A Study of $\langle v_2 \rangle$ with NeXSPheRIO

R. P. G. Andrade*, Y. Hama*, F. Grassi*, O. Socolowski Jr.†, and T. Kodama‡
*Instituto de Física, Universidade de São Paulo, C.P. 66318, 05315-970, São Paulo-SP, Brazil
†CTA/ITA, Praça Marechal Eduardo Gomes 50, CEP 12228-900, São José dos Campos-SP, Brazil
‡Instituto de Física, Universidade Federal do Rio de Janeiro, C.P. 68528, 21945-970, Rio de Janeiro-RJ, Brazil

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Elliptic flow at RHIC is computed event by event with NeXSPheRIO. Reasonable agreement with experimental data on $v_2(\eta)$ and $v_2(pt)$ is obtained. Various effects are studied as well: equation of state (with or without critical point), emission mechanism (Cooper-Frye prescription or continuous emission), type of the initial conditions (average or fluctuating initial conditions).

Keywords: Elliptic flow; Equation of state; Continuous emission; Hydrodynamics

I. INTRODUCTION

The elliptic flow parameter v_2 is defined as the second Fourier coefficient of the azimuthal distribution of particles $dN/d\phi$. The average value of v_2, over N_{ev} events, is given by

$$\left\langle v_2^b \right\rangle \equiv \left(\sum_{j=1}^{N_{ev}} N_j \right)^{-1} \sum_{j=1}^{N_{ev}} \int_0^{2\pi} \left(\frac{dN}{d\phi} \right)_j \cos\left[2\left(\phi - \Phi_b\right)\right] d\phi. \tag{1}$$

Here, N_j is the particle number of the j-th event and Φ_b is the angle between the impact parameter $\vec{b}$ and the Ox axis[8]. The index b indicates that the elliptic flow is calculated with respect to the impact parameter. We can understand $\left\langle v_2^b \right\rangle$ as a measure of the stretch of $\langle dN/d\phi \rangle$ in the direction of $\vec{b}$. In order to compute $dN/d\phi$, in each event, we use the NeXSPheRIO code.

NeXSPheRIO is the tool which we use to do hydrodynamical calculations. It is a junction of two codes: Nexus+SPheRIO.

The Nexus code is used to compute the initial conditions $T^{\mu\nu}$, j^μ and u^μ on a proper time hypersurface [1]. In figure 1 we show an example of initial condition for one random event (in this case we show the initial energy density at mid-rapidity plane).

The SPheRIO code is used to compute the hydrodynamical evolution. It is based on Smoothed Particle Hydrodynamics, a method originally developed in astrophysics and adapted to relativistic heavy ion collisions [2]. Its main advantage is that any geometry in the initial conditions can be incorporated.

NeXSPheRIO is run many times, corresponding to many different events or initial conditions. At the end, an average over final results is performed. Such process mimics the experimental conditions. This is different from the canonical approach in hydrodynamics where initial conditions are adjusted to reproduce same selected data and are very smooth (see figure 2).

Summarizing, we can compute elliptic flow from fluctuating initial conditions (event by event) or from average initial conditions.

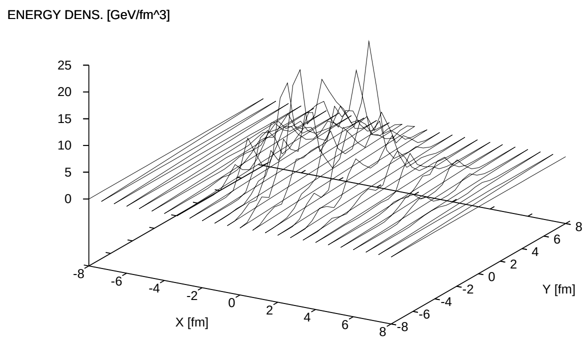

FIG. 1: Example of initial energy density for Au+Au collisions given by Nexus [1] at mid-rapidity plane (one random event). This type of initial conditions is called fluctuating initial conditions.

II. RESULTS

A. centrality and η dependence of $\left\langle v_2^b \right\rangle$

In Fig. 3 we show $\left\langle v_2^b \right\rangle$, as a function of η, in three centrality windows. We have checked that $\left\langle v_2^b \right\rangle$ reproduces the characteristic shape of the experimental data, with a maximum at $\eta = 0$ and decreasing as $|\eta|$ increases. Moreover, $\left\langle v_2^b \right\rangle$ decreases as the centrality increases.

B. Effect of the continuous emission on $\left\langle v_2^b \right\rangle$

In Fig. 4 we compare results obtained from Cooper-Frye prescription [3] and from continuous emission [6]. We have checked that $\left\langle v_2^b \right\rangle$ decreases when we use the continuous emission mechanism. Indeed, in this mechanism, some particles are emited earlier and these particles present a more isotropic distribution as a function of azimuthal angle.

In the case of $\left\langle v_2^b \right\rangle$, as a function of p_t (figure 5), we observe a considerable reduction of the elliptic flow in the region

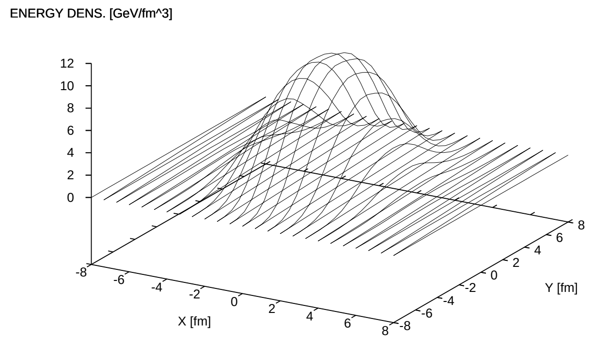

FIG. 2: Average over 1000 random events (corresponding to the smooth initial conditions in the usual hydro approach).

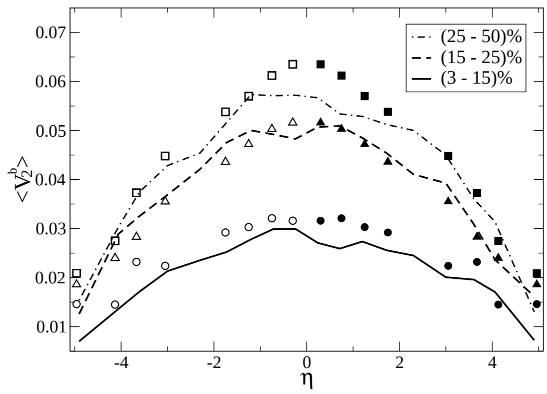

FIG. 3: $\langle v_2^b \rangle$ for charged particles, as a function of η, computed event by event at $T_f = 150MeV$ [3]. Here we use an equation of state without critical point (first order phase transition [4]). The curves are the theoretical results and the circles $(3\% - 15\%)$, triangles $(15\% - 25\%)$ and squares $(25\% - 50\%)$ are the experimental data of the PHOBOS collaboration [5].

of high p_t. However, such reduction does not characterize a saturation (observed in experimental data for $p_t > 1.5GeV$).

C. Effect of the EoS with critical point on $\langle v_2^b \rangle$

In Figs. 6 ($T_f = 150MeV$) and 7 ($T_f = 140MeV$) we show the effect of the EoS with critical point on $\langle v_2^b \rangle$. We observe that $\langle v_2^b \rangle$ is greater when we use the EoS with critical point [7]. Indeed, we expect a larger elliptic flow for the cross over region, since the matter is always accelerated in that region. Note that the effect is better observed when we use $T_f = 140MeV$, *i.e.*, when the time of expansion of the fluid is increased.

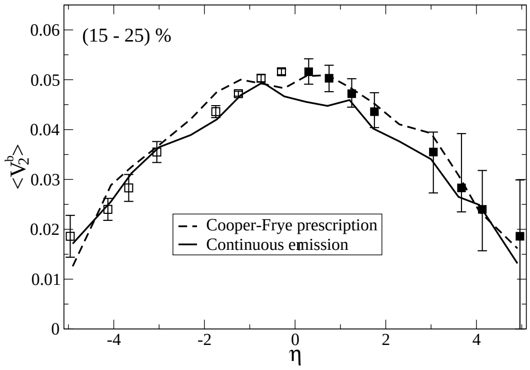

FIG. 4: $\langle v_2^b \rangle$ for charged particles, as a function of η, computed event by event. Two emission mechanisms are used: Cooper-Frye prescription [3] ($T_f = 150MeV$, dashed line) and continuous emission [6] (solid line). The squares $(15\% - 25\%)$ are the experimental data of the PHOBOS collaboration [5].

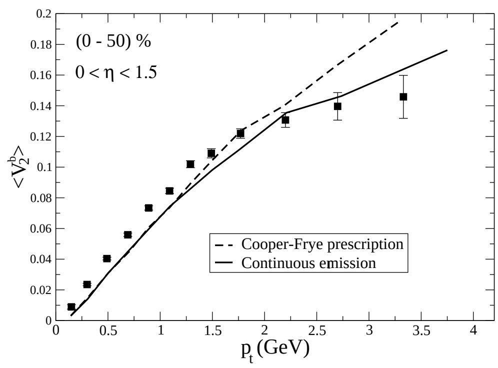

FIG. 5: $\langle v_2^b \rangle$ for charged particles, as a function of p_t, computed event by event. Two emission mechanisms are used: Cooper-Frye prescription [3] ($T_f = 150MeV$, dashed line) and continuous emission [6] (solid line). The squares $(0\% - 50\%)$ are the experimental data of the PHOBOS collaboration [5].

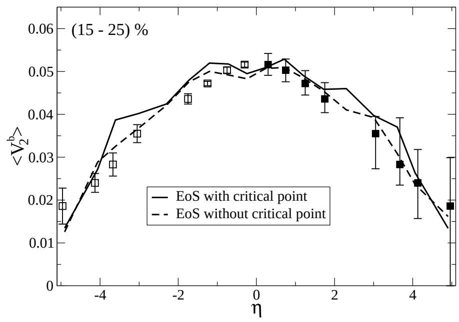

FIG. 6: $\langle v_2^b \rangle$ for charged particles, as a function of η, computed event by event at $T_f = 150MeV$. Two EoS are used: with (solid line) and without (dashed line) critical point [7]. The squares $(15\% - 25\%)$ are the experimental data of the PHOBOS collaboration [5].

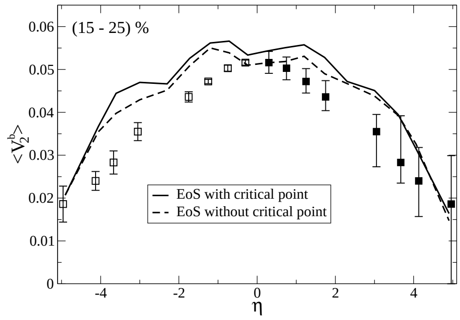

FIG. 7: Analogous plot to figure 6, but at a lower freeze-out temperature $T_f = 140 MeV$.

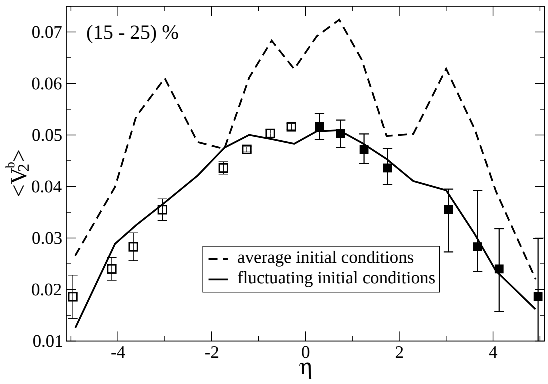

FIG. 8: $\langle v_2^b \rangle$ for charged particles, as a function of η. Two type of the initial conditions are used: fluctuating (solid line) and average (dashed line) initial conditions [4]. The squares $(15\% - 25\%)$ are the experimental data of the PHOBOS collaboration [5].

D. Effect of the type of initial conditions on $\langle v_2^b \rangle$

Finally, in Fig. 8 we compare $\langle v_2^b \rangle$ computed event by event (solid line) and computed from average initial conditions (dashed line) [4]. We observe that the latter is greater and presents three peaks. The central peak is related to the central rapidity region where the temperature is very high. The left and right peaks are probably related, to the participant nucleons after the collision.

It seems that smooth initial conditions favor longer expansion as compared to fluctuating initial conditions.

III. CONCLUSION

In this work, we calculated the elliptic flow parameter v_2, as a function of the pseudorapidity η, the transverse momentum p_t and the centrality of the collision. We found that v_2, as a function of η, reproduces the characteristic shape of the experimental data, with a maximum at $\eta = 0$ and decreasing as $|\eta|$ increases. We also observed that v_2 increases linearly as a function of p_t. It does not show the saturation observed in experimental data, for $p_t > 1.5\,GeV$ (when we use the Cooper-Frye prescription). Using the continuous emission mechanism, we observed a considerable reduction of the elliptic flow in the region of high p_t. However, such a reduction does not characterize a saturation in the present computation, probably because of a two rough approximation used for continuous emission [4]. In the case of v_2 as a function of centrality, the results are consistent with the experimental data. We also verified that the effect of a equation of state with critical point is of little importance to the elliptic flow. On the other side, we found a strong dependence of v_2 on the type of initial conditions used (average or fluctuating initials conditions).

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[8] In this case the z axis is parallel to beam axis.