from hot nuclear matter effects in Pb–Pb collisions. The production of electrons from heavy-flavour hadron decays has been measured with ALICE in minimum-bias p–Pb collisions at $\sqrt{s_{NN}}=5.02$ TeV in the interval $0.5 < p_T < 12 \text{ GeV}/c$. The ElectroMagnetic Calorimeter (EMCal) together with the Time Projection Chamber (TPC) are used to identify electrons at high $p_T$. In addition, during the p–Pb run the EMCal provided a trigger for hard probes such as high-$p_T$ electrons and photons. This allows to measure electrons up to a $p_T$ of about 18 GeV/c. We will present the heavy-flavour decay electron measurement in minimum-bias p–Pb collisions at 5.02 TeV using the TPC and EMCal and show some results from the EMCal triggered data.

On behalf of collaboration:

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**Poster Session - Board: 0526 / 215**

φ meson measurement in Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV with the PHENIX Muon Arms at RHIC

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A major objective in nuclear physics is to quantify and characterize the hot and dense state of strongly interacting matter formed in high-energy heavy-ion collisions. The φ meson is an excellent probe for studying this deconfined state of nuclear matter due to its very short lifetime, and the absence of strong interactions between muons and the surrounding hot hadronic matter makes the φ to dimuon decay channel particularly interesting. Since the φ meson is composed of a strange and antistrange quark, its nuclear modification in heavy-ion collisions can be used to study strangeness enhancement in-medium. Additionally, the rapidity dependence of φ production in asymmetric heavy-ion collisions provides a unique means of accessing different mixtures of initial and final state effects. In this poster, we present the measurement of φ meson production and nuclear modification in asymmetric Cu+Au heavy-ion collisions at $\sqrt{s_{NN}} = 200$ GeV at both forward (Cu-going direction) and backward (Au-going direction) rapidities.

On behalf of collaboration:

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**Poster Session - Board: 0527 / 29**

Inclusive and tagged beauty jets in Pb+Pb collisions at the LHC

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Heavy flavor jets at the LHC have emerged as a new tool to test the theory of heavy flavor production and parton shower formation initiated by prompt b-quarks. They provide new insights into the mechanism of heavy flavor propagation and energy loss in dense QCD matter. B-jets are also an important physics thrust of the RHIC heavy ion program. In this talk we present recent theoretical advances in understanding single inclusive beauty jet production, as well as photon-tagged and B-meson-tagged b-jet production in heavy ion collisions at the
LHC. We find that predictions for the nuclear-induced attenuation of inclusive b-jets, based on the theory of coherent energy loss in the QGP, agree well with recent CMS experimental data at a center-of-mass energy 2.76 TeV. We further extend our results to photon-tagged and B-meson tagged b-jet production at 5.1 TeV for comparison to data from the upcoming LHC Pb+Pb run. We find that photon-tagged b-jets exhibit smaller momentum imbalance shift in nuclear matter, and correspondingly smaller energy loss, than photon-tagged light flavor jets. Our results show that B-meson tagging is most effective in ensuring that the dominant fraction of recoiling jets originate from prompt b-quarks. Interestingly, in this channel the large suppression of the cross section is not accompanied by a significant momentum imbalance shift, a behavior quite different from the one observed in dijet asymmetry distributions. Last but not least, we present comparison between the b-jet attenuation and the quenching of open heavy flavor (D and B mesons) in heavy ion collisions.


On behalf of collaboration:

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**Poster Session** - Board: 0528 / 543

**Effects of soft/hard correlation and initial state geometry on heavy quark observables**

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Heavy quarks observables, such as the nuclear modification factor $R_{AA}$ and the elliptic flow coefficient $v_2$, are sensitive to the transport properties and space-time evolution of the quark-gluon-plasma. Generally this connection is made via transport calculations of the time-evolution of the collision. However, how the choice of the initial condition model for the QGP medium as well as spatial correlations between the medium and the initial production vertices of the heavy quarks affect these observable is still unclear. Of particular interest is the effect of initial correlation between heavy quark production vertices with the underlying event (referred as soft-hard correlation). Experimentally, open charm production in pp collisions is found to increases with charged particle multiplicity, indicating a strong correlation between the heavy quark production with sub-nucleonic fluctuation of soft matter density, which is often overlooked in existing initial conditions.

In this work, we focus on the response of heavy quark observables to various initial condition models with different hard-soft correlation behavior and soft matter geometry. We study D meson $R_{AA}$ and $v_2$ in AA collision with TRENTo, a recently developed effective model for initial entropy deposition, and a Langevin transport model. Comparing calculations with and without initial sub-nucleonic hard-soft correlations, and for different modes of entropy deposition, we assess the sensitivity of heavy quark observables to these correlations. Results will be presented for Pb+Pb collisions at LHC energies.

On behalf of collaboration:

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**Poster Session** - Board: 0529 / 550

**Calculation of k*/k+ ratio assuming the partial chemical equilibration**

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Page 78
Production of K mesons in the relativistic heavy-ion collisions at LHC draws strong interest since the ratio involving K mesons such as K/π or K/K+ doesn’t fit to the statistical model calculations while most of other ratios fit nicely. The reason is possibly that the K doesn’t chemically freeze-out at the same temperature $T_{ch}$ as other particles do. Rather K maintains partial chemical equilibrium through the process $K^* \rightarrow K + \pi$ until the thermal freeze-out temperature, $T_{th}$. In this presentation, after fitting the momentum spectra of measured hadrons and ratios involving them measured by the ALICE collaborations with a blast-wave model which assumes the chemical freeze-out at higher $T_{ch}$ and the thermal freeze-out at lower $T_{th}$, the ratio $K^*/\pi$ is calculated from the parameters thus obtained assuming the partial chemical equilibration of $K^*$, K and $\pi$ until $T_{th}$, and the result is compared with the data.

On behalf of collaboration:

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**Poster Session** - Board: 0530 / 724

**B meson analysis with CMS**

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Hadrons with heavy quarks are promising probes to investigate the detailed properties of hot and dense medium generated by heavy-ion collisions at collider energies. Since heavy quarks are sensitive to the transport properties of the medium, the energy-loss pattern of them is expected to be quite different from that of light quarks in a strongly-interacting matter. On the other hand, in order to elicit the actual effects caused by the hot and dense medium, it is necessary to understand the cold nuclear matter effect in pA collisions. For example, the pPb data is expected to provide a baseline for the study of the b-quark energy loss in medium produced by PbPb collisions. Therefore, the CMS Collaboration at the Large Hadron Collider (LHC) has analyzed the production cross sections of $B^+$, $B^0$, $B^0_s$ mesons in pPb collisions as a function of rapidity and the transverse momentum at the nucleon-nucleon center-of-mass energy of 5.02 TeV. In addition, the nuclear modification factors of the B mesons have been constructed using the theoretical pp reference spectra estimated by the perturbative Quantum ChromoDynamics (pQCD) model.

On behalf of collaboration:

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**Poster Session** - Board: 0531 / 704

**Nuclear modification factor of D meson in PbPb collisions at 2.76 TeV with CMS**

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The measurement of D meson production is a powerful tool to investigate the c-quark in-medium energy loss. In this poster, we will present the measurement of the nuclear modification factor of $D^0$ mesons as a function of transverse momentum and centrality. The reconstruction of D meson and the combinatorial background rejection are detailed. The prospects of heavy flavor meson analysis with Run II data are also discussed.

On behalf of collaboration:
Are charmed mesons thermalized in heavy ion collisions at RHIC and LHC?

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Studying the charmed hadron production is a particularly useful tool to probe properties of hot and dense matter created in ultrarelativistic heavy ion collisions. It allows one also to extract the information about mechanisms of in-medium heavy quark thermalization. In this talk, the phenomenological analysis of various characteristics of charmed hadrons (J/Psi and D mesons) in heavy ion collisions at RHIC and LHC has been done in the frameworks of two-component HYDJET++ model. Among other heavy ion event generators, HYDJET++ focuses on the detailed simulation of jet quenching effect taking into account medium-induced radiative and collisional partonic energy loss (hard “non-thermal” component), and also reproducing the main features of nuclear collective dynamics by the parametrization of relativistic hydrodynamics with preset freeze-out conditions (soft “thermal” component). The charmed meson production pattern in heavy ion collisions at RHIC and LHC is reproduced by HYDJET++ simulations. The possibility of thermalization of J/Psi and D mesons at RHIC and LHC energies is discussed.

On behalf of collaboration:

Heavy Flavor Triggered Azimuthal Correlations in p+p Collisions at [U+FFFC] center-of-mass energy of 500GeV

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Heavy quarks are mostly produced through initial hard scatterings at RHIC energies and they carry clean information of sQGP medium dynamics. Heavy flavor triggered correlation offers an unique insight into early interaction dynamics. Investigations of heavy quark production and correlation mechanisms in proton-proton collisions are of great importance and interest as a fundamental perturbative QCD (pQCD) test and baseline measurement for heavy-ion collisions. This poster reports the new STAR measurements of heavy flavor triggered correlations in p+p collisions at [U+FFFC] center-of-mass energy of 500 GeV using D mesons. Azimuthal angular correlation distributions between trigger D mesons and associated charged hadrons (D-h) as well as anti-D mesons (D−h) are measured in p+p collisions at center-of-mass energy of [U+FFFC] 500 GeV for the first time. These results are compared with pQCD calculations to improve the understanding of charm quark production in elementary hadron collisions. Meanwhile, prospects of heavy flavor correlation measurements in heavy-ion collisions utilizing the new STAR Heavy Flavor Tracker are discussed.

On behalf of collaboration:

Poster Session - Board: 0534 / 624
Fate of meson states and broken symmetries at high temperature

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Thermal fluctuations cause modifications of meson bound states as well as restoration of broken chiral and $U_A(1)$ symmetries. The former (latter) plays an important role in the analysis of sequential melting patterns of open-flavor mesons (the nature of phase transition in QCD) in hot and dense matter created in relativistic heavy-ion collisions. We present recent results on lattice QCD calculations of meson correlations which express in-medium modifications of mesonic excitations containing up/down, strange and charmed quarks. Thermal effects are clearly visible in the spatial correlations which, unlike the temporal correlations, can be calculated at separations larger than the inverse of temperature. This makes them more sensitive to thermal modifications of hadrons. Moreover the spatial correlations provide a direct signal for the thermal modification of spectral functions which carry all the information about in-medium properties of mesons and their dissolution. As a consequence of lattice QCD simulations using Highly Improved Staggered Quarks with physical strange quark mass and (nearly) physical up/down quark masses, we find that light-unflavored, open-strange and open-charm mesons in the pseudo-scalar ($\pi, K$ and $D$) and vector ($\rho, K^*$ and $D^*$) channels show significant modifications even below the critical temperature ($T_c$). The modification pattern of these mesons is very similar below $T_c$, whereas a clear flavor dependence appears above $T_c$ where lighter mesons suffer larger modifications. The strange meson ($\phi$) and strange-charmed mesons ($D_s$ and $D_s^*$) show slight modification already at $T_c$, while the charmonium states ($\eta_c$ and $J/\psi$) feel thermal effects only at $T > 1.2T_c$. This confirms that 1S charmonium states can survive beyond $T_c$. From degeneracies of parity partner it is also found that at $T_c$ the chiral symmetry is restored, whereas the breaking of the $U_A(1)$ symmetry is significant.

**On behalf of collaboration:**

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**Poster Session** - Board: 0535 / 285

**Using Unfolding Techniques to Separate Charm and Bottom Contributions to Single Electron Yields from Semi-leptonic Decays of Heavy Flavor Hadrons Measured by PHENIX**

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Measurements of heavy quark (charm and bottom) production provide important constraints on the nature of the quark gluon plasma produced in high energy heavy ion collisions, as they are created only during the initial collision and therefore probe the full evolution of the medium. The PHENIX Collaboration has previously measured open heavy flavor production via the yields of electrons from semi-leptonic decays of charm and bottom hadrons in $p+p$ and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The results indicate a significant suppression of the combined charm and bottom decay electrons for $p_T > 5$ GeV/$c$, but by themselves provide little constraint on the modification of the separate parent hadron distributions. The installation of the PHENIX silicon vertex detector in 2011 allowed for the measurement of the displaced vertex of these electrons for the first time at RHIC. In order to separate the contributions from charm and bottom hadrons, Bayesian unfolding techniques can be applied to the $p_T$ and displaced vertex dependence of the yield of electrons from open heavy flavor decays. This separation provides further constraints on energy loss and transport mechanisms in the
medium produced in heavy ion collisions. This poster will present the unfolding techniques utilized in separating these contributions, as well as the status of the analysis in $p+p$ and $Au+Au$ collisions from PHENIX.

On behalf of collaboration:

Poster Session - Board: 0536 / 200

Midrapidity Hyperon Production in pp and pA Collisions from Low to LHC Energies

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The experimental data on p, Lambda, Xi-, Omega- baryons and the corresponding antibaryons spectra obtained by different experimental collaborations are compared to results of the calculations performed into the frame of the Quark-Gluon String Model. The contributions of String Junction diffusion, and the inelastic screening corrections are accounted for. The predictions for pp and pA collisions up to the LHC energies are presented.

On behalf of collaboration:

Poster Session - Board: 0537 / 5

(Anti-)strangeness production in heavy-ion collisions

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We study the production of (anti-) strange and multi-strange hadrons in heavy-ion collisions from FAIR/NICA to LHC energies within the Parton-Hadron-String Dynamics (PHSD) microscopic transport approach, which contains the partonic and hadronic dynamics. By showing the channel decomposition for the strangeness production we demonstrate how with increasing energy the production in the QGP dominates the hadronic production. We observed traces from the QGP by looking at a verity of ‘bulk’ observables like the excitation functions of particle yields, $pt$- and rapidity distributions, centrality dependencies of yields, $\langle pt \rangle$ etc. At RHIC energies strange and anti-strange hadrons are produced at mid-rapidity with the same amount, while with decreasing energy the particles dominate more and more over antiparticles.

On behalf of collaboration:

Poster Session - Board: 0538 / 120

$\Lambda - \Lambda$ Correlation in High Energy Heavy Ion Collisions

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Co-author(s): OHNISHI, Akira ; FURUMOTO, Takenori
We show that $\Lambda\Lambda$ intensity correlation function $C(Q = k_1 - k_2)$ measured in high energy heavy ion collisions can constrain the interaction between two $\Lambda$ [1].

For various $\Lambda\Lambda$ interaction potentials in literature, summarized in the figure with corresponding low energy scattering parameters, we compute the $\Lambda\Lambda$ relative wave function $\Psi(x_1, x_2; Q)$ by assuming modification of the wave function in $S$-wave and discuss the relation between the scattering parameters and the behavior of the correlation function

$$C(Q, K) = \frac{\int dx_1 \int dx_2 S(x_1, K) S(x_2, K) |\Psi(x_1, x_2; Q)|^2}{\int dx_1 S(x_1, k_1) \int dx_2 S(x_2, k_2)},$$

where $S(x, K)$ denote the source function which is the phase space distribution of $\Lambda$ at freeze-out.

Employing a Gaussian source model with longitudinal and transverse expansion as a source function of $\Lambda$, we discuss the parameter ranges of the scattering length $a_0$ and the effective range $r_{\text{eff}}$ constrained from experimental data in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV measured by the STAR collaboration [2]. The contribution from electromagnetic decay $\Sigma^0 \rightarrow \Lambda \gamma$ is found to be important. We also point out the existence of residual correlation in the high $Q$ region which cannot be explained in the present framework.

Consequently, we obtained a constraint on the scattering length $1/a_0 < -0.8\, fm^{-1}$. We will also address an application of this method to other systems, such as $\Omega - N$ [3].

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We investigate the two-particle momentum intensity correlation function for \(\Omega N\) pairs

\[
C(Q, K) = \int \frac{dx_1}{S_\Omega(x_1, k_1)} \int \frac{dx_2}{S_N(x_2, k_2)} |\Psi(x_1, x_2; Q)|^2
\]

where \(Q\) is the relative momentum of the two emitted particles and \(S_i(x, k)\) denote the source function of particle species \(i\). \(C(Q, K)\) has been used as a sensitive probe for the source size in nucleus-nucleus collisions, but recently has been investigated for \(\Lambda \Lambda\) pairs to probe their interaction \(^{1}\).

The \(N \Omega\) system with \(S = -3\) is particularly interesting, since it is one of two multiplets in which the Pauli blocking does not take place thus can form a bound state. Indeed, a recent lattice QCD calculation by the HAL QCD collaboration \(^{2}\) predicts the existence of \(N \Omega\) bound state in the \(^5S_2 (J = 2, S = 2)\) channel. We adopt the \(N \Omega\) interaction potential obtained by the HAL QCD collaboration and calculate the \(N \Omega\) correlation function through the relative wave function \(\Psi(x_1, x_2; Q)\). Moreover, we also study the variation of the correlation function against the change of the property of the bound state.

We show that the correlation function \(C(Q)\) is sensitive to whether the system has a bound state or not (see figure). If the system has a bound state, the behavior of \(C(Q)\) at low \(Q\) also depends on the binding energy. We discuss how the behavior the scattering wave function can influence the behavior of \(C(Q)\) and its interplay with the source size. Our result indicates that high energy heavy ion collisions at RHIC and LHC may provide information on the possible existence of the \(N \Omega\) dibaryon.


On behalf of collaboration:

Posterior Session - Board: 0540 / 321

Single electrons from heavy flavor decays in Au+Au collisions at \(\sqrt{s_{NN}} = 200\) GeV in PHENIX RUN14 data
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Heavy quarks (charm and bottom) are important probes of the energy loss mechanism in the quark gluon plasma formed in high-energy heavy-ion collisions. Heavy quarks are produced only by hard scattering in the initial stage of a heavy-ion collision, since the charm and bottom masses are larger than the energy scale of QCD \( m_{c,b} \gg \Lambda_{QCD} \). The energy loss of heavy quarks would be expected to be smaller than that of light quarks due to the Dead-Cone-Effect that leads to a strong suppression of small angle gluon radiation.

We will present the status of the analysis of single electrons from heavy flavor decays in Au+Au collisions from the PHENIX Run14 dataset. The goal of the analysis is to understand the quark mass dependence of QCD medium effects via the \( p_T \) spectrum of single electrons from charm and bottom hadron decays separately. The first step of the analysis is the evaluation of key variables such as the Distance of Closest Approach (DCA) distributions of electrons and hadrons, inclusive electron \( p_T \) spectra and variables for electron identification. The total resolution of the transverse DCA and primary vertex is \( \sim 80 \mu m \) at \( p_T > 1 \text{GeV/c} \), which is enough to separate decay electrons from charm and bottom hadrons.

On behalf of collaboration:

Poster Session - Board: 0542 / 280

Measurements of Charm and Bottom Productions in Semi-leptonic Channels at STAR

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Heavy flavor quarks are suggested as excellent probes to study the strongly interacting Quark-Gluon Plasma (QGP) created in high-energy heavy-ion collisions. Measurements of Non-Photonic Electron (NPE) production from open heavy flavor hadron decays have revealed strong suppression at large transverse momentum in Au+Au collisions relative to p+p collisions at the Relativistic Heavy Ion Collider (RHIC). Such suppression has been attributed to energy losses of heavy flavor quarks within the QGP. Theoretical predictions that are able to describe existing NPE data suggest that bottom quarks lose less energy than charm quarks, but it varies among models depending on the impact parameter distributions. In this poster, we will present a first attempt to separately measure charm and bottom quark productions through semi-leptonic channels in Au+Au collisions at \( \sqrt{s_{NN}}=200 \text{ GeV} \) at RHIC, utilizing the new Heavy Flavor Tracker of the STAR experiment.

On behalf of collaboration:

Poster Session - Board: 0543 / 429

Feasibility studies for the measurement of D-meson production in jets in pp and Pb–Pb collisions with ALICE at the LHC

Author(s): OLIVEIRA DA SILVA, Antonio Carlos

Co-author(s): AIOLA, Salvatore
The production of heavy quarks (charm and beauty) is a process calculable in perturbative QCD. Heavy-flavour measurements provide valuable tests of QCD based models. Furthermore, since they are produced in the early stages of ultra-relativistic heavy-ion collisions, heavy quarks are an ideal probe to study the properties of the Quark-Gluon Plasma. Finally, due to the high collision energy, charm quarks are produced abundantly at the LHC.

D mesons can be used to identify jets containing charm quarks. The comparison of the distribution of the jet momentum fraction carried by D mesons in Pb–Pb and pp collisions is a key observable to spot possible modifications of charm-jet properties induced by the presence of the medium.

In this contribution, we report on the prospects for the measurement of D mesons in jets in pp and Pb–Pb collisions using the ALICE detector which have been studied through Monte Carlo simulations. These studies show the unique capability of the ALICE experiment to measure D mesons carrying a small fraction of jet momentum.

Radiative decay of heavy hadron molecules in charm and strange sector

Author(s): PATEL, SMRUTI
Co-author(s): Prof. P. C., Vinodkumar

A theoretical analysis of radiative decay of heavy hadron molecules has been carried out in charm and strange sector within the Lagrangian formalism. We have studied the dependence of radiative decay width on the mass of the constituting mesons and on the binding energies. Besides this, we have also included finite size effects in terms of size parameter $\Lambda_H$ which gives appropriate physical description of the heavy hadron molecule. This analysis can shed light on their still unresolved structure. In this work, we have focused particularly on $Y(3940)$ and $Y(4140)$ states. We have predicted $Y(3940)$ state as a molecular bound state of $D_s^*$ and $\bar{D}_s^*$ and $Y(4140)$ as a loosely bound molecular state of $D_s^*$ and $\bar{D}_s^*$. The narrow decay widths of these states are in good agreement with the available experimental data given by BELLE and BaBar experiments. The predictions for the radiative decays can serve further to distinguish between the different structure identification of these heavy hadron states. The detailed results will be presented at the time of conference.

Measurement of D meson–charged particle azimuthal angular correlations in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ALICE

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A Large Ion Collider Experiment (ALICE) is a general purpose heavy-ion experiment with the main goal of exploring the characteristics of the medium formed in high-energy nuclear collisions, composed of deconfined and strongly-interacting quarks and gluons (Quark-Gluon Plasma, QGP). Heavy quarks (charm and beauty) are produced in the initial hard scatterings and interact with the medium constituents throughout its whole evolution. Therefore, they serve as sensitive probes to study the properties of the medium.

The study of the angular correlation between D mesons and charged particles can provide relevant information on the processes by which heavy quarks lose energy in the QGP and help to spot possible modifications of the charm parton shower and hadronisation induced by the presence of the medium. The measurement of this observable in pp collisions, besides furnishing the necessary reference for future Pb–Pb studies, is interesting to study the fragmentation of charm quarks as well as their production mechanism providing a testing ground for perturbative QCD calculations. Data from p–Pb collisions are important to constrain possible modifications of the angular correlation pattern that could be induced by cold nuclear matter effects in the initial and final state of the nuclear collision.

In this contribution, we present the results of the measurement of azimuthal correlations between D mesons and charged particles using the data collected with ALICE in p–Pb collisions at \( \sqrt{s_{NN}} = 5.02 \) TeV. They are compared to the results obtained in pp collisions at \( \sqrt{s} = 7 \) TeV. D mesons were reconstructed from their hadronic decays at central rapidity \(|y| < 0.5\) in the transverse momentum range \(3 < p_T(D) < 16\) GeV/c and were correlated with charged hadrons reconstructed in the pseudorapidity range \(|\eta| < 0.8\).

On behalf of collaboration:

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**Poster Session** - Board: 0546 / 569

**Strangeness production in high energy collisions**

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One of the major goals of high-energy heavy-ion research is to explore the properties of strongly interacting matter, as it may undergo a phase transition into a system of deconfined quarks and gluons (quark-gluon plasma, QGP). Strange particle production has been one of the most important observable in the search for the QGP. In this work, the pion and kaon enhancement factors from Au+Au collisions at RHIC energies (the yield per mean number of participating nucleons, Npart, in heavy-ion collisions divided by the respective value in p+p collisions) will be presented. The rapidity and Npart (collision centrality) dependence of these enhancement factors will be shown and discussed. We will also present the rapidity and baryo-chemical potential dependence of the produced particle ratios. In addition, comparisons with the simulated heavy ion collisions at future CBM-FAIR energies using different simulation codes (UrQMD, HIJING, AMPT) integrated in the YaPT system will be shown and discussed.

On behalf of collaboration:

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**Poster Session** - Board: 0547 / 430

**D⁺-meson production as a function of charged-particle multiplicity in p–Pb collisions with ALICE**
The measurement of heavy-flavour production cross sections in pp collisions at the LHC has provided a reference for heavy-ion studies and a test for perturbative QCD calculations. Moreover, the LHC has started the Run 2 operations this year, and the study of D-meson production in pp collisions at $\sqrt{s} = 13$ TeV could provide a measurement of heavy-flavour production cross section at an unprecedented energy. In p–Pb collisions, heavy-flavour measurements are essential to assess the effects due to the presence of a nucleus in the initial state, such as the modification of the parton densities and the $k_T$-broadening resulting from multiple soft scatterings of the partons. In this poster, we will focus on D$^+$-meson measurements as a function of the multiplicity of charged particles produced in the collision. These measurements are sensitive to the interplay between hard and soft contributions to particle production in p–Pb collisions and, in particular, could give insight into the role of multi-parton interactions (MPI), i.e., several hard partonic interactions occurring in a single collision at high centre-of-mass energies. The measurement is performed in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV recorded with the ALICE detector in 2013. D$^+$ mesons are reconstructed in their hadronic $K^-\pi^+\pi^+$ decay channels in the central rapidity region, and their yields are measured in different multiplicity and $p_T$ intervals. The per-event yield of D$^+$ mesons in the different multiplicity intervals, normalized to its multiplicity-integrated value, and its evolution with $p_T$ will be compared for pp and p–Pb collisions. The nuclear modification factor of D$^+$ mesons in p–Pb collisions, defined as the ratio of the D-meson yield in p–Pb and pp collisions scaled by the number of binary collisions $N_{\text{coll}}$, will be discussed in terms of its event activity dependence.

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Poster Session - Board: 0548 / 426

Heavy-flavour jet studies by tagging electrons from heavy-flavour hadron decays with ALICE

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In heavy-ion collisions, charm and beauty (heavy flavour) quarks are produced in the initial hard partonic interactions. They successively interact with the hot and dense Quark-Gluon Plasma (QGP) formed in such collisions. Therefore, measurements of heavy-flavour production provide relevant information on the properties of the QGP. In Pb–Pb collisions, a strong suppression of heavy-flavour yields has been observed at high $p_T$ with respect to pp collisions scaled by the number of binary collisions which is attributed to energy loss of heavy quarks in the QCD medium. Further information about energy-loss mechanism can be obtained by measuring the production of jets containing charm and beauty. In ALICE, inclusive jet production has been measured for $p_T > 20$ GeV/$c$ in pp and Pb-Pb collisions. Heavy-flavour jets can be identified via heavy-flavour decay electrons inside the jet cone. In this poster, we show studies of heavy-flavour jet production tagged by electrons from heavy-flavour hadron decays with ALICE.

On behalf of collaboration:

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Poster Session - Board: 0549 / 220

$\phi$ production in $^3$He+Au collisions at $\sqrt{s_{NN}} = 200$ GeV with the PHENIX detector at RHIC
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The \( \phi \) production in high-energy heavy-ion collisions provides key information on the hot and dense state of the strongly interacting matter produced in such collisions. They are sensitive to the medium-induced effects such as strangeness enhancement, modification of the resonance line shapes and their relative production rates in leptonic and hadronic decay modes linked to the chiral symmetry restoration. Measurements in the dilepton channels are especially interesting since leptons interact only electromagnetically, thus carrying the information from their production phase directly to the detector. Measurements of \( \phi \) production in \(^3\)He+Au collisions, a new collision system, add to the existing results (\( p+p, d+Au \) and \( Cu+Au \)) which extends our ability to have a systematic study of nuclear medium effects on \( \phi \) production. The PHENIX detector provides the capabilities to measure the \( \phi \) production in a wide range of transverse momentum and rapidity to study various cold nuclear effects such as soft multiple parton rescattering and modification of the parton distribution functions in nuclei.

In this poster, we report the current status of the \( \phi \) meson production measurement from \(^3\)He+Au collisions at \( \sqrt{s_{NN}} = 200 \) GeV.

On behalf of collaboration:

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Poster Session - Board: 0550 / 552

\( \Lambda \) and \( K^0 \) production in \( \text{Au+Au} \) collisions at 1.23 AGeV with the HADES experiment

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Over the years an extensive amount of data in the 1-2 AGeV energy regime has been collected leading to enormous improvements of our understanding of particle production mechanisms and HIC dynamics. At these beam energies the production of hadrons is observed below or slightly above their free elementary production threshold. Due to this fact a comparison to reference data from elementary collisions is not straightforward and phenomenological models are mandatory.

For this analysis, 7.3 billion of the 40% most central \( \text{Au(1.23 AGeV per nucleon)+Au} \) reactions have been used to reconstruct the weakly decaying strange hadrons \( K^0_s \) and \( \Lambda \). In order to draw conclusions on strangeness production mechanisms the yields will be compared to non-strange particle production and phenomenological models, allowing to further deepen our understanding of hadron production in HIC.

Supported by BMBF (05P12RFGHJ), HIC for FAIR, GSI, HGS-HIRe and H-QM.

On behalf of collaboration:

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Poster Session - Board: 0552 / 528

Charged kaon- and \( \phi \)-reconstruction in \( \text{Au+Au-collisions at 1.23 AGeV} \)

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In Au+Au-collisions at 1.23 AGeV incident energy, strangeness is produced below the free nucleon-nucleon threshold. In baryon dominated matter $K^+$ and $K^-$ mesons exhibit different properties, since only $K^-$ can be resonantly absorbed by nucleons. Although strangeness exchange reactions have been proposed to be the dominant channel for $K^-$ production in this energy regime, the production yield could also be explained in Ar+KCl-reactions at 1.76 AGeV based on a statistical hadronization model fit to the measured particle yields. To guarantee strangeness conservation, strangeness is calculated canonically within $R_c$ in these models, and therefore the ratio of $\phi/K^-$ is predicted to rise with decreasing beam energies and as a consequence the feed-down of $\phi$-mesons to kaons becomes important.

In total 7.3 Billion 40% most central Au(1.23 GeV per nucleon)+Au collisions have been analyzed for this investigation. The data has been recorded with HADES and a substantially improved reconstruction method has been employed to reconstruct the hadrons with high purity in a wide phase space region. In this contribution, we present results on charged kaons and $\phi$-mesons.

Supported by BMBF (05P12RFGHJ), HIC for FAIR, HGS-HIRe, H-QM and GSI.

On behalf of collaboration:

Poster Session - Board: 0553 / 286

Heavy flavor muons at forward rapidities in Cu+Au collisions with the PHENIX detector

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The dynamics of heavy quark and their suppression in A+A collisions offers a unique opportunity to study the properties of Quark-Gluon Plasma produced at RHIC. They are produced early in the collision and experience the full evolution of the medium. Studying the related observables in p(d)+A and A+A collisions can allow for the quantification of cold nuclear matter effects and energy loss in the produced hot medium. Asymmetric collisions of heavy nuclei, such as Cu+Au, provide an initial geometrical configuration where an interplay between cold and hot nuclear effects can be explored. Recent measurements of single muon invariant yields and nuclear modification factors at forward rapidities in Cu+Au collisions using the PHENIX detector will be presented.

On behalf of collaboration:

Poster Session - Board: 0554 / 256

Bottom cross-section measurement in $p+p$ collisions using dielectrons at $\sqrt{s} = 200$ GeV measured by the PHENIX Experiment at RHIC

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The dielectron mass spectrum is a unique probe to directly access the different stages of a heavy-ion collision. The intermediate ($1 < m_{e^+e^-} < 3$ GeV/$c^2$) and high ($4 < m_{e^+e^-} < 8$ GeV/$c^2$) mass regions are dominated by semi-leptonic decays of open charm and beauty respectively, and so provide information about the heavy flavor dynamics. We will present the current status on the bottom cross-section extracted in $p+p$ collisions. The method utilizes
the double differential fit done in $m_{e^+e^-}$ and $p_T$ space, which provides sensitivity to the regions where either charm or bottom dominates. A comparison to the $p_T$ spectrum and cross-section extracted from the $d+Au$ dielectron mass spectrum using the same technique will be presented.

On behalf of collaboration:

**Poster Session - Board: 0555 / 408**

**Λ⁺ c baryon production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV**

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Baryon/meson ratios (p/π, Λ/Κ⁰) are observed to be significantly enhanced in central heavy-ion collisions compared with peripheral heavy-ion collisions and p+p collisions at RHIC and LHC. Several model calculations suggest that coalescence hadronization between charm quarks and light quarks will also lead to an enhancement in the $Λ_c/D⁰$ ratio. Therefore, it is of great interest to study the $Λ_c$ baryon production to further understand the hadronization scheme in the charm sector and constrain total charm yield in heavy-ion collisions. The possible $Λ_c/D⁰$ enhancement in heavy-ion collisions will introduce additional suppression for charm decay electrons due to smaller semi-leptonic decay branching ratios of $Λ_c$, which could lead to a different interpretation of the heavy flavor decay electron results. $Λ_c$ baryons have an extremely small lifetime ($c\tau \sim 60$ µm) and have not been measured in heavy-ion collisions yet. The newly installed STAR Heavy Flavor Tracker (HFT) has shown high efficiency and a superior pointing resolution that facilitate the reconstruction of hadronic decays in heavy-ion collisions. In 2014 run, STAR has collected 1.2 B events of minimum bias Au+Au collisions $\sqrt{s_{NN}} = 200$ GeV.

In this poster, we will discuss the feasibility of $Λ_c$ measurement with the HFT in Au+Au collisions. We will report reconstruction of $Λ_c$ baryons via hadronic decays, including decay channels through the involvement of various intermediate resonance states using 2014 Au+Au data at $\sqrt{s_{NN}} = 200$ GeV. In addition, we will discuss the improvement on $Λ_c$ reconstruction using the HFT with reduced material that is taking data in 2015 (p+p, p+A) and is planned for future 2016 (Au+Au) collisions.

On behalf of collaboration:

**Poster Session - Board: 0556 / 447**

**Production of Ξ(1530)⁰ in p-Pb collisions at the LHC with ALICE**

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The measurement of resonance properties in p-Pb collisions allows for the study of nuclear effects in the absence of hot and dense nuclear matter. The production of the Ξ(1530)⁰ baryonic resonance (and its antiparticle) has been studied with the ALICE detector in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV at the CERN LHC.

The transverse momentum ($p_T$) spectrum of the Ξ(1530)⁰ baryon in the rapidity range (0 < $y_{CMS}$ < 0.5) is reported in different multiplicity classes. The integrated yield $dN/dy$ and
average $p_T$ as a function of the event multiplicity ($dN_{ch}/d\eta$) are also presented. These results are compared with corresponding results in pp collisions.

On behalf of collaboration:

Poster Session - Board: 0557 / 579

Modifications of heavy-light mesons in inhomogeneous chiral condensation phases

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In this talk, we propose that heavy-light mesons can be good probes to investigate the nuclear matter. It is said that inhomogeneous chiral condensation phases in which neutral pion condense can exist in high density and low temperature region near the chiral restoration point. Then, we put heavy-light mesons into such phases and investigate what happens. At first, we put heavy-light mesons on some inhomogeneous phases and see the modification of their masses. In this case, heavy-light mesons carrying different spin and iso-spin mix each other. And this causes the mass splitting of heavy-light mesons, e.g., $D(0^-)$ and $D^*(1^-)$ degenerated in the vacuum. Furthermore, these splitting patterns reflect what kind of inhomogeneous phase occurs. Next, we show the dispersion relations for heavy-light mesons in the Chiral Density Wave (CDW) phase. The CDW is one of the inhomogeneous phases where scalar mode and neutral pseudo-scalar mode can condense. In this phase, potentials for heavy-light mesons are periodic, so that we have to employ the Bloch’s theorem to get the dispersion relations. Thereby, dispersion relations drastically change, i.e., the existence of the Brillouin zones and the emergence of collective modes. These modifications are signal of the existence of the inhomogeneous phases.

On behalf of collaboration:

Poster Session - Board: 0558 / 630

Heavy hadron systems in a magnetic field

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Quantum chromodynamics (QCD) in a strong magnetic field is one of the most exciting topics in hadron physics. In relativistic heavy-ion collision experiments performed in RHIC and LHC, it is predicted to be produced a strong magnetic field by non-central collision of charged nuclei. In particular, hadron properties under such external field can be drastically modified by perturbative and non-perturbative effects.

In this study, we investigate theoretically the properties of heavy hadrons (especially, D mesons) including a charm quark in a magnetic field by using some theoretical approaches.
such as the QCD sum rules and effective models. From our approaches, we can predict the D meson mass shifts by magnetic effects such as the Landau level for a charged particle, the mixing effect between different hadron states and magnetic field dependence of condensates. Technically, in the QCD sum rules, the OPE up to the order of the square of magnetic field is calculated and the magnetic field dependences of condensates are taken from the recent results of lattice QCD or effective field theory. For the phenomenological side, we introduce a new structures induced by a magnetic field to go beyond the analysis by (conventional) “pole + continuum” assumption.

As a result, we discuss some magnetic properties of the hadrons induced by a magnetic field, such as Landau level of the charged meson, mixing effect with other hadron states and magnetic field dependence of QCD condensates. Furthermore, we discuss comparison with recent indications from the lattice QCD and experimental possibilities.

On behalf of collaboration:

Poster Session - Board: 0559 / 427

Prospects of measuring heavy-flavour dijets in pp collisions with the ALICE detector

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Heavy quarks (charm and beauty) have masses significantly above $\Lambda_{\text{QCD}}$ and, hence, their production cross sections and phase-space distributions in proton-proton (pp) collisions can be well described by perturbative QCD calculations. Therefore, measurements of jets containing heavy-flavour hadrons can shed light on underlying QCD dynamics. Measurements of inclusive heavy-flavour cross sections do not allow to distinguish between different production mechanisms of heavy quarks (pair production, gluon splitting and flavour excitation). More exclusive studies using dijet events might provide further insight on the relevant production mechanisms.

Heavy-flavour dijets can be measured by tagging jets containing electrons originating from decays of heavy-flavour hadrons. In this contribution, the prospects for and the feasibility of such measurements in pp collisions with the ALICE detector at the LHC will be discussed based on Monte-Carlo simulations.

On behalf of collaboration:

Poster Session - Board: 0560 / 416

Strangeness production in U+U collisions at STAR

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Enhanced strange quark production in high-energy heavy-ion collisions relative to p+p collisions was proposed as a possible signature of the deconfined phase of quarks and gluons [1]. It was suggested that the dominant process for the production of strange quarks in the quark gluon plasma is gluonic fusion. Chemical equilibration of strange quarks formed in such medium happens faster than would be the situation in hadronic scenario [2].

With 20% larger energy density expected [3] and a larger lifetime of fireball than Au+Au collisions, we can have a better insight of testing these facts in U+U collisions.
We will present transverse momentum ($p_T$) spectra of $K_s$, $\Lambda(\bar{\Lambda})$ and $\Xi(\bar{\Xi})$ in U+U collisions at $\sqrt{s_{NN}} = 193$ GeV in STAR experiment at RHIC. These strange particles are reconstructed from their weak decay topology via dominant hadronic decay modes using the Time Projection Chamber (TPC) detector of STAR. Measured masses of these particles are consistent with PDG values. A clear centrality dependence of $p_T$ spectra is observed for these particles. We’ll also show comparison of these results with Au+Au 200 GeV results.

References

On behalf of collaboration:

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**Poster Session - Board: 0561 / 422**

D$^{*+}$-meson production in p–Pb collisions in ALICE

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Heavy quarks (charm and beauty) are effective probes to investigate the properties of the Quark-Gluon Plasma created in high-energy heavy-ion collisions at the LHC. They are primarily produced in hard scattering processes in the early stage of the collision, after which they experience the full evolution of the system. Previous measurements have shown that the production of prompt D mesons in central Pb–Pb collisions is strongly suppressed in comparison to binary-scaled pp collisions. This suppression may be interpreted as an energy loss of the heavy quarks in the hot and dense medium due to collisional and radiative processes. To obtain a more complete picture on the Pb–Pb results, an understanding of cold nuclear matter effects in the initial and final state such as modification of parton densities in nuclei, $k_T$ broadening and energy loss in cold nuclear matter, is required. These effects are accessible in p–Pb collisions. Here, the measurement of prompt D$^{*+}$ production in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ALICE detector will be presented.

On behalf of collaboration:

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**Poster Session - Board: 0562 / 403**

Measurements of D$^{*+}$-meson production in Pb–Pb and pp collisions with ALICE at the LHC

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The measurement of open heavy-flavour production is a powerful tool to test next-to-leading-order perturbative QCD calculations in hadronic collisions in the TeV energy regime of the Large Hadron Collider (LHC). Moreover, the D$^{*+}$-meson $p_T$-differential production cross section in pp collisions provides the reference for the study of nuclear matter effects on D$^{*+}$-meson yields in Pb–Pb collisions, as quantified by the nuclear modification factor ($R_{AA}$). This observable compares the measured particle yield in Pb–Pb collisions with the yield in binary-scaled pp collisions. As heavy-flavour quarks (charm and beauty) are primarily produced in hard scattering processes in the early stage of collisions, they provide excellent probes for the Quark-Gluon Plasma produced in Pb–Pb collisions.
The ALICE detector at the LHC collected data in pp collisions at center-of-mass energies of 2.76, 7, 8 TeV and, starting from June 2015, at 13 TeV, as well as in Pb–Pb collisions at 2.76 TeV and in p–Pb collisions at 5.02 TeV. In ALICE, D*+ mesons are reconstructed at mid-rapidity via the D*+ → D0 π+ → K− π+ π+ decay channel. In this contribution, we present the latest results on the D*+-meson nuclear modification factor in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV as well as discuss prospects for D*+-meson measurements in pp collisions at $\sqrt{s} = 13$ TeV using the LHC run-2 data.

On behalf of collaboration:

Poster Session - Board: 0565 / 144

Heavy-flavor dynamics in relativistic proton-nucleus and nucleus-nucleus collisions

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Heavy-flavor hadrons serve as valuable probes for the quark-gluon plasma (QGP): low transverse momentum ($p_T$) heavy quarks provide important information about thermal properties of the system, while high $p_T$ heavy quarks provide a reference to quantify the in-medium modification. We establish a comprehensive framework to describe the full heavy flavor evolution in heavy-ion collisions: the QGP medium is described in a (3+1)-dimensional viscous hydrodynamics model, the dynamics of heavy quarks are studied in an improved Langevin framework incorporating both radiative and collisional energy loss, and the hadronization of heavy quarks is described with a hybrid model of fragmentation and recombination. In this talk, we present first calculations of heavy flavor energy loss and collective behavior in p+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The nuclear modification factor shows a centrality dependence: in the untra-central collisions, in-medium energy loss leads to suppression of heavy quarks; while cold-nuclear-matter effects are dominant in mid-central to peripheral collisions. The comparison between the elliptic flow of mesons and light charged hadrons indicates an incomplete coupling of heavy quarks with the medium due to the reduced temperature and medium size. We propose to use centrality dependence of the observables in p+Pb collisions in order to disentangle hot-nuclear-matter effects from cold-nuclear-matter effects. In addition, we go beyond the typically studied systems in heavy-ion collisions and focus on small systems (Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV) and on a lower collisional energy (Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV). Looking at the nuclear modification factor and collective flow of D and B mesons, we are able to quantify the QGP modifications to heavy quark over the entire $p_T$ range: suppression at high $p_T$, and collective behavior as well as signs for partial thermalization at low $p_T$.

On behalf of collaboration:

Poster Session - Board: 0566 / 655

Exotic hadrons and/or molecules from relativistic heavy ion collisions

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Exotic hadrons are one of the most interesting topics recently studied in the hadron physics as their structure are related to the fundamental ingredients in QCD. Moreover, the production of light nuclei and excited states became realistic in heavy ion collisions. Hence, we will discuss the production of exotic hadrons with strange, charm and bottom quarks in heavy ion collisions, and how the production rates can be used to discriminate between compact multiquark configuration from hadronic molecular configurations [1,2].

Specifically, we consider the coalescence model and the statistical model, which have been successful for explaining the productions of normal hadrons, to calculate the production yields of exotic hadrons. We give a detailed discussions for applications of the coalescence model to resonant states by including finite decay widths. We present that the production yields are sensitive to structures of exotic hadrons, namely compact multi-quark states or extended hadronic molecule states. As specific examples, we investigate the production of scalar mesons, $\Lambda(1405)$, dibaryons, and $D_s$ mesons. We furthermore investigate charmonium-like and bottomonium-like states called $X$, $Y$, $Z$, which have been recently reported in several accelerator facilities, Belle, BaBar, BESS, LHCb and so on.


On behalf of collaboration:

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**Poster Session** - Board: 0567 / 385

**Measurements of heavy flavor decay electron production in p+p collisions at $\sqrt{s}=200$ GeV at STAR**

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Heavy quarks are believed to be produced at early stages of high-energy heavy-ion collisions. Measurements of heavy quarks can improve our understanding of parton interactions with the Quark-Gluon Plasma (QGP) and its properties. Heavy quark production in p+p collisions is a baseline to investigation of the QGP in heavy-ion collisions and is expected to be well described by perturbative Quantum Chromodynamics (pQCD). However, the pQCD calculations have large uncertainties at low transverse momentum ($p_T$). Thus measurements of heavy quark production at low $p_T$ in p+p collisions, which can be studied by measuring electrons from semi-leptonic decays of heavy flavor hadrons, are crucial for constraining the pQCD models. In this poster, we will present the STAR measurements of low $p_T$ heavy flavor decay electron production in p+p collisions at $\sqrt{s}=200$ GeV in RHIC run 2012 with 6[U+FF5E]7 times more statistics than measurements of run 2009 data.

On behalf of collaboration:

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Production of Muons from Heavy-Flavour Hadron Decays in Pb–Pb Collisions at $\sqrt{s_{\text{NN}}} = 2.76$ TeV with ALICE at the LHC

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The LHC heavy-ion physics program aims at investigating the properties of QCD matter at extremely large temperature and energy density, where the formation of the Quark-Gluon Plasma (QGP) is expected. In high-energy heavy-ion collisions, heavy quarks (charm and beauty) are regarded as efficient probes of the properties of the QGP as they are created on a very short time scale in initial hard scattering processes and subsequently interact with the medium.

At high transverse momentum ($p_T$), heavy-flavour yields are suppressed due to in-medium parton energy loss. This suppression is quantified by the nuclear modification factor $R_{AA}$, defined as the ratio of the particle yield measured in Pb-Pb collisions to the cross section in pp collisions scaled with the average nuclear overlap function.

At low $p_T$ the heavy-flavour azimuthal anisotropy provides insight into whether heavy quarks participate in the collective expansion of the medium, and at high $p_T$ it carries information on the path-length dependence of parton energy loss. The heavy-flavour azimuthal anisotropy is quantified via the measurement of the second order coefficient ($v_2$) of the Fourier expansion of particle azimuthal distributions, also called elliptic flow.

With ALICE, designed and optimised for the study of heavy-ion physics, we can measure open heavy flavours at forward rapidity ($2.5 < y < 4$) via their muonic decays. The latest results on the nuclear modification factor and elliptic flow of muons from heavy-flavour hadron decays in Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 2.76$ TeV will be presented.

On behalf of collaboration:

D$^\pm_s$ meson production in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV in STAR

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Heavy quarks, produced in hard scattering processes in the initial stages of the collisions, are considered as excellent probes for the strongly interacting deconfined medium formed in heavy-ion collisions. The $D_s(c\bar{s}/c\bar{s})$ production is affected by the strangeness enhancement and the primordial charm quark production. Thus the modification of the $D_s$ meson spectra in ultra-relativistic heavy-ion collisions provides a new interesting probe to the key properties of the hot nuclear medium.

The Heavy Flavor Tracker, installed in STAR in 2014, has been designed to extend STAR’s capability of measuring heavy flavor production by the topological reconstruction of displaced decay vertices. It provides a unique opportunity for precise measurement of the $D_s$ meson production. We will present the first measurement of $D_s$ meson production via two decay channels $D_s \rightarrow \phi(1020)+\pi$, and $D_s \rightarrow K+K^*(892)$ in Au+Au collisions at 200GeV. Preliminary results on the central-to-peripheral nuclear modification factor ($R_{cp}$) will also be presented.

On behalf of collaboration:
Predictions for the upcoming LHC data: an interplay of energy loss and initial distributions

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High momentum hadron suppression is considered to be an excellent probe of jet-medium interactions in QCD matter created in ultra-relativistic heavy ion collisions. The dynamical energy loss formalism is shown to be able to accurately explain suppression measurements at 200 GeV Au+Au collisions at RHIC and 2.76 TeV Pb+Pb collisions at the LHC [1,2]. With the upcoming LHC measurements at notably higher collision energies, there is a question of what differences, with respect to the current (2.76 TeV) measurements, can be expected. We will concentrate on light and heavy flavor suppression at the upcoming 5.1 TeV Pb+Pb collisions energy at the LHC. Naively, one would expect a notably (∼30%) larger suppression at 5.1 TeV collision energy, due to the estimated (significant) energy loss increase when transitioning from 2.76 to 5.1 TeV. Surprisingly, more detailed calculations predict nearly the same suppression results at these two energies; note that this prediction is in agreement with the similar suppression patterns observed for light flavor observables at lower beam energies at RHIC and LHC. We will show that this unexpected result is due to interplay of the following two effects [3], which essentially cancel each other: i) flattening of the initial distributions with increasing collision energies, and ii) significantly slower than naively expected increase in the energy loss. Therefore, the obtained nearly the same suppression provides a clear (qualitative and quantitative) test of the dynamical energy loss formalism. [1] M. Djordjevic and M. Djordjevic, Phys. Lett. B 709, 229 (2012) [2] M. Djordjevic, M. Djordjevic, B. Blagojevic, Phys. Lett. B 737, 298 (2014) [3] M. Djordjevic and M. Djordjevic, arXiv:1505.04316

On behalf of collaboration:

Quarkonium melting in the QGP fireball from the stochastic potential

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Elucidating the sequential suppression patterns of Bottomonium discovered in dilepton yields during run1 at the LHC urges theory to develop non-perturbative real-time descriptions of in-medium quark bound states out of equilibrium. The recent treatment of Bottomonium as open-quantum system [1,2] promises a viable path towards this goal. Here we present results from a first simulation of quarkonium dynamics in a realistic quark-gluon plasma, based on the concept of stochastic potential [3]. The values of this proper potential is extracted from first principles (Nf=2+1) lattice QCD simulations and does not contain modeling input [3]. Initializing with the wave function of a localized quark-antiquark pair obtained in non-relativistic QCD effective theory [4] we solve the stochastic Schrödinger equation for Bottomonium according to the local temperature obtained from 2+1 dimensional hydrodynamics [5]. Including the effect of feed down after bottomonium hadronization, we compare our results
with experimental data, in particular the centrality dependence of the bottomonium nuclear modification factor $R_{AA}$. Possible signatures of thermalization are discussed by comparing to the predictions of the statistical model of hadronization.


On behalf of collaboration:

**Poster Session** - Board: 0602 / 581

**Analysis of charmonium at finite temperature from complex Borel sum rules**

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Recently, we proposed a new type of QCD sum rules i.e. the complex Borel sum rules (CBSR) [1]. It has been found that the CBSR is superior to the conventional QCD sum rules from the point of view of the maximum entropy method (MEM) analysis. Specifically, we have demonstrated that our novel method can be used to study the excited states of hadrons. The suppression of quarkonium states (e.g. J/psi and upsilon) is an important signature of the hot matter produced in relativistic heavy-ion collisions at RHIC and LHC. Recently, the behavior of the excited states at finite temperature, which can be different from the ground state, has attracted much attention. The suppression of the quarkonium ground states has already been analyzed by conventional QCD sum rules with MEM [2,3]. In this presentation, we report on the results of a reanalysis by CBSR with MEM to investigate the thermal behavior of the charmonium excited states.


On behalf of collaboration:

**Poster Session** - Board: 0603 / 666

**Quarkonia Disintegration due to time dependence of the q̅q potential in Relativistic Heavy Ion Collisions**

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Rapid thermalization in ultra-relativistic heavy-ion collisions leads to fast changing potential between a heavy quark and antiquark from zero temperature potential to the finite temperature one. Time dependent perturbation theory can then be used to calculate the survival probability of the initial quarkonium state. In view of very short time scales of thermalization at RHIC and LHC energies, we calculate the survival probability of $J/\psi$ and $\Upsilon$ using sudden approximation. Our results show that quarkonium decay may be significant even when temperature of QGP remains low enough so that the conventional quarkonium melting due to Debye screening is ineffective.
Medium Screening Effects on the Quarkonia States

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We have studied the stability of heavy quarkonia states in a QGP by incorporating color screening effects, vacuum screening effects and the color screening radii. We have particularly looked into the ground state, orbitally excited state and radially excited states of charmonia and bottomonia. The dependence of energy eigenvalues on screening parameter \( \mu \) and the strength of the quark-antiquark potential have been studied. It is observed that with increase in the potential strength, color screening radii \( r_D \) increases, while vacuum screening parameter \( \mu_v \) decreases with increase in potential strength. Also noticed that \( J/\psi \) is more stable against the vacuum screening effects. The detailed results and calculations will be presented at the time of conference.

Production of charmonium states by recombination

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We investigate the production of charmonia by focusing on their production by recombination in heavy ion collisions. Starting from the discussion on Wigner functions for charmonium states we consider the dependence of charmonia production on their wave functions. We show that wave function distributions of charmonium states in momentum space play significant roles in understanding the transverse momentum distribution of charmonium states, providing a possible way of understanding the recent measurement of the nuclear modification factor ratio between the \( \psi(2S) \) and \( J/\psi \) meson.

PHENIX Results on Excited Charmonia Production at Forward and Backward Rapidity

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Recent measurements from RHIC and the LHC have shown that the excited charmonium state \( \psi(2S) \) is preferentially suppressed over the more tightly bound \( J/\psi \) in ultrarelativistic \( p(d) + A \) collisions. The exact mechanism behind this difference in suppression is not immediately clear. Since all primordial charm quark production is subject to similar initial state effects inside the nucleus, and the time the \( c\bar{c} \) pair spends in the nucleus is so short, it may be that interactions outside the nucleus with co-moving particles are partially responsible for the
disruption of the charmonium wavefunction. Therefore it is interesting to study charmonium production at forward and backward rapidity, where the co-moving particle density varies considerably between the Au-going and p-going directions. The introduction of the Forward Silicon Vertex Tracker (FVTX) in front of the PHENIX muons arms has improved the dimuon mass resolution such that the $\psi(2s)$ peak can now be distinguished from the $J/\psi$ peak and measured at forward and backward rapidity. Here, we present the status of measurements of forward and backward $\psi(2s)$ production in $p+p$ and $p+Au$ collisions at 200 GeV/n, from the 2015 PHENIX dataset.

On behalf of collaboration:

Poster Session - Board: 0608 / 134

Classical and quantum evolution of quarkonium in a plasma

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New developments have changed the picture of quarkonium suppression in the last years. On one hand, perturbative and lattice computations indicate that the potential describing the interaction of two heavy quarks in a plasma has an imaginary part that effectively takes into account the collisions of the heavy quarks with the plasma constituents. There are also experimental indications that recombination plays an important role in determining the observed suppression. Both of these developments force us to deepen our understanding of the dynamics of quarkonia in a medium, beyond the static or equilibrium picture that prevails in most discussions. In this talk we investigate the quantum evolution of quarkonium in a thermal medium, including finite momentum effects that are usually ignored in potential models. By treating color degrees of freedom in a rigorous way we are able to understand under which circumstances a classical evolution, similar to that given by a Langevin equation, can be obtained. This classical equation can be generalized to an arbitrary number of heavy quarks, allowing us to study within the same formalism quarkonium suppression and recombination.

On behalf of collaboration:

Poster Session - Board: 0609 / 35

Magnetic Field Effect on Charmonium Formation in High Energy Nuclear Collisions

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It is important to understand the strong external magnetic field generated at the very beginning of high energy nuclear collisions. We study the effect of the magnetic field on the anisotropic charmonium formation in Pb+Pb collisions at the LHC energy. The time dependent Schrödinger equation is employed to describe the motion of $c\bar{c}$ pairs. We compare our model prediction of the non-collective anisotropic parameter $v_2$ of $J/\psi$ with CMS data at high transverse momentum. This is the first attempt to measure the strong magnetic field at the very initial stage of high energy nuclear collisions.

On behalf of collaboration:
**Poster Session** - Board: 0610 / 559

**J/psi production measurements in p-Pb collisions with ALICE**

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In heavy-ion collisions at the LHC, the ALICE experiment studies nuclear matter at very high energy densities where the formation of a Quark-Gluon Plasma (QGP) is expected. Quarkonium production is an important probe to characterize the properties of the QGP. High precision data in pp and p-Pb collisions serve, respectively, to provide the baseline for the Pb-Pb measurement and to quantify the amount of initial and/or final state effects related to cold nuclear matter, that are largely unknown at LHC energies. Since 2010, the LHC delivered Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, pp collisions at various energies and, in 2013, p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The inclusive J/$\psi$ production in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV was studied by ALICE down to zero transverse momentum ($p_T$) in the backward (-4.46 < $y_{c.m.s}$ < -2.96) and forward (2.03 < $y_{c.m.s}$ < 3.53) center-of-mass rapidity intervals in the dimuon decay channel and in the mid-rapidity region (-1.37 < $y_{c.m.s}$ < 0.43) in the dielectron decay channel. The two former rapidity intervals correspond to the Pb-going and p-going directions, respectively. In this presentation, the J/$\psi$ nuclear modification factors will be presented as a function of the J/$\psi$ rapidity and $p_T$ and of the centrality of the collision, as estimated from the energy deposited in the Zero Degree Calorimeters. The forward-to-backward ratios and the average $p_T$-square values will be also reported. The measurements will be compared to theoretical models and the implication of these measurements to the interpretation of the nuclear modification factor measured in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV will be discussed.

On behalf of collaboration:

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**Poster Session** - Board: 0611 / 551

**Transverse and longitudinal spectral functions of charmonia at finite temperature on the lattice**

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We study the charmonium spectral functions with finite momentum from lattice Euclidean correlators using the maximum entropy method. In medium, the spectral function of vector channel with finite momentum is decomposed into transverse and longitudinal components because of the lack of Lorentz invariance. We investigate these spectral functions, their residues and the dispersion relations on the quenched lattice below and above the critical temperature.

On behalf of collaboration:

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**Poster Session** - Board: 0612 / 548

**Masses and Decay Constants of B Mesons**

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Masses and decay constants of the $B$ meson have been studied in a framework employing phenomenological quark-antiquark potential (coulomb + linear) model with kinematic relativistic corrections to the kinetic energy term. Variational method using gaussian wave functions both in position and momentum space have been used to obtain low lying masses of the $B$ meson by including spin-orbit, spin-spin and tensor interactions within the potential. Decay constants are also evaluated using the wave function at the origin. The results are compared with various theoretical model predictions and experimental measurements.

On behalf of collaboration:

**Poster Session - Board: 0613 / 532**

$\Upsilon$ measurements in $\{itp\} + \{itp\}$ collisions at $\sqrt{s} = 500 \text{ GeV}$ with the STAR experiment

KOSARZEWSKI, Leszek

Studies of quarkonium production in heavy-ion collisions can provide insight into thermodynamic properties of the quark-gluon plasma (QGP). Suppression of $\Upsilon$ states is expected at a sufficiently high temperature in the QGP and can be measured using the nuclear modification factor $R_{\text{AA}}$. Measurements of $p_T$ spectra for separate $\Upsilon$ states in $\{itp\} + \{itp\}$ collisions provide constraints for models of the quarkonium production, which is an important factor in the interpretation of the heavy-ion results. In addition, high quality data from $\{itp\} + \{itp\}$ collisions at $\sqrt{s} = 500 \text{ GeV}$ can be used as a baseline for $R_{\text{AA}}$ in $\{itAu\} + \{itAu\}$ collisions at $\sqrt{s} = 200 \text{ GeV}$, after rescaling to lower energy. Also, studies of ratios of $\Upsilon$ states as a function of event multiplicity may help better understand the interactions with hadronic co-movers, because the higher states have larger geometrical sizes and thus should have larger cross section for such interactions compared to $\Upsilon(1S)$.

In this poster, we will focus on experimental aspects and report the preliminary results of $\Upsilon$ measurements in $\{itp\} + \{itp\}$ collisions at $\sqrt{s} = 500 \text{ GeV}$ with the STAR experiment. Furthermore, the prospects of $\Upsilon$ measurements with the newly installed Muon Telescope Detector (MTD) will be discussed.

On behalf of collaboration:

**Poster Session - Board: 0614 / 432**

Study of angular distributions for $J/\psi \rightarrow \mu^+\mu^-$ decays in $p+p$ collisions at $\sqrt{s} = 510 \text{ GeV}$ by the PHENIX Collaboration at RHIC.

Dr. LEBEDEV, Alexandre

Measurements of heavy quark bound states, like $J/\psi$ meson, provide a unique opportunity to access basic QCD properties. One of the observables important for understanding $J/\psi$...
production and dynamics is angular distribution of decay products, sometimes also called "polarization". $J/\psi$ polarization measurements can help to differentiate between various models of $J/\psi$ production.

We present the status of our study of angular distributions for $J/\psi \rightarrow \mu^+ \mu^-$ decays in $p+p$ collisions at $\sqrt{s} = 510$ GeV by the PHENIX Collaboration at RHIC. The analysis is done in four different reference frames. We discuss the methods used in the analysis, uncertainty calculations, and possible interpretation of the results.

On behalf of collaboration:

Poster Session - Board: 0616 / 602

Charmonium suppression in QGP at LHC energy using temperature dependent formation time

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The charmonium wavefunction is expected to expand with the temperature of the quark-gluon plasma (QGP) formed in the heavy-ion collision experiments. We model the effect of this expansion on the formation time of the charmonium bound states and eventually, the effect of this temperature dependent formation time on the $J/\psi$ suppression in the QGP medium. The effect of charm quark and anti-charm quark via recombination to form secondary charmonium states is also incorporated in the present work. A set of coupled rate equations is established which incorporates color screening, gluonic dissociation, collisional damping and recombination of uncorrelated $c$ and $\bar{c}$ pair in the QGP medium. The effect of light quarks is also evaluated. Shadowing as a cold nuclear matter (CNM) effect is also incorporated in the current work. The final $J/\psi$ suppression, thus determined as a function of centrality, is compared with the ALICE (low $p_T$) experimental data at both, mid rapidity and forward rapidity and CMS (high $p_T$) experimental data at mid rapidity obtained from the Large Hadron Collider (LHC) at center-of-mass energy, $\sqrt{s_{NN}} = 2.76$ TeV. We find that our predicted result on suppression depicts reasonably good agreement with the data. We also find that contribution of color screening in determining the total suppression of $J/\psi$ in QGP medium becomes insignificant due to employing temperature dependent formation time.

On behalf of collaboration:

Poster Session - Board: 0617 / 578

Photoproduction of vector mesons at low $p_T$ in peripheral and semi-central Pb+Pb collisions at the LHC

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The cross section for photoproduction of vector meson in ultra-peripheral collisions, i.e. collisions without nuclear overlap ($b > 2R$), is huge at high collision energies. This process can, however, occur also in peripheral and semi-central nucleus-nucleus collisions, where there are large spectator fragments, which can act as photon sources and targets.

As this presentation will show, one can expect significant photoproduction of $J/\psi$ in Pb+Pb collisions with impact parameters in the range 10 - 15 fm at the LHC. This contribution is important to understand in order to be able to determine the true centrality dependence of the $J/\psi$ yield from hadronic sources. It also addresses some interesting questions about how
the electromagnetic field translates into a flux of equivalent photons in a semi-central collision: if the number of photons is “frozen” before the collision and all protons contribute to the photon flux, or if only the protons in the spectator fragments contribute. Similarly, it is not clear if the photon target is restricted to the spectator fragments or if production can occur also in the participant region. In the latter case, photoproduction will provide a novel probe of strongly interacting matter, and the interplay with hadronic production, e.g. regarding regeneration and thermalization, would merit further experimental and theoretical study.

The model used to calculate the photoproduction cross section will be discussed and the expected yield as function of centrality will be compared with the expected hadronic contribution. The transverse momentum and rapidity distributions of the two production mechanisms will be compared. The calculations indicate that the yield from photoproduction changes from a few percent of the hadronic yield for the 50-60% most central collisions to around 50% of the hadronic yield for the 80-90% most central collisions.

On behalf of collaboration:

**Poster Session** - Board: 0618 / 345

**Velocity-induced dissociation of Heavy Quarkonium in the gauge-gravity prescription**

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Using the gauge-gravity duality we have obtained the potential between a heavy quark and an antiquark pair, which is moving transverse to the direction of orientation. For the purpose we work on a metric in the gravity side, i.e. OKS-BH geometry, whose dual in the gauge theory side runs with the energy and hence proves to be a better background for thermal QCD. The potential obtained has confining term both in vacuum and medium, in addition to the Coulomb term alone usually reported in the literature. As the velocity of the pair is increased the screening of the potential gets screened, which may be understood by the decrease of effective temperature with the increase of velocity. The chief finding of our work is that the potential develops an imaginary part beyond a critical separation of the heavy quark pair, which is nowadays believed to be the main source of dissociation. The imaginary part is found to vanish at small \( r \), thus agrees with the perturbative result. Finally we have estimated the thermal width for the ground and first excited states and found that non-zero rapidities lead to an increase of thermal width. This implies that the moving medium facilitates the dissociation of quarkonium states than in the static medium, thus agrees with other calculations. However, the width in our case is larger than other calculations due to the presence of confining terms and hence dissolves earlier.

On behalf of collaboration:

**Poster Session** - Board: 0619 / 346

**Heavy Quark Potential at Finite Temperature - a Dual Gravity Calculation**

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In gauge-gravity duality, the heavy quark potential at finite temperature is usually calculated with the pure AdS background, which does not take care of the renormalization group (RG) running in the gauge theory part. As a consequence, the potential obtained does not yield any confining term in both confined as well as deconfined phase. Following the developments in Klebanov-Strassler geometry, we employ a geometry, which captures the RG flow similar to QCD, to obtain the complex heavy quark potential by analytically continuing the string configurations into the complex plane. In addition to the attractive terms, the potential has confining terms both at $T = 0$ and $T \neq 0$, compared to the calculations usually done in the literature, where only the Coulomb-like term is present in the deconfined phase. The potential also develops an (negative) imaginary part above a critical separation, $r_c = 0.53z_h$. Moreover, our potential exhibits a behavior different from the usual Debye screening obtained from perturbation theory.

On behalf of collaboration:

**Poster Session** - Board: 0620 / 593

**Nuclear modification of J/$\psi$ in Pb-Pb collisions at LHC energies**

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The inclusive J/$\psi$ differential production cross-sections and nuclear modification factor as a function of $p_T$ in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV have been calculated at forward rapidity ($2.5 < y < 4$) and compared with the results reported by the ALICE Collaborations [arXiv:1506.08804v1]. The calculations have been carried out by estimating the pp cross-sections at $\sqrt{s} = 2.76$ TeV within the framework of NRQCD [J. Phys. G: Nucl. Part. Phys. 42 065101 (2015)]. The cross-sections have been scaled by the Glauber model for Pb-Pb collisions and convoluted with the survival probability fraction due to color screening [Phys. Rev. D 37, 1851 (1988)]. The feed-down contributions from $\psi(2S)$, $\chi_c$ and $B$ mesons to J/$\psi$ have been included to compare the inclusive results from ALICE. The comparison with experimental values shows a good agreement beyond $p_T = 4$ GeV for the three centrality bins namely, 0%–20%, 20%–40% and 40%–90%. These results indicate that the cold nuclear matter and recombination effects on J/$\psi$ production at forward rapidities in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV is negligible for $p_T > 4$ GeV. Thus, in the high $p_T$ domain ($p_T > 4$ GeV), the observed suppression in the J/$\psi$ yield by ALICE Collaboration can solely be accounted by color screening. Results will also be shown for Pb-Pb collisions at higher energies.

On behalf of collaboration:

**Poster Session** - Board: 0621 / 14

**Interpretation of charmonium like states as a dimesonic molecules**

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The molecular dimesonic states (meson-antimeson) are being studied in potential model framework in heavy flavor sector. The confined one gluon exchange interaction potential (COGEP), one pion exchange interaction potential (OPEP) is being used between meson-antimeson pairs to calculate their masses and binding energy. We searches various exotic
states like X(3872), X(3940), Y(4008), X(4050) etc. as molecular states. The decay width and two photon decay width are also studied for dimesonic states.

On behalf of collaboration:

Poster Session - Board: 0622 / 362

Bottomonia suppression in 2.76 TeV Pb-Pb collisions

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We compute the QGP suppression of $\Upsilon(1s)$, $\Upsilon(2s)$, and $\Upsilon(3s)$, $\chi_{b1}$ and $\chi_{b2}$ states in $\sqrt{s_{NN}} = 2.76$ TeV Pb-Pb collisions. Using the suppression of each of these states, we estimate the inclusive $R_{AA}$ for the $\Upsilon(1s)$ and $\Upsilon(2s)$ states as a function of $N_{\text{part}}$, $y$, and $p_T$ including the effect of excited state feed down. We find that our model provides a reasonable description of recently obtained CMS results for the $N_{\text{part}}$-, $y$-, and $p_T$-dependence of $R_{AA}$ for both the $\Upsilon(1s)$ and $\Upsilon(2s)$. Comparing to our previous results, we find a flatter rapidity dependence, thereby reducing some of the tension between our model and ALICE forward-rapidity results for $\Upsilon(1s)$ suppression.

On behalf of collaboration:

Poster Session - Board: 0623 / 297

Heavy quarkonia and Drell-Yan gauge boson production in the color dipole picture

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We present a extensive phenomenological study of Drell-Yan and heavy quarkonia production at LHC and RHIC energies within the color dipole formalism. Using Color-Singlet model (CSM) we calculate several different observables including quarkonia $p_T$ spectra and rapidity/azimuth difference between $J/\psi$ or $Y$ and leading hadron in p-p and p-A collisions. Moreover, the gauge boson (Z0, W±) production in association with hadron that fragments from the incoming quark is calculated, and then applied to study gauge boson-hadron correlations at LHC energies. This provides a complementary analysis tool to prompt-photon–hadron and hadron-hadron correlations within the color dipole formalism. As a very promising measurement we suggest to study correlations between forward high-$p_T$ pion and $J/\psi$ or $Y$ produced at mid-rapidity at RHIC energies. Such forward-midrapidity correlations test higher order pQCD in pp collisions at modest energies. All suggested variables have a strong potential for better constraining CSM contribution to the $J/\psi$ and $Y$ production at RHIC and LHC.

On behalf of collaboration:
J/psi polarization measurement in p+p collisions at $\sqrt{s} = 500$ GeV with the STAR experiment

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Despite extensive studies, the J/$\psi$ production mechanism in hadron collisions is not yet exactly known. For many years, mostly J/$\psi$ differential cross-section measurements have been used to test different J/$\psi$ production models. While many models can reasonably well describe the experimental data on the J/$\psi$ cross-section in $p + p$ collisions, they have different predictions for the J/$\psi$ polarization. Therefore, measurements of the J/$\psi$ polarization may provide further constraints for the models and new insight into the J/$\psi$ production mechanism.

In this presentation, a measurement of J/$\psi$ polarization in $p + p$ collisions at $\sqrt{s} = 500$ GeV via the dielectron decay channel at mid-rapidity with the STAR experiment will be shown. This measurement has been performed in a wide transverse momentum range of $5 < p_T < 16$ GeV/c. Two polarization parameters $\lambda_\theta$ and $\lambda_\phi$, related to the polar and azimuthal anisotropy respectively, have been extracted in two reference frames: helicity and Collins-Soper. The frame invariant parameter, $\tilde{\lambda}$, has also been determined as a function of $p_T$ in these two frames.

On behalf of collaboration:

Poster Session - Board: 0625 / 192

Quarkonium production with soft gluon radiation in the CGC framework

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We study initial soft gluon radiation effect on quarkonium production at low transverse momentum in the color glass condensate (CGC) framework. In high energy pp (pA) collisions, the quarkonium production at forward rapidity can be described by adopting usual collinear pdf for dilute proton and the dipole gluon distribution function for dense proton (nucleus) [1]. The small-$x$ quantum correction is embedded in the dipole amplitude which follows the BK equation with running coupling effect (rcBK). In the CGC framework, the parton saturation is expected to characterize the low-$P_T$ spectrum. Meanwhile, the initial soft gluon radiation also can affect the low-$P_T$ spectrum [2]. Therefore, in order to study the parton saturation quantitatively, both the small-$x$ resummation and the low-$P_T$ resummation have to be considered simultaneously.

In this talk, we consider the Sudakov factor associated with the initial soft gluon resummation by following the Collins-Soper-Sterman (CSS) formalism [3]. We will present some numerical results of quarkonium production at the LHC including both the small-$x$ resummation and the low-$P_T$ resummation.


On behalf of collaboration:

Poster Session - Board: 0626 / 270
Non-Prompt J/ψ Measurements with the STAR experiment

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Because of their large masses and long lifetimes, heavy quarks are dominantly produced from initial hard parton scattering processes and can experience the whole evolution of the Quark Gluon Plasma (QGP) created in high-energy heavy-ion collisions. Therefore heavy quarks have been suggested as excellent probes to study the properties of the QGP. Measurements of non-prompt J/ψ produced from B hadron decays are very interesting because they may provide an opportunity to access bottom quark production in heavy-ion collisions at the Relativistic Heavy Ion Collider. Such measurements have become possible with the installation of the Heavy Flavor Tracker (HFT) and Muon Telescope Detector (MTD) into the STAR experiment in 2014. The HFT can precisely measure track impact parameters, and thus allows a separation between prompt and non-prompt J/ψ through measuring their decay lengths. The MTD enables J/ψ reconstruction in the dimuon channel at STAR for the first time, which is important for J/ψ measurements at transverse momentum \( p_T < 5 \) GeV/c and complementary to those in the dielectron channel at higher \( p_T \). In this poster, we will discuss the current status and prospect of non-prompt J/ψ measurements in both the dielectron and the dimuon channels using the p+p, p+Au and Au+Au data at \( \sqrt{s_{NN}} = 200 \) GeV taken in 2014-2016 with the STAR experiment.

On behalf of collaboration:

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Poster Session - Board: 0627 / 639

Bottomonium production in coupled Langevin and transport approach

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In heavy ion collisions, quarkonium is produced in a rapidly thermalized deconfined medium. Quarkonium production can be understood in terms of Langevin dynamics of heavy quarks interacting through medium modified potential [1]. This framework was used successfully to understand charmonium production at RHIC [1,2] including recombinant production [2] when realistic values of the heavy quark diffusion constant are used together with a lattice QCD inspired potential. It also explains the J/psi production at LHC including its centrality independence [3]. We extend this framework to upsilon production by including the thermal dissociation of formed bottomonia. This is done with a transport (local rate) equation followed by Langevin dynamics of the correlated \( Q \bar{Q} \) states. The bulk evolution of the medium is treated using MUSIC, a 3+1-dimensional hydrodynamical simulator of heavy ion collisions, while we make use of the latest lattice results on the \( Q \bar{Q} \) potential. We make prediction for the bottomonium production at full LHC energy.


On behalf of collaboration:

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Poster Session - Board: 0701 / 571
Mutual relations of the W charge asymmetry in p-p, p-Pb and Pb-Pb collisions

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We consider the production of inclusive W bosons in variety of high-energy hadronic collisions: p-p, p-p̄, p-Pb, and Pb-Pb. In particular, we focus on the resulting distributions of charged leptons from W decays, which can be measured with relatively low backgrounds. By inspecting the corresponding leading-order expressions within the collinearly factorized QCD we find that the center-of-mass energy dependence at forward/backward direction should be describable by a simple power law. The physical interpretation of the scaling exponent is in the small-x behaviour of the parton densities. The most thrilling consequence, however, is the resulting extremely simple scaling law for the lepton charge asymmetry which also relates measurements in different collision systems. For example, this allows an almost-direct comparison of measurements in p-p and p-Pb or in p-Pb and Pb-Pb, pairwise, even if the center-of-mass energies would be different! The expectations are contrasted with the existing data and a very good overall agreement is indeed found. The understanding of the underlying physics allows us to make very accurate predictions for upcoming LHC measurements and we also propose a precision observable to be measured.

On behalf of collaboration:

Poster Session - Board: 0702 / 641

Photon production from the Color Glass Condensate in the pA collisions

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I will talk about our calculation of the photon spectrum in the pA collision using the Color Glass Condensate framework. We used a systematic expansion in terms of the proton source \( \rho_p \) and succeeded in obtaining a full analytical formula for the photon emission from virtual quarks that scatter multiply with dense gluonic fields:

\[
\frac{dN}{d\hat{2} p_{\perp} dy} = \frac{g^2 Q^2}{16\pi^2} \left[ \prod_{i=1}^6 \int \frac{d\hat{2} q_{i\perp}}{(2\pi)^2} \right] \left\langle \text{tr} \left( U(-\hat{2} q_{5\perp} - \hat{2} q_{6\perp}) \rho_p(-\hat{2} q_{4\perp} - \hat{2} q_{5\perp}) U^\dagger(\hat{2} q_{3\perp} - \hat{2} q_{4\perp}) \right) \right\rangle \mathcal{T}(\{\hat{2} q_{i\perp}\}, \hat{2} p_{\perp}, y) ,
\]

where \( \mathcal{T}(\{\hat{2} q_{i\perp}\}, \hat{2} p_{\perp}, y) \) is an explicitly calculated function. The expectation value over the Wilson line product is calculated in the McLerran-Venugopalan model through which the photon spectrum is characterized by the saturation scale. The production of photons from virtual quarks considered here is of order \( \mathcal{O}(\rho_p) \), while the bremsstrahlung process \( q \rightarrow q \gamma X \) seems to be the leading contribution parametrically. However, the bremsstrahlung process should involve also the real quark distribution function in the initial state that brings in theoretical uncertainties, but our formula is free from such external input and closed within the McLerran-Venugopalan model. I will also discuss some of the kinematical properties and where the virtual quark contribution that we calculated would become relevant to experiments.

On behalf of collaboration:

Poster Session - Board: 0703 / 587
Measurement of low-mass dielectrons in p-Pb collisions with ALICE
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Low-mass dielectrons are an important probe for the hot and dense medium which is created in ultrarelativistic heavy-ion collisions. Since leptons do not interact strongly, they carry information from all collision stages with negligible final state interaction. While pp collisions provide a reference measurement for a medium-free environment, the impact of cold nuclear matter effects on the dielectron production can be estimated from p-Pb collisions. Moreover, the measurement of low-mass dileptons has a high sensitivity to the production of charmed mesons at low $p_T$ via their decay into correlated $e^+e^-$ pairs.

In this poster the results of the dielectron measurements at mid-rapidity in minimum bias p-Pb collisions at $\sqrt{s} = 5.02$ TeV with the ALICE detector will be presented. The dielectron invariant mass and transverse momentum distributions will be compared to expectations from light hadrons and semi-leptonic charm decays.

On behalf of collaboration:

Poster Session - Board: 0704 / 486

Photon production from gluon mediated quark-anti-quark annihilation prior to hadronization
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Heavy ion collisions produce direct photons at low transverse momentum, $p_T$ from 1-3 GeV/c, in excess of the $p+p$ spectra scaled by the nuclear overlap factor, $T_{AA}$. These low $p_T$ photons have a large azimuthal anisotropy, $v_2$, suggesting late-stage production. Theoretical models, including hydrodynamic models, struggle to quantitatively reproduce the large low $p_T$ direct photon excess and $v_2$. This talk investigates increased photon production as the system becomes color neutral from soft-gluon mediated $q\bar{q}$ interactions in a process analogous to coalescence. This production mechanism will generate photons that follow constituent quark number, $n_q$, scaling of $v_2$ with an $n_q$ value of two for direct photons. A $\chi^2$ comparison of the published direct photon and identified particle $v_2$ measurements and a coalescence-like Monte Carlo is used to test this description. The $\chi^2$ comparison finds that $n_q$-scaling applied to the direct photon $v_2$ data prefers the value $n_q = 1.8$ and agrees with $n_q = 2$ within errors in most cases. The coalescence-like Monte Carlo simulation calculates the direct photon $v_2$ while describing the shape of the direct photon $p_T$ spectra in an internally consistent manner. The simulation, while systematically low when compared to the data, is in agreement with the 0-20% and 20-40% Au+Au PHENIX measurement at $p_T$ less than 3 GeV/c. This model predicts that higher-order flow harmonics, $v_n$, in direct photons will follow the modified $n_q$-scaling laws seen in identified hadron $v_n$ with an $n_q$ value of approximately two. Comparisons to preliminary direct photon results, including higher-order anisotropies and the status of simulations at LHC energies, will also be shown.

On behalf of collaboration:

Poster Session - Board: 0705 / 654

Centrality dependence of photon anisotropic flow at RHIC
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Page 111
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We calculate elliptic and triangular flow of thermal photons for different collision centralities at RHIC using event–by-event hydrodynamic model with fluctuating initial conditions. Photon $v_3$ as a function of $p_T$ calculated with respect to the participant plane angle is found to be comparable to the elliptic flow parameter $v_2(p_T)$ for 0—20% centrality bin at RHIC. However, $v_2(p_T)$ rises much faster than $v_3(p_T)$ towards peripheral collisions and $v_3(p_T)$ is found to be largest for 20—40% centrality bin.

We study the event-by-event distributions of $v_2$ and $v_3$ and their corresponding initial state anisotropies to understand the correlation between them. A significant linear correlation between $v_2$ and $\epsilon_2$ is observed at different $p_T$ values, however we do not see any correlation between photon $v_3$ and the initial triangularity $\epsilon_3$. This is unlike the case of hadrons where a clear mapping between hadronic $v_3$ and $\epsilon_3$ has been observed. We conclude that indirect effects of initial state fluctuations, such as buildup of large transverse flow velocity contribute significantly to the observed $v_3$ results beyond leading to an overall triangular geometry.

On behalf of collaboration:

Poster Session - Board: 0707 / 585

Dilepton and photon production in the semi-quark gluon plasma

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We discuss the dilepton and photon production in the semi-quark gluon plasma (semi-QGP), at temperatures above but near the critical temperature for deconfinement. Working to leading order in the coupling constant of QCD, we find that there is a mild enhancement, $\sim 20\%$, for dilepton production in the semi-QGP over that in the perturbative QGP. In contrast, we find that photon production is strongly suppressed in the semi-QGP, by about an order of magnitude, relative to the perturbative QGP. In the perturbative QGP photon production contains contributions from $2\rightarrow2$ scattering and collinear emission with the Landau-Pomeranchuk-Migdal (LPM) effect. In the semi-QGP we show that the two contributions are modified differently. The rate for $2\rightarrow2$ scattering is suppressed by a factor which depends upon the Polyakov loop. In contrast, the collinear rate is suppressed not by the Polyakov loop, but by $1/N$. We compute the rate from $2\rightarrow2$ scattering to the leading logarithmic order and the collinear rate with the LPM effect to leading order in the semi-QGP. We also discuss that the effect of the photon suppression to the photon elliptic flow. Reference: Yoshimasa Hidaka, Shu Lin, Robert D. Pisarski and Daisuke Satow, 1504.01770[hep-ph]

On behalf of collaboration:

Poster Session - Board: 0708 / 389

Study of direct photon production with internal conversion method in Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV at PHENIX
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Photons and dileptons in high-energy heavy-ion collisions are good probes to understand space-time evolution of the produced system. The PHENIX experiment has measured low-pT direct photons with internal conversion method in p+p, d+Au, and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. PHENIX has recently reported low-pT direct photon in Au+Au collisions with external conversion method. But the results on direct photon in Cu+Cu collisions have not been published yet. Direct photons via internal conversion are measured with $e^+e^-$ pairs as an excess compared to hadronic cocktail after subtracting uncorrelated and correlated backgrounds. Since the PHENIX detector has an excellent electron-identification capability, dielectron are focused on as the probe for direct photon measurement. In this poster, we report the current status of direct photon measurement with internal conversion method in Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV.

On behalf of collaboration:

Poster Session - Board: 0709 / 322

Gauge invariant non-perturbative production rate of photons and dileptons above $T_c$

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We analyze the production rates of photons and dileptons from the deconfined medium using a quark propagator obtained from a first principle lattice QCD numerical simulation. We calculate the production rates non-perturbatively at two temperatures above $T_c$. The photon-quark vertex is determined gauge-invariantly, so as to satisfy the Ward-Takahashi identity. The photon production rate shows an enhancement and a peculiar structure reflecting kinematics of quasi-particles. We discuss the origin of the structure.

On behalf of collaboration:

Poster Session - Board: 0710 / 237

Nuclear effects in direct photon and Drell-Yan production at the LHC

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Using the color dipole formalism we study production of direct photons and Drell-Yan pairs in proton-nucleus interactions in the kinematic region corresponding to LHC experiments. Real photons and lepton pairs produced in a hard scattering are not accompanied with any final state interaction, either energy loss or absorption. Consequently, such observables as transverse momentum pT and rapidity distributions of real photons and lepton pairs at low
and high dilepton invariant masses $M$ may, therefore, serve as more efficient and cleaner probes for nuclear modification effects than inclusive hadron production. We have shown that shadowing effects in production of lepton pairs coming from the coherence are suppressed at large invariant masses and at very large $p_T$ at mid-rapidities. So naively one should not expect any nuclear effects is this kinematical regime. Contrary to this expectation, we found a significant large-$p_T$ suppression which was already observed by PHENIX experiment in $d+Au$ and central $Au+Au$ collisions, as well as by fixed-target FNAL E772 and E866 experiments at large Feynman $x_F$. This new effect can be treated as an effective energy loss proportional to the initial energy and is universally induced by multiple initial state interactions.

Besides, we present a systematic analysis of the nuclear effects in production of real photons and Drell-Yan pairs in $p+Pb$ interaction at the LHC. We perform predictions for nuclear suppression as a function of $p_T$, rapidity and dilepton invariant mass that can be verified by the LHC experiments. We include and analyze also a contribution of coherent effects associated with gluon shadowing affecting the observables predominantly at small and medium-high $p_T$. 

On behalf of collaboration:

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**Poster Session - Board: 0711 / 257**

**Systematic study of real photon and Drell-Yan pair production in $p+A$ ($d+A$) interactions**

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We investigate nuclear effects in production of Drell-Yan pairs and direct photons in proton(deuteron)-nucleus collisions. For the first time, these effects are studied within the colour dipole approach using path integral technique based on the Green function formalism which naturally incorporates the colour transparency and quantum coherence effects. Numerical results for the nuclear modification factor are compared with available data. Besides, we present a variety of predictions for the nuclear suppression as function of transverse momentum, rapidity and invariant mass of the lepton pair that can be verified by experiments at RHIC and LHC. We found that the nuclear suppression is caused predominantly by effects of quantum coherence (shadowing corrections) and by the effective energy loss induced by multiple initial state interactions. Whereas the former dominates at small Bjorken $x_2$ in the target, the latter turns out to be significant at large $x_1$ in the projectile beam and is universal at different energies and transverse momenta. Remarkably, the second new source of suppression appears to be significant even in those kinematic regions where the shadowing corrections are naturally suppressed.

On behalf of collaboration:

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**Poster Session - Board: 0712 / 32**

**EVOLUTION OF QUARK-GLUON PLASMA AND QUARK-HADRON PHASE TRANSITION**

Author(s): Dr. KUMAR, Yogesh$^1$
Co-author(s): Mrs. JAIN, Poonam$^2$

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We study the effect of thermal quark mass in the free energy evolution of a quark-gluon plasma using simple statistical model after incorporating the curvature term. In this study, the thermal quark mass is dependent on parametrization factor and temperature. Also a thermodynamic variable like entropy and specific heat show a nature of phase transition. The results are found to produce significant improvements over earlier results.

On behalf of collaboration:

Poster Session - Board: 0713 / 521

Role of chemical potential in the electromagnetic emission from quark gluon plasma
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We use the phenomenological model to study the electromagnetic emission from quark gluon plasma with the effect of chemical potential. The chemical potential plays an important role in the enhancement of electromagnetic yield in heavy ion collision. We find that various processes significantly enhance the production rate. The results are compared with other works.

On behalf of collaboration:

Poster Session - Board: 0714 / 313

Photon and dilepton production in heavy-ion collisions
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We address the properties of the hot QCD matter created in relativistic heavy-ion collisions by examining the spectra, elliptic flow $v_2$ and triangular flow $v_3$ of the emitted real and virtual photons. Comparing our calculations within the PHSD transport approach to the multitude of data by the ALICE Collaboration at the LHC as well as by the STAR and PHENIX Collaborations at RHIC allows us to determine the space-time evolution of the collision, the shear viscosity of the produced matter and to put experimental constrains on its electric conductivity. We model the heavy-ion collisions using the PHSD microscopic transport approach, which includes the dynamics of quarks, antiquarks and gluons as well as a covariant dynamical hadronization scheme and the subsequent off-shell hadronic reaction dynamics. The implementation of photon bremsstrahlung in transport approaches has been based until now on the soft photon approximation, which is valid only at low energy of the produced photon. Presently, we have improved the calculation of this channel beyond the soft photon approximation by using the one-boson-exchange model. In order to clarify the channel decomposition of the direct photon spectra, we investigate the centrality dependence of the photon yield at RHIC and, most recently, also at the LHC. We will also present predictions for the photon production in the RHIC Beam-Energy-Scan and the comparison of dilepton data to the results of the PHENIX Collaboration with the Hadron-Blind Detector. Additionally, we propose a new observable with the potential to monitor the dynamics of the QGP equilibration in the initial stages of the collision.

On behalf of collaboration:
**Poster Session** - Board: 0715 / 260

**Photon flow harmonics \( v_n \) with chemical equilibration and non-ideal gas distribution**

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Elliptic flow \( v_2 \) of direct photons are found to be larger than those from most hydrodynamic estimations at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC), which is recognized as the “photon \( v_2 \) puzzle”. The recent discovery of large triangular flow \( v_3 \) hints that this is at least partially due to the medium properties. Theoretical explanation of the photon data should be essential for understanding the dynamical properties of the quark-gluon plasma (QGP).

We discuss enhancement of direct photon flow harmonics due to (i) quark chemical equilibration \[1\] and (ii) in-medium corrections to phase-space distributions \[2\], both of which modify the photon emission rate. The former scenario is motivated by the observation that chemical equilibration can be slower than thermalization in the transition from the gluon-rich color glass condensate to the QGP \[3\]. In the latter scenario, we consider non-ideal gas distributions using a quasi-particle picture so that they reproduce the equation of state from \( (2+1) \)-flavor lattice QCD. Both mechanisms reduce the effective number of degrees of freedom for the quark distribution. This suppresses early photons with smaller anisotropy, leading to larger anisotropy in total direct photons.

We use a hydrodynamic model to numerically estimate thermal photon \( v_2 \) and \( v_3 \) with and without the above effects. The calculations show visible enhancement of the photon flow harmonics. Quadrangular \( v_4 \) and pentagonal \( v_5 \) flow are also estimated as theoretical guides to quantify possible anomalous enhancement of anisotropy.


On behalf of collaboration:

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**Poster Session** - Board: 0716 / 303

**Direct photons in \( p\)-Pb collisions at \( \sqrt{s_{NN}} = 5.02 \) TeV measured with ALICE/PHOS**

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Direct photons produced at early stages of a proton-proton or proton-nucleus collision provide good tool for tuning pQCD predictions, checking PDF and fragmentation functions. Moreover, direct photon yield in \( p\)-A collisions can be used as a baseline for thermal direct photon measurements in Pb-Pb collisions.

In this poster, we present the status of analysis of direct photon yield in \( p\)-Pb collisions at \( \sqrt{s_{NN}} = 5.02 \) TeV measured with the highly segmented photon spectrometer PHOS of the ALICE experiment.

On behalf of collaboration:

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Exclusive photo-production of upsilon in pPb collisions at CMS

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Relativistic heavy ions are a copious source of virtual photons, which allow to study the gamma-proton and gamma-gamma interactions in ultraperipheral collisions (UPC). The exclusive photoproduction of heavy vector mesons provide a clean probe of the gluon distribution at very small values of parton fractional momenta (Bjorken $x$) $x \approx 10^{-2}$ to $10^{-4}$ at central rapidities ($|y| < 2.5$) and search for saturation phenomena. We present the first measurement of exclusive photoproduction of $\Upsilon (1S,2S,3S)$ states in their dimuon decay channel in ultraperipheral collisions of protons and heavy ions (pPb) with the CMS experiment at $\sqrt{s_{NN}} = 5.02$ TeV for an integrated luminosity $L_{int} = 33$ nb$^{-1}$. The photoproduction cross-section of $\Upsilon (1S)$ is measured as a function of photon-proton center-of-mass energy $W_{\gamma p}$. The differential cross-section $d\sigma/dt$, where $t$ is the squared four-momentum transfer at the photon-proton vertex, is measured in the range $|t| < 1.0$ (GeV/c)$^2$. The results are compared with other measurements and theoretical predictions.

On behalf of collaboration:

Poster Session - Board: 0718 / 589

Time evolution of EOS and contribution of thermal dilepton at FAIR energy using Bjorken hydrodynamics

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We have estimated initial temperature and chemical potential of the QGP system, relevant for FAIR energy, using Bjorken hydrodynamics. We have also calculated time evolution of temperature, chemical potential as well as the equation of states of the QGP system. Finally, we have estimated invariant-mass distribution of thermal dilepton for quark antiquark annihilation process. This thermal dilepton produces a continuum background which is important in the intermediate invariant mass region (1.4 – 3Gev).

On behalf of collaboration:

Poster Session - Board: 0719 / 296

Polarization of exclusive di-electron production in pion-nucleon collisions

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A study of the polarization of the virtual photon in the process $\pi N \rightarrow Ne^+e^-$ is presented [E. Speranza, M. Zetenyi, and B. Friman (to be published)]. An effective relativistic Lagrangian model containing baryon resonances up to spin-5/2 is employed to compute the spin-anisotropy coefficient for isolated intermediate baryon resonances. It is shown that a given spin state of
the intermediate resonance exhibits a characteristic angular dependence of the spin-anisotropy coefficient. Furthermore, the anisotropy coefficient resulting from the interference between resonances with different spin is presented. Our results show that the polarization of the photon provides information that is useful for disentangling the resonance contributions to elementary di-lepton production processes [W. Przygoda (HADES Collaboration), talk presented at The 10th International Workshop on the Physics of Excited Nucleons, NSTAR2015, 25-28 May 2015, Osaka]. Moreover, it is argued that the study of polarization observables can provide information on the production process and equilibration mechanism in heavy-ion collisions.

On behalf of collaboration:

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**Poster Session - Board: 0720 / 271**

**Dilepton production from the quark-gluon plasma using leading-order (3+1)D anisotropic hydrodynamics**

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Dilepton production from the quark-gluon plasma (QGP) phase of ultra-relativistic heavy-ion collisions is computed using the leading-order (3+1)-dimensional anisotropic hydrodynamics. It is shown that high-energy dilepton spectrum is sensitive to the initial local-rest-frame momentum-space anisotropy of the QGP. Our findings suggest that it may be possible to constrain the early-time momentum-space anisotropy in relativistic heavy-ion collisions using high-energy dilepton yields.

On behalf of collaboration:

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**Poster Session - Board: 0721 / 75**

**Photon production from the quark-gluon plasma using (3+1) dimensional anisotropic dissipative hydrodynamics**

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We calculate the medium photon production due to Compton and annihilation processes by taking into account the (3+1)-dimensional anisotropic hydrodynamics of the quark gluon plasma (QGP) expected to be formed in relativistic heavy ion collisions. The anisotropic hydrodynamics equations describe the full spatiotemporal evolution of the transverse temperature, spheroidal momentum-space anisotropy parameter and the associated three-dimensional collective flow of the matter. We have taken the momentum-space anisotropy also into account in the computation of the photon production rate finally. We present the predictions for high-energy photon yields as a function of transverse momentum and rapidity. We conclude that high-energy photon production is extremely sensitive to the assumed level of initial momentum-space anisotropy of the quark-gluon plasma. As a result, it may be possible to experimentally constrain the early-time momentum-space anisotropy of the quark-gluon plasma generated in relativistic heavy ion collisions using high energy photon yields. The sensitivity of the results on the initial condition is also discussed.

On behalf of collaboration:
**Poster Session - Board: 0722 / 608**

**Nucleon-nucleon interactions within an extended linear sigma model**

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In the intermediate- and low-energy regime, hadrons (instead of quarks and gluons) are the relevant degrees of freedom. Their masses and interactions can be well described by effective approaches to QCD. The extended linear sigma model is an effective model based on chiral and dilatation symmetries (together with their explicit as well as spontaneous breaking). It includes (axial-) vector mesons in addition to (pseudo-) scalar ones, which turns out to be very successful in describing the mass spectrum and decay widths of mesons up to 1.7 GeV \([1,2]\). Moreover, including two baryon doublets in the so-called mirror assignment as suggested in \([3]\) allows for introducing a chirally invariant mass term for baryons as well as the interaction with a low-mass four-quark field, related to the resonance \(f_0(500)\). Thus, the mass of the nucleon arises not solely from the chiral condensate, but also from the four-quark condensate \([4,5,6]\). The model has been used to describe elastic nucleon-nucleon collisions as well as inelastic nucleon-nucleon interactions involving the production of mesons and electromagnetic radiation. A comparison of the theoretical results with experimental data will be shown.

**References:**


**On behalf of collaboration:**

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**Poster Session - Board: 0723 / 307**

**Hadronic Spectral Functions at Finite Temperature and Density**

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We have recently developed a new method to obtain real-time quantities such as spectral functions or transport coefficients at finite temperature and density within a non-perturbative Functional Renormalization Group approach\([1]\). Our method is based on a thermodynamically
consistent truncation of the flow equations for 2-point functions with analytically continued frequency components in the originally Euclidean external momenta. The feasibility of the method is demonstrated at the example of the mesonic spectral functions in the quark-meson model at different temperatures and quark chemical potentials, in particular around the critical endpoint in the phase diagram of the model. An extension of the method to finite spatial momenta [2] furthermore allows to compute transport coefficients such as the shear viscosity and the shear viscosity over entropy-density ratio at finite temperature and density.


On behalf of collaboration:

Poster Session - Board: 0725 / 284

Search for light dark photon with neutral meson decays at the PHENIX experiment

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A hypothetical \( U(1) \) gauge field has been introduced to explain several experimental results that the Standard Model (SM) can not describe, such as the high energy positron excess in cosmic rays, the muon g-2 anomaly and so on. The hypothetical \( U(1) \) field is considered to very weakly couple with SM, and its gauge boson called as a ‘dark photon’ mixes in ordinary photons as a result.

The PHENIX experiment has a good capability to measure low mass electron pairs with a good mass resolution. We have conducted a search for electron pairs possibly showing up from dark photons within Dalitz decays of \( \pi^0 \) and \( \eta \). An upper limit of the dark photon mixing strength with ordinary photons has been obtained for \( 30 < m_{ee} < 90 \) MeV/c\(^2\). Combining with other experimental results, the possibility of explanation by the dark photon for the 3.6 sigma deviation of the measured muon g-2 value from the SM calculations was excluded.

We will present our latest result on the dark photon search and discuss a possibility for future light dark matter searches with heavy ion collisions as well.

On behalf of collaboration:

Poster Session - Board: 0726 / 10

Viscous Leptons and Fluid-like Photons in the Strongly Coupled Quark Gluon Plasma

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In the quark gluon plasma (QGP), the transport properties of electromagnetic (EM) probes such as leptons and photons could be modified by the lepton/photon-parton scattering compared with the case in the QED plasma. In order to incorporate the non-perturbative effects from the strongly couple QGP on the lepton/photon-parton collisions, a semi-holographic approach which combines the Boltzmann equation and the gauge/gravity duality is applied to compute the shear viscosity of thermal leptons and photons. It is found that the lepton shear viscosity due to the lepton-quark scattering is inversely proportional to the ratio of
electric conductivity of the QGP to temperature up to the leading logarithmic order of the
EM coupling and is suppressed compared with the one from lepton-lepton scattering. On
the other hand, the photon shear viscosity up to the leading order of the EM coupling is
suppressed by the photon-parton scattering, where the suppression is favored by the coupling
of the QGP. Such suppression stems from the blue shift of the thermal-photon spectrum at
fixed temperature when the coupling of the QGP is increased. On the contrary, the lepton
shear viscosity behaves oppositely due to the decrease of electric conductivity of the QGP
at stronger coupling. Moreover, in a holographic model breaking conformal symmetry, both
the conductivity and the amplitude of the thermal-photon spectrum scaled by temperature
decrease rapidly near the deconfinement transition. Accordingly, a sharp enhancement of the
shear viscosity of both thermal leptons and thermal photons close to the critical temperature
is observed. In conclusion, our findings imply that the thermal leptons and photons in the
QGP are less viscous than in the QED plasma. In particular, thermal photons may become
fluid-like in the strongly coupled scenario. We argue that it may strengthen the anisotropic
flow of direct photons. Part of the talk is based on Phys.Rev. D91 (2015) 12, 125010.

On behalf of collaboration:

Poster Session - Board: 0727 / 352

The specific charged hadron multiplicity in $e^-+p$ and $e^-+D$
semi-inclusive deep-inelastic scattering in the PYTHIA and
PACIAE models

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We employed the PYTHIA 6.4 model and the extended parton and hadron cascade model PA-
CIAE 2.2 to comparatively investigate the DIS normalized specific charged hadron multiplicity
in the 27.6 GeV electron semi-inclusive deep-inelastic scattering off proton and deuteron. The
PYTHIA and PACIAE results calculated with default model parameters not well and fairly
well reproduce the corresponding HERMES data, respectively. In addition, we have discussed
the effects of the differences between the PYTHIA and PACIAE models.

On behalf of collaboration:

Poster Session - Board: 0728 / 489

Measurement of W and Z-boson production in p-Pb colli-
sions with ALICE at the LHC

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The high collision energies available at the LHC allow for an abundant production of hard
probes, such as quarkonia, high-$p_T$ jets and vector bosons (W, Z). The latter are produced in
initial hard parton scattering processes and they decay before the formation of the Quark-
Gluon Plasma (QGP), which is a deconfined phase of QCD matter produced in high-energy
heavy-ion collisions. Furthermore, their leptonic decay products do not interact strongly with
the QGP. The electroweak boson introduces a way for benchmarking in-medium modifications
to coloured probes. In Pb–Pb and p–Pb collisions, precise measurements of W and Z-boson
production can constrain the Nuclear Parton Distribution Functions (nPDFs), which could
be modified with respect to the nucleon due to shadowing or gluon saturation, and they can be used to test the scaling of hard particle production with the number of binary nucleon–nucleon collisions. Especially in p–Pb collisions, the measurement of W yields at forward and backward rapidity allows us to probe the modification of nPDFs at small and large Bjorken- \( x \), respectively. Such measurements can be benchmarked in pp collisions, where W and Z-boson production is theoretically known with good precision. Also, the charge asymmetry of leptons from W-boson decays is a sensitive probe of up and down quark densities in a nucleon inside a nucleus.

The production of W and Z bosons in p–Pb collisions at \( \sqrt{s_{NN}} = 5.02 \) TeV is measured with the ALICE muon spectrometer via the inclusive \( p_T \)-differential muon yield and the invariant mass of opposite-sign muon pairs, respectively. The rapidity coverage of the muon spectrometer is \(-4.46 < y_{\text{CMS}} < -2.96 \) and \( 2.03 < y_{\text{CMS}} < 3.53 \), which is complementary to the one of ATLAS and CMS. The results are compared with model calculations accounting for the nuclear modification of the PDFs. The W production as a function of the event activity will be discussed as well.

**On behalf of collaboration:**

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**Poster Session - Board: 0791 / 749**

**Future measurements of vector mesons in nucleus at J-PARC**

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Mass spectra of vector mesons attract wide interest in high energy heavy ion physics and hadron physics in the point of view of restoration of chiral symmetry and hadron mass. The mass spectra of vector mesons are theoretically connected to q\( \bar {q} \)-q contents of a QCD medium. Even in nucleus matter, modifications of vector mesons are predicted\(^1\). The KEK-PS E325 experiment was performed to study mass properties of vector mesons and partial chiral symmetry restoration in nuclear medium. The KEK experiment measure mass spectra of phi mesons using electron-positron decays. The experiment reports significant mass modification in nucleus\(^2\). New experiment is being prepared at J-PARC to continue this measurement. In this presentation, details of new experiment are presented. A new beam line is under construction at the Hadron Experimental Facility of the Japan Proton Accelerator Research Complex (J-PARC) to perform the experiment. A new beam line delivers a primary 30 GeV proton beam and intensities of the beam is 10¹⁰ Hz. The first experiment using the beam line is under preparation. The experiment will measure mass spectra of vector mesons in nucleus with 100 times larger statistics than the KEK-PS E325 experiment. The new experiment aims to confirm results of the previous KEK experiment and have a large statistics to discuss more details. The new experiment uses new detector techniques, such as a GEM tracker and a Hadron Blind Detector, to achieve such a large statistics.


\(^2\) R. Muto et al. (KEK-PS E325 collaboration), Phys. Rev. Lett. 98(2007), 042501

**On behalf of collaboration:**

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**Poster Session - Board: 0801 / 308**

**Transition from Multifragmentation to Flow in Relativistic Nuclear Collisions at CBM energies**

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The CBM experiment aims the study of the QCD phase diagram at low temperatures and high baryonic densities, mainly to find out the order of the phase transition between hadrons and partons under these conditions. Between the many predictions about signals to detect the phase transition point: fluctuations, hydrodynamics [2], baryon-baryon correlations [3], etc., in our previous studies [4-5] we found as an interesting tool for the analysis of relativistic nuclear collisions: the "nuclear matter jets". Having a non-partonic origin, the number of jets indicates the centrality of the collision, i.e. the amount of incident energy pumped into the system, and the jet-kinematic and dynamic properties allowed us to make assumptions about their origin. A liquid-gas nuclear phase transition was indicated by the disappearance of jets. At CBM energies, varying the projectile mass, we intend to study the evolution of the number and characteristics of nuclear matter jets when passing from the small projectile (p+Au) whose energy is converted into thermal energy leading to multifragmentation, to a symmetric projectile (Au+Au) when flow is unleashed. For this, we made jetology studies on UrQMD and AMPT simulations (performed at the computing system YaPT from “Nuclear Matter in Extreme Conditions” Research Center – Faculty of Physics, Bucharest University) in the 4-25 A GeV incident energies range. We will extract the usefulness of the “nuclear matter jets” variable for relativistic nuclear collisions.

Transport + hydrodynamics approach has proved to be successful in describing the particle spectra and elliptic flow in the heavy ion collisions at the collision energy range investigated in RHIC beam energy scan. However, it has been difficult to determine the uncertainties associated with the chosen values of input parameters, due to the massive amount of computational resources required for evaluating all possible input parameter combinations. A way to reduce the computational effort is to run a set of simulations for semi-random, space-filling selection of points in parameter space, and then use an emulator trained on this data to predict the output for arbitrary input. Gaussian processes are an attractive choice for the emulator, as they are very flexible and predict probability distributions with quantitative uncertainty.

In this study, we investigate the input parameters, including the ratio of shear viscosity over entropy density η/s, of the UrQMD + viscous hydrodynamics hybrid model[1]. Focusing on Au+Au collisions at the higher end of the RHIC beam energy scan energy range, √s_{NN} = 62.4 and 39 GeV, we determine the most probable parameter values and their uncertainties using

Poster Session - Board: 0802 / 164

Determining eta/s in Au+Au collisions at 62.4 GeV and below via a statistical analysis of a hybrid model

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Transport + hydrodynamics approach has proved to be successful in describing the particle spectra and elliptic flow in the heavy ion collisions at the collision energy range investigated in RHIC beam energy scan. However, it has been difficult to determine the uncertainties associated with the chosen values of input parameters, due to the massive amount of computational resources required for evaluating all possible input parameter combinations. A way to reduce the computational effort is to run a set of simulations for semi-random, space-filling selection of points in parameter space, and then use an emulator trained on this data to predict the output for arbitrary input. Gaussian processes are an attractive choice for the emulator, as they are very flexible and predict probability distributions with quantitative uncertainty.

In this study, we investigate the input parameters, including the ratio of shear viscosity over entropy density η/s, of the UrQMD + viscous hydrodynamics hybrid model[1]. Focusing on Au+Au collisions at the higher end of the RHIC beam energy scan energy range, √s_{NN} = 62.4 and 39 GeV, we determine the most probable parameter values and their uncertainties using
the state-of-the-art statistical analysis based on Bayesian statistics. Following the methods described in [2,3], the probability distributions for the parameters are produced by calibrating the model to experimental data using Markov Chain Monte Carlo sampling, utilizing Gaussian processes to emulate the hybrid model behavior for uninvestigated input values. The results illustrate how much the input parameters are constrained by a given set of observables and reveal the correlations between the parameters.


On behalf of collaboration:

Poster Session - Board: 0803 / 324

Elliptic flow in heavy ion collisions at SIS100/300 energies

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In heavy ion collisions the matter highly compressed generated a strong anisotropic flow described by relativistic hydrodynamics. Over the years several methods have been developed to study the flow. In this work we are discussing methods for determining elliptic flow in Au-Au collisions between 2 and 45 A GeV. The correlations between v2 coefficient and the geometry of the initial state is made. Our analysis is focused on CBM (Compressed Baryonic Matter) experiment at FAIR (Facility for Antiproton and Ion Research) in Darmstadt, Germany. This experiment will use SIS-100/SIS-300 accelerators, under construction at FAIR, producing heavy ion collisions at incident beam energies between 2 and 45 AGeV corresponding to the high net-baryon densities and moderate temperatures of the phase diagram of nuclear matter, an area which is incompletely investigated by other experiments[1]. The study is made using YaPT system [2] with specific codes (UrQMD, AMPT, HIJING) and the results are compared with the existing experimental data.


On behalf of collaboration:

Poster Session - Board: 0805 / 715

Beam energy dependence of Specific Heat in Ultra-relativistic Heavy-Ion Collisions

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Experiments at RHIC and LHC are on the quest to unearth the nature of the QCD phase transition and to get a glimpse of how matter behaves at such extreme conditions. Phase
transitions are governed by a set of thermodynamic parameters, like, temperature ($T$), pressure, entropy, and energy density ($E$), and can be further characterized by their response functions, like, specific heat, compressibility, and susceptibility. In thermodynamics, the heat capacity ($C$) is defined in terms of the ratio of the event-by-event fluctuations of the energy of a part of a finite system in thermal equilibrium to the energy ($\Delta E^2 = T^2 C(T)$). This can be applied for a locally thermalized system produced during the evolution of heavy-ion collisions. But for a system at freeze-out, specific heat can be expressed in terms of the event-by-event fluctuations in temperature of the system where volume is fixed:

$$\frac{1}{T} = \frac{\langle (T^2) - (T)^2 \rangle}{\langle (T)^2 \rangle}.$$  

We define the specific heat as the heat capacity per pion multiplicity within the experimentally available phase space in rapidity and azimuth. For a system in equilibrium, the mean values of temperature and energy density are related by an equation of state. However, the fluctuations in energy and temperature have quite different behavior. Energy being an extensive quantity, its fluctuations have a component arising from the volume fluctuations, and not directly suited for obtaining the heat capacity. Here, we obtain the specific heat for heavy-ion collisions at SPS, RHIC beam energy scan energies and for LHC energy. Experimental results from NA49, STAR, PHENIX, PHOBOS and ALICE are combined to obtain the specific heat as a function of beam energy. The results are compared to results from AMPT event generator, HRG model and lattice calculations. We also present local hot spot search at LHC energy for better understanding the collision dynamics.

On behalf of collaboration:

Poster Session - Board: 0806 / 84

A study of vorticity formation in high energy nuclear collisions

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We present a quantitative study of vorticity formation in peripheral ultrarelativistic heavy ion collisions at $\sqrt{s_{NN}} = 200$ GeV by using the ECHO-QGP numerical code, implementing relativistic dissipative hydrodynamics in the causal Israel-Stewart framework in 3+1 dimensions with an initial Bjorken flow profile. We consider and discuss different definitions of vorticity which are relevant in relativistic hydrodynamics. After demonstrating the excellent capabilities of our code, which proves to be able to reproduce Gubser flow up to 8 fm/c, we show that, with the initial conditions needed to reproduce the measured directed flow in peripheral collisions corresponding to an average impact parameter $b = 11.6$ fm and with the Bjorken flow profile for a viscous Quark Gluon Plasma with $\eta/s = 0.1$ fixed, a vorticity of the order of some $10^{-2}$ c/fm can develop at freezeout. The ensuing polarization of $\Lambda$ baryons does not exceed $1.4\%$ at midrapidity. We show that the amount of developed directed flow is sensitive to both the initial angular momentum of the plasma and its viscosity.

On behalf of collaboration:

Poster Session - Board: 0807 / 331

Characterization of the initial state and QGP medium from a combined Bayesian analysis of RHIC and LHC data

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A primary goal of heavy-ion physics is the measurement of the fundamental properties of the quark-gluon plasma (QGP), notably its transport coefficients, such as the specific shear viscosity $\eta/s$. Since these properties are not directly measurable, one relies on a comparison of the data to computational models of the time-evolution of the collision to connect measured observables to the properties of the transient QGP state. The computational model parameters are tuned such that simulated observables optimally match experimental data.

We employ a Bayesian model-to-data comparison method for extracting QGP properties [1303.5769, 1502.00339]. First, we choose a set of salient model parameters – including physical properties such as $\eta/s$ – then evaluate a modern event-by-event heavy-ion collision model at a small set of points in the multidimensional parameter space, varying all parameters simultaneously. We use a Gaussian process emulator to non-parametrically interpolate the parameter space, providing fast predictions at any point in parameter space with quantitative uncertainty. Finally, we systematically explore the parameter space with Markov chain Monte Carlo (MCMC) to obtain rigorous constraints on all parameters simultaneously, including all correlations.

In this work, we apply the Bayesian methodology to the new TRENTO initial condition model [1412.4708] and standard MC-Glauber initial conditions, coupled to event-by-event viscous 2+1D hydrodynamics and UrQMD [1409.8164]. We calibrate several initial condition and medium parameters to experimentally observed particle yields, spectra, and flows from RHIC and the LHC.

This systematic model-to-data comparison yields rigorous constraints on the nature of the initial state and on fundamental QGP medium properties. The method is general and easily extensible to future studies.

On behalf of collaboration:

Poster Session - Board: 0808 / 281

An evidence for the hadron-quark-gluon mixed phase formation in nuclear collisions

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With the help of an advanced version of the hadron resonance gas model we have found remarkable irregularities of relativistic heavy ion collisions at chemical freeze-out. They include an abrupt change of the effective number of degrees of freedom at laboratory energies 8.9-11.6 AGeV and plateaus in the collision energy dependence of the entropy per baryon, pion number per baryon, and a sharp peak in the dimensionless trace anomaly at at chemical freeze-out laboratory energy 11.6 AGeV [1,2]. On the basis of the generalized shock-adiabat model we demonstrate that these observations give evidence for the anomalous thermodynamic
properties of the mixed phase at its boundary to the QGP [2]. We argue that the trace anomaly peak and the local minimum of the generalized specific volume observed at a laboratory energy of 11.6 AGeV provide a signal for the formation of a mixed phase between the QGP and the hadron phase. This is also supported by an independent meta-analysis [3]: we compare the quality of hadron spectra and multiplicities description from 10 different models in the range of $\sqrt{s_{NN}}$ from 2.1 GeV to 17.3 GeV and find that at 5-10.8 GeV and above 12 GeV models assuming QGP perform notably better, while at 4.4-4.87 GeV and 10.8-12 GeV QGP models perform as good as purely hadron ones.

Based on these findings, the practical suggestions for the collision energies of the future experiments on RHIC, NICA and FAIR are formulated.


On behalf of collaboration:

Poster Session - Board: 0809 / 626

A new Riemann solver for ultrarelativistic nuclear collisions

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We present a new shock-capturing numerical scheme for ideal relativistic hydrodynamics based on an exact solution of Riemann problem for an arbitrary equation of state. Having performed standard numerical tests such as sound wave propagation and shock tube problem, we show that the scheme has low numerical viscosity and high precision and thus is particularly suitable for modeling of ultrarelativistic nuclear collisions.

On behalf of collaboration:

Poster Session - Board: 0810 / 604

Comparison of RHIC and LHC flow data with NeXSPheRIO

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A large experimental effort is dedicated to measuring the QGP properties in heavy ion collisions. To describe these collisions, relativistic viscous hydrodynamics is used. However, various points are still under investigation such as terms to be incorporated in the equations of motion, distribution functions at freeze out, temperature dependence of the viscosity coefficients. As a consequence, ideal hydrodynamics can be considered a benchmark. NeXSPheRIO (3+1 ideal hydro code with NeXus initial conditions) was the first event-by-event code developed and used extensively to describe RHIC data. It is therefore of interest to discuss how well it works at LHC energy. In this contribution, we present a comparison of the description of available flow data (longitudinal, transverse, flow harmonics and their distributions) at RHIC and LHC.

On behalf of collaboration:
**Poster Session** - Board: 0811 / 507

**Quark coalescence from RHIC to LHC**

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In a coalescence plus independent fragmentation approach we calculate the $p_T$ spectra of the main hadrons $\pi, K, p, \bar{p}, \Lambda, \phi$ in a wide range of transverse momentum from low $p_T$ up to about 10 GeV. We show that the approach correctly predicts the evolution of the $p_T$ spectra from RHIC to LHC energy and in particular the baryon-to-meson ratios $p/\pi, \bar{p}/\pi, \Lambda/K$ that reach a peak value of the order of unit at $p_T \sim 3$ GeV, while $p/\phi$ remains nearly constant showing the mass against the quark number effect in the coalescence process. Recombination of minijet partons with the partons from the QGP is also included and plays a role at $p_T \sim 2 - 5$ GeV where the baryon to meson anomaly is observed experimentally. The more recent availability of experimental data up to $p_T \sim 10$ GeV for the spectra as well as for $p/\pi, \bar{p}/\pi, \Lambda/K$ ratios allows to spot some lack of yield in a limited $p_T$ range around 6 GeV. Finally, we discuss also the origin of a significant breaking of the quark number scaling of the elliptic flow $v_2$.

**Reference**


**On behalf of collaboration:**

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**Poster Session** - Board: 0812 / 436

**Particle spectra and HBT radii for simulated central nuclear collisions of C+C, Al+Al, Cu+Cu, Au+Au, and Pb+Pb from \( \sqrt{s} = 62.4 - 2760 \) GeV**

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We study the temperature profile, pion spectra, and HBT radii in central, symmetric, and boost-invariant nuclear collisions, using a super hybrid model for heavy-ion collisions (SONIC), combining pre-equilibrium flow with viscous hydrodynamics and late-stage hadronic rescatterings. In particular, we simulate Pb+Pb collisions at $\sqrt{s} = 2.76$ TeV, Au+Au, Cu+Cu, Al+Al, and C+C collisions at $\sqrt{s} = 200$ GeV, and Au+Au and Cu+Cu collisions at $\sqrt{s} = 62.4$ GeV. We find that SONIC provides a good match to the pion spectra and HBT radii for all collision systems and energies, confirming earlier work that a combination of pre-equilibrium flow, viscosity, and QCD equation of state can resolve the so-called HBT puzzle. For reference, we also show $p+p$ collisions at $\sqrt{s} = 7$ TeV. We make tabulated data for the 2+1 dimensional temperature evolution of all systems publicly available for the use in future jet energy loss or similar studies.

**On behalf of collaboration:**

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Longitudinal Hydrodynamical Evolution

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The ALICE/LHC and BRAHMS/RHIC data allow for an access to hadronic observables over a large range of rapidity. We employ a 1+1 hydrodynamical model to relate freeze-out data and the early hot stage. We study (i) the impact of longitudinal pressure gradients and deviations off the Bjorken symmetry, (ii) bulk viscosity (derived in a holographic model\textsuperscript{[1]} effects, and (iii) electromagnetic emission spectra from the thermalized era.


vHLLE, a code for hydrodynamic modelling of relativistic heavy ion collisions

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We present vHLLE, a 3+1 dimensional relativistic hydrodynamic code for the simulations of quark-gluon/hadron matter expansion in ultra-relativistic heavy ion collisions. The code solves the equations of relativistic viscous hydrodynamics in the Israel-Stewart framework. In addition to energy and momentum, charge densities are explicitly propagated and included in the equation of state, making the code suitable for simulations of matter expansion with finite baryon density. With the help of ideal-viscous splitting, we keep the ability to solve the equations of ideal hydrodynamics in the limit of zero viscosities using a Godunov-type algorithm. Milne coordinates are used to treat the predominant expansion in longitudinal (beam) direction effectively. The results are successfully tested against known analytical relativistic inviscid and viscous solutions including viscous Gubser solution, as well as against existing 2+1D relativistic viscous code.


Derivation of Causal Hydrodynamic Equation by Renormalization Group Method

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We derive the second-order hydrodynamic equation systematically from the relativistic Boltzmann equation for multi-component and multi-conserved-charge systems by the renormalization-group method [1,2]. It is confirmed that the resultant microscopic expressions of the transport coefficients coincide with those derived in the Chapman-Enskog expansion method. Furthermore, we show that the microscopic expressions of the relaxation times have natural and physically plausible forms. We prove that the propagating velocities of the fluctuations of the hydrodynamical variables do not exceed the light velocity, and that the equilibrium state is stable for any perturbation described by our equation. We also confirm that the entropy production rate is positive definite quantity and our equation satisfies the Onsager's reciprocal theorem. All these confirmations strongly support the validity of our formulation. 1 K. Tsumura, Y. Kikuchi, and T. Kunihiro, (2015), arXiv:1506.00846 [hep-ph]. [2] Y. Kikuchi, K. Tsumura, and T. Kunihiro, in preparation.

On behalf of collaboration:

Poster Session - Board: 0816 / 645

Sensitivity of anisotropy flow coefficients and lengths of homogeneity to different equations of state

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In this work we perform a systematic study of the dependence on the equation of state of the collective flow coefficients and of the Hanbury-Brown and Twiss femtoscopic parameters, by using the SPheRIO hydrodynamic code to describe the evolution of heavy-ion collisions. The calculations are carried out both in the center-of-mass frame and in the longitudinal co-moving system, for heavy ion collisions at 130 GeV and 200 GeV energies at the Relativistic Heavy Ion Collider. The resulting anisotropy flow coefficients v2, v3, v4, as well as the femtoscopic lengths of homogeneity, are compared with the data from STAR, PHOBOS and PHENIX Collaborations. It is shown that, although the three different types of equation of state investigated in this work give a reasonable description of the observed data, none is clearly favored in this comparison.

On behalf of collaboration:

Poster Session - Board: 0817 / 392

Hydrodynamic evolution of the event-by-event fluctuating initial state

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In high energy heavy ion collisions of RHIC and LHC, a strongly interacting quark gluon plasma (sQGP) is created. Due to the finite number of nucleons, the initial distribution fluctuates on an event-by-event basis. This medium undergoes a hydrodynamic evolution, before it freezes out to form a hadronic matter. In the last years it has been revealed that if measuring relative to higher order event planes $\Psi_n$, higher order flow coefficients $v_n$ for $n > 2$ can be measured. It also turned out that Bose-Einstein (HBT) correlation radii also show 3rd order oscillations if measured versus the third order event plane $\Psi_3$. The initial transverse plane
anisotropy causing these phenomena can be translated into a series of anisotropy coefficients or eccentricities: \( \epsilon_2, \epsilon_3, \epsilon_4 \), etc. These anisotropies then evolve in time, and result in measurable momentum-space anisotropies, to be measured with respect to their respective symmetry planes. In our work we investigate the time evolution of the asymmetries and the mixing of spatial and momentum space anisotropies via numerical viscous hydrodynamics and via analytic solutions.

On behalf of collaboration:

**Poster Session** - Board: 0818 / 36

**Principal component analysis and factorization breaking**

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We perform a Principal Component Analysis (PCA) of \( v_3(p_T) \) in event-by-event hydrodynamic simulations of Pb+Pb collisions at the LHC. We show that factorization matrix \( r_3(p_T, p_T') \) can be economically presented in terms of two dominant principal components of the two particle correlation function. We find that the subleading flow is predominantly a response to the radial excitations of third order eccentricity. We present a systematic study of the hydrodynamic response to these radial excitations in 2+1D viscous hydrodynamics. Finally, we construct a good geometrical predictor for the orientation angle and magnitude of the leading and subleading flows using two Fourier modes of the initial geometry.

**References:**

A. Mazeliauskas and D. Teaney, Phys. Rev. C 91,(2015) 044902

On behalf of collaboration:

**Speed of Sound at Chiral Phase Transition**

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The speed of sound \( c_s^2 = (\partial P/\partial \varepsilon)_{\text{adiabatic}} \) plays an important role in the hydrodynamic evolution of the hot and dense matter. We calculate the behavior of \( c_s^2 \) in a chiral quark-meson model at finite temperature and baryon density and discuss possible consequences of the chiral phase transition which belongs to 3d \( \mathcal{O}(4) \) universality class. By comparing the results from the no-sea mean-field approximation, the mean field approximation with fermion vacuum polarization and the case where fluctuations are fully incorporated via functional renormalization group (FRG) approach, we show that the chiral phase transition does not produce a minimum in \( c_s^2 \).

Our result may imply that such minimum of \( c_s^2 \) observed in lattice QCD at finite temperature is entirely attributed to the deconfinement phenomenon.

On behalf of collaboration:
Measurement of charged hadron anisotropic flow in Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at RHIC-PHENIX

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Anisotropic flow is one of the important probes to investigate the characteristics of the quark-gluon plasma (QGP). Flow has as its origin, the initial collision geometry, and hence is sensitive to the transport properties of QGP. So far, flow has been studied in symmetric collisions systems such as Au+Au, Cu+Cu. In 2012 the first asymmetric collisions of heavy nuclei at collider energies, Cu+Au, were made available at RHIC. Measurement of anisotropic flow in asymmetric collisions is a subject of special interest because asymmetric collisions provide different density profiles, pressure gradients and initial geometry comparing to symmetric collisions in mid-central collisions. In this poster, we present current status of flow observables in Cu+Au collisions with center of mass energy, 200 GeV, as a function of transverse momentum, as measured by the PHENIX detector at RHIC.

QGP properties from azimuthal-angular dependence of charged-pion interferometry

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Recently the results of HBT measurements of charged pions with respect to the second and third order event plane are presented by PHENIX [1]. They extract $\epsilon_2$ and $\epsilon_3$ from the HBT measurements which contain information about not only the source shape at freezeout but also the space-time evolution of QGP matter. They show the relation between initial $\epsilon_{2,3}$ which are obtained from a Glauber model and final $\epsilon_{2,3}$ which are extracted from the HBT radii. They find that the final $\epsilon_2$ from the HBT radii is finite and smaller than the initial $\epsilon_2$. On the other hand, the final $\epsilon_3$ is significantly reduced and potential reversed by the end in spite of existence of finite initial $\epsilon_3$. The interesting different response of $\epsilon_2$ and $\epsilon_3$ during space-time evolution gives us a clue to understand the detailed QGP properties. For analyses of such high statistics experimental results, we develop a state of the art numerical scheme of causal viscous hydrodynamics for relativistic heavy ion collisions, which has a shock-wave capturing scheme and less numerical dissipation [2]. Furthermore, using the hydrodynamic algorithm, we construct a hybrid model of hydrodynamic model plus UrQMD to include the realistic freezeout processes. Using the model we investigate the time evolution of spatial anisotropies $\epsilon_n$. We find that the sign of $\epsilon_3$ changes from positive to negative during the space-time evolution, which suggests a solution of the vanishing final $\epsilon_3$ from the HBT radii by PHENIX. From detailed analyses, we discuss the initial conditions of hydrodynamic model and the detailed QGP properties such as transport coefficients.


On behalf of collaboration:

Extracting the shear viscosity of the QGP in the presence of bulk viscosity

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The interplay between shear and bulk viscosities on the flow harmonics, $v_n$'s, at RHIC is investigated using the 2+1 hydrodynamical code v-USPhydro\[1\] that includes bulk and shear viscosity effects (on an event by event basis) both in the hydrodynamic evolution and also at freeze-out. While shear viscosity is known to attenuate the flow harmonics, the inclusion of bulk viscosity decreases the shear viscosity-induced suppression of the flow harmonics at RHIC bringing them closer to their values in ideal hydrodynamical calculations [2].

In this talk, NeXuS initial conditions [3] are used to investigate not only how initial flow can alter the hydrodynamic evolution of the quark-gluon plasma but also how different models for bulk viscosity to entropy density ratio, $\zeta/s$, ranging from strong coupling holographic models to hadron gas+lattice calculations, can be used to determine the sensitivity of current hydrodynamic modelling to temperature dependent transport coefficients. We find that flow harmonic data at RHIC can only be adequately described with viscous hydrodynamics \[4\] if the shear viscosity to entropy density ratio, $\eta/s$, of the quark-gluon plasma is two to three times as large as the AdS/CFT viscosity bound.


Sensitivity of flow harmonics to sub-nucleon scale fluctuations in heavy ion collisions

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Event by event hydrodynamic simulations of AA and pA collisions involve initial energy densities with large spatial gradients. This is associated with the presence of large Knudsen numbers ($K_n \sim 1$) at early times, which may lead one to question the validity of the hydrodynamic approach in these rapidly evolving, largely inhomogeneous systems. A new procedure to smooth out the initial energy densities is employed to show that the initial spatial eccentricities, $\varepsilon_n$, are remarkably robust with respect to variations in the underlying scale of initial energy density spatial gradients, $\lambda$. For $\sqrt{s} = 2.76$ TeV LHC initial conditions generated by the MCKLN code\[1\], $\varepsilon_n$ (across centralities) remains nearly constant if the fluctuation scale varies by an order of magnitude, i.e., when $\lambda$ varies from 0.1 to 1 fm. Given that the local Knudsen number $K_n \sim 1/\lambda$, the robustness of the initial eccentricities with respect to changes in the fluctuation scale suggests that the $v_n$'s cannot be used to distinguish between events with large $K_n$ from events where $K_n$ is in the hydrodynamic regime. We use the 2+1
Lagrangian hydrodynamic code v-USPhydro\cite{2} to show that this is indeed the case: anisotropic
flow coefficients computed within event by event viscous hydrodynamics are only sensitive
to long wavelength scales of order $1/\Lambda_{QCD} \sim 1$ fm and are incredibly robust with respect to
variations in the initial local Knudsen number (see \cite{3}). This robustness can be used to justify
the somewhat unreasonable effectiveness of the perfect fluid paradigm in heavy ion collisions.

\cite{3} J.Noronha-Hostler, J.Noronha, M.Gyulassy, “The unreasonable effectiveness of hydrodynam-
ics in heavy ion collisions”, to appear.

On behalf of collaboration:

\textbf{Poster Session - Board: 0824 / 145}

\textbf{Strong coupling calculation of hydrodynamic transport co-
efficients for the QGP at the crossover phase transition}

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In this talk we use the holographic correspondence to determine for the first time the tempera-
ture dependence of 13 transport coefficients that appear in 2nd order hydrodynamics\cite{1}. These
coefficients may be relevant to determine the regime of applicability of hydrodynamics in small
systems such as in pA collisions. The holographic model goes beyond the simple conformal
scenario and is, thus, especially suited to describe the properties of a strongly coupled QGP
near the crossover phase transition. We construct an Israel-Stewart-like theory containing
these 13 temperature-dependent transport coefficients that is suitable for phenomenological
applications in the context of numerical hydrodynamic simulations. We give parametrizations
for the temperature dependence of all the second-order transport coefficients that appear in
this theory in a format that can be easily implemented in current numerical hydrodynamic
codes.

Reference:
\cite{1} S. I. Finazzo, R. Rougemont, H. Marrochio and J. Noronha, “Hydrodynamic transport
coefficients for the non-conformal quark-gluon plasma from holography,” JHEP \textbf{\{bf 1502\}},

On behalf of collaboration:

\textbf{Poster Session - Board: 0825 / 154}

\textbf{Constraining the validity of hydrodynamic approaches by
using a new exact solution of the Boltzmann equation}

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Relativistic hydrodynamics plays an important role in the quantitative description of the
space-time evolution of the strongly coupled QGP created in Ultrarelativistic Heavy-Ion
Collisions. Thus, it is necessary to have under control the physical assumptions made in the
hydrodynamical modelling. In this work we present a new exact solution to the relativistic
Boltzmann equation. This solution describes a system undergoing boost-invariant longitudinal
and azimuthally symmetric radial expansion for arbitrary shear viscosity to entropy density ratio. The resulting solution is invariant under the $SO(3)_q \otimes SO(1,1) \otimes Z_2$ group symmetry. We test the efficiency of various hydrodynamic approximation methods by comparing the evolution of the moments of the exact solution (such as energy density and shear viscous tensor) with the corresponding solutions of the macroscopic hydrodynamic equations. In addition, we briefly discuss the phase-space evolution of this new exact solution and the physical constraints on its applicability.

References:


On behalf of collaboration:

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**Poster Session** - Board: 0826 / 580

**Kelvin-Helmholtz instability in relativistic heavy ion collisions**

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Relativistic hydrodynamic simulations play a key role in understanding the property of the QGP and the QCD phase transition from analyses of high-energy heavy ion collisions. Recently, significant developments are achieved in construction of realistic hydrodynamic models with viscosity effects and event-by-event fluctuations. As a result, we can discuss the bulk feature of the QGP such as transport coefficients and the equations of state in detail from comparison between hydrodynamic calculations and experimental results at RHIC and LHC. One of the current hottest topics is higher flow harmonics which has the information of initial conditions through event-by-event fluctuations and the space-time evolution of the QGP matter. In particular, it is pointed out that the higher flow harmonics is related to the ridge structure which is remnant of long correlations in the longitudinal direction \(^1\). The dynamics in the longitudinal direction may affect that on the transvers plane. Here, we investigate the effect of longitudinal fluctuations to the higher flow harmonics, using a hydrodynamic simulation \(^2\). Especially, we discuss possible existence and time evolution of the Kelvin-Helmholtz instability in high-energy heavy ion collisions. If the Kelvin-Helmholtz instability occurs through longitudinal fluctuations, the vortexes form, which may affect the expansion in the transvers direction. We also argue the influence of the Kelvin-Helmholtz instability to physical observables such as particle distributions and higher flow harmonics.


On behalf of collaboration:
Quantifying deviations from local equilibration in a coarse-grained transport approach

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Event-by-event hybrid models construct the initial conditions for the hydrodynamic evolution from non-equilibrium approaches by matching the corresponding energy-momentum tensor. After splitting the obtained energy-momentum tensor and four-current into ideal-hydrodynamics part and viscous correction, it often appears that the “correction” is large. However, all the existing models neglect viscous correction, assuming instant thermalization and violating angular momentum conservation.

Here we study the complete time evolution of heavy ion collisions within the coarse-grained UrQMD transport approach and quantify deviations from local equilibrium. Since these deviations are expected to be larger at lower beam energies and in more peripheral collisions, Au+Au collisions from $E_{lab} = 5 - 160$ A GeV at different centralities are investigated. At every position in space-time the energy-momentum tensor and net baryon four-current are determined in the Landau rest frame.

We find that the largest contribution to the deviation from local equilibrium is the pressure difference in the transverse and longitudinal direction, while the off-diagonal components of the tensor and baryon charge flow play a minor role in most of the cases. In addition, for every considered energy and centrality there exists a rather sharp time $t_0$, after which the energy-momentum tensor from UrQMD is close to ideal hydrodynamics in a vast space region. This time $t_0$ decreases with collision energy and slightly increases with centrality, being larger than the typical times of hydrodynamics initialization found in the literature. By comparing the result from single events to the average result we also investigate the effect of event-by-event fluctuations on $t_0$.

On behalf of collaboration: 

Poster Session - Board: 0828 / 494

Viscous corrections to anisotropic flow and transverse momentum spectra within a transport approach

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Viscous hydrodynamics is commonly used to model the evolution of the matter created in an ultra-relativistic heavy-ion collision. It provides a good description of transverse momentum spectra and anisotropic flow. These observables, however, cannot be consistently derived using viscous hydrodynamics alone, because they depend on the microscopic interactions at freeze-out. We derive the ideal hydrodynamic limit and the first-order viscous correction to anisotropic flow ($v_2$, $v_3$ and $v_4$) and momentum spectrum using a transport calculation. We find that the linear response coefficient to the initial anisotropy, $\nu_n(p_T) / \epsilon_0$, depends little on $n$ in the ideal hydrodynamic limit. The viscous correction to the spectrum depends not only on
the differential cross section, but also on the initial momentum distribution. This dependence is not captured by standard second-order viscous hydrodynamics. The viscous correction to anisotropic flow increases with $p_T$ in agreement with the recent analytical solutions of viscous hydrodynamic [2].


On behalf of collaboration:

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**Poster Session - Board: 0829 / 567**

**Tsallis fits to the transverse momentum spectra in high energy collisions**

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Transverse momentum distributions of the final-state particles are very useful observables for the understanding of the dynamics of the high energy collisions. It has been shown that the Tsallis distribution gives an excellent description of $p_T$ spectra measured in relativistic nuclear collisions at different energies and under different kinematical conditions of the data collection. The Tsallis distribution parameters can be related to the temperature fluctuations and the non-equilibrium degree of the produced system. In this work, a study of Tsallis fits performed to the transverse momentum spectra obtained in p-p and Au-Au collisions at RHIC energies, will be presented in order to obtain valuable insights on the thermodynamical evolution of the hot and dense partonic matter. The centrality and rapidity dependence of the nonextensivity parameter $q$ will be analyzed. In addition, comparisons with different simulation code predictions (UrQMD, HIJING, AMPT) will be shown and discussed.

On behalf of collaboration:

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**Poster Session - Board: 0830 / 380**

**superSONIC – a super-hybrid model for simulating relativistic ion collisions**

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superSONIC is an evolution package that couples pre-equilibrium flow (inspired by AdS/CFT) to viscous hydrodynamics to a hadron cascade (B3D) for event-by-event simulations of relativistic ion collisions. I’ll briefly review the ingredients before discussing results for AA and pA collisions.

On behalf of collaboration:
Poster Session - Board: 0831 / 434

The importance of the bulk viscosity and hadronic afterburner in relativistic heavy ion collisions

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This work presents a comprehensive description of hadronic observables in heavy-ion collisions at RHIC and LHC energies using a hybrid model that combines IP-Glasma initial conditions, full second-order viscous hydrodynamics (MUSIC) with both the shear and bulk viscosities, and a hadronic afterburner (UrQMD) [1].

In this hybrid approach, it is found that the temperature-dependent bulk viscosity plays a crucial role in simultaneously describing the multiplicity, mean \( p_T \) and the integrated \( v_n \) of all identified particles. Importantly, the extraction of the shear viscosity of QGP very much depends on the bulk viscosity resulting in smaller value of the shear viscosity. These calculations are also in good agreement with HBT measurements.

Finally, it will be shown that a hybrid approach is critical in describing identified particle \( p_T \)-spectra and the \( v_n \) including baryons and multi-strange hadrons. The afterburner is also found to be important in describing the angular correlations.


On behalf of collaboration:

Poster Session - Board: 0832 / 327

Medium Effects on Transport Coefficients of a Hadron Gas

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We evaluate transport coefficients in the kinetic approach explicitly including medium effects in the collision term. For the case of a pion gas the temperature dependence of shear and bulk viscosities as well as thermal conductivity evaluated in the Chapman-Enskog approach show significant medium dependence which enter via the pion-pion scattering cross-section. The in-medium rho and sigma propagators used here also affect the relaxation of dissipative flows evaluated using the Grad’d 14-moment method. Results for a interacting gas of pions and nucleons will be presented.

On behalf of collaboration:

Poster Session - Board: 0833 / 351

Energy and centrality dependence of identified particle elliptic flow in relativistic heavy-ion collisions

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The Beam Energy Scan (BES) program at the RHIC facility was initiated in the year 2010 to study the Quantum Chromodynamics (QCD) phase diagram[1]. In the years 2010, 2012 and
2014 the STAR experiment recorded Au + Au collisions at $\sqrt{s_{NN}} = 7.7, 11.5, 14.5, 19.6, 27, 39,$ and 62.4 GeV within a pseudo rapidity range of $|\eta| < 1$. Recently reported results from identified particle elliptic flow in minimum bias (0–80%) collisions revealed an energy dependent difference in elliptic flow between particles and antiparticles [2]. This difference is increasing with decreasing collision energy and is almost identical for all baryons. These observations attracted various theory groups, that tried to reproduce the results with different assumptions in their model calculations [3].

In this talk, we present the elliptic flow of identified particle for three centrality classes in Au + Au collisions at $\sqrt{s_{NN}} = 7.7 - 62.4$ GeV. The centrality dependence and the data at $\sqrt{s_{NN}} = 14.5$ GeV are new. Except at the lowest beam energies, we observe a similar relative $v_2$ baryon-meson splitting for all centrality classes which is in agreement within 15% with the number-of-constituent quark scaling. The larger $v_2$ for most particles relative to antiparticles, already observed for minimum bias collisions shows a clear centrality dependence, with the largest difference in the most central collisions. The new beam energy (14.5 GeV) and centrality dependence would be useful to distinguish between the different models or to improve their input parameters.


On behalf of collaboration:

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**Poster Session - Board: 0834 / 304**

**Measurement of elliptic flow of neutral pions with ALICE-EMCal in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV**

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The measurement of azimuthal anisotropy in bulk particle production plays a key role in understanding the property of quark gluon plasma. The second order Fourier component of the particle azimuthal distribution is referred as elliptic flow ($v_2$), whose transverse momentum dependence is suggested to be a sensitive probe for different physics processes, like hadron production mechanism and path-length dependence of energy loss in intermediate and high $p_T$ range, respectively. Neutral pions are considered to carry more direct information from the early stage of collisions.

In this work, we present the current status and strategy for the measurement of the elliptic flow of neutral pions in mid and high $p_T$ range in Pb + Pb collisions at ALICE with Electromagnetic Calorimeter (EMCal[1]). Neutral pions are identified by the study of the shape of the overlapping electromagnetic showers developed in the calorimeter by the 2 decaying photons at high $p_T$ (>6 GeV) or via invariant mass analysis at low $p_T$. $v_2$ is measured in standard event plane way[2]. This measurement will serve as an important check for the current knowledge of neutral pion flow as well as corresponding physics interpretation.


On behalf of collaboration:

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**Poster Session - Board: 0835 / 445**

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K*(892)\(^0\) and \(\phi(1020)\) production as a function of charged particle multiplicity in pp collisions at \(\sqrt{s} = 7\) TeV

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Recent measurements in high-multiplicity proton-proton (pp) and proton-lead (p-Pb) events show some characteristics of heavy ion (Pb-Pb) collisions. Further understanding of such observations can be provided by the measurement of transverse momentum (\(p_T\)) spectra of the resonances like \(K^*(0)\) and \(\phi\).

The unique capability of the ALICE detector allows one to directly identify charged hadrons (i.e. pions, kaons and protons) and therefore to reconstruct \(K^*(0)\) and \(\phi\) mesons via their hadronic decay channels. We will report on the measurement of transverse momentum spectra and \(\langle p_T \rangle\) of these resonances as a function of pseudo-rapidity charged-particle density \((dN_{ch}/d\eta}) at mid-rapidity region.

On behalf of collaboration:

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Poster Session - Board: 0837 / 553

Measuring correlation between flow harmonics with moments in ALICE experiment in LHC

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One of the important results in Heavy Ion collisions is anisotropic distribution of particle production. This collective phenomena is known as anisotropic flow, and successfully parameterized by a Fourier harmonics. The correlation between different flow harmonics may provide a new window into both the early stage dynamics and transport properties of QGP. Several flow observables have been studied by measuring moments\(^1\) with two symmetric sub-events group separated by a single rapidity gap. The advantage of using this method is that we can suppress non-flow (e.g from jets and/or resonances) in addition to suppressing self-correlation effects. We measure the correlation between different flow harmonics (both magnitude and event plane angle direction) and estimate non-linear coefficients of the hydrodynamic response. In this presentation, our methods will be discussed in detail, and our results will be compared to the AMPT simulation and various hydrodynamic calculations.


On behalf of collaboration:

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Poster Session - Board: 0838 / 163

STUDY OF ELLIPTIC FLOW AT RHIC AND LHC ENERGIES

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We study the elliptic flow ($v_2$) in the framework of PACIAE2.1b model. The theoretical
results of charged hadrons (K, p, π) as a function of transverse momentum ($p_T$) dependence
and pseudorapidity ($\eta$) dependence are compared with LHC and RHIC experimental data in
Pb+Pb and Au+Au collisions at center of mass energy 0.2 - 2.76 TeV. The results cover a broad
kinematic range, $0.3 < p_T < 20$, $|\eta| < 2.4$. It is found that a moderate increase in $v_2 (p_T)$
at low $p_T$ from the highest RHIC to LHC, despite the large increase in the center of mass
systematic uncertainties. The value of $v_2 (\eta)$ is found to be weakly dependent on pseudorapidity
in central collisions for peripheral collisions the values of $v_2 (\eta)$ gradually decrease as the
pseudorapidity increase.

On behalf of collaboration:

Poster Session - Board: 0839 / 78

Study the particle transverse-momentum spectra at LHC
with nonextensive statistics
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The hydro-dynamic inspried thermal approach - Blast-Wave (BW) model - implemented with
non-equilibrium Tsallis statistics has gained increasing interest (and application) in high-
energy heavy-ion physics. With the come out of recent LHC results on particle production
of various species, we find it a good opportunity to use this approach to interpret the data.
The transverse-momentum spectra, from both $p+p$ and Pb+Pb collisions, are systematically
studied within the Tsallis Blast-Wave (TBW) model, and compared to the RHIC results.
Good agreement between the data and the fit is achieved over a broad kinetic range - 0-10
GeV/c for $p+p$ collisions from 200 to 7000 GeV, and 0-5 GeV/c for Pb+Pb collisions at 2.76
TeV.

From the fit the kinetic freeze-out temperature $T$, the average radial flow velocity $<\beta>$ and
the parameter $q$, which is a measure of the degree of non-equilibrium of the system, can be
extracted. The evolution of these parameters with collision energy and centrality will be
presented. For $p+p$ collisions, the radial flow is found to be consistent with zero at beam
energy below 900 GeV and increases to $\sim 0.3$ at 7 TeV. For Pb+Pb collisions, the TBW
model illustrates better fit stability compared with the normal BW model. The centrality
dependence of $T$, $<\beta>$ and $q$ are demonstrated. A detailed fit to non-strange, single-strange
and multi-strange particle species separately will be given. The multi-strange particle shows
distinct characteristics at kinetic freeze-out compared to the non-strange and single-stranged
particles. Together with the observations at lower energy, the physics implication of the
particle production during the fireball evolution in heavy-ion collisions will be discussed.

On behalf of collaboration:

Poster Session - Board: 0840 / 266

Latest developments in anisotropic hydrodynamics
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In ultrarelativistic heavy-ion collisions nuclear matter is heated to a temperature exceeding that necessary to create a quark-gluon plasma (QGP). Traditionally, second order viscous hydrodynamics has been used to reproduce the soft collective flow of the QGP and hadronic spectra; however, due to rapid longitudinal expansion in the early stages of evolution, the system may possess substantial pressure anisotropies which are a consequence of large viscous corrections, even for small shear viscosity over entropy ratios. These large corrections violate the viscous hydrodynamics assumption of small deviation from local equilibrium. They may lead to unphysical results, and, comparing to the exact 0+1 solutions of the Boltzmann equation, they often badly reproduce the longitudinal pressure (especially for initial stages) and provide the wrong asymptotic behavior. In order to more accurately treat systems possessing large pressure anisotropies, a new approach called anisotropic hydrodynamics was recently developed. In this approach, the pressure anisotropy is treated in a non perturbative manner at the leading order in the hydrodynamic expansion. In previous works simplifying symmetries were considered in order to extract the leading order of of anisotropic hydrodynamics, like longitudinal boost invariance, or cylindrically symmetric radial expansion. The equations have been extended to the 3+1-dimensional expansion, however in the first attempt it were not possible to fully recover the very good agreement with the exact solutions of the Boltzmann equation. We present the very latest prescription, which is lacking any symmetry constraint on the space-time evolution, it is fully consistent with second order hydrodynamics in the close-to-equilibrium limit, and it is providing an unprecedented agreement with the exact solutions in the 0+1 dimensional expansion, comparing to other leading order prescriptions and second order viscous hydrodynamics.

On behalf of collaboration:

Poster Session - Board: 0841 / 449

Search for collective phenomena in high multiplicity pp and p-Pb collisions with the ALICE experiment
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The measurement of transverse momentum ($p_T$) spectra for light flavor hadrons ($\pi$, $K$, $p$) as a function of event multiplicity in $\sqrt{s}=7$ TeV pp collisions is presented. Based on these results, the integrated yields, mean $p_T$ and ratios of baryon to meson spectra are extracted. Common patterns in the evolution of the spectral shapes in pp, p-Pb and Pb-Pb collisions are observed and compared to predictions from hydrodynamical models.

On behalf of collaboration:

Poster Session - Board: 0842 / 72

Beyond the thermal model
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The statistical hadronization (or thermal) model was initially developed by Hagedorn for hadron collisions above 10 GeV/c primary laboratory momentum [1]. In relativistic heavy-ion physics, many authors have developed it further and compared to a large amount of data in particular for hadron production rates, e.g. [2,3,4], where it yields excellent results. To decide whether the system is indeed in thermal equilibrium, the distribution functions rather than production yields are decisive: In the transverse momentum distributions of
produced particles, deviations from thermal behaviour plus collective expansion occur beyond about 8 GeV/c. Not only the rapidity distributions of net baryons, but also the pseudorapidity distributions of produced mesons deviate from pure thermal behaviour: the thermal model does not generate a plateau in dN/dy, or a dip in dN/deta. Such non-equilibrium effects can to a certain extent be accounted for in a relativistic diffusion model [5,6] with three sources - two fragmentation sources, and a mid-rapidity source arising from gluon-gluon collisions - that merges with the thermal model only for time to infinity. Given the short interaction times of AuAu at RHIC or PbPb at LHC, the fragmentation sources still contribute substantially, providing good results when compared [6,7] to data from PHOBOS and ALICE, and also for asymmetric systems such as dAu at RHIC and pPb at LHC.

1 R. Hagedorn, Nuovo Cim. Suppl. 3, 147 (1965)

On behalf of collaboration:
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Poster Session - Board: 0843 / 116

Analytical and numerical Gubser solutions of the second-order hydrodynamics

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Evolution of quark-gluon plasma (QGP) near equilibrium can be described by the second-order relativistic viscous hydrodynamic equations. Consistent and analytically verifiable numerical solutions are critical for phenomenological studies of the collective behavior of QGP in high-energy heavy-ion collisions. A novel analytical solution based on the conformal Gubser flow which is a boost-invariant solution with transverse fluid velocity is presented. Due to the non-linear nature of the equation, the analytical solution is non-perturbative and exhibits features that are rather distinct from solutions to usual linear hydrodynamic equations. It is used to verify with high precision the numerical solution with a newly developed state-of-the-art (3+1)-dimensional second-order viscous hydro code (CLVisc). The perfect agreement between the analytical and numerical solutions demonstrates the reliability of the numerical simulations with the second-order viscous corrections. This lays the foundation for future phenomenological studies that allow one to gain access to the second-order transport coefficients.

On behalf of collaboration:
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Poster Session - Board: 0902 / 70

Localized event-by-event charge separation in Au+Au collisions at 200 GeV
In the recent years, there have been lot of interests in measuring and understanding the azimuthal correlations, amongst particles produced in heavy ion collisions, separately for same-sign pairs and for opposite-sign pairs and to see their differences. This is because the Chiral Magnetic Effect (CME) states that Parity-odd domains can interact with the very large magnetic fields in non-central heavy-ion collisions resulting charge-separation parallel to the system’s orbital angular momentum. Both at RHIC and LHC energies, differences have been found in the azimuthal correlations for same-sign and for opposite-sign pairs.

We propose to use the Sliding Window Method, SWM, (Phys. Lett. B638 (2006) 39) to search for localized Event-by-Event charge separation in different azimuthal windows in the pseudorapidity region $|\eta| < 1$ in non-central Au+Au collisions at 200 GeV. The efficiency of the SWM as a function of injected signal will be presented for 2M Au+Au hijing events at 200 GeV.

**On behalf of collaboration:**

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**Poster Session - Board: 0903 / 575**

**Fluctuation Evolution in Au+Au Collisions at FAIR energy**

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Event by event fluctuations of particle multiplicities and their ratios are considered to be sensitive probes to the exotic phenomena in high energy heavy ion collisions like phase transition or the occurrence of critical point. These phenomena might take place at different time after the collision based on fulfilling the required conditions at a particular time. Fluctuations are therefore expected to show non-monotonic behaviour at the time of occurrence of these phenomena. Experimentally, fluctuations are measured at freezeout. In this work, using the hybrid version of the UrQMD event generator, we have investigated the propagation of fluctuations of particle multiplicities, their ratios and the ratio of total positive and negative charges in AuAu collisions at $E_{lab} < 90$ AGeV. Two commonly used experimental measures i.e., $\sigma^2$/mean and $\nu_{dyn}$ have been used in the analysis in a given acceptance. The hybrid model, i.e., UrQMD with hydrodynamic evolution has been used to study the effect of hydrodynamic evolution on these conventional fluctuation measures. It is observed that the fluctuations as measured by $\sigma^2$/mean and $\nu_{dyn}$ gets reduced considerably at freezeout. The dominant structures present at the initial stage of the evolution get smoothen out. However, the energy dependence of the fluctuations remain preserved till the freezeout. The hydrodynamic evolution of the model with chiral equation of state shows considerably higher fluctuation at lower collision energy as compared to pure hadronic transport version or the hybrid version with hadronic equation of state. The time evolution of the higher order moments of net-proton distributions for particles in a specified coverage showed similar behaviour.

**On behalf of collaboration:**

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**Poster Session - Board: 0904 / 418**

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Impact of higher mass-states on the freeze-out conditions in heavy ion collisions
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Fluctuations of conserved charges have proven to be a good tool to investigate the QCD phase diagram in many aspects, like the conditions for the deconfinement transition from hadrons to quarks and the determination of the chemical freeze-out parameters. We use a Hadron Resonance Gas (HRG) model to study the hadronic phase of an Heavy-Ion collision, and compare our results with recent lattice QCD simulations and experimental measurements. We show that the inclusion of higher mass states, recently measured in the experiments, improves the agreement with the lattice results for a key set of observables related to strangeness fluctuations. We find that, with these new states, the freeze-out conditions resulting from the analysis of net-proton and net-charge moments are consistent with our previous findings. A comparison with experimental data from the STAR collaboration on ratios of particle yields still hints at a shift between the freeze-out temperatures needed to describe the light and the (multi-)strange sectors.

On behalf of collaboration::

Poster Session - Board: 0905 / 599

Initial state correlations and the ridge
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The ridge observed in high multiplicity pp and in pPb collisions at the LHC is one of the most striking phenomena in high energy hadronic collisions. One very successful explanation has been given within the Color Glass Condensate, in terms of the so-called Glasma graphs. In this talk, we point out that the origin of the correlations in the Glasma graphs is actually rooted on a basic physical mechanism, namely Bose enhancement of gluons in the incoming wave function\textsuperscript{[1]}. We also discuss a immediate consequence of these correlations in the initial stage of the collisions, their effect on intensity interferometry radii for particles separated by large rapidities.

\textsuperscript{[1]} T. \textasciitilde Altinoluk, N. \textasciitilde Armesto, G. \textasciitilde Beuf, A. \textasciitilde Kovner and M. \textasciitilde Lublinsky, arXiv:1503.07126 [hep-ph].

On behalf of collaboration::

Poster Session - Board: 0906 / 557

Event-by-Event Identified Particle Ratio Fluctuations in Pb-Pb Collisions with ALICE using the Identity Method
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The study of event-by-event fluctuations of identified hadrons may reveal the degrees of freedom of the strongly interacting matter created in heavy-ion collisions and reflect the underlying dynamics of the system. The observable $\nu_{\text{dyn}}$, which is given in terms of the moments of identified-particle multiplicity distributions, is used to quantify the magnitude of the dynamical fluctuations in event-by-event measurements of given particle ratios. The ALICE detector
at the LHC is well suited for the study of $\nu_{\text{dyn}}$, due to its excellent particle identification capabilities. Particle identification that is based on the measurement of the specific ionisation energy loss $dE/dx$ works well on a statistical basis, but suffers from ambiguities when applied on the event-by-event level. A novel experimental technique called the “Identity Method” was recently proposed to overcome such limitations. The method follows a probabilistic approach using the inclusive $dE/dx$ distributions measured in the ALICE TPC, and determines the moments of the multiplicity distributions by an unfolding procedure. In this contribution, an analysis of identified particle ratio fluctuations that applies the Identity Method to Pb-Pb data from ALICE will be presented.

On behalf of collaboration:

Poster Session - Board: 0907 / 700

Global and Local Temperature Fluctuations in High Energy Heavy-ion Collisions

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Heavy-ion collisions at ultra-relativistic energies create matter at extreme conditions of energy density and temperature, similar to the ones that existed within a few microseconds after the Big Bang. The fireball produced in the collision goes through a rapid evolution from an early partonic phase of deconfined quark-gluon plasma (QGP) to a hadronic phase and ultimately freezing out after a few tens of fm. Temperature fluctuations have been discussed in the literature as a means of characterizing the evolving system. The fluctuations may have two distinct origins, first, quantum fluctuations that are initial state fluctuations, and second, thermodynamical fluctuations. We discuss a method of extracting the thermodynamic temperature from the mean transverse momentum of pions, by using controllable parameters such as centrality of the system, and range of the transverse momenta. Event-by-event fluctuations in global temperature over a large phase space provide the specific heat of the system. We present Beam Energy Scan of sp. heat from data, AMPT and HRG model prediction. For Pb-Pb collisions at the Large Hadron Collider (LHC) energies, because of the production of a large number of particles in every event, it is possible to divide the phase space into small bins and obtain local temperature for each bin. Event-by-event fluctuations in local temperature can be obtained by following a novel procedure of making fluctuation map of each event. The origin of the local fluctuations has been studied with the help of event-by-event hydrodynamic calculations, which shows that the system exhibits fiercely large fluctuations at early times after the collision, which diminishes with the elapse of time. Any observation of non-zero local fluctuations may imply that a part of the early fluctuations might have survived till freeze-out. We discuss the hydrodynamic calculations and a feasibility study at LHC using AMPT simulated data.

On behalf of collaboration:

Poster Session - Board: 0908 / 140

Characterizing flow fluctuations with moments

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1 TIFR
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We present a complete set of multiparticle correlation observables for ultrarelativistic heavy-ion collisions. These include moments of the distribution of the anisotropic flow in a single harmonic, and also mixed moments, which contain the information on correlations between event planes of different harmonics. We explain how all these moments can be measured using just two symmetric subevents separated by a rapidity gap. This procedure is less demanding in terms of detector acceptance than the one based on several rapidity windows separated pairwise by gaps. These moments present a multi-pronged probe of the physics of flow fluctuations. For instance, they allow to test the hypothesis that event-plane correlations are generated by non-linear hydrodynamic response. They can be measured easily at LHC and even with detectors having smaller acceptance, and can be directly compared with theoretical calculations. We illustrate the method with simulations of events in A MultiPhase Transport (AMPT) model\textsuperscript{[1]}. It is important to test if experimental data at LHC confirm these predictions.


On behalf of collaboration:

\section*{Fluctuations, Instabilities and Collective Dynamics}

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Fluid dynamical processes became a dominant direction of research in high energy heavy ion reactions. The QuarkGluon plasma formed in these reactions has low viscosity \textsuperscript{[1]}, which leads to significant fluctuations and turbulent instabilities \textsuperscript{[2]}. One has to study and separate these two effects \textsuperscript{[3]}, but this is not done yet in experiments. When such separation is performed, both fluctuations and new collective effects, like rotation and turbulence and the arising polarization \textsuperscript{[1]} and two particle correlations \textsuperscript{[5]} can be studied. The polarization arises from the shear flow based on the equipartition principle between local flow vorticity \textsuperscript{[6]} and particle spin. Vorticity increases with beam energy in peripheral collisions, while higher temperatures counteract spin alignment. Due to these two effects polarization is expected to be observable at lower energies also \textsuperscript{[6]}.


FIG. 1. (Color online) The relativistic weighted thermal vorticity calculated in the reaction [x-z] plane at t=3.72 fm/c. The energy of the U+U collision is $\sqrt{s_{NN}} = 4.0 + 4.0$ GeV, b = 0.5bmax, and the cell size is dx = dy = dz = 0.61 fm. The average, energy weighted vorticity, is 0.0856 / 0.0658 for the two selected times. From ref. \textsuperscript{[6]}.


On behalf of collaboration:

\section*{Poster Session - Board: 0911 / 703}
Two-particle correlations with identified pions, kaons and protons in pPb collisions

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Two-particle angular correlations are studied between identified pions, kaons, protons and unidentified charged particles in pPb collisions with an integrated luminosity of approximately 35 nb$^{-1}$ at a nucleon-nucleon center-of-mass energy of 5.02 TeV by the CMS experiment. The particles are identified via their energy loss in the silicon tracker. In order to eliminate short-range correlations we impose a wide $\Delta \eta$ gap of at least two units. The long-range azimuthal correlations are characterized by the second-order ($v_2$, elliptic flow) and third-order ($v_3$, triangular flow) anisotropy harmonics. The anisotropy harmonics are measured as a function of transverse momentum and wide range of particle multiplicity, which is made possible by the dedicated high-multiplicity triggers implemented in CMS. The new results can help further differentiate between the competing models that aim to explain the origin of the ridge effect.

On behalf of collaboration:

Poster Session - Board: 0913 / 533

Rapidity Dependence of Transverse Momentum Correlations

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Experiments demonstrate the profound effect of initial state fluctuations in nuclear collisions, but theory demands that further fluctuations arise and are dissipated throughout the subsequent hydrodynamic evolution. Our earlier work shows that viscous dissipation broadens the rapidity dependence of two-particle transverse momentum correlations $^1$; this work stimulated an experimental analysis by STAR $^2$. That analysis uncovered puzzling new features in the detailed rapidity dependence of these correlations. We present new work on correlation observables computed using the second order Israel-Stewart hydrodynamics with stochastic noise and latest lattice QCD equations of state and transport coefficients. We also compute these observables using the first order Navier-Stokes theory. We find that the second order theory with causal constraints is needed to explain the new features uncovered by the experiment.


On behalf of collaboration:

Poster Session - Board: 0914 / 495

Heavy Flavor Triggered Azimuthal Correlations in p+p and Au+Au Collisions from STAR

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At RHIC energies, heavy quark pairs are mostly produced through initial hard scatterings, leading to a cleaner interpretation and understanding of the measurements in heavy-ion collisions. Correlations between heavy flavor quark (c, b) pairs offer a unique insight into early interaction dynamics of the hot and dense QCD matter. In the meantime, a comprehensive investigation of heavy quark pair production mechanisms in proton-proton collisions is of great importance and interest as a fundamental perturbative QCD (pQCD) test and baseline measurement for heavy-ion collisions.

We report new STAR measurements of heavy flavor correlations in p+p and Au+Au collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \) and p+p collisions at \( \sqrt{s} = 500 \text{ GeV} \) using D mesons, Non-Photonic Electrons (NPE) from semileptonic decays of open heavy flavor hadrons as well as J/\( \psi \)'s as trigger particles. Azimuthal angular correlation distributions between trigger D mesons and associated charged hadrons (D-h), NPE (D-NPE) as well as anti-D mesons (D-\( \bar{D} \)) are measured in p+p 500 GeV for the first time. Results with much improved precisions are also obtained on J/\( \psi \)-h and NPE-h correlations in p+p collisions at \( \sqrt{s} = 200 \) and 500 GeV, respectively. These results are compared with pQCD calculations to improve understanding of charm and bottom quark production in elementary hadron collisions. NPE-h correlations are also measured in Au+Au collisions at \( \sqrt{s_{NN}} =200 \text{ GeV} \) and compared with those in p+p collisions at \( \sqrt{s}=200 \text{ GeV} \) to investigate parton-medium interactions. Finally, the first measurement of electron-muon correlations from heavy flavor quark-antiquark pair decays is presented, utilizing the new STAR Heavy Flavor Tracker and Muon Telescope Detector in Au+Au collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \). Prospects of heavy flavor correlation measurements in heavy-ion collisions are discussed.

On behalf of collaboration:

Poster Session - Board: 0915 / 483

Pion femtoscopy of small systems in ALICE at the LHC

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Femtoscopic correlations carry key information about the size and dynamics of the medium formed by heavy-ion collisions. They provide critical constraints to hydrodynamic predictions of radial flow, and have recently been measured in pp and p-A collisions where the hydrodynamic description is being explored. In particular, models based on hydrodynamics and gluon saturation models provide predictions for system size in p-A collisions. We present new results on femtoscopic correlations, where the treatment of non-femtoscopic background has been greatly improved. The background is relatively large in smaller systems, therefore a careful treatment is essential. We explore two methods; one uses Monte-Carlo models to determine the jet-related background, and the other removes hard events using cuts on the transverse sphericity. We will compare homogeneity radii determined using both methods, and compare our results to data from other heavy-ion experiments.

On behalf of collaboration:

Poster Session - Board: 0916 / 138

Non-Gaussian eccentricity fluctuations

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The observation of a non-zero $v_n\{4\}$ in systems where anisotropic flow is solely due to fluctuations ($v_2\{4\}$ in p+Pb collisions, $v_3\{4\}$ in Pb+Pb collisions) implies that initial eccentricity ($\varepsilon_n$) fluctuations are not Gaussian. This is confirmed by simulations using various initial-state models.

It has been argued that non-Gaussianities may not reflect underlying microscopic dynamics. On the contrary, there are indications that they are to a large extent universal and arise from the global condition $|\varepsilon_n| < 1$. On the other hand, systematic investigations of second and fourth-order cumulants $\varepsilon_n\{2\}$ and $\varepsilon_n\{4\}$ reveal deviations from this universal behavior in large systems, which suggests that non-Gaussianities may carry non-trivial dynamical information.

In this talk, we present results from Monte Carlo simulations and analytic calculations which we have done in order to investigate what non-Gaussianities tell us about the early stage of heavy-ion collisions. We find that the non-Gaussianities are essentially universal in p+Pb collisions, but not in large systems like Pb+Pb collisions. We show that the initial density field has intrinsic non-Gaussianities (in particular a non-trivial 3-point function) which are instrumental in explaining experimental observations.

On behalf of collaboration:

**Poster Session** - Board: 0917 / 675

**Technique for Performing High Accuracy Forward-Backward Multiplicity Correlation Measurements**

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Forward-backward multiplicity correlation measurements are used to study the soft component of high energy collisions. The observable is sensitive to the dynamics of the collision and is relatively less affected by the following hadronization processes. In proton-proton collisions, forward-backward multiplicity correlation measurements allow one to study the underlying event while, in heavy-ion collisions, they can provide insight into effects such as gluon saturation.

The measurement requires one to determine the variances of and covariance between the forward and backward multiplicities. Realistic detector effects such as acceptance and efficiency alter the required measured quantities. Exactly how these quantities are altered is neither straightforward nor intuitive compelling one to use Monte Carlo simulations to determine the unaltered values. However, the robustness of using Monte Carlo simulations is difficult to determine as they depend on the initial assumptions.

A Monte Carlo independent technique to determine multiplicity correlation measurements which accounts for acceptance and efficiency is presented here. The goal is to allow one to perform these measurements while minimizing measurement bias and allowing one to exploit the full capability of their detector (full acceptance and largest pseudorapidity separations), where one may otherwise limit the acceptance with a fiducial cut. Larger separations and highest accuracy provide the maximum ability to distinguish between various models implementing different mechanisms for particle production.

On behalf of collaboration:

**Poster Session** - Board: 0919 / 277

**Three-dimensional source function from a hydro + cascade model**
Femtoscopic analyses have a long history towards comprehensive understanding of the space-time structure of dynamically evolving matter created in high-energy nuclear collisions. Among them, the source imaging technique enables us to extract the source function, namely distribution of the relative distance between two emission points for observed particles, directly from two particle correlation functions. Since the source function looks no longer a Gaussian in general, it contains richer information about the space-time distribution of emission source than HBT radii and is an ideal quantity to compare experimental data with theoretical results. In this study, we discuss one- and three-dimensional source functions for pions and kaons from a hydro + hadronic cascade hybrid model simulations. Our model consists of event-by-event Glauber-type initial conditions, (3+1)-dimensional ideal hydrodynamics for the quark gluon plasma and a hadronic cascade for the hadron resonance gas. We first confirm the $p_T$ spectra for pions and kaons in Au + Au collisions at the top RHIC energy and find that hadronic rescatterings play a significant role to describe non-Gaussian tail which was observed by the PHENIX Collaboration. We also analyze three-dimensional source functions at the RHIC energy, where a special attention is paid to obtain the source function by decomposing them into coefficients of Cartesian spherical harmonics as the PHENIX Collaboration employed the same technique. Finally, we also predict the source functions of pions and kaons from hybrid model simulations of Pb+Pb collisions at the LHC energy and compare them with the ones at the RHIC energy.


Poster Session - Board: 0920 / 542

Non-Gaussian fluctuation in stochastic diffusion equation

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We study a description of non-Gaussian fluctuations in stochastic diffusion equation which is defined by introducing a noise term into diffusion equation. Usually, the noise term in stochastic diffusion equation is assumed to be a Gaussian white noise. With this assumption, the fluctuation of the particle number in equilibrium becomes of Gaussian. On the other hand, experimental results on fluctuations of conserved charges in heavy ion collisions suggest that the fluctuations approach the equilibrated one having nonzero non-Gaussian cumulants in the diffusive process in hadronic stage. To describe this diffusive process by stochastic diffusion equation, this formalism has to be modified to have non-Gaussian fluctuations in equilibrium. We investigate modifications of the stochastic diffusion equation to allow for nonzero non-Gaussian fluctuations in equilibrium, and compare the time evolution of non-Gaussian cumulants described by the equation with the one obtained in the diffusion master equation.
Poster Session - Board: 0921 / 9

Magnetic and Electric Fields in Heavy-ion Collisions

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Heavy-ion collisions can generate very strong magnetic fields and also electric fields. We study the general properties of these fields, including the field strength, spatial distribution, collision-energy dependent, time evolution. We will also discuss how the event-by-event fluctuation affects the correlation between the azimuthal orientation of the fields and the participant matter geometry, namely, the participant planes. The implications of these results on the experimental searching of the chiral magnetic/separation effects, chiral electric separation effect will be also presented.

On behalf of collaboration:

Poster Session - Board: 0922 / 199

Influence of quantum conservation laws on particle production in hadron collisions

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Conservation laws strongly influence particle production. Effects connected to this mechanism were studied in details using correlation techniques in $e^+e^-$ collisions. At the time models were tuned to correctly reproduce measured data. Similar studies for hadron-hadron collisions have never been performed, until recent ALICE measurement. ALICE reported on studies of untriggered two-particle angular correlations of identified particles ($\pi$, $K$, and $p$) measured in pp collisions at center-of-mass energy of $\sqrt{s} = 7$ TeV. The ALICE results confirm that also in hadron-hadron collisions conservation laws strongly influence the shape of the correlation functions for different particle types and must be taken into account while analysing the data. Moreover, now, when ALICE results are available, it can be observed that the contemporary models (Pythia, Phojet) no longer reproduce the data well. It should be noted, that also in heavy-ion collisions conservation laws (i.e. local charge conservation) provide crucial elements that are needed to describe experimental data.

In the talk we would like to present a brief history of experimental measurements of correlations induced by conservation laws, also including the newest Preliminary results from ALICE. We explain interesting structures observed in ALICE LHC data employing a dedicated model, called CALM (ConservAtion Laws Model). CALM is a model developed to study analytically the influence of the conservation laws on the shape of the $\Delta\eta\Delta\phi$ correlation functions. With this model we demonstrate that local conservation of charge, strangeness, and baryon number in hadron production mechanism is essential for description of experimental data.


On behalf of collaboration:
**Event-by-Event Fluctuations in Identified Particle Ratios in ALICE at LHC**

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In ultra-relativistic heavy-ion collisions, the nuclear matter undergoes a phase transition from hadronic matter to a state of quark and gluons. Phase transitions are often associated with enhanced fluctuations in various globally conserved quantities, such as electric charge, baryon number, strangeness, etc. Therefore, the study of the event-by-event fluctuations of these quantities can be a probe to explore the properties of the matter created in heavy ion collisions and its phase structure. A study of particle ratio fluctuations has been carried out by using the variable $\nu_{dyn}$ which, by its construction, is free from collisional biases, i.e. impact parameter fluctuations and fluctuations from the finite number of particles within the detector acceptance.

We present the first results on event-by-event dynamical fluctuations of identified particle ratios, such as, $K/\pi$, $p/K$ and $p/\pi$ in Pb-Pb collisions at 2.76 TeV using the ALICE detector at the LHC. In order to gain insight into the origin of these fluctuations, we measure $\nu_{dyn}$ for all like-sign and unlike-sign particle pairs as a function of number of participants. We will also make comparisons with measurements at lower center-of-mass energies from the SPS and RHIC, and discuss the results to models.

**On behalf of collaboration:**

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**Evolution of net-charge fluctuations in heavy ion collisions**

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Recent publications have postulated that charge fluctuations in heavy ion collisions can provide a possible signature for the existence of the deconfined Quark Gluon Plasma phase. The charge fluctuations are sensitive to the number of charges in the system, thus the fluctuations in the QGP, with fractionally charged partons, are significantly different from those of a hadron gas with unit-charged particles. We investigate the evolution of fluctuations in rapidity space, which hints at signal damping as a function of rapidity. We estimate the magnitude of the diffusion of signal by taking the global charge conservation into consideration. Further, we emphasize the minimum rapidity gap required to estimate the diffusion of the signal in experiment.

**On behalf of collaboration:**

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**Recent Results on Event-by-Event Fluctuations in ALICE at LHC**

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Non-statistical event-by-event fluctuations in relativistic heavy-ion collisions have been proposed as a probe of phase instabilities near the QCD phase transition. In a thermodynamical picture of the strongly interacting system formed in heavy-ion collisions, the fluctuations of the mean multiplicity, particle ratios, mean transverse momentum, and net-particle higher moments are related to the fundamental properties of the system and therefore may reveal information about the QCD phase transition. Detailed studies of particle ratio fluctuations and higher moments have been carried out in Pb-Pb collisions at 2.76 TeV in ALICE. The first results will be shown as a function of collision centrality and pseudorapidity. We will also make comparisons with measurements at lower center-of-mass energies from the SPS and RHIC, and discuss the status and perspectives for future fluctuations measurements at ALICE.

On behalf of collaboration:

Poster Session - Board: 0926 / 539

Rapidity window dependences of higher order cumulants of conserved charges

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We study the rapidity window dependences of higher order cumulants of conserved charges observed in relativistic heavy ion collisions. The time evolution and the rapidity window dependence of the non-Gaussian fluctuations are described by a simple model composed of Brownian particles. We discuss that the rapidity window dependences of the non-Gaussian cumulants have characteristic structures reflecting the non-equilibrium property of fluctuations, which can be observed in relativistic heavy ion collisions with the existing detectors. It is argued that various information on the thermal and transport properties of the hot medium can be revealed experimentally by the study of the rapidity window dependences, especially by the combined use, of the higher order cumulants.

On behalf of collaboration:

Poster Session - Board: 0927 / 628

The effects of initial state fluctuations and of shear and bulk viscosities on two-particle correlations in pA and AA collisions

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Recent developments in the field give evidence of the QGP formation in central proton-nucleus collisions. This gives grounds to studying both proton-nucleus and nucleus-nucleus systems within hydrodynamical framework. We extend our 3+1D hydro model to include effects of bulk viscosity and provide comparative analysis of the obtained results to an extensive set of comprehensive experimental measurements. In particular, we confirm our finding of the weak dependence on viscosity of the double-differential two-particle momentum correlations \( r_n(p_T, p_T') \) and \( r_n(\eta, \eta) \) and its strong sensitivity to the parameters of the initial conditions. This allows us to consider latest experimental observations of the rapidity profile of two particle correlations as a source for studying initial conditions fluctuations in longitudinal direction.
The influence of broad resonances on strangeness fluctuations

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Motivated by recent lattice QCD (LQCD) studies on fluctuations of conserved charges and their interpretation within the Hadron Resonance Gas (HRG) model, we explore the effects of interactions on strangeness fluctuations in hadronic matter at finite temperature. We focus on the s-wave K-pi interactions and discuss the role of the attractive isospin-1/2 channel, with the broad κ(869) and the K*(1430) resonances, as well as the repulsive isospin-3/2 channel. The interaction contributions to the thermodynamics are handled within the S-matrix formalism using the empirical K-pi phase shifts as input.

We show that a simplified treatment of interactions in this channel, using a Breit-Wigner spectral function for each resonance, as frequently employed in applications of the hadron resonance gas, systematically overestimates the strangeness fluctuations. Thus, when modeling the LQCD results and experimental data on strangeness fluctuations the contribution of broad resonances must be treated with particular caution.

Perspectives of gamma-jet correlation analysis in Run2 in ALICE

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The ALICE experiment is dedicated to studies of the quark-gluon plasma (QGP) state, which is created in heavy ion collisions. Both photons and jets are excellent probes of QGP. Photons are produced during the different stages of the expansion of the initial hot matter fireball. They do not interact strongly with the medium and passing through it, they carry information on the properties of the matter at the space-time point of their emission. The direct photons are formed at the early stage of the collision in two processes: annihilation (q{overline{q}} → gγ) and Compton scattering (qg → qγ). They enable a test of perturbative QCD constraining parton distributions and fragmentation functions. Moreover, they estimate the energy of correlated back-to-back jet.

A parton formed in the hard scattering at the early stage of the collision lose the energy when traversing the hot and dense matter and then fragments into a spray of particles called jet. Modification of the jet structure in medium compared to vacuum can provide hints to the properties of QGP.

Both direct photons and jets have been measured by the ALICE experiment at LHC. However, back-to-back correlation between photon and reconstructed jet in the ALICE experiment can be observed only with large statistics available in Run 2 due to the relatively small cross-section. Both the algorithm of selection of correlated gamma-jet events and prediction of the expected yield will be shown for both systems pp, Pb-Pb and p-Pb for available at LHC energies √s_{NN}. 
= 13 TeV, 5 TeV and 5.02 TeV, respectively. Additionally, transverse momentum ratio and fragmentation function of jets for binary collisions will be shown. Photons are measured in ALICE directly in the two electro-magnetic calorimeters (PHOS, EMCal). Jets are clustered from charged tracks reconstructed in the central tracking detectors (TPC and ITS) and neutral constituents reconstructed in EMCal and PHOS.

On behalf of collaboration:

Poster Session - Board: 0930 / 663

Effects of Momentum Cuts on Higher Order Cumulants of Conserved Charges

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We discuss the effects of momentum cuts in the fluctuations of conserved charges in the following contexts:
1) Kinematic momentum cuts of pions in electric charge fluctuations. 2) Soft momentum scale in net-baryon number fluctuations at chiral crossover.
In 1), we show that the normalized kurtosis $\kappa_{\sigma^2}$ is substantially reduced by the $p_T$ cut because it suppresses the effect of Bose statistics. The reduced value of $\kappa_{\sigma^2}$ is found to be consistent with the recently measured data by PHENIX [1].
In 2), using the functional renormalization group (FRG) method, we calculate the higher order cumulants of net-baryon number as a function of infrared momentum scale $k$ in a chiral quark-meson model [2]. We show that the characteristic negative values of the sixth order cumulants at vanishing $\mu$ and fourth order one at large $\mu$ turn to positive if the momentum scale below $2m_\pi$ are not taken into account.


On behalf of collaboration:

Poster Session - Board: 0931 / 563

Event-by-event Multiplicity Fluctuations in Pb-Pb Collisions at LHC Energies in ALICE

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Fluctuations of various observables in heavy-ion collisions at ultra-relativistic energies have been extensively studied as they provide important signals regarding the formation of Quark Gluon Plasma. Because of the large number of produced particles in each event, a detailed study of event-by-event multiplicity fluctuation has been proposed as one of the signatures of the phase transition. In addition, understanding of the multiplicity fluctuations is essential for other event-by-event measurements. In this presentation, we have calculated the scaled variance $\omega = \sigma^2/\mu$ of the charged particle multiplicity distributions as a function of centrality in Pb-Pb collisions at LHC energies. Here, $\mu$ and $\sigma$ denote the mean and the width of the multiplicity distributions, respectively. The trend of scaled variances as a function of centrality will be presented and discussed. Volume fluctuations play an important role when measuring the multiplicity fluctuations. These will be discussed. The results are expected to provide vital input to theoretical model calculations.
Baryon number cumulant ratios at finite density in the strong-coupling lattice QCD

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Cumulants of conserved charges contain information of fluctuations across the phase boundary, then can be the signal of criticality of the QCD phase transition. The net-proton number cumulant ratios observed at RHIC show non-monotonic behavior as a function of the incident energy. In order to confirm the conjecture that the non-monotonic behavior could suggest the existence of the QCD critical point, we need calculation of cumulant ratios hopefully in lattice QCD at finite density.

We have recently calculated the cumulant ratios of net baryon numbers at finite density in the chiral limit in the strong-coupling lattice QCD. Fluctuation effects beyond the mean field treatments are included in the auxiliary field Monte-Carlo method. We find that show oscillatory behavior; one negative valley around the phase boundary is sandwiched by two positive peaks as a function of . With increasing lattice size, the negative region is narrowed while the amplitude grows. This behavior may be in agreement with the potential surface argument and the scaling function analysis.

In the presentation, we will briefly introduce the strong-coupling lattice QCD, and show results of higher-order cumulant ratios around the phase boundary. We may also discuss recent developments including effects in the strong-coupling expansion.

On behalf of collaboration:

Anisotropic flow fluctuations in heavy ion collisions at the LHC energy with HYDJET++ model

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The LHC data on elliptic and triangular flow fluctuations from PbPb collisions at center-of-mass energy 2.76 TeV per nucleon pair are analysed and interpreted within the HYDJET++ model. The final state in HYDJET++ represents the superposition of two independent components: the soft state (parametrization of relativistic hydrodynamics with preset freeze-out conditions) and hard state (multi-paron fragmentation taking into account medium-induced partonic energy loss and nuclear shadowing effect). The simple modification of the model via introducing the distribution over spatial anisotropy parameters allows us to reproduce the basic features of anisotropic flow pattern at the LHC including event-by-event flow fluctuations.
**Poster Session** - Board: 0936 / 465

**Initial State fluctuations in ultra-central collisions in an event-by-event transport approach**

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We discuss the generation of anisotropic flows $v_n$ for a fluid at fixed $\eta/s(T)$ by means of an event-by-event transport approach. Such an approach, as shown in [1], recovers the universal features of the ideal hydrodynamics showing an agreement with the recent analytical solutions. We discuss the effect of the $\eta/s$ and its temperature dependence on the build up of the $v_n(p_T)$ revealing that only in ultra-central collisions (0 − 0.2%) the $v_n(p_T)$ have a stronger sensitivity to the $T$ dependence of $\eta/s$ in the QGP phase and this sensitivity increases with the order of the harmonic $n$. Moreover, the study of the correlations between the initial spatial anisotropies $\epsilon_n$ and the final flow coefficients $v_n$ shows that at LHC energies there is more correlation than at RHIC energies. The degree of correlation increases from peripheral to central collisions, but only in ultra-central collisions at LHC, we find that the linear correlation coefficient $C(n,n) \approx 1$ for $n = 2, 3, 4$ and 5. This suggests that the final correlations in the $(v_n,v_m)$ space reflect the initial correlations in the $(\epsilon_n,\epsilon_m)$ space. Moreover the recent event shape engineering (ESE) technique allows to have a new insight into the initial state fluctuations and $\epsilon_n$ correlations [5]. Finally, we discuss in ultra-central collisions the structure of the integrated $(v_n,n)$ plot and its relation with the kinetic freeze out dynamics.


On behalf of collaboration:

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**Poster Session** - Board: 0937 / 517

**ATLAS measurement of the pseudorapidity multiplicity correlation in Pb+Pb collisions**

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ATLAS measurements of the pseudorapidity multiplicity correlation are presented. These correlations are sensitive to the early time dynamics, one of the most poorly constrained stages in the evolution. These measurements suggest sources of fluctuation that seem to be directly related to the forward-backward asymmetry in the initial geometry, and they are important for understanding the correlation of event activities between disconnected rapidity ranges.

On behalf of collaboration:
Posters Session - Board: 0938 / 51

Fluctuations and particle multiplicities in pA collisions

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We argue that large fluctuations of the proton saturation scale are necessary to explain recent ATLAS and ALICE data on pA collisions at the LHC. We first show that, in contrast to the lower energy RHIC data, neither the wounded nucleon model nor the Color Glass Condensate are able to describe slopes of pseudorapidity distributions of charged particles. Next, we argue that non-linear evolution equations used within the CGC framework exhibit fluctuations whose width is growing with the scattering energy. Motivated by this observation we introduce fluctuations into the CGC formalism and find a remarkably good description of the data. We discuss consequences of such fluctuations for the proton cross-section and other observables.

On behalf of collaboration:

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Posters Session - Board: 0939 / 565

Study of fluctuations and correlations within finite volumes in 2+1 flavor Polyakov–Nambu–Jona-Lasinio model

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The hot and dense matter created through the high-energy heavy ion collision experiments possesses a very rich phase structure characterized by the confining and chiral properties. In these experiments, the matter is produced within a finite volume, finiteness of which depends on the size of the colliding nuclei, the centre of mass energy (\(\sqrt{s}\)) and the centrality of collisions. The effect of finiteness of the system sizes have important consequences on the system’s phase structure. Fluctuations and correlations of conserved charges on the other hand are sensitive indicators of the transitions occurring in such strongly interacting systems and are therefore needed to be studied extensively. Here, we intend to present the analysis under the framework of 2+1-flavor Polyakov–Nambu–Jona-Lasinio model with different system sizes revealing important consequences.

On behalf of collaboration:

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Posters Session - Board: 0940 / 540

Non-Markov effect on time evolution of conserved-charge fluctuations in heavy ion collisions

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It is suggested that fluctuations of conserved charges in a given rapidity window contain information on the properties of the QGP created in heavy ion collisions. This is because these fluctuations can relax to the thermal hadronic value only due to charge diffusion in the hadronic stage and cannot change from thermal QGP value immediately. We discuss the non-Markov effects on the time evolution of higher order cumulants of conserved charges for the first time in order to describe diffusion phenomena in heavy ion collisions and to relate the observables to these properties of the QGP in a more realistic way. Specifically, we obtain charge fluctuations with non-Markov effects from the solution of Cattaneo equation and also directly from Langevin equation for phase space and compare both results. In addition, we show that Cattaneo equation is derived from Langevin equation by eliminating the fast variable. We also discuss the non-Markov nature of the rapidity window dependences of charge fluctuations, which are experimental observables in heavy ion collisions, in detail.

On behalf of collaboration:

Poster Session - Board: 0941 / 181

Thermodynamics and fluctuations of conserved charges in a hadron resonance gas model in a finite volume

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The thermodynamics of hot and dense matter created in heavy-ion collision experiments are usually studied as a system of infinite volume. Here we report on the possible effects of considering a finite system size for such matter in the framework of a hadron resonance gas model. The bulk thermodynamic variables as well as the fluctuations of conserved charges are considered. We find that the finite size effects are insignificant once the observables are scaled with the respective volumes. The only substantial effect is found in the fluctuations of electric charge which may therefore be used to extract information about the volume of fireball created in heavy-ion collision experiments.

On behalf of collaboration:

Poster Session - Board: 0942 / 588

Exploring effects of magnetic field on the Hadron Resonance Gas

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We present a study of the effects of magnetic fields on various physical quantities in hadron resonance gas model. We find significant non-trivial dependence of particle ratios on the magnetic field. Depending on the charge and spin, some of the particle ratios are even getting inverted due to the magnetic field. There is also significant changes in the fluctuations of net
baryon number, electric charge and strangeness. This is also reflected in various fluctuation ratios along the freezeout curve.

On behalf of collaboration:

Poster Session - Board: 0944 / 556

Event shape dependent same charge pion femtoscopy in pp collisions at 7 TeV with the ALICE detector

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Particle interferometry in high-energy collisions is a powerful tool for investigating spatio-temporal characteristics of the created system. In femtoscopy, measuring homogeneity radii as a function of pair $k_T$ is of fundamental importance. From numerous investigations it is known that the accessible range in $k_T$ is highly limited in small collision systems due to a steady rise in background correlations, which are associated to the mini-jet collimation effect. In this analysis we propose a novel method of event shape dependent two-particle interferometry with the aim of removing a large portion of the jet-background. By categorizing events by their transverse sphericity ($S_T$) we identify two classes of events, which significantly differ in hardness. Spherical event ($S_T>0.7$) show a strong reduction in background correlations while jet-like ($S_T<0.3$) carry all the characteristics of previously observed background. Here we present extracted homogeneity radii for both categories of events and offer several interpretations for their difference.

On behalf of collaboration:

Poster Session - Board: 0945 / 506

Measurement of the pT-integrated flow harmonics $v_2$-$v_5$ and the elliptic flow of $K_{S0}$ in $\text{Pb}+\text{Pb}$ collisions at $\sqrt{s_{\text{NN}}}=2.76$ TeV with the ATLAS detector

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The measurement of centrality and pseudorapidity dependence of the pT-integrated flow harmonics, $v_2$ up to $v_5$, in Pb+Pb collisions at $\sqrt{s_{\text{NN}}}=2.76$ TeV is presented. The flow harmonics are measured with the standard event plane method and compared to the scalar product method. The measurement is focused on the pT-integrated observables dominated by particles with low transverse momenta ($p_T<2$ GeV) and thus sensitive to the hydrodynamic response of the medium to the fluctuating initial conditions. The full potential of the ATLAS detector inner tracker is exploited, including charged particle track reconstruction at very low transverse momentum ($p_T>100$ MeV). To reduce uncertainties due to low efficiency and high fake rate, affecting especially particles with lowest transverse momenta, a unique data set of Pb+Pb collisions recorded with the solenoid magnet switched off is also used. A simplified tracking is performed to reconstruct two-point pixel tracklets with estimated minimum $p_T$ as low as 70 MeV. The event plane and scalar product methods are also used to measure $v_2$ of $K_{S0}$. The topological reconstruction of the $K_{S0} \rightarrow \pi^+\pi^-$ decay in the ATLAS inner detector is used to measure $K_{S0}$ elliptic flow in a wide range of transverse momentum and in the central rapidity region ($|y|<1$) as a function of collision centrality.

On behalf of collaboration:
Statistical errors, efficiency and acceptance corrections in cumulants of measured net-charge \((N^+ - N^-)\) distributions, a theorem from Quantitative Finance and NBD fits to the PHENIX \(\{N^+\text{ and } N^-\}\) distributions.

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Total charged multiplicity distributions, \(P(N = N^+ + N^-)\), in p+p collisions and A+A collisions cut on centrality are well fit by Negative Binomial Distributions (NBD). Recently it was found that the individual \(P(N^+)\) and \(P(N^-)\) distributions in PHENIX are also well fit by NBD. A theorem from Quantitative Finance states that for integer valued Levy processes such as the difference between two Poisson or two Negative Binomial Distributions, the cumulants \(\kappa_j\) of \(P(N^+ - N^-)\), the difference of samples from two such distributions, \(P(N^+)\) and \(P(N^-)\) which are both Poisson or NBD, with cumulants \(\kappa_j^+\) and \(\kappa_j^-\) respectively, is the same as if the \(P(N^+)\) and \(P(N^-)\) were statistically independent, i.e. \(\kappa_j = \kappa_j^+ + (-1)^j\kappa_j^-\), so long as the distributions are not 100\% correlated. This was tested and verified with the PHENIX measurements of \(P(N^+ - N^-)\), \(P(N^+)\) and \(P(N^-)\) from central (0-5\%) Au+Au collisions at \(\sqrt{s_{NN}}\) from 7.7 to 200 GeV, leading to simplified calculations of the measured “raw” cumulants, their statistical errors and the Binomial efficiency corrections. Applications to acceptance corrections, which are complicated by correlations in both \(\delta\eta\) and \(\delta\phi\), will also be presented.

On behalf of collaboration:

Investigations for transition regime apparition in nuclear matter through the study of cumulative particles production in relativistic nuclear collisions using the CBM experiment at FAIR-GSI

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The CBM (Compressed Baryonic Matter) Experiment is one of the major experiments at the future Facility for Antiproton and Ion Research (FAIR) from GSI Darmstadt (Germany). In this experiment will be studied nucleus-nucleus collisions at energies lower than those at RHIC-BNL (USA) and LHC CERN (Switzerland) colliders, at lower temperatures, but
at baryonic densities estimated at the highest attended up to now. The main goal of this experiment - currently under construction - is the exploration of the phase diagram of nuclear matter, in the energy range from 2 A GeV up to 45 A GeV [1]. Therefore, one of the objectives of the collaboration is to provide highlights on the transition regime in the nuclear matter thus formed [2]. A possible way could be related to cumulative particles production [3,4]. Using YaPT system [5-7], simulations with field specific codes (UrQMD, AMPT, HIJING), as well as one’s own code based on specific chaos theory assumptions [8,9], at energies between 2 A GeV and 25 A GeV, specific for SIS-100 accelerator, for Au -Au collisions, have been done. The estimations of the cumulative numbers, as well as the models for complex parton systems formation - which allow production of particles with anomalous kinematics from nucleon-nucleon collision kinematics - can offer interesting information on nuclear matter, as well as on the formation of this phase in these collisions at SIS-100 available energies.

On behalf of collaboration:

Poster Session - Board: 0948 / 259

Systematic searches for the chiral magnetic effect and chiral vortical effect using identified particles at RHIC/STAR

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QCD allows for chirality imbalance as a consequence of the vacuum transition[1]. When coupled with the strong magnetic field produced in heavy-ion collisions, the chirality imbalance in local domains can lead to electric charge separation along the magnetic field direction, manifested as the chiral magnetic effect (CME). Recently, an analogous effect, the chiral vortical effect(CVE) [2] was also theorized, in which the vorticity of the collision system replaces the magnetic field, and a baryonic charge separation appears instead of the electric charge separation. This would result in a distinct hierarchy in the particle dependent correlation magnitudes: proton – \( K_0^* \) (no CME/CVE), proton – \( \pi^\pm \) (CME only), proton – \( \Lambda \) (dominated by CVE), and proton – proton (both CME and CVE). In order to explore this physics, we report correlation measurements for these identified particle pairs in Au+Au at 200GeV with the STAR detector. The physics backgrounds due to collective flow[3] and resonance decays are evaluated.

In addition, the measurements to search for the chiral magnetic effect and the chiral magnetic wave will also be presented for Au+Au at 14.5 GeV, which completes the Phase I of the Beam Energy Scan at RHIC.


On behalf of collaboration:

Event by event multiplicity fluctuations in the statistical model

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Thermal fluctuations are important baselines in search of the critical point for the RHIC beam energy scan program. In this work, we prove that the traditional Poisson distributions in the statistical model are translated into the negative-binomial-like distributions in the event-by-event measurements. With the modified multiplicity distributions, we suggest how to
construct the basic statistical expectations for the high moments of multiplicity distributions in experiment. Meanwhile, we also calculate the approximate solutions of these high moments and show that this solution can qualitatively or quantitatively describe most of the observables related to multiplicity fluctuations (e.g., the scale variance, the mean value saturation and variance decreasing in most central collisions, the centrality resolution effect, et. al.)

On behalf of collaboration:

**Poster Session** - Board: 0950 / 353

**The beam energy dependence of HBT correlation radii from a blast-wave model**

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The ultra-relativistic heavy ion collisions aim at forming the quark-gluon plasma (QGP) and presenting properties of QGP phase transition. The fireball created in the ultra-relativistic heavy ion collisions will reach kinetic freeze-out stage from the initial ultra-hot-dense state. The temperature, system size and lifetime, and expansion velocity at radial direction may inherit some properties of the QGP phase transition. HBT correlation function can provides the system evolution information, such as system size parameters, system lifetime. By fitting the HBT correlation radii in the blast-wave model, the system size and lifetime are presented with the kinetic temperature and radial flow extracted from transverse momentum distribution measured in experiments. The beam-energy dependence of HBT radii significantly depends on the range of the system size parameter and system lifetime. And we also find the blast-wave can describe transverse momentum dependence of HBT correlation radii (Rside, Rout and Rlong) at LHC energy with same fixed parameters but it failed to fit Rlong while fitting Rside and Rout successfully at RHIC top energy with the same fixed parameters. This implies the different evolution mechanism for LHC and RHIC energy and suggests a long system lifetime for the fireball created at LHC energy.

On behalf of collaboration:

**Poster Session** - Board: 0951 / 402

**Torque effect and long-range rapidity fluctuations**

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We investigate the torque effect (decorrelation of event planes in rapidity) [1,2] and find that the recent CMS results for p+Pb and Pb+Pb collisions suggest specific fluctuations of the initially deposited entropy. In our model, the extent in rapidity of the initial sources is randomly distributed over the available range. These fluctuations increase the event-plane decorrelation: for Pb+Pb they bring the results closer to the data, while for p+Pb collisions they are essential to generate sizable decorrelation.

We also make predictions of the torque effect for the collisions of Au+Au and Cu+Au at RHIC energies, which may be used as baseline for future experiments.


On behalf of collaboration:

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**Poster Session** - Board: 1001 / 126

**FRG Approach to Nuclear Matter in Compact Stars**

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Functional renormalization group (FRG) is an exact method for taking into account the effect of quantum fluctuations in the effective action of the system. The FRG method applied to effective theories of nuclear matter yields equation of state which incorporates quantum fluctuations of the fields. Using the local potential approximation the equation of state for Walecka-type models of nuclear matter under extreme conditions is determined. These models are tested by solving the corresponding Tollman-Oppenheimer-Volkov (TOV) equations and investigating the properties (mass and radius) of the corresponding compact star models.

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**Poster Session** - Board: 1003 / 135

**Compact Stars with a Dyson-Schwinger Quark Model**

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Based on a Dyson-Schwinger quark model with various choices of the quark-gluon vertex and gluon propagator, we study the equation of states of cold dense quark matter and the interior structure of compact stars. For the hybrid quark stars, we combined with a hadronic equation of state derived within the Brueckner-Hartree-Fock many-body theory. We found possible results of 2-solar-mass hybrid stars. We also investigate possibilities of strange quark stars with the quark model and study some effects of rotation on compact stars.

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**Poster Session** - Board: 1004 / 667

**Effects of phase transition induced density fluctuations on pulsar dynamics**

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Density fluctuations during phase transitions in pulsar cores may have non-trivial effects on pulsar timings, and may also possibly account for glitches and anti-glitches. These density fluctuations invariably lead to non-zero off-diagonal components of the moment of inertia,
leading to transient wobbling of star. Thus, accurate measurements of pulsar timing and intensity modulations (from wobbling) may be used to identify the specific pattern of density fluctuations, hence the particular phase transition, occurring inside the pulsar core. Changes in quadrupole moment from rapidly evolving density fluctuations during the transition, with very short time scales, may provide a new source for gravitational waves.

On behalf of collaboration:

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Poster Session - Board: 1005 / 409

LHCf experiment; astrophysics connection of high-energy nucleus collisions

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Ultrarelativistic nucleus-nucleus collisions take place not only in the particle accelerators but also in the earth’s atmosphere, namely cosmic rays interacting with the atmospheric molecules. Majority of cosmic-ray nuclei is known to vary from proton to iron, and their target in the atmosphere is light nuclei such as nitrogen and oxygen. To study the high-energy cosmic rays with low flux, atmospheric air showers are observed instead of primary particles. To interpret the air shower observation to the properties of primary particles, the knowledge of the high-energy interaction is indispensable. The Large Hadron Collider forward (LHCf) experiment was designed to study the particle production at LHC. Though the ultimate target of the experiment is the ultrarelativistic nucleus collisions, LHCf has so far measured precise cross sections in the LHC proton-proton collisions. LHCf has measured particle production at pseudo-rapidity >8.4, where the secondary particles carry a large fraction of collisions energy, with the LHC sqrt(s)=0.9, 2.76, 7 and 13 TeV proton-proton collisions. To study the nuclear effect at an extreme condition, measurements with the sqrt(s_NN)=5 TeV proton-lead collisions were also performed. The observed production cross sections of pi^0’s and neutrons, nuclear effect of the pi^0 production in p-Pb collisions are so far well explained by the major interaction models used in the cosmic-ray physics. These data are important inputs to estimate the nuclear interaction in the atmosphere. In this talk, we will present the general introduction to the LHCf experiment together with the experimental results. Some ideas of the next experiment including the measurements at RHIC are also presented.

On behalf of collaboration:

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Poster Session - Board: 1006 / 79

Cosmic Phase Transition- a hint of Cold Dark Matter in the Standard model

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Witten1 and others2 have argued that “small” supercooling leading to “little inflation” was the reality at the primordial era of cosmic phase transition from quarks to hadrons. This will necessarily shift the direction of the phase transition from a “cross over” to a first order phase transition. Strange quark nuggets (SQM) with baryon number of ~ 10^{34} as relics of this phase transition will survive2 the entire cosmic time scale upto now. The presentation will demonstrate the SQM’s can be the most plausible candidate of cold dark matter discovered around 1996. The “MACHO” observations and the recent observations of strangelets of Bose Institute (Kolkata) seem to corroborate the just mentioned concept. This is quite natural
within the ambit of the standard model; exotica like axioms even WIMPS, not observed, do not have to be invoked.


On behalf of collaboration:

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**Poster Session** - Board: 1007 / 650

**MC study of proton-Nitrogen collisions at RHIC for cosmic-ray physics**

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To understand the origin of high-energy cosmic rays, many experiments were carried at ground level, thereby observing air showers. Many measurements confirm a steepening and a flattening of the all-particle spectrum at $10^{15.5}$ and $10^{18.5}$ eV, that are called ‘knee’ and ‘ankle’, respectively. Both are considered to be the indices of change in propagation or origin of cosmic rays. Despite the high statistics, interpretation of the results depend strongly on the hadronic interaction model used in the Monte Carlo calculation which has larger uncertainties than the statistical errors. Chemical composition of cosmic ray (from proton to iron nucleus) is one interest of astroparticle physics, but results are not settled yet. Calibration of interaction models is an urgent need for air shower measurements. LHCf experiment has measured data of the forward region in proton-proton collision at $\sqrt{s} = 0.9$, 7 and 13 TeV and proton-lead collision at $\sqrt{s_{NN}} = 5.02$ TeV at LHC. Nuclear effect must be well understood, since air shower consists of interactions between cosmic ray (proton to iron nucleus) and the atmosphere (mainly nitrogen); lead and gold are too heavy target. Unfortunately, no high energy collision of light ion has been provided. RHIC and LHC are good candidates that can provide such collisions. We focus on the result expected with proton-nitrogen inelastic collision at $\sqrt{s_{NN}} = 200$ GeV ($10^{14}$ eV in lab frame) where we use the LHCf detector in the forward region ($\eta > 6$) of the proton-remnant side at RHIC. We compare the energy spectrum with that of proton-proton inelastic collision at $\sqrt{s}=200$ GeV to evaluate the nuclear effect. A MC calculation shows that it is possible to discriminate nuclear effect incorporated in some models widely used in air shower measurements and demonstrates that it can be the first good test to evaluate air shower.

On behalf of collaboration:

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**Poster Session** - Board: 1008 / 49

**On the effect of the Bose-Einstein condensed dark matter for the magnetic field in neutron stars**

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Nature of dark matter (DM) is not known in both particle physics and astrophysics perspectives. Recently, there are lots of arguments to give some constraints on the physical quantities of DM by using neutron stars (NSs) when it is assumed to be weakly interacting massive particle (WIMP). If DM is the WIMP, there exists a finite DM-nucleon cross section, which may result in DM capture in NSs. Once DM is captured, it could have various sizable effects on NSs. So from the NS observations, one can provide some constraints on DM properties such as the mass and the cross sections. Here we propose some new effect. If DM is a boson, it might be able to form a Bose-Einstein condensate (BEC). In this presentation, we discuss a possibility that such a BEC state of DM can influence the magnetic field or the magnetic field formation of NSs.

On behalf of collaboration:

Poster Session - Board: 1009 / 424

Spontaneous magnetization of quark matter in the inhomogeneous chiral phase

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Recently, a possible appearance of the inhomogeneous chiral phase has been extensively studied by the use of the effective models of QCD like the NJL models. Here, we study the magnetic properties of the inhomogeneous chiral phase, taking the contribution of “dual chiral density wave (DCDW)”[1] where both scalar and pseudoscalar condensates are spatially modulated. We study the response of quark matter to a tiny external magnetic field to show the spontaneous magnetization in the DCDW phase. In an external magnetic field, the energy spectrum of quarks becomes asymmetric about zero in the lowest Landau level [2], and it gives rise to chiral anomaly [3]. We find that this spectral asymmetry also gives rise to the spontaneous magnetization, since a new term linearly proportional to the magnetic field is induced in the thermodynamic potential. Furthermore, this spontaneous magnetization includes not only the contribution of chiral anomaly [1] but also one of valence quarks. Such spontaneous magnetization might be a candidate of the origin of the strong magnetic field in neutron stars. We also show the peculiar behavior of magnetic susceptibility at the ferromagnetic transition point: it never diverges unlike the usual ferromagnetic transition, which suggested a different mechanism of spontaneous magnetization from spin alignment.

References

On behalf of collaboration:

Poster Session - Board: 1101 / 468

Universality of multiplicity distribution in proton-proton and electron-positron collisions

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I show that the charged particle multiplicity distribution in proton-proton (p+p) collisions, which is often parameterized by the negative binomial distribution, results from the multiplicity distribution measured in electron-positron collisions, once the fluctuating energy carried by two leading protons in p+p is taken into account. It is suggestive of a universal mechanism of particle production in both systems, controlled mainly by the actual energy deposited into particle creation. Its consequences for p+A and A+A physics will be discussed.


**On behalf of collaboration:**

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**Poster Session - Board: 1102 / 454**

**The mixing effects of scalar mesons in a Skyrme model**

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We study the effects of light scalar mesons on the Skyrmion properties by first constructing a mesonic model including pion, rho and omega mesons as well as a two-quark and a four-quark scalar states. In our model, the physical scalar mesons are defined as mixing states of the two- and four-quark states. We find that the scalar mesons reduce the Skyrmion mass as expected and the lighter scalar meson is, the smaller soliton mass and larger soliton size become.

**On behalf of collaboration:**

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**Poster Session - Board: 1103 / 339**

**Dynamic critical behavior for the relativistic O(N) model in the framework of the real-time functional renormalization group and applications to QCD**

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We investigate the transition from unitary to dissipative dynamics in the relativistic $O(N)$ model with a $\lambda(\varphi^2)^2$ interaction using the nonperturbative functional renormalization group in the real-time formalism. We quantify the dynamic properties of the model in $2 \leq d \leq 4$ dimensions in terms of the scale-dependent dynamic critical exponent $z$, which controls the phenomenon of critical slowing down - with an important effect: For QCD it characterizes the maximal achievable correlation length in the process of the rapid cooling of the quark-gluon plasma through the critical region and thereby sets the typical strength of event-by-event fluctuations in heavy ion collisions probed at RHIC or the LHC. We provide an outlook on what one may conclude from low-energy effective models as the $O(N)$ theory for the dynamics of fluctuations close to the chiral phase transition in the phase diagram of QCD.

**On behalf of collaboration:**
Particle spectra measurements and Tsallis thermodynamics at LHC energies

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The identified and charged particle spectra have been measured in p-p and p-Pb collisions at LHC energies. A thermodynamically consistent form of the Tsallis distribution at $y = 0$ has been used for fitting the transverse momentum spectra $d^2N/dp_Tdy$ and to evaluate the particle yields. The Tsallis distribution described the $p_T$ spectra very well. The values of $dN/dy|_{y=0}$ obtained from the Tsallis distribution are in agreement with the values measured by the LHC experiments. The centre-of-mass energy dependence of $dN/dy|_{y=0}$ and data to fit ratio will be presented and discussed.

On behalf of collaboration:

Reaction-diffusion equation for quark-hadron transition in heavy-ion collisions

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Reaction-diffusion equations with suitable boundary conditions have special propagating solutions which very closely resemble the moving interfaces in a first order transition. We show that the dynamics of chiral order parameter for chiral symmetry breaking transition in heavy-ion collisions, with dissipative dynamics, is governed by one such equation, specifically, the Newell-Whitehead equation. Further, required boundary conditions are automatically satisfied due to the geometry of the collision. The chiral transition is, therefore, completed by a propagating interface, exactly as for a first order transition, even though the transition actually is a crossover for relativistic heavy-ion collisions. Same thing also happens when we consider the initial confinement-deconfinement transition with Polyakov loop order parameter. The resulting equation, again with dissipative dynamics, can then be identified with the reaction-diffusion equation known as the Fitzhugh-Nagumo equation which is used in population genetics. We discuss the implications of these results for heavy-ion collisions. We also discuss possible extensions for the case of early universe.

On behalf of collaboration:

Hydrodynamics, all orders gradient expansion and beyond

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Hydrodynamic gradient expansions are in general divergent series. As a typical property of nonlinear systems, the late terms of the series grow factorially and in order to have a well-defined answer, the usual hydrodynamic gradient expansion is required to be supplemented by an infinite tower of exponentially damped terms which are non-hydrodynamic modes. In this work we analyze in a concrete way such an enhanced gradient expansion for a plasma that undergoes a boost invariant expansion. We show that, remarkably, the usual hydrodynamic gradient expansion carries information about the non-hydrodynamic modes. Moreover different non-hydrodynamic modes are also interrelated in a similar fashion. We explain precisely how to extract that information and also discuss various resummation techniques that can be useful to improve the accuracy numerical computations.

On behalf of collaboration:

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**Poster Session** - Board: 1204 / 332

**Soft pion production signals of new phenomena at the LHC**

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The LHC data on hadron production, transverse-momentum spectra, and particle correlations in Pb+Pb collisions demonstrate a peculiar behavior [1,2], which can be interpreted as a coherent emission of pions with low momenta [2-5]. It can be a consequence of the prior gluon condensation [6,7], or the overcooling of the quark-gluon plasma deeply into the hadronic phase [8]. In both cases a possible consequence is the formation of the Bose-Einstein condensate (BEC) of pions at the freeze-out. The presence of the condensate decreases the non-equilibrium parameters [5], and therefore improves the agreement of the non-equilibrium thermal model with the data for heavy nuclei. The combined analysis of the hadronic multiplicities and the pion transverse momentum spectra indicates that about 5% of pions at each centrality of the collision could be in the condensate [5]. The data on two- and three-pion correlations support even larger coherent fraction of 23% [2]. This could be the consequence of the fact that correlations are much more sensitive observables [9]. The correlated pions have a momentum below 150-200 MeV [5,8]. It is on the edge of the current acceptance range of the LHC [1,8]. Therefore some efforts are required in order to clarify whether the BEC of pions is reached. However, if the BEC of pions is formed, then its temperature is 10^10 times higher than the temperature of the famous BEC of ultra-cold atoms. There are also much higher densities, smaller volumes and different interaction forces involved. The studies of the properties of the high temperature pion condensate could open a wide new field of research, similar to the studies of the BEC of ultra-cold atoms. This talk is proposed to bring the attention of the heavy-ion community to this interesting and promising opportunity.

On behalf of collaboration:

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**Poster Session** - Board: 1206 / 472

**A Holographic Description of 3-jet Events in Strongly Coupled Plasma**

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We numerically simulate classical falling string configuration with non-trivial transverse dynamics in thermal AdS 5. These strings develop kink-like structures which, in the dual
theory, can be interpreted as the propagation of hard gluons produced in association with a quark anti-quark pair. We observe the appearance of two physically distinct regimes of the in-plasma dynamics depending on whether the medium is able to resolve the transverse structure of the string prior its total quench. From these regimes we extract the transverse resolution scale of the strongly coupled plasma of N=4 SYM and confront it with perturbative results.

On behalf of collaboration:

Poster Session - Board: 1207 / 41

CP violation in $B^0$ and $\bar{B}^0$ decay and the flavor-tagged $\Delta t$ distributions

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The BABAR experiment shows that the flavor-tagged $\Delta t$ distribution of $B^0 \to J/\Psi K^0_L$ agrees with the theoretical prediction, but that of $\bar{B}^0 \to J/\Psi K^0_L$ shows discrepancy at large $|\Delta t|$ region[1]. The difference could appear from the presence of tree diagrams of $B^0 \to K^0_L J/\Psi$ but absence corresponding tree diagram of $\bar{B}^0 \to K^0_L J/\Psi$, in the Cartan’s supersymmetry[2]. The tree diagram could contain retarded time effect before $J/\Psi$ creation during propagation of the W boson. The model can be extended to the decay of $B^0 \to K^+ \pi^-$ and $\bar{B}^0 \to K^- \pi^+$[3], and $B^0 \to D^{*-} X \ell^+ \nu$[4]. The $Z_3$ symmetry of leptons and quarks[5] suggests that CP violation effects in the $B^0 \to D^{*-} X \ell^+ \nu$ cannot be detected by our electromagnetic detectors. Possibility of detecting the retarded time effect by rapidly moving the detector[6] will be discussed.

2 S.Furui, Cartan’s Supersymmetry and the violation of the CP symmetry, arXiv:1505.05830
6 M.Bitbol, l’erreur d’Einstein, La recherche 418, (2008) p.31

On behalf of collaboration:

Poster Session - Board: 1208 / 591

Quantum corrections to the stress-energy tensor in thermodynamic equilibrium with acceleration

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We show that the stress-energy tensor has additional terms with respect to the ideal form in states of global thermodynamic equilibrium in flat spacetime with non-vanishing acceleration and vorticity. These corrections are of quantum origin and their leading terms are of second order in the gradients of the thermodynamic fields. The relevant coefficients can be expressed in terms of correlators of the stress-energy tensor operator and the generators of the Lorentz group. With respect to previous assessments, we find that there are more second order...
coefficients and that all thermodynamic functions including energy density receive acceleration and vorticity dependent corrections. Notably, also the relation between ρ and p, that is the equation of state, is affected by acceleration and vorticity. We have calculated the corrections for a free real scalar field – both massive and massless – and we have found that they increase, particularly for a massive field, at very high acceleration and vorticity and very low temperature. Finally, these non-ideal terms depend on the explicit form of the stress-energy operator, meaning that different stress-energy tensor of the scalar field – canonical or improved – are thermodynamically inequivalent.

On behalf of collaboration:

Poster Session - Board: 1209 / 607

Chiral magnetohydrodynamics from quantum field theory

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Hydrodynamics is a low-energy effective theory which describes a long-distance and long-time behavior of many-body systems. It has been recently pointed out that quantum anomalies affect macroscopic transport properties and generate novel anomaly-induced transports. One example is the chiral magnetic effect, which represents the existence of a dissipationless vector current along the magnetic field and is expected to occur in heavy-ion collisions.

For the description of the anomaly-induced transport in the QGP, we have established formalism, so-called anomalous hydrodynamics, that captures effects of quantum anomalies. Since the QGP consists of electrically charged particles, it is necessary to consider a back reaction to electromagnetic fields in order to describe the space-time evolution of them together with that of the QGP. However, in the conventional anomalous hydrodynamics, electromagnetic fields are treated as external ones and the back reaction is neglected. Moreover, the magnitude of magnetic fields is assumed to be small. Therefore, we need to construct chiral magnetohydrodynamics in the strong magnetic field in order to assess the contribution from anomalous transports.

In this study, considering the recent development of non-equilibrium statistical mechanics, we derive the chiral magnetohydrodynamics under strong magnetic fields from the underlying microscopic theory, that is, the quantum field theory. In order to derive the chiral magnetohydrodynamic equation, we use a solid basis in our previous study on the derivation of the first-order hydrodynamics [1], in which we assume that the local Gibbs distribution is realized at initial time. As a result, we derive the chiral magnetohydrodynamic equation with the the field theoretical expression of Green-Kubo formulas for the all transport coefficients.

References:

On behalf of collaboration:

Poster Session - Board: 1210 / 8

Chiral Electric Separation Effect

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An applied magnetic field can induce electric current and axial current in chiral-imbalanced medium. These are the famous chiral magnetic and chiral separation effect. We show that there is one additional anomalous current in chiral-imbalanced medium, namely, an axial current induced by an applied electric field. This can be called chiral electric separation effect (CESE). We will discuss its origin and possible implications in heavy-ion collisions.

**Poster Session - Board: 1211 / 149**

**Chiral vortical wave and induced flavor charge transport in a rotating quark-gluon plasma**

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In this talk we report our recent finding of a new gapless collective excitation in a rotating fluid system with chiral fermions, named as the Chiral Vortical Wave (CVW). The CVW has its microscopic origin at the quantum anomaly and macroscopically arises from interplay between vector and axial charge fluctuations induced by chiral vortical effects. An intuitive picture for the underlying mechanism of CVW will be provided, and the CVW wave equation will be derived both from anomalous hydrodynamic current equations and from chiral kinetic theory framework. The solutions of such wave equation show nontrivial CVW-induced charge transport from various initial conditions, which could give rise to observable signals. Using the rotating quark-gluon plasma in heavy ion collisions as a concrete example, we demonstrate the formation of induced flavor quadrupole in QGP and estimate the elliptic flow splitting effect for Lambda baryons that may be experimentally measured. [arXiv:1504.03201, submitted to PRL]

**On behalf of collaboration:**

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**Poster Session - Board: 1212 / 470**

**Heavy meson mass spectrum at finite temperature based on AdS/CFT**

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In heavy-ion collisions, the medium experiences hard and soft scatterings as it expands and a temperature cools down. Therefore the temperature of the medium plays a key role for getting the dynamical information of the medium, such as the energy/momentum distributions of emitting hadrons. Existing meson types at each stage can provide the temperature information of the medium since each meson has its own melting temperature. These temperatures can be estimated from their masses at those temperatures but the only experimental information is given at zero temperature. At non-zero temperatures, there are several models to estimate the meson masses, where the temperature-dependence of quark-quark interactions is necessary.
Most calculations use the free energies from Lattice results or their modifications, for this input. Recently, AdS/CFT offered the temperature-dependent potentials between quarks by introducing infrared cutoff on the AdS Schwarzschild space, which inhibit the two characteristic features, confinement at long ranges and asymptotic freedom at small ranges. We adopted these temperature-dependences on our model potential, which is composed of a screened Coulomb-type strong potential plus a Coulomb potential as a vector potential and the linear plus constant potential as a scalar potential. Here the temperature dependence of the screening radius and tangent of the linear potential is determined based on AdS/CFT. For two quark system, we used the Dirac’s constraint dynamics to get the Schrodinger-type equations with all dynamical and spin-dependent terms expressed by our model potential. In this presentation, we calculated the meson mass spectrum, especially for quarkonia and B_{c} meson. Heavy meson masses are almost constant for T=0-0.4T_{c} but decrease after 0.4T_{c} as temperatures increase up to 1.4T_{c}, especially linearly after T=T_{c}. Our results are consistent with others based on the Lattice calculation.

On behalf of collaboration:

Poster Session - Board: 1213 / 197

Stationary fluctuation theorem in high-energy nuclear collisions

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The QGP created at RHIC and LHC behaves like a perfect fluid, which suggests it reaches thermal equilibrium state. Stability of thermal equilibrium state is a consequence of an interplay between thermal fluctuation and dissipation. On the other hand, only dissipation has been taken into account in event-by-event hydrodynamic simulations for the past years. In addition to dissipation, thermal fluctuations during hydrodynamic evolution (a.k.a., hydrodynamic fluctuation) must be taken into account to consistently describe the dynamics of the QGP. To study this, causal fluctuating hydrodynamics was formulated [1] and implemented in numerical hydrodynamic simulations recently [2].

In this study, we apply this framework to the (0+1)-dimensional Bjorken expansion and show that, under some limited conditions, the dynamics of the QGP satisfies “stationary fluctuation theorem” [3] which was established in non-equilibrium statistical physics. Through this theorem, we focus on the entropy fluctuation and claim that the thermal fluctuation becomes more important in the smaller systems such as p-A and peripheral A-A collisions. We further investigate the effects of finite relaxation time in causal hydrodynamics and find it significantly affects the final entropy distribution. This suggests we have an opportunity to extract some information about relaxation time from final observables on multiplicity.


On behalf of collaboration:

Poster Session - Board: 1215 / 114

QCD $\theta$-vacua from the chiral limit to the quenched limit

MAMEDA, Kazuya¹
We investigate the dependence of the QCD vacuum structure on the $\theta$-angle and quark mass, using the Di-Vecchia–Veneziano model. Although the Di-Vecchia–Veneziano model is a chiral effective model, it contains the topological properties of the pure Yang–Mills theory. It is shown that within this model, the ground state energies for all $\theta$ are continuous functions of quark mass from the chiral limit to the quenched limit, even including the first order phase transition at $\theta = \pi$. Based on this effective model, we discuss (i) how the ground state depends on quark mass, and (ii) why the phase transition at $\theta = \pi$ is present in both the chiral and the quenched limit. In order to analyze the relation between quark mass and the $\theta$-vacua, we calculate the chiral condensate as a function of quark mass. Also, considering the presence of the innate metastable states included in the QCD $\theta$-vacuum, we also give a unified understanding of the phase transitions at $\theta = \pi$ in the chiral and quenched limit.

On behalf of collaboration:

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Poster Session - Board: 1216 / 576

Real time simulation of the Chiral Magnetic Effect

MORALES, Pablo

How do flavor degrees of freedom emerge in the quark-gluon plasma formed at heavy ion collisions is a challenging open question for both experiment and theory. In this work as a mean to approach this problem we study fermion production under a background electromagnetic field at real time. Using a simple enough time profile for such external electromagnetic field, allows us to define a proper Bogoliubov transformation between in and out states. In this way, we take on the problem of fermion production by numerically evolving the wave functions in real time and computing the proper observables, we obtained the net currents produced. In particular, the chiral magnetic effect is simulated considering finite parallel electric and magnetic components, exploring thus, its CP-odd domain. The net electric current produced by the chiral magnetic effect is computed for different values of the fermion mass in order to replicate the damping expected by the theory.

On behalf of collaboration:

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Poster Session - Board: 1218 / 705

A calculation of transport coefficients in 2-nd order hydrodynamics

Dr. MUROYA, Shin

Based on the Nakajima-Zubarev type non-equilibrium density operator, we derive a 2-nd order hydrodynamic equation. Microscopic Kubo-formulas for all coefficients in the equation are systematically obtained. Coefficients $\beta_i$ and $\alpha_i$ in the Israel-Stewart equation are given as current-weighted correlation lengths which are to be calculated in statistical mechanics. We also numerically evaluate the coefficients by using a hadro-molecular simulation and discuss the temperature dependences and the baryon number density dependences.

On behalf of collaboration:
**Poster Session** - Board: 1219 / 112

**Is there dark radiation accompanying QGP Hadronization?**

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The deconfined quark-gluon plasma has color and chiral symmetries. At hadron level pions express the breaking of chiral symmetry, color gauge symmetry is invisible – SU(3) c is broken at boundary between deconfined and confined domains. Goldstone Bosons associated with a weak symmetry breaking are of extreme low mass and therefore today are invisible to lattice-QCD. It turns out that such very light particles introduced besides neutrinos, and photons, into the cosmic background\footnote{J. Birrell, J.Rafelski: Quark-Gluon Plasma as the Possible Source of Cosmological Dark Radiation, Phys. Lett. B {\bf 741}, 77, (2015)} are also nearly invisible. In this lecture we present a) the impact of darkness produced in cosmological QGP hadronization on cosmological evolution; b) strategies how presence of such ‘darkness’ can be recognized in RHI collisions in study of energy balance and matter flow, and c) we argue that presence of darkness can sharpen the hadronization criterion of QGP as function of temperature and density.

On behalf of collaboration:

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**Poster Session** - Board: 1220 / 130

**Vortical structures and strange hyperon polarization in heavy-ion collisions**

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We study vorticity and hydrodynamic helicity in semi-peripheral heavy-ion collisions using the kinetic model of Quark-Gluon Strings. The angular momentum, which is a source of P-odd observables, is preserved with a good accuracy. We observe formation of the specific toroidal structures of the vorticity field. Their existence, accompanied by the strange chemical potential, is mirrored in the polarization of hyperons of the percent order.

On behalf of collaboration:

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**Poster Session** - Board: 1221 / 643

**Lefschetz-thimble method for evading the mean-field sign problem**

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Lefschetz-thimble method is a recently developing tool to evaluate the path integral with the sign problem. In the case of finite-density QCD and its effective models, the fermion sign
problem causes some illness even within the mean-field approximation. We showed that the 
sign problem appearing in the mean-field approximation can be completely solved by applying 
this technique. We will consider its application to the heavy-dense quark system in order to 
demonstrate its usefulness.

On behalf of collaboration:


Poster Session - Board: 1222 / 1

Is the ideal fluid limit stable against microscopic perturbations?

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We discuss the zero-viscosity limit of fluid dynamics in the presence of microscopic thermal 
fluctuations. The interplay between these fluctuations and the generally non-linear evolution 
of fluid flow makes the existence of a well-defined hydrostatic limit ambiguous. We investigate 
these issues taking microscopic thermal perturbations into account non-perturbatively via 
lattice field theory techniques, where their effect is absorbed into the functional integral. 
We find intriguing evidence, that the vacuum of such a theory is non-trivial, casting doubts 
on whether the gradient expansion can provide a good effective field theory for this type of 
system. The non-trivial vacuum looks like a “turbulent” state where some of the entropy is 
carried by macroscopic degrees of freedom. We describe further steps to strengthen or falsify 
this evidence, and conclude with a discussion of the role of these issues in the “perfect fluid” 
phenomenology of heavy ion collisions.

Based on http://arxiv.org/abs/1502.05421

On behalf of collaboration:


Poster Session - Board: 1223 / 568

Polyakov–Nambu–Jona-Lasinio model:: Revisited

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QCD-inspired non-perturbative models provide an effective approach to study strongly interacting matter at high temperature and/or high density. The simultaneous onset of confinement and chiral symmetry-breaking phenomena in lattice QCD (LQCD) simulations inspired their coupling in effective models. The Polyakov-Nambu-Jona-Lasinio or the PNJL model is one such QCD-inspired non-perturbative model. The physics reflected from the behavior of thermodynamic observables extracted from this model, gives an insight into QCD. LQCD results have been recently obtained in the continuum limit which consequently lowers the transition temperature. This motivates us to modify the effective potential in the PNJL model. Analysis of important thermodynamic observables with this potential encouragingly show a similarity
on comparison to LQCD continuum data. We use this modified potential to sketch the phase diagram.

On behalf of collaboration:

Poster Session - Board: 1224 / 6

Chiral magnetic effect and Berry phase through quantum kinetic approach

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We derive a relativistic chiral kinetic equation with manifest Lorentz covariance from Wigner functions. It contains vorticity terms and a four-dimensional Euclidean Berry monopole which gives an axial anomaly. This provides a unified interpretation of the chiral magnetic and vortical effects, chiral anomaly, Berry curvature, and the Berry monopole in the framework of Wigner functions.

On behalf of collaboration:

Poster Session - Board: 1225 / 16

Chiral Hall Effect and Chiral Electric Waves in Strongly Coupled Plasmas

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The electromagnetic-field-induced transport related to the axial chemical potential may play an important role in many chiral systems such as the quark gluon plasma (QGP) created in relativistic heavy ion collisions. It has been found that the presence of both a vector and an axial chemical potential could induce an axial current parallel to the applied electric field known as the chiral electric separation effect (CESE), where the axial conductivity is proportional to the product of the small vector and axial chemical potentials in QED and weakly coupled QCD plasmas. By implementing the gauge/gravity duality, we qualitatively obtain the same relation in the strongly coupled scenario. On the other hand, we find that an axial Hall current can also be generated when introducing an electric field and a magnetic field perpendicular to each other with an axial chemical potential, which could be dubbed as the chiral Hall effect (CHE). The fluctuations of chemical potentials will further result in chiral electric waves (CEW) as propagating density waves led by the applied electromagnetic fields. Interestingly, the Hall density waves propagating perpendicular to both applied fields may exist even at zero chemical potentials and become non-dissipative. The transport coefficients including the Hall conductivities, damping times, wave velocities, and diffusion constants of CEW in a strongly coupled plasma via the AdS/CFT correspondence will be presented. We argue that the CHE could lead to nontrivial charge distributions at different rapidity in asymmetric heavy ion collisions. The presentation is based on Phys.Rev. D89 (2014) 8, 085024 and Phys.Rev. D91 (2015) 2, 025011.

On behalf of collaboration:
**Poster Session** - Board: 1226 / 33

**Gluon transport in a semi-holographic model of QCD**

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A semi-holographic approach combining the Boltzmann equation and the gauge/gravity duality is applied to study a gluon plasma which consists of hard and soft degrees of freedom, where the former is at the saturation scale of QCD and the latter is around the temperature of the quark gluon plasma in relativistic heavy ion collisions. The model aims at analyzing gluonic transport in the phase after the thermalization of soft degrees of freedom. The hard sector is presumed to be weakly interacting, where its dynamics is characterized by kinetic theory with the collisional term incorporating the scattering of hard and soft gluons. In contrast, the soft sector is strongly interacting, which could be described by an infrared conformal field theory (IR-CFT) as the gauge theory dual of a supergravity theory in thermal equilibrium. In general, the dynamics of the IR-CFT could be captured by hydrodynamics and the interaction with the hard sector then appears as a driving force through the conservation equation, while the input of holography is to obtain the transport coefficients. The corrections on both sectors could be solved order by order in terms of the marginal coupling of two sectors on the boundary. It is found that the correction on the hard gluons is sub-leading compared with that on the soft gluons. In early times, the hard gluons could be characterized by classical Yang-Mills theory with large occupation numbers. In the longitudinal expanding system, the energy density of the IR-CFT receives non-hydrodynamic correction, which depends on the dynamics of the hard gluons captured by the non-thermal attractor solution. In late times, we may expect the thermalization of the hard sector, which then gives rise to hydrodynamic correction on the soft sector.

On behalf of collaboration:

**Poster Session** - Board: 1227 / 225

**Self-similar inverse cascade of magnetic helicity driven by the chiral anomaly, and its signatures in heavy ion collisions**

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For systems with charged chiral fermions, the imbalance of chirality in the presence of magnetic field generates an electric current - this is the Chiral Magnetic Effect (CME). We study the dynamical real-time evolution of electromagnetic fields coupled by the anomaly to the chiral charge density and the CME current by solving the Maxwell-Chern-Simons equations. We show that the CME induces the inverse cascade of magnetic helicity, and that at late times the evolution of magnetic helicity is self-similar and is characterized by universal exponents. We also find that in coordinate space the inverse cascade represents the transition from linked electric and magnetic fields to the knotted configuration of magnetic field (a visualization of this evolution will be presented). We devise a (possibly unique) experimental signature of this phenomenon in heavy ion collisions.

On behalf of collaboration:

**Poster Session** - Board: 1301 / 131

**eA collisions at the LHeC and the FCC**

ARMESTO PEREZ, Nestor\(^1\)
The LHeC \footnote{http://lhec.web.cern.ch/} is a proposed upgrade of the LHC to study ep/eA collisions in the TeV regime, by adding a 60 GeV electron beam through an Energy Recovery Linac. This electron beam can be combined with the FCC hadron beams in the future. A Conceptual Design Report \cite{2,3,4} was released in 2012, and present studies focus on producing a technical design for the next European Strategy for Particle Physics in 2018. In this talk the proposal will be presented, the CDR content on eA collisions reviewed, and new results on the physics prospects on energy frontier eA collisions with these machines will be shown, with emphasis on the precise determination of nuclear parton densities.

\cite{3} J. L. Abelleira Fernandez et al. [LHeC Study Group], arXiv:1211.4831 [hep-ex].
\cite{4} J. L. Abelleira Fernandez et al. [LHeC Study Group], arXiv:1211.5102 [hep-ex].

For the upgrade of the ALICE Time Projection Chamber (TPC) at the CERN LHC, the present multiwire proportional readout chambers will be replaced by stacks of four Gas Electron Multipliers (GEMs). GEMs are able to cope with the high Pb-Pb interaction rates of 50 kHz anticipated in LHC Run3 and can be operated in continuous mode. The main goal of optimization is the minimization of the ion backflow (IBF) to avoid space-charge distortions in the drift volume. At the same time, good energy resolution must be provided in order to retain the excellent particle identification capabilities of the TPC via dE/dx. In this poster, the results of a detailed R&D program, aimed at the optimization of the field configurations in a stack of four GEMs, employing foils with different hole size, will be presented.

An important open question related to the low-x structure of hadrons is the postulated existence of gluon saturation. We propose the measurement of forward direct photons in proton-nucleus collisions at the LHC as a decisive probe of gluon saturation. Due to the harsh environment of such a measurement, existing detectors are not suitable. In particular an extremely high-granularity electromagnetic calorimeter is required, which we propose as a detector upgrade to the ALICE experiment covering 3.5 < \eta < 5.3, the Forward Calorimeter (FoCal). To facilitate the design of the upgrade and to perform generic R&D necessary for such a novel calorimeter, a compact high-granularity electromagnetic calorimeter prototype
has been built. The corresponding R&D studies will be the focus of this presentation. The prototype is a Si/W sampling calorimeter using CMOS sensors of the MIMOSA type with a pixel pitch of 30 μm and binary readout with a total of ~39 million pixels. We will report on performance studies of the prototype with test beams at DESY and CERN in a broad energy range. The results of the measurements demonstrate a very small Molière radius (~11mm) and good linearity of the response. Unique results on the detailed lateral shower shape, which are crucial for the two-shower separation capabilities, will be presented. We will compare the measurements to GEANT-based MC simulations, which additionally include a modeling of charge diffusion. The studies demonstrate the feasibility of this high-granularity technology for use in the proposed detector upgrade. They also show the extremely high potential of this technology for future calorimeter development. Finally, we will briefly discuss the projected performance for measurements of the nuclear modification factor R_{pPb} for forward isolated photons at the LHC.

On behalf of collaboration:

Poster Session - Board: 1304 / 481

Towards a first look at forward neutral pions with PHENIX’s MPC and MPC-EX detectors

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The MPC-EX detector is a Si-W preshower detector located in front of PHENIX’s well-established Muon Piston Calorimeter. The combined energy measurement from these two detectors in concert with the improved position resolution and detailed early shower information provided by the MPC-EX expands PHENIX’s neutral pion reconstruction capabilities in the rapidity range 3.1 < |η| < 3.8 out to high energies, E < 80 GeV, a factor of four improvement over our current ability and close to the luminosity limit. Forward π⁰ measurements in p+Au provide a signal to study nuclear shadowing, initial state energy loss and/or gluon saturation effects as a function of rapidity, centrality and energy. Furthermore, by looking at angular correlations between neutral pions and varying their rapidity and p_T, we can examine the flow-like ridge correlations with low p_T π⁰s and selectively sample correlations from dijet events, extending down to an x of 10⁻³, with high p_T π⁰s. In 2015, the MPC-EX was installed in PHENIX and had its first data taking during in RHIC’s √s_{NN} = 200 GeV transversely polarized p+p and p+Au collision running. The status of the analysis of this new data will be presented focusing on neutral pion reconstruction and related observables.

On behalf of collaboration:

Poster Session - Board: 1306 / 289

sPHENIX: A New Experiment at RHIC

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sPHENIX is a proposal for a second generation experiment at RHIC capable of measuring jets, jet correlations and upsilons to determine the temperature dependence of transport coefficients of the quark-gluon plasma using electromagnetic and hadronic calorimetry and precision tracking. The experiment enables a program of systematic measurements near the transition temperature at RHIC with a detector capable of acquiring a huge sample of events in p+p, p+A, and A+A collisions from a large acceptance spectrometer. The poster will summarize the key measurements enabled by the new detector, progress on the realization of the apparatus, and possibilities for future enhancements to it.
Combined Gas Electron Multipliers and MicroMeGas as Gain Elements in a High Rate Time Projection Chamber.

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A new generation of Time Projection Chamber (TPC) has been proposed for an ALICE (A Large Ion Collider Experiment at CERN) upgrade for continuous readout at high luminosity. Such a continuously sensitive high-rate imaging detector is also highly desirable as a central tracking detector for a future electron-ion collider and a linear electron collider. This device would rely on the intrinsic ion back flow (IBF) suppression of micro-pattern gas detectors to minimize space charge build-up in the main drift volume and thus would not require the standard gating grid and the resulting intrinsic dead time. We have proposed, simulated, and measured the properties of a combination of a MicroMeGas (MMG) detector with two Gas Electron Multipliers (GEM) for this application. We have measured the positive ion backflow (IBF) and energy resolution of this structure at various settings of the gains of the elements and electric field between the elements with different working gases. At a gain of 2000, this configuration allows achievement of both an ion back-flow below 0.4% and an energy resolution better than 12% (standard deviation) for 55Fe x-rays. Spark rates measured for a variety of conditions also will be presented.

Prototype Studies for the Hadronic Calorimeter System of the Proposed New Experiment (sPHENIX) at RHIC

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A major new experiment has been proposed for systematically studying the properties of Quark-Gluon Plasma with jet probes and upsilon production at RHIC. One of the major detector systems of the experiment is an accordion-like hadronic calorimeter (HCal) which consists two segments sandwiching a superconducting solenoid magnet. This poster will present the results from the first HCal prototype beam test at Fermilab and the plans for the second HCal prototype to be tested in Spring of 2016.

Detector R&D of the Forward Calorimeter with PAD read-out for the ALICE upgrade

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FoCal is a proposed upgrade project for the ALICE experiment at LHC to study the initial state of the high-energy heavy-ion collisions. FoCal comprises two calorimeters: an electromagnetic calorimeter (FoCal-E) to measure the direct photons is complemented by a hadron calorimeter (FoCal-H) to improve isolation and jet measurements. FoCal-E consists of low-granularity silicon-pad (PAD) modules and high-granularity silicon-pixel (Monolithic Active Pixel Sensors: MAPS) modules, and has been designed as a Si+W sampling calorimeter. In the current design, the FoCal-E structure consists of four PAD modules and two MAPS modules. The main purpose of the MAPS modules is the precise location of the position of the shower and the two-shower separation, while the PAD modules are essential for a good measurement of the shower energy. One PAD module has four layers each consisting of a tungsten tile and an 8x8 silicon photodiode (of size 11.3x11.3 mm²) array, respectively. The summed signal of four photodiode cells in same lateral position is read out via a summing board and APV25 hybrid chips. In this presentation, we show the detector performance of FoCal-E PAD system, which has been evaluated in two test beam experiment at CERN PS and SPS test beam lines in September and November in 2014, respectively. Energy resolution, linearity in energy, and position resolution have been measured at these beam tests. We also present an outlook and the current status of faster readout system for the FoCal-E PAD using the SRS and VMM chips.

On behalf of collaboration:

**Poster Session** - Board: 1310 / 674

The RICH detector for the CBM experiment at FAIR

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The CBM fixed-target experiment at FAIR will investigate highly compressed baryonic matter at moderate temperatures in heavy-ion collisions with 2-15 AGeV beam energy at the SIS100 accelerator at FAIR from 2020 on and at SIS300 with beam energies up to 45 AGeV once this becomes available. The CBM experiment aims at understanding and characterizing nuclear matter at high net-baryon densities but moderate temperatures focusing on the investigation of rare probes as for example electromagnetic radiation. The major detector for clean electron identification in the CBM experiment at SIS 100 will be a RICH detector using CO₂ as radiator gas, spherical glass mirrors with reflective Al+MgF₂ coating as focusing elements and a photodetector plane consisting of an array of H12700 MAPMTs from Hamamatsu. This detector concept has been tested extensively with a real-size RICH prototype in testbeams and proven to show a high performance. The testbeam evaluations included a detailed study of layers of wavelength-shifting films for enhanced UV sensitivity and the development of MAPMT readout. Several MAPMT sensors were tested in this setup but also for radiation hardness in separate experimental campaigns with thermal neutron and gamma irradiation. As result the H12700 sensor was ordered from Hamamatsu in spring 2015. First delivery is expected for autumn 2015. In order to make use of the early delivery of these photosensors with respect to the CBM time scales and to recuperate performance losses of the HADES RICH detector due to aging of the CsI photocathode, the HADES RICH detector will be upgraded with these photosensors and readout electronics as developed for CBM. This upgrade program will be finished for the next HADES data taking period starting 2017. In this contribution we will report on the design and status of the CBM RICH development, on the beamtime results obtained with the RICH prototype and the HADES RICH upgrade plans.

On behalf of collaboration:

**Poster Session** - Board: 1311 / 471
A Summary Trigger Unit for the ALICE Electromagnetic Calorimeters

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After a successful three-year data taking period, the Summary Trigger Unit, a FPGA-based embedded device implementing the ALICE EMCal L1 trigger algorithms, has demonstrated efficient real-time selection of events with high transverse momentum jets and photons. LHC LS1 has been the opportunity for ALICE to upgrade its calorimetry system with DCal, a second arm situated back-to-back in azimuth to EMCal. The flexibility and scalability of STU hardware design has then proven to be a major asset to extend its use to both DCal and PHOS calorimeters implementing even more complex L1 Jet Patch algorithms featuring on-line configurable patch sizes, spatial windowing over DCal and PHOS aggregated regions, and dynamic threshold adjustment based on median background estimation through EMCal-DCal custom serial link communication. The poster will present all these new STU developments for the upcoming LHC Run 2.

On behalf of collaboration:

Poster Session - Board: 1312 / 315

Performance of the ALICE Photon Spectrometer in LHC Run2

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One of the photon detectors in the ALICE experiment is the fine-granularity high-resolution photon spectrometer (PHOS) composed of lead tungstate crystals. Major upgrade of the PHOS has been completed by the LHC Run2, which covers high-rate readout, advanced trigger system and charged particle veto detector. Performance of the PHOS in first pp data of Run2 will be presented. Perspectives for data taking with forthcoming pp, Pb-Pb and p-Pb collisions will be discussed.

On behalf of collaboration:

Poster Session - Board: 1313 / 473

Performance simulation studies for the ALICE TPC GEM Upgrade

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The ALICE collaboration plans major upgrades to its detectors for Run 3 and 4 of the LHC, in 2020 and beyond. For the TPC, the upgrade is aimed at increasing the rate capability to record an expected collision rate of 50 kHz Pb-Pb collisions, which requires continuous readout. The current TPC will therefore be reinstrumented with new Gas Electron Multipliers (GEM) readout chambers that can suppress ~99% of the ion back flow. The remaining 1% ion
back flow will still give rise to significant space charge distortions that have to be corrected. In
this poster I will show how these corrections are foreseen to be done and report the expected
performance obtained from simulations studies. In order to understand the time dependence
of the space charge distortions, a dynamic simulation has been developed. Results from this
simulations will also be presented here.

On behalf of collaboration:
1

Poster Session - Board: 1314 / 600

A Tungsten Powder Epoxy Scintillating Fiber EMCAL for sPHENIX
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The sPHENIX detector is a proposed new detector at the Relativistic Heavy Ion Collider
(RHIC). The sPHENIX physics program focuses on jets and hard probes of the quark gluon
plasma (QGP). The proposed design of the electromagnetic calorimeter (EMCAL), made of a
tungsten powder and epoxy composite with embedded scintillating fibers, is designed to have
a small Moliere radius and short radiation length, and will be located at a radius of about 90
cm from the interaction region. It will have an energy resolution $\sigma_E/E = 12\%/\sqrt{E}$ and will be used
in conjunction with a new hadronic calorimeter (HCAL) to provide a jet energy resolution $\sigma_E/E = 120\%/\sqrt{E}$ to resolve single photons and electrons, as well as photon jets, in the high
multiplicity environment of central heavy ion collisions. The $\eta$ and $\phi$ segmentation of the
EMCAL is 0.024 x 0.024. Preliminary tests of the calorimeter design have taken place and we
plan to test new prototypes of the EMCAL and HCAL in the spring of 2016 in the test beam
at Fermilab.

On behalf of collaboration:

Poster Session - Board: 1315 / 249

Status of the STAR Event Plane Detector (EPD)
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The first phase of Beam Energy Scan (BES) program of the Relativistic Heavy Ion Collider
(RHIC) was an exploration of the QCD phase diagram. The second phase is an exploration
for criticality and phase transition signals. For the Solenoidal Tracker at RHIC (STAR)
a quantitative understanding of these signals requires an increase in statistics in 7.7, 11.5,
14.5 and 19.6 GeV AuAu collisions as well as dedicated hardware upgrades. The Event
Plane Detector (EPD) is a proposed high $\eta$ hit detector that would replace the STAR Beam
Beam Counter (BBC – a 32 channel hit detector $3.3 < |\eta| < 5.0$ used for BES triggering
and first order event plane reconstruction) for BES II, which is scheduled to begin in 2019.
The EPD would provide improved triggering, increased detector coverage in jet-like $\eta-\phi$
correlation measurements, improved resolution for event plane determination independent of
the TPC ($|\eta| < 1$), and provide a TPC independent centrality definition. Divorcing event plane
and centrality determination from the TPC via a forward detector is crucial for correlation
measurements performed at mid-rapidity.
The EPD design consists of two scintillator discs at $\pm 3.75m$, each is separated into ~500 tiles.
A tile has embedded wavelength shifting fiber coupled to clear fiber outside of the tile which
is, in turn, coupled to a silicon photomultiplier (SiPM) – an inexpensive and magnetic field
insensitive replacement for traditional phototubes. A pre-prototype of the detector, featuring
scintillator with embedded fiber coupled to SiPMs was integrated into STAR during the 2015 run. Currently tile designs varying geometry and detector specifications are being fabricated and tested along with latest generation SiPMs. Additionally simulations have been performed to optimize tile $\eta/\phi$ segmentation, size, and shape. A newly machined prototype featuring the anticipated geometry of the EPD will be put in place during RHIC run 2016.

On behalf of collaboration:
15

**Poster Session** - Board: 1317 / 283

**Precision Charged Particle Tracking with sPHENIX**

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The PHENIX collaboration is pursuing a series of aggressive upgrades aimed at excellent jet reconstruction capabilities to make use of the enhanced luminosity at RHIC, complement measurements being made at the LHC, and shed new light on the microscopic structure of the quark-gluon plasma. With a new detector, sPHENIX, offering large coverage electromagnetic and hadronic calorimetry and precision charged particle tracking, we will be well positioned to provide a broad and exciting program of jet probe and upsilon measurements. This poster will present the role that a precision charged particle tracking and vertex detector will play in the sPHENIX program. Details will be given on the tracking design and performance for reconstructing charged particles. The capabilities for bottom jet identification, upsilon reconstruction, and fragmentation function measurements in heavy ion collisions will be covered.

On behalf of collaboration:
13

**Poster Session** - Board: 1318 / 634

**Silicon strip detector R&D for the sPHENIX tracker**

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The sPHENIX detector is a major upgrade to the PHENIX detector at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory and is designed for exploring a vast range of physics areas including heavy quarkonia suppression via the three $\Upsilon$ states and tagging of charm and beauty jets. Among the sPHENIX detector, additional precision tracking inside the 1.5 tesla BaBar superconducting solenoid, as well as the currently operating PHENIX silicon vertex tracker, play a crucial role to reduce fake track contributions and improve the momentum resolution, thus leading to separation of the three $\Upsilon$ states and to separation of charm and bottom quarks. A charged particle tracking system, consisting of two layers of the silicon pixel detectors and five layers of the silicon strip detectors placed circumferentially in the radial space from 2-80 cm, will perfectly satisfy the above requirements. In this poster, we will discuss the physics potential of the sPHENIX detector, the design and technology choices for the sPHENIX silicon tracker system, and the performance of the prototype tracker module.

On behalf of collaboration:
13
Use of a high multiplicity trigger for the ALICE data in proton-proton interactions at \( \sqrt{s} = 13 \) TeV

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ALICE is collecting pp data at \( \sqrt{s} = 13 \) TeV also employing high multiplicity triggers that guarantee a significant statistics of low pile-up data for rare pp interactions having a multiplicity around ten times higher than the average or more. Validation and preliminary investigation of the basic features of this high multiplicity data sample are presented.

On behalf of collaboration:

A small current measurement system for gaseous micropattern detectors suitable for operation at high voltages

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Future upgrades of several large particle detectors intend to employ gaseous micropattern detectors. This class of detectors, which include Gas Electron Multipliers (GEMs), Micro-MEsh Gaseous Structure detectors (MicroMegas) and similar, usually require the measurement of small currents (pA) at high potentials (kV) with respect to ground. While only this in itself presents an obstacle, the measurements very often need to satisfy other strict requirements, such as small current resolution, low power consumption, high readout frequencies (1 kHz) or simultaneous readouts of multiple channels.

Several instruments that overcome some of these difficulties have been proposed or developed, often lacking in characteristics that would make them universally applicable. We present a description of a high-resolution picoammeter developed in our laboratory. Tests of the prototype with a local Gas Electron Multiplier sheet setup demonstrate that it satisfies all the aforementioned requirements, including a current resolution of less than 15pA, a readout frequency of 1kHz, the ability of simultaneous readout of multiple channels (up to 16) and low battery power consumption. Several prototypes have been sent for independent testing to other institutions, providing feedback for possible improvements, which are either already under way or planned as future upgrades.

Optimizing the Calorimeter Design for sPHENIX

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The PHENIX collaboration has proposed a major upgrade of the existing experiment at the Relativistic Heavy Ion Collider for the 2020-2022 time frame. The new experiment, code-named “sPHENIX”, is built around the former BaBar magnet, and consists of tracking systems and 3 calorimeters: an electromagnetic calorimeter based on scintillating fibers embedded in a tungsten-expoxy matrix, and two steel-scintillator hadronic calorimeters, one inside the magnetic field, and one outside. The BaBar magnet has an inner diameter of 280cm and a length of 385cm, which translates into a pseudorapidity coverage of $|\eta| < 1.0$ and a most extreme angle of incidence of 65° with respect to a vector pointing straight to the beam line. Starting from an optimally projective design with double-tapered EmCal modules, which are extremely challenging to produce, we present studies of various tilted calorimeter designs to find the best tradeoff between the uniformity of the sampling fraction, avoidance of “channeling” paths for particles, and project costs. We will show the results from simulations exploring the parameters governing the achievable energy resolutions and the detector complexity for the three calorimeters.

On behalf of collaboration:

Poster Session - Board: 1322 / 318

Upgrade of ALICE TPC and its readout electronics for the LHC RUN3 and beyond

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ALICE experiment at the LHC studies high-energy heavy-ion collisions (Pb-Pb) to characterize the strongly interacting matter at extreme energy densities. After the long shutdown of LHC in 2018, RUN3 of ALICE experiment is planned where the Pb-Pb collision rate of 50 kHz is expected. To cope with this high collision rate, the present Multi-Wire Proportional Chamber based TPC will be replaced with the high rate capable Gas Electron Multiplier (GEM) based TPC and continuous readout system will replace the conventional triggered readout. In the continuous TPC readout, the current signals from the GEM detector pads will be processed using the Front-End Cards (FECs). In the FECs, five custom-made SAMPA ASICs, will process the data from its 160 readout channels (32 channels/each). The SAMPA contains most of the Front-End Electronics such as charge-sensitive preamplifier, shaper, 10 bit 10 MHz digitizer and digital signal processing part. The data from the SAMPA will then be multiplexed and transmitted using GigaBit Transceiver (GBT) via optical links to a Common Readout Unit (CRU). The CRU is an interface to the on-line farm, trigger and detector control system. The first version of the SAMPA chip (MPW1) has been produced in 2014. In the presentation, the performance test results of MPW1 with the GEM detector prototype (10 x 10 cm²) will be reported.

On behalf of collaboration:

Poster Session - Board: 1323 / 316

SRU readout system of the ALICE Photon Spectrometer

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The ALICE experiment at the LHC aims to unravel a new state of matter called the quark-gluon plasma (QGP) produced in high-energy heavy-ion collisions. The PHOS detector in ALICE is an electromagnetic calorimeter composed of 12,544 lead-tungstate (PWO) crystals attached with avalanche photodiodes (APD). The PHOS realizes a fine granularity as well as
a high energy-resolution of $\sigma/E = 3.5\%$ at 1 GeV. One of important physics goals by the detector is to reveal thermal properties of the QGP by measuring thermal photons. For this goal, it is essential to accumulate high statistics in Pb-Pb collisions with a peak luminosity of $L = 6 \times 10^{27} \text{cm}^{-2}\text{s}^{-1}$. The PHOS team has decided to upgrade its readout system to a new one based on the point-to-point readout technique after the end of RUN-1. The new readout system is composed of 392 Front-End Electronics (FEE) boards and 14 Scalable Readout Units (SRU) and makes it possible to read faster. The current status of the PHOS detector performed in RUN-2 for pp collisions at $\sqrt{s} = 13$ TeV will be presented.

On behalf of collaboration:
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**Poster Session - Board: 1324 / 357**

**Performance of Fast Interaction Trigger for ALICE Upgrade.**

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Fast Interaction Trigger (FIT) will be the main forward trigger, luminometer and time zero detector for the ALICE experiment during LHC Run 3 and 4(from ~2020 onwards). It will also determine multiplicity, centrality, and reaction plane of heavy ion collisions. FIT will consist of two arrays of Cherenkov radiators coupled to MCP-PMT sensors and of a segmented scintillator ring increasing the acceptance, improving the performance, adding sensitivity to detect beam-gas events and providing some degree of redundancy. The arrays will be placed on the opposite sides of the interaction point (IP). Because of the asymmetry imposed by the presence of the hadron absorber, also the placement of the FIT arrays will be asymmetric: ~800 mm from IP on the absorber side and ~3200 mm from IP on the opposite side. Scheduled for installation during the Long Shutdown 2 (from mid 2018 till the end of 2019) FIT is in the midst of an intense R&D and prototyping period. The timing, amplitude and efficiency characteristics are determined with relativistic particles at CERN PS and with fast lasers. The ongoing Monte Carlo studies verify the physics performance and refine the geometry of the FIT arrays. The presentation will give a short description of FIT, summary of the performance, and the outcome of the simulations.

On behalf of collaboration:
1

**Poster Session - Board: 1325 / 400**

**Prospects for ALICE with the Muon Spectrometer Upgrade and the new Muon Forward Tracker**

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The ALICE experiment is dedicated to an in-depth characterisation of the Quark Gluon Plasma (QGP) formed at the LHC in relativistic heavy-ion collisions. Prominent results from the LHC Run1 involved the measurement of single and dimuons in the ALICE Muon Spectrometer (MS) at $-4 < \eta < -2.5$ to look for low mass vector mesons, rare probes from the charmonium and bottomonium families, and open-heavy flavor. These probes allow to investigate the chiral symmetry restoration, to test the predictions from the lattice QCD about the melting temperature of a tightly bound heavy qqbar pair, to test the in-medium regeneration scenario, and to scrutinise the gluon density in the QGP using the in-medium heavy-quark energy loss. By the end of the Run2, the ALICE experiment will accumulate around 1/nb of Pb–Pb collisions. However, at least 10/nb will be needed to conduct high
precision multidifferential studies on rare probes. To that end, LHC will be able to provide high rate running conditions for Run3 and beyond, i.e. 50 kHz for Pb–Pb collisions. The ALICE apparatus will have to inspect all heavy-ion collisions to achieve the physics goals. We will present the required upgrade for the MS. The new Front-End and Read-Out Electronics are designed to cope with a peaking readout rate of 100 kHz, to be compared with the current capability of 1 kHz. In addition, a new CMOS monolithic pixel tracking detector, the Muon Forward Tracker (MFT), will be added upstream of the absorber located before the MS, to provide vertexing capabilities at $-3.6 < \eta < -2.45$. On top of substantially improving the current performances of the MS, the MFT also opens a wealth of new measurements not accessible presently, such as open charm/beauty separation, $\psi(2S)$ in central Pb–Pb collisions, prompt and non-prompt $J/\psi$ separation. We will present a selection of this new physics program. We will also discuss the design of the MFT and the on-going tests of the prototype pixels.

On behalf of collaboration:

Poster Session - Board: 1326 / 657

A new cold atom experiment to study the hot quark-gluon plasma

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The hot quark-gluon plasma ($\sim 10^{12}$ K) and the cold atom systems ($\sim 10^{-6}$ K) exhibit amazingly similar phenomenon of azimuthal anisotropy [K.M.O’Hara et al., Science 298, 2179 (2002)]. This has been postulated as stemming out of a common underlying mechanism–both systems are strongly interacting and expand hydrodynamically–despite of the very different nature of their interactions. However, recent transport model studies suggest that the anisotropy in heavy-ion collisions may not be dominated by hydrodynamics, but the escape mechanism [L.He et al., arXiv:1502.05572 (2015)]. Moreover, quantum uncertainty principle may be relevant for the anisotropy of the quark-gluon plasma [D.Molnar et al., arXiv:1404.4119 (2014)]. In this talk I will illustrate why the hot quark-gluon plasma and the cold atom experiments performed to date are not similar as have been envisaged, and what it takes to truly use cold atoms to simulate the conditions of the quark-gluon plasma. I will outline a possible future cold atom experiment and discuss the technical challenges of such an experiment as well as the physics opportunities coming with it.

On behalf of collaboration:

Poster Session - Board: 1327 / 349

Performance of the Muon Forward Tracker of ALICE at the LHC for the low mass dimuon physics

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The ALICE experiment at LHC is designed to study the quark-gluon plasma (QGP) created in ultra-relativistic heavy ion collisions. The Muon Forward Tracker (MFT) project is a part of the ALICE program of detector upgrade for Runs 3 and 4, starting from 2020. The MFT is designed as a silicon pixel detector covering the $-3.6 < \eta < -2.5$ region in the Muon Spectrometer acceptance to be installed between collision point and the hadron absorber. Owing to this new detector, the resolution for the measurement of the muon production vertex will be improved dramatically and a broader physics program could be developed improving
the performance of the current muon spectrometer. One of the main goals of the MFT project is to perform measurements providing information on the restoration of chiral symmetry in the QGP, as predicted by lattice QCD calculations. Properties of low-mass vector mesons ($\rho, \omega, \phi$) composed of light u, d and s quarks are expected to change under the chiral symmetry restoration. This phenomenon can’t be easily observed in hadronic decay channels because of final-state re-interactions of the decay particles in the later stages of the collisions. For this reason, dilepton measurements are preferred, allowing the information from the hot and dense QGP phase to be extracted without significant degradation. In this contribution, the performance for low-mass dimuon measurements physics will be presented.

On behalf of collaboration:

Poster Session - Board: 1328 / 170

Development of a low noise highly pixelated electrode array for high energy physics

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We have developed a highly pixelated electrode array named Topmetal-II-. It contains a 72×72 pixel array of 83.2 $\mu$m pitch size. The key feature of TopMetal-II- is that it can directly collect charge via metal nodes of each pixel to form two-dimensional images of charge cloud distribution. Topmetal-II- sensor is designed with a low power consumption of 104 mW and low ENC value of 30 e-. From our measurement by injecting pulse signal into the top metal of each pixel, we got the ENC value of 13 e-, which is even better than the design value. Furthermore, the noise distribution of the sensor is almost uniform among pixel matrix. With such a low noise, we can measure charge particle track without any gas amplification, achieving high energy and spatial resolution. Thus making Topmetal-II- a competitive candidate for next generation of TPC readout node in high energy physics.

On behalf of collaboration:

Poster Session - Board: 1391 / 750

Development of FVTX high-multiplicity trigger system for the RHIC-PHENIX experiment

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Particle angular correlation measurements in small colliding systems, such as p+Pb, d+Au and $^3$He+Au at RHIC and the LHC have recently attracted significant interest. In particular, high multiplicity events from such collisions exhibit azimuthal correlations between rapidity separated hadrons, so called ridge. To investigate the ridge phenomena in small colliding systems at RHIC, a new high multiplicity trigger was developed using forward silicon vertex detector (FVTX) in the PHENIX experiment. FVTX is a new multi-layer silicon endcap in PHENIX at forward/backward rapidities, mainly intended for muon DCA measurements but here being used as a high multiplicity trigger in small colliding systems. The trigger signal is formed based on the coarse online tracking of raw hits processed in the FVTX readout electronics. Details of the new trigger system and its applicability for different collision systems will be presented and discussed.

On behalf of collaboration:
Performance of FVTX high-multiplicity trigger system for the RHIC-PHENIX experiment

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The performance of the new high multiplicity trigger for the FVTX detector is evaluated. The consistency between online and offline tracking is one of the key performances of the high multiplicity trigger. The consistency is evaluated for proton-proton, proton-Au, and proton-Al cases observed in Run15.

On behalf of collaboration: