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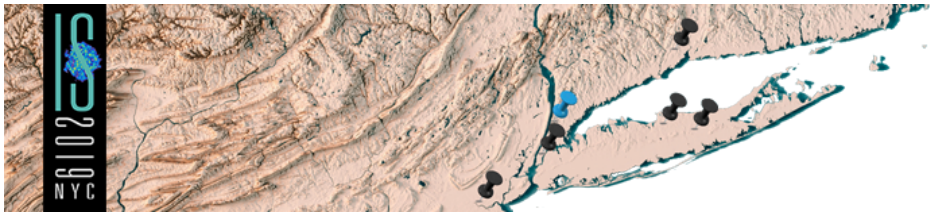

Book of Abstracts

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Hydrodynamic simulations of relativistic nuclear collisions with nucleon substructure: combined analysis of p+Pb and Pb+Pb collision systems at 5.02 TeV

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Simulations of relativistic heavy-ion collisions based on viscous hydrodynamics provide an accurate description of the bulk observables measured at RHIC and LHC beam energies, including identified particle yields, mean p_T and multiparticle correlations. The success of the hydrodynamic framework, however, is naturally expected to break down in the dilute limit where discrete particle degrees of freedom dominate.

It was thus surprising when the multiparticle correlations measured in high-multiplicity proton-lead collisions were found to be similar in magnitude to those observed in lead-lead collisions. The observation suggests that hydrodynamic behavior could be manifest in small droplets of quark-gluon plasma (QGP), and that flow might develop at length scales smaller than a proton.

In this work, we assume the existence of hydrodynamic flow in small collision systems and evaluate the likelihood of our assertion using Bayesian inference. Specifically, we model the dynamics of proton-lead and lead-lead collisions at 5.02 TeV using QGP initial conditions with parametric nucleon substructure, a pre-equilibrium free-streaming stage, event-by-event viscous hydrodynamics with shear and bulk coupling, and a microscopic hadronic afterburner to simulate the dynamics of the collision below the QGP transition temperature.

The model is evaluated on a scaffolding of parameter points, and emulators are trained to interpolate the model predictions at intermediate regions of parameter space. Markov chain Monte Carlo importance sampling is then used to explore the Bayesian posterior probability distribution as a function of the model input parameters.

We use the resulting posterior distribution to sample preferred regions of parameter space and evaluate the performance of the model with optimally chosen parameter values This semi-exhaustive model validation enables us to to comment on the implied viability of hydrodynamics in small collision systems subject to the approximations of the chosen framework. We also present marginalized posterior distributions for each model input parameter, e.g. nucleon substructure degrees of freedom, which demonstrate the constraining power of global statistical analysis and reveal new insight into nuclear matter at extreme temperatures and densities.

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New heavy flavor program for the future Electron Ion Collider

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The proposed high-luminosity high-energy Electron Ion Collider (EIC) will provide one of the cleanest environments to precisely determine the nuclear parton distribution functions (nPDFs) in a wide

x-Q^2 phase space. Heavy flavor production at the EIC can access up to the confinement boundary, which allows us to directly study nPDFs, quark/gluon fragmentation processes, and energy loss within the poorly constrained high Bjorken-x region. The group at Los Alamos National Laboratory propose to develop a new experimental and theoretical physics program to study the heavy flavor products, flavor tagged jets and heavy flavor hadron-jet correlations in the nucleon/nucleus going direction at the future EIC. The proposed measurements will provide a unique path to explore the flavor dependent fragmentation functions and energy loss in heavy nucleus, which can constrain the initial state effects for previous and ongoing heavy ion measurements at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC). Details of the proposed physics program will be discussed in this presentation.

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Small-x calculations with a Biased Ensemble

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Computing observables in high-energy collisions requires a functional average over the configurations of small-x gluons in the wave functions of the colliding hadrons. We discuss a method for performing biased averages, for example due to a multiplicity or centrality bias, where the gluon distributions of the hadrons are modified from their unbiased average. We consider specifically potential effects due to a bias on the correlator of two Wilson lines, i.e. the dipole scattering amplitude, and on azimuthal angular correlations of gluons at high transverse momentum (the "glasma graphs").

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Anisotropic hydrodynamics with a realistic collisional kernel

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In this work, we implement an effective kinetic theory based scattering kernel in the anisotropic hydrodynamics (aHydro) formalism. We compare the realistic kernel results to those obtained from aHydro with the Anderson-Witting scattering kernel (RTA). For the purpose of this study, we consider a conformal system undergoing transversally-homogenous and boost-invariant Bjorken expansion. The collisional kernel is given by the leading order $2 \leftrightarrow 2$ scattering kernel in the massless scalar $\lambda\phi^4$. We explicitly enforce number conservation through the incorporation of a dynamical chemical potential (fugacity) in the underlying aHydro distribution function and focus on the case of a system obeying classical statistics. We first compare the time evolution of the aHydro microscopic parameters and components of the energy-momentum tensor. Then, we determine the anisotropic non-equilibrium attractor for a system subject to this realistic collisional kernel. Our results indicate that when the near-equilibrium relaxation-times in the Anderson-Witting and scalar collisional kernels are matched, the aHydro dynamics receive quantitatively important corrections using the LO scalar kernel, however, the aHydro attractor itself is not substantially modified.

Parallel: Forward/saturation/spin / 13

Non-linear evolution in QCD at high-energy beyond leading order

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The next-to-leading order (NLO) Balitsky-Kovchegov (BK) equation describing the high-energy evolution of the scattering between a dilute projectile and a dense target suffers from instabilities unless it is supplemented by a proper resummation of the radiative corrections enhanced by large transverse logarithms. Earlier studies have shown that if one expresses the evolution in terms of the rapidity of the dilute projectile, the dominant, anti-collinear, contributions can be resummed to all orders. However, in applications to physics, the results must be re-expressed in terms of the rapidity of the dense target (which corresponds to Bjorken x). We show that although they lead to stable evolution equations, resummations expressed in the rapidity of the projectile show a strong, unwanted, scheme dependence when translated in the rapidity of the target. We circumvent this problem by working directly with the rapidity of the dense target [1]. This avoids the large anti-collinear contributions but introduces new, collinear, instabilities, which are however milder since disfavoured by the typical BK evolution. We propose several prescriptions for resumming these new double logarithms and find only little scheme dependence. The resummed equations are non-local in rapidity and can be extended to full NLO accuracy. We present the first applications of these resummed equations to deep inelastic scattering at HERA.

[1] B. Ducloué et al, e-Print: arXiv:1902.06637 [hep-ph]

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Non-Gaussian fluctuations of v_1, v_2, v_3 and v_4 and their correlations in Pb+Pb collisions with the ATLAS detector

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The measurements of the flow phenomena in Xe+Xe and Pb+Pb collisions provide an excellent opportunity to study the interplay of viscous effects – which diminish the azimuthal anisotropies more in Xe+Xe compared to Pb+Pb – and initial geometry fluctuations which have an opposite effect. With the recently developed techniques, used for suppression of non-flow correlations in small systems, applied to 0.49 nb^{-1} of Pb+Pb and 3$\mu\mathrm{b}^{-1}$ of Xe+Xe data significant reduction of non-flow biases is achieved with respect to the previous measurements both at high p_{T} and in peripheral collisions. An interesting scaling relationships is observed in the v_n across different centralities, where up to an overall scaling the the v_n as a function of p_{T} have identical shapes. The origin of this scaling and its implications are discussed in the framework of hydrodynamic models. Multi-particle azimuthal cumulants measured in the Pb+Pb collisions provide information on the event-by-event fluctuations of harmonic flow coefficients v_n and correlated fluctuations between two harmonics v_n and v_m. For the first time, a non-zero four-particle cumulant is observed for dipolar flow, v_1. The four-particle cumulants for elliptic flow, v_2, and triangular flow, v_3, exhibit a strong centrality dependence and change sign in ultra-central collisions. Correlations between two harmonics are studied with three- and four-particle mixed-harmonic cumulants, which also decrease in strength towards central collisions and either approach zero or change sign in ultra-central collisions. To investigate the possible flow fluctuations arising from intrinsic centrality or volume fluctuations, the results are compared between two different event classes used for centrality definitions. In peripheral and mid-central collisions where the cumulant signals are large, only small differences are observed. In ultra-central

collisions, the differences are much larger and transverse momentum dependent. These results provide new information to disentangle flow fluctuations from the initial and final states, as well as new insights on the influence of centrality fluctuations.

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v_n–p_{T} correlations in 5.02 TeV Pb+Pb and p+Pb collisions with the ATLAS detector

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Recently collected data by the ATLAS experiment at the LHC offer opportunities to explore dynamic properties of quark-gluon plasma. A new tool to study these properties is the modified Pearson's correlation coefficient, ρ, that quantifies the correlation between the mean transverse momentum in an event,$[p_{\mathrm{T}}]$, and the square of the flow harmonic magnitude, v_n^2. To suppress non-flow effects, v_n^2 is calculated by correlating charged particles from two sub-events covering opposite pseudorapidity ranges of $0.75 < |\eta| < 2.5$ while $[p_{\mathrm{T}}]$ is evaluated for particles with $|\eta| < 0.5$. The measurement of ρ is performed using minimum-bias p+Pb and Pb+Pb collisions at the same energy $\sqrt{s_{\mathrm{NN}}} = 5.02$~TeV allowing for a comparison of the medium dynamics in small and large systems. In Pb+Pb collisions, values of ρ coefficients are found to significantly deviate from zero for studied harmonics (v_2, v_3, and v_4). The coefficients as a function of centrality are observed to be weakly dependent on the transverse momentum range of the selected particles, despite large differences in the mean transverse momentum in an event and the magnitude of fluctuations of flow harmonics. The ρ coefficient in Pb+Pb collisions for the second order harmonics has a positive value for mid-central collisions and decreases in the most central events. In p+Pb collisions the ρ coefficient is measured only for the second order flow harmonics. In both p+Pb and peripheral Pb+Pb collisions, it is found to be negative. All measured coefficients are compared to theoretical models.

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Recent ATLAS results on correlations in small collisions systems and photon-induced processes in ultra-peripheral Pb+Pb collisions at 5.02 TeV

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This talk presents ATLAS measurements of azimuthal anisotropies in pp and p+Pb collisions, performed via two-, four- and six-particle correlations, with modifications to ensure suppression of correlations arising from jets and dijets. In pp collisions, the strength of the correlations quantified by the anisotropy parameter v_2 does not show any dependence on the charged-particle multiplicity. Recent theoretical models suggest that this can be due to lack of correlation between the charged-particle multiplicity and the impact parameter of the pp collision. To test this hypothesis, correlation measurements are performed in pp collisions tagged by the presence of a Z boson – which acts as an independent handle on the impact parameter – and compared to inclusive pp collisions. Additionally, results of correlations between flow harmonics of different order in pp and p+Pb collisions measured via symmetric and asymmetric cumulants are also presented, and are shown to follow similar trends as those observed in Pb+Pb collisions. Measurements of HBT radii with respect to the second-order event-plane in p+Pb collisions are also presented. Azimuthal modulations in the HBT radii consistent with the hydrodynamic evolution of a short-lived medium are observed. The ultra-peripheral collisions (UPCs) of relativistic heavy ion beams lead to both photon-nucleus and photon-photon processes. The measurements of particle production in photo-nuclear reactions can shed light on the QCD dynamics of novel, extremely asymmetric colliding systems, with energies between those available at RHIC and the LHC. Understanding the hadronic fluctuation spectrum of

the photon in this fashion is also critical for maximizing the precision of measurements at a future Electron Ion Collider facility. Finally, new measurements of light-by-light scattering with substantially reduced uncertainties will be presented in this talk. This process provides a precise and unique opportunity to investigate extensions to the Standard Model such as higher-dimension operators and axion-like particles.

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ATLAS measurements of azimuthal anisotropy of heavy flavor hadrons in Pb+Pb, p+Pb and pp collisions

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ATLAS measurements of azimuthal anisotropy and suppression of muons from heavy flavor decays in Pb+Pb collisions are presented. The measurements are extended to smaller systems of p+Pb and pp collisions, where no significant modification of the heavy flavor production are observed.In the smaller systems, a template fit method is used to subtract non-flow contributions using simultaneous fit to low and high charged-particle multiplicity samples. The heavy flavor flow in p+Pb is studied using multiple probes, including prompt D^0 mesons, J/ψ, and muons from semi-leptonic decays of heavy flavor hadrons. In pp collisions, new measurements of flow coefficient of muons from heavy flavor decays are also presented. The observed heavy flavor azimuthal anisotropies in p+Pb and pp collisions are found to be qualitatively similar to those of light hadrons indicating a similar origin for both types of particles.

Parallel: High pT probes of the initial state / 18

Jet and photon probes of small and large systems in ATLAS

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Jets and photons have been studied to constrain the initial and final stages of collisions between two large nuclei at the Large Hadron Collider.
Measurements of photon and jet production p+Pb collisions are potentially sensitive to novel effects such as gluon saturation, the onset of non-linear QCD, and the energy loss of partons in the nuclear matter. In A+A collisions jets are modified as they pass through the hot nuclear matter. This talk presents recent ATLAS measurements of jets and photons in p+Pb, Pb+Pb and Xe+Xe collisions. Results on forward-forward and forward-central di-jet production in 5.02 TeV p+Pb and pp collisions in regions where the momentum fraction of a parton compared to a nucleon in the lead nucleus is small are presented. Also, measurements of photon production in 8.16 TeV p+Pb data over a large kinematic range is presented and compared to measurements in pp collisions and theoretical models. The comparison of di-jet balance in pp, Xe+Xe, and Pb+Pb collisions presented in this talk will to provide information about the path-length dependence and role of fluctuations in the energy loss. Finally, measurements of the distributions of charged particles in and around jets as well as measurements of the energy and fragmentation functions of jets opposite photons are presented.

Parallel: nPDF/CNM / 19

Heavy electroweak boson production in Pb+Pb collisions with ATLAS

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Electroweak bosons provide a unique opportunity to extract the information about the beginning of the temporal evolution of the heavy-ion collision system and understand how the cold nuclear matter effects influence the observables that are measured in heavy-ion collisions. Z and W bosons decaying in leptonic channels are unaffected by the presence of the quark-gluon plasma and carry the information from the time when bosons were created, i.e. from the moment of the collision itself. Measurement of Z and W bosons allows to quantify the modification of the nuclear parton distribution functions and verify our understanding of the geometry of the colliding nuclei.
In the 2015 heavy-ion data-taking period at the LHC, the ATLAS experiment obtained 0.49/nb of the Pb+Pb data and 25/pb of the proton-proton data at the centre of mass energy of 5.02 TeV. The fully analysed data presented in this talk addresses the nuclear modification of the parton distribution functions PDF at a new level of precision. Comparison between the lead-lead and proton-proton systems gives an opportunity to subject the Glauber model used by all heavy ion experiments to a stringent test performed over a wide range of collision centralities.

Parallel: Initial conditions for hydrodynamics & transport coefficients / **26**

Longitudinal fluctuations and decorrelations of anisotropic flows in relativistic heavy-ion collisions

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We study the longitudinal decorrelations of elliptic, triangular and quadrangular flows in heavy-ion collisions at the LHC and RHIC energies. The event-by-event CLVisc (3+1)-dimensional hydrodynamics model, combined with the fully fluctuating AMPT initial conditions, is utilized to simulate the space-time evolution of the strongly-coupled quark-gluon plasma. Detailed analysis is performed for the longitudinal decorrelations of flow vectors, flow magnitudes and flow orientations. We find strong correlations between final-state longitudinal decorrelations of anisotropic flows and initial-state longitudinal structures and collision geometry: the decorrelation of elliptic flow shows a non-monotonic centrality dependence due to initial elliptic geometry, while the longitudinal flow decorrelations are typically larger in lower energy and less central collisions where the mean lengths of the string structure are shorter in the initial states.

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Precision QCD with the LHeC and the FCC-eh

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The Large Hadron-electron Collider (LHeC) is a proposed upgrade of the LHC at CERN. An ERL will provide electrons to collide with the HL-LHC, HE-LHC and the FCC-hh proton beams to achieve centre-of-mass energies 1.3-3.5 TeV and luminosities 10^{34} cm^{-2}s^{-1}. They will enlarge the kinematic plane by more than one order of magnitude towards smaller x and larger Q^2 than HERA. DIS measurements in

such configurations offer unprecedented possibilities to enlarge our knowledge on parton densities through a complete unfolding of all flavours, both in a single experimental setup and combined with data from hadron colliders where precise factorisation tests can be performed. In this talk we review the most recent developments on the determination of proton PDFs and the measurement of α_s at both the LHeC and the FCC-eh.

Parallel: Future facilities / **29**

LHCb fixed target results and prospects

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Among the main LHC experiments, LHCb is the only detector that can run both in collider and fixed-target mode. Internal gas targets of helium, neon and argon have been used so far to collect samples corresponding to integrated luminosities up to 0.1 pb-1. An upgraded target, allowing for a wider choice of target gas species and increasing the gas density by up to two orders of magnitude, is going to be installed for the LHC Run 3. This offers a unique opportunity for measurements of great interest going from QCD to astroparticle in unexplored kinematic regions. Results and prospects on open and hidden charm productions will be presented, which can provide crucial constraints on cold nuclear matter effects and nPDF at large x.

Parallel: High pT probes of the initial state / **33**

A complete set of splitting functions in nuclear matter to any order in opacity and applications to jet physics

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I will present the first calculation of all $calO(\alpha_s)$ medium-induced branching processes to any order in opacity. The splitting functions results are given as iterative solutions to matrix equations with initial conditions set by the leading order branchings in the vacuum. The flavor and quark mass dependence of the in-medium $q \to qg$, $g \to gg$, $q \to gq$, $g \to q\bar{q}$ processes is fully captured by the light-front wavefunction formalism and the color representation of the parent and daughter partons. I will further present numerical results in a realistic QCD medium. The numerical simulations show that the second order in opacity corrections can change the energy dependence of the in-medium shower intensity. Corrections to the longitudinal and angular distributions of the in-medium splitting kernels that may have important implications for jet substructure phenomenology. Last but not least, I will show how these splitting function can be used to evaluate the modification of hadron jet production in SIDIS, such as at the future EIC.

Parallel: Forward/saturation/spin / **34**

Magnetic field in expanding quark-gluon plasma

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Intense electromagnetic fields are created in the quark-gluon plasma by the external ultra-relativistic valence charges. The time-evolution and the strength of this field are strongly affected by the electrical conductivity of the plasma. Yet, it has recently been observed that the effect of the magnetic field on the plasma flow is small. We compute the effect of plasma flow on magnetic field and demonstrate that it is less than 10\%. These observations indicate that the plasma hydrodynamics and the dynamics of electromagnetic field decouple. Thus, it is a very good approximation, on the one hand, to study QGP in the background electromagnetic field generated by external sources and, on the other hand, to investigate the dynamics of magnetic field in the background plasma. We also argue that the wake induced by the magnetic field in plasma is negligible.

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Stochastic hydrodynamics and long time tails of a non-equilibrium fluid

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We investigate the impact of hydrodynamic fluctuations on correlation functions of a relativistic fluid with a conserved U(1) charge. The kinetic equations for the two-point functions of pressure, momentum and heat energy densities are derived within the framework of stochastic hydrodynamics. The leading non-analytic contributions to the energy-momentum tensor as well as the U(1) current are determined from the solutions to these kinetic equations. In the case of a static homogeneous background we show that the long time tails obtained from hydro-kinetic equations reproduce the one-loop results derived from statistical field theory. We use these results to establish bounds on transport coefficients. We generalize the stochastic equation to a scale invariant background flow undergoing Bjorken expansion. We compute the leading fractional power $\mathcal{O}((\tau T)^{-3/2})$ correction to the U(1) current and compare with the first order gradient term. Finally, we discuss the extension of stochastic hydrodynamics to study the effects of critical behavior of the heat conductivity, shear and bulk viscosities in heavy ion collisions for a system close to the QCD critical point.

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Non-perturbative aspects of hydrodynamization for the far-from-equilibrium Bjorken flow

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In relativistic kinetic theory, the one-particle distribution function is approximated by an asymptotic perturbative power series in Knudsen number which is divergent. For the Bjorken flow, we expand the distribution function in terms of its moments and study their nonlinear evolution equations. The resulting coupled dynamical system can be solved for each moment consistently using a multi-parameter transseries which makes the constitutive relations inherit the same structure. A

new non-perturbative dynamical renormalization scheme is born out of this formalism that goes beyond the linear response theory. As a result, the transport coefficients get dynamically renormalized at every order in the time-dependent perturbative expansion by receiving non-perturbative corrections present in the transseries. The renormalized transport coefficients feature a transition to their equilibrium fixed point, which is a neat diagnostics of transient non-Newtonian behavior. Furthermore, we show that the first dissipative correction to the distribution function is not only determined by the known effective shear viscous term but also a new high energy non-hydrodynamic mode. Finally, we briefly discuss some possible phenomenological applications of the proposed non-hydrodynamic transport theory.

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Linear and non-linear response of two-particle correlations to initial-geometry fluctuations

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We investigate the importance of different features of the initial geometry to anisotropic flow fluctuations in heavy-ion collisions. To that end, we explore the hydrodynamic response of differential flow harmonics $v_n(p_T)$ to generalized eccentricities $\epsilon_{n,m}$ of the initial density profile within a realistic hydrodynamic model. Special attention is paid to two-particle angular correlations, characterized in detail by the principal-component analysis (PCA). We address the relevance of non-linear response, as well as the stability of the results against the inclusion of extra eccentricities. Additionally, we study new effects from multiplicity fluctuations, which could lead to redundancies in the experimental PCA data.

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Initial state fluctuations in Pythia 8

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Initial state geometry has proved to be decisively important for quantitative descriptions of collective behavior in large collision systems, such as PbPb and AuAu. One of the most remarkable lessons from LHC has been the discovery of collective behavior in small collision systems, but here the notion of spatial structure is not as obvious as in nuclear collisions. In Monte Carlo event generators, ad hoc phenomenological schemes are usually employed with clear room for improvement. In this talk we present progress on including a transverse space structure of pp collisions based on the Mueller dipole formulation of QCD, into the Pythia8 event generator. This formalism has the advantage that parameters can be estimated from inclusive quantities in ep and pp collisions, such that the spatial structure becomes a true prediction of the model. Besides the importance for collective behavior, in particular in pp, but also in fluctuation dominated pA and peripheral AA collisions, the dipole picture also serves as an important starting point for including electron-ion initial states in

the model for heavy-ion collisions in Pythia8, the Angantyr framework, a perspective which also will be discussed.

Parallel: Future facilities / **46**

Computing the gluon Sivers function at low-x

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The TMD parton distributions can have azimuthal asymmetry in the transverse plane for the transversely polarized nucleon. This is called the Sivers effect and is phenomenologically important for the description of single spin asymmetries. I will present our recent calculation of the gluon Sivers function at small-x obtained by using the known connection between the Sivers function and the odderon.

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New paradigm for fluctuations in heavy-ion collisions

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We present a first-principles description of the primordial state of relativistic nucleus-nucleus collisions, whose density fluctuations and anisotropy we evaluate in the color glass condensate (CGC) framework of high-energy QCD. Relating the primordial anisotropy of the system in our approach to the measured final-state anisotropic flow through a simple linear mapping, we achieve an excellent description of both RHIC and LHC data.

Our description does not make any explicit reference to the usual, ad hoc fluctuations due to the random positions of the incoming nucleons: Primordial initial-state fluctuations are generated solely by McLerran-Venugopalan correlators of color charges. The good agreement found with the data implies, then, that QCD interactions alone can provide the system with enough density fluctuations to explain the measured triangular flow, and elliptic flow fluctuations.

This suggests a fundamental paradigm shift in our understanding of fluctuations in heavy-ion collisions: At ultrarelativistic energies, the standard Monte Carlo Glauber picture of nuclear collisions, which until now has been understood as the dominant source of fluctuations, can be abandoned.

Based on:
https://arxiv.org/abs/1902.07168

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Self-similarity and spectral functions of non-Abelian plasmas in 2+1D

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To better understand the dynamics of initial stages in heavy-ion collisions, we perform classical-statistical simulations of SU(2) gauge theory in 2+1 dimensions. We find that highly occupied non-Abelian plasmas approach the same 2+1D self-similar state at late times of their far-from-equilibrium evolution, irrespective of details of their initial conditions, and we determine the scaling exponents. We extract the spectral function non-perturbatively and show that for larger momenta than the mass scale p » m, one sees a pronounced peak in the frequency domain, while at low momenta p < m, quasi-particle assumptions become invalid. The hard-thermal loop (HTL) formalism is not applicable to 2+1D gauge theories at low momenta p <= m, and indeed, our results are inconsistent with its predictions. This challenges our detailed understanding of plasma instabilities at initial stages that is mostly based on HTL calculations of highly anisotropic gluonic matter.

Parallel: Forward/saturation/spin / 50

EPR paradox and quantum entanglement at sub-nucleonic scales

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In quantum mechanics, Einstein, Podolsky, and Rosen (EPR) formulated an apparent paradox of quantum theory in 1935. They considered two quantum mechanical systems were first brought to interaction, then later separated to large distance. A measurement of a physical observable in one system would have an immediate effect on the conjugate observable in the other system, even when they are causally disconnected. Therefore, EPR concluded that there is an inconsistency in the quantum theory. In the parton model formulated by Bjorken, Feynman, and Gribov, the partons inside of a nucleon are viewed as "quasi-free" particles when they are boosted into the infinite momentum frame, where the parton probed by the virtual photon is causally disconnected from the rest of the nucleon. Since the parton and the rest of the nucleon have to form a color-singlet state due to confinement, we encounter the EPR paradox at sub-nucleonic states for the first time. In this work we propose a resolution of this apparent paradox via quantum entanglement. We test this idea by measuring the entanglement entropy of the system using data from proton-proton collisions at the Large Hadron Collider, and our results provide a strong direct indication of quantum entanglement at sub-nucleonic scales.

Parallel: nPDF/CNM / 53

Measurement of electroweak-boson production in p–Pb and Pb–Pb collisions at the LHC with ALICE

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Electroweak bosons are created in the hard scattering processes at the initial stage of heavy-ion collisions and they are insensitive to the presence of the strongly-interacting medium. This makes them clean probes of the initial-state effects in heavy-ion collisions, such as the nuclear modification of the Parton Distribution Functions (nPDFs). Furthermore, their measurement in heavy-ion collisions is a powerful test of the binary scaling of hard processes as well as a reference for hot-matter effects on other probes.

The measurement of electroweak-boson production in p–Pb and Pb–Pb collisions at the LHC provides constraints on the nPDFs of (anti)quarks in phase-space regions which are poorly constrained from previous experiments. At forward rapidity ($2.5 < y < 4$), ALICE can measure W and Z bosons via their muon decay in all collisions systems provided by the LHC. These measurements are complementary to those by ATLAS and CMS at central rapidity.

In this contribution, focus will be given to the most recent ALICE electroweak-boson measurements. Exploiting the data collected by ALICE in 2015 and 2018, centrality and rapidity-differential measurements of the Z-boson production yield in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ will be discussed. The first measurement of the Z-boson production cross-section in p–Pb collisions at $\sqrt{s_{\rm NN}} = 8.16$ TeV will also be shown as a function of rapidity. The status of ongoing W-boson analyses in various collision systems will also be reported. All the presented results will be compared to theoretical calculations including nPDFs.

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Particle production as a function of system size and underlying-event activity measured with ALICE at the LHC

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ALICE has performed several measurements aimed at understanding the heavy-ion-like patterns observed in small collision systems. New approaches can be helpful to clarify particle production mechanisms in pp collisions, as well as the similarities observed among the systems created in pp, p-A and A-A collisions.

In this talk we report on charged-particle transverse momentum distributions as a function of event multiplicity. The distributions are obtained using a 2D-unfolding procedure. We compare unidentified charged-particle production at different collision energies, as well as that for pp, p-Pb and Pb-Pb collisions at the same energy. In order to understand the role of autocorrelations in small systems, it has been proposed to exploit the usage of the underlying event as a multiplicity estimator to factorize the hardest and the softer components of the events. This approach can also be used to study collective effects in events with exceptionally large activity in the underlying-event region with respect to the event-averaged mean. For this purpose, in this talk we also present the charged particle transverse momentum distributions as a function of underlying-event activity in pp collisions. All results will be compared with QCD-inspired event generators, as well as with existing measurements adopting the mid- and forward-pseudorapidity multiplicity estimators.

Parallel: Future facilities / 57

A Forward Rapidity Upgrade for the STAR Detector

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The STAR Collaboration plans to design, construct, and install a suite of new detectors in the forward rapidity region ($2.5 < \eta < 4$) over the next two years, enabling a program of novel measurements in pp, pA, and AA collisions. This extension of STAR's kinematic reach will allow detailed studies of cold QCD physics at both very high and very low partonic momentum fraction, i.e. when the colliding quarks and gluons carry very large or very small amounts of the nucleon energy. Previous STAR efforts using the Forward Pion Detector (FPD) and Forward Meson Spectrometer (FMS) detectors have demonstrated that there are outstanding QCD physics opportunities in the forward rapidity region. To fully explore these physics opportunities, a forward upgrade [1] with detection capability for neutral pions, photons, electrons, jets, and leading hadrons is proposed which adds charged-particle tracking, electromagnetic, and hadronic calorimetry to STAR's capabilities at high pseudorapidity. The upgrade will greatly expand the kinematic reach for ongoing measurements of the spin and flavor structure of the nucleon, and will enable studies of the longitudinal structure of the nuclear initial state that leads to breaking of boost invariance in heavy-ion collisions. Transport properties of the hot and dense matter formed in heavy-ion collisions will also become accessible with the proposed measurement capabilities at forward rapidity. Details on the proposed upgrade and the scientific opportunities it will enable will be presented.

[1] "The STAR Forward Calorimeter System and Forward Tracking System," https://drupal.star.bnl.gov/STAR/starnotes/public/s

Parallel: nPDF/CNM / 60

Measurement of open heavy-flavour hadron production in pp, p-Pb and Pb-Pb collisions with ALICE

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Heavy quarks (charm and beauty) are effective probes to test perturbative QCD-based calculations in pp collisions and to study cold nuclear matter (CNM) effects such as gluon saturation, shadowing, k_{T} broadening and energy loss in CNM in p-Pb collisions.

With the ALICE detectors, open heavy flavours are measured via the full reconstruction of hadronic decays of non-strange D mesons, $\mathrm{D_s^+}$ mesons and Λ_{c}^+ baryons, and the semi-electronic decay channels of electrons from open charm and open beauty hadron decays and Ξ_{c}^0 at mid-rapidity and, via the semi-muonic decays at forward rapidity. The measurements of Λ_{c}^+ and Ξ_{c}^0 production can shed light on charm hadronisation mechanisms in the absence of the hot and dense QCD medium. The comparisons of charmed baryon-to-meson ratios with models tuned to e^+e^- collisions allow us to examine the possible contributions of charm quark recombination or coalescence, which may be more prevalent at large charged-particle multiplicities, and to potentially disentangle these effects from pure vacuum fragmentation. Recent observations in pp and p-Pb collisions showed remarkable similarities with Pb-Pb collisions, which might suggest the presence of collectivity. To further explore the origin the collective-like effects observed in pp and p-Pb collisions, the study of open heavy-flavour production as a function of the charged-particle multiplicity naturally links soft and hard processes that occur in the collision and allows one to study their interplay.

In this contribution, the production cross sections of D mesons and open heavy-flavour decay electrons measured at mid-rapidity, and open heavy-flavour decay muons measured at forward rapidity

in pp collisions at $\sqrt{s} = 5.02$ TeV with ALICE detector will be presented. The latest ALICE results on Λ_c^+ and Ξ_c^0 production and Λ_c^+/D^0 ratio in pp collisions at $\sqrt{s} = 7$ TeV and in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, and Ξ_c^0/D^0 ratio in pp collisions at $\sqrt{s} = 7$ TeV and their comparison to model calculations and to equivalent results from the light-flavour sector will the discussed. The results of beauty production using beauty-decay electrons and non-prompt D mesons in pp collisions at $\sqrt{s} = 5.02$ TeV and the self-normalized yield of open heavy-flavour decay electrons and muons as a function of multiplicity in pp and p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV will be presented. Finally, the nuclear modification factor (Q_{pPb}) of D mesons in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and the comparison of the experimental results with theoretical models will be discussed as well.

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Non-equilibrium Green's functions for energy-momentum perturbations around Bjorken flow from the Boltzmann equation in relaxation time approximation

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Non-equilibrium Green's functions provide an efficient tool to describe the evolution of the energy-momentum tensor during the early time pre-equilibrium stage, and provide a meaningful to address the question when and to what extent a hydrodynamic description of the system becomes applicable. We present a calculation of the Green's functions describing the evolution of energy density perturbations in the transverse plane, based on the Boltzmann equation in relaxation time approximation. We discuss the approach towards viscous hydrodynamics along with the emergence of various scaling phenomena for conformal systems. By comparing our results obtained in the relaxation time approximation to previous calculations in QCD kinetic theory, we further address the question which macroscopic features of the energy momentum tensor are sensitive to the underlying microscopic dynamics.

Parallel: High pT probes of the initial state / 63

Measurement of heavy-flavour jets and correlations and elliptic flow in small systems with ALICE

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The ALICE Collaboration studied extensively heavy-flavour production at mid- and forward rapidities in small systems at the LHC. The data provide precise tests for pQCD calculations based on the factorization approach and set constraints to Cold Nuclear-Matter effects that can modify heavy-flavour production in p-Pb collisions with respect to pp collisions. At mid-rapidity the study of the angular correlation of heavy-flavour particles with charged particles produced in the event allows us to further characterize charm and beauty production and fragmentation processes in pp collisions and investigate their possible modifications due to nuclear effects in p-Pb and Pb-Pb collisions. In p-Pb collisions these studies can also set constraints on the dependence of Cold Nuclear-Matter effects on the collision geometry and on the density of final-state particles. In addition, the study of the angular correlation pattern in p-Pb collisions as a function of the event multiplicity allows studying the features of long-range correlations similar to the one found in heavy-ion collisions whose origin is still debated. Finally, the measurement of heavy-flavour jets, besides constituting the necessary

baseline for similar studies in the Pb-Pb collision system, gives more direct access to the initial parton kinematics and can provide further constraints on pQCD based models.

In this contribution, the latest ALICE results from pp and p-Pb collisions collected during the LHC Run 2 will be presented. In particular, measurements of the angular correlation of D mesons and heavy-flavour decay electrons with charged particles in pp and p-Pb collisions will be shown. The measurement of heavy-flavour decay leptons elliptic flow in p-Pb collisions at high multiplicity at mid-and forward rapidities will also be presented together with the D-meson central to peripheral ratio (Q_{CP}). Finally, ALICE measurements on D-tagged jets will be discussed both in pp and p-Pb collisions together with the status of b-jet measurements. All the results shown will be compared with theoretical models.

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Toward a full mapping of the hydrodynamic response to initial conditions

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Anisotropic flow is well understood as a hydrodynamic response to spatial anisotropies in the system density at early times. This response function can be written explicitly as a systematic expansion in terms of length scales, such that the leading contribution is the familiar eccentricity ε_n that represents global structure. These relations have allowed for direct connections to be made between the initial state and experimental data, and constraints to be put on the initial stages.

However, the initial conditions for hydrodynamics consist of an entire tensor $T^{\mu\nu}$ (as well as conserved currents). Although they are thought to be less important than energy density, other components such as momentum density and shear tensor can also contribute, and their affects should have increasing importance for smaller collision systems. It is therefore interesting to extend the response framework in order to probe these aspects of the initial stages and their affect on flow observables.

I will present a framework for including the effects of the full hydrodynamic initial conditions, along with numerical tests from full hydrodynamic simulations to demonstrate its efficacy. In addition, I will present an extension to include rapidity dependence.

Parallel: nPDF/CNM / 65

Quarkonium production in pp and p–Pb collisions with ALICE at the LHC

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Quarkonia, bound states of either a charm and anti-charm quark pair (e.g. J/ψ, ψ(2S)), or a beauty and anti-beauty charm pair (Υ(1S), (2S) and (3S)), are considered a prominent tool to study the properties of the Quark-Gluon Plasma (QGP) formed in high-energy heavy-ion collisions such as those delivered by the LHC. However, their production is also sensitive to so called initial state effects,

such as the modifications of the parton distribution functions in the nucleus or the occurrence of gluon saturation at low Bjorken x, and thus provide some insight on the initial conditions of such collisions.

Recently, proton-proton (pp) and proton-lead (p–Pb) collisions with high charged-particle multiplicities have been found to exhibit phenomena similar to those attributed to the QGP formation. Measuring quarkonia in such collisions could contribute to a better understanding of the underlying physics processes leading to these observations and in any case provide a more detailed understanding of their production mechanism.

ALICE has measured quarkonium production in both pp collisions for collision energies $\sqrt{s}$ ranging from 2.76 to 13 TeV and p–Pb collisions at center of mass energies per nucleon-nucleon collisions $\sqrt{s_{\rm NN}} = 5.02$ and 8 TeV. These measurements have been carried out down to zero transverse momentum and at both mid and forward rapidity. Beyond quarkonium cross sections in pp collisions and nuclear modification factors in p–Pb collisions as a function of rapidity, transverse momentum and centrality, this presentation will also focus on correlations between the quarkonium and the underlying event, including recent results on the charged-particle multiplicity dependence of quarkonium relative yields and mean transverse momentum at both mid and forward rapidity, J/ψ-hadron correlations at mid rapidity and J/ψ azimuthal anisotropy in high-multiplicity p–Pb collisions.

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Heavy-quark diffusion coefficient in out-of-equilibrium plasmas

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We study the heavy-quark momentum diffusion coefficient in gluon plasmas in a self-similar regime using real-time lattice techniques. We observe that the time-evolution of the momentum diffusion coefficient is consistent with a t^(-5/7) power law, as predicted by HTL perturbation theory and self-similarity. Using HTL with our recently acquired data on the spectral function of over-occupied gluodynamics, we find that the main contribution to the diffusion coefficient arises from the longitudinal Landau damping in the spectral function and study further features of the signal. Finding consistent results between lattice simulations and HTL results is an important step forward in understanding the evolution of the diffusion coefficient at initial stages.

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Measurement of long-range correlations in pp collisions at $\sqrt{s}$ = 13 TeV with ALICE at the LHC

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The observed azimuthal modulations of long-range correlations in pseudorapidity in small systems like pp or p-Pb collisions show strikingly similar features to those seen in heavy ion collisions. Many theoretical approaches to interpreting this effect have been developed. However, it is still unclear whether these long-range correlations are due to final or initial state effects.

To further investigate these effects, we studied long-range correlations as a function of transverse momentum in very high multiplicity pp collisions at $\sqrt{s}$ = 13 TeV, collected with the high multiplicity event trigger during 2016 and 2017 with ALICE. In this talk, we present the near side per-trigger yield at large pseudorapidity separation (ridge yield) as a function of transverse momentum in pp collisions at $\sqrt{s}$=13 TeV. The results will be compared to previous measurements from CMS and ATLAS. In addition, we present the ridge yield in events where harder fragmentation processes are present, to explore possible physical origins of long range correlations.

Parallel: Approach to Equilibrium / 71

Holographic collisions with baryon number at intermediate coupling

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In holographic heavy ion collisions it is possible to follow both the energy density and a globally conserved (baryon) number density throughout the evolution, dual to a metric and Maxwell field in the dual bulk theory, respectively. At infinite coupling, past work has shown that after the collision the baryon number ends up around mid-rapidity, which is different from high energy heavy ion collisions. In this talk I will present first results for the flow of baryon number in holographic collisions away from the infinite coupling limit, which also means we study the collisions at a larger shear viscosity over entropy density ratio than $1/4\pi$. I will give an introduction to the holographic set-up, which is interesting since it contains an extra coupling of the gravitational Ricci scalar with the Maxwell field. Remarkably, depending on the value of this extra coupling, we find that the flow of baryon number during the collision can be affected drastically. In particular, we find that at intermediate coupling it is possible for almost no baryon number to end up at mid-rapidity. We further show how the matter produced in the collision relaxes into a flow as described by hydrodynamics with a conserved baryon current.

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Flow vs Nonflow in Ultracentral U-U and Be-Be Collisions

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An ongoing question in the field is if the collectivity originating in small systems arises from:

- Flow scenario: initial conditions coupled to relativistic hydrodynamics leading to independent particle emissions from the fluid hyper-surface.

or

- Non-flow scenario: genuine 2,4 etc particle correlations from, e.g. a saturation framework.

We note that, in general, the experimentally measured $v_n\{m\}$'s can include non-trivial contributions from both pictures (and mixing terms between the two) so we caution that the calculations of $v_n\{m\}$ must consider both contributions, which look different in each framework.

Using the Color-Glass Condensate (CGC) formalism in the (semi)dilute-(semi)dilute regime for $p_T \gg Q_s$, we can compare the ultra-central scaling of azimuthal anisotropies with the multiplicities of deformed ion-ion collisions. We consider deformed ion-ion collisions as a testing bed for these comparisons because due to either tip-tip or side-side collisions, one expects the geometrical shape immediately after the collision (eccentricities) to scale inversely with the final multiplicity. Because hydrodynamics is predominately driven by linear response in ultracentral collisions, this inverse scaling of $v_2\{2\}$ with dN/dy is preserved in the final hydrodynamic picture. In contrast to hydrodynamics, in the CGC framework $v_2\{2\}$ and $v_3\{2\}$ increase monotonically with the multiplicity. We repeat these calculations for Beryllium-Beryllium collisions and predict the same effect. Different parameterizations of Uranium are also studied and constrained by data. Thus, we argue that deformed ions can be a perfect testing ground for comparing the CGC to hydro pictures in small systems. Additionally, we calculate other flow observables such as $(v_2\{4\}/v_2\{2\})^4$ and symmetric cumulants, NSC(3,2). We find that due to the suppression of 4 particle correlations in our framework that the CGC picture produces an imaginary $v_2\{4\}/v_2\{2\}$ while we find a positive NSC(3,2).

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A Principal Component Analysis of event-by-event fluctuations in hydrodynamic simulations at the LHC

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Hydro simulations are compared with recent experimental data by CMS, on a Principle Component Analysis. The trends for the scaled leading and sub-leading components for n=2,3 agree with data. In contrast, for n=0 there is a qualitative disagreement: the leading component increases with p_T while it is constant in data. Using a toy model where the principal components can be computed analytically, it is shown that the n=0 leading and sub-leading components are extremely dependent on fluctuations in N and $\bar{p_T}$ as well as their covariance and provide a new and clean way to study fluctuations and rule out initial condition models.

Parallel: Collectivity in small systems 1 / **79**

Investigation of collectivity in small collision systems with ALICE

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Measurements of anisotropic flow in heavy-ion collisions are an important tool to investigate the nature of the created collectively expanding medium called the Quark-Gluon Plasma (QGP). Recently, striking similarities have been observed in numerous measurements in high multiplicity proton-proton and proton-lead collisions, where no such medium was expected.

In this talk, we will present the latest ALICE measurements of flow coefficients, and their magnitude correlations using Symmetric Cumulants for charged particles in pp collisions at $\sqrt{s}$ = 13 TeV, p–Pb at $\sqrt{s_{\rm NN}}$ = 5.02 TeV, Xe–Xe at $\sqrt{s_{\rm NN}}$ = 5.44 TeV and Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV, collected during the Run 2 LHC data taking period. In addition, the flow coefficients of identified particles in p–Pb collisions will be presented. Non-flow effects, which are azimuthal correlations not originating from a common symmetry plane, are suppressed with a pseudorapidity separation and a subtraction method. Both methods are particularly important for studies of collectivity in small systems. The results from a broad spectrum of colliding systems and wide range of multiplicity are compared to various theoretical models, providing a deep insight into initial conditions and the nature of collective phenomena in different collision systems.

Parallel: Initial conditions for hydrodynamics & transport coefficients / 80

Hydrodynamics far-from-equilibrium: a concrete example in kinetic theory

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The applicability of hydrodynamical models in the extreme conditions produced in heavy ion collisions has not yet been properly understood theoretically. This happens mostly because the derivation of hydrodynamics from microscopic theory often relies on the assumption that the system is sufficiently close to equilibrium – something difficult to justify in the rapidly expanding systems created in heavy ion collisions. In this talk we propose a more general derivation of relativistic hydrodynamics from kinetic theory, in which the fluid is assumed to be close to an *isotropic nonequilibrium* state instead of an equilibrium one. We demonstrate that, for a wide variety of nonequilibrium states, a hydrodynamic theory that is identical to the traditional hydrodynamic equations applied to heavy ion collisions is obtained. The only difference appears in the form of the transport coefficients that enter the equations of motion. Simulations of the Boltzmann equation equation in 0+1D Bjorken flow in the ultrarelativistic limit are performed to demonstrate this effect, showing that the same evolution for the energy-momentum tensor is obtained even when the momentum distribution function of partons is very different from an equilibrium one.

Parallel: Approach to Equilibrium / 81

Connecting far-from-equilibrium hydrodynamics, resummed transport coefficients, and attractor solutions

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After briefly reviewing recent developments in the field, we show how far-from-equilibrium hydrodynamics may be systematically defined, for arbitrary flow profiles, in terms of a generalized

tensorial expansion with transport coefficients that contain an all order resummation in gradients. We discuss how this approach naturally relates to *hydrodynamic attractor* solutions found both at weak and strong coupling. In this formulation, the transport coefficients of far-from-equilibrium fluid dynamics depend not only on the microscopic properties of the system but also on the nonlinear properties of the underlying state of the fluid itself. In contrast to previous works, no additional assumptions about the symmetries of the flow are necessary. An example of this proposal is constructed using Israel-Stewart theory and, in this case, the novel resummed transport coefficients decrease with increasing Knudsen number according to formulas that can be readily investigated in current numerical simulations of the quark-gluon plasma, which can be especially relevant to small collision systems.

Parallel: Initial conditions for hydrodynamics & transport coefficients / 82

Principal Component Analysis of collective flow in Heavy-Ion collisions

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Principal Component Analysis (PCA) is a mathematical tool that can capture the most important information in data. As one of the unsupervised algorithms of machine learning, PCA is good at discovering modes or hidden patterns in huge amount of data. It has seen successful applications of PCA in computer vision, data science and physics. Compared with deep learning algorithms, the advantage of PCA lies in its simple and elegant mathematical formulation, which is understandable and traceable. In this talk, we implement PCA to analyze collective flow in Relativistic Heavy-Ion Collisions.

In the first part [1], we demonstrate the ability of PCA to automatically discover flow without any guidance from human beings. PCA is applied to particle yields distribution as a function of transverse plane angle φ in the reaction plane. The eigenmodes decomposed by PCA are similar to, but not identical with traditional Fourier bases. Furthermore, we define new flow harmonics with PCA modes and the new ones serve as better linear predictors for initial eccentricities than traditional ones. Specifically, correlations between same and different harmonics of initial and final states increase and decrease respectively, showing smaller mode-mixing effects.

In the second part [2], as another application of PCA, we study factorization breaking in two-particle correlation $V_{n\Delta}(p_{T1}, p_{T2})$ with respect to transverse momentum p_T [3]. In particular, we focus on the sub-leading flow, which hopefully sheds light on different sources in initial geometries [4]. However, the stability and interpretation of PCA results have to be re-examined. We design different tests to explore the limitations of PCA, arguing that improper choice of p_T range and weight matrix might lead to confusing and inconsistent results. As a consequence, these mentioned technical issues should be addressed before we could come to any conclusions or truly understand physics from PCA results.

[1] Z. Liu, W. Zhao and H. Song, in preparation.
[2] Z. Liu, A. Behera, H. Song and J. Jia, in preparation.
[3] CMS Collaboration, Phys.Rev. C.96.064902
[4] A. Mazeliauskas and D. Teaney, Phys.Rev. C91 (2015) no.4, 044902

Parallel: Collectivity in small systems 2 / 83

Measurement of elliptic and triangular flow with multiparticle correlations in pPb collisions at 8.16 TeV

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The second- and third-order azimuthal anisotropy Fourier harmonics are studied in pPb collisions at $\sqrt{s_{\rm NN}} = 8.16$ TeV over a wide range of event multiplicities. Multiparticle correlations are used to isolate global properties stemming from the collision overlap geometry. The second-order, elliptic" harmonic moment is obtained with high precision through four-, six-, and eight-particle correlations and, for the first time, the third-order,triangular" harmonic moment is studied using four-particle correlations. A sample of peripheral PbPb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV that covers a similar range of event multiplicities to the pPb results is also analyzed. Model calculations of initial-state fluctuations in pPb and PbPb collisions can be directly compared to the high precision experimental results. This work provides new insight on the fluctuation-driven geometry at the earliest stages of heavy ion collisions.

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Higher order flow correlations and their non-linear modes in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with ALICE

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One of the primary goals of flow studies in heavy-ion collisions during recent years is a better understanding of the transport properties of the quark-gluon plasma (QGP), such as the temperature dependence of the shear viscosity to entropy ratio, $\eta/s(T)$. Flow observables, such as the higher order harmonics (n>3) and their non-linear responses to the initial state anisotropy have a strong potential to constrain $\eta/s(T)$ because of different sensitivities for various stages of heavy-ion collisions. These observables have been published in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV by the ALICE Collaboration. However, only harmonics up to the fifth order have been measured with good precision, leaving the orders highly sensitive to η/s as predicted un-investigated.

In this talk, we present the measurements of the symmetry-plane correlations and the non-linear coefficients up to the eighth harmonic order in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV for unidentified charged hadrons. In addition, we present the results of $p_{\rm T}$-differential non-linear flow modes for charged pions, kaons, and (anti-)protons. The results are compared to the lower energy measurements at 2.76 TeV and calculations from state-of-the-art hydrodynamic models.

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Early stage momentum anisotropies and electromagnetic probes of quark-gluon plasma

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Various microscopic models suggest that local rest frame momentum anisotropies can be large during the early stages of evolution of the quark-gluon plasma (QGP). In recent years, the framework

of relativistic anisotropic hydrodynamics (aHydro) has been developed in order to incorporate momentum anisotropic distributions of the QGP constituents into the phenomenological studies of ultra-relativistic heavy-ion collision experiments. In this talk, the question of how much we can learn about the early-time momentum anisotropies by studying the yield and flow of electromagnetic probes will be addressed. In particular, we compare the sensitivity of hadronic and electromagnetic probes to the initial momentum anisotropy used in hydrodynamic calculations.

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Measurement of bottomonia in pp, pPb and PbPb collisions at 5.02 TeV with the CMS detector

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Recent measurements of the $\Upsilon(1S)$, $\Upsilon(2S)$, and\Upsilon(3S)$ mesons in pp, pPb and PbPb collisions at 5.02 TeV are presented. The analysis was performed as a function of rapidity and transverse momentum. In addition, the dependence on the event activity and collision centrality is studied in pPb and PbPb collisions, respectively. New results of the upsilon production in pPb collisions will be reported, compared with the results from PbPb collisions. In this presentation, the results are discussed in terms of the 'cold nuclear matter' effects in pPb collisions and sequential melting scenario in dense partonic matter, as well as the effect from recombination of uncorrelated quarks. The results are also compared with theory models, which can help to improve and constrain the theoretical calculations.

Parallel: nPDF/CNM / 88

Contraining nPDFs with Z boson and Drell-Yan measurements in pPb collisions with CMS

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Nuclear parton distribution functions (nPDFs) of quarks and antiquarks affect the production electroweak bosons in proton-lead (pPb) collision. In this presentation the measurement of Z bosons in pPb collision at center of mass energies of 5.02 TeV and 8.16 TeV with CMS is presented. The rapidity dependence is particularly sensitive to nPDFs, but further information can be gained by studying the mass dependence of DY production, measured for the first time in pPb collisions at 8.16 TeV, down to 15 GeV. In addition, differential measurements in the dimuon pt or ϕ^* (an angular variable correlated with pt, measured for the first time in pPb) provide insights on soft gluon emission at low pt. Finally, prospects on Z boson production with future HL-LHC data are presented.

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Studies of the top quark production in nuclear collisions and impact on nuclear PDFs in CMS

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In proton-nucleus collisions, the top quark is a novel and theoretically precise probe of the nuclear gluon density at high virtualities $Q^2 \approx m_{\mathrm{top}}$ and in the less explored high Bjorken-x region. The first observation of the inclusive $\mathrm{t\bar{t}}$ production has been performed using 174 ± 6 nb^{-1} of data in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV. However, the total uncertainty of about 17% is not sufficient for imposing constraints on current nPDF parameterizations, the dominant source of uncertainty in the theoretical prediction of $\sigma(\mathrm{pPb} \rightarrow \mathrm{t\bar{t}} + X)$. The prospects of measuring σ differentially have recently been examined and a feasibility study of the measurement with the CMS detector at the High-Luminosity LHC (HL-LHC) era is therefore carried out as a function of the reconstructed lepton p_{T} and rapidity. The relative statistical uncertainty in both variables is found to be at the level of $4-5$% in each bin, and it is expected to be the dominant uncertainty at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV for an integrated luminosity scenario of 2 pb^{-1}. The motivations for measurements of top quarks in nucleus-nucleus collisions are multifold and are discussed: the top quark decay products are sensitive to the energy loss of heavy quarks, and a probe of the space-time structure of the QGP at HL-LHC.

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Influence of neutron skin in heavy ion collisions at RHIC energies

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A key ingredient to model heavy ion collisions dynamically is the initial spatial distribution of protons and neutrons inside the nucleus. Traditionally in most theoretical calculations there is no difference between them and their positions are sampled with the Woods-Saxon distribution. However, this assumption has been invalidated by experimental measurements [1]: The diffusiveness of the neutron distribution is larger than the proton one, resulting in a larger amount of neutrons distributed on the outer layers of the nucleus.
We implement the neutron skin together with nucleon-nucleon correlations, in the initial nuclear distribution of the SMASH transport model [2]. With this new state-of-the-art nuclear parametrization [3] we look at different collision systems (Pb+Pb, Zr+Zr, Ru+Ru) at RHIC energies i.e. $7.7 < \sqrt{s} < 200GeV$. We compute eccentricity distributions, charge and isospin densities, and the corresponding magnetic fields. As expected, we observe an increased number of neutron-neutron interactions for peripheral collisions leading to a modification of electric charge dependent observables. In addition, we found a ~10% enhancement of the strength of the magnetic field. The implication of this result for the Chiral Magnetic Effect searches with the isobar run at RHIC is discussed.

[1] Phys. Rev. Lett. 112, 242502
[2] Phys. Rev. C 94, 054905
[3] arXiv:1811.10078v1

Parallel: Collectivity in small systems 1 / 92

IP-Jazma critical assessment of physics attributions

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The IP-Jazma model was constructed to elucidate which features of calculations in the color glass condensate framework are attributable to simple geometry and scaling, and which are manifestations of more complex physics. In this talk we detail comparisons with CGC calculations in the dilute-dense limit, in the dense-dense limit (via IP-Glasma), and more phenomenological models such as Trento. Our result indicate that many results attributed in the literature to complex QCD phenomena are in fact dominated by simple geometric effects.

Parallel: Forward/saturation/spin / 94

Measurements of nuclear parton distribution functions using di-jets, forward jets, and photo-nuclear jets at the CMS detector & prospects for measurements in Run III

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Measurements of dijet production and photo-nuclear interactions in heavy-ion collisions probe several nuclear mechanisms. In particular, dijet measurements in pPb collisions have been shown to be one of the most important tools for constraining the gluon nuclear parton distribution functions (PDFs) at large Bjorken-x. Dijet production in pp and pPb collisions at a nucleon-nucleon centre-of-mass energy of 5.02 TeV is reported with the data samples collected with the Compact Muon Solenoid detector at the Large Hadron Collider. The dijet pseudorapidity distributions are measured as a function of dijet average transverse momentum in order to study the nuclear modifications of PDFs at various factorization scales. The final results from pp and pPb data samples are compared with next-to-leading-order perturbative QCD predictions obtained from both nucleon and nuclear PDFs. A significant modification of dijet pseudorapidity distributions in pPb collisions with respect to the measured pp reference is observed which indicates that the gluon PDF in lead ions is modified and the results are incompatible with predictions with DSSZ PDF without gluon EMC effects. Photo-nuclear jets are also measured in pp and pPb collision systems. The yield and angular correlation of low-pT jets at forward rapidity, $5.0 < |\eta| < 6.5$, are studied using the CASTOR calorimeter, which is sensitive to PDFs at low values of x and Q^2. The prospects of future measurements of forward and ultra-peripheral jets in various collision systems as well as dijet production in pPb at 8.16 TeV and in Run III will also be discussed.

Parallel: Forward/saturation/spin / 95

First measurement of Diffraction in pPb collisions and recent results on ultra-peripheral heavy-ion processes

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In this talk, first results on diffraction measurements in pPb collisions will be presented. This measurement utilizes the larger rapidity acceptance of the CMS detector using forward calorimeters such as the forward hadronic calorimeters HF, CASTOR and ZDC. This measurement provides important information for models related to the initial state in pPb collisions, and can also be used to tune Monte Carlo event generators of cosmic ray physics. In addition, recent results on exclusive vector meson photoproduction of Rho0, J/psi and Upsilon in both pPb and PbPb collisions will be presented. The measured integrated and differential cross sections as a function of rapidity and transverse momentum will be compared to theoretical models.

Parallel: Future facilities / 96

Partonic spatial imaging at an electron-ion collider

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The 2015 U.S. Nuclear Physics Long-Range Plan recommended the realization of an electron-ion collider (EIC) as the next large construction project in the United States. A U.S.-based EIC has also recently been endorsed by the U.S. National Academy of Sciences.
With the design of an EIC, advancements in theory and further development of phenomenological tools, we are now preparing for the next step in subnuclear tomographic imaging. The collider's large range of center-of-mass energy, in combination with very high luminosity and polarization of both the lepton and the hadron beams, will open a unique opportunity for very high precision measurements of both cross sections and spin-asymmetries. This will allow us for a detailed investigation of the partonic substructure of hadrons in multi-dimensions, as well as addressing the role of orbital angular momentum with respect to the nucleon spin.
Generalized parton distributions (GPDs) describe the multi-dimensional partonic structure of a nucleon in coordinate space, providing new information about the internal dynamics of quarks and gluons. Extraction of GPDs from hard exclusive processes and all related probes, is a pillar of the EIC science program.
This talk will highlight key measurements, experimental challenges, and finally discuss the EIC's expected impact over the current knowledge of the partonic multidimensional structure of hadrons in space coordinates.

Parallel: Future facilities / 97

Semi-inclusive Deep-Inelastic Scattering, Parton Distributions and \\ Fragmentation Functions at a Future Electron-Ion Collider

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We present a quantitative assessment of the impact a future Electron-Ion Collider would have in the determination of parton distribution functions in the proton and parton-to-hadron

fragmentation functions through semi-inclusive deep-inelastic electron-proton scattering data. Specifically, we estimate the kinematic regions for which the forthcoming data are expected to have the most significant impact in the precision of these distributions, computing the respective correlation and sensitivity coefficients. Using a reweighting technique for the sets of simulated data with their realistic uncertainties for two different center-of-mass energies, we analyse the resulting new sets of parton distribution functions and fragmentation functions, which have significantly reduced uncertainties.

Parallel: Initial conditions for hydrodynamics & transport coefficients / 98

Measurement of rapidity-odd directed flow for D^0 and $\overline{D^0}$ mesons using the STAR detector at RHIC

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Heavy quarks, owing to their large masses, are predominantly created in the initial hard scatterings in heavy-ion collisions. Therefore, they can play a crucial role in probing the initial-time dynamics in these collisions. Hydrodynamic model calculations suggest that the rapidity-odd directed flow ($v_1(y)$) of particles produced at mid-rapidity can originate from a tilt in the reaction plane of the thermalized matter caused by the asymmetry between the number of participants from projectile and target nuclei as a function of rapidity. Recently, it has been predicted that the slope of the directed flow at mid-rapidity of D^0 mesons, arising from the transport of charm quarks in the tilted medium, can be several times larger than that of light flavor hadrons. A notable feature from the model calculation is the enhanced sensitivity of the D-meson v_1 slope (dv_1/dy), compared to that of light flavor hadrons, to the initial longitudinal profile of the QGP source. It has also been predicted that the transient electromagnetic field at early times can induce a much larger charge dependent directed flow for heavy quarks than for light quarks.

The Heavy Flavor Tracker (HFT) detector at STAR has demonstrated an excellent performance in reconstructing D^0 and $\overline{D^0}$ via hadronic decay channels. In this talk, we will report on the first evidence for a non-zero rapidity-odd directed flow for D^0 and $\overline{D^0}$ mesons in 10-80$\%$ central Au+Au collisions at $\sqrt{s}_{\rm NN}$ = 200~GeV using high statistics data collected with the HFT during the 2014 and 2016 RHIC runs. The average dv_1/dy for D^0 and $\overline{D^0}$ mesons is -0.081 $\pm$ 0.021 $\pm$ 0.017, while that of charged kaons is -0.0030 $\pm$ 0.0001 $\pm$ 0.0002, suggesting a significantly larger slope of the D^0 mesons. The results will be compared to model calculations and physics implications will also be discussed.

Parallel: High pT probes of the initial state / 101

Probing collision dynamics of small system collisions via high p_T hadrons and direct photons by the PHENIX experiment at RHIC

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The recent finding of collective behavior of particles emitted in small system collisions calls for reexamination of such systems to determine whether or effects beyond the initial state nuclear effects play a significant role.

High p_T hadrons from jets and direct photons have been powerful probes to explore the dynamics of the heavy ion collisions, since they are produced at the early stages of the collisions. While photons do not interact strongly and therefore escape the medium largely unmodified, the high p_T hadrons originate from color charged objects that lose significant energy while traversing the medium. Taken together, these provide significant evidence in support of QGP formation in heavy ion collisions. Measurements of these two probes in small system collisions may provide insight to the dynamics of small collision systems and help assess their apparent similarity to heavy ion collisions.

PHENIX has measured mid to high p_T hadrons over wide range of rapidity in $p/d/^3$He+A collisions. PHENIX also has measured direct photons in p/d+A collisions. In this talk, the latest results on the high p_T hadrons and direct photons are presented and the possible additional effects explored by these probes will be discussed.

Parallel: High pT probes of the initial state / 103

How to infer the shape of the QGP droplet from the data

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We propose an approach to extract the spatial anisotropy of QGP formed in ultrarelativistic heavy-ion collisions from measured high-pt observables R_{AA} and v_2. We show, through analytical arguments, numerical calculations, and comparison with experimental data, that $v_2/(1-R_{AA})$ reaches a well-defined saturation value at high $p_\perp$, which is in turn proportional to the initial anisotropy. We provide first anisotropy estimates from our approach, and compare them with predictions of various (fundamentally unrelated) initial state models. With expected future significant reduction of experimental errors, the anisotropy extracted from experimental data will strongly constrain the calculations of initial particle production in heavy-ion collisions and thus test our understanding of QGP physics.

Parallel: nPDF/CNM / 104

PHENIX measurements of muon pairs from $c\bar{c}$, $b\bar{b}$, and Drell-Yan in p+p and p+Au at 200 GeV

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In this talk we present the measurement of the muon pair continuum in p+p and p+Au collisions at a center of mass energy of 200 GeV. Our novel analysis technique enables the isolation of correlated pairs from semi-leptonic decays of charm and bottom hadrons and from the Drell-Yan process. The measured azimuthal correlations of muon pairs from heavy flavor decays are used to constrain the relative contributions of different production mechanisms of ccbar and bbar pairs in p+p collisions.

For bottom production, data from p+Au places limits on possible cold nuclear modifications. Measuring the in Drell-Yan cross-section in p+p and p+A collisions constrains nuclear parton distribution functions and furthers our understanding of initial state effects.

Parallel: Collectivity in small systems 1 / 106

Centrality dependence of collectivity in kinetic theory

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To what extent are fluid-dynamic or particle-like excitations at the origin of the flow phenomena observed in pp, pA and AA collisions? And how does the interplay between these two sources of collectivity change as a function of system size and energy density? Here, we address this question in a simple transport theory that interpolates between free-streaming and viscous fluid dynamics. We discuss how this transport theory accounts for the centrality dependence of v_2 and v_3 between 1\% and 90\% centrality. Investigating the properties of the energy-momentum tensor evolved in this kinetic theory, we conclude that kinetic theory is consistent with a fluid dynamic picture of central PbPb collisions at the LHC, but that it strongly deviates from such a picture in peripheral PbPb collisions.

based on A. Kurkela, U.A. Wiedemann and B. Wu, arXiv:1803.02072 arXiv:1805.04081 and work in preparation.

Parallel: Forward/saturation/spin / 107

Relaxation dynamics of chiral transports and spin polarization in Quark-Gluon Plasma

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We study relaxation dynamics of chiral transport phenomena and spin polarization in Quark-Gluon Plasma in both weakly and strongly coupled regimes. These relaxation dynamics determine the important dynamical time scale for achieving equilibrium spin-polarization of quasi-particles in the presence of magnetic field and fluid vorticity, which are time-dependent in heavy-ion collisions. This is also important in the time-dependence of the Chiral Vortical Effect. Our results should be crucial in a reliable quantitative study of Λ baryon polarization in off-central heavy-ion collisions.

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Forward-backward centrality fluctuation in heavy ion collisions

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Centrality fluctuations is one of the main uncertainties for interpreting the centrality dependence of many experimental observables. The centrality fluctuation is constrained by selection based on particle multiplicity in a reference subevent, and contributes to observables measured in another subevent. Due to the asymmetry between forward- and backward-going participating nucleons, the number of sources for particle production is a function of η even in a single event, which leads to centrality decorrelation between different rapidities. Using a Glauber-based independent source model, we study the influence of centrality decorrelations on multi-particle cumulants. In mid-central collisions, a general relation is established between the multiplicity fluctuation and resulting centrality resolution in given subevent. In ultra-central collisions, where distribution of particle production sources is strongly distorted, we find these cumulants exhibit different behavior, due to observable-dependent non-Gaussianity in the underlying distributions. Furthermore, we investigate the influence centrality fluctuations in HIJING and UrQMD models. This study can be considered as a first step towards detailed understanding of the longitudinal dynamics for particle production in heavy-ion collisions.

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Examination of Flow and Non-Flow Factorization Methods in Small Collision Systems

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Two particle correlations have been used extensively to study hydrodynamic flow patterns in heavy-ion collisions. In small collision systems, such as p+p and p+A, where particle multiplicities are much smaller than in A+A collisions, non-flow effects from jet correlations, momentum conservation, particle decays, etc. can be significant, even when imposing a large pseudorapidity gap between the particles. A number of techniques to subtract the non-flow contribution have been developed by experiments at the LHC for use in p+p and p+Pb collisions. Recently, experiments at RHIC have explored the possibility of adopting these techniques for small collision systems at lower energies. In this talk, we systematically test these techniques using the Monte Carlo generators PYTHIA and HIJING, which do not include any collective flow, and AMPT, which does. We find that it is crucial to examine the results of such tests at the LHC and RHIC both as a function of multiplicity and particle p_{T}. Our results indicate reasonable non-flow subtraction for p+p collisions at the highest LHC energies, while failing if applied to p+p collisions at RHIC. In the case of p+Au collisions at RHIC, both HIJING and AMPT results indicate a substantial over-subtraction of non-flow for $p_{\mathrm{T}} \geq 1$ GeV/c and hence an underestimate of elliptic flow.

Parallel: Collectivity in small systems 2 / **115**

Observation of collectivity in p+Au, d+Au and ^{3}He+Au collisions with PHENIX

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In order to investigate the origin of collectivity in small systems, the PHENIX experiment has collected data of p+Au, d+Au and ^{3}He+Au collisions at 200 GeV, giving a unique set of initial geometries. In this talk we present a complete set of elliptic and triangular flow measurements, which taken together provide unprecedented model discrimination between initial-state momentum correlation effects and final-state effects. This talk also covers the elliptic anisotropies measured in the d+Au beam energy scan, with collision energies ranging from 200 GeV to 19.6 GeV. The d+Au beam energy scan data leaves the intrinsic geometry unchanged but varies the system lifetime and the duration of the possible QGP phase. Measurements of $v_2(p_T)$ and $v_2(\eta)$ at different energies provide important insights about the system dynamics and allow further input for model comparison.

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Investigation of the linear and mode-coupled flow harmonics in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

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The elliptic and triangular flow coefficients, v_2 and v_3, are expected to be driven by the initial anisotropy coefficients of the same order, ϵ_2 and ϵ_3, respectively. However, the higher order flow coefficients, v_n (n > 3), are comprised of linear contributions driven by ϵ_n, as well as mode-coupled contributions derived from the lower order coefficients. The study of these disparate contributions to v_n can give important insight to discern initial-state models and to constrain the temperature-dependent specific shear viscosity, $\frac{\eta}{s}(T)$. In recent work, we have made detailed measurements of both the linear and the mode-coupled coefficients, v_n (n=4,5), in Au+Au collisions ($\sqrt{s_{NN}}$ =200 GeV) using 2- and multi-particle correlations based on the standard and subevent cumulant methods. These measurements will be presented as a function of centrality, p_T and particle species. The comparisons to the LHC measurements and different theoretical calculations will be presented. The implications of these comparisons for initial-state models and $\frac{\eta}{s}(T)$ will be discussed.

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Viscous Hydrodynamics with Finite Baryon Number, Strangeness, and Electric Charge

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Relativistic viscous hydrodynamics has been an essential tool in studying the evolution of the Quark Gluon Plasma (QGP) produced in heavy-ion collisions as well as in searching for the critical point expected to be present for more baryon dense systems. With the coming runs of the Beam Energy Scan II at the Relativistic Heavy Ion Collider (RHIC), it will be necessary to implement conserved

Baryon number, B, electric charge, Q, and strangeness, S, into the hydrodynamic description in order to have relevant theoretical predictions. This requires knowledge of an equation of state that contains thermodynamic information on the associated chemical potentials for B, Q, and S. In this work, we use the most up-to-date equation of state which includes all of the necessary thermodynamic information to make relevant predictions about the effect of transport coefficients on system dynamics. In particular, we will explore how a large bulk viscosity near the critical point could lead to effects such as the possibility of a cavitating system, as well as the slowing down of dynamics leading to a longer lifetime of the fluid.

Parallel: Collectivity in small systems 2 / **120**

Correlations between mid-rapidity charged tracks and large-rapidity event activity in p+Au collisions at sqrt(s_NN)=200 GeV

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Measurements of "small," p+A or d+A, systems at the LHC and RHIC have suggested possible collective flow and, for high event activity collisions, jet modification that may scale with Bjorken x. They also provide input to related questions of the initial state of the proton prior to and throughout its collision with the opposing heavy ion nucleus. This talk presents preliminary measurements of correlations between mid-rapidity charged tracks and high-rapidity event activity measured by scintillator tiles in $\sqrt{s_{\rm NN}} = 200$ GeV p+Au collisions at STAR. These correlations are important because they inform the current discussion regarding the use of the Glauber model in small systems and have implications for calculating nuclear modification and quenching observables in these systems. The results support concerns about centrality binning in p+Au collisions, and as such motivate using ratios of semi-inclusive, as opposed to fully inclusive, jet spectra to look for jet enhancement or suppression.

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NLO+NLLx computation of inclusive photon+dijet production in e+A DIS as a probe of gluon saturation

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We present the first computation of the NLO photon+dijet impact factor in e+A DIS at small x. When combined with the recent derivation of JIMWLK small x evolution to NLLx accuracy, this result provides us with a prediction of the photon+dijet cross-section in e+A DIS to O($\alpha_S^3 \ln(1/x)$) accuracy. The comparison of this result with photon+dijet measurements at a future EIC therefore provides a precision test of the systematics of gluon saturation. In the soft photon limit, one obtains a compact representation of the state-of-the art results for fully inclusive DIS. The novel techniques developed in this computation can also be applied to promote existing LO computations of photon+dijet production in p+A collisions to NLO+NLLx accuracy.

Parallel: Approach to Equilibrium / 126

Off-equilibrium infrared structure of self-interacting scalar fields: Universal scaling, Vortex-antivortex superfluid dynamics and Bose-Einstein condensation

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We map the infrared dynamics of a relativistic single component (N=1) interacting scalar field theory to that of nonrelativistic complex scalar fields. The Gross-Pitaevskii (GP) equation, describing the real time dynamics of single component ultracold Bose gases, is obtained at first nontrivial order in an expansion proportional to the powers of λϕ^2/m^2 where λ, ϕ and m are the coupling constant, the scalar field and the particle mass respectively. Our analytical studies are corroborated by numerical simulations of the spatial and momentum structure of overoccupied scalar fields in (2+1)-dimensions. Universal scaling of infrared modes, vortex-antivortex superfluid dynamics and the off-equilibrium formation of a Bose-Einstein condensate are observed. Our results for the universal scaling exponents are in agreement with those extracted in the numerical simulations of the GP equation. As in these simulations, we observe coarsening phase kinetics in the Bose superfluid with strongly anomalous scaling exponents relative to that of vertex resummed kinetic theory. Our relativistic field theory framework further allows one to study more closely the coupling between superfluid and normal fluid modes, specifically the turbulent momentum and spatial structure of the coupling between a quasi-particle cascade to the infrared and an energy cascade to the ultraviolet. We outline possible applications of the formalism to the dynamics of vortex-antivortex formation and to the off-equilibrium dynamics of the strongly interacting matter formed in heavy-ion collisions.

Parallel: Initial conditions for hydrodynamics & transport coefficients / 127

Factorization breaking - flow angle and magnitude decorrelation

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The factorization breaking of collective flow in transverse momentum or in pseudorapidity is equivalent to a small decorrelation of flow in different phasespace regions. ATLAS has measured, besides the usual factorization breaking (including both flow magnitude and angle decorrelation), the flow angle decorrelation in pseudorapidity. The latter accounts for about half of the total decorrelation. These observations are confirmed in hydrodynamic calculations for the flow decorrelation, both in pseudorapidity [1] and in transverse momentum [2]. The general relation between flow angle and flow magnitude decorrelation can be understood within a simple model with a random component of the flow vector [3].
Our work makes also predictions for additional observables, that could be tested experimentally.

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[2] P. Bozek, Phys. Rev. C98 (2018) 064906.
[3] P. Bozek, H. Mehrabpour, in preparation

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Emergence of collectivity near a critical point

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Ever since the discovery of the quark-gluon plasma (QGP) the location of the critical point in the QCD phase diagram - the end point of the supposed first-order transition between hadronic matter and the QGP - has been a principal research goal for heavy-ion collision experiments at RHIC. We use the gauge/gravity duality to study a four-dimensional, strongly-coupled gauge theory with a first-order, second-order and crossover thermal phase transition. In the dual gauge theory we calculate the formation, evolution and saturation of the spinodal instability. We uncover a new surprising example of the applicability of hydrodynamics to systems with large gradients (JHEP 1706 (2017) 129 + upcoming work).
We discover with out-of-equilibrium shockwave collisions that in theories near a critical point a long-lived, quasi-static state may be formed. moreover, we show the Mueller-Israel-Stewart-type formulation of hydrodynamics to fail to describe pressures (Phys.Rev.Lett. 121 (2018), no.26, 261601) near a critical point. We provide the necessary correction terms and demonstrate that large second-order spatial derivatives need to be accounted for.

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Probing initial stages with scale dependent observables of the QGP in sPHENIX

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Our understanding of QCD under extreme conditions has advanced tremendously following the discovery of the Quark Gluon Plasma and its detailed characterisation in heavy ion collisions at RHIC and the LHC. The sPHENIX experiment at RHIC will provide precision measurements of jet, upsilon and open heavy flavor probes, complementing analogous measurements at the LHC. The physics program enabled by these measurements will advance understanding of QCD dynamics through all phases of the collision, connecting the initial stage in which one expects large temperature and parton density differences between collisions at RHIC and LHC energies, to subsequent stages in which the properties of scale sensitive probes can be further modified. We will describe the current status of the sPHENIX detector and its physics program, with an emphasis on the physics program enabled by the experiment's large coverage, high rate capability and precision vertexing.

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Cold QCD Physics with sPHENIX and Potential Forward Upgrades

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The sPHENIX detector at RHIC, together with the accelerator's unique capabilities, will enable a spectrum of new or improved measurements enhancing our understanding of the initial state for nuclear collisions. Specifically, sPHENIX measurements in spin polarized proton-proton and proton-nucleus collisions will reveal more about how partons behave in a nuclear environment, explore spin-spin and spin-momentum correlations in the nucleon, and provide data to investigate effects of non-universality. A potential upgrade to sPHENIX with forward instrumentation could significantly enhance these physics capabilities. The cold QCD nuclear physics program for the proposed sPHENIX midrapidity detector as well as the enhanced program enabled with forward upgrades will be presented.

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IAC Dinner

Hosted by the Center for Frontiers in Nuclear Science at Miss Mamie's Spoonbread Too, 366 W 110th St, New York, NY 10025 (10 minute walk from Columbia)

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Theory overview

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RHIC/LHC overview

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Low-x frontier

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CMS overview

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STAR overview

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LHCb overview

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ALICE overview

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ATLAS Overview

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PHENIX overview

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Panel discussion: reactions to new data

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PDF+small x resummation

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nPDF overview

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PDF from lattice

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Saturation overview

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Deep Inelastic Scattering in the Valence Regime

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Nucleon imaging

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GPDs/Wigner functions

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Hydrodynamic matching

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Hydro attractors

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Flow: small & large systems

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Initial state correlations

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Hydro in small systems: How small can a QGP be?

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EMC from short range correlations

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Proton shape fluctuations

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Hydro perspectives on BES / Longitudinal dynamics

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Chiral magnetohydrodynamics

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Evidence for EM fields

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Entanglement at collider energies

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Strong & weak coupling approaches

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Transport coefficients

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Corresponding Author: parnold@virginia.edu

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LHC forward physics from hard probes

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Initial stages using EM probes

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Heavy flavor in small systems

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Ridge in e+e-/DIS

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UPC: theory & experiment

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Flash talks & toward the EIC / **176**

v_n–p_{T} correlations in 5.02 TeV Pb+Pb and p+Pb collisions with the ATLAS detector

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Recently collected data by the ATLAS experiment at the LHC offer opportunities to explore dynamic properties of quark-gluon plasma. A new tool to study these properties is the modified Pearson's correlation coefficient, ρ, that quantifies the correlation between the mean transverse momentum in an event,$[p_{\mathrm{T}}]$, and the square of the flow harmonic magnitude, v_n^2. To suppress non-flow effects, v_n^2 is calculated by correlating charged particles from two sub-events covering opposite pseudorapidity ranges of $0.75 < |\eta| < 2.5$ while $[p_{\mathrm{T}}]$ is evaluated for particles with $|\eta| < 0.5$. The measurement of ρ is performed using minimum-bias p+Pb and Pb+Pb collisions at the same energy $\sqrt{s_{\mathrm{NN}}} = 5.02$~TeV allowing for a comparison of the medium dynamics in small and large systems. In Pb+Pb collisions, values of ρ coefficients are found to significantly deviate from zero for studied harmonics (v_2, v_3, and v_4). The coefficients as a function of centrality are observed to be weakly dependent on the transverse momentum range of the selected particles, despite large differences in the mean transverse momentum in an event and the magnitude of fluctuations of flow harmonics. The ρ coefficient in Pb+Pb collisions for the second order harmonics has a positive value for mid-central collisions and decreases in the most central events. In p+Pb collisions the ρ coefficient is measured only for the second order flow harmonics. In both p+Pb and peripheral Pb+Pb collisions, it is found to be negative. All measured coefficients are compared to theoretical models.

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Linear and non-linear response of two-particle correlations to initial-geometry fluctuations

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We investigate the importance of different features of the initial geometry to anisotropic flow fluctuations in heavy-ion collisions. To that end, we explore the hydrodynamic response of differential flow harmonics vn(pT) to generalized eccentricities ϵn,m of the initial density profile within a realistic hydrodynamic model. Special attention is paid to two-particle angular correlations, characterized in detail by the principal-component analysis (PCA). We address the relevance of non-linear response, as well as the stability of the results against the inclusion of extra eccentricities. Additionally, we study new effects from multiplicity fluctuations, which could lead to redundancies in the experimental PCA data.

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Spin at low-x

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pA vs. eA universality

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RHIC/LHC forward physics & upgrades

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EIC perspective

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CERN perspective

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Conference summary

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Measurement of electroweak-boson production in p–Pb and Pb–Pb collisions at the LHC with ALICE

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Heavy electroweak boson production in Pb+Pb collisions with ATLAS

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Constraining nPDFs with Z boson and Drell-Yan measurements in pPb collisions with CMS

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Quarkonium production in pp and p–Pb collisions with ALICE at the LHC

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Measurement of open heavy-flavour hadron production in pp, p–Pb and Pb–Pb collisions with ALICE

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PHENIX measurements of muon pairs from $c\bar{c}$, $b\bar{b}$, and Drell-Yan in p+p and p+Au at 200 GeV

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Non-linear evolution in QCD at high-energy beyond leading order

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Measurements of nuclear parton distribution functions using di-jets, forward jets, and photo-nuclear jets at the CMS detector & prospects for measurements in Run III

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First measurement of Diffraction in pPb collisions and recent results on ultra-peripheral heavy-ion processes

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EPR paradox and quantum entanglement at sub-nucleonic scales

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Magnetic field in expanding quark-gluon plasma

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Relaxation dynamics of chiral transports and spin polarization in Quark-Gluon Plasma

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Connecting far-from-equilibrium hydrodynamics, resummed transport coefficients, and attractor solutions

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Stochastic hydrodynamics and long time tails of a non-equilibrium fluid

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Self-similarity and spectral functions of non-Abelian plasmas in 2+1D

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Off-equilibrium infrared structure of self-interacting scalar fields: Universal scaling, Vortex-antivortex superfluid dynamics and Bose-Einstein condensation

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Holographic collisions with baryon number at intermediate coupling

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Anisotropic hydrodynamics with a realistic collisional kernel

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Hydrodynamics far-from-equilibrium: a concrete example in kinetic theory

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Factorization breaking - flow angle and magnitude decorrelation

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Non-Gaussian fluctuations of v_1, v_2, v_3 and v_4 and their correlations in Pb+Pb collisions with the ATLAS detector

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Longitudinal fluctuations and decorrelations of anisotropic flows in relativistic heavy-ion collisions

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Principal Component Analysis of collective flow in Heavy-Ion collisions

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New paradigm for fluctuations in heavy-ion collisions

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Investigation of the linear and mode-coupled flow harmonics in Au+Au collisions at sqrt(s_NN) = 200 GeV

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ATLAS measurements of azimuthal anisotropy of heavy flavor hadrons in Pb+Pb, p+Pb and pp collisions

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Centrality dependence of collectivity in kinetic theory

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Recent ATLAS results on correlations in small collisions systems and photon-induced processes in ultra-peripheral Pb+Pb collisions at 5.02 TeV

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Investigation of collectivity in small collision systems with ALICE

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IP-Jazma critical assessment of physics attributions

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Measurement of elliptic and triangular flow with multiparticle correlations in pPb collisions at 8.16 TeV

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Observation of collectivity in p+Au, d+Au and ^{3}He+Au collisions with PHENIX

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Correlations between mid-rapidity charged tracks and large-rapidity event activity in p+Au collisions at sqrt(s_NN)=200 GeV

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Hydrodynamic simulations of relativistic nuclear collisions with nucleon substructure: combined analysis of p+Pb and Pb+Pb collision systems at 5.02 TeV

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Initial state fluctuations in Pythia 8

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Measurement of rapidity-odd directed flow for D^0 and $\overline{D^0}$ mesons using the STAR detector at RHIC

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Jet and photon probes of small and large systems in ATLAS

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Measurement of bottomonia in pp, pPb and PbPb collisions at 5.02 TeV with the CMS detector

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Probing collision dynamics of small system collisions via high p_T hadrons and direct photons by the PHENIX experiment at RHIC

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How to infer the shape of the QGP droplet from the data

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A complete set of splitting functions in nuclear matter to any order in opacity and applications to jet physics

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Measurement of heavy-flavour jets and correlations and elliptic flow in small systems with ALICE

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Partonic spatial imaging at an electron-ion collider

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Computing the gluon Sivers function at low-x

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A Forward Rapidity Upgrade for the STAR Detector

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LHCb fixed target results and prospects

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Semi-inclusive Deep-Inelastic Scattering, Parton Distributions and Fragmentation Functions at a Future Electron-Ion Collider

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Probing initial stages with scale dependent observables of the QGP in sPHENIX

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Influence of neutron skin in heavy ion collisions at RHIC energies

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Welcome and conference logistics

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Tribute to Roy Glauber (1925-2018)

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Welcome from Berndt Mueller

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CMS Overview

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Conformal invariance of TMD rapidity evolution

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I discuss conformal properties of TMD operators and present the result of the conformal rapidity evolution of TMD operators in the Sudakov region.

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Conformal invariance of TMD rapidity evolution

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I discuss conformal properties of TMD operators and present the
result of the conformal rapidity evolution of TMD operators in the Sudakov region

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