QUARK MATTER

Parallel Session Abstract Book

2009

Knoxville, Tennessee

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1B: Bulk Properties of the Medium I: Collective Flow #1

1 2:00 PM *Stephen Sanders*
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High p_T Correlations of Charged Particles in Pb+Au collisions at 158 A·GeV/c

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Results of a two-particle correlation analysis of high p_T charged particles in Pb+Au collisions at 158 A·GeV/c are presented. The data have been recorded by the CERES experiment at the CERN-SPS. The correlations are studied as function of transverse momentum, particle charge and collision centrality. We observe a jet-like structure in the vicinity of a high p_T trigger particle and a broad back-to-back distribution. The yields of associated particles per trigger show a strong dependence of the trigger/associate charge combination. A comparison to PYTHIA confirms the jet-like pattern at the near-side but suggests a strong modification at the away-side, possibly implying significant energy transfer of the hard-scattered parton to the medium.

Investigating Sources of Two-particle Angular Correlations in Nucleon–Nucleon and Nucleus–Nucleus Collisions at the CERN SPS

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Angular correlations of high-p_T hadrons can serve as a probe of interactions of partons with the dense medium produced in high-energy heavy-ion collisions but other sources of such correlations exist which can be non-negligible at SPS energies. In an attempt to determine their primary source, NA49 has performed an energy and system-size scan of two-particle azimuthal correlations in Pb+Pb, Si+Si and $p + p$ collisions at $158A\cdot$ GeV, as well as central Pb+Pb collisions at 20, 30, 40 and 80 $A\cdot$GeV. All of these results have also been compared to UrQMD simulations, both with and without jet production enabled. Last but not least, a transverse-momentum scan of two-particle azimuthal and $(\Delta\eta, \Delta\phi)$ correlations in central Pb+Pb collisions at $158A\cdot$GeV has also been performed, to investigate evolution of back-to-back correlation as well as to search for possible occurrence of the ridge phenomenon observed at the RHIC.

Experimental results obtained so far show a flattened away side peak of the two-particle azimuthal correlation function in central Pb+Pb (Au+Au) collisions which only weakly depends on collision energy even for low SPS energies. This result is at odds with present-day expectations of when the hot, dense medium is produced but is consistent with global momentum conservation. These results match the output of UrQMD, regardless of whether jet production was enabled or not. On the other hand, the amplitude of the near-side peak in central Pb+Pb (Au+Au) collisions drops visibly with decreasing collision energy, flattening out around $40A\cdot$GeV and turning into a depletion below that energy - possibly an effect of passing the phase-transition line.

Quantifying Dynamical Effects on Jet Energy Loss in QCD Medium

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In order to make reliable quantitative predictions for jet quenching in ultra-relativistic heavy ion collisions, it is necessary to have accurate calculations of energy loss. However, all currently available radiative heavy flavor energy loss studies suffer from a crucial drawback, which is an assumption that a medium is composed of static scattering centers. Since in reality the constituents of the medium are dynamical, it is necessary to include effects of dynamically screened QCD medium in order to obtain reliable theoretical predictions for jet quenching. We develop a theory which allows calculating, to first order in the number of scattering centers, the energy loss of a heavy quark traveling through a dynamical QCD medium [1,2]. We show that the result for a dynamical medium is significantly larger compared to a medium consisting of randomly distributed static scattering centers. Therefore, a quantitative description of jet suppression in RHIC and LHC experiments must correctly account for the dynamics of the medium's constituents. Furthermore, predictions of jet suppression, which take into account dynamical effects and are relevant for the upcoming experiments, will also be presented.

References

[1] M. Djordjevic and U. Heinz, Phys.Rev.Lett.101:022302,2008

[2] M. Djordjevic, in preparation (2009).

Jet Correlation Observations from the PHENIX Experiment to Provide Information on Energy Lost by High-p_T Partons

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Properties of the hot QCD matter created in collisions at RHIC can be characterized by the amount of energy lost by a high-p_T parton as it travels through the medium. We extend the information that is available from single-particle spectra to include a variety of jet correlation measurements. Correlations have the potential to provide the relative amount of energy-lost by the back-to-back partons as they travel through different lengths of matter. We present the latest 2 and 2+1 particle jet correlations observations from the PHENIX experiment, including from the large Au-Au data set taken in 2007. The correlations are over a broad kinematic range and are presented as a function of collision system, centrality, particle identification, and orientation with respect to the reaction plane. These various selections and correlations allow for different distributions of parton path lengths through the medium to be probed and hence different amounts of energy-loss. Quantified statistical and systematic uncertainties are included that allow detailed comparison with theoretical calculations of the energy lost by high-p_T partons.

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LPM-Effect in Monte Carlo Models of Radiative Energy Loss

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The non-abelian Landau-Pomeranschuk-Migdal (LPM) effect arises from the quantum interference between spatially separated, inelastic radiation processes in matter. A consistent probabilistic implementation of this LPM effect is a prerequisite for extending the use of Monte Carlo (MC) event generators to the simulation of jet-like multi-particle final states in nuclear collisions. In [1], we proposed a local MC implementation, based on relating the LPM effect to the probabilistic concept of formation time for virtual quanta. This proposal does not rely on medium-modified splitting functions, which assign non-local information to local parton branching processes. This study established that implementation of a simple formation time constraint alone can account fully for the non-abelian LPM-effect, including the characteristic L^2-dependence of average energy loss and the $1/\sqrt{\omega}$-dependence of the gluon energy distribution.

Here, we show first results for medium-modified jets, obtained from implementing this MC algorithm in the Monte Carlo generator JEWEL [2]. JEWEL interfaces a perturbative final state parton shower with elastic and inelastic interactions with the dense QCD matter produced in heavy ion collisions.

References

[1] K. Zapp, J. Stachel and U. A. Wiedemann, arXiv:0812.3888 [hep-ph].

[2] K. Zapp, G. Ingelman, J. Rathsman, J. Stachel and U. A. Wiedemann, arXiv:0804.3568 [hep-ph].

High p_T Measurements of Reaction Plane Dependent Jet-Suppression and Azimuthal Anisotropy in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV at PHENIX

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The phenomena of jet suppression is well established via separate measurements of the nuclear modification factor R_{AA}, azimuthal anisotropy and di-hadron correlations. The current challenge is to quantitatively understand the underlying suppression mechanism, as well as to understand the interplay between jet suppression, collective flow and coalescence as function p_T. Meeting this challenge requires new measurements which extend the current experimental p_T reach and combine the constraining power of R_{AA} and anisotropy.

In a recent experimental run (Year-2007), the PHENIX experiment collected over 800 μb^{-1} in integrated luminosity of Au+Au collisions. Augmented with a newly installed high resolution reaction plane detector, this wealth of high statistics data not only allow detailed measurements of R_{AA} relative to the reaction plane, but also measurements of the azimuthal anisotropy coefficients v_2 and v_4 up to p_T of 14 GeV/c and 8 GeV/c respectively. The results from these measurements will be presented and compared with various energy loss model calculations. We also compare the eccentricity scaling behavior of v_2 between high p_T and low p_T, and contrast the v_2 measurements using reaction plane determined in various η windows. The former can shed light on the interplay between jet suppression, collective flow and coalesces, the later can help us to quantify the non-flow effects due to jets.

Forward-Rapidity Azimuthal and Radial Flow of Identified Particles for $\sqrt{s_{NN}} = 200$ GeV Au+Au and Cu+Cu Collisions

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A strong azimuthal flow signature at RHIC suggests rapid system equilibration leading to an almost perfect fluid state. The longitudinal extent of the flow behavior depends on the formation dynamics for this state and can be studied by measuring the pseudorapidity dependence of the second Fourier component (v_2) of the azimuthal angular distribution. We report on a measurement of identified-particle v_2 as a function of p_T (0.5-2.0 GeV/c), centrality (AuAu: 0-25%, 25-50%; CuCu: 0-30%), and pseudorapidity ($0 \leq \eta < 3.2$) for $\sqrt{s_{NN}} = 200$ GeV Au+Au and Cu+Cu collisions. The BRAHMS spectrometers are used for particle identification (π, K, p) and momentum determination and the BRAHMS global detectors are used to determine the corresponding reaction-plane angles. The results will be discussed in terms of the rapidity dependence of constituent quark scaling and in terms of models that develop the complete (azimuthal and radial) hydrodynamic aspects of the forward dynamics at RHIC.

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System Size and Collison Energy Dependence of v_2 for Identified Charged Hadrons at RHIC-PHENIX

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An important finding at RHIC is the observation that hydrodynamic calculations that model a locally equilibrated quark gluon plasma (QGP), can account for elliptic flow (v_2) measurements in the low transverse momentum region (~ 1 [GeV/c]). A universal scaling of elliptic flow, suggestive of quark-like degrees of freedom has also been reported for a broad range of particle species produced in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

Additional detailed insights on the reaction dynamics can be obtained via measurements of both the collision energy dependence and the system size dependence of v_2.

In recent experiments in year 2004 and 2005, the PHENIX experiment has made such measurements of v_2 for identified charged hadrons in Au+Au and Cu+Cu collisions at the collision energies $\sqrt{s_{NN}} = 200$ GeV and 62.4 GeV. The v_2 flow coefficients from these measurements will be presented in conjunction with detailed validation tests of eccentricity scaling and quark number scaling. The implications of the result of these scaling tests will also be discussed.

Event Anisotropy v_2 in Cu+Cu Collisions at RHIC — Particle Type, Beam Energy and Centrality Dependence

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The measurement of event anisotropy, often called v_2, provides a powerful tool for studying the properties of hot and dense medium created in high-energy nuclear collisions. The important discoveries of partonic collectivity and the brand-new process for hadronization - quark coalescence were all obtained through a systematic analysis of the v_2 for 200 GeV Au+Au collisions at RHIC [1]. However, it is still under debate on to what degree the system has reached the local thermalization and hence the ideal hydro limit. The answer to the question depends on both systematic size and colliding energy.

In order to facilitate the study, we have carried out a analysis of event anisotropy v_2 from Cu + Cu collisions at both 62.4 and 200 GeV. In the analysis the non-flow contributions were suppressed by utilizing the large pseudorapidity gap between STAR's Forward Time Projection Chambers ($\langle\Delta\eta\rangle \approx 6.6$) for reaction plane determination. The non-flow effect at relatively high p_T region is removed by subtracting similar azimuthal correlation arising from p+p collisions at the same energy. In this talk, the preliminary v_2 results for K_S^0, Λ and charged hadrons from Cu+Cu collisions will be reported. Together with the published results from Au+Au collisions, we will test the hydro limit of the system created at RHIC within a framework of transport model approach [2].

References

[1] B. I. Abelev et al., (STAR Collaboration), Phys. Rev. **C 77**, 054901 (2008).

[2] H. J. Drescher, A. Dumitru, C. Gombeaud, and J. Y. Ollitrault, Phys. Rev. **C 76**, 024905 (2007).

Eccentricity Fluctuation in Initial Conditions of Hydrodynamics

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One of the major discoveries at RHIC is that large elliptic flow, which is comparable with an ideal hydrodynamic prediction, is observed for the first time in relativistic heavy ion collisions [1]. Systematic studies [2, 3] showed, however, that the agreement between ideal hydrodynamics and elliptic flow data is achieved only by a particular combination of dynamical modeling, namely initial conditions from the Glauber model, the perfect fluid quark gluon plasma (QGP) core and the dissipative hadronic corona. For example, when one switches to the color glass condensate (CGC) initial conditions instead of the conventional Glauber model ones, the result overshoots the elliptic flow data due to larger initial eccentricity than that from the Glauber model [2]. Even within the Glauber model initializations, the agreement between hydrodynamic results with the data is not perfect probably due to an absence of initial fluctuation effects [2, 3]. Therefore, further investigation is indispensable toward reproduction of elliptic flow data and, in turn, understanding of transport properties of the QGP.

In this study, we employ the Monte-Carlo version of factorized Kharzeev-Levin-Nardi (fKLN) model [4] (MC-KLN) to improve the treatment of entropy production processes near the edge regions and implement the fluctuation of eccentricity in hydrodynamic initial conditions. We first calculate a transverse entropy density profile in each event for a given centrality and rotate the profile to match the apparent reaction plane to the true reaction plane. We next repeat this procedure and average the profiles over many events. The resultant initial conditions are smooth in the transverse plane, but contain fluctuation effects. Thus, even in case of vanishing impact parameter, eccentricity is finite due to its fluctuation. We finally calculate the elliptic flow parameter as a function of the number of participants in the hydro+hadronic cascade model [2, 3] and find that the effect of eccentricity fluctuation is quite large in very central and peripheral Au+Au collisions and in Cu+Cu collisions. This strongly suggests that the effects of eccentricity fluctuation have to be included in the dynamical model if one wants to precisely reproduce elliptic flow data.

References

[1] http://www.bnl.gov/bnlweb/pubaf/pr/PR_display.asp?prID=05-38

[2] T. Hirano, U. W. Heinz, D. Kharzeev, R. Lacey and Y. Nara, Phys. Lett. B **636**, 299 (2006).

[3] T. Hirano, U. W. Heinz, D. Kharzeev, R. Lacey and Y. Nara, Phys. Rev. C **77**, 044909 (2008).

[4] H. J. Drescher and Y. Nara, Phys. Rev. C **75**, 034905 (2007).

[1] T. H. is supported in part by the Grants-in-Aid of the Japanese Ministry of Education, Culture, Sports, Science, and Technology (No. 19740130)

The Kolmogorov-Smirnov Test in Event-by-Event Analysis

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We propose a technique capable of searching for novel event-by-event physics in nuclear collisions, based on the use of the Kolmogorov-Smirnov (KS) test [1,2]. It allows to identify any kind of differences (whether based on fluctuations, correlations, or higher moments) between events in the examined event sample without any previous bias of what to look at. The use of the method is illustrated with an example of a fireball that fragments during hadronisation [3]. The KS method is very sensitive to whether the fireball decays into hadrons directly or first into bigger fragments which then evapoprate. In the latter case it is also sensitive to the size of the fragments. Momentum conservation and correlations due to resonance decays influence the results strongly, but these "trivial" correlations can be put under control. We perform benchmark studies by making use of the transport code URQMD and a blast-wave like Monte Carlo generator.

References

[1] A. Kolmogorov, Giornale dell' Instituto Italiano degli Attuari 4 (1933), 83-91.

[2] N.V. Smirnov, Mat. Sb. **6**, (1939), 3-26. [In Russian];
N.V. Smirnov, Moscow, Bull. Univ. **2**, (1939), 3-14. [In Russian].

[3] G. Torrieri, B. Tomášik, I.N. Mishustin, Phys. Rev. C **77** (2008) 034903

Do $p + p$ Collisions Flow at RHIC? Understanding One- and Two-Particle Distributions, Multiplicity Evolution, and Conservation Laws

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Strong explosive collective flow is the defining bulk characteristic of heavy ion collisions at RHIC; its observation is central to claims of "matter" creation and the applicability of hydrodynamics. The flow is clearly revealed both in space-momentum correlations, measured by HBT and non-identical particle correlations, and the mass systematics of m_T spectra. It is commonly assumed that very peripheral Au+Au, or $p + p$ collisions, there is insufficient time or particle density for thermalization or generation of collective flow. We argue that measurements in the soft sector at RHIC challenge this assumption.

Preliminary two-pion correlation functions reported by the STAR collaboration show clear structures associated with "HBT effects," sensitive to the space-time distributions at freezeout. Especially important for lower multiplicity states, they observe another, non-femtoscopic structure. We argue that, based on its amplitude and shape, this structure arises from phasespace constraints due to energy and momentum conservation [1]. We deconvolute the femtoscopic and phasespace-constraint contributions.

These phasespace constraints have immediate implications for the multiplicity evolution of the single-particle spectra. Taking these into account, we argue that almost all of the observed differences between low- and high- multiplicity collisions (e.g. $p + p$ versus central Au+Au collisions) are due to the relaxation of phasespace contraints with increasing multiplicity [2]. Putting these observations together for the first time, we find that the HBT and spectra data argue as strongly for flow in $p + p$ collisions, as they do in Au+Au collisions. These results raise important questions regarding the existence, nature and timescale of thermalization and collective motion in all ultrarelativistic collisions, and have direct relevance to the upcoming LHC program.

References

[1] Z. Chajęcki and M. Lisa, Phys. Rev. **C78** (2008) 064903

[2] Z. Chajęcki and M. Lisa, ArXiv:0807.3569

1C: Theory I: QCD Transport Processes

1 2:00 PM *Pol Bernard Gossiaux*
"Revealing QGP Hot Core with Heavy Quarks Tomography"

2 2:20 PM *Teiji Kunihiro*
"Second-order Relativistic Hydrodynamic Equations Compatible with Boltzmann Equation and Critical Opalescence Around the QCD Critical Point"

3 2:40 PM *Peter Arnold*
"Gluon Bremsstrahlung in Weakly-Coupled Plasmas"

4 3:00 PM *Jorge Casalderrey Solana*
"Prediction of a Photon Peak in Heavy Ion Collisions"

5 3:20 PM *Anton Wiranta*
"Bulk Viscosity of Interacting Hadrons"

6 3:40 PM *Masakiyo Kitazawa*
"Spectral Properties of Quarks at Finite Temperature in Lattice QCD"

1D: Heavy Quarkonia I

1 2:00 PM *Cesar Luiz da Silva*
"Quarkonia measurement in *p*+*p* and *d*+Au Collisions at $\sqrt{s}$ = 200 GeV by the PHENIX Detector"

2 2:20 PM *Chris Perkins*
"J/Ψ Production in *p*+*p* and d+Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV at STAR"

3 2:40 PM *Haidong Liu*
"Upsilon Production in *d*+Au Collisions at STAR"

4 3:00 PM *Enrico Scomparin*
"J/Ψ Production in *p*+A Collisions at 158 and 400 GeV: Recent Results from the NA60 Experiment"

5 3:20 PM *Kirill Tuchin*
"Gluon Saturation Effects on J/Ψ Production in Heavy Ion Collisions"

6 3:40 PM *Yu Maezawa*
"Free Energies of Heavy Quarks in Full-QCD Lattice Simulations with Wilson-Type Quark Action"

Revealing QGP Hot Core with Heavy Quarks Tomography

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Heavy quarks and mesons are one of the few probes which allow for studying the time evolution the quark gluon plasma, presumably created at RHIC and LHC energies. Over the last years we (the Nantes group) have developed a comprehensive model based on pQCD cross sections with a running coupling constant and an infrared regulator based on HTL calculations and a hydrodynamical expansion of the plasma [1]. The results have been extensively confronted with RHIC data (R_{AA}, elliptical flow, centrality classes) and will be presented during the talk, as well as some predictions for LHC.

The recent studies have produced four essential results which allow to probe the medium in detail and to constrain the models:

- If the heavy quarks interact by pQCD cross sections with the plasma the simultaneously produced $c\bar{c}$ pair shows strong correlations at large p_T.
- By triggering on pairs which show a similar energy loss, one can suppress a part of the heavy quarks produced in the corona and hence look into the interior of the reaction. There the observed R_{AA} values show a minimum because at high momentum the relative importance of energy loss decreases. This results can be confronted with future experiment.
- AdS/CFT calculations yield a different energy loss than pQCD calculation. After the RHIC upgrade, the results for the R^{cb} ratio – a quantity proposed initially by Horowitz and Gyulassy – one will be able to distinguish between pQCD and AdS/CFT.
- Besides the elementary cross sections and processes, the results are strongly influenced by the description of the expanding plasma: Fireball calculations, which have been used since long, and hydrodynamical calculations differ for the same cross sections by a factor of 2 in the predicted value of v_2 .

References

[1] P.B. Gossiaux, J. Aichelin, Phys. Rev. C 78, 014904 (2008), [hep-ph/0802.2525]

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Second-order Relativistic Hydrodynamic Equations Compatible with Boltzmann Equation and Critical Opalescence around the QCD Critical Point

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Recently, Tsumura, Kunihiro and Ohnishi (abbreviated as TKO)[1] derived generic covariant hydrodynamic equations for a viscous fluid through a reduction of the dynamics described by the relativistic Boltzmann equation in a systematic manner, with no heuristic arguments, on the basis of the so-called renormalization group (RG) method[2]. The generic equation derived by TKO can produce a relativistic dissipative hydrodynamic equation in any frame; the resulting equation in the energy frame coincides with that of Landau and Lifshitz, while that in the particle frame is similar to, but slightly different from, the Eckart equation. We have demonstrated[3] that the equilibrium state is stable with respect to the time evolution described by TKO equation in the particle frame, in striking contrast with the original Eckart equation. TKO equation can be a proper starting point for constructing second-order causal relativistic hydrodynamics, to replace Eckart's particle-flow theory.

In this report[4], we extend the previous work and derive the second-order relativistic hydrodynamic equation for viscous fluids on the basis of the RG method: Although the resultant equation has a good correspondence with that derived by the Grad's 14 moment method, it has a novel terms due to the Burnet term, which are absent even in the Grad's 14 moment method.

Since the QCD critical point belongs to the same universality class as the liquid-gas phase transition point, the density fluctuation diverge at the critical point [5]. The large density fluctuation around the critical point scatters the light so randomly that the fluid turns to look white, which is called the critical opalescence; the analysis is nicely made by using the non-relativistic hydrodynamics, i.e., Navier-Stokes equation[6].

We extend this analysis to the relativistic case and elucidate how the anomalous increase of the bulk viscosity affect observables in the vicinity of the QCD critical point.

References

[1] K. Tsumura, T. Kunihiro and K. Ohnishi, Phys. Lett. **B646**, (2007) 134.

[2] L. Y. Chen, N. Goldenfeld and Y. Oono, Phys. Rev. Lett. **73**, (1994) 1311; T. Kunihiro, Prog. Theor. Phys. 94 (1995) 503; 95(1996) 835 (E); S.-I. Ei, K. Fujii and T. Kunihiro, Ann. Phys. **280**, (2000) 236; Y. Hatta and T. Kunihiro, Ann. Phys. **298**, (2002) 24.

[3] K. Tsumura and T. Kunihiro, Phys. Lett. **B668**, (2008) 425.

[4] K. Tsumura and T. Kunihiro, in preparation.

[5] H. Fujii, Phys. Rev. **D67**, 094018 (2003); D. T. Son and M. Stephanov, Phys. Rev. **D 70**, 056001 (2004).

[6] R. D. Mountain, Rev. Mod. Phys. **38**, 205 (1966); L. E. Reichl, "*Modern Course in Statistical Physics*", (Woley-Interscience, 1988).

Gluon Bremsstrahlung in Weakly-Coupled Plasmas

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I will report some theoretical progress concerning the calculation of gluon bremsstrahlung for very high energy particles crossing a weakly-coupled quark-gluon plasma, with focus on the simple case of an effectively infinite-size medium. A popular approximation (allowing for analytic results) is to consider particle energies so high that $\ln(E/T)$ can be considered large because then analytic results are possible. By comparing next-to-leading-log analytic results to more complete numerical results, I discuss when the "large logarithm" approximation is a good one. I discuss the status of calculations of $\hat{q}$ in weak coupling—the squared transverse momentum picked up per unit length—which enters into calculations of gluon bremsstrahlung. Finally, time permitting, I will mention a recent very simple theoretical formula for leading-log gluon bremsstrahlung for the case of an arbitrary finite, expanding medium.

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Prediction of a Photon Peak in Heavy Ion Collisions

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We show that if a flavour-less vector meson remains bound after deconfinement, and if its limiting velocity in the quark-gluon plasma is subluminal, then this meson produces a distinct peak in the spectrum of thermal photons emitted by the plasma. We also demonstrate that this effect is a universal property of all strongly coupled, large-N_c plasmas with a gravity dual. For the J/ψ the corresponding peak lies between 3 and 5 GeV and could be observed at LHC.

Bulk Viscosity of Interacting Hadrons

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Recent interest in the bulk viscosity η_v of strongly interacting matter stems from the observation that in the phase transition from hadronic matter to a strongly interacting quark-gluon system η_v exhibits a drastic change (for a summary of recent developments, see for example [1], and references therein). In general, η_v is expresssible in terms of factors that depend on the sound speed v_s, the enthalpy, and the interaction (elastic and inelastic) cross sections. It is curious that different dependencies on the factor $(\frac{1}{3} - v_s^2)$ ensue depending on the method employed for calculation, In this work, we undertake a systematic investigation of the origin and importance of these differences. In addition, we provide numerical results from different approaches such as the Chapman-Enskog, the variational, the relaxation time and the Green-Kubo approaches. We first examine the bulk viscosity in a mixture of pions, kaons, and nucleons (for earlier treatments, see Refs. [2,3]). In the second step, a theoretical approach is developed to tackle a mixture comprising of many hadronic resonances whose masses extend up to 2 GeV. The interesting feature of bulk viscosity is that dominant contributions arise from particles of intermediate relativity captured in the ratio of mass to temperature. Hadron-hadron transport cross sections also play a significant role. In order to capture the essence of interactions, a generic effective field-theoretical approach that reproduces the basic features of hadron-hadron interactions of various masses and intrinsic quantum numbers (strangeness, charm, etc.) is being developed. Integrating over the known mass spectrum would then reveal the identity of particles that dominantly contribute to the bulk viscosity.

Our quantitative results would serve as a benchmark to gauge the extent to which bulk viscosity would affect current descriptions of heavy-ion collisions.

References

[1] J.I Kapusta, arXiv:0809.3746, (2008) [nucl-th].

[2] M. Prakash, M. Prakash, R. Venugopalan and G. Welke, Phys. Rept. **227**, (1993) 321.

[3] S. Gavin, Nucl. Phys. A **435**, (1985) 826.

[1]Research support of the US Department of Energy under grant DE-FG02-93ER40756 is gratefully acknowledged.

Spectral Properties of Quarks at Finite Temperature in Lattice QCD

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We analyze the quark spectral function above and below the critical temperature for deconfinement and at finite momentum in quenched lattice QCD [1]. The simulation is performed in Landau gauge using clover improved Wilson fermions.

It is found that the temporal quark correlation function in the deconfined phase near the critical temperature is well reproduced by a two-pole ansatz for the spectral function, which indicates that excitation modes of the quark field have small decay rates. The bare quark mass and momentum dependences of the spectral function are analyzed with this ansatz. In the chiral limit we find that even near the critical temperature the quark spectral function has two collective modes corresponding to the normal and plasmino excitations in the high temperature (T) limit. The pole mass of these modes at zero momentum, which should be identified to be the thermal mass of the quark, is approximately proportional to T in a rather wide range of T in the deconfined phase. With large bare quark masses the plasmino mode ceases to exist and the spectral function is dominated by a single pole. The accounts for quasi-particle properties of physical quarks in the deconfined phase, especially that of the charm quark, are also given.

In the confined phase, it is found that the pole ansatz for the spectral function fails completely.

References

[1] F. Karsch and M. Kitazawa, Phys. Lett. B **658**, 45 (2007) [arXiv:0708.0299 [hep-lat]].

Quark Matter 2009 : March 30th - April 4th, 2009 : Knoxville, Tennessee

Quarkonia Measurement in $p + p$ and d+Au Collisions at $\sqrt{s} = 200$ GeV by the PHENIX Detector

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Charmonium suppression in hot and dense nuclear matter has been argued to be a unique signature for the production of the quark gluon plasma (QGP). In order to search for this effect in heavy ion collisions one must have a clear understanding of quarkonia production and the modifications present in their spectrum resulting from the interaction with normal cold nuclear matter. The PHENIX experiment has measured J/ψ's spectra from deuteron-gold (d+Au) interactions at $\sqrt{s} =$ 200 GeV and compared these with a new proton-proton baseline (2006 RHIC run) in order to constrain these cold nuclear matter effects. For $p + p$ collisions we will present the transverse momentum dependence of the J/ψ yield for the higher integrated luminosity, a new ψ' spectrum, J/ψ polarization and the latest status of searches for other quarkonium states (χ_c and Υ). We will also report the status of the analysis from the d+Au 2008 RHIC run, with an integrated luminosity of 80 nb^{-1}, compared to the 2.4 nb^{-1} collected in the 2003 RHIC run.

Quark Matter 2009 : March 30th - April 4th, 2009 : Knoxville, Tennessee

J/Ψ Production in $p+p$ and d+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR

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We present analysis of J/Ψ production over the range $-1.0 < \eta < 4.2$ in $p+p$ and d+Au collisions using di-electron data taken during the 2008 run with the STAR experiment at Brookhaven National Laboratory. STAR's unique forward capabilities, especially the Forward Meson Spectrometer electromagnetic calorimeter, allow us the possibility of investigating the intrinsic charm components of the proton wave function using high-x_F forward particles produced in asymmetric partonic collisions. Forward J/Ψ (in the direction of the deuteron beam) from d+Au collisions complement data at mid-rapidity to further our understanding of the mechanisms underlying heavy quarkonium production and its transport through cold nuclear matter. Variation in matter thickness is achieved by observing J/Ψ produced on the d or on the Au side of the interaction. An integrated sampled luminosity of 50 nb^{-1} from d+Au and 7.8 pb^{-1} from $p+p$ were collected for this analysis. The analysis focuses on pairs of clustered energy in the calorimeters, with the J/Ψ detected through its leptonic decay to electron-positron pairs.

Υ Production in d+Au Collisions at STAR

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The production of heavy quarkonia states in $p+p$, p+A and A+A collisions provides insight into the properties of the Quark-Gluon Plasma. The suppression pattern of these states can be used as a thermometer of the excited QCD matter. Therefore, the study of Υ production is of paramount importance.

In the high luminosity (32 nb^{-1}) d+Au Run in year 2008, STAR has reduced the material in front of the TPC, which significantly reduced the photonic electron background by a factor of ~ 10. This provides an opportunity to measure Υ production in d+Au collisions with an improved signal-to-noise compared to the previous runs.

In this talk, we present the Υ measurements in d+Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV from the STAR experiment. We also compare the Υ yields measured in $p+p$ and Au+Au collisions from previous runs. This measurement provides a first look at quantifying cold nuclear matter effects for bottomonium.

J/ψ Production in p+A Collisions at 158 and 400 GeV: Recent Results from the NA60 Experiment

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The study of p+A collisions is an essential tool for estimating cold nuclear matter effects on charmonium production. A correct evaluation of such an effect is a necessary pre-requisite for the interpretation of the J/ψ suppression seen in nucleus-nucleus collisions.

The NA60 experiment has studied for the first time charmonium production in p+A collisions at 158 GeV incident energy, in the same kinematical conditions already used for collecting In+In (NA60) and Pb+Pb (NA50) data. It has also performed the same study at 400 GeV incident energy, where data already exist and the results are therefore very useful to investigate possible systematic effects.

Preliminary results on this topic, reported during 2008, have now undergone a severe scrutiny, including a re-assessment of the evaluation of the experimental efficiencies that play an important role in the measurement of the production cross-section as a function of the mass number of the nucleus.

We will present final results on J/ψ production in p+A and we will show an estimate of cold nuclear matter effects at both investigated energies. Previous results on nucleus-nucleus collisions will also be reviewed taking into account the newly available information.

Finally, we will present a new study of J/ψ polarization, reporting the complete decay angular distributions (polar and azimuthal components) in three different polarization frames: Collins-Soper, Gottfried-Jackson and helicity.

Gluon Saturation Effects on J/Ψ Production in Heavy Ion Collisions

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We consider a novel mechanism for J/Ψ production in nuclear collisions arising due to the high density of gluons. We calculate the resulting J/Ψ production cross section as a function of rapidity and centrality. We evaluate the nuclear modification factor and show that the rapidity distribution of the produced J/Ψ's is significantly more narrow in A+A collisions due to the gluon saturation effects. Our results indicate that gluon saturation in the colliding nuclei is a significant source of J/Ψ suppression and can explain the experimentally observed rapidity and centrality dependencies of the effect.

Free Energies of Heavy Quarks in Full-QCD Lattice Simulations with Wilson-Type Quark Action

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We present recent results of free energies between a heavy quark and antiquark, and a heavy quark and quark in lattice simulations. The heavy-quark free energies express inter-quark interactions at finite temperature, and are intimately related to the fate of charmoniums and bottomoniums in quark-gluon plasma created in relativistic heavy-ion collisions. Lattice simulations are performed with dynamical fermions of two degenerated u, d-quarks and one strange quark. We employ an $O(a)$ imporved Wilson-type quark action of which lattice discretization properties is precisely investigated by CP-PACS/JLQCD Collaboration [1], and calculate the free energies from correlations of the Polyakov loops for various color channels. From spatial behavior of the heavy-quark free energies, we discuss confinement properties before and after the deconfinement transition. Screening properties of quark-gluon plasma are also discussed and compared with previous studies which do not include the dynamical strange quark [2]. This is the first calculations of the heavy-quark free eneries in full-QCD lattice simulations with Wilson-type quark action.

References

[1] T. Ishikawa et al. (CP-PACS/JLQCD Collaborations), Phys. Rev. D **78**, 011502 (2008)

[2] Y. Maezawa et al. (WHOT-QCD Collaboration), Phys. Rev. D **75**, 074501 (2007)

2A: High p_T II: Full Jet Evolution and Reconstruction

1 4:30 PM *Yue Shi Lai*
"Probing Medium-induced Energy Loss with Direct Jet Reconstruction in *p*+*p*, Cu+Cu, and Au+Au Collisions at PHENIX"

2 4:50 PM *Mateusz Ploskon*
"Inclusive Cross Section and Correlations of Fully Reconstructed Jets in $\sqrt{s_{NN}}$ = 200 GeV Au+Au and *p*+*p* Collisions"

3 5:10 PM *Ivan Vitev*
"A Theory of Jet Shapes and Cross Sections: from Hadrons to Nuclei"

4 5:30 PM *Helen Caines*
"Exploring Jet Properties in *p*+*p* Collisions at 200 GeV with STAR"

5 5:50 PM *Elena Bruna*
"Measurements of Jet Structure and Fragmentation from Full Jet Reconstruction in Heavy Ion Collisions at RHIC"

6 6:10 PM *Carlos Salgado*
"Monte Carlo for Jet Showers in the Medium"

2B: Bulk Properties of the Medium II: Collective Flow #2

1 4:30 PM *Arkadiy Taranenko*
"Differential Measurements of Hexadecapole (v_4) and Elliptic (v_2) Flow as a Probe for Thermalization at RHIC-PHENIX"

2 4:50 PM *Lokesh Kumar*
"Bulk Properties in Au+Au Collisions at $\sqrt{s_{NN}}$ = 9.2 GeV in STAR Experiment at RHIC"

3 5:10 PM *Arthur M. Poskanzer*
"Effect of Eccentricity Fluctuations and Nonflow on Elliptic Flow Methods"

4 5:30 PM *Hannah Petersen*
"A Transport Calculation with an Embedded (3+1)d Hydrodynamic Evolution: Elliptic Flow Results from E_{lab} = 2-160 A*GeV"

5 5:50 PM *Ulrich Heinz*
"Can the Energy Dependence of Elliptic Flow Reveal the QGP Phase Transition?"

6 6:10 PM *Chiho Nonaka*
"Signals of the QCD Critical Point in Hydrodynamic Evolution"

Probing Medium-Induced Energy Loss with Direct Jet Reconstruction in $p+p$, Cu+Cu, and Au+Au Collisions at PHENIX

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Direct jet reconstruction in heavy ion collisions can provide crucial constraints on the mechanism for in-medium parton energy loss and jet-medium interactions. However, in $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ central Au+Au collisions at RHIC, the combination of a large soft background and the low cross section for moderate transverse momentum (p_T) jets impedes the application of traditional jet reconstruction algorithms, since they give rise to combinatorical fake jets well above the real production rate of high-p_T partons. We present the application of a new jet reconstruction algorithm that uses a Gaussian filter to locate and reconstruct the jet energy [1] to $p+p$ and heavy ion data from the PHENIX detector. This algorithm is combined with a fake jet rejection scheme that provides efficient jet reconstruction with acceptable fake rate. We show results on the measured jet spectra, fragmentation properties, and jet-jet angular correlation in $p+p$, $\mathrm{Cu}+\mathrm{Cu}$, and $\mathrm{Au}+\mathrm{Au}$ collisions. The implications of these new results for jet quenching models are discussed.

References

[1] Y.-S. Lai and B.A. Cole, arXiv:0806.1499 (2008).

Inclusive Cross Section and Correlations of Fully Reconstructed Jets in $\sqrt{s_{NN}} = 200$ GeV Au+Au and $p+p$ collisions

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Jet measurements in heavy ion collisions, in which the jet is fully reconstructed independent of the details of its fragmentation, would enable a much more complete understanding of jet quenching than inclusive hadron distributions and correlations. However, full jet reconstruction has traditionally been thought to be difficult in heavy ion events, due to high multiplicity. In this talk we present a quantitative study of complete jet reconstruction in such a high multiplicity environment. We utilize high integrated luminosity $\sqrt{s_{NN}} = 200$ GeV $p+p$ and central Au+Au data measured by the STAR experiment at RHIC, and apply several modern jet reconstruction algorithms (both sequential recombination and cone-based) and the background correction algorithm from FastJet[1,2]. For both systems we report measurements of the inclusive differential jet production cross section, as well as high p_T hadron+jet and di-jet coincidence measurements. The analysis in data and model calculations of inclusive cross sections, coincidence measurements, and their variation with jet reconstruction algorithm and parameters, are used to assess the accuracy of jet reconstruction in the high background environment of heavy ion collisions. We report new measurements that address the mechanisms of partonic energy loss in hot QCD matter. These measurements include the ratio of inclusive jet cross sections in Au +Au and $p+p$ compared to the expectation of Nbinary-scaling; the comparison between Au+Au and $p+p$ of coincidence rates for both hadron +jet and di-jets; and the variation of all such measurements with jet resolution parameter.

References

[1] M. Cacciari, G. P. Salam, Phys. Lett. B641 (2006) [hep-ph/0512210]

[2] G. P. Salam, G. Soyez, JHEP 05 (2007) 086 [arXiv:0704.0292 (hep-ph)]

Quark Matter 2009 : March 30th - April 4th, 2009 : Knoxville, Tennessee

A Theory of Jet Shapes and Cross Sections: from Hadrons to Nuclei

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For jets, with great power comes great opportunity. The unprecedented center of mass energies available at the LHC open new windows on the QGP: we demonstrate that jet shape and jet cross section measurements become feasible as a new, differential and accurate test of the underlying QCD theory. We present a first step in understanding these shapes and cross sections in heavy ion reactions. Our approach allows for detailed simulations of the experimental acceptance/cuts that help isolate jets in such high-multiplicity environment. It is demonstrated for the first time that the pattern of stimulated gluon emission can be correlated with a variable quenching of the jet rates and provide an approximately model-independent approach to determining the characteristics of the medium-induced bremsstrahlung spectrum. Surprisingly, in realistic simulations of parton propagation through the QGP we find a minimal increase in the mean jet radius even for large jet attenuation. Jet broadening is manifest in the tails of the energy distribution away from the jet axis and its quantification requires high statistics measurements that will be possible at the LHC.

References

[1] I. Vitev, S. Wicks, and B.W. Zhang, JHEP 0811:093, 2008; arXiv:0810.2807 [hep-ph].

Exploring Jet Properties in $p+p$ collisions at 200 GeV with STAR

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The mechanisms underlying hadronization are not well understood, both in vacuum and in hot QCD matter. Precise characterization of jet fragmentation to hadrons in p+p collisions will help elucidate the fundamental process of hadronization, and will serve as essential reference to measure the modification of hadronization in heavy ion collisions. We present measurements of fragmentation functions for unidentified and identified particles in jets produced in p+p collisions at 200 GeV using the STAR detector at RHIC. Particle identification includes strange hadrons and hadrons identified via ionization energy loss in the TPC. The results from different jet reconstruction algorithms are compared, including variations of the cone radius. It is found that the results are largely insensitive to details of the jet-finding algorithm at RHIC energies. Identified particle production inside jets and outside jets will be compared to improve our understanding of the hadronization mechanisms for soft and hard particles in $p+p$ events at RHIC energies. The presented results also serve as a baseline for similar measurements in Au+Au collisions, where modifications of fragmentation functions and hadron composition of jets are expected to occur.

Measurements of Jet Structure and Fragmentation from Full Jet Reconstruction in Heavy Ion Collisions at RHIC

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Measurements of inclusive hadron suppression and di-hadron azimuthal correlations in ultra-relativistic nuclear collisions have provided important insights into jet quenching in hot QCD matter, but are limited in their sensitivity due to biases toward hard fragmentation and small energy loss. Full jet reconstruction in heavy-ion collisions is expected to alleviate such biases, thereby enabling a complete study of the modification of jet structure due to quenching, but are made difficult by the high multiplicity environment. In this talk we present measurements of fully reconstructed jet structure in 200 GeV $p + p$ and central Au+Au collisions by the STAR collaboration. To make contact with jet quenching results established from single and di-hadron analyses we compare fragmentation functions measured in 200 GeV $p + p$ and central Au+Au collisions and assess the systematic uncertainties of their ratio. Other jet structure measurements that may also be sensitive to quenching will be discussed.

Monte Carlo for Jet showers in the Medium

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The most commonly employed formalisms of radiative energy loss have been derived in the high-energy approximation and, in their present form, are reliable only for the medium modification of inclusive particle spectra. Therefore, when dealing with less inclusive distributions, they have to be modified. This is especially relevant for reconstructed jets in heavy-ion collisions, which are becoming available only recently. We present some ideas to overcome this limitation. Specifically, we show an implementation of radiative energy loss within a parton cascade. This implementation has been done within the PYTHIA Monte Carlo event generator. We present the publicly available routine Q-PYTHIA and discuss some of the obtained results, namely the modification at parton level of the hump-backed plateau, and of the transverse momentum and angular spectra with respect to the parent parton. Effects of hadronization are also shown.

References

[1] N. Armesto, L. Cunqueiro and C. A. Salgado, arXiv:0809.4433 [hep-ph].

Differential Measurements of Hexadecapole (v_4) and Elliptic (v_2) Flow as a Probe for Thermalization at RHIC-PHENIX

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An important goal of current experiments at the Relativistic Heavy ion Collider (RHIC) is the extraction of the transport coefficients of the plasma produced in energetic heavy ion collisions. Harmonic flow measurements play an important role for such extractions.

During the 2007 running period, the PHENIX experiment performed a comprehensive set flow measurements for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, with an improvement of more than a factor of 10 in integrated luminosity. For central collisions, these measurements validate the hydrodynamic scaling patterns expected for a nearly inviscid medium close to thermal equilibrium. The measurements also indicate a short mean free path and values of viscosity to entropy density ratio $\frac{\eta}{s}$ which decrease to within a factor of 2 of the conjectured lower bound, as collisions become more central.

Detailed differential hexadecapole (v_4) and elliptic (v_2) flow coefficients will be reported for a broad range of collision centralities, particle species and particle transverse momenta p_T. Validation tests for several hydrodynamic scaling patterns, as well as estimates for the degree of thermalization, mean free path λ, and $\frac{\eta}{s}$ will also be presented and discussed.

Bulk Properties in Au+Au Collisions at $\sqrt{s_{NN}} = 9.2$ GeV in the STAR Experiment at RHIC

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One of the primary goals of high-energy heavy-ion collisions is to establish the QCD phase diagram and search for possible phase boundaries. The planned RHIC energy scan program will explore this exciting physics topic using heavy-ion collisions at various center of mass beam energies. The first test run with Au+Au collisions at $\sqrt{s_{NN}} = 9.2$ GeV took place in early 2008. The large acceptance STAR detector collected data for about 4000 minimum bias collisions at this beam energy.

In this talk, we will present the first results of the centrality dependence of identified particle (pion, kaon and proton) transverse momentum spectra and ratios. In addition, we will present results of the azimuthal anisotropy parameters (v_2) and pion interferometry analysis. These results will be compared to data for both lower and higher energies taken at the SPS and RHIC. The new data are being used as input to an evaluation of the capabilities of the STAR detector for exploring the QCD phase diagram. Finally, a brief overview of the STAR collaboration's proposed plan for the beam energy scan program at RHIC will be presented.

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Effect of Eccentricity Fluctuations and Nonflow on Elliptic Flow Methods

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We discuss how the different estimates of elliptic flow are influenced by eccentricity fluctuations and nonflow effects. It is explained why the event-plane method yields estimates between the two-particle correlation methods and the multi-particle correlation methods. It is argued that nonflow effects and fluctuations cannot be disentangled without other assumptions. However, we provide equations where, with reasonable assumptions about fluctuations and nonflow, all measured values of elliptic flow converge to a unique mean elliptic flow in the participant plane and, with a Gaussian assumption on eccentricity fluctuations, can be converted to the mean elliptic flow in the reaction plane. Thus, the 20% spread in observed elliptic flow measurements from different analysis methods is no longer mysterious.

A Transport Calculation with an Embedded (3+1)d Hydrodynamic Evolution: Elliptic Flow Results from $E_{\rm lab} = 2 - 160A{\cdot}$GeV

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The elliptic flow excitation function calculated in a full (3+1)d Boltzmann approach with an intermediate hydrodynamic stage for heavy ion reactions from GSI-SIS to the highest CERN-SPS energies is discussed in the context of the experimental data. Within this integrated dynamical approach different equations of state are explored without adjusting parameters. Here, we employ a hadron gas equation of state to investigate the differences in the dynamics and viscosity effects, a chiral equation of state with a moderate first order phase transition and a critical endpoint and a bag model equation of state with a rather large latent heat. The specific event-by-event setup with initial conditions and freeze-out from a non-equilibrium transport model allows for a direct comparison between ideal fluid dynamics and transport simulations. At higher SPS energies, where the pure transport calculation cannot account for the high elliptic flow values, the smaller mean free path in the hydrodynamic evolution leads to higher elliptic flow values. Event-by-event fluctuations are directly taken into account via event wise non-equilibrium initial conditions generated by the primary collisions and string fragmentations in the microscopic UrQMD model. This leads to non-trivial velocity and energy density distributions for the hydrodynamical initial conditions. Due to the more realistic initial conditions and the incorporated hadronic rescattering the results are in line with the experimental data almost over the whole energy range from $E_{\rm lab} = 2 - 160A{\cdot}$GeV. This newly developed approach leads to a substantially different shape of the v_2/ϵ scaling curve as a function of $(1/SdN_{ch}/dy)$ which is now in line with the experimental data compared to previous ideal hydrodynamic calculations. We also present predictions for the differential flow measurements in the RHIC low energy run.

References

[1] H. Petersen, J. Steinheimer, G. Burau, M. Bleicher and H. Stöcker, Phys. Rev. **C78**, (2008) 044901.

[2] J. Steinheimer, M. Bleicher, H. Petersen, S. Schramm, H. Stöcker and D. Zschiesche, Phys. Rev. **C77**, (2008) 034901.

[3] H. Petersen, Q. Li, X. Zhu and M. Bleicher, Phys. Rev. **C74**, (2006) 064908.

[1] Financial support by the Deutsche Telekom Stiftung is gratefully acknowledged.

Can the Energy Dependence of Elliptic Flow Reveal the QGP Phase Transition?

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The beam energy dependence of collective flow has long been advertised as a tool to search for the QCD quark-hadron phase transition through the softening of the equation of state near this transition. Using ideal relativistic hydrodynamics in 2+1 dimensions, we study the collision energy dependence of radial and elliptic flow, of the emitted hadron spectra, and of the transverse momentum dependence of several hadronic particle ratios, covering the range from Alternating Gradient Synchrotron (AGS) to Large Hadron Collider (LHC) energies [1]. These calculations establish an ideal fluid dynamic baseline that can be used to assess non-equilibrium features manifest in future LHC heavy-ion experiments. We find that, at sufficiently high collision energies, $v_2(p_T)$ at fixed p_T *decreases* with increasing beam energy even when the matter is initially so dense that all elliptic flow is generated far above the phase transition and therefore not affected by the softening of the EOS near the critical temperature $T_{\rm cr}$. This *decrease* of the p_T-differential elliptic flow at fixed p_T is accompanied by a simultaneous *increase* of the p_T-integrated elliptic flow. Inclusion of viscous effects might further acerbate this trend if the specific shear viscosity η/s were larger at LHC energies than at RHIC. Contrary to earlier suggestions, we thus conclude that a saturation and even decrease of the differential elliptic flow $v_2(p_T)$ with increasing collision energy cannot be unambiguously associated with the QCD phase transition.

References

[1] G. Kestin and U. Heinz, arXiv:0806.4539 [nucl-th], Eur. Phys. J. C, in press.

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Signals of the QCD Critical Point in Hydrodynamic Evolution

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The existence and location of the QCD critical point (QCP) in the QCD phase diagram have been attracting many physists' interests in heavy ion collision physics. However recent studies based on effective theories show many possible location of the QCP in the QCD phase diagram. In addition, the latest finite temperature and imaginary chemical potential lattice QCD calculation shows that even the existence of the QCD critical point is uncertain. At present experiments and quantitative phenomenological analyses for the QCP are needed, because it seems to be very difficult to reach a solid conclusion about the QCP just from effective theories.

First, we construct the equation of state with the QCP on the basis of the universality hypothesis and find that the presence of a critical point in the QCD phase diagram can deform the trajectories describing the evolution of the expanding fireball in the $\mu_{\rm B}$-T phase diagram [1]. If the average emission time of hadrons is a function of transverse velocity, as microscopic simulations of the hadronic freezeout dynamics suggest, the deformation of the hydrodynamic trajectories will change the transverse velocity dependence of the proton-antiproton ratio when the fireball passes in the vicinity of the critical point [2]. An unusual -dependence of the $\bar{p}/p$ ratio in a narrow beam energy window would thus signal the presence of the critical point.

Towards quantitative study of the consequences of the QCP in heavy ion collisions, we use a combined fully three-dimensional macroscopic/microscopic transport approach employing relativistic 3D-hydrodynamics for the early, dense, deconfined stage of the reaction and a microscopic non-equilibrium model for the later hadronic stage where the equilibrium assumptions are not valid anymore [3]. Within this approach we study the dynamics of hot, bulk QCD matter, which is being created in ultra-relativistic heavy ion collisions at RHIC. Our approach is capable of self-consistently calculating the freezeout of the hadronic system, while accounting for the collective flow on the hadronization hypersurface generated by the QGP expansion.

References

[1] C. Nonaka and M. Asakawa, Phys. Rev. **C71**, (2005) 044904.

[2] M. Asakawa, S. A. Bass, B. Mueller, C. Nonaka, Phys. Rev. Lett. **101**, (2008) 122302.

[3] C. Nonaka and S. A. Bass, Phys. Rev. **C75**, (2007) 014902.

2C: Theory II: Strongly Coupled Gauge Theories

1 4:30 PM *Aninda Sinha*
"Holographic Hydrodynamics at Finite Coupling"

2 4:50 PM *Anastasios Taliotis*
"Deep Inelatsic Scattering in AdS/CFT"

3 5:10 PM *Mohammed Mia*
"Jet Quenching and η/s from Gauge Gravity Duality"

4 5:30 PM *Cyrille Marquet*
"Heavy-Quark Energy Loss and Thermalization in a Strongly Coupled SYM Plasma"

5 5:50 PM *Javier L. Albacete*
"Heavy Quark Potential in AdS/CFT"

6 6:10 PM *Claudia Ratti*
"The Role of Monopoles in a Gluon Plasma"

2D: Heavy Quarkonia II

1 4:30 PM *Andrea Beraudo*
"In-medium Quarkonia Propagators: The Static and the Finite Mass Cases"

2 4:50 PM *Adrian Dumitru*
"Quarkonium States in an Anisotropic (Viscous) QGP"

3 5:10 PM *Daniel Kikola*
"J/Ψ Production in Minimum Bias Au+Au and Cu+Cu Collisions at $\sqrt{s_{NN}}$ = 200 GeV at STAR"

4 5:30 PM *Ermias Tujuba Atomssa*
"J/ΨElliptic Flow and High p_T Suppression Measurements in A+A Collisions by the PHENIX Experiment"

5 5:50 PM *Nu Xu*
"Transverse Momentum Dependence of J/Ψ Production in Heavy Ion Collisions at RHIC"

6 6:10 PM *Magdalena Malek*
"Quarkonia Measurement with ALICE"

The Viscosity Bound in String Theory

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The ratio of shear viscosity to entropy density is a quantity of great interest in RHIC, LHC physics. AdS/CFT methods have led to the famous viscosity bound $\eta/s \geq 1/(4\pi)$. For the first time, this is rigorously established in the context of AdS/CFT with adjoint matter in N=4 SYM [1]. This is achieved by consider the full set of relevant higher derivative corrections at eight-derivative order including the 5-form flux in IIB string theory. It is further shown that the compact manifold decouples from the equations of motion even after including the correction, thereby leading to universality in all hydrodynamic quantities at this order [2]. When one incorporates fundamental matter, the higher derivative corrections begin at the four-derivative order. This leads to a violation of the bound at order $1/N$. Various examples are considered using the holographic Weyl anomaly and in all cases, this bound is found to be violated [3].

References

[1] R. C. Myers, M. F. Paulos and A. Sinha, arXiv:0806.2156.

[2] A. Buchel, R. C. Myers, M. F. Paulos and A. Sinha, arXiv: 0808.1837.

[3] A. Buchel, R. C. Myers and A. Sinha, arXiv:0812.2521.

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Deep Inelatsic Scattering in AdS/CFT

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Abstract: The total cross section for the scattering of a quark anti-quark dipole on a large nucleus at high energy is calculated [1]. The system is studied within the framework of a strongly coupled $\mathcal{N} = 4$ super Yang-Mills theory and the problem is solved using the AdS/CFT correspondence. The nucleus is modeled by a metric of a shock wave in the AdS_5 space. The expectation value of the Wilson loop (the dipole) is calculated by finding the extrema of the Nambu-Goto action for an open string attached to the quark and antiquark lines of the loop in the background of the AdS_5 shock wave. Two physically meaningful extremal string configurations are found. For both solutions, the forward scattering amplitude N for the quark dipole-nucleus scattering is found and is being investigated. The results are analyzed and compared with those in the literature. In particular for both solutions the saturation scale Q_s (i.e. the scale where the partons densities inside the nucleus reach their maximum values) at high enough energy, becomes energy independent. In addition, the pomeron intercept that corresponds to a single graviton exchange is calculated and conjectured to be equal to $\alpha_P = 1.5$ [2].

References

[1] J. L. Albacete, Y. V. Kovchegov and A. Taliotis, JHEP 0807:074, 2008, arXiv:0806.1484 [hep-th].

[2] J. L. Albacete, Y. V. Kovchegov and A. Taliotis, arXiv:0811.0818 [hep-th].

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Jet Quenching and η/s from Gauge Gravity Duality

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We compute the momentum broadening of an energetic parton as it moves through a hot plasma, using the gravity dual of a gauge theory incorporating logarithmic running of the coupling. Our approach can address a host of different gauge theories by considering distinct geometries. For a given set of degrees of freedom, we obtain $\hat{q}$ as a function of temperature. We then compare with results obtained from the AdS/CFT correspondence. In addition, using the gravity dual we compute the shear viscosity, the entropy and the ratio η/s. Finally, we report on a possible violation of the bound $1/4\pi$ for a class of non-conformal field theories which may contain QCD.

References

[1] M. Mia, K. Dasgupta, C. Gale and S. Jeon, "Five easy pieces: The Dynamics of Quarks in Strongly Coupled Plasma", arXiv:0902.1540 [hep-th]; "Five not-so-easy pieces", "Thermal QCD from gravity dual of cascading gauge theories", to appear.

Heavy-Quark Energy Loss and Thermalization in a Strongly Coupled SYM Plasma

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Using the AdS/CFT correspondence, we compute the radiative energy loss of a slowly decelerating heavy quark with energy E and mass M moving through a supersymmetric Yang Mills plasma at temperature T at large t'Hooft coupling λ. The quark propagates on a brane close to the AdS boundary with a string attached to it, hanging down in the fifth dimension u. The classical dynamics of the string is given by the Nambu-Goto action. The energy loss is determined from the energy flow along the string, obtained from the string shape.

Our starting point is the trailing-string picture of [1-2] in which a force drags the heavy quark at a constant speed v. In this talk we describe what happens if one stops pulling on the heavy quark. Then the energy loss of the quark is not compensated anymore and the heavy quark decelerates. We are working in the limit of large mass M and the deceleration is slow, $\dot{v} \sim \sqrt{\lambda}T^2/M$ can be treated as a perturbation. The deceleration modifies the shape of the string which in turns modifies the rate of energy loss by a correction of order $\sqrt{\lambda}T/M$. This adds a higher order correction to $\dot{v}$ and so on. This is the problem that we solve [3].

In the stationary problem solved in [1-2] it doesn't matter at what value of u the energy flow is computed because it is constant when $\dot{v} = 0$. However in our study, we actually let the heavy quark slow down and the point on the string where the energy loss is evaluated becomes crucial. Our choice to evaluate it at $u = \pi T\sqrt{\gamma}$ (with $\gamma = E/M$) is motivated by the fact that the part of the string below that point is not causally connected to the part of the string above [4], and therefore corresponds to emitted radiation on the gauge theory side.

The result for the radiative energy loss (up to second order in $\sqrt{\lambda}T/M$) is:

$$-\frac{dE}{dt} = \frac{\sqrt{\lambda}}{2\pi}(\pi T)^2\gamma v^2\left[1+\frac{1}{3\gamma^{3/2}}\frac{\sqrt{\lambda}T}{2M}+\left(\frac{\pi}{8}-\frac{1}{4}\log 2-\frac{7}{32}\right)\gamma\left(\frac{\lambda T^2}{4M^2}\right)+\mathcal{O}\left(\frac{\lambda^{3/2}T^3}{8M^3}\right)\right] .$$

In this picture the trailing string slowly gets straighter to eventually become that of a static quark. Of course we do not except our picture to apply that far. What will happen is that the heavy quark will eventually thermalize and when that happens, the discussion should be modified. However our calculation allows to estimate the thermalization time:

$$\tau = \frac{2M}{\sqrt{\lambda}\pi T^2} .$$

References

[1] C. P. Herzog, A. Karch, P. Kovtun, C. Kozcaz and L. G. Yaffe, JHEP **0607** (2006) 013.

[2] S. S. Gubser, Phys. Rev. **D74** (2006) 126005.

[3] G. Beuf, C. Marquet and B. W. Xiao, 0812.1051[hep-ph].

[4] F. Dominguez, C. Marquet, A. H. Mueller, B. Wu and B. W. Xiao, Nucl. Phys. **A811** (2008) 197.

Heavy Quark Potential at Finite Temperurature from AdS/CFT

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I will summarize the calculation of a heavy quark potential in $\mathcal{N} = 4$ supersymmetric Yang-Mills theory at finite temperature using the AdS/CFT correspondence performed in [1]. As is widely known, the potential calculated in the pioneering works of Rey et al. [2] and Brandhuber et al. [3] is zero for separation distances r between the quark and the anti-quark above a certain critical separation, at which the potential has a kink. We point out that by analytically continuing the string configurations into the complex plane, and using a slightly different renormalization subtraction, one obtains a smooth non-zero (negative definite) potential without a kink. The obtained potential also has a non-zero imaginary (absorptive) part for separations $r > r_c = 0.870/\pi T$. Most importantly at large separations r the real part of the potential does not exhibit the exponential Debye falloff expected from perturbation theory and instead falls off as a power law, proportional to $1/r^4$ for $r > r_0 = 2.702/\pi T$. The phenomenological implications related to the melting of in heavy quarkonia in a strongly coupled Quark Gluon Plasma will also be discussed.

References

[1] J. L. Albacete, Y. V. Kovchegov and A. Taliotis, arXiv:0807.4747 [hep-th].

[2] S. J. Rey, S. Theisen and J. T. Yee, Nucl. Phys. B **527** (1998) 171 [arXiv:hep-th/9803135].

[3] A. Brandhuber, N. Itzhaki, J. Sonnenschein and S. Yankielowicz, Phys. Lett. B **434** (1998) 36 [arXiv:hep-th/9803137].

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The Role of Monopoles in a Gluon Plasma

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We study the role of magnetic monopoles at high enough temperature $T > 2T_c$, when they can be considered heavy, rare objects embedded into matter consisting mostly of the usual "electric" quasiparticles, quarks and gluons. We study classical and quantum charge-monopole scattering, solving the problem of gluon-monopole scattering for the first time. We find that, while this process hardly influences thermodynamic quantities, it does produce a large transport cross section, significantly exceeding that for pQCD gluon-gluon scattering up to quite high T [1]. Thus, in spite of their relatively small density at high T, monopoles are extremely important for QGP transport properties, keeping viscosity small enough for hydrodynamics to work at LHC.

References

[1] C. Ratti and E. Shuryak, 0811.4174 [hep-ph].

In-medium Quarkonia Propagators: The Static and the Finite Mass Cases

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Long time ago Matsui and Satz proposed the anomalous suppression of the J/ψ, due to the Debye screening, as a signal of deconfinement. Screened potential model calculations, based on lattice data, predicted for the latter a melting temperature around T_c. The first results on finite temperature Meson Spectral Functions (reconstructed from lattice quarkonia correlators) signalling the survival of the J/Ψ till $T \sim 2T_c$ came as a surprise and forced people to reconsider the validity of potential model calculations.

The possibility of describing in-medium quarkonia in terms of an effective "real-time" potential has been recently investigated by different authors (Laine et al. [1], Brambilla et al [2]. and us [3,4]). We focus on the case of a hot-QED plasma, for which it is possible to write an effective (HTL) action, correctly accounting for medium effects on the propagation of long wave-length modes. Such an action, being gaussian, allows, in the case of static quarks, to get an effective potential from a first principle calculation. The latter displays both a REAL (embodying screening) and an IMAGINARY part, describing collisional damping.

We wish to report also on recent progresses in the case of finite-mass heavy quarks [5]. Also in this case the gaussian effective action allows dramatic simplifications. Our strategy is the following: we treat the heavy quarks as point-like particles in Quantum-Mechanics moving in a given background configuration of the gauge field, summing then over all possible field configurations weighted by the HTL effective action. The integration over the gauge field can be performed exactly and one is left with an ordinary Quantum-Mechanical path-integral over the trajectories of the heavy quarks, with a non-local potential represented by the HTL resummed Matsubara propagator of the photon. We can show preliminary results on the modification of the single-particle spectrum (corrections to the rest and kinetic mass, thermal width). We believe that this approach, which allows to concentrate on many-body effects, leaving aside the complications of QCD, may help to answer many fundamental questions related to the problem of bound-states in a hot medium.

References

[1] M. Laine, O. Philipsen, P. Romatschke and M. Tassler, JHEP 0703, 054 (2007).
[2] N. Brambilla, J. Ghiglieri, A. Vairoand P. Petreczky, Phys. Rev. D 78, 014017 (2008).
[3] A. Beraudo, J.P. Blaizot and C. Ratti, Nucl. Phys. A 806, 312 (2008).
[4] A. Beraudo, J.P. Blaizot and C. Ratti, Proceedings of the 8th Conference "Quark Confinement and the Hadron Spectrum", September 1-6, Mainz, Germany, 0812.1130 [hep-ph].
[5] A. Beraudo, J.P. Blaizot, P. Faccioli and G. Garberoglio, *work in progress*.

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Quarkonium States in an Anisotropic (Viscous) QGP

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The attraction of a heavy quark and anti-quark in a hot QCD plasma is weaker than in vacuum due to screening of static electric fields. Non-equilibrium effects due to expansion and viscosity, however, reduce the screening mass and lead to a potential carrying angular dependence. Properties of charmonium and of bottomonium states in a plasma are determined by solving a three-dimensional Schrödinger equation with such a potential. At given temperature, binding is stronger than in an ideal plasma: near $T_c \sim 200$ MeV, the binding energy of the J/Ψ and of the χ_b may increase by $\sim 50\%$, that of the Υ by $\sim 30\%$. The anisotropic medium induces a polarization of the χ_b states, favoring $L_z = 0$ over $L_z = \pm 1$.

References

[1] A. Dumitru, Y. Guo and M. Strickland, Phys. Lett. B662, 37 (2008).

[2] A. Dumitru, Y. Guo, A. Mocsy and M. Strickland, "Quarkonium states in an anisotropic QGP", manuscript in preparation.

J/ψ Production in Minimum Bias Au+Au and Cu+Cu Collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR

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J/ψ production is considered to be a sensitive probe of the properties of quark gluon plasma created in nucleus+nucleus collisions at RHIC. It has been intensively studied in Au+Au and Cu+Cu collisions in the last years, and new Au+Au data taken by the STAR detector in year 2007 with significantly improved statistics has recently become available.

In this presentation, the analysis of mid-rapidity ($|y| < 1$) J/ψ production via the dielectron decay channel in minimum bias Au+Au (year 2007) and Cu+Cu (year 2005) collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR is reported. It will be compared to STAR $p + p$ results in order to study the nuclear modification factor as a function of transverse momentum and centrality. The results will be compared to previously published data and available theoretical models.

J/ψ Elliptic Flow and High p_T Suppression Measurements in A+A Collisions by the PHENIX Experiment

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J/ψ suppression measurements have been widely used as a tool to explore the hot and dense deconfined matter that is formed in high-energy heavy ion collisions. In recent years, data from PHENIX has shed new light on the understanding of the centrality and kinematical dependence of J/ψ suppression in A+A collisions. J/ψ's at high p_T are of particular interest. The formation time of the J/ψ, hence the duration in which the formed J/ψ and the prehadronic $c\bar{c}$ states evolve in the hot medium depend on momentum. The measurement of the p_T dependence of the suppression can therefore provide a constraint on the relative strength of the interaction of J/ψ with the medium in the hadronic and prehadronic states. An extension of the suppression measurement beyond the previous limit of p_T=5 GeV/c in Cu+Cu and possibly Au+Au collisions will be shown.

Suppression of J/ψ in A+A collisions was also investigated as a function of rapidity. In Au+Au interactions, the rapidity dependence of the suppression is opposite to what is expected from local energy density dependent suppression models. This has led to the speculation that regeneration of J/ψ from uncorrelated c and $\bar{c}$ quarks could play a strong role. J/ψ elliptic flow is a potential test of regeneration, since regenerated J/ψ are expected to inherit the observed strong elliptic flow of heavy quarks. The latest results of the p_T dependence of J/ψ elliptic flow from the 2007 Au+Au running period will be presented. Progress towards measuring higher mass quarkonia (ψ', Υ) in Au+Au collisions will also be reviewed.

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Transverse Momentum Dependence of J/ψ Production in Heavy Ion Collisions at RHIC

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The transverse momentum (p_T) dependence of J/ψ production in heavy ion collisions is investigated in a transport model with both initial production and regeneration of charmonia. By solving the coupled hydrodynamic equation for evolution of the hot medium and the transport equation for charmonia motion, the competition between the initial production and regeneration explains well the p_T suppression in central collisions and the valley structure of R_{AA} at low p_T found in Au+Au and Cu+Cu collisions at RHIC.

Quarkonia Measurement with ALICE

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ALICE (A Large Ion Collider Experiment) is the LHC (Large Hadron Collider) detector dedicated to the study of heavy ion collisions in an unprecedented energy regime. The goal of the experiment is to study the properties of the deconfined matter: the Quark Gluon Plasma (QGP).

The LHC will collide Pb+Pb at $\sqrt{s_{NN}} = 5.5$ TeV opening up new perspectives in the QGP study. To extract information about the QGP from Pb+Pb collisions, the comparison to less complex systems, for which deconfinement effects are not expected, is mandatory. Thus, the LHC will also deliver $p+p$ collisions ($\sqrt{s_{NN}}$=14 TeV) and p+Pb collisions ($\sqrt{s_{NN}} = 8.8$ TeV) giving a solid baseline for Pb+Pb system.

At such ultra-relativistic energies, new experimental probes of the QGP become accessible such as heavy flavour with copious production rates. At LHC energies heavy quarks are produced in the early stage of the collision mainly through gluon-gluon fusion processes. Central Pb+Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV are expected to produce around a hundred (five) $c\bar{c}$ ($b\bar{b}$) pairs. Less than one percent of all heavy quark pairs form colourless bound states: the quarkonia. The study of quarkonia production in heavy ion collisions is one of the most powerful method to investigate the collision dynamics at both short (formation process) and long (medium effects) timescales. Therefore, a primary focus of the ALICE physics program is the measurement of quarkonia in different colliding systems via di-muon and di-electron channels.

Quarkonia decaying into di-muons will be measured in the Dimuon Forward Spectrometer (DFS) that covers a high rapidity domain ($-4 \leq \eta \leq -2.5$). The expected invariant mass resolution in central Pb+Pb collisions is about 70 (100) MeV/c^2 for charmonia (bottomonia).

Di-electronic decays will be detected in the central barrel covering a mid-rapidity range ($|\eta| \leq 0.9$). The detectors used for this study are the TRD (Transition Radiation Detector), ITS (Inner Tracking System) and the TPC (Time Projection Chamber). The invariant mass resolution is expected to be around 30 (90) MeV/c^2 for charmonia (bottomonia). The ITS has a high precision secondary vertexing which should allow to distinguish the J/ψ from beauty hadron decays.

In this talk we will present the main physics motivations for the study of heavy quarkonia at LHC energies. The expected performances of the DFS and the central barrel for the quarkonia detection will be shown.

3A: High p_T III: Gamma-Hadron Correlations and Direct Photons

1 2:00 PM *Hanzhong Zhang*
"Gamma-jet Tomography of High-energy Nuclear Collisions in NLO pQCD"

2 2:20 PM *Megan Connors*
"Direct Photon-Hadron Correlations Measured with the PHENIX Detector"

3 2:40 PM *Ahmed Hamed*
"Direct Gamma - Charged Hadron Azimuthal Correlation Measurements from STAR"

4 3:00 PM *Ali Hanks*
"Measurements of Photon Fragmentation and the Flavor Dependence of Jet Fragmentation with the PHENIX Detector"

5 3:20 PM *Guang-You Qin*
"Jet Energy Loss and Photon Production at High p_T in Hot QGP"

3B: Bulk Properties of the Medium III: Transport Coefficients #1

1 2:00 PM *Raimond Snellings*
"Global Fits of v_2 and Their Implications to Hydrodynamical Limit and Effective η/s"

2 2:20 PM *Huichao Song*
"Elliptic Flow and the Shear and Bulk Viscosities of the QGP"

3 2:40 PM *Akihiko Monnai*
"Effects of Bulk Viscosity on p_T Spectra and Elliptic Flow Parameter"

4 3:00 PM *Denes Molnar*
"Applicability of Viscous Hydrodynamics at RHIC"

5 3:20 PM *Volker Koch*
"Elliptic Flow with Large Viscosity"

Gamma-Jet Tomography of High-Energy Nuclear Collisions in NLO pQCD

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High p_T photon-hadron correlations are studied within the next-to-leading order (NLO)[1,2,3] perturbative QCD parton model with modified parton-jet fragmentation functions due to jet quenching in high energy A+A collisions[4,5]. Since direct photons do not suffer energy loss, they reflect more accurately the initial jet energy associated with the away-side hadrons. However, in NLO calculation the initial jet energy could exceed that of the direct photon and therefore leading to hadrons with transverse momentum larger than that of the photons. In central A+A collisions, hadrons with large z_T will be strongly suppressed and the suppression factor is controlled mainly by the surface emission of the gamma-jet events, while small z_T region will still be influenced by the parton energy loss. Therefore study of the modified gamma-triggered fragmentation functions in the whole z_T region will help to obtain the detailed picture of jet quenching. Furthermore, gamma-jets for small z_T region are found to be slightly more sensitive to the medium properties than gamma-jets for large z_T region.

References

[1] J. F. Owens (Florida State U.), *Rev. Mod. Phys*, **59**, (1987) 465.

[2] H. Baer, J. Ohnemus, J.F. Owens (Florida State U.), *Phys. Rev. D*, **42**, (1990) 61.

[3] J. F. Owens, *Phys. Rev. D*, **65**, (2002) 034011. B. W. Harris and J. F. Owens, *Phys. Rev. D*, **65**, (2002) 094032.

[4] Xin-Nian Wang, *Phys. Lett. B* **595**, (2004) 165; **579**, (2004) 299.

[5] Hanzhong. Zhang, J. F. Owens, Enke. Wang and Xin-Nian Wang, *Phys. Rev. Lett*, **98**, (2007) 212301; *J. Phys. G* **34**, (2007) S801.

Direct Photon-Hadron Correlations Measured with the PHENIX Detector

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Direct photon-hadron correlations greatly improve our ability to perform jet tomography in heavy-ion collisions because the momentum of the direct photon can be used to constrain the initial momentum of the opposing jet. By comparing the spectra of away-side particles observed in heavy ion collisions to the spectra seen in nucleon collisions we can quantify the medium modifications to the fragmentation function due to energy loss of the away-side parton.

High p_T direct photon-hadron correlations have been measured by the PHENIX detector using a statistical subtraction method to remove the photon contribution from meson decays. Previous results from this method were limited by large uncertainties. However the systematic uncertainties can be reduced by applying event by event techniques to remove the decay background. Furthermore, the increased integrated luminosity in the most recent Au+Au RHIC run at $\sqrt{s_{NN}} = 200$ GeV provides substantially improved statistical precision and enhances the kinematic reach. These measurements are compared to PHENIX $p + p$ results to probe the modification of the away-side spectra. An initial study of photon-hadron correlations in d+Au collisions looking for cold nuclear effects and as another baseline comparison for the Au+Au results is underway.

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Direct γ - Charged Hadron Azimuthal Correlation Measurements from STAR

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After eight years of operation, the primary goal of the RHIC heavy-ion program is progressing from qualitative statements about the formation of new matter to rigorous quantitative conclusions about the basic characteristics of such matter. The ultimate goal for characterizing any system is to determine its equation of state. The energy density is a basic quantity for the equation of state. The color charge density of the medium can be probed by its effect on the propagation of a fast parton, therefore the interaction and absorption of the high-p_T particles in the medium can be used to obtain a tomographic image of the color structure of the medium. Direct photons decouple from the medium upon creation without any further interaction with the medium. Furthermore the transverse momentum of the direct photon balances the initial transverse momentum of the parton ($p_T^{\gamma} = p_T^{parton}$) in the dominant Compton-like scattering process $qg \rightarrow q\gamma$, modulo negligible corrections from initial state radiation. Therefore the direct γ-hadron azimuthal correlation measurements provide a powerful tool to quantify the energy loss.

We present STAR results for direct γ-charged hadron azimuthal correlation measurements in $\sqrt{s_{\rm NN}} = 200$ GeV Au+Au collisions from Run-7. Identical measurements from $p + p$ collisions Run-6 and d+Au collisions Run-8 are performed as a baseline for studies of medium effects. The transverse shower shape analysis in the STAR Barrel Electromagnetic Calorimeter is used to discriminate between the direct photons and photons from neutral pion decays at high p_T. A comparison between the direct $\gamma-$charged hadron azimuthal correlations and π^0-charged hadron azimuthal correlations is also shown. Data from the most recent d+Au run with its increased statistics is used to reduce the experimental uncertainties. This greatly improves the ability to constrain the medium parameters through a comparison with the energy loss models.

Measurements of Photon Fragmentation and the Flavor Dependence of Jet Fragmentation with the PHENIX Detector

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Direct photons are largely insensitive to the final state effects that lead to jet quenching in A + A collisions, making them a powerful penetrating probe of the medium produced in heavy ion collisions. Specifically, photons associated with jets provide a direct measurement of the effects of energy loss on the fragmentation of the parton as it propagates through the medium. Perturbative QCD calculations describe the direct photon cross section well at next-to-leading order, predicting a significant contribution from photons produced through parton fragmentation. On the other hand, hadron production opposite isolated direct photon triggers is believed to be largely due to quark fragmentation while hadrons produced opposite π^0 triggers are expected to result predominatly from gluon jets. Therefore a comparison of associated hadron yields for such triggers can serve to elucidate quark and gluon energy loss. However in both cases non-perturbative quantities such as the photon and gluon fragmentation functions, which are poorly constrained, lead to large theoretical uncertainties. The measurement of photons correlated with jets in $p+p$ collisions serves as an important test of these calculations and is an essential baseline measurement for comparison to A+A collisions. Similar measurements in d+Au collisions are also crucial to understand cold nuclear matter effects that may modify jet fragmentation.

A natural way of selecting photons associated with jets is to study hadron-photon correlations. Since the signal is small compared to contributions from photons produced through mesonic decays, a very precise determination of the backgrounds is required. Results for the production of photons associated with high p_T hadron triggers are presented for PHENIX $p+p$ data at 200 GeV center-of-mass energy. Associated proton and pion production for isolated direct photon triggers vs π^0 triggers, with comparisons to several fragmentation functions, will be presented as well. The application of similar studies in d+Au is also discussed.

Jet Energy Loss and Photon Production at High p_T in Hot QGP

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Jet-quenching and photon production at high transverse momenta are studied together at RHIC energies, with additional information provided by the correlations between back-to-back hard jets and photons. The energy loss of hard jets traversing through the hot medium is evaluated in the AMY formalism, by consistently taking into account both induced gluon emission and elastic collisions. The production of high p_T photons in Au+Au collisions is calculated by incorporating a complete set of photon-production channels. Putting all ingredients together with a (3+1)-dimensional ideal relativistic hydrodynamical description of the thermal medium created at RHIC, we achieve a good description of the current experimental data. Our results illustrate that both radiative and collisional energy loss are important for jet quenching. The interaction between the hard jets and the soft medium is found to be important for a complete understanding of photon data and jet-photon correlations at RHIC.

References

[1] G.-Y. Qin, J. Ruppert, C. Gale, S. Jeon, G. D. Moore and M. G. Mustafa, Phys. Rev. Lett. **100**, 072301 (2008); arXiv:0805.4594 [hep-ph].

[2] G.-Y. Qin, J. Ruppert, C. Gale, S. Jeon and G. D. Moore, arXiv:0809.2030 [hep-ph]; *in preparation.*

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Quark Matter 2009 : March 30th - April 4th, 2009 : Knoxville, Tennessee

Global Fits of v_2 and Their Implications to Hydrodynamical Limit and Effective η/s

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It is generally accepted that in heavy ion collisions at RHIC hydrodynamical models do a good job describing the bulk properties. Comparisons of v_2 measurements with ideal hydro calculations have shown that the ideal hydrodynamical limit might be reached in central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. However due to the various possible initial conditions and Equations of State, and the unknown magnitude of the viscous corrections there is significant uncertainty in this apparent match between data and ideal hydrodynamics.

In this talk, v_2/ϵ from RHIC, as a function of 1/S dN/dy, is fitted with an equation motivated by transport model calculations for charged and identified particles. Systematics of the fitting procedure and the different initial conditions will be discussed. It is found that the 1/S dN/dy dependence of v_2/ϵ can be described well by transport models with finite Knudsen numbers, even for central collisions. The Knudsen number extracted from this procedure is found to be consistent with that obtained from the study of transverse momentum dependence of v_4/v_2^2. The result indicates that the system is 20-30% away from the ideal hydro limit. In addition, from this fit, the 1/S dN/dy dependence of effective η/s for Au+Au collisions at 200 GeV is extracted.

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Elliptic Flow and the Shear and Bulk Viscosities of the QGP

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Using VISH2+1, a (2+1)-dimensional code for solving the Israel-Stewart equations for causal viscous relativistic hydrodynamics in two transverse dimensions assuming longitudinal boost invariance [1,2], we have explored the effects of viscosity on the buildup of elliptic flow $v_2(p_T)$ in non-central Au+Au and Cu+Cu collisions at RHIC energies. We report on the results [3] of a successful code verification effort between VISH2+1 and two other codes developed by Romatschke *et al.* [4] and Dusling *et al.* [5], executed by the TECHQM collaboration, and present systematic studies exploring the variation of $v_2(p_T)$ resulting from uncertainties in the coefficients of some second-order terms in the Israel-Stewart equations and from still insufficiently constrained features of the QCD equation of state near T_c. The interplay between bulk and shear viscosity in generating radial and elliptic flow is studied and it is shown that, at RHIC energies, bulk viscosity can have significant effects and complicate the extraction of the specific shear viscosity η/s from experimental hadron spectra. A systematic study of the system size dependence of the eccentricity-scaled elliptic flow and its scaling with final hadron multiplicity is presented. This includes an investigation of the question whether in viscous hydrodynamics uncertainties in the initial source eccentricity can be eliminated, at least on the theoretical side, by scaling the final elliptic flow by the initial eccentricity.

References

[1] U. Heinz, H. Song and A. K. Chaudhuri, Phys. Rev. C **73** (2006) 034904.

[2] H. Song and U. Heinz, Phys. Lett. B **658** (2008) 279; Phys. Rev. C **77** (2008) 064901; Phys.Rev.**C78** (2008) 024902.

[3] https://wiki.bnl.gov/TECHQM/index.php/Code_verification_for_viscous_hydrodynamics

[4] P. Romatschke and U. Romatschke, Phys. Rev. Lett. **99** (2007) 172301; M. Luzum and P. Romatschke, Phys. Rev. **C78** (2008) 034915.

[5] K. Dusling and D. Teaney, Phys. Rev. C **77** (2008) 034905.

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Effects of Bulk Viscosity on p_T-Spectra and Elliptic Flow Parameter

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One of the major discoveries at RHIC is that the quark gluon plasma (QGP) created in relativistic heavy ion collisions is well described within a framework of relativistic hydrodynamics [1]. The next task of the physics of the QGP is to quantify the bulk and transport properties of the QCD matter through quantitative analyses of experimental data using hydrodynamic models. One of the hot topics in this direction has been to quantitatively understand the role of shear viscosity in hydrodynamic evolution of the QGP. On the other hand, bulk viscosity turns out to be important in the vicinity of the (pseudo-)critical temperature, T_c, due to the violation of conformal invariance of QCD [2]. This could trigger a violation of applicability of hydrodynamic framework around T_c [3] and support the success of hybrid approaches [4] in which the hydrodynamic description of the QGP is followed by the kinetic description of the hadron gas.

In ideal hydrodynamic calculations, the Cooper-Frye formula is conventionally employed to calculate the particle spectra at freezeout. In dissipative hydrodynamics, viscous effects are taken into account in the Cooper-Frye formula in two ways: One is a variation of flow profile $u_0^\mu + \delta u^\mu$ as a matter of viscous correction to the dynamical evolution, the other is distortion of phase space distribution $f_0 + \delta f$ from its equilibrium form. So far, no full three dimensional viscous hydrodynamic simulations are available. Given this situation, we neglect δu^μ and take u_0^μ from a full (3+1)-dimensional ideal hydrodynamic simulation [5]. We estimate the correction from *bulk* viscosity as well as from shear viscosity to the distribution function by matching macroscopic quantities with the ones calculated in the kinetic theory and see how this affects p_T-spectra and elliptic flow parameter $v_2(p_T)$. In spite of the smallness of the bulk viscosity compared with the shear viscosity, we find that its correction to equilibrium distribution is of the same order as that of the shear viscosity. This non-trivial result comes from a fact that, in δf, factors in front of the bulk pressure Π are larger than the one in front of the stress tensor $\pi^{\mu\nu}$. This indicates the importance of *both* shear and bulk viscosity if one wants to constrain the transport coefficients with better accuracy from experimental data.

References

[1] http://www.bnl.gov/bnlweb/pubaf/pr/PR_display.asp?prID=05-38

[2] D. Kharzeev and K. Tuchin, JHEP **0809**, 093 (2008).

[3] G. Torrieri and I. Mishustin, Phys. Rev. C **78**, 021901 (2008).

[4] T. Hirano, U. W. Heinz, D. Kharzeev, R. Lacey and Y. Nara, Phys. Lett. B **636**, 299 (2006); Phys. Rev. C **77**, 044909 (2008).

[5] T. Hirano, Phys. Rev. C65, 011901 (2002).

[1] T. H. is supported in part by the Grants-in-Aid of the Japanese Ministry of Education, Culture, Sports, Science, and Technology (No. 19740130)

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Applicability of Viscous Hydrodynamics at RHIC

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During the past few years a lot of have progress has been made in applying causal dissipative hydrodynamics to model heavy-ion collisions at RHIC. 2+1D calculations that employ shear viscosity now agree between the various groups (Seattle, Ohio, Stony Brook, Purdue), and the primary focus has shifted towards the extraction of the shear viscosity to entropy density ratio η/s from the data. However, it is important to realize that viscous hydrodynamics, even its second-order formulations (such as Israel-Stewart theory), is an approximation with a certain region of validity.

Using numerical solution techniques we developed for Israel-Stewart hydrodynamics and fully nonequilibrim covariant transport in 2+1D, we establish the region of validity of Israel-Stewart hydrodynamics and find that it is only accurate in RHIC applications when $\eta/s <\sim$ few$/(4\pi)$. A useful rule of thumb we obtain is that hydrodynamics becomes inaccurate when dissipative corrections to pressure and entropy exceed about 20%. The question of validity becomes even more important if bulk viscosity plays a significant role in the dynamics because, as we show, the additional entropy generation strongly restricts initial conditions and thermalization times admissible to hydrodynamics.

References

[1] P. Huovinen and D. Molnar, Phys. Rev. C in press [arXiv:0808.0953]

[2] P. Huovinen and D. Molnar, J. Phys. G35, 104125 (2008) [arXiv:0806.1367]

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Elliptic Flow with Large Viscosity

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Lattice QCD calculations [1] of flavor off-diagonal susceptibilities and higher order baryon number fluctuations suggest an independent particle picture for the quarks at temperatures $T \geq 1.2\,T_c$ [2]. Conjecturing independent particle dynamics also for the gluons, the equation of state obtained from the lattice requires the introduction of a *repulsive* single particle potential.

This repulsive potential naturally leads to a positive elliptic flow even without any parton scattering, i.e. with *infinite* viscosity. Based on a schematic model, we will show that single particle dynamics combined with a repulsive potential result in p_t-depended elliptic flow which is a pure function of the kinetic energy of the particles, as observed in experiment. We further study the elliptic flow of heavy quarks which are embedded in a potential generated by light partons. We find that the elliptic flow of the heavy quarks is suppressed by the ratio of m_{light}/M_{heavy}. Assuming quark recombination we, therefore, predict $v_2(J/\Psi) \simeq 0$ and $v_2(p_t)_{D-meson} \simeq \frac{1}{2}v_2(p_t)_{pion}$.

Using Vlasov-Boltzmann transport, we have carried numerical studies of the single particle dynamics based on a single particle potential fitted to the lattice equation of state. We find a similar behavior as the schematic model.

We will disccuss the implications of this picture and the limitations posed by recent lattice QCD results.

References

[1] C. R. Allton et al. Phys. Rev. **D71** (2005) 054508; R. V. Gavai and S. Gupta Phys. Rev. **D73** (2006) 014004.
[2] V. Koch et al., Phys. Rev. Lett. **95** (2005) 182301; S. Ejiri et al., Phys. Lett. **B633** (2006) 275.

3C: EM Radiation I: Electromagnetic Probes of the Medium

1 2:00 PM *Filip Krizek*
"Inclusive Dielectron Production in Ar+KCl Collisions at 1.756 A*GeV with HADES"

2 2:20 PM *Yuji Tsuchimoto*
"In-medium Modifications of Low-Mass Vector Mesons in PHENIX at RHIC"

3 2:40 PM *Olena Linnyk*
"Dileptons from the Nonequilibrium Quark-Gluon Plasma"

4 3:00 PM *Dmitri Peressounko*
"Photon Physics in ALICE"

5 3:20 PM *Mark Baker*
"Direct Photon and Photon-Jet Measurement Capability of the ATLAS Experiment at the LHC"

3D: Early Times I: Correlations, Hydrodynamics, Entropy and Photoproduction

1 2:00 PM *Berndt Mueller*
"From 0 to 5000 in 10^{-24} Seconds: Toward a Theory of Entropy Production in Relativistic Heavy-Ion Collisions"

2 2:20 PM *Yury Gorbunov*
"Photoproduction at the Relativistic Heavy Ion Collider with STAR"

3 2:40 PM *Zaida Conesa del Valle*
"Photoproduction of J/Ψ and High-Mass Dielectrons in Ultra-Peripheral Au+Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV by PHENIX"

4 3:00 PM *Joshua Vredevoogd*
"Universal Flow in the First fm/c at RHIC"

5 3:20 PM *Rupa Chatterjee*
"Formation Time of QGP from Thermal Photon Elliptic Flow"

Inclusive Dielectron Production in Ar+KCl Collisions at 1.756A·GeV with HADES

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Results of the HADES measurement of inclusive dielectron production in Ar+KCl collisions at a kinetic beam energy of 1.756A·GeV will be presented. For the first time at SIS, high mass resolution (3 % at omega mass pole) spectroscopy of the vector meson region was performed. Pair spectra will be compared with predictions of the microscopic transport code HSD as well as with previous HADES experiments carried out with lighter collision systems to reveal predicted medium effects in dilepton decay of vector mesons.

In-medium Modifications of Low-Mass Vector Mesons in PHENIX at RHIC

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Measurements of heavy-ion collisions at RHIC have established the creation of a Quark Gluon Plasma (QGP) in the most central collisions. An important tool to understand its properties is the study of the spectral shape of the Low Mass Vector Mesons (LVM's), ρ, ω and ϕ, which can be modified in the medium by the partial restoration of Chiral symmetry. This modification can be accessed directly by measuring low-momentum LVM via their decay into electron pairs inside the hot matter. Since leptons are not subject to strong interaction, they will not rescatter on their way out of the medium.

The PHENIX experiment at RHIC has measured LVM production at mid-rapidity at $\sqrt{s_{\rm NN}} =$ 200 GeV $p+p$, d+Au and Au+Au collisions. Mass peaks for the LVM have been observed in the di-electron invariant mass spectra with a resolution of 10 MeV/c^2 in all three system. The extracted spectrum, mass and width of the ω and ϕ in $p+p$, d+Au and Au+Au, in the leptonic and hadronic decay channel will be reviewed.

Since the width of the meson may be affected in the medium, the branching ratios of various decay modes may also be modified from vacuum values. We compare the relative branching ratio of $\phi \to e^+e^-$ and $\phi \to K^+K^-$, which may be sensitive to the modification due to the small Q-value of $\phi \to K^+K^-$.

Dileptons from the Nonequilibrium Quark-Gluon Plasma

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We present our latest results on dileptons produced in heavy-ion collisions at SPS and RHIC energies using the nonequilibrium microscopic Parton-Hadron-String Dynamics (PHSD) transport approach [1]. The approach includes the off-shell dynamics of quarks, antiquarks and gluons as well as a covariant dynamical hadronization scheme in addition to the familiar hadronic reaction dynamics as incorporated in HSD [2]. While the low mass dilepton sector ($M < 1$ GeV) at SPS energies [3] (measured by NA60 and CERES) is rather well described by hadronic degrees of freedom when a collisional broadening of the vector mesons (ρ, ω) is incorporated, this no longer holds for Au+Au collisions at top RHIC energy of $\sqrt{s}$ =200 GeV. Here the in-medium effects for the ρ and ω vector mesons do not explain the large enhancement observed in the invariant mass regime from 0.2 to 0.6 GeV by the PHENIX collaboration [3,4]. Furthermore, the intermediate mass regime from 1 to 2 GeV demonstrates – within the NA60 acceptance at SPS energies – a dominant contribution from 'massive' $q + \bar{q}$ annihilation in the sQGP phase, while hadronic channels like $\pi + a_1$ and $\rho + \rho$ show up to be subdominant (in PHSD) for In+In reactions at 160A·GeV. At RHIC energies, the decay of open charm mesons is demonstrated to dominate the dilepton spectrum, when the D and D^* dynamics is treated in analogy to Ref. [5]. This is due to a significantly larger production of $c\bar{c}$ pairs at RHIC energies compared to SPS energy scales. The dileptons in the the J/Ψ and Ψ' invariant mass regime signal a nontrivial suppression pattern of the charmonia with respect to rapidity y at RHIC energies. This clearly indicates rather strong interactions of the charm degrees of freedom in the sQGP phase [5]. Finally, possible solutions to the 'low mass dilepton puzzle at RHIC' – such as gluon-Compton radiation – are discussed and compared to the PHENIX data.

References

[1] W. Cassing, E.L. Bratkovskaya, Phys. Rev. C 78 (2008) 034919.

[2] W. Cassing, E.L. Bratkovskaya, Phys. Rep. 308 (1999) 65.

[3] E.L. Bratkovskaya, W. Cassing, O. Linnyk, Phys. Lett. B,*in press*, arXiv:0805.3177, doi:10.1016/j.physletb.2008.11.034.

[4] A. Toia et al., PHENIX Collab., Eur. Phys. J. 49 (2007) 243; S. Afanasiev et al., arXiv:0706.3934.

[5] O. Linnyk, E.L. Bratkovskaya, W. Cassing, Int. J. Mod. Phys. **E17** (2008) 1367.

Photon Physics in ALICE

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Photon physics cover almost all topics of physics of hard probes on heavy ion collisions. Direct photons are produced during the entire evolution of nucleus-nucleus collisions and provide possibility to study both initial state of the collision and inner part of the fireball during evolution of hot matter. Decay photons can be used to measure nuclear modification factors of neutral mesons, π^0, η, ω, etc. In addition to this, photon-jet and photon-hadron correlations can considerably clarify studies of parton energy loss.

ALICE experiment at LHC is well equipped by various photon detectors. The Photon Spectrometer, PHOS is a high-resolution electromagnetic calorimeter of the ALICE experiment dedicated for precise measurement of direct photon and neutral medon yields in $p+p$ and A+A collisions at mid-rapidity $|\eta| < 0.12$ in a p_T range up to 100 GeV/c. Electromagnetic calorimeter, with its capability to detect photon in a wide solid angle, $|\eta| < 0.7$ at $p_T < 250$ GeV/c, will study jets via their photon component. Photon multiplicity detector, PMD, will measure photon flux in forward direction at $2.3 < |\eta| < 3.5$.

In this talk, we give an overview of photon physics which will be studied by the ALICE experiment in proton-proton and heavy ion collisions at LHC. More detailed physics will be discussed within the scope of the PHOS detector. The physics potential of PHOS to study direct photons and neutral meson spectra in $p+p$ and Pb+Pb collisions, present experimental methods to perform these measurements, give predictions for direct photon, π^0, η and $\omega(782)$ meson production in both $p+p$ and Pb+Pb collisions, calculate expected event rates for them in PHOS in the first LHC runs and demonstrate the performance of the analysis chain from raw data to physics results.

Direct Photon and Photon-Jet Measurement Capability of the ATLAS Experiment at the LHC

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Direct photon and photon-jet correlations are ideal tools for tomographic studies of the dense medium created in heavy ion collisions at LHC energies. Due to their weak interactions with the medium, direct photons serve as standard candles for hard-scattering processes, providing a clean calibration of the momentum of the associated jets. The ATLAS detector has excellent capabilities to make these measurements. In particular, the electromagnetic calorimeter, covering the full azimuth for $|\eta| < 4.9$, has longitudinal segmentation and fine transverse segmentation along η in the range $|\eta| < 2.4$. This combination of fine granularity, longitudinal segmentation and large acceptance is unique among the LHC detectors. We show how this will provide an optimal capability to distinguish direct photon clusters from neutral meson clusters based on their shower profile over a wide acceptance in $\eta - \phi$ out to 200 GeV in p_T. This opens up the possibility for studying various final state photons, including those from jet fragmentation, in-medium gluon conversion and medium-induced bremsstrahlung. Combined with a photon isolation cut, we show that ATLAS should be able to measure a relatively background-free direct photon yield from 10–200 GeV along with the corresponding gamma-jet correlations for one nominal LHC Pb+Pb year. These high p_T photons allow a clean and statistically significant measure of the gamma-jet correlation and the fragmentation function for photon-tagged jets.

From 0 to 5000 in 2×10^{-24} Seconds: Toward a Theory of Entropy Production in Relativistic Heavy-Ion Collisions

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The agreement of hydrodynamic calculations of the flow anisotropy of the matter produced in nuclear collisions at RHIC with the elliptic flow measurements rests on the assumption of an early equilibration of the matter on a time-scale of less than 1 fm/c. An important problem in the description of relativistic heavy ion reactions is thus to understand how the produced matter equilibrates so quickly. From a thermodynamic standpoint, this question can be answered by studying when and how entropy is created in the reaction. One can distinguish five different stages of entropy production:

1. Decoherence of the initial nuclear wave functions;
2. Thermalization of the partonic plasma ("glasma");
3. Dissipation due to shear viscosity in the hydrodynamic expansion;
4. Hadronization accompanied by large bulk viscosity;
5. Viscous hadronic freeze-out.

In this talk, we review what is known about the contributions to the final entropy from the different stages of the nuclear collision, including recent results on the decoherence entropy [1] and the entropy produced during the hydrodynamic phase by viscous effects [2]. We recently developed a general framework for the calculation of entropy growth in quantum field theories, which is applicable to the earliest ("glasma") phase of the collision during which most of the entropy is generated. Our new approach [3] is based on the Husimi distribution, which is derived from the Wigner functional by Gaussian smearing. We show that the entropy calculated from the Husimi distribution exhibits linear growth when the quantum field contains unstable modes, and prove that the long-time limit of the growth rate is equal to the Kolmogorov-Sinaï (KS) entropy of the field. We outline how our approach can be used to investigate the problem of entropy production in a relativistic heavy-ion reaction from first principles.

References

[1] R.J. Fries, B. Müller and A. Schäfer, arXiv:0807.1093 [nucl-th].

[2] R.J. Fries, B. Müller and A. Schäfer, Phys. Rev. C **78**, 034913 (2008).

[3] T. Kunihiro, B. Müller, A. Ohnishi and A. Schäfer, arXiv:0809.4831 [hep-ph].

Quark Matter 2009 : March 30^{th} - April 4^{th}, 2009 : Knoxville, Tennessee

Photoproduction at the Relativistic Heavy Ion Collider with STAR

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The strong electromagnetic fields of short duration associated with relativistic heavy ions make a heavy-ion collider a unique tool to study two-photon and photonuclear collisions.

In this talk, we introduce the principles of photoproduction at hadron colliders, review recent results from RHIC on meson and e^+e^- production. We compare RHIC measurements with corresponding results from CDF at Fermilab and discuss prospects for photoproduction physics at LHC. At RHIC, STAR has studied exclusive ρ^0 vector meson production and ρ^0 production accompanied by electromagnetic dissociation of both nuclei in collisions of Au+Au and d+Au at 62, 130 and 200 GeV. Recent results suggest the validity of the Glauber calculations for the vector meson photoproduction and incosistency of the model based on the parton saturation phenomenon. We are also sensitive to interference between production on the two nuclei: either ion can be the photon emitter or the target. The level of observed interference suggests that the final state wave function carries information about all possible decays long after the decay occurs. The lowest order QED calculations for the e^+e^- pair-production in photon-photon interactions overpredict the data. This has been addressed in a recent calculation that includes realistic phenomenological treatment of the nuclear Coulomb excitation. We also observe coherent photoproduction of a $\pi^+\pi^-\pi^+\pi^-$ state which may be associated with ρ^{0*} (1450) .

Photoproduction of J/ψ and High-Mass Dielectrons in Ultra-Peripheral Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV by PHENIX

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Relativistic heavy ions are copious sources of virtual photons. Ultra-peripheral heavy ion collisions (UPC) provide the possibility to study particle photoproduction in electromagnetic processes with an equivalent two-photon luminosity which is proportional to the fourth power of the nuclei atomic number (Z^4). At RHIC energies, the heaviest vector meson accessible in gamma A interactions with heavy ions such as Au is the J/ψ. In addition, the strong electromagnetic fields can also excite the nuclei and lead to forward neutron emission with an approximate probability of 55%, allowing Zero-Degree-Calorimeter triggering on this process.

At RHIC energies, photoproduction of the J/ψ probes the gluon distribution function $G_A(x, Q^2)$ in nuclei and vector meson dynamics in nuclear matter in an unexplored kinematic region (Bjorken-x $\sim 10^{-2}$). High-mass dielectron production allows a test of QED in a strongly interacting regime where the perturbative calculations are expected to break down.

We report PHENIX studies on J/ψ and high-mass dielectron production in UPC Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV tagged with forward neutron emission. Results are compared to various theoretical predictions and prospects for the future are discussed.

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Universal Flow in the First fm/c at RHIC

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We will show how both elliptic and radial flow generated during the first fm/c at RHIC is independent of the state of matter and depends only on the initial energy density profile. Descriptions based on partons or classical fields, thermalized or highly anisotropic, all lead to the same collective velocity given a few easily satisfied conditions. This significantly narrows the uncertainty for initializing hydrodynamic prescriptions.

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Formation Time of QGP from Thermal Photon Elliptic Flow

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Azimuthal anisotropy or in particular elliptic flow of thermal photons is a very powerful tool to explore the early time dynamics and properties of Quark Gluon Plasma (QGP). Photon flow at large transverse momentum (p_T) reflects the anisotropies of the initial partonic phase, which is formed at the beginning soon after the collision [1]. Although the direct photon spectrum is dominated by prompt and jet contributions at large p_T, elliptic flow (v_2) of thermal photons controls the nature of photon v_2 curve, as the contributions from other sources of photons to v_2 are very small in that p_T range [2]. The prompt photon spectrum at large p_T can in principle be estimated using pQCD. The initial thermalization time or the formation time (τ_0) of QGP, beyond which hydrodynamics can be used to describe the evolution of the system is a very important input, which needs to be determined accurately for correct estimation of the quark matter contribution. We have found that the p_T dependent elliptic flow of thermal photons for a fixed entropy or particle density is quiet sensitive to τ_0 and can be used to determine its value precisely with the help of experimental measurement [3]. The $v_2(p_T)$ for photons decreases with smaller values of τ_0 at large p_T as it admits a larger contribution from the QGP phase which has a smaller v_2. On the other hand the p_T dependent elliptic flow and spectra for different hadrons are almost independent of the value of τ_0 as they are emitted only from freeze-out surface. Thus hadronic v_2 and spectra are rather insensitive to the formation time of QGP, whereas photon v_2 has enough potential to estimate the value of τ_0 rather accurately.

References

[1] R. Chatterjee, E. Frodermann, U. Heinz and D. K. Srivastava, *Phys. Rev. Lett.* **96**, (2006) 202302.

[2] S. Turbide, C. Gale, E. Frodermann and U. Heinz, *Phys. Rev. C* **77**, (2008) 024909.

[3] R. Chatterjee and D. K. Srivastava, arXiv:0809.0548 [nucl-th].

4A: LHC Instrumentation

1 4:10 PM *Marzia Rosati*
"Dimuon Measurements in Pb+Pb Collisions with the ATLAS Detector at the LHC"

2 4:30 PM *Christof Roland*
"Triggering on Hard Probes in Heavy-Ion Collisions with the CMS Experiment at the LHC"

3 4:50 PM *Francesco Prino*
"Results from the Commissioning of the ALICE Inner Tracking System with Cosmics"

4 5:10 PM *Jens Wiechula*
"Commissioning and Calibration of the ALICE TPC"

5 5:30 PM *MinJung Kweon*
"The Transition Radiation Detector for ALICE at LHC"

6 5:50 PM *Giacomo Volpe*
"Results from Cosmics and First LHC Beam with the ALICE HMPID Detector"

4B: QCD Phase Plane I: Fluctuations and QCD Critical Point #1

1 4:10 PM *Dimitri Kharzeev*
"Parity Violation in Hot QCD Matter"

2 4:30 PM *Katarzyna Grebieszkow*
"Search for the Critical Point of Strongly Interacting Matter in NA49"

3 4:50 PM *Hung-Ming Tsai*
"Phenomenology of the Three-Flavour PNJL Model and Thermal Strange Quark Production"

4 5:10 PM *Tapan Nayak*
"Fluctuations of Conserved Quantities in Cu+Cu and Au+Au Collisions at RHIC Energies Using Higher Order Moments in STAR Experiment"

5 5:30 PM *Andras Laszlo*
"The NA61/SHINE Experiment at the CERN SPS"

6 5:50 PM *Johann M. Heuser*
"The Compressed Baryonic Matter Experiment at FAIR: Progress with Feasibility Studies and Detector Developments"

Dimuon Measurements in Pb+Pb Collisions with the ATLAS Detector at the LHC

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The ATLAS detector, currently being commissioned at CERN, is designed to provide precise measurements of $\sqrt{s_{NN}} = 5.5$ TeV Pb+Pb collisions at the LHC. One of the major detector components is the Muon Spectrometer which consists of more than 1,200 single drift-tube chambers. The Muon Spectrometer provides an independent high precision measurement of the momenta of muons, allowing study of particles decaying into two muons such as quarkonia and Z bosons.

At the LHC, large energy will be available in the center-of-mass, enabling the possibility to produce Z bosons. Their production cross-sections are known with a precision dependent on the parton distribution functions (PDFs) uncertainties. Since electroweak bosons are probes produced in hard primary collisions and they do not interact strongly with the surrounding medium created in the collision, they will allow binary scaling cross-checks in A+A collisions. Z boson production in Pb+Pb collisions will be sensitive to the nuclear modification effects of the quark PDFs at high Q^2.

The measurement of quarkonia production in heavy-ion collisions provides a powerful tool to study the properties of hot and dense matter created in such collisions. We studied the possibility of measuring and J/ψ and Υ quarkonia families that are expected to dissociate at different temperatures of the medium.

We will present the simulation results for expected reconstruction efficiency, mass resolution, rates and background estimates for Υ states, J/ψ's and Z bosons in Pb+Pb collisions at LHC.

Triggering on Hard Probes in Heavy-Ion Collisions with the CMS Experiment at the LHC

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Studies of heavy-ion collisions at the LHC will benefit from an array of qualitatively new probes not readily available at lower collision energies. These include fully formed jets at $E_T > 50$ GeV, Z^0's and abundantly produced heavy flavors. For Pb+Pb running at LHC design luminosity, the collision rate in the CMS interaction region will exceed the available bandwidth to store data by several orders of magnitude. Therefore an efficient trigger strategy is needed to select the few percent of the incoming events containing the most interesting signatures. This will be crucial for collecting statistically significant samples of the rarest probes, like Z^0's, and to facilitate highly differential studies of more common processes.

The CMS experiment has developed a unique trigger system for high luminosity p+p running, dealing with event rates of 40 MHz using a two-layer trigger architecture. The first layer ("Level-1") is implemented using custom electronics and provides a trigger decision based on local data from the calorimeter and muon systems. The second layer, the High Level Trigger (HLT), is implemented using a large cluster of commodity computers. At the HLT, the full information for each event accepted by the Level-1 is available, allowing for "offline" algorithms to be used for making the final trigger decision on each event.

In this talk, we will present an overview of the CMS heavy-ion trigger architecture and strategy. HLT performance results obtained with a 240 CPU-core prototype system dedicated to Heavy-Ion studies in CMS will be shown. Based on rate estimates of hard probes at full LHC luminosity, we will discuss the extension of the physics reach that can be achieved by dedicated jet, photon and di-muon trigger algorithms executed on each Pb+Pb event occurring in the interaction region. As benchmark physics analysis, we will present the p_T reach of a charged particle R_{AA} measurement based on jet triggered Pb+Pb events and jet fragmentation functions obtained from a full simulation of triggered events in the γ+jet channel.

Results from the Commissioning of the ALICE Inner Tracking System with Cosmics

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ALICE is a general-purpose heavy-ion detector, aimed at studying nuclear matter under the extreme density and temperature conditions that will be attained in Pb+Pb collisions at the LHC. The Inner Tracking System (ITS) is the detector of the ALICE central barrel located closest to the beam axis and it is therefore a key detector for an accurate measurement of the positions of the primary (interaction) vertex and of the secondary (decay) vertices of hyperons and open heavy flavours. It is composed of six cylindrical layers of silicon detectors, covering the pseudorapidity range $-0.9< \eta <0.9$. The two innermost layers (at radii of $\approx$ 4 and 7 cm) are equipped with pixel detectors (SPD), the two intermediate layers (radii $\approx$15 and 24 cm) are made of drift detectors (SDD), while strip detectors (SSD) are used for the two outermost layers (radii $\approx$39 and 44 cm). Tracks reconstructed in the large ALICE Time Projection Chamber are matched to the ITS hits and prolonged inward to the innermost SPD layer using a Kalman filter algorithm. The four layers equipped with SDD and SSD provide also particle identification capability via dE/dx measurement. This feature allows to use the ITS also as a standalone spectrometer, able to track and identify particles down to momenta below 200 MeV/c. Furthermore, the SPD Fast-OR digital pulses allow to implement a unique prompt trigger capability

In this talk, the main results from the ITS commissioning with cosmic rays in 2008 will be presented. The hardware status of detectors, front-end electronics, cooling and data acquisition will be shown, focusing in particular on detector operation and on-line monitoring during the data taking period. The performance and the calibration strategy for each of the three different detector types will also be discussed as well as the reconstruction of the cosmic ray tracks using the ITS as a standalone tracker. The methods developed for the alignment of the ITS detectors using reconstructed tracks and their application to the cosmic ray data sample will be presented. The results obtained so far demonstrate that the detector is well performing and ready for the forthcoming proton-proton data taking.

Commissioning and Calibration of the ALICE TPC

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ALICE is the dedicated heavy ion experiment at the Large Hadron Collider at CERN. The main tracking device of ALICE is a large volume time projection chamber (TPC).

After the assembly of the detector on surface level, the TPC was transported to the experimental area underground in 2007 and installed in the experiment. In 2008 the full TPC was brought into operation and extensive runs over a period of more than 6 months took place to commission the detector and start calibration. Calibrations were performed with laser triggers, by admixing radioactive Kr into the detector gas, and with cosmic ray triggers. Part of the commissioning runs took place with different field settings of the solenoid magnet which houses the central part of the ALICE experiment.

The milestones of the TPC commissioning as well as the current status of the detector calibration will be presented. We will discuss the obtained transverse momentum, spatial as well as dE/dx resolutions and address results from noise and electron drift velocity measurements.

The Transition Radiation Detector for ALICE at LHC

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The Transition Radiation Detector (TRD) for the ALICE experiment at the Large Hadron Collider (LHC) identifies electrons and performs online tracking in the challenging high multiplicity environment of heavy-ion collisions within 6 microsecond after the interaction and thus requires excellent position resolution and pion rejection capability. The TRD consists of 540 Xe gas-filled pad readout drift chambers with radiators arranged in 18 super-modules in barrel geometry in the central part of the ALICE detector. The large active area of roughly 700 m^2 is covered by almost 1.2 million readout channels. Presently, four of in total 18 TRD super-modules are installed in the ALICE central barrel and commissioning of the detector using tracks from cosmic radiation coacting with other ALICE sub-detectors was successfully performed. For a period of six months, four installed super-modules of the detector were commissioned with cosmic radiation including a cosmic trigger generated by the TRD at level 1. We will report on the performance and current understanding of the detector based on these data.

Results from Cosmics and First LHC Beam with the ALICE-HMPID Detector

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The ALICE-HMPID (High Momentum Particle IDentification) detector has been designed to identify charged pions and kaons in the range $1 < p_T < 3$ GeV/c and protons in the range $2 < p_T < 5$ GeV/c in a limited acceptance configuration. It consists of seven identical proximity focusing RICH (Ring Imaging Cherenkov) counters, covering in total 11 m^2, which exploits large area MWPC equipped with CsI photocathodes for Cherenkov light imaging emitted in a liquid C_6F_{14} radiator. The ALICE detector has been widely commissioned using cosmics and LHC beam from December 2007 until October 2008. During the cosmics data taking the HMPID detector collected a large set of data, using mainly the trigger provided by the TOF detector, which matches with its geometrical acceptance. We present here preliminary results of detector alignment using TPC tracking. The HMPID could be operated in a stable way, at a safe HV setting, also during LHC beam injection and circulation tests, when a very large occupancy (up to 50%) was achieved. Resulting gain mapping and overall detector performance will also be discussed.

Parity violation in hot QCD matter

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Parity violation means that our world is distinguishable from its mirror image. It has been known for fifty years that parity is violated in weak interactions. Recent result from RHIC [1] suggests that strong interactions can also violate parity under the extreme conditions of very high energy density. The violation of parity in strong interactions arises due to the coupling of space-time to the color space which is mediated by the topological configurations of gluon field. It is not a global violation, i.e. the sign of left–right asymmetry fluctuates from one event to another.

The violation of parity manifests itself in heavy ion collisions at RHIC through the spatial separation of positive and negative hadrons with respect to the reaction plane [2]; this charge separation induces the electric dipole moment of the produced hot quark-gluon matter. The charge separation stems from the interplay of strong magnetic field (and/or the angular momentum) in the early stage of the heavy ion collision and the presence of topological configurations in hot matter ("the chiral magnetic effect") [2-5]. This effect is only possible in the deconfined quark-gluon plasma phase because it is requires the separation of quarks over a large ("macroscopic" on the scale of hot matter size) distance.

It is very important to verify the observed effect and to study all possible backgrounds. The magnitude and the qualitative features of the asymmetry had been predicted [2] prior to the observation, but more detailed theoretical work is needed to establish unambiguously the origin of the effect. New theoretical results and proposals for future measurements will be presented in this talk.

If confirmed decisively, the observed parity violation would establish the creation of a new state of matter and modify our view of the Early Universe.

References

[1] S.A. Voloshin et al [STAR Collaboration], arXiv:0806.0029.

[2] D. Kharzeev, Phys. Lett. **B633**, (2006) 260; hep-ph/0406125.

[3] D. Kharzeev and A. Zhitnitsky, Nucl. Phys. **A797**, (2007) 67.

[4] D. Kharzeev, L. McLerran, H. Warringa, Nucl. Phys. **A803**, (2008) 227.

[5] K. Fukushima, D. Kharzeev, H. Warringa, Phys. Rev. **D78**, (2008) 074033.

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Search for the Critical Point of Strongly Interacting Matter in NA49

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The critical point of strongly interacting matter, if exists, is believed to be located in the SPS energy range. Several experimental observables have been proposed to look for it in ultra-relativistic heavy ion collisions. In this talk the NA49 results relevant to critical point search will be presented and discussed. These are:
- event-by-event transverse momentum and multiplicity fluctuations,
- elliptic flow of baryons and mesons,
- transverse mass spectra of baryons and anti-baryons,
- pion-pion intermittency analysis.

The energy and the system size dependence of event-by-event fluctuations of mean transverse momentum and multiplicity will be shown and compared to several hadronic model predictions, as well as to the fluctuation signal expected in the vicinity of the critical point.

The energy dependence of anisotropic flow is considered to be sensitive to the critical point. Its presence should lead to a decrease of the baryon flow and an increase of the meson flow. NA49 results on the elliptic flow parameter v_2 for protons and pions will be presented for middle and top SPS energies.

It has been suggested recently that the presence of a critical point can deform the trajectories describing the evolution of the expanding fireball in the $(T - \mu_B)$ phase diagram. As a consequence the $\bar{p}/p$ ratio should fall with increasing transverse momentum instead of a rise or flat behavior in a scenario without the critical point. NA49 results on the $\bar{p}/p$ ratio versus m_T will be shown for five SPS energies.

The critical opalescence in QCD matter can be a clear signature of the QCD critical end-point. This phenomenon is detectable through intermittency analysis in transverse momentum space (power-law behavior of factorial moments expected). The NA49 results on pion pair production will be shown for $p + p$, C+C, Si+Si and Pb+Pb collisions at the top SPS energy, and compared to predictions of critical QCD.

Phenomenology of the Three-Flavour PNJL Model and Thermal Strange Quark Production

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In this paper, we explore the thermal strange quark pair-production processes, $q\bar{q} \to s\bar{s}$ and $gg \to s\bar{s}$, in a theoretical framework of the phase transformations of QCD matter due to deconfinement and chiral symmetry breaking, i. e., the three-flavour PNJL model. By a well-defined thermal averaging procedure, the adjoint Polyakov loop is obtained as a function of temperature, whose validity is sustained by a temperature-independent scaling, observed in the lattice QCD, between the Polyakov loops in different representations. This self-consistent thermal averaging procedure allows us to compute the thermal average of any function of the eigenvalues of the Polyakov loops, for instance, the thermal average of the momentum spectrum for gluons. By the Polyakov-loop dependent momentum spectra for quarks and gluons, we evaluate the strange quark pair-production rates and analyze the effects of the order parameters of the phase transformations on the temperature dependence of production rates, by comparing them with those obtained from the free perturbation theory.

References

[1] H. -M. Tsai and B. Müller, arXiv:0811.2216 [hep-ph].

Fluctuations of Conserved Quantities in Cu+Cu and Au+Au Collisions at RHIC Energies Using Higher Order Moments in the STAR Experiment

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Fluctuations of conserved quantities like net charge and net baryon number have been considered as a signature for the search of Quark Gluon Plasma formation and the QCD critical point. Recent lattice QCD calculations have shown [1-5] that the distribution of conserved quantities becomes non-Gaussian at the critical end point. Such long range correlations can be readily tested in the experiment via the analysis of higher order moments of the hadron distributions.

With its large acceptance and excellent particle identification capabilities, STAR provides the best environment for such a study. In this talk, we present the preliminary results on the beam energy and system size dependence of the second and fourth moments of the distributions of net charge, proton and net proton ($p-\bar{p}$) in the STAR experiment at RHIC. First results on p_T dependence of the cumulants of the net charge distributions will also be presented. The results for most peripheral Cu+Cu and Au+Au collisions are similar to those of the $p+p$ collisions. As expected, the kurtosis of net charge and net proton distributions are seen to decrease with the increase in the number of participating nucleons. Furthermore, the kurtosis of net charge distributions also decrease with increase in p_T. The results will be compared with model predictions. Finally the benefits from the full installation of STAR Time-of-Flight and the plans for the RHIC energy scan program will be discussed.

References

[1] B. Stokic, B. Friman, K. Redlich, e-Print: arXiv:0809.3129 [hep-ph]

[2] S. Ejiri, F. Karsch and K. Redlich, Physics Letters, B633 (2006) 275

[3] R.V. Gavai and S. Gupta, Physical Review D72 (2005) 054006

[4] M.A. Stephanov, arXiv:0809.3450 [hep-ph]

[5] V. Koch, arXiv:0810.2520 [nucl-th]

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The NA61/SHINE Experiment at the CERN SPS

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The second generation experiment NA61/SHINE at the CERN SPS was proposed in order to investigate four main physics questions. According to numerical lattice calculations, the phase diagram of the strongly interacting matter contains (at least) two phases: a hadron gas phase and a phase where the color degrees of freedom are deconfined. These phases are expected to be separated by the first order phase boundary at high baryochemical potential, which ends in a critical point where the transition becomes second order. One of the main physics goals of NA61/SHINE is to discover the critical point by performing an energy - system size scan of hadron production properties, in particular, event-by-event multiplicity and transverse momentum fluctuations. Furthermore, the scan will allow to establish the system size dependence of the rapid changes of hadron production properties discovered by NA49 in central Pb+Pb collisions at the low SPS energies and predicted as signals of the onset of deconfinement.

A next important task of the experiment is to measure transverse mass spectra of identified hadrons in $p + p$ and p+nucleus interactions above 2.5 GeV/c transverse momentum to supply a base line for a comparison with nucleus+nucleus reactions. These data will allow to establish an energy dependence of the strong suppression of hadron production at high transverse momenta observed first at the BNL RHIC.

Furthermore, the NA61/SHINE experiment measures differential cross-section of identified hadrons in proton interactions on carbon and the T2K replica targets at 31 GeV/c. These data are necessary for the T2K neutrino experiment to calculate the properties of the neutrino beam produced at the J-PARC. Last but not least the differential cross-section of identified hadrons will be measured in hadron-nucleus interactions at the SPS energies for the cosmic ray experiments, Pierre Auger Observatory and KASCADE. They are needed to refine the models used in the simulations of the extensive air showers and consequently to reduce significantly systematic errors on the measured cosmic ray properties.

The NA61/SHINE physics goals pose rather demanding criteria for the experimental hardware. Therefore, the necessary and the already implemented upgrades are also discussed. The presentation of the first physics results and the data taking schedule will close the talk.

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The Compressed Baryonic Matter Experiment at FAIR: Progress with Feasibility Studies and Detector Developments

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The CBM experiment is being planned at the international research center FAIR, under realization next to the GSI laboratory in Darmstadt, Germany. Its physics programme addresses the QCD phase diagram in the region of highest net baryon densities. Of particular interest are the expected first order phase transition from partonic to hadronic matter, ending in a critical point, and modifications of hadron properties in the dense medium as a signal of chiral symmetry restoration.

Laid out as a fixed-target experiment at the synchrotrons SIS100/300, the detector will record both proton-nucleus and nucleus-nucleus collisions at beam energies up to $45A{\cdot}$GeV. Hadronic, leptonic and photonic observables have to be measured with large acceptance. The interaction rates will reach 10 MHz to measure extremely rare probes like charm near threshold. Two versions of the experiment are being studied, optimized for either electron-hadron or muon identification, combined with silicon detector based charged-particle tracking and micro-vertex detection.

The CBM physics requires the development of novel detector sytems, trigger and data acquisition concepts as well as innovative real-time reconstruction techniques. Progress with feasibility studies of the CBM experiment and the development of its detector systems will be discussed.

[1]Supported by EU-FP6 HadronPhysics

4C: EM Radiation II: QGP Thermal Radiation

1 4:10 PM *Yasuyuki Akiba*
"Dilepton Radiation Measured in PHENIX Probing the Strongly Interacting Matter Created at RHIC"

2 4:30 PM *Zhong-Bo Kang*
"Low-mass Lepton Pair Production at Large Transverse Momentum"

3 4:50 PM *Yorito Yamaguchi*
"Measurements of Soft and Intermediate p_T Photons from Hot and Dense Matter at RHIC-PHENIX"

4 5:10 PM *Dinesh Srivastava*
"A Reanalysis of Single Photon Data at CERN SPS"

5 5:30 PM *Gianluca Usai*
"First Results on Angular Distributions of Thermal Dileptons in Nuclear Collisions"

6 5:50 PM *Fuming Liu*
"Centrality-Dependence of Direct Photon Production from Au+Au Collisions"

4D: Early Times II: Physics at Small- and Large-*x*

1 4:10 PM *Raju Venugopalan*
"Novel Universal Parton Distributions and Long Range Rapidity Correlations at RHIC and LHC"

2 4:30 PM *Beau Meredith*
"Probing High Parton Densities at Low-*x* in *d*+Au Collisions at PHENIX Using the New Forward and Backward Muon Piston Calorimeters"

3 4:50 PM *Hannu Paukkunen*
"EPS09 - Global NLO Analysis of Nuclear PDFs and Their Uncertainties"

4 5:10 PM *Ermes Braidot*
"Looking Forward for Color Glass Condensate Signatures with STAR"

5 5:30 PM *Zvi Citron*
"Single Particle Probes of *d*+Au Collisions in PHENIX"

6 5:50 PM *Michel Sumbera*
"Physics of Large-*x* Nuclear Suppression"

Dilepton Radiation Measured in PHENIX Probing the Strongly Interacting Matter Created at RHIC

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Since the late 70's dileptons have been considered an ideal probe for the hot and dense matter produced in heavy ion collisions. PHENIX has recently measured electron-positron pairs from $p+p$, Cu+Cu and Au+Au collisions at RHIC. The $p+p$ data can be fully accounted for by the expected contributions from light meson decays, open heavy flavor production as well as prompt virtual photon emission contributing to the region where p_T is much larger than the mass of the e^+e^- pair. In contrast, Au+Au data show significant additional contributions to the dilepton continuum over a wide range in mass and transverse momentum beyond the properly scaled $p+p$ data. The enhancement in the low mass region from 150 to 750 MeV/c^2, which at lower beam energies has been successfully modeled by $\pi\pi$ annihilation including broadening of the spectral function, is much larger than predicted by these models. Its yield increases with centrality significantly faster than the number of participating nuclei. At high p_T ($1 < p_T < 5$ GeV/c) and low mass ($m < 300$ MeV/c^2), where prompt virtual photons can be isolated in the $p+p$ data, an additional source of direct virtual photons was detected in Au+Au collisions. This source has an inverse slope of about 220 MeV/c , when extrapolated to zero mass or real photons. Details of the data analysis, the results and implications of the results will be presented.

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Low-Mass Lepton Pair Production at Large Transverse Momentum

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PHENIX collaboration has recently measured the transverse momentum distribution of lepton pair production at RHIC with the pair's invariant mass as low as $100 < Q < 300$ MeV. We will show that the distribution of low mass lepton pair production at large transverse momentum $Q_T \gg Q$ can be systematically calculated in terms of the perturbative QCD factorization approach. All factorized short-distance parotnic hard parts are evaluated at a distance scale $\sim 1/Q_T$, while all long-distance non-perturbative physics are factorized into the universal parton-to-lepton pair fragmentation functions. We introduce a model for the input lepton pair fragmentation functions at a scale $\mu \sim 1$ GeV, which are then evolved perturbatively to scales relevant at RHIC. Using the evolved fragmentation functions, we calculate the transverse momentum distributions of low mass lepton pair production in hadron-hadron, hadron-nucleus, and nucleus-nucleus collisions. We demonstrate that the transverse momentum distribution of low mass lepton pairs is extremely sensitive to the shape of gluon distribution.

References

[1] Zhong-Bo Kang, Jian-Wei Qiu, Werner Vogelsang, arXiv:0811.3662 [hep-ph].

Measurements of Soft and Intermediate p_T Photons from Hot and Dense Matter at RHIC-PHENIX

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Direct photons are one of the most important probes to investigate properties of the matter created by heavy ion collisions at RHIC since they leave the medium without a strong interaction once they are generated. Special interest is put on direct photons in the low and moderate p_T region ($p_T <\sim 5.0$ GeV/c) since primary contributors are considered to be thermal photons from QGP and photons produced in jet-medium interactions such as jet-photon conversions and in-medium bremsstrahlung. Measurements of direct photon yields with respect to the reaction plane can help disentangle the contributions from various production process. Such information together with model calculations will provide deeper insight into the time evolution of the produced matter.

In the PHENIX experiment, two different analysis methods, namely, a real photon method and a virtual photon method, have been successfully developed and direct photon spectra in a wide-ranging p_T region have been obtained for both $p + p$ and Au+Au collisions. A clear enhancement over the binary-scaled $p + p$ yield is seen in Au+Au collisions for $p_T < 3.0$ GeV/c [1]. In order to evaluate the net contributions from thermal radiation and jet-medium interactions, results from d+Au are required to evaluate cold nuclear matter effects.

In this talk, the latest measurements of direct photons and their reaction plane dependence at $\sqrt{s_{NN}} = 200$ GeV will be presented. In particular, comparison between the results in $p + p$, d+Au and Au+Au collisions will be made to determine the possible photon production mechanism in hot and dense matter. The thermodynamical properties of the medium will be discussed.

References

[1] A. Adare *et al.,* for the PHENIX Collaboration, arXiv:0804.4168[nucl-ex].

A Reanalysis of Single Photon Data at CERN SPS

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Single photons produced in relativistic heavy ion collisions were first observed by WA98 collaboration for collision of lead nuclei at CERN SPS and this observation gave a new dimension to the study of the properties of Quark Gluon Plasma (QGP) [1]. A reanalysis of the single photon SPS data has been done. For the prompt photon contribution we include the effect of iso-spin and shadowing corrected NLO pQCD treatment for prompt photon production using an optimized scale for factorization, renormalization and fragmentation [2]. For the thermal photons, ideal hydrodynamics along with a well tested equation of state (admitting a quark hadron phase transition) has been used and a set of initial thermalization time (τ_0) is considered keeping the entropy and net baryon number fixed, looking at the sensitivity of hydrodynamics to the initial parameters. Centrality dependent hydrodynamics calculations are performed to accurately model the evolution.

The WA98 data can be explained well considering a small τ_0 ($\sim$ 0.2 fm/c) or large initial temperature with a moderate increase of prompt photon yield, attributing it to the intrinsic k_T of the partons in the nuclei. For a relatively smaller initial temperature or larger τ_0 ($\sim$ 1.0 fm/c) the prompt yield needs to be multiplied with a large factor in order to explain the data. The differential elliptic flow of thermal photons is found to be quite sensitive to the value of τ_0.

References

[1] M. M. Aggarwal *et al.* [WA98 collaboration] Phys. Rev. Lett. **85**, 3595 (2000).

[2] R. Chatterjee, D. K. Srivastava, S. Jeon and C. Gale, [in preparation].

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First Results on Angular Distributions of Thermal Dileptons in Nuclear Collisions

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The NA60 experiment at the CERN SPS has studied dimuon production in $158A$·GeV In+In collisions. The strong excess of pairs above the known sources found in the complete mass region $0.2 < M < 2.6$ GeV has previously been interpreted as thermal radiation. We now present first results on the associated angular distributions. Using the Collins-Soper reference frame, the structure function parameters λ, μ and ν are measured to be zero, and the projected distributions in polar and azimuth angles are found to be uniform. The absence of any polarization is consistent with the interpretation of the excess dimuons as thermal radiation from a randomized system. While this is a necessary condition, it is not sufficient. However, together with other features like the Planck-like shape of the excess mass spectra, the exponential shape of the m_T spectra and the global agreement with theoretical models both as to spectral shapes and absolute yields, the thermal interpretation has become more plausible than ever before.

Centrality-Dependent Direct Photon Production from Au+Au Collisions

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Jet quenching makes a similar suppression pattern to π^0 and η production whereas the nuclear modification factor $R_{\rm AA}$ of direct photon indicates completely different p_T and centrality dependence.

We investigate the medium effect (within 0-60% centrality) in direct photon production based on a 3+1D hydrodynamical description of the expanding hot dense matter. Parton energy loss in plasma is fixed via the measured neutral pion data.

The competition between different photon sources is predicted at various centralities. The measured p_T spectra are well reproduced and the observed $R_{\rm AA}$ of direct photons are explained over a large p_T range and centrality range.

We also study the elliptic flow of direct photons.

At high p_T region, the scheme of jet quenching plays an important role. One can reproduce the measured p_T spectra with various energy loss schemes, while the resultant v_2 depends on the energy loss schemes evidently.

In the low p_T region where thermal production dominates, we find the elliptic flow of thermal photons first increases with p_T, and then decreases for $p_T > 2\,\mathrm{GeV/c}$, because of the weak transverse flow at the early stage. Contrary to hadronic observables, thermal photons carry early/inner information about the created hot and dense matter. On the other hand, the p_T-integrated v_2 of thermal photons has a centrality dependence similar to that of hadrons: It reaches a maximum at about 50% centrality and decreases with centrality, also because of the interplay between the eccentricity and the strength of transverse flow, both for photons and hadrons from the bulk.

References

[1]Fu-Ming Liu, Tetsufumi Hirano, Klaus Werner, Yan Zhu, e-Print: arXiv:0811.0666 [hep-ph], for the proceeding of SQM 2008 international conference

[2] Fu-Ming Liu, Tetsufumi Hirano, Klaus Werner, Yan Zhu, Phys. Rev. **C79** 014905 (2009); arXiv:0807.4771 [hep-ph].

[3]Fu-Ming Liu, Tetsufumi Hirano, Klaus Werner, Yan Zhu, arXiv:0902.1303 [hep-ph].

[4] R. Chatterjee, E. Frodermann, U. Heinz, and D.K. Srivastava, Phys. Rev. Lett. **96**, 202302 (2006).

Universal Multi-Parton Density Functionals and Long Range Rapidity Correlations at RHIC and LHC

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Multi-parton dynamics in QCD at high energies is described by the JIMWLK Hamiltonian equation for parton density functionals [1]. We show that these objects are universal, whether they are measured in deep inelastic scattering, hadron+nucleus or nucleus+nucleus collisions [2,3]. The factorization theorems thus established, provide for the first time, an *ab initio* theory of multi-parton production in heavy ion collisions. We demonstrate how this theoretical framework underlies the Glasma flux tube picture of heavy ion collisions [4]. Of particular interest are long range near side "ridge" rapidity correlations. We present new results for 3 particle near side correlations [5]. Further, we develop our theoretical framework to compute n-particle correlations that have an arbitrarily wide separation in rapidity, thereby allowing for bremsstrahlung between tagged mini-jets [6]. The $\Delta\eta$ variations of these correlations, especially with the wide coverage of the LHC, is a powerful diagnostic tool of highly coherent initial state multi-parton dynamics.

References

[1] *The color glass condensate and high energy scattering in QCD*,
E. Iancu and R. Venugopalan, arXiv:hep-ph/0303204.

[2] *High energy factorization in nucleus-nucleus collisions-I*,
F. Gelis, T. Lappi and R. Venugopalan, Phys. Rev. D **78**, 054019 (2008).

[3] *High energy factorization in nucleus-nucleus collisions. II. Multigluon correlations*,
F. Gelis, T. Lappi and R. Venugopalan, Phys. Rev. D **78**, 054020 (2008).

[4] *Glasma flux tubes and the near side ridge phenomenon at RHIC*,
A. Dumitru, F. Gelis, L. McLerran and R. Venugopalan, Nucl. Phys. A **810**, 91 (2008).

[5] K. Dusling, D. Fernandez-Fraille and R. Venugopalan, *in preparation.*

[6] *High energy factorization and long range rapidity correlations in the Glasma*,
F. Gelis, T. Lappi and R. Venugopalan, arXiv:0810.4829, submitted to *Phys. Rev. Lett.*

Probing High Parton Densities at Low-x in d+Au Collisions at PHENIX Using the New Forward and Backward Muon Piston Calorimeters

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Deuteron-gold collisions at RHIC provide a system wherein one can explore nuclear effects on initial-state parton densities in the absence of final-state medium effects. RHIC experiments have shown a suppression in nuclear modification factors (R_{dA}, R_{cp}) for $\sqrt{s_{NN}} = 200$ GeV d+Au collisions in the forward (deuteron) direction and an enhancement in the backward (gold) direction [1-3]. Multiple theories exist that can explain the observed suppression and enhancement, but a conclusive measurement discriminating between the different mechanisms has yet to be carried out. Two new forward electromagnetic calorimeters (Muon Piston Calorimeters or MPCs, $-3.7 < \eta < -3.1$, $3.1 < \eta < 3.9$) were recently installed in the PHENIX experiment allowing study of parton densities at low-x. The MPCs make it possible to measure nuclear modification factors in the forward and backward directions as well as the azimuthal correlation of di-hadron pairs at different pseudorapidities. The analysis presented is based on the high integrated luminosity data sample of d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV taken at RHIC in 2008. The correlation measurements are especially interesting because it is expected that they provide a test of gluon saturation at low-x in the Au nucleus [4].

References

[1] J. Adams, *et al.* (STAR), Phys. Rev. Lett. 97, 152302 (2006).

[2] I. Arsene, *et al.* (BRAHMS), Phys. Rev. Lett. 93, 242303 (2004).

[3] S. S. Adler, *et al.* (PHENIX), Phys. Rev. Lett. 94, 082302 (2005).

[4] D. Kharzeev, E. Levin and L. McLerran, Nucl. Phys. A748, 627640 (2005).

EPS09 — Global NLO Analysis of Nuclear PDFs and Their Uncertainties

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We present the results of our next-to-leading order (NLO) global DGLAP analysis of the nuclear parton distribution functions (PDFs) and, in particular, their uncertainties. In line with the earlier studies, we confirm that the good description of world data obtained already at the leading-order level can be lifted up to NLO. This lends strongly support to the conventional factorization-theorem-based approach in describing hard processes in nuclear collisions. Compared with earlier analyses, the present work is an extension in two important ways.

First, the experimental input in our analysis consists of three types of processes instead of the usual two: deep inelastic scattering (DIS), Drell-Yan dilepton production (DY), and inclusive pion production. Out of these, the pion production data has not been traditionally included in the global analyses. A careful analysis shows, however, that the shape of the nuclear modification factor $R_{\rm dAu}$ of the pion p_T-spectrum at midrapidity, measured in d+Au collisions at RHIC, retains some sensitivity to the large-x gluons, which provides evidence for an EMC-effect in the gluon sector. Also, the suppression in the low-p_T part of $R_{\rm dAu}$ can be easily reproduced down to $p_T \sim 1.7\,{\rm GeV}$ by gluon and quark shadowings alone. Thus, this type of data (at $\eta = 0$) is found to be fully consistent with DIS and DY in the factorization framework. Although not included in the EPS09 global fit, we also compare our results with the forward-η $R_{\rm dAu}$ data.

Our second main objective is to bring the error analysis of the nPDFs up to a similar level as it is in the free proton PDFs. We use the Hessian method to quantify the nPDF uncertainties which originate from the uncertainties in the data. In this method the sensitivity of χ^2 to variations of the fitting parameters is mapped out to a collection of 30 nPDF error sets. We will release a computer code for practical applications, allowing a general user to independently calculate how the nPDF uncertainties propagate to any factorizable nuclear cross section. Such error analysis should be particularly important for detailed analyses of the signatures and properties of QCD matter at the LHC and RHIC.

Looking Forward for Color Glass Condensate Signatures with STAR

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The first runs at the RHIC collider operated at $\sqrt{s_{NN}} = 200$GeV have demonstrated the possibility to probe the gluon distribution in heavy nuclei using forward electromagnetic calorimeters. STAR results from modular calorimeters mounted at large rapidity show general agreement of inclusive forward π^0 yields from $p + p$ collisions at $\sqrt{s} = 200$ GeV with next-to-leading order pQCD calculations. Yields of π^0 in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV in the forward direction relative to the deuteron beam are found to be smaller than expected from shadowing effects. Exploratory measurements of azimuthal correlations of the forward π^0 with charged hadrons at midrapidity show a recoil peak in $p + p$ that is suppressed in d+Au at low pion energy. The results are consistent with qualitative expectations from the Color Glass Condensate (CGC) model of the saturation of the gluon density at small momentum fractions (x) in the gold nucleus. These results prompted construction of the Forward Meson Spectrometer (FMS) at STAR. The FMS is an electromagnetic calorimeter (EMC) spanning the full azimuth and $2.5 < \eta < 4.0$, providing 20 times more acceptance in the forward direction than the earlier modular calorimeters. The FMS, with the existing barrel and endcap EMC, gives STAR almost contiguous acceptance from $-1.0 < \eta < 4.0$ over the full azimuth. This large acceptance provides sensitivity to the gluon density in a heavy nucleus over a broad range of x, at different scales related to the transverse momentum of produced particles. Forward π^0 production has been measured with the FMS from $p+p$ and d+Au collisions during the 2008 RHIC run. In this talk, we present the first azimuthal correlation results involving a forward π^0 produced in $p + p$ and d+Au collisions to search for onset of saturation effects.

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Single Particle Probes of d+Au Collisions in PHENIX

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Deuteron-gold collisions provide insights into the nuclear structure function and a valuable baseline for Au+Au collisions. Measurement of the nuclear modification factor, R_{dAu}, in d+Au in the PHENIX central arms for hadrons and photons allows us to disentangle cold nuclear matter effects from the hot medium effects that are important in Au+Au collisions. Since the nuclear modification factors for direct photons give a clean view of the initial state structure functions, comparing R_{dAu} to R_{AuAu} is key. In addition, the d+Au system can yield important insights into the gluonic structure of the Au nucleus. RHIC experiments have previously measured suppression of forward rapidity particle production relative to $p + p$ scaled by the number of binary N-N collisions, but a definitive explanation of these data is thus far elusive. Correlations between hadrons with a large rapidity gap are a particularly sensitive probe of gluon saturation. We will discuss probing this physics via particle production in events tagged with high momentum particles at different rapidities, along with R_{dAu} in new forward rapidity regions.

Physics of Large-x Nuclear Suppression

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We will discuss a common feature of all known reactions on nuclear targets - a significant suppression of the relative production yields at large-x. Interpretation of this effect in terms of energy conservation driven multiple parton rescatterings in nuclear matter [1,2] will be given. Using the light-cone dipole approach such a common suppression mechanism is demonstrated to control reaction dynamics on nuclear targets: high-p_T hadron production at forward rapidities [1] and at midrapidities [2], forward production of light hadrons, the Drell-Yan process, direct photon production, heavy flavor production [3,4,5]. We argue that since the same mechanism of large-x suppression is important also at lower (SPS) energies where coherent nuclear effects are not expected, interpretation of observed phenomena in terms of the models based on the Color Glass Condensate is excluded.

References

[1] J. Nemchik, V. Petráček, I. K. Potashnikova and M. Šumbera, Phys. Rev. **C78**, 025213 (2008); e-Print: **arXiv:0805.4267** [hep-ph].

[2] J. Nemchik and M. Šumbera, **arXiv:0811.3837** [hep-ph].

[3] J. Nemchik and I.K. Potashnikova, AIP Conf. Proc. **1056**, 207 (2008); e-Print: **arXiv:0807.1605** [hep-ph].

[4] B.Z. Kopeliovich, J. Nemchik, I.K. Potashnikova, M.B. Johnson and I. Schmidt, Phys. Rev. **C72**, 054606 (2005); e-Print: **hep-ph/0501260**.

[5] B.Z. Kopeliovich, J. Nemchik, I.K. Potashnikova, M.B. Johnson and I. Schmidt, Nucl. Phys. Proc. Suppl. **146**, 171 (2005).

5A: High p_T IV: Ridge Phenomena and Jet Flavor Conversion

1 2:00 PM *Pawan Kumar Netrakanti*
"Addressing the Physics of the Ridge by 2- and 3-Particle Correlations at STAR"

2 2:20 PM *Kolja Kauder*
"Jet Fragmentation in STAR via Di-jet Triggered (2+1) Multi-hadron Correlations"

3 2:40 PM *Bjoern Schenke*
"Jet Broadening and Energy Loss in Wong-Yang-Mills Simulations"

4 3:00 PM *Rainer Fries*
"High-p_T Physics with Identified Particles"

5 3:20 PM *Ronald Belmont*
"PHENIX Results on Energy Loss and Flavor Conversion from Single Particle Spectra in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV"

6 3:40 PM *Yichun Xu*
"Measurements of K^0_S and $K^\pm$ Production at High p_T up to 15 GeV/c at STAR as a Probe for Jet Flavor Conversion at RHIC"

5B: QCD Phase Plane II: Fluctuations and QCD Critical Point #2

1 2:00 PM *Chuan Miao*
"Higher Moments of Charge Fluctuations in QCD at High Temperature"

2 2:20 PM *Larry McLerran*
"The Quarkyonic Phase Transition and the FPP-NJL Model in Large and Finite N_c"

3 2:40 PM *Owe Philipsen*
"The Chiral Critical Surface of QCD"

4 3:00 PM *Shinji Ejiri*
"Critical Point in Finite Density Lattice QCD by Canonical Approach"

5 3:20 PM *Joseph Kapusta*
"Critical Points in the QCD Phase Diagram with Two Flavors of Quarks"

6 3:40 PM *Ron Soltz*
"The Lattice QCD Equation of State and Implications for Hydrodynamic Modeling of Heavy Ion Collisions"

Addressing the Physics of the Ridge by 2- and 3-Particle Correlations at STAR

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The observation of the near-side ridge (long range $\Delta\eta$ correlation) has motivated many theoretical investigations on the formation mechanism of the ridge which may provide insight into the early dynamics of relativistic heavy ion collision [1,2]. The ridge magnitude was found to decrease with trigger particle azimuth relative to reaction plane (ϕ_s) from in-plane to out-of-plane [3]. The broadness of the ridge was found to be event-by-event from 3-particle $\Delta\eta$-$\Delta\eta$ correlations [4]. In this talk, we present new results on 2-particle azimuthal correlation relative to reaction plane and 3-particle $\Delta\eta$-$\Delta\eta$ correlation. The data are from d+Au and Au+Au collisions at 200 GeV by STAR and are presented as a function of collision centrality, trigger and associated p_T. We use these data to address two important questions:

- **Is the ridge formed from jet-medium interaction?**
  Motivated by our data [3], Hwa *et al.* [2] suggested that the ridge is formed from correlated particle emission due to aligned jet propagation and medium flow direction and predicted asymmetric near-side $\Delta\phi$ correlations. We test this prediction by analyzing 2-particle $\Delta\phi$ correlations with trigger particles *separately* in ϕ_s>0 and ϕ_s<0. We show the asymmetry parameter as a function of ϕ_s. If the ridge and jet are causally connected due to jet-medium interaction, there should be cross-talk between them on event-by-event basis. We quantify this cross-talk term in our 3-particle $\Delta\eta$-$\Delta\eta$ correlations.

- **Is the ridge uniform in $\Delta\eta$?**
  The $\Delta\eta$-shape of the ridge has important bearing on the physics mechanism, but cannot be obtained from dihadron measurements because of the large jet-like contribution at small $\Delta\eta$. Charge ordering differs between jet and ridge and can be used to *experimentally* separate them by analyzing 3-particle $\Delta\eta$-$\Delta\eta$ correlations of different charge combinations. We found like-sign triplets are dominated by the ridge. The separated jet-like component is confined and symmetric between ϕ and η. The separated ridge, while narrow in $\Delta\phi$, is extremely broad with Gaussian width $\sigma_{\Delta\eta}$ ∼1.5. We discuss which model(s) could accommodate this broad $\Delta\eta$ distribution.

References

[1] N. Armesto *et al.*, *Phys. Rev. Lett.* **93**, 242301 (2004); C. B. Chiu and R. Hwa, *Phys. Rev. C* **72**, 034903 (2005); S. A. Voloshin, *Phys. Lett. B* **632**, 490 (2006); M. Strickland *et al.*, *Eur. Phys. J.* **A29**, 59 (2006); A. Majumder *et al.*, *Phys. Rev. Lett.* **99**, 042301 (2007); E. Shuryak, *Phys. Rev. C* **76**, 047901 (2007); C. Y. Wong, arXive:0712.3282 (2007).
[2] C. B. Chiu and R. C. Hwa, arXiv:0809.3018 (2008).
[3] A. Feng (for STAR Collaboration), *J. Phys. G* **35**, 104082 (2008).
[4] P. K. Netrakanti (for STAR Collaboration), *J. Phys. G* **35**, 104010 (2008).

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Jet Fragmentation in STAR via Di-Jet Triggered (2+1) Multi-Hadron Correlations

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Strongly-interacting partonic medium created in heavy ion collisions has been evident in multiple observables at RHIC. One of the prominent manifestations of this medium — the jet-quenching effect — has been found in single-particle spectra as well as in di-hadron angular correlations. The latter has already provided additional information regarding the medium properties. Away-side quenching demonstrates that the medium is dense, transverse momentum distributions of associated hadrons are indicative of thermalization. Alteration of angular distributions of associated hadrons on both (same- and away-) sides of a high-p_T trigger reveals a strong modification of known hadron production mechanisms. Alternatively, it has been argued that the peculiar features found in the triggered di-hadron distributions, such as a double-humped away-side structure and a "ridge", formed on the same-side of the trigger, could be caused by the response of the medium to propagated jets.

To further address these experimental findings, we study the jet-medium interactions via the recently developed multi-hadron correlation technique. For our studies, we employ a pair of approximately back-to-back high-p_T hadron triggers, restricting the di-jet kinematics, and study associated particles with respect to the di-hadron trigger. Variation of relative trigger thresholds makes it possible to adjust the relative strength of modified and unmodified jets, and thus provides more differential means for studies of jet properties. Here we present our study of di-jet systematics comparing the measurements of associate yields and fragmentation functions in 200 GeV Au+Au and d+Au collisions obtained with this method.

Jet Broadening and Energy Loss in Wong-Yang-Mills Simulations

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We present results for collisional energy loss and momentum broadening of high momentum partons in a hot and dense non-Abelian plasma, obtained by solving the coupled system of Wong-Yang-Mills equations on a lattice in real time. Including hard elastic collisions among the particles we obtain cutoff independent results for the collisional energy loss dE/dx and the transport coefficient $\hat{q}$. The latter is found to receive a sizable contribution from a power-law tail in the transverse momentum distribution of high-momentum partons [1].

We also estimate the nuclear modification factor (R_{AA}) due to elastic energy loss of a jet in a classical Yang-Mills field.

References

[1] B. Schenke, M. Strickland, A. Dumitru, Y. Nara, C. Greiner, arXiv:0810.1314 [hep-ph] (2008).

High-p_T Physics with Identified Particles

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The suppression of high-p_T particles in nuclear collisions at high energies has been one of the key discoveries at the Relativistic Heavy Ion Collider. It is a manifestation of the energy loss suffered by the leading particle of a jet in the surrounding medium. Energy loss is usually quantified by the average momentum squared per mean free path transferred to this particle, $\hat{q} = \mu^2/\lambda$.

Here we argue that measurements of identified particles at high-p_T can lead to additional, complementary information. We will explore the simple fact that a high-p_T particle can change its identity (flavor) when interacting with the medium. An immediate consequence of this idea is the realization that the distinction between quark and gluon jets is not well defined in a nuclear environment.

This leads to the notion of hadro-chemistry at high-p_T which could allow us to constrain the mean free path λ of probes in a quark gluon medium independently from measurements of $\hat{q}$. In this talk we review the basic concepts and discuss their relation to observables, e.g. the proton/pion ratio, the yield of additional photons from jets, and a couple of new double ratio observables. We also discuss how we get inverted, i.e. negative, elliptic flow from flavor conversions. We make a prediction that strangeness should be enhanced at high-p_T at RHIC energies while its elliptic flow is suppressed. We also take a look at heavy quarks, and at the situation at LHC energies. We conclude by discussing the possibility of negative elliptic flow for J/ψ mesons.

References

[1] W. Liu and R. J. Fries, Phys. Rev. C **77**, 054902 (2008).

[2] W. Liu and R. J. Fries, Phys. Rev. C **78**, 037902 (2008).

[3] W. Liu and R. J. Fries, arXiv:0805.3721 [nucl-th].

PHENIX Results on Energy Loss and Flavor Conversion from Single Particle Spectra in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV

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One of the most intriguing results from the early years of RHIC operation was the apparent non-suppression of baryon production at intermediate values of transverse momentum p_T. This result stimulated new models for hadronization mechanisms in the quark-gluon plasma (QGP), many of them based on some form of parton recombination. These models have shown qualitative agreement with the published experimental data, but more detailed results with extended p_T reach are needed to further discriminate between them. Additionally, the flavor dependence of parton energy loss is expected to become apparent at sufficiently high p_T. The difference in energy loss between gluon and quark jets in a pure color field is the Casimir factor of 9/4, but this effect may be mitigated by parton flavor conversion. This study uses the data set collected by PHENIX during RHIC operations in the year 2007, which is over 800 μb^{-1} in integrated luminosity of Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. New results on identified particles will include charged particles using the high p_T PID capabilities of the time-of-flight and aerogel cherenkov counter detectors in the west arm of the PHENIX spectrometer, which provide track-by-track identification of protons and charged pions up to a p_T of at least 6 GeV/c and charged kaons up to a p_T of at least 4 GeV/c. These detectors also aid the reconstruction of lambdas and antilambdas up to $p_T \geq 8$ GeV/c. We will also include the latest results from high-p_T $K_S^0 \rightarrow \pi^0 + \pi^0$ reconstructed using the PHENIX electromagnetic calorimeter. In this talk we will present p_T spectra, particle yield ratios, nuclear modification factors R_{AA} and R_{CP}, and double ratios for this broad range of identified particles, and we will compare the results to model predictions.

Measurements of K_S^0 and $K^{\pm}$ Production at High p_T up to 15 GeV/c at STAR as a Probe for Jet Flavor Conversion at RHIC

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Neutral and charged Kaon spectra at high transverse momentum (p_T) in $p+p$ collisions can test calculations using perturbative quantum chromodynamic (pQCD) framework, in which the inclusive hadron production depends on convolution of parton distribution functions, parton interaction cross-sections and fragmentation functions. Measurements of the nuclear modification factor of Kaons and Lambdas at high p_T have been predicted to be an unique signal for jet flavor conversion in the Quark-Gluon plasma (QGP) [1]. To be relevant for parton energy loss in the dense medium the measured particle p_T has to reach above 5 GeV/c where there is no published data on Kaon production at RHIC.

In this talk, we'll report STAR results on identified $K^{\pm}$ spectra up to $p_T\sim$ 15 GeV/c and $K_S^0 \rightarrow \pi^+\pi^-$ production up to $p_T\sim$12 GeV/c at mid-rapidity in $p+p$ collisions at $\sqrt{S} = 200\ GeV$. The particle ratios of $\frac{K^+(K^-)}{\pi^+(\pi^-)}$, $\frac{K_S^0}{(\pi^++\pi^-)/2}$, $\frac{p(\overline{p})}{\pi^+(\pi^-)}$, $\frac{K^-}{K^+}$, $\frac{\pi^-}{\pi^+}$ and $\frac{\overline{p}}{p}$ will be presented in $p+p$ and Au+Au collisions. The nuclear modification factors of K_S^0, pions and protons and physics implications on color-charge dependence of jet quenching and jet flavor conversion in the dense medium will also be discussed.

References

[1] W. Liu and R. Fries, Phys. Rev. C 77, 054902 (2008)

Higher Moments of Charge Fluctuations in QCD at High Temperature

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Charge fluctuations are sensitive indicators for the structure of the thermal media produced in heavy ion collisions. We present lattice results for baryon number, strangeness and electric charge fluctuations as well as their correlations at finite temperature and vanishing chemical potentials, i.e. under conditions relevant for RHIC and LHC. The calculations are performed with an improved staggered fermion action (p4-action) with almost physical up and down quark masses and physical strange quark mass. We use two sets of lattice cut-offs ($Ta = 1/4, 1/6$) to control the discretization effects. We find that the fluctuations change rapidly at the transition temperature T_c and approach the ideal quark gas limit already at approximately $1.5T_c$. This indicates that quarks are the relevant degrees of freedom that carry the quantum numbers of conserved charges at $T \gtrsim 1.5T_c$. At low temperature, qualitative features of the lattice results are well described by a hadron resonance gas model. We find, however, that higher moments of charge fluctuations differ from resonance gas predictions in the vincinity of the transition temperature. This talk is based on work of the RBC-Bielefeld collaboration [1].

References

[1] M. Cheng, P. Hegde, C. Jung, F. Karsch, O. Kaczmarek, E. Laermann, R.D. Mawhinney, C. Miao, P. Petreczky, C. Schmidt, W. Soeldner, **arXiv:0811.1006** [hep-lat].

The Quarkyonic Phase Transition and the FPP-NJL Model at Large and Finite N_c

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The Fukushima-Pisarski-Polyakov-NJL model provides a solvable theory of confined quarks. It allows for a confinement phase transition, and chiral symmetry breaking transition and a quarkyonic phase. We generalize the theory to large numbers of colors and find that as N_c approaches infinity, there are three phases in accord with the arguments of Pisarski and McLerran. The quarkyonic phase is a degenerate Fermi gas of quarks whose thermal excitations are confined For finite N_c of order 3, the quarkyonic and confinement phase transitions become sharp cross overs. The chiral transition remains and is near the quarkyonic cross over. The critical end point of the chiral transition sits very near the intersection of the cross over for the the confinement and quarkyonic cross overs. Finally, we discuss the experimental implications of these results.

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The Chiral Critical Surface of QCD

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The critical endpoint of the QCD phase diagram is usually expected to belong to the chiral critical surface, i.e. the surface of second order transitions bounding the region of first order chiral phase transitions for small quark masses in the $\{m_{u,d}, m_s, \mu\}$ parameter space. We report progress on lattice calculations of the chiral critical surface for degenerate and non-degenerate quarks. On coarse $N_t = 4$ lattices, we find the area of first order transitions to significantly shrink with chemical potential, which excludes a chiral critical point for physical QCD and moderate chemical potentials $\mu_B < 500$ MeV. Finer $N_t = 6$ lattices reveal that cut-off effects are stronger than finite density effects. The sign of the curvature of the critical surface is not yet significant at the time of writing, however its absolute value is small so that the qualitative picture remains unchanged.

Critical Point in Finite Density Lattice QCD by Canonical Approach

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We study the critical point in lattice QCD at finite temperature (T) and chemical potential (μ_q) by Monte-Carlo simulations. The critical point terminating a first order phase transition line in the high density region is one of the most characteristic features that may be discovered in heavy-ion collision experiments.

One of the interesting approaches to finding a first order phase transition is to construct the canonical partition function $\mathcal{Z}_{\rm C}(T,N)$ by fixing the total quark number (N). If there is a first order phase transition, we expect that two different states coexist at the transition point. To investigate the quark number giving the largest contribution to the grand partition function $\mathcal{Z}_{\rm GC}(T,\mu_q)$, we introduce an effective potential $V_{\rm eff}$ in terms of N as follows,

$$\mathcal{Z}_{\rm GC}(T,\mu_q) = \sum_N \mathcal{Z}_{\rm C}(T,N) e^{N\mu_q/T} \equiv \sum_N e^{-V_{\rm eff}(N,T,\mu_q)}. \tag{1}$$

Using the effective potential for the quark number, one can identify the order of phase transitions, i.e. this effective potential has minima at more than one value of N corresponding to the hot and cold phases for a first order phase transition.

We propose a new method to probe the nature of the phase transition calculating the canonical partition function $\mathcal{Z}_{\rm C}(T,N)$ by Monte-Carlo simulations of lattice QCD [1] and analyze the data obtained by a simulation with two-flavor p4-improved staggered quarks in [2]. The quark mass used in this calculation is heavier than the real quark mass, e.g. the pion mass value is $m_\pi \approx 770$MeV in this simulation. We find, however, that the shape of the effective potential $V_{\rm eff}(N)$ changes gradually as the temperature decreases and a first order phase transition appears in the low temperature and high density region [1]. This result strongly suggests the existence of the critical point in the (T,μ_q) phase diagram.

References

[1] S. Ejiri, Phys. Rev. D **78**, (2008) 074507 `[arXiv:0804.3227]`.

[2] C.R. Allton, M. Döring, S. Ejiri, S.J. Hands, O. Kaczmarek, F. Karsch, E. Laermann, and K. Redlich, Phys. Rev. D **71**, (2005) 054508.

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Critical Points in the QCD Phase Diagram with Two Flavors of Quarks

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If a critical point exists, then one can go around it without crossing the curve of first order phase transition. The effective degrees of freedom should not change too much in following such a path. Therefore, if quarks are considered to be reasonably useful degrees of freedom on the higher temperature side then they should be useful on the lower temperature side too. Thus we use a simple effective field theory model, the linear σ model with quarks, to study the chiral phase transition or rapid crossover for two quark flavors at finite temperature and density. In particular, we determine the phase diagram in the plane of temperature and baryon chemical potential as a function of the pion mass. An interesting phase structure occurs which results in zero, one or two critical points depending on the value of the vacuum pion mass. This may have implications for heavy ion collisions at FAIR and for low energy runs at RHIC.

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The Lattice QCD Equation of State and Implications for Hydrodynamic Modeling of Heavy Ion Collisions

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We present results from recent calculations of the QCD equation of state and transition temperature from the HotQCD Collaboration and review the implications for hydrodynamic modeling. The QCD Equation of State of at zero baryon density was calculated on a lattice of dimensions $32^3 \times 8$ with $m_l = 0.1\ m_s$ (corresponding to a pion mass of $\sim$220 MeV) using two improved staggered fermion actions, p4 and asqtad [1]. Calculations were performed along lines of constant physics using more than 100M cpu-hours on BG/L supercomputers at LLNL, NYBlue, and SDSC. Results on final state freeze-out dimensions, spectra, and flow, for the HotQCD and bag model equation of state with first order phase transition will be directly compared for hydrodynamic models for a set of initial conditions at RHIC and the LHC. The impact of statistical and systematic errors in the Equation of State will be presented, and the effects of variations in the temperature and order of the transition will be discussed.

References

[1] R. Gupta for HotQCD Collaboration, arXiv:0810.1764

5C: Bulk Properties of the Medium IV: Transport Coefficients #2

1 2:00 PM *Gabriel Denicol*
"Lattice QCD Bulk Viscosity and Elliptic Flow"

2 2:20 PM *Nasser Demir*
"Shear-Viscosity to Entropy Density Ratio of a Relativistic Hadron Gas at RHIC: Approaching the AdS/CFT Bound?"

3 2:40 PM *Marcus Bluhm*
"Viscosities of the Quark-Gluon Plasma vs. Quasiparticle Model"

4 3:00 PM *Ioannis Bouras*
"Relativistic Shock Waves in Viscous Gluon Matter"

5 3:20 PM *Jacquelyn Noronha-Hostler*
"Chemical Equilibration and Transport Properties of Hadronic Matter Near T_c"

6 3:40 PM *Sourendu Gupta*
"The Continuum Limit of GluoN_c Plasmas"

5D: ϕ Production and Open Heavy Flavor I

1 2:00 PM *Alessandro De Falco*
"NA60 Results on ϕ Production in the Hadronic and Leptonic Channels in In-In collisions at 158 GeV"

2 2:20 PM *Maxim Naglis*
"Anomalous ϕ Meson Suppression in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV Measured by the PHENIX Experiment at RHIC"

3 2:40 PM *Jinhui Chen*
"Observation of Hypertriton and Anti-Hypertriton at RHIC"

4 3:00 PM *Alan Dion*
"Heavy Flavor Physics from Lepton Measurements in PHENIX"

5 3:20 PM *Andrea Dainese*
"Preparation for Heavy-Flavour Measurements with ALICE at the LHC"

6 3:40 PM *William Horowitz*
"Shock Treatment: Heavy Quark Energy Loss from Novel AdS/CFT Geometries"

Lattice QCD Bulk Viscosity and Elliptic Flow

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The effect of viscosity in heavy ion collisions has been investigated extensively [1,2] showing that the shear viscosity has considerable effects in the elliptic flow observables. However, the effect of the bulk viscosity has not been analyzed in detail yet. On the other hand, the lattice results [3] indicate that the bulk coefficient cannot be neglected near the phase transition, although becomes small for higher temperatures. Bulk viscosity coefficient has also been calculated for the hadron gas phase [4].

In this work, we investigate the effect of bulk viscosity in the eliptic flow with a 2+1 dimensional hydrodynamical model incorporating the features above both in the equation of state (EoS) and the bulk viscosity coefficient. For the EoS, we interpolate the lattice EoS for the QGP phase [5] smoothly to the hadronic resonance gas EoS at $T_c = 200$ MeV. The bulk viscosity coefficient is also constructed by interpolating the lattice result [3] for the the QGP phase with the results from the hadron gas phase [4]. The viscous correction to the distribution function due to the bulk viscosity in the freeze-out is estimated using the above values of hadronic phase.

We found that the bulk viscosity has significant effects in the ellipitic flow and crucially depends on the EoS used. Therefore, the analysis of collective flow and viscosity coefficients should be done considering the bulk visosity effect, together with the correct EoS near the phase transition.

References

[1] P. Romatschke and U. Romatschke, Phys. Rev. Lett. **99**, (2007) 172301.

[2] H. Song and U. W. Heinz, Phys. Rev. C **77**, (2008) 064901.

[3] F. Karsch *et al*, Phys. Lett. B **663**, (2008) 217-221.

[4] J. Noronha-Hostler *et al*, arXiv:0811.1571.

[5] C. Bernard *et al*, Phys. Rev. D **75**, (2007) 094505.

Shear-Viscosity to Entropy Density Ratio of a Relativistic Hadron Gas at RHIC: Approaching the AdS/CFT bound?

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Ultrarelativistic heavy-ion collisions at the Relativistic Heavy-Ion Collider (RHIC) are thought to have produced a state of matter called the Quark-Gluon-Plasma, characterized by a very small shear viscosity to entropy ratio η/s, near the lower bound predicted for that quantity by Anti-deSitter space/Conformal Field Theory (AdS/CFT) methods. However, as the produced matter expands and cools, it evolves through a phase described by a hadron gas with rapidly increasing η/s. We use a microscopic transport model known as the Ultrarelativistic Quantum Molecular Dynamics (UrQMD) model to simulate infinite equilibriated hadronic matter in order to calculate η/s as a function of temperature for the hadronic phase. We find that its value poses a challenge for viscous relativistic hydrodynamics, which requires small values of η/s throughout the entire evolution of the reaction in order to successfully describe the collective flow observables at RHIC [1]. We show that the inclusion of non-unit fugacities will reduce η/s in the hadronic phase, yet not sufficiently to be compatible with viscous hydrodynamics. We therefore conclude that the origin of the low viscosity matter at RHIC must be in the partonic phase of the reaction [2].

References

[1] M. Luzum and P. Romatschke, Phys. Rev. **C78**:034915,2008, arXiv: 0804.4015 [nucl-th]

[2] N. Demir and S. A. Bass, arXiv: 0812.2422 [nucl-th]

[1] This work was supported by DOE grants DE-FG02-03ER41239 and DE-FG02-05ER41367.

Viscosities of the Quark-Gluon Plasma vs. Quasiparticle Model

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A quasiparticle model, featuring dynamically generated self-energies of excitation modes, successfully describes many lattice QCD results for the equation of state and related quantities (e.g. susceptibilities [1]) at small net baryon density relevant for LHC and RHIC energies [2]. Within this approach also larger baryon densities, as relevant for FAIR physics, are reliably accessible as demonstrated for imaginary baryon density [3]. Here, we focus on transport properties (shear and bulk viscosities) within the formalism of [4] and investigate the compatibility of the employed quasiparticle ansatz with the apparent low viscosities of the strongly coupled deconfined medium.

References

[1] M. Bluhm, B. Kampfer, Phys. Rev. D 77 (2008) 114016 [2] M. Bluhm, B. Kampfer, R. Schulze, D. Seipt, U. Heinz, Phys. Rev. C 76 (2007) 034901 [3] M. Bluhm, B. Kampfer, Phys. Rev. D 77 (2008) 034004 [4] C. Sasaki, K. Redlich, arXiv:0806.4745, arXiv:0811.4708

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Relativistic Shock Waves in Viscous Gluon Matter

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Considering the relativistic Riemann problem with a discontinuity of pressure in viscous gluon matter, we investigate the existence of relativistic shock waves at RHIC. Calculations employing the parton cascade BAMPS demonstrate for the first time the transition from viscous to ideal shocks by varying the shear viscosity to the entropy density ratio η/s from infinity towards zero [1,2]. We show that if the η/s ratio of the medium is larger than 0.2, relativistic shocks will be hardly observed. Comparisons with viscous hydrodynamic calculations using vSHASTA confirm our findings. Moreover, on the contrary to the parton cascade, the recent version of vSHASTA fails to create shocks in a strong dissipative medium. The Knudsen number in the shock front is a proper quantity to understand the break down of hydrodynamics in an out of equilibrium state.

References

[1] I. Bouras *et al.*, arXiv:0811.4133v1 [hep-ph]

[2] I. Bouras *et al.*, arXiv:0902.1927v1 [hep-ph]

Chemical Equilibration and Transport Properties of Hadronic Matter near T_c

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In this talk, we explain how the inclusion of Hagedorn states near T_c leads to short chemical equilibration times of baryons anti-baryon pairs, $K\bar{K}$ pairs, and $\Lambda\bar{\Lambda}$ pairs, which implies that hadrons do not need to be "born" into chemical equilibrium [1, 2]. Comparing the K/π and $(B+\bar{B})/\pi$ ratios to experimental results at RHIC we find they match very well [1]. Moreover, when recent lattice results for T_c [3, 4] are used we find that hadrons reach chemical equilibrium at $T_{chem} \approx 160$ MeV [2], which matches thermal fit results [5]. Furthermore, our new statistical model that includes Hagedorn states is able to estimate η/s in the hadronic phase [6] and produces a result comparable to the string theory viscosity bound $\eta/s = 1/4\pi$ [7]. Our model [6] provides a good description of the recent lattice results for the trace anomaly close to $T_c = 196$ MeV [3]. We also comment on the effects of Hagedorn states on the bulk viscosity of hadronic matter near the phase transition [6]. Even when Hagedorn states are included in thermal fits, the results for the T_{chem} and baryon chemical potential do not change significantly [8].

References

[1] J. Noronha-Hostler, C. Greiner and I. Shovkovy, Phys. Rev. Lett. **100**, 252301 (2008).

[2] J. Noronha-Hostler, C. Greiner and I. Shovkovy, to appear.

[3] M. Cheng *et al.*, Phys. Rev. D **77**, 014511 (2008).

[4] Y. Aokia *et al.*, arXiv:hep-lat/0510084v2.

[5] A. Andronic, P. Braun-Munzinger and J. Stachel, Nucl. Phys. A **772**, 167 (2006) J. Manninen and F. Becattini, arXiv:0806.4100 [nucl-th].

[6] J. Noronha-Hostler, J. Noronha and C. Greiner, arXiv:0811.1571 [nucl-th].

[7] P. Kovtun, D. T. Son and A. O. Starinets, Phys. Rev. Lett. **94**, 111601 (2005) [arXiv:hep-th/0405231].

[8] J. Noronha-Hostler, H. Ahmad, and C. Greiner, to appear.

The Continuum Limit of GluoN_c Plasmas

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In recent years the AdS/CFT approach to hot QCD has yielded many interesting new directions [1]. This approach makes two drastic assumptions: the first is that the limit of large number of colours, N_c, is taken, the second is that $\mathcal{N} = 4$ supersymmetry is assumed. In some recent works the amount of supersymmetry is reduced without changing the results dramatically.

Here we report some lattice computations in (non-supersymmetric) pure gauge theory, where N_c is increased beyond the physical value of 3. We take the continuum limit for each N_c, and compare with previous works at finite lattice cutoff [2]. Our aim is to check whether there is a window of temperatures where a non-trivial conformal field theory (CFT) is obtained.

We demonstrate two-loop scaling of T_c, thus obtaining the variation of $T_c/\Lambda_{\overline{MS}}$ with N_c, and fixing the temperature scale. We study the equation of state of the gluoN_c plasma, the conformal anomaly, and the approach to the weak coupling theory. In addition we investigate whether hydrodynamics is sensitive to N_c.

References

[1] G. Policastro, D. T. Son and A. O. Starinets, Phys. Rev. Lett. **87**, (2001) 081601; C. P. Herzog *et al.*, J. H. E. P. **0607**, (2006) 013; H. Liu, K. Rajagopal and U. A. Wiedemann, Phys. Rev. Lett. **97**, (2006) 182301; S. Caron-Huot *et al.*, J. H. E. P. **0612**, (2006) 015; D. Bak, A. Karch and L. G. Yaffe, J. H. E. P. **0708**, (2007) 049; R. C. Myers, A. O. Starinets and R. M. Thompson, J. H. E. P. **0711**, (2007) 091; J. Mas, J. P. Shock, J. Tarrio, arXiv:0811.1750.

[2] A. Gocksch and M. Okawa, Phys. Rev. Lett. **52** (1984) 1751; G. G. Batrouni and B. Svetitsky, Phys. Rev. Lett. **52** (1984) 2205; M. Wingate and S. Ohta, Phys. Rev. **D63** (2001) 094502; R. V. Gavai, *Nucl. Phys. Proc. Suppl.*, 106 (2002) 480; B. Lucini and M. Teper, J. H. E. P. **0502** (2005) 033.

NA60 Results on ϕ Production in the Hadronic and Leptonic Channels in In+In collisions at 158 GeV

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The NA60 experiment at the CERN SPS studied ϕ meson production in In+In collisions at 158A·GeV both in muon and kaon pairs. In this talk the results in the hadronic channel are presented for the first time. These are discussed in the framework of the so-called ϕ puzzle through the comparison with the previous NA60 measurements in the muon channel. The yield and inverse m_T slopes observed in the two channels are compatible within errors, showing that the large discrepancies seen in Pb+Pb collisions between NA50 (muon pairs) and NA49 (kaon pairs) are not seen in the NA60 In+In data.

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Anomalous ϕ Meson Suppression in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV Measured by the PHENIX Experiment at RHIC

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The suppression of hadrons with high transverse momentum in ultra-relativistic heavy ion collisions compared to expectations from scaled $p+p$ results is one of the most interesting findings at RHIC. A clear difference between the suppression patterns of baryons and light mesons is observed in the intermediate p_T range suggesting that the suppression is governed by the number of valence quarks rather than the mass of the hadron.

The PHENIX experiment at RHIC has studied the production of ϕ meson in the K^+K^- decay channel in $p+p$, d+Au, Cu+Cu and Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV using three different techniques, involving different levels of kaon identification. This talk presents recent results on the production of the ϕ meson and its nuclear modification factor R_{AA} measured over the p_T range of 1.0−7.0 GeV/c. The production of the ϕ meson is suppressed in central Au+Au collisions as compared to $p+p$ results scaled with the number of binary collisions. The amount of suppression is smaller than for π^0 and η mesons and larger than for baryons in the intermediate p_T region suggesting a quark flavor dependence of the hadron suppression.

Observation of Hypertriton and Anti-Hypertriton at RHIC

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We report the discovery of an anti-hypernucleus at the Relativistic Heavy Ion Collider (RHIC) at BNL. The anti-hypertriton ($^{3}_{\bar{\Lambda}}\bar{H}$) and the hypertriton are reconstructed and identified in the Time Projection Chamber at the Soneloidal Tracker at RHIC (STAR) via secondary vertex of $^{3}_{\bar{\Lambda}}\bar{H} \rightarrow {}^{3}\bar{H}e + \pi^{+}$. The mass and lifetime parameters of the newly observed anti-hypernucleus will be presented. The ratios of the production cross-sections for anti-hypertriton/ hypertriton and anti-hypertriton/anti-Helium3 will be reported. Physics implications and future hypernucleus program at RHIC will be discussed.

Heavy Flavor Physics from Lepton Measurements in PHENIX

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PHENIX has studied many important observables related to heavy flavor through its lepton measurements. The invariant yield of electrons from non-photonic sources, which are dominated by decays of D and B mesons, has been measured at mid-rapidity from 0.3-9 GeV/c in p_T from both $p+p$ and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The suppression of the yield of non-photonic electrons from Au+Au collisions relative to that from binary-scaled $p+p$ collisions has indicated a strong coupling in the produced medium. Furthermore, the azimuthal anisotropy of non-photonic electrons measured at PHENIX suggests that charm and bottom quarks could flow as strongly as the light quarks. To obtain bounds on the relative production and suppression of charm and bottom, PHENIX has measured the invariant mass distribution of electron-hadron pairs. Complimentary to the electron measurement at mid-rapidity, the invariant yield of muons from $p+p$ and Cu+Cu collisions have been measured at more forward rapidity. In this talk, we will give an overview of these results and the methods used to obtain them, discuss what questions remain, and describe what PHENIX is doing to improve upon its heavy flavor measurements.

Preparation for Heavy-Flavour Measurements with ALICE at the LHC

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ALICE [1,2] will study nucleus-nucleus collisions at the LHC in order to investigate the properties of QCD matter at extreme energy densities. The measurement of open charm and open beauty production allows to investigate the mechanisms of heavy-quark propagation, energy loss and hadronization in the hot and dense medium formed in high-energy nucleus-nucleus collisions. In particular, in-medium energy loss is predicted to be different for massless partons (light quarks and gluons) and heavy quarks at moderate momentum [3,4]. The ALICE experiment can measure open heavy-flavour particles in several decay channels and with a wide phase-space coverage [2].

Most of the ALICE subdetectors are now installed, have been commissioned with cosmics during Summer 2008, and are ready to start taking data from proton–proton collisions at the LHC.

After reviewing the rich heavy-flavour program of ALICE, we will describe the preparation of the first measurements in $p + p$ and Pb+Pb runs, including relevant results on the calibration and alignment of the involved subdetectors with cosmics.

References

[1] ALICE Collaboration, Physics Performance Report Vol. I, *J. Phys. G*, v. 30, p. 1517, 2003, and CERN/LHCC 2003-049.

[2] ALICE Collaboration, Physics Performance Report Vol. II, *J. Phys. G*, v. 32, p. 1295, 2006, and CERN/LHCC 2005-030.

[3] Yu.L. Dokshitzer and D.E. Kharzeev, *Phys. Lett. B*, v. 519, p. 199, 2001.

[4] N. Armesto, A. Dainese, C.A. Salgado and U.A. Wiedemann, *Phys. Rev. D*, v. 71, p. 054027, 2005.

Shock Treatment: Heavy Quark Energy Loss from Novel AdS/CFT Geometries

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We extend the momentum regime for which AdS/CFT drag methods may be experimentally falsified into the ultrarelativistic, considering the heavy quark quenching represented by a string blowing in a shockwave wind. We argue [1] that, unlike the well-known strong coupling viscosity to entropy ratio result [2], the double ratio of charm to bottom nuclear modification factors is a robust experimental measurement that can directly test both pQCD and AdS/CFT techniques as applied to heavy ion collisions. Crucially, self-consistency in the original supergravity approach [3] imposes a "speed limit" on the momenta of the heavy quarks while for perturbative methods there is a "speed minimum." Using a shock geometry [4,5] to represent a heavy ion collision we reproduce the energy loss behavior of the pioneering drag papers [3] but valid for heavy quarks *above* a minimum threshold momentum, guaranteeing a momentum range of self-consistent application overlapping that of pQCD. With these results as a guide, we continue by investigating strong coupling drag in the background most similar to realistic heavy ion collisions known, one whose real-world analogue is a thermal, time-dependent, Bjorken-expanding, deconfined medium [4].

References

[1] W. A. Horowitz and M. Gyulassy, Phys. Lett. B **666**, 320 (2008) [arXiv:0706.2336];
W. A. Horowitz and M. Gyulassy, J. Phys. G **35**, 104152 (2008) [arXiv:0804.4330]

[2] P. Kovtun, D. T. Son and A. O. Starinets, Phys. Rev. Lett. **94**, 111601 (2005).

[3] C. P. Herzog, A. Karch, P. Kovtun, C. Kozcaz and L. G. Yaffe, JHEP **0607**, 013 (2006) [arXiv:hep-th/0605158];
S. S. Gubser, Phys. Rev. D **74**, 126005 (2006) [arXiv:hep-th/0605182]

[4] R. A. Janik and R. B. Peschanski, Phys. Rev. D **73**, 045013 (2006) [arXiv:hep-th/0512162]

[5] J. L. Albacete, Y. V. Kovchegov and A. Taliotis, JHEP **0807**, 074 (2008) [arXiv:0806.1484]

6A: High p_T V: Medium Response and Future Perspectives

1 4:30 PM *Barbara Betz*
"Conical Correlations, Bragg Peaks, and Transverse Flow Deflections in Jet Tomography"

2 4:50 PM *Wolf Gerrit Holzmann*
"Using Two and Three-Particle Correlations in PHENIX to Probe the Response of Strongly Interacting Partonic Matter to High-p_T Partons"

3 5:10 PM *Giorgio Torrieri*
"Conical Flow in Mesons and Baryons from Coalescence of a Perfect Quark Fluid"

4 5:30 PM *Richard Neufeld*
"The Sound Produced by a Fast Parton in the Quark-Gluon Plasma is a Long 'Crescendo'!"

5 5:50 PM *Gabor Veres*
"Measurements of High-p_T Probes in Heavy Ion Collisions at CMS"

6 6:10 PM *Nathan Grau*
"Elucidating Jet Energy Loss Using Jets: Prospects from ATLAS"

6B: QCD Phase Plane III: Equation of State, Thermalization, Interferometry

1 4:30 PM *Kazuyuki Kanaya*
"Fixed Scale Approach to the Equation of State on the Lattice"

2 4:50 PM *Zoltan Fodor*
"QCD Transition Temperature: Approaching the Continuum on the Lattice"

3 5:10 PM *George Stephans*
"Centrality Dependence of Two-Particle Correlations in Heavy Ion Collisions"

4 5:30 PM *Monika Sharma*
"Measurements of Differential Transverse Momentum Correlation Function from the STAR Experiment"

5 5:50 PM *Clement Gombeaud*
"Does Interferometry Probe Thermalization?"

6 6:10 PM *Wojciech Florkowski*
"Describing Transverse Dynamics and Space-Time Evolution at RHIC with Hydrodynamic Models with Statistical Hadronization"

Conical Correlations, Bragg Peaks, and Transverse Flow Deflections in Jet Tomography

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New results since QM08 are presented on away side jet correlations [1] computed in a variety of (3+1)d hydrodynamic scenarios extending our work in Ref. [2] to include stopped jets, the effects of possible Bragg peak deposition as well as transverse background expansion. We also study the correlations associated with a pQCD-based source term [3] and discuss strategies for experimental falsification of models using tagged heavy quark jet tomography.

References

[1] H. Stöcker, Nucl. Phys. A **750** (2005) 121; F. Antinori and E. V. Shuryak, J. Phys. G **31**, L19 (2005); A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. C **78**, 014901 (2008); J. G. Ulery [STAR Collaboration], Nucl. Phys. A **783**, 511 (2007).

[2] B. Betz, M. Gyulassy, J. Noronha and G. Torrieri, arXiv:0807.4526 [hep-ph].

[3] R. B. Neufeld, B. Muller and J. Ruppert, Phys. Rev. C **78**, 041901 (2008).

Using Two and Three-Particle Correlations in PHENIX to Probe the Response of Strongly Interacting Partonic Matter to High-p_T Partons

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The properties of the high energy density matter created at RHIC can be probed by measuring how this matter responds to energy deposited by the passage of a hard-scattered parton. Several theoretical models for the interaction of a high-p_T parton with the medium have been proposed and angular correlations are a sensitive tool for the study of the medium response that is included in these models. Two-particle correlations at intermediate p_T show a distinct double peak structure on the away-side. Furthermore, correlations relative to the reaction plane reveal no large dependence of the away-side peak position on the collision geometry. This then suggests that the away-side peaks may reflect a property of the medium.

We will present three-particle correlations, correlations relative to the reaction plane, as well as two-particle correlations opposite a high p_T trigger particle. Taken together, these measurements provide a powerful test for models of the medium's response. We will utilize these data to infer properties of the partonic medium. A connection between the results and the larger emerging picture of heavy ion collisions at RHIC will also be made.

Conical Flow in Mesons and Baryons from Coalescence of a Perfect Quark Fluid

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We examine the two-particle azimuthal correlation signal resulting from a Mach cone in a perfect quark fluid hadronizing via quark coalescence.

We show that a Mach cone too weak to leave a "Conical" imprint on observable correlations in the "thermal" Cooper-Frye hadronization scenario (such as [1]) can nevertheless yield a conical signal if quarks coalesce into hadrons. The "Mach cone angle" in this scenario contains information about quark coalescence dynamics, rather than the equation of state.

We further show that, to test this scenario, the "Mach cone angle" of Baryon and meson associated particles needs to be compared [2].

References

[1] J. Noronha, M. Gyulassy, and G. Torrieri, arXiv:0807.1038 [hep-ph]; M. Gyulassy, J. Noronha, and G. Torrieri, arXiv:0807.2235 [hep-ph];

[2] V. Greco, C. M. Ko and P. Levai, Phys. Rev. C **68** (2003) 034904 [arXiv:nucl-th/0305024].

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The Sound Produced by a Fast Parton in the Quark-Gluon Plasma is a Long "Crescendo"!

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We calculate the total energy deposited into the medium per unit length by fast partons traversing a quark-gluon plasma. The medium excitation due to collisons is taken to be given by the well known expression for the collisional drag force. The radiative energy loss of the parton contributes to the energy deposition because each radiated gluon acts as an additional source of collisional energy loss in the medium. We derive a differential equaiton which governs how the spectrum of radiated gluons is modified when this energy loss is taken into account. This modified spectrum is then used to calculate the differential energy loss due to the interactions of radiated gluons with the medium. We find that the energy deposited into the medium is much less than the total radiative energy loss. The sum of the energy deposition by the primary parton and the secondary gluons is then treated as the coefficient of a local hydrodynamic source term. Numerical results are presented for the medium response for the case of two energetic back-to-back partons created in a hard interaction.

Measurements of High-p_T Probes in Heavy Ion Collisions at CMS

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In this talk we will describe the CMS capability for measuring high-p_T hadrons, photons and jets in heavy ion collisions. High-p_T processes have proven to be an important tool in investigating the hot, dense matter created in the collision of relativistic heavy ions. The large suppression observed for high-p_T hadronic yields in central heavy ion collisions relative to the binary scaling of $p + p$ collisions is evidence of large partonic energy loss in the medium.

At RHIC, the medium-induced energy loss is so large that it is difficult to discern the transport properties of the medium either from high-p_T spectra or from back-to-back hadron correlations. Because of the increased jet cross-section at the LHC, measurements of photon-jet or Z-jet correlations become possible. Since the photon (or Z) escapes from the medium with little interaction, it gives a calibrated probe of the original parton energy without the surface bias seen in dijet correlations. We will show detailed simulations of the CMS capability for the measurement of in-medium fragmentation functions using high-p_T photon-jet correlations.

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Elucidating Jet Energy Loss Using Jets: Prospects from ATLAS

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The details of jet energy loss, as measured at RHIC with single particles and multi-particle correlations, are unresolved, and new experimental measurements are necessary in order to shed light on the mechanism and behavior of energy loss. Utilizing the ATLAS electromagnetic and hadronic calorimetry, full jet reconstruction in a heavy ion environment will be performed over a wide range of p_T and rapidity. With fully reconstructed jets, new and more sensitive probes are available to test models of energy loss. In this talk, we present a series of observables such as the jet R_{AA}, the transverse momentum, j_T, spectrum of fragments, the fragmentation function $D(z)$, jet shapes, and di-jet correlations, that are sensitive to perturbative and non-perturbative energy loss. We also discuss the current level of sensitivity to expected modifications using several different jet algorithms, the cone, k_T, and anti-k_T algorithms.

Fixed Scale Approach to the Equation of State on the Lattice

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The QCD Equation of State with Wilson-type quarks is important to finalize the lattice calculation of the EOS. Our final goal is to study EOS with $2+1$ flavors of Wilson quarks based on the $T=0$ simulations by PACS-CS. To realize such calculations we propose a new method ("T-integration method"[1]) to calculate the EOS in lattice QCD.

In our method temperatures T are varied by N_t at fixed lattice spacings to minimize costly $T=0$ simulations. The idea is to introduce a new integration scheme for the pressure. From the data of $(e-3p)/T^4$, we calculate the pressure using a thermodynamic relation $(e-3p)/T^4 = Td(p/T^4)/dT$. Some advantages in our method are

(1) Zero temperature subtraction is performed using a common zero temperature calculation.

(2) The line of constant physics is trivially exact.

(3) Only the beta functions at the simulation point are required.
No further Karsch coefficients are necessary.

We test the T-integral method in quenched QCD on isotropic and anisotropic lattices. We find that our method is powerful to obtain reliable results for the equation of state especially at intermediate and low temperatures. Our method much reduces the computational cost of $T=0$ simulations, which is demanding in particular in full QCD simulations. We comment on the status of our study with dynamical quarks too.

References

[1] T. Umeda et al. (WHOT-QCD Collaboration), arXiv:0809.2842 [hep-lat].

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QCD Transition Temperature: Approaching the Continuum on the Lattice

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In order to clarify the source of the discrepancy between our previous transition temperature determination and that of the Bielefeld-Brookhaven-Columbia-Riken collaboration we improved our calculations by taking even smaller lattice spacings (12 in the temporal direction) and by using physical quark masses also for the T=0 quantities. Our previous findings were confirmed.

Centrality Dependence of Two-Particle Correlations in Heavy Ion Collisions

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The uniquely large coverage of the PHOBOS multiplicity detector allows the study of 2-particle angular correlations over a broad range of pseudorapidity and azimuthal angle. Data have been extracted for both inclusive charged particles and for events containing a high-p_T trigger particle in the PHOBOS spectrometer.

Projections of inclusive 2D correlations in relative azimuth ($\Delta\phi$) and pseudorapidity ($\Delta\eta$) onto 1D $\Delta\eta$ correlations have been interpreted in the context of a simple cluster model. Average cluster sizes and widths from Cu+Cu and Au+Au collisions are found to be similar for events with the same fractional cross-section. Cluster size results for peripheral heavy ion collisions are larger than those for p+p and initially change slowly with centrality before displaying a pronounced decrease towards very central events. The acceptance of $|\eta| < 3$ used in the current analysis results in smaller cluster parameters than would be found with a full acceptance measurement. Using several models, a correction has been extracted allowing an extrapolation of the results to full phase space.

For central Au+Au collisions, correlations using a $p_T > 2.5$ GeV/c trigger particle exhibit a near-side 'ridge' structure, extending to at least $\Delta\eta \approx 4$. The size of this ridge contribution diminishes in magnitude for more peripheral events and disappears completely, possibly as early as collisions with 80 participating nucleons.

This talk will present these and other aspects of the large acceptance PHOBOS correlation data, focusing in particular on centrality dependence and the possibility of evidence for the onset of modified behavior in heavy ion collisions.

Measurements of Differential Transverse Momentum Correlation Function from the STAR Experiment

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The event anisotropy measurements at RHIC suggest the strongly interacting matter created in heavy ion collisions flows with very little shear viscosity. Precise determination of "viscosity-to-entropy" ratio is currently a subject of extensive study [1]. We present measurements of differential transverse momentum correlation function from the STAR experiment in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. We compare two differential correlation functions, namely *inclusive* [2] and a differential version of the correlation measure $\tilde{C}$ introduced by Gavin/Abdel-Aziz [1, 3] for the experimental study of the shear viscosity per unit entropy of the matter produced in A+A collisions. We present measurements of correlation functions as a function of pseudo-rapidity and azimuthal angle in the range of $0.2 < p_T < 2.0$ GeV/c and $|\eta| < 1.0$ for various collision centralities. Our approach also provides a means to study features in the ridge region observed in two particle correlations.

References

[1] S. Gavin and M. Abdel-Aziz, Phys. Rev. Lett. **97** (2006) 162302.

[2] J. Adams *et al.* (STAR Collaboration), Phys. Rev. C **72** (2005) 044902.

[3] M. Sharma and C. A. Pruneau, arXiv:nucl-ex/0810.0716.

Does Interferometry Probe Thermalization?

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Hydrodynamical models have generally failed to describe interferometry radii measured at RHIC. In order to investigate this "HBT puzzle", we carry out a systematic study of HBT radii in ultrarelativistic heavy-ion collisions within a two-dimensional transport model. We compute the transverse radii R_o and R_s as a function of p_T for various values of the Knudsen number, which measures the degree of thermalization in the system.

In the case of central collisions, we show that the large difference between R_o and R_s, which is seen in hydrodynamical models but not in data (HBT puzzle), appears only for unrealistically small values of the Knudsen number. For realistic values of the Knudsen number [1], we obtain $R_o/R_s \simeq 1.2$, much closer to data than standard hydrodynamical results. The p_T dependence of R_o and R_s, which is usually said to reflect collective flow, also has a very limited sensitivity to the degree of thermalization.

The absolute magnitude of the radii are much smaller in our calculation than in data. We argue that this results from the stiffness of our equation of state (which is that of a perfect gas), and that the larger magnitude of measured radii is a clear signature that the number of degrees of freedom decreases (from quarks and gluons to pions) during the evolution of the system.

Finally, we study the azimuthal oscillations of R_o, R_s, and R_{os} for non central collisions. Their amplitudes depend very little on the Knudsen number. In particular, the azimuthal dependence of R_s is found to reflect the initial eccentricity of the overlap area.

References

[1] H. J. Drescher, A. Dumitru, C. Gombeaud and J. Y. Ollitrault, Phys. Rev. C **76**, 024905 (2007) [arXiv:0704.3553 [nucl-th]].

Describing Transverse Dynamics and Space-Time Evolution at RHIC with Hydrodynamic Models with Statistical Hadronization

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Hydrodynamic model coupled to statistical hadronization via Therminator has been used to study a diverse set of observables in the soft sector at RHIC. A satisfactory description of pt spectra and elliptic flow is obtained, similar to other hydrodynamic models. Transverse femtoscopic radii are also reproduced, providing a solution of the "RHIC HBT puzzle". STAR data for azimuthally sensitive HBT vs. the full dependence on transverse momentum and centrality, coupled to the elliptic flow data are a strict test of the transverse dynamics of any model. A unique study with our model shows good agreement with this data. Non-identical particle femtoscopy probes average emission point differences which are shown to be intimately related to collective transverse dynamics of the system. Model results are compared to RHIC data, again exhibiting consistency. Features of the model essential for the successful description of the transverse dynamics at RHIC are underlined. Based on the model parameters extrapolation, a complete set of predictions for the LHC heavy-ion collisions is given.

References

[1] W. Broniowski, M. Chojnacki, W. Florkowski and A. Kisiel, Phys. Rev. Lett. **101** 022301, 2008.

[2] M. Chojnacki, W. Florkowski, W. Broniowski and A. Kisiel, Phys. Rev. **C78** 014905, 2008.

[3] A. Kisiel, W. Broniowski, M. Chojnacki, W. Florkowski, Phys. Rev. **C79** 014902, 2009.

6C: Bulk Properties of the Medium V: Flavor Production and Correlations

1 4:30 PM *Pawel Staszel*
"Baryon-to-Meson Production in a Wide Range of Baryo-Chemical Potential at RHIC"

2 4:50 PM *Anthony Timmins*
"Strangeness Production in Heavy-Ion Collisions at STAR"

3 5:10 PM *Andrew Glenn*
"Recent HBT results in Au+Au and *p*+*p* collisions from PHENIX at RHIC"

4 5:30 PM *Patricia Fachini*
" ρ^0 Production in Cu+Cu Collisions at $\sqrt{s_{NN}}$ = 200 and 62.4 GeV in STAR"

5 5:50 PM *Hans Hjersing Dalsgaard*
"Baryon Stopping in Au+Au and *p*+*p* Collisions at 62 and 200 GeV"

6 6:10 PM *Xianglei Zhu*
"Strangeness Production and Cronin Effect in *d*+Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV in STAR"

6D: Open Heavy Flavor II

1 4:30 PM *Bertrand Biritz*
"Non-photonic Electron-Hadron Azimuthal Correlation for Au+Au, Cu+Cu and *p*+*p* Collisions at $\sqrt{s_{NN}}$ = 200 GeV"

2 4:50 PM *Tatia Engelmore*
"Heavy Flavor Production and Energy Loss with Two-Particle Correlations at RHIC-PHENIX"

3 5:10 PM *Rishi Sharma*
"A Light-Front Wave-Function Approach to Heavy Quark Fragmentation in the QGP"

4 5:30 PM *Ralf Rapp*
"Nonperturbative Heavy-Quark Transport in the Quark-Gluon Plasma"

5 5:50 PM *Yukinao Akamatsu*
"Langevin + Hydrodynamics Approach to Heavy Quark Propagation and Correlation in QGP"

6 6:10 PM *Spencer Klein*
"Muon Production in Ultra-Relativistic Cosmic Ray Interactions"

Baryon-to-Meson Production in a Wide Range of Baryo-Chemical Potential at RHIC

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The BRAHMS measurement of proton-to-pion ratios in Au+Au and p+p collisions at $\sqrt{s_{NN}} = 62.4$ GeV and $\sqrt{s_{NN}} = 200$ GeV will be presented as a function of transverse momentum and collision centrality within the pseudo-rapidity range $0 \leq \eta \leq 3.8$. We will focus on the pseudo-rapidity evolution of measured p/π^+ and $\bar{p}/\pi^-$ratios. The results for Au+Au at $\sqrt{s_{NN}} = 200$ GeV will be compared with predictions by models which incorporate hydro-dynamics, hadron rescattering and the jet production, in the covered η interval. The baryo-chemical potential, μ_B , for the indicated data spans from $\mu_B \approx 26$ MeV ($\sqrt{s_{NN}} = 200$ GeV, $\eta = 0$) to $\mu_B \approx 260$ MeV ($\sqrt{s_{NN}} = 62.4$ GeV, $\eta \approx 3$) [1]. In Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, $\eta \approx 2.2$, and at $\sqrt{s_{NN}} = 62.4$ GeV, $\eta = 0$, the bulk medium can be characterised by the common value of $\mu_B \approx 65$ MeV. The $p/\pi^+(p_T)$ ratios measured for these two selections display a striking agreement in the covered p_T range (up to 2.2 GeV/c). The p/π ratio measured for Au+Au system at $\sqrt{s_{NN}} = 62.4$ GeV, $\eta \approx 3$ reaches value of 8-10 at $p_T \geq 1.5$ GeV/c. For this low energy and pseudo-rapidity interval no centrality dependency of p/π ratio is observed. Moreover, the baryon-to-meson ratio of nucleus-nucleus data is consistent with results obtained for $p + p$ interactions at the same energy and rapidity.

References

[1] I.C. Arsene [for the BRAHMS Collaboration], IJMPE **16**, (2007) 2035.

Strangeness Production in Heavy-Ion Collisions at the STAR Experiment

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Although measurements of strangeness production in heavy-ion collisions were originally conceived to be the smoking gun of Quark Gluon Plasma formation [1], a complete theoretical description of strangeness enhancement at RHIC remains elusive. To this end, we carry out a comprehensive review of new measurements from Cu+Cu $\sqrt{s_{NN}} = 62$ GeV collisions and the latest measurements from Au+Au $\sqrt{s_{NN}} = 62$ GeV, Cu+Cu $\sqrt{s_{NN}} = 200$ GeV, and Au+Au $\sqrt{s_{NN}} = 200$ GeV collisions, and make detailed comparisons to the recent theoretical predictions. Specifically, we compare mid-rapidity K, Λ, $\bar{\Lambda}$, ϕ, Ξ, $\bar{\Xi}$, Ω, and $\bar{\Omega}$ integrated yields to predictions from the AMPT model [2] and core-corona models [3,4], and find key features of the data are reproduced. Where applicable, we extend these model comparisons to low-p_T to mid-p_T spectra and again find various aspects of the data are reproduced. Subsequent implications for QGP formation will be discussed.

References

[1] J. Rafelski and B. Müller, Phys. Rev. Lett. 48 (1982) 1066
[2] Z. Lin, C. Ming Ko, B. Li, B. Zhang, S. Pal, Phys.Rev. C72 (2005) 064901
[3] F. Becattini and J. Manninen, J. Phys. G 35 (2008) 104013
[4] K. Werner, Phys. Rev. Lett. 98 (2007) 152301

Recent HBT Results in Au+Au and $p+p$ Collisions from PHENIX at RHIC

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Measurements of the Hanbury-Brown Twiss effect for hadrons in relativistic heavy-ion collisions provide information on the source size and hadron emission duration, allowing a mapping of the freeze-out hyper-surface. Advancement of both HBT experimental analysis methods and hydrodynamic modeling must continue in order to extract precise information and resolve discrepancies between data and models. Femtoscopic techniques can also impact our understanding of arguably the most important effects observed at RHIC, i.e. the strong modification of jets by the produced Quark Gluon Plasma, and conversely, the feedback of the jet into the medium. The comparison of correlations from minimum bias data to those in the region of a triggered jet, similarly to measurements relative to the reaction plane, can lead to a deeper understanding of these effects.

In this vein, we will present the most recent results for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV as a function of mean transverse pair momenta and collision centrality. These results will include traditional 3D HBT radii and also 1D imaging analyses for kaon pairs. The status of the first HBT analysis for pions from $\sqrt{s} = 200$ GeV p+p collisions measured by the PHENIX collaboration will be presented. Implications for and modeling of jet triggered heavy ion collisions will be discussed.

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ρ^0 production in Cu+Cu collisions at $\sqrt{s_{NN}}$ = 200 and 62.4 GeV in STAR

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The study of the short-lived ρ^0 vector meson in relativistic heavy-ion collisions provides information on the properties of the hot and dense medium created in such collisions. The ρ^0 measured via its hadronic decay channel can be used as a sensitive tool to examine the collision dynamics in the hadronic medium through the rescattering and regeneration. In this talk, STAR mid-rapidity results of the ρ^0 mass, transverse momentum (p_T) spectra, and invariant yields in Cu+Cu collisions at $\sqrt{s_{NN}}$ = 200 GeV and 62.4 GeV will be presented. The 20-60% centrality in Cu+Cu collisions is selected for the optimal ρ^0 signal. The measurement of the event anisotropy v_2 of hadrons shows that the v_2 scales with the number of constituent quarks. It has been proposed that the measurement of the v_2 of resonances can distinguish whether the resonance was produced at hadronization via quark coalescence or later in the collision via hadron re-scattering. The ρ^0 v_2 results and its production mechanism will be discussed.

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Baryon Stopping in Au+Au and $p + p$ Collisions at 62 and 200 GeV

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BRAHMS has measured rapidity density distributions of protons and antiprotons in both $p + p$ and Au+Au collisions at 62 GeV and 200 GeV. From these, the yields of so- called 'net-protons', that is the difference between the proton and antiproton yields, can be determined. The net-proton distribution can be used together with model calculations to find the net-baryon yield and thus the amount of stopping in these collisions. This, then, allows us to extract information on baryon transport, as well as to calculate the total energy available for particle production.

This talk will present results, both preliminary and final, for $p + p$ and Au+Au at both beam energies. Furthermore results for several centralities of Au+Au collisions will be shown. It will be shown that net-protons exhibit longitudinal scaling after subtracting the 'projectile' contribution to the net baryon distribution. The differences between $p + p$ to Au+Au results will be discussed as will the possible implications of these results on expectations for LHC measurements.

Strangeness Production and Cronin Effect in d+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV in STAR

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Measurements of strange hadron production in d+Au collisions provide a crucial reference to separate the cold nuclear effects and those of deconfined matter on strangeness production in Au+Au collisions. In particular, we address two important physics topics: the strangeness enhancement from $p + p$, d+Au to A+A collisions; the particle-type dependence (baryon and meson grouping) of the nuclear modification factors from Au+Au collisions.

We will report collision centrality dependence of the transverse momentum spectra of strange hadrons (K_s^0, Λ, Ξ, Ω) in $\sqrt{s_{NN}} = 200$ GeV d+Au collisions, collected with the STAR detector at RHIC. The nuclear modification factor R_{CP} of these hadrons will be presented and compared with data from Au+Au collisions. Implications on particle production dynamics and Cronin effect will be discussed.

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Non-photonic Electron-Hadron Azimuthal Correlation for Au+Au, Cu+Cu, d+Au and $p+p$ Collisions at $\sqrt{s_{NN}} = 200$ GeV

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Data for di-hadron correlations in Au+Au and d+Au using the STAR detector show a suppression of high-p_T hadron yields and modifications in the azimuthal correlation in central Au+Au collisions. On the away-side of the trigger particles, the observed broadening in the correlations reflects the presence of strong jet-medium interactions, possibly a Mach cone effect. Non-photonic electron triggered particle correlations probe heavy quark jet-medium interactions. Electron-hadron (e-h) correlations on the near side, triggered by non-photonic electrons from charm and bottom decays, have different patterns due to the large mass difference between D and B mesons. Using e-h correlations from $p+p$ collisions in comparison with PYTHIA calculations, we can estimate the relative D and B contributions to the non-photonic electrons.

This talk will present preliminary STAR results of azimuthal correlations between non-photonic electrons and hadrons in Au+Au, Cu+Cu and $p+p$ at $\sqrt{s_{NN}} = 200$ GeV. Comparison of the e-h correlations from these colliding systems allows one to study the system-size dependence of heavy quark jet-medium interactions. We also report on the relative D and B contributions to non-photonic electrons extracted from correlations measured in $p+p$ collisions. Our results, when combined with R_{AA} measurements of non-photonic electrons, constrain the B and D energy loss in the dense medium.

Heavy Flavor Production and Energy Loss with Two-Particle Correlations at RHIC-PHENIX

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Heavy quarks are a valuable probe of the hot, dense medium created in a heavy ion collision, and are an important test of proposed mechanisms of energy loss. Originally, theoretical models for charm and beauty energy loss predicted small values of suppression in the medium compared to light quarks. However, single non-photonic electrons are suppressed at a similar level to light hadrons, implying a comparable level of energy loss between light and heavy partons. Because theory has had a difficult time explaining the level of heavy quark energy loss, it is crucial to better understand charm and bottom suppression. A measurement in $p + p$ is important because there are large uncertainties in the FONLL predictions of heavy quark yields; furthermore it serves as a baseline for heavy ion measurements. Correlated electron-muon pairs provide a clean measurement of heavy quark production in a rapidity range not yet studied. Modifications of the angular correlation between these pairs are sensitive to the amount of energy loss. A complementary measurement of electron-hadron correlations has also been made at PHENIX. These correlations are used to obtain bounds on the rate of charm versus bottom production, and they indicate heavy quark suppression.

Presented in this talk is a measurement of electron-muon azimuthal angular correlations in $p + p$ collisions. This provides a baseline for a heavy ion measurement, and can also be used to extract the charm cross section. We will discuss the strategy for making this measurement in Au+Au collisions, which will allow us to study the mechanisms of heavy flavor energy loss. In addition to this measurement, electron-hadron correlation studies in $p + p$ and Au+Au will be reviewed.

A Light-Front Wave-Function Approach to Heavy Quark Fragmentation in the QGP

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The early production of heavy quarks makes them some of the most important probes of the QGP formed in relativistic heavy ion collisions. Precise and direct measurements of the differential distributions and multiplicities of charm and beauty hadrons will soon become available with the vertex detector upgrades at RHIC, and at the LHC. This will allow to quantitatively address the key observable in heavy ion physics - the apparent modification of particle production by energetic jets traversing a region of hot and dense nuclear matter.

Extensive studies have focused so far exclusively, with varying degree of sophistication, on the kinematic re-distribution of the leading parton or particle energy via radiative and collisional energy loss and, more recently, via meson dissociation in the QGP. It is, therefore, surprising that to date there are no theoretical calculations of the modification of the fragmentation functions themselves. We start by introducing the formalism of light-front quantization and light-front wave-functions to rigorously define the quark and gluon decay probabilities. Next, we discuss medium size-independent corrections to parton fragmentation when it occurs in the background of a thermal QCD medium. We give explicit examples for the charm and beauty mesons that are much more accurately described by the lowest-lying states in the Fock decomposition of their wave-function than light hadrons. Our theoretical results are incorporated in a QCD-based model of heavy quark/meson production and propagation in the QGP. Detailed numerical simulations of the experimentally observable cross sections at center of mass energies of 200 GeV and 5.5 TeV in Au+Au and Pb+Pb collisions at RHIC and the LHC, respectively, are presented. We conclude by identifying the relative importance of the above described competing QGP effects as a function of the charm and beauty transverse momentum.

References

[1] R. Sharma and I. Vitev, in preparation.

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Nonperturbative Heavy-Quark Transport in the Quark-Gluon Plasma

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We evaluate charm- and bottom-quark diffusion in the Quark-Gluon Plasma (QGP) based on a T-matrix approach for elastic heavy-quark (HQ) scattering off light partons in the medium [1]. The key ingredient are interaction potentials extracted from the HQ free energy computed in thermal lattice QCD. For the potentials we employ both the internal energy as well as a (nonlinear) combination of internal and free energies controlled by the thermal relaxation time of the heavy quark [2]. The resulting T-matrices are applied to compute HQ selfenergies, transport coefficients and observables at RHIC. The relative strengths of c- and b-quark modifications are discussed. We finally attempt to reconcile existing approaches to HQ diffusion (both perturbative and nonperturbative) by identifying their common grounds.

References

[1] H. van Hees, M. Mannarelli, V. Greco and R. Rapp, Phys. Rev. Lett. **100** (2008) 192301.

[2] F. Riek and R. Rapp, in preparation.

Langevin + Hydrodynamics Approach to Heavy Quark Propagation and Correlation in QGP

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We developed a relativistic Langevin dynamics under the background of strongly interacting quark-gluon fluid described by the (3+1)-dim. hydrodynamics [1]. The drag force acting on charm and bottom quarks is parametrized according to the formula obtained from AdS/CFT correspondence [2].

In this setup, we calculate the nuclear modification factor R_{AA} for the single electrons from the charm and bottom quarks to extract the magnitude of the drag force from the PHENIX and STAR data [2,3]. The R_{AA} for electrons with $p_T \geq 3$ GeV indicates that the drag force is much stronger than the pQCD prediction and is rather close to the AdS/CFT prediction. Effect of the drag force to the elliptic flow of single electrons will be also discussed.

Moreover, we will report our prediction of the electron-hadron correlation which is closely related to the heavy-quark correlation in matter and is planned to be measured.

References

[1] Y. Akamatsu, T. Hatsuda and T. Hirano, arXiv:0809.1499 [hep-ph].

[2] C.P. Herzog *et al.*, JHEP **07**, (2006) 013;
S.S. Gubser, Phys. Rev. **D74**, (2006) 126005;
J. Casalderrey-Solana and D. Teaney, Phys. Rev. **D74**, (2006) 085012.

[3] A. Adare *et al.* (PHENIX Collaboration). Phys. Rev. Lett. **98**, (2007) 172301;
B.I. Abelev *et al.* (STAR Collaboration). Phys. Rev. Lett. **98**, (2007) 192301.

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Muon Production in Ultra-Relativistic Cosmic Ray Interactions

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Cosmic-rays with energies up to 3×10^{20} eV have been observed The nuclear composition of these cosmic rays is unknown but if the incident nuclei are protons then the corresponding center of mass energy is $\sqrt{s_{NN}} = 700$ TeV. Many measurements have been made of the characteristics of cosmic-ray air shower collisions. The energy spectra of high-energy (> 1 TeV) cosmic ray induced muons have previously been measured with detectors that are deep underground or are buried in Antarctic ice. These muons come from pion and kaon decays and from charm production in the atmosphere. These sources may be differentiated by their energy spectra.

Ground-based experiments are most sensitive to far-forward muons so the production rates are sensitive to high-x partons in the incident nucleus and low-x partons in the nitrogen/oxygen targets. In this talk, I will review muon production data from previous experiments, and discuss some non-perturbative (soft) models that have been used to interpret cosmic-ray data, and the effect of phenomena like nuclear shadowing and strangeness enhancement on the rates. I will also discuss some questions of special interest to cosmic-ray physicists that can be probed at RHIC and the LHC. Finally, I will show measurements of TeV muon transverse momentum spectra in cosmic-ray air showers from MACRO, and describe how the IceCube neutrino observatory and the proposed Km3Net detector will extend these measurements to a higher p_T region, where perturbative QCD controls the muon production. With a 1 km^2 surface array and an equally sized muon detector, the full IceCube detector should observe several thousand muons/year with $p_T > 3$ GeV/c.