Fluctuations and initial state granularity in heavy ion collisions and their effects on observables from hydrodynamics *

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A comparison is made between results obtained using smooth initial conditions and event-by-event initial conditions in the hydrodynamical description of relativistic nuclear collisions. Some new results on directed flow are also included.

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1. Objective

Hydrodynamics has been rather successful at describing data obtained in relativistic nuclear collisions at RHIC. Usually, smooth initial conditions are assumed (see e.g. fig.1 in [1] and fig.3 in [2]. On the other side, microscopic codes such as NeXus predict initial conditions event-by-event, which are quite irregular as shown in fig.1.

The question we address here is whether such structures (hot spots or more precisely hot tubes) can have a sizable effect on variables.

To solve the hydro equations with very irregular initial conditions, we use the SPheRIO code. This code is based on the method of Smoothed

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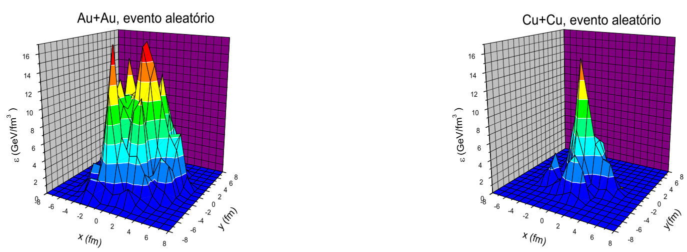

Fig. 1. $\eta = 0$ slice for initial energy density of a RHIC collision in the 6-15 % centrality window.

Particle Hydrodynamics, originally developed in astrophysics and adapted to relativistic heavy ion collisions in [3]. The version of NeXSPheRIO used here has initial conditions provided by NeXus [4] and normalized by an η-dependent factor to reproduce $dN_{ch}/d\eta$ in each centrality window [5]. The equation of state has a critical point [6]. $T_{f.out}$ is fixed (mostly) by $dN_{ch}/p_t dp_t$ and depends on the centrality window (i.e. number of participants). Centrality windows are defined using participant number and not impact parameter [7]. An ideal fluid is assumed, a code with Smoothed Particle Hydrodynamics and dissipation is under development [8].

2. Comparison between fluctuating and average IC

In the following, we present a summary of results obtained using smooth initial conditions and running once the SPheRIO hydro code (standard approach) or using a set of NeXuS initial conditions, running for each initial conditions the SPheRIO hydro code and computing averages over the set for various observables (event-by-event hydrodynamics).

2.1. p_t distribution

As can be seen in figure 2 (left), the high p_t part is lifted. This is expected since hot tubes must expand more violently, producing more high p_t particles [9, 10].

2.2. elliptic flow

$v_2(p_t)$ is flatter as seen in figure 2 (centre). This is also expected as the isotropic expansion of hot tubes produces more high p_t particles and lowers $v_2(p_t)$ [9, 10]. In addition, $v_2(\eta)$ has no shoulder [11] as seen in figure 2

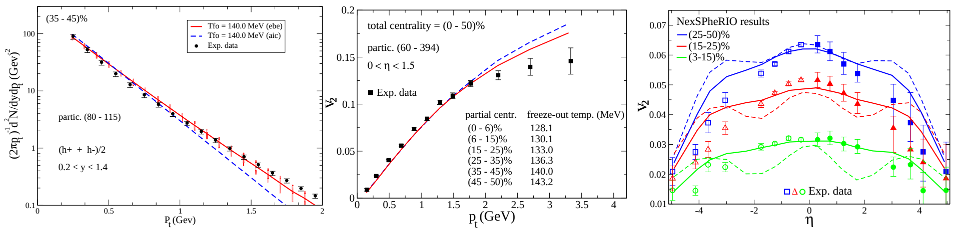

Fig. 2. Left: charged particle p_t distribution. Solid line: e-by-e initial conditions. Dashed: smooth initial conditions. Data: [12]. Center: p_t dependence of $\langle v_2 \rangle$. Data: [13]. Right: η dependence of $\langle v_2 \rangle$. Data: [13].

(right). The effects (isentropic expansion) of the hot tubes are more visible in regions of lower matter density present at larger η's [9, 10].

2.3. Other comparisons

In [14], we argued that the hot tubes should manifest themselves giving smaller HBT radii. However, the situation might be more complicated.

Another observable where hot tubes might manifest themselves is the ridge, a structure observed in the 2 particle correlations, plotted as function of pseudorapitity difference $\Delta\eta$ and azimutal angle difference $\Delta\phi$ between a high p_t trigger hadron and its associated hadrons (see e.g. [15]). The structure is $\Delta\eta$ independent. In NeXSPheRIO, the hot tubes can lead to such a ridge for the e-by-e initial conditions and not the smooth ones [16].

Finally, the fluctuations in the e-b-e initial conditions also manifest themselves in fluctuations of v_2 (as well as v_1). The predicted values for v_2 at 130 A GeV [17] and estimates at 200 A GeV [5] are in agreement with data [18, 19]. Improvements to remove the non-flow effects have been reported by STAR and PHOBOS, see e.g. [20].

3. New results on directed flow

In this section, we present some new *preliminary* results obtained with NeXSPheRIO on directed flow.

3.1. What is directed flow and what is expected

If a nucleus-nucleus collision is a number of independent nucleon-nucleon collisions, the momentum distribution is isotropic. If instead, it leads to thermalized matter in the overlap region, the momentum distribution is stretched along the impact parameter direction, v_2 is a measure of this stretching (so teaches about IC, thermalization, etc). There is also the possibility that the momentum distribution be shifted/deformed towards one of the sides in the x-y plane, v_1 is a measure of this shift.

At some energy, a “wiggle” in $v_1(\eta)$ is predicted. In some microscopical models such as RQMD and UrQMD, this could be the case for nucleons at RHIC energy [21, 22]. In hydro models, this could be the case for the fluid, if a QGP phase occurs [23, 24, 25, 26].

At SPS energy (40 A GeV and 158 A GeV), it was shown [27] that pions and protons behave oppositely. Pion directed flow as function of rapidity has no wiggle and crosses y=0 with a negative slope while nucleon directed flow has no wiggle and crosses y=0 with a positive slope (except perhaps at the higher energy, in the more peripheral bin, where there is a hint of wiggle).

3.2. RHIC results on directed flow

At RHIC, directed flow for charged particles is rather similar to what was obtained at SPS for pions: it crosses $\eta = 0$ with a negative slope [28, 29, 30]. This is understandable since charged particles are mostly pions, the fluid directed flow must be dominated by pions. The turnover in $v_1(\eta)$ occurs for different values of η in PHOBOS and in STAR (see below).

Results for identified particles are becoming available [31].

In addition, comparison of results for directed flow in Cu+Cu and Au+Au collisions show no system-size dependence [30].

3.3. NeXSPheRIO results on directed flow

NeXSPheRIO results are in qualitative agreement with PHOBOS for all η's and quantitative agreement for $\mid \eta \mid < 3$ (figure 3 left). They are in qualitative agreement with STAR for $\mid \eta \mid < 3$ but turnover occurs for smaller η than for STAR (figure 3 right).

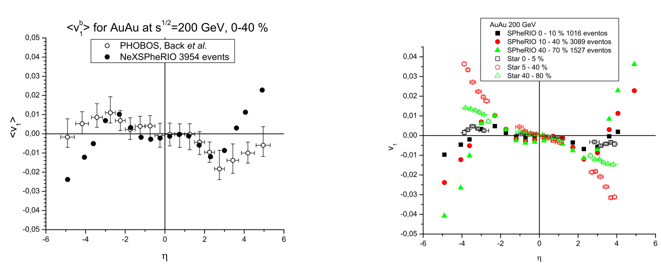

Fig. 3. Comparison of charged particle $\langle v_1 \rangle$ for NeXSPheRIO with (left) PHOBOS [28] and (right) STAR [30].

$v_1(\eta)$ from NeXSpheRIO for various centrality windows for Au+Au and Cu+Cu at 200 A GeV is shown in figure 4. Little dependence on A is seen in the windows 6-15% to 45-55%. Statistics must be improved.

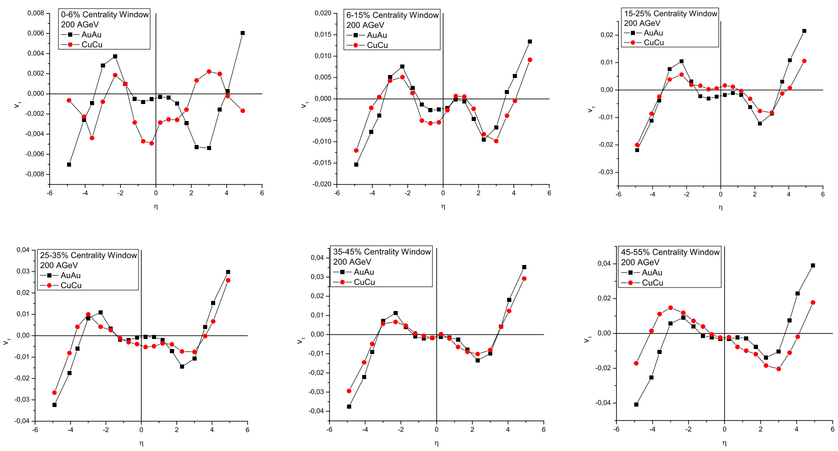

Fig. 4. Comparison of $\langle v_1 \rangle$ obtained in Cu+Cu and Au+Au, from NeXSPheRIO.

Figure 5 (left) illustrates particle dependence. In NeXSPheRIO, protons have a big wiggle, pions have a plateau (left). A similar result was obtained using UrQMD [22]. In figure 5 (right), it is seen that $v_1(\eta)$ has a plateau for fluctuating initial conditions and a somewhat stronger negative inclination for smooth initial conditions.

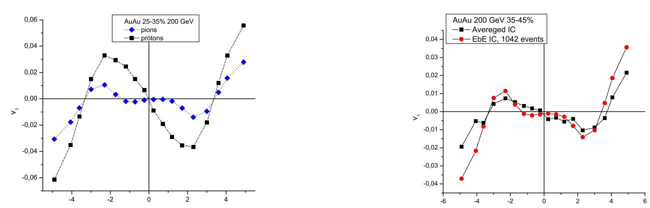

Fig. 5. Left: $\langle v1 \rangle$ for pions and protons. Right: $\langle v_1 \rangle$ for e-by-e and smooth initial conditions.

4. Summary

A short review of possible effects of fluctuating initial conditions, rather than smooth ones, was presented. In addition to providing a reasonable description of various observables, as is possible with smooth initial conditions, some new effects were listed, most notably the ridge effect and the v_2 fluctuations, which do not appear when using the smooth initial conditions.

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