

# Quark Matter 2012

Sunday 12 August 2012 - Saturday 18 August 2012



## Book of Abstracts



# Contents



**Student's Day A (Chair S. Bass) / 685**

## **The QCD Phase Diagram**

**Corresponding Author:** misha@uic.edu

**Student's Day A (Chair S. Bass) / 686**

## **Small-x Physics and Saturation**

**Student's Day A (Chair S. Bass) / 687**

## **Soft Hadronic Probes**

**Corresponding Author:** prsorensen@bnl.gov

**Teacher's Day / 692**

## **Visualizing the "little bangs": Simulations and visualizations of relativistic heavy ion collisions**

**Student Day B (Chair G. Roland) / 688**

## **Hydro & Transport**

**Corresponding Author:** bschenke@quark.phy.bnl.gov

**Teacher's Day / 693**

## **Peering through the haze: Reconstructing the QGP's properties**

**Corresponding Author:** lisa@physics.osu.edu

**Student Day B (Chair G. Roland) / 689**

## **Hard Probes**

**Corresponding Author:** yen-jie.lee@cern.ch

**Teacher's Day / 695**

## **Unexpected connections: Hot quark matter, black holes, and superstring theory**

**Corresponding Author:** pchesler@mit.edu

**Student and Teacher Joint Session (Chair R. Venugopalan) / 690**

## **Quest for the QGP**

**Corresponding Author:** zajc@nevis.columbia.edu

**Student's Day C (Chair R. Venugopalan) / 691**

## **Proton-Nucleus collisions at LHC and Electron-Nucleus collisions at an EIC**

**Corresponding Author:** nestor.armesto@usc.es

**Plenary IA: Opening Session (Chairs: J. Harris, D. Kharzeev, T. Ullrich) / 700**

## **Welcome**

**Plenary IA: Opening Session (Chairs: J. Harris, D. Kharzeev, T. Ullrich) / 619**

## **Opening Keynote Address**

**Plenary IA: Opening Session (Chairs: J. Harris, D. Kharzeev, T. Ullrich) / 620**

## **Broad Overview**

**Corresponding Author:** urs.wiedemann@cern.ch

**Plenary IB: Experimental Highlights (Chair: J. Stachel) / 621**

## **PHENIX Highlights**

**Corresponding Author:** takao@bnl.gov

**Plenary IB: Experimental Highlights (Chair: J. Stachel) / 622**

## **STAR Highlights**

**Co-author:** Xin Dong <sup>1</sup>

<sup>1</sup> *Northeastern University*

**Corresponding Authors:** [xdong@lbl.gov](mailto:xdong@lbl.gov), [xin.dong@cern.ch](mailto:xin.dong@cern.ch)

**Plenary IB: Experimental Highlights (Chair: J. Stachel) / 623**

## **Overview of recent ALICE results**

**Corresponding Author:** [karel.safarik@cern.ch](mailto:karel.safarik@cern.ch)

**Plenary IB: Experimental Highlights (Chair: J. Stachel) / 624**

## **ATLAS Highlights**

**Corresponding Author:** [barbara.wosiek@ifj.edu.pl](mailto:barbara.wosiek@ifj.edu.pl)

**Plenary IB: Experimental Highlights (Chair: J. Stachel) / 625**

## **Experimental highlights from the CMS Collaboration**

**Corresponding Author:** [gunter.roland@cern.ch](mailto:gunter.roland@cern.ch)

**Plenary IC: Initial State, Global & Collective Dynamics (Chair: L. McLerran) / 626**

## **Review of CGC & Developments**

**Corresponding Author:** [adrian.dumitru@baruch.cuny.edu](mailto:adrian.dumitru@baruch.cuny.edu)

**Plenary IC: Initial State, Global & Collective Dynamics (Chair: L. McLerran) / 627**

## **Initial-state fluctuations to Final State Physics**

**Corresponding Author:** [kdusling@gmail.com](mailto:kdusling@gmail.com)

**Plenary IC: Initial State, Global & Collective Dynamics (Chair: L. McLerran) / 628**

## **PHENIX Results on Cold Nuclear Matter**

**Corresponding Author:** matthew.g.wysocki@gmail.com

**Plenary IC: Initial State, Global & Collective Dynamics (Chair: L. McLerran) / 629**

## **Hydro Overview**

**Corresponding Author:** jean-yves.ollitrault@cea.fr

**Plenary IC: Initial State, Global & Collective Dynamics (Chair: L. McLerran) / 630**

## **Azimuthal Anisotropy Results from STAR**

**Corresponding Author:** cebra@physics.ucdavis.edu

**Plenary ID: Initial State, Global & Collective Dynamics (Chair: B. Jacak) / 631**

## **Results on flow from ALICE**

**Corresponding Author:** sergey.voloshin@cern.ch

**Plenary ID: Initial State, Global & Collective Dynamics (Chair: B. Jacak) / 632**

## **Overview of results on flow and correlations from the CMS collaboration**

**Corresponding Author:** stephen.james.sanders@cern.ch

This talk will present an overview of collective flow phenomena and dihadron correlations from the CMS experiment at the LHC in pp and PbPb collisions. Fourier components of the anisotropic azimuthal distribution, ranging from the second to the sixth component, are obtained using different analysis techniques, which have different sensitivities to non-flow and flow fluctuation effects. Utilizing a novel and unique high-pT single-track high-level trigger, the results are presented over a broad pT range up to approximately 60 GeV/c, as a function of pseudorapidity and collision centrality. These new data will provide essential information on both the hydrodynamic properties of the medium at low pT and path length dependence of in-medium parton energy loss at high pT. Dihadron correlations are measured over a wide acceptance and pT range. Long-range near-side ("ridge") correlation structures are observed from low pT (1 GeV/c) to very high pT (at least 20 GeV/c). Their connection to the single-particle azimuthal anisotropy is extensively investigated via the factorization studies of Fourier decomposition of dihadron correlations. Short-range jet-like correlations are also systematically studied as a function of pT, pseudorapidity, centrality and compared to the results in pp collisions.

**Plenary ID: Initial State, Global & Collective Dynamics (Chair: B. Jacak) / 633**



## **ATLAS Flow & Correlations**

**Corresponding Author:** adam.trzupek@cern.ch

**Plenary ID: Initial State, Global & Collective Dynamics (Chair: B. Jacak) / 634**

## **Extraction of transport coefficients**

**Corresponding Author:** huichaosong@gmail.com

**Plenary IIA: Jets (Chair M. Gyulassy) / 636**

## **Theoretical overview of jet quenching**

**Corresponding Author:** guilherme.milhano@cern.ch

**Plenary IIA: Jets (Chair M. Gyulassy) / 637**

## **ATLAS Jets**

**Corresponding Author:** martin.spousta@cern.ch

**Plenary IIA: Jets (Chair M. Gyulassy) / 638**

## **Results on jet spectra and structure from ALICE**

**Corresponding Author:** andreas.morsch@cern.ch

**Plenary IIA: Jets (Chair M. Gyulassy) / 639**

## **Overview of results on jets from the CMS collaboration**

**Corresponding Author:** gabor.veres@cern.ch

**Plenary IIA: Jets (Chair M. Gyulassy) / 640**

## **PHENIX High $p_T$**

**Plenary IIA: Jets (Chair M. Gyulassy) / 641**

## **Results on identified particle spectra from ALICE**

**Corresponding Author:** marian.ivanov@cern.ch

Plenary IIA: Jets (Chair M. Gyulassy) / 642

## **Jet Discussion**

Plenary IIB: Heavy Flavor (Chair: P. Giubellino) / 643

## **Heavy Flavor Results from STAR**

**Corresponding Author:** wei.xie@cern.ch

Plenary IIB: Heavy Flavor (Chair: P. Giubellino) / 644

## **PHENIX Heavy Flavors**

**Corresponding Author:** mrosati@iastate.edu

Plenary IIB: Heavy Flavor (Chair: P. Giubellino) / 645

## **Results on heavy flavors from ALICE**

**Corresponding Author:** zconesa@in2p3.fr

Plenary IIB: Heavy Flavor (Chair: P. Giubellino) / 646

## **Heavy quark production and energy loss**

**Corresponding Author:** wa.horowitz@gmail.com

Plenary IIB: Heavy Flavor (Chair: P. Giubellino) / 647

## **Heavy Flavor Discussion**

Parallel 1C: Correlations & Fluctuations (Chair J. Schukraft) / 291

## Detailed HBT measurement with respect to event plane and collision energy in Au+Au collisions at PHENIX

**Author:** Takafumi for the PHENIX Collaboration Niida<sup>1</sup>

<sup>1</sup> *University of Tsukuba*

**Corresponding Author:** takafumi.niida@cern.ch

The HBT measurement provides the information on the space-time evolution of particle emitting source in relativistic heavy ion collisions. Azimuthal component of 3D HBT radii relative to event plane gives us the information of the source shape at freeze-out. It also provides the information of the system evolution by comparing with the initial source shape.

The recent measurement of higher harmonic flow ( $v_3$ ,  $v_4$ , etc) are measured at RHIC and LHC, which are primarily coming from the spatial fluctuation of the initial density on the collision area. Hydrodynamic model calculation reports that the shape by the initial fluctuation resulting in triangular component may be preserved until freeze-out. The HBT measurement relative to higher order event plane may show the feature if this is the case.

We will present the recent results of azimuthal HBT measurement relative to 2<sup>nd</sup> and 3<sup>rd</sup> order event plane in Au+Au 200 GeV collisions at PHENIX. Eccentricity at freeze-out for charged pions and kaons will be compared and discussed. Also, triangularity at freeze-out for charged pions will be reported. The recent HBT measurement at lower energies will also be shown, and compared with 200GeV results.

**Parallel 1A: Global & Collective Dynamics (Chair U. Heinz) / 551**

### Shocks in Quark-Gluon Plasma

**Author:** Edward Shuryak<sup>1</sup>

<sup>1</sup> *stony brook university*

**Corresponding Author:** edward.shuryak@stonybrook.edu

Large energy deposition from LHC quenching jets restarted interest to shock formation. Shocks also have theoretical significance as the simplest out-of-equilibrium setting without time dependence. While weak shocks have small gradients and can be treated hydrodynamically in the Navier-Stokes (NS) approximation, the ones without a small parameter (strong shocks) needs other methods. Two of those will be applied: (i) the “resummed hydrodynamics” proposed earlier by Lublinsky and myself; and (ii) AdS/CFT correspondence, which uses the modified Einstein equations. In the latter case we apply novel variational approach and find approximate solution good to within fraction of a percent. The conclusion from both treatments is that the strong shocks deviate from NS only be few percent, in the direction of thinner shocks. We also discuss how shock formation should modify the predictions for jet-hadron and hard hadron-hadron correlators.

**Parallel 1B, Jets (Chair X.N. Wang) / 219**

### Study of jet quenching using photon-jet events in PbPb collisions at 2.76 TeV with CMS

**Author:** Collaboration CMS<sup>1</sup>

<sup>1</sup> CERN**Corresponding Authors:** ylai@mit.edu, wyslouch@mit.edu

The first measurement of the transverse momentum ( $p_T$ ) imbalance of isolated-photon+jet pairs in relativistic heavy ion collisions is reported. The analysis uses data from PbPb collisions at a center-of-mass energy of 2.76 TeV per nucleon pair and corresponding to an integrated luminosity of 150/ub recorded by the CMS experiment at the LHC in 2011. For events containing an isolated photon with transverse momentum  $p_T > 60$  GeV/c and an associated jet with  $p_T > 30$  GeV/c, the photon-jet  $p_T$  imbalance is studied as a function of collision centrality and compared to pp data and PYTHIA calculations at the same center-of-mass energy. Using the  $p_T$  of the isolated photon as an estimate of the energy of the associated parton at production, this measurement allows an unbiased characterization of the in-medium parton energy loss.

**Parallel 1D: Heavy Flavor & Quarkonia (Chair R. Granier de Cassagnac) / 229**

## Detailed measurements of charmonium suppression in PbPb collisions at 2.76 TeV with CMS

**Author:** Collaboration CMS<sup>1</sup><sup>1</sup> CERN**Corresponding Authors:** dong.ho.moon@cern.ch, wyslouch@mit.edu

CMS has measured the nuclear modification factors of prompt  $J/\psi$  in PbPb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV. For prompt  $J/\psi$  with relatively high  $p_T$  ( $6.5 < p_T < 30$  GeV/c), a strong, centrality-dependent suppression is observed in PbPb collisions, compared to the yield in pp collisions scaled by the number of inelastic nucleon-nucleon collisions. During the 2011 data taking period the data sample has been increased by a factor of twenty, which allows for more detailed charmonium measurements, e.g. mapping the transverse momentum and centrality dependence of the nuclear modification simultaneously. New results on charmonium suppression based on the full available 2011 data sample will be reported.

**Parallel 1B, Jets (Chair X.N. Wang) / 478**

## Study of correlations between neutral bosons and jets in lead-lead collisions at 2.76 TeV with the ATLAS detector

**Author:** Zdenek ATLAS Collaboration<sup>1</sup><sup>1</sup> Charles University Prague**Corresponding Authors:** zvi.citron@cern.ch, zdenek.dolezal@cern.ch

The correlations of jets with neutral bosons is a particularly powerful tool to probe the underlying physics of jet quenching. To gain insight into the physics of this process we can study Z-jet and gamma-jet correlations. Because the Z and photons do not directly couple to the strong force, in a jet+boson event the unmodified bosons allow us to access the modification of the opposite side jet; unlike dijet events, where both jets potentially lose energy, these bosons provide an excellent calibration of the energy of the recoil jet. The jets are measured in the same calorimeter, over a range of jet radii, and benefit from the detailed information about the shower profile. The ATLAS experiment has measured jet correlations with both direct photons as well as with Z bosons via dilepton channels in Pb+Pb collisions with  $\sqrt{s_{NN}}=2.76$  TeV in a data sample of nearly 150  $\text{ub}^{-1}$  of integrated luminosity. The measurement of these correlations will be presented.

**Parallel 1A: Global & Collective Dynamics (Chair U. Heinz) / 328****PHENIX Measurements of Higher-order Flow Harmonics for Identified Charged Hadrons in Au+Au Collisions at 39 – 200 GeV****Author:** YI GU<sup>1</sup><sup>1</sup> D**Corresponding Author:** ygu@bnl.gov

Collective flow measurements continue to play an important role in ongoing efforts to map out the temperature dependence of the transport coefficient  $\eta_s(T)$ , for the strongly interacting matter produced in heavy ion collisions at RHIC. Recently, PHENIX has performed a detailed set of measurements of the higher-order flow coefficients ( $v_n$  for  $n=2,3,4$ ), for both inclusive and identified charged hadrons. The results from these new measurements in Au+Au collisions will be presented, as a function of  $p_T$ , centrality and beam collision energy, in concert with several scaling properties observed for these data. The role of these results as additional constraints for  $\eta_s(T)$  will also be discussed.

**Parallel 1C: Correlations & Fluctuations (Chair J. Schukraft) / 373****Femtoscropy of identified particles at STAR.****Author:** Piotr Krystian Ostrowski<sup>1</sup><sup>1</sup> *Warsaw University of Technology (PL)***Corresponding Authors:** neau2802@gmail.com, neha@physics.ucla.edu, piotr.krystian.ostrowski@cern.ch

Measurement of correlations of pair of particles with small relative momenta provides insight into geometry and lifetime of particle emitting source in relativistic heavy ion collisions.

Kaon femtoscopy extends the range of pair transverse mass covered and provides a sample less affected by decay resonances as compared to pions. The correlation functions of non-identical particles in the three-dimensional  $\vec{k}^*$  space can reveal a space-time offset of one particle species (e.g. kaons) with respect to another (e.g. pions). Measurement of  $\Lambda - \Lambda$  correlation is closely related to  $H_0$ -dibaryon, a six quark state predicted by Jaffe[1], which could appear as a bump in the  $\Lambda - \Lambda$  invariant mass spectra or depletion in pair correlation near the threshold depending on the nature of  $H_0$ -dibaryon state.

We present new measurements of pion-kaon, kaon-kaon and hyperon-hyperon correlations measured in Au+Au collisions at the STAR experiment during Run 10 and Run 11. The analysis greatly benefits from the STAR Time of Flight detector to extend particle identification capabilities. Kaon source sizes are extracted by using spherical harmonics decomposition technique. Dependence of the kaon source radii on event centrality and pair transverse momentum for  $\sqrt{s_{NN}} = 7.7-200$  GeV are presented. Centrality dependence of pion-kaon femtoscopy in at Au+Au  $\sqrt{s_{NN}} = 200$  GeV and a similar analysis for p+p collisions at  $\sqrt{s_{NN}} = 200$  GeV will be presented for the first time. Finally, we will present the measurement of  $\Lambda - \Lambda$  correlations for  $\sqrt{s_{NN}} = 39-200$  GeV.

[1] R. L. Jaffe, Phys. Rev. Lett. 38(1977) 195.

**Parallel 1D: Heavy Flavor & Quarkonia (Chair R. Granier de Cassagnac) / 497****Jpsi and psi (2S) production in Pb-Pb collisions with the ALICE Muon spectrometer at the LHC**

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Philippe Rosnet<sup>2</sup>

<sup>1</sup> *CERN Geneva, Switzerland*

<sup>2</sup> *Lab. de Physique Corpusculaire (LPC) - Inst. Nat. Phys. Nucl. et*

**Corresponding Authors:** arnaldi@to.infn.it, vercelli@to.infn.it

ALICE is the LHC experiment dedicated to the study of heavy ion collisions. The main purpose of ALICE is to investigate the properties of a new state of deconfined nuclear matter, the Quark Gluon Plasma. Quarkonium measurements will play a crucial role in this investigation. In particular, the sequential suppression of the quarkonium states by color screening has long been suggested as a signature and thermometer of the QGP.

**Parallel 1D: Heavy Flavor & Quarkonia (Chair R. Granier de Cassagnac) / 374**

## Heavy quark potential at non-zero temperature and quarkonium spectral functions

**Author:** Peter Petreczky<sup>1</sup>

**Co-author:** Alexei Bazavov<sup>1</sup>

<sup>1</sup> *BNL*

**Corresponding Author:** petreczk@bnl.gov

We calculate different types of Wilson loops of temporal size  $t < 1/T$  at non-zero temperatures on the lattice using Highly Improved Staggered Quark (HISQ) action and temporal extent  $Nt=8$  and  $12$ . Unlike other static correlators which go around the periodic boundary these Wilson loops are not related to the free energy of static quark anti-quark pair. Therefore from the analysis of the Wilson loop we extract the real part of the heavy quark potential. We find that the extracted potential is systematically larger than the singlet free energy calculated on the lattice. At  $T > 200 \text{ MeV}$  we supplement the calculated real part of the potential with the imaginary part obtained in perturbation theory and evaluate the quarkonium spectral functions. We find that all quarkonium states except the Upsilon(1S) melt at temperatures  $T > 300 \text{ MeV}$ . Finally from the obtained spectral functions we calculate the Euclidean correlation functions and compare them with available lattice data.

**Parallel 1B, Jets (Chair X.N. Wang) / 317**

## Prompt Photon Production and Photon-Jet Hadron Correlations in PHENIX at RHIC

**Author:** Justin Edward Frantz<sup>1</sup>

<sup>1</sup> *Ohio University (US)*

**Corresponding Author:** frantz@ohio.edu

A variety of heavy-ion data from RHIC and recently also from the LHC on hard direct photon production testifies that this “white” probe of the densely colored QGP continues to lend new insights to understanding jet suppression and energy loss. It also allows first comparisons between RHIC and LHC energies for the behavior of energy loss, for example whether jet fragmentation function is indeed modified by the energy loss process at any jet energy. Additionally, direct photon measurements in A+A since they are not affected by the final state QGP, offer an excellent way to test for non-trivial initial state effects, complementing recent PHENIX d+Au collision jet and single electron spectra data. To this end, we will report in this talk on new results of high  $p_T$  single direct photon production in both p+p and Heavy Ion systems.

For the hot final state QGP studies, PHENIX results on direct photon-jet “photon-hadron” correlations for QGP studies will also be presented. This will include a report on analyses of new datasets, which should be able to directly address the question of fragmentation function modification, along with the status of new analysis directions in PHENIX for this channel, such as event by event photon identification techniques in high multiplicity.

**Parallel 1C: Correlations & Fluctuations (Chair J. Schukraft) / 425**

## Meson and baryon femtoscopy in heavy-ion collisions at ALICE

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Maciej Pawel Szymanski<sup>2</sup>

<sup>1</sup> CERN, Geneva, Switzerland

<sup>2</sup> Warsaw University of Technology (PL)

**Corresponding Authors:** maciej.szymanski@cern.ch, panos.christakoglou@cern.ch

In heavy-ion collisions produced at the LHC two-particle correlations of mesons and baryons carry important information about the emitting source. At low relative momentum femtoscopic correlations arise, which are sensitive to the homogeneity lengths of the system. Hydrodynamic models predict that these will decrease with increasing transverse mass of the pair. Such decrease is universally reported for pions, also at the LHC. Kaons and baryons, having a much larger mass, allow to significantly extend the range of measured  $m_T$ . The femtoscopic results for heavier particles would put a strong constraint on such predictions. Non-identical baryon and meson pairs are also sensitive to emission asymmetries.

Femtoscopic correlations between baryons arise mostly due to the strong interaction, which is not precisely known for some baryon pair types. Most notable example is the lambda-lambda interaction which has an unknown contribution due to the potential existence of the H0 dibaryon. Equally interesting are baryon-antibaryon potentials, which have a significant contribution from annihilation channels. These processes may have an impact on single-particle spectra, and should be investigated as one of the possible sources of the small proton yield at the LHC.

We show the two-particle correlation functions for several pair types (baryon-baryon, baryon-antibaryon and meson-meson), consisting of neutral and charged kaons, protons and lambdas. Femtoscopic analysis is carried out for them, taking into account, when necessary, residual correlations and annihilation channels. Results are presented as a function of transverse mass and event multiplicity, comparing with the pp collisions results when possible. Correlations with lambdas are analyzed both with femtoscopic methods as well as to study the unknown interaction potentials.

**Parallel 1A: Global & Collective Dynamics (Chair U. Heinz) / 156**

## Beam Energy Dependence of First and Higher-Order Flow Harmonics from the STAR Experiment at RHIC

**Author:** Yadav Pandit<sup>1</sup>

<sup>1</sup> *Kent State University*

**Corresponding Author:** ypandit@kent.edu

A primary goal of the RHIC Beam Energy Scan (BES) is to search for evidence of a transition between a hadron gas and a Quark Gluon Plasma. The dependence of  $v_1$  and higher flow harmonics on system size and beam energy may be sensitive to the degrees of freedom in the system, as a consequence of early pressure gradients and a potential softening in the equation of state. In this talk, we present STAR measurements of  $v_1$  for  $\pi^\pm$ ,  $K^\pm$ , protons and antiprotons along with  $v_n$  for charged particles from 7.7 GeV to 200 GeV. A striking observation is that

the  $v_1$  slope  $F = dv_1/dy$  for net protons, which is an estimate of the directed flow contribution from baryon number transported to the midrapidity region, changes sign twice within the BES energy range. In contrast,  $F$  for all other particle types is negative at all studied energies. For charged particles, we observe a local minimum in integrated ( $0.2 < p_T < 2.0$  GeV/c and  $|\eta| < 1.0$ ) directed flow between 11.5 and 27 GeV for central 0-20% collisions. At a similar centrality, we observe a shallow minimum in the energy dependence of  $v_3$  for charged hadrons. We also show the ratio of the two-particle cumulant  $v_n\{2\}$  to participant eccentricity ( $\varepsilon_{n,\text{part}}$ ) to quantify how well the system converts initial geometry fluctuations into momentum-space correlations for different collision energies, system sizes and harmonics.

**Parallel 1B, Jets (Chair X.N. Wang) / 439**

## Correlation between isolated photons and charged hadrons in pp and Pb-Pb collisions measured with ALICE

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Nicolas Arbor<sup>2</sup>

<sup>1</sup> *CERN, Geneva, Switzerland*

<sup>2</sup> *Centre National de la Recherche Scientifique (FR)*

**Corresponding Authors:** nicolas.arbor@cern.ch, jochen@thaeader.de

Gamma-hadron correlations measured in heavy-ion collisions produced at the LHC allow to investigate medium induced jet modifications in a transverse momentum ( $p_t$ ) range below 50 GeV/c, where jet reconstruction is challenging because of the relatively large contribution from the underlying event. At high  $p_t$  direct photons, produced in Compton and annihilation QCD leading order processes, are associated to a jet in opposite direction. Such processes are tagged experimentally by identifying leading isolated photons and their correlated associated hadrons in opposite azimuthal direction. The jet fragmentation is estimated from the hadrons and the photon  $p_t$  via the imbalance parameter  $x_E = -\frac{|\vec{p}_{t,h}|}{|\vec{p}_{t,g}|} / |\vec{p}_{t,g}|^2$ . The remaining contamination from neutral meson decay photons is subtracted statistically. We present the first results extracted from gamma-hadron correlations measured in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV, triggered by the ALICE electromagnetic calorimeters. Medium effects will be studied by comparison to results from pp collisions data at  $\sqrt{s} = 7$  TeV, combined with a smaller dataset at  $\sqrt{s} = 2.76$  TeV.

**Parallel 1D: Heavy Flavor & Quarkonia (Chair R. Granier de Cassagnac) / 306**



## Recent Heavy Quarkonia Results from PHENIX

**Author:** Darren McGlinchey<sup>1</sup>

<sup>1</sup> *F*

**Corresponding Author:** dmcglinchey@fsu.edu

The idea of using heavy quarkonia production as a direct probe of the screening length in the quark gluon plasma (QGP) has been around for over two decades. Suppression of quarkonia production in heavy ion collisions has been measured at the SPS, RHIC, and the LHC, including new measurements of  $\Upsilon(1S + 2S + 3S)$  production in Au+Au collisions by PHENIX. However, a full understanding of these results in terms of direct contributions from the QGP is still evolving. An incomplete knowledge of the baseline cold nuclear matter (CNM) effects, as well as the possibility of competing effects present in the QGP, such as recombination, has hindered a full understanding of the observed heavy ion results.

In order to quantify the CNM effects present at RHIC, PHENIX has measured both  $J/\psi$  and  $\Upsilon$  production in  $d+Au$  collisions over a wide range in rapidity with the inclusion of new measurements of  $\Upsilon(1S + 2S + 3S)$  production at midrapidity. PHENIX finds a suppression relative to  $p+p$  collisions which is greater at forward rapidity and similar between the  $J/\psi$  and  $\Upsilon$ , leading to interesting implications of the RHIC heavy ion results. New measurements of the transverse momentum dependence of the  $J/\psi$  nuclear modification factor provide further constraints on CNM effects, as well as constraining the Cronin effect at RHIC energies. This talk will present recent heavy quarkonia results in  $p+p$ ,  $d+Au$  and Au+Au collisions from PHENIX, as well as the implications of the measured CNM effects on the heavy ion data.

**Parallel 1A: Global & Collective Dynamics (Chair U. Heinz) / 32**

## Collision Energy Dependence of Viscous Hydrodynamic Flow in Relativistic Heavy-Ion Collisions

**Author:** Chun Shen<sup>1</sup>

**Co-author:** Ulrich Heinz<sup>2</sup>

<sup>1</sup> *Ohio State University*

<sup>2</sup> *The Ohio State University*

**Corresponding Author:** shen@mps.ohio-state.edu

We present a systematic study on the evolution of hadron spectra and their azimuthal anisotropy from the lowest collision energy studied at the Relativistic Heavy Ion Collider (RHIC),  $\sqrt{s} = 7.7A$  GeV, to the highest energy reachable at the Large Hadron Collider (LHC),  $\sqrt{s} = 5500A$  GeV [1]. As the collision energy increases, the resulting increases of the initial temperature, and fireball lifetime, as well as the evolution of the centrality dependence of final charged particle multiplicity are quantitatively studied and compared between the two most popular initial state models, the Monte Carlo Glauber and Monte-Carlo Kharzeev-Levin-Nardi (MC-KLN) models. For Glauber model initial conditions with a small specific shear viscosity  $\eta/s = 0.08$ , the differential charged hadron elliptic flow  $v_2\{ch\}(pT, \sqrt{s})$  is found to exhibit a very broad maximum as a function of  $\sqrt{s}$  around top RHIC energy, rendering it almost independent of collision energy for  $39 < \sqrt{s} < 2760A$  GeV. Compared to ideal fluid dynamical simulations [2], this “saturation” of elliptic flow is shifted to higher collision energies by shear viscous effects. For color-glass motivated MC-KLN initial conditions, which require a larger shear viscosity  $\eta/s = 0.2$  to reproduce the measured elliptic flow, a similar “saturation” is not observed up to LHC energies, except for very low pT. We emphasize that this “saturation” of the elliptic flow is not associated with the QCD phase transition, but arises from the interplay between radial and elliptic flow which shifts with  $\sqrt{s}$  depending on the fluid’s viscosity and leads to a subtle cancellation between increasing contributions from light and decreasing contributions from heavy particles to  $v_2$  in the  $\sqrt{s}$  range where  $v_2\{ch\}(pT, \sqrt{s})$  at fixed pT is maximal. By generalizing the

definition of spatial eccentricity  $ecc_x$  to isothermal hyper-surfaces, we calculate  $ecc_x$  on the kinetic freeze-out surface at different collision energies. Up to top RHIC energy,  $\sqrt{s}=200A$  GeV, the fireball is still out-of-plane deformed at freeze out, while at LHC energy the final spatial eccentricity is predicted to approach zero.

[1] Chun Shen and Ulrich Heinz, "Collision Energy Dependence of Viscous Hydrodynamic Flow in Relativistic Heavy-Ion Collisions," arXiv:1202.6620 [nucl-th].

[2] Gregory Kestin and Ulrich Heinz, "Hydrodynamic radial and elliptic flow in heavy-ion collisions from AGS to LHC energies," Eur. Phys. J. C 61, 545 (2009)

**Parallel 1C: Correlations & Fluctuations (Chair J. Schukraft) / 228**

## Short- and long-range very-high-pT triggered dihadron correlations in PbPb collisions at 2.76 TeV with CMS

**Author:** Collaboration CMS<sup>1</sup>

<sup>1</sup> CERN

**Corresponding Authors:** rylan.towne.conway@cern.ch, wyslouch@mit.edu

New precision measurements of dihadron correlations triggered by a very high-pT particle in 2.76 TeV PbPb collisions over a broad range of pseudorapidity and the full range of azimuthal angle will be presented. Utilizing a novel and unique high-pT single-track high-level trigger, the analysis explores the full 2011 PbPb data set corresponding to an integrated luminosity of 150/ub collected by CMS. For the first time, a long-range correlation structure up to  $|\Delta\eta|^4$  at small  $\Delta\phi$  (near side) is observed for such very high-pT (e.g.,  $p_T \sim 20$  GeV/c) trigger particles correlated with low-pT (a few GeV/c) associated particles. The observed long-range correlations in  $|\Delta\eta|$  on the near side are consistent with the single-particle azimuthal anisotropy (characterized by the Fourier harmonics,  $v_n$ ) of high-pT trigger particles measured relative to the event-plane angle determined with the forward hadronic calorimeters. After subtracting the  $v_n$  harmonics component, the shape and yield on the near ( $|\Delta\phi| < 1$ ) and away ( $|\Delta\phi| > 1$ ) side of the residual dihadron correlations have been studied systematically over a wide kinematic range in trigger ( $12 < p_T[\text{trig}] < 50$  GeV/c) and associated ( $0.5 \text{ GeV/c} < p_T[\text{assoc}] < p_T[\text{trig}]$ ) particle  $p_T$ , as a function of pseudorapidity and collision centrality. The results are compared to those in pp collisions at the same energy.

**Parallel 1A: Global & Collective Dynamics (Chair U. Heinz) / 521**

## Non-linear anisotropic flow with ideal and viscous hydrodynamics

**Author:** Derek Teaney<sup>1</sup>

**Co-author:** Li Yan<sup>1</sup>

<sup>1</sup> Stony Brook University

**Corresponding Author:** goodwill.yan@gmail.com

The particle spectrum from RHIC and LHC can be decomposed into harmonic series that defines the dipolar flow  $v_1$ , the elliptic flow  $v_2$ , the triangular flow  $v_3$ , and  $v_4$ , and  $v_5$  etc. To understand the origin of higher order harmonics, we extend the linear response formalism for anisotropic flow to include the non-linear response which results from the interactions between the lowest harmonics and the elliptic flow. For example,  $v_{5(23)}/(\epsilon_2\epsilon_3)$  records the  $v_5$  generated by the non-linear interactions between  $v_2$  and  $v_3$ . Ideal and viscous hydrodynamic calculations show that the non-linear response

becomes dominant for  $n=4$  and  $n=5$  in non-central collisions. This trend is much more pronounced for viscous hydrodynamics where the linear response for  $n=4$  and  $n=5$  is negligible.

**Parallel 1D: Heavy Flavor & Quarkonia (Chair R. Granier de Cassagnac) / 375**

## Quarkonia production in the STAR experiment

**Author:** Barbara Trzeciak<sup>1</sup>

<sup>1</sup> *Warsaw University of Technology*

**Corresponding Author:** barbara.trzeciak@gmail.com

The suppression of quarkonia production in high energy nuclear collisions relative to proton-proton collisions, due to the Debye screening of the quark-antiquark potential, was proposed as a signature of the formation of Quark-Gluon Plasma. However, there are other effects that may affect the observed quarkonia production, such as cold nuclear matter effects, final state nuclear absorption and statistical coalescence of quark-antiquark pairs. Studies of production of various quarkonia states in heavy-ion collisions can provide insight into the properties of the hot and dense medium created in relativistic heavy-ion collisions at RHIC. Systematic measurement of the quarkonia production for different colliding systems, centralities and collision energies may help to understand the quarkonia production mechanisms as well as the medium properties. Furthermore, at RHIC energies the  $\Upsilon$  meson is a clean probe of the early system due to negligible contributions from  $b\bar{b}$  recombination and non-thermal suppression from co-mover absorption.

In this talk we will present results on  $J/\psi$  and  $\Upsilon$  production via the dielectron decay channel in Au+Au,  $d+Au$  and  $p+p$  collisions at midrapidity at  $\sqrt{s_{NN}} = 200$  GeV in the STAR experiment. We will show the  $J/\psi$  nuclear modification factor as a function of centrality and  $p_T$  and the  $\Upsilon$  nuclear modification factor computed using the new preliminary  $p+p$  result from 2009, in Au+Au and  $d+Au$  collisions. We will also present the  $J/\psi$  polarization measurement in  $p+p$  collisions and the  $J/\psi$  elliptic flow measurement in Au+Au collisions. Furthermore analysis status of  $J/\psi$  production in Au+Au collisions at 39 GeV and 62.4 GeV will be reported.

**Parallel 1C: Correlations & Fluctuations (Chair J. Schukraft) / 176**

## Event shape engineering with ALICE

**Author:** Collaboration ALICE<sup>1</sup>

**Co-authors:** Alexandru Florin Dobrin<sup>2</sup>; Alexandru Florin Dobrin<sup>3</sup>

<sup>1</sup> *CERN, Geneva, Switzerland*

<sup>2</sup> *Wayne State University (US)*

<sup>3</sup> *Department of Physics-Lund University-Unknown*

**Corresponding Authors:** alexandru.florin.dobrin@cern.ch, panos.christakoglou@cern.ch, alexandru.dobrin@hep.lu.se

Strong fluctuations of the anisotropic flow and the large acceptance of the ALICE detector allow an efficient selection of the events corresponding to a specific initial geometry. This opens many new possibilities to study the properties of the system created in ultra-relativistic nuclear collisions. In this talk, using the Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV data, we demonstrate the ability of the method to select events with anisotropic flow values significantly larger or smaller than the average. For those events we present results on centrality and momentum dependence of the anisotropic flow obtained with different methods including two- and many-particle correlations. We also investigate obtaining the full  $v_2$  distribution via unfolding methods.

**Parallel 1B, Jets (Chair X.N. Wang) / 162**

## Electroweak boson-tagged jet event asymmetries at the Large Hadron Collider

**Author:** Ivan Vitev<sup>1</sup>

**Co-author:** Bryon Neufeld<sup>1</sup>

<sup>1</sup> LANL

**Corresponding Author:** ivitev@lanl.gov

Tagged jet measurements provide a promising experimental channel to quantify the similarities and differences in the mechanisms of jet production in proton-proton and nucleus-nucleus collisions. We present the first calculation of the transverse momentum asymmetry of  $Z^0/\gamma^*$ -tagged jet events in  $\sqrt{s} = 2.76$  TeV reactions at the LHC. Our results combine the  $\mathcal{O}(G_F\alpha_s^2)$  perturbative cross sections with the radiative and collisional processes that modify parton showers in the presence of dense QCD matter. We find that a strong asymmetry is generated in central lead-lead reactions that has little sensitivity to the fluctuations of the underlying soft hadronic background. We present theoretical model predictions for its shape and magnitude. We also demonstrate the connection of our results to photon-tagged jet events and inclusive electroweak boson production.

**Parallel 1D: Heavy Flavor & Quarkonia (Chair R. Granier de Cassagnac) / 146**

## Comprehensive Analysis of in-Medium Quarkonia from SPS to LHC

**Author:** Xingbo Zhao<sup>1</sup>

**Co-authors:** Andrew Emerick<sup>2</sup>; Ralf Rapp<sup>3</sup>

<sup>1</sup> Iowa State University

<sup>2</sup> University of Minnesota

<sup>3</sup> Texas A&M University

**Corresponding Author:** rapp@comp.tamu.edu

We employ a kinetic rate-equation approach in a thermally expanding medium to compute the suppression and regeneration of quarkonia in heavy-ion collisions [1]. The in-medium properties of quarkonia figuring into the rate equation (widths, binding energies and heavy-quark masses) are constrained by euclidean correlators from lattice QCD. Input cross sections for heavy quarks and quarkonia, as well as cold nuclear matter effects, are constrained by pp and pA/dA data as available. Formation-time effects and bottom feeddown, mostly relevant at high transverse momentum ( $p_t$ ), are accounted for. The thermal relaxation time of heavy quarks, controlling the regeneration contribution, is adjusted to central AA data at SPS and RHIC. The approach is applied to pre- and postdict charmonium [1,2] and bottomonium [3] production as a function of centrality,  $p_t$ , rapidity, and collision energy in comparison to data from NA50, PHENIX, STAR, ALICE, CMS and ATLAS. Systematic trends and areas of potential disagreement are identified.

[1] X. Zhao and R. Rapp, Phys. Rev. C82 (2010) 064905.

[2] X. Zhao and R. Rapp, Nucl. Phys. A859 (2011) 114.

[3] A. Emerick, X. Zhao and R. Rapp, Eur. Phys. J. A (2012) in press.

**Parallel 1A: Global & Collective Dynamics (Chair U. Heinz) / 79**

## Derivation of transient relativistic fluid dynamics from the Boltzmann equation for a multi-component system

**Author:** Gabriel Denicol<sup>1</sup>

**Co-authors:** Dirk Rischke<sup>2</sup>; Harri Niemi<sup>3</sup>

<sup>1</sup> Frankfurt University

<sup>2</sup> U

<sup>3</sup> Frankfurt Institute for Advanced Studies

**Corresponding Author:** gsdenicol@gmail.com

We present a general derivation of relativistic fluid dynamics from the relativistic Boltzmann equation using the method of moments [1]. The main difference between our approach and the traditional 14-moment approximation is that we do not close the fluid-dynamical equations of motion by truncating the expansion of the single-particle momentum distribution function. Instead, we keep all the terms in the moment expansion and truncate the exact equations of motion for these moments according to a systematic power counting scheme in Knudsen and inverse Reynolds numbers. We apply this formalism to obtain an approximate expression for the non-equilibrium single-particle momentum distribution function of a hadron resonance gas. Then, we investigate the implications of our new formalism in the freeze-out description of the hadron resonance gas and compare it with the method traditionally used in heavy-ion collisions, the 14-moment approximation.

[1] G.S. Denicol, H. Niemi, E. Molnar, and D.H. Rischke, arXiv:1202.4551 [nucl-th].

**Parallel 1C: Correlations & Fluctuations (Chair J. Schukraft) / 225**

## Azimuthal anisotropy of charged hadrons at very high pT in PbPb collisions at 2.76 TeV with CMS

**Author:** Collaboration CMS<sup>1</sup>

<sup>1</sup> CERN

**Corresponding Authors:** victoria.zhukova@cern.ch, wyslouch@mit.edu

Measurements of the azimuthal anisotropy of charged hadrons are presented for PbPb collisions at 2.76 TeV over an extended transverse momentum range up to approximately 60 GeV/c. The data were collected with the CMS detector at the LHC. Utilizing a novel and unique high-pT single-track high-level trigger, the analysis explores the full 2011 PbPb data set corresponding to an integrated luminosity of 150/ub. Anisotropy parameters ( $v_2$ ,  $v_3$  and  $v_4$ ) are extracted by correlating charged tracks with the event plane angle reconstructed using the energy deposited in the forward calorimeters. By utilizing the broad coverage of the CMS forward calorimetry, contamination from back-to-back dijets is suppressed. The results presented in this talk significantly improve on the statistical precision of previous  $v_2$  measurements for  $p_T > 12$  GeV/c, and explore for the first time the harmonic components of the azimuthal dependence in the very high pT region beyond 20 GeV/c. Beyond  $p_T > 10$  GeV/c, the observed  $v_2$  values show a moderate decrease with pT, being consistent with zero only above  $p_T \sim 40$  GeV/c and for mid-central (30-60%) collisions. A common trend in the centrality dependence of  $v_2$  is observed for particles over a wide range of pT up to approximately 48 GeV/c that is independent of pseudorapidity, suggesting a potential connection to the initial geometry. These new data can impose quantitative constraints on the details of in-medium parton energy loss models, particularly the influence of the path length and the shape of the interaction region.

**Parallel 2A: Global & Collective Dynamics (Chair A. Poskanzer) / 487**

## Measurement of elliptic and higher-order harmonics at 2.76 TeV Pb-Pb collisions with the ATLAS detector

**Author:** Zdenek ATLAS Collaboration<sup>1</sup>

<sup>1</sup> *Charles University Prague*

**Corresponding Authors:** dominik.karol.derendarz@cern.ch, zdenek.dolezal@cern.ch

Anisotropy coefficients  $v_n$  are important observables for studying the hot, dense medium created in heavy ion collisions. They not only probe the collective flow of the bulk medium (at  $p_T < 3-4$  GeV), but also probe the path-length dependent energy loss (at higher  $p_T$ ), both are associated with the asymmetries in the initial geometry. However, auto-correlations not related to initial geometry, commonly referred to as non-flow effects, can contribute to these coefficients, hence need to be systematically suppressed. We present comprehensive measurements of coefficients  $v_2-v_6$  using the event plane method and two-particle correlations method in broad  $p_T$ ,  $\eta$  and centrality ranges using the Pb-Pb data from the ATLAS experiment. The phase space regions where the two methods are consistent and where they disagree are explored, and the role of harmonic flow, path-length dependence of jet quenching, and non-flow effects in different part of the phase space are clarified. These detailed measurements provide new insights into the hydrodynamic picture at low  $p_T$ , the jet energy loss picture at high  $p_T$ , and the nature of the fluctuations in the initial geometry; they also provide a natural explanation for the “ridge” structures observed in two-particle correlation functions.

**Parallel 2D: Heavy Flavor & Quarkonia (Chair J.-P. Blaizot) / 232**

## Detailed measurements of bottomonium suppression in PbPb collisions at 2.76 TeV with CMS

**Author:** Collaboration CMS<sup>1</sup>

<sup>1</sup> *CERN*

**Corresponding Authors:** guillermo.breto.rangel@cern.ch, wyslouch@mit.edu

The three Y states (1S, 2S, 3S) can be separated using the CMS experimental apparatus via their dimuon decays in both pp and heavy-ion collisions. A suppression of the Y(1S) and Y(2S) mesons is observed in PbPb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV, compared to the yield in pp collisions scaled by the number of inelastic nucleon-nucleon collisions. Furthermore, a suppression of the excited Y states has been measured with respect to the Y(1S) state, expressed as a double ratio  $[Y(2S+3S)/Y(1S)]_{\{PbPb\}} / [Y(2S+3S)/Y(1S)]_{\{pp\}}$ . The centrality dependence of the double ratio, as well as the nuclear modification factors (RAA) of the Y(1S) and Y(2S) states will be presented as a function of collision centrality, based on the analysis of the full data sample collected during the 2011 PbPb run, which corresponds to an integrated luminosity of 150/ub.

**Parallel 2C: Correlations & Fluctuations (Chair X. Dong) / 167**

## Search for QCD Phase Transitions and the Critical Point Utilizing Particle Ratio Fluctuations and Transverse Momentum Correlations from the STAR Experiment.

**Author:** Prithwish Tribedy<sup>1</sup>

<sup>1</sup> *for the STAR collaboration*

Dynamical fluctuations in globally conserved quantities such as baryon number, strangeness, charge, and isospin are suggested to carry information about the de-confinement and chiral phase transitions. An observation of enhanced dynamical fluctuations or non-monotonic behavior of transverse momentum correlations as a function of colliding energy might indicate the system has probed the predicted QCD critical point.

The STAR experiment has performed a comprehensive study of the energy and charge dependence of dynamical particle ratio ( $K/\pi$ ,  $p/\pi$ , and  $K/p$ ) fluctuations, net-charge fluctuations, and transverse momentum correlations in the STAR TPC at mid-rapidity, as well as neutral-charge pion fluctuations at forward rapidity. The charge dependence of particle ratio fluctuations exhibit differences between same and opposite sign dynamical particle ratio fluctuations compared to inclusive charged dynamical fluctuations. Neutral-charge pion fluctuations at forward rapidity are measured by detecting neutral pion decay photons in the Photon Multiplicity Detector and charged pions by the Forward Time Projection Chamber, which cover the same pseudorapidity region.

The centrality, energy, and charge dependence from new measurements of the fluctuation observables  $\nu_{dyn}$  and  $r_{m,1}$  and the energy dependence of transverse momentum correlations from  $\sqrt{s_{NN}} = 7.7-200$  GeV Au+Au collisions will be presented. These results are also compared to theoretical predictions from models such as HIJING and UrQMD.

**Parallel 2B: Jets (Chair P. Jacobs) / 213**

## Studies of jet quenching and b-jet tagging in PbPb collisions at 2.76 TeV with CMS

**Author:** Collaboration CMS<sup>1</sup>

<sup>1</sup> CERN

**Corresponding Authors:** matthew.nguyen@cern.ch, wyslouch@mit.edu

This presentation describes jet measurements in PbPb collisions at a nucleon-nucleon center-of-mass energy of 2.76 TeV performed with the CMS detector at the LHC.

With data from the 2011 Run, dijet measurements have been extended to large transverse momentum, up to 350 GeV/c. The dijet momentum balance and angular correlations are studied in detail as a function of collision centrality and leading jet transverse momentum. For the most peripheral PbPb collisions, the dijet momentum balance distributions are in good agreement with pp data and with reference calculations at the same collision energy. More central collisions show a strong imbalance between the leading and subleading jet transverse momenta, which is found to persist to the largest values of leading jet transverse momenta studied.

The flavor dependence of jet quenching is a powerful handle to discriminate models of parton energy loss in heavy ion collisions. We demonstrate the capacity of CMS to identify jets initiated by bottom quarks using displaced vertices reconstructed in the silicon tracking system. The b-jet to inclusive jet ratio is measured in PbPb collisions and compared pp collisions at the same center-of-mass energy.

**Parallel 2B: Jets (Chair P. Jacobs) / 480**

## Measurements of jet suppression with ATLAS

**Author:** Zdenek ATLAS Collaboration<sup>1</sup>

<sup>1</sup> *Charles University Prague*

**Corresponding Authors:** aaron.richard.angerami@cern.ch, zdenek.dolezal@cern.ch

The energy loss of high-pt partons through the phenomenon of jet quenching provides insight into the transport properties of the medium created in relativistic heavy ion collisions. Evidence for this energy loss was first experimentally established through observation of high-pt hadron suppression at RHIC. This observable is not ideal for detailed quenching measurements as the final state hadrons are only related to the jet through the fragmentation. More recently, measurements of fully reconstructed jets have been performed at the LHC. This talk presents the latest experimental results from the ATLAS collaboration on jet suppression. These results establish qualitative features of the jet quenching mechanism as experimental fact and provide constraints on models of jet energy loss.

**Parallel 2D: Heavy Flavor & Quarkonia (Chair J.-P. Blaizot) / 349**

## Momentum dependences of charmonium properties from lattice QCD

**Author:** Heng-Tong Ding<sup>1</sup>

<sup>1</sup> *Brookhaven National Lab*

**Corresponding Author:** htding@quark.phy.bnl.gov

We study the momentum dependence of charmonia in a hot medium using lattice QCD calculations. We analyze correlation functions and extract spectral functions from quenched calculations on large lattices close to the continuum limit in the temperature region  $1.5 < T/T_c < 3$  as well as for  $T \simeq 0.75T_c$ . We examine the modifications of dissociation temperatures of the bound states when they are in motion with respect to the heatbath frame. We will also discuss the charm diffusion coefficients in connection with transport properties of charm quark at finite momentum. Furthermore, we expect to be able to present preliminary results at temperatures closer to the transition temperature, i.e.  $T_c < T < 1.5T_c$ , which is crucial to locate the dissociation temperature of  $J\psi$  and examine the sequential suppression scenario[1].

[1] H.-T. Ding, A. Francis, O. Kaczmarek, F. Karsch, H. Satz and W. Soeldner, BI-TP 2012/13, to appear on arXiv soon

**Parallel 2A: Global & Collective Dynamics (Chair A. Poskanzer) / 66**

## Shear viscosity of the quark-gluon plasma from flow in heavy-ion collisions

**Authors:** Jean-Yves Ollitrault<sup>1</sup>; Matthew Luzum<sup>2</sup>

<sup>1</sup> *CNRS*

<sup>2</sup> *IPhT Saclay*

**Corresponding Author:** matthew.luzum@cea.fr

We report an extraction of the ratio of shear viscosity to entropy density ( $\eta/s$ ) of the medium created in relativistic heavy-ion collisions at the LHC. With a significant improvement of one of the main sources of theoretical uncertainty, we are able for the first time to quote a precise average value with



robust error bars, systematically accounting for all known sources of systematic error (theoretical and experimental).

**Parallel 2C: Correlations & Fluctuations (Chair X. Dong) / 186**

## Studies of net-charge fluctuations and balance functions with the ALICE detector at the LHC

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Michael Weber<sup>2</sup>

<sup>1</sup> CERN, Geneva, Switzerland

<sup>2</sup> University of Houston (US)

**Corresponding Authors:** m.weber@cern.ch, panos.christakoglou@cern.ch

The creation of a strongly interacting deconfined Quark Gluon Plasma (QGP) phase in relativistic heavy-ion collisions can be studied by the fluctuations of conserved quantities like net-charge, and correlations between positive and negative pairs by using the method of Balance functions. Net-charge fluctuations are sensitive to the number of charges present in the system, thus the fluctuations in the QGP, with fractionally charged partons, are expected to be different from those of the hadron gas with unit charged particles. Lattice calculations suggest that the higher moments of net-charge distributions and their products are sensitive to the correlation length, and are related to the thermodynamic susceptibilities of the system. The method of the Balance function, on the other hand, is sensitive to collective flow and the breakup temperature and was proposed to give a handle on the hadronization time. A combined study of net-charge fluctuations with Balance functions provides insight to the properties of matter created in high energy collisions. We will present the first results of net-charge fluctuations, higher moments of net-charge distributions and Balance functions for Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV measured by the ALICE experiment at the LHC. The results from net-charge fluctuations, presented in terms of  $v_{dyn}$  and D-measure, are compared to predictions for a system initially dominated by a QGP, as well as for a hadron resonance gas. The widths of the Balance functions in pseudorapidity and azimuthal angle for non-identified charged particles show a clear centrality dependence, consistent with the picture of a delayed hadronization but also with a system exhibiting larger radial expansion in central collisions. A comparison of the results will be made to lower energy collisions at SPS and RHIC as well as to several models that incorporate collective effects.

**Parallel 2D: Heavy Flavor & Quarkonia (Chair J.-P. Blaizot) / 472**

## J/ $\psi$ production at mid-rapidity in Pb-Pb collisions at 2.76 TeV

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Ionut Cristian Arsene<sup>2</sup>

<sup>1</sup> CERN Geneva, Switzerland

<sup>2</sup> GSI - Helmholtzzentrum für Schwerionenforschung GmbH (DE)

**Corresponding Authors:** ionut.cristian.arsene@cern.ch, vercelli@to.infn.it

The hot and dense nuclear matter created in nuclear collisions at relativistic energies consists of a plasma of deconfined quarks and gluons. Due to their large mass, the charm quarks are mainly formed in the first instants of the nuclear collision and will consequently experience the full history of the system. It was predicted that the strongly bound J/ $\psi$  state will be suppressed in the hot and deconfined quark-gluon plasma due to the color screening effect. This effect was already observed

in Au-Au collisions at  $\sqrt{s_{NN}} = 200$  GeV at RHIC. It was also predicted that high production yields of charm quarks in nucleus-nucleus collisions at RHIC and especially at LHC energies will make possible (re)combination thus possibly leading to  $J/\psi$  enhancement compared to lower energy nuclear collisions and to pp collisions.

ALICE measures the  $J/\psi$  at mid-rapidity,  $|y| < 0.9$ , down to zero transverse momentum. The reconstruction is performed using the  $J/\psi$  decay into the di-electron channel. The electron identification is done using energy loss in gaseous detectors (the Time Projection Chamber and the Transition Radiation Detector) and the time-of-flight method (Time Of Flight detector). We will present the  $J/\psi$  nuclear modification factor as a function of the collision centrality. Discussions and comparisons to theoretical calculations will be provided. First results and perspectives on the  $J/\psi$  production with respect to the event plane (elliptic flow) will also be shown.

**Parallel 2A: Global & Collective Dynamics (Chair A. Poskanzer) / 400**

## **Pseudorapidity density of charged particles in a wide pseudorapidity range and its centrality dependence in Pb-Pb collisions at 2.76 TeV**

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Maxime Rene Joseph Guilbaud<sup>2</sup>

<sup>1</sup> CERN, Geneva, Switzerland

<sup>2</sup> Universite Claude Bernard-Lyon I (FR)

**Corresponding Author:** maxime.rene.joseph.guilbaud@cern.ch

In this talk we present a measurement of the pseudorapidity distribution in the range  $-5 < \eta < 5.25$ , for different centralities in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV. This also allows us to estimate the total number of produced charged particles. The measurement is performed exploiting LHC satellite bunches, that is bunches captured in non-nominal RF buckets. These give rise to displaced vertices in the range  $-187.5 < z_{vtx} < 375$  cm, allowing the ALICE forward detectors (VZERO and FMD) to cover a wide pseudorapidity window. The dependence of  $dN_{ch}/d\eta$  on the number of participant nucleons or on the number of binary collisions is sensitive to mechanisms underlying particle production (eg. the effect of gluon saturation). In this contribution ALICE data will be compared to current models and an analysis of the longitudinal scaling will be performed.

**Parallel 2B: Jets (Chair P. Jacobs) / 208**

## **Inclusive jet and charged hadron nuclear modification factors in PbPb collisions at 2.76 TeV with CMS**

**Author:** Collaboration CMS<sup>1</sup>

<sup>1</sup> CERN

**Corresponding Authors:** marguerite.belt.tonjes@cern.ch, wyslouch@mit.edu

Measurements of charged hadron and inclusive jet transverse momentum ( $p_T$ ) spectra in pp and PbPb collisions at a nucleon-nucleon center-of-mass energy of 2.76 TeV with the CMS detector will be reported. These measurements make use of the high-statistics jet-triggered data recorded in 2011, including the total available PbPb luminosity of 150/ub. Charged particles are reconstructed using an iterative algorithm and spurious high- $p_T$  tracks are suppressed by requiring appropriate energy deposits in the calorimeter system. Jets are reconstructed with the anti- $k_T$  algorithm, using combined information from tracking and calorimetry. The charged particle and jet transverse momentum distributions are measured in the pseudorapidity range of  $|\eta| < 1$  and  $|\eta| < 1.6$ , and in  $p_T$  up to 100

GeV/c, and from 100 to 300 GeV/c, respectively. The nuclear modification factors, RAAs, for charged hadrons and jets are presented as a function of  $p_T$  and collision centrality. In the range  $p_T = 5$ -10 GeV/c the charged hadron production in PbPb collisions is suppressed by up to a factor of seven, compared to the pp yield scaled by the number of incoherent nucleon-nucleon collisions. The charged hadron RAA increases at higher  $p_T$  and approaches a value of approximately 0.5 in the range  $p_T = 40$ -100 GeV/c.

**Parallel 2C: Correlations & Fluctuations (Chair X. Dong) / 168**

## Study of the Sixth Order Cumulant of Net-proton Distributions Measured in STAR at RHIC

**Author:** Lizhu Chen<sup>1</sup>

<sup>1</sup> *Central China Normal University*

**Corresponding Author:** chenlziopp@gmail.com

In high-energy nuclear collisions, we study the properties of the excited nuclear matter with QCD degrees of freedom and search for the signals of the QCD phase transition. The ratios of the cumulants of conserved number distributions are sensitive to the correlation length of the system created in heavy-ion collisions, hence they are considered as good observables to study phase transitions. QCD based calculations suggests that the ratios of the sixth to second ( $C_6/C_2$ ) order cumulants of the net baryon number distributions will change rapidly in the phase transition region of the QCD phase diagram. They are found to deviate considerably from predictions of the hadron resonance gas model which reproduce the fourth to second ( $C_4/C_2$ ) order cumulants of the net proton number distributions at RHIC top energies.

The STAR experiment, with large and uniform acceptance and excellence in particle identification, is ideal to study the QCD phase structure. The data collected in 2010 and 2011 allow us to study the  $C_6/C_2$  ratio. In this talk, we will present the ratio of the sixth to second order cumulants of net-proton multiplicity distributions from minimum biased Au+Au collisions at  $\sqrt{s_{NN}} = 19.6, 27, 39, 62.4$  and 200 GeV. Both protons and anti-protons are cleanly identified within  $|y| < 0.5$  and  $0.4 < p_T < 0.8$  GeV/c by the STAR Time Projection Chamber. For beam energies above 39 GeV, the ratios are consistently close to but below unity, while they have larger values below 39 GeV. Some implications of the new results will be discussed within the context of Polyakov loop-extended-Quark-Meson (thermal model) and UrQMD (transport model) models.

**Parallel 2B: Jets (Chair P. Jacobs) / 2**

## Quantifying a Possibly Reduced Jet-Medium Coupling of the sQGP at the Large Hadron Collider

**Author:** Barbara Betz<sup>1</sup>

**Co-author:** Miklos Gyulassy<sup>2</sup>

<sup>1</sup> *Frankfurt University*

<sup>2</sup> *Columbia University*

**Corresponding Author:** betz@th.physik.uni-frankfurt.de

Recent LHC data on the nuclear modification factor of jet fragments suggest that the jet-medium coupling at the Large Hadron Collider (LHC) may be reduced relative to the coupling at the Relativistic Hadron Collider (RHIC). We estimate the magnitude of that reduction from a combined fit to the data on the nuclear modification factor and on the elliptic flow at both

RHIC and LHC energies over a broad centrality range and a momentum range of 5-100 GeV. We also compare Glauber and Color Glass Condensate initial conditions using a simple analytic energy-loss model that can interpolate between weakly-coupled tomographic and strongly-coupled holographic jet-energy loss models. We find that an approximately 10% reduction of the jet-medium coupling from RHIC to LHC can account for the observed LHC data in reasonable accord with the magnitude expected from a running coupling associated with doubling the density of the strongly-coupled Quark-Gluon Plasma (sQGP) from RHIC to LHC.

**Parallel 2C: Correlations & Fluctuations (Chair X. Dong) / 420**

## Mixed harmonic charge dependent azimuthal correlations in Pb-Pb collisions at 2.76 TeV measured with the ALICE experiment at the LHC

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Yasuto Hori<sup>2</sup>

<sup>1</sup> CERN, Geneva, Switzerland

<sup>2</sup> University of Tokyo (JP)

**Corresponding Authors:** yhori@cns.s.u-tokyo.ac.jp, panos.christakoglou@cern.ch

The charge dependence of the azimuthal correlations between produced hadrons is an important probe of the QGP matter created in relativistic heavy-ion collisions. In this talk, we will present the mixed harmonic charge dependent azimuthal correlations measured at mid-rapidity in Pb-Pb collisions at  $\sqrt{s_{\text{NN}}} = 2.76$  TeV by the ALICE Collaboration at the LHC. We observe a clear charge separation of hadrons with respect to the reaction plane measured via the mixed harmonic multi-particle technique. Implications from these measurements for the possible effects of local parity violation in the strong interaction and for models which incorporate the effects of local charge conservation on freeze-out surface and azimuthal flow will be discussed.

**Parallel 2D: Heavy Flavor & Quarkonia (Chair J.-P. Blaizot) / 523**

## Gluon saturation effects on the color singlet J/Psi production in high energy dA and AA collisions

**Author:** Kirill Tuchin<sup>1</sup>

<sup>1</sup> Iowa State University

**Corresponding Author:** tuchink@gmail.com

We discuss the gluon saturation/color glass condensate effects on J/Psi production in high energy pA and AA collisions. We report the results of numerical calculations of the corresponding nuclear modification factors. We found a good agreement between our calculations and the experimental data on J/Psi production in pA collisions. We also observe that cold nuclear modification effects alone cannot describe the data on J/psi production in AA collisions. Our numerical calculations indicate that the discrepancy arises in a significant part from the higher pT's. Additional final state suppression (at RHIC) and enhancement (at LHC) mechanisms are required to explain the experimental observations.

**Parallel 2A: Global & Collective Dynamics (Chair A. Poskanzer) / 206**

## **Pseudorapidity and centrality dependence of transverse energy flow in PbPb collisions at 2.76 TeV from CMS**

**Author:** Collaboration CMS<sup>1</sup>

<sup>1</sup> *CERN*

**Corresponding Authors:** magdalena.malek@cern.ch, wyslouch@mit.edu

The transverse energy flow in PbPb collisions at 2.76 TeV nucleon-nucleon center-of-mass energy has been measured over a broad range of centrality for pseudorapidities between -5.2 and 5.2 using the CMS detector at the LHC. This analysis is based on 0.306/ub of data from 2010, with recently extended number (and range) of pseudorapidity and centrality bins. The transverse energy per unit of pseudorapidity increases faster with collision energy than the multiplicity of charged particles. This implies that the mean energy per particle and hence the temperature of the system is increasing with collision energy. The amount of transverse energy produced per participating nucleon increases with centrality and with collision energy. The centrality dependence of transverse energy production has only a weak dependence on pseudorapidity and collision energy. For the most central collisions, the energy density is estimated to be  $11.3 \pm 0.6$  GeV/fm<sup>3</sup> at a time of 1 fm/c after the collision, which is 2.8 times higher than the value reported at  $\sqrt{s_{NN}}=200$  GeV.

**Parallel 2B: Jets (Chair P. Jacobs) / 442**

## **Inclusive jet spectra in 2.76 TeV Pb-Pb collisions from the ALICE experiment**

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Rosi Jan Reed <sup>2</sup>

<sup>1</sup> *CERN, Geneva, Switzerland*

<sup>2</sup> *Yale University (US)*

**Corresponding Authors:** rosi.jan.reed@cern.ch, helen.caines@yale.edu

Measurements of high-pt particle production in heavy-ion collisions at RHIC have shown that medium-induced energy loss affects the partons produced in the early stage of a heavy-ion collision. The increased initial production cross section for partons at LHC energies makes fully reconstructed jets available in a wide kinematic range, which allows for a differential investigation of parton energy loss. Partonic energy loss allows us to access important observables for the study of the hot deconfined nuclear matter produced in heavy ion collisions. The inclusive cross-section of reconstructed jets using the ALICE tracking detectors and electromagnetic calorimeter is presented from data collected during the 2.76 TeV Pb-Pb runs. The procedures used to reconstruct jets and extract them from a fluctuating background are discussed. The results will also be compared with jet yields from proton-proton collisions, which allows quantification of the medium-induced quenching effects.

**Parallel 2C: Correlations & Fluctuations (Chair X. Dong) / 575**

## **Charge balancing and the fall off of the ridge**

**Author:** Wojciech Broniowski<sup>1</sup>

**Co-author:** Piotr Bozek

<sup>1</sup> IFJ PAN & UJK

**Corresponding Author:** wojciech.broniowski@ifj.edu.pl

The puzzle of the fall-off of the same-side ridge in relative pseudorapidity, found in unbiased two-particle correlations, is solved. We show that the event-by-event hydrodynamics followed by statistical hadronization with proper charge conservation provides the crucial non-flow component and leads to agreement with the data at soft transverse momenta ( $p_T < 2$  GeV). The fall-off of the same-side ridge follows from the fact that a pair of particles with opposite charges is emitted from the same fluid element, whose collective velocity collimates the momenta of the pair. Basic experimental features of the two-dimensional correlation functions are then represented, including the dependence on the relative charge (like-sign and unlike-sign pairs) and centrality. Related quantities, such as the charge balance functions or the dependence of the harmonic flow coefficients on relative pseudorapidity, are also properly explained in our approach.

**Parallel 2D: Heavy Flavor & Quarkonia (Chair J.-P. Blaizot) / 83**

## High transverse momentum quarkonium production and dissociation in heavy ion collisions

**Author:** Rishi Sharma<sup>1</sup>

**Co-author:** Ivan Vitev<sup>2</sup>

<sup>1</sup> TRIUMF

<sup>2</sup> LANL

**Corresponding Author:** rishi@triumf.ca

We calculate the yields of quarkonia in heavy ion collisions at RHIC and the LHC as a function of the transverse momentum. We focus on the consistent implementation of dynamically calculated nuclear matter effects, such as coherent power corrections, cold nuclear matter energy loss, and the Cronin effect in the initial state, and collisional dissociation of quarkonia in the final state as they traverse through the QGP. This formalism has been previously used to successfully describe the phenomenology of open heavy flavor (B and D mesons) both at RHIC and the LHC. We will briefly review the comparison with new open heavy flavor data and describe the extension of the calculation for quarkonium production. Based upon non-relativistic quantum chromodynamics, our calculations include both color-singlet and color-octet contributions and feed-down effects from excited states. Theoretical results are presented for  $J/\psi$  and  $\Upsilon$  and compared to experimental data where applicable. At RHIC, a good description of the high- $p_T$   $J/\psi$  modification observed in central Cu+Cu and Au+Au collisions can be achieved within the model uncertainties. We find that  $J/\psi$  measurements in proton(or deuteron)-nucleus reactions are needed to constrain the magnitude of cold nuclear matter effects, and new data from d+Au collisions at RHIC already puts a strong limit on the Cronin enhancement for  $J/\psi$ . At the LHC, a good description of the experimental data can be achieved only in mid-central and peripheral Pb+Pb collisions. The large five-fold suppression of prompt  $J/\psi$  in the most central nuclear reactions suggests the presence of thermal effects at the level of the quarkonium wavefunction, even at large transverse momentum.

**Parallel 2A: Global & Collective Dynamics (Chair A. Poskanzer) / 114**

## E-by-E MUSIC Afterburner

**Author:** Sangyong Jeon<sup>1</sup>

**Co-authors:** Bjoern Schenke ; Charles Gale<sup>2</sup>; Clint Young<sup>1</sup>; Sangwook Ryu<sup>1</sup>

<sup>1</sup> McGill University

<sup>2</sup> *Unknown*

**Corresponding Author:** jeon@physics.mcgill.ca

Hydrodynamic models enjoy much success in describing and predicting the bulk dynamics of relativistic heavy ion collisions. Recent studies have clearly shown that including initial and final fluctuations is essential for detailed study of the evolving QGP. So far, however, not many studies appeared which incorporate both fluctuations at the same time. Here we present our first results in including both the initial and final state fluctuations by combining the event-by-event 3-D viscous hydrodynamics model (MUSIC) with the publicly available UrQMD afterburner. Influence of these fluctuations on particle spectra, elliptic flow and higher harmonics will be presented.

618

## **Energy for the 21st Century World Economy: Problems and Opportunities**

**Corresponding Author:** bauer@pa.msu.edu

**Parallel 3D: Pre-Equilibrium & Initial State (Chair K. Eskola) / 235**

## **Studies of the nuclear stopping power in PbPb collisions at 2.76 TeV with CMS**

**Author:** Collaboration CMS<sup>1</sup>

<sup>1</sup> *CERN*

**Corresponding Authors:** clemens.wohrmann@cern.ch, wyslouch@mit.edu

The energy flow at very high pseudorapidity in PbPb collisions is sensitive to the very low- $x$  components of the nuclear wave-function. The CASTOR calorimeter extends the pseudorapidity coverage of CMS to -6.6, which is only 1.4 units away from the beam rapidity. A comparison of the centrality dependence of forward energy flow to that at lower pseudorapidities can shed light on the gluon saturation at low- $x$ . This problem can also be approached by a direct comparison of PbPb and pp energy flow in the forward region. This analysis is based on data taken in 2010. The energy flow in the pseudorapidity range of -5.2 to -6.6 has been measured for 2.76 TeV PbPb collisions over a wide range of centrality and also for minimum bias pp collisions. These data are compared to energy-flow measurements for pseudorapidities between -5.2 and +5.2. The very large angular coverage of the CMS detector allows for a test of limiting fragmentation of energy flow, and for an estimate of nuclear stopping. Finally, these data are compared to predictions of hydrodynamic models and microscopic event generators.

**Parallel 3A: Global & Collective Dynamics (Chair T. Kodama) / 75**

## **Bulk viscosity, particle spectra and flow in heavy-ion collisions**

**Author:** Thomas Schaefer<sup>1</sup>

**Co-author:** Kevin Dusling

<sup>1</sup> *N***Corresponding Author:** tmschaef@ncsu.edu

We study the effects of bulk viscosity on  $p_T$  spectra and elliptic flow in heavy ion collisions. For this purpose we compute the dissipative correction  $\delta f$  to the single particle distribution functions in leading-log QCD, and in kinetic models of a hadronic resonance gas. We find that for a near conformal fluid the bulk viscosity is suppressed by two powers of the conformal breaking parameter, but the viscous correction to the spectra is only suppressed by the first power. This implies that bulk viscous corrections to flow profiles are typically small, but corrections to the spectra can be significant. From an analysis of the spectra at RHIC and LHC we find that the bulk viscosity at freezeout cannot be large,  $\zeta/s < 0.05$ . We also find, however, that a non-zero bulk viscosity improves the description of the hadrochemistry of flow, for example the splitting between the  $v_2(p_T)$  of protons and pions.

**Parallel 3C: Electro-Weak Probes (Chair J. Kapusta) / 119**

## Thermal dileptons in high-energy heavy ion collisions with 3+1D relativistic hydrodynamics

**Author:** Gojko Vujanovic<sup>1</sup>**Co-authors:** Bjoern Schenke<sup>2</sup>; Charles Gale<sup>1</sup>; Clint Young<sup>1</sup>; Ralf Rapp<sup>3</sup>; Sangyong Jeon<sup>1</sup><sup>1</sup> *McGill University*<sup>2</sup> *Brookhaven National Laboratory*<sup>3</sup> *Texas A&M University***Corresponding Authors:** vujanovic.1@osu.edu, gale@physics.mcgill.ca

The penetrating nature of dileptons makes them suitable probes to explore the properties of the strongly-interacting medium created in relativistic nuclear collisions. This study investigates thermal dilepton production using MUSIC (a Monotone Upstream-centered Scheme for Ion Collisions): a 3+1D hydrodynamic simulation with or without shear viscosity. We utilize dilepton emission rates that are derived from in-medium hadronic spectral functions, and from pQCD. In addition to the invariant mass and momentum distributions, the elliptic flow of lepton pairs is calculated, and the effects of a finite shear viscosity coefficient are also analyzed. We present results appropriate for measurements by the PHENIX and STAR collaborations, and make predictions for the LHC.

**Parallel 3B: Jets (Chair S. Mioduszewski) / 45**

## Understanding LHC jets in the light of RHIC data

**Author:** Thorsten Renk<sup>1</sup><sup>1</sup> *University of Jyväskylä***Corresponding Author:** thorsten.i.renk@jyu.fi

Hard probes are a cornerstone in the ongoing program to determine the properties of hot and dense QCD matter as created in ultrarelativistic heavy ion collisions. The first two runs at the LHC have resulted in a wealth of measurements of both reconstructed jets and single inclusive high  $P_T$  hadrons,



opening new kinematic windows and offering high statistics. Yet on first glance, several observations are counter-intuitive and seem to contradict results from the RHIC high  $P_T$  program. I present a combined analysis of high  $P_T$  hadronic observables at RHIC and LHC and reconstructed jets at LHC in a framework testing a large number of theoretical models for both medium evolution and shower-medium interactions against the systematics of the data. I demonstrate how a consistent picture of shower-medium interaction emerges from the combined results and explain where and why results appear counter-intuitive. In particular, I discuss the role of jet measurements in constraining models critically and suggest measurements sensitive to the gaps in our knowledge.

**Parallel 3B: Jets (Chair S. Mioduszewski) / 432**

## Jet structure in 2.76 TeV Pb–Pb collisions at ALICE

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Leticia Cunqueiro<sup>2</sup>

<sup>1</sup> *CERN, Geneva, Switzerland*

<sup>2</sup> *Unknown-Unknown-Unknown*

**Corresponding Authors:** leticia.cunqueiro.mendez@cern.ch, helen.caines@yale.edu

To capture the full dynamics of the mechanisms of energy loss of hard partons in their passage through the dense medium created in Heavy Ion Collisions, jet reconstruction is required. In this analysis we explore the radiation pattern of jets in Pb–Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV and compare it to that of baseline pp jets at the same collision energy. Di-jets are selected by requiring a high-pt ('trigger') fragment back-to-back with respect to the jet that is studied. Then, the shape and energy distribution of those quenched jets is explored via jet-hadron azimuthal correlations and via the mapping of the energy contained in different cones with radius  $R$  around the jet axis.

**Parallel 3D: Pre-Equilibrium & Initial State (Chair K. Eskola) / 528**

## Highly-anisotropic hydrodynamics in 3+1 space-time dimensions and the early thermalization puzzle

**Authors:** Michael Strickland<sup>1</sup>; Wojciech Florkowski<sup>2</sup>

**Co-author:** Radoslaw Ryblewski<sup>3</sup>

<sup>1</sup> *Gettysburg College*

<sup>2</sup> *Institute of nuclear Physics, Krakow*

<sup>3</sup> *Institute of Nuclear Physics PAS*

**Corresponding Authors:** wojciech.florkowski@ifj.edu.pl, mstrickl@gettysburg.edu

Recently formulated model of highly-anisotropic and strongly dissipative hydrodynamics is used in 3+1 dimensions to study behavior of matter produced in ultra-relativistic heavy-ion collisions. We search for possible effects of the initial high anisotropy of pressure on the final soft-hadronic observables. We find that by appropriate adjustment of the initial energy density and/or the initial pseudorapidity distributions, the effects of the initial anisotropy of pressure may be easily compensated and the final hadronic observables become insensitive to early dynamics.

Our results indicate that the early thermalization assumption is not necessary to describe hadronic data, in particular, to reproduce the measured elliptic flow  $v_2$ . The complete thermalization of matter (local equilibration) may take place only at the times of about 1–2 fm/c, in agreement with the results of microscopic models.

Work based on recent publications:

1. Highly-anisotropic hydrodynamics in 3+1 space-time dimensions,  
Radoslaw Ryblewski, Wojciech Florkowski, arXiv:1204.2624
2. Projection method for boost-invariant and cylindrically symmetric dissipative hydrodynamics in 3+1 space-time dimensions.  
Wojciech Florkowski, Radoslaw Ryblewski,  
Phys.Rev. C85 (2012) 044902
3. Highly-anisotropic and strongly-dissipative hydrodynamics with transverse expansion.  
Radoslaw Ryblewski, Wojciech Florkowski, Eur.Phys.J. C71 (2011) 1761
4. Highly anisotropic hydrodynamics – discussion of the model assumptions and forms of the initial conditions.  
Radoslaw Ryblewski, Wojciech Florkowski  
Acta Phys.Polon. B42 (2011) 115
5. Non-boost-invariant motion of dissipative and highly anisotropic fluid.  
Radoslaw Ryblewski, Wojciech Florkowski,  
J.Phys.G G38 (2011) 015104
6. Highly-anisotropic and strongly-dissipative hydrodynamics for early stages of relativistic heavy-ion collisions.  
Wojciech Florkowski, Radoslaw Ryblewski  
Phys.Rev. C83 (2011) 034907

### Parallel 3C: Electro-Weak Probes (Chair J. Kapusta) / 137

## Dielectron measurements by PHENIX using the HBD

**Author:** Ermias Atomssa<sup>1</sup>

<sup>1</sup> *Stony Brook University*

**Corresponding Author:** etatomssa@gmail.com

Measurements of lepton pair spectra are a crucial tool to map out the evolution of the hot dense matter created in ultra-relativistic heavy ion collisions. At low pair mass, direct photons and low mass vector mesons are the main center of interest. Interpretation of lepton pair production rates in excess of expectations from hadronic decays observed by PHENIX and how the data constrains theoretical models on thermalization and chiral symmetry restoration is a hotly debated topic. At intermediate and high mass, the di-electron spectrum has been used by PHENIX to measure cross sections of open charm and open bottom, as well as Quarkonium suppression with implications for color screening and recombination.

Due to the small signal to background ratio, measurement of the dielectron spectrum, especially at low mass, is very challenging. In PHENIX, the background results mainly from random combinations of electron positron pairs from uncorrelated sources, mostly  $\pi^0$  Dalitz decays and photon conversions. The Hadron Blind Detector (HBD) was developed to address this issue. The HBD accomplishes this by tagging and rejecting tracks from conversions and  $\pi^0$  Dalitz decays. It was successfully operated in RHIC run years 2009 to 2010, where Au+Au and reference p+p data sets were taken. We will present the dielectron results from the analysis of these data sets.

### Parallel 3A: Global & Collective Dynamics (Chair T. Kodama) / 123

## Initial state fluctuations and higher harmonic flow in heavy-ion collisions

**Author:** Bjoern Schenke<sup>None</sup>

**Co-authors:** Charles Gale<sup>1</sup>; Sangyong Jeon<sup>1</sup>

<sup>1</sup> *McGill University*

**Corresponding Author:** bschenke@quark.phy.bnl.gov

We present recent developments in describing anisotropic flow in heavy-ion collisions at the Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Laboratory and the Large Hadron Collider (LHC) at CERN with a relativistic 3+1 dimensional viscous event-by-event hydrodynamic simulation.

We present results for elliptic, triangular and higher harmonic flow coefficients, including comparisons to first experimental data as well as predictions. We demonstrate the great potential of a systematic study of higher harmonic and directed flow to pin down the shear viscosity to entropy density ratio of the created quark gluon plasma and the details of the initial state.

**Parallel 3A: Global & Collective Dynamics (Chair T. Kodama) / 366**

## Higher harmonics flow measurement of charged hadrons and electrons in wide kinematic range with PHENIX VTX tracker

**Author:** maki kurosawa<sup>1</sup>

<sup>1</sup> *RBRC*

**Corresponding Author:** kurosawa@riken.jp

Collective flow is one of the key measurements to study the hot and dense matter created in heavy ion collisions, because it relates closely to early evolution of the matter. In particular, higher harmonic flow measurements plays an important role in constraining theoretical model calculations describing properties of the matter.

The silicon vertex tracker (VTX) was installed into the PHENIX experiment in 2010 and it successfully collected approximately 5 billion events of Au+Au collisions at 200 GeV in 2011 RHIC run. The VTX is a four-layer silicon tracker and it can reconstruct charged particle tracks in a wide range of pseudorapidity ( $|\eta| < 1.2$ ) and almost  $2\pi$  in  $\phi$ . With this capability, it can measure elliptic flow  $v_2$  and higher harmonics flow ( $v_3, v_4, \dots$ ) of charged hadrons in a wide  $\eta$  range.

The main function of the VTX is separation of heavy flavor hadrons, charm and bottom. By identifying electrons with PHENIX central detectors, higher harmonic flow of electrons from heavy flavor decay can be determined over a broad  $p_T$  range.

In this talk, we will present measurement results on  $v_2$  and higher harmonic flow of charged hadrons and heavy flavor electrons, as well as comparison with theoretical models.

**Parallel 3D: Pre-Equilibrium & Initial State (Chair K. Eskola) / 525**

## Azimuthal angular correlations in two-particle production in proton-nucleus collisions

**Author:** Jamal Jalilian-Marian<sup>1</sup>

**Co-author:** Amir Rezaeian<sup>2</sup>

<sup>1</sup> *Baruch College*

<sup>2</sup> *Santa Maria University*

**Corresponding Author:** jamal.jalilian-marian@baruch.cuny.edu

Di-hadron azimuthal angular correlations in the forward rapidity region of deuteron-nucleus collisions at RHIC show a disappearance of the away side peak with centrality and transverse momentum. This can be understood, in the Color Glass Condensate (CGC) formalism, to be due to multi-gluon exchanges between the projectile and target. We show that CGC formalism predicts a similar disappearance of the away side peak in the prompt photon-hadron azimuthal angular correlations. We make detailed predictions for transverse momentum and centrality dependence of this disappearance in deuteron-gold collisions at RHIC and proton-nucleus collisions at the LHC.

**Parallel 3B: Jets (Chair S. Mioduszewski) / 216**

## Jet shapes in pp and PbPb collisions at the CMS Experiment

**Author:** Collaboration CMS<sup>1</sup>

<sup>1</sup> *CERN*

**Corresponding Authors:** pelin.kurt@cern.ch, wyslouch@mit.edu

Jet shape measurements are important for many applications. When measured in pp collisions they can be used to constrain generator and showering settings. When measured in PbPb collisions they can be used to probe for distortions from energy loss in the hot and dense medium. Fully unfolded jet shape measurements will be presented and compared with generator expectations in 7 TeV pp collisions, corresponding to an integrated luminosity of  $36\text{pb}^{-1}$ . In addition, jet shape measurements in PbPb collisions will be presented and compared with observations in 2.76 TeV pp collisions to probe for the effects of suppression from the medium. The full PbPb data set collected in 2011 is analyzed, corresponding to an integrated luminosity of  $150\mu\text{b}^{-1}$ . The jets are reconstructed with the anti-kT clustering algorithm by utilizing particle-flow objects with a radius parameter  $R=0.7$  and  $R=0.3$ .

**Parallel 3C: Electro-Weak Probes (Chair J. Kapusta) / 268**

## Di-electron differential cross section in Au+Au collisions at different beam energies at STAR

**Author:** Huang Bingchu<sup>1</sup>

<sup>1</sup> *Brookhaven National Lab*

**Corresponding Author:** huangbc@bnl.gov

Di-leptons serve as clean and bulk penetrating probes to study the properties of the strongly interacting hot and dense medium created in heavy ion collisions. They are produced in all stages of the heavy-ion collisions and are not affected by strong interactions, hence can probe the entire evolution of the collision. Di-lepton production in the low mass range ( $M_{ll} < 1.1 \text{ GeV}/c^2$ ) allows the study of vector meson in-medium properties, an observable possibly connected to chiral symmetry restoration. In the intermediate mass region ( $1.1 < M_{ll} < 3.0 \text{ GeV}/c^2$ ), di-lepton measurements serve as a tool to extract the medium thermal radiation, which provides direct information on the temperature of the early system. Quantitative studies on these properties require systematic

measurements of di-lepton production yields as well as elliptic flow as a function of invariant mass and transverse momentum ( $p_T$ ). An extension of these studies to energy and centrality dependent measurements offer crucial information on how the system properties evolve with collision energies and system sizes. The STAR experiment, with its large and full azimuthal acceptance, clean electron identification over a wide momentum range and low material environment, is very well suited to carry out systematic studies on di-lepton production. In the years 2010 and 2011, more than one billion events were taken in 200 GeV Au+Au collisions and several hundred million events were recorded at lower energies by the STAR experiment. In this presentation, results from di-electron mass spectra as a function of  $p_T$  and centrality as well as the dependence of elliptic flow on invariant mass in 200 GeV Au+Au collisions will be presented. The results on mass, width,  $dN/dy$ ,  $p_T$  spectra of  $\omega$  and  $\phi$  mesons will be reported. The first STAR results of di-electron mass spectra and  $p_T$  distributions at midrapidity for Au+Au collisions at  $\sqrt{s_{NN}} = 19.6, 39$  and 62.4 GeV will be presented. These distributions will be compared to model calculations of in-medium vector and thermal radiation contributions to infer medium properties.

**Parallel 3B: Jets (Chair S. Mioduszewski) / 479**

## Jet fragmentation and jet properties in 2.76 TeV Pb+Pb collisions using the ATLAS Detector at LHC

**Author:** Zdenek ATLAS Collaboration<sup>1</sup>

<sup>1</sup> Charles University Prague

**Corresponding Authors:** martin.rybar@cern.ch, zdenek.dolezal@cern.ch

The recent measurements of jet suppression at LHC indicate a presence of “jet quenching” – strong energy loss of energetic jets in hot and dense QCD medium which has been already observed at RHIC experiments. We present a measurement of jet properties which sheds more light on the mechanism of jet energy loss. We will discuss the results of measurement of longitudinal, and transverse structure of jets, as well as the spectra, and multiplicities of charged particles constituting jets. The measurement has been performed using 158  $nb^{-1}$  of lead-lead collision data provided at a nucleon center-of-mass energy of 2.76 GeV by the Large Hadron Collider and collected by the ATLAS Detector during November and December 2011.

**Parallel 3C: Electro-Weak Probes (Chair J. Kapusta) / 359**

## Jet-Tagged Back-Scattering Photons For Quark Gluon Plasma Tomography

**Author:** Rainer Fries<sup>1</sup>

**Co-authors:** Dinesh Srivastava<sup>2</sup>; Somnath De<sup>2</sup>

<sup>1</sup> Texas A&M University

<sup>2</sup> Variable Energy Cyclotron Centre, Kolkata

**Corresponding Author:** rjfries@comp.tamu.edu

We investigate the correlations of photons produced by back scattering of fast partons in quark gluon plasma with their away-side jets. Back scattering with photon emission, or jet-photon conversion, was originally proposed as a novel source of photons in Phys. Rev. Lett. 90, 132301 (2003).

The unique appeal of this photon source lies in the fact that its photons carry information about both the medium via a  $T^2 \log 1/T$  dependence of the yield and about the energy loss of partons before the back scattering occurs. Attempts to identify this source in experiment through inclusive direct photon spectra or direct photon  $v_2$  at intermediate PT at RHIC have been inconclusive so far. We show that the capability to measure jets in coincidence with photons at the upgraded STAR or SPHENIX experiment, or at one of the LHC experiments, offers a unique opportunity to identify back scattering photons at large photon momenta. Jet-triggered back-scattering photons can be distinguished from bremsstrahlung through their strong correlation with the given trigger ET, and from prompt hard photons through the energy loss of their parent parton. We demonstrate with leading and next-to-leading order calculations that jet-triggered direct photon spectra and nuclear modification factors in nuclear collisions as a function of photon PT show a distinct feature around the trigger ET due to back-scattering photons. The height and width of this structure are correlated with the medium temperature and parton energy loss spectrum, respectively.

**Parallel 3A: Global & Collective Dynamics (Chair T. Kodama) / 368**

## **Two- and Multi-particle cumulant measurements of $v_n$ and isolation of flow and nonflow in 200 GeV Au+Au Collisions by STAR**

**Author:** Li Yi<sup>1</sup>

<sup>1</sup> *Purdue University*

**Corresponding Author:** yil@purdue.edu

Azimuthal anisotropic flows  $v_n$ , arising from the anisotropic collision geometry, reflect the hydrodynamic properties of the quark gluon plasma created in relativistic heavy-ion collisions. A long standing issue in  $v_n$  measurements is the contamination of nonflow, caused by intrinsic particle correlations unrelated to the collision geometry. Nonflow limits, in part, the precise extraction of the viscosity to entropy density ratio  $\eta/s$  from data-model comparisons. Isolation of flow and nonflow is critical to the interpretation of the Fourier decomposition of dihadron correlations.

In this talk we report measurements of  $v_n$  azimuthal anisotropies using the two- and multi-particle Q-cumulants method from STAR in Au+Au collisions at 200 GeV. The centrality and pT dependence of  $v_n$  will be presented. We compare the four- and six-particle cumulant measurements to gain insights on the nature of flow fluctuations [1,2]. We further analyze two- and four-particle cumulants between pseudo-rapidity ( $\eta$ ) bins. Exploiting the collision symmetry about mid-rapidity, we isolate the  $\Delta\eta$ -dependent and  $\Delta\eta$ -independent correlations in the data with a data-driven method [3]. The  $\Delta\eta$ -dependent part arises from near-side nonflow correlations, such as HBT interferometry, resonance decays, and jet-correlations. The  $\Delta\eta$ -independent part is dominated by flow and flow fluctuations with relatively small contribution from away-side jet-correlations. The method does not make assumptions about the  $\eta$  dependence of flow. Our isolated  $\Delta\eta$ -independent part from data, dominated by flow, however, is found to be also  $\eta$ -independent within the STAR TPC of  $\pm 1$  unit of pseudo-rapidity. The  $\Delta\eta$  drop in the measured two-particle cumulant appears to entirely come from nonflow. We assess the effect of the nonflow on  $\eta/s$  extraction. We reexamine the high-pT triggered dihadron correlations with background subtraction of our decomposed flows.

[1] S.A. Voloshin, A.M. Poskanzer, A. Tang, and G. Wang, Phys. Lett. B659, 537 (2008).

[2] L. Yi, F. Wang, and A. Tang, arXiv:1101.4646 [nucl-ex].

[3] L. Xu, L. Yi, D. Kikola, J. Konzer, F. Wang, and W. Xie, arXiv:1204.2815 [nucl-ex].

**Parallel 3D: Pre-Equilibrium & Initial State (Chair K. Eskola) / 343****Cold Nuclear Matter Effects in 200 GeV d+Au Collisions at PHENIX****Author:** Matthew Wysocki<sup>1</sup><sup>1</sup> *Oak Ridge National Laboratory***Corresponding Authors:** sahlmul@gmail.com, matthew.g.wysocki@gmail.com

While the study of the quark-gluon plasma has been the primary focus of the RHIC experiments, much work has also been done to understand so-called cold nuclear matter (CNM) effects through  $d+Au$  collisions where no hot plasma is produced. Effects such as nuclear shadowing, Cronin enhancement, and initial-state parton energy loss, among others, are not only interesting in their own right, but have direct implications on QGP-related measurements in  $A + A$  collisions.

Recently PHENIX has measured CNM effects at midrapidity in  $\sqrt{s_{NN}} = 200$  GeV  $d+Au$  collisions. Measurements of reconstructed jets reveal the centrality dependence of both jet suppression and broadening of the away-side jet. Meanwhile, single electrons from heavy flavor decays exhibit enhancement over a broad  $p_T$  range and increasing with centrality. These results will be presented and compared to our present understanding of CNM effects to see if simultaneous constraints on nuclear shadowing, initial state energy loss, and Cronin effects can be found. The centrality dependence of the nuclear modification, for which there is no a priori model, will be examined in the context of available theoretical models of CNM effects, including the EPS09 nuclear-modified parton distribution functions.

**Parallel 3C: Electro-Weak Probes (Chair J. Kapusta) / 441****Measurement of direct photons in pp and Pb-Pb collisions with ALICE****Author:** Collaboration ALICE<sup>1</sup>**Co-author:** Martin Rudolf Wilde<sup>2</sup><sup>1</sup> *CERN, Geneva, Switzerland*<sup>2</sup> *Westfaelische Wilhelms-Universitaet Muenster (DE)***Corresponding Authors:** m\_wild03@uni-muenster.de, jochen@thaeeder.de

Direct photons are an important probe in diagnosing the highly excited state of nuclear matter created in heavy-ion collisions: They allow access to various stages of the collision including the initial state.

The ALICE detector is equipped with two high resolution electromagnetic calorimeters and a central tracking system that make it well suited to study direct photon production at low and intermediate  $p_t$ . In addition to classical calorimeter measurements the low  $p_t$  regime can be targeted via the measurement of photon conversion products by the ALICE TPC with high tracking efficiency.

In this talk the analysis of direct photon production in pp (at  $\sqrt{s} = 7$  TeV) and Pb-Pb (at  $\sqrt{s_{NN}} = 2.76$  TeV) collisions is presented. The inclusive photon and neutral pion spectrum is measured via photon conversions in the ALICE setup. From the neutral pion yield a decay photon cocktail is deduced. The signal is obtained by calculating the double ratio  $(\gamma/\pi^0)/(\gamma_{\text{decay}}/\pi^0)$ . Implications on the search for a direct photon excess at low  $p_t$  will be discussed.

**Parallel 3D: Pre-Equilibrium & Initial State (Chair K. Eskola) / 87**

## Jet probes of cold and hot QCD matter

**Author:** Ben-Wei Zhang<sup>1</sup>

**Co-authors:** Enke Wang<sup>1</sup>; Ivan Vitev<sup>2</sup>; R D Neufeld<sup>3</sup>; Wei Dai<sup>1</sup>; Yuncun He<sup>1</sup>

<sup>1</sup> *Central China Normal University*

<sup>2</sup> *Los Alamos National Lab*

<sup>3</sup> *Los Alamos National Lab.*

**Corresponding Author:** benweizhang@gmail.com

Parton energy loss in the hot QCD medium will manifest itself not only in leading hadron spectra but also in reconstructed jet productions in high-energy nucleus-nucleus collisions. With its more differential power full jets in heavy-ion collisions can then provide excellent tools to study the properties of the QGP and impose constraints on different parton energy loss models.

With this motivation, we investigate the cold nuclear matter(CNM) effects on jet productions in high-energy nuclear collisions at LHC with the NLO perturbative QCD. The nuclear modifications for dijet angular distributions, dijet invariant mass spectra, dijet transverse momentum spectra and dijet momentum imbalance due to CNM effects are calculated by incorporating EPS, EKS, HKN and DS parametrization sets of parton distributions in nucleus. It is found that dijet angular distributions and dijet momentum imbalance are insensitive to the initial-state CNM effects and thus provide optimal tools to study the final-state hot QGP effects such as jet quenching.

Furthermore we present the results and predictions at NLO for productions of the single, double and tagged jets in relativistic heavy-ion collisions by including parton energy loss effect in the QGP and the CNM effects. We demonstrate how an enhanced di-jet transverse momentum imbalance in central Pb+Pb reactions at the LHC, recently measured by the ATLAS and CMS experiments, can be derived from these results. We show quantitatively that a significant fraction of this enhancement may be related to the ambiguity in the separation between the jet and soft background medium and point to a suite of measurements that can help build a consistent picture of parton shower modification in heavy ion collisions at the LHC.

**Parallel 3A: Global & Collective Dynamics (Chair T. Kodama) / 201**

## Study of higher harmonics based on (3+1)-dimensional relativistic viscous hydrodynamics

**Author:** Chiho Nonaka<sup>1</sup>

**Co-authors:** Makoto Takamoto<sup>2</sup>; Yukinao Akamatsu<sup>3</sup>

<sup>1</sup> *Kobayashi-Maskawa Institute for the Origin of Particles and the Universe (KMI) and Department of Physics, Nagoya University*

<sup>2</sup> *Department of Physics, Nagoya University*

<sup>3</sup> *Kobayashi-Maskawa Institute for the Origin of Particles and the Universe (KMI), Nagoya University*

**Corresponding Author:** nonaka@hken.phys.nagoya-u.ac.jp

Currently a possible origin of “Mach-Cone-like structure” is regarded as triangular flow and higher harmonics which are produced through event-by-event fluctuated initial states, which is a push to implement effects of event-by-event fluctuations in the initial conditions of relativistic hydrodynamic models.

When the hydrodynamic simulation is performed with initial conditions with the event-by-event fluctuation, shock-wave capturing schemes should be used to describe the hydrodynamic expansion correctly.

Here we develop a fast numerical scheme for causal relativistic hydrodynamics with dissipation for analyses of relativistic high energy collisions, which is based on



Ref. [1]. This shock-wave capturing scheme for solving relativistic viscous hydrodynamic equation suffers less artificial dissipative effect and is more suitable for physical viscosity analyses, compared to SHASTA, Kurganov-Tadmor (KT) and rHLLE schemes which are mainly used in current analyses based on hydrodynamic models.

Using the relativistic viscous hydrodynamic model first we evaluate the viscosity effect in collective flow such as elliptic flow, triangular flow and higher harmonics. In particular, we investigate the time evolution of them and discuss the relation between the initial geometry and final states.

[1] M. Takamoto and S. Inutsuka, J. Comput. Phys. 230 (2011), 7002.

**Parallel 3B: Jets (Chair S. Mioduszewski) / 217**

## Jet fragmentation functions in PbPb and pp collisions at 2.76 TeV with CMS

**Author:** Collaboration CMS<sup>1</sup>

<sup>1</sup> CERN

**Corresponding Authors:** teng.ma@cern.ch, wyslouch@mit.edu

The jet fragmentation function of inclusive jets with  $p_T > 100$  GeV/c in PbPb collisions is measured for reconstructed charged particles with  $p_T > 1$  GeV/c within the jet cone. A data sample of PbPb collisions collected in 2011 at a center of mass energy of  $\sqrt{s_{NN}} = 2.76$  TeV corresponding to an integrated luminosity of  $L_{int} = 129 \mu\text{b}^{-1}$  is used. The results for PbPb collisions as a function of collision centrality are compared to reference distributions based on pp data collected at the same collision energy. For the most central collisions a significant rise of the PbPb/pp fragmentation function ratio for the softest fragmentation products with  $p_T < 3$  GeV/c is observed.

**Parallel 3D: Pre-Equilibrium & Initial State (Chair K. Eskola) / 609**

## Gravitational collapse and holographic thermalization

**Author:** Paul Chesler<sup>1</sup>

<sup>1</sup> MIT

**Corresponding Author:** pchesler@mit.edu

A remarkable result from heavy ion collisions at the Relativistic Heavy Ion Collider and Large Hadron Collider is that, shortly after the collision event, the quark-gluon plasma produced behaves as a nearly ideal liquid. Understanding the dynamics responsible for such rapid “hydroization” is a challenge using traditional perturbative field theory. In recent years holography has emerged as a powerful tool to study non-equilibrium phenomena, mapping the dynamics of certain quantum field theories onto the dynamics of semi-classical gravity. Via holography, the production of quark-gluon plasma maps onto the process of gravitational collapse and black hole formation, with the relaxation of the black hole’s gravitational field encoding hydroization of the dual quark gluon plasma. Thermalization of the quark-gluon plasma is encoded in the thermalization of the black hole’s Hawking radiation. I will describe several processes which mimic heavy ion collisions and present results for both hydroization and thermalization times and mechanisms.

**Parallel 3B: Jets (Chair S. Mioduszewski) / 200**

## Medium-induced soft gluon distribution inside a jet

**Authors:** Edmond Iancu<sup>1</sup>; Fabio Dominguez<sup>2</sup>; Jean-Paul Blaizot<sup>3</sup>; Yacine Mehtar-Tani<sup>None</sup>

<sup>1</sup> CEA Saclay

<sup>2</sup> IPhT Saclay

<sup>3</sup> CNRS

**Corresponding Author:** fabio.dominguez@cea.fr

The new studies of heavy ion collisions performed at the LHC have shown the necessity to improve our understanding of parton propagation and gluon emission in the presence of a hot QCD medium. In particular, the ability to measure jets in heavy ion collisions implies that, in order to fully understand jet quenching phenomena, we must go beyond leading parton energy loss and attempt to describe how the jet structure is modified by the presence of the quark-gluon plasma. In this spirit, we study in-medium jet evolution by considering the multiple emission of soft gluons, for which the formation time is much smaller than the size of the medium. This separation of scales implies that one can consider the multiple emissions as independent and ordered in time, therefore allowing for a probabilistic interpretation where the parton shower is built as a classical branching process.

**Parallel 3A: Global & Collective Dynamics (Chair T. Kodama) / 169**

## Systematic Investigation of Partonic Collectivity through Centrality Dependence of Elliptic Flow of Multi-strange Hadrons in Au+Au collisions at 200 GeV in STAR

**Author:** NASIM MD<sup>1</sup>

<sup>1</sup> Variable Energy Cyclotron Centre

**Corresponding Author:** mnasim2008@gmail.com

One of the main goals of the STAR experiment at Relativistic Heavy Ion Collider (RHIC) is to study the properties of the QCD matter at extremely high energy and parton densities, created in the heavy-ion collisions. Understanding the partonic collectivity through the measurement of elliptic flow ( $v_2$ ) of multi-strange hadrons ( $\phi$ ,  $\Xi$  and  $\Omega$ ) is believed to be a sensitive way to characterize the system created in the heavy-ion collisions. Multi-strange hadrons freeze-out close to the quark-hadron transition temperature predicted by lattice QCD. They also have small hadronic interaction cross sections. Hence, the multi-strange hadrons are expected to provide information from the partonic stage of the evolution in heavy-ion collisions. Furthermore, the multi-strange hadron anisotropic flow in heavy-ion collisions when compared to those from  $K_s^0$  and  $\Lambda$ , single strange valence quark carrying hadrons, will be useful for understanding the collective dynamics of the strange quarks.

In this presentation we will present the new results of elliptic flow of multi-strange hadrons ( $\phi$ ,  $\Xi$  and  $\Omega$ ) in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV, using a high statistics data set collected in 2010 by the STAR experiment. Centrality dependence measurements of multi-strange hadron elliptic flow allow systematic investigation on how partonic collectivity is developed across different sizes of collision system. These results will be compared with the elliptic flow measurements of light hadrons  $\pi^\pm$ ,  $K^\pm$ ,  $p(\bar{p})$ ,  $K_S^0$  and  $\Lambda(\bar{\Lambda})$ . The centrality evolution of the number of quark scaling of  $v_2$  at the intermediate  $p_T$  will be presented. The effect of re-scattering at the late hadronic stage on elliptic flow

will be addressed using the  $\phi$  and  $p$   $v_2$  measurements at the low transverse momentum ( $p_T$ ).

**Parallel 4A: Global & Collective Dynamics (Chair P. Sorenson) / 270**

## Deviation from quark number scaling of the anisotropy parameter $v_2$ of pions, kaons, and protons in Au+Au collisions at 200 GeV

**Author:** shengli huang<sup>1</sup>

<sup>1</sup> PHENIX Collaboration

**Corresponding Author:** shengli.huang@vanderbilt.edu

The number of quark ( $n_q$ ) scaling, which is manifested as  $v_2^{hadron}(p_T) \approx n_q * v_2(p_T/n_q)$ , is an approximate scaling that comes from the addition of the valence quark momenta at hadronization. The observation of  $n_q$  scaling has been claimed that a partonic matter with quark-like degrees of freedom and significant collectivity has been generated in heavy ion collisions<sup>ref{1,2}</sup>. However, there are several theoretical considerations that suggest that the  $n_q$  scaling should be violated in certain conditions. For example, the contribution of sea quarks and gluons have been shown to affect the  $n_q$  scaling in the models including higher Fock states. And models that consider recombination between “thermal” and “shower” partons predict centrality dependent deviations from  $n_q$  scaling.

Understanding the limits of the recombination domain is important in relation to viscous hydrodynamics and the extraction of the shear viscosity over entropy density ( $\eta/s$ ) from the data, as well as for developing a unified approach in describing jet energy loss and high  $p_T$   $v_2$ . Searches for deviations from  $n_q$  scaling are also important for the low-energy scan program at RHIC as they have been considered as a signature of the transition between sQGP formation and a hadronic system. In this talk, we will report on high-statistics measurements of the second order Fourier coefficient  $v_2$  for identified pions, kaons and protons, which extend to relatively high  $p_T$  around 6 GeV/c. Comparisons with published measurements of  $K_S^0$  and  $\Lambda$  are shown for the different centralities. With these new measurements, the  $p_T$  limits and centrality dependence of the  $n_q$  scaling deviations are being carried out in PHENIX.

[1] V. Greco, C. M. Ko, and P. Levai, Phys. Rev. Lett. 90, 42 202302 (2003). 43

[2] D. Molnar and S. A. Voloshin, Phys. Rev.Lett. 91, 44 092301 (2003).

**Parallel 4D: Pre-Equilibrium & Initial State (Chair T. Ludlam) / 93**

## Multigluon correlations in the color glass condensate

**Author:** Tuomas Lappi<sup>1</sup>

<sup>1</sup> *U*

**Corresponding Author:** tuomas.v.v.lappi@jyu.fi

Multiparticle correlations, such as the “ridge” effect in pp and AA collisions and forward dihadron correlations in pA collisions, are an important probe of the strong color fields that dominate the initial stages of a heavy ion collision. We argue that the Color Glass Condensate framework provides the most natural way to understand them.

We describe recent progress in understanding two-particle correlations in the dilute-dense system, e.g. in forward dihadron production in deuteron-gold collisions. This requires computing the energy dependence of higher point Wilson line correlators from the JMWLK renormalization group equation. We find that the large  $N_c$  approximation used so far in the phenomenological literature is not very accurate. On the other hand a Gaussian finite  $N_c$  approximation is a surprisingly close to the full result.

**Parallel 4C: Electro-Weak Probes (Chair D. D’Enterria) / 476**

## Measurement of isolated direct photons in lead-lead collisions at 2.76 TeV with the ATLAS detector

**Author:** Zdenek ATLAS Collaboration<sup>1</sup>

<sup>1</sup> *Charles University Prague*

**Corresponding Authors:** iwona.grabowskabold@gmail.com, zdenek.dolezal@cern.ch

Direct photons are a powerful tool to study heavy ion collisions. Their production rates provide access to the initial state PDFs, which are expected to be modified by nuclear effects. They also provide a means to calibrate the expected energy of jets that are produced in the medium, and thus are a tool to probe the physics of jet quenching more precisely both through jet rates and fragmentation properties. The ATLAS detector measures photons with its hermetic, longitudinally segmented calorimeter, which gives excellent spatial and energy resolution, and detailed information about the shower shape of each measured photon. This gives powerful rejection against the expected background from neutral pions coming from jets. Rejection against jet fragmentation products is further enhanced by isolation criteria, which can be based on calorimeter energy or the presence of high  $p_T$  tracks. First results on the rates of isolated direct photons from approximately  $140 \mu\text{b}^{-1}$  of lead-lead data will be shown, as a function of transverse momentum, pseudorapidity and centrality, and their rates compared to expectations from perturbative QCD.

**Parallel 4B: Jets (Chair N. Armesto) / 423**

## Jet-medium interactions in Pb-Pb collisions

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Federico Antinori<sup>2</sup>

<sup>1</sup> *CERN, Geneva, Switzerland*

<sup>2</sup> *Universita e INFN (IT)*

**Corresponding Authors:** ulery@uni-frankfurt.de, panos.christakoglou@cern.ch

Previous experimental measurements from nuclear collisions have indicated modifications of jets by interaction with the medium created in the collision. Observables from particle correlations in

the ALICE detector continue to provide access to key properties of the hot deconfined nuclear matter. New results from two- and three-particle number and transverse momentum correlations are presented. Specifically, correlation function properties are characterised as a function of transverse momentum and centrality and for different charge combinations. Fourier decompositions are performed, the jet-like peak is characterised, and identified particle ratios are studied in the jet-like peak and compared to those in the bulk. These results suggest strong modifications of the peak shape and particle ratios in central collisions, compared to proton-proton or peripheral data. Model comparisons are included to assist interpretation of these results.

**Parallel 4A: Global & Collective Dynamics (Chair P. Sorenson) / 488**

## Measurement of dipole flow associated with initial geometry fluctuations in Pb-Pb collisions with the ATLAS detector

**Author:** Zdenek ATLAS Collaboration<sup>1</sup>

**Co-author:** Jiangyong Jia<sup>2</sup>

<sup>1</sup> Charles University Prague

<sup>2</sup> Brookhaven National Laboratory (BNL)-Unknown-Unknown

**Corresponding Authors:** jjia@bnl.gov, zdenek.dolezal@cern.ch

A study of the dipole flow ( $v_1$ ) associated with initial geometry fluctuations is presented using the 2010 Pb-Pb data. This analysis involves a systematic decomposition of the first order Fourier coefficient of the two-particle correlation into a dipole flow component and a global momentum conservation component. The dipolar flow is extracted as function of  $p_T$  (0.5-10 GeV), centrality (0-50%) and pseudorapidity ( $|\eta| < 2.5$ ). The magnitude of the extracted global momentum conservation component is used to estimate the effective size of the system that conserve momentum as a function of centrality. These results are compared with recent model calculations and their implications on the initial dipole asymmetry are discussed.

**Parallel 4B: Jets (Chair N. Armesto) / 409**

## Study of jet fragmentation with particle correlations in Pb-Pb collision at 2.76 TeV by ALICE

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Filip Krizek<sup>2</sup>

<sup>1</sup> CERN, Geneva, Switzerland

<sup>2</sup> Helsinki Institute of Physics (FI)

**Corresponding Authors:** filip.krizek@cern.ch, panos.christakoglou@cern.ch

A high- $p_T$  jet suppression first observed at RHIC has been reported also at the LHC. The ALICE collaboration has recently reported an observation of an enhanced intra-jet yield of charged particles associated with the high- $p_T$  trigger particle ( $I_{AA}$ ) in central Pb-Pb collisions at  $\sqrt{s_{NN}}=2.76$  TeV which may be also interpreted as a hint of the modification of the fragmentation function due to induced gluon radiation. In order to study further the nature of the intra-jet correlation yield enhancement an analysis of the jet-fragmentation transverse momentum was performed. Modification of this distribution with the centrality of the collision will be presented. A possible path length dependency of the induced radiation is studied using a comparison of the two-particle correlation for different orientations of the trigger particle with respect to the event plane and comparing the jet-fragmentation transverse momentum distribution measured in different event-by-event anisotropy classes.

**Parallel 4C: Electro-Weak Probes (Chair D. D'Enterria) / 209**

## **Inclusive isolated photons in pp and PbPb collisions at 2.76 TeV with CMS**

**Author:** Collaboration CMS<sup>1</sup>

<sup>1</sup> *CERN*

**Corresponding Authors:** george.stephans@cern.ch, wyslouch@mit.edu

Final data on isolated photon production will be presented, measured in both pp and PbPb collisions at a nucleon-nucleon center-of-mass energy of 2.76 TeV with the CMS detector at the LHC. The isolated photon transverse energy (ET) spectra, covering the pseudorapidity range  $|\eta| < 1.44$  and transverse energy  $ET > 20$  GeV, are found to be in good agreement with next-to-leading-order perturbative QCD predictions. The measured isolated photon RAA, with a reference based on pp data, is consistent with unity for all PbPb collision centralities.

**Parallel 4D: Pre-Equilibrium & Initial State (Chair T. Ludlam) / 161**

## **Effect of longitudinal fluctuation in event-by-event (3+1)D hydrodynamics**

**Authors:** Long-Gang Pang<sup>1</sup>; Qun Wang<sup>None</sup>; Xin-Nian Wang<sup>2</sup>

<sup>1</sup> *l*

<sup>2</sup> *Lawrence Berkeley National Laboratory*

**Corresponding Author:** lgpang@lbl.gov

Hadron spectra and elliptic flow in high-energy heavy-ion collisions are studied within a (3+1)D ideal hydrodynamic model with fluctuating initial conditions given by the AMPT Monte Carlo model and compared to experimental data. Fluctuation in the initial energy density comes from not only the coherent soft interaction of overlapping nucleons but also the number of mini-jets within each binary nucleon collision. Mini-jets produced via semi-hard parton scatterings are assumed to be locally thermalized through a Gaussian smearing and give rise to fluctuation in rapidity distribution along the longitudinal direction. The longitudinal fluctuation is found to lead to sizable reduction of elliptic flow at large transverse momentum.

**Parallel 4C: Electro-Weak Probes (Chair D. D'Enterria) / 474**

## **Measurements of W and Z boson production in Pb+Pb collisions at 2.76 TeV with the ATLAS detector.**

**Author:** Zdenek ATLAS Collaboration<sup>1</sup>

<sup>1</sup> *Charles University Prague*

**Corresponding Authors:** dolejsi@ipnp.troja.mff.cuni.cz, zdenek.dolezal@cern.ch

Collisions of lead nuclei at the LHC allow study of the deconfined phase of QCD matter at unparalleled temperatures and energy densities. The use of leptonic observables is particularly appealing as a consequence of their electroweak nature, allowing them to traverse the strongly-coupled medium essentially unaffected. W and Z bosons, observed through their semi-leptonic decay channels, may serve as a proxy for investigating phenomenological processes associated with particle interactions

in the QCD medium as well as exploring hitherto unattainable regions of nuclear PDFs. The yields of these bosons in heavy ion collisions can be used for sensitive tests of binary scaling. This presentation will describe measurements of the W boson using single muon decay, and measurements of  $Z \rightarrow ee$  and  $Z \rightarrow \mu\mu$ , both performed with nearly 150 nb<sup>-1</sup> of collision data collected at a center-of-mass energy per nucleon pair  $\sqrt{s_{NN}}=2.76$  TeV with the ATLAS detector during the 2011 heavy ion run.

**Parallel 4A: Global & Collective Dynamics (Chair P. Sorenson) / 512**

## Baryon anomaly in heavy-ion collisions and colour correlations in QGP

**Authors:** Eugene Levin<sup>1</sup>; Karel Safarik<sup>2</sup>; Mikhail Ryskin<sup>3</sup>

<sup>1</sup> *Tel Aviv University and Universidad Tecnica Federico Santa Maria Valparaiso*

<sup>2</sup> *CERN*

<sup>3</sup> *Petersburg Nuclear Physics Institute*

**Corresponding Author:** karel.safarik@cern.ch

A baryon anomaly – an increase baryon-to-meson production ratio at intermediate transverse momenta in heavy-ion collisions when compared to proton–proton collisions – is observed at RHIC and the LHC. This effect is usually explained by recombination of constituent quarks during QGP hadronisation, or as a consequence of a strong radial flow developed during the heavy-ion collision. In this contribution, a different mechanism to favour baryon-over-meson production is proposed: when hadrons are formed in the recombination of nearby quarks and antiquarks, only colour-singlet combinations can be chosen. Hadron formation, in particular the probability to create baryons or mesons, depends on the distribution of colour charges among quarks. If the distribution is random – a reasonable assumption for Quark–Gluon Plasma (QGP) – the baryon-to-meson ratio is nearly twice higher than in the situation where quark colours are pre-arranged to obtain a white hadron in the combination of nearest quarks and antiquarks. The correlation of colour charges in the QGP also influences the distance over which recombination occurs. A study of the dependencies of the baryon-to-meson ratio and of the size of the recombination domain on the colour-correlation configuration will be presented.

**Parallel 4D: Pre-Equilibrium & Initial State (Chair T. Ludlam) / 135**

## Imprinting quantum fluctuations on hydrodynamic initial conditions

**Author:** J. Scott Moreland<sup>1</sup>

**Co-authors:** Ulrich Heinz<sup>2</sup>; Zhi Qiu<sup>2</sup>

<sup>1</sup> *Duke University*

<sup>2</sup> *Ohio State University*

The precise value of the QGP kinematic shear viscosity  $\eta/s$  is a question of intense topical interest. Viscous hydrodynamic simulations are a tool for extracting this information from experiment. The key observables are the anisotropic flow coefficients  $v_n$  which (i) can be measured very precisely and (ii) are very sensitive to  $\eta/s$  which controls the “conversion efficiency”  $v_n/ecc_n$  for turning initial fireball eccentricities of harmonic order  $n$  into final flows of the same harmonic order.

Both  $ecc_n$  and  $v_n$  fluctuate strongly from collision to collision. These event-by-event fluctuations have a key influence on the measurements [1] and must be properly taken into account when extracting  $\eta/s$ . Until recently, most initial-state models accounted only for the shape and density

fluctuations arising from the fluctuating positions of the nucleons in the colliding nuclei. This leads to fluctuations in the location of the newly produced matter, and thus of the initial energy density profile of the expanding fireball and its eccentricities  $ecc_n$ , but does not account for additional quantum fluctuations in the quark and gluon fields inside the nucleons that lead to fluctuating numbers of secondary particles per nucleon-nucleon interaction. Several recent papers have addressed the implementation of these quantum fluctuations in the hydrodynamic initial conditions for the expanding collision fireball.

Starting from the Monte Carlo Kharzeev-Levin-Nardi (MC-KLN) model for generating fluctuating initial profiles for the gluon saturation momentum  $Q_{\text{sat}}(x_T)$  in the transverse plane, we have developed a Monte Carlo algorithm that uses a Gaussian Random Field (GRF) generator [2] to generate a distribution of gluonic energy densities centered at the value corresponding to the field  $Q_{\text{sat}}(x_T)$ , but fluctuating around this profile with the two-point covariance function derived in [3] from the Glasma model. To ensure that the energy density is everywhere positive the GRF is mapped to an appropriate negative binomial distribution (NBD) with the same variance. NBD fluctuations have been recently shown to arise naturally from the Glasma model and to describe the measured multiplicity distributions in pp collisions at the LHC. The resulting density profile features “hot spots” as in the MC-KLN model overlaid with a fluctuating field texture characterized by an intrinsic length scale  $1/Q_{\text{sat}}(x_T)$ .

We show that inclusion of these additional gluonic quantum field fluctuations leads to only a small (few percent) increase of the initial eccentricities  $ecc_n$  in central collisions and to almost negligible effects at larger impact parameters. These findings disagree with some of the results reported in [4], and we will discuss possible origins for this discrepancy. Our results imply that an earlier extraction of the QGP shear viscosity from a combined analysis of elliptic and triangular flow data from Pb-Pb collisions at the LHC [5] is robust.

#### References

- [1] Zhi Qiu and U. Heinz, “Event-by-event shape and flow fluctuations of relativistic heavy-ion collision fireballs,” *Phys. Rev. C* 84, 024911 (2011).
- [2] X. Emery and C. Lantuejoul, “TBSIM: A computer program for conditional simulation of 3-dimensional Gaussian random fields via the turning bands method,” *Computers and Geosciences* 32, 1615 (2006).
- [3] B. Muller and A. Schafer, “Transverse energy density fluctuations in the Color Glass Condensate Model,” arXiv:1111.3347 [hep-ph].
- [4] B. Schenke, P. Tribedy and R. Venugopalan, “Fluctuating Glasma initial conditions and flow in heavy ion collisions,” arXiv:1202.6646 [nucl-th]; F. Gelis, T. Lappi and L. McLerran, “Glittering Glasma,” *Nucl. Phys. A* 828, 149 (2009); A. Dumitru and Y. Nara, “KNO scaling of fluctuations in pp and pA, and eccentricities in heavy-ion collisions,” *Phys. Rev. C* 85, 034907 (2012).
- [5] Z. Qiu, C. Shen and U. Heinz, “Hydrodynamic elliptic and triangular flow in Pb-Pb collisions at  $\sqrt{s}=2.76\text{A TeV}$ ,” *Phys. Lett. B* 707, 151 (2012).

**Parallel 4B: Jets (Chair N. Armesto) / 252**

## Measurements of the Correlation between Jets and the Reaction Plane in STAR at RHIC

**Author:** Alice Ohlson<sup>1</sup>

<sup>1</sup> *Yale University*

**Corresponding Author:** alice.ohlson@yale.edu

The relationship between jet properties and the underlying geometry of the medium produced in heavy ion collisions can be explored through a measurement of the correlation between the axes



of reconstructed jets and the reaction plane (defined as jet  $v_2$ ). Such a measurement provides information on the pathlength dependence of medium-induced parton energy loss as well as biases in jet-finding methods. In addition, an estimate of jet  $v_2$  is necessary for background-subtraction in jet-triggered correlation analyses, which are used to study medium-induced jet shape modification. However, jet  $v_2$  measurements are complicated by biases in the event plane calculation due to the presence of the jet, leading to an overestimation of jet  $v_2$ . In order to reduce the artificial jet-event plane bias, we utilize detectors at forward pseudorapidity ( $\eta$ ), such as the Forward Time Projection Chambers located at  $2.5 < |\eta| < 4$  and the Zero Degree Calorimeter Shower Maximum Detectors at  $|\eta| > 6.3$ , to determine the event plane when measuring  $v_2$  of reconstructed jets at mid-rapidity ( $|\eta| < 1$ ). We present first results of jet  $v_2$  measurements in  $\sqrt{s_{NN}} = 200$  GeV Au+Au collisions in STAR and their implications.

**Parallel 4B: Jets (Chair N. Armesto) / 440**

## Neutral meson production in pp and Pb-Pb collisions at the LHC measured with ALICE

**Author:** Collaboration ALICE<sup>1</sup>

<sup>1</sup> CERN, Geneva, Switzerland

**Corresponding Authors:** dmitri.peressounko@cern.ch, jochen@thaeher.de

Identified hadron spectra are considered to be sensitive to transport properties of strongly interacting matter produced in high-energy nucleus-nucleus collisions.

We present measurements of  $\pi^0$  and  $\eta$  mesons at mid-rapidity in a wide transverse momentum range in pp and Pb-Pb collisions at LHC energies measured with the ALICE detector. The mesons are reconstructed via their two-photon decays by two complementary methods, using the electromagnetic calorimeters and the central tracking system for photons converted to electron-positron pairs on the material of the inner ALICE barrel tracking detectors.

The spectrum and the nuclear modification factor ( $R_{AA}$ ) of the  $\pi^0$  production measured in Pb-Pb collisions at different collision centralities show a clear pattern of strong suppression with respect to pp collisions. The azimuthal anisotropy ( $v_2$ ) of the  $\pi^0$  production is consistent with  $v_2$  for other hadron species. Comparison of the ALICE results on neutral mesons with those of lower-energy experiments is discussed.

**Parallel 4A: Global & Collective Dynamics (Chair P. Sorenson) / 96**

## Midrapidity antibaryon-to-baryon ratios in pp and Pb-Pb collisions measured by the ALICE experiment

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Christine Nattrass<sup>2</sup>

<sup>1</sup> CERN, Geneva, Switzerland

<sup>2</sup> University of Tennessee (US)

**Corresponding Author:** michal.broz@cern.ch

The ALICE Experiment features low material budget and high resolution tracking, which allow for precise measurements of charged particle production.

The measurement of the antibaryon to baryon ratios ( $\bar{B}/B$ ), in particular, probes the baryon transport and the degree of baryon stopping in high energy collisions, providing insight into the collision dynamics and the structure of baryons. In this talk, we discuss the measurement of different  $\bar{B}/B$

ratios  $(\bar{p}/p, \bar{\lambda}/\lambda, \xi^+/\xi^-, \omega^+/\omega^-)$  in pp collisions at  $\sqrt{s} = 0.9, 2.76, \text{ and } 7 \text{ TeV}$  and in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76 \text{ TeV}$ , as a function of charged particle multiplicity, rapidity and transverse momentum. Results from pp and Pb-Pb collisions are presented and compared to models.

**Parallel 4C: Electro-Weak Probes (Chair D. D'Enterria) / 233**

## Z and W boson production in PbPb collisions at 2.76 TeV with CMS

**Author:** Collaboration CMS<sup>1</sup>

<sup>1</sup> CERN

**Corresponding Authors:** lamia.benhabib@cern.ch, wyslouch@mit.edu

The Compact Muon Solenoid (CMS) is fully equipped to measure leptonic decays of electroweak probes in the high multiplicity environment of nucleus-nucleus collisions. Electroweak boson production is an important benchmark process at hadron colliders. Precise measurements of W and Z production in heavy-ion collisions can help to constrain nuclear PDFs as well as serve as a standard candle of the initial state in PbPb collisions at the LHC energies. The inclusive and differential measurements of the Z boson yield in the muon decay channel will be presented, establishing that no modification is observed with respect to next-to-leading order pQCD calculations, scaled by the number of incoherent nucleon-nucleon collisions. Measurements of the yield of W to  $\mu\nu$  decays as a function of centrality and the W charge asymmetry as a function of rapidity show no modifications beyond the expected effect of isospin when compared to pp collisions.

**Parallel 4D: Pre-Equilibrium & Initial State (Chair T. Ludlam) / 261**

## The spectrum of quantum fluctuations and space-time evolution in the little bang

**Author:** Francois Gelis<sup>None</sup>

**Co-authors:** Kevin Dusling ; Raju Venugopalan <sup>1</sup>

<sup>1</sup> Brookhaven National Laboratory

**Corresponding Authors:** rajuv@mac.com, kdusling@gmail.com

We outline significant recent progress in a program to include quantum corrections to the evolution of the classical color fields produced in high-energy ultra-relativistic heavy ion collisions. Previous work in this direction for a scalar  $\phi^4$  theory [1] has now been extended to QCD. Leading contributions from unstable quantum modes can be resummed to all loop orders and expressed in terms of a gauge invariant spectrum of initial quantum fluctuations, which has been computed recently [2]. These fluctuations play a key role in decoherence of the high occupancy fields, and in their possible isotropization and flow, and in the matching of this initial dynamics to hydrodynamic flow, thereby potentially eliminating a big source of uncertainty in hydrodynamic simulations. We report on progress in the 3+1-D numerical computations implementing these pre-equilibrium dynamics.

[1] K. Dusling, T. Epelbaum, F. Gelis and R. Venugopalan, "Role of quantum fluctuations in a system with strong fields: Onset of hydrodynamical flow," Nucl. Phys. A **850**, 69 (2011); T. Epelbaum and F. Gelis,

“Role of quantum fluctuations in a system with strong fields: Spectral properties and Thermalization,”  
Nucl. Phys. A **872**, 210 (2011).

[2] K. Dusling, F. Gelis and R. Venugopalan, “The initial spectrum of fluctuations in the little bang,”  
Nucl. Phys. A **872**, 161 (2011).

**Parallel 4A: Global & Collective Dynamics (Chair P. Sorenson) / 699**

## Late Result - Ds RAA from ALICE

**Corresponding Author:** gian.michele.innocenti@cern.ch

The measurement of heavy-flavour production provides insights on the properties of the high-density QCD medium created in heavy-ion collisions.

In particular, the comparison of charm production in pp and in Pb-Pb collisions allows to study the mechanism of in-medium energy loss of heavy quarks. Furthermore, since strange quarks are abundant in the medium, the relative yield of D+s mesons with respect to non-strange charm mesons (D0 and D+) is predicted to be largely enhanced if in-medium hadronization is the dominant mechanism for charm hadron formation in the low momentum region.

We will present the measurement of the D+s production in pp collisions at  $\sqrt{s} = 7$  TeV and in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV performed with the ALICE detector at central rapidity through the exclusive reconstruction of the hadronic decay channel  $D+s \rightarrow \Phi \pi^+ \rightarrow K+K-\pi^+$ . The ratios between the yields of D+s and non-strange D mesons as a function of the transverse momentum will be shown for both pp and Pb-Pb collisions.

**Parallel 4D: Pre-Equilibrium & Initial State (Chair T. Ludlam) / 25**

## Forward azimuthal correlations in 200 GeV p+p and d+Au collisions at STAR

**Author:** Xuan Li<sup>1</sup>

<sup>1</sup> Shandong University

**Corresponding Author:** fishone23@gmail.com

The proton gluon distribution function increases rapidly with decreasing  $x$  at fixed  $Q^2$ , but cannot increase indefinitely as  $x$  goes to 0. Gluon saturation is expected at a low  $x$  value when gluon recombination balances gluon splitting. The nuclear (with atomic mass number  $A$ ) gluon distribution is approximately  $A^{1/3}$  larger than the nucleon gluon distribution function at the same  $x$  [1]. STAR is sensitive to  $x$  between 0.001 and 0.02 for the nuclear gluon distribution via di-jet measurements with calorimeter subsystems covering  $-1 < \eta < 4$ . The STAR collaboration has measured forward  $\pi^0$ - $\pi^0$  correlations and forward+mid-rapidity correlations in p+p and d+Au collisions at  $\sqrt{s} = 200$  GeV. The suppression of the away-side peak observed in forward-forward correlations in central d+Au collisions is consistent with the CGC expectation [2,3]. Such suppression does not appear in the forward+mid-rapidity correlations.

The Endcap Electromagnetic Calorimeter (EEMC) at STAR covers pseudo-rapidity between 1.08 and 2, providing the opportunity to probe gluons at intermediate  $x$  via forward+near-forward correlations. Azimuthal correlations between  $\pi^0$  in the Forward Meson Spectrometer (FMS) and jet-like clusters in the EEMC are sensitive to the nuclear gluon distribution in  $0.003 < x < 0.02$  region. Together with the forward+forward correlations and forward+mid-rapidity correlations, we will be able to determine the sharpness of the transition along  $x$  from a dilute parton gas to the expected CGC state at low  $Q^2$ . In this talk, we will focus on FMS- $\pi^0$  + EEMC-jet-like-cluster azimuthal correlations in p+p

and d+Au collisions. The impact from underlying-event contributions to the jet-like clusters and effective p+Au results, via a deuteron-beam-facing neutron tag, will be discussed as well.

[1] H. Kowalski, D. Teaney, Phys. Rev. D 68, 114005, 2003.

[2] E. Braidot, arXiv:1005.2378, 2010.

[3] J. L. Albacete, C. Marquet, Phys. Rev. Lett , 105,162301, 2010.

**Plenary IVA: Real & Virtual Photons (Chair: T. Nayak) / 652**

## **Di-Lepton Physics Program at STAR**

**Corresponding Author:** frank.geurts@cern.ch

**Plenary IVA: Real & Virtual Photons (Chair: T. Nayak) / 653**

## **PHENIX Low Mass Di-leptons**

**Corresponding Author:** itzhak.tserruya@cern.ch

**Plenary IVA: Real & Virtual Photons (Chair: T. Nayak) / 655**

## **Photons and electroweak probes in ATLAS**

**Corresponding Author:** peter.steinberg@bnl.gov

**Plenary IVA: Real & Virtual Photons (Chair: T. Nayak) / 656**

## **Overview of results on photon and electroweak boson production from the CMS collaboration**

**Corresponding Author:** raphael@cern.ch

**Plenary IVB: Quarkonia, Real & Virtual Photons (Chair Y. Schutz) / 648**

## **Overview of results on heavy flavor and quarkonia from the CMS collaboration**

**Corresponding Author:** camelia.mironov@cern.ch

**Plenary IVB: Quarkonia, Real & Virtual Photons (Chair Y. Schutz) / 649**

## **Results on quarkonia from ALICE**

**Corresponding Author:** enrico.scomparin@cern.ch

Plenary IVB: Quarkonia, Real & Virtual Photons (Chair Y. Schutz) / 650

## Heavy quarkonium in hot medium

**Corresponding Author:** hatsuda@phys.s.u-tokyo.ac.jp

Plenary IVB: Quarkonia, Real & Virtual Photons (Chair Y. Schutz) / 651

## Quarkonia Discussion

Plenary IVB: Quarkonia, Real & Virtual Photons (Chair Y. Schutz) / 658

## Search for Chiral Magnetic Effects in High-Energy Nuclear Collisions

**Corresponding Author:** gwang@physics.ucla.edu

Parallel 5B: QCD at Finite Temperature and Density (Chair F. Karsch) / 526

## Photon production in hot QCD plasmas at NLO and two-to-three processes

**Author:** Derek Teaney<sup>1</sup>

**Co-authors:** Aleski Kurkela<sup>2</sup>; Guy Moore<sup>2</sup>; Jacopo Ghiglieri<sup>2</sup>; Juhee Hong<sup>1</sup>

<sup>1</sup> *Stony Brook University*

<sup>2</sup> *McGill University*

**Corresponding Author:** derek.teaney@stonybrook.edu

We determine the photon production rate at next to leading order, i.e. through order  $g^2 m_D/T$ . At leading order, photon production is determined by three processes: hard two-to-two collisions, collinear bremsstrahlung, and quark-conversions, i.e. a process where the incoming quark transfers almost all of its momentum to the produced photon and the final state quark is soft. At NLO, wider angle bremsstrahlung must be treated carefully, and the LPM suppressed leading order rate smoothly matches onto two-to-three processes. Similarly, asymmetric bremsstrahlung, when the photon carries a large momentum fraction of the incoming momentum and the final state quark is soft, must be smoothly matched onto the quark conversion process present at leading order. We carefully include these rates without double counting to determine the full photon production rate at NLO.

Parallel 5D: New Theoretical Developments (Chair B. Sinha) / 338

## Calculating Jet Transport Coefficients in Lattice Gauge Theory

**Author:** Abhijit Majumder<sup>1</sup>

<sup>1</sup> *Wayne State University*

**Corresponding Author:** abhijit.majumder@wayne.edu

The in-medium modification of a hard jet is reformulated to consider the process of a hard parton propagating through a finite sized QCD medium, held at a fixed high temperature and vanishing chemical potential. The process is factorized into a hard part representing the propagation and scattering of the parton, and a soft part representing the non-perturbative color field experienced by the jet in the medium. A series of such non-perturbative, soft, transport coefficients are identified, and formulated in terms of well defined operator products. These operator products are then expanded in a series of power suppressed local operators, which are then evaluated non-perturbatively using quenched lattice gauge theory.

**Parallel 5A: Hadron Thermodynamics and Chemistry (Chair R. Stock) / 98**

## Identified charged hadron production at the LHC with the ALICE experiment

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Leonardo Milano<sup>2</sup>

<sup>1</sup> *CERN, Geneva, Switzerland*

<sup>2</sup> *Universita e INFN (IT)*

**Corresponding Author:** leonardo.milano@cern.ch

Identified particle spectra are a basic observable to understand the behaviour of the matter created in high-energy heavy-ion collisions. The transverse momentum distributions of identified hadrons contain informations about the transverse expansion of the system and constrain the freeze-out properties of the matter created. The ALICE experiment has very good particle identification capabilities over a broad pT-range. Particles are identified using the energy loss signal in the Inner Tracking System and Time Projection Chamber detectors, complemented with the information from the Time of Flight detector to identify hadrons up to pT ~ 5 GeV/c. In this contribution the results for identified pions, kaons and protons in pp collisions at 0.9 and 7 TeV center-of-mass energy and heavy-ion collisions at 2.76 TeV center-of-mass energy will be presented. These results are compared with other identified particle measurements obtained by the ALICE experiment, and discussed in terms of the thermal and hydrodynamical pictures. The status of extensions of this analysis, with the study of identified particles as a function of event-by-event flow in Pb-Pb collisions and as a function of multiplicity in pp collisions, will also be discussed.

**Parallel 5C: High pt and Jets (Chair B. Cole) / 59**

## Systematic Monte-Carlo studies of dijets at the LHC and RHIC

**Author:** Christopher Coleman-Smith<sup>1</sup>

**Co-authors:** Berndt Muller<sup>2</sup>; Steffen A. Bass<sup>2</sup>

<sup>1</sup> *Duke Physics*

<sup>2</sup> *Duke University*

**Corresponding Author:** cec24@phy.duke.edu

Recent results from Pb+Pb collisions at the LHC have shown evidence of dramatic medium modification of di-jets. Although asymmetric di-jets are also seen in p+p collisions, di-jets with a large energy asymmetry are found much more often in Pb+Pb collisions. E.g., events with a 200 GeV leading jet and a 80 GeV subleading jet were frequently observed. The increase in the average energy asymmetry is believed to be caused by in-medium energy loss that arises from the interaction of the colored jet constituents with the hot deconfined matter formed in the collision. The modified di-jets provide a means to study the nature of the high energy interactions of this deconfined matter.

The observed di-jet suppression has been quantified in terms of the asymmetry  $A_j$ , the ratio of the difference between the two jet energies to their sum. It is not a priori clear that this is the observable best suited to extract information about the modification of the di-jets and the nature of their interactions with the deconfined medium. Understanding the sensitivity of di-jet observables to properties of the deconfined medium and to experimental factors is vital if they are to become a useful tool for jet tomography of hot QCD matter.

We have examined the response of the di-jet asymmetry and other di-jet observables to variations in the jet modification mechanism and to variations of the observables. We present a systematic study of di-jet suppression at RHIC and the LHC using the VNI/BMS parton cascade. VNI/BMS is a jet+medium Monte-Carlo code which provides a controllable testbed with sufficient complexity to model jet modification without confounding results with fluctuations from hydrodynamics and hadronization.

We consider the medium modification of the di-jet asymmetry  $A_j$  and the energy distribution within the di-jets (jet shape). Di-jets are examined under the modification of: the jet transport coefficient  $q_{\text{hat}}$ ; the path length of leading and sub-leading jets; cuts on the jet energy distributions; jet cone angle and the jet-medium interaction mechanism and the strong coupling constant. We find that, while the jet asymmetry and jet shape are similarly sensitive to the in-medium path length, the jet-shape is more sensitive to the nature of the interaction with the medium and the value of  $q_{\text{hat}}$  than the jet asymmetry.

## Parallel 5A: Hadron Thermodynamics and Chemistry (Chair R. Stock) / 78

### The statistical model in Pb-Pb collisions at the LHC

**Author:** Peter Braun-Munzinger<sup>1</sup>

**Co-authors:** Anton Andronic<sup>1</sup>; Johanna Stachel<sup>2</sup>; Krzysztof Redlich<sup>3</sup>

<sup>1</sup> *GSI - Helmholtzzentrum für Schwerionenforschung GmbH (DE)*

<sup>2</sup> *Ruprecht-Karls-Universität Heidelberg (DE)*

<sup>3</sup> *University of Wrocław*

**Corresponding Author:** p.braun-munzinger@gsi.de

We investigate, using the newest LHC data, the energy dependence of hadron production within the framework of the statistical hadronization model. The data are confronted with predictions based on extrapolation from lower (RHIC) energies. While the yields of hadrons made from light (u,d,s) quarks generally exhibit little change apart from the overall increase in multiplicity, a characteristic energy dependence is observed for  $J/\psi$  production. This feature is well described by statistical generation of  $J/\psi$  mesons at the phase boundary, as predicted in [1,2]. We also search for possible deviations from the statistical picture in the yields of (anti-)baryons and light (anti-)nuclei.

- [1] P. Braun-Munzinger, J. Stachel,  
Phys. Lett. B 490 (2000) 196.  
[2] A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel,  
Nucl. Phys. A 789 (2007) 334; Phys. Lett. B 652 (2007) 259.

**Parallel 5D: New Theoretical Developments (Chair B. Sinha) / 614**

## A Non-AdS/CFT bound on $\eta/s$

**Author:** Paul Romatschke<sup>1</sup>

<sup>1</sup> *FIAS Frankfurt*

**Corresponding Author:** romatschke@fias.uni-frankfurt.de

Hydrodynamics predicts long-lived sound and shear waves. Thermal fluctuations in these waves can lead to the diffusion of momentum density, contributing to the shear viscosity and other transport coefficients. Within viscous hydrodynamics in 3+1 dimensions, this leads to a positive contribution to the shear viscosity, which is finite but inversely proportional to the microscopic shear viscosity. Therefore the effective infrared viscosity is bounded from below. The contribution to the second-order transport coefficient  $\tau_\pi$  is divergent, which means that second-order relativistic viscous hydrodynamics is inconsistent below some frequency scale. We estimate the importance of each effect for the Quark-Gluon Plasma, finding them to be minor if  $\eta/s = 0.16$  but important if  $\eta/s = 0.08$ .

**Parallel 5B: QCD at Finite Temperature and Density (Chair F. Karsch) / 384**

## Transverse Momentum Broadening in Weakly Coupled Quark-Gluon Plasma

**Authors:** Francesco D'Eramo<sup>1</sup>; Hong Liu<sup>1</sup>; Krishna Rajagopal<sup>1</sup>; Mindaugas Lekaveckas<sup>1</sup>

<sup>1</sup> *MIT*

**Corresponding Author:** lekaveck@mit.edu

We calculate  $P(k_{\perp})$ , the probability distribution for an energetic parton propagating for a distance  $L$  through a medium to pick up transverse momentum  $k_{\perp}$ , for a medium consisting of weakly coupled quark-gluon plasma. We use full or HTL self-energies in appropriate regimes, resumming each in order to find the leading large- $L$  behavior. We estimate the jet quenching parameter and compare to results in the literature. And, we compare  $P(k_{\perp})$  at weak coupling to the  $P(k_{\perp})$  expected from holographic calculations that presume the quark-gluon plasma to be strongly coupled at all length scales. We find that the weak coupling and strong coupling results need not differ greatly at modest  $k_{\perp}$ , but we find that  $P(k_{\perp})$  must be parametrically larger in a weakly coupled plasma than in a strongly coupled plasma at large enough  $k_{\perp}$ . By looking for rare large-angle deflections of the jet resulting from a parton produced initially back-to-back with a hard photon, experimentalists can find the weakly coupled quark and gluon short-distance constituents of the strongly coupled liquid quark-gluon plasma, much as Rutherford found the nuclei within atoms or Friedman, Kendall and Taylor found the quark within nucleons.



**Parallel 5C: High pt and Jets (Chair B. Cole) / 401****Production of Charged Pions, Kaons, and Protons in 2.76 TeV Pb-Pb Collisions at high  $p_t$  measured with the ALICE Experiment.****Author:** Collaboration ALICE<sup>1</sup>**Co-author:** Antonio Ortiz Velasquez<sup>2</sup><sup>1</sup> CERN, Geneva, Switzerland<sup>2</sup> Lund University (SE)**Corresponding Author:** antonio.ortiz.velasquez@cern.ch

The main tracking detector in the central barrel ( $|\eta| < 1$ ) of the ALICE experiment is the Time Projection Chamber. In addition to charged particle tracking it provides particle identification (PID) through the measurement of the specific energy loss,  $dE/dx$ . At low momentum ( $p < 1$  GeV/c), pions, kaons, and protons can be cleanly separated. Thanks to the relativistic rise of the  $dE/dx$ , the relative yield of pions, kaons, and protons can also be extracted statistically at higher momenta,  $p > 3$  GeV/c.

In this talk, spectra for charged pions, kaons, and protons from pp collisions at  $\sqrt{s} = 2.76$  TeV and Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV for  $3 < p_t < 20$  GeV/c will be presented, and the nuclear modification factor  $R_{AA}$  will be derived. The evolution of  $R_{AA}$  with collision centrality and transverse momentum will be discussed, and compared to unidentified charged particles,  $K_s^0$ ,  $\Lambda$ , and theoretical predictions.

**Parallel 5C: High pt and Jets (Chair B. Cole) / 492****Charged particle spectra and nuclear modification factor in lead-lead collisions at 2.76 TeV with the ATLAS detector at the LHC.****Author:** Zdenek ATLAS Collaboration<sup>1</sup><sup>1</sup> Charles University Prague**Corresponding Authors:** petr.balek@cern.ch, zdenek.dolezal@cern.ch

The measurement of charged particle spectra in heavy ion collisions is a direct way to study properties of hot and dense matter created in these interactions. The centrality dependence of the spectral shape is an important tool to understand the energy loss mechanism. The ATLAS detector at the LHC accumulated 150 $\mu$ b-1 of lead-lead data at 2.76 TeV per nucleon-nucleon pair. Due to the excellent capabilities of the ATLAS detector, and its stable operation in 2010 and 2011 heavy ion physics runs, these data allow measurements of the charged particle spectra and their ratios in different centrality bins over a wide range of transverse momenta and pseudorapidity.

**Parallel 5B: QCD at Finite Temperature and Density (Chair F. Karsch) / 279****Electric and baryonic charge fluctuations from lattice QCD****Author:** Christian Schmidt<sup>1</sup><sup>1</sup> Universitaet Bielefeld

**Corresponding Author:** schmidt@physik.uni-bielefeld.de

We calculate electric and baryonic charge fluctuations on the lattice. Results have been obtained with the highly improved staggered quark action (HISQ) and almost physical quark masses on lattices with temporal extent of  $N_{\text{tau}}=6,8,12$ . Higher cumulants of the net-charge distributions are increasingly dominated by a universal scaling behavior, which is arising due to a critical point of QCD in the chiral limit. Considering cumulants up to the 6th order, we observe that they generically behave as expected from universal scaling laws, which is quite different from cumulants calculated within the hadron resonance gas model. Taking ratios of these cumulants, we obtain volume independent results that can be directly compared to the experimental measurements. Such a comparison will unambiguously relate the QCD transition temperature that has been determined on the lattice with, the freeze out temperature of the heavy ion collision at LHC and the 200 GeV RHIC run.

**Parallel 5D: New Theoretical Developments (Chair B. Sinha) / 537**

## Coupling dependence of jet quenching in hot strongly-coupled gauge theories

**Authors:** Diana Vaman<sup>1</sup>; Peter Arnold<sup>1</sup>

<sup>1</sup> *University of Virginia*

**Corresponding Author:** parnold@virginia.edu

Previous top-down studies of jet stopping in strongly-coupled QCD-like plasmas with gravity duals have been in the infinite 't Hooft coupling limit  $\lambda \rightarrow \infty$ . They have found that, though a wide range of jet stopping distances are possible depending on initial conditions, the maximum jet stopping distance  $\ell_{\text{max}}$  scales with energy as  $E^{1/3}$  at large energy. But it has always been unclear whether the large-coupling and high-energy limits commute. We use the string  $\alpha'$  expansion in AdS-CFT to study the corrections to the  $\lambda=\infty$  result in powers of  $1/\lambda$  by assessing the effects of all higher-derivative corrections to the supergravity action for the gravity dual. We find that sometimes  $\lambda = \infty$  results can be trusted for jet stopping, but other times the expansion in  $1/\lambda$  breaks down.

**Parallel 5A: Hadron Thermodynamics and Chemistry (Chair R. Stock) / 188**

## Strange hadrons and resonances in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with ALICE experiment at LHC

**Author:** Collaboration ALICE<sup>1</sup>

<sup>1</sup> *CERN, Geneva, Switzerland*

**Corresponding Author:** subhash.singha@cern.ch

The ALICE experiment at the LHC has measured the production of strange hadrons and resonances in Pb-Pb and pp collisions at unprecedentedly high beam energies. The study of strange hadrons and resonances helps us to understand the medium properties and its evolution at different stages. We will present the pT spectra and yields at mid-rapidity for strange hadrons ( $\Lambda$ ,  $\Lambda_b$ ,  $\Xi$ ,  $\Omega$ , their anti-particles and  $K^0_S$ ) and resonances ( $\Lambda(1520)$  and  $K^0$ ) for different collision centrality. The results from Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV will be presented and compared to corresponding results from pp collisions and lower energy measurements. Baryon to meson ratios, resonance to non-resonance particle ratios relative to pp collisions will be shown as a function of collision centrality and compared with the results at low energies. Finally, the spectral shapes will also be discussed in terms of hydrodynamical-inspired models.

**Parallel 5B: QCD at Finite Temperature and Density (Chair F. Karsch) / 244****Lattice QCD thermodynamics in the presence of the charm quark**

**Authors:** Claudia Ratti<sup>1</sup>; Kalman Szabo<sup>2</sup>; Sandor Katz<sup>None</sup>; Stefan Krieg<sup>2</sup>; Szabolcs Borsanyi<sup>2</sup>; Zoltan Fodor<sup>3</sup>

<sup>1</sup> *Torino University*

<sup>2</sup> *Wuppertal University*

<sup>3</sup> *BUW*

**Corresponding Author:** ratticlaudia@yahoo.it

We present our estimate for the charm quark's contribution to the equation of state and to the fluctuations of conserved charges. Our results are based on simulations with dynamical charm at physical quark masses. We also address the question, to what extent staggered simulations are reliable. We give comparisons with the Wilson formulation as well as with results using dynamical overlap fermions.

**Parallel 5C: High  $p_T$  and Jets (Chair B. Cole) / 249****R<sub>CP</sub> and R<sub>AA</sub> Measurements of Identified and Unidentified Charged Particles at High  $p_T$  in Au+Au Collisions at 7.7, 11.5, 19.6, 27, 39, and 62.4 GeV in STAR**

**Author:** Evan Sangaline<sup>1</sup>

**Co-author:** Stephen Horvat<sup>2</sup>

<sup>1</sup> *UC Davis*

<sup>2</sup> *Y*

**Corresponding Author:** esangaline@gmail.com

The suppression of high  $p_T$  hadrons in 200 GeV Au+Au collisions at RHIC has been seen as a signature for a partonic medium being formed. The evolution of this key QGP signature is a powerful tool for studying the QCD phase structure in the RHIC Beam Energy Scan (BES). In this talk, we will present measurements of identified  $\pi^\pm$ ,  $K^\pm$ , and  $p(\bar{p})$  and unidentified charged particles in Au+Au collisions at  $\sqrt{s_{NN}} = 7.7, 11.5, 19.6, 27, 39,$  and  $62.4$  GeV. We will report nuclear modification factors  $R_{CP}$  and  $R_{AA}$  where published p+p references are available. These results offer insight into the  $\sqrt{s_{NN}}$  dependence of high  $p_T$  suppression in nuclear collisions.

**Parallel 5D: New Theoretical Developments (Chair B. Sinha) / 172****Shining a Gluon Beam through Quark-Gluon Plasma**

**Author:** Krishna Rajagopal<sup>1</sup>

**Co-authors:** Paul Chesler<sup>1</sup>; Ying-Yu Ho<sup>1</sup>

<sup>1</sup> *MIT*

**Corresponding Author:** krishna@mit.edu

A holographic calculation of the quenching of a beam of gluons with typical momenta  $q$  shining through strongly coupled quark-gluon plasma shows that such a beam is attenuated rapidly over a distance of order  $q^{-1/3} (\pi T)^{-4/3}$  as it propagates at the speed of light, shedding trailing sound waves with momenta of order  $(\pi T)$ . At larger and larger  $q$ , the trailing sound wave becomes less and less prominent. The outward-going beam of gluon radiation itself shows no tendency to spread in angle or to shift toward larger wavelengths, even as it is completely attenuated. In this regard, the behavior of the beam of gluons that we analyze is reminiscent of the behavior of jets produced in heavy ion collisions at the LHC that lose a significant fraction of their energy without appreciable change in their angular distribution or their momentum distribution as they plow through the strongly coupled quark-gluon plasma produced in these collisions. However, we know that quark-gluon plasma must be weakly coupled at short enough distance scales. This means that even if jet quenching typically occurs as in a strongly coupled plasma, there should be rare events in which a hard parton is scattered by a larger angle, picking up significant transverse momentum.

**Parallel 5A: Hadron Thermodynamics and Chemistry (Chair R. Stock) / 266**

## Beam Energy Dependence of Strange Hadron Production from STAR at RHIC

**Author:** Xiaoping Zhang<sup>1</sup>

<sup>1</sup> *Tsinghua University*

**Corresponding Author:** xpzhangnju@gmail.com

Strange hadron production is sensitive to parton dynamics in nucleus-nucleus collisions. In particular, the strange quark production rate and its subsequent evolution in the dense partonic medium depend on the beam energy and the net baryon density. We will present STAR measurements of  $K_s^0$ ,  $K^\pm$ ,  $\phi$ ,  $\Lambda$ ,  $\Xi$ , and  $\Omega$  at mid-rapidity from Au+Au collisions at  $\sqrt{s_{NN}} = 7.7, 11.5, 19.6, 27,$  and  $39$  GeV from the RHIC Beam Energy Scan (BES) program. We will report the strangeness enhancement through the ratios  $K/\pi$ ,  $\Lambda/\pi$ ,  $\phi/\pi$  and  $\Xi/\pi$ , and strangeness equilibration as a function of beam energy at RHIC. Nuclear modification factors and baryon to meson ratios will be discussed to understand recombination and parton energy loss mechanisms. Further, the particle ratios will be compared to ultra relativistic quantum molecular dynamics, hadron string dynamics, statistical hadronization models and SPS measurements. Implications on partonic vs. hadronic dynamics at low beam energies will also be discussed.

**Parallel 5B: QCD at Finite Temperature and Density (Chair F. Karsch) / 275**

## Freeze-out conditions from lattice QCD

**Author:** Swagato Mukherjee<sup>1</sup>

<sup>1</sup> *Brookhaven National Laboratory*

**Corresponding Author:** swagato@bnl.gov

Traditionally the freeze-out conditions in the heavy-ion collision experiments are obtained by comparing the experimentally measured hadron yields with that from the statistical hadron resonance gas model. In this talk we will present how the freeze-out chemical potentials and the freeze-out temperature can be obtained in a model independent way from ab-initio lattice QCD calculations by utilizing observables related to conserved charge fluctuations. We will show that the freeze-out strangeness and electric charge chemical potentials can be fixed by imposing strangeness neutrality and isospin asymmetry constraints in the lattice QCD calculations. Further, we will present how the

freeze-out baryon chemical potential and the freeze-out temperature can be determined by comparing lattice QCD results for various ratios of conserved charge susceptibilities with the corresponding ratios of moments of conserve charge fluctuations that are currently being measured by the STAR experiment. A comparison of the freeze-out parameters obtained from the lattice QCD calculations with that from the hadron resonance gas model will also be presented.

**Parallel 5C: High pt and Jets (Chair B. Cole) / 330**

## **Strange hadrons at intermediate and high transverse momentum in p+p, d+Au, Cu+Cu and Au+Au collisions at 200 GeV measured with PHENIX detector**

**Author:** Prashant Shukla<sup>1</sup>

<sup>1</sup> *Bhabha Atomic Research Centre (IN)*

**Corresponding Author:** prashant.shukla@cern.ch

The hadrons containing strange quark(s) are among the most interesting probes of the hot and dense matter produced in heavy ion collisions at Relativistic Heavy Ion Collider (RHIC). While p+p collisions are used as a baseline for comparison with heavier collision systems and provide a cross check for pQCD calculations, d+Au collisions are used to study cold nuclear matter effects for mesons and baryons and their dependence on particle mass and flavor. Heavy ion collisions provide an insight into effects of quark recombination and jet quenching. Experimental measurements reveal if strange particles are suppressed at high transverse momentum ( $p_T$ ) similarly to light hadrons and if the quark recombination mechanisms boosts strange hadron production at intermediate  $p_T$ . The PHENIX experiment provides excellent capabilities to measure particles with strangeness content over a wide  $p_T$  range using a combination of different analysis techniques.

In this talk we present the latest PHENIX result on production of  $K^\pm$ ,  $K_s$ ,  $K^*$ ,  $\phi$  and  $\Lambda$  which considerably extend the  $p_T$  range for p+p, d+Au, Cu+Cu and Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV. The nuclear modification factors are obtained for d+Au and heavy ion collisions at different centralities. These systematic study advance the understanding of the strange meson and baryon production and their difference from light hadrons.

**Parallel 5A: Hadron Thermodynamics and Chemistry (Chair R. Stock) / 191**

## **(Anti) matter and hyper-matter production at the LHC with the ALICE experiment**

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Benjamin Doenigus<sup>2</sup>

<sup>1</sup> *CERN, Geneva, Switzerland*

<sup>2</sup> *GSI - Helmholtzzentrum für Schwerionenforschung GmbH (DE)*

**Corresponding Author:** benjamin.doenigus@cern.ch

The excellent particle identification capabilities of the ALICE experiment allow the studies of (anti) matter and hyper-matter production. (Anti) deuterons, tritons,  $^3\text{He}$  and  $^4\text{He}$  as well as the corresponding antinuclei can be cleanly identified based on their specific energy loss in the Time Projection Chamber and velocity information in the Time-Of-Flight detector. The (anti) hyper-triton signal can be extracted from the study of its mesonic decay ( $^3_\Lambda\text{H} \rightarrow ^3\text{He} + \text{pion}$ ) via the topological identification of secondary vertices.

The ( $^3\text{He}$ , pion) invariant mass spectrum will be shown, and the measurement of production yield will be provided. Transverse momentum (pt) spectra of (anti) nuclei along with their production

yield and mean  $p_T$  will be presented.

In addition to this, searches for even lighter hyper-matter systems, i.e.  $\Lambda$ - $\Lambda$  and  $\Lambda$ - $n$  bound states will be discussed. The results will also be compared with the expectations from the thermal and coalescence models.

**Parallel 5D: New Theoretical Developments (Chair B. Sinha) / 590**

## Color decoherence of jets in Heavy Ion Collisions

**Authors:** Carlos A. Salgado<sup>1</sup>; Konrad Tywoniuk<sup>2</sup>; Yacine Mehtar-Tani<sup>3</sup>

<sup>1</sup> *University of Santiago de Compostela*

<sup>2</sup> *Lund University*

<sup>3</sup> *IPhT-Saclay*

The recent jet measurements at RHIC and the LHC have challenged the heavy-ion community to a better understanding of jet fragmentation in the presence of the Quark-Gluon-Plasma (QGP).

Jet fragmentation in vacuum is well described by perturbative QCD and is characterized by color coherence effects that lead to the angular ordering of successive branchings along the jet. To investigate the alteration of color coherence in jets in the QGP we study the radiation pattern of a color-correlated quark-anti-quark antenna which is in fact the building block of jet evolution in vacuum.

We show that in a dense medium the onset of coherence is governed by the hardest scale induced by the presence of the medium. In a medium of length  $L$  and transport coefficient  $\hat{q}$  this can either be the typical transverse momentum broadening of the gluon in the medium,  $\sqrt{\hat{q}L}$ , or the inverse of the size of the antenna as probed by the medium, namely  $r_{\perp}^{-1} = (\theta_{qq}L)^{-1}$ , where  $\theta_{qq}$  is the opening angle of the antenna. Therefore, for  $k_{\perp} < \max(\sqrt{\hat{q}L}, r_{\perp}^{-1})$  we obtain complete decoherence of the antenna; for larger momenta color coherence is restored.

We expect the transition from color decoherence to coherence to play an important role in in-medium jet fragmentation.

**Parallel 5C: High  $p_T$  and Jets (Chair B. Cole) / 348**

## A Running Coupling Explanation of the Surprisingly Transparency of the QGP at LHC

**Author:** Alessandro Buzzatti<sup>1</sup>

**Co-author:** Miklos Gyulassy<sup>1</sup>

<sup>1</sup> *Columbia University*

**Corresponding Author:** buzzatti@phys.columbia.edu

The CUJET1.0 Monte Carlo Jet Energy loss model is applied to predict the jet flavor, centrality and density dependence of the nuclear modification factor  $R_{AA}$  and the elliptic flow  $v_2$  at RHIC and LHC. Running coupling effects due to combined  $x$ ,  $k_{\perp}$  and  $q_{\perp}$  evolution are included for the first time in the dynamical DGLV opacity expansion framework and are shown to provide a natural dynamical QCD tomographic solution to the surprising transparency<sup>1</sup> of the quark gluon plasma produced at LHC as suggested by  $p_T > 10$  GeV  $R_{AA}$  data from ALICE, ATLAS, and CMS.

(Ref: 1: W.H.Horowitz et al, NPA872(2011)265, A.Buzzatti et al, PRL108(2012)022301, B.Betz et al arXiv:1201.0281 [nucl-th])

Parallel 5B: QCD at Finite Temperature and Density (Chair F. Karsch) / 393

## The QCD Equation of State with 2+1 flavors of Highly Improved Staggered Quarks

**Author:** Alexei Bazavov<sup>1</sup>

<sup>1</sup> B

**Corresponding Author:** obazavov@quark.phy.bnl.gov

The physics of the Quark-Gluon Plasma (QGP), currently explored experimentally in heavy-ion collisions, is non-perturbative for temperatures below approximately 1 GeV. One of the fundamental properties of the QGP, the Equation of State, is a subject of extensive studies in lattice QCD. The lattice QCD Equation of State is now an essential requirement for the correct hydrodynamic modeling of heavy-ion collisions. Lattice QCD provides first-principle calculations with physical results recovered in the continuum limit. Thus, understanding of the discretization effects is of great importance. I report on recent progress by the HotQCD collaboration in studying the 2+1 flavor Equation of State on lattices with the temporal extent  $N_t=6, 8, 10$  and  $12$  in Highly Improved Staggered Quarks (HISQ) discretization scheme. In the low-temperature phase, where the Hadron Resonance Gas (HRG) model is expected to be a good approximation, a comparison of HRG and lattice results is also presented. Comparisons with Equation of State calculations with different fermion actions will also be discussed.

Parallel 5A: Hadron Thermodynamics and Chemistry (Chair R. Stock) / 165

## Beam Energy Dependence of Hypertriton Production and Lifetime Measurement at STAR

**Author:** Yuhui Zhu<sup>1</sup>

<sup>1</sup> Shanghai Institute of Applied Physics

**Corresponding Author:** yhzhu.sinap@gmail.com

The hyperon-nucleon(Y-N) interaction is of great physical interest because it introduces a new quantum number strangeness in nuclear matter. It is predicted to be the decisive interaction in some high-density matter systems, such as neutron stars [1]. RHIC, the Relativistic Heavy Ion Collider, provides an ideal laboratory to study Y-N interaction because hyperons and nucleons are abundantly produced at high energy nucleus-nucleus collisions.

The lifetime and decay modes of the hypertriton, the lightest hypernucleus, which consists of a proton, a neutron and the lightest hyperon Lambda, and the antimatter hypertriton discovered at RHIC[2], provide valuable insights into the Y-N interaction.

The strangeness population factor  $S_3$ , defined as  $\frac{\Lambda^3 H / {}^3He}{\Lambda/p}$ , is a good representation of the local correlation between baryon number and strangeness[2]. It is predicted that  $S_3$  has a different behavior in QGP and pure hadron gas[3,4] thus can be used as a tool to distinguish Quark-Gluon Plasma (QGP) from a pure hadronic phase.

The RHIC beam energy scan program in 2010-2011 allowed STAR to collect data from Au+Au collisions over a broad range of energies. This provides an opportunity to study the beam energy dependence of  $S_3$ . In addition, due to the beam energy independence of our lifetime measurement method, with increased statistics of present datasets, an improved result of lifetime measurement of hypertriton can be obtained.

In this talk, the hypertriton analysis results for Au+Au collisions at  $\sqrt{s_{NN}} = 7.7, 11.5, 19.6, 27, 39$  and  $200$  GeV will be presented. With the excellent particle identification of Time Projection Chamber, we are able to reconstruct  ${}^3_{\Lambda}H({}^3_{\Lambda}\bar{H})$  via its two-body decay channel to  ${}^3He$  and  $\pi^-$  ( ${}^3\bar{H}$  and  $\pi^+$ ).

The combined  ${}^3_{\Lambda}H$  plus  ${}^3_{\Lambda}\bar{H}$  raw yield is about 600 and its significance can reach  $9.5\sigma$ . With this increased statistics, our lifetime measurement will be presented and the beam energy dependence of S3 will also be discussed.

- [1]J. M. Lattimer, M. Prakash, Science **{\bf304}**, 536 (2004)
- [2]B. I. Abelev *{it et al.}*(STAR Collaboration), Science **{\bf328}**, 58 (2010)
- [3]S. Zhang *{it et al.}*, Phys. Lett. B. **{\bf 684}**, 224 (2010)
- [4]J. Steinheimer *{it et al.}*, arXiv:1203.2547v1

#### Parallel 5D: New Theoretical Developments (Chair B. Sinha) / 49

### Temperature dependence of the shear viscosity in the semi-QGP

**Author:** Robert Pisarski<sup>1</sup>

**Co-author:** Vladimir V. Skokov<sup>1</sup>

<sup>1</sup> *Brookhaven National Lab.*

**Corresponding Author:** pisarski@bnl.gov

An effective theory for the region near the critical temperature, the “semi”-QGP, has been developed. In QCD, this is dominated by the partial ionization of color, up to temperatures about 300 MeV. Using the effective model, the temperature dependence for the ratio of the shear viscosity, to the entropy, is computed. This predicts a sharp increase in this ratio between  $\sim 160$  MeV and  $\sim 300$  MeV.

#### Poster Session Reception / 464

### J/Psi suppression in high multiplicity proton-proton collisions at LHC energies

**Author:** Thomas Lang<sup>None</sup>

**Co-author:** Marcus Bleicher<sup>1</sup>

<sup>1</sup> *Uni Frankfurt*

**Corresponding Author:** lang@th.physik.uni-frankfurt.de

We study charmonium physics in heavy-ion collisions within the framework of the non-equilibrium transport model UrQMD at SPS, RHIC and LHC energies. For pp collisions at LHC energies we find a considerable J/Psi suppression in dependence of the particle multiplicity.

#### Poster Session Reception / 367

### The Effect of $3 \leftrightarrow 2$ Rates on Thermalization in Covariant Transport

**Author:** Dustin Hemphill<sup>1</sup>



**Co-author:** Denes Molnar

<sup>1</sup> *Purdue University*

**Corresponding Author:** molnar@physics.purdue.edu

We employ a grid based stochastic technique to solve the on-shell Boltzmann transport equation including inelastic  $3 \leftrightarrow 2$  processes. The case of an interacting massless partonic gas in a longitudinally expanding Bjorken geometry is considered. The numerical accuracy of the algorithm is first rigorously established from comparisons to both static box calculations and earlier results from the MPC cascade with  $2 \leftrightarrow 2$  interactions. We then study the effect of inelastic  $3 \leftrightarrow 2$  collision rates and particle production on thermalization, chemical equilibration, and entropy production in the partonic system.

**Poster Session Reception / 356**

## **A Technique for Charm and Beauty Separation via DCA Unfolding**

**Author:** Michael McCumber<sup>1</sup>

<sup>1</sup> *University of Colorado*

The PHENIX experiment at the Relativistic Heavy Ion Collider recently took data in p+p and Au+Au collisions with a new silicon vertex detector (VTX). This upgrade detector is capable of measuring the off-vertex decay of heavy flavor decay electrons via distance of closest approach (DCA). The resulting measured DCA distributions will be a convolution of the parent meson momenta, decay lifetimes, and yields, combined with detector irresolution and backgrounds. We will describe an algorithm to unfold the full set of DCA distributions as a function of  $p_{\perp}\{T\}$ , thereby allowing improved extraction of the charm and beauty yields. The progress for applying this technique to the heavy ion collision VTX data set will also be shown.

**Poster Session Reception / 44**

## **Fourth order corrections to the MV model, multiplicity distributions and KNO scaling**

**Author:** Elena Petreska<sup>1</sup>

<sup>1</sup> *Graduate Center/Baruch College CUNY*

**Corresponding Author:** epetreska@gc.cuny.edu

A scaling law for the multiplicity distribution in high-energy hadronic collisions has been proposed by Koba, Nielsen, and Olesen (KNO). Experiments at the LHC observed that multiplicities in the central region of proton-proton collisions follow a negative binomial distribution and that they do exhibit KNO scaling. The negative binomial distribution has been theoretically reproduced in the Color Glass Condensate (CGC) formalism with a Gaussian (McLerran-Venugopalan) action. We derive corrections to the MV model up to fourth order in the density of color charges ( $\rho^4$ ) and investigate their implication on the multiplicity distribution and on KNO scaling. We find that KNO scaling constrains the deviation of the small-x effective action from a Gaussian.

**Poster Session Reception / 65**

## Critical fluctuations of the higher moments of order parameter and energy from 3D-Ising, O(2) and O(4) models

**Author:** Yuanfang Wu<sup>1</sup>

**Co-author:** Xue Pan<sup>2</sup>

<sup>1</sup> *Institute of Particle Physics, CCNU, Wuhan, China*

<sup>2</sup> *Institute of Particle Physics, CCNU, Wuhan China*

**Corresponding Author:** wuyf@phy.ccnu.edu.cn

Higher moments of net-baryon are suggested to be sensitive probe of QCD critical end point [1] in relativistic heavy ion collisions. Their critical fluctuations are highly interesting and instructive for the exploration of QCD phase diagram from both theoretical and experimental sides.

According to the universality of critical behavior, the QCD critical end point, and the chiral phase transition in two-flavor QCD are argued to be the same universality class of 3 dimensional Ising model [2], and O(2), or O(4) model[3], respectively. The generic structures of net-baryon fluctuations at QCD critical end point and chiral phase transition in the chiral limit with vanishing baryon chemical potential can be discussed by the order-parameter fluctuations in Ising model and the energy fluctuations in O(2), or O(4) model [4,5]. So in the present work, the higher moments of order parameter and energy from 3D-Ising, O(2) and O(4) models near the critical temperature at finite size are systematically studied, and compared with those obtained from effective models, and Lattice QCD calculations.

It is found that the generic structures of order-parameter fluctuations in 3D-Ising, O(2) and O(4) models are similar. So do energy fluctuations. On the other hand, the singular structures of order parameter fluctuations appear at lower moments, e.g., the oscillation structures of 4th moment of order parameter, which may reflect the generic structure of 4th order moment of baryon number in the vicinity of critical end point, are similar to the 3rd moments of energy, which corresponding to the 6th moment of net-baryon number at chiral phase transition in the chiral limit with vanishing baryon chemical potential. This means that even higher moments, such as 6th moments of net-baryon number, are necessary in probing the chiral phase transition temperature, the same as what suggested in ref. [5].

The generic singular structures of order-parameter fluctuations in 3D-Ising and energy fluctuations in O(2), or O(4) models are qualitatively consistent with corresponding estimations of Nambu-Jona-Lasinio [6], Linear Sigma model [7], Polyakov-Nambu-Jona-Lasinio [8], Polyakov Quark Meson models [9], and current lattice QCD calculations [10].

[1] M.A. Stephanov, Phys. Rev. Lett 102, 032301 (2009)

[2] R.D. Pisarski and F. Wilczek, Phys. Rev. D 29, 338(1984); F. Wilczek, Int. J. Mod. Phys. A 7, 3911(1992), A.M. Halasz, A.D. Jackson, R.E. Shrock, M.A. Stephanov and J.J.M. Verbaarschot, Phys. Rev. D 58, 096007(1998);

[3] R.D. Pisarski and F. Wilczek, Phys. Rev. D 29, 338(1984);F. Wilczek, Int. J. Mod. Phys. A 7, 3911(1992); K.Rajagopal and F. Wilczek, Nucl. Phys. B 399, 395(1993)

[4] J. J. Rchr and N. D. Mcrmin, Phys. Rev. A 8, 472(1973); Nigel B Wilding, J. Phys.: Condens. Matter 9, 585(1997); Chiho Nonaka and Masayuki Asakawa, Phys. Rev. C 71, 044904 (2005)

[5] B. Friman, F. Karsch, K. Redlich and V. Skokov, arXiv:1103.3511(2011)

[6] Masayuki Asakawa, Shinji Ejiri, and Masakiyo Kitazawa, Rev. Lett 103, 262301(2009)

[7] M.A. Stephanov, Phys. Rev. Lett 107, 052301(2011)

[8] Wei-jie Fu, Yu-xin Liu and Yue-Liang Wu, phys. Rev. D 81, 014028 (2010)

[9] V. Skokov et al., Phys. Rev. D 82, 034029 (2010)

[10] M. Cheng et al., Phys. Rev. D 79, 074505 (2009)

**Poster Session Reception / 57**

## Directed flow at midrapidity at the LHC

**Author:** Ekaterina Retinskaya<sup>1</sup>

**Co-authors:** Jean-Yves Ollitrault<sup>2</sup>; Matthew Luzum<sup>1</sup>

<sup>1</sup> *IPhT Saclay*<sup>2</sup> *CNRS***Corresponding Author:** ekaterina.retinskaya@cea.fr

We present the first extraction of the recently-proposed rapidity-even directed flow observable  $v_1$ , obtained from an analysis of published two-particle correlation data from the ALICE Collaboration. An accounting of the correlation due to the conservation of transverse momentum restores the factorization seen in all other Fourier harmonics and thus indicates that the remaining correlation gives a reliable measurement of directed flow. We also present results from the first viscous hydrodynamic calculation of directed flow, and show that it is less sensitive to viscosity than higher harmonics. This allows for a direct extraction of the dipole asymmetry of the initial state, providing a strict constraint on the non-equilibrium dynamics of the early-time system.  
(Reference: arXiv:1203.0931)

**Poster Session Reception / 592**

## Speed of sound and dynamics of relativistic heavy ion collisions

**Authors:** Rajarshi Ray<sup>1</sup>; Ramaprasad Adak<sup>2</sup>; Sanjay Ghosh<sup>2</sup>; Subhasis Samanta<sup>2</sup>; Supriya Das<sup>2</sup><sup>1</sup> *B*<sup>2</sup> *Bose Institute***Corresponding Author:** supriya@bosemain.boseinst.ac.in

Collective flow is an essential component in describing the dynamics of relativistic heavy ion collisions. The flow characteristics are intimately related to the equation of state of the thermally equilibrated matter created in these collisions through the speed of sound. Using either the Bjorken or Landau hydrodynamics or a combination thereof it is possible to relate the particle yields to the speed of sound. Here we study the flow properties using the equation of state from an effective model and discuss the possible distinctive signatures at low densities and high temperature relevant for LHC and at high densities and low temperatures relevant for FAIR. The difference in characteristics of these two scenarios may help us in identifying the region around the critical end point.

**Poster Session Reception / 509**

## Luminosity determination in pp and Pb-Pb collisions at the LHC with the ALICE detector

**Author:** Collaboration ALICE<sup>1</sup>**Co-author:** Martino Gagliardi<sup>2</sup><sup>1</sup> *CERN Geneva, Switzerland*<sup>2</sup> *Universita e INFN (IT)***Corresponding Authors:** emilia.leogrande@cern.ch, vercelli@to.infn.it

Luminosity is an essential ingredient for the measurement of the cross section of physical processes. Luminosity determination in ALICE at the LHC is based on the visible cross sections measured in dedicated calibration experiments (van der Meer scans).

Besides serving as reference for the determination of integrated luminosities, the cross sections measured in van der Meer scans can, with suitable extrapolation, provide direct access to physical quantities such as the inelastic interaction cross section.

Van der Meer scans have been performed at the LHC in pp collisions at  $\sqrt{s} = 2.76, 7$  and  $8$  TeV and in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV. A detailed description of the ALICE setup and analysis will be given; the measurement uncertainties will be discussed and compared to the requirements of the ALICE physics program.

**Poster Session Reception / 90**

## Density fluctuations at the QCD phase transition

**Author:** Christoph Herold<sup>None</sup>

**Co-author:** Marcus Bleicher<sup>1</sup>

<sup>1</sup> *Uni Frankfurt*

We study the nonequilibrium dynamics of a quark fluid coupled to a sigma field and a Polyakov loop near the QCD phase boundary. As the system evolves through the first order transition line, baryon density fluctuations are enhanced in comparison with an evolution through the crossover or the critical point.

**Poster Session Reception / 450**

## Measurement of $\omega \rightarrow 3\pi$ in pp collision at 7TeV with ALICE

**Author:** Collaboration ALICE<sup>1</sup>

**Co-author:** Satoshi Yano<sup>2</sup>

<sup>1</sup> *CERN, Geneva, Switzerland*

<sup>2</sup> *Hiroshima University (JP)*

**Corresponding Authors:** [satoshi.yano@cern.ch](mailto:satoshi.yano@cern.ch), [jochen@thaeder.de](mailto:jochen@thaeder.de)

The  $\omega$  meson is a promising probe to investigate the properties of the QGP. It is well known that the yield of high- $p_t$  particles is suppressed in nucleus-nucleus collisions relative to that in pp collisions. The effect is attributed to the energy loss of the energetic parent partons traversing the created medium.

Since  $\pi^0$  and  $\omega$  mesons have the same quark content (u and d), the comparison of the suppression between  $\pi$  and  $\omega$  can provide information whether the energy loss occurs at the parton level or not.

The ALICE detector covers a wide central region ( $|\eta| < 0.9$ ) to reconstruct charged particles and has two electro-magnetic calorimeters with good energy resolution. The  $\omega$  meson is reconstructed in the  $\pi^0\pi^+\pi^-$  channel in pp collisions at  $\sqrt{s} = 7$  TeV over a wide  $p_t$  range. This is facilitated by a high-photon energy trigger. We discuss the trigger performance and cut optimization and present the latest results of the analysis.

**Poster Session Reception / 141**

## Observation of a difference in $v_2$ between particles and anti-particles in Au+Au collisions at $\sqrt{s_{NN}} = 7.7-62.4$ GeV with STAR

**Author:** Alexander Schmah<sup>1</sup>

<sup>1</sup> *Lawrence Berkeley National Lab*

**Corresponding Author:** aschmah@lbl.gov

The RHIC Beam Energy Scan covers a wide range in the QCD phase diagram temperature vs. baryon chemical potential. A phase transition between the Quark Gluon Plasma and the hadron gas phase is expected in this region of the QCD phase diagram. The elliptic flow  $v_2$  is one of the observables which is sensitive to the pressure gradients in the initial stage of heavy-ion collisions. Hence it can provide important information about the properties of the fireball in the early stage of heavy ion collisions.

Elliptic flow measurements at midrapidity from Au+Au collisions at  $\sqrt{s_{NN}} = 7.7, 11.5, 19.6, 27, 39$  and  $62.4$  GeV for identified hadrons ( $\pi^\pm, K^\pm, K_s^0, p, \bar{p}, \phi, \Lambda, \bar{\Lambda}, \Xi^-, \Xi^+, \Omega^-, \bar{\Omega}^+$ ) are presented. We observe a significant difference in  $v_2$  between particles and corresponding anti-particles at the lowest energies of the beam energy scan. Baryons show a larger difference compared to mesons. The centrality, particle species and energy dependence of the difference will be presented. Furthermore we compare the data to several models and discuss their implications.

**Poster Session Reception / 341**

## Thermal Photons in Heavy Ion Collisions at RHIC

**Author:** Richard Petti<sup>1</sup>

<sup>1</sup> *S*

**Corresponding Author:** rpetti@bnl.gov

The hot and dense fireball produced in high energy heavy ion collisions, such as that at RHIC, exhibits complicated dynamics and time evolution. Thermal photons have a negligible cross-section with the medium and so pass through unmodified, thus measuring their properties gives access to the entire time evolution of the fireball. Thermal photons are expected to be observable at low momentum. They compete in yield with photons from hadron decays and, at high momentum (above roughly 4 GeV), direct photons that result from initial hard scatterings of partons in the colliding nuclei. PHENIX has measured the yield of direct photons in Au+Au collisions, as well as the baseline measurements in p+p and d+Au. Recently PHENIX has also measured elliptic flow of direct photons. The latest results on low momentum direct photons will be discussed, including measurements of real photons using photon conversions and a novel method to reduce systematic uncertainties.

**Poster Session Reception / 517**

## Perturbative calculation in 1+1dimensional relativistic viscous hydrodynamics

**Author:** Kyohei Fukuda<sup>1</sup>

<sup>1</sup> *Nagoya*

**Corresponding Author:** fukuda@hken.phys.nagoya-u.ac.jp

We discuss the evolution of the fluctuation in the initial conditions of entropy densities (energy densities) using 1+1 dimensional hydrodynamic calculations. We explore not only the evolution of the fluctuation but also the origin of it. If the local thermal equilibrium is established at early time of the heavy ion collision and the mean free path of produced particles is sufficiently short, then the later evolution of the system may be described by relativistic hydrodynamics. Most of studies have been performed with ideal hydrodynamics, but it is necessary to take into account of viscosity effect in hydrodynamical expansion to understand experimental data in detail. In particular, we focus on the dynamics along the collision axis and investigate how the viscous effects appear in evolution of the fluctuation in the framework of perturbation with respect to the bulk and shear viscosities. Assuming that the bulk and shear viscosities are small we calculate the entropy production during hydrodynamic evolution and the initial condition dependence of it. Here we use the Bjorken's solution for the ideal part (0th-order) in our perturbative approach and show detail calculated results.

#### Poster Session Reception / 332

### Collective Flow of Charged Hadrons in Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV at RHIC PHENIX

**Author:** Damian Reynolds<sup>1</sup>

**Co-authors:** Jiangyong Jia<sup>2</sup>; Roy Lacey<sup>3</sup>; YI GU<sup>4</sup>

<sup>1</sup> S

<sup>2</sup> State University of New York (US)

<sup>3</sup> Stony Brook University

<sup>4</sup> D

**Corresponding Author:** dlreynol@rf.rhic.bnl.gov

The collective flow of charged hadrons emitted in heavy ion collisions can be characterized using the Fourier coefficient  $v_2$  (elliptic flow), as well as with the higher order coefficients,  $v_3$ ,  $v_4$ , etc, which result primarily from fluctuations in the initial conditions of the colliding nuclei. The latter is of paramount importance since it can provide insight on the hydrodynamic behavior of the medium, as well as constraints for reliable extraction of transport coefficients. For example,  $v_3$  has been critical in discriminating between different models and the application of viscosity. In recent measurements, PHENIX has extracted  $v_{2,3,4}$  coefficients for charged hadrons via two independent methods. The first correlates the azimuthal distribution of particles at mid-rapidity in the central arm of PHENIX with event planes determined by the detectors widely spaced in pseudorapidity to avoid non-flow effects.

The second method is a two particle correlation between a charge weighted azimuthal angle in the Beam Beam Counters and the azimuthal angle of a track in the central arms of the PHENIX detector. Again, the pseudorapidity gap is present to avoid non-flow effects. This method has the added benefit of not requiring that the reaction plane angle be determined.

These coefficients, measured as a function of the number of participating nucleons, centrality, and  $p_T$  for charged hadrons, will be presented and compared to earlier measurements for Au+Au collisions at the same energy so as to see the effect of system size.

#### Poster Session Reception / 426

### Source chaoticity in heavy-ion collisions at the LHC

**Author:** Collaboration ALICE<sup>1</sup>