Initial Stages 2021

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Weizmann Institute of Science

Book of Abstracts

Contents

IS / 6

Nonperturbative properties of overoccupied gluonic plasmas

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In ultrarelativistic heavy-ion collisions a quark-gluon plasma is created. Its pre-equilibrium evolution includes some fascinating phenomena of QCD. Focusing on the regime when gluonic occupation numbers are large, which can be achieved in the high energy and weak coupling limit, classical-statistical lattice simulations can be used to extract nonperturbative information on the dynamics. In this talk, we will focus on spectral functions and condensation phenomena in overoccupied gluonic plasmas. We find that spectral functions for different spatial dimensions exhibit quasiparticle excitations at all momenta, while partially showing deviations from perturbative expectations. Our results point towards an effective kinetic theory description even for extremely anisotropic systems. We also find that the large density of gluons can lead to the formation of a gauge-invariant condensate, which we identify using spatial Wilson loops. This reveals intriguing similarities to recent discoveries of condensation phenomena out of equilibrium in table-top experiments with ultracold Bose gases.

IS / 7

Heavy quark diffusion in an overoccupied gluon plasma

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We extract the heavy-quark diffusion coefficient κ and the resulting momentum broadening $\langle p^2 \rangle$ in an overoccupied gluon plasma. We find several features in the time dependence of the momentum broadening: a short initial rapid growth of $\langle p^2 \rangle$ followed by linear growth in time due to Langevin-type dynamics and damped oscillations around this growth at the plasmon frequency. We show that these oscillations arise from an excess of gluons in the infrared and are therefore a gauge invariant confirmation of the infrared enhancement we have previously observed in gauge-fixed correlation functions. We argue that the kinetic theory description becomes less reliable in the presence of this IR enhancement.

IS / 8

Direct photon interferometry as tool to probe the space-time evolution of heavy-ion collisions

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We investigate the measurement of Hanbury Brown-Twiss (HBT) photon correlations [1] as an experimental tool to discriminate different sources of photon production. To showcase that HBT correlations can distinguish between such sources, we consider two different scenarios in which we enhance the yields from standard hydrodynamical simulations. In the first, additional photons are produced from the early pre-equilibrium stage computed from the "bottom-up" thermalization scenario [2-4]. In the second, the thermal rates are enhanced close to the pseudo-critical temperature $T_c \approx 155\,\mathrm{MeV}$ using a phenomenological ansatz [5]. We compute the correlators for relative momenta q_o, q_s and q_l for different transverse pair momenta, $K_\perp$, and find that the longitudinal correlation is the most sensitive to different photon sources. Our results also demonstrate that including anisotropic pre-equilibrium rates enhances non-Gaussianities in the correlators, which can be quantified using the kurtosis of the correlators. Finally, we study the feasibility of measuring a direct photon HBT signal in the upcoming high-luminosity LHC runs. Considering only statistical uncertainties, we find that with the projected $\sim 10^{10}$ heavy ion events a measurement of the HBT correlations for $K_\perp < 1$ GeV is statistically significant.

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CGC / 9

Saturation and forward jets in proton-lead collisions at the LHC

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Particle production at forward rapidities in proton-nucleus collisions provides access to the target structure at very small momentum fraction x, where non-linear QCD dynamics is expect to play an important role. Recently, the CASTOR calorimeter at CMS [1], covering pseudodapidity region -6.6 < eta < -5.2, has released first jet spectra measurements in proton-lead collisions, probing nuclear structure down to Bjorken-x values of the order of 10ˆ(-6).

In this talk, based on Ref[2] we investigate the forward-jet energy spectrum within the Color Glass Condensate framework, focusing on the kinematic range covered by the CMS-CASTOR calorimeter. We show that our saturation-model calculations are compatible with the CASTOR measurements and that to optimally reproduce the data, effects of multiparton interactions need to be included on top on non-linear QCD dynamics. We predict a significant nuclear suppression — reaching down to 50% at the lowest considered jet energies E_jet~500 GeV.

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CGC / 11

Color Glass Condensate at next-to-leading order meets HERA data

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The Color Glass Condensate (CGC) effective field theory (EFT) at leading order describes well the Deep Inelastic Scattering (DIS) inclusive cross section data at small-x as measured by the HERA experiments [1-3]. Recently the inclusive DIS impact factors have been calculated in Next-to-Leading Order (NLO) accuracy in CGC EFT [4-6], and the soft gluon divergence present at NLO has been factorized succesfully [7].

In this talk we discuss our recent work [8] on the first comparisons of the NLO DIS cross sections to HERA data. Fitting the HERA reduced cross section data fixes the the non-perturbative initial condition to the BK evolution. Since the available NLO DIS inclusive cross sections are calculated in the massless quark limit, we construct and fit a dataset of light quark only cross sections using an independent parametrization of HERA total and heavy quark data. We find an excellent description of the HERA data. As the NLO BK is computationally expensive [9], we compare a number of beyond LO prescriptions that approximate the full NLO BK, including the recent evolution parametrized in target rapidity [10]. These beyond LO evolution equations include important higher order contributions by resumming corrections enhanced by large transverse logarithms.

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FE / 12

Heavy flavor and jet studies for the future Electron-Ion Collider

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The proposed high-luminosity high-energy Electron-Ion Collider (EIC) will explore the proton/nuclear structure, search for gluon saturation and precisely determine the nuclear parton distribution functions (nPDFs) in a wide x-Q^2 phase space. Heavy flavor and jet measurements at the future EIC will allow us to better constrain the nPDFs within the poorly constrained high Bjorken-x region, precisely determine the quark/gluon fragmentation processes and directly study the quark/gluon

energy loss within the nuclear medium. Heavy flavor hadrons, flavor tagged jets and their correlations are golden channels to explore flavor dependent jet fragmentation processes at the EIC. These proposed measurements will provide a unique path to explore the flavor dependent fragmentation functions and energy loss in heavy nuclei, which can constrain the initial state effects for previous and ongoing heavy ion measurements at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC). These studies will not only shed light into the ongoing EIC physics developments, but also provide guidance on the detector design and technology selections. Details of recent simulation studies for heavy flavor and jet developments at the EIC and their physics projections will be shown in this presentation.

FE / 13

Probing gluon saturation via semi-inclusive deep inelastic scattering at the EIC

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Within the dipole picture for electron-nucleus (eA) deep inelastic scattering (DIS) at small Bjorken x, we consider special, "aligned jet", configurations, which are very asymmetric: one of the quarks from the dipole fluctuation of the virtual photon carries most of the longitudinal momentum of its parent. We argue that such configurations correspond to relatively large dipole sizes and thus can be sensitive to saturation effects in the nuclear target even for relatively hard processes, where the photon virtuality Q^2 is considerably larger than the target saturation momentum Q_s^2. This offers a possibility to push the physics of saturation to larger values of Q^2, or to higher values for x. We propose to explore this possibility at the future Electron Ion Collider via special measurements of semi-inclusive DIS in which the longitudinal momentum of the tagged jet (or hadron) is measured as well. We predict new phenomena associated with gluon saturation in the very-forward regime, where the longitudinal momentum fraction z of the measured jet is close to one. In particular, we predict the emergence of a Cronin peak in the nuclear modification factor for $1-z \ll 1$ and moderate $x \sim 0.01$, and disappearance of this peak when further decreasing x, or increasing $1-z$. We also predict a very strong z-dependence of the SIDIS cross-section near $z = 1$: a power in $1/(1-z)$.

Poster / 14

Jet Substructure for heavy ion collisions

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We develop an Effective Field Theory (EFT) framework to compute jet substructure observables for heavy ion collision experiments.
We consider dijet events that accompany the formation of a Quark Gluon Plasma medium in a heavy ion collision and look at the simultaneous measurement of jet mass along with the transverse momentum imbalance between the jets accounting for both vacuum and medium evolution.

The jets are groomed using a soft drop grooming algorithm in order to mitigate effects of soft contamination from Multi-parton interactions as well as the QGP medium. Treating the energetic jet as an open quantum system interacting with a QGP bath, we write down a factorization formula within the SCET(Soft Collinear Effective Theory) framework, including the recent addition accounting for the forward scattering regime. This leads us to a Lindblad type master equation for the evolution of the reduced density matrix of the jet in the Markovian approximation. The resulting solution allows us to resum large logarithms that arise due to the final state measurements imposed while simultaneously summing over multiple interactions of the jet with the medium. We find that the the decoherence between the hard interaction that creates the jet and the subsequent medium interactions lead to $physical$ Infra-Red(IR) collinear divergences that are otherwise absent in pure vacuum evolution. We show that these IR divergences are completely regulated by the medium induced gluon mass and highlight the need to develop a multi-scale EFT approach in the future to resum the new logarithms that arise from these divergences.

Poster / **15**

Initializing BSQ Across System Size With Open Source ICCING

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A new model denoted ICCING (Initial Conserved Charges in Nuclear Geometry) reconstructs the initial conditions of BSQ conserved charges in the QGP by sampling the ($g \to q\bar{q}$) splitting function over the initial energy density. I will discuss the new open source C++ version of ICCING, coupled to TRENTO. We find that even at top LHC energies that the initial conditions due to local fluctuations probe a large range of baryon chemical potentials, $\mu_B \sim \pm 400 MeV$, even though the global net baryon density is approximately zero. The new information provided by these conserved charges opens the door to a wealth of new charge- and flavor-dependent correlations in the initial state which we explore through a system size scan.

Poster / **16**

Hydrodynamic attractors, initial state energy and particle production in relativistic nuclear collisions

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We exploit the concept of hydrodynamic attractors to establish a macroscopic description of the early time out-of-equilibrium dynamics of high energy heavy-ion collisions. One direct consequence is a general relation between the initial state energy and the produced particle multiplicities measured in experiments. When combined with an ab initio model of energy deposition, the entropy production during the pre-equilibrium phase naturally explains the universal centrality dependence of the measured charged particle yields in nucleus-nucleus collisions. Further, we estimate the energy

density of the far-from-equilibrium initial state and discuss how our results can be used to constrain non-equilibrium properties of the quark-gluon plasma.

Ref: G. Giacalone, A. Mazeliauskas, S. Schlichting, Phys.Rev.Lett. 123 (2019) 26, 262301 [arXiv:1908.02866]

CD / 17

Discovering partonic rescattering in light nucleus collisions

Authors: Aleksas Mazeliauskas[1]; Alexander Yohei Huss[1]; Eero Aleksi Kurkela[2]; Risto Sakari Paatelainen[1]; Urs Wiedemann[1]; Wilke Van Der Schee[3]

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Medium induced parton energy loss is not conclusively established neither in very peripheral heavy-ion collisions nor in proton-ion collisions. However, the standard interpretation of azimuthal momentum anisotropies in theses systems implies some partonic rescattering. The upcoming light-ion runs at the LHC provide a unique opportunity to search for parton energy loss in different systems of similar size. We demonstrate that oxygen-oxygen (OO) collisions at the LHC provide unprecedented sensitivity to parton energy loss in a system whose size is comparable to those created in very peripheral heavy-ion collisions. With leading and next-to-leading order calculations of nuclear modification factors, we show that the baseline in the absence of partonic rescattering is known with up to 2% theoretical accuracy in inclusive OO collisions. Surprisingly, a Z-boson normalized nuclear modification factor does not lead to higher theoretical accuracy within current uncertainties of nuclear parton distribution functions. We study a broad range of parton energy loss models and we find that the expected signal of partonic rescattering can be disentangled from the baseline by measuring charged hadron spectra in the range $20\,\mathrm{GeV} < p_T < 100\,\mathrm{GeV}$.

Refs.: A. Huss, A. Kurkela, A. Mazeliauskas, R. Paatelainen, W. van der Schee, U.A. Wiedemann [arXiv:2007.13754, 2007.13758]

Poster / 19

Non-equilibrium attractor in high-temperature QCD plasmas

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We establish the existence of a far-from-equilibrium attractor in weakly-coupled gauge theory undergoing one-dimensional Bjorken expansion. We demonstrate that the resulting far-from-equilibrium evolution is insensitive to certain features of the initial condition, including both the initial momentum-space anisotropy and initial occupancy. We find that this insensitivity extends beyond the energy-momentum tensor to the detailed form of the one-particle distribution function. Based on our results, we assess different procedures for reconstructing the full one-particle distribution function from the energy-momentum tensor along the attractor and discuss implications for the freeze-out procedure used in the phenomenological analysis of ultra-relativistic nuclear collisions.

IS / 20

Preequilibrium dilepton production: concepts, estimates and feasibility

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Early time dynamics of heavy-ion collisions represents an important quest to connect the initial conditions with the hydrodynamic evolution and to understand thermalisation in general. Directly sensitive measurements have remained elusive so far. Electromagnetic radiation is a sensitive probe to study QCD systems throughout the full time evolution including the very early stages. In this contribution, we propose an approach to estimate the production of dilepton pairs from the pre-equilibrium phase of heavy-ion collisions. We are employing a generalization of the thermal dilepton production rates for anisotropic systems, where the pre-equilibrium evolution of the system is described by non-equilibrium attractors that connect the highly anisotropic initial state at early times with the late stage viscous hydrodynamic evolution. Based on this framework, we investigate the sensitivity of the dilepton production yields on the macroscopic features of the pre-equilibrium stage; the required kinematics and open points will be pointed out. Finally, we will address the main background and the measurement feasibility with dimuons at forward rapidity for the future LHCb U2 set-up.

MPI / 21

D-meson duos in p-p and p-Pb collisions

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The LHCb collaboration has recently measured cross sections for the simultaneous production of two charmed-particles in p-p [1] and p-Pb [2] collisions. These include opposite-sign and same-sign D-meson pairs offering, for the first time, a chance to study the interplay of single-parton (SPS) and double-parton scattering (DPS) across different collision systems.

In this talk, we discuss our NLO QCD framework [3] used to calculate the double D-meson cross sections. The setup is based on factorized PDFs and D-meson fragmentation functions, taking into into account both the SPS and DPS contributions. The DPS contributions are estimated with an effective cross section approach neglecting the partonic correlations. We find a nice agreement with the LHCb p-p and p-Pb data when using values for the effective cross section consistent with other measurements. In particular, we conclude that the same-sign D-meson data provide the first quantitative confirmation of DPS at work in p-Pb collisions.

We also compare our results to Pythia Monte Carlo simulations and discuss the implications of DPS on the two-particle azimuthal correlations and possibilities to resolve signatures of saturation phenomena.

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IS / 22

Production of W, Z, and charged hadrons in Pb+Pb collisions with the ATLAS detector

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Measurements of $W^{\pm}$, Z, and charged-hadron production in Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV are presented using data recorded by the ATLAS experiment at the LHC in 2015 corresponding to a total integrated luminosity of 0.49\,nb^{-1}.
The the electro-weak (EW) bosons are reconstructed in both the electron and muon decay channels. The EW boson yields measured in Pb+Pb collisions, normalised by the total number of minimum-bias events and the mean nuclear thickness function, are compared with similar measurements made in pp collisions at the same centre-of-mass energy.
The results are compared with predictions based on next-to-leading-order calculations with CT14 parton distribution functions as well as with nuclear modifications to PDFs implemented in EPPS16. The central and mid-central collisions are consistent with the calculations and a small excess above the calculations is observed in the peripheral collisions.
The inclusive charge-hadron yield in Pb+Pb, Xe+Xe and p+Pb collisions is also normalized by the mean nuclear thickness function and is also compared against the yields of charged hadrons in pp collisions.
The comparison of the nuclear modification of EW bosons and charged particles in central and periperhal Pb+Pb collisions will provide constraints on the relative importance of initial- and final-state effects in these measurements.

CGC / 23

Two-particle azimuthal correlations in photo-nuclear ultra-peripheral Pb+Pb collisions at 5.02~TeV with ATLAS

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The ultra-peripheral collisions (UPCs) of relativistic heavy ion beams lead to a diverse set of photon-nucleus interactions. The measurements of particles and their interaction produced in photo-nuclear reactions can shed light on the QCD dynamics of novel, extremely asymmetric colliding systems, with energies between those available at RHIC and the LHC. Understanding the hadronic fluctuation spectrum of the photon in this fashion is also critical for maximizing the precision of measurements at a future Electron Ion Collider facility. This talk presents a measurement of two-particle long-range azimuthal correlations in photo-nuclear collisions using 1.73~nb^{-1} of 5.02~TeV~Pb+Pb data collected in 2018 by ATLAS with a dedicated photo-nuclear event trigger. Candidate photo-nuclear events are selected using a combination of the single-sided zero-degree calorimeter activity and reconstructed pseudorapidity gaps constructed from calorimeter clusters and charged-particle tracks. Correlation functions are constructed using charged-particle tracks, separated in pseudorapidity. A template fitting procedure is utilized to subtract the non-flow contribution. Elliptic and triangular flow coefficients are presented as a function of charged-particle multiplicity and transverse momentum, and significant non-zero values of the flow coefficients are observed. The results are compared to flow coefficients obtained in proton–proton and proton–lead collisions in similar multiplicity ranges.

Poster / **24**

Dimuon production from two-photon scattering in ultra peripheral Pb+Pb collisions with the ATLAS detector

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Relativistic heavy-ion beams are accompanied by a large flux of equivalent photons, giving rise to a set of photon-induced processes. These ultra-peripheral collisions (UPCs) can lead to photon-photon interactions. This poster presents a new measurement of exclusive dimuon production, which provides detailed constraints on the nuclear photon flux and its dependence on impact parameter and photon energy. In particular, the study of the dimuon cross sections in the presence of forward neutron production provides an additional experimental handle on the impact parameter range sampled in the observed events.

Poster / **25**

Light-by-light scattering in ultra-peripheral Pb+Pb collisions in the ATLAS experiment

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The ultra-peripheral Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV performed at the ATLAS experiment are used to
study a rare light-by-light scattering process, $\gamma\gamma \to \gamma\gamma$, allowed in Quantum Electrodynamics via a loop diagram.
The poster summarises recent light-by-light measurements conducted using a combination of 2015 and 2018 datasets recorded by the ATLAS experiment,
corresponding to an integrated luminosity of 2.2 nb^{-1}.
The light-by-light event candidates are required to consist of only two photons produced exclusively, each with transverse energy
$E_{\mathrm{T}} >$ 2.5 GeV, pseudorapidity $|\eta| < 2.4$, diphoton invariant mass $m_{\gamma\gamma} > 5$ GeV,
and with diphoton transverse momentum $p_{\mathrm{T}\gamma\gamma}$ < 1 GeV and acoplanarity below 0.01.
The differential distributions, presented as functions of kinematic and angular variables of the final-state photons, are unfolded for detector effects.
The fiducial and differential cross-sections are presented and compared with theoretical predictions.
The diphoton invariant mass distribution is used to set limits on the production of axion-like particles.

Poster / **26**

Measurement of $\gamma\gamma \to \mu^+\mu^-$ pairs in non-ultra peripheral Pb+Pb collisions with the ATLAS detector

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ATLAS measurements of dimuons produced via $\gamma\gamma$ scattering processes in inelastic, non-ultra-peripheral Pb+Pb collisions at 5.02 TeV are presented using an integrated luminosity of 1.9 nb^{-1}. The $\gamma\gamma \rightarrow \mu^+\mu^-$ pairs are identified via selections on pair momentum asymmetry and acoplanarity, and the contribution from the heavy flavor decay background is estimated using both template and asymptotic fit methods. The pair yields are measured differentially as functions of the centrality, average transverse-momentum, (p_T) and rapidity of the pair. The measurement shows a depletion in the number of muon pairs near zero acoplanarity in central events, resulting in the distributions peaking at non-zero values of acoplanarity. Fits to the perpendicular transverse momentum ($k_\perp$) distributions are used to estimate the centrality dependence of this peak position. The most probable is shown to increase from the most peripheral to the most central collisions, reaching a value of $k_\perp = 36 \pm 1$ MeV in the 0-5\% most-central collisions. The ability of these measurements to qualitatively differentiate between different physical origins of the observed centrality and p_T dependence, including comparisons to several theoretical calculations, are discussed.

IS / **27**

Recent heavy-flavor and quarkonium measurements with the ATLAS detector

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Measurements of open heavy-flavor hadron and quarkonium
in heavy-ion collisions provide a powerful tool
to study both initial-state effects on heavy-quark production and final-state interactions
between heavy quarks and the quark-gluon plasma (QGP).
Recent ATLAS measurements of azimuthal anisotropy of muons from heavy-flavor decays in pp and Pb+Pb collisions are presented.
Muons with charm and bottom origins are separated from each other
based on the transverse impact parameter with respect to the primary collision vertex.
Muons from both charm and bottom hadrons are
found to have significant azimuthal anisotropies in Pb+Pb collisions,
with larger anisotropies for muons from charm hadrons than for muons from bottom hadrons observed.
In pp collisions, the azimuthal anisotropy of muons from charm hadron decays
is similar to that of light hadrons,
while muons from bottom hadron decays show no significant anisotropy.
The different patterns in Pb+Pb and pp collisions challenge the picture
of a common origin of azimuthal anisotropy for heavy flavor in different systems.
New ATLAS measurements of suppression of muons from heavy flavor decays
and bottomonia in Pb+Pb collisions are also presented.
The relative suppression between different bottomonium states in Pb+Pb,
together with the same observable measured in p+Pb collisions,
provides strong constraints on the relative contributions of initial- and final-state effects on the observed suppression.

Poster / **29**

Sensitivity of jet quenching to the initial geometry in Pb+Pb collisions with ATLAS

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Measurements of jet suppression and modification in heavy-ion collisions provide powerful and broad information on the dynamics of the hot, dense plasma formed in relativistic nucleus-nucleus collisions.
In this talk at the Initial Stages conference, we present measurements of jet energy loss and modification which are sensitive to the initial transverse geometry of Pb+Pb collisions.
The measurements are performed using the high-statistics Pb+Pb collision data at 5.02 TeV recorded during 2018 with the ATLAS detector at the LHC.
These data can provide insight into the path length or system size dependence of energy loss, and the sensitivity to fluctuations in the transverse geometry.
This talk will first present a broad measurement of the single jet yields as a function of the azimuthal angle with respect to the 2nd, 3rd, and 4th event planes in Pb+Pb collisions.
The azimuthal anisotropies for jets are reported as a function of jet pT and centrality.
Second, this talk will present a measurement of the fully unfolded dijet momentum balance in high-statistics Pb+Pb and pp data.
The balance distributions are presented as a function of centrality and leading jet pT, exploring a significantly higher kinematic range than Run 1 results.
Finally, these results will be placed in context of other jet measurements in ATLAS, such as recent measurements of Z+hadron correlations which, due to the Z selection, sample an unbiased set of hard scattering production points in the nuclear overlap region.

IS / 30

Dimuons from photon-photon fusion in ultraperipheral and hadronic Pb+Pb collisions with ATLAS

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Relativistic heavy-ion beams are accompanied by a large flux of equivalent photons, giving rise to a set of photon-induced processes. These can lead to photon-photon interactions in both ultraperipheral collisions, where the nuclei do not overlap, as well as in hadronic processes accompanied by the production of hot, dense matter. The latter provides a potentially sensitive electromagnetic probe of the quark-gluon plasma. This talk presents a series of measurements of such processes performed by the ATLAS Collaboration. New measurements of exclusive dimuon production, which provide detailed constraints on the nuclear photon flux and its dependence on impact parameter and photon energy. In particular, the study of the dimuon cross sections in the presence of forward neutron production provides an additional experimental handle on the impact parameter range sampled in the observed events. First measurements by ATLAS and STAR of dileptons produced via two-photon scattering in non-ultra-peripheral (non-UPC) nucleus-nucleus collisions showed an unexpected centrality-dependent broadening of the angular correlation between the two leptons and/or of the two-lepton p_{T} distribution. ATLAS has recently measured dimuons produced via two-photon scattering in non-UPC Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV using an integrated luminosity of $1.9\ \mathrm{nb}^{-1}$. This data set represents a factor of ~ 4 increase in statistics over the 2015 data set used for the first ATLAS measurement. The increased statistics allow new features to be observed in the data, both in the yields of the pairs as well as in their angular distributions. Differential measurements of the dependence of the pair-distribution on the transverse-momentum and rapidity of the two muons, as well as the dependence on the event centrality will be presented, and the possible physics implications will be discussed.

Poster / 31

Flow and transverse momentum correlations in Pb+Pb and Xe+Xe collisions with ATLAS

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Fluctuations of event-wise average transverse momentum ($[p_{\mathrm{T}}]$) and the harmonic flow (v_n) carry important information about initial-state geometry.
Collisions of nuclei with large quadrapole deformation are predicted to produce an initial state with enhanced shape and size fluctuations, and result in non-trivial correlation between v_n and $[p_{\mathrm{T}}]$ in the final state.
In particular, the $v_2 - [p_{\mathrm{T}}]$ correlations are predicted to be different between collisions of spherical ^{208}Pb and collisions of deformed ^{129}Xe.
This poster presents new measurement of $v_n - [p_{\mathrm{T}}]$ correlation in $\sqrt{s_{\mathrm{NN}}} = 5.44$~TeV Xe+Xe collisions and compared with Pb+Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02$~TeV for harmonics $n = 2$, 3 and 4.
The correlation strength is found to depend strongly on centrality and also on the choice of transverse momentum range of the particles for all harmonics.
Comparison with theoretical model calculations are used to shed light on the system-size dependence of this correlation and the influence of deformations.
This measurement provides inputs for better understanding of the initial-state nuclear geometry and dynamics of heavy ion collisions.

Poster / **34**

Measurement of the sensitivity of two particle correlations in pp collisions at $\sqrt{s} = 13$~TeV to the presence of jets with the ATLAS detector

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Measurements of two-particle correlations in *pp* collisions show the presence of long-range correlations along $\Delta\eta$ that are strikingly similar to those seen in heavy-ion collisions.
In heavy-ion collisions, the long-range correlations are known to arise from the collective dynamics of the produced quark-gluon plasma (QGP).
The similarity between the *pp* and heavy-ion measurements raises the possibility that a tiny droplet of the QGP is produced even in *pp* collisions.
However, models that attribute the correlation in *pp* collisions to semi-hard processes can qualitatively reproduce the measurements.
Thus performing the *pp* measurements with an active rejection of particles associated with semi-hard processes, such as low-p_{T} jets, can further elucidate the origin of the long-range correlations.
This poster presents measurements of two-particle correlations in *pp* collisions at $\sqrt{s} = 13$~TeV, when removing tracks associated with jets from the event.
The jets are reconstructed from tracks using the anti-k_t algorithm, and all tracks within one unit of pseudorapidity of the jet are removed from the correlation analysis.
It is demonstrated that such removal of particles in the vicinity of jets affects the magnitude of long-range correlations only by a few percent.

Poster / 35

Longitudinal structure of the initial state from 3+1D CGC simulations

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We develop a framework to simulate the 3+1D dynamics of the initial energy deposition in heavy-ion collisions by taking into account the finite longitudinal extent of the colliding nuclei in the Color-Glass Condensate framework. Based on a simple model for the color charge distributions of the colliding nuclei, we demonstrate how the boost-invariant limit is recovered at high energies along with certain contrasting results that signify deviation from the high energy limit. We then develop a physical model of the three-dimensional color charge distributions in terms of small-x TMDs and study the non-trivial rapidity profile and the longitudinal fluctuations that emerge naturally within our framework.

Poster / 36

Non-equilibrium attractors of QCD kinetic theory at zero and finite density

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The out-of-equilibrium quark-gluon plasma and how it equilibrates in the pre-equilibrium stage of ultrarelativistic heavy-ion collision is of decent interest. Based on effective kinetic QCD theory including both gluon and all light quark/antiquark degrees of freedom, we investigate the pre-equilibrium dynamics of the quark-gluon plasma and how it connects to near-equilibrium viscous hydrodynamics. Based on numerical calculations we establish the presence of a universal attractor towards viscous hydrodynamics and discuss how the evolution changes gradually for systems with non-zero net baryon density. We finally discuss phenomenological applications of our results to connect the initial energy and charge density immediately after the collision with the entropy density and chemical potential at the beginning of hydrodynamics.

Poster / 38

Probing the partonic degree of freedom in high multiplicity p-Pb at 5.02 TeV collisions.

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Probing the quark gluon plasma in small system is a hot topic nowadays. By combining the thermal and hard parts, with the Cooper-Frye freeze-out, quark coalescence and hard parton fragmentation hadronization mechanisms, we investigate the p_T-spectra, the differential elliptic flow and the number of constituent quark (NCQ) scaling of pions, kaons and protons of high multiplicity p+ Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. More detailly, at low p_T range, thermal hadrons are generated by the hydrodynamics, at intermediate and high p_T range, we firstly coalescence the thermal and hard quarks, including the thermal-thermal, thermal-hard, hard-hard quark pairs recombinations, then the remnant hard partons those haven't found recombination partners are subjected to string fragmentation. We obtain a satisfactory description of elliptic flow and spectra over the p_T range from 0 to 6 GeV, and demonstrate that the coalescence process is indispensable for the differential elliptic flow and NCQ scaling at intermediate p_T. This provides an opportunity to distinguish the origin of the collectivity in high multiplicity p+Pb collisions.
[1] W.Zhao, C.M.Ko, Y.X.Liu, G.Y.Qin and H.Song, Phys.Rev.Lett. 125, 72301 (2020).
[2] W.Zhao, C.M.Ko, Y.X.Liu, G.Y.Qin and H.Song, arXiv:2001.10689 [nucl-th].

CGC / 39

Relativistic corrections to the vector meson light front wave function

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Exclusive vector meson production is a powerful process to probe the gluonic structure of protons and nuclei at small Bjorken-x, and it also makes it possible to study the geometry of the nuclei in the transverse plane. An accurate description of the process requires us to use a vector meson light front wave function that correctly represents the meson. Currently, the light front wave function is not fully understood and for heavy vector mesons the used light front wave functions are mostly either phenomenological or fully nonrelativistic.

We present our recent work [1] where we develop a new method to compute a light front wave function for heavy vector mesons based on long distance matrix elements constrained by decay width analyses in the Non Relativistic QCD framework. Our approach provides a systematic expansion of the wave function in quark velocity. The first relativistic correction included in our calculation is found to be significant, and crucial for a good description of the HERA exclusive J/Ψ-production data. When looking at cross section ratios between nuclear and proton targets, the wave function dependence does not cancel out exactly. In particular, the fully nonrelativistic limit is found not to be a reliable approximation even in this ratio. The important role of the Melosh rotation to express the rest frame wave function on the light front is illustrated.

[1] T. Lappi, H. Mäntysaari and J. Penttala, arXiv:2006.02830 [hep-ph], accepted for publication in Phys. Rev. D

Poster / 40

Finding α-clustering in ultrarelativistc heavy-ion collisions

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Measurements of anisotropic flow in relativistic heavy-ions have been shown to be highly sensitive to nuclear structure. With a proposed ^{16}O^{16}O run at the Large Hadron Collider and RHIC we study the potential for finding α-clustering in ^{16}O. Here we couple the iEBE-VISHNU event-by-event hydrodynamic package with ^{16}O nucleonic configurations from ab initio nuclear lattice effective field theory simulations. The transport model parameters used were obtained from a state-of-the-art Bayesian analysis in p-Pb and Pb-Pb collisions. We argue for two clear signals of α-clustering at both RHIC and LHC energies: first, that $c_2\{4\}$ should experience a sign change at ~20% centrality with α-clustering (in contrast to ˜50% using a Woods-Saxon), and second, that the centrality dependence of $v_n\{2\}$ should differ dramatically between the two beam energies.

CD / **41**

Linearized kinetic description of non-equilibrium dynamics in pp and pA collisions

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Momentum anisotropies caused by collective flow phenomena in HICs have been known to convey a rich amount of information on the collision geometry. In pp and pA collisions the system size is too small for the hydrodynamic description of these anisotropies to be applicable. Instead, a microscopic description of the non-equilibrium dynamics has to be employed. Indeed, kinetic theory simulations have reproduced the anisotropies, but detailed insight into the mechanisms of their emergence is obscured by the algorithmical implementation. This prompts attempts to complement them with analytical treatments, which is highly nontrivial. We simplify the problem by applying an appropriate expansion scheme of the Boltzmann equation and linearizing it in small anisotropic perturbations on top of an isotropic Gaussian background. To estimate the range of validity of these appoximations, we compare with numerical treatments of the same problem.

IS / **42**

Nuclear suppression in inelastic nucleon-nucleon cross section

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In high-energy heavy-ion collisions the standard procedure to turn the measured hard-process yields into centrality dependent cross sections is to use normalization factors calculated with the Monte-Carlo Glauber model. Canonically it is assumed that a necessary input, the inelastic nucleon-nucleon cross section, is unmodified wrt. the measured cross section in proton-proton collisions. At the LHC energies particle production is, however, dominated by the small-x region where nuclear suppression due to shadowing or saturation phenomena is expected. In this talk we elaborate this idea by using the recent Run 2 ATLAS data for electro-weak boson production in lead-lead collisions. Using the state-of-the art NNLO calculations we turn the canonical approach around and use the minimum-bias Z and W boson production measurements to obtain the normalization factors preferred by the data. Through Monte-Carlo Glauber simulations we find that the data prefer a significantly suppressed value for the inelastic nucleon-nucleon cross section, $41.5^{+16.2}_{-12.0}$ mb instead of the nominal 70 ± 5 mb. Furthermore, using the obtained value, the unexpected rise of Z and W boson nuclear modification ratios towards more peripheral collisions is tamed and the data become compatible with a flat behaviour or even hint of a mild decrease. Also, we demonstrate that the obtained suppression is in line with an eikonal minijet model including nuclear shadowing.

Poster / **44**

The dipole picture and the non-relativistic expansion

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We study exclusive quarkonium production in the dipole picture at next-to-leading order (NLO) accuracy, using the non-relativistic expansion for the quarkonium wavefunction. This process offers one of the best ways to obtain information about gluon distributions at small x, in ultraperipheral heavy ion collisions and in deep inelastic scattering. The quarkonium light cone wave functions needed in the dipole picture have typically been available only at tree level, either in phenomenological models or in the nonrelativistic limit. In this paper, we discuss the compatibility of the dipole approach and the non-relativistic expansion and compute NLO relativistic corrections to the quarkonium light-cone wave function in light-cone gauge. Using these corrections we recover results for the NLO decay width of quarkonium to e+e− and we check that the non-relativistic expansion is consistent with ERBL evolution and with B-JIMWLK evolution of the target. The results presented here will allow computing the exclusive quarkonium production rate at NLO once the one loop photon wave function with massive quarks, currently under investigation, is known. This talk is based on Phys.Rev.D 101 (2020) 3, 034030.

Poster / **45**

Measurements of longitudinal decorrelation of anisotropic flow in 27, 54.4 and 200 GeV Au+Au collisions from STAR

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Studies of longitudinal decorrelation of anisotropic flow provide unique constraints on the initial conditions and dynamical evolution of the quark- gluon-plasma in heavy-ion collisions. With data collected by the STAR experiment at RHIC, the factorization ratio for flow harmonics, rn(η, ηref)(n = 2,3), are obtained over a wide η range for 27, 54.4 and 200 GeV Au+Au collisions as a function of centrality. We observe a clear collision energy dependence indicating a stronger longitudinal decorrelation at lower collision energies. The 4-particle correlator (Rn(η, ηref)(n = 2, 3)) used to separate the event-plane twist from vn magnitude fluctuations, will also be presented. The results provide new insights into the three-dimensional modeling of the initial stage and the evolution of relativistic heavy-ion collisions, especially their collision energy dependence.

IS / 46

Far-From-Equilibrium Initial Conditions and the Search for the QCD Critical Point

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Initial conditions for relativistic heavy-ion collisions may be far-from-equilibrium but it is expected that on very short time scales the dynamics converge to a universal attractor that defines hydrodynamic behavior. We investigate how far-from-equilibrium effects may influence experimentally driven searches for the Quantum Chromodynamic critical point at RHIC. We find that the path to the critical point is heavily influenced by far from equilibrium initial conditions where viscous effects lead to dramatically different $\{T, \mu_B\}$ trajectories through the QCD phase diagram. We compare hydrodynamic equations of motion with shear and bulk coupled together at finite μ_B for both DNMR and phenomenological Israel-Stewart equations of motion and discuss their influence on potential attractors at finite μ_B and their corresponding $\{T, \mu_B\}$ trajectories. First we explore this systematically in a 0+1 system exhibiting Bjorken symmetries and then we relax these symmetries and investigate the implementation of this kind of study for 2+1 viscous BSQ hydrodynamics.

Poster / 47

Towards the discovery of primordial momentum anisotropies in nuclear collisions

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Momentum anisotropy, quantified by the coefficients of anisotropic flow, v_n, is observed in the final states of both small and large nuclear collision systems. In large A-A systems, anisotropy is of geometric origin, and determined by a hydrodynamic response to the initial spatial anisotropy of the system. In smaller systems, such as p-A, d-A or peripheral A-A collisions, a range of theoretical work suggests that the observed anisotropy also receives an important contribution from the momentum anisotropy present in the earliest stages of the collision. Such anisotropy is for example predicted by the color glass condensate effective theory of QCD. Until now, there has not been a clear way to obtain experimental evidence of this contribution to the observed anisotropy in small systems.

We show that a promising way to obtain such experimental evidence is by studying the correlation between v_2 and the average hadron transverse momentum, $\langle p_t \rangle$. We make clear predictions for phenomenological manifestations of the initial-state momentum anisotropy to be observed in future measurements. By means of a hybrid IP-GLASMA+MUSIC+UrQMD framework, we predict that in small systems, such as p-A or d-A, the correlation between v_2 and $\langle p_t \rangle$ decreases as a function of multiplicity, presenting a sign change from positive to negative. We further predict a qualitative change of the correlator in A-A collisions, as the collision energy is changed from top RHIC to LHC energies.

The experimental verification of these qualitative features will provide striking evidence of the presence and importance of the primordial momentum anisotropy predicted by the CGC.

Based on:
G. Giacalone, B. Schenke, C. Shen, https://arxiv.org/pdf/2006.15721.pdf

IS / 50

Beam-energy and collision-system size dependence of the anisotropic flow measurements from STAR

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For various centrality selections, we will present v_2 and v_3 measurements as a function of particle species and transverse momentum for several beam energies and system size. The longitudinal flow decorrelation $r_n(\eta, \eta_{ref})$ $(n = 2, 3)$ will be also presented at three different collision energies.

Investigating the beam-energy and collision-system size dependence of the anisotropic flow measurements (high momentum v_n, identified hadron v_n, and longitudinal flow decorrelation) is expected to provide crucial insights on the initial conditions and the transport properties of the QGP.

CD / 51

Measurements of v_2 and v_3 in pAu, dAu and ^{3}HeAu collisions at RHIC energy from STAR

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In this presentation, measurements of v_2 and v_3, in the p/d/^{3}He+Au collisions at 200 GeV will be shown as a function of p_T and multiplicity from STAR. The non-flow is studied with several different methods using p+p collision as a reference. It has been found that non-flow subtracted v_n signals are not sensitive to these methods. The v_2 signals are also extracted using four-particle azimuthal correlations for comparison. A system independence of v_3 has been observed for three small systems as a function of p_T. Comparison with hydro-calculations with different assumptions on the initial

conditions indicates that the initial geometry in small system may be dominated by sub-nulceon fluctuations. Similar to large systems, at comparable centralities, v_n in p+Au at RHIC has also been found to be similar to those in p+Pb at the LHC. In the context of our measurement we will also discuss the prospects of the proposed O+O run at RHIC. It will facilitate a direct comparison with the results from an anticipated O+O run at the LHC, and further help us to address the underlying physics for the anisotropic behavior and initial geometry in small system.

Poster / 52

A comparison of thermodynamical properties in high multiplicity pp and heavy ion collision

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Studying the QCD matter produced under extreme condition of temperature and density called Quark Gluon Plasma (QGP) is among the important goals of ongoing as well as upcoming particle physics experiments. QGP state is so far believed to be formed only in heavy ion collision and not in the pp collision. Unlike heavy ion collision, *pp* collision does not create QGP and hence the data from *pp* collision is being used to set a baseline to study the QGP formation in heavy ion collision. However, recent results from high multiplicity *pp* collision show some effects that are so far considered typical of heavy-ion collision. ALICE experiment in 2017 reported an enhancement in production of strange hadrons that may be a signature of QGP formation in high multiplicity *pp* collision. This result demonstrated the similarity in underlying physics mechanism that is responsible for particle production in high multiplicity *pp* and heavy ion collision opening up a new avenue in high energy physics to search for QGP state. With the availability of data at different multiplicities and energies, it may be interesting to analyse variation of different thermodynamical properties with multiplicity in *pp* collision and compare it with the variation shown by data from heavy ion collision experiment. \\

We will present a comparative study of thermodynamical properties obtained from transverse momentum spectra (p_T) of charged hadrons produced in heavy ion collision as well as in high multiplicity *pp* collision. Non extensive parameter q is a thermodynamical parameter which indicates how much a system deviate from thermal equilibrium. We will discuss interesting results related to the variation of parameter q with centrality as well as multiciplitiy over different p_T-range. We will also discuss the effect of hard processes on q parameter in *pp* and heavy ion collision.

Poster / 53

Beam-energy and system-size dependence of the high-pT azimuthal anisotropy with the STAR experiment

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Studying the quenching of high momentum particles in collision systems of various shapes and sizes provides crucial insights on the initial conditions and the transport properties of the QGP. Such insights can be obtained via investigations of the high transverse momentum (p_T) anisotropy

harmonics and their collision energy and system-size dependence. We present the beam-energy and system-size dependence of the elliptic and triangular anisotropy coefficients, v_2, and v_3, for several centrality selections as a function of p_T up to 15-20 GeV/c, from the STAR experiment. Our recent detailed measurements, with different long-range non-flow subtraction techniques, will be presented for U+U at 193 GeV, Cu+Au at 200 GeV, and Au+Au at 200, 54, and 27 GeV. The scaling properties of these data, as well as the comparisons to similar LHC measurements, are expected to provide unique constraints on both the initial-state geometry and the transport coefficient $\widehat{q}/T^3$. The implications of our measurements for a future O+O run at RHIC will also be discussed.

IS / **55**

Study of nuclear deformation effects in Au+Au and U+U collisions from STAR experiment

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Nuclear deformation is a ubiqutous phenomenon for most atomic nuclei, reflecting collective motion induced by interaction between valance nucleons and shell structure. In most cases, the deformation has a quadrupole shape β that is axially and refection symmetric, either prolate $\beta > 0$ or oblate $\beta < 0$. Collisions of deformed nucleus lead to large shape and size fluctuations in the initial state geometry, which after collective expansion, lead to enhance fluctuation of harmonic flow v_n and event-by-event mean transverse momentum $[p_T]$. Therefore detailed study of the v_n, and $[p_T]$ and correlations between them could probe the deformation parameter. In this talk, we present results of $[p_T]$ fluctuations and $v_n^2 - [p_T]$ correlation for $n = 2, 3, 4$ in near-spherical ^{197}Au+^{197}Au collisions at $\sqrt{s_{NN}} = 200$ GeV and highly-deformed ^{238}U+^{238}U collisions at $\sqrt{s_{NN}} = 193$ GeV. Significant differences for mean, variance c_2 and skewness c_3 of $[p_T]$ fluctuations are observed between the two systems as a function of centrality. The recently proposed intensive skewness of $c_3\langle[p_T]\rangle/c_2^2$, sensitive to the initial size fluctuation, is found to differ significantly between the two systems, particular in the ultra-central collisions. The $v_2^2 - [p_T]$ results remain positive over the full centrality in Au+Au collisions, while they change sign in 0-5\% central U+U collisions. In contrast, the $v_3^2 - [p_T]$ and $v_4^2 - [p_T]$ results are nearly identical between these two systems. The sign-change of $v_2^2 - [p_T]$ is used to provide novel ways to constrain β for Uranium nuclei in heavy ion collisions. Comparison with state-of-art model calculations is discussed.

CD / **56**

On the way to collectivity in rarely interacting systems

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We present the time resolved evolutions of the anisotropic flow coefficient v_n with consideration of both the linear and non-linear dependence on the initial eccentricities ϵ_m. The relativistic Boltzmann equation is utilized in the few collision regime in order to model the evolution of the phase space distribution.

Our analytically calculated time-dependent flow harmonics are compared to results of transport simulations.
Eventually, we discuss the important impact of the non-linear eccentricity contributions on the dynamical build-up of flow coefficient.

Poster / 57

Fluctuations of anisotropic flow in transport

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It is well established that the spatial asymmetries of the overlap region in the initial state of a heavy ion collision, together with their fluctuations, are quite faithfully translated into final-state momentum anisotropies by a fluid-dynamical evolution. We investigate the relationship between initial-state eccentricities and final-state anisotropic flow harmonics for a simplified two-dimensional gas of massless particles. We show how geometrical fluctuations from a Monte Carlo Glauber picture are mapped onto flow fluctuations, in particular the dependence on the mean number of rescatterings per particle in the expanding system.

PDF / 58

Low-p_T e^+e^- pair production in Au+Au collisions and exclusive J/ψ production in d+Au collisions at STAR

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In ultrarelativistic heavy-ion collisions, strong electromagnetic fields arising from the Lorentz-contraction of highly charged nuclei generate a large flux of quasi-real photons. STAR measurements of the Breit-Wheeler photon-photon fusion process in Ultra-Peripheral Collisions (UPC) have recently demonstrated that the colliding photons are linearly polarized and that the linear polarization leads to azimuthal angle modulations in the final state particle distribution. Similar measurements in peripheral collisions provide an opportunity to directly test the energy and impact parameter dependence of this newly observed phenomenon of QED.

It has been recently suggested that exclusive photo-nuclear J/ψ production in electron-deuteron scattering at the Electron-Ion Collider (EIC) would provide new insights into the Short-Range Correlations inside nuclei, particularly from the perspective of the underlying quark-gluon dynamics. While awaiting for EIC, data from deuteron-gold (d+Au) UPCs recorded by the STAR detector at the Relativistic Heavy Ion Collider can be used as a proxy to test various techniques and hypotheses.

In this presentation, we will present measurements of the $\gamma\gamma \rightarrow e^+e^-$ process at low transverse momentum in peripheral (80-100\%) Au+Au collisions and exclusive J/ψ photo-production measurements in ultraperipheral d+Au collisions. The implications of the related results will also be discussed.

Poster / 60

Multivariate cumulants in flow analyses: The Next Generation

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When two heavy ions collide at ultrarelativistic energies a very rich and non-trivial sequence of stages emerges in the evolution of the produced fireball. An important ongoing program in the field is the development of new observables and analysis techniques for anisotropic flow measurements, which would be sensitive only to one particular stage at a time in the heavy-ion evolution (e.g. only to the initial stages, to the deconfined Quark-Gluon plasma stage, etc.). In addition, the new observables which can disentangle the effects of different system properties (e.g. shear and bulk viscosities) are called for. In this contribution, we introduce new experimental methods and observables for anisotropic flow analyses in high-energy physics, which address these open questions.

We start by presenting the theory behind the recently developed observables dubbed higher order Symmetric Cumulants, whose development introduced a new paradigm in the field on how multivariate cumulants need to be used in flow analyses [1]. Since these are the first multivariate cumulants of flow amplitudes, by definition their measurements extract information that is not accessible to the previous lower order measurements. When it comes to fluctuations, these observables have revealed the new possible patterns of event-by-event flow fluctuations, which cannot be described with previous results. The current state-of-the-art in the field is that there are no observables which can separate effects of shear and bulk viscosities — since higher order Symmetric Cumulants exhibit in mid-central heavy-ion collisions different sensitivity to the isotropic fluctuations (predominantly sensitive to bulk viscosity) and shape fluctuations (predominantly sensitive to shear viscosity), they are the pioneering work in that direction.

Next, we present the new estimator for the improved measurements of symmetry plane correlations [2]. We demonstrate that the previous measurements, obtained with the standard Event Plane and Scalar Product methods are plagued by large systematic biases, and present how our new estimator removes them. We discuss the particular use case of constraining the true event-by-event symmetry plane correlations, which are inaccessible to the other methods.

Finally, we generalize in [3] the new paradigm for flow analysis with cumulants introduced in [1] for other observables of interest. We attempt for the first time to reconcile the strict mathematical formalism of multivariate cumulants, with the traditional usage of cumulants in the last two decades in this field. We demonstrate that, somewhat surprisingly, such reconciliation is not feasible in most of the cases. For instance, we prove that a widely used observable in this context, $v_n\{4\}$, fails to satisfy the mathematical properties of cumulants. As a consequence, this study yields to the next generation of multivariate cumulants to be used in flow analyses, which satisfy all mathematical properties of cumulants [3].

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[2] AB, M. Lesch, S. F. Taghavi, *''New estimator for symmetry plane correlations in anisotropic flow analyses,''* Phys. Rev. C **102**, 024910 (2020), arXiv:2004.01066 [nucl-ex].

[3] AB, M. Lesch, C. Mordasini, S. F. Taghavi, *''Multivariate cumulants in flow analyses: The Next Generation,''* work in progress (to be posted on arXiv and submitted for publication before the conference).

IS / 61

Towards fully 3-D simulations of heavy-ion collisions in the IP-Glasma Initial State

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In this talk, we report on phenomenological studies using the recently developed 3-D IP-Glasma initial state. Our 3-D formulation generalizes the boost invariant formulation by including both the rapidity evolution (JIMWLK) and the temporal evolution (Classical Yang-Mills) in the longitudinal direction. Special attention is paid to the local realization of Gauss law in a 3D+1 environment. Hydrodynamic evolution was carried out using MUSIC and the hadronic interaction was carried out using UrQMD to simulate full heavy ion collisions. Comparisons with the $\sqrt{s} = 2.76$ TeV LHC data including spectra, flow harmonics and correlations will be discussed.

IS / 62

Search for the chiral magnetic effect with spectator and participant planes in STAR

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In the initial stages of heavy-ion collisions, topological QCD vacuum fluctuations can induce local parity and charge-parity violations, evincing charge separation in the presence of strong magnetic field, a phenomenon known as the chiral magnetic effect (CME). The CME-driven charge separation is along the magnetic field direction, mainly produced by the spectator protons in relativistic heavy-ion collisions. The major background to the CME is related to the elliptic flow anisotropy (v_2), determined by the initial participant geometry. Because of fluctuations, the harmonic planes determined by spectators ($\psi_{\rm sp}$) and participants ($\psi_{\rm pp}$) are different. In other words, a heavy-ion collision provides us two distinct planes; the v_2 is stronger along $\psi_{\rm pp}$ and weaker along $\psi_{\rm sp}$, whereas the magnetic field is weaker along $\psi_{\rm pp}$ and stronger along $\psi_{\rm sp}$. The $\Delta\gamma$ measured with respect to $\psi_{\rm sp}$ and $\psi_{\rm pp}$, therefore, contain different amounts of the CME signal and non-CME background and this offers us an opportunity to separate these two contributions˜[1]. We report the azimuthal correlator $\Delta\gamma$ measurements with respect to $\psi_{\rm sp}$ measured by spectator neutrons using the zero degree calorimeters with shower maximum detector (ZDC-SMD) and to $\psi_{\rm pp}$ measured by the 2nd harmonic event plane of produced particles using time projection chamber (TPC). We extract the fraction of the possible CME signal (and the background) from those measurements in 200 GeV Au+Au collisions, and discuss implications on topological QCD and future opportunities.

[1] Hao-Jie Xu, et al., Chin. Phys., C42 (2019) 084103, arXiv:1710.07265

Poster / 63

A collision geometry-based 3D initial condition for relativistic heavy-ion collisions

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We present a way to construct 3D initial conditions for relativistic heavy-ion collisions based on the Glauber collision geometry [1]. Local energy and momentum conservation conditions are imposed to set non-trivial constraints on our longitudinal profiles' parameterizations for the system's initial energy density and flow velocity. We show that the $\sqrt{T_A T_B}$ scaling of initial energy density profiles results from the longitudinal momentum conservation. After calibrating parameters with charged hadron rapidity distributions in central Au+Au collisions, we test model predictions for particle rapidity distributions in d+Au and peripheral Au+Au collisions in the Beam Energy Scan (BES) program at Relativistic Heavy-Ion Collider (RHIC). Simulations and comparisons with measurements are also made for Pb+Pb collisions at Super Proton Synchrotron (SPS) energies. We demonstrate that elliptic flow measurements in heavy-ion collisions at $\sqrt{s} \sim 10$ GeV can set strong constraints on the dependence of Quark-Gluon Plasma shear viscosity on temperature and net baryon chemical potential. The effects of event-by-event fluctuations on flow observables will be quantified in this approach.

[1] C. Shen and S. Alzhrani, "A collision geometry-based 3D initial condition for relativistic heavy-ion collisions," Phys. Rev. C 102, 014909 (2020)

FE / **64**

STAR Heavy Ion and Cold QCD programs for 2021+ runs

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The STAR Collaboration has performed several detector upgrades in the last few years, including the replacement of the inner chambers of the Time Projection Chamber (iTPC, with pseudorapidity $0 < |\eta| < 1.5$), the Event Plane Detector (EPD, $2.1 < |\eta| < 5.1$) and the Endcap Time of Flight (eTOF, $-1.5 < \eta < -1.0$) that are commissioned and fully operational since 2019. A full suite of forward detectors, including a tracking system consisting of a silicon and small Thin Gap Chamber (sTGC) coupled with both electromagnetic and hadronic calorimetry, will be installed covering the forward pseudorapidity region of $2.5 < \eta < 4$ before 2022. These upgrades will substantially extend STAR's kinematic reach and further enhance its particle identification capabilities.

The primary scientific goal for the STAR Collaboration in 2021 is to complete the second phase Beam Energy Scan (BES-II) program. We will also explore the origin of small system collectivity via O+O collisions in 2021. In 2023 and 2025, with the anticipated Au+Au runs, we will be able to map out the 3-dimensional initial state of heavy-ion collisions at RHIC energies. Beginning in 2022, STAR will be in a unique position to provide the essential exploration of the spin and flavor structure of nucleons with the installation of the full suite forward detectors. This enables studies of the universality and factorization in transverse spin phenomena, nuclear PDFs, and fragmentation functions over a wide range of momentum fractions, x. To carry out these measurements, the STAR collaboration is planning to collect data from transversely polarized p+p collisions at 500 and 200 GeV and p+Au collisions at 200 GeV in 2024.

In this talk, we will outline prospects for key measurements envisioned to be carried out in the next few years, as well as report on the progress of the STAR forward upgrade preparations.

CD / **65**

Dynamical modeling of the initial energy-momentum and baryon

charge distributions for heavy-ion collisions at RHIC Beam Energy Scan energies

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Building upon Ref. [1], we present an improved three-dimensional dynamical initialization model for heavy-ion collisions, implementing local energy-momentum conservation and baryon charge fluctuations at string junctions [2]. These improvements lead to an excellent description of the charged hadron and net proton rapidity distributions in Au+Au collisions from 7.7 to 200 GeV. Based on these results, we quantify the amount of baryon stopping at the initial impact, and baryon transport during the hydrodynamic evolution and hadronic scattering phases. The effects of the finite overlap time at low collision energies on hadronic flow observables are quantified. Keeping all model parameters fixed, we extrapolate our model to asymmetric (p, d, ^{3}He, Cu)+Au collisions at RHIC BES energies. We achieve a good description of the measured particle rapidity distributions for those collision systems, demonstrating our model's predictive power. We present first results on studies of anisotropic flow and net-proton cumulants, relevant for the critical point search.

[1] C. Shen and B. Schenke, "Dynamical initial state model for relativistic heavy-ion collisions," Phys. Rev. C97 (2018), 024907
[2] D. Kharzeev, "Can gluons trace baryon number?," Phys. Lett. B 378, 238 (1996)

IS / **66**

Accessing the initial stages of heavy ion collisions with photons

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We present new results on photon production in heavy ion collisions, including prompt, pre-equilibrium, and thermal photon production from quark gluon plasma and hadron gas phases. We use a model consisting of IP-Glasma initial condition, KoMPoST pre-equilibrium evolution, MUSIC hydrodynamics, and UrQMD transport to both describe hadron production and provide input for the calculation of photon production. We consider photon rates from the pre-hydrodynamic and hydrodynamic stages, and for several channels corrections due to deviations from thermal equilibrium are included for both shear and bulk viscous effects. We present results on the photon azimuthal momentum anisotropy and photon-hadron event plane decorrelation, which have the potential to provide information on the early stages of the collision.

Poster / **67**

Novel relaxation time approximation to the relativistic Boltzmann equation

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In 1974, J. L. Anderson and H. R. Witting proposed the Relaxation Time Approximation (RTA) to the relativistic Boltzmann equation [1], following all the development already made in the non-relativistic case by Bhatnagar, Gross and Krook [2]. This approximation is used in several fields of physics and has been recently employed to study the hydrodynamization of the matter produced in ultrarelativistic heavy ion collisions [3]. However, we shall demonstrate that the approximation proposed by Anderson and Witting contains basic flaws, not being consistent with fundamental properties of the collision operator. The main issue is that this approximation is in general inconsistent with microscopic and macroscopic conservation laws, which leads to several problems when trying to model relativistic gases using energy dependent relaxation times or general matching conditions. In this contribution, we propose a new relaxation time approximation which fixes these basic flaws. We then show how such a new formulation of the approximation affects the expression of transport coefficients and the energy dependence of the nonequilibrium single particle distribution function.

CGC / 68

Di-hadron correlations in p+p, p+Au and p+Al collisions at STAR

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Two-particle azimuthal correlation has been proposed to be one of the most direct and sensitive channels to access the underlying nonlinear gluon dynamics.
In hadron collisions at RHIC, forward particle production probes gluons at small x where the gluon density rises sharply.
During the 2015 RHIC run, STAR has collected data for measuring azimuthal correlations of neutral pions detected with the Forward Meson Spectrometer (FMS, 2.6 $\leq \eta \leq$ 4.0) in p+p, p+Au and p+Al collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV.
In this talk, we will present the measurement of di-hadron correlations as a function of A and transverse momenta of both the trigger π^0 (1.4 GeV/c $< p_T <$ 5 GeV/c) and the associated back-to-back π^0 (1 GeV/c $< p_T <$ 2.8 GeV/c).

Poster / 69

The effect of the equation of state on η/s of strongly interacting matter

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The properties of QCD matter produced in ultrarelativistic heavy ion collisions can be determined in a global analysis of LHC and RHIC observables. Bayesian analysis [1] has provided meaningful credibility ranges for the ratio of shear viscosity to entropy density η/s, as well as for key parameters describing the initial state, essentially confirming earlier results like those obtained using the EKRT model [2]. We report here the results of our study [3] where we investigate the temperature dependence of η/s using a piecewise linear parametrization. We perform a global Bayesian model-to-data comparison on Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and Pb+Pb collisions at 2.76 TeV and 5.02 TeV, using a 2+1D hydrodynamical model, with the initial entropy distribution taken as an average of a large number of fluctuating event-by-event EKRT initial states. We provide three new parametrizations of the equation of state (EoS) based on contemporary lattice results and hadron resonance gas. We use these parametrizations, named $s83s_{18}$, $s87h_{04}$, and $s88h_{18}$, along with the earlier $s95p$ parametrization to explore the uncertainties caused by the choice of the EoS. We find η/s most constrained and almost independent of T in the temperature range $T \approx 150$–220 MeV, where, for all EoSs, $0.08 < \eta/s < 0.23$ when taking into account the 90% credibility intervals. In this temperature range the EoS parametrization has only a small $\sim$10% effect on the favored η/s value, which is less than the $\sim$30% uncertainty of the analysis using a single EoS parametrization. Our parametrization of $\eta/s(T)$ leads to a slightly larger minimum value of $\eta/s(T)$ than the previously used parametrizations.

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[2] H. Niemi, K. J. Eskola and R. Paatelainen, Phys. Rev. C 93, no.2, 024907 (2016).
[3] J. Auvinen, K.J. Eskola, P. Huovinen, H. Niemi, R. Paatelainen and P. Petreczky, arXiv:2006.12499 [nucl-th], to appear in Phys. Rev. C.

Poster / 72

Kinematic dependence of the v2 measured in small collision systems at PHENIX

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We present the results of the second-order Fourier coefficients (v2), which characterizes the azimuthal anisotropy, in p+p, p+Au, and d+Au collisions at sqrt(sNN) = 200 GeV. The v2 values are calculated via the two-particle correlation method. To investigate the role of initial geometry effects, the measured v2 is extracted by two different kinematic selections. The two results are compared and its ratio will be shown as a function of pT and charged-particle multiplicity to evaluate the validity of the flow factorization. The results are compared to AMPT calculations, which reproduces the flow factorization breaking in small collisions systems.

PDF / 74

PHENIX Results on J/ψ production in small systems

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The production of heavy quarkonia states in p+A collisions is sensitive to a range of initial- and final-state effects that must be quantified in order to fully understand the dynamics of heavy quarks in the QCD medium. One way to disentangle the various effects is by measuring charmonia production in different rapidity and momentum regions, using various beam species. Here we present finalized PHENIX results on J/ψ modification from the RHIC system-size scan, which include p+Al, p+Au, and ^{3}He+Au measurements at forward and backward rapidity. Comparisons with state-of-the-art theory calculations and LHC data will be discussed.

NT / **75**

Using machine learning to understand the properties of the QCD critical point

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One of the main goals of the second phase of the Beam Energy Scan program at RHIC is to search for the QCD critical point. In order to study the thermodynamic effects of the presence of a critical point, we constructed a family of equations of state using a model that couples Lattice QCD results to a parameterized critical point from the 3D Ising model universality class. The mapping of the Ising critical point onto the QCD phase diagram gives rise to free parameters that control its position and size/shape of the critical region. In this work, we demonstrate how active sampling coupled with a variety of machine learning models can be used as a tool to identify choices of free parameters that result in inconsistent thermodynamics. In particular, we study the performance of supervised logistic regression, Support Vector Machine (SVM), random forest, and deep learning algorithms, in both passive and active learning settings. This approach can rule out pathological parameter sets at a low computational cost. Our procedure can be applied to constrain other high-dimensional models relevant to experimental searches in heavy-ion collisions.

Poster / **76**

Spin Polarization in QGP

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Measurements made recently by the STAR collaboration show that the Lambda hyperons produced in relativistic heavy-ion collisions are subject to global spin polarization with respect to an axis coincident with the axis of rotation of the produced matter. Recently formulated formalism of relativistic hydrodynamics with spin, which is a generalization of the standard hydrodynamics, is a natural tool

for describing the evolution of such systems. This approach is based on the conservation laws and the form of the energy-momentum tensor and spin tensor postulated by de Groot, van Leeuwen, and van Weert (GLW). Using Bjorken symmetry we show how this formalism may be used to determine observables describing the polarization of particles measured in the experiment.

Poster / 78

I_{AA} in pp, p-Pb and Pb-Pb collisions as a function of the Underlying Event activity with ALICE

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It is well established that high multiplicity pp and p-Pb collisions exhibit many of the signatures associated with the formation of a sQGP in heavy-ion collisions. If final-state interactions are responsible for this, one would also expect some amount of jet modification.

Here, we present the search for jet quenching effects by studying the yield of charged particles associated with high transverse momentum triggered particles measured with the ALICE detector in pp, p-Pb and Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. The study has been performed as a function of charged-particle multiplicity in the transverse region with respect to the leading-charged particle in the event. We observe a significant suppression in the yield of associated charged particles with p_{T} $>$ 4 GeV/c in central Pb-Pb collisions relative to minimum bias pp collisions, while on the near side a moderate enhancement is found. However, we do not observe any suppression (enhancement) in away (near) side in pp and p-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV relative to minimum bias pp collisions, which indicates that jet-quenching effects are small or absent in these systems.

CGC / 79

Color charge correlations in the proton

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Color charge correlations in the proton at moderately small x are extracted from its light-cone wave function. The charge fluctuations are far from Gaussian. Correlators are described by n-body GPDs which exhibit interesting dependence on impact parameter as well as on the relative transverse momentum (or distance) of the gluon probes.

This analysis provides initial conditions for small-x Balitsky-Kovchegov evolution of the dipole scattering amplitude which include impact parameter and r*b dependence, and with non-zero C-odd component due to three-gluon exchange.

The color charge correlators could be measured through various exclusive processes at the EIC. They also determine unintegrated gluon distributions of the proton relevant for gamma - p, p - p, and p - A collisions.

IS / 80

Probing the initial stages of heavy ion collisions with direct photons at PHENIX

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Direct photons are emitted unscathed from all the stages of the relativistic heavy ion collisions and therefore are an excellent probe to study the properties of Quark Gluon Plasma (QGP) as they do not interact strongly with the medium. PHENIX has already measured a direct photon excess in Au+Au collisions at 200 GeV in the low momentum region with respect to p+p collisions. With the results from RHIC and LHC hinting at the onset of QGP in small systems and the access to a large dataset of p+p and p/d/3He+Au collisions at 200 GeV, it will be interesting to examine the production of low momentum direct photons and search for indications of thermal photon emissions in these systems. In this talk, the recent measurements of low-momentum direct photons from p+p, p+Au and Au+Au collisions will be presented and the status of the measurement in d/3He+Au will be discussed.

Poster / 81

Pre-equilibrium dynamics of heavy ion collisions based on hadronic transport

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We present a systematic study of the pre-equilibrium dynamics of relativistic heavy-ion collisions using the microscopic transport model SMASH. We focus on the time evolution of the distributions of energy-momentum currents and three types of conserved charges, produced by string excitation and fragmentation at intermediate and high energies. We address their dependence on the system size and collision energy by analyzing (Au, Cu, d)+Au collisions at $\sqrt{s_{\rm NN}} = 19.6$ GeV and 200 GeV. The space-time and momentum correlations for net baryon, strangeness, and electric charges are studied as a function of the longitudinal proper time. Especially, we investigate the spectators' contributions to the conserved charge distributions within this transport approach. The rapidity decorrelations of initial eccentricities, initial orbital angular momentum, and vorticity tensor distributions are studied as functions of centrality for those collisions.

Poster / 82

Prospects of exploring nucleon and nucleus structures in hadronic collisions with the STAR experiment in 2022 and beyond

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The exploration of the fundamental structures of nucleon and nucleus has always thrived on the complementarity of lepton scattering and purely hadronic probes. With the Electron Ion Collider (EIC) on the horizon, it becomes more urgent than ever to complete key measurements in this regard with high precision in hadonic p+p and p+Au collisions during the final years of RHIC running. When combined with future data from the EIC, these measurements will be essential to establish the validity and limits of factorization and universality.

To carry out these measurements, the STAR collaboration is planning to collect data from transversely polarized p+p collisions at $\sqrt{s}$ = 510 GeV in 2022 and transversely polarized p+p and p+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV in 2024. A full suite of forward detectors will be installed at STAR prior to the p+p run in 2022, providing excellent charged-particle tracking at high pseudorapidity ($2.5 < \eta < 4$) for the first time, coupled with both electromagnetic and hadronic calorimetry. In addition, detector upgrades realized for the Beam Energy Scan II program further extend and improve STAR's tracking and particle identification capabilities beyond those existed for previous p+p and p+Au runs. %The planned two years of running and detector upgrades will allow STAR to measure fundamental proton properties, such as the Sivers and transversity distributions, over nearly the entire range of $0.005 < x < 0.5$. By exploiting these new capabilities, STAR will determine fundamental proton properties such as the Sivers and transversity distributions over nearly the entire range of $0.005 < x < 0.5$. We will also probe fundamental properties of heavy nuclei including nonlinear low-x gluon dynamics, nuclear PDFs, nuclear fragmentation functions, and spin-dependent hadronization.

In this talk, we will outline prospects for key measurements envisioned to be carried out in 2022 and 2024, as well as briefly reporting on the progress of the STAR forward upgrade preparations.

Poster / 83

Hot spots and gluon field fluctuations as causes of eccentricity in small systems

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We calculate eccentricities in dilute-dense limit of pA collisions, by calculating correlations functions of the energy density field of the Glasma immediately after the collision event at proper time $\tau = 0^+$. The proton is treated as a collection of a finite number of hot spots of Gaussianly distributed color charges, as in the IPGlasma setup. The correlations of its color charges are assumed to be Gaussian and are described by the MV model. However, instead of performing averages using Monte Carlo implementations we calculate the color charge and hot spot averages analytically to allow for better control over model parameters. The nucleus is taken to be an infinite sheet of color charge, and its color charge correlations are also assumed to be Gaussian and are described by the GBW model. For the nucleus we evaluate the full nonlinear Gaussian color charge correlations and the proton is expanded to the first order in the proton saturation scale in the dilute limit. We proceed to compute the one and two point functions for the energy density, performing the CGC and hot spot averaging procedures analytically. We then use these results to compute eccentricities originating from proton and nucleus side fluctuations separately, and find that proton fluctuations are the dominating source of eccentricity and the nucleus color fluctuations only give a negligible correction.

Poster / 84

Exploring the magnetic field in heavy-ion collisions through spin alignment measurements at ALICE

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Spin alignment of vector mesons produced in non-central heavy-ion collisions could occur due to the large angular momentum and intense magnetic field expected in the initial stages of these collisions. Experimentally, vector meson polarization is observed from the angular distribution of the decay daughters with respect to a quantization axis. The study of the angular distribution of the decay products leads to a measurement of the zeroth element of the spin density matrix element ρ_{00}. Any deviation of the value of ρ_{00} from 1/3 would indicate the presence of spin alignment. We report on recent measurements of spin alignment for K*(892)^0 and $\phi(1020)$ mesons at midrapidity in Pb-Pb and pp collisions at the LHC with the ALICE detector. The transverse momentum, centrality and energy dependence of ρ_{00} will be shown. The results will be discussed together with those obtained for the K^0_s scalar meson and obtained with respect to the random orientations of the production and event planes.

Poster / 85

Studies of light-flavor hadron production in pp, pA and AA collisions with ALICE at the LHC

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Studies of the production of light-flavor hadrons in different collision systems are of prominent importance to investigate the hadronisation process. Recently, the ALICE Collaboration has presented results from pp, pA and AA collisions, exploiting its detector's excellent tracking and PID capabilities down to low transverse momentum. Pions, kaons, protons and (multi-)strange hadrons have been measured at different energies. The results revealed unexpected features, such as strangeness enhancement and collective-like behavior in small collision systems, formerly thought to be achievable only in heavy-ion collisions. These features are quantitatively similar across colliding systems if the charged particle multiplicity generated in the collision is used as a reference. To understand the origins of these unexpected phenomena, event shape observables can be exploited, as they serve as a powerful tool to disentangle soft and hard contributions to particle production.
Results on strange particle production as a function of event multiplicity in different collision systems and at different center-of-mass energies will be presented. Measurements on the production of light-flavor hadrons as a function of Transverse Spherocity (S_0) and Relative Transverse Activity (R_{T}) will be also shown. The evolution of charged particle average transverse momentum with multiplicity, S_0, and R_{T} will be discussed in the context of radial flow and state-of-the-art phenomenological models.

MPI / 86

Exploring strangeness enhancement through strange-hadron correlation studies at ALICE

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Interesting features in the production of strange hadrons have been revealed in heavy-ion collisions. Observations include: the development, with centrality, of a peak in the Λ/K^0_S ratio at intermediate p_{T}; and the enhanced yield of strange and multi-strange baryons, compared to minimum bias pp collisions. These features have been further investigated by studying pp collisions as a function of the produced charged particle multiplicity. Both features exhibit changes in this multiplicity range with the increase in the yield of the multi-strange Ξ and Ω baryons, normalised to the pion yield, being particularly striking.

The origin of these phenomena remains an open question. Are they related to particles produced in soft interactions or is a growth hard processes, such as jets, responsible?

The ALICE experiment has extended this study to look differentially at particle production by selecting regions of events associated with hard scattering in both pp and p-Pb collisions. New measurements in this area are presented including: the measurement of strange and multi-strange particle production in pp and p-Pb collisions in and outside of jets, using the standard jet reconstruction technique; two-particle azimuthal correlations of high-p_{T} charged hadrons with strange and multi-strange particles; and strangeness production in defined different regions with respect to the azimuthal direction of leading particle (R_T). They indicate that soft (out of jet) processes are the dominant contribution to strange particle production.

Poster / **87**

Search for jet quenching effects in small collision systems in ALICE

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Jet quenching is a possible consequence of the formation of a quark-gluon plasma (QGP) in collision systems, but to date no significant jet quenching has been observed in small systems. At the same time final states of pp and pPb collisions with large underlying event activity exhibit collective behavior that resembles hydrodynamic evolution. It is believed that observed level of the underlying event activity is related to intensity of multipartonic interactions and consequently also to the created volume of the hot and dense QCD matter.

Recent ALICE results on particle production in pp, p-Pb and Pb-Pb as a function of the (relative) transverse activity, (*RT*) NT, will be presented and compared to models. By subtracting the transverse activity and comparing to minimum-bias pp collisions, it is possible to obtain IAA as a function of NT. This IAA has a smooth trend in both near and away regions across all three systems and is consistent with little or no jet quenching in pp and p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. Further we will report results of jet quenching searches in high-multiplicity pp collisions at $\sqrt{s} = 13$ TeV, where we look for the broadening of the acoplanarity distribution measured by the semi-inclusive distribution of jets recoiling from a high-p_{T} hadron. Here, significant broadening is observed in the acoplanarity distribution obtained from high-multiplicity events w.r.t. minimum bias events, consistent with jet quenching. However, qualitatively similar features are also seen in pp collisions generated by the PYTHIA which does not include the simulation of jet quenching or any other QGP effects. We will discuss the current status of this analysis, and give prospects to understand the origin of this striking phenomenon.

CGC / **88**

Charged- and neutral-particle production in proton-lead collisions at 5.02 and 8.16 TeV with ALICE

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Particle production at LHC energies results from the interplay of hard- and soft-QCD processes and is sensitive to non-linear QCD evolution in the initial state. In particular, for p-Pb collisions, one can use the proton to probe the low-x dense gluonic fields of the Pb nuclei. The multiplicity and rapidity dependence of charged- and neutral-particle production, therefore, provides important constraints for initial state models and calculations describing the particle production mechanisms.

ALICE has unique coverage at forward rapidity. The Photon Multiplicity Detector can measure neutral-particle production over a kinematic range of $2.3 < \eta < 3.9$. The Forward Multiplicity and the Silicon Pixel Detectors can measure charged particles over a wide range of $-3.4 < \eta < 5.0$. For the first time, results at forward rapidity will be presented for both charged and neutral particles in p-Pb collisions at 5.02 TeV and 8.16 TeV. The multiplicity and centrality dependence will be discussed. In this case, the centrality of the collisions is determined using the energy deposited in the Zero-Degree Calorimeters. Finally, the results will be compared to model calculations based on different particle-production mechanisms and initial conditions in the forward soft-QCD regime, in which perturbative-QCD calculations are impossible.

MPI / 89

Very forward energy emission as a function of particle production at midrapidity in pp and p-Pb collisions with the Zero Degree Calorimeters of ALICE

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Using the ALICE Zero Degree Calorimeters (ZDC) it is possible to study the very forward charged and neutral energy in pp and p-Pb collisions. By correlating these measurements with the midrapidity particle production, one obtains new direct insights into the initial stages of the collisions. New results on the energy detected in neutron and proton ALICE ZDC in pp collisions at $\sqrt{s}$ = 13 TeV will be discussed and compared with results for the proton breakup in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV. These measurements, performed for the first time at LHC, cover over 18 units of pseudorapidity.

Studying correlations between high-p_{T} particles at midrapidity and the forward energy provides complementary information to the underlying event (UE) measurements, which are usually interpreted in the framework of models implementing centrality dependent MPI production. The results will be compared with the expectations of several hadronic interaction models. These new measurements provide fundamental indications on the validity of models in describing the beam remnants at very-forward rapidities, where perturbative QCD cannot be used.

CD / 90

First measurements of genuine three-harmonic correlations in Pb-Pb collisions with ALICE

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Multiparticle azimuthal correlations have proved their usefulness to study and constrain the properties of the quark-gluon plasma (QGP) produced in ultrarelativistic heavy-ion collisions. Recently, the event-by-event correlated fluctuations between two different flow amplitudes have been measured using Symmetric Cumulants. These results exhibit a better sensitivity to the transport properties of the QGP and the initial state than the studies of single flow amplitudes.

The question of the existence of genuine correlations between three and more flow amplitudes naturally arose. To answer it, the generalization of the Symmetric Cumulants to more than two flow amplitudes has been recently proposed. The measurements of such correlations can provide new information on the initial state and dynamical properties of the system created in heavy-ion collisions, which is by definition inaccessible through the previous flow measurements.

In this talk, we will focus on the first results of these new higher order Symmetric Cumulants in the case of three different flow amplitudes obtained in Pb–Pb collisions collected by ALICE at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV and 5.02 TeV. In particular, the centrality dependence and comparison with the predictions from state-of-the-art hydrodynamics models will be shown.

CD / 91

Fluctuations and correlations of flow in heavy-ion collisions measured by ALICE

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Heavy-ion collisions at ultra-relativistic energies at the LHC provide a unique opportunity to study the strongly interacting quark-gluon plasma (QGP). Anisotropic flow phenomena provide valuable information on the initial conditions of heavy-ion collisions, the transport coefficients, and the dynamic evolution of the created QGP. In this talk, we present investigations of the transverse-momentum dependent flow vector fluctuations in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. Using newly proposed multiparticle correlations, for the first time we separate the potential contributions from flow angle and flow magnitude fluctuations and report the first evidence of both effects in Pb–Pb collisions.

In addition, we discuss how to use event shape engineering (ESE) techniques to select the initial conditions and change the event-by-event v_n distribution. Furthermore, we show a novel approach to study the correlations between different order coefficients v_n and v_m, as well as the nonlinear flow modes, using the ESE technique. Together with the comparisons to the state-of-the-art hydrodynamic calculations, we can significantly improve the understanding of the initial conditions and the dynamic evolution of the created systems in heavy-ion collisions at the LHC.

Poster / 93

Characterizing system dynamics with two-particle transverse momentum correlations in pp, p-Pb, and Pb-Pb collisions at ALICE

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In ultrarelativistic heavy-ion collisions, two-particle transverse momentum correlations provide information on the system dynamics and properties. Recently published results by ALICE on the two-particle transverse momentum correlator G_2 in Pb-Pb collisions demonstrate a narrowing of the correlation function in the azimuthal direction from peripheral to central collisions, which has initially been attributed to radial flow and delayed hadronization, and a broadening trend in the longitudinal direction, which has been associated with momentum transfer due to viscous effects. Furthermore, the longitudinal broadening is found to be consistent with the hypothesized lower bound of η/s and is in qualitative agreement with values obtained from anisotropic flow measurements. It is thus of high interest to elucidate how those transverse momentum correlators behave in small collision systems.

In this contribution we will present new measurements of G_2 in pp and p-Pb collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s_{\rm NN}} = 5.02$ TeV, respectively, by the ALICE experiment at the LHC. The evolution of the correlation function with multiplicity from small to large collision systems will be discussed. The results will be compared and contrasted with two-particle number correlations (R_2) and balance functions, as well as Monte Carlo models.

Poster / **94**

Quarkonia production and excited state suppression in pp and p-Pb with ALICE

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Quarkonia are considered a distinguished tool to study the strongly-interacting medium formed in ultra-relativistic heavy-ion collisions. However, their production is also sensitive to initial state effects such as the modifications of the parton distribution functions (PDF) in the nucleus or the gluon saturation at low Bjorken-x. These phenomena are typically studied using proton-nucleus (p-A) collisions where their effects are considered to be the dominant. Moreover, quarkonium measurements in high-multiplicity proton-proton (pp) collisions can shed light on the role of Multiple Parton Interactions (MPI) which are expected to be relevant for the production of heavy quarks at the LHC energies.
In this contribution, the latest quarkonium measurements performed by the ALICE Collaboration in pp and p-Pb collisions will be presented. Final results on the nuclear modification factor for ψ(2S), Υ(1S) and Υ(2S), measured at forward and backward center-of-mass rapidities in p-Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV will be shown, with a focus on the new centrality dependent ψ(2S) results. A broad collection of multiplicity-dependent quarkonium measurements in pp collisions at $\sqrt{s} = 13$ TeV at mid- and forward-rapidity will be also presented. This includes, among others, recent results on the inclusive ψ(2S) and bottomonium production at forward rapidity. The current theoretical interpretation of the various results will be also discussed.

IS / **96**

Low-mass dielectron measurements with ALICE at the LHC

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Dileptons and photons are unique tools to study the space-time evolution of the hot and dense matter created in ultrarelativistic heavy-ion collisions. They are produced continuously by a variety of sources, in particular prompt and thermal photons and semi-leptonic heavy-flavour hadron decays, during the entire history of the collision and traverse the medium with negligible final state interaction. So they can carry undistorted information on early stages of the collision.

In this contribution, we will present results from the recent measurements of e^+e^- pair production in pp and p-Pb collisions at the center-of-mass energy $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. Charm and beauty cross sections are extracted to investigate possible cold nuclear matter effects such as shadowing by comparing different nPDFs on the nuclear modification factor R_{pPb}. New results obtained in Pb-Pb collisions at the same center-of-mass energy will be also shown.

The expected performance of dielectron measurements with the upgraded ALICE detector beyond LHC Run 3 will also be discussed.

Poster / 98

Study of global and local polarization of Λ and $\bar{\Lambda}$ hyperons in Pb-Pb collisions at ALICE

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The system created in relativistic nucleus-nucleus collisions may possess large orbital angular momentum leading to the particle global polarization perpendicular to the reaction plane. The local asymmetries in the velocity fields due to anisotropic flow can generate vorticity and particle polarization along the beam direction. In parity violating weak decays of hyperons, the momentum direction of the decay baryon is correlated with the hyperon spin and can be used to measure the hyperon polarization and thus estimate the global and local vorticity of the system created in relativistic heavy ion collisions. In this talk, the recent experimental measurements of the global and local polarization along the beam direction of the Λ and $\bar{\Lambda}$ hyperons in Pb-Pb collisions at 2.76 and 5.02 TeV in ALICE will be discussed.

CGC / 99

Study of open heavy-flavour production and anisotropy in p-Pb collisions with ALICE

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Heavy quarks (charm and beauty) are primarily produced in hard-scattering processes with large momentum transfer due to their large masses. They are effective probes to study cold-nuclear-matter (CNM) effects such as gluon saturation, shadowing, k_{T} broadening and energy loss in CNM in p-Pb collisions. In recent years, effects ascribed to the collective expansion of the deconfined nuclear matter, the quark-gluon plasma (QGP) produced in Pb-Pb collisions, such as long-range flow-like correlations and the enhancement of baryon production, have also been observed at high multiplicity in small system (pp and p-Pb) collisions. The study of open heavy flavours in high-multiplicity p-Pb collisions provides important information to understand how the possible presence of collective effects could modify the production of heavy flavours.

In this contribution, the nuclear modification factors ($R_{\rm pPb}$ and $Q_{\rm pPb}$) of D mesons measured with the ALICE detector via their hadronic decays at midrapidity in p-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV will be presented. The results provide a significant constraint on the nuclear-modified parton distribution function at small Bjorken-x. The elliptic flow of open heavy-flavour particle at mid and forward-rapidity in p-Pb collisions at $\sqrt{s_{\rm NN}}$ = 8.16 and 5.02 TeV will be discussed. Such studies are important to explore the origin of the collective-like effects observed in small systems. At final, the self-normalized yield of open heavy-flavour particle as a function of multiplicity in p-Pb collisions at $\sqrt{s_{\rm NN}} = 8.16$ TeV, which provides a natural link between soft and hard processes that occur in the collision and allows one to study their interplay, will be discussed as well.

IS / **100**

Directed, elliptic and triangular flow of D mesons in ALICE

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Heavy quarks (charm and beauty) are produced in abundance during the early stage of ultrarelativistic heavy-ion collisions. They therefore experience the full evolution of the quark-gluon plasma (QGP). This makes them unique probes of the initial conditions and of the collective behaviour of the medium as it expands and cools.

The elliptic flow (v_2) is an observable that reflects the initial geometry and the degree of collectivity in this expanding system. The directed flow (v_1) of heavy-flavour particles is sensitive to the unprecedentedly strong magnetic fields present in the early stages of the collision, and so measurements of its charge dependence are key to constraining the electrical conductivity of the QGP. Finally, the triangular flow (v_3) is driven by fluctuations in the initial state of the system, and is sensitive to the ratio of the shear viscosity to the entropy density, η/s.

This talk will present the latest measurements by the ALICE Collaboration on the directed, elliptic and triangular flow of charmed hadrons in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV. The charge-dependent v_1 of $\rm D^0$ mesons will be shown, as well as the average D-meson v_2 measured by standard and Event-Shape Engineering (ESE) techniques, and the non-strange D-meson v_3. The non-strange D-meson v_2 results will also be compared with those of strange D mesons to study in addition the effects of quark recombination. Comparisons with predictions from theoretical models will be discussed.

FE / **104**

Probing small-x gluons with the ALICE Forward Calorimeter upgrade

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We will present the design and physics performance of a high-granularity Forward Calorimeter (FoCal) upgrade for ALICE. The main goal of the FoCal detector is to measure isolated direct photon production to constrain the low-x gluon density in the proton and nuclei and to look for deviations from linear QCD evolution in the high gluon-density regime. In addition, correlation measurements using forward hadrons and photons will be used to explore possible CGC effects as well as long-range flow-like phenomena.
The detector will cover the pseudorapidity range from 3.4 to 5.8 with a Si-W electromagnetic calorimeter (ECal) with pad and pixel readout and a hadronic calorimeter with conventional metal-scintillator technology with optical readout.
The high granularity of the ECal will allow us to separate decay photons from neutral pions with unprecedented spatial resolution, providing a reconstruction efficiency for neutral pions above 80% over a large range in transverse momentum.
The impact of the direct photon measurements with the FoCal on the gluon density is evaluated by reweighting the nNNPDF 2.0 nuclear PDFs with pseudo data. It is shown that the FoCal accesses a unique small-x range down to $x \approx 10^{-5}$.

Poster / **105**

Exploration of shape deformation in Uranium nuclei via flow transverse-momentum correlation from STAR

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Collective phenomena in heavy-ion collisions are very sensitive to initial geometry including nuclei deformation effects. Recent hydrodynamic model calculations suggest that such deformation effects can be probed by studying event-by-event mean p_T ($\langle p_T \rangle$) fluctuation and the correlation between mean p_T and harmonic flow. In particular, due to prolate shape of the Uranium nuclei, significant difference between Au+Au and U+U collisions is expected for these observables. This poster presents new measurements as a function of centrality from Au+Au at $\sqrt{s_{NN}}$ = 200 GeV and U+U at $\sqrt{s_{NN}}$ = 193 GeV collisions with the STAR detector. Results on the high-order cumulants of $\langle p_T \rangle$ fluctuations and Pearson correlation coefficient between $\langle p_T \rangle$ and harmonic flow v_n from these two systems will be presented. The results will be compared with model calculations to constrain initial geometry as well as medium properties and final state effects in these collisions.

Poster / **106**

Measurement of the jet-particle v_2 in p–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$~TeV with ALICE at the LHC

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In heavy-ion collisions, the observed non-zero second-order azimuthal anisotropy coefficient, v_2, for particles with high transverse momenta $p_{\rm T}$ is driven by the path-length dependent energy loss

of hard partons travelling in the QGP, known as the jet quenching effect. Recent measurements show also a non-zero v_2 values for high p_{T} charged particles at high multiplicities in small collision systems (pp and p–Pb). Various mechanisms, such as parton energy loss in the cold nuclear matter, hydrodynamic evolution in the final state and initial state gluon correlations, are proposed to describe the observations whose origin is still debated.

In this contribution, the v_2 of particles within jets at mid-rapidity ($-0.8 < \eta < 0.8$) in the 10% most central p–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$~TeV, measured with the ALICE detector, is presented. The v_2 signal of jet particles is extracted with 2-particle correlation method using a template fit and subsequently long-range correlations with particles at forward rapidities. The non-flow contribution is suppressed by subtracting the low-multiplicity from high-multiplicity collisions. The measurements will provide new insight into the understanding of the origin of long-range correlations observed in small systems.

Poster / **107**

Multi-particle quantum-statistical correlation functions in a Hubble-expanding hadron gas

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Quantum-statistical correlation measurements in high-energy physics represent an important tool to obtain information about the space-time structure of the particle-emitting source and hence, the spatio-temporal evolution of the fireball. Out of the several final state effects which may modify the measured femtoscopic correlation functions; one may be the interaction of the investigated particles with the expanding hadron gas, constituted by the other final state particles. This may cause the trajectories – and hence the phases – of the quantum-correlated pairs to be modified, when compared to free streaming. The resulting effect could be interpreted as an Aharonov–Bohm-like phenomenon, in the sense that the possible paths of a quantum-correlated pair represent a closed loop, with an internally present field caused by the hadron gas. In this study, the possible role of the effect in heavy-ion experiments is presented with analytical calculations and a simple numerical model. The modification of the strength of multi-particle Bose-Einstein correlation functions is investigated and it is observed that, in case of sufficiently large source density, this effect may play a non-negligible role.

IS / **108**

Distribution of Nuclear Matter and Radiation in the Target Fragmentation Region

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Recent work by Kajantie, McLerran, and Paatelainen studies, in a completely classical setting, the gluon bremsstrahlung produced when a sheet of colored glass interacts with a color-charged point particle. Remarkably, the radiation spectrum thus calculated is in qualitative agreement with experiment. I will present here the results of our paper, where we extend these results to describe the target fragmentation region in nucleus-nucleus relativistic collisions. Assuming a constituent "quark" model of the target and classical dynamics, we calculate the subsequent evolution of baryons and the associated radiation. We confirm that the struck nucleus is compressed by a factor proportional to the saturation momentum of the projectile and that the dynamics of the early times of the collision are best described by two separate fluids as the produced radiation's velocity distribution is very different to the velocity distribution of the matter in the struck nucleus.

CD / 109

Linear and non-linear flow coefficients from transport theory

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The observation of fluid-like behavior in nucleus-nucleus (AA), proton-nucleus (pA) and high-multiplicity proton-proton (pp) collisions motivates systematic studies of how different measurements approach their fluid-dynamic limit. We have developed numerical methods to solve the ultra-relativistic Boltzmann equation for systems of arbitrary size and transverse geometry. Here, we apply these techniques for the first time to the study of azimuthal flow coefficients v_n including non-linear mode-mode coupling and to an initial condition with realistic event-by-event fluctuations. We show how both linear and non-linear response coefficients extracted from v_n develop as a function of opacity from free streaming to perfect fluidity. We note in particular that away from the fluid-dynamic limit, the signal strength of linear and non-linear response coefficients does not reduce uniformly, but that their hierarchy and relative size shows characteristic differences.

Poster / 110

Machine Learning and Multi-Parton Interactions in pp collisions from RHIC to LHC energies

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Over the last years, Machine Learning (ML) tools have been successfully applied to a wealth of problems in high-energy physics. Supervised ML methods allow for significant improvements in classification problems by taking into account correlations among observables and by learning the optimal selection from prepared samples. In this talk, we will discuss the application of ML for the extraction of the average number of Multi-Parton Interactions (MPI) from pp data. Boosted Decision Trees (BDT) are trained considering observables calculated with primary charged particles in minimum-bias pp collisions at $\sqrt{s} = 13$ TeV simulated with Pythia 8.244 tune 4C. Simulations at lower center-of-mass energies ranging from $\sqrt{s} = 0.2$ up to 13 TeV are processed with the trained BDT, the target values are found to be consistent with the expected MPI activity. Consistent results are also obtained in simulations where MPI and color reconnection are not activated. The method is also found to be robust against both the MPI and the hadonization models. Using the existing LHC data on transverse momentum spectra as a function of multiplicity in pp collisions at $\sqrt{s} = 5.02$, 7 and 13 TeV, we extract the average MPI (target variable) for minimum-bias pp collisions as well as the multiplicity dependence of MPI. The multiplicity dependent results are compared with existing ALICE measurements sensitive to MPI. Finally, we discuss the possibility of using ML in order to build an event classifier with strong sensitivity to MPI.

Poster / **111**

Decoupling the rates of charmonium dissociation and recombination reactions in heavy-ion collisions at LHC energy

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The charmonium states with their different binding energies and radii dissolve at different temperatures of the medium produced in relativistic heavy-ion collisions. Relative yields of charmonium and thus their survival have potential to map the properties of Quark Gluon Plasma, the medium created in the collisions. In this study, we estimate the combined effect of color screening, gluon-induced dissociation and recombination on charmonium production in heavy-ion collisions (Pb+Pb ions) at center of mass energy 5.02 TeV. This is a remarkable study that the rate equations of dissociation and recombination are decoupled and solved separately. To solve the recombination rate equation, we have used a naive approach of Bateman solution which ensures the dissociation of the recombined charmonium in the QGP medium and the effects of the correlated mechanism of recombination and the dissociation of newly formed pairs. The modifications of charmonium states are estimated with help of decoupled equations of gluon dissociation and recombination in an expanding QGP with the conditions relevant for Pb+Pb collisions at LHC.

Poster / **112**

In-medium properties of η mesons

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We study the modification of η meson mass in a medium comprise of nucleons and hyperons. The interaction terms for the η mesons are derived using chiral hadronic mean field SU(3) model. Within chiral SU(3) model, in-medium properties of nucleons and hyperons are modified through their interactions with the scalar (σ, ζ and δ) and vectors fields (ω, ρ and ϕ). We solve the coupled equations of motion for these scalar and vector fields for finite strangeness fraction and isospin asymmetry of the medium and evaluate the optical potentials of η mesons in hot and dense matter. The present results on in-medium properties may play an important role in understanding η-nuclei bound states and also the photo-production of η mesons.

Poster / **113**

In medium partial decay width of \psi(4008) state decaying to $D\bar{D}$

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In the present investigation we use $^3P_0$ model to calculate the partial decay width of Y(4008) state decaying to $D\bar{D}$ pairs in hot and dense nuclear medium. The impact of nuclear density and temperature is inculcated through the mass modification of pseudoscalar D meson, calculated using chiral

hadronic SU(3) plus QCD sum rule approach. The results of the present work will prove as one step forward in-order to predict an exact state of Y(4008) state.

Poster / 114

Study of Underlying Event activity in pp and p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ALICE.

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One of the most important discoveries at the LHC is the observation of collective-like behavior and strangeness enhancement in small collision systems (e.g. pp and p-Pb collisions). They effects are strikingly similar to those observed in heavy-ion collisions, where they are attributed to the production of a deconfined hot and dense medium, known as strongly interacting Quark-Gluon Plasma. In order to gain insight into the physics mechanisms behind these effects in small systems, in this work we measure Underlying Event (UE) activity in pp and p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. UE collects contributions from Multi-Partonic Interactions (MPI) as well as particles from initial- and final-state radiation related to the hardest component. The average number density and the average total transverse momentum (p_{T}) as a function of the p_{T} of the leading particle will be presented. Results for three topological regions will be shown: near and away side (sensitive to the jet-like component) and the transverse side (sensitive to UE). Three different cut-off values for track p_{T} are considered. i.e. 0.15, 0.5 and 1 GeV/c. The jet-like component is also analyzed after the subtraction of the UE component. Comparisons between the UE activity for pp collisions at different center of mass energies, and among pp and p-Pb collisions will be shown. Moreover, we will compare the measurements to QCD-inspired Monte Carlo event generators for the three different topological regions.

Poster / 115

The singlet, triplet and octet axial-vector form factors of the decuplet baryons in the chiral quark constituent model

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The axial-vector form factors of the decuplet baryons are investigated in the chiral constituent quark model using their explicit quark spin polarizations. The quark sea" arises from the chiral symmetry breaking which results in the Goldstone bosons mediating the interaction between constituent quarks. The axial-vector form factors which have some physical significance corresponding to the flavor singlet current, flavor isovector (triplet) current and the flavor hypercharge axial (octet) current at zero momentum transfer are respectively $G^0_{AV,B^*\frac{3}{2}}(0)$, $G^3_{AV,B^*\frac{3}{2}}(0)$ and $G^8_{AV,B^*\frac{3}{2}}(0)$. In order to further understand the Q^2 dependence of these form factors, we have used the dipole form of parametrization. The qualitative and quantitative contribution of thequark sea" has also been investigated by varying the transition probability of the chiral fluctuation.

Poster / 116

Evolution of energy density correlations in the Glasma

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By describing the initial stage of heavy ion collisions in terms of freely-evolving classical fields, we perform a first-principles calculation of the energy density one- and two-point correlation functions at finite proper time. Our approach allows us to systematically resum the contributions of high momentum modes that would make a power series expansion in proper time divergent. In order to obtain numerical results and draw comparisons to other initial stage models, we evaluate the field correlators using the Glasma Graph approximation and the simple GBW saturation model. Our results provide analytical insight into the pre-equilibrium phase of heavy ion collisions. Upon further refining of our calculations, our expressions could be applied to constrain the initial conditions of hydrodynamical evolution, as well as potentially save computing time for models based on numerical solutions to the Yang-Mills equations.

PDF / 117

Heavy Quark Energy Loss and Angular Distribution of the Radiation in the Moller Theory

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We calculate the energy loss and angular radiation distribution for heavy quark propagating through the quark-gluon plasma at the LHC in the framework of the QCD extended Moller theory i.e. BDMPS formalism plus large Coulomb logarithms. We study the role of Coulomb Logarithms in heavy quark propagation. We calculate the energy loss and estimate the Quenching Weights both including the phase space constraints, and neglecting them.

In the limit of massless quarks, our results for energy loss coincide with the previously known ones. We show that for heavy quarks the Coulomb gluons feel the dead cone, and lead to significant improvement of the agreement between theoretical prediction and experimental data for heavy quark quenching weights.

Poster / 118

Flavor dependent parton cascades in expanding media

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Going beyond the simplified gluonic cascades, we have introduced full flavor treatment by including both gluon and quark degrees of freedom for partonic cascades inside the medium. We then solve the set of coupled evolution equations with splitting kernels calculated analytically for exponentially expanding and Bjorken media to arrive at medium-modified parton spectra for quark and gluon initiated jets. For our calculations, we have included phenomenologically driven flavor fractions for the calculation of inclusive jet R_{AA} and its rapidity dependence. Finally, we have studied the path-length dependence of jet quenching for different types of expanding media by calculating the jet v_2. These studies help to quantify a discriminating power of different observables for distinguishing the type of the medium expansion.

Poster / 119

In-medium effects on kaons and antikaons observables in nucleus-nucleus collisions

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In the present work, we study the effect of mass-modifications of kaons (K) and antikaons ($\bar{K}$) on the experimental observables relevant for nucleus-nucleus collisions. The in-medium masses of K and $\bar{K}$ mesons evaluated using effective hadronic chiral SU(3) mean field model are implemented in A Multi-Phase Transport (AMPT) model to calculate different experimental observables. The impact of finite density of the medium on the masses of K and $\bar{K}$ mesons in chiral effective models is calculated through their interactions with nucleons whose properties are modified because of the presence of scalar and vector fields. Along with the usual Weinberg-Tomozawa term, we consider the impact of explicit symmetry breaking term and three range terms to calculate the in-medium masses using chiral model and the observables within AMPT model. Explicit consideration of different terms in the model will have substantial effect on the flow splitting between K and $\bar{K}$ mesons. Along with the flow splitting, we also study the transverse mass spectra, production ratio and rapidity spectra of kaons and antikaons.

PDF / 120

Probing the nucleus with linearly polarized photons

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The intense electromagnetic fields produced by ultra-relativistic heavy nuclei have been proposed as a source of quasi-real photons i.e. in the Weizsacker-Williams equivalent photon method. A photon from one nucleus can fluctuate into a quark antiquark pair and interact directly with the other nucleus to produce a vector meson (e.g. ρ^0). Recent STAR measurements of the Breit-Wheeler pair poduction process - $\gamma\gamma \rightarrow e^+e^-$ have demonstrated that the interacting photons are linearly polarized, and that photon polarization induces angular modulations in the final state particle distribution.

In this talk we present STAR measurements of diffractive photo-production of the ρ^0-meson (and direct $\pi^+\pi^-$ pairs) in ultra-peripheral Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. We measure azimuthal angular distributions of the final state $\pi^+\pi^-$ pairs and observe $\cos 2\Delta\phi$ and $\cos 4\Delta\phi$ modulations (where $\Delta\phi = \Delta\phi[(\pi^+ + \pi^-), (\pi^+ - \pi^-)]$. Theoretical predictions suggest that such modulations may provide new insight into nuclear structure and may shed light on the transverse momentum dependent (TMD) distributions of gluons within large nuclei - a topic of great interest both at existing experiments and at a future Electron Ion Collider.

1 C. Weizsäcker, Zeitschrift für Physik 88 (1934): 612–25.
2 H. Xing, C. Zhang, J. Zhou, and Y.-J. Zhou, ArXiv:2006.06206 [Hep-Ph] (2020).
[3] A. Metz, and J. Zhou. Physical Review D 84 5 (2011).

PDF / 122

Hard probes production in pPb collisions at LHCb

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Within the p-Pb data sample collected by the LHCb detector at sqrt(s_NN) = 8.16 TeV, a rich set of open charm hadrons is observed with abundant statistics.
Thanks to the LHCb forward acceptance that is complementary to general purpose detectors, with excellent performance in particle reconstruction and identification,these charm states are studied down to zero pT with overwhelming precision.
In this talk, we present latest measurements of charm mesons in pPb collisions by LHCb. Among them, comparisons between theory predictions and data regarding the double charm production are made. In addition, the collaboration has measured the Chi_c states and the Z boson in pPb data for the first time at the LHC, which are ideal probes for the so-called cold nuclear matter effect such as nuclear PDFs and comover interactions..

PDF / 124

Charmonia photo-production in ultra-peripheral and peripheral PbPb collisions with LHCb

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In 2018, LHCb recorded ˜210 microbarn^{-1} integrated luminosity of PbPb collisions at sqrt(s_NN) = 5.02 TeV. With an increase of the luminosity by a factor 20 compared to the previous 2015 PbPb dataset, precise measurements on photo-produced charmonia in ultra-peripheral collisions are foreseen. Moreover, the great momentum resolution of the detector allows to study photo-produced J/psi in collisions with a nuclear overlap. This new type of probe is sensitive to the geometry of the collisions but also to the electromagnetic field of the Pb nuclei. In this talk, we present the latest results on photo-production obtained by LHCb measurements in peripheral and ultra-peripheral PbPb collisions.

Poster / 125

X(3872) production in pp with particle multiplicity

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The last decade of hadron spectroscopy has unveiled a wealth of states that do not have the properties expected of particles composed of 2 or 3 valence quarks.
Among the most intriguing of these exotics is the X(3872), which various models attempt to describe as a hadronic molecule, a compact tetraquark, an unexpected charmonium state, or their mixtures.
Production in heavy ion collisions, as well as high multiplicity pp collisions, offer a new window on the properties of this poorly understood hadron. In these systems, promptly produced X(3872) hadrons can interact with other particles in the nucleus and/or those produced in the collision.
The influence of these interactions on the observed X(3872) yields provides information that can help discriminate between the various models of its structure, as well as give insight into the dynamics of the bulk particles produced in these collisions. With a full range of precision vertexing, tracking, and particle ID capabilities covering 2 to 5 in units of rapidity, the LHCb experiment is especially well suited to measurements of both prompt and non-prompt exotic hadrons.
This talk will present new LHCb measurements X(3872) production in high multiplicity pp collisions through the decay to $J/\psi\pi^+\pi^-$.

Poster / 126

Dielectron production in pp and p-Pb collisions at sqrt(s_NN) = 5.02 TeV

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Dileptons are a prime probe of the deconfined state of strongly interacting matter, the quark–gluon plasma (QGP), produced in high-energy heavy-ion collisions, as they are not affected by strong interactions after their creation.
A measurement of the thermal radiation from the QGP in the mass region between the ϕ and the J/ψ allows to estimate the medium temperature. In this region the main component of the dielectron continuum is originating from correlated semileptonic decays of open-charm and beauty hadrons.
The production of dielectrons originating from the decays of heavy-flavour hadrons in small systems can provide crucial insight for the measurement of thermal radiation in nucleus-nucleus collisions.

In this talk, the latest results on dielectron production in pp and p–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV will be presented.
We will discuss the production of heavy-flavour quarks in pp collisions compared with model predictions including different quark production mechanisms, as well as a possible modification of their production cross sections in p–Pb collisions. The data from both collision systems will be presented in terms of the dielectron nuclear modification factor R_{pPb}.
Possible deviations from the vacuum baseline will be addressed in the light of present cold nuclear matter effects along with possible collective effects in small systems.

Poster / 127

Search for the Chiral Magnetic Wave using the ALICE detector in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

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In heavy-ion collisions a strong magnetic field is created ($\sim 10^{15}$ T), which together with the presence of a non-zero electric and axial charge density, leads to vector and axial currents called the Chiral Magnetic Effect (CME) and Chiral Separation Effect (CSE), respectively. Their coupling gives rise to a collective excitation in the quark-gluon plasma (QGP) called the Chiral Magnetic Wave (CMW), causing a charge-dependent elliptic flow. As a result, the normalized difference of v_2 of positive and negative charges, (Δ $v_{2_{Norm}}$), exhibits a positive slope as a function of charge asymmetry A_{ch}. However, non-CMW mechanisms like Local Charge Conservation (LCC) can also describe the Δ v_2 dependence on A_{ch} and can be probed by a similar kind of measurement with v_3 as we expect it not to be affected by the CMW.\\

In this talk, we present ALICE measurement of v_2, Δ $v_{2_{Norm}}$, v_3 and Δ $v_{3_{Norm}}$ of charged hadrons as function of the charge asymmetry (A_{ch}) in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The slope parameters from v_2 and v_3 are compared to estimate the background contribution in CMW phenomena at LHC energies.

CGC / 128

Finite Nc corrections in the Balitsky-Kovchegov equation at next-to-leading order

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The Colour Glass Condensate effective field theory is a useful framework for studying heavy ion collisions at ultra-relativistic energies, such as those reached at the Large Hadron Collider. In this framework, we study the rapidity evolution of Wilson lines that appear explicitly in cross section expressions. The next-to-leading order BK (Balitsky-Kovchegov) equation for the 2-point Wilson line correlator involves 6-point correlators of Wilson lines. These correlators are typically calculated only in the large-Nc limit. I will present a fully analytic calculation of these correlators in the finite-Nc case, using the Gaussian Approximation. We use these results to find the relative importance of finite-Nc corrections to the next-to-leading order (NLO) evolution equation. I will also present some results from our study of the correlators that appear in the NLO BK equation and the equation itself.

IS / 129

Rapidity evolution of collision geometry from the improved TRENTo-3D model

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We propose a new parameterization of the three-dimensional initial condition for the application of the hydrodynamic model to relativistic heavy-ion collisions. In particular, we implement different average-energy production scaling behaviors for different rapidity regions in this proposed ansatz. Near mid-rapidity, the energy deposition is given by the well-tested TRENTo model, with and without the proton shape fluctuation. At forward/backward rapidity, the energy density asymptotically scales as the local participant density of the projectile/target, suggested by the limiting fragmentation hypothesis. On top of the average-energy production, event-by-event longitudinal fluctuations are modeled by random fields with specified one-point and two-point correlation functions.

Approximating a scaled initial energy production to final-state particle multiplicities, we reverse-engineer the three-dimensional initial geometry using the charged-particle pseudo-rapidity density in both large and small collision systems at both the RHIC and the LHC. Finally, we emphasize the impact of the inclusion of limiting fragmentation regions and longitudinal fluctuations on the rapidity evolution of collision geometry and the participant-plane decorrelation.

Poster / 130

Investigating the pion source function in heavy-ion collisions with the EPOS model

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By measuring the momentum correlations of pions created in heavy-ion collisions we can gain information about the space-time geometry of the particle emitting source. Recent experimental results from multiple different collaborations demonstrated that to properly describe the shape of the measured correlation functions, one needs to go beyond the Gaussian approximation. Some studies suggest that the Levy distribution could provide a good description of the source. While there are already many experimental results, there is very little input from the phenomenology side in explanation of the observed non-Gaussian source shapes. The EPOS model is a sophisticated hybrid model where the evolution of the newly-created system is governed by Parton-Based Gribov-Regge theory. It has already proved to be successful in describing many different experimental observations for the systems characterized by baryon chemical potential close to zero, but so far the source shape has not been explored in detail. In my talk I will discuss studies of the pion emitting source based on the theoretical approach of the EPOS model.

Poster / 131

Jet momentum broadening in real-time lattice simulations of the glasma

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The study of jets in heavy ion collisions provides important information about the interaction of partons with the quark-gluon plasma. Originating from hard scatterings among partons of the colliding nuclei, jets are affected by the entire space-time evolution of the medium, including the pre-equilibrium stage. I report on our numerical lattice simulations of jets traversing the boost-invariant, non-perturbative glasma as created at the early stages of collisions at RHIC and LHC 1. We find that during the glasma stage, quark jets quickly accumulate transverse momentum up to the saturation momentum. Additionally, we observe a peculiar anisotropy in transverse momentum broadening of jets with more efficient broadening along rapidity compared to azimuthal broadening. The origin of this momentum broadening anisotropy can be traced back to correlations among the longitudinal color-electric and color-magnetic flux tubes in the initial state of the glasma.

1 A. Ipp, D. I. Müller, D. Schuh, Phys. Lett. B 810 (2020), arXiv:2009.14206
https://doi.org/10.1016/j.physletb.2020.135810

Poster / **132**

Transverse momentum broadening of jets in the weak field limit of the glasma

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The seeds of jets are highly energetic partons, which are produced from hard scatterings in heavy ion collisions. As such, they might be affected by the precursor state of the quark-gluon plasma, the so-called glasma, via strong classical color fields. Starting from the glasma initial conditions, the Yang-Mills equations are solved analytically to leading order within the weak-field approximation of the color glass condensate framework. In this talk I show how the transverse momentum of a parton is related analytically to the initial longitudinal flux tubes of the glasma in the weak field limit 1. We find interesting features such as an anisotropy in transverse momentum broadening. This analytic treatment allows for a better understanding of the physical mechanisms behind momentum broadening in the glasma. Furthermore, it facilitates the interpretation of numerical results from lattice simulations, which are able to deal with non-perturbatively strong color fields required for realistic models of heavy ion collisions.

1 A. Ipp, D. I. Müller, D. Schuh, Phys. Rev. D 102 (2020), arXiv:2001.10001
https://doi.org/10.1103/PhysRevD.102.074001

Poster / **133**

The wake of jets from linearized hydrodynamics

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Recently, jet substructure observables have been widely used in the study of jets. Some observables are sensitive to the wide angle soft particles within the jet, for example, the Lund plane distribution with different jet radii and soft drop parameters. As the jet loses energy and momentum during its evolution inside the quark-gluon plasma (QGP), the "lost" energy and momentum is deposited in the medium, evolves therein — the wake of the jet. This wake ultimately hadronizes into particles whose net momentum must be correlated with the jet direction, since it corresponds to the momentum lost by the jet. This means that when a jet reconstruction algorithm is then used to find the jet, some of the particles originating from the wake must end up being counted as a part of the jet. Since these particles are generally soft, and are spread over a wide angle with respect to the jet axis, they can significantly modify those jet substructure observables that are sensitive to the soft physics and/or to physics at wide angles. To understand the predictions of any model of jet quenching for such observables, it is mandatory to quantify the dynamics of the back-reaction of the medium to the jet, namely the wake of the jet. Understanding of the back-reaction will also deepen our understanding of the collective dynamics.

In this talk, we will report progress toward addressing this question by treating the energy and momentum loss as a perturbation on the background of a Bjorken flow. By working to linear order in the perturbation and solving the resulting evolution equations numerically in momentum space, we study how the wake evolves within the hydrodynamically evolving droplet of QGP and explore the dependence of the dynamics of the wake on the viscosity of the QGP and model uncertainties. Via this study, we upgrade the previous numerical implementation of the jet wake in the hybrid model, in particular for the component of the wake that yields particles with transverse momenta of a few GeV after hadronization. Further we will assess the phenomenological impact of the improved wake treatment on a range of jet observables.

NT / 134

Chromoelectric Distribution Function of Nuclear Matter Probed by Quarkonium

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Quarkonium suppression in heavy ion collisions has been used as a probe of the quark-gluon plasma (QGP) for decades. The intuitive picture of sequential suppression based on the Debye screening of the heavy quark potential is obscured by other in-medium processes such as dissociation and recombination. A natural question to ask is what we can learn about the QGP from measurements of quarkonium suppression.

In this talk, we will try to address this question using effective field theory techniques and the open quantum system formalism. We argue that when the quarkonium size is small, the interaction between quarkonium and the hot medium is weak. Then the density matrix of the heavy quark pair, as a subsystem, and the hot nuclear environment can be factorized. The time evolution of the subsystem is governed by the Lindblad equation. By applying the Wigner transform to the Lindblad equation and carrying out a gradient expansion, we derive the semiclassical Boltzmann equation and work out the leading quantum correction. The reaction rates are factorized into a quarkonium dipole transition function and a chromoelectric distribution function of the nuclear medium. For differential reaction rates, the chromoelectric distribution function is momentum dependent, defined by two electric fields connected via a staple-shaped Wilson line. For inclusive reaction rates, it becomes momentum independent and the Wilson line collapses into a straight line along the time axis. The relation between the Wilson line structures in the differential and inclusive reaction rates is similar

to that between the gluon PDF and the gluon TMDPDF, except that the time here is the real time rather than the lightcone time. The construction can be easily generalized to the interaction between quarkonium and cold nuclear matter, which is of much relevance for quarkonium production in eA collisions, to be carried out in the future Electron Ion Collider.

CGC / 135

Particle production beyond eikonal accuracy in dilute-dense CGC framework

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Within the Color Glass Condensate effective theory, most observables are computed by adopting the eikonal approximation. At asymptotic energies, this corresponds to treating the dense target as an infinitely thin shockwave. However, finite longitudinal width corrections to the shockwave approximation might be important at realistic energies. In such a case, the propagation of a parton through the medium is defined by a background propagator that follows a Brownian trajectory. In previous works [1,2] we used the two gluon exchange approximation - called glasma graphs -on the propagators to compute particle production and correlations in pp collisions. In order to extend the calculation to dense targets, thus in proton-nucleus collisions, here we propose a new way to compute correlators of two background propagators by discretizing the path integrals and using a localized version of the GBW model at each discretized step. We compare our result with the multiple soft scattering approximation applied in jet quenching calculations and apply them to single inclusive gluon production.

1 P. Agostini, T. Altinoluk and N. Armesto, Eur.Phys.J.C 79 (2019) 7, 600, e-Print: 1902.04483 [hep-ph].

2 P. Agostini, T. Altinoluk and N. Armesto, Eur.Phys.J.C 79 (2019) 9, 790, e-Print: 1907.03668 [hep-ph].

Poster / 136

Polarization in heavy-ion collisions via local initial energy deposition

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In the recent past the STAR collaboration reported the measurement of Λ hyperon in non-central AuAu collisions. The origin of this polarization was successfully modeled as the vorticity present in the QGP fluid due to the non-zero angular momentum in non-central collisions. Other phenomena may generate vorticity in a fluid. A fast parton crossing the QGP transfers momentum and energy to it and will introduce a gradient in velocity, which will lead to vorticity generation. In our work, we model such energy-momentum deposition as a spot of high energy and high velocity a few cells wide. We embed it in a smooth initial condition based on central PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV and evolve it using (3+1)D hydrodynamic using MUSIC. We show that our initial condition generates a vortex ring in the hydrodynamic evolution, with noticeable effects on the spin polarization of Λ hyperons. We present a study showing the dependance of this effect with shear viscosity and parameters of the energy-momentum deposition.

IS / 137

Dynamical initialization of hydrodynamics for heavy-ion collisions at Beam Energy Scan energies

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At Relativistic Heavy Ion Collider (RHIC) Beam Energy Scan (BES) energies, the dynamics of the pre-hydrodynamic stage and the effects from a nonzero net baryon current become essential components of the dynamical evolution of the collision fireball. We develop a (3+1)-dimensional initial stage model for both energy-momentum and the net baryon current, as dynamical initial conditions for a hydrodynamic evolution module, before the colliding nuclei interpenetrate and the produced system gets completely hydrodynamized. More specifically, during the initial pre-hydrodynamic stage, the four-momenta and baryon numbers carried by secondary particles created within a transport module (modified-UrQMD), after a short hydrodynamization time, are deposited continuously into a (3+1)-dimensional viscous hydrodynamic evolution module (BEShydro). The sensitivity of the hydrodynamic evolution to its initialization will be studied by comparing this approach to other previously proposed dynamical initialization algorithms. We show the dependence on the hydrodynamization time of correlations between rapidity and space-time rapidity of the secondary particles from UrQMD. We also present the interplay between the hydrodynamic module and the dynamical initial conditions by comparing the evolution of eccentricities, temperature and flow velocities, etc., with and without the hydrodynamic module.

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CGC / 138

Completing the first saturation correction to single inclusive gluon production in high energy pA collisions

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The leading order result of single inclusive gluon production in high energy pA collisions has been calculated by various approaches for more than two decades . The first saturation correction to the leading order result, terms that are enhanced by $\alpha_s^2 A^{1/3}$ with α_s the strong coupling constant and A the atomic number of nucleus, was only analytically attempted recently through a diagrammatic approach despite many relevant numerical studies. In this talk, I will present our efforts in completing this calculation analytically. Our approach is to solve the classical Yang-Mills equations in the dilute-dense regime and use the LSZ reduction formula to calculate gluon production from classical gluon fields. Exact next-to-leading order solutions of the Yang-Mills equations in the dilute-dense regime will be presented. The systematic approach in completing the first saturation correction to single inclusive gluon production will be explained and final results will be presented.

NT / **139**

Simulating real-time dynamics of hard probes in nuclear matter on a quantum computer

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We present a framework to simulate the dynamics of hard probes such as heavy quarks or jets in a hot, strongly-coupled quark-gluon plasma (QGP) on a quantum computer 1. Hard probes in the QGP can be treated as open quantum systems governed in the Markovian limit by the Lindblad equation. However, due to large computational costs, most current phenomenological calculations of hard probes evolving in the QGP use semiclassical approximations of the quantum evolution. Quantum computation can mitigate these costs, and offers the potential for a fully quantum treatment with exponential speedup over classical techniques. We report a simplified demonstration of our framework on IBM Q quantum devices, and apply recently developed error mitigation techniques. Our work demonstrates the feasibility of simulating open quantum systems on current and near-term quantum devices, which is of broad relevance to applications in both hot and cold nuclear matter.

1 https://arxiv.org/abs/2010.03571

Poster / **140**

Searching for the chiral magnetic effect in heavy-ion collisions with the sliding dumbbell method

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The deconfined state of matter created in hot and dense medium at ultra relativistic heavy-ion collision causes back-to-back charge separation along the direction of magnetic field produced due to energetic spectator protons, a
phenomena known as the chiral magnetic effect (CME). A new technique, the Sliding Dumbbell Method (SDM), is developed to search for back-to-back charge separation on event-by-event basis. The SDM is applied to AMPT generated Au + Au collisions at $\sqrt{s}_{\mathrm{NN}}$ = 200 GeV. The CME like signal is externally injected in each event by flipping the charges (one/two) of particles perpendicular to the reaction plane. Here, whole azimuthal plane is scanned by sliding the dumbbell of 90° in steps of 1°, searching for the maximum of the sum, $Db_{\pm}^{max}$, of the positive charge fraction on one side and the negative charge fraction on the other side of the dumbbell. The fractional dumbbell charge separation is sliced into 10 percentile bins for each centrality to get sample of events enriched with CME like signal. Two- and three- particle correlations will be presented for different charge separations in each collision centrality along
with those of the charge reshuffled background. A significant enhancement of
the CME-sensitive γ-correlator is reported for the top percentile bin of the $Db_{\pm}^{max}$ distribution in each centrality, which bacame possible using the SDM. The CME-sensitive γ-correlator is also estimated for the particles inside the dumbbell. The γ-correlator dependence on fractional dumbbell charge separation will also be discussed.

Poster / 141

Probing quark-gluon plasma at “mesoscopic scale” via jet-medium interaction

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We study the response of a Bjorken-expanding quark-gluon plasma (QGP) to the passage of an energetic parton through it. By comparing results from Boltzmann equation under the relaxation time approximation with those from viscous hydrodynamics, we observe that the non-hydrodynamic response is significant when the medium excitations with wavelength shorter than the inverse of the relaxation time are not fully damped. Such non-hydrodynamic response is characterized by a supersonic effective group velocity and a dissipative rate smaller than the viscous damping. We construct a novel model which is similar to M\"uller-Israel-Stewart (MIS) theory, but contains two additional free parameters that respectively control the effective group velocity and dissipation in the non-hydrodynamic regime. We demonstrate how to use this model to describe both the non-hydrodynamic and hydrodynamic response, and discuss applying of this model to extract the properties of QGP at the “mesoscopic scale” through jet-medium interaction.

Poster / 142

Dynamical evolution of eletromagnetic field in out-of-equilibrium Quark-Gluon Plasma

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In high energy heavy-ion collisions, the pre-equilibrium stage of the quark-gluon plasma (QGP) is the most crucial ingredient in the estimate of electromagnetic (EM) fields, especially for the lifetime of the magnetic field that plays a key role in the chiral magnetic effect (CME).

In this talk, we present a theoretical estimate for the realistic dynamical evolution of EM fields in the pre-equilibrium QGP meidum at RHIC and the LHC energies, from the solution of coupled Boltzmann equation for quarks and gluons and Maxwell equation the EM fields. The Boltzmann equation, with a diffusion approximation applied with respect to QCD scatterings among quarks, anti-quarks and gluons, has been used to describe a 1D expanding QGP evolving from far from equilibrium towards hydrodynamization 1. When EM fields are involved, splittings between the out-of-equilibrium quark and anti- quark distributions are induced. Accordingly, an effective electric conductivity can be obtained in the pre-equilibrium QGP, which determines the dynamical evolution of EM fields. The dynamical decay of EM fields is found to be delayed comparing to the case of vacuum, but still faster than the expectation in a QGP in equilibrium 2.

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Poster / **143**

Searching for the chiral magnetic effect with the sliding dumbbell method in Pb-Pb collisions at √sNN = 2.76 TeV with ALICE

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The chiral imbalance along with the magnetic field produced during heavy-ion collisions may cause a charge separation in the magnetic field direction, a phenomenon known as the chiral magnetic effect (CME). A new technique, the sliding dumbbell method (SDM), is designed to study the CME-like charge separation. In the SDM, the whole azimuthal plane is scanned for each event by sliding the dumbbell of 90 degree size in steps of 1 degree searching for the maximum of sum of the positive charge fraction on one side and the negative charge fraction on the other side of the dumbbell, the Db_{\pm}^{max}. The distribution of maxima is divided into 10 percentile bins for each centrality to get sample of events enriched in CME-like signal. In this contribution, two- and three-particle azimuthal correlations for different charge separations will be presented in Pb-Pb collisions at √sNN = 2.76 TeV measured with the ALICE detector. Results will be shown for different bins in each collision centrality, along with those of reshuffled charges to estimate the background contribution to the measurement. The CME-like signal is significantly magnified in the top percentile bin of the Db_{\pm}^{max} distribution for each collision centrality, which became possible using the SDM method.

Poster / **144**

Properties of the strongly intensve observable Σ in high energy pp collisions in a string fusion model

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The properties of the strongly intensive variable Σ 1 characterizing correlations between the number of particles produced in two observation windows separated by a rapidity interval in pp interactions at LHC energies are studied in the framework of the string fusion approach [2,3]. The analytical calculations are supplemented by the MC simulations permitting to take into account the experimental conditions of pp collisions at LHC energies. We perform the MC simulations of string distributions in the impact parameter plane and take into account the string fusion processes, leading to the formation of string clusters, using a finite lattice (a grid) in the impact parameter plane [4].
As a result, the dependences of this variable both on the width of the observation windows and on the value of the gap between them were calculated for several initial energies. Analyzing these dependencies we see that in pp collisions at LHC energies the string fusion effects have a significant impact on the behavior of this observable and their role is increasing with the initial energy and centrality of collisions. We show that in the case with different emitting string clusters this observable loses its strongly intensive nature. It becomes equal to the combination of the ones for different clusters with the weights depending on details of the collision - its energy and centrality.
Nevertheless the analysis of these dependencies of the Σ enables to extract the important information on the characteristics of string clusters and on this base to explain the Σ behavior. In particular, we found that the increase of this variable with initial energy and collision centrality takes place due to the growth of the portion of the dense string clusters in string configurations arising in pp interactions.

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Poster / 145

Spectator induced electromagnetic effects in heavy-ion collisions and space-time-momentum conditions for pion emission

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We present our calculation of electromagnetic effects, induced by the spectator charge on Feynman-xF distributions of charged pions in peripheral Pb+Pb collisions at CERN SPS energies, including realistic initial space-time-momentum conditions for pion emission. The calculation is performed in the framework of our simplified implementation of the fire-streak model, adapted to the production of both π− and π+ mesons. Isospin effects are included to take into account the asymmetry in production of π+ and π− at high rapidity. A comparison to a simpler model from the literature is made. We obtain a good description of the NA49 data on the xF and pT dependence of the ratio of cross sections π+/π−. The experimental data favors short times ($0.5<\tau<2$ fm/c) for fast pion creation in the local fire-streak rest frame. The possibility of the expansion of the spectators is considered in our calculation, and its influence on the electromagnetic effect observed for the π+/π− ratio is discussed. In addition we discuss the relation between anisotropic flow and the electromagnetic distortion of π+/π− ratios, and study the influence of transverse expansion of fire streaks as well as their vorticity on this distortion. In this latter study we find that inclusion of rotation of fire streaks

in our model gives a satisfactory description of the rapidity dependence of pion directed flow. We conclude that our implementation of the fire-streak model, which properly describes the centrality dependence of π− rapidity spectra at CERN SPS energies, also provides a quantitative description of the electromagnetic effect on the π+/π− ratio as a function of xF.

CGC / **146**

Structure functions for inclusive and diffractive DIS at future EICs

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We present predictions for proton and nuclear structure functions using numerical solutions to the Balistky-Kovchegov equation with the collinearly improved kernel and including the impact-parameter dependence. Two different approaches to the nuclear case are studied: a solution obtained using a newly proposed type of initial condition which represent the given nucleus and the solutions based on an initial condition representing a proton coupled to a Glauber-Gribov prescription to obtain dipole-nucleus amplitudes. We study the influence from the different energy evolutions of these two approaches in the nuclear structure functions and calculate the nuclear suppression factors that lead to the predictions for the energy dependence of nuclear shadowing. We also apply this approach to obtain the predictions for proton and nuclear diffractive structure functions. We compare our predictions with the available data and also with the results obtained using the IP-Sat and b-CGC models for the dipole-proton amplitude. We demonstrate that the contribution of the diffractive events is enhanced in nuclear collisions and that the study of the ratio between the nuclear and proton predictions will be useful to discriminate among different models. These studies are therefore of interest for future measurement at the currently planned electron-ion colliders, which can allow us to constrain the description of QCD dynamics in parton densities.

Poster / **147**

Upgrade of Monitored Drift Tube detector of the Muon spectrometer during LHC LS2

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During the large hadron collider long shutdown 2 (LHC-LS2), the Muon Spectrometer of the ATLAS experiment known a major upgrade in the region $1.0 < \eta < 1.3$. motivated by the improving of the high-Pt measurement within the trigger system, where the old monitored drift tube chambers will be replaced by new ones in which an additional trigger detector RPC (resistive plate chambers) will be included, the trigger performance will be significantly boosted in this region, the number of tube layers will be 2 times more within the same detector volume, 10 times high rate capability compared to the current MDT chambers.. etc. two of the new small MDT chambers already integrated, commissioning is going on. The installation of the rest chambers scheduled to be done by the first week of December.

CGC / **148**

Entanglement, partial set of measurements, and diagonality of the density matrix in the parton model

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Abstract: We analyze the entanglement in the context of high energy QCD. First, in order to provide a firm connection to experimental observables, we define the "entropy of ignorance" which quantifies the entropy associated with ability to perform only a partial set of measurement on a quantum system. For the parton model the entropy of ignorance is equal to the Boltzmann entropy of a classical system of partons. We analyze a calculable model used for describing low x gluons in Color Glass Condensate approach, which has similarities with the parton model of QCD. In this model we calculate the entropy of ignorance in the particle number basis as well as the entanglement entropy of the observable degrees of freedom. We find that the two are similar at high momenta, but differ by a factor of order unity at low momenta. We explicitly demonstrate that that the reduced density matrix of the small x gluons is not diagonal in the particle number basis. We then show that the reduced density matrix can be diagonalized in a quasi-particle basis. Moreover, the matrix elements have the form of Boltzmann weights $\mathrm{diag}(e^{-n\beta\omega})$, $n = 0, 1...$, where n is the number of quasi-particles. At small momenta, $\beta\omega$ is proportional to k/Q_s, demonstrating the apparent thermal behavior of small x gluons at low transverse momentum. We discuss the implication of our results in the context of the future EIC.

FE / 149

Prospects for the NA60+ experiment at the CERN SPS

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In this talk, the prospects and the physics goals of a new fixed-target experiment, NA60+, which has been proposed for taking data with heavy-ion collisions at the CERN SPS in the next years, will be presented. The competitiveness and complementarity of the NA60+ physics program in the landscape of the experiments foreseen at other facilities in the next decade will also be discussed.

The high-intensity beams provided by the CERN SPS in a wide energy interval provide a unique opportunity to investigate the region of the QCD phase diagram at high baryochemical potential, μ_{B}, via measurements of rare signals. In particular, the main goals of the NA60+ experiment will be focused on precision studies of heavy quark and thermal dimuon production in Pb-Pb collisions via a beam-energy scan in the centre-of-mass energy interval $\sqrt{s_{\mathrm{NN}}} = 5 - 17$˜GeV. The proposed experimental apparatus consists of a vertex telescope located close to the target, and a muon spectrometer located downstream of a hadron absorber. The vertex telescope will consist of several planes of monolithic active pixel sensors embedded in a dipole magnetic field. The muon spectrometer will utilize GEM and RPC detectors for muon tracking and trigger, and a toroidal magnet based on a new light-weight and general-purpose concept. This apparatus, based on state-of-the-art technologies, will allow a very broad and ambitious physics program.

The high-precision measurements of dimuon invariant mass distributions will open the possibility to investigate the order of the phase transition from the quark-gluon plasma to the hadron gas in the interval $\mu_{\mathrm{B}} \approx 200 - 400$˜MeV via the first measurement of the caloric curve. In addition, the first direct measurement of $\rho - \mathrm{a}_1$ chiral mixing could be achieved by a precision measurement of the dimuon yield in the a_1 mass region. Furthermore, a simultaneous precision study of hidden and open charm will be carried out, by measuring charmonium states though dimuon decays and open-charm hadrons from their hadronic decays reconstructed from the tracks in the vertex telescope. These measurements in the charm sector will provide new insights into the transport properties of the QGP and into the threshold energy for the onset of deconfinement.

Poster / 150

Spinodal instability with varying criticality in holography

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The spinodal instability is the prime signal for the first-order phase transition in the Quantum-ChromoDynamics phase diagram relevant for the RHIC beam energy scan. We evolve planar unstable black branes dual to a plasma with a first order phase transition subject to the spinodal instability. By varying criticality we extract characteristics of the interface between the cold and hot stable phases. We explain a new criterium for distinguishing the inhomogeneous states formed by the spinodal instability. Approaching the critical point we demonstrate the first holographical dynamical dissipation into the preferred fully phase separated final solution.

NT / 151

A New Approach to First-Order Relativistic Hydrodynamics

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In this talk we explain how the novel first-order approach proposed by Bemfica, Disconzi, Noronha 1, and Kovtun 2 naturally solved the long-standing problems of causality, stability, and well-posedness of relativistic Navier-Stokes theory. We discuss the differences between this new approach and Israel-Stewart theory, emphasizing how such distinctions could affect our current understanding of the hydrodynamic evolution of the quark-gluon plasma. We also explain how to derive this hydrodynamic approach from kinetic theory using a new coarse-graining method that is different from the well-known Chapman-Enskog expansion and the method of moments. Finally, we discuss how this new first-order theory emerges at strong coupling using holography.

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CGC / 153

Full next-to-eikonal quark propagator in the CGC and applications

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Within the Color Glass Condensate effective theory or other related frameworks, the theoretical description of low-x (or high-energy) QCD processes sensitive to the nonlinear gluon saturation physics relies on two main pillars.
The first one is the semiclassical approach: due to the high density of low x gluons in an incoming proton or nucleus target, scattering processes off that target reduce to scattering processes on a semiclassical background gluon field. In particular, dense-dilute scattering processes at low x can then be formulated within perturbation theory in presence of a strong background gluon field.
The second main pillar is the eikonal approximation, which amounts to neglecting power-suppressed corrections in the high-energy limit. Within the semiclassical framework, the eikonal approximation is equivalent to an infinite Lorentz boost of the background field, which is then contracted to a gluon shockwave. This approximation is crucial to make possible the systematic resummation of multiple interactions with the target. It is by definition a better and better approximation as the energy of the collision increases. But corrections beyond the eikonal approximation can be large at intermediate energies, in particular at RHIC and EIC, and their study is thus becoming a priority.

In this talk, I will present the calculation of the complete next-to-eikonal corrections (first subleading power) to the quark propagator through the target, including both the effects of the finite longitudinal width of the target and of the transverse components of the background field. It extends our previous results on the gluon propagator, which included finite target width corrections only.
I will also present the first applications of this next-to-eikonal quark propagator to the calculation of next-to-eikonal corrections to a few selected observables in pA collisions or DIS.

IS / 154

Emergence of prescaling in far-from-equilibrium quark-gluon plasma

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Recently, in the context of the effective kinetic theory developed by Arnold, Moore and Yaffe 1, Berges and Mazeliauskas 2 have shown that the quark-gluon plasma after a sufficiently energetic heavy-ion collision exhibits prescaling, i.e., that the distribution function can be characterized by a scaling distribution plus three dynamical exponents that converge to the universal scaling exponents of the far-from-equilibrium scaling solution. However, the mechanism through which prescaling is realized has remained unclear thus far.

In this work we study an analytic description of the kinetic theory in terms of a Fokker-Planck collision integral, akin to the small-angle approximation of the full collision kernel, and show that prescaling emerges naturally when the solution approaches the scaling attractor. In the light of the recently proposed adiabatic hydrodynamization scenario by Brewer, Yan and Yin [3], we show that the scaling regime is driven by the slow modes of this system, whereas prescaling is realized when faster modes give competing but decaying contributions to the system's state. For some choices of initial conditions, the prescaling exponents can even be extended to arbitrarily early times, smoothly connecting the free-streaming regime and the scaling non-thermal fixed point. While (pre)scaling

phenomena are only present at very early times, we discuss how the emergence of hydrodynamic-like features at this and later times are likely related to the dominance of a few slow modes driving the evolution of the whole plasma [4].

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IS / **155**

Fixing the nuclear charge density with finite nucleons

Authors: Mauricio Hippert[1]; David Dobrigkeit Chinellato[1]; Matthew Luzum[2]; Willian Matioli Serenone[1]; Jorge Noronha[3]; Tiago Jose Nunes da Silva[4]; Jun Takahashi[1]

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The measured charge distribution of a nucleus is often used to sample positions of nucleons within the nucleus. However, since nucleons have finite size, the resulting charge distribution is different from the sampled distribution. We show that this can have significant observable effects: Not only does it increase the size of the nucleus, but also changes the surface diffusiveness. This in turn can have effects as simple as an overestimate of the transverse size of the collision system resulting in an underestimate of the final transverse momentum, to changes in centrality determination and even total nucleus-nucleus cross section. These differences can, for example, add significant bias to Bayesian parameter estimation. We then show a simple method for correcting this, so that nucleons are sampled in a way that the average charge distribution is fixed to the desired function, and approximately independent of the size of the nucleon. This method can be easily implemented in existing Monte Carlo simulations that utilize a spherical Woods-Saxon distribution. We also discuss a more general treatment that can be used for an arbitrary charge distribution.

Poster / **156**

Exclusive and inclusive dijet production in electron-proton and electron-nucleus collisions at small-x

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We present the computation of exclusive and inclusive dijet production in electron-proton and electron-nucleus collisions at small-x within the Color Glass Condensate effective field theory. We compute the cross- sections differentially in mean dijet momentum and momentum imbalance, as well as its corresponding elliptic anisotropy. For exclusive dijet production, we employ a dipole model with impact parameter and orientation dependence from a modified McLerran-Venugopalan model that incorporates the finite-size charge density of the target (Refs. 1 & 2). For inclusive dijet production, we confirm and extend existing results in the correlation limit approximation by computing the differential cross-section and elliptic anisotropies from full multi-gluon correlations using the Gaussian approximation of high energy correlators, and Balitsky-Kovchegov evolution with running coupling (Ref. 3). For both exclusive and inclusive production, we highlight kinematical regions for observing potential signals of saturation and measuring multi-gluon correlations in a future Electron-Ion Collider.

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CD / **157**

Probing quantum entanglement and collectivity effects in DIS and photo-production e+p collisions at HERA

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Charged particle multiplicity spectra and hadron entropies are measured using the H1 detector at HERA, where positrons of energy 27.6 GeV collided with protons of energy 920 GeV. For the analysis, data on deep-inelastic scattering in the momentum transfer range $5 < Q^2 < 100$ GeV^2 and inelasticity range $0.0375 < y < 0.6$ are used. The observed multiplicity spectra of charged hadrons are compared to Monte Carlo models based on leading-order matrix element, parton showers and string fragmentation. The hadron entropy determined from the multiplicity spectra is compared to the gluon entropy predicted from a quantum-entanglement model.

Observations of two- and multi-particle correlations in high multiplicity p-A, p-p and ultra-peripheral Pb+Pb collisions at RHIC and LHC reveal the collective nature of particle production in small collision systems. These results motivate a study in even smaller systems such as e+p collisions in order

to understand the origin of the observed collectivity. Here, multi-particle correlations are studied in ep collisions using the DIS data described above, as well as, for the first time, photoproduction events. The photoproduction sample corresponds to collisions of quasi-real photons with protons at a center-of-mass energy of about 270 GeV. Collectivity effects are studied as a function of track multiplicity. The data are compared to predictions from Monte Carlo generators.

Poster / 159

Influence of fluctuating initial-state shape deformations in ultra-central collisions

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It is a long standing puzzle that hydrodynamic calculations give larger elliptic flow for ultra-central Pb+Pb events than experiments. One explanation is that sampling from a single particle distribution in Glauber model generates too much shape fluctuation, which can be expected to be modified by NN correlations. We study the fluctuation of shape-deformation as currently implemented in MC-Glauber-like models and its consequences on the magnitude of eccentricities. We show that for both deformed and spherical species, there are large fluctuations in the deformation that emerge event-by-event. For each nucleonic configuration, we characterize the deformation with parameters β and γ, calculated using quadruple moments. The second order eccentricity ε_2 shows a strong correlation with the E-by-E deformation β's for ultra-central collisions. We further show, via acoustic scaling, with a moderate reduction of β by rescaling, the eccentricities we get then agree with the measured values of v_n, for all experimentally available centrality bins. Therefore, the model provides eccentricities that describe experimental data, both where geometry dominates and where fluctuation dominates. We further show that this modification has important implication for the novel observable, the dependence of mean p_T of v_2, for ultra-central collisions.

NT / 160

The renormalization of sound and viscosity from non-equilibrium effective field theory

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In small colliding systems and near the QCD critical point, the effects due to hydrodynamic fluctuations can be significant. The effective field theory of fluctuating hydrodynamics has recently been formulated on the closed time path (Schwinger-Keldysh formalism) 1. Such formulation allows for a systematic treatment of non-linear interaction among energy-momentum densities and

hydrodynamics noise. We present the first complete leading order analysis of the effects of hydrodynamic fluctuations on stress-energy tensor correlations and show how those fluctuations modify the dispersion of sound and shear modes. We find the contributions of hydrodynamic fluctuations are parametrically more important than those from the second-order terms in hydrodynamics. We discuss the potential implications of our results for heavy-ion collision phenomenology 2.

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2 P.H.C. Lau, H. Liu and Y. Yin, in preparation.

Poster / 161

Photon emission in initial and hydrodynamic stages of nuclear collisions

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Direct photons are a powerful tool to study the properties of QCD matter in nuclear collisions. We investigate the contribution of pre-equilibrium photons before hydrodynamization in addition to those of conventional prompt and thermal photons to obtain a comprehensive picture of direct photon emission in the hybrid model based on relativistic hydrodynamics 1. Numerical simulations at an LHC energy suggest that the pre-equilibrium photons can be important at intermediate transverse momentum near the saturation momentum scale, increasing particle spectra and reducing elliptic flow of direct photons.

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CGC / 162

Two particle correlations in pA collisions from the CGC

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The ridge phenomena observed in small size systems such as high multiplicity pp and pA collisions triggered a lot of activity to study the two particle correlations from the initial state point of view. In this talk, we will discuss the multiplicity and mean transverse momentum dependence of v2 by adopting CGC-based calculations in pA collisions. More precisely, we apply CGC techniques to study the correlations between v2 and the total multiplicity of particles produced in the collision and the correlations between v2 and the mean transverse momentum of these particles.

Poster / 163

Emergence of slow modes: the governing degrees of freedom in rapidly-expanding quark–gluon plasma

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A crucial open question is why many models of expanding systems exhibit an apparent simplification in their description while gradients in the system are still large and hydrodynamics is not expected to apply. We discuss a new conceptual approach to understand the pre-equilibrium bulk evolution of a system in terms of a reduced set of slow modes. We propose that the emergent dominance of these modes at early times results in a simplified description of the evolution, but is distinct from hydrodynamics since the slow modes are qualitatively distinct from the hydrodynamic modes.

For concreteness we consider a kinetic theory describing a general expanding system with transverse flow and spatial gradients. For a class of collision integrals, these slow modes can be explicitly identified as the instantaneous ground states of an effective Hamiltonian describing the evolution of moments of the distribution function. We show explicitly that the structure of these modes is rich and that only some are "pre-hydrodynamic" in the sense that they become hydrodynamic modes in the hydrodynamic limit. We propose and test that the pre-equilibrium evolution should be described by a reduced set of slow modes whenever the gradients are small compared to the energy gap between the ground and excited states. This suggests a simplified description even when gradients are large, as long as they are small compared to an energy gap which may also be large, for example at early times.

Based on Brewer, Yan, and Yin [arXiv:1910.00021] and Brewer, Ke, Yan, and Yin (in preparation)

Poster / **164**

Initial Stages of the upgraded ALICE TPC

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The ALICE experiment, located at the CERN LHC, is dedicated to study the physics of ultra-relativistic heavy-ion collisions. In order to operate the ALICE Time Projection Chamber (TPC) in continuous mode, recording the full minimum-bias interaction rate of 50 kHz in Pb − Pb collisions, as anticipated at the LHC in Run 3 and beyond, the gated Multi Wire Proportional Chambers (MWPCs) were replaced by Gas Electron Multiplier-based readout chambers (GEMs). After the assembly and before commissioning of the TPC underground, pre-commissioning was performed in the clean room at the LHC Point 2 during November 2019 – August 2020, in order to ensure the functionality of all readout chambers (ROCs) and Front End Electronics (FEE).

During this pre-commissioning phase, an idea emerged to document some aspects of the upgrade. This resulted in a music video filmed inside the clean room, featuring close-ups of the detector as well as typical issues encountered during the shifts, as experienced by two master students.

Youtube link : https://www.youtube.com/watch?v=G0RS−32VvA&ab_channel=AnnaYiota

IS / 165

Observation of impact parameter dependence of $\mu^+\mu^-$ acoplanarity in ultra-peripheral PbPb collisions

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The CMS Collaboration reports on new differential measurements of $\gamma\gamma \to \mu^+\mu^-$ production in ultra-peripheral PbPb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02~TeV, using data collected during the 2018 LHC run with an integrated luminosity of 1.5~nb^{-1}. Photon-photon interactions have been observed in hadronic heavy-ion collisions by STAR and ALTAS experiments at very low transverse momentum (p_T) regions and the measured p_T and azimuthal angular correlations of lepton pairs via $\gamma\gamma$ scattering in hadronic events exhibit significant broadening compared to that from vacuum production in ultra-peripheral events. There is still no consensus on the origin of the observed broadening, which is mainly from p_T hardening of initial scattered photons as impact parameter (b) decreases toward central hadronic collisions or final-state electromagnetic modifications of lepton pairs in presence of a QGP medium. In this talk, the azimuthal angular correlations and mass spectra of $\mu^+\mu^-$ pairs via $\gamma\gamma$ scattering will be presented as a function of b and rapidity. The b dependence of $\gamma\gamma \to \mu^+\mu^-$ production provides key insights to the origin of observed broadening for photon-photon produced lepton pairs in hadronic collisions while rapidity dependence constrains the relative contributions from leading order and high order photon-photon interactions to measured $\mu^+\mu^-$ pairs.

CD / 166

Probing heavy quark dynamics via multiparticle azimuthal correlations of D0 mesons in PbPb collisions at 5.02 TeV

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In this presentation, we show measurements of the second Fourier coefficient of the azimuthal distribution (elliptic flow, v2) of prompt D0 and D0bar mesons using the four-particle cumulants technique at midrapidity (|y| < 1). These measurements are performed using data from PbPb collisions at 5.02 TeV collected by the CMS detector at the LHC in 2018. The v2 of prompt D0 and D0bar mesons are studied in differential transverse momentum (pT) and event centrality (a measure of the overlap of the two Pb nuclei) bins. Compared to inclusive charged particles, the v2 ratio of measurements using four-particle cumulants and two-particle method, v2{4}/v2{2}, is studied to investigate the contribution of soft and hard physics fluctuations. The results illustrate, for the first time, an indication of charm quark v2 fluctuation from energy loss.

CGC / 168

Search for azimuthal anisotropies in $gamma$p interactions within ultra-peripheral pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV

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In recent years there has been a great effort to search for collectivity in small collision systems. Ultra-peripheral pPb events offer the possibility to study photon-proton collisions at center of mass energies of several hundred GeV, and provide a new arena for the search of collectivity at very small systems. The CMS experiment has collected a large dataset of photon-proton collisions by selecting very asymmetric pPb events which are characterized by a large rapidity gap in the lead going side and no neutron emission from the lead nucleus. These events are compared to a sample of minimum-bias pPb events with the same multiplicity. The observed azimuthal correlations at large relative pseudorapidity are used to extract the first, second, and third-order two-particle anisotropy harmonics, $V_{1\triangle}$, $V_{1\triangle}$, and $V_{1\triangle}$ as a function of track multiplicity and transverse momentum p_T. For both the γp and minimum-bias hadronic pPb samples, significant negative $V_{1\triangle}$ and positive $V_{2\triangle}$ values are observed, while the $V_{3\triangle}$ values are consistent with zero. The single-particle second-order harmonic $v_2(p_T)$ is larger for $gamma$p events than for minimum-bias hadronic pPb collisions at the same multiplicity. These results will be discussed within the context of other recent results to shed light on the emergence of collectivity in small systems.

CGC / **170**

First measurement of the forward rapidity gap distribution in pPb collisions at 8 TeV

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We present the forward rapidity gap spectra from proton-lead collisions for both pomeron-lead and pomeron-proton topologies measured at CMS. The analysis is performed over 10.4 units of pseudorapidity at a center-of-mass energy of $\sqrt{s_{NN}} = 8.16$ TeV, i.e. almost 300 times higher than previous measurements of diffractive production in proton-nucleus collisions. For the pomeron-lead topology, the cross-section predicted by EPOS-LHC is a factor of two lower than the measured data while the model gives a reasonable description of the shape of the spectrum. For the pomeron-proton topology, the EPOS-LHC, QGSJET II, and HIJING generator predictions are lower than the data by at least a factor of five. This effect can be explained by a significant contribution of ultra-peripheral photoproduction events mimicking the signature of diffractive processes. The obtained data may be of significant input for understanding the high energy limit of QCD and modeling cosmic ray air showers.

IS / **171**

Probe the initial stages of the QGP and final state interactions with heavy flavor meson spectra and DDbar correlations in PbPb collisions

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Heavy quarks are produced by hard scattering in relativistic heavy-ion collisions. Since heavy quarks are created early in time, those could be used as effective probes for the lead ions and the QGP. In this parallel talk, new results on beauty and charm meson spectra based on the CMS data collected in Run 2 are presented. Those spectra depend on the nuclear parton distribution functions of the lead ion in the theoretical calculations and could be used to reveal the QGP properties from the early stages of its creation. Moreover, a detailed analysis of fully reconstructed and flavor identified charm mesons could be used to probe the in-medium final-state effects and the strangeness content of the QGP. Finally, the first measurement of D meson pair angular correlation is also presented to provide unprecedented constraints on the heavy quark energy loss mechanism.

Poster / 176

Multiplicity dependence of charged jet properties in pp collisions at √s = 13 TeV with ALICE

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Jets are powerful tools for probing the properties of quark-gluon plasma (QGP) formed in high-energy nucleus-nucleus (AA) collisions. Recent results in high-multiplicity pp collisions suggest that QGP is also formed in such collisions since they show similar features to those that are associated with QGP production in AA collisions. Measurement of jet properties in pp collisions as a function of event multiplicity may elucidate the formation of a QGP in small colliding systems. In this presentation, we report the multiplicity dependence of charged jet observables (average charged particle multiplicity, radial transverse momentum density and fragmentation functions) for leading jets in the range of jet p_{T} from 5 - 120 GeV/c at midrapidity in pp collisions at $\sqrt{s}$ = 13 TeV with ALICE. Jets are reconstructed using anti-k_{T} jet finding algorithm for jet resolution parameter R = 0.4.

Poster / 177

Apparent modification of the jet-like yield in proton-proton collisions with large underlying event

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High-energy proton-proton (pp) collisions at large final state particle multiplicities exhibit heavy ion-like behaviors. Among many others, one of the peculiar feature of heavy ions is partonic energy loss (aka jet quenching) in the produced Quark-Gluon Plasma. The search for jet quenching effects also in small collision systems (such as pp) is warranted. To date no evidence of jet quenching has been observed in pp collisions. The presented work aims to contribute to these searches by studying possible event selection biases which may distort the observed effects measured in pp collisions, and this way can affect the interpretation of observables used to study jet-quenching. Two-particle angular correlations are used in simulated events by the PYTHIA 8 Monte Carlo model to investigate the unavoidable underlying event (UE) background and the consequence of the increased number of multiple parton interactions, which cause the signal distribution to be distorted. A stategy for the modelling and subtraction of the UE is discussed. We found that the signal in the away region

of the azimuthal correlation is less affected by biases and more suitable to examine in experimental measurements.

Reference: https://arxiv.org/pdf/2007.03857.pdf

Poster / **178**

Probing the neutron skin with ultrarelativistic isobaric collisions

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Neutron structure and skin thickness in nuclei have been traditionally measured by low-energy scatterings where the nuclei are only gently disturbed. Their precisions have been limited by theoretical uncertainties in modeling the nuclear force. Here, we propose an unconventional approach to probe the neutron skin by smashing isobar nuclei completely apart at relativistic energies to compare their produced hadron multiplicities. Because particle production in relativistic heavy-ion collisions depends on the details of the nucleon density distributions in the colliding nuclei, we demonstrate that the small difference in hadron multiplicities between isobar collisions, together with state-of-the-art calculations of nuclear structure, can provide an exquisite sensitivity to the poorly constrained neutron density distributions and skin thickness, which can in turn put stringent constraints on the nuclear symmetry energy. Such a premise may already be in stock in the isobar collision data taken at BNL's Relativistic Heavy-Ion Collider in 2018. If realized, it can significantly advance our knowledge of nuclear matter in normal nuclei as well as in astronomical objects like neutron stars.

H. Li, H. Xu, Y. Zhou, X. Wang, J. Zhao, L. Chen, F. Wang, "Probing the neutron skin with ultrarelativistic isobaric collisions", arXiv:1910.06170, Phys.Rev.Lett. in press

FE / **179**

The sPHENIX experiment at RHIC

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The sPHENIX experiment at RHIC is currently under construction and on schedule for first data in early 2023. Built around the excellent BaBar superconducting solenoid, the central detector consists of a silicon pixel vertexer adapted from the ALICE ITS design, a silicon strip detector with single event timing resolution, a compact TPC, novel EM calorimetry, and two layers of hadronic calorimetry. The hybrid streaming/triggered readout of the detector enables full exploitation of the luminosity provided by RHIC. The science program of sPHENIX focuses on jets and heavy flavor, observables with specific relevance to questions of the initial state in heavy ion collisions.
The talk will describe the readiness of the experiment for operations, present an overview of the envisioned physics program. The science program

of sPHENIX focuses on jets and heavy flavor, observables with specific relevance to questions of the initial state in heavy ion collisions.
The talk will describe the readiness of the experiment for operations, present current projections of key jet and heavy flavor measurements, and discuss their potential scientific impact.

Poster / 181

Heavy Flavor Capabilities of the sPHENIX experiment

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The sPHENIX detector at BNL's Relativistic Heavy Ion Collider (RHIC) will measure a suite of unique jet and Upsilon observables with unprecedented statistics and kinematic reach at RHIC energies. A MAPS-based vertex detector upgrade to sPHENIX, the MVTX, will provide a precise determination of the impact parameter of tracks relative to the primary vertex in high multiplicity heavy ion collisions. These new capabilities will enable precision measurements of open heavy flavor observables, covering an unexplored kinematic regime at RHIC. The physics program, its potential impact, and recent detector development will be discussed in this talk.

Poster / 182

Fluctuations of energy density in ultra-central collisions

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No existing model for the initial stages of a heavy-ion collision, when used as initial conditions for hydrodynamics simulations, can provide a satisfactory description of flow in ultra-central collisions. It is therefore useful to understand what properties the initial stages must have in order to be compatible with experimental data. To this end, we parameterize the early-time energy density and its fluctuations via its 1-point and 2-point function, and constrain them by using experimental data for vn{2} in conjunction with hydrodynamic simulations.We find that it is possible to describe experimental data, but it requires larger fluctuations in regions of low density, as compared to existing Monte Carlo models. We comment on the implications of this finding, as well as the limitations of this initial analysis and how it can be improved in the future.

Poster / 183

Non-perturbative renormalization of the average color charge and multi-point correlators of color charge from a non-Gaussian small-x action

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The McLerran-Venugopalan (MV) model is a Gaussian effective theory of color charge fluctuations at small-x in the limit of large valence charge density, i.e. a large nucleus made of uncorrelated color charges. In this work, we explore the effects of the first non-trivial (even C-parity) non-Gaussian correction on the color charge density to the MV model in SU(2) and SU(3) color groups in the non-perturbative regime. We also compare our results to existing perturbative ones on a lattice setup, where multi-point correlators of color charges can be computed for fixed configurations. We investigate three different choices for the renormalization of the couplings figuring in the non-Gaussian small-x action and find that one of them allows to control the deviations from the MV model as one approaches the continuum while the other two lead to a scenario where the small-x action evolves towards a critical theory dominated by strong non-Gaussian fluctuations regardless of the system size.

Poster / **184**

Exploring the QCD phase diagram within a microscopic transport approach

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We study the thermal equilibration and properties of the matter produced at the Beam Energy Scan (BES) program by employing the Parton-Hadron-String Dynamics (PHSD) transport approach which consistently describes the whole non-equilibrium dynamics of heavy-ion collisions, from the early nucleon hard scatterings, to the partonic phase based on the effective propagators and couplings from the Dynamical QuasiParticle Model (DQPM), and up to the final hadron rescatterings. We calculate the energy-momentum tensor and charge currents as a function of the proper time τ and the space-time rapidity η in order to extract local thermodynamic variables such as energy density and charge densities. We combine the equation of state from the hadron resonance gas model and lattice QCD results in order to illustrate the regions probed in the QCD phase diagram for each collisional energy. We find that, on average, our results follow closely the isentropic trajectories at fixed $\langle s\rangle/\langle n_B\rangle$, however the spread of the trajectory in the $(T-\mu_B)$-plane is significant. Finally, we study the dissipative currents and the associated inverse Reynolds numbers in order to assess the degree of equilibration throughout the heavy-ion collision.

IS / **185**

Pre-hydrodynamic evolution and conformal symmetry in small systems

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The pre-hydrodynamic evolution of a heavy-ion collision can have important effects on final state observables, and has received significant renewed interest. Here, we utilize a state-of-the-art simulation chain of heavy ion collisions to extend our previous investigation on the effects of pre-hydrodynamic evolution on final-state observables to small systems. Our simulations include different pre-hydrodynamic scenarios, but which all share an underlying assumption of scale invariance, a common and ubiquitous approximation. This assumption artificially generates a large out-of-equilibrium bulk pressure when switching from (conformal)
pre-hydrodynamic evolution to hydrodynamics (via the non-conformal QCD equation of state), increasing the system transverse momentum, masking other pre-hydro effects, and ultimately poisoning transportcoefficients extracted under these models. We investigate the extent to which these effects are present for small systems compared to large systems, reinforcing the need for the use of improved, non-conformal models for early time dynamics.

Poster / **186**

Thermalization time constrained by high-pt QGP tomography

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We show that high-$p_\perp$ R_{AA} and v_2 are way more sensitive to the QGP thermalization time, τ_0, than the distributions of low-$p_\perp$ particles, and that the high-$p_\perp$ observables prefer relatively late thermalization at τ_0 ~ 1 fm/c. To calculate high-$p_\perp$ R_{AA} and v_2, we employ our newly developed DREENA-A formalism, which combines state-of-the-art dynamical energy loss model with 3+1dimensional hydrodynamical simulations. The model applies to both light and heavy flavor, and we predict a larger sensitivity of heavy observables to the thermalization time. Elliptic flow parameter v_2 is also more sensitive to τ_0 than R_{AA} due to non-trivial differences in the evolution of in-plane and out-of-plane temperature profiles. This presents the first time when a parameter describing bulk QGP has been constrained by high-$p_\perp$ observables and related theory, i.e., by so-called QGP tomography.

Poster / **187**

Forward-backward multiplicity correlations with strongly intensive observables in pp collisions with ALICE

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Strongly intensive observables can be used to measure forward-backward (FB) correlations between charged particles produced in hadronic collisions in two separate pseudorapidity intervals. Within the model of independent statistically identical particle sources, these observables do not depend on the mean value and fluctuations in the number of the sources, therefore the deviation from the value calculated in the model may provide a signature of collective behavior in the system. It was shown that in heavy ion collisions, correlations between particles in two sufficiently separated pseudorapidity intervals are mostly determined by the initial conditions of hadronic interactions. pp collisions can serve as the reference for the analysis of heavy ion collision dynamics. We will present the collision energy and multiplicity class dependence of these observables in pp collisions using ALICE data. Results are compared with calculations in the PYTHIA event generator.

Poster / **188**

Heavy quarks traversing glasma

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Heavy quarks, which are produced at the earliest stage of relativistic heavy-ion collisions, probe the entire history of the quark-gluon plasma that is created in the collision. Initially the plasma is populated with chromodynamic fields which can be treated as classical. In the talk transport of heavy quarks interacting with such long-wavelength chromodynamic fields will be discussed. The method how to obtain field correlators needed to calculate the collision terms of the transport equation will be presented. Then, the energy loss and momentum broadening of heavy quarks traversing the glasma will be evaluated.

NT / **189**

Quantum simulations for heavy ion physics

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Applications of quantum computing to nuclear physics have been studied intensively in recent years. One natural application of quantum computing is the simulation of real-time dynamics of a QCD matter via first principles, which is difficult on a classical computer due to the sign problem. In this talk, I will focus on the viscosity and discuss a general quantum algorithm for computing the viscosity via first principles. Due to the limitation of resources, such calculation on a quantum computer is possible only for small-volume systems in the foreseeable future. I will discuss finite-volume effects on the computation of the viscosity in the context of the quantum algorithm.

Poster / 190

Bayesian analysis of the Trajectum framework

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We introduce the *Trajectum* framework, a new heavy ion code which incorporates many of the necessary components to perform a heavy ion collision simulation in one executable. We use *Trajectum* to study a generalization of the TRENTo initial conditions, namely varying the free streaming velocity $v_{\rm fs}$. In addition, we show the results of a Bayesian analysis performed with this generalized model. This gives mild constraints on second order transport coefficients, and additionally gives a hint suggesting fast hydrodynamization.

CD / 191

A global analysis of Heavy Ion Collisions with transverse momentum dependence

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The understanding of heavy ion collisions and its quark-gluon plasma (QGP) formation requires a complicated interplay of rich physics in a wealth of experimental data. In this talk I will show how for identified particles as a function of transverse momentum both the spectra as well as the anisotropic flow coefficients for both PbPb and pPb collisions can be compared in a global analysis of QGP evolution. Part of our testing includes an elaborate closure test. Interestingly, we find that our large model containing 21 parameters and also utilising this wide range of experimental data leads to a bulk viscosity that is consistent with zero. We conclude with the most precise estimates for the temperature-dependent shear and bulk viscosity to-date.

Poster / 192

Multiparticle correlations from direct calculation of cumulants using the particle azimuthal angles

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Multiparticle correlation techniques have been used to study the nature of long-range collectivity in small collision systems. The subevent cumulant method was shown to significantly reduce the non-flow contributions compared to the standard cumulant method. However, a jet could fall across the boundary between two neighboring subevents and residual nonflow exists in this method. Requiring an additional pseudorapidity gap between neighboring subevents could suppress the nonflow, but it reduces the statistical precision as the gap increases. In this work, We propose calculating the cumulants directly by looping over the particle azimuthal angles. This method is not possible for central and mid-central AA collisions due to the required computing resources, but is feasible for smaller collision systems and peripheral AA collisions. Multiparticle correlations are studied as a function of the pseudorapidity gap between each of the particles in all combinations. The method is tested with PYTHIA and AMPT, and demonstrates that a pseudorapidity gap of 0.8 between or larger successfully removes the nonflow correlations.

Poster / 193

Using PYTHIA as an initial condition generator for hydrodynamics

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A colliding system of ultra-relativistic heavy-ions is commonly simulated with phenomenological models, which include relativistic hydrodynamics and a hadronic cascade afterburner. Typically, any model of heavy-ion collisions must include some estimate of the initial conditions, whose properties are a subject of intense research. Also, many of the common approaches used in the field have no clear connection to the hard scatterings that must have occurred at the very beginning of a heavy-ion collision. In this work, we aim to remedy that by using PYTHIA Angantyr as an initial condition model to a hydrodynamics simulation chain. Those will then be evolved as a fluid using a hybrid model that employs the MUSIC hydrodynamic simulator, and the UrQMD package to emulate the hadronic phase. The resulting simulation outputs will then be compared with available experimental data from the ALICE collaboration.

Poster / 194

Comparison for initial density fluctuations in relativistic heavy ion collisions

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We have compared four models of initial conditions of a fluid dynamic description of high energy heavy ion collisions, focusing on the expectation values and event-by-event fluctuations in the initial transverse energy density profiles from Pb-Pb collisions. Specifically, introducing a Fourier-Bessel mode expansion for fluctuations, we determine expectation values and two-mode correlation functions of the expansion corresponding coefficients. The analytically solveable independent point-sources model is compared to an initial state model based on Glauber theory and two models based on the Color Glass Condensate framework. We find that the large wavelength modes of all investigated models show universal properties for central collisions and also discuss to which extent general properties of initial conditions can be understood analytically.

Poster / 195

Characterizing the initial stages of a heavy-ion collision for determining final state evolution: including conserved charges, momentum, and stress.

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There exist simple and direct relations between the state of the system at early times, and final-state observables. For example, the final elliptic flow is approximately proportional to the initial eccentricity, which represents the leading term in a cumulant expansion of the initial density. This expansion is a systematic method written in terms of length scales that contains the global structure of the initial distribution density.
We describe how to extend this framework to include more information about the early-time system — specifically, conserved currents and additional components of the energy-momentum tensor. These contributions may have particular importance in collisions of small systems and at low energy, respectively, raising the importance of having a complete framework such as this.
We perform hydrodynamic simulations to validate and investigate the proposed extensions. With this information, we can identify what properties of the initial stages are relevant to and accessible by final-state observables, and how they can be constrained by carefully-chosen observables in systems of different size and collision energy.

Poster / 196

The geometry of isobaric collisions as a precision probe of the structure of atomic nuclei

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Measurements of elliptic flow in relativistic nuclear collisions are known to be sensitive to the quadrupole deformation of the colliding nuclear species. We explore the possibilities offered by high-precision data collected in Ru+Ru and Zr+Zr collisions at RHIC for studies of nuclear deformation at high energy. By exploiting the fact that isobaric systems share the same hydrodynamic properties, we consider observables that can be predicted from their initial-state geometry, for instance, ratios of cumulants of flow fluctuations of the kind: $\frac{v_2\{2k\}[\mathrm{Ru+Ru}]}{v_2\{2k\}[\mathrm{Zr+Zr}]} = \frac{\varepsilon_2\{2k\}[\mathrm{Ru+Ru}]}{\varepsilon_2\{2k\}[\mathrm{Zr+Zr}]}$, where v_2 is the final-state elliptic flow, while ε_2 is the initial-state ellipticity. In the measurement of such

ratios, systematic errors cancel to a large extent thanks to the day-by-day swapping between Ru+Ru and Zr+Zr collisions, so that even deviations of order 1% from unity can be precisely determined, due the large statistics of recorded events.

We perform high-quality predictions for these observables by implementing different prescriptions, motivated by state-of-the-art nuclear structure frameworks, for the deformation of the colliding isobars. Our results demonstrate that the deviations from unity in the above ratios driven by the effect of the deformation of nuclei are in general much larger than the expected experimental errors. This gives the opportunity to make unprecedented tests of the predictions of nuclear structure models with RHIC data. We discuss, thus, the possibilities offered by a potential systematic species scan to be performed at RHIC, aimed at studying the geometric shape of atomic nuclei at high energy.

IS / **197**

Onset of deconfinement and critical point searches in NA61/SHINE experiment at SPS

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Studies of the phase diagram of the strongly interacting matter is one of the hottest topics in high energy physics. While the transition from hadronic matter to Quark-Gluon Plasma (onset of deconfinement) is now rather uncontroversial, the difficulties in obtaining a unique and quantitative prediction of the QGP signal within the QCD theoretical framework remain and the scientific community still awaits the confirmation of an experimental observation of the critical endpoint of the transition line.
In this talk, we will briefly report some recent results obtained by the NA61/SHINE Collaboration on those important issues. In particular, we will present the study of the proton-proton momenta intermittency phenomenon as a possible approach to the search of the QCD critical point. Up to now, an indication of second-order fluctuations has been observed in the freeze-out state of central Si+Si collisions at the NA49 Super Proton Synchrotron (SPS) experiment with beam energy √sNN=17.2 GeV.
As its direct successor, the NA61/SHINE experiment is carrying on this search with the ability to scan the QCD phase diagram by varying the colliding nuclei (system size) and the collision energy.

IS / **198**

Constraining the initial state through many-body observables

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Initial state geometry is a key quantitative component of theoretical descriptions of relativistic heavy-ion collisions. Phenomenological models of the initial state are typically designed to reproduce one-body observables, e.g. charged hadron multiplicity and coefficients of the spatial Fourier decomposition, ⊠⊠. However, these models may not simultaneously describe many-body observables such as event plane correlators. In this talk, we present the results of state of the art simulations of heavy-ion collisions by combining Trento and IP-Glasma initial states with MUSIC, iS3D, and

SMASH to demonstrate that Color Glass Condensate inspired models such as IP-Glasma with minimal tuning to one body observables better predict correlation observables than flexible geometric models. We will also present results demonstrating the source of these event plane correlators in the IP-Glasma framework. Together, these demonstrate the advantage of microscopic models of the initial stage of heavy-ion collisions which include the important correlations over simpler schematic models and motivates their use in Bayesian extractions of the properties of the initial state. We assert that by using an interpretable model of microscopic initial stage physics, we can gain insight into the properties of collective behavior in strongly interacting matter and reduce systematic uncertainties.

Poster / 199

Monte Carlo for initial energy density with correlated fluctuations

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We present a new Monte Carlo that generates events based on statistics specified with any 1-point and 2-point function, including arbitrary correlations.
Such a code can be useful for quickly generating events when analytic formulas are known (for example from recent derivations of CGC fluctuations), and for use in Bayesian analyses, where the initial state can be characterized by physical-meaningful parameter such as mean energy density, variance, skewness, correlation length, etc. We use the new code to perform investigations of CGC fluctuations.
We study the effect of model parameters such as saturation scale and regulators (both infrared and ultraviolet), as well as the effects of higher order fluctuations, which are currently unknown.
This provides useful information, even beyond the particular model, of how such fluctuation and correlation properties can appear in observable quantities. We investigate how correlated and uncorrelated events compare, and quantify the sensitivity of relevant properties such as eccentricities ε_n to correlation lengths

CD / 200

Inferring properties of quark-gluon plasma

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Using Bayesian inference, we present state-of-the-art quantifications of initial conditions as well as pre-hydrodynamic and hydrodynamic transport properties of quark-gluon plasma based on hadronic observables from both the Relativistic Heavy Ion Collider and the Large Hadron Collider [1,2]. Estimations of initial state properties are performed by marginalizing over the theoretical uncertainties in the subsequent dynamical evolution. We quantify the effect of theoretical modeling uncertainty at late stages of the collision which can influence the estimation of initial condition properties. We also quantify the experimental evidence for the evolution with collision energy of model parameters describing the initial condition's transverse profile 2.

This work is supported by the NSF through the JETSCAPE Collaboration, grants ACI-1550223 and ACI-1550300.

1 D. Everett et al., arxiv:2010.03928

2 D. Everett et al., in preparation

CD / 201

One fluid might not rule them all

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In this talk, we present our recent investigations on hydrodynamic collectivity in high-multiplicity proton–proton collisions at 13 TeV using the VISHNU hybrid model with different initial condition models, called HIJING, super-MC and TRENTo. We find that with carefully tuned parameters, hydrodynamic simulations can give reasonable descriptions of the measured two-particle correlations. However, multi-particle single and mixed harmonics cumulants can not be described by hydrodynamics with these three initial conditions, even for the signs in a few cases. Further studies show that the non-linear response plays an important role in the hydrodynamic expansion of the p–p systems. Such an effect can change c2{4} from a negative value in the initial state to a positive value in the final state. The failure of the hydrodynamic description of multi-particle cumulant triggers the questions on whether the hydrodynamics can rule all collision systems, including p–p collisions at the LHC.

Poster / 202

Study of nuclei deformation effect on fluctuations and correlations to geometry response mapping with AMPT

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Preliminary STAR-BNL data shows Pearson coefficient ($\rho\left(v_n\{2\}^2,[p_\mathrm{T}]\right)$) could be an intriguing observable to probe the shape deformation in atomic nuclei. Using a well-built and popular multi-phase transport calculation (AMPT), millions of collision events are produced from initial stages to final hadrons comparing with limited statistics from hydrodynamics. The flow fluctuations, event-by-event mean p_T ($\langle p_T\rangle$) fluctuations and Pearson correlations ($\rho\left(v_n\{2\}^2,[p_\mathrm{T}]\right)$) between mean p_T and anisotropy flow are performed mapping from final particles to initial geometry in Au+Au at $\sqrt{s_{NN}}$ = 200 GeV and U+U at $\sqrt{s_{NN}}$ = 193 GeV collisions. These observables can serve as direct probes of the deformation in the colliding nuclear species in our transport AMPT model. An instructive description of hadronic evolution is also achieved, and such kind of study can be helpful to compare with STAR data to further constrain the deformation value, medium properties as well as final state effects in these collisions.

Poster / 203

Initial Motion of Nuclei After High Energy Collisions

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We study the kinematics of nuclei after a collision at close to the speed of light. The nuclei are treated as sources of color-glass condensate that form gluon fields between the nuclei after the collision. We consider this field to be the driving force in the subsequent deceleration and transverse motion of the nuclei. We solve this problem for early times in the general situation, and we also look at full solutions in the weak field approximation. We discuss results for various impact parameters at RHIC and LHC energies. Our results could improve the initial conditions used for subsequent 3+1D fluid dynamic simulations of nuclear collisions.

Poster / 204

Toward full result for next-to-leading order dijet production in proton-nucleus collisions

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Using the CGC effective theory together with the hybrid factorisation, we study forward dijet production in proton-nucleus collisions beyond leading order. In this paper, we compute the "real" next-to-leading order (NLO) corrections, i.e. the radiative corrections associated with a three-parton final state, out of which only two are being measured. To that aim, we start by revisiting our previous results for the three-parton cross-section presented in our previous paper. After some reshuffling of terms, we deduce new expressions for these results, which not only look considerably simpler, but are also physically more transparent. We also correct several errors in this process. The real NLO corrections to inclusive dijet production are then obtained by integrating out the kinematics of any of the three final partons. We explicitly work out the interesting limits where the unmeasured parton is either a soft gluon, or the product of a collinear splitting. We find the expected results in both limits: the B-JIMWLK evolution of the leading-order dijet cross-section in the first case (soft gluon) and, respectively, the DGLAP evolution of the initial and final states in the second case (collinear splitting). The "virtual" NLO corrections to dijet production will be presented in a subsequent publication.

Poster / 205

Measurement of non-prompt J/ψ at midrapidity in Pb–Pb collisions at √sNN = 5.02 TeV with ALICE detector at the LHC

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Abstract: J/ψ-meson is a bound state of charm and anti-charm ($\bar{c}c$) quark pair, whereas the heavy (anti)charm quarks are produced in the initial stages of ultrarelativistic heavy-ion collisions. The J/ψ production is sensitive to the presence of the deconfined state of quarks and gluons, quark-gluon plasma, which is expected to form in the nuclear collisions. Prompt J/ψ-mesons are produced at the primary vertex either directly or via strong or radiative decays of heavier quarkonium states whereas

non-prompt J/ψ-mesons come from decays of b-hadrons. The comparison of these two classes of J/ψ-mesons allows one to probe the charm as well as beauty interaction with the medium.

ALICE has obtained results for non-prompt J/ψ production in a wide pT and centrality range in Pb–Pb collisions at √sNN = 2.76 TeV (LHC Run 1). Larger statistics collected in LHC Run 2 allows more precise results for Pb–Pb collisions at √sNN = 5.02 TeV. In this talk, new results for non-prompt J/ψ in Pb–Pb collisions at √sNN = 5.02 TeV at midrapidity are presented.

PDF / 206

New results on ultra-peripheral collisions with ALICE

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Photon-induced reactions in ultra-peripheral collisions (UPCs) of Pb-emphasized textPb nuclei at the LHC have been studied using the ALICE detector for several years. The ALICE detector can measure the photoproduction cross section for vector mesons at various rapidities, centre-of-mass energies and collision systems. This process allows us to study the energy evolution of the gluon content of the different targets: protons and Pb nuclei.

First measurements of the ρ^0 photoproduction cross section in Xe-Xe UPCs and the t-dependent photonuclear cross section of J/ψ in Pb-Pb UPCs, both at midrapidity, unveil new routes to disentangle the different γ-Pb contributions to the UPCs cross sections and to understand the high-energy limit of QCD via shadowing or saturation, respectively.

Additionally, new ALICE results on rapidity-differential cross section measurements for different nuclear-breakup classes in Pb-Pb at $\sqrt{s_{\mathrm{NN}}}$=5.02 TeV will be presented. The results on J/ψ and ψ' cross sections at midrapidity are complementary to previous findings in the forward rapidity region.

CD / 207

Characterizing system dynamics with short- and long-range correlations in pp, p-Pb, and Pb-Pb collisions at ALICE

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In this contribution we will present the latest results on two-particle number and transverse momentum correlations from the ALICE Collaboration in order to study the initial stages and dynamic evolution of nucleus-nucleus collisions from small to large systems.

In pp and p-Pb collisions, the physical origin of long-range flow-like correlations remains an open question, with implications for our understanding of collective dynamics in both small and large systems. We will present recent measurements of the second Fourier harmonic v_2 as a function of multiplicity in pp collisions using the Forward Multiplicity Detector, which makes it possible to measure the correlations between particles which are separated by up to eight units of pseudorapidity, the largest $\Delta\eta$ gap at the LHC. To further probe the origin of long-range correlations in small systems, we will present a quantitative study of the ridge in high-multiplicity pp collisions which contain a high-momentum charged particle or reconstructed jet, in order to determine whether long-range correlations are correlated with hard processes. The experimental results are compared to the Pythia and EPOS Monte Carlo models which employ different mechanisms to generate ridge-like features, in order to draw conclusions about the underlying physical processes that produce long-range correlations.

We will also present new measurements of the transverse momentum correlator G_2 in pp and p-Pb collisions, and discuss the evolution of the correlation function with multiplicity from small to large collision systems. Measurements of these correlations in Pb-Pb collisions have been recently published by the ALICE Collaboration, and demonstrate features attributed to radial flow, delayed hadronization, momentum transfer due to viscous effects, and system properties like η/s. It is thus of high interest to elucidate how those transverse momentum correlators behave in small collision systems.

PDF / **208**

Heavy gauge boson and photon production for initial state constraints with ALICE

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The parton distribution functions of nuclei are not well constrained for most of the kinematic domain probed with heavy-ion collisions at the LHC. Direct photons in proton-nucleus, W and Z boson production in proton-nucleus and nucleus-nucleus collisions at the LHC can be used to constrain the nuclear parton distribution functions. In this contribution, we present recent results on W- and Z-boson production in p-Pb collisions at $\sqrt{s_{\rm NN}} = 8.16$ TeV and in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV with the ALICE forward muon spectrometer. The results will be compared to calculations obtained with or without including the nuclear modifications of the PDFs. Furthermore, we will present the latest ALICE results on the direct (isolated) photons and their correlations in pp and in p-Pb collisions at midrapidity.

IS / **209**

Quarkonia as probe of the initial stages of the pp, pPb and PbPb collisions with ALICE

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Quarkonia are considered a distinguished tool to study the strongly-interacting medium formed in ultrarelativistic heavy-ion collisions and they are sensitive to the dense gluonic system at low-x in the initial state of heavy-ion collisions. This can be investigated in photonuclear or proton-nuclear collisions. Furthermore a modification of the quarkonium vector states polarization in heavy-ion collisions with respect to pp collisions may give insights on QGP dynamics. Moreover, quarkonium measurements in high-multiplicity proton-proton (pp) collisions can shed light on the role of multi-parton interactions (MPI) which are expected to be relevant for the production of heavy quarks at the LHC energies. ALICE measures quarkonium production down to zero transverse momentum, at forward rapidity (2.5 < y < 4) and midrapidity (|y| < 0.9). In this contribution, we will report on the first measurement of J/ψ polarization in Pb-Pb collisions at the LHC as a function of transverse momentum and centrality. The coherent J/ψ photoproduction cross section measurement in Pb-Pb

collisions with nuclear overlap at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV will be shown for the first time considering the full Run 2 data sample, and extended towards most central collisions. Final results on the nuclear modification factor for ψ(2S),Υ(1S) and Υ(2S) at forward and backward center-of-mass rapidities in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV will be shown, with a focus on the new centrality dependent ψ(2S) results. A broad collection of multiplicity-dependent quarkonium measurements in pp at $\sqrt{s} = 13$ TeV at mid- and forward-rapidity will be also presented. This includes, among others, recent results on the inclusive ψ(2S) and bottomonium production at forward rapidity.

CD / 210

Collectivity of strange, charm, and bottom hadrons in pPb and PbPb with CMS

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We present the elliptic azimuthal anisotropy coefficient (v_2) of the identified strange hadrons (K^0_S and Λ) in pPb and PbPb collisions at 5.02 TeV, and the heavy-flavor hadrons (J/psi, D^0) in pPb at 8.16 TeV and high-multiplicity pp at 13 TeV, using data collected by the CMS experiment at the LHC.
The v_2 values of identified strange hadrons were measured for the first time using the scalar product and multi-particle method as a function of p_T for different centralities in PbPb and event multiplicities in pPb collisions.
The results are compared to the inclusive charged hadrons as well as the hydrodynamic model calculations with different initial state conditions. The positive v_2 results for charm hadrons in high-multiplicity pp and pPb collisions suggest the collectivity of charm quarks.
The v_2 values of open heavy flavor hadrons and J/psi mesons in pp and pPb collisions are measured using the long-range two-particle correlation technique. The collectivity of b hadrons is also studied via non-prompt D^0 mesons (decay products of bottom hadrons) for the first time. The flavor ordering is indicated for p_{T} from $2 - 5$ GeV. The multiplicity dependence of prompt D^0 mesons shows the collectivity diminishes towards the small event activity regime. These measurements provide insights into the origin of the collective phenomena in small and large systems.

CD / 211

Recent results of charmonium and bottomonia in pp, pPb, and PbPb collisions with the CMS detector

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We present the recent results of J/ψ-jet correlation and the cross-sections Y(nS) states in heavy-ion collisions, using the data collected by the CMS experiment at $\sqrt{s_{\mathrm{NN}}} = 5.02$~TeV.
J/ψ production has long been known to be modified in heavy-ion collisions, via, among many, the Debye screening effect. Indirect evidence of, in particular, the non-vanishing v_2 of J/ψ at large transverse momentum, however, suggests that jet quenching may also play an important role in J/ψ suppression. We present the final results of reconstructed J/ψ-jets in heavy-ion collisions. We measure the jet fragmentation function of jets containing a J/ψ meson, to study the dependence of quenching effects on the degree of associated hadro-production inside the jet.

We also present the production cross-sections of Υ(1S), Υ(2S), and Υ(3S) states pPb collision, and their nuclear modification factors (RpPb). The result shows that Υ states are suppressed in pPb collision compared to pp collision, while less pronounced than it is in the lead-lead collision. Sequential ordering of the Υ RpPb, with Υ(1S) least suppressed and Υ(3S) most suppressed, indicates the final-state modification of Υ states in pPb collisions. Predictions using the final-state comover interaction model, which incorporates sequential suppression of bottomonia in pPb collisions, are in better agreement with the measured RpPb versus rapidity than predictions using initial-state modification models.

PDF / 212

Measurement of initial stages via color neutral probes in pPb and PbPb with the CMS detector

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The electroweak process is often used to probe the parton distribution functions (PDFs) in a proton and the nuclear parton distribution functions (nPDFs) in heavy ions. In this presentation, the measurements of the Drell-Yan process in pPb collisions at 8.16 TeV and of Z bosons decaying to pairs of leptons in PbPb collisions using data collected at 5.02 TeV from the CMS experiment at the LHC will be summarized.

In pPb collisions, the dimuon rapidity, mass, p_{T}, and ϕ^* (which is an angular variable correlated with p_{T} measured for the first time in pPb collisions) dependences are shown. In addition, comparisons to theoretical proton PDF and nPDF models show that the data are sensitive to the presence of nuclear modifications to the parton distributions in the lead nucleus, and can help improve and constrain theoretical calculations.

In PbPb collisions, the differential cross-sections of Z bosons decaying to pairs of leptons are measured as a function of transverse momentum \pt and rapidity y. The measurements are performed with an integrated luminosity of 1.7 nb^{-1}, using the dimuon and dielectron decay channels. High precision measurement of the Z boson elliptic azimuthal anisotropy is found to be compatible with zero, showing that Z bosons do not experience a significant final-state modification in heavy-ion collisions. Yields of Z bosons in various centrality bins are compared to Glauber model predictions for the production rates of hard probes not modified by the presence of initial collision geometry and centrality selection effects.

Plenary / 214

Overview of the ALICE results

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Overview of the ALICE results

Plenary / 215

Overview of the CMS results

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Overview of the CMS results

CD / 216

Recent ATLAS measurements of correlations from small to large collision systems

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Measurements of two-particle correlations in pp collisions show features that are strikingly similar to those seen in heavy-ion collisions, suggesting that a tiny droplet of the QGP is produced even in such collisions. In the pp collisions models that attribute the correlations to semi-hard processes can also qualitatively reproduce the measurements. In this talk, we report on a series of ATLAS measurements exploring detailed properties of flow in small, medium, and large collision systems.
New ATLAS measurements of two-particle correlations with active selection on particles associated with jets from the event are performed to elucidate the origin of the long-range correlations. If the correlations are indeed generated by semi-hard processes, then the long-range correlations between particles associated with jets would be stronger than the inclusive hadron correlations, while removing jet-associated particles would weaken the correlations.
Additionally, measurements of the azimuthal anisotropy in p+Pb collisions reaching the transverse momentum of charged particles up to 50 GeV, in minimum-bias and jet-triggered events are presented. In the jet-triggered events, v_2 is non-zero over the entire kinematic range of the measurement, and is $\approx$ 2-3% at $p_{\mathrm{T}} \approx 50$ GeV.
In large collision systems, we focus on understanding the longitudinal structure of the initial-state in heavy-ion collisions as a key for modeling the early-time dynamics. This talk presents results of flow decorrelations in Xe+Xe and Pb+Pb collisions.
In AA collisions, the decorrelations for v_2 show a strong centrality and p_{T} dependence, while no such dependencies are observed for v_3 and v_4 decorrelations. Decorrelations in Xe+Xe collisions, when compared to Pb+Pb collisions, are found to be larger for v_2, but smaller for v_3. These system-dependent trends are not reproduced in current initial-state models when coupled with hydrodynamic evolution.

IS / 217

Correlations between flow and transverse momentum in Pb+Pb and Xe+Xe collisions with ATLAS

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Fluctuations of event-wise average transverse momentum ($[p_{\rm T}]$) and the harmonic flow (v_n) carry important information about initial-state geometry. Collisions of nuclei with large quadrupole deformation are predicted to produce an initial state with enhanced shape and size fluctuations, and result in a non-trivial correlation between v_n and $[p_{\rm T}]$ in the final state. In particular, the $v_2 - [p_{\rm T}]$ correlations are predicted to be different between collisions of spherical ^{208}Pb and collisions of deformed ^{129}Xe. This talk present new measurement of $v_n - [p_{\rm T}]$ correlation in $\sqrt{s_{\rm NN}} = 5.44$ TeV Xe+Xe collisions and compared with Pb+Pb at $\sqrt{s_{\rm NN}} = 5.02$ TeV TeV for harmonics $n = 2$, 3 and 4. The correlation strength is found to depend strongly on the centrality and also on the choice of transverse momentum range of the particles for all harmonics. Comparison with theoretical model calculations is used to shed light on the system-size dependence of this correlation and the influence of deformations. This measurement provides inputs for a better understanding of the initial-state nuclear geometry and dynamics of heavy-ion collisions.

Plenary / **218**

Recent heavy-ion results from ATLAS

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Overview of the ATLAS results

Plenary / **219**

Overview of the LHCb results

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Overview of the LHCb results

Plenary / **220**

Collectivity in small systems in experiment

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Collectivity in small systems

Plenary / 221

Overview of the PHENIX results

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Overview of the PHENIX results

Plenary / 222

Overview of the STAR results

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Overview of the STAR results

Plenary / 223

Review of Low-x and CGC Physics

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Tribute to Genya Levin

Plenary / 224

Connections between the CGC and Transverse Momentum Distributions

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Plenary / 225

Connections Between Hydrodynamics and Spin Physics

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Plenary / **226**

Matching Conditions Across Time Evolution Stages of the Collision

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Interfacing the initial stage with fluid dynamics

Plenary / **227**

Charge Conservation in Initial Conditions and Hydrodynamics

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Plenary / **228**

Hard probes as Initial Stage Probes

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Plenary / **229**

Attribution of Fluctuations in Azimuthal Anisotropies

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Plenary / **230**

Review of Flow, Non-flow, and Decorrelation Observables

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Plenary / **232**

New developments in QCD-based kinetic transport theory

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Plenary / **233**

Influence of Initial Conditions with Sub-Structure in Small Systems

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Plenary / **234**

Adiabatic hydrodynamization

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Plenary / **235**

What have we learned and what do we still need to learn about nPDF?

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Plenary / **236**

What do we learn from small systems about the physics of heavy ion collisions?

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How do two paradigms meet

Plenary / **237**

Flash-1: Measurement of $\gamma\gamma \to \mu^+\mu^-$ pairs in non-ultra peripheral Pb+Pb collisions with the ATLAS detector

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ATLAS measurements of dimuons produced via $\gamma\gamma$ scattering processes in inelastic, non-ultra-peripheral Pb+Pb collisions at 5.02 TeV are presented using an integrated luminosity of 1.9 nb^{-1}. The $\gamma\gamma \to \mu^+\mu^-$ pairs are identified via selections on pair momentum asymmetry and acoplanarity, and the contribution from the heavy flavor decay background is estimated using both template and asymptotic fit methods. The pair yields are measured differentially as functions of the centrality, average transverse-momentum, (p_T) and rapidity of the pair. The measurement shows a depletion in the number of muon pairs near-zero acoplanarity in central events, resulting in the distributions peaking at non-zero values of acoplanarity. Fits to the perpendicular transverse momentum $(k_\perp)$ distributions are used to estimate the centrality dependence of this peak position. The most probable is shown to increase from the most peripheral to the most central collisions, reaching a value of $k_\perp = 36 \pm 1$ MeV in the 0-5\% most-central collisions. The ability of these measurements to qualitatively differentiate between different physical origins of the observed centrality and p_T dependence, including comparisons to several theoretical calculations, are discussed.

Plenary / **238**

Flash-2: X(3872) production in pp with particle multiplicity

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The last decade of hadron spectroscopy has unveiled a wealth of states that do not have the properties expected of particles composed of 2 or 3 valence quarks.
Among the most intriguing of these exotics is the X(3872), which various models attempt to describe as a hadronic molecule, a compact tetraquark, an unexpected charmonium state, or their mixtures. Production in heavy ion collisions, as well as high multiplicity pp collisions, offer a new window on the properties of this poorly understood hadron. In these systems, promptly produced X(3872) hadrons can interact with other particles in the nucleus and/or those produced in the collision. The influence of these interactions on the observed X(3872) yields provides information that can help discriminate between the various models of its structure, as well as give insight into the dynamics of the bulk particles produced in these collisions. With a full range of precision vertexing, tracking, and particle ID capabilities covering 2 to 5 in units of rapidity, the LHCb experiment is especially well suited to measurements of both prompt and non-prompt exotic hadrons.
This talk will present new LHCb measurements X(3872) production in high multiplicity pp collisions through the decay to $J/\psi\pi^+\pi^-$.

Plenary / 239

Flash-3: Monte Carlo for initial energy density with correlated fluctuations

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We present a new Monte Carlo that generates events based on statistics specified with any 1-point and 2-point function, including arbitrary correlations. Such a code can be useful for quickly generating events when analytic formulas are known (for example from recent derivations of CGC fluctuations), and for use in Bayesian analyses, where the initial state can be characterized by physical-meaningful parameter such as mean energy density, variance, skewness, correlation length, etc. We use the new code to perform investigations of CGC fluctuations. We study the effect of model parameters such as saturation scale and regulators (both infrared and ultraviolet), as well as the effects of higher-order fluctuations, which are currently unknown. This provides useful information, even beyond the particular model, of how such fluctuation and correlation properties can appear in observable quantities. We investigate how correlated and uncorrelated events compare, and quantify the sensitivity of relevant properties such as eccentricities ε_n to correlation lengths

Plenary / 240

Flash-4: Longitudinal structure of the initial state from 3+1D CGC simulations

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We develop a framework to simulate the 3+1D dynamics of the initial energy deposition in heavy-ion collisions by taking into account the finite longitudinal extent of the colliding nuclei in the Color-Glass Condensate framework. Based on a simple model for the color charge distributions of the colliding nuclei, we demonstrate how the boost-invariant limit is recovered at high energies along with certain contrasting results that signify deviation from the high energy limit. We then develop a physical model of the three-dimensional color charge distributions in terms of small-x TMDs and study the non-trivial rapidity profile and the longitudinal fluctuations that emerge naturally within our framework.

Plenary / **241**

Flash-5: Novel relaxation time approximation to the relativistic Boltzmann equation

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In 1974, J. L. Anderson and H. R. Witting proposed the Relaxation Time Approximation (RTA) to the relativistic Boltzmann equation 1, following all the development already made in the non-relativistic case by Bhatnagar, Gross and Krook 2. This approximation is used in several fields of physics and has been recently employed to study the hydrodynamization of the matter produced in ultrarelativistic heavy ion collisions 3. However, we shall demonstrate that the approximation proposed by Anderson and Witting contains basic flaws, not being consistent with fundamental properties of the collision operator. The main issue is that this approximation is in general inconsistent with microscopic and macroscopic conservation laws, which leads to several problems when trying to model relativistic gases using energy dependent relaxation times or general matching conditions. In this contribution, we propose a new relaxation time approximation which fixes these basic flaws. We then show how such a new formulation of the approximation affects the expression of transport coefficients and the energy dependence of the nonequilibrium single particle distribution function.

Poster / **242**

A novel formulation of the unintegrated gluon distribution for DIS

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Understanding the relation between QCD evolution in the Bjorken limit and the Regge limit is crucial to achieve a complete and smooth picture of proton and nuclear structure. The hope in the small x regime, where gluon density is expected to reach saturation and the naif partonic picture is expected to break down, was that by computing higher-order corrections to small x evolution (BK equations) one would capture more and more of the physics at moderate x. However, this research program has encountered some challenges. At NLO large collinear logarithms are present and need to be resummed spoiling the renormalization group structure established at LO.

In order to overcome these formal difficulties, we propose to revisit the shock wave approach for high energy scattering by proposing a new gauge invariant operator definition of hadronic operators that account systematically for the collinear limit of structure functions. I will discuss in particular inclusive DIS as a first application.

NT / **243**

Invited: New theoretical developments

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IS / 244

Invited: Electroweak probes of the initial stages

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CGC / 245

Invited: Experimental observables of CGC

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CD / 246

Invited: Correlations and HF

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IS / 247

Invited: Recent developments in UPC

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MPI / 248

Invited: MPI in HI

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FE / 249

Invited: Theory questions to FE

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IS / 250

Invited: Matter-Antimatter collective flows as a signature of strong initial electromagnetic fields

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PDF / 251

Invited: Status of nPDF.

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Discussion / 258

Light ions and future experiments: Panelist Inputs

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Discussion / 259

Light ions and future experiments: Discussion

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