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Eccentricity fluctuations from the color glass condensate in ultrarelativistic heavy ion collisions

Hans-Joachim Drescher[1] and Yasushi Nara[2]
[1]*Frankfurt Institute for Advanced Studies (FIAS), Johann Wolfgang Goethe-Universität, Max-von-Laue-Str. 1, D-60438 Frankfurt am Main, Germany*
[2]*Akita International University 193-2 Okutsubakidai, Yuwa-Tsubakigawa, Akita-city, Akita 010-1211, Japan*

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In this Rapid Communication, we determine the fluctuations of the initial eccentricity in heavy-ion collisions caused by fluctuations of the nucleon configurations. This is done via a Monte Carlo implementation of a color glass condensate k_t-factorization approach. The eccentricity fluctuations are found to nearly saturate elliptic flow fluctuations measured recently at RHIC. Extrapolations to LHC energies are shown.

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In a high energy noncentral heavy ion collision the asymmetry of the coordinate space, the overlap area, is transferred into an asymmetry in momentum space, and measured as the elliptic flow $v_2 = \langle \cos(2\phi) \rangle$, where ϕ is the angle of a particle with respect to the reaction plane. The initial asymmetry in coordinate space is characterized by the eccentricity

$$\varepsilon = \frac{\langle r_y^2 - r_x^2 \rangle}{\langle r_y^2 + r_x^2 \rangle}\,, \tag{1}$$

where r_x and r_y denote the coordinates in the plane transverse to both the beam axis and the reaction plane. The brackets $\langle \ldots \rangle$ indicate an average over the transverse plane, using some appropriate weight. Here, we use the number density of produced gluons.

In ideal hydrodynamics, assuming a short thermalization time, the final elliptic flow is proportional to the initial eccentricity $v_2 = c\varepsilon$. The proportionality constant depends on the equation of state but is roughly $c = 0.2$ [1].

Fluctuations of the eccentricity therefore should translate into fluctuations of the elliptic flow [2]. Recently, these v_2 fluctuations have been measured by the PHOBOS and the STAR collaborations [3,4].

In this note, we examine the fluctuations of ε based a color glass condensate model and compare with standard Glauber results (see, for example [6,7]).

In Ref. [5] we introduced a Monte Carlo implementation of the Kharzeev-Levin-Nardi (MC-KLN) [8] approach to particle production in heavy ion collisions. Gluon production is calculated individually for each configuration of nucleons in the colliding nuclei. Thanks to the implementation of perturbative gluon saturation in this approach, the multiplicity can be determined via the well-known k_t-factorization formula [8] without the need to introduce infrared cutoffs (and additional models for the soft regime). The saturation scale is taken to be proportional to the local density of nucleons which, in turn, is measured by counting nucleons in a given sampling area. However, if the radius of the sampling area is $r_{\max} = \sqrt{\sigma_{\text{inel}}/\pi}$, one overestimates the interaction probability especially in the periphery, since nucleon pairs can have a distance up to $2r_{\max}$. Therefore, we improved on our previous model by rejecting those pairs with $r > r_{\max}$. In the $p + p$ limit this results in an additional factor 0.58 which is very close to the value found in Refs. [7,8] by accounting for the difference between the inelastic and the geometric cross section of a nucleon. We further assume here that $\sigma_{\text{inel}} = 42$ mb at full RHIC energy ($\sqrt{s_{NN}} = 200$ GeV), and $\sigma_{\text{inel}} = 66$ mb at LHC energy ($\sqrt{s_{NN}} = 5500$ GeV).

This refined treatment allows for an excellent description of the charged multiplicity at RHIC over the entire range of centralities (for both Cu and Au nuclei), essentially down to $p + p$ collisions. Figure 1 depicts our results for full RHIC energy, as well as an extrapolation to Pb+Pb collisions at LHC energy. Since there is some uncertainty regarding the evolution of the saturation scale, we show results for both fixed coupling evolution, $Q_s^2 = Q_{s,0}^2(x_0/x)^\lambda$ with $\lambda = 0.28$, and running coupling evolution of Q_s^2 (see, e.g., [8]). For the latter case, the initial condition $Q_{s,0}$ and x_0 was set such that at RHIC energy Q_s agrees with previous estimates.

The participant eccentricity $\varepsilon_{\text{part}}$, which corrects for fluctuations of the major axes and of the center of mass of the overlap region, is defined by

$$\varepsilon_{\text{part}} = \frac{\sqrt{\left(\sigma_y^2 - \sigma_x^2\right)^2 + 4\sigma_{xy}^2}}{\sigma_y^x + \sigma_x^2}, \tag{2}$$

where σ_x and σ_y are the rms widths of the gluon density projected on the r_x and r_y axes, respectively, and $\sigma_{xy} = \langle r_x r_y \rangle - \langle r_x \rangle \langle r_y \rangle$. The fluctuations of this variable for a given centrality class (here defined by the number of participants) are determined via

$$\sigma_{\varepsilon_{\text{part}}} = \sqrt{\langle \varepsilon_{\text{part}}^2 \rangle - \langle \varepsilon_{\text{part}} \rangle^2}\,. \tag{3}$$

Figure 2 shows the result together with data from PHOBOS [3] and STAR [4], and a simple Glauber model, where the number density of gluons scales with the number of participants N_{part} (note that this model fails to account for the growth of $dN/d\eta/N_{\text{part}}$ with centrality seen in Fig. 1). These measurements are rather difficult, and therefore the error bars are quite large, as is the discrepancy between experiments, especially at high centralities where neither the Glauber model, nor the CGC result can be ruled out. For semicentral collisions, the CGC predicts somewhat lower relative fluctuations than the Glauber model. We note that $\sigma_{\varepsilon_{\text{part}}}$ itself is quite independent

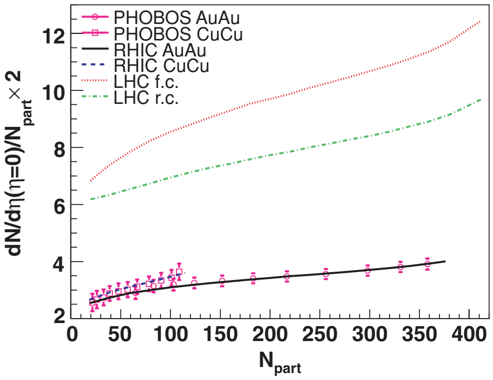

FIG. 1. (Color online) Multiplicity for Au+Au and Cu+Cu collisions at 200 GeV and PbPb collisions at 5500 GeV. The data are from the PHOBOS collaboration [9,10].

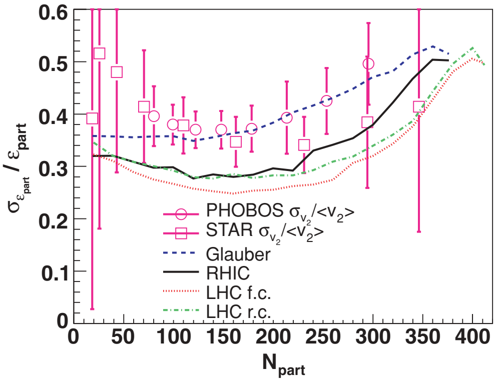

FIG. 2. (Color online) Relative fluctuations of the eccentricity as a function of centrality in Au+Au/Pb+Pb collisions.

of the underlying model and energy. The main reason for the lower *relative* eccentricity fluctuations in the MC-KLN model is the larger average eccentricity for semicentral Au+Au collisions in this approach, see the discussion in Refs. [5,14].

To check for other possible sources of fluctuations in the participant eccentricity, we implemented additional Poissonian (uncorrelated) fluctuations of the number of gluons produced at a given point in the transverse plane. These may arise, for example, from fluctuations of the gluon evolution ladders. However, we found that they did not noticeably affect $\sigma_{\varepsilon_{\rm part}}$. One should also keep in mind that so-called nonflow effects [11,12] may increase fluctuations of the measured v_2. Moreover, hydrodynamic fluctuations may contribute to σ_{v_2} as well [13]. Hence, σ_{v_2}/v_2 should be viewed only as an upper limit for $\sigma_{\varepsilon_{\rm part}}/\varepsilon_{\rm part}$.

To summarize, we have calculated the fluctuations of the initial eccentricity within a simple Glauber model and for a color glass condensate (CGC) approach which includes fluctuations in the positions of the hard sources (nucleons). Both models predict eccentricity fluctuations which nearly saturate the experimentally measured fluctuations of the elliptic flow. The CGC approach gives slightly lower *relative* fluctuations than the Glauber model, which is largely due to a higher average eccentricity $\varepsilon_{\rm part}$. Their magnitude at LHC energy is similar.

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[1] J. Y. Ollitrault, Phys. Rev. D **46**, 229 (1992).
[2] O. J. Socolowski, F. Grassi, Y. Hama, and T. Kodama, Phys. Rev. Lett. **93**, 182301 (2004).
[3] B. Alver *et al.* (PHOBOS Collaboration), arXiv:nucl-ex/0702036.
[4] P. Sorensen (STAR Collaboration), J. Phys. G **34**, S897 (2007).
[5] H. J. Drescher and Y. Nara, Phys. Rev. C **75**, 034905 (2007).
[6] R. S. Bhalerao and J. Y. Ollitrault, Phys. Lett. **B641**, 260 (2006).
[7] W. Broniowski, P. Bozek, and M. Rybczynski, arXiv:0706.4266 [nucl-th].
[8] D. Kharzeev, E. Levin, and M. Nardi, Nucl. Phys. **A747**, 609 (2005).
[9] B. B. Back *et al.* (PHOBOS Collaboration), Phys. Rev. C **65**, 061901(R) (2002).
[10] G. Roland *et al.* (PHOBOS Collaboration), Nucl. Phys. **A774**, 113 (2006).
[11] P. M. Dinh, N. Borghini, and J. Y. Ollitrault, Phys. Lett. **B477**, 51 (2000).
[12] N. Borghini, P. M. Dinh, and J. Y. Ollitrault, Phys. Rev. C **62**, 034902 (2000).
[13] S. Vogel, G. Torrieri, and M. Bleicher, arXiv:nucl-th/0703031.
[14] A. Adil, H. J. Drescher, A. Dumitru, A. Hayashigaki, and Y. Nara, Phys. Rev. C **74**, 044905 (2006).