Vol. 40 (2009) ACTA PHYSICA POLONICA B No 4

FLUCTUATION OF THE INITIAL CONDITIONS AND ITS CONSEQUENCES ON SOME OBSERVABLES*

Y. Hama, R.P.G. Andrade, F. Grassi, W.-L. Qian

Instituto de Física/USP, C.P. 66318, 05314-970 São Paulo, SP Brazil

T. Kodama

Instituto de Física/UFRJ, C.P. 68528, 21945-970 Rio de Janeiro, RJ Brazil

(Received February 4, 2009)

We show effects of the event-by-event fluctuation of the initial conditions (IC) in hydrodynamic description of high-energy nuclear collisions on some observables. Such IC produce not only fluctuations in observables but, due to their bumpy structure, several non-trivial effects appear. They enhance production of isotropically distributed high-p_{T} particles, making v_2 smaller there. Also, they reduce v_2 in the forward and backward regions where the global matter density is smaller, so where such effects become more efficacious. They may also produce the so-called *ridge effect* in the two large-p_{T} particle correlation.

PACS numbers: 25.75.–q, 24.10.Nz, 24.60.–k, 25.75.Ld

1. Introduction

Hydrodynamics is one of the main tools for studying the collective flow in high-energy nuclear collisions. In this approach, it is assumed that, after a complex process involving microscopic collisions of nuclear constituents, at a certain early instant a hot and dense matter is formed, which would be in local thermal equilibrium. After this instant, the system would expand hydrodynamically, following the well known set of differential equations.

The initial conditions (IC) for the hydrodynamic expansion are usually parametrized as smooth distributions of thermodynamic quantities and four-velocity. However, since our systems are small, important *event-by-event fluctuations* are expected in the IC of the real collisions. Moreover, each set of IC should presents strongly *inhomogeneous structure*. Our purpose here is to discuss some of the effects caused by such fluctuating and bumpy IC on observables.

* Presented at the IV Workshop on Particle Correlations and Femtoscopy, Kraków, Poland, September 11–14, 2008.

2. Event-by-event fluctuating hydrodynamics

The main tool for our study is called NeXSPheRIO. It is a junction of two computational codes: NeXus and SPheRIO. The NeXus code [1] is used to compute the IC. It is a microscopic model based on the Regge–Gribov theory and, once a pair of incident nuclei and their incident energy are chosen, it can produce, in the event-by-event basis, detailed space distributions of energy-momentum tensor, baryon-number, strangeness and charge densities, at a given initial time $\tau = \sqrt{t^2 - z^2} \sim 1$ fm. We show in Fig. 1 an example of such a fluctuating event, produced by NeXus event generator, for central Au + Au collision at 200 A GeV. As seen, the energy-density distribution is highly irregular and in a transverse plane (left panel) it presents several high-density blobs, whereas in a longitudinal plane (right panel) it presents a baton-like structure. When averaged over many events, these bumps disappear completely giving smooth IC, as those commonly used in hydro calculations. However, this bumpy structure gives important effects as we will show below. The SPheRIO code [2, 3], based on Smoothed Particle Hydrodynamics (SPH) algorithm [4], is well suited to computing the evolution of such systems, so complex as the one shown in Fig. 1.

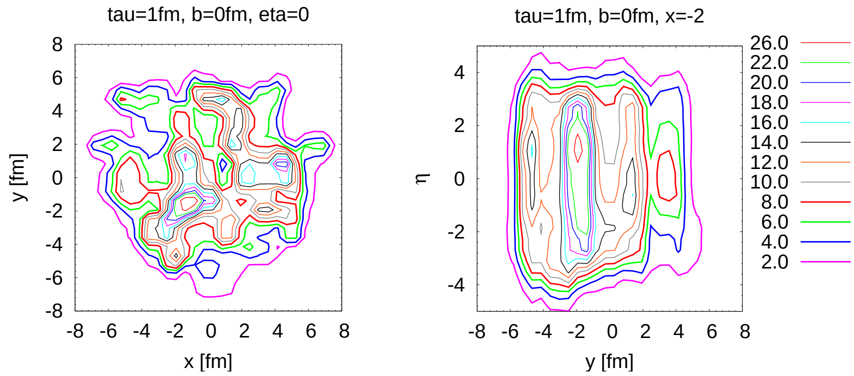


Fig. 1. Fluctuating IC, produced by NEXUS generator, for the most central Au + Au collisions at 200 A GeV. Left: Energy density distribution is plotted in the $\eta = 0$ plane. Right: Corresponding plot in the $x = 2$ fm plane.

3. Effects of bumpy and fluctuating IC

In a previous paper [5], we discussed some effects of the bumpy structure of IC, as shown in Fig. 1, on $p_{\rm T}$ spectra and v_2 coefficient. The main consequence of baton structure[1] is a violent and cylindrically isotropic expansion of the batons, which produces additional isotropic high-$p_{\rm T}$ particles.

[1] In that paper, we have considered only the transverse structure of IC and, then called it *granular*, but all the discussions remain valid replacing granular by *baton* there.

3.1. Transverse-momentum spectra

As clearly shown in Fig. 2, this implies that high-$p_{\rm T}$ part of the $p_{\rm T}$ spectrum becomes enhanced as compared with the smooth averaged IC case, making it more concave and closer to data.

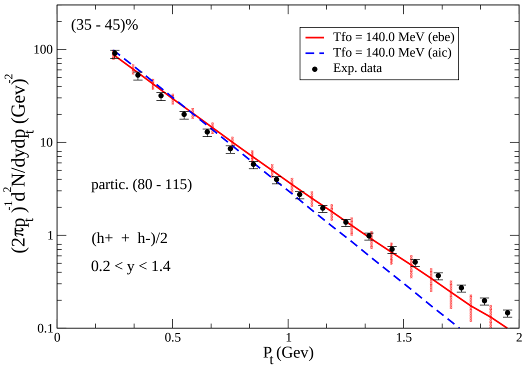


Fig. 2. Charged-particle $p_{\rm T}$ distributions (including those from resonance decays) computed in two different ways. The solid line indicates result for fluctuating IC, whereas the dotted line the one for the averaged IC. Data points [6] are also plotted for comparison.

3.2. $p_{\rm T}$ *dependence of* $\langle v_2 \rangle$

As for the anisotropy of the transverse flow, we illustrate in Fig. 3 that the elliptic-flow coefficient v_2 suffers reduction as we go to high-$p_{\rm T}$ region, due to the additional high-$p_{\rm T}$ isotropic component included now. The result is closer to the available data.

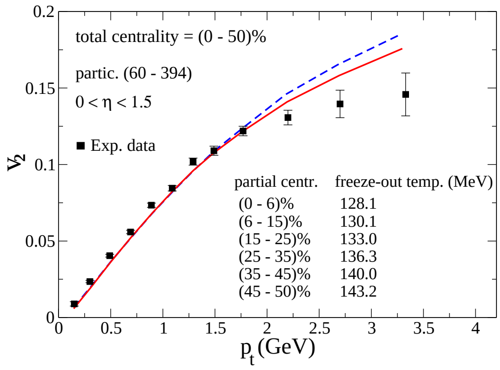


Fig. 3. $p_{\rm T}$ dependence of $\langle v_2 \rangle$ in the centrality window and η interval as indicated, compared with data [7]. The solid line indicates result for fluctuating IC, whereas the dotted one that for the averaged IC. The curves are averages over PHOBOS centrality sub-intervals with freeze-out temperatures as indicated.

3.3. η dependence of $\langle v_2 \rangle$

As for the η dependence of v_2, we know that the average matter density decreases as $|\eta|$ increases as reflected in the η distribution of charged particles, so the isotropic expansion effect of the batons becomes more efficacious there and, therefore, v_2 suffers a considerable reduction in those regions, as shown in Fig. 4.

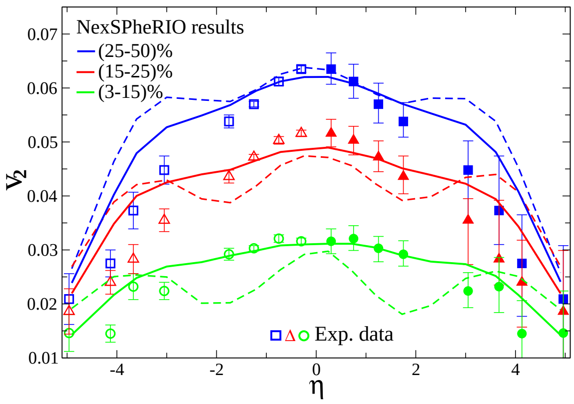


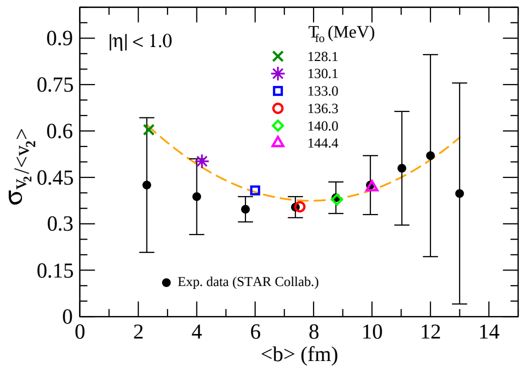
Fig. 4. η dependence of $\langle v_2 \rangle$ for three centrality windows. The solid lines indicate results for fluctuating IC, whereas the dotted lines the ones for the averaged IC. Data points [7] are also plotted for comparison. $T_{\rm fo}$ has been taken as in Fig. 3.

3.4. v_2 fluctuation

The IC fluctuation also implies a large v_2 fluctuation. In preliminary works [8] on Au + Au collisions at 130 A GeV, we showed that this actually happens. The results, with QGP included, have indeed been confirmed in recent experiments [9, 10]. More recent computations for Au + Au at 200 A GeV [11] gave similar results. In Fig. 5, we compare the latter with those data.

3.5. Ridge effect

Another effect, which is produced naturally by the longitudinal baton structure of IC, as shown in Fig. 1, is the so-called *ridge phenomenon* which has been experimentally seen in high-$p_{\rm T}$ nearside correlations [12]. Since batons in fluctuating IC which are close to the surface produce longitudinally correlated high-$p_{\rm T}$ particles, always in the same side of the hot matter, the ridge structure naturally appears. This is shown in Fig. 6, as computed with NeXSPheRIO by Takahashi *et al.* [13]. The ridge phenomenon has been discussed also in connection with glasma flux tubes [14].



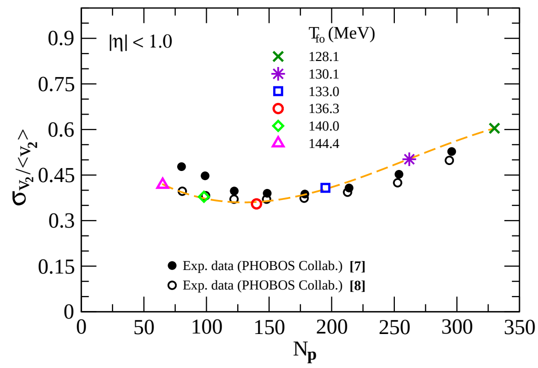


Fig. 5. $\sigma_{v_2}/\langle v_2\rangle$ computed for Au + Au collisions at 200 A GeV, compared with data. Upper: $\sigma_{v_2}/\langle v_2\rangle$ is given as function of the impact parameter $\langle b\rangle$ and compared with the STAR data [9]. Lower: the same results are expressed as function of participant nucleon number N_p and compared with the PHOBOS data [10].

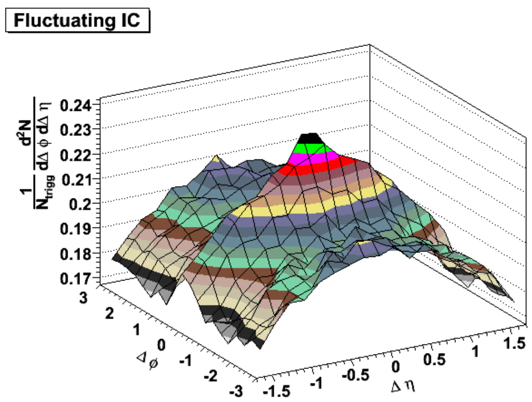


Fig. 6. Two high-p_T particle correlation, computed with event-by-event fluctuating IC [13].

4. Summary

In this paper, we presented several consequences of event-by-event fluctuating IC with baton structure, computed with NeXSPheRIO code. The main results are: (1) The baton structure of IC produces more concave p_{T} spectra, as compared with smooth IC; (2) It reduces $\langle v_2 \rangle$ both in the high-p_{T} and large-$|\eta|$ regions; (3) It also produces the *ridge structure* in the nearside correlations; (4) Large v_2 fluctuations occurs, in good agreement with data.

This work was partially supported by FAPESP, CNPq, FAPERJ and PRONEX. We are grateful to Jun Takahashi for providing us with Fig. 6.

REFERENCES

[1] H.J. Drescher, M. Hladik, S. Ostapchenko, T. Pierog, K. Werner, *J. Phys. G* **25**, L91 (1999); *Nucl. Phys.* **A661**, 604 (1999).

[2] C.E. Aguiar, T. Kodama, T. Osada, Y. Hama, *J. Phys. G* **27**, 75 (2001).

[3] Y. Hama, T. Kodama, O. Socolowski, *Braz. J. Phys.* **35**, 24 (2005).

[4] L.B. Lucy, *Ap. J.* **82**, 1013 (1977); R.A. Gingold, J.J. Monaghan, *Mon. Not. R. Astr. Soc.* **181**, 375 (1977).

[5] R.P.G. Andrade, F. Grassi, Y. Hama, T. Kodama, W.L. Qian, *Phys. Rev. Lett.* **101**, 112301 (2008).

[6] B.B. Back *et al.* [PHOBOS Collaboration], *Phys. Lett.* **B578**, 297 (2004).

[7] B.B. Back *et al.* [PHOBOS Collaboration], *Phys. Rev.* **C72**, 051901 (2005).

[8] T. Osada, C.E. Aguiar, Y. Hama, T. Kodama, in Proc. of the VI RANP Workshop, eds. T. Kodama *et al.*, World Scientific, Singapore 2001, p. 174 [`nucl-th/0102011`]; C.E. Aguiar, Y. Hama, T. Kodama, T. Osada, *Nucl. Phys.* **A698**, 639c (2002).

[9] P. Sorensen [STAR Collaboration], *J. Phys. G* **34**, S897 (2007).

[10] C. Loizides [PHOBOS Collaboration], *J. Phys. G* **34**, S907 (2007); also B. Alver *et al.*, `nucl-ex/0702036`.

[11] Y. Hama, R.P.G. Andrade, F. Grassi, W.L. Qian, T. Osada, C.E. Aguiar, T. Kodama, *Phys. At. Nucl.* **71**, 1558 (2008).

[12] J. Putschke [STAR Collaboration], *J. Phys. G* **34**, S679 (2007).

[13] J. Takahashi *et al.*, private communication; also talk at the VIII RANP Workshop, Rio de Janeiro, 03-06/11/2008.

[14] A. Dumitru, F. Gelis, L. McLerran, R. Venugopalan, *Nucl. Phys.* **A810**, 91 (2008).