# CPOD2017: Critical Point and Onset of Deconfinement

Monday, 7 August 2017 - Friday, 11 August 2017

Stony Brook University

# Book of Abstracts

# Contents

**Parallel 3** / **2**

## The Critical Point and particle correlations under thermal stochastic influence

**Author:** Gennady Kozlov[1]

[1] *JINR*

**Corresponding Author:** kozlov@jinr.ru

The critical phenomena of strongly interacting matter are presented in the dual flux tube model at finite temperature. The phase transitions are considered in systems where the Critical Point (CP) is a distinct singular one existence of which is dictated by the dynamics of conformal symmetry breaking.
The physical approach to the effective CP is predicted through the influence fluctuations of two-particle quantum correlations to which the critical mode couples. The finite size scaling effects are used to extract location of deconfinement phase transition.
We obtain the size of the particle emission source, the transverse momenta of correlated particles affected by the stochastic forces in thermal medium characterized by the Ginzburg-Landau (GL) parameter (for the vacuum criterium) which is defined by the correlation length of characteristic dual gauge field. The size above mentioned is blows up when the temperature approaches the critical value, where GL parameter tends to infinity as correlation length becomes large enough.
The results are the subject to the physical programs at accelerators to seach the hadronic matter produced at extreme conditions.

**Parallel 2** / **3**

## Instanton-dyon ensembles reproduce deconfinement and chiral restoration phase transitions

**Author:** Edward Shuryak[1]

[1] *Stony Brook*

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

Paradigm shift in gauge topology at finite temperatures, from the instantons to their constituents – instanton-dyons – has recently lead to studies of their ensembles and very significant advances. Like instantons, they have fermionic zero modes, and their collectivization at sufficiently high density explains the chiral symmetry breaking.
Unlike instantons, these objects have electric and magnetic charges. Simulations of the instanton-dyon ensembles have demonstrated that their back reaction on the Polyakov line modifies its potential and generate the deconfinement transition.
For Nc=2 gauge theory the transition is second order, for Nc=2 Nf=2 QCD both transitions are weak crossovers at happening at about the same condition. Introduction of quark-flavor-dependent periodicity phases (imaginary chemical potentials) leads to drastic changes in both transitions. In particulaly, in the so called $Z(N_c)-QCD$ model the deconfinement transforms to strong first order transition, while the chiral condensate does not disappear at all. The talk will also cover more detailed studies of correlations between the dyons, effective eta' mass and other screening masses. We also studied fluctuations of topological and magnetic charges in sub-volume: those should be compared to corresponding lattice studies.

**Parallel 3** / **4**

## Effective thermal models from the lattice

**Author:** Sourendu Gupta[1]

**Co-author:** Rishi Sharma [1]

[1] *TIFR, Mumbai*

**Corresponding Author:** sgupta@theory.tifr.res.in

We build effective models of the thermodynamics of QCD and match the couplings using a few measurements from the lattice. We discuss further predictions from the models, including corners where the lattice cannot reach yet.

**Parallel 3 / 6**

## Bulk viscous corrections to screening and damping in the deconfined phase at high temperature

**Author:** Adrian Dumitru[1]

[1] *Dept. of Natural Sciences, Baruch College (CUNY)*

**Corresponding Author:** adrian.dumitru@baruch.cuny.edu

Non-equilibrium corrections in a hot and dense QCD medium modify the "hard thermal loops" (HTL) which determine the resummed propagators for gluons with soft momenta as well as the Debye screening and Landau damping mass scales. We compute bulk viscous corrections to a thermal as well as to a non-thermal fixed point. The screening and damping mass scales are sensitive to the bulk pressure and perhaps to (pseudo-) critical dynamical scaling of the bulk viscosity in the vicinity of a second-order critical point. This should affect the properties of quarkonium bound states in the deconfined phase and the dynamics of soft gluon fields.

**Summary**:

Bulk viscous non-equilibrium corrections to Hard Thermal Loops

**Parallel 2 / 7**

## Understand Confinement from Deconfined Phase

**Author:** JINFENG LIAO[1]

[1] *INDIANA UNIVERSITY*

**Corresponding Author:** liaoji@indiana.edu

To understand the mechanism of confinement in QCD (and QCD-like theories) remains a great challenge. In the past decade an interesting new approach to this problem has emerged by studying the confinement mechanism from above". That is, one could probe how confinement occurs by first studying the finite temperature plasma phase above but close to the confinement transition temperature Tc. Important progress has been made along this direction, particularly driven by empirical findings about plasma properties from heavy ion collision experiments and lattice simulations as well as by theoretical developments on topological objects with nontrivial holonomy at finite temperature. In this talk, we report recent progress along this line on two interesting problems. We will first show how the confinement/deconfinement phase transition properties of the SU(2) Yang-Mills theory, as from first principle lattice computations, could be quantitatively described by

a statistical ensemble of the so-called instanton-monopoles with particular short-range monopole-anti-monopole correlations. We will then examine the jet energy loss phenomenon, which provides highly informativeimaging" of the hot medium created in heavy ion collisions. In particular we will demonstrate how a unified description for the currently comprehensive sets of available data, from average suppression to azimuthal anisotropy, from light to heavy flavors, from RHIC 200GeV to LHC 2.76TeV as well as 5.02TeV collisions, can be achieved in a modeling framework called CUJET3, built upon a nonperturbative microscopic model for the hot medium as a semi-quark-gluon-monopole plasma (sQGMP) which integrates two essential elements of confinement, i.e. the Polyakov-loop suppression of quarks/gluons and emergent magnetic monopoles.

**Parallel 3 / 11**

## Traces of non-equilibrium dynamics in relativistic heavy-ion collisions

**Author:** Pierre Moreau[1]

[1] *Frankfurt Institute for Advanced Studies, Johann Wolfgang Goethe Universität*

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

The impact of non-equilibrium effects on the dynamics of heavy-ion collisions is investigated by comparing a non-equilibrium transport approach, the Parton-Hadron-String-Dynamics (PHSD), to a 2D+1 viscous hydrodynamical model, which is based on the assumption of local equilibrium and conservation laws. Starting the hydrodynamical model from the same non-equilibrium initial condition as in the PHSD, using an equivalent lQCD Equation-of-State (EoS), the same transport coefficients, i.e. shear viscosity $\eta$ and the bulk viscosity $\zeta$ in the hydrodynamical model, we compare the time evolution of the system in terms of energy density, Fourier transformed energy density, spatial and momentum eccentricities and ellipticity in order to quantify the traces of non-equilibrium phenomena. In addition, we also investigate the role of initial pre-equilibrium flow on the hydrodynamical evolution and demonstrate its importance for final state observables. We find that due to non-equilibrium effects, the event-by-event transport calculations show large fluctuations in the collective properties, while ensemble averaged observables are close to the hydrodynamical results. [preprint arXiv:1703.09178 [nucl-th]]

**Parallel 2 / 15**

## "Identified hadron production in Ar+Sc collisions at SPS energies"

**Author:** Maciej Piotr Lewicki :[1]

[1] *University of Wroclaw*

NA61/SHINE is a fixed target experiment at the CERN Super Proton Synchrotron. The main goals of the experiment are to discover the critical point of strongly interacting matter and to study the properties of the onset of deconfinement.
In order to reach these goals, a study of hadron production properties is performed in nucleus-nucleus, proton-proton and proton-nucleus interactions as a function of collision energy and size of the colliding nuclei. In this talk, the newest preliminary results on identified hadron spectra produced in Ar+Sc collisions at six beam momenta (13A, 19A, 30A, 40A, 75A and 150A GeV/c) will be shown. The distributions of transverse mass and rapidity will be compared with NA61/SHINE and NA49 p+p, Be+Be and Pb+Pb results, as well as with available world data.

**Summary**:

For the NA61/SHINE Collaboration

**Parallel 2 / 16**

## Net-baryon number fluctuations in the quark-meson-nucleon model at finite baryon density

**Author:** Michał Michał Marczenko[1]

[1] *Institute of Theoretical Physics, Wroclaw*

One of the most significant aspects of QCD thermodynamics is understanding how the transition from hadrons to their constituents—quarks and gluons—relates to the underlying deconfinement and chiral
dynamics. This is of major relevance for heavy-ion collisions, as well as in the study of cold and dense systems, such as compact stars. The latter, however, is often studied exclusively in models of either hadron or quark degrees of freedom. In this talk, we present the mean-field thermodynamics of an effective hybrid
quark-meson-nucleon (QMN) model for QCD phase transitions at low temperatures and finite baryon densities. In this framework, the chiral dynamics is described within the linear sigma model, whereas the deconfinement transition is driven by a medium-dependent modification of the particle distribution functions, where an additional scalar field is introduced. The structure of the net-baryon number fluctuations along with its higher order cumulants is discussed as possible probes for the chiral and deconfinement phase
transitions. A qualitative comparison of the results obtained in the nucleonic (parity doublet) and quark (NJL)models is also presented.

**Parallel 3 / 17**

## Traces of the deconfined phase transition

**Author:** Elena Bratkovskaya[1]

[1] *GSI and Uni. Frankfurt, Germany*

**Corresponding Author:** e.bratkovskaya@gsi.de

We address the issue of the deconfined phase transition from hadronic to partonic matter on microscopic basis.
We report about results from an extended dynamical quasiparticle model (DQPM*) in which the effective parton propagators have a complex selfenergy that depends on the temperature $T$ of the medium as well as on the chemical potential $\mu_q$ and the parton three-momentum $\vec{p}$ with respect to the medium at rest. It is demonstrated that this approach allows for a good description of QCD thermodynamics with respect to the entropy density, pressure etc. above the critical temperature $T_c \approx$ 158 MeV. Furthermore, the quark susceptibility $\chi_q$ and the quark number density $n_q$ are found to be reproduced simultaneously at zero and finite quark chemical potential. The shear and bulk viscosities $\eta, \zeta$, and the electric conductivity $\sigma_e$ from the DQPM* also turn out in close agreement with lattice results for $\mu_q$ =0. The DQPM*, furthermore, allows to evaluate the momentum $p, T$ and $\mu_q$ dependencies of the partonic degrees of freedom also for larger

$\mu_q$ which are mandatory for transport studies of heavy-ion collisions in the regime 5 GeV $< \sqrt{s_{NN}} <$ 10 GeV.

Furthermore, based on the microscopic off-shell PHSD model for strongly interacting matter we analyse the possible traces of the deconfinement and chiral phase transitions in different observables of heavy-ion collisions - particle spectra and ratios, collective properties and fluctuations. In particular, we discuss the perspectives to identify a possible critical point in the $(T, \mu_B)$ phase diagram exploring the strangeness degrees of freedom.

**Parallel 2 / 18**

## Phenomenological QCD equations of state for neutron star mergers

**Author:** TORU KOJO[1]

[1] *Central China Normal University*

**Corresponding Author:** kojo.toru@gmail.com

Based on phenomenological construction of QCD equations of state for the neutron structure, we extend the framework to finite temperature equations of state which have direct relevance to neutron star mergers and supernovae. Our primary target is a matter at baryon density of 5-10n0 (n0: nuclear saturation density) and temperature of ~10-100 MeV in which quark matter may be important. Using a schematic quark model which leads to the color-flavor-locked phase at high density, we study the excitation modes which contribute to the zero point energy and thermal corrections to the equations of state. Goldstone modes, soft modes, and continuum states are taken into account by the phase shift representation of the thermodynamic potential. We argue how the contributions beyond the mean field treatments affect the structure of equations of state.

**Parallel 2 / 19**

## Quasiparticle anisotropic hydrodynamics for ultrarelativistic heavy-ion collisions

**Author:** Mubarak Alqahtani[1]

**Co-author:** Michael Strickland [1]

[1] *Kent State University*

**Corresponding Author:** malqaht3@kent.edu

We present the first comparisons of experimental data with phenomenological results from 3+1d quasiparticle anisotropic hydrodynamics (aHydroQP). We compare charged-hadron multiplicity, identified-particle spectra, identified-particle average transverse momentum, charged-particle elliptic flow, and identified-particle elliptic flow produced in LHC 2.76 TeV Pb+Pb collisions. The dynamical equations used for the hydrodynamic stage utilize non-conformal aHydroQP. The resulting aHydroQP framework naturally includes both shear and bulk viscous effects in addition to higher-order nonlinear transport coefficients. The 3+1d aHydroQP evolution obtained is self-consistently converted to hadrons using anisotropic Cooper-Frye freezeout performed on a fixed-energy-density hypersurface. The final production and decays of the primordial hadrons are modeled using a customized version of THERMINATOR 2. In this first study, we utilized smooth Glauber-type initial conditions and a single effective freeze-out temperature $T_{\rm FO} = 130$ MeV with all hadronic species in full chemical equilibrium. With this rather simple setup, we find a very good description of many heavy-ion observables.

**Parallel 1 / 20**

## Studies of charge-dependent azimuthal correlations in search for the chiral magnetic effect in pPb and PbPb collisions at CMS

**Author:** Sergey Petrushanko[1]

[1] *Moscow State University (RUSSIA)*

**Corresponding Authors:** zhoudunming.tu@cern.ch, serguei.petrouchanko@cern.ch

Studies of charge-dependent azimuthal correlations for same- and opposite-sign particle pairs are presented in PbPb collisions at 5 TeV and pPb colisions at 5 and 8.16 TeV, with the CMS experiment at the LHC. The azimuthal correlations are evaluated with respect to the second- and also higher-order event planes, as a function of particle pseudorapidity and transverse momentum, and event multiplicity. By employing an event-shape engineering technique, the dependence of correlations on azimuthal anisotropy flow is investigated. New results presented provide new insights to the origin of observed charge-dependent azimuthal 1correlations, and have important implications to the search for the chiral magnetic effect in heavy ion collisions.

**Parallel 2 / 21**

## Functional renormalization group study on the phase structure of the Quark-Meson model with ω meson

**Authors:** Defu Hou[1]; Hui Zhang[1]; Toru Kojo[1]

[1] *CCNU*

**Corresponding Author:** houdf@mail.ccnu.edu.cn

We study the phase diagram of two-flavor massless QCD at finite baryon density
by applying the functional renormalization group (FRG) for a quark-meson model with σ, π,and ω mesons. The dynamical fluctuations of quarks, σ, and π are included into the flow equations,while the amplitudes of ω-fields are also allowed to fluctuate. At high temperature the effects of the ω-field on the phase boundary are qualitatively similar to the mean-field results, while the transition line toward the low temperature approaches the FRG results without ω-fields; the order of the phase transition changes from the second to the first order as the temperature is lowered. The critical chemical potential at the tricritical point is affected by the ω-field effects but its critical
temperature stays around the similar value. The origin of the first order line in our FRG results is the fluctuation rather the quark density. Some caveats are given in interpreting our model results in the QCD context.

**Parallel 3 / 22**

## Production of DS meson in Au+Au collision at √sNN = 200 GeV

**Author:** Md Nasim[1]

[1] *UCLA*

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

The primary purpose of relativistic heavy–ion collisions at the Relativistic Heavy Ion Collider (RHIC) is to create QCD matter under high temperature and high density – Quark-Gluon Plasma (QGP), and study its properties. Due to their large masses, heavy quarks are produced on a short time scale in hard partonic scatterings during the early stages of the nucleus–nucleus collisions and the probability of thermal production in the QGP phase is expected to be small. Therefore, they are considered a good probe to study the QGP. Among all the open charm mesons, the charm-strange meson, DS, is particularly sensitive to the charm quark hadronization in the hot nuclear medium because of its unique valence quark composition. The production of DS can be influenced by the charm-quark recombination with strange quarks whose production is enhanced in the deconfined matter. The Heavy Flavor Tracker at STAR provides an opportunity for DS measurements by reconstructing displaced decay vertices.

We will present the invariant yield and elliptic flow of DS as a function of transverse momentum in Au+Au collisions at √sNN = 200 GeV. The ratio between the yields of strange and non-strange open charm mesons will also be presented. The elliptic flow of DS will be compared to those of light mesons.

**Parallel 3 / 23**

## Transport coefficients in Polyakov loop quark meson coupling model: a quasiparticle approach

**Author:** Hiranmaya Mishra[1]

**Co-author:** Aman Abhishek [1]

[1] *Physical Research Laboratory, Ahmedabad*

**Corresponding Author:** hm@prl.res.in

We compute the transport coefficients, namely, the coefficients of shear and bulk viscosity as well as thermal conductivity for hot and dense matter within the Polyakov loop extended Quark meson coupling model.
The estimation of the transport coefficients is made by solving the Boltzmann kinetic equation in presence of mean fields of chiral as well as Polyakov loop within the relaxation time approximation.
The transition rates are calculated in a manifestly covariant manner to estimate the thermal-averaged cross sections for quark-quark and quark-antiquark scattering as well as meson meson scatterring.
The calculations are performed for finite chemical potential also.
Within the parameters of the model, the ratio of shear viscosity to entropy density has a minimum at the Mott transition temperature. At vanishing chemical potential, the ratio of bulk viscosity to entropy density, on the other hand, shows a peak at the critical temperature but vanishes only asymptotically at very high temperature. The effect of Polyakov loop as well as chiral condensates remain significant even for temperatures beyond the transition temperature. The coefficient of thermal conductivity also shows a minimum at the critical temperature.

**Parallel 3 / 25**

## Spectral Functions from the Functional Renormalization Group

**Author:** Jochen Wambach[1]

[1] *ECT* Trento, Italy*

**Corresponding Author:** jwambach@ectstar.eu

In this talk I discuss the modification of mesons in hot and dense QCD matter. After a brief review of changes of the spectral distribution of vector mesons, measured through dilepton-pair production in relativistic heavy-ion collisions, I present new results for the spectral functions of parity partners within the Functional Renormalization Group approach.

**Parallel 2 / 26**

## PHQMD- a novel transport approach for relativisitc heavy ion collisions

**Author:** Joerg Aichelin[1]

**Co-authors:** Arnaud Le Fèvre [2]; Elena Bratkovskaya [3]; Yvonne Leifels [2]

[1] *SUBATECH*

[2] *GSI*

[3] *GSI & Uni. Frankfurt, Germany*

**Corresponding Author:** aichelin@subatech.in2p3.fr

We present the novel microscopic n-body dynamical transport approach PHQMD (Parton-Hadron-Quantum-Molecular-Dynamics) for the description of particle production and cluster formation in heavy-ion reactions at relativistic energies.
The PHQMD extends the established PHSD (Parton-Hadron-String-Dynamics) transport approach by introducing a n-body quantum molecular dynamic type propagation of hadrons.
The n-body origin of this approach allows for a dynamical description of cluster formation (including that of hypernuclei) as well as for studying fluctuations of fragments and hadrons associated with a first order phase transition predicted by phenomenological models for a finite baryon chemical potential and as expected for FAIR and NICA energies. Due to their one-body nature, this is not possible with the presently existing mean-field transport models.
We show that this new approach reproduces the available single particle observables such as rapidity and $p_T$ spectra of produced hadrons and protons in the energy regime from SIS to SPS. We furthermore show that the presently available fragment data in this energy regime are well reproduced for fragments in the projectile/target rapidity as well as for the small fragments observed at midrapidity. We conclude with predictions for the expected fragments and hypernuclei produced at NICA and FAIR energies and the results for the midrapidity fragments observed at RHIC energies.

**Parallel 2 / 27**

## Multi moment cancellation of participant fluctuations - MMCP method

**Author:** Viktor Begun[1]

[1] *Warsaw University of Technology*

**Corresponding Author:** viktor.begun@gmail.com

We propose a new way to correct for finite centrality bin width effect i.e. participant fluctuations in high energy nucleus-nucleus collisions. The MMCP method allows to separate participant fluctuations and obtain fluctuations from one participant - a source - from a combination of the experimentally measured first four moments. The EPOS model is used for the numerical check of the MMCP for the net electric charge fluctuations in the forward rapidity region in Ar+Sc reactions at beam momentum 150 GeV/c. We show that using the existing methods - decreasing a centrality bin width, or

using the Centrality Bin Width Correction procedure, one may still leave some residual participant fluctuations in the sample. Moreover, we show that the Centrality Bin Width Correction procedure may alter the fluctuation measures. The most important advantage of the MMCP is it's precision even when the amount of measured events does not allow to decrease the centrality bin width, or the experimental determination of participants is difficult, e.g. in collider experiments. Even for the largest centrality bin in the considered case, c = 0 − 20%, the relative error of the MMCP for the scaled variance of a source is below 2%. It is especially important in determination of the base line of the fluctuations in the search for the QCD Critical Point and the signals of the QCD phase transition. https://arxiv.org/abs/1705.01110

**Parallel 1** / **28**

## Clusters and higher moments of proton number fluctuations

**Author:** Boris Tomasik[1]

**Co-authors:** Jan Steinheimer [2]; Marcus Bleicher [2]; Zuzana Paulinyova [3]

[1] *Univerzita Mateja Bela*

[2] *Frankfurt Institute for Advanced Studies*

[3] *Pavol Jozef Safarik University*

**Corresponding Author:** boris.tomasik@cern.ch

We show how the skewness and kurtosis of the proton number distribution are influenced by the fact, that some of the produced protons are bound in deuterons. Although the number of deuterons may not be high, the higher moments of proton multiplicity distribution are so sensitive to details that the effect is large. This is relevant for experimental studies of these moments which aim at identifying the deconfinement phase transition. We also propose to use higher moments of deuteron distribution as an efficient tool for pinning down the mechanism of deuteron production.

**Plenary** / **29**

## Vorticity and polarization in baryon-rich matter

**Authors:** Alexander SORIN[1]; Konstantin Gudima[2]; Mircea Baznat[2]; Oleg Teryaev[3]

[1] *Joint Institute for Nuclear Research*

[2] *Institute of Applied Physics, Academy of Sciences of Moldova*

[3] *JINR*

**Corresponding Author:** teryaev@jinr.ru

We study the structure of vorticity and hydrodynamic helicity fields in peripheral heavy ion collisions using the kinetic Quark-Gluon String and Hadron-String Dynamics models. We observe the formation of specific toroidal structures of vorticity field (vortex sheets). Their existence is mirrored in the polarization of hyperons of the percent order. Its rapid decrease with energy was predicted and recently confirmed by STAR collaboration. The energy dependence is sensitive to the temperature dependent term derived and discussed in various theoretical approaches. The antihyperon polarization is of the same sign and larger magnitude. The crucial role of strange vector mesons is also discussed.

**Parallel 1** / **30**

# φ spin alignment w.r.t global angular momentum reconstructed with 1st order event plane

**Author:** Chensheng Zhou[1]

[1] *Brookhaven National Laboratory*

**Corresponding Author:** xanthus@rcf.rhic.bnl.gov

The spin alignment of the φ-meson could be sensitive to different hadronization scenarios and the vorticity of the colliding system. We present the spin alignment measurements of φ-mesons produced at mid-rapidity with transverse momentum up to 5 GeV/c in STAR. The alignment is quantified by the diagonal spin density matrix elements ρ00 with respect to the normal of the 1st order event plane, which itself is reconstructed with the Zero Degree Calorimeter. The results will be presented as a function of the transverse momentum and collision centrality for the beam energies of 11.5, 19.6, 27, 39 and 200 GeV. The implications of our results will be discussed.

**Parallel 2** / **33**

# Strange Hadron ($K_S^0$ and $\Lambda$) Production in Fixed-Target Al+Au collisions at \sqrtsNN\,\, = 4.9 GeV and Au+Au collisions at \sqrtsNN\,\, = 4.5 GeV in STAR

**Author:** Muhammad Usman Ashraf[1]

[1] *Tsinghua University*

**Corresponding Author:** musman_mughal10@yahoo.com

STAR has collected data from \sqrtsNN\,\, = 39 GeV down to \sqrtsNN\,\, = 7.7 GeV Au+Au collisions to complete the BES-I program in 2014. The motivations of this program include looking for the turn-off of signatures of the Quark-Gluon plasma (QGP), searching for the possible QCD critical point and studying the nature of the phase transition between hadronic and partonic matter. According to the results from the NA49 experiment at CERN, the onset of deconfinement may occur at \sqrtsNN\,\, $\approx$ 7 GeV, the low end of the BES range. In 2015, Au+Au and Al+Au fixed-target (FXT) test runs were conducted at \sqrtsNN\,\, = 4.5 GeV and \sqrtsNN\,\, = 4.9 GeV respectively. The fixed-target program proposes to extend the $\mu_B$ range from 420 MeV (\sqrtsNN\,\, = 7.7 GeV) to about 720 MeV (\sqrtsNN\,\, = 3.0 GeV).

In this talk, first physics results of the production of strange hadrons $K_S^0$ and $\Lambda$ from Al+Au fixed-target collisions at \sqrtsNN\,\, = 4.9 GeV, as well as from Au+Au fixed-target collisions at \sqrtsNN\,\, = 4.5 GeV, will be systematically presented and compared. These results demonstrate that STAR has good particle identification capabilities for fixed-target configuration and can efficiently reconstruct the fixed-target events. We will report the spectra, yield and particle ratios of these strange hadrons. The physics implications on the collision dynamics will also be discussed. These results will also be compared with the published results from similar collision energies. The implications of these results on the future STAR fixed-target physics program will be discussed.

**Parallel 1** / **34**

# Collective flow measurements with HADES in Au+Au collisions at 1.23A GeV

**Author:** Behruz Kardan[1]

[1] *IKF, Goethe-Universität Frankfurt*

**Corresponding Author:** bkardan@ikf.uni-frankfurt.de

HADES has a large acceptance combined with a good mass-resolution and good particle-identification capability, and is well equipped to study the azimuthal flow pattern not only for protons and charged pions, but also for lambdas, kaons, $\phi$-mesons and electrons-positron pairs, as well as deuterons, tritons and light nuclear fragments. With the statistics of seven billion Au-Au collisions at 1.23A GeV recorded in 2012, a multi-differential ($p_t$, rapidity, centrality) investigation with unprecedented precision is possible.

At the BEVALAC and SIS18 directed and elliptic flow has been measured for pions, charged kaons, protons, neutrons and fragments, but higher-order harmonics have not yet been studied. They provide additional information on the properties of the dense hadronic medium produced in heavy-ion collisions, such as its viscosity, and provide thus an important reference to measurements at higher energies. We present here a high-statistics, multi-differential measurement of radial flow, obtained with blast wave fit analysis, and of $v_1$, $v_2$ and $v_3$ for protons in Au+Au collisions at 1.23A GeV.

Supported by BMBF (05P15RFFCA), GSI, HGS-HIRe and H-QM.

**Parallel 1 / 35**

## van der Waals Interactions in Hadron Resonance Gas: From Nuclear Matter to Lattice QCD

**Author:** Volodymyr Vovchenko[1]

**Co-authors:** Horst Stoecker [2]; Mark Gorenstein [3]

[1] *Goethe University Frankfurt*

[2] *Frankfurt Institute for Advanced Studies*

[3] *Bogolyubov Institute for Theoretical Physics*

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

We construct an extension of the ideal hadron resonance gas (HRG) model which includes attractive and repulsive van der Waals (VDW) interactions between hadrons, and analyze different observables with this model [1]. The VDW parameters a and b are fixed by the ground state properties of nuclear matter, and this VDW-HRG model yields the nuclear liquid-gas transition at low temperatures and high baryonic densities.

The predictions of the model are confronted with the lattice QCD calculations at zero chemical potential.
The inclusion of baryonic interactions leads to a qualitatively different behavior of the fluctuations of conserved charges in the crossover region.
In many cases it resembles the lattice data. For instance, the VDW-HRG model predicts the drop of the \chi_4/\chi_2 cumulant ratio for the net baryon number fluctuations in the crossover region, which is also seen on the lattice.

Calculations are also performed at finite chemical potentials.
The VDW-HRG model predicts a non-monotonic behavior of the net baryon \chi_4/\chi_2 ratio with respect to the collision energy, in stark contrast to the ideal HRG.
This implies that non-trivial fluctuations of net-baryon number
in heavy-ion collisions
manifest traces of the nuclear liquid-gas phase transition.

We also analyze the preliminary lattice data at imaginary chemical potential [2] with the VDW-HRG model.
The lattice behavior of the Fourier coefficients in the Fourier expansion of baryon density at imaginary baryochemical potential is shown to be consistent with presence of eigenvolume-type repulsive baryonic interactions.
The same conclusion is obtained by analyzing the phase shifts of nucleon-nucleon scattering.

[1] V. Vovchenko, M.I. Gorenstein, H. Stoecker, Phys. Rev. Lett. 118, 182301 (2017)

[2] S. Borsanyi et al. [Wuppertal-Budapest Collaboration], Talk at Quark Matter 2017 conference (5-11 February 2017, Chicago, USA)

**Parallel 2** / **36**

## An Improved Event Plane Detector for the STAR Experiment

**Author:** Prashanth Shanmuganathan[1]

[1] *Lehigh University*

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

During the first phase of the beam energy scan (BES-I), the STAR collaboration investigated observables as a function beam energy in order to map the QCD phase diagram.
Some of these observable showed hints of non-monotonic behavior, but limited statistics, analysis dependent collision centrality estimation, and poor event plane resolution did not allow firm conclusions for discovery.
Therefore, BES-II has been approved to take data in 2019 and 2020.
A Low Energy RHIC electron Cooling upgrade underway will provide increased luminosity at BES energies.
Several ongoing detector upgrades at STAR will improve acceptance and improve particle identification.

An Event Plane Detector (EPD), is one such upgrade to the existing detector.
The EPD replaces the existing Beam-Beam Counter detector with larger granularity, acceptance and leaves a large $\eta$ gap between the centrality detector
and the main tracking detector (TPC).
Thus the EPD provide collision centrality independent of TPC, better event plane resolution and allows STAR to trigger on high luminosity collisions at lower energies, so that significant enhancements of the measurements can be achieved.
In this talk we will present detector design, results from prototype testing in 2016, ongoing commissioning status in 2017, and plans for assembling the full detector for running in 2018.

**Parallel 1** / **37**

## Search for the critical point of strongly interacting matter through power-law fluctuations of the proton density in NA61/SHINE

**Authors:** Fotios Diakonos[1]; Nikolaos Antoniou[1]; Nikolaos Davis[2]

[1] *University of Athens, Physics Department, Section of Nuclear and Elementary Particle Physics, GR-15771*

[2] *Institute of Nuclear Physics, Polish Academy of Sciences (PAN), Krakow, Poland*

**Corresponding Author:** nikolaos.davis@ifj.edu.pl

The search for experimental signatures of the critical point (CP) of strongly interacting matter is one of the main objectives of the NA61/SHINE experiment at CERN SPS. In the course of the experiment, an energy (beam momentum 13A – 150/158A GeV/c) and system size (p+p, p+Pb, Be+Be, Ar+Sc, Xe+La) scan is performed. Proposed observables include non-monotonic fluctuations of integrated quantities, as well as local critical fluctuations connected to the critical behavior of the order parameter in the CP neighborhood, which scale according to universal power-laws.

We investigate proton density fluctuations as a possible order parameter of the phase transition in the neighborhood of the CP. To this end, we perform an intermittency analysis of the proton second scaled factorial moments (SSFMs) in transverse momentum space. A previous analysis of this sort revealed significant power-law fluctuations in the NA49 heavy ion collision experiment for the "Si"+Si system at 158A GeV/c. The fitted power-law exponent was consistent with the theoretically expected critical value, within errors, a result suggesting a baryochemical potential for the critical point in the vicinity of ~250 MeV. We now extend the analysis to NA61 systems of similar size, Be+Be and Ar+Sc, at 150A GeV/c.

We adapt statistical techniques for the calculation of scaled factorial moments, in order to subtract non-critical background and enhance the signal in cases of low statistics. Our analysis is supplemented by both critical and non-critical Monte Carlo simulations, through which we estimate non-critical background effects on the quality and magnitude of uncertainties of the intermittency power-law fit, as well as explore the possibility of non-critical effects producing an intermittency signal.

**Parallel 2 / 38**

## Non-local Dynamics

**Author:** Scott Pratt[1]

[1] *Michigan State University*

**Corresponding Author:** prattsc@msu.edu

Adding gradient terms to thermodynamic quantities has long been a means to incorporate finite-range interactions into descriptions of equilibrated physics. Here, we show how gradient terms can be incorporated into hydrodynamic treatments, thus making it possible to dynamically model the growth of fluctuations and correlations of charge, energy and momentum in a consistent fashion for any hydrodynamic evolution. A single parameter, along with constraints from Kubo relations, then determines all the behavior. Sample calculations will be presented for simple systems, with the immediate goal of understanding the degree to which novel features of the phase diagram can manifest themselves in final-state measurements.

**Parallel 1 / 40**

## Characterizing hydrodynamical fluctuations in heavy-ion collisions from effective field theory approach

**Author:** Pak Hang Lau[1]

**Co-authors:** Hong Liu [1]; Yi Yin [1]

[1] *MIT*

**Corresponding Author:** phcl2@mit.edu

Recently, an effective field theory for fluctuating dissipative hydrodynamics has been developed in 1511.03646 and 1701.07817. We apply this theory to investigate hydrodynamic fluctuations on the Bjorken expanding quark-gluon plasma (QGP). In particular, we explore effects due to nonlinear interactions among hydrodynamical variables and noises which are systematically incorporated in the present framework but are not fully captured in conventional approaches. Finally, we discuss its application to model bulk evolution of QCD matter near the critical point.

**Parallel 3 / 41**

## Transport Properties of Quark-Gluon Plasma in Magnetic Fields

**Authors:** Daisuke Satow[1]; Ho-Ung Yee[2]; Kenji Fukushima[3]; Kiminad Mamo[4]; Koichi Hattori[5]; Shiyong Li[4]; Yi Yin[6]

[1] *Kyoto university*

[2] *University of Illinois at Chicago*

[3] *University of Tokyo*

[4] *University of Illinois, Chicago*

[5] *Fudan University*

[6] *MIT*

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

Motivated by a strong, transient magnetic field that may affect the Quark-Gluon Plasma formed in off-central heavy-ion collisions, we present our recent progress on the computation of several key transport properties of the Quark-Gluon Plasma in the presence of magnetic field, in leading order of perturbative QCD that is applicable in high enough temperature.
These include the longitudinal electric conductivity, the sphaleron transition rate, the jet-quenching parameter, and the heavy quark diffusion constant in the case of a strong magnetic field ($eB \gg T^2$), as well as the shear viscosity in a soft magnetic field ($eB \sim g^4 \log(1/g)T^2$).

**Parallel 1 / 42**

## Anatomy of Chiral Magnetic Effect In and Out of Equilibrium

**Authors:** Dmitri Kharzeev[1]; Ho-Ung Yee[2]; Mikhail Stephanov[3]

[1] *Stony Brook University*

[2] *University of Illinois at Chicago*

[3] *UIC*

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

We identify a new contribution to the chiral magnetic conductivity at finite frequencies-the magnetization current. This allows us to quantitatively reproduce the known field-theoretic time-dependent (AC) chiral magnetic response in terms of kinetic theory. We evaluate the corresponding AC chiral magnetic conductivity in two-flavor QCD plasma at weak coupling. The magnetization current results from the spin response of chiral quasiparticles to magnetic field, and is thus proportional to the quasiparticle's g-factor. In condensed matter systems, where the chiral quasiparticles are emergent and the g-factor can significantly differ from 2, this opens up the possibility of tuning the AC chiral magnetic response.

**Parallel 1 / 43**

## Thermodynamics of baryon rich hadronic matter

**Author:** Peter Petreczky Petreczky[1]

**Co-author:** Pasi Huovinen [2]

[1] *BNL*

[2] *University of Wroclaw*

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

We study the thermodynamics of hadronic matter using
the hadron resonance gas model with repulsive interactions
between baryons. The repulsive interactions are modeled
using the mean field approach. We study higher order fluctuations
of baryon number and strangeness within this approach and compare
the calculations with the most recent lattice results.
We find that the repulsive mean field reduces the thermodynamic
properties as expected. More interestingly, however, we find that
the reduction is bigger for the higher order fluctuations,
in particular the repulsive mean field approach predicts
chi_4^B/chi_2^B (the ratio of the fourth to second order baryon number fluctuations)
should decrease close to Tc as seen on the lattice.
After validating the model through detailed comparison with the lattice
data we extend the study of thermodynamics in the baryon dense region with
muB>400 MeV, which is not accessible with current lattice calculations.

**Summary**:

We study fluctuations of conserved charges and QCD thermodynamics at non-zero baryon density using hadron resonance gas model with repulsive interactions.

**Parallel 1** / **46**

## Partial Thermalization of Long Range Fluctuations in Nuclear Collisions

**Author:** Sean Gavin[1]

[1] *Physics Department, Wayne State University*

**Corresponding Author:** sean@physics.wayne.edu

Correlations born before the onset of hydrodynamic flow can leave observable traces on the final state particles. Measurement of these correlations can yield important information on the isotropization and thermalization process. Starting with Israel-Stewart hydrodynamics and Boltzmann-like kinetic theory in the presence of dynamic Langevin noise, we derive a new partial differential equations for two-particle correlation functions [1,2].

To illustrate how these equations can be used, we study the effect of thermalization on long range correlations. Specifically, at early times we characterize the degree of thermalization in terms of the average probability S that a parton suffers no interactions. We show quite generally that fluctuations of transverse momentum, multiplicity and related quantities scale differently with S, in a manner dictated by the conservation laws. We then illustrate how to measure the degree of thermalization in pp and pA collisions.

[1] S. Gavin, G. Moschelli, C. Zin, Phys. Rev. C 94, 024921 (2016).
[2] S. Gavin, G. Moschelli, C. Zin, arXiv:1612.07856 [nucl-th].

**Parallel 2** / **49**

## Possible higher order phase transition in large-N gauge theory at finite temperature

**Author:** Hiromichi Nishimura[1]

**Co-authors:** Vladimir Skokov [1]; rob pisarski [2]

[1] *BNL*

[2] *bnl*

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

We use a semiclassical method to analyze the phase structure of SU(N) gauge theory at infinite N in the presence of the external field. The effective potential can be written in terms of a Landau free energy for Polyakov loops, and we construct it using the perturbative contribution and a double trace deformation as the unknown confining potential. We show that there is a surface of a continuous phase transition analogous to the Gross-Witten-Wadia transition, whose boundary terminates at a tricritical point of a critical first-order phase transition. Depending on the confining potential we have considered, it gives rise to a different critical exponent with a different universality class: In the Ehrenfest classification, the order of phase transition can be third, fourth, or fifth. Because the specific heat and the eigenvalue distribution of the Polyakov loop are sensitive to the confining potential, we argue that lattice simulations for large N could probe the order of phase transition as well as the form of the confining potential in any 1+d dimensions.

**Parallel 2 / 51**

## Self-consistent resummation for description of the hadron matter properties in critical region

**Author:** David Blaschke[1]

**Co-authors:** Agnieszka Wergieluk [2]; Aleksandr Dubinin [3]; Alexandra Friesen [1]; Andrey Radzhabov [4]

[1] *BLTP, JINR Dubna*

[2] *UCLA, USA*

[3] *Jagellonian University Cracow, Poland*

[4] *Irkutsk, Russia*

**Corresponding Author:** david.blaschke@gmail.com

The effective models of QCD, like NJL or PNJL model describe properties of hadron matter using mean field approximation. At that time at critical region quark-meson correlations can play crushing role. We consider \Phi-derivable approximation as an instrument for description of matter at finite temperature and density. Such approach treats interactions in terms of fully-dressed propagators. In such approximation it becomes possible to resolve the entropy of relativistic plasma from interacting elementary excitations. Such approximation also lets describe back-reaction of pions on quark dynamics (Pauli-blocking) in critical region.

**Parallel 3 / 52**

## Holographic Hadronization and Thermal Hadron Emission Rate in N=4 SYM Plasma on the Coulomb Branch

**Author:** Kiminad Mamo[1]

[1] *UIC/Stony Brook University*

**Corresponding Author:** kiminad.mamo@stonybrook.edu

We study N=4 super Yang-Mills theory on the Coulomb branch (cSYM) in the strong coupling limit by using the AdS/CFT correspondence. The dual geometry is the rotating black 3-brane Type IIB supergravity solution with a single non-zero rotation parameter r_0 which sets a fixed mass scale corresponding to the scalar condensate <O>~r^4_0 in the coulomb branch. We introduce a new ensemble where T and r_0 are held fixed, and show that r_0 plays a similar role as Λ_QCD. We compute the equation of state (EoS) of N=4 cSYM at finite T, as well as the heavy quark-antiquark potential V(L) and the quantized mass spectrum of the scalar and spin-2 glueballs at T=0. By computing the Wilson loop (minimal surface) at T=0, we determine the heavy quark-antiquark potential V(L) to be Cornell potential. At T≠0, we find two black hole branches: the large black hole and small black hole branches. For the large black hole branch, that has positive specific heat, we find qualitatively similar EoS to that of pure Yang-Mills theory on the lattice. For the small black hole branch, that has negative specific heat and Hawking radiate, we find an EoS where the entropy and energy densities decrease with T. Moreover, we show that the large and small black holes are connected to each other by a second-order phase transition. We conjecture that the small black hole branch should be identified as dual to a thermal gauge theory (N=4 cSYM) in its hadronizing phase. We argue that our conjecture naturally resolves the small black hole information paradox. We also propose a formula which relates the Hawking radiation rate with the thermal hadron emission rate, and in the hydrodynamic limit reduces to Cooper-Frye formula in the local frame.

**Parallel 1** / **53**

## Out-of-equilibrium hydrodynamic fluctuations in the expanding QGP

**Author:** Aleksas Mazeliauskas[1]

**Co-authors:** Derek Teaney [2]; Yukinao Akamatsu [3]

[1] *University of Heidelberg*

[2] *Stony Brook*

[3] *Osaka University*

**Corresponding Author:** a.mazeliauskas@thphys.uni-heidelberg.de

We develop a set of kinetic equations for a correlator of thermal fluctuations which are equivalent to nonlinear hydro-dynamics with noise. We first show that the kinetic response precisely reproduces the one-loop renormalization of the shear viscosity for a static fluid previously discussed by Kovtun, Moore and Romatschke.

We then use the hydro-kinetic equations to analyze thermal fluctuations for a Bjorken expansion. The rapid Bjorken expansion of a medium drives the hydrodynamic fluctuations out of equilibrium prescribed by the fluctuation-dissipation theorem. The steady state solution to the kinetic equations determine the coefficient of the first fractional power of the gradient expansion ($\propto 1/(\tau T)^{3/2}$ ), which was computed for the first time for Bjorken expansion. Away from the conformal limit, such non-linear noise corrections also induce a non-vanishing bulk viscosity.

The formalism of hydro-kinetic equations can be applied to more general background flows, non-conformal systems and coupled to existing viscous hydrodynamic codes to incorporate the physics of hydrodynamic fluctuations, which become dominant near the critical point.

Reference:
Phys. Rev. C 95, 014909 (2017)

**Parallel 3** / **54**

## Dileptons at low energies

**Author:** Itzhak Tserruya[1]

[1] *Weizmann Institute*

**Corresponding Author:** itzhak.tserruya@weizmann.ac.il

An excess of dileptons has been observed from the top RHIC energies of sqrt(s_NN)=200 GeV down to the lowest SPS energies of sqrt(s_NN)= 9 GeV. The RHIC beam energy scan and the new facilities under construction NICA and FAIR will allow to push the measurement of dileptons to much lower energies and to establish the onset of the low-mass excess related to chiral symmetry restoration and of the intermediate mass excess related to the QGP thermal radiation. I will review the potential, challenges and prospects of these measurements.

**Parallel 2** / **55**

## Two-particle correlations in azimuthal angle and pseudorapidity in Be+Be collisions at SPS energies

**Author:** Bartosz Maksiak[1]

[1] *Warsaw University of Technology*

**Corresponding Author:** maksiak@if.pw.edu.pl

The NA61/SHINE experiment aims to discover the critical point of strongly interacting matter and study the properties of the onset of deconfinement. These goals are to be achieved by performing a two dimensional phase diagram (T-mu_B) scan by measurements of hadron production properties in proton-proton, proton-nucleus and nucleus-nucleus interactions as a function of collision energy and system size. In this contribution, the results on two-particle correlations in pseudorapidity and azimuthal angle will be presented for the first time for Be+Be interactions at beam momenta: 20, 30, 40, 75 and 150 GeV/c per nucleon. The NA61 results will be compared with the already presented results of proton-proton at similar beam momenta. The results will be compared to the EPOS model results.

**Parallel 3** / **58**

## Color screening in 2+1 flavor QCD

**Author:** Johannes Heinrich Weber[1]

**Co-authors:** Alexei Bazavov [2]; Peter Petreczky Petreczky [3]

[1] *Technische Universität München*

[2] *University of California/University of Iowa*

[3] *BNL*

**Corresponding Author:** johannes.weber@tum.de

We study correlation functions of static quark antiquark pair in spatial separation in 2+1 flavor QCD in order to better understand the nature of color screening at high temperatures. We performed lattice calculations in a wide temperature range 140 MeV < T < 5.8 GeV using the highly improved staggered quark (HISQ) action and several lattice spacings to control discretization effects. From the entropy of static quarks we derive a scheme-independent deconfinement temperature and study its relation to chiral symmetry restoration. By comparing our lattice results to the weak coupling calculations as well as to the zero temperature result on the energy of static quark anti-quark pair we show that color screening sets in at distances rT ~ 0.3. We also conclude that in the distance range 0.3 < rT < 0.6 the weak coupling approach provides adequate picture for color screening.

**Parallel 3** / **59**

## Holographic collisions in non-conformal theories

**Authors:** David Mateos[1]; Jorge Casalderrey Solana[2]; Maximilian Attems[1]; Miguel Zilhao[1]; Miquel Triana[1]

[1] *University of Barcelona*

[2] *University of Oxford*

**Corresponding Author:** attems@icc.ub.edu

We use the gauge/gravity duality to model the out-of-equilibrium first stage of a heavy ion collision through the collision of gravitational shockwaves in numerical relativity. This investigation of collisions of sheets of energy density in a non-conformal theory with a gravity dual is the first non-conformal holographic simulation of a heavy ion collision. I will discuss the new physics that arises (as compared to the much simpler conformal case) such as a new plasma relaxation channel, the equilibration of the conformal symmetry breaking scalar condensate and the presence of a sizeable bulk viscosity. These ingredients are crucial to make qualitative contact of the fast hydrodynamization process of hot plasmas with real-world QCD deconfinement matter above the critical point.

**Summary**:

We numerically simulate gravitational shock wave collisions in a holographic model consisting of Einstein gravity coupled to a scalar field with a non-trivial potential.

**Parallel 3** / **60**

## Freezeout and extent of the hadron resonance gas phase - role of the missing resonances

**Authors:** Bedangadas Mohanty[1]; Debadeepti Mishra[1]; Subhasis Samanta[1]; sandeep chatterjee[2]

[1] *NISER, Jatni*

[2] *AGH-UST, Krakow*

**Corresponding Author:** mail2sandchatt@gmail.com

We study the effect of the missing resonances from the hadron spectrum on the extracted freezeout temperatures and chemical potentials from data on particle yields. We study several decay schemes for these missing resonances and estimate their influence in different freezeout schemes like 1CFO (unified freezeout of all hadrons), 1CFO+$\gamma_S$ ($\gamma_S$ accounting for undersaturation of strangeness) and 2CFO (early freezeout of strangeness). Further, based on monotonicity of several thermodynamic quantities we provide a bound on the extent of the hadron resonance gas phase on the (T, \mu_B) plane. We also discuss how the missing resonances affect this bound.

**Summary**:

We study the effect of the missing resonances from the hadron spectrum on the extracted freezeout temperatures and chemical potentials from data on particle yields as well as the extent of the hadron resonance gas phase on the QCD phase diagram.

**Parallel 1** / **61**

## Presence of Non-dynamical Fluctuations in the Higher Moments of Net-proton Measurements

**Author:** Prakhar Garg[1]

**Co-author:** Dipak Mishra [2]

[1] *Stony Brook University*

[2] *Bhabha Atomic Research Center*

**Corresponding Author:** prakhar.garg@stonybrook.edu

The recent net-proton fluctuation results of the STAR experiment from the beam energy scan (BES) program at the BNL Relativistic Heavy Ion Collider (RHIC) have drawn much attention to explore the QCD critical point and the nature of the deconfinement phase transition. The non-monotonic behavior of $\kappa\sigma^2$ around $\sqrt{s_{NN}}$ = 19.6 GeV in the STAR results even increased the excitement in the field, as it may be associated with the existence of a QCD critical point. Although the presence of many statistical fluctuations become the background for the dynamical fluctuations and it is important to disentangle and identify them to have a correct interpretation. In this presentation we will demonstrate our recent findings for the stopped proton fluctuations and event-pile up scenarios as a background and their influence on the interpretation of net-proton fluctuations.

**Parallel 1** / **62**

## On spinodal points and Lee-Yang edge singularities

**Authors:** David Mesterházy[1]; Mikhail Stephanov[2]; Xin An[3]

[1] *Albert Einstein Center for Fundamental Physics, Institute for Theoretical Physics, University of Bern*

[2] *UIC*

[3] *University of Illinois, Chicago*

**Corresponding Author:** anxin627@gmail.com

The experimental signatures of the QCD critical point rely on the universal singular behavior of the equation of state at the critical point. Therefore, we study singularities of the universal scaling equation of state of the phi4 theory, or the Ising model. We focus on
the relation between spinodal points that limit the domain of metastability for temperatures below the critical temperature, i.e., T<Tc, and Lee-Yang edge singularities that limit the domain of analyticity around the point of zero magnetic field H for T>Tc. The extended analyticity conjecture (due to Fonseca and Zamolodchikov) that for T<Tc the Lee-Yang edge singularities are the closest singularities to the real H axis have interesting implications, in particular, that the spinodal singularities do not lie on the real H axis. We find that the Ising model parametric equation of state obtained in the epsilon=4-d expansion, as well as the related O(N) model equation of state at large N, are both non-trivially consistent with this conjecture, and analyze the reason for the difficulty of addressing this question using the epsilon-expansion. In particular, we resolve the long-standing paradox associated with the fact that the vicinity of the Lee-Yang edge singularity is described by Fisher's phi3 theory, which is non-perturbative even for d>=4 where the equation of state of the phi4 theory is expected to become mean-field-like. We derive the Ginzburg criterion that determines the size of the region around the Lee-Yang edge singularity, where the mean-field theory no longer applies.

**Parallel 3** / **63**

## How a Lifshitz point changes the phase diagram of QCD

**Authors:** Vladimir Skokov[1]; rob pisarski[2]

[1] *RBRC*

[2] *bnl*

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

We consider the implications for spatially inhomogenous phases,
and an associated Lifshitz point, in the phase diagram
of QCD. This could produce two critical endpoints in the plane
of T and $\mu$: a Lifshitz point at a higher $T$ and a smaller $\mu$ than for the "usual" critical endpoint (where the quartic scalar coupling vanishes).
The most dramatic signature of a spatially modulated phase is elementary,
with particle production peaked at some characteristic value of the spatial momentum. Such
a signal is suggestive of recent STAR data in the recent Beam
Energy Scan.

**Parallel 1 / 64**

## Volume dependence of baryon number cumulants and their ratios

**Author:** Vladimir Skokov[1]

[1] *RBRC*

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

It is well known that finite volume effects have marginal influence on the chiral condensate at zero temperature and chemical potential. However, in hot and dense medium, higher order cumulants of baryon number, including skewness and kurtosis, are expected to be more sensitive.
We explore the influence of finite volume effects on baryon number fluctuations in a non-perturbative chiral model. In a finite volume there are only apparent critical points, about which we compute the ratio of the fourth to the second order cumulant of quark number fluctuations. When the volume is sufficiently small the system has two apparent critical points; as the system size decreases, the location of the apparent critical point can move to higher temperature and lower chemical potential. In this talk, we demonstrate the dependence of the higher order baryon number cumulants on volume.

**Parallel 1 / 66**

## Parametrized Equation of State for QCD from 3D Ising Model

**Author:** Paolo Parotto[1]

[1] *University of Houston*

**Corresponding Author:** pparotto@uh.edu

The only first principle knowledge of the QCD equation of state at finite baryonic density is given from Lattice QCD as a Taylor expansion around $\mu_B = 0$. The coefficients of such an expansion are currently available up to order $calO(\mu_B^6)$. The expected critical behavior of QCD is in the same static universality class as the 3D Ising model. By means of a suitable parametrization for the scaling equation of state of 3D Ising and a parametrized map to connect to QCD, we present an equation of state matching first principle Lattice QCD calculations, which spans the values of baryonic densities explored in the BES-II program, and includes the correct scaling behavior in the proximity of the critical point.

This EoS can serve as an important ingredient for the fluid dynamical simulations of heavy ion collisions at BES energies needed as a basis for the calculation of observables. Future comparisons between such calculations and BES-II data can constrain the parameters in the EoS – including the parameters that describe the location of the critical point.

This contribution reports on work done within the Fluctuations/Equation of State working group of the BEST Collaboration.

**Parallel 2** / **68**

## Chiral phase diagram in soft-wall AdS/QCD

**Author:** Sean Bartz[1]

[1] *Macalester College*

**Corresponding Author:** sbartz@macalester.edu

The holographic connection between strongly-coupled gauge theories and extra-dimensional gravitational theories has succeeded in describing many features of non-perturbative QCD. Phenomenological models called AdS/QCD use a five-dimensional AdS black hole to study thermodynamic properties of the quark-gluon plasma. In this talk, we focus on the phase transition that occurs as chiral symmetry is restored at high temperature and chemical potential.

Using a Reissner-Nordstrom metric for a charged black hole, we find a critical temperature around 150 MeV and a critical quark chemical potential around 560 MeV. We qualitatively reproduce the Columbia plot, showing the dependence of the phase transition order on the light and strange quark masses. We show that the introduction of a chemical potential does not affect the order of the phase transition, implying the absence of a critical point in this simple model. Finally, we discuss efforts to include a Hawking-Page deconfinement transition or a critical point in the chiral phase diagram.

**Parallel 1** / **69**

## World-line approach to chiral kinetic theory

**Author:** Raju Venugopalan[1]

**Co-author:** Niklas Mueller [2]

[1] *BNL*

[2] *University of Heidelberg*

In heavy-ion collisions, an interesting question of phenomenological relevance is how the chiral imbalance generated at early times persists through a fluctuating background of sphalerons in addition to other "non-anomalous" interactions with the QGP. To address this question, we construct a relativistic chiral kinetic theory using the world-line formulation of quantum field theory. This permits an intuitive and elegant interpretation of chiral kinetic dynamics in terms of a supersymmetric world-line action for spinning, colored, Grassmanian point particles in external backgrounds. We outline how Berry's phase arises in this framework, and how its effects can be clearly distinguished from those arising from the chiral anomaly.
We will outline how this framework can be matched to classical statistical simulations at early times and to anomalous chiral hydrodynamics at late times. Finally, we will briefly discuss the applications of our framework to the transport of chiral fermions in other many-body contexts.
References:
[1] The chiral anomaly, Berry's phase and chiral kinetic theory, from world-lines in quantum field theory, N. Mueller and R. Venugopalan, arXiv:1701.03331 [hep-ph], submitted to Phys. Rev. Lett.

[2] World-line construction of a covariant chiral kinetic theory, N. Mueller and R. Venugopalan, arXiv:1702.01233 [hep-ph], submitted to Phys. Rev. D

**Parallel 3** / **70**

## Fluctuations and hadronic correlation functions from the instanton-dyon ensembles

**Author:** Edward Shuryak[1]

[1] *Stony Brook*

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

Instanton dyons are topological objects generalizing instantons to the case of nonzero VEV of the Polyakov line. Previous simulations of their ensembles have reproduced the location and the order of the deconfinement transition in pure gauge theories. They also explain the location and crossover nature of the chiral transition in QCD with dynamical quarks. In the deformed QCD with nonzero imaginary chemical potentials, called Zn QCD, both the deconfinement and the chiral transition completely change, to strong first order and no transition, respectively.
New studies focus on fluctuations of topological, electric and magnetic charges in sub volumes, as well as on hadronic correlation functions, for mesonic and baryonic local operators. We observe that this theory reproduces well all known vacuum phenomenology of correlators, at its lowest temperatures, provided there is certain strong correlation in locations of M-type and L-type dyons.

**Parallel 3** / **71**

## The fate of U(1)A and topological features of QCD at finite temperature

**Author:** Sayantan Sharma[1]

[1] *BNL*

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

The nature of chiral phase transition for QCD with two light quark flavors is not yet completely resolved. This is primarily because one has to understand whether or not the anomalous U(1) symmetry in the flavor sector is effectively restored along with the chiral symmetry.
Since the physics near the chiral phase transition is essentially non-perturbative, we employ first principles lattice techniques to address this issue. We use overlap fermions, which have exact chiral symmetry on the lattice, to probe the anomalous U(1) symmetry violation of 2+1 flavor dynamical QCD configurations with domain wall fermions. The latter also optimally preserves chiral and flavor symmetries on the lattice. We observe that the anomalous U(1) is not effectively restored in the chiral crossover region. We perform a systematic study of the finite size and cut-off effects since the signals of U(1) violation are sensitive to it. For the same reasons we also compare our results from the continuum extrapolated results of the QCD Dirac spectrum obtained from a different lattice discretization called Highly Improved Staggered Quarks. Our studies also provide a glimpse of the microscopic topological structures of the QCD medium that are responsible for the strongly interacting nature of the quark gluon plasma phase and related to the physics of confinement and chiral symmetry breaking.

**Parallel 3 / 72**

# Jet-medium interaction and the Gubser flow

**Author:** Li Yan[1]

**Co-authors:** Charles Gale [1]; Sangyong Jeon [1]

[1] *McGill University*

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

We study the effects of expansion and viscous corrections on the hydrodynamical medium response to a high energy jet parton. More specifically, using a semi-analytical Gubser solution to relativistic fluid dynamics, modifications to the formed Mach cone, diffusive wake, and the momentum flow of the medium response along and perpendicular to the jet particle, are analyzed mode-by-mode. This should provide intuition and guidance for analyses of the experimentally measured jet sub-structures in heavy-ion collisions.

**Parallel 2 / 73**

# Locating the critical end point

**Author:** Christian Fischer[1]

[1] *JLU Giessen*

**Corresponding Author:** christian.fischer@physik.uni-giessen.de

In this talk I will summarize our recent efforts to determine the location of the critical end point within the framework of Dyson-Schwinger equations. We work in an approximation that reproduces lattice results for the temperature dependent condensate and the unquenched gluon propagator at zero chemical potential.
I discuss results for the phase diagram with 2+1 and 2+1+1 quark flavours at physical quark masses. Furthermore I summarize results for the corresponding quark spectral functions and discuss their temperature dependence.

**Plenary / 74**

# Transiting the QCD Critical Point

**Author:** Derek Teaney[1]

**Co-authors:** Fanglida Yan [2]; Yi Yin [3]; Yukinao Akamatsu [4]

[1] *Stony Brook*

[2] *Stony Brook University*

[3] *MIT*

[4] *Osaka University*

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

Building on an analysis of hydrodynamic long time tails for a Bjorken expansion (Akamatsu 2016), we discuss the hydrodynamic scales associated with transiting the critical point. First, we consider the case where the nuclear medium passes directly through the critical point. In this case, the modes

with wave-number of order the inverse Kibble-Zurek length and smaller fall out of equilibrium during the transit, and limit the growth of critical fluctuations in a characteristic way which depends on the wave-numbers involved. This Kibble-Zurek wavenumber will be contrasted to smaller wave numbers associated with "long-time-tails" which are always out of equilibrium, even away from the critical point (Akamatsu 2016). Subsequently we generalize to the situation when the system misses the critical point by an amount, $\Delta$. In this case there is an additional scale, and Kibble-Zurek scaling is only relevant if $\Delta$ is sufficiently small. We will define "sufficiently small" in the talk and analyze the intermediate case.

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Y. Akamatsu, A. Mazeliauskas and D. Teaney, "A kinetic regime of hydrodynamic fluctuations and long time tails for a Bjorken expansion," Phys. Rev. C95, no. 1, 014909 (2017 [arXiv:1606.07742 [nucl-th]].

**Parallel 1** / **75**

## Excitation and saturation of the spinodal instability

**Authors:** David Mateos[1]; Jorge Casalderrey-Solana[2]; Maximilian Attems[1]; Miguel Zilhao[1]; Miquel Triana[1]; Yago Bea[1]

[1] *University of Barcelona*

[2] *University of Oxford*

**Corresponding Author:** attems@icc.ub.edu

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 first-order transition between hadron matter and QGP - has been a main research goal for heavy-ion collisions experiments. We use the gauge/gravity duality to study as first a four-dimensional, strongly-coupled gauge theory with a first-order thermal phase transition. Placing the theory on a cylinder in a set of homogeneous, unstable initial states the black branes are afflicted by a Gergory-Laflamme instability. In the dual gauge theory this corresponds to a spinodal instability, which drives parts of the spacetime to locally stable regions. We uncover a new surprising example of the applicability of hydrodynamics to systems with large gradients: We show that the time evolution of the spinodal instability and the static final states are accurately described by second-order hydrodynamics.

**Parallel 3** / **76**

## Recent progress in understanding Confinement and Chiral symmetry from Instanton-dyons

**Author:** Rasmus Larsen[1]

**Co-author:** Edward Shuryak [2]

[1] *Stony Brook University*

[2] *Stony Brook*

**Corresponding Author:** rasmus.n.larsen@stonybrook.edu

I will talk about the confinement and Chiral symmetry transitions from the perspective of an interacting ensemble of Instanton-dyons in SU(2) for two flavors. The confinement to deconfinement transition is seen as a transition from entropy dominated to energy dominated, due to the size of the Instanton-dyons being dependent on the Polyakov Loop. Towards higher temperatures the Polyakov

loop value increases, which decreases the range of the anti-periodic fermionic zero-modes, and restores Chiral symmetry. Changing one fermion flavor to periodic boundary condition restores explicit center symmetry, and results in Chiral symmetry never being restored.

**Parallel 1** / **77**

## Beam energy dependence of Levy fit parameters of the HBT correlation functions measured by PHENIX at RHIC

**Author:** Senta V Greene[1]

[1] *Vanderbilt*

**Corresponding Author:** senta.v.greene@vanderbilt.edu

Bose-Einstein correlations of identical hadrons provide information about
the space-time structure of the hadron emission source which reflects the
transition from the sQGP to the hadron gas stage in relativistic heavy ion
collisions. In the beam energy scan runs at RHIC, this analysis will can
provide a primary information for exploring the change from crossover to
first order phase transition is expected to occur.
The description of the measured correlation functions has been assumed to
be Gaussian, but a detailed analysis revealed that the statistically
correct assumption is a generalized Gaussian, the so-called Levy
distribution. One of the resulting source parameters, the Levy stability
parameter alpha, describing the shape of the source, is related to one of
the critical exponents (the so-called correlation exponent eta), and thus
may shed light on the location of the critical endpoint.
In this presentation we report the detailed measurement of the Levy source
parameters as a function of transverse mass in Au+Au collisions at
sqrt(s_NN)
= 39, 62 and 200GeV. We will also discuss a newly found scaling parameter,
Rhat, as a function of transverse mass (lambda(mT)).

**Parallel 3** / **79**

## Low Momentum Direct Photons in Au+Au collisions at 39 GeV and 62.4 GeV measured by the PHENIX Experiment at RHIC

**Author:** Vladimir Khachatryan[1]

[1] *Stony Brook*

**Corresponding Author:** vladimir.khachatryan@stonybrook.edu

Direct photons, which are produced during all stages of a heavy-ion
collision, directly probe
the conditions of their production environment. The large yield and large
anisotropy of low
momentum direct photons observed in 200 GeV Au+Au collisions poses a
significant
challenge to theoretical models. Measurements at a lower collision energy
may provide
new insight on the origin of the low momentum direct photons. PHENIX has
already measured
the direct photons at 200 GeV via their external conversion on detector
material to di-electron

pairs. The advantage of this method is a very good purity in photon identification. This method is also used in our current analysis of the direct photons at two lower energies. We present the results of the measurements of the low momentum direct photons at 39 GeV and 62.4 GeV.

**Parallel 2** / **80**

## Color-flavor center symmetry in QCD and its order parameter

**Author:** Srimoyee Sen[1]

[1] *University of Arizona, Tucson*

Common lore suggests that no well-dened order parameters exist in N-color QCD with massive quarks which are non-trivial at zero baryon density. However we find that, such order parameters do exist when there are n_f quark flavors with a common mass and gcd(nf ;N) > 1. Such theories have Zd color-flavor center symmetry arising from intertwined color-center transformations and cyclic flavor permutations. The realization of this symmetry changes depending on the values of the temperature, baryon chemical potential, and nf/N, with implications for conformal window studies and the QCD phase diagram.

**Parallel 3** / **81**

## Critical endpoint of 4-flavor QCD on the lattice

**Author:** Hiroshi Ohno[1]

[1] *Center for Computational Sciences, University of Tsukuba*

At vanishing chemical potential the chiral phase transition in QCD with three degenerate quark flavors is expected to be of first order in the massless limit. As increasing the quark mass, a region of the first-order phase transition should terminate at a second-order critical endpoint before a crossover region appears. However, lattice studies with staggered-type quarks have shown that the region of the first-order phase transition keeps shrinking by decreasing the lattice spacing and with more improved actions, which may indicate possibility of no first-order phase transition at any finite quark mass. Results with Wilson-type quarks also have the same trend but they are still quantitatively different from those with staggered-type quarks. To understand these puzzling results we studied the nature of phase transition in 4-flavor QCD at vanishing chemical potential on the lattice with $O(a)$-improved Wilson quarks. An advantage of studying 4-flavor QCD is that there is expected to be a stronger first-order phase transition and accordingly, a larger critical quark mass than in 3-flavor, which allows more detailed investigations with numerically less expensive costs. Another advantage is that one can make a better comparison between staggered-type and Wilson-type quarks as there is no issue of rooting. In this talk we determine the critical endpoint from an intersection point of kurtosis of the chiral condensate with three different volumes on lattices with temporal size of 4, 6 and 8. Then, we discuss a location of the critical endpoint in the continuum limit.

**Plenary** / **82**

## Hydrodynamic modeling of RHIC BES

**Author:** Chun Shen[1]

[1] *Brookhaven National Lab*

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

I will review the recent progress on modeling event-by-event bulk dynamics of relativistic heavy-ion collisions at Beam Energy Scan (BES) collision energies at the Relativistic Heavy Ion Collider (RHIC) using a hybrid (viscous hydrodynamics + hadronic cascade) framework. The effects of net baryon current and its dissipative diffusion on the system's evolution will be discussed. The non-trivial longitudinal structure and dynamics of the collision systems, for example, the baryon stopping and transport, as well as longitudinal fluctuations will be highlighted. Quantitative effects of boost-invariance breaking and net-baryon current/diffusion on hadronic flow observables and HBT interferometry will be addressed. Finally, I will discuss the newly proposed dynamical initialization scheme which allows us to study the importance of the pre-equilibrium dynamics at RHIC BES energies.

**Plenary / 83**

## Global Lambda polarization in heavy-ion collisions

**Author:** Qun Wang[1]

[1] *University of science and technology of China*

**Corresponding Author:** qunwang@ustc.edu.cn

We give a brief overview about recent developments in theories and experiments on the global and local spin polarization in heavy ion collisions. We also present our recent results on the energy dependence of the global Lambda polarization in off-central Au+Au collisions in the energy range s_NN=7.7−200 GeV using A Multi-Phase Transport (AMPT) model. The observed polarizations with two different impact parameters agree quantitatively with recent STAR measurements.

**Plenary / 84**

## Proton number fluctuations in Au+Au collisions investigated with HADES

**Author:** Romain Holzmann[1]

[1] *GSI Helmholtzzentrum*

**Corresponding Author:** r.holzmann@gsi.de

Exploiting the (nearly) full range of particles emitted in pion, nucleon, and heavy-ion induced reactions, the HADES experiment at SIS18 is pursuing a systematic investigation of nuclear matter effects at high baryochemical potential. Here, I will give an update on our study of proton number fluctuations in central Au+Au collisions at sqrt(s) = 2.4 GeV with special emphasis on the influence of various contributing effects, namely
efficiency corrections, volume fluctuations and protons bound in fragments.

**Plenary / 85**

## Overview of HADES results

**Author:** Manuel Lorenz[1]

[1] *GU Frankfurt*

**Corresponding Author:** m.lorenz@gsi.de

HADES is a multi-purpose charged-particle detector operated at the SIS18 synchrotron located at the GSI Helmholtz Center for Heavy Ion Research in Darmstadt, Germany. The provided ion beam energies of 1-2 A GeV are the lowest of all currently running heavy-ion experiments and result in the highest baryo-chemical potentials at freeze-out in case of Au+Au collisions. With the high statistics of seven billion Au-Au collisions at $\sqrt{s_{NN}} = 2.4$ GeV recorded in 2012 the investigation of rare and up to now unexplored observables in this energy regime have become possible. We present an overview of our results on (subthreshold) strangeness production, particle flow and its anisotropies, virtual photon emission and net-proton number fluctuations. In addition, we discuss the kinetic and chemical freeze-out conditions of the created system.

**Plenary / 86**

## Beam energy dependence of the viscous damping of anisotropic flow

**Author:** Niseem Abdelrahman[1]

[1] *Stony Brook University*

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

Measurements of the beam energy dependence of anisotropic flow can provide crucial insight on the baryon chemical potential ($\mu_B$) and temperature ($T$) dependences of viscous damping and its associated specific shear viscosity $\eta/s$ in QCD matter. It has been predicted that the $\mu_B$ and $T$ dependence of $\eta/s$ could be sensitive to the critical endpoint (CEP) in the phase diagram for this matter. We will present and discuss recent STAR measurements of the anisotropic flow coefficients $v_n$ ($2 \leq n \leq 5$) as a function of harmonic number ($n$), transverse momentum ($p_T$), and centrality in Au+Au collisions across the full span of BES-I energies ($7.7-200$~GeV). The implications of the extracted excitation function for viscous damping will be discussed as well.

**Plenary / 87**

## Parameter extractions for RHIC BES using Bayesian statistics

**Author:** Jussi Auvinen[1]

**Co-authors:** Iurii Karpenko [2]; Jonah Bernhard [1]; Steffen Bass [3]

[1] *Duke University*

[2] *INFN Florence*

[3] *Duke*

**Corresponding Author:** jaa49@phy.duke.edu

We present the latest results on the collision energy dependence of eta/s, obtained from a Bayesian model-to-data analysis of UrQMD + viscous hydrodynamics hybrid model [1] to RHIC beam energy scan data for Au+Au collisions at 19.6, 39 and 62.4 GeV. A change in eta/s over beam energy scan range would suggest that, in addition to temperature, eta/s depends also on baryon chemical potential mu_B.

Analyzing the dependence of the multiple interconnected parameters of the model on a large set of experimental data necessitates a novel Bayesian statistics approach, including Markov chain Monte Carlo methods and model emulation using Gaussian processes. The end result is a multidimensional conditional probability distribution, where the peak position indicates the most likely combination for the model parameters given the experimental data, and the width of the distribution provides a measure of uncertainty on the choice of the best-fit parameter values.

This approach has been successfully utilized in constraining the temperature dependence of eta/s in Pb+Pb collisions at the LHC [2], and some tentative results, albeit with large uncertainties, have already been obtained also for the mu_B dependence of eta/s in the RHIC beam energy scan [3-5]. For this latest analysis, we have revised the uncertainty estimations in the likelihood calculations, which has led to stronger constraints on the model parameters.

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**Plenary / 88**

## Baryon rich matter research at NICA

**Authors:** Alexander Kovalenko[1]; Alexander SORIN[1]; Grigory Trubnikov[1]; Igor Meshkov[1]; Richard Lednicky[1]; Victor Matveev[1]; Vladimir Kekelidze[1]

[1] *Joint Institute for Nuclear Research*

**Corresponding Author:** sorin@theor.jinr.ru

The NICA (Nuclotron-based Ion Collider fAcility) project is now under active realization stage at the Joint Institute for Nuclear Research (JINR, Dubna). The main goal of the project is an experimental study of hot and dense baryon rich QCD matter in heavy ion collisions at centre-of-mass energies √s_NN = 4 - 11 GeV (NN-equivalent) and the average luminosity of 10E27 cm-2 s-1 for Au(79+) in the collider mode (NICA collider). In parallel, the fixed target experiment BM@N (Baryonic Matter at Nuclotron) at the upgraded JINR superconducting synchrotron Nuclotron are carried out with extracted beams of various nuclei species up to Au(79+) with maximum momenta 13 GeV/c (for protons). The project also foresees a study of spin physics with extracted and colliding beams of polarized deuterons and protons at the energies up
to √s = 27 GeV (for protons). The proposed program allows to search for possible signs of the phase transitions and critical phenomena as well as to shed light on the problem of nucleon spin structure. General design and construction status, physical program of the NICA complex is presented.

**Plenary / 97**

## Spectra and multiplicities from NA61/SHINE

**Author:** Szymon Pulawski[1]

[1] *University of Silesia*

**Corresponding Author:** s.pulawski@cern.ch

One of the main physics goals of the NA61/SHINE programme on strong interactions is the study of the properties of the onset of deconfinement. This goal is pursued by performing an energy (beam momentum 13A - 158A~GeV/c) and system size (p+p, p+Pb, Be+Be, Ar+Sc, Xe+La) scan.
This talk reviews results and plans of NA61/SHINE.

In particular, recent inclusive spectra in inelastic p+p and centrality selected Be+Be, Ar + Sc interactions at the SPS energies will be shown. The energy dependence of quantities inspired by the Statistical Model of the Early Stage (kink, horn and step) show interesting behavior
in p+p collisions, which is not described by Monte-Carlo models.
Moreover a comparison with Be+Be and other heavy ion experiments
will be performed.

**Plenary** / **98**

## Global polarization of Lambda hyperons in Au+Au Collisions at RHIC

**Author:** Isaac Upsal[1]

[1] *Ohio State University*

**Corresponding Author:** upsal.1@osu.edu

Non-central heavy-ion collisions have large ($\sim 10^3\hbar$ in the BES) angular momentum which may be transferred, in part, to the quark-gluon plasma through shear forces that generate a vortical substructure in the hydrodynamic flow field. The vortical nature of the system is expected to polarize emitted hadrons along the direction of system angular momentum. $\Lambda$ and $\overline{\Lambda}$ hyperons, which reveal their polarization through their decay topology, should be polarized similarly.

These same collisions are also characterized by dynamic magnetic fields with magnitudes as large as $10^{14}$ Tesla. A splitting between $\Lambda$ and $\overline{\Lambda}$ polarization may signal a magnetic coupling and provide a quantitative estimate of the field strength at freeze out.

This presentation will discuss the first observation of a global hyperon polarization in non-central Au+Au collisions at the RHIC suite of energies as well as the dependence of this signal on $\Lambda$ kinematic variables ($\phi$, $y$, and $p_T$). The $\phi$ dependence of the signal is of particular interest as one naively expects of larger vorticity in-plane vs. out-of-plane, but the opposite can be found in model calculations. Either way, an in-plane vs. out of plane asymmetry must be related to the details of the fluid properties, including the shear viscosity.

**Plenary** / **99**

## Prospect of heavy-ion collision experiments at J-PARC

**Author:** Hiroyuki Sako[1]

**Co-authors:** Hiroyuki Harada [2]; Kyoichiro Ozawa [3]; Masakiyo Kitazawa [4]; Takao Sakaguchi [5]

[1] *Japan Atomic Energy Agency / University of Tsukuba*

[2] *J-PARC/Japan Atomic Energy Agency*

[3] *J-PARC/High Energy Accelerator Rsearch Organization*

[4] *Osaka University*

[5] *BNL*

**Corresponding Author:** hiroyuki.sako@j-parc.jp

In order to explore phase structures in high-baryon density regime of the QCD phase diagram and to study dense quark/hadronic matter which may exist in the core of neutron stars, we proposed a heavy-ion program at J-PARC (J-PARC-HI). In heavy-ion collisions at J-PARC (1-19 AGeV/c), the maximum baryon density will reach 5-10 times the normal nuclear density.
We designed a heavy-ion acceleration scheme at J-PARC. A heavy-ion beam will be produced in a

new heavy-ion injector (a linac and a booster ring) and accelerated in the existing 3-GeV and 50-GeV synchrotrons. One of the world's highest intensity proton accelerator complex J-PARC is expected to produce the world's highest heavy-ion beams (up to U) of 10^{11} Hz, which provides extremely high rate heavy-ion collisions to measure rare observables in high statistics.
We aim at measuring dileptons (di-electrons and di-muons), photons, higher-order fluctuations of conserved charges, collective flow to explore phase structures, multi-strangeness hadrons and nuclei, and two-particle correlations for physics related to neutron stars.
We designed a multi-purpose large acceptance Toroidal magnet spectrometer for lepton, photon, and hadron measurements. We also designed a spectrometer which measures hadrons and nuclei around beam rapidity region to search for various hypernuclei and strangelets. The latter spectrometer could accept the full beam intensity of J-PARC.
In this talk, physics goals, experimental design of the spectrometers, and expected physics results will be discussed.

**Plenary** / **100**

## The physics program of the CBM experiment

**Author:** Ingo Deppner[1]

[1] *Physikalidches Institut, Uni Heidelberg*

**Corresponding Author:** deppner@physi.uni-heidelberg.de

The Compressed Baryonic Matter (CBM) experiment aims at exploring the QCD phase diagram at large baryon densities in the beam energy range from 2 A GeV to 11 (35) A GeV at the SIS100 (SIS300) accelerator of FAIR/GSI. The CBM detector is designed to measure in a triggerless readout mode both bulk observables with large acceptance and rare diagnostic probes such as charmed particles and vector mesons decaying into lepton pairs with an unprecedented interaction rate of up to 10 MHz. The presentation will describe the concept of the experiment, its overall physics program and highlight observables that are sensitive to the phase structure like collective flow of multi-strange hyperons and the di-lepton mass spectra.

**Plenary** / **101**

## Fluctuations and correlation from NA61/SHINE

**Author:** Marek Gazdzicki[1]

[1] *Goethe-University Frankfurt am Main and Jan Kochanowski University Kielce*

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

Recent results on fluctuations and correlations in p+p, Be+Be and Ar+Sc collisions at the CERN SPS energies will be reviewed. In particular, results on multiplicity fluctuations will be presented and discussed. The scaled variance of multiplicity distribution decreases rapidly when going from Be+Be to Ar+Sc collisions. At the same time the ratio of mean multiplicity of positively charged kaons and pions shows a significant increase. The two observations will be interpreted as the first evidence of the percolation threshold in high energy nucleus-nucleus collisions.

**Plenary** / **102**

## Comparison of Spectra, Strangeness, Flow and HBT Results from STAR Au + Au $\sqrt{s_{NN}} = 4.5$ GeV Fixed-Target and AGS Au + Au Fixed-Target Collisions

**Author:** Kathryn Meehan[1]

[1] *UC Davis*

**Corresponding Author:** kcmeehan@ucdavis.edu

The goal of the Fixed-Target Program at STAR (FXT) is to extend BES-II to energies below 7 GeV and to baryon chemical potentials, μB, up to about 720 MeV. Studying these lower energy collisions could clarify the behavior of several observables studied during BES-I that suggest a transition from a parton-dominated regime to a hadron-dominated regime. In this talk we present results from STAR's first dedicated fixed-target test run conducted in 2015 with Au + Au collisions at $\sqrt{s_{NN}}$ = 4.5 GeV. Directed flow of protons, elliptic flow of identified hadrons, HBT radii, as well as spectra of π,K_S^0, and Λ are compared with previous results from the Alternating Gradient Synchrotron (AGS) experiments. These results demonstrate that STAR has good event reconstruction and particle identification capabilities for this fixed-target configuration. The implications of these results on future STAR fixed-target physics runs are discussed.

**Plenary** / **103**

## Rapidity correlations in the RHIC Beam Energy Scan

**Author:** William Llope[1]

**Co-author:** . for the STAR Collaboration [2]

[1] *Wayne State University*

[2] .

**Corresponding Author:** wjllope@wayne.edu

A pair-normalized two-particle covariance versus the rapidity of the two particles, called $R_2$, was originally studied [1] in ISR and FNAL data in the 1970's and has recently seen renewed interest [2] to study the dynamics of heavy-ion collisions in the longitudinal direction. These rapidity correlations can be decomposed onto a basis set of Legendre polynomials with prefactors, $a_{mn}$, which can be considered the rapidity analog of the decomposition of azimuthal anisotropies into a basis set of cosine functions with prefactors $v_n$. The $a_{mn}$ values have been suggested [2] to be sensitive to the number of sources, baryon stopping, viscosities, and criticality. The rapidity correlations have been measured by the STAR collaboration as a function of the centrality and beam energy in the range of 7.7 to 200 GeV. The experimental results and comparisons to those from the UrQMD model [3] will be presented.

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**Plenary / 104**

## Chiral magnetic effect and anomalous transport in real time

**Author:** Soeren Schlichting[1]

[1] *University of Washington*

We present a first-principle study of anomaly induced transport phenomena based on real-time lattice simulations with dynamical fermions coupled simultaneously to non-Abelian $SU(Nc)$ and Abelian $U(1)$ gauge fields. Based on such simulations I will discuss the behavior of vector and axial currents during a sphaleron transition in the presence of an external magnetic field, and demonstrate how the interplay of the Chiral magnetic (CME) and Chiral separation effect (CSE) lead to the formation of a propagating wave. Phenomenological consequences, concerning e.g. the quark mass dependence of these phenomena, will also be discussed along with future prospects for the modeling of anomalous transport phenomena in heavy-ion collisions.

**Plenary / 105**

## Hydrodynamics with critical slowing down

**Author:** Yi Yin[1]

**Co-author:** Mikhail Stephanov [2]

[1] *MIT*

[2] *UIC*

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

The search for the QCD critical point in heavy-ion collision experiments requires dynamical modeling of the bulk evolution of the QCD matter as well as of the fluctuations near the critical point. We develop a general formalism which couples hydrodynamics of a relativistic fluid to critical fluctuations. The resulting "Hydro+" theory extends hydrodynamics into the regime where the critical slowing down would otherwise make hydrodynamics inapplicable. At the same time, Hydro+ also describes non-trivial off-equilibrium effects on the critical fluctuations, allowing to simulate the coupled evolution of the bulk hydrodynamic modes and the critical fluctuations in one framework. As an illustration, we consider a simple Bjorken-like model of heavy-ion collisions near the critical point.

**Plenary / 106**

## Properties of chiral magnetohydrodynamics

**Author:** Yuji Hirono[1]

**Co-authors:** Ho-Ung Yee [2]; Koichi Hattori [3]; Yi Yin [4]

[1] *Brookhaven National Laboratory*

[2] *University of Illinois at Chicago*

[3] *Fudan University*

[4] *MIT*

**Corresponding Author:** yuji.hirono@gmail.com

The chiral magnetic effect (CME) is a macroscopic manifestation of the quantum anomaly. We will discuss the recent progress in theoretical understanding the nature of chiral plasmas, in which the CME and other anomaly-induced transports take place. We show that a nontrivial interplay of anomalous currents and dynamical electromagnetic fields leads to the modification of the properties of waves in such plasmas.

**Plenary / 107**

## Measurement of the cumulants of net-proton multiplicity distributions by STAR

**Author:** Roli Esha[1]

[1] *UCLA*

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

Fluctuations and correlations of conserved quantities (baryon number, strangeness, and charge) can be used to probe phases of strongly interacting QCD matter and the possible existence of a critical point in the phase diagram. The cumulants of the multiplicity distributions related to these conserved quantities are expected to be sensitive to possible increased fluctuations near a critical point and their ratios can be directly compared to the ratios of the susceptibilities from Lattice QCD.

In this talk, we will present the measurements of the cumulants of net-proton multiplicity distributions from Au+Au collisions at √sNN = 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4 (up to fourth order) and 200 GeV (up to sixth order) as measured by the STAR experiment at RHIC. Multi-particle correlation functions will also be presented.

The higher order cumulants are also very sensitive to experimental artifacts that one has to deal with in the analyses of heavy-ion collision data. We will demonstrate a data-driven approach to measure the cumulants of event-by-event distributions of physical variables using large samples of AMPT events. Our approach investigates the corrections for non-Binomial detector response and efficiency variations. The comparison of the various correction approaches should provide important guidance towards a reliable experimental determination of the multiplicity cumulants.

**Plenary / 108**

## Critical and non-critical fluctuations at RHIC BES

**Author:** Huichao Song[1]

[1] *Peking University*

**Corresponding Author:** huichaosong@pku.edu.cn

The recent STAR measurements of the higher cumulants of net protons present large deviations from the Poisson baselines and non-monotonic behavior at lower collision energies, indicating the potential of discovery the QCD critical point [1]. In this
talk, I will first introduce our recent investigations on both equilibrium and dynamical critical fluctuations near the QCD critical point. Then, I will show our recent calculations on the thermal (non-critical) fluctuations of (net) charges and (net) protons within the framework of {\tt IEBE-VISHNU} hybrid model, and discuss how various effects such as volume corrections, hadronic scatterings and evolution, resonance decays, as well as realistic centrality cuts and acceptance cuts, etc. influence the thermal fluctuation baselines of (net) charges and (net) protons. \\

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[4] Jixing Li, Haojie Xu and Huichao Song, paper in preparation.

**Plenary / 109**

# Recent lattice QCD results at non-zero baryon densities

**Author:** Jana Günther[1]

[1] *Bergische Universität Wuppertal*

**Corresponding Author:** jana.guenther@t-online.de

At zero baryon density lattice QCD is an established tool, that provides precise theoretical results. Calculations at non zero densities however require new techniques to deal with the sign problem. In this talk I will review the recent progress that is made in lattice QCD to investigate QCD at non-vanishing baryon chemical potential.

**Plenary / 110**

# Directed flow from RHIC Beam Energy Scan Au+Au collisions using the STAR experiment

**Author:** Subhash Singha[1]

[1] *Kent State University*

**Corresponding Author:** subhash@rcf.rhic.bnl.gov

A goal of the research at the Relativistic Heavy Ion Collider (RHIC) is to explore deconfined quark-gluon matter. Directed flow ($v_1$) is one observable that is sensitive to the dynamics of the system at early times of the collisions. Model calculations have indicated that the $v_1$-slope ($dv_1/dy$) at mid-rapidity is sensitive to the Equation of State (EoS) of the system. STAR has taken data over a wide range of beam energies (7.7 - 200~GeV) to explore the QCD phase diagram. Measurements of the beam energy dependence of $dv_1/dy$ for protons and net-protons near mid-rapidity have been interpreted in the literature as favoring a softening of the QCD EoS around $\sqrt{s_{\rm NN}}$ = 10 - 20~GeV. $v_1$ measurements with different hadron species can help disentangle the roles of produced quarks versus those transported from the initial nuclei. Moreover these measurements allow us to investigate the $v_1$ pattern of the constituent quarks. Recently, it was predicted that the transient magnetic field in heavy-ion collisions can induce a larger $v_1$ for heavy quarks than for light quarks. The model calculation also suggested that the sign of $dv_1/dy$ at mid-rapidity is opposite for charm ($c$) and anti-charm ($\bar{c}$) quarks. This argues for heavy quark $v_1$ measurement being a new approach to study the initial electromagnetic field. The Heavy Flavor Tracker (HFT) in STAR has demonstrated an excellent performance in reconstructing $D^0(\bar{u}c)$ and $\overline{D^0}(u\bar{c})$ via hadronic decay channels.

We will report results of $v_1$ and $dv_1/dy$ near mid-rapidity for $\pi^{\pm}$, $K^{\pm}$, $K^0_s$, $p$, $\bar{p}$, $\Lambda$, $\bar{\Lambda}$ and $\phi$ in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 7.7 - 200~GeV, and for $D^0$ and $\overline{D^0}$ at $\sqrt{s_{\rm NN}}$ = 200~GeV. The results will be compared with recent theoretical calculations and the physics implications will be discussed.

**Plenary / 111**

## Chiral Magnetic Effect from Event-by-Event Anomalous-Viscous Fluid Mechanics

**Author:** Shuzhe Shi[1]

**Co-authors:** JINFENG LIAO [2]; Yin Jiang [3]

[1] *Indiana University, Bloomington*

[2] *INDIANA UNIVERSITY*

[3] *Heidelberg Universität*

**Corresponding Author:** shishuz@indiana.edu

Chiral Magnetic Effect (CME) is the macroscopic manifestation of the fundamental chiral anomaly in a many-body system of chiral fermions, and emerges as anomalous transport current in hydrodynamic framework. Experimental observation of CME is of great interest and significant efforts have been made to look for its signals in heavy ion collisions. Encouraging evidence of CME-induced charge separation has been reported from both RHIC and LHC, albeit with ambiguity due to potential background contributions. Crucial for addressing such issue, is the need of quantitative predictions for both CME signal and the non-CME background consistently, with sophisticated modeling tool.

In this talk we report a recently developed Anomalous Viscous Fluid Dynamics (AVFD) framework, which simulates the evolution of fermion currents in QGP on top of the data-validated VISHNU bulk hydro evolution. In particular, this framework has been extended to event-by-event simulations with proper implementation of known flow-driven background contributions. We report, for the first time, quantitative results from such simulations and evaluate the implications for interpretations of current experimental measurements.

**Plenary / 113**

## Rapidity dependence of proton cumulants

**Author:** Adam Bzdak[1]

**Co-authors:** Nils Strodthoff [2]; Vladimir Skokov [3]; Volker Volker Koch [4]

[1] *Krakow*

[2] *LBNL*

[3] *BNL*

[4] *MS70A-3307*

**Corresponding Author:** adam.bzdak.phy@gmail.com

I will discuss in detail the rapidity and transverse momentum dependence of higher order proton cumulants and multi-proton correlation functions in the context of potential proton clustering. I will also argue that the cumulant ratios possibly satisfy a specific scaling with the number of observed protons. The contribution of genuine four-proton correlation functions at the lowest RHIC energies is discussed.

**Plenary / 114**

## Summary

**Author:** Mikhail Stephanov[1]

[1] *UIC*

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

The summary of CPOD2017

**Plenary / 115**

## Cumulant ratios of net baryon-number fluctuations at small values of the baryon chemical potential

**Author:** Christian Schmidt[1]

[1] *Universitaet Bielefeld*

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

We calculate ratios of up to $4^{th}$ order cumulants of net baryon number fluctuations in (2+1)-flavor QCD using
next-to-leading order Taylor expansions in terms of temperature and the the baryon number, strangeness, and electric charge chemical potentials.
We establish relations between these cumulant ratios, which hold at small values of the chemical potentials. These QCD results are in contrast to hadron resonance gas model calculations where, for instance, the kurtosis ratio, $\kappa_B \sigma_B^2 = \chi_4^B / \chi_B^2$ and the skewness
ratio $S_B \sigma_B = \chi_3^B / \chi_B^1$ are unity
at all values of the temperature and baryon chemical potential. We show that the experimentally observed pattern
of net proton-number fluctuations for beam energies larger than 19.6 GeV is in qualitative agreement with the next-to-leading order lattice QCD calculations.
We also present updates of our calculation of the QCD equation of state in a $6^{th}$ order Taylor expansion.

**Plenary / 117**

## TBA

**Author:** Berndt Mueller[1]

[1] *Duke University*

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

TBA

**Parallel 2 / 118**

## Strangeness production in high multiplicity pp collisions

**Author:** Marek Bombara[1]

[1] *Kosice University*

**Corresponding Author:** marek.bombara@cern.ch

Over the last three decades, proton-proton (pp) collisions have successfully provided a reference sample for the study of nucleus-nucleus collisions and have helped to unveil features attributed there to QGP formation. The results from the LHC pp program show some intriguing trends where the pp collisions resemble those of nucleus-nucleus collisions and therefore bring into question the reference sample paradigm at TeV scale. One of these measured effects is strangeness enhancement from low-multiplicity to high-multiplicity pp collisions where production rates of (multi-)strange particles similar to peripheral Pb-Pb collisions are reached. In the presentation a review of the multiplicity dependence of strange and multi-strange particle production in pp collisions at 7 and 13 TeV measured by the ALICE experiment will be reported.

**Plenary** / **120**

## Searches for Chiral Effects and Prospects for Isobaric Collisions at STAR/RHIC

**Author:** Liwen Wen[1]

[1] *UCLA*

Searches for the chiral effects (the Chiral Magnetic Effect, the Chiral Vortical Effect and the Chiral Magnetic Wave) in heavy-ion collisions have been under intensive theoretical and experimental investigations in recent years [1]. A three-point correlator γ, has been used to measure electric charge separations across the reaction plane [2]. Considerable background sources arising from charge/momentum conservation coupled with the elliptic flow have also been identified. Disentanglement of backgrounds and the CME signal has been central to theoretical and experimental efforts. Isobaric collisions are proposed to potentially disentangle the flow related background and real charge separation signals in heavy-ion collisions.

In this talk, we will report recent STAR results on the γ correlator using charged hadrons and identified particles in 200 GeV Au+Au collisions. As background references, γ correlators for 200 GeV p+Au and d+Au collisions evaluated with different event planes will be also presented. We will show the projection of the CME signal significance vs. background level [3] and a few other physics opportunities in the Zr+Zr and Ru+Ru collisions scheduled in 2018 RHIC run.

[1] Kharzeev, D.E. et al. Prog. Part. Nucl. Phys. 88, 1 (2016).
[2] S. A. Voloshin, Phys. Rev. C 70, 057901 (2004).
[3] W. Deng, X. Huang, G. Ma and G. Wang, Phys. Rev. C 94, 041901 (2016).

**Plenary** / **121**

## Recent Flow Results in d+Au Collisions from Beam Energy Scan at RHIC-PHENIX

**Author:** ShinIchi Esumi[1]

[1] *Tsukuba*

The resent results on flow and correlation from small collision system are presented and discussed especially focusing on d+Au collisions from Beam Energy Scan Program at RHIC-PHENIX experiment.

**Plenary / 122**

## Phase Transitions in Dense Matter

**Author:** Veronica Dexheimer[1]

[1] *Kent State University*

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

As the density of matter increases, atomic nuclei disintegrate into nucleons and, eventually, the nucleons themselves disintegrate into quarks. The phase transitions (PTs) between these phases can vary from steep first order phase transitions to smooth crossovers, depending on certain conditions. First order phase transitions with more than one globally conserved charge, so-called non-congruent PTs, have characteristic differences compared to congruent PTs (e.g., dimensionality of phase diagrams, location and properties of critical points). I investigate the non-congruence of the quark deconfinement PT at high densities and/or temperatures in Coulomb-less models, relevant for heavy ion collisions, neutron stars, proto-neutron stars, supernova explosions and compact star mergers.

**Plenary / 123**

## Measurements of the fluctuations of identified particles in ALICE at the LHC

**Author:** Alice Ohlson[1]

[1] *Heidelberg University*

The event-by-event fluctuations of conserved quantities within a fixed rapidity range in ultrarelativistic nucleus-nucleus collisions give information about the state of matter created in these collisions as well as the phase diagram of nuclear matter. We will present the latest results from ALICE on net-proton fluctuations, which are closely related to net-baryon number fluctuations. Net-kaon and net-pion fluctuations will also be shown, and the effects of volume fluctuations and global conservation laws on these observables will be discussed. Furthermore, fluctuations in the identified particle ratios, which are quantified by the observable $\nu_{dyn}$, will also be shown and compared with Monte Carlo models. These measurements are performed in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV using the novel Identity Method and take advantage of the excellent particle identification capabilities of ALICE.

**Parallel 2 / 125**

## The LSMq to locate the CEP

**Author:** Luis Hernandez[1]

[1] *Universidad Nacional Autónoma de México*

We use the linear sigma model coupled to quarks to compute the effective potential beyond the mean field approximation, including the contribution of the ring diagrams at finite temperature and baryon density and the thermal corrections of the coupling constants. This effective potential is then used to study the fluctuations of the order parameter v. In this work, we specifically localize the critical end point in the baryon chemical potential-temperature plane.

**Plenary / 126**

## CPOD-2018 announcement

**Author:** Nikolaos Davis[1]

[1] *Institute of Nuclear Physics, Polish Academy of Sciences (PAN), Krakow, Poland*

**Corresponding Author:** nikolaos.davis@ifj.edu.pl

Announcement of CPOD-2018

**Parallel 1 / 127**

## Mean pion multiplicities in Ar+Sc collisions

**Author:** Michał Naskret[1]

[1] *University of Wroclaw*

Final results for mean negatively charged pion multiplicities $\langle \pi^- \rangle$ from Ar+Sc collisions are the main topic of the talk. The data was taken recently by the NA61/SHINE collaboration for a wide range of momenta - 13, 19, 30, 40, 75 and 150 \textit{A} GeV/c. Starting with rapidity distribution of differential spectra $\frac{dn}{dy}$ extrapolated to unmeasured regions, the procedure of obtaining the final multiplicities is presented. A new scheme to calculate the mean number of wounded nucleons $\langle W \rangle$ utilizing the EPOS MC model is described. Using data from other experiments, a comparison of $\frac{\langle \pi \rangle}{\langle W \rangle}$ for different collisions and momenta is discussed

**Parallel 1 / 128**

## Multiplicity, transverse momentum and forward energy fluctuations from the NA61/SHINE experiment CERN

**Author:** Andrey Seryakov[1]

[1] *St. Petersberg State University*

Preliminary results for multiplicity, transverse momentum and forward energy fluctuations are presented for Be+Be and Ar+Sc collisions at 13A, 19A, 30A, 40A, 75A and 150A GeV/c beam momentum. The data were obtained by the NA61/SHINE detector at the CERN SPS. Centrality selection and forward energy measurement are based on the nucleon spectator energy in the forward hemisphere determined by the Projectile spectator detector. The scaled variance ω of the multiplicity distribution and the strongly intensive quantities Δ, Σ and Ω of multiplicity, transverse momentum and forward energy fluctuations were calculated for all, negatively and positively charged hadrons. The presented comparison of ω and Ω quantities shows, in particular, complete elimination of volume fluctuations for the most central collisions. A comparison with p+p results from NA61/SHINE, Pb+Pb data of NA49 and EPOS 1.99 simulations is shown.