INPC 2013

INTERNATIONAL NUCLEAR PHYSICS CONFERENCE

FIRENZE, ITALY 2-7 JUNE 2013

Book of Abstracts

04 – Hot and Dense Nuclear Matter

Foreword

In the present booklet we have collected the one-page abstracts of all contributions (invited, oral and poster) accepted at the INPC2013 Conference in the topic

Hot and Dense Nuclear Matter

The submitted abstracts have been divided into the various topics of the Conference following mostly the indication given by the authors. In few cases, where the subject was on the borderline of two scientific areas or it appeared misplaced, the abstracts have been moved to the booklet of the more appropriate topic.

The abstracts are numbered and arranged alphabetically according to the name of the first author. In the parallel and poster sessions of the Conference, each contribution will be identified by the number of the corresponding abstract.

We wish you a pleasant and stimulating Conference.

The Organizing Committee

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HD 067.	Color glass condensate initial conditions and formation of collective flow in a kinetic theory approach *Marco Ruggieri, Francesco Scardina, Salvatore Plumari and Vincenzo Greco* Contact email: *marco.ruggieri@lns.infn.it*

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HD 078.	Hadron Formation in Relativistic Nuclear Collisions and the QCD Phase Diagram *R. Stock, F. Becattini, M. Bleicher, T. Schuster and J. Steinheimer* Contact email: *stock@ikf.uni-frankfurt.de*
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HD 082.	Effects of volume fluctuations on various thermodynamic quantities from the Polyakov-Nambu-Jona-Lasinio model *Sudipa Upadhaya* Contact email: *sudipa.09@gmail.com*
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HD 084.	Centrality dependence of pseudorapidity spectra of charged particles produced in the nucleus-nucleus collisions at high energies *Z. Wazir* Contact email: *zafar_wazir@yahoo.com*
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The centrality dependence of multiplicity and of the spectra of identified particles is a core-corona effect

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To understand the centrality dependence of measured observables, like the multiplicity $< p_t^2 >$ and the elliptic flow of identified particles at midrapidity as well as the elliptic flow of charges hadrons, has been a challenge for theory since many years. Although the multiplicity of different particles in central collisions corresponds exactly to the expectation for a completely thermalized source the centrality dependence is incompatible with this assumption.

A while ago it has been realized that even in the most central collisions there remain particles (usually close to the surface of the interaction zone) which do not come to equilibrium (corona particles) whereas others come to a local equilibrium (core particles). Corona particles produce hadrons like pp collision. The relative fraction of corona particles can be calculated in the Glauber approach. It increases with decreasing centrality and this is the origin of the centrality dependence of the observables. In this core-corona model [1] there is no free parameter. Later this model has been extended to dynamical variables like the centrality dependence of $< p_t >$ of identified particles.Even more important, it has reproduced quantitatively the centrality dependence of the elliptic flow of charged particles without any new parameter [2].

Recently we have extended the core-corona model to describe the centrality dependence of spectra of identified particle from the low energy RHIC 7.7 AGeV to LHC energies. Surprisingly we find that all spectra are in good agreement with the core-corona model. This agreement includes the centrality dependence of the spectral slope which varies for some particles by a factor of two or more between central and peripheral collisions. In the presentation we will display the model and make comparisons with the EPOS event generator which is based as well on the distinction between core and corona particles and describes the rapidity dependence of many observables. Then we demonstrate that the centrality dependence of the spectra The interpretation of the results in physical terms concludes the presentation.

[1] J. Aichelin and K. Werner, Phys. Rev. C **79** (2009) 064907 [Erratum-ibid. C **81** (2010) 029902] [arXiv:0810.4465 [nucl-th]].

[2] J. Aichelin and K. Werner, J. Phys. G **37** (2010) 094006 [arXiv:1008.5351 [nucl-th]].

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Quarkonium production in heavy-ion collisions

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The production of quarkonium states in heavy-ion collisions plays a crucial role among the probes to investigate the formation of a plasma of quarks and gluons (QGP). In a hot and deconfined medium quarkonium production is expected to be significantly suppressed, due to color screening mechanism, with respect to the p-p yield scaled by the number of binary nucleon-nucleon collisions. Such a suppression was indeed observed first at SPS and then at RHIC experiments and it was found to be significantly larger than the one due to cold nuclear matter effects, as shadowing and absorption in nuclear matter. In spite of the different center of mass energy of the two accelerators, the observed suppression patterns present similar features. To explain this unexpected behaviour, other additional mechanisms as J/ψ production via (re)combination of charm and anti-charm quarks were proposed.

Now, after more than 25 years since the first quarkonium studies in heavy ion collisions, the Large Hadron Collider (LHC) provides a new wealth of data, opening a new energy regime for the study of quarkonium. At $\sqrt{s_{NN}}$ = 2.76 TeV, the charm quark density produced in the collisions is expected to increase dramatically with respect to SPS and RHIC and this may result in the enhancement of the probability to create J/ψ from combination of charm quarks in the QGP. This additional production mechanism may, at LHC, become dominant and, therefore, counteract, in certain kinematic regions, the J/ψ suppression in the QGP. High quality results from ALICE, ATLAS and CMS should allow to shed some light on these mechanisms.

Furthermore at LHC, other quarkonium states, as the Υ(1S), Υ(2S) and Υ(3S), which were barely accessible at lower energies, can be studied in details. Bottomonia states, being less affected by cold nuclear matter effects and regeneration, turn out to be golden probes providing information towards a comprehensive description of the quarkonia behaviour in the extremely hot medium.

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Recent heavy ion results from ATLAS experiment

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An overview of the recent results from the ATLAS experiment measuring collisions of relativistic heavy ions is presented. The results were obtained with 2012-13 proton-lead runs at $\sqrt{s_{NN}} = 5.02$ TeV with integrated luminosity of approximately 30 nb^{-1} and lead-lead data recorded in 2010-11 LHC at $\sqrt{s_{NN}} = 2.76$ TeV with integrated luminosity of approximately 0.15 nb^{-1}. The talk will discuss recently measured similarities in two particle correlations observed both collisions system and their possible relation to collective dynamics. New constraints on the initial geometry models and on hydrodynamic evolution of the system are coming from the probability distributions of anisotropic flow coefficients measured on the event-by-event basis. Measurements of the bulk particle production are complemented with a detailed studies performed with high-p_T probes. The new results include the first analysis of the forward jet production in proton-lead collisions and a detailed study of high-p_T charged hadrons, jets and electroweak bosons measured by the ATLAS experiment. Yields of electro-weak probes are found to be consistent with binary collision scaling for all collision centralities. On the contrary, charged hadrons, heavy quarks and jets are suppressed in central collisions relative to peripheral events. These measurements, supplemented with the results on correlations between electro-weak probes and jets, provide new insights into the mechanism of in-medium parton energy loss.

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Open heavy-flavor measurements at high-energy hadron colliders

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Hadrons carrying heavy flavor, *i.e.* charm or beauty quarks, are unique probes in particle and nuclear collisions at high energies. Given their large masses, charm and beauty quark-antiquark pairs are produced almost exclusively via hard partonic scattering processes. As such, the measurement of heavy-flavor hadron production cross sections in proton-proton (pp) collisions at high energies serves as a sensitive test for perturbative quantum chromodynamics, the theory of strong interactions.

In proton-nucleus (pA) collisions heavy-flavor hadron yields and kinematical distributions are subject to cold nuclear matter effects such as modifications of the parton densities in nuclei with respect to nucleons, parton scattering in the initial state, or energy loss in cold nuclear matter.

Measurements in pp and pA collisions provide a mandatory reference for heavy-flavor studies in high-energy nucleus-nucleus (AA) collisions, where the heavy quarks propagate through and interact with the produced hot and dense medium. The investigation of medium modifications of heavy-flavor observables can shed light on the nature of the interaction of partons with the medium and, furthermore, it will help to constrain the properties of the medium.

Systematic measurements of heavy-flavor hadron production in pp, pA, and AA collisions are conducted at the high energy frontier at the CERN Large Hadron Collider and, at lower energies, at the BNL Relativistic Heavy-Ion Collider. Current results from these studies will be reviewed.

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Strange hadrons and resonances at LHC energies with the ALICE detector

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The characteristics of strange hadron and resonance production are powerful probes of the properties of the deconfined and chirally restored medium formed in ultrarelativistic heavy- ion collisions. Moreover they permit to test the evolution of the dense and hot matter during its different stages . In particular, the modification of the resonance masses and widths is expected to be a probe of the restoration of chiral symmetry, while the corresponding production yields can give information on the hadronic phase evolution. The enhancement of strange particles in heavy-ion collisions relative to pp is considered among the signatures of the deconfined quark gluon plasma phase. Measurements of strange particles and resonances in proton-proton collisions not only provide an important baseline for heavy-ion data, but also allow for the tuning of QCD-inspired particle production models. The ALICE experiment, thanks to its excellent tracking and particle identification capabilities, allows one to detect strange hadrons and resonances in an extended transverse momentum range. In this talk the latest ALICE results on their production and characteristics in pp, p-Pb and Pb-Pb collisions at the LHC energies will be presented.

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Test of Nuclear Effects in pA Collisions at RHIC and LHC

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To test cold nuclear (initial state) effects is one of the most excited experiment of the RHIC and LHC. Especially, early 2013 the LHC perform measurements in pPb collisions to have a baseline for the hot $PbPb$ measurements. What can we expect? Are there nuclear effetcs at high-p_T? How nuclear multiple scattering and shadowing interplay at low-x?

To answer the above 'hot' questions we use collinear factorized perturbative QCD model predictions which are compared for $p{+}\mathrm{Pb}$ at $5.02A$ TeV to test nuclear shadowing of parton distribution at the Large Hadron Collider (LHC). The nuclear modification factor (NMF), $R_{p\mathrm{Pb}}(y = 0, p_T < 20\ \mathrm{GeV}/c) = dn_{p\mathrm{Pb}}/(N_{\mathrm{coll}}(b)dn_{pp})$, is computed within HIJING/B$\overline{\mathrm{B}}$ v2.0 model, and kTpQCD_v2.0 (See. Fig. 1 below). Both models predict in the above p_T range a sizable suppression, $R_{p\mathrm{Pb}}(p_T) = 0.7 - 0.8$ at mid-pseudorapidity that is similar to the color glass condensate (CGC) model predictions. Moreover, prediction for correlation in pPb collisions is presented as well.

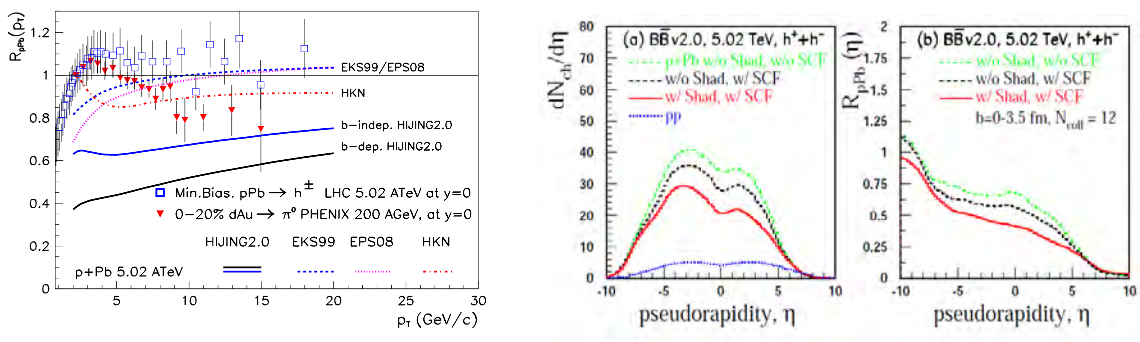

Figure 1: *Comparison of calculated nuclear modification factor, $R_{pPb}(p_T)$ with RHIC (triangles) and preliminary LHC (squares) energy data (left), pseudorapidity distribution (middle) and forward/backward nuclear mofifications (right). See more in Ref.[1-3]*

[1] J.L. Albacete *et al.*, arXiv:1301.3395 (2013)
[2] G.G. Barnaföldi, J. Barrette, M. Gyulassy, P. Lévai, M. Petrovici, V.Topor Pop, arXiv:1211.2256 (2012)
[3] G.G. Barnaföldi, J. Barrette, M. Gyulassy, P. Lévai, V. Topor Pop., Phys.Rev. C85 (2012) 024903 (2012)

Rapidity dependence of particle densities in pp and AA collisions

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We use multiple scattering and energy conservation arguments to describe $dn/d\eta|_{NANA}$ as a function of $dn/d\eta|_{pp}$ in the framework of string percolation. We discuss the pseudo-rapidity η and beam rapidity Y dependence of particle densities. We present our results for pp, Au- Au, and Pb-Pb collisions at RHIC and LHC.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Higher moment measurements of conserved quantum numbers in heavy ion collisions at the highest RHIC and LHC energies

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The relationship between higher cumulants of particle multiplicities measured in relativistic heavy ion collisions and susceptibilities calculated using lattice QCD, has been firmly established in the past few years. These measurements thus give us a direct tool to confirm certain quantum number dependencies predicted by lattice QCD for the crossover region between the deconfined partonic phase and the hadronic phase in the QCD phase diagram. I will review available measurements of conserved quantum numbers, in particular flavor and baryon number, at energies near zero baryo-chemical potential from all RHIC and LHC experiments. I will propose more detailed measurements based on higher order cumulants, which will allow us to determine the specific hadronization features independent of any assumed model.

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Heavy flavour spectra in nucleus-nucleus collisions within a Langevin approach

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We present the outcomes of a theoretical study of heavy-flavour spectra in nucleus-nucleus (AA) collisions. The core of the analysis is represented by the study of the propagation of heavy (c and b) quarks in the Quark Gluon Plasma (QGP) formed in the relativistic AA collisions: their dynamics is described through a relativistic Langevin equation, whose transport coefficients are evaluated within a thermal-field-theory approach. Results obtained with lattice-QCD transport coefficients will be also shown. The Langevin approach, at variance with standard radiative energy-loss calculations, allows one to address more general situations, describing in particular the asymptotic relaxation of a heavy-quark sample to thermal equilibrium with the surrounding plasma. In facing the actual experimental situation, the numerical solution of the Langevin equation enters into a multi-step setup including:

- The initial hard production of the q-qbar pairs, given by the POWHEG-BOX event generator (based on NLO pQCD);
- In the AA case, the Langevin dynamics in the QGP, with the fireball evolution described by relativistic hydrodynamics;
- The hadronization stage according to the most up-to-date branching fractions and fragmentation functions;
- The final decays into the experimentally accessible channels (open charm hadrons, displaced J/psi, heavy-flavour electrons);
- The evaluation of the experimental observables: inclusive spectra (in pp and AA), R_AA and v_2 (in AA) and comparison with the most recent experimental results obtained in Pb-Pb collisions at the LHC at 2.76 TeV.

Our analysis represents an improvement of the calculations presented in Eur.Phys.J. C71 (2011) 1666., in particular

- for what concerns the simulation of the initial hard production, performed according to the most up-to-date QCD approaches, with NLO calculations interfaced with a parton-shower stage (measurements of exclusive open-charm spectra which became available at the LHC allowing one to fix the pp benchmark with tighter constraints);
- for the wider systematic study of the coupling of the heavy quarks with the QGP, with weak-coupling results compared to lattice-QCD findings.

Such a kind of transport study allows one to establish a link between what is possible to derive from the underlying microscopic theory (the transport coefficients) and the final experimental observables, enabling one to extract information on the properties of the produced medium.

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Recent results on transport models

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We review current concepts and models used to describe the evolution of the hot and dense matter created in heavy ion collisions at LHC, RHIC and FAIR. To this aim, we will discuss recent extensions of models based on the Boltzmann equation to include a hydrodynamical stage that allows for a consistent treatment of all stages of the reaction. Then we discuss how a dynamical model for the exploration of the critical point of QCD and the phase transition can be constructed and present some first results.

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Equation of state of QCD matter at finite net baryon density

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A firm knowledge of the Equation of State (EoS) of QCD matter under extreme conditions is essential for advancing our understanding of the properties of compact stellar objects such as neutron stars, the evolution of the early universe or the mechanisms taking place inside the strongly coupled fluid that is created in high-energy nuclear collision experiments. Describing the bulk properties of QCD matter in equilibrium, the EoS enters as an important input into hydrodynamical models that aim at a quantitative, dynamical and realistic description of the time-evolution of the experimentally produced matter after its fast thermalization. Here, a concise inclusion of finite net baryon density (n_B) effects into the EoS is of particular importance when exploring the QCD phase diagram and searching, for example, for possible signatures of the QCD critical point.

In this talk we present a state-of-the-art Equation of State for QCD matter at finite n_B that is based on the most recent first-principle lattice QCD results from the Wuppertal-Budapest collaboration [1] in combination with a realistic Hadron Resonance Gas (HRG) model EoS that takes the decays of resonances properly into account. In [1], finite n_B-effects are quantified via Taylor-series expansions of the thermodynamic quantities in terms of the chemical potentials, which clearly limits the range of applicability of our EoS. Nonetheless, our approach allows for a realistic treatment of the evolution of conserved charges across the confinement/deconfinement transition in the hot and dense QCD matter. Prospects of applications of our EoS are being presented, which go beyond the mere utilization in hydrodynamic simulations.

[1] Sz. Borsányi *et al.*, J. High Energy Physics **08** (2012) 053.

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Neutral meson and direct photon production in high-energy pp and PbPb collisions at the LHC with ALICE

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Transverse momentum spectra of pi0 mesons and direct photons, as well as their azimuthal anisotropies, at mid-rapidity in pp and Pb-Pb collisions have been measured at LHC energies by the ALICE detector. The mesons are reconstructed via their two-photon decays by two complementary methods, using the electromagnetic calorimeters and the central tracking system for photons converted to electron-positron pairs on the material of the inner ALICE barrel tracking detectors. The nuclear modification factor R_AA of the pi0 production in Pb-Pb collisions at different collision centralities shows a clear pattern of strong suppression in a hot QCD medium with respect to pp collisions. The direct photon transverse momentum spectrum has been derived from the measured inclusive photon and neutral pion spectra. For central Pb-Pb collisions, a next-to-leading-order perturbative QCD calculation describes the spectrum above 4 GeV/c, but underpredicts the data below 4 GeV/c where the spectrum is expected to have a contribution from thermal photons. Related results from the 2013 p-Pb run will be included if available at the time of the conference.

Parton-hadron matter in- and out-off equilibrium

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We study the equilibrium properties of strongly-interacting infinite parton-hadron matter and the non-equilibrium dynamics of heavy-ion collisions within the Parton-Hadron-String Dynamics (PHSD) transport approach, which incorporates explicit partonic degrees of freedom in terms of strongly interacting quasiparticles (quarks and gluons) in line with an equation of state from lattice QCD as well as the dynamical hadronization and hadronic collision dynamics in the final reaction phase.

We present the equilibration of observables and their fluctuations in the QGP and also transport coefficients, such as shear and bulk viscosity [1], as well as out-off equilibrium phenomena seen in azimuthal angular distribution in higher harmonics (v1,v2,v3,v4) in heavy-ion collisions at ultrarelativistic energies [2].

We find that the ratio of the shear viscosity to entropy density $\eta(T)/s(T)$ from PHSD shows a minimum (with a value of about 0.1) close to the critical temperature T_c, while it approaches the perturbative QCD (pQCD) limit at higher temperatures in line with lattice QCD results. Within statistics, we obtain practically the same results in the Kubo formalism and in the relaxation time approximation. The bulk viscosity $\zeta(T)$ – evaluated in the relaxation time approach – is found to depend strongly on the effects of mean fields (or potentials) in the partonic phase. We find a significant rise of the ratio $\zeta(T)/s(T)$ in the vicinity of the critical temperature T_c, when consistently including the scalar mean-field from PHSD, which is also in agreement with that from lQCD calculations.

In non-equlibrium case of heavy-ion collisions the experimentally observed increase of the elliptic flow v_2 of charged hadrons with collision energy is successfully described in terms of the PHSD approach. The PHSD scaling properties of various collective observables are confronted with experimental data as well as with hydrodynamic predictions. The analysis of higher-order harmonics v_3 and v_4 in the azimuthal angular distribution shows a similar tendency of growing deviations between partonic and purely hadronic models with increasing collision energy. This demonstrates that the excitation functions of azimuthal anisotropies reflect the increasing role of quark-gluon degrees of freedom in the early phase of relativistic heavy-ion collisions. Furthermore, the specific variation of the ratio $v_4/(v_2)^2$ with respect to bombarding energy, centrality and transverse momentum is found to provide valuable information on the underlying dynamics.

[1] V. Ozvenchuk, O. Linnyk, M. I. Gorenstein, E. L. Bratkovskaya and W. Cassing, arXiv:1212.5393 [hep-ph]; arXiv:1203.4734 [nucl-th].

[2] V. P. Konchakovski, E. L. Bratkovskaya, W. Cassing, V. D. Toneev, S. A. Voloshin and V. Voronyuk, Phys. Rev. C **85** (2012) 044922 [arXiv:1201.3320 [nucl-th]].

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Charmonium production at the LHC measured with the ALICE detector

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Among the various suggested probes of the Quark-Gluon Plasma (QGP), which is expected to be formed in ultra-relativistic heavy-ion collisions, charmonium states play a distinctive role. A mechanism of suppression (melting) in deconfined matter was proposed early on for the J/psi meson, based on the colour analogue of Debye screening. At the LHC energies, due to the abundant production of c-cbar pairs, this suppression can be counterbalanced by (re-)combination of c-cbar pairs in the QGP or at the phase boundary.

The ALICE measurements of J/ψ production in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV are performed as a function of collision centrality, transverse momentum and rapidity. Analogue measurements have been performed in pp collisions at $\sqrt{s}$=2.76 and 7 TeV, which represent a crucial test for theoretical models based on QCD, besides providing the natural reference for the Pb-Pb system.

The nuclear modification factor (R_{AA}) is defined as the ratio of the differential particle yield in Pb–Pb to that in pp, scaled by the number of binary nucleon–nucleon collisions. In Pb-Pb collisions at the LHC a larger R_{AA} at low transverse momentum compared to that at lower energies is observed. Comparisons to data at lower energies and to model predictions suggest that a sizeable fraction of J/ψ production may occur in deconfined matter or at hadronization, with the above mentioned (re-)combination mechanism.

For non-central collisions, the geometrical overlap of the colliding nuclei is anisotropic. This initial spatial asymmetry can be converted via multiple collisions into an anisotropic momentum distribution of the produced particles, which is referred to as "elliptic flow". The second moment of the particle azimuthal distribution (v_2 coefficient) is used to quantify this flow. The Alice results suggest a non-zero v_2 coefficient for the J/psi particle that would corroborate the recombination hypothesis.

Results on the production of the ψ(2S) and the Υ particles will be also presented.

Finally, proton-nucleus collisions (collected in the early 2013) are needed to determine cold nuclear matter effects and are crucial for the interpretation of the Pb-Pb results. The analysis of this important data sample will be also discussed.

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Direct photons at large p_T: from RHIC to LHC

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Using the color dipole approach we study production of direct photons in proton-nucleus and nucleus-nucleus collisions at energies corresponding to RHIC and LHC experiments. Prompt photons produced in a hard reaction are not accompanied with any final state interaction, either energy loss or absorption. Therefore, in the RHIC energy range besides small isotopic corrections one should not expect any nuclear effects at large p_T. However, data from the PHENIX experiment exhibits a significant large-p_T suppression in central $Au + Au$ collisions that cannot be accompanied by coherent phenomena. We demonstrate that such an unexpected result is subject to the energy sharing problem universally induced by multiple initial state interactions (ISI) at large p_T and/or at forward rapidities. In the LHC kinematic region ISI corrections are irrelevant at mid rapidities but cause rather strong suppression at forward rapidities. We present for the first time predictions for expected nuclear effects at large p_T in $p + Pb$ and $Pb+Pb$ collisions at different rapidities. We include and analyze also a contribution of coherence effects associated with shadowing modifying nuclear effects at small and medium p_T.

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[5] J. Cepila and J. Nemchik, Nucl. Phys. **B198**, 30 (2010).

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Quarkonium measurements in PbPb and pPb collisions with CMS

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The results from the study of charmonium and bottomonium production via the dimuon decay channel in the CMS experiment will be discussed. In PbPb collisions a sequential suppression of the quarkonium states ordered by the binding energy of the hadron is observed. These observations are consistent with theoretical predictions of the effects of the hot QCD medium on the quarkionium states. The effects from the initial state (cold nuclear matter) can be assessed utilizing pPb collisions. First results from measurements in the pPb system will be presented.

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Hard probes in PbPb and pPb collisions in CMS

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This talk will review results on jet production and properties in heavy-ion collisions from the CMS experiment. These studies include various energy loss phenomena (dijet and photon-jet energy imbalance, jet nuclear modification factors, tagged b-quark jets), and observables characterizing the jet properties (jet shapes and fragmentation functions) measured in PbPb collisions at a nucleon-nucleon center-of-mass energy of 2.76 TeV. First results from similar studies conducted in pPb collisions at 5 TeV will also be presented.

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Different approaches to analyze the QCD Phase Diagram in the Context of the Polyakov–Nambu–Jona-Lasinio Model.

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We investigate the phase diagram of the so-called Polyakov–Nambu–Jona-Lasinio model at finite temperature and nonzero chemical potential. The calculations are performed in the framework of the PNJL Lagrangian in the light and strange quark sector (*u,d,s*) which includes the 't Hooft instanton induced interaction term that breaks the axial symmetry, and the quarks are coupled to the (spatially constant) temporal background gauge field. Analyzing the relevant order-like parameters, possible interrelations between chiral symmetry restoration and deconfinement are discussed.

A special attention is payed to the critical end point (CEP): the influence of the strangeness on the location of the CEP is studied; also the strength of the flavor-mixing interaction alters the CEP location, once when it becomes weaker the CEP moves to low temperatures and can even disappear [1,2].

We also use the in-medium mesonic correlations as a probe of the phase diagram of QCD. The information obtained with them is coherent with the one given by mean field order parameters.

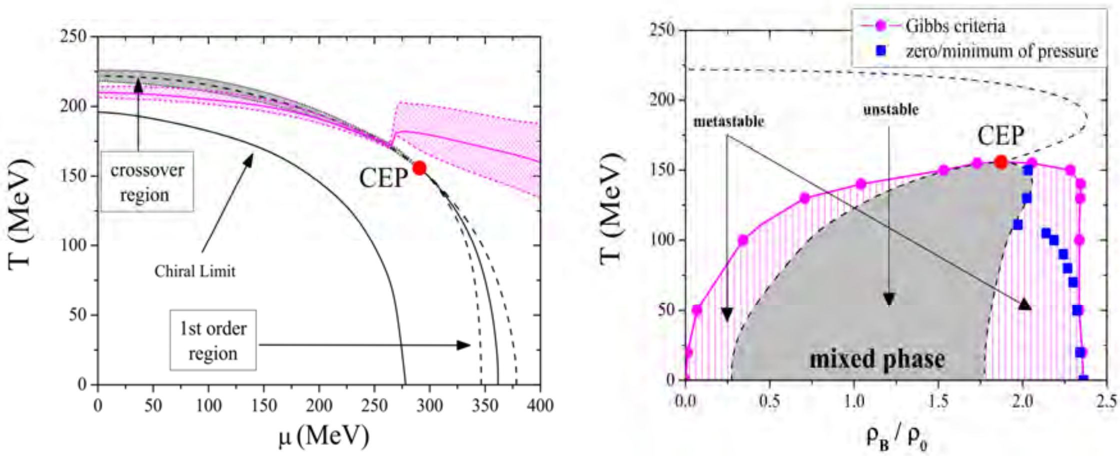

Figure 1: *QCD phase diagram in the PNJL model.*

[1] P. Costa, C. A. de Sousa, M. C. Ruivo, H. Hansen, Europhys. Lett.86, 31001 (2009).
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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Review of Recent Results in Heavy Ion Fluid Dynamics

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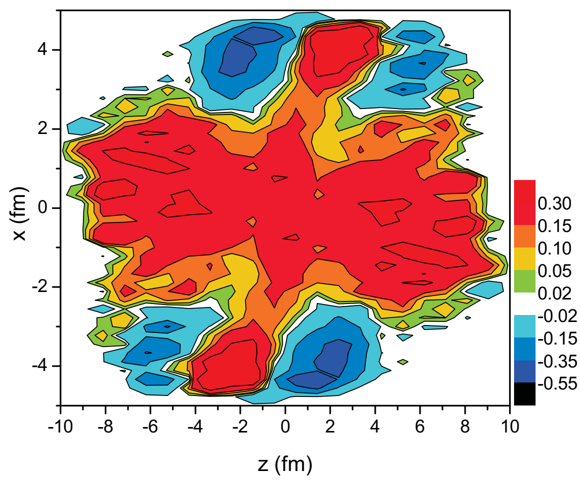
Fluid dynamical phenomena in high energy heavy ion reactions were predicted in the 1970s and still today these are the most dominant and basic observables. With increasing energy and the reach of QGP the low viscosity of the plasma became apparent both theoretically [1] and experimentally and this brought a new revolution in the fluid dynamical studies. The high energy and low viscosity made it possible to observe fluctuations up to high multipolarity flow harmonics [2]. This is an obvious, direct proof of the low viscosity of QGP. Many aspects of these fluctuations are under intensive study today. The low viscosity opened ways to observe special fluid dynamical turbulent phenomena. These may arise from random fluctuations [3], as well as from the global symmetries of peripheral collisions. At LHC energies the angular momentum of the participant matter can reach $10^6\hbar$, which makes rotation [4] and turbulent instabilities, like the Kelvin-Helmholtz instability [5], possible. Low viscosity ensures that these remain observable at the final freeze-out stages of the collision. This leads to possible new investigations in addition to the standard flow analysis methods. Femtoscopy may also detect rotation and turbulence. The high thermal vorticity makes it possible that particle polarization and orbital rotation reach thermal and mechanical equilibrium [6]. This leads to baryon polarization which, in given directions may be detectable at the LHC. The role of the electromagnetic fields in the hydrodynamical evolution of the plasma is briefly addressed.



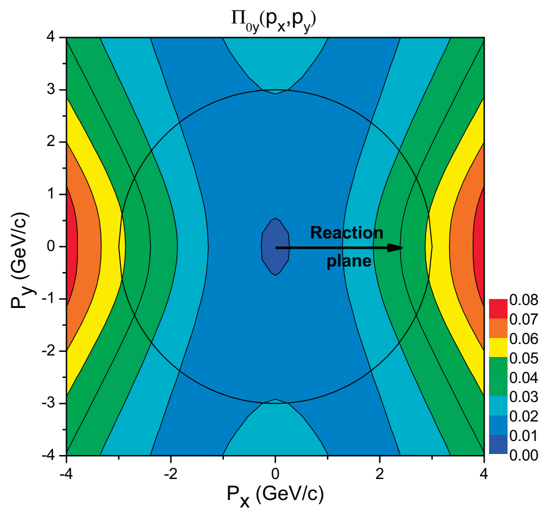


Figure 1: *The thermal vorticity of the flow projected to the reaction plane for a peripheral, LHC Pb+Pb collision at the freeze-out stage in a 3+1D fluid dynamical model (Left). The arising y-component of the polarization of Λs emitted in the reaction plane, showing peaks in the $\pm x$-direction [6] (Right).*

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[4] L.P. Csernai, V.K. Magas, H. Stöcker, and D.D. Strottman, Phys. Rev. C **84**, 024914 (2011).
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Measurement of inclusive and recoil jets in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV with ALICE at the LHC

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The hot and dense medium created in heavy-ion collisions is expected to modify the fragmentation of high energy partonic projectiles leading to changes in the energy and structure of the reconstructed jets with respect to vacuum jets. The study of modified jets aims at the understanding of the detailed mechanisms of in medium energy loss and their relation to transport properties of the medium itself.
Here, we present recent ALICE results on jet measurements in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV. The observables under study are the inclusive jet spectrum and the spectrum of jets recoiling from a high-p_{T} ('trigger') hadron back-to-back in azimuth, the latter being a subsample of the first with maximal in medium path length. We study the dependence of these two observables with jet p_{T} , minimum constituent p_{T} cut-off and jet resolution R to explore changes in the jet radiation pattern with respect to baseline pp or PYTHIA jets.

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Forward backward multiplicity correlations in pp collisions at LHC energies with the ALICE detectors

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Forward-backward multiplicity correlations have been studied across a wide range of energies and colliding species. From these previous measurement, several physical interpretations have been made. The correlations over small range in rapidity are believed to be dominated by short-range effects which are due to the particles produced from cluster and resonance decays or jet correlations, while those extending over a wide range in pseudorapidity could be interpreted as coming from the multiple parton interactions.

We report the forward-backward multiplicity correlations of charged particles in pp collisions at $\sqrt{s}$ = 0.9, 2.76 and 7 TeV. This study has been made with minimum bias pp events within the acceptance of $|\eta| < 0.8$ and 0.3<pT<1.5 (GeV/c). Two separate pseudorapidity windows with a bin width of 0.2 to 0.8 rapidity units have been chosen symmetrically around $|\eta|$ = 0. The multiplicity correlation strength has been studied as a function of η-gap between the two windows as well as the width of these windows. It is observed that correlation strength decreases with increasing η gap i.e. with increasing distance between two η windows and increases with the width of the each window. The results have been compared with the MC generators PYTHIA Perugia - 0 and PHOJET. It is found that the PYTHIA does a better job in describing the data as compared to PHOJET. The relative correlations have been studied in terms of the ratio of the correlation strength of 7 TeV and 2.76 TeV with respect to 0.9 TeV and are found to increase significantly with beam energy.

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J/Ψ photo-production in Pb-Pb ultra-peripheral collisions at sqrt(s_{NN}) = 2.76 TeV with ALICE at LHC

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The photo-production of vector mesons in Ultra-Peripheral Collisions (UPC) is a powerfull tool to probe the nuclear gluon-distribution, for which there is considerable uncertainty in the low-*x* region. We present the first measurements in Pb-Pb collisions at sqrt(s_{NN}) = 2.76 TeV, performed with the ALICE detector. The J/Ψ is identified via its dimuon decay in the forward rapidity region and via dimuon and dielectron decay at mid-rapidity.
The results are compared to theoretical models for coherent J/Ψ production and found to be in good agreement with models which include nuclear gluon shadowing. Finally, we present the cross section measurement for incoherent J/Ψ and $\gamma\gamma \rightarrow e^+e^-$.

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Chiral Condensates in Hot and Dense Matter

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A region of the QCD phase map still inaccessible through experiments is the high-density ($\mu_B \sim$ nucleon mass) region at temperatures T below the deconfinement temperature Tc. Exploring this region both theoretically and experimentally can help us answer fundamental questions like the location of the QCD critical point, the order of the chiral phase transition and its dependence on density and temperature, as well as whether deconfinement and chiral symmetry restoration separate from each other at high densities. Nambu-Jona-Lasinio (NJL) models, which lack confinement, are typically useful to gain insight on the chiral dynamics in hot and dense matter. While most of the phases found using these models are homogeneous, it has been recently shown that the most favored phase at high densities and low temperatures is a crystalline one characterized by a real and inhomogeneous chiral condensate [1]. On the other hand, it has been argued [2] that the ground state of the dense and cold region could be described by the chiral spiral inhomogeneous condensate that is realized in the large Nc limit of QCD in the so-called quarkyonic matter [3], on which quarks are still confined like in the hadronic phase, but chiral symmetry is almost restored. Although these two results predict an inhomogeneous intermediate phase in the cold and dense region, the symmetries of the phases have important differences, even when the NJL model is supplemented with confinement with the help of the Polyakov-NJL extension [4]. Using a QCD-inspired NJL model and taking into account the spontaneous breaking of the rotational symmetry produced by the inhomogeneous chiral condensate, I will show how the chiral spiral is energetically favored over the crystalline ground state, thereby establishing a connection between the quarkyonic matter, found within the large Nc limit of confined QCD, and the unconfined NJL theory [5].

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Non-extensive self-consistency in hadronic medium

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The high energy experiments have provided us with many data which has confirmed that a tail-like distribution, as that which follows from the Tsallis statistics, can describe the transversal momentum, p_T, distributions. Nonetheless, the use of non-extensive statistics remains a rather controversial subject.

The non-extensive self-consistent theory recently proposed [1] predicts that hot hadronic matter should present a limiting effective temperature and a limiting entropic index. Also, it predicts that the p_T-distribution at high energy collision should be described by the expression

$$\frac{d^2N}{dp_T\,dy} = gV\frac{p_T m_T coshy}{(2\pi)^2}\left(1+\frac{m_T coshy-\mu}{T}\right)^{-\frac{q}{q-1}}, \qquad (1)$$

which is somewhat different from the most used expression for fitting experimental data [2], and that the cumulative hadron mass spectrum should be given by [3]

$$r(m) = \int_o^m \rho(m')dm' = \frac{-2\gamma}{3}m^{-3/2}\,{}_2F_1\left(-\frac{3}{2},-\frac{1}{q-1};-\frac{1}{2};-(q-1)\beta m\right)+k\,. \qquad (2)$$

It will be shown that existing experimental data for p_T distributions and for observed hadron states give support to the theory [4], and therefore show that the non-extensivity passes the restrictive test mentioned above. Wit these results one can obtain a complete description of the thermodynamics for hadronic systems at high temperatures. Some thermodynamical functions are calculated and compared with lattice-QCD results.

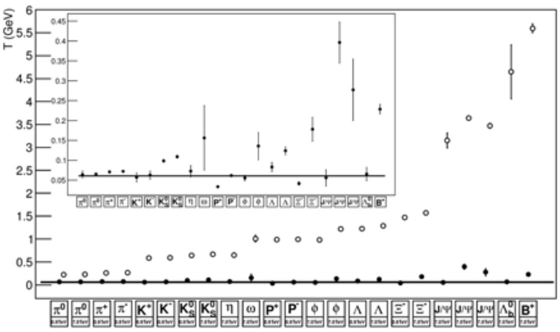

Figure 1: *Effective temperature, T, resulting from the fittings of Eq.(1) (full symbols) and from the usual expression for fittings [2] (open symbols). The inset shows the effective temperature obtained through the use of Eq.(1) in more details. Full lines indicate the constant value, T_o, which best fits the data obtained with Eq.(1) assuming $y = 0$ and $\mu = 0$.*

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Dense Matter and Renormalization Group

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As a contribution to the ongoing discussion on the question of a critical endpoint of a chiral phase transition, a nucleon-meson model was studied recently [1]. There was no evidence of a chiral phase transition in the region of chemical freeze-out for larger chemical potential. We try to extend and solidify the calculations previously done at the mean field level by including mesonic fluctuations with help of the functional renormalization group equations.

Supported in part by BMBF and by the DFG cluster "Origin and Structure of the Universe"

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Chiral Symmetry Breaking of Quark Matter in a Magnetic Field

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The investigation of phase transitions in hadronic matter is a fundamental problem in strong-interaction physics. This topic has gained even more relevance in recent years with the experimental possibilities opened at RHIC and LHC facilities. In the (T-μ)-diagram, where T is the temperature and μ is the baryonic chemical potential, a reach phase structure is found, separated by phase-transition boundaries between chiral restored and broken phases, different phases of color superconductivity, confined and deconfined phases, etc. In this talk I will present a new fact that is present in the chiral phase transition of quark matter in the presence of a magnetic field: that is, the dynamical induction of an anomalous magnetic moment for the quarks, which takes place together with the induction of a dynamical mass that has been previously reported in the literature [1]. The importance to introduce the magnetic field as a new ingredient in the phase diagram of quark matter is dictated by the fact that large magnetic fields of the order of $m_\pi^2 \sim 10^{18} - 10^{19}$ G can be produced in non-central heavy-ion collisions [2]; and on the other hand, that if quark matter is realized in the core of neutron stars, it could sustain inner magnetic field with estimated values at the core of order $10^{19} - 10^{20}$ G [3]. I will discuss how the induced anomalous magnetic moment affects the critical temperature for the chiral phase transition at different magnetic field values and how it can also affect the equation of state of magnetized quark matter.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Light-flavour hadron production in pp, p-Pb and Pb–Pb collisions at the LHC

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The ultimate goal of Heavy-Ion collisions is the study of the properties of the deconfined and chirally restored medium known as the Quark-Gluon plasma.
With the advent of the Large Hadron Collider (LHC) a new energy regime is being studied.
Light-flavour hadrons allow for the inference of the bulk properties of the matter created in heavy ion collisions.

The shape of the transverse momentum distributions of identified hadrons and their evolution with the collision centrality allows constraints to be placed on the collective expansion properties of the fireball.
The study of identified particle spectra at intermediate transverse momentum provides a handle on the hadronization mechanism, allowing for testing of the so-called "recombination models".
At higher transverse momentum, the study of identified particles provides insight into the mechanism of parton energy loss in the hot and dense medium.
The particle densities at mid-rapidity allow for the study of the hadrochemistry of the event, providing a window on the chemical properties of the medium at the phase transition to hadrons.
Measurement of identified particles in pp collisions at the LHC are also very important, as they provide stringent constraints for QCD-inspired models and they serve as a reference for the Pb-Pb measurements.
The LHC also recently collected data for p-Pb collisions, which permit to study the effects of cold nuclear matter allowing initial and final state effects in Pb-Pb collisions to be disentangled. First results from a short pilot run already provided surprise: two-particle angular correlations display a two-ridge pattern reminiscent of the one observed for Pb-Pb collisions. The identified-particle results from the p-Pb run scheduled in January will represent a crucial test of collective models of p-Pb at the LHC.

The ALICE experiment is the LHC experiment dedicated to the study of heavy ion collisions. It features a very small material budget (~10% X/X_0), a low solenoidal magnetic field (0.5 T) and excellent tracking and particle identification capabilities. Those features make it very well suited for the study of identified particles over an extended transverse momentum range.
In this talk we will present the latest ALICE results on identified and inclusive light-flavour charged particles in pp, p-Pb and Pb-Pb collisions at LHC energies. We will discuss their implications for the interpretation of the heavy ion results at the LHC. A particular emphasis will be given to recent results from the p-Pb run.

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Anisotropic hydrodynamics

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Due to the rapid longitudinal expansion of the quark-gluon plasma created in relativistic heavy ion collisions, potentially large local rest frame momentum-space anisotropies are generated. The magnitude of these momentum-space anisotropies can be so large as to violate the central assumption of canonical viscous hydrodynamical treatments which linearize around an isotropic background. In order to better describe the early-time dynamics of the quark gluon plasma, one can consider instead expanding around a locally anisotropic background which results in a dynamical framework called anisotropic hydrodynamics. In my contribution I will review the basic concepts of the anisotropic hydrodynamics framework and discuss phenomenological consequences following from this approach. In particular, I will discuss the problem of early thermalization and propose its solution. This text is taken from the NUPECC Long Range Plan 2004.

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Pseudorapidity density and anisotropic flow of charged particles over a wide pseudorapidity range in Pb+Pb collisions with the ALICE experiment at the LHC

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The pseudorapidity density and the anisotropic flow of charged-particles provide fundamental information about global variables and correlations in heavy ion collisions. The pseudorapidity density can be used to characterize the energy density produced in heavy-ion collisions and to test models for particle production. The anisotropic flow provides information about the initial spatial anisotropy of the participant region and can be tied to the internal properties of the hot and dense collision zone, such as the viscosity.

We present measurements over more than 10 units of pseudorapidity allowing for an accurate estimate of the total number of particles produced in these collisions, using a new technique based on displaced vertices at LHC. For both measurements we investigate longitudinal scaling. Under simple but robust transformations we can also derive the rapidity density distribution, and compare to the predictions from the Landau and Bjorken pictures.

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Thermodynamic instabilities in warm and dense nuclear matter

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We investigate the presence of thermodynamic instabilities in a warm and dense nuclear medium ($T \leq 50$ MeV and $\rho_B \geq \rho_0$) where a phase transition from nucleonic matter to resonance-dominated Δ-matter can take place. The analysis is performed by requiring the global conservation of baryon and electric charge numbers in the framework of a relativistic equation of state. Similarly to the liquid-gas phase transition, we show that the nucleon-Δ matter phase transition is characterized by both mechanical instability (fluctuations on the baryon density) that by chemical-diffusive instability (fluctuations on the charge concentration) in asymmetric nuclear matter [1]. We then perform an investigation and a comparative study on the different nature of such instabilities and phase transitions.

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Energy loss and elliptic flow of heavy quarks traversing a quark gluon plasma.

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It is generally assumed that in ultrarelativistic heavy ion collisions a plasma of quarks and gluons is produced but it is difficult to study its properties. The reason is that the initial momentum distribution of the light quarks is not known and that before being detected the system passes the chiral/confinement phase transition in which hadrons are formed. Hadrons interact on the way to the detectors what modifies their spectrum. Therefore soft light hadrons do not carry information on the early stage of the plasma.

The situation is much better for heavy quarks (c and b) which are created in hard processes. Here perturbative QCD allows for the calculation of the production cross sections (in contradistinction to light quarks) and these cross sections have also been measured. Also the details of the chiral /confinement phase transition are less important than for light quarks because, due to its mass, the momentum of the heavy quark determines the momentum of the open charm hadrons. In addition, the momentum distribution at production and at the transition is very different from that one expects if the heavy quarks are in thermal equilibrium with the plasma of light quarks and gluons. Therefore the modification of the initial momentum distribution by the interaction of the heavy quarks with the plasma carries information on the plasma properties. The final hadronic interaction is small due to the small cross section and only elastic.

The interaction of the heavy quark with the plasma has two parts, elastic collisions and radiative collisions. For the first we developed a model [1] in which the cross section of the elementary interactions are calculated by perturbative QCD but in contradistinction to earlier calculations we use running coupling constants, fixed by other experiments, as well as an effective infrared regulator determined by hard thermal loop calculations. Recently this model has been extended to include radiative interactions[2]. In a medium radiative interactions are not independent like in the Bethe Heitler formalism but are modified by the Landau Pomeranschuk Migdal effect and by the absorption of gluons in the medium.

Embedding this approach in a hydrodynamical calculation, like EPOS, which describes the time evolution of the plasma we can calculate the modification of the heavy meson spectra due to the plasma as well as correlations between two heavy mesons. We compare our results with those from RHIC and LHC experiments. This includes a detailed discussion of the nuclear modification factor R_{AA} and of the elliptic flow v_2, both being a direct measure of the interaction of the heavy quarks with the plasma particles.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Anisotropic collective flows in a kinetic transport theory at fixed η/s(T)

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The Relativistic Heavy-Ion program has shown that a key properties of the QGP is its very low shear viscosity to density entropy ratio η/s(T). A key observable is supplied by the different harmonics of the collective flows $v_n(p_T)$. We present a transport approach, developed with η/s(T) as an external parameter similarly to the hydrodynamical approach, able to naturally describe the $v_n(p_T)$ in a wide range of p_T and η/s(T) (including the rise and fall observed at LHC).
Furthermore kinetic theory allows to implement properly the non-equilibrium Color Glass Condensate conditions determined by the Q_S saturation scale. We find that in the build-up of $v_2(p_T)$ the initial non-equilibrium distribution significantly compensates the larger space eccentricity of the CGC respect to the Glauber modeling.
We will show, exploring the T dependence of η/s(T), that a study of v_n allows to understand the differences behind the build of collective flows from low energy scan at RHIC to LHC energies. Finally we will show that including a mean field dynamics from quasi-particle model the dynamics evolves according to recent lattice QCD equation of state and predicts a chemical evolution from gluon to quark dominance close to T_c.

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From microscopic interactions to the dynamics of the fireball

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Incorporating the dynamic nature of the quark-gluon plasma into models is crucial to the theoretical interpretation of experimental results from heavy ion collisions at RHIC and LHC. We have developed a transport framework, BAMPS (Boltzmann Approach to Multi-Parton Scatterings), that based on perturbative QCD matrix elements describes the partonic stage of such heavy ion collisions. The Monte Carlo approach allows for the investigation of various observables and assumptions within one single framework. It uniquely features the consistent inclusion of partonic radiation and annihilation processes, obeying the principle of detailed balance. We show that the inelastic processes drive the system into thermal equilibrium on time scales on the order of 1 fm/c, well in accordance with experimental observations of the elliptic flow. Accordingly the viscosity of the medium is found to be small, close to the conjectured lower bound. The dynamic origin of quarkonia production, flow and suppression is successfully studied within the model as well as their open heavy flavor equivalents. Also the investigation of light flavor phenomena at large transverse momenta - both on the level of single inclusive and of jet observables - is possible, allowing for a comparative study of medium versus high-pt predictions. Based on analytical and numerical studies we demonstrate that the commonly used Gunion-Bertsch approximation to the radiative matrix element needs to be modified when being applied in rate-based approaches. We discuss possible implications on the dynamic description of the medium.

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Quarkonium spectra at finite T: Comparison between QCD sum rules and lattice QCD

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The behavior of quarkonia in a hot medium has attracted much interest, mostly because these systems can provide useful signals for the properties of the quark-gluon plasma formed in heavy-ion collisions. Recently, quarkonium spectral functions at finite temperature have been studied using a combination of QCD sum rules and the maximum entropy method (MEM) [1,2]. QCD sum rules incorporate temperature effects in form of changing values of the various gluonic condensates that appear in the operator product expansion (OPE). These changes depend on the energy density and pressure at finite temperature, which we extract from lattice QCD. As a result, it was found that the charmonium states dissolve into the continuum already at temperatures only slightly above the deconfinement temperature T_c. This can be clearly seen in the left plot of Fig. 1. On the other hand, the bottomonium states are less influenced by temperature effects, surviving up to about 2.5 T_c or higher for S-wave states (see the right plot of Fig. 1). Having extracted these spectral functions, it is possible to calculate the imaginary time correlator, a quantity directly obtainable from lattice QCD. In the conference presentation, we plan to compare the sum rule and lattice results in detail and to explain possible discrepancies between the two approaches. Furthermore, we will discuss the role of higher order α_s-corrections to the OPE, which have been neglected so far.

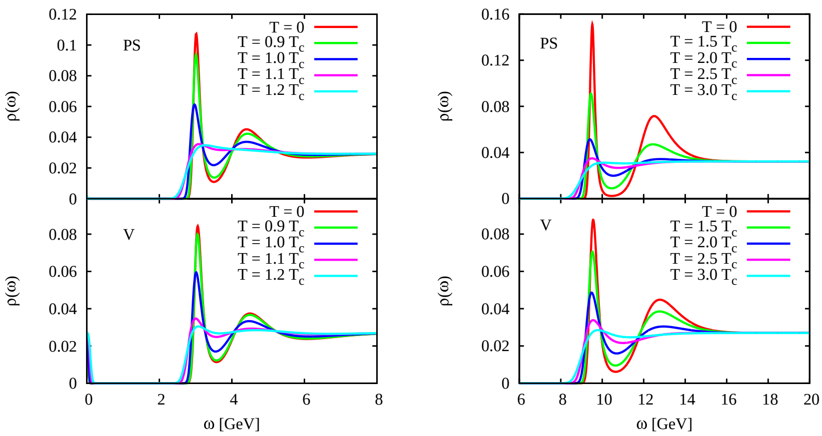

Figure 1: *Quarkonium spectral function at zero and finite temperature. Left plot: Charmonium pseudoscalar (upper plot) and vector (lower plot) channels. Right plot: Bottomonium pseudoscalar (upper plot) and vector (lower plot) channels.*

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Holographic mean-field theory for baryon many-body systems

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We will summarize the main points of Ref. [1], where we propose a mean-field approach to analyze many-body systems of fermions in the gauge/gravity duality. We introduce a nonvanishing classical fermionic field in the gravity dual, which we call the holographic mean-field for fermions. The holographic mean-field takes account of the many-body dynamics of the fermions in the bulk. The regularity condition of the holographic mean-field fixes the relationship between the chemical potential and the density unambiguously. Our approach provides a new framework of gauge/gravity duality for finite-density systems of baryons in the confinement phase.

We apply our method to the model given in [2] where the baryon field is introduced into the Sakai-Sugimoto model [3]. Figure 1 shows the resultant equation of state (solid curve) compared with the one for the free baryons (dashed curve): $\mu/\mu_{n\to 0} = \sqrt{1 + (3\pi^2 n/2)^{2/3}/\mu_{n\to 0}^2}$. Here, the horizontal axis is n/n_0, while the vertical axis is $\mu/\mu_{n\to 0}$. This result shows that the chemical potential μ increases as the density grows, which can be understood as an effect of repulsive interactions among the baryons.

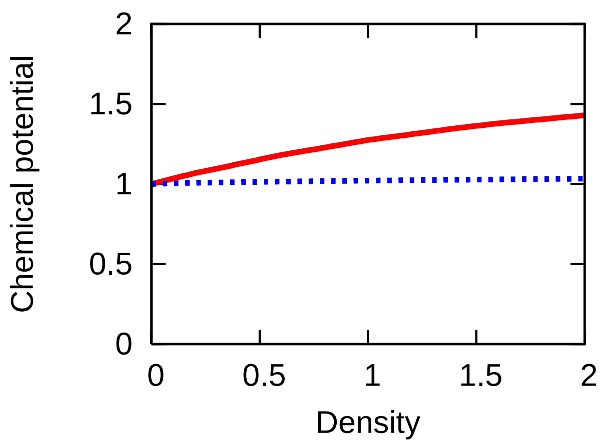

Figure 1: *The EOS of the model (solid) compared with the one for the free baryons (dashed).*

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How kaons explore nuclear properties and nuclei explore kaon properties

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In recent years the increasing amount of experimental results as well as effort the develop simulation programmes which allow to simulate heavy ion collisions from the initial separation of projectile and target up to the final stage consisting of nucleons and fragments had made possible to study and to understand many details of heavy ion reactions in the energy range between 500 AMeV and 2 AGeV.

One of the most challenging questions in this energy domain is the understanding of strangeness production and the interaction of the produced strangeness with the nuclear environment. This is a double challenge: On the one side strangeness production depends on nuclear properties like the fermi motion and on the density at the point of creation, on the other side the nucleus can serve as a laboratory to study the interaction between strange particles and nucleons, especially for strangeness exchange reactions like $\Lambda\pi \to K^-N$

Recently it has been shown that not only these simulation programs yield stable results and that therefore conclusions about the physics involved is robust.

In this contribution we will address three of the interesting physics topics [3].

1) The KN interaction can be directly inferred from experimental data. This is the first time that the interaction between a meson and nuclear matter is measurable.

2) The K^+ yield is a direct measure of the hadronic equation of state The available high precision measurements allow to conclude that the compressibility modulus is around 200 MeV.

3) The large difference between K^- yield and the K^- spectra in pp(pA) and AA collision is due to the fact that in heavy ion collision the dominant channel for K^- production is $\Lambda\pi \to K^-N$, which is absent in pp(pA) collisions.

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How neutron stars constrain the nuclear equation of state

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Recently, the mass of the pulsar PSR J1614-2230 has been measured with high accuracy to be 1.97 ± 0.04 solar masses. This, in addition to statistical analyses of neutron-star radii, leads to tight constraints for the equation of state of dense baryonic matter inside neutron stars. We combine a realistic phenomenological equation of state at low densities with equations of state around nuclear density derived from chiral effective field theory, on one hand, and from the Polyakov-loop-extended Nambu–Jona-Lasinio model, on the other. In the latter case, we investigate also the particular role of a vector interaction for the chiral phase transition. Our analysis strongly supports a very stiff equation of state of ordinary nuclear matter, without the need of exotic-matter admixtures, in order to reproduce the empirical observations for neutron stars.

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Signals of QCD phase transitions studied with nonequilibrium chiral fluid dynamics

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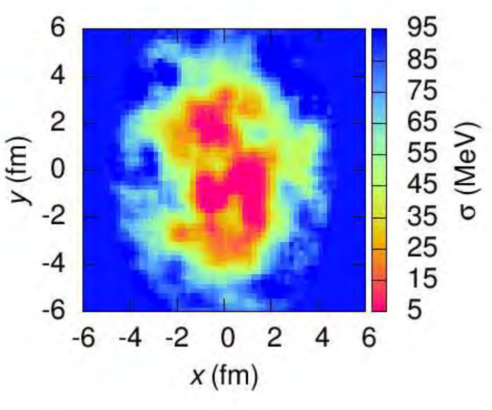
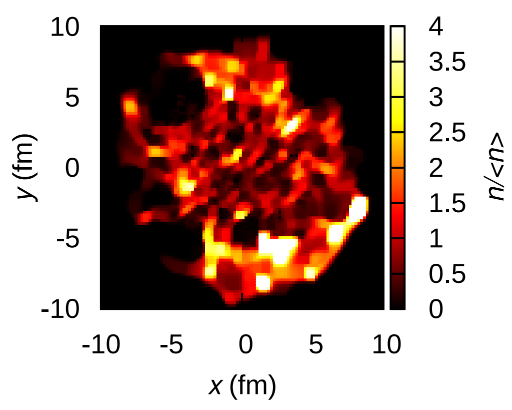
We study the impact of nonequilibrium effects on signals of the QCD phase transition within a chiral fluid dynamics model including explicit propagation of the Polyakov loop [1,2]. An expanding heat bath of quarks is self-consistently coupled to the Langevin dynamics of the order parameter fields [3]. The model is able to describe relaxational processes, including critical slowing down and the enhancement of soft modes near the critical point. At the first-order phase transition we observe domain formation and phase coexistence in the sigma and Polyakov loop field leading to a significant amount of clumping in the energy density [1]. This effect gets even more pronounced if we go to systems at finite baryon density [cf. Fig. 1]. Here the formation of high-density clusters could provide an important observable signal for upcoming experiments at FAIR and NICA. Hadronization of these clusters will lead to large nonstatistical fluctuations in the hadron rapidity density within single events. We conclude that improving our understanding of dynamical symmetry breaking is important to give realistic estimates for experimental observables connected to the QCD phase transition.



(a)



(b)

Figure 1: (a) Sigma field for $z = 0$ at the first-order phase transition. (b) Relative baryon number density for $z = 0$ in the late stage of the evolution through the first-order transition.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

QCD at small x: from Color Glass Condensate to Pomerons and Odderons in high energy proton-nucleus collisions at RHIC and LHC

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Proton-nucleus collisions at high energy provide an excellent environment for studying extreme QCD. At high energies (small Bjorken x), a nucleus is a dense system of gluons and can be investigated by an effective theory of QCD at small x known as the Color Glass Condensate (CGC). This effective theory has been used extensively to understand multi-particle production in high energy hadron and nucleus collisions at RHIC and LHC. Among the observables which are investigated using CGC formalism and are sensitive to high gluon density environment is di-hadron azimuthal angular correlations. This correlation been measured at RHIC and shows a disappearance of the away side peak in the forward rapidity region. We show that this disappearance is due to exchange of multiple Reggeized gluon states which obey the BJKP evolution equations. We show that the BJKP hierarchy of equations are contained in the CGC formalism as the low density limit of the JIMWLK equations for the Quadrupole. We show that at high transverse momenta the dominant exchange is a Pomeron (a state of two Reggeized gluons) exchange which leads to back to back hadrons. As one lowers the hadron transverse momenta, 4-Reggeized gluon exchanges become important and lead to the disappearance of the away side peak.

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Variational approach to the inhomogeneous chiral phase in quark matter

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Recently the inhomogeneous chiral phases have been actively studied in the QCD phase diagram; where the chiral condensates have spatial dependence. Inhomogeneous order parameters have been studied as well in condensed matter physics; e.g., spin density wave, charge density wave, the FFLO state in superconductor and so on. We here consider the similar subject within QCD. It has been shown that the inhomogeneous chiral phases may appear in the low temperature and/or moderate density region before chiral transition in the QCD phase diagram[1-3]. However, many studies have considered only idealized situation such as no external magnetic field, no isospin asymmetry, and no current quark mass. External magnetic field and isospin asymmetry are especially important in relation to realistic implications on compact-star phenomena. The finite current mass is also important in the low temperature and/or density region, since the pion mass is generated to be 138 MeV from massless Nambu-Goldstone particle. Moreover, in the vicinity of the critical point, where the dynamical mass becomes very small, we should take into account the effect of current quark mass. Actually, it has been demonstrated that the properties of the chiral transition have been very much modified not only quantitatively but also qualitatively [4]. We here elucidate the effect of the current quark mass on the inhomogeneous chiral phases, especially the dual chiral density wave (DCDW) state. Exact solutions have been already known for other solutions such as real kink crystal in the massive case, and its effects on the phase diagram have been investigated [1]. The exact solution, however, have not been obtained for the DCDW state, while this configuration bears rich physical contents and might have important phenomenological implications. One way to discuss such effect is a perturbative approach from the chiral limit, without changing quark wave function and the form of chiral condensate. This approach has been discussed in [5], but may not be sufficient to study the DCDW state. As we shall see, the functional form of the chiral condensates has been largely changed, especially near the critical point. Perturbative approach is then not legitimate.

We propose here a variational approach to this problem and figure out some features of the DCDW state in the presence of the current mass. To begin with we assume the form of the chiral condensate as $\langle \bar{q}q \rangle = \Delta \cos\theta(z), \langle \bar{q}i\gamma_5\tau_3 q \rangle = \Delta \sin\theta(z)$ with a uniform amplitude Δ. The chiral angle $\theta(z)$ is now a dynamical variable, and reduced to qz in the chiral limit. Using the derivative expansion of the thermodynamic potential, we can find $\theta(z)$ obeys the sine-Gordon (SG) equation in the leading order, $d^2\theta(z)/dz^2 - m_\pi^2 \sin\theta(z) = 0$ by way of the Gell-Mann-Oakes-Renner relation. The solution is then given by the Jacobi amplitude function with a modulus parameter k. Note that $k \to 0$ in the chiral limit, and accordingly $\theta(z) \to qz$, while $k \to 1$ near the critical point and $\theta(z)$ takes the SG kink form. The quark wave function can be obtained by solving the Dirac equation in the presence of $\theta(z)$, but it is a hard task. Instead, we use the wave function in the chiral limit, which corresponds to the replacement of $d\theta(z)/dz$ by its average in the Dirac equation. The validity of this approximation should be examined after getting the phase diagram.

Using this variational approach we discuss how the phase diagram is changed by the finite current mass and clarify how the form of the condensate is modified near the phase boundaries. The difference from the perturbative calculation is also demonstrated in the phase diagram.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Future of physics with RHIC at BNL and major upgrade to PHENIX detector

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Hadronic matter under conditions of extreme temperature or net baryon density transitions to a new state of matter called the quark-gluon plasma. The QGP is believed to have filled the universe a few microseconds after it came into existence. It can also be created in collisions of relativistic heavy ions at Relativistic Heavy Ion Collider at BNL and Large Hadron Collider at CERN.

The quark-gluon plasma at RHIC has been found experimentally to be a perfect fluid. Its temperature of 3×10^{12}°C was inferred from the distribution of energies of emitted photons. The next stage in physics program at RHIC will address fundamental questions about the nature of QGP and how it behaves in the vicinity of strongest coupling (near 1–2 Tc):

- how to reconcile the observed strongly coupled quark-gluon plasma with the asymptotically free theory of quarks and gluons;
- how sharp is the transition of the quark-gluon plasma from the most strongly coupled system near Tc to a weakly coupled system of partons known to emerge at asymptotically high temperatures;
- what are the underlying dynamical changes to the medium (for example quasiparticles and excitations) as one crosses the transition temperature and above.

It will rely on world-class jet observables at RHIC energies, in conjunction with higher temperature quark-gluon plasma measurements at the Large Hadron Collider.

This new program of exciting research at RHIC and a related proposal to upgrade the PHENIX experiment at RHIC to become a full-fledged jet detector will be reviewed in the talk.

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Exclusive electromagnetic production of pion pairs in lead-lead collisions at LHC

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We shall discuss a possibility to study the $\gamma\gamma \to \pi\pi$ processes in ultrarelativistic ultraperipheral heavy ion collisions.

The $\gamma\gamma \to \pi\pi$ reactions are more complicated than commonly believed. We shall present an approach which takes into account many mechanisms not included so far in the literature. We shall also present how our approach describes world $\gamma\gamma \to \pi\pi$ data for the first time both for the total cross section and angular distributions for $\gamma\gamma \to \pi^+\pi^-$ and $\gamma\gamma \to \pi^0\pi^0$ reactions from kinematical threshold up to maximal accessible experimentally energy $\sqrt{s_{\gamma\gamma}} = 6$ GeV.

Several reaction mechanisms are identified. We include dipion continuum due to $\rho^\pm$ exchange for $\pi^0\pi^0$ and Born approximation for $\pi^+\pi^-$ as well as pronounced dipion $\sigma(600)$, $f_0(980)$ and $f_2(1270)$ s-channel resonances. We will discuss also possible contribution of less pronounced scalar resonances $f_0(1500)$ and $f_0(1710)$ being glueball candidates as well as tensor resonances $f_2'(1525)$, $f_2(1565)$ and $f_2(1950)$. We find that the inclusion of high-spin $f_4(2050)$ resonant state improves the situation at $\sqrt{s_{\gamma\gamma}} \approx 2$ GeV. At higher energies the pQCD inspired Brodsky-Lepage and hand bag mechanisms are included in addition.

Finally, we will present nuclear cross sections for exclusive production of two neutral and two charged pions in peripheral ultrarelativistic heavy ion collisions. We shall present the prediction for lead-lead collisions at an energy of $\sqrt{s_{NN}} = 5.5$ TeV which could be measured e.g. by the ALICE collaboration at the LHC. The cross section for this process is calculated in the impact parameter space Equivalent Photon Approximation (EPA) with realistic charge form factor of ^{208}Pb nuclei being Fourier transform of realistic charge distribution.

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Long-range rapidity correlations in high energy AA collisions in Monte Carlo model with string fusion

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The study of long-range correlations between observables in two windows separated in rapidity was proposed [1] as a signature of the string fusion and percolation phenomenon, which is one of the collectivity effects [2] in ultrarelativistic heavy ion collisions. Different types of correlations are considered [3]: n-n, pt-n, pt-pt, where n is the event multiplicity of charged particles in a given rapidity window and p_t is their mean transverse momentum:

$$p_t = \frac{1}{n} \sum_{i=1}^{n} p_{t_i} \ .$$

In the present work we calculate the correlation functions and coefficients for Pb-Pb collisions at the LHC energy in the framework of the Monte Carlo string-parton model, based on the picture of elementary collisions of color dipoles [4]. It enables to describe AA scattering without referring to the Glauber picture of independent nucleons collisions. The interaction of strings, stretched between partons of the target and projectile, in the transverse plane is implemented in the framework of the cellular version of string fusion model [5].

The dependence of the correlation coefficients on the width of the rapidity windows and on the gap between them is studied. The domination of pt-pt correlation over pt-n at the LHC energy is found by the model MC simulations. It is demonstrated that the values of correlation coefficients strongly depend on the method of collision centrality fixation. In this connection different ways of centrality determination in the analysis of experimental nucleus-nucleus scattering data are also discussed and taken into account in calculations of the centrality dependence of the correlation coefficients.

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Cronin effect at different energies: from RHIC to LHC

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We study production of hadrons with large transverse momenta pT in nucleon-nucleon collisions at different energies corresponding to experiments at RHIC and LHC. For this purpose we use the QCD improved quark-parton model including the intrinsic parton transverse momenta. For investigation of large-pT hadrons produced on nuclear targets we include additionally the nuclear broadening calculated within the color dipole approach and the nuclear modification of parton distribution functions.

We found a nice agreement of high-pT particle spectra and nucleus-to-nucleon ratios with data at different energies corresponding to RHIC and LHC experiments. We also perform predictions for expected nuclear effects in production of various hadrons in proton-lead collisions at c.m. energy \sqrt{s} = 5.02 TeV and at larger \sqrt{s} = 5.5 TeV planned after the LHC shutdown.

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Jet Quenching with ATLAS and CMS

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An overview of the most recent results on jet quenching physics obtained using PbPb collision data collected with the ATLAS and the CMS experiments at $\sqrt{s}$ = 2.76 TeV will be presented. These measurements make use of many different observables, including momentum imbalance of dijet and photon-jet events, nuclear modification factors Raa and Rcp, as well as jet fragmentation functions, jet shapes, and flavor dependence of jet quenching. The measurements in PbPb collisions will be compared to those obtained from pp collisions at the same center-of-mass energy. The effects of the parton energy loss in the hot and dense medium probed with the different observables will be discussed.

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Review on Flow and Correlations

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Ultra-relativistic heavy ion collisions produce a hot and dense plasma of quarks and gluons (QGP) akin to the plasma which existed a few microseconds after the Big Bang. Flow and correlation measurements play a central role in ongoing efforts to study the transport properties of the QGP produced in collisions at both the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC). I will review recent flow and correlation measurements with emphasis on what we learn from them.

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Anomalous Transport: Kubo Formulae and Fluid/Gravity Correspondence

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Quantum anomalies give rise to new transport phenomena in relativistic fluids. In particular a magnetic field can induce an anomalous current via the chiral magnetic effect [1] and a vortex can also induce a current via the chiral vortical effect [2]. The related transport coefficients can be calculated via Kubo formulae [3]. In this work we derive the Kubo formulae relevant for anomalous transport, and perform a computation in quantum field theory and AdS/CFT. In both cases we conclude that the anomalous vortical conductivity receives contributions induced by the gauge-gravitational anomaly, and this produces a T^2 dependence in the vorticity [4,5].

As a second step of this work, we perform a holographic computation in the framework of the fluid/gravity correspondence [6] up to first order and second order in the hydrodynamical expansion, including chiral and gauge-gravitational anomalies and external electromagnetic fields [7]. We reproduce previous results with no external fields [6], and obtain new coefficients induced by these anomalies.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Baryon production mechanisms and jet energy loss in heavy ion collisions at RHIC and LHC energies

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Hadron production in relativistic heavy ion collisions consists of two main channels in the intermediate-p_T region at RHIC and LHC energies: parton coalescence/recombination and jet fragmentation. This is valid for baryon and antibaryon production. We have explored a new channel, namely hadron production from strong time dependent coherent field produced in heavy ion collisions. One can investigate direct hadron production from strong field or quark-antiquark production and later hadron formation from these elementary ingredients. We focus on pair-production and investigate the influence of this new channel on baryon production. In the momentum window of 5 GeV/c < p_T < 25 GeV/c this channel could yield an extra baryon production not considered earlier. However, in this momentum window jet energy loss is strongly modifying hadron spectra in heavy ion collisions. The overlap of hadron production yields and energy loss effects creates a very complex environment, which is worthwhile to investigate for obtaining information on the hot and dense partonic matter produced in heavy ion collisions. We study the details of this overlap and investigate it at RHIC and LHC energies. We present our recent results obtained on the basis of our previously published papers [1][2].

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Small-x Physics in eA Collisions at the LHeC: Understanding the Initial State of Ultra-Relativistic Heavy Ion Collisions

The LHeC Study Group

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The proposed Large Hadron-electron Collider at CERN will collide 60 GeV electrons and positrons against the LHC beams, providing center-of-mass energies around 1 TeV per nucleon. It will give access to a completely unexplored region of extremely small x at relatively large Q^2, which exceeds those explored in previous DIS experiments by a factor 20 for protons and by four orders of magnitude for nuclei. Thus, it will open the window to a novel regime of QCD at small x in which the hadron becomes a dense but weakly coupled parton system, and parton densities saturate. In the case of nuclei, this low x system represents the initial state of heavy ion collisions and its understanding is fundamental to a complete description of the dynamics of quark gluon plasma formation. After a brief introduction, the possibilities for establishing the relevance of physics beyond the standard, fixed-order perturbative DGLAP approach - either linear resummation schemes or non-linear dynamics - will be discussed. First, inclusive cross sections will be examined. Then the possibilities in diffraction and exclusive vector meson production will be analysed. Finally, hadron and jet measurements sensitive to the QCD dynamics at small x will be presented.

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Latest results on electromagnetic radiation from the strongly interacting matter in and out of equilibrium

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Recent measurements of the real and virtual photons produced in the relativistic heavy ion collisions at RHIC and LHC by the PHENIX, STAR and ALICE Collaborations reveal several gaps between current theories and the data. We investigate the spectra and elliptic flow of dileptons and photons produced in relativistic heavy ion collisions in the scope of the covariant off-shell transport approach Parton-Hadron String Dynamics (PHSD). We account for the dilepton and photon production by the (in-medium) meson decays and meson interaction, (correlated) decays of charm and bottom quarks, and the quark and gluon interactions in the early stages of relativistic heavy-ion collisions. The implemented dilepton and photon production rates in equilibrium agree with the lattice QCD results. PHSD treats the full non-equilibrium evolution of a relativistic heavy-ion collision from the initial hard scatterings and string formation through the dynamical deconfinement phase transition to the strongly interacting quark-gluon plasma as well as hadronization and to the subsequent interactions in the hadronic phase. By comparing our results for the radiation from the heavy-ion collisions to the available data, we determine the relative importance of the various dilepton and photon production sources and address the possible origin of the observed strong anisotropy of photons. In this respect, also the photon production under the influence of the strong magnetic fields in the initial stage of the collisions is discussed. Predictions are presented for dilepton spectra from the Pb+Pb collisions at sqrt(s)=2.76 TeV and p+p collisions at sqrt(s)=7 TeV.

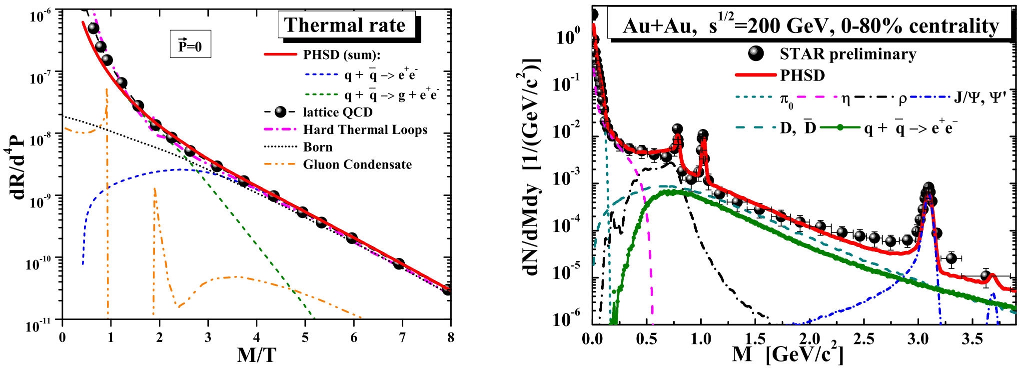

Figure 1: **Left hand side:** *Rates for dilepton production from the back-to-back $q + \bar{q}$ interactions in a thermal medium. PHSD results are shown by the red solid line, which is the sum of the $q + \bar{q} \to e^+e^-$ (blue dash line) and $q + \bar{q} \to g + e^+e^-$ (green dash) contributions. The lattice QCD calculations are presented by the line with round symbols, the HTL results by the magenta dash-dot line, the Gluon Condensate rate by the orange dash-dot-dot line and leading order (Born) prediction by the black dot line.* **Right hand side:** *The PHSD results for the invariant mass spectra of inclusive dileptons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV for 0 - 80 % centrality within the cuts of the STAR experiment.*

International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

First results from proton-lead collisions at sqrt(sNN)=5.02 TeV measured with ALICE

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Measurements from proton-lead collisions at sqrt(s_NN)=5.02 TeV obtained by the ALICE experiment at the CERN LHC will be presented. These include the pseudo-rapidity density and transverse momentum distributions of unidentified charged particles, as well as angular correlations between charged trigger and associated particles, which are based on 1/mub recorded during the one-day pilot run in September 2012. Furthermore, first results using data from the 2013 run, which is expected to deliver a factor of 10000 more collisions, will be presented. Where possible, the results will be compared to previous p-p, A-A and d-A experimental results at different collision energies and to the available theoretical model predictions.

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Detecting the Anti-helium 4 and anti-hypertriton from the RHIC

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In this talk, I will present a brief review on the recent measurements of antimatter particles at RHIC. The observations of the antihypertriton [1] and antihelium-4 nucleus [2] from the STAR collaboration are highlighted. I will also discuss the new lifetime measurement of hypertriton [3] as well as the strangeness population factor as a function of collision energy of Au + Au [4]. The current experimental search for antinuclei in cosmic rays is also mentioned in this talk. Finally I present a mechanism of antinuclei formation at RHIC with the help of thermal and coalescence models [5].

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A Chiral quark-soliton model with broken scale invariance for nuclear matter

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Soliton models based on the linear σ-model fail to describe nuclear matter already at densities close to ρ_0 due to the restrictions on the scalar field dynamics imposed by the Mexican hat potential [1].
To overcome this problem we used a chiral Lagrangian, including a logarithmic potential associated with the breaking of scale invariance, based on quarks interacting with chiral fields, σ and π, and with vector mesons [2]. It has already been shown that an hadronic model based on this dynamics provides a good description of nuclear physics at densities about ρ_0 and it describes the gradual restoration of chiral symmetry at higher densities [3]. In the same work the authors have shown a phase diagram, where the interplay between chiral and scale invariance restoration lead to a scenario similar to that proposed by McLerran and Pisarski in [4].

Using the Wigner-Seitz approximation [5-6] to mimic a dense system, we show that the model admits stable solitonic solutions at higher densities respect to the linear-σ model and that the introduction of vector mesons, besides stabilizing the solutions at high densities, it also provides the necessary repulsion to obtain saturation.

The Wigner-Seitz lattice represents a configuration of static solitons with a specific symmetry given by the boundary conditions imposed on each cell; it follows that for instance the isospin degrees of freedom of the soliton are not exploited to reach perhaps a lower energy configuration of the system.

In order to start developing a more sophisticated multisoliton lattice, as e.g. in [7], we also present a first attempt to go beyond the Wigner-Seitz approach, namely by building up the baryon number $B = 2$ system and by evaluating how the interaction energy between the two solitons depends on the relative orientation of the hedgehog quills. We study the interaction energy defined as $V_{int}(d) = E_{B=2} - 2E_{B=1}$ as a function of the inter-soliton distance d and we discuss if it is possible to obtain bound states.
In particular we investigate the behaviour of the system in the range of long and intermediate distances by adopting the *product ansatz* approach [8] while as the two solitons get closer we solve the six quarks bag field equations [9]. We show that for small separations the six quarks bag, assuming a hedgehog structure, provides a stable bound state that at large separations connects with a special configuration coming from the product ansatz.

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The Polyakov loop and the Hadron Resonance Gas Model

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The Polyakov loop has been used repeatedly as an order parameter in the deconfinement phase transition. We describe results [1] for the confinement-deconfinement phase transition as predicted by the Nambu–Jona-Lasinio model where the local and quantum Polyakov loop is coupled to the constituent quarks in a minimal way (PNJL). We observe that the leading correlation of two Polyakov loops describes the chiral transition accurately [2]. On the other hand, using quite general chiral quark models of QCD featuring spontaneous chiral symmetry breaking and implementing the quantum and local nature of the Polyakov loop [1,3], we argue that, in the confined phase, its expectation value can be represented in terms of hadrons, similarly to the hadron resonance gas model for the pressure [4,5,6]. Specifically,

$$L(T) \approx \frac{1}{2} \sum_{\alpha} g_\alpha e^{-\Delta_\alpha/T},$$

where g_α are the degeneracies and Δ_α are the masses of hadrons with exactly one heavy quark (the mass of the heavy quark itself being subtracted). We show that this approximate sum rule gives a fair description of available lattice data with N_f = 2+1 for temperatures in the range $150\,\mathrm{MeV} < T < 190\,\mathrm{MeV}$ with conventional meson and baryon states from two different models. For temperatures below $150\,\mathrm{MeV}$ very recent lattice results [7,8] can be described only if exotic hadrons are present in the QCD spectrum

This work opens the possibility of a Polyakov loop spectroscopy, i.e. using the Polyakov loop in fundamental and higher representations to deduce multiquark states, gluelumps, etc, containing one or several heavy quark states.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Exploring the QCD phase diagram through relativistic heavy-ion collisions

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Quantum chromodynamics (QCD) phase diagram is usually plotted as temperature (**T**) versus the chemical potential associated with the conserved baryon number ($\boldsymbol{\mu_B}$). Two fundamental properties of QCD, related to confinement and chiral symmetry, allows for two corresponding phase transitions when **T** and $\boldsymbol{\mu_B}$ are varied. Theoretically the phase diagram is explored through non-perturbative QCD calculations on lattice. The energy scale for the phase diagram (Λ_{QCD} ~ 200 MeV) is such that it can be explored experimentally by colliding nuclei at varying beam energies in the laboratory. In this talk we review some aspects of the QCD phase structure as explored through the experimental studies using high-energy nuclear collisions. Specifically, we discuss observations related to the formation of a strongly coupled plasma of quarks and gluons in the collisions and experimental search for the QCD critical point on the phase diagram.

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Chiral density waves in dense quark matter using an extended NJL model

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Due to the critical role played by dynamical chiral symmetry breaking in low energy hadron phenomenology the Nambu-Jona-Lasinio model [1] is widely regarded as an useful tool for study of the low energy regime of strongly interacting matter. Working in the light quark sector (u, d and s) the inclusion of eight quark interactions [2] (which can be split in an two parts one of which violates the Okubo-Zweig-Iizuka (OZI) rule) solves the problem of the absence of a globally stable ground state in the model which comes with the inclusion of the t Hooft determinantal six quark interaction (which is introduced to break the unwanted axial symmetry) [3]. It was shown that the strength of these OZI-violating eight quark interactions can be chosen over a wide range of values without affecting the meson spectra (one has to simultaneously lower the strength of the NJL four quark interaction when raising the eight quark strength), except for the meson mass which is lowered by stronger eight quark interactions [3]. Despite this fact these interactions have been shown to greatly influence several model observables in the presence of external parameters such as for instance the location of the critical endpoint in the phase diagram, the behavior of susceptibilities around the transitions (deconfinement and chiral restoration) as well as the behavior under the influence of external magnetic fields [4]. Furthermore it was also shown that the using a Pauli-Villars regulator with two subtractions in the integrand [5] we can obtain the expected high-temperature asymptotic behaviour for the NJL model (as well as in its extension to include the Polyakov loop) while consistently using the same regularization procedure for both the vacuum and medium contributions for the relevant integrals.

The moderate to high density/low temperature regime of strongly interacting matter has been the subject of several studies and is of great relevance for instance for astrophysical objects and relativistic heavy ion collisions. One of the proposed scenarios is that of chiral density waves (see for instance [6]) which refers the possibility of instability with respect to the formation of a non-uniform, anisotropic phase which is described by a dual standing wave in scalar and pseudoscalar condensates on the chiral circle. Here we are going to present some results on the influence of the eight-quark interactions on the properties of this particular phase.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Upsilon suppression in relativistic heavy-ion collisions

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We suggest that the combined effect of gluon-induced dissociation, collisional damping, screening, and reduced feed-down explains most of the suppression of Upsilon states that has been observed by CMS [1] in PbPb relative to pp collisions at $\sqrt{s_{NN}}$ = 2.76 TeV at the CERN LHC. The suppression is thus a clear, albeit indirect, indication for the presence of a Quark-Gluon Plasma.

In particular, we calculate the suppression of the Υ(1S, 2S, 3S) and the χ_b states in the quark-gluon plasma in minimum-bias and centrality-dependent PbPb collisions. We explicitly consider the effect of gluodissociation [2] and collisional damping [3] on the widths of the states, and the time dependence of the suppression in the expanding fireball. The influence of the confining string contribution on the dissociation rates is included in the calculations of the wavefunctions and widths.

As compared to pp collisions at the same energy, the feed-down cascade leading to the Υ(1S) ground state is drastically modified due to the substantial suppression of the excited states through screening, damping and gluodissociation. The 1S ground state remains very stable with respect to screening, its suppression is essentially due to damping, gluodissociation and reduced feed-down.

Our results [4] for the centrality-dependent suppression of the Υ(1S) ground state are in good agreement with the CMS data [1] for reasonable plasma temperatures at Upsilon formation time. For the excited states we find less suppression than CMS, in particular for peripheral collisions. This leaves room for additional suppression mechanisms.

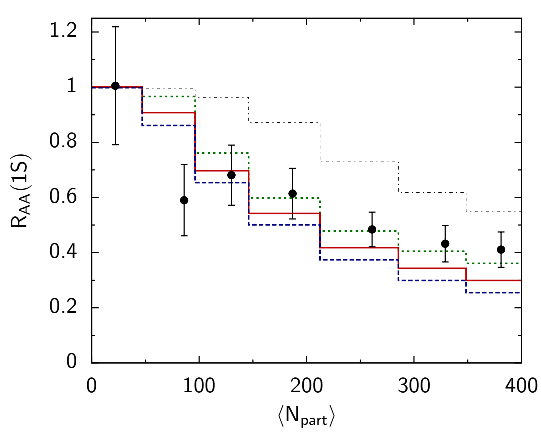

Figure 1: *Calculated Υ(1S) suppression [4] compared to CMS data [1].*

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

In-medium hadron properties measured with HADES

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The HADES spectrometer [1] designed to measure e+e- pairs (dielectrons) in the SIS⁄BEVALAC energy regime is currently being operated at GSI Darmstadt and is foreseen as one of the first experiments at the future FAIR facility. One of the main objectives of the experimental approach is to systematically explore electromagnetic emissivity of compressed baryonic matter formed in the course of heavy ion collisions and to ultimately assess in-medium hadron properties. For this purpose a dedicated programme focusing on systematic investigation of dielectron production in nucleon-nucleon, proton-nucleus and heavy ion reactions has been conducted. A comparison of the nucleon-nucleon data to the one obtained in more complex systems allows for the isolation of in-medium effects [2][3]. Furthermore, as the spectrometer features excellent particle identification capabilities, the investigations have been extended to strangeness production, which in this energy regime is confined to the high density zone of the collision. In particular, appealing new results on hadrons containing two strange quarks (ϕ, Ξ(1321)) [4][5] have been obtained.
In this contribution, an overview of recent results as well as of future perspectives, in particular with the focus on the FAIR project, will be given.

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Partonic mean field impact on the splitting of baryon and anti-baryon elliptic flow at low relativistic energy

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Using a partonic transport model based on the Nambu-Jona-Lasinio (NJL) model [1,2], we study the effect of scalar and vector mean fields on the elliptic flows of quarks and antiquarks in relativistic heavy ion collisions. Converting quarks and antiquarks at hadronization to hadrons via the quark coalescence model, we further study the dependence of the transverse momentum integrated relative elliptic flow differences between protons and antiprotons, lambda and anti-lambdas, and positively and negatively charged kaons on the strength of the quark vector coupling. Our results suggest that a sizeable vector coupling seems to be needed to describe the experimental data measured by the STAR Collaboration in the Beam Energy Scan (BES) program at the Relativistic Heavy Ion Collider (RHIC).

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Measurement of energy and centrality dependence of triangular flow and higher harmonics by STAR in Au+Au collisions

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Initial state geometry fluctuations in relativistic heavy ion collisions can lead to flow fluctuations which induce non-zero higher harmonics in the final momentum space. These higher harmonics may dominate the near-side ridge and away-side structures seen in two-particle correlations. We present measurement of triangular flow (v_3) as well as higher harmonics (v_4-v_7) in Au+Au collisions at $\sqrt{s_{NN}}$=7.7 – 200 GeV recorded with the STAR detector at RHIC using two-particle cumulant corrected for short-range $\Delta\eta$ correlations. We will also present the ratio of the corrected two-particle cumulant $v_n\{2\}$ to participant eccentricity ($\varepsilon_{n,\mathrm{part}}$) from Monte-Carlo Glauber model. This provides a picture of how the efficiency for converting initial state geometry fluctuations into momentum space correlations changes with collision energy, system-size and harmonic.

Phenomenological Study of QGP-fireball Thermodynamics

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November 30, 2012

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Abstract

We propose an algebraic form for the density of states of quarks and gluons in a Quark-Gluon Plasma (QGP)fireball in quasi-equilibrium with a hadronic medium as $\rho(k) = \frac{\alpha}{k} + \beta k + \delta k^2$, and determine the parameters α, β and δ using Lattice Gauge results on the velocity of sound in QGP. The behaviour of the resulting $\rho(k)$ can be easily compared with the thermodynamic data on QGP that is expected from LHC and other RHIC experiments. Our numerical result shows a linear rise of the value of $\rho(k)$ for $k \sim T \approx 160\ to\ 180\ MeV$,which is significant, and throws light on the evolution of the QGP phase.This in turn reproduces the sound velocity profile of the lattice calculation.

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Flavor hierarchy in the QCD phase transition

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Recent advances in the study of the QCD phase transition, using lattice QCD, have revealed a potential flavor dependent hadronization sequence of the deconfined matter as a function of the temperature of the system [1,2]. This is of particular interest for the strange quark sector, since strange quarks are likely to be in thermal equilibrium with light quarks. I will review the most recent lattice QCD results on higher order quark number fluctuations, from which the flavor hierarchy emerges [3]. Possible experimental evidence for the flavor hierarchy from recent Alice data will also be discussed.

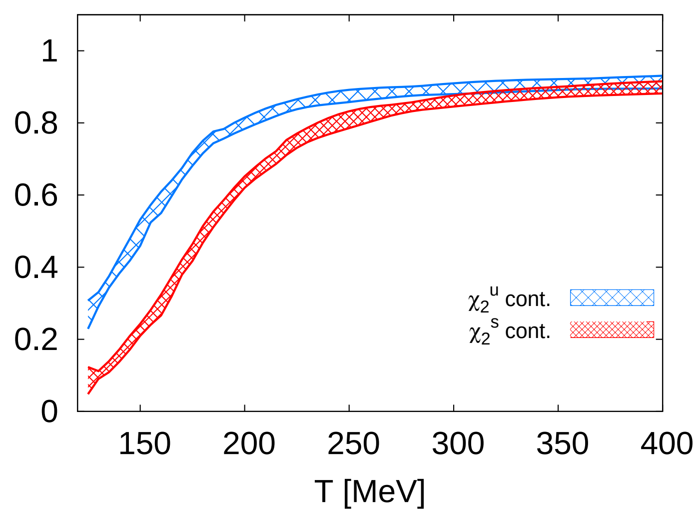

Figure 1: *Comparison between the lattice results for light and strange quark number susceptibilities, obtained with the stout action at physical quark masses in the continuum limit (from Ref. [1]): the two curves are separated by 15-20 MeV.*

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Di-electron measurements with Hadron Blind Detector in the PHENIX experiment at RHIC

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The PHENIX experiment at the Relativistic Heavy Ion Collider (RHIC) is a large multipurpose experiment especially devoted to the measurement of rare probes, low mass dileptons in particular. The observation of spectral shape modifications of the vector mesons could provide direct information on the chiral symmetry restoration. However, the measurement of low mass electron pairs in the original PHENIX detector configuration is limited by a huge background from random combination of uncorrelated electron pairs. This background is dominated by π^0 Dalitz decays and γ conversions.

In order to address this issue a Hadron Blind Detector (HBD) has been developed as an upgrade of the PHENIX experiment. The HBD is a Cherenkov detector with a 50 cm long CF_4 radiator connected in a windowless configuration to a triple GEM coupled to pad readout and with a CsI photocathode layer evaporated on the top face of the GEM stack. The detector exploits the distinctive feature of the electron pairs from π^0 Dalitz decays and γ conversions, namely their very small opening angle. The HBD is therefore installed and operated in a field-free region in order to preserve the original emission direction of electrons. Those electron tracks identified in the PHENIX central arm detectors that have a hit in the HBD with double amplitude or have a nearby hit within a typical opening angle are rejected as likely partners of π^0 Dalitz decay or a γ conversion pair. The detector was successfully operated in the 2009 and 2010 RHIC runs, where large samples of p+p and Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV were recorded. Di-electron results from the analysis of these data sets will be presented.

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Study of the multiplicity distributions in relativistic nucleus-nucleus collisions using the multiplicity distribution moments method

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For obtaining some experimental information on the possibility to observe interesting phenomena in nucleus-nucleus collisions – like thermalization degree, flow, etc - the multiplicity distributions of the particles generated in such collisions, as well as specific correlations can be used. We apply the multiplicity distribution moments method [1,2] for a few interesting estimations for the behavior of the highly excited and dense nuclear matter that will be produced in nucleus-nucleus collisions at the energies of the future SIS-100 accelerator, at FAIR-GSI, using experimental set-up of the CBM Collaboration. The stopping of the projectile nucleus in the target nucleus and possible influences on the hydrodynamic flow are analyzed using the method of moments, as well as the specific correlations. The role of the collision geometry and beam energy is emphasized. Different calculations are compared with experimental results for negative pion yield in nucleus - nucleus collisions at 4.5A GeV/c, results obtained in collisions performed at the Syncrophasotron from JINR Dubna, using SKM 200 Spectrometer.

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Study of the particle transverse momentum spectra in relativistic heavy ion collisions using the Tsallis statistics

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Heavy-ion collisions at relativistic energies offer an unique opportunity to investigate the properties of highly excited dense nuclear matter in the laboratory. An interesting phenomenon at the kinetic freeze-out stage of the system evolution is the collective transverse expansion as it is entirely generated during the collision and therefore reflects the collision dynamics. Fenomenologically, transverse spectra of various hadrons produced in high-energy nucleus-nucleus collisions, can be described by the Tsallis distribution, with a new parameter, the non-extensive parameter q, which is identified with fluctuations of the parameter T, the ”temperature” of the hadronizing fireball [1,2]. In this work, we will present a study of Tsallis fits performed to the transverse momentum spectra obtained from simulated heavy ion collisions at future CBM-FAIR energies using the most important simulation codes from this field. In addition, comparisons with results from Au-Au collisions at RHIC energies will be presented to provide more detailed insight into the properties of the space-time evolution such as collective dynamics of the dense matter.

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Overview of Heavy Ion Results from CMS at the LHC

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The first runs colliding lead nuclei at the LHC occurred in late 2010 and 2011, with the latter increasing the available event sample by more than an order of magnitude. Collisions of protons with lead were studied in a pilot run in late 2012 and a higher statistics physics run in early 2013. Heavy ion collisions at the LHC are expected to produce a partonic medium which has a higher energy density and a longer life-time than could be created at RHIC. Proton-nucleus collisions serve two purposes. The primary goal is to study possible differences between pp, pPb, and PbPb due to initial state effects. In addition, particle multiplicities in some pp and pPb events approach those seen for smaller nuclei and lower energies at RHIC. Comparison of these extreme pp and pPb events to those from heavy ion data can probe the separate influences of particle density and system size. The CMS detector systems are well suited to measuring a wide array of observables in the high multiplicity environment of these collisions. In particular, the detector is optimized to identify and characterize the high transverse momentum photons and charged particles which result predominantly from hard partonic scatterings, as well as having excellent resolution for the decays of heavy particles. Such hard scatterings and heavy produced particles are significantly enhanced at the higher beam energies provided by the LHC. This talk will give an overview of what has been learned about the nature of the hot and dense medium created in high energy heavy ion collisions as well as their similarities/differences with extreme collisions in pp and pPb.

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Color glass condensate initial conditions and formation of collective flow in a kinetic theory approach.

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In this talk, we present our recent results about simulations of relativistic heavy ion collisions at RHIC as well as LHC energies, obtained within relativistic kinetic transport theory using a parton cascade approach. One characteristic of our computations is to keep the viscosity to entropy density ratio fixed as an external constraint during time evolution. This results in the possibility to either keep the ratio fixed (relevant for RHIC), or to introduce a temperature dependence for the ratio itself (more relevant for the case of LHC). Our main objective is to analyze the collective flow properties of several (melted) color glass condensate (CGC) models. We find that assuming a non thermalized initial distribution which embeds the saturation scale typical of a color glass condensate model, then the elliptic flow is smaller than the same quantity computed assuming a thermalized initial spectrum. This novel picture, able to account for non-equilibrium distributions, is different from the more usual one, mainly based on hydrodynamics simulations, in which the larger initial eccentricity of the CGC induce to estimate a larger shear viscosity in order to have an elliptic flow in agreement with experimental data. Our findings indicate that the larger eccentricity of CGC may be compensated by the Q_s saturation scale, hence lowering considerably the estimated viscosity of the QGP when initial conditions of CGC are assumed.

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Measurement of the Inclusive Spectrum of Fully Reconstructed Jets in Central Au+Au Collisions at $\sqrt{(s_{\mathrm{NN}})}$=200 GeV by the STAR Collaboration

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QCD jets are collimated sprays of particles originating from the hard scattering of partons in high energy collisions. Jets, and the modification of jet structure ("jet quenching"), provide important probes of the hot and dense nuclear matter created in the collision of heavy nuclei at collider energies. While much can be learned about jet quenching from studying single particles and few-particle correlations, ultimately the study of fully reconstructed jets is required for a comprehensive understanding of jet quenching and a corresponding measurement of medium properties. However, full reconstruction of inclusive jets is an extremely challenging task in heavy ion collisions, due to the large and fluctuating background.

In this talk, we present a new measurement of the inclusive spectrum of fully reconstructed jets in central Au+Au collisions at $\sqrt{(s_{\mathrm{NN}})}$=200 GeV, by the STAR collaboration at RHIC. We utilize an experimental technique in which jet reconstruction is infrared-safe (i.e. jet reconstruction is stable against emission of an additional soft hadron), even in the large-background environment of such events. The large combinatorial background is suppressed by a threshold cut on the leading hadron of each jet candidate. This cut is however unsafe against colinear splitting of hard partons (i.e. a true jet may be rejected for certain splitting configurations), and its systematics are explored. The influence of the remaining background density fluctuations on the inclusive jet spectrum is then corrected by an unfolding technique based on Bayes's Theorem. We compare this measurement to the jet spectrum in p+p collisions, and to model predictions.

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D-Measure as a viable signal of QGP from Polyakov-Nambu-Jona-Lasinio model

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Strongly interacting matter at high temperatures and densities is expected to go through a phase transition from hadronic to Quark-Gluon-Plasma phase. It is quite interesting to comprehend signals of the same. From theoretical calculations, it is obvious that fractional charges carried by quarks gives rise to such a viable signal. This leads to construct a quantity, D-measure [1] which is the ratio of the net charge fluctuation to the total charge and is expected to provide a signature of the aforesaid transition.

To perceive the same, the behaviourial pattern of D [2] is studied with variation of temperature and chemical potential. The same is done, normalised by D_{free}, which is the free massless but T and μ dependent limit of D. D always remains above its free field limit for all T and μ_B. With an input of temperature and chemical potential from particle multiplicities at the freeze-out surface in heavy ion collision experiments, one may get a flavour of D for different collision energies. This drives to discuss D vis-a-vis findings from the ALICE collaboration [3].

Our work is carried out within the framework of the Polyakov-Nambu-Jona-Lasinio (PNJL) model [4-7] and the results obtained show an encouraging similarity with that obtained from experiment.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Profiling hot and dense nuclear medium with high transverse momentum hadrons produced in d+Au and Au+Au collisions by the PHENIX experiment at RHIC

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After the accumulation of data in various collision systems at different energies at RHIC, the hot dense medium created in Au+Au collisions has been found to have very low shear viscosity (η/s), meaning the system is strongly coupled and has very short mean free path. The interaction of jets produced in the initial hard scattering and the hot dense medium created in heavy ion collisions have been of interest from the beginning of RHIC, since it provides characteristic properties of the medium, such as mean free path and opacity. PHENIX has measured the identified high transverse momentum (p_T) hadrons, such as π^0 and η, with large data sets taken in Year-7 and -10 Au+Au runs and Year-8 d+Au run. We have found that the fractional energy loss ($\Delta E/E$) for high p_T π^0 is strongly dependent on centrality (Figure 1), p_T, and collision energy[1,2]. The azimuthal angle dependence of π^0 nuclear modification factors (R_{AA}) indicated that the energy loss of hadrons is path-length (L) dependent, and that the power is greater than 2 (L^n, n>2), which is inconsistent with pQCD-inspired models as demonstrated in Figure 2. Cold nuclear matter effects, such as k_T smearing can be measured with d+Au collisions. PHENIX has measured high p_T π^0 and η in addition to reconstructed jets in d+Au collisions and quantified these effects.

In this presentation, the latest results on high p_T π^0, η, and jet-related observables in d+Au and Au+Au collisions are presented and discussed.

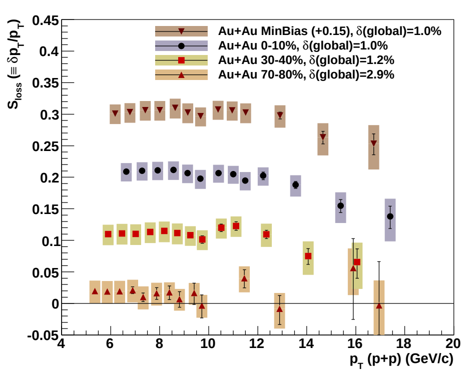

Figure 1: *Centrality dependence of fractional energy loss ($\Delta E/E$) of π^0 in 200GeV Au+Au collisions.*

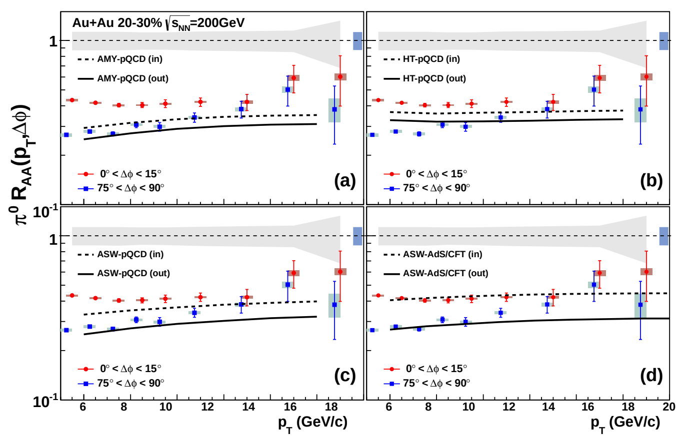

Figure 2: *Azimuthal angle dependence of π^0 R_{AA} in semi-central Au+Au collisions. Top panels show pQCD-inspired, and bottom panels show AdS/CFT-inspired models on data.*

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Higher moments of net kaon multiplicity distributions at RHIC energies for the search of QCD Critical Point

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The Relativistic Heavy-Ion Collider (RHIC), at BNL, has started its beam energy scan(BES) program by colliding heavy-ions extending the reach in baryonic chemical potential upto 400 MeV. One of the main goals of this beam energy scan program is to locate the critical point which is postulated to lie at the end of the phase transition boundary between partonic and hadronic matter. Finite temperature lattice QCD calculations at baryon chemical potential $\mu_B = 0$ suggest a crossover above a critical temperature $T_c \sim 170 - 190$ MeV from a system with hadronic degrees of freedom to a system where the relevant degrees of freedom are quarks and gluons. Several QCD based calculations find the quark-hadron phase transition to be first order at large μ_B. The point in the QCD phase plane (T vs μ_B) where the first order phase transition ends is the QCD critical point (CP). In a static, infinite medium, the correlation length (ξ) diverges at the CP. ξ is related to various moments of the distributions of conserved quantities such as net baryons, net charge, and net strangeness[1]. Typically variances ($\sigma^2 = \langle(\Delta N)^2\rangle; \Delta N = N - M$;where M is the mean) of these distributions are related to ξ as $\sigma^2 \simeq \xi^2$[2]. Finite size and time effects in heavy-ion collisions put constraints on the values of ξ. A theoretical calculation suggests $\xi \simeq 2 - 3$ fm for heavy-ion collisions[2, 3]. It was recently shown that higher moments of distributions of conserved quantities, measuring deviations from a Gaussian, have a sensitivity to CP fluctuations that is better than that of σ^2, due to a stronger dependence on ξ[2, 3, 4]. The numerators in skewness ($S = \langle(\Delta N)^3\rangle/\sigma^3$) go as $\xi^{4.5}$ and kurtosis (k = $[\langle(\Delta N)^4\rangle/\sigma^4] - 3$) go as ξ^7[5]. Presence of a Critical Point might result in divergences of the correlation lengths.

Here we report the measurements of the various moments (standard deviation (σ), skewness (S) and kurtosis (k)) and their products ($k\sigma^2$, $S\sigma$) of the net kaon multiplicity measured by the STAR detector at mid-rapidity for Au+Au collisions at $\sqrt{s_{NN}}$ =7.7 to 200 GeV center of mass energies. The energy and centrality dependence of higher moments of net-kaons and their products (such as $S\sigma$ and $k\sigma^2$) will be presented in all BES energies. Theoretical calculations, containing the non-CP physics from the HIJING, AMPT, UrQMD models will be compared to the data.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Exploring dense baryonic matter with the CBM experiment at FAIR

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Substantial experimental and theoretical efforts worldwide are devoted to explore the phase diagram of strongly interacting matter. At top RHIC and LHC energies, the QCD phase diagram is studied at very high temperatures and very low net-baryon densities. These conditions presumably existed in the early universe about a microsecond after the big bang. For larger net-baryon densities and lower temperatures, it is expected that the QCD phase diagram exhibits a rich structure such as a critical point, a first order phase transition between hadronic and partonic or quarkyonic matter, and the chiral phase transition. The experimental discovery of these prominent landmarks of the QCD phase diagram would be a major breakthrough in our understanding of the properties of nuclear matter.

The Compressed Baryonic Matter (CBM) experiment will be one of the major scientific pillars of the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt. The goal of the CBM research program is to explore the QCD phase diagram in the region of high baryon densities using high-energy nucleus-nucleus collisions. This includes the study of the equation-of-state of nuclear matter at neutron star core densities, and the search for the deconfinement and chiral phase transitions. The CBM detector is designed to measure both bulk observables with large acceptance and diagnostic probes such as multi-strange hyperons, charmed particles and vector mesons decaying into lepton pairs. Most of these probes of dense matter will be measured for the first time with the CBM experiment in the FAIR energy range. The layout, the physics performance, and the status of the proposed CBM experimental facility will be discussed.

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Correlations and flow measurements in PbPb and pPb collisions with CMS

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An overview of measurements of collective flow and dihadron correlations from the CMS experiment will be presented. In PbPb collisions, the Fourier components of the anisotropic azimuthal distribution, ranging from the second to the sixth component, are obtained using different analysis techniques, which have different sensitivities to non-flow and flow fluctuation effects. Dihadron correlations are measured over a wide acceptance and transverse momentum range. Long-range near-side ("ridge") correlation structures and short-range jet-like correlations are systematically studied as a function of pT, pseudorapidity, centrality. These measurements are compared to similar studies performed in pPb collisions and the evolution of the observed correlations with system size and multiplicity of the produced particles is discussed.

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Quark-Gluon-Plasma fireball evolution with one loop correction in the Peshier potential

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We study free energy evolution of Quark-Gluon Plasma (QGP) fireball with one loop correction factor in the peshier potential. The energy evolution with the effect of the correction factor in peshier potential shows increasing the transition temperature and it is obtained in the range of temperature ~T=160-200~MeV. The transition temperature is also effected with the decrease of dynamical flow parameter of quark and gluon used in the potential and it shows the observable QGP droplets of the stable size of fermi radius viz 2.5-4.5 fm.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Direct Photon and Lepton Pair Production from Viscous Quark-Gluon Plasma (QGP)

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We simulate direct photon and lepton production from a viscous Quark Gluon Plasma (QGP). The viscous effect on both di-leptons and photons is very strong. Large invariant mass di-leptons, due to their lower velocity are less affected by viscosity than low invariant mass di-leptons. From the slope of the di-lepton spectra, sensitive to viscosity as well as from the di-lepton invariant mass window, QGP viscosity can be extracted from the experimental data.

We also show that the ratio of photon to di-leptons is sensitive to the viscosity and indeed can serve as a viscometer for QGP.

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Relics of the Cosmological QCD Phase Transition

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Driven by Baryogenesis one can naturally introduce a "tepid inflation" of 7e leading to a first – order phase transition from quarks to hadrons at the primordial epoch of a microsecond after the Big Bang when the Universe was horn. The abundance and size distribution of Quark Nuggets (QN's) formal immediately after the phase transition to hadrons has been estimated. It appears that the stable QN's (Baryon no. $\geq 10^{43}$) could easily be viable candidate for cosmological dark matter. During and after the phase transition the "Naked Quarks" could be reasonable candidate, at least, part of the dark energy.

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Electromagnetic Signals from Au+Au Collisions at RHIC Energy, $\sqrt{S_{NN}} = 200$ GeV and Pb+Pb Collisions at LHC Energy, $\sqrt{S_{NN}} = 2.76$ TeV

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We analyze the recently available experimental data on direct photon productions from Au+Au Collisions at $\sqrt{S_{NN}}$ =200 GeV at RHIC and from Pb+Pb collisions at $\sqrt{S_{NN}}$ =2.76 TeV LHC energies. The transverse momentum distributions have been evaluated with the assumption of an initial quark gluon plasma phase at energy densities E_i = 41 and 70 GeV/ fm^3 and with initial thermalization times τ_i= 0.2 and 1.0 fm/c respectively for RHIC and LHC energies. The theoretical prediction agree remarkably well with the experimentally observation over a wide range of energies. The window for thermal radiation as predicted earlier lies within the p_τ range $1.5 \leq p_\tau$ (GeV) ≤ 3.5. The ratio of thermal photons to di-leptons, determines the window more preciously.

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Hadron Formation in Relativistic Nuclear Collisions and the QCD Phase Diagram

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We analyze hadrochemical freeze-out in central Pb+Pb collisions at CERN SPS and LHC energies. We determine the effects of baryon and antibaryon annihilation and/or regeneration occuring during the final cascade expansion stage of the collisions, deriving survival factors for each hadronic species and all energies considered, by employing the UrQMD hybrid model(1,2). These survival factors are shown to resemble the observed pattern of data deviation from the statistical equilibrium calculations with the statistical hadronization model(1). We apply them in the SHM data analysis, obtaining a novel form for the hadronic freeze-out curve(3). The points in the T - mu(B) plane obtained at each energy now follow closely the parton-hadron phase boundary that was recently predicted by lattice QCD(4)at finite baryochemical potential, up to about 450MeV. We conclude that with this novel method of taking accout for the distortions of the chemical equilibrium established during (or directly after) hadronization, in the course of the subsequent hadronic expansion phase, the SHM data analysis now confirms the QCD predictions at finite mu(B).

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

What RHIC taught the LHC and Vice Versa

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RHIC introduced the method of hard scattering of partons as an in-situ probe of the the medium produced in A+A collisions. A suppression $R_{AA} \approx 0.2$ relative to binary-scaling was discovered for π^0 production in the range $5 \leq p_T \leq 20$ GeV/c in central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, and surprisingly also for single-electrons from the decay of heavy quarks. Both these results have been confirmed in Pb+Pb collisions at the LHC at $\sqrt{s_{NN}} = 2.76$ TeV. Interestingly, in this p_T range the LHC results for pions nearly overlap the RHIC results. Thus, due to the flatter spectrum, the energy loss in the medium at LHC in this p_T range must be $\sim 25\%$ larger than at RHIC. Unique at the LHC are the beautiful measurements of the fractional transverse momentum imbalance $1 - \langle \hat{p}_{T_2}/\hat{p}_{T_1} \rangle$ of di-jets in Pb+Pb collisions. When corrected for the fractional imbalance of di-jets with the same cuts in p-p collisions, the relative fractional jet imbalance in Pb+Pb/p-p is $\approx 15\%$ for jets with $120 \leq \hat{p}_{T_1} \leq 360$ GeV/c. This is compared to the same quantity derived at RHIC from two-particle correlations of di-jet fragments, corresponding to jet $\hat{p}_T \approx 10 - 20$ GeV/c, which appear to show a much larger fractional jet imbalance $\approx 45\%$ in this lower $\hat{p}_T$ range. The variation of apparent energy loss in the medium as a function of both p_T and $\sqrt{s_{NN}}$ is striking and presents a challenge to both theory and experiment for improved understanding. Another issue well known from experiments at the CERN ISR, SpS and SpS collider is that parton-parton hard-collisions make negligible contribution to multiplicity or transverse energy production in p-p collisions—soft particles, with $p_T \leq 2$ GeV/c, predominate. From recent measurements at RHIC in p-p, d+Au and Au+Au collisions, it will be shown that the fundamental element of particle production in A+A collisions is the constituent quark; and that the formula in use for many years for the average values as a function of centrality, $\left\langle dN_{\rm ch}^{AA}/d\eta \right\rangle = \langle dN_{\rm ch}^{pp}/d\eta \rangle \left[x N_{\rm part}/2 + (1-x) N_{\rm coll}\right]$, gives non-physical results when applied to the distributions and should be deprecated. Another topic is how the results of Higgs particle measurements in p-p collisions at the LHC might influence the understanding of heavy quark suppression in A+A collisions.

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Quark spin polarization in high density quark matter

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One of recent interests about the field governed by the quantum chromodynamics (QCD) is to understand the phase structure on the plane depicted by the temperature and the baryon chemical potential. In the area of astrophysics, it is reported that there exist neutron stars with very large magnetic field which are called magnetars. In these extreme conditions such as, especially, at high baryon density in the hadronic and/or the quark-gluon matter, it is interesting to understand what phase is realized. Here, we show that there exists a possibility of spontaneous spin polarization in high density symmetric quark matter [1], which leads to the spin polarized phase or ferromagnetic phase, by using the Nambu-Jona-Lasinio (NJL) type effective model of QCD. In a preceding work [2], the pseudovector-type interaction between quarks was considered, which seems to lead to the spontaneous quark spin polarization. However, the quark spin alignment disappears if the quark mass is zero in the chiral symmetric phase.

Here, we introduce the four-point tensor-type interaction between quarks in the NJL model. Figure 1 (a) shows the effective potential for the vacuum expectation value of spin polarization, $F = -G\langle\bar{\psi}\Sigma_3\tau_3\psi\rangle$, where Σ_3 and τ_3 are a spin and an isospin matrix, respectively, and G is the strength of the tensor-type interaction. In the quark chemical potential $\mu > \mu_{\rm cr} = 0.406$ GeV with model parameter $G = 20$ GeV^{-2}, the spin polarization F exists with non-vanishing value. Thus, the quark spin is aligned and the magnetic field appears spontaneously. The critical baryon density, which corresponds to one third of the critical quark number density, is about 3.47 times the normal nuclear density. In Fig. 1 (b) and (c), the pressure is shown as a function of the quark chemical potential and the baryon density divided by the normal nuclear density $\rho_0 = 0.17$ fm^{-3}, respectively. For quark chemical potential $\mu < \mu_{\rm cr}$, the branch with $F_{\rm min} = 0$ is realized without spin polarization. From $\mu_{\rm cr}$ to $\mu = 0.565$ GeV, partial spin polarization is realized. For large quark chemical potential or baryon density, full spin polarization with $F_{\rm min} > \mu$ is realized. As a result, under tensor-type interaction, the quark spin polarized phase may be realized at high baryon density in quark matter.

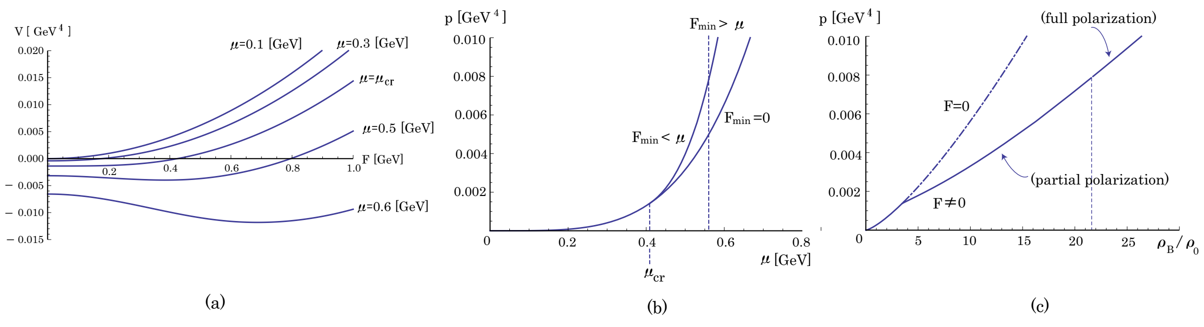

Figure 1: *The effective potential is shown as a function of spin polarization F in (a). From top, $\mu = 0.1$ GeV, 0.3 GeV, $\mu_{\rm cr}$, 0.5 GeV and 0.6 GeV, respectively. The pressure is shown as a function of (b) quark chemical potential μ and (c) baryon density divided by the normal nuclear density $\rho_0 = 0.17$ fm^{-3}.*

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Dense hadron star in quark degree of freedom

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The quark degree of freedom may play an important role as one studies very dense hadron stars which can help to understand the universe'e origin. We apply a quark-quark interaction adopted from QCD to probe properties of quark matter. Based on this interaction, quark matter's equation of state is obtained and its thermodynamic characteristics is investigated in detail. Stability of a star made of such matter is examined with and without strange quarks. The Tolman-Oppenheimer-Volkov equation along with the condition that $dm/dr = 4\pi r^2 E$ are used to calculate mass and radius of such a star. Comparison of our results with those obtained from calculations in pure hadron phase and in mixed hadron-quark phases will be made and the physics significance will be carefully interpreted and discussed.

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Effects of volume fluctuations on various thermodynamic quantities from the Polyakov-Nambu-Jona-Lasinio model

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It has always been of prime importance to study strongly interacting systems from both theoretical and experimental point of view. In order to study its phase transition properties, one is motivated to look for probes which can provide appropriate signals for the same. However, there can be different sources of systematic uncertainties inherent in it. Here, the effect of one such source namely volume fluctuation is studied.

This work has been carried out within the framework of the Polyakov-Nambu-Jona-Lasinio (PNJL) model [1-4]. With the incorporation of volume fluctuation [5], the usual formalism for quark number susceptibilities (QNS) gets modified. To start with, Gaussian distribution for volume is considered, with a small width. Behaviour of ratios of baryon number cumulants, immensely important for aforesaid study of strong interactions and corresponding phase transition properties, are also examined including the same. Some other important thermodynamic quantities like specific heat (C_v), speed of sound (v_s^2), conformal measure (C) are analysed. As per theoretical considerations, inclusion of volume fluctuations is realised through an extra term dependent on temperature with positive powers. So breaking of usual free field limit in high temperature regime is expected. Our results support the idea e.g. ratios of cumulants of net baryon number are enhanced by volume fluctuation in this region.

The quantities mentioned here are already established to perform as candidates for signature of phase transition from hadronic to Quark-Gluon-Plasma (QGP) phase. Inclusion of volume fluctuation reduces the strength of that signal considerably.

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International Nuclear Physics Conference INPC2013: 2-7 June 2013, Firenze, Italy

Chiral Symmetry Restoration - what can we observe at FAIR?

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The observation of Chiral Symmetry Restoration is one of the major goals of the high energy nuclear collision program at the Facility for Antiproton and Ion Research (FAIR). Chiral symmetry is spontaneously broken in nature, but expected to be restored at sufficiently high densities and temperatures. The restoration of chiral symmetry implies a change in the spectral functions of vector mesons (e.g. the ρ meson) and leads to a degeneracy of the spectral functions of the ρ and its chiral partner, the a_1 meson. This means that the masses of the chiral partners become equal in the case of full chiral symmetry restoration or approach each other in the case of a partial restoration of the symmetry. Although this signal is being searched for various decades a clear and distinctive proof is not available yet. Experiments at FAIR are ideally suited to observe the restoration of chiral symmetry due to their setup with high luminosity beams and cutting edge detectors.

This contribution will present various theoretical investigations regarding chiral symmetry restoration and will explain observables in detail. New observables for FAIR experiments will be proposed and quantitatively discussed. Special focus will be put on the degeneracy of the a_1 and ρ mesons, which serves as the only unambiguous signal for chiral symmetry restoration.

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Centrality dependence of pseudorapidity spectra of charged particles produced in the nucleus-nucleus collisions at high energies

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We have analyzed the pseudorapidity spectra of charged relativistic particles with $\beta > 0.7$ produced in Si (at energy 4 A GeV and 14 A GeV), Au (at energy 11.6 A GeV) and Pb+Em (at energy 158 A GeV) reactions as a function of the centrality. The relativistic nucleus beams were obtained from AGS and SPS machines. The number of g-particles ($0.23 \leq \beta \leq 0.7$) was used to fix the centrality. We have applied the Maximum Entropy Method and found some selected pseudorapidity values – nontrivial structure, the number of which depends on energy; increases from 2 to 4 with energy.

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Measurements of Open Heavy Flavor Hadrons and Future Upgrade in STAR Experiment

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Heavy flavor quarks are dominantly produced in the initial hard interactions in high energy heavy ion collisions at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory in Upton, New York. Their interaction with QCD medium is sensitive to the medium dynamics. Thus heavy flavor quarks are suggested as an ideal probe to study the properties of the hot and dense nuclear matter created at RHIC. In this talk, we will present the recent results of open heavy flavor measurements by the STAR experiment through both hadronic and semi-leptonic decay channels in proton-proton and heavy ion collisions. We will also discuss the ongoing STAR heavy flavor tracker upgrade and its anticipated physics reach in the coming years.

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Equilibrium and equilibration in a gluon plasma with improved matrix elements

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Nuclear matter under extreme conditions similar to those existed in the early Universe can be created and studied in the laboratory. In particular, the hot and dense matter created in the very early stage of a relativistic heavy ion collision is composed mainly of gluons. The interactions among these gluons bring the system toward equilibrium. In addition to elastic collisions, radiative processes can play an important role for a hot partonic system. The dominant parton number changing processes are the ones that involve the emission or absorption of one gluon. They can be described by the Gunion-Bertsch formula. We show that the cross section from the exact matrix element for the lowest order radiative process could be significantly smaller than that based on the Gunion-Bertsch formula [1]. This is consistent with some recent studies on the specific shear viscosity using the exact formula [2]. In light of this, we discuss the role of radiative processes on the equilibrium and equilibration of a gluon plasma.

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Quarkonium Production and Quark-Gluon Plasma

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The quarkonium transverse momentum distribution is sensitive to the hot medium created in relativistic heavy ion collisions. We predicted the J/Ψ elliptic flow and averaged transverse momentum in a full transport approach. The data from LHC ALICE support our theoretical calculations.

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