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Measurement of Non-flow Correlations and Elliptic Flow Fluctuations in Au+Au Collisions at RHIC

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We present the first quantitative determination of the contribution of non-flow effects to the elliptic flow fluctuations in 200 GeV Au+Au collisions reported by PHOBOS [1]. In a hydrodynamical scenario, fluctuations in the shape of the initial collision region would naturally lead to corresponding fluctuations in the elliptic flow signal. Measurements of elliptic flow fluctuations can therefore shed light on the connection between observed flow, the initial geometry and the hydrodynamic evolution of the system. However, non-flow correlations can lead to a broadening of the observed event-by-event v_2 distribution and thereby modify the observed v_2 fluctuation signal.
We have developed a new analysis procedure to quantify the contribution of non-flow correlations to the v_2 signal. This analysis crucially relies on the large pseudorapidity coverage of the PHOBOS multiplicity array. The flow signal is disentangled from the non-flow contributions, quantified using δ defined in [2], by a systematic study of the v_2 magnitude extracted from two particle correlations at different rapidity gaps.

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Some Evidences of Multiple Particle Sources from Nuclear Matter Jets in He+A_T Collisions at Relativistic Energies

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Abstract: In a few previous works we analyzed the competition between different particle production mechanisms in nucleus–nucleus collisions at 4,5 A GeV/c, like: hydrodynamic models, thermodynamic models and cumulative production [1-5]. We used some specific tensors of the global analysis (flow tensor, thrust tensor, sphericity tensor, etc.) in a Greiner–Stöcker formalism [6] and the jet analysis [2]. We found hydrodynamic specific effects (the bounce-off of the projectile and target spectator fragments and the squeeze–out or the splash–out of participant matter), as well as jets of nuclear matter. Searching for intersting variables which contains information about the compression stage of a relativistic nucleus-nucleus

collision the concept of "nuclear matter jets" is an interesting tool for selecting different event structures as: single-jet events, two-jet events, three-jet events, and non-jet events. We found a relation between the number of jets and the centrality of the collision, and then we observed an increased sideway peaking of the emitted particles and fragments in central collisions. The analysis of the jet properties allowed us to make assumptions about their origin. The cumulative particles enclosed into the jets can offer information about the quark-gluonic degrees of freedom in the He+A_T analyzed collisions at 4.5 GeV/c. The founded jets in these interactions have a hadronic origin and not a partonic one.

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Correlation radii and elliptic flow from the fast hadron freeze-out generator - FASTMC

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One of the most spectacular features of the RHIC data, known as the "RHIC puzzle", is the impossibility to describe simultaneously momentum-space measurements and the freeze-out configuration-space information from femtoscopic correlation measurements by the existing hydrodynamic and cascade models or their hybrids. We analyze the RHIC data at $\sqrt{s}_{NN}=$ 200 GeV within our fast hadron freeze-out MC generator (FASTMC) [1,2] using the same set of model parameters for the description of both the momentum-space observables, i.e. transverse mass (m_t) spectra and p_t-dependence of elliptic flow, and the observables related to space-time freeze-out structure, i.e. k_t-dependence and azimuthal angle (Φ) dependence of the correlation radii. The chemical composition of the fireball was fixed by the particle ratios analysis. In FASTMC, particle multiplicities are calculated at the chemical freeze-out. Particles and hadronic resonances are generated on the thermal freeze-out hypersurface, the hadronic composition at this stage being defined by the parameters of the system at chemical freeze-out. Fixing the temperatures of the chemical and thermal freeze-out at 0.165 GeV and 0.100 GeV respectively, and using the same set of model parameters as for the central collisions, we have described the single particle spectra at different centralities with an accuracy of $\sim 13\%$. The comparison of the RHIC v_2 measurements with our MC generation results shows that the scenario with two separated freeze-outs describes better the p_t-dependence of the elliptic flow. The description of the k_t-dependence of the correlation radii has been achieved within $\sim 10\%$ accuracy. The experimentally observed values of the correlation strength parameter λ have been reproduced due to the account of the weak decays. The achieved good simultaneous description of particle spectra, elliptic flow and femtoscopic correlations within the considered model could be useful for a better understanding of the dynamical picture of the matter evolution in A+A collisions.

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ASPECTS OF CAUSAL VISCOUS HYDRODYNAMICS

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We investigate the phenomenology of freely expanding fluids, with different material properties, evolving through the Israel-Stewart (IS) causal viscous hydrodynamics, and compare our results with those obtained in the relativistic Eckart-Landau-Navier-Stokes (ELNS) acausal viscous hydrodynamics. We consider the following three models of the viscous fluid:

• Simple fluid: material properties namely, the coefficient of shear viscosity (η_V), the corresponding relaxation time (τ_π), and the speed of sound (c_s) are assumed to be temeprature (T)-independent.

• Boltzmann fluid (massless Boltzmann gas): η_V and τ_π depend on T, so does the energy density ϵ, but $\epsilon\tau_\pi/\eta_V = 9/2$, if $c_s^2 = 1/3$.

• Conformal fluids: $\eta_V/s = 1/4\pi$, $\tau_\pi = a/T$, where s is the entropy density and a a dimensionless positive constant. Hence $\epsilon\tau_\pi/\eta_V = 3\pi a$, if $c_s^2 = 1/3$.

In each case, we first construct the solutions for one-dimensional boost-invariant flows, and then study fluctuations about these boost-invariant backgrounds.

We find that the estimates of initial energy densities from observed final values are strongly dependent on the dynamics one chooses. For the same material, and the same final state, IS hydrodynamics gives the smallest initial energy density. In other words, Bjorken hydrodynamics and ELNS hydrodynamics significantly overestimate the initial energy density.

In each of the above cases, we study the evolution of the total entropy. Expansion of viscous fluids is slower than that of one-dimensional ideal fluids, resulting in entropy production. At late times, scaling solutions in the IS hydrodynamics are reasonably well approximated by those in the ELNS hydrodynamics.

The fluctuations are damped in ELNS hydrodynamics but can become sound waves in IS hydrodynamics. The difference is obvious in power spectra due to clear signals of wave-interference in IS hydrodynamics, which is completely absent in ELNS hydrodynamics.

In nonrelativistic fluid dynamics, one has the Knudsen number, the Mach number, and the Reynolds number. We present relativistic analogues of these dimensionless numbers and the law of similarity. In ideal hydrodynamics, thermalization and freezeout are notions which are imposed from the outside. Through the analysis of scaling invariants we give a definition of thermalization time which can be self-consistently determined in viscous hydrodynamics.

Flow measurements at RHIC: An evaluation of the different techniques and the influence of non-flow effects

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The measurements of strong azimuthal correlations in produced charged hadrons were among the first significant results from collisions of ultrarelativistic heavy ions at RHIC. The elliptic flow, or v_2, is the second coefficient of a Fourier decomposition of the particle distribution with respect to the reaction plane. The PHOBOS collaboration has utilized the unique angular coverage of the PHOBOS detector to extract v_2 values over the full range of collision energies for the Au+Au and Cu+Cu systems, as a function of pseudorapidity, centrality (N_{part}) and transverse momentum. The extraction of a value for v_2 can be influenced by both instrumental limitations and physical properties of the interacting system. The PHOBOS detection system allows flow values to be derived from two sub-detectors: the octagon and the spectrometer. This talk will highlight how the techniques used to extract the flow can impact the strength of the resultant signal. Comparisons will be made to methods used by STAR and PHENIX to evaluate the influence of non-flow effects on the v_2 values obtained.

FAR-FROM-EQUILIBRIUM ANISOTROPIC COLLECTIVE FLOW

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Novel analytical results for the anisotropic collective flow of particles with a low interaction cross-section are presented, in particular for the second and fourth harmonics v_2 and v_4. Tentative examples of relevance for the heavy-ion programs at RHIC or at the LHC will be explored.

Eccentricity fluctuations in Glauber models

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Measures of the azimuthal asymmetry, in particular the *participant* harmonic moments, ε^*, are analyzed [1] in a variety of Glauber-like models for the early stage of collisions at RHIC. For all considered models the values of $\sigma(\varepsilon^*)/\varepsilon^*$ range from ~ 0.5 for the central collisions to ~ 0.3-0.4 for peripheral collisions. These values are dominated by statistics and change only by 10-15% from model to model. For central collisions the central limit theorem yields the simple analytic formula $\sigma(\varepsilon^*)/\varepsilon^*(b=0) \simeq \sqrt{4/\pi - 1} \simeq 0.52$, independent on the collision energy, mass number, or the number of sources. In consequence, with smooth hydrodynamics at *central* collisions $\sigma(v_2)/v_2(b=0) \simeq \sqrt{4/\pi - 1}$. We show, that the same value is achieved also at *peripheral* collisions, as long as the particles come from a number of independent *pp* collisions. We investigate the shape-fluctuation effects on jet quenching and find that they are relevant only for very central events.

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Elliptic flow without using hydrodynamics

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The elliptic flow v_2 for pion, proton and kaon etc is reconsidered within the framework of the quark recombination model, without using hydrodynamics. It is found that the ridge is responsible for the increase of v_2 at small p_T, while for large p_T v_2 comes from the azimuthal dependence of the energy loss. The property of ridge is sensitive to the initial configuration, but does not require early thermalization. The centrality dependence of v_2 can be explained naturally from colliding geometry and jet quenching. No free parameters are introduced.
A partonic elliptic flow can be defined and calculated. This partonic v_2 can be compared with that of pion, proton, etc., to test the constituent quark number scaling. Reasons for small deviation of v_2 from that scaling are given.

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Various aspects of exact accelerating hydrodynamical solutions

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Collective properties of particles produced in relativistic high-energy collisions are well understood in terms of models based on hydrodynamics. A hot topic is how to determine the viscosity of this new form of matter. Exact (or parametric) solution of these equations make the connection between initial and final state transparent. We present exact, analytic and accelerating solutions of relativistic perfect fluid hydrodynamics. Found more than 50 years after the previous similar result (the Landau-Khalatnikov solution), these new solutions have a simple form, that also generalizes the renowned Hwa-Bjorken solution. We present exact solutions of nonrelativistic viscous hydrodynamics as well. Both the Navier-Stokes equations and the relativistic equations of perfect fluid dynamics are extremely nonlinear, thus every new exact result deepens our understanding on the nature of them. These new solutions lead to an advanced estimate of the initial energy density and life-time of high energy heavy ion reactions. We will also show that scaling properties of final state observables based on perfect fluid hydrodynamics are retained even if dissipation effects become relevant.

Simulating elliptic flow with viscous hydrodynamics

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In this talk we discuss the recent work [1] on the simulation of a viscous hydrodynamical model of non-central Au-Au collisions in 2+1 dimensions, assuming longitudinal boost invariance. The hydrodynamical model is based off the work of [2] and the model fluid equations with viscosity were proposed by Öttinger and Grmela [3]. Freezeout is signaled when the viscous corrections become large relative to the ideal terms. Then viscous corrections to the transverse momentum and differential elliptic flow spectra are calculated. When viscous corrections to the thermal distribution function are not included, the effects of viscosity on elliptic flow are modest. However, when these corrections are included, the elliptic flow is strongly modified at large p_T. We also investigate the stability of the viscous results by comparing the non-ideal components of the stress tensor (π^{ij}) and their influence on the v_2 spectrum to the expectation of the Navier-Stokes equations ($\pi^{ij} = -\eta\langle\partial_i u_j\rangle$). We argue that when the stress tensor deviates from the Navier-Stokes form the dissipative corrections to spectra are too large for a hydrodynamic description to be reliable. For typical RHIC initial conditions this happens for $\eta/s \leq 0.3$.

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v_2 measurement using the CMS Detector

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The azimuthal anisotropy of charged particles in heavy ion collisions is an important probe of quark-gluon plasma evolution at early stages. The nuclear reaction plane can be determined independently by different detector subsystems and using different analysis methods. This talk addresses the capability of the CMS detector at the LHC to reconstruct the reaction plane and to measure elliptic flow with calorimetry and tracking systems. The analysis is based on a full CMS detector simulation of Pb+Pb events with the HYDJET event generator. It is shown that at central rapidities ($|\eta| < 2.5$) CMS will be able to determine the reaction plane for a very wide range of particle multiplicities and elliptic flow magnitudes, using the calorimeters and the tracker. The transverse momentum and rapidity dependencies of the elliptic flow coefficient v_2 can be reconstructed in the CMS Tracker with high accuracy using the event plane as well as the cumulant methods. The estimated systematic error of the v_2 determination due to CMS track reconstruction performance is about 3%. Additional cross-checks reconstructing event plane with CMS calorimetry will be useful. The CMS electromagnetic calorimeter is found to be more suitable than the hadron calorimeter for event plane determination. Using the endcaps for the event plane reconstruction and reconstructing the jets in the barrel should provide a more robust analysis of elliptic flow.

EARLY EVOLUTION OF ENERGY DENSITY, PRESSURE AND FLOW IN HIGH ENERGY HEAVY ION COLLISONS

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Experimental results from the Relativistic Heavy Ion Collider (RHIC) indicate a rapid thermalization of partonic matter after a relatively short time of less than 1 fm/c, and a subsequent hydrodynamic expansion of the system consistent with the behavior of a perfect fluid. Here, we discuss the early time evolution of a high energy heavy ion collision — from the initial overlap of the nuclei up to the time of thermalization — by describing the time dependence of the energy momentum tensor.
Immediately after the collision, a strong longitudinal gluon field emerges from the original color glass state in the two nuclei. It is complemented by jets from hard processes. A quantitative description of the energy and momentum of the system requires a careful matching between both the field and particle components. The gluon field leads to an initial longitudinal pressure which is large and negative. Rapid decoherence of the field on the time scale $\sim 1/Q_s$ allows for a relaxation of this pressure anisotropy towards equilibrium.
For the picture outlined above we derive the time evolution of the energy density and the pressure. We also point out the emergence of radial and elliptic flow in the pre-equilibrium phase with possible consequences for the future interpretation of flow data from RHIC and LHC. A matching to a further hydrodynamic evolution after thermalization, which is consistent with energy and momentum conservation, is discussed as well.

NeXSPheRIO results on elliptic flow and direct flow for Au+Au and Cu+Cu collisions at RHIC

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Hydrodynamics has been rather successful at describing results obtained in relativistic nuclear collisions at RHIC. Here we show results obtained with the code developed by our group, NeXSPheRIO [1,2]. These results concern Au+Au and the less studied Cu+Cu collisions. We study elliptic flow and its connection with eccentricity comparing with Phobos conclusion on the importance of the participant eccentricity (QM05 and QM06). We also present results for directed flow, discuss its physical origin and compare with Phobos and Star data, in particular on the observed similariry of Au+Au and Cu+Cu (QM06).

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Recents Results on Elliptic Flow and Fluctuations in High-Energy

Nuclear Collisions using NeXSPheRIO Code

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Using the NexSPheRIO code, we study the effect of the initial condition fluctuations on the elliptic flow in Au+Au collisions at 200 A GeV. We show that, by fixing the parameters of the model to correctly reproduce the charged pseudo-rapidity and the transverse-momentum distributions, reasonable agreement of $< v_2 >$ with data is obtained both as function of pseudo-rapidity as well as of transverse momentum. In particular, our results on elliptic flow fluctuations are in good agreement with the recently measured data on experiments [1,2]. The role of the granular structure of the initial conditions is stressed.

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CAUSAL RELATIVISTIC HYDRODYNAMICS FOR VISCOUS FLUIDS

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We compute the differential elliptic flow $v_2(p_T)$ of pions, kaons and protons in non-central relativistic heavy-ion collisions, using a (2+1)-dimensional code with longitudinal boost-invariance to simulate viscous fluid dynamics in the causal Israel-Stewart formulation [1]. We explore the effects of shear viscosity on the time evolution of the spatial eccentricity and momentum anisotropy of the collision fireball, on the final hadron spectra, and on their elliptic flow, using two different equations of state and two sets of initial conditions. We show that even "minimal" shear viscosity $\eta/s = \hbar/(4\pi)$ leads to a large reduction of elliptic flow compared to ideal fluid dynamics, raising questions about the interpretation of recent

experimental data from the Relativistic Heavy Ion Collider [2]. We also explore the validity of v_2/ϵ_x scaling with the transverse areal density $(1/S)(dN_{\rm ch}/dy)$, in both ideal and viscous hydrodynamics, by studying Cu+Cu and Au+Au collisions at a variety of impact parameters and collision energies [3].

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HADRONIC DISSIPATIVE EFFECTS ON TRANSVERSE DYNAMICS AT RHIC

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We simulate the dynamics of Au+Au collisions at the Relativistic Heavy Ion Collider (RHIC) with a hybrid model that treats the dense early quark-gluon plasma (QGP) stage macroscopically as an ideal fluid, but models the dilute late hadron resonance gas (HG) microscopically using a hadronic cascade. By comparing with a pure hydrodynamic approach we identify effects of hadronic viscosity on the transverse momentum spectra and differential elliptic flow $v_2(p_T)$. We investigate the dynamical origins of the observed mass-ordering of $v_2(p_T)$ for identified hadrons, focusing on dissipative effects during the late hadronic stage. We find that, at RHIC energies, much of the finally observed mass-splitting is generated during the hadronic stage, due to build-up of additional radial flow. The ϕ meson, having a small interaction cross section, does not fully participate in this additional flow. As a result, it violates the mass-ordering pattern for $v_2(p_T)$ that is observed for other hadron species. We also show that the early decoupling of the ϕ meson from the hadronic rescattering dynamics leads to interesting and unambiguous features in the p_T-dependence of the nuclear suppression factor R_{AA} and of the ϕ/p ratio.

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ELLIPTIC FLOW FROM VISCOUS HYDRODYNAMICS AND TRANSPORT

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Relativistic viscous hydrodynamics provides a method to estimate how large viscosity the elliptic flow data at RHIC allows. However, the question remains whether viscous hydrodynamics is applicable at RHIC or whether dissipative corrections are too large.
We calculate the elliptic flow in non-central collisions using Israel-Stewart hydrodynamics and compare those results to covariant parton transport calculations. We show when and how the difference builds up and whether viscous hydrodynamics can be considered applicable at RHIC.

System size and beam energy dependence of azimuthal anisotropy from PHENIX

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The azimuthal anisotropy in particle emission provides a unique tool to probe the dynamics of the hot and dense matter produced in relativistic heavy ion collisions. Previous PHENIX analyses of the azimuthal anisotropy in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV have revealed striking scaling properties, most notably with respect to the transverse kinetic energy ($\mathrm{KE_T}$) of particles. The extension of these studies to the Au+Au and Cu+Cu systems at different beam energies is crucial to help characterize the partonic fluid formed at RHIC. Detailed azimuthal anisotropy measurements in Au+Au and Cu+Cu collisions at center-of-mass energies in the range 62.4 - 200 GeV will be studied as a function of p_T, $\mathrm{KE_T}$, centrality and η and the results will be discussed in the context of thermalization and coalescence. The study of the influence of non-flow effects in the different systems is important in order to ascertain the accuracy of the azimuthal anisotropy measurements. This can be done by using

different methods which have different sensitivities to non-flow effects. Comparisons between the azimuthal anisotropy in Au+Au and Cu+Cu collisions, obtained from the reaction plane and cumulant methods of flow measurement, will be presented as a function of p_T up to 10 GeV/c. The relative importance of non-flow correlations will be discussed for different colliding systems and centralities.

QCD THERMODYNAMICS AND HYDRODYNAMICS

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The two-loop Φ-functional approach to hot QCD, supplemented by an effective coupling, results in a quasi-particle model [1] which accounts for a large number of thermodynamic quantities: equation of state at $\mu = 0$ and Taylor expansion coefficients thereof in both real and imaginary μ directions, various diagonal and off-diagonal susceptibilities as well as flavor and quark mass dependencies. Critical point properties can be addressed additionally [2]. These quantities compare astonishingly well with available lattice QCD data. An accordingly useable equation of state is employed in hydrodynamical calculations of $p_\perp$ spectra and differential azimuthal anisotropy v_2 for RHIC and LHC conditions [3] and extended towards large baryon density effects being important for SPS and FAIR.

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Universal centrality and collision-energy trends for elliptic flow from two-dimensional angular correlations at STAR

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We have measured the p_t-integrated quadrupole component of two-particle azimuth correlations (which is related to elliptic flow measure v_2, denoted in this case by $v_2\{2D\}$) via two-dimensional (2D) autocorrelations on (η,ϕ) for unidentified hadrons in Au-Au collisions at 62 and 200 GeV. The 2D autocorrelation provides a method to distinguish flow from nonflow contributions to v_2 under the assumption that most non-flow processes produce significant dependence on pair-wise relative eta within the acceptance [1]. We hypothesize that nonflow contributions to v_2 are dominated by minijets or minimum-bias jets. Using the optical Glauber eccentricity as a preferred model for initial-state geometry we find simple and accurate universal energy and centrality trends for the quadrupole component. Centrality trends are determined only by the initial collision geometry (impact parameter or n_{binary}). The observed energy trend (linear with $\log \sqrt{s}$) is the same as observed for mean-p_t fluctuations and correlations. There is no apparent dependence on evolving system dynamics (e.g., equation of state or number of secondary collisions). Our results also have implications for conventional flow (v_2) measurements. Observed systematic differences between $v_2\{2\}$ or $v_2\{4\}$ and $v_2\{2D\}$ correspond to measured properties of minijets and provide a small upper limit on v_2 fluctuations (v_2 fluctuations are now consistent with zero). Any measurement of flow fluctuations would require understanding minijet correlations at the same level of accuracy.

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Quasi-Particle Degrees of Freedom versus the Perfect Fluid as Descriptors of the Quark-Gluon Plasma

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Approaches for understanding the hydrodynamic flow of the hot and dense medium created in the collisions of relativistic heavy ions are discussed, focusing on their implications on scenarios where quasi-particles are assumed to carry the thermodynamic degrees of freedom. Well-defined quasi-particle degrees of freedom are in principle inconsistent with inviscid hydrodynamics, which implies a vanishing mean free path. However, quasi-particles may play a role as the density of the medium decreases. It is thus an open question whether the freeze-out of the fluid stage proceeds directly into hadrons, or via a fleeting intermediate state with effectively-free constituent quarks, which may well be identified with QCD quasi-particle degrees of freedom. The empirical observation of the "n_q" scaling of elliptic flow [1] (the universality of v_2/n_q as a function of $(m_T - m)/n_q$, where n_q is the number of constituent quarks in the hadron) is scrutinized in detail. It is found that, at all transverse momenta, the data favors n_q scaling over hydrodynamic calculations followed by Cooper-Frye hadronization. The influence of resonance decays are found to be sub-dominant in the inclusive identified spectra. It is argued that the observation of quark scaling in the final state by no means implies a strong role for those degrees of freedom in the early stages of the interaction, when the flow develops. This point is emphasized by noting similar scaling laws for hadron transport models, as well as light nuclei formed by coalescence.

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Current Status and Further Improvements of A Multi-Phase Transport (AMPT) Model

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The AMPT model is a multi-phase transport model that was constructed specifically for the study of the quark-gluon plasma created in high energy heavy ion collisions, as it contains an explicit partonic phase and descriptions of the bulk hadronization of a partonic matter into a hadronic matter. The model also includes initial conditions for the partonic phase and a later hadronic phase. The current versions of the AMPT model [1] are available at http://nt3.phys.columbia.edu/OSCAR/models/list.html#AMPT . The model has been used to study many aspects of heavy ion collisions including the elliptic flow [2,3] and two-meson interferometry [4] at RHIC. The current status of the AMPT model will be reviewed.

Further improvements of the AMPT model will then be discussed. For heavy ion collisions at the upcoming LHC, parton distribution functions at small-x ($x \sim 0.001$) in the heavy nuclei become very important. However, the current AMPT model uses old parton distribution functions [5] implemented in the HIJING model [6], therefore predictions from the AMPT model at LHC energies have large uncertainties. Furthermore, the bulk hadronization in the AMPT model is being described by a simple parton coalescence after all scatterings in the parton cascade are over. As a result, the average parton density at which partons hadronize depends on the parton scattering cross section σ_p. Therefore predictions from the AMPT model not only include the (physical) effect of σ_p on the partonic dynamics, they also include the (mostly unphysical) effect of σ_p on the hadronization process that may be important for certain observables. A recent study on the AMPT model [7] shows that the equations of state indeed depend on the parton cross section and are quite different from that calculated using the lattice QCD methods. The AMPT model thus needs to be improved with up-to-date parton distribution functions for heavy nuclei, and the bulk hadronization needs to be improved in order to have a more realistic equation of state, which will consequently affect the space-time evolution of the dense matter in the AMPT model and its predictions for heavy ion collisions at RHIC and LHC.

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v_2 FLUCTUATION IN HIGH-ENERGY NUCLEAR COLLISIONS

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Elliptic flow has been proven to be sensitive to early dynamics in high-energy nuclear collisions. At RHIC, the measurements of v2 have demonstrated the hot and dense matter with partonic collectivity [1]. The fluctuations of v2 reflect both the initial variation of the eccentricity, caused by the quantum nature of the elementary collisions, and the dynamic evolution of the system. It is a promising observable that will provide crucial information on early thermalization in high-energy nuclear collisions.
In order to understand the recent experimental results from PHOBOS [2] and STAR [3], we carried out a systematic model (AMPT [4]) study of the v2 fluctuation in 200 GeV Au+Au collisions at RHIC. The dependence on collision centrality, rapidity, and transverse momentum are analyzed. The results show that the initial geometrical fluctuation dominants the relative fluctuation $\frac{<v_2>}{\sigma_{v_2}}$. The increasing of the partonic interactions leads to stronger collective flow v2 and reduce the fluctuation due to thermalization.

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DISSIPATIVE OR JUST NONEXTENSIVE HYDRODYNAMICS?
- Nonextensive/Dissipative correspondence -

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The hydrodynamical models are at present widely used to describe the high energy multiparticle production processes and therefore they are subject to constant theoretical scrutiny and development. We would like to present results of our investigations in this field. In particular we would like to present a nonextensive version of hydrodynamical model for multiparticle production processes we have recently proposed [1]. It is based on the nonextensive statistics assumed in the form proposed by Tsallis and characterized by a nonextensivity parameter q. In this formulation the parameter q characterizes some specific form of local equilibrium, which is characteristic for the nonextensive thermodynamics and which replaces the usual local thermal equilibrium assumption of the usual hydrodynamical models. It accounts in a natural way for some intrinsic fluctuations possibly existing in the hadronizing system and/or for all possible long range correlations and memory effects usually not accounted for when using the usual formulation. In its new form our model resembles, in its ideal fluid version, a nonextensive perfect fluid. In particular, in this formulation we have that

$$\mathcal{T}^{\mu\nu}_{q;\mu} = \left[\varepsilon_q(T_q)u^\mu_q u^\nu_q - P_q\Delta^{\mu\nu}_q\right]_{;\mu} = 0, \tag{1}$$

with ε_q, P_q and u^μ_q being the respective q-modified energy density, pressure and flow vector, whereas $\Delta u^\mu_q \equiv u^\mu_q - u^\mu$ with flow field u^μ correspondsing to $q = 1$. Using now relations (T and T_q are, respectively, temperature and its q equivalent) $\varepsilon(T) = \varepsilon_q(T_q) + 3\Pi$ and $P(T) = P_q(T_q)$ (with $\Pi \equiv \frac{1}{3}(\varepsilon_q + P_q)[x^2 + x]$ where $x \equiv u^\mu_q u_\mu$) one gets the standard form of dissipative hydrodynamic equation (here $W^\mu = (g^{\mu\alpha} - u^\mu u^\alpha)\,\mathcal{T}_{q\ \alpha\beta}u^\beta$),

$$\left[\varepsilon(T)u^\mu u^\nu - (P(T) + \Pi)\Delta^{\mu\nu} + W^\mu u^\nu + W^\nu u^\mu + \pi^{\mu\nu}\right]_{;\mu} = 0. \tag{2}$$

Therefore solving Eq. (1) is equivalent to solving the corresponding dissipative equation Eq. (2) and the corresponding nonextensive entropy current includes automatically higher order terms in dissipative entropy current. The possibility of such *nonextensive/dissipative* correspondence is then further investigated and elucidated in more detail with the connection between the perfect nonextensive hydrodynamical model and dissipative phenomena being stressed and discussed.

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Elliptic flow and onset of deconfinement in a hydro+Boltzmann hybrid approach

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We present first results from a hydro+Boltzmann hybrid approach to heavy ion reactions from GSI-SIS to BNL-RHIC energies. Event-by-event fluctuations are directly taken into account via the non-equlibrium initial conditions generated by the microscopic UrQMD

model. After the (3+1)-dimensional hydrodynamic evolution, the freezeout process is performed via the Cooper-Frye formula and an subsequent hadronic cascade calculation using again UrQMD to incorporate important final state effects.
We investigate the excitation function of elliptic flow (v_2) and compare the results from the hybrid approach to previous purely hadronic calculations. The influence of the hydrodynamical evolution and the phase transition on the elliptic flow is discussed in the context of the available experimental data. Furthermore, we investigate the expansion paths in the T-μ-plane using different equations of state. Defining a critical area around the critical point, we show at what beam energies one can expect to have a sizable fraction of the system close to the critical point. We explore how much energy is needed to reach the phase transition to the Quark-Gluon-Plasma in this approach.

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ANISOTROPIC FLOW MEASUREMENTS IN ALICE

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Anisotropic flow, particularly elliptic flow, has proved to be a powerful probe to understand the dynamics of heavy ion collisions. Its observation and systematic study have provided enough evidence to indicate the presence of a thermally equilibrated strongly interacting matter in relativistic heavy ion collisions. The large values of elliptic flow observed at Relativistic Heavy Ion Collider propound the ideal hydrodynamic description for the evolution of a heavy ion collision system, where the equation of state can be constrained empirically. However, more detailed investigations on measurements of differential flow of identified particles, and the rapidity dependence of flow, have questioned the validity of the ideal hydrodynamic picture, maintaining the need for further studies of collective flow in heavy ion collisions. It is imperative that further flow measurements of identified particles are made in a variety of interacting systems, at larger energies and in different phase space regions. The ALICE experiment at the Large Hadron Collider is ideally suited for this and we will present some examples of expected flow measurements using the various detectors.

To measure anisotropic flow, a variety of analysis methods exist, with their relative merits. A common feature of all of them is that each method works the best with increasing multiplicity and increasing flow, both expected to be large at the LHC, and therefore allowing for a more accurate determination of the flow coefficients. Use of different methods in ALICE will provide a good estimate of the systematic uncertainties.

Theoretical calculations predict values of integrated flow of about 5-10% at the LHC energies. Simulations have demonstrated the capability of reconstructing the assumed transverse momentum dependence of flow for charged particles and also for identified particles measured in the Time Projection Chamber (TPC). The measurements in Silicon Pixel Detectors (SPD), the Photon Multiplicity Detector (PMD) and the Forward Multiplicity Detector (FMD), in addition to those in TPC, will determine the rapidity dependence of elliptic flow up to forward rapidities. Further, correlations with event planes from different sub-detectors will allow a consistency check on the values of v_2 and provide the systematic uncertainty in the measurement. The segmented zero degree calorimeter will also provide an estimate of the reaction plane for any sizable amount of directed flow at the LHC. These estimates of the reaction plane make it amenable to obtain any possible anisotropy in the J/ψ absorption, (or any other particle/resonance), helping in discerning between the Glauber and comover absorption of the charmonium in matter.

In summary, the ALICE experiment at the LHC, with the expected higher multiplicity and increased flow compared to lower energies, will provide an environment for improved estimates of non-statistical fluctuations in flow. In addition, measurement of higher harmonics will provide another probe to test the ideal fluid behaviour.

Super-horizon fluctuations and acoustic oscillations in relativistic heavy-ion collisions

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We focus on the initial state spatial anisotropies, originating at the thermalization stage, for central collisions in relativistic heavy-ion collisions. We propose that a plot of the root mean square values of the flow coefficients $\sqrt{\overline{v_n^2}} \equiv v_n^{rms}$ for a large range of n, from 1 to about 30, can give non-trivial information about the initial stages of the system and its evolution. We also argue that for all wavelengths λ of the anisotropy (at the surface of the plasma region) larger than the acoustic horizon size H_s^{fr} at the freezeout stage, the resulting values of v_n^{rms} should be suppressed by a factor of order $2H_s^{fr}/\lambda$. For non-central collisions these arguments naturally imply a certain amount of suppression of the elliptic flow. Further, by assuming that initial flow velocities are negligible at the thermalization stage, we discuss the possibility that the resulting flow could show imprints of coherent oscillations in the plot of v_n^{rms} for subhorizon modes. For gold-gold collision at 200 GeV/A center of mass energy, these features are expected to occur for $n \geq 5$, with $n < 4$ modes showing suppression due to being superhorizon. This has strong similarities with the physics of the anisptropies of the cosmic microwave background radiation (CMBR) resulting from inflationary density fluctuations in the universe (despite important differences such as the absence of gravity for the heavy-ion case). It seems possible that the statistical fluctuations due to finite multiplicity may not be able to mask these features in the flow data, or, atleast a non-trivial overall shape of the plot

[1] Talk to be presented by P.S. Saumia

of v_n^{rms} may be inferred. In that case, the successes of analysis of CMBR anisotropy power spectrum to get cosmological parameters can be applied for relativistic heavy-ion collisions to learn about various relevant parameters at the early stages of the evolving system.

Elliptic flow fluctuations and non-flow correlations measured by STAR

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We present STAR measurements of the non-statistical width in the distribution of the length of the flow vector in 200 GeV Au+Au collisions. This width depends on the magnitude of v_2 fluctuations and non-flow correlations and is directly related to the difference between 2- and 4-particle cumulants. Using these measurements, along with charge and pseudo-rapidity dependences, we place upper limits on the magnitude of v_2 fluctuations and derive minimum values for non-flow. The v_2 fluctuation upper limit challenges current models for the initial conditions in heavy-ion collisions.

ATLAS potential for elliptic flow measurements in Pb+Pb collisions at LHC

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The measurements of particle azimuthal anisotropies, quantified by coefficients of the Fourier decomposition of the azimuthal angle distributions, provide important information on the early stages of nucleus-nucleus collisions. The large coverage in pseudorapidity of the ATLAS tracking detectors and calorimetric system, both with the full azimuthal acceptance, will allow these measurements to be performed with a high precision.
In this talk the capability of measuring elliptic flow, the second Fourier coefficient, will be presented. The studies are based on the HIJING generated events with implemented variety of flow effects which then passed through the GEANT simulations of the detector response. It will be shown that with the ATLAS detector various analysis techniques like standard event plane method [1], multi-particle correlations [2] and Lee-Yang Zeros method [3] can be applied for different combinations of the detector sub-systems. A systematic comparison of various analysis methods will be presented.

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PQCD calculations of elliptic flow and shear viscosity at RHIC

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The elliptic flow parameter v_2, its dependence on centrality, rapidity and transverse momentum of gluon matter are calculated from the relativistic pQCD based parton cascade BAMPS [1] using Glauber-type minijets initial conditions. For Au+Au collisions at RHIC energy $\sqrt{s} = 200$ AGeV the gluon plasma generates large v_2 values as measured at RHIC [2].
The relation between the shear viscosity coefficient and the recently introduced transport rate is derived within relativistic kinetic theory [3], which is used to extract the ratio of the shear viscosity to the entropy density, η/s, from the BAMPS calculations. We find that standard pQCD yields $\eta/s \approx 0.08 - 0.15$ as small as the lower bound found from the AdS/CFT conjecture.
The large v_2 values and the small η/s ratios found in the simulations indicate that the gluon plasma created behaves as a nearly perfect fluid. This can be understood by perturbative QCD without regarding to exotic explanations such as found from the AdS/CFT conjecture: Gluon bremsstrahlung dominates yielding rapid thermalization, and, therefore, early pressure buildup, and a small shear viscosity in the gluon gas.

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ELLIPTIC FLOW: ECCENTRICITY AND FLUCTUATIONS IN HEAVY-ION COLLISIONS FROM AGS TO LHC

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We study the energy dependence of the elliptic flow produced in collisions of heavy and light nuclei at energies varying from AGS to LHC within the microscopic quark-gluon string model (QGSM). In microscopic calculations hadrons are continuously emitted from the whole reaction volume, and different species decouple at different times. The hadrons contribute differently to the formation and evolution of the anisotropic flow [1], which can be decomposed onto three components: (i) flow created by hadrons emitted from the surface at the onset of the collision; (ii) flow produced by jets; (iii) hydrodynamic flow. Due to these features, the elliptic flows of mesons and baryons have different transverse momentum dependences.
Partonic recombination and fusion processes were implemented in the QGSM to model effectively the dynamics of a strongly coupled quark-gluon plasma produced at ultrarelativistic nuclear collisions [2]. It was found that the recombination leads to significantly shorter equilibration times and improves the theoretical description of measured elliptic flow, particularly, its pseudorapidity dependence.
Comparison with experimental data reveals that centrality, rapidity, and transverse momentum dependences of the elliptic flow are well reproduced in the model. We predict further increase of the integrated elliptic flow at LHC energies compared to that observed at RHIC. Event-by-event fluctuations are studied. In accord with the experimental results, the scaling of the elliptic flow with the participant eccentricity [3] is observed for both light and heavy systems of colliding nuclei.

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Elliptic Flow of Inclusive Photons in AuAu & CuCu Collisions at 200 A GeV from STAR Experiment

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Ideal fluid hydrodynamic description of relativistic heavy ion collisions successfully explains the large values of flow measured at RHIC energies. However, there is limited success of the same models in explaining the observed flow at forward rapidities. While this suggests the possible need for dissipative hydrodynamic models for theoretical development, it also provides motivation to measure the flow away from mid rapidity.

In the present work, we shall present results on the observed flow in inclusive photons in AuAu and CuCu collisions at 200 A GeV. The inclusive photons are measured in the preshower Photon Multiplicity Detector (PMD), away from midrapidity, where the photons are identified by applying cuts on the cluster parameters, ADC and size. The PMD is sensitive to photons of very low momentum ($p_T \sim 30$ MeV/c) and hence flow measured in these

photons yields the true p_T integrated flow. Any possible difference in the flow values of neutral and charged pions will manifest in the low p_T region and is expected to be discernible in the distribution of the low p_T photons which will be measured in the PMD.

To avoid the contribution from non-flow correlations, the event plane has been determined using charged particles measured in the TPC, and in the two FTPCs. The stability of the results is investigated by obtaining the event planes in different pseudo-rapidity regions. The systematic error on v_2 due to uncertainties in the efficiency and purity of the photon sample are estimated by varying the values of cluster parameters that identify the inclusive photons. Results of observed elliptic flow as a function of event centrality and pseudorapidity will be discussed, both for AuAu collsions and CuCu collisions at 200 A GeV.

STAR measurement of directed flow of identified particles from Au+Au & Cu+Cu Collisions at RHIC

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The study of collective flow in ultra-relativistic nuclear collisions provides insight into the equation of state of the hot, dense matter created by ultra-relavistic heavy ion collisions. Directed flow is the first coefficient (v_1) of the Fourier expansion of particle's distribution with respect to the reaction plane. The magnitude and the shape of directed flow, in particular for protons, are of special interest because they might carry an "anti-flow" or "third flow component" resulted from a strong QGP expansion. The Multi-strange baryons, with presumably small hadronic cross sections, may not participate well in the expansion and decouple early from the collision system. Therefore the directed flow of strange baryons and mesons may shed the light on the dynamics happened at the very early stage of the collision. We present $p, \bar{p}, K^+, K^-, \Lambda, \bar{\Lambda}$ and K_s^0 directed flow in Au+Au & Cu+Cu collisions at $\sqrt{s_{NN}}$ =62GeV and $\sqrt{s_{NN}}$ =200GeV, measured by the STAR experiment. $P, \bar{p}, K^+, K^-$ are identified by their energy loss inside STAR's main Time Projection Chamber(TPC). The $K_s^0 \to \pi^+ + \pi^-$ and $\Lambda(\bar{\Lambda}) \to p + \pi^-(\bar{p} + \pi^+)$ are reconstructed from their charged daughter tracks inside TPC. At RHIC energies, it is a challenge to measure v_1 accurately due to the small signal of v_1 itself and the large systematic error arising from non-flow correlations. To improve the event plane resolution and minimize the non-flow effects, we determine the event plane from the sideward deflection of the spectator neutron measured by STAR's Shower Maximum Detector at Zero Degree Calorimeter (ZDC-SMDs), together with tracks reconstructed with the Forward Time Projection Chambers(FTPC). STAR's preliminary v_1 results will be obtained from the tracks reconstructed with the TPC. Our result will be presented as a function of pseudorapidity, transverse momentum and centrality. And we will compare the identified particle v_1 in the different collision system and energy.

Deuteron elliptic flow in relativistic heavy-ion collisions

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Recently, the elliptic flow of deuterons produced in Au+Au collisions at $\sqrt{s_{NN}}$ has been measured by both the PHENIX [1] and STAR [2] collaborations. These measurements show that the deuteron elliptic flow seems to scale with its constituent nucleon number, implying thus that the quark number scaling of elliptic flows holds not only for hadrons but also for the deuteron. To understand this result, we have used a simple dynamical model that is based on deuteron production from the hadronic matter at freeze out via the NN $\rightarrow d\pi$, NNN $\rightarrow d$N, and NN$\pi \rightarrow d\pi$ reactions [3]. Using measured proton and pion transverse momentum spectra and elliptic flows, we find that the resulting deuteron elliptic flow approximately reproduces the observed one except at transverse momentum less than 0.5 GeV/c, where the theoretical value is positive while the measured one is negative. Also, the calculated deuteron transverse momentum spectrum is softer than that in experiments. Our results are, however, similar to those from the coalescence model, and the similarity can be understood from consideration of the allowed nucleon phase space in these reactions. To improve our model, the dominant reaction NN $\rightarrow d\pi$ for deuteron production and its inverse for deuteron destruction as well as the deuteron elastic scattering with pions are being included in a multiphase transport (AMPT) model [4] to study explicitly the time evolution of deuteron production and thermalization in the hadronic matter produced in relativistic heavy ion collisions. Results from this improved study on the deuteron transverse momentum spectrum and elliptic flow will be reported.

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Non-equilibrium entropy density and dissipative processes in relativistic nuclear collisions

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The ratio of shear viscosity to the volume density of entropy has generated much interest even beyond RHIC and LHC physics. In this presentation we focus on the dissipative fluxes/processes that might be responsible for entropy production. We compare the relative strength of each dissipative flux/process with regard to entropy production. This is done by taking the ratio of individual flux to the volume density of entropy. Finally we compare the ratio of all relevant dissipative fluxes to the entropy density.

Search for the Extended High Density Phase in U + U Collisions at 0.52GeV/c

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Search for the evidences for the formation of Quark-Gluon Plasma is one of the goals for high-energy nuclear collisions. The other important issue is the QCD phase diagram: the phase boundary and the possible end-point of the phase boundary. In this talk, we will discuss the properties of matter created in $U + U$ collisions at 0.52GeV/c. The focus will be given to the extended high density phase in the collisions. We have developed a observable that allows us to select the tip-tip* orientation in $U + U$ collisions. In transport model ART[1], the collisions with the special orientation provide an extend lifetime for the high density phase in the collisions by almost a factor of 2 compared to the collisions with the body-body*∗ orientation. Collective expansion and anisotropy in the $U + U$ collisions will be discussed.

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* aligned with both long axis of U nuclei

*∗ aligned with both short axis of U nuclei.

Trace initial interaction from final observable in relativistic heavy ion collisions

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In order to trace the initial interaction in all azimuthal directions in ultra-relativistic heavy ion collision, two azimuthal multiplicity-correlation patterns – neighboring and fixed-toarbitrary angular-bin correlation patterns – are suggested. They reveal the existence of two opposite model-independent azimuthal correlations in current ultra-relativistic heavy ion collisions. One is dominated in peripheral collisions and is caused by the anisotropic expansion, the same reason as the formation of (in-plane) elliptic flow. Another one appears at near-central collisions and has been recognized as out-of-plane elliptic flow due to squeezeout effect at low colliding energy, which is supposed to be ignorable at RHIC energy region, as elliptic flow (v_2) keeps positive there. These two opposite correlation effects are not visible simultaneously at RHIC from conventional observable, such as, direct flow, elliptic flow v2 and 2-particle azimuthal correlations, but can be clearly traced by suggested two azimuthal multiplicity-correlation patterns.

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Testing the resonance gas model with hydrodynamics

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Hadron gas models typically have a cutoff, Λ, such that all hadrons with masses below Λ are taken into account, and all others are ignored. The stability of thermodynamic variables to changes in Λ for such a resonance gas is investigated. It is assumed each hadron enters as a species of an ideal gas, and that decay and regeneration of hadrons through their mutual interactions are included thereby through detailed balance. It is found that the predictions for thermodynamic quantities such as the energy density (E), pressure (P) and the entropy density (S) are more stable than quantities such as the speci
c heat (c_v), speed of sound (c_s) and conformal invariance breaking density (Δ).
This resonance gas model is extended by including a Hagedorn spectrum of hadrons with masses above Λ, where the parameters in the Hagedorn spectrum are
tted to the observed hadron spectrum. It was found that the predictions for E, P and S are absolutely stable in the sense that the width of the allowed band of predictions, determined by the allowed band of parameters decreases with increasing Λ. For c_v, c_s and Δ the band becomes unacceptably broad in the neighbourhood of T $\sim$ 170 Mev.
We remark on the comparison of resonance gas and lattice computations of the equation of state, a topic of some importance in the search for the critical end point of QCD. We put the resonance gas model to use in computing boost invariant longitudinal expansion and
nd that the freeze out time can change from $2.0\tau_0$ to $3.7\tau_0$, where τ_0 is the initial time for hydrodynamics. Finally we investigate the energy per final-state particle in the fireball and compare it with observation.

Elliptic flow fluctuations in two models of eccentricity fluctuations

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We discuss flow fluctuations due to fluctuations in the initial spatial x (reaction plane direction) and y (perpendicular to the reaction plane) eccentricity components $\{\langle(\sigma_y^2-\sigma_x^2)/(\sigma_x^2+\sigma_y^2)\rangle, \langle 2\sigma_{xy}/(\sigma_x^2+\sigma_y^2)\rangle\}$. Two cases are investigated : 1) Eccentricity fluctuates with the same width in the x and y directions according to Gaussian distribution [1]. 2) Eccentricity fluctuates with different widths in the x and y directions [2]. For case 1), we find that $v_2\{4\}$, elliptic flow determined from 4-particle cumulants, exactly equals the average flow value in the reaction plane coordinate system $\langle v_{RP}\rangle$, the relation which, in an approximate form, was found earlier by Bhalerao and Ollitrault in a more general analysis [3]. Analysis of the distribution in the magnitude of the flow vector, the $Q-$distribution, reveals that it is totally defined by two parameters, $v_2\{2\}$ and $v_2\{4\}$, thus providing information equivalent to cumulants. The flow obtained from the $Q-$distribution is again $v_2\{4\} = \langle v_{RP}\rangle$. For case 2), we present a method for determining event-by-event fluctuations of elliptic flow to the extent that the fluctuations in the x direction are different from those in the y direction. By studying the event-by-event distribution of v_2 with respect to the 1st-order event plane, average flow and these event-by-event flow fluctuations can be separately determined, making appropriate allowance for the effects of finite multiplicity and nonflow.

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The Importance of Correlations and Fluctuations on the Initial Source Eccentricity in High-Energy Nucleus–Nucleus Collisions

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One of the early, important discoveries at RHIC was that the magnitude of the elliptic flow component, v_2, was not only large, but also for the first time reached the limit predicted by

hydrodynamical calculations. In a hydrodynamics picture, elliptic flow is understood to be a consequence of the spatial anisotropy of the initial matter distribution. This anisotropy is usually characterized by the eccentricity of the overlap region of the colliding nuclei. Thus, the interpretation of the anisotropic flow data requires a detailed understanding of the effective initial source eccentricity.
In this talk, we discuss various ways of defining this effective eccentricity. In particular, we examine the participant eccentricity, which quantifies the eccentricity of the initial source shape by the major axes of the overlap ellipse formed by the interaction points of the participating nucleons. We will show that reasonable variation of the density parameters in the Glauber simulation, as well as variations in how matter production is modeled, do not significantly change the already established behaviour of the participant eccentricity. Instead, as we will outline, we find that participant spatial correlations in the interaction of two nuclei play an essential role, in particular for the Cu+Cu system. Including these correlations in the calculation of the participant eccentricity results in larger values for the eccentricity. One particularily important consequence is that the fourth order participant eccentricity cumulant does not approach the spatial anisotropy obtained assuming a smooth nuclear matter distribution.

Elliptic flow fluctuations in heavy ion collisions and the perfect fluid hypothesis

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We analyse the recently measured v_2 fluctuation in the context of establishing the degree of fluidity of the matter produced in heavy ion collisions. We argue that flow observables within systems with a non-negligible mean free path should acquire a "dynamical" fluctuation, due to the random nature of each collision between the system's degrees of freedom. Because of this, v_2 fluctuations can be used to estimate the Knudsen number of the system produced at RHIC. To illustrate this quantitatively, we study fluctuations of v_2 within the UrQMD transport model (with hadronic degrees of freedom) and with the parton Cascade model (with partonic degrees of freedom). We vary the cross section by an overall parameter to illustrate the scaling of the v_2 fluctuations with the Knudsen number. Using our results, we infer that collisions at RHIC have a Knudsen number at least one order of magnitude above the expected value for a weakly coupled system. We further argue that the Knudsen number is bound from above by the v_2 fluctuation data, because too large a Knudsen number would break the observed scaling of v_2 fluctuations due to the onset of turbulent flow. We propose, therefore that v_2 fluctuation measurements, together with an understanding of the turbulent regime for relativistic hydrodynamics, will provide an upper as well as a lower limit for the Knudsen number.

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Elliptic flow of jet triggered events from STAR

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In relativistic heavy ion collisions jets are quenched as they traverse the hot QCD medium. The shape of the matter created in these collisions may also be influenced by very energetic jets created early in the collision. In this talk we present the STAR measurements of elliptic flow and non-flow correlations in events with several high pt tracks. We also statistically extract the <v2> for the events that yielded i) uncorrelated di-hadron pairs, ii) correlated pairs at small $\Delta\phi$ and wide $\Delta\eta$(ridge), iii) jets with small $\Delta\phi$ and small $\Delta\eta$ and iv) away side pairs in the mach-cone region. We will discuss how these measurements could be related to strong color fields and instabilities in the early stages of heavy ion collisions .

Measurements of High p_T Identified Hadron v_2 and v_4 in Au+Au Collisions at $\sqrt{S_{NN}} = 200$ GeV by the PHENIX Experiment

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Measurements of the anisotropic flow coefficients v_2 and v_4 at RHIC have provided sensitive information about the earliest stages of heavy ion collisions and the thermal properties of the created matter. The elliptic flow coefficient v_2 of identified hadrons has been found empirically to scale with the number of constituent quarks, providing evidence that partonic degrees of freedom determine the early dynamics of the system. The ratio of v_4/v_2^2 is expected to be a probe of the degree of thermalization of the system. Present measurements of identified particles such as pions, kaons, protons and deuterons anisotropic flow have been limited to p_T around 4 GeV/c due to the lack of particle identification and insufficient statistics. For Run 7 of RHIC, the PHENIX experiment was upgraded with a time of flight detector with 80 ps intrinsic timing resolution and a reaction plane detector with 70% resolution. Both of these detectors performed well during the whole Run 7 at RHIC in which PHENIX collected over 5.5 billion minimum bias 200 GeV Au+Au events. The large data sample combined with upgraded detector capabilities is expected to extend the anisotropic flow measurements of identified particles such as pions, kaons, protons and deuterons to p_T around 7 GeV/c. We will present identified particle v_2 and v_4 measurements as a function of centrality and further test the quark-number scaling of v_2 in the high p_T region