Trying to understand the ridge effect in hydrodynamic model

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In a recent paper, the hydrodynamic code NeXSPheRIO was used in conjunction with STAR analysis methods to study two-particle correlations as function of $\Delta \eta$ and $\Delta \phi$. Both the ridge-like near-side and the double-hump away-side structures were obtained. However, the mechanism of ridge production was not clear. In order to understand it, we study a simple model with only one high-energy density peripheral tube in a smooth cylindrical background, with longitudinal boost invariance. The results are rather surprising, but the model does produce the triple-ridge structure with one high ridge plus two lower ones placed symmetrically with respect to the former one. The shape of this structure is rather stable in a wide range of parameters.

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I. INTRODUCTION

The Ridge Effect has been observed in two-particle long-range correlation measurements [1, 2, 3]. The main characteristic is a narrow $\Delta \phi$ and wide $\Delta \eta$ correlation around the trigger. There is also some awayside structure but experimentally less known, especially with respect to $\Delta \eta$. Originally, the trigger was chosen a high-$p_T$, presumably jet, particle, but now data are available also for low-$p_T$ trigger or no-trigger [4].

In a previous work [5], we got the ridge structure in a hydrodynamic model. In hydrodynamic approach of nuclear collisions, 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. This state is characterized by some initial conditions (IC), usually parametrized as smooth distributions of thermodynamic quantities and four-velocity. However, evidently smooth IC do not produce ridges. Since our systems are small, important event-by-event fluctuations are expected in real collisions. In earlier works, by using NeXuS event generator [6], we introduced fluctuating IC in hydrodynamics and studied several effects. In particular, the fluctuations of $v_2$, showing good agreement with data [7, 8, 9].

We call NeXSPheRIO the junction of NeXuS with our hydro code SPheRIO [10], based on the smoothed-particle hydrodynamic algorithm. The IC for high-energy nuclear collisions are not only event-by-event fluctuating but, if the thermalization is verified at very early time, they should be very bumpy. In Figure 1, we show an example of such IC, generated by NeXuS, for a Au+Au collision at 200A GeV. Observe the tubular structure in $\eta$.

The main objects of this contribution are i) to show some further results with our NeXSPheRIO code, which will be done in the next Section; and ii) to discuss what we learned about the mechanism of ridge production in our hydro model. The latter will be done in Section III.

II. SOME RESULTS ON TWO-PARTICLE CORRELATION

In this Section, we are going to show some of our recent results on two-particle correlation in Au+Au collisions at 200A GeV.

A. Centrality dependence

Data on the centrality dependence of the two-particle correlation have been reported [4]. In general, the nearside ridge decreases in height with decreasing centrality, or going from most...
FIG. 1: Energy density distribution at \( \tau = 1 \text{fm} \) for a central Au+Au collision at 200 \(^A\) GeV, given by NeXuS generator, in the collision plane (left) and in the mid-rapidity transverse plane (right).

FIG. 2: Two-particle correlation, as computed with our NeXSPheRIO code, for different centrality windows of Au+Au collisions at 200 \(^A\) GeV (a: 0-5\%, b: 5-10\%, c: 10-20\%, d: 20-30\%, e: 30-40\%, f: 40-50\%). The transverse momenta are chosen as \( p_{T \text{trig}} > 2.5 \text{ GeV} \) and \( p_{T \text{ass}} > 1.5 \text{ GeV} \) for triggers and associated particles, respectively.

central to peripheral windows, and at the same time the awayside structure in \( \Delta \phi \) changes from double humps to single peak. In Figure 2, we show our results with NeXSPheRIO. It is clearly seen there the tendency we described above (compare with Figures 36-38 of Reference 4).

B. In-plane out-of-plane effect

Another effect which has been experimentally studied is the dependence of the correlation on the azimuthal angle \( \phi_t \) of the trigger with respect to the event plane [11]. In a mid-central window, the away-side structure in \( \Delta \phi \) is a peak at \( \Delta \phi = \pi \), if the trigger is close to the event plane, and it is split into two peaks, as \( \phi_t \) goes closer to \( \pi/2 \). We show in Figure 3 our results for the 20 - 30\% centrality window. It is seen that the results show precisely the expected behavior from the data (see Figure 1 of Reference [11]).
III. ORIGIN OF THE RIDGE-STRUCTURE IN HYDRODYNAMICS

As seen, the NeXSPheRIO code does produce nice results on ridges, if we restrict ourselves to appropriate $p_T$ domain for hydrodynamic model application. However, what is the origin of ridges? Since each event in our model presents IC with many high-energy density tubes, one may associate these tubes + transverse expansion with the ridge structure. But, the phenomenon is not so trivial. Moreover, why away-side ridges? By considering mainly the central collisions, we tried to understand the origin of the ridge structure, especially the away-side one.

A. Method of study - 2D model

Let us fix our attention to one of the tubes, located close to the surface of the hot matter, for instance the one where the arrow 1 passes on in Figure 1. To study closely what happens in the neighborhood of this tube, we replace the complex background, as shown there, by a smooth one. Then, we use a 2D model with boost-invariant longitudinal expansion, to simplify the computation. We find these assumptions quite reasonable for our purpose.

Then, we parametrize the energy density as

$$\epsilon = 12 \exp[-0.0044r^5] + \frac{34}{845\pi} \exp[-\frac{|r-r_0|^2}{845}] ,$$

where $r_0 = 5.4$ fm, and the initial velocity of the fluid as

$$v_T = \tanh[4.57 \exp(-27.2/r)] ,$$

corresponding to the average NeXuS IC.

We show in Figure 4 a comparison of the parametrization above with the original energy density distribution as given by the NeXuS event we are studying. Notice that, except for the inner region, the agreement is reasonable.

B. Results

What does the high-energy tube produce, in conjunction with the background? The result is: it deflects the otherwise isotropic radial flow of the background, in such a way to produce two symmetrical peaks in the resultant flow. In Figure 5, we show the azimuthal distribution of the produced particles in different $p_T$ intervals, with respect to the tube position, set $\phi_{tube} = 0$.

Let us see what the corresponding two-particle correlation looks like. In Figure 6, we show similar plots as in Figure 5, but in polar coordinates and for triggers with $p_T > 2$ GeV and $p_{ass} > 1$ GeV.
FIG. 5: Angular distributions of particles in some different \( p_T \) intervals, in the 2D model.

FIG. 6: Top panel: Angular distributions of trigger particles (\( p_T > 2 \text{GeV} \)) and the associated particles (\( p_T > 1 \text{GeV} \)). Bottom panel: Corresponding correlations, if the triggers are 1) at \( \sim \pi/4 \) (green); 2) at \( \sim -\pi/4 \) (cian); and 3) half of them at \( \sim \pi/4 \) and the other half at \( \sim -\pi/4 \) (black).

associate particles with \( p_T > 1 \text{GeV} \). Now, if a trigger is found at \( \phi_t \sim \pi/4 \) (trigger 1), then, the corresponding correlation will be exactly the associated-particle distribution plotted there, but turned clockwise the same angle \( \phi_t \). Similarly, if a trigger is at \( \phi_t \sim -\pi/4 \) (trigger 2), the correlation will be equal to the associated-particle distribution, but now turned counter-clockwise the same angle. Now, the triggers 1 and 2 are equally probable, so for a sample of events with half of the triggers of type 1 and the other half of type 2, the correlation will be an average of these two as plotted in black in the bottom panel of Figure 6. Actually, we have to integrate over \( \phi_t \) to obtain the resultant correlation in our model. The results are shown in Figure 7, together with the associated-particle-momentum dependence.

C. Parameter dependence

We studied how our previous results depend on the several parameters which define our energy density and the velocity distributions of IC given by Eqs. (1) and (2). The two-particle correlation is almost insensitive to some of the parameters like the height of the background and the transverse velocity. Other parameters importantly affect the intensity of the correlation, without changing the shape of the three-peak
structure. See some of the results in Figure 8. An important result, which we could not include here due to the space limitation, is the shape of the background. Long-tailed background like Gaussian one, does not produce strong correlation through the mechanism described here.

IV. CONCLUSIONS

In conclusion, the hydrodynamic expansion starting from fluctuating IC with tubular structure produces the ridge structure in the 2-particle correlation. We showed in this paper that the NeXSPheRIO code can reproduce several observed characteristics of the ridge effect.

In central collisions, a high-density tube, close to the surface of the hot matter, causes flow with two maxima in azimuth, symmetrical with respect to the tube position. Such a flow implies a near-side peak and double, symmetrical away-side peaks in $\Delta \phi$ in the 2-particle correlation, with respect to the high-$p_T$ trigger.

The shape of 2-particle correlation curve is more or less stable in a wide range of parameters. The intensity of the correlation depends strongly on the height and the radius of the tube and its position, but not sensitive neither to the height of the background nor to the initial transverse velocity. The shape of the background is an important factor. Long-tailed background like Gaussian one, does not produce strong correlation through this mechanism.

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[1] Putschke J [for the STAR Collaboration] (2007) Nucl Phys A783 507.
[2] McCumber MP [for the PHENIX Collaboration] (2008) J Phys G35 014081.
[3] Li W [for the PHOBOS Collaboration] (2008) J Phys G35 104142.
[4] PHENIX Collaboration, Adare A., et al. (2008) Phys Rev C78 014901.
[5] Takahashi J, Tavares BM, Qian WL, Andrade RPG, Grassi F, Hama Y, Kodama T, and Xu N, arXiv:0902.4870.
[6] Drescher HJ, Liu FM, Ostapchenko S, Pierog T and Werner K (2002) Phys Rev C65 054902.
[7] Osada T, Aguiar CE, Hama Y and Kodama T,
[8] Aguiar CE, Hama Y, Kodama T, and Osada T, (2002) Nucl Phys A698 639.

[9] Hama Y, Andrade RPG, Grassi F, Qian WL, Osada T, Aguiar CE, and Kodama T (2008) Phys Atom Nuclei 71 1588.

[10] Aguiar CE, Kodama T, Osada T and Hama Y, (2001) J Phys G27 75.

[11] Feng A [for the STAR Collaboration] (2008) J Phys G35 104082.