COMPARATIVE STUDY OF HADRON- AND γ-TRIGGERED AZIMUTHAL CORRELATIONS IN RELATIVISTIC HEAVY-ION COLLISIONS*

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In the framework of a multi-phase transport model, initial fluctuations in the transverse parton density lead to all orders of harmonic flows. Hadron-triggered azimuthal correlations include all contributions from harmonic flows, hot spots, and jet-medium excitations, which are isolated by using different initial conditions. We found that different physical components dominate different pseudorapidity ranges of dihadron correlations. Because γ-triggered azimuthal correlations can only be caused by jet-medium interactions, a comparative study of hadron- and γ-triggered azimuthal correlations can reveal more dynamics about jet-medium interactions.

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1. Introduction

Jets are good probes to study the properties of partonic matter created in relativistic heavy-ion collisions [1]. Experimentally, one can measure high transverse-momentum ($p_{\rm T}$) hadron-triggered azimuthal correlations, *i.e.*, dihadron correlations, to learn how jets and medium interact. However, it is

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a key question for dihadron studies how to remove the harmonic flow background completely. The large initial fluctuations play important role for the formation of collective flow, which includes not only even but also odd orders of harmonic flows [2]. Since these odd orders of harmonic flows were ignored in previous background subtractions of dihadron correlations, it is essential to take all orders of harmonic flows into account. On the other hand, γ-triggered azimuthal correlations, *i.e.*, γ-hadron correlations, are unique probes because direct photons have neither strong interactions with medium nor harmonic flows. It implies that γ-hadron correlations are only due to jet-medium interactions. Therefore, a comparative study of hadron- and gamma-triggered azimuthal correlations can reveal more dynamics about jet-medium interactions in relativistic heavy-ion collisions [3, 4].

2. Model introduction

A multi-phase transport (AMPT) model is employed in our simulations. The AMPT model consists of four main processes: the initial condition, partonic interactions, conversion from partonic to hadronic matter, and hadronic interactions. The initial condition is obtained from the Heavy Ion Jet Interaction Generator (HIJING) model. Within HIJING, multiple nucleon scatterings, which include soft and hard interactions, can lead to fluctuations in local parton number density or hot spots. Scatterings among partons are modeled by Zhang's Parton Cascade (ZPC) model, which includes only two-body scatterings currently. There are two versions of AMPT models with different mechanisms for parton evolution and hadronization. In the default version of the AMPT model, partons only include minijet partons, and recombine with their parent strings when they stop interactions, then the resulting strings are converted to hadrons by using the Lund string fragmentation mechanism. While in the version with the string melting mechanism, partons include both minijet partons and partons from melted strings, and a quark coalescence model is used to combine partons into hadrons. The dynamics of the subsequent hadronic matter is then described by a relativistic transport (ART) model for both versions. Details of the AMPT model can be found in a review [5].

In this work, we choose the AMPT model with string melting mechanism (partonic interaction cross section is set to 10 mb) to study both hadron- and γ-triggered azimuthal correlations in most central Au+Au collisions ($b = 0$ fm) at $\sqrt{s_{NN}} = 200$ GeV, with considering of the background subtraction including all orders of harmonic flows.

3. Initial fluctuations and harmonic flows

So far, one has no alternative and has to gain the information about the initial state from models, because experimentalists can measure only the momentum space of hadrons in the final state. In traditional hydrodynamical models, they treat the initial energy density distribution as a smooth profile. Because of the geometrical symmetry, only even orders of harmonic flows can be built up while odd orders of harmonic flows do not exist. However, there are large initial fluctuations in the initial state, therefore, it is not smooth in fact. Figure 1 shows contour plots of initial parton density in the transverse plane, $dN/dxdy$ (left panel), and in x–η (pseudorapidity) plane, $dN/dxd\eta$ within a slice $|y| < 1\,\text{fm}$ (right panel), for a typical AMPT event. We found that there are indeed large fluctuations with many hot spots in the energy density distribution (left panel). On the other hand, hot spots in the fluctuating initial parton density distribution are extended in the longitudinal direction (right panel), which is thought as an important source for the formation of ridge-like structure [3].

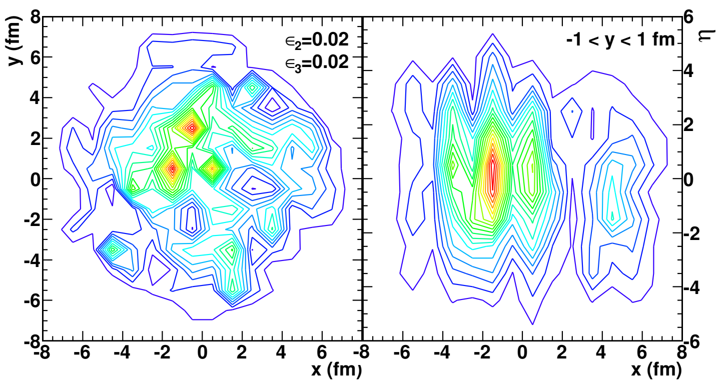

Fig. 1. (Color online) Contour plots of initial parton density (in arbitrary units), $dN/dxdy$ in x–y plane (left panel) and $dN/dxd\eta$ in x–η plane (right panel) within a slice $|y| < 1\,\text{fm}$ for a typical AMPT event.

These fluctuations could result in different geometry shapes of initial distributions, which implies that the transverse shape is not always an isotropic circle any more even for $b = 0\,\text{fm}$ events. It is also possible that it shapes as an ellipse, a triangle, a square, and so on. Since these different shapes can be translated to final momentum space by final interactions, it is no wonder that harmonic flows have all kinds of orders (even and odd). We reconstruct event planes for different orders by the following equation

$$\psi_n = \frac{1}{n}\left[\arctan\frac{\langle r^2\sin(n\varphi)\rangle}{\langle r^2\cos(n\varphi)\rangle} + \pi\right], \tag{1}$$

where (r, φ) are polar coordinates of each initial parton and the average $\langle \cdots \rangle$ is density weighted. Figure 2 shows the harmonic flows, $v_n = \langle \cos n(\phi - \psi_n) \rangle$, of final hadrons for $b = 0$ fm and Au+Au collisions at $\sqrt{s} = 200$ GeV. We found that the different orders of harmonic flows are not zero even for $b = 0$ fm events.

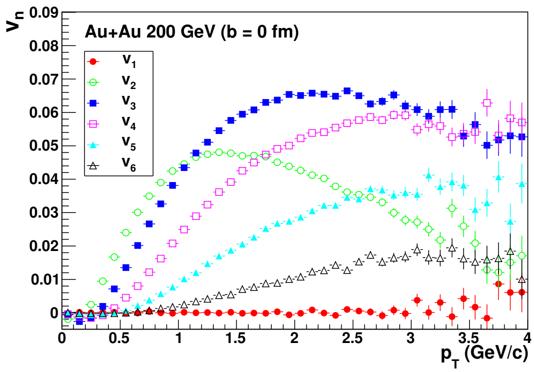

Fig. 2. (Color online) Azimuthal anisotropies of hadron spectra $v_n(p_T)$ ($n = 1$–6) from AMPT calculations.

4. Hadron-triggered azimuthal correlations

Many experimental results on dihadron correlations have shown that jets quench significantly and the lost energies may excite the medium. However, it is a critical question for the dihadron studies how to completely remove harmonic flow background to see the medium responses. Because traditional dihadron studies only remove even orders of harmonic flows, it is necessary to remove all orders of the harmonic flow background including odd orders of harmonic flows as well.

Figure 3 shows dihadron correlations before (dot-dashed) and after (solid) the removal of contributions from harmonic flows for $p_T^{\rm trig} > 2.5$ GeV/c and $1 < p_T^{\rm asso} < 2$ GeV/c. The contributions from each harmonic flow, $n = 2$–6 (dashed), are also shown. These contributions are significant up to $n = 5$ harmonics. We subtract the harmonic flow background, as shown in Eq. (2), from the combinatorial dihadron correlation, where B is a normalization factor determined by the zero-yield-at-minimum (ZYAM) method

$$f(\Delta\phi) = B\left(1 + \sum_{n=1}^{\infty} 2\left\langle v_n^{\rm trig} v_n^{\rm asso}\right\rangle \cos n\Delta\phi\right) . \qquad (2)$$

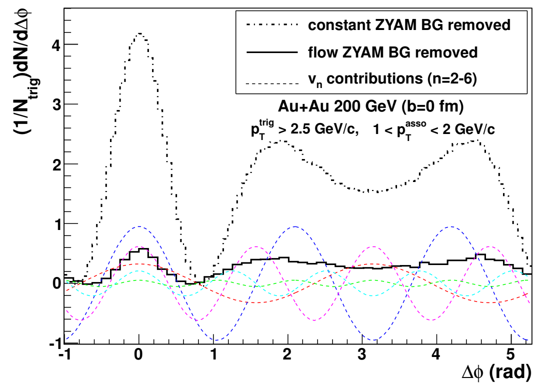

Fig. 3. (Color online) AMPT results on dihadron correlations before (dot-dashed) and after (solid) subtraction of the contribution from harmonic flows $v_n (n = 2–6)$ (dashed).

It is expected that after all components of the harmonic flow background are subtracted, the remaining dihadron correlation should be independent of initial geometry irregularities. Figure 4 presents that the dihadron correlations after subtraction of contributions from harmonic flows become independent of the initial geometric triangularity ϵ_3.

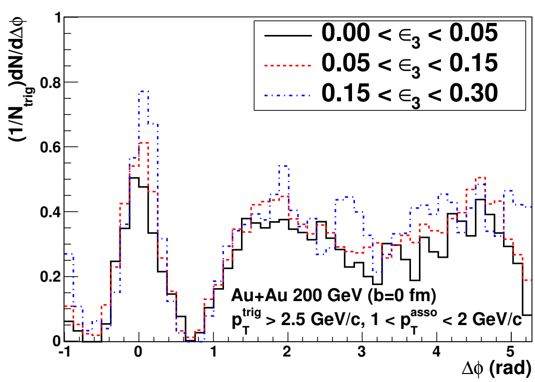

Fig. 4. (Color online) AMPT results on dihadron correlations after subtraction of harmonic flow background with different values of the geometric triangularity ϵ_3.

In order to study how initial conditions affect final dihadron correlations, we employ four different initial conditions in our AMPT model simulations. We first randomize the azimuthal angle of each jet shower parton in the initial condition from HIJING simulations. This effectively switches off the initial back-to-back correlation of dijets. The dihadron correlation (dashed) denoted as "hot spots" in Fig. 5 still exhibits a double-peak on the away-side that comes only from hot spots. It has roughly the same opening angle

$\Delta\phi \sim 1$ (rad) as in the "full" simulation (solid). However, the magnitude of the double-peak in the away-side correlation is reduced by about 40%, which can be attributed to dihadrons from medium modified dijets and jet-induced medium excitations. When jet production is turned off in the HIJING initial condition, fluctuations in soft partons from strings can still form "soft hot spots" that lead to a back-to-back dihadron correlation (dot-dashed) with a weak double-peak. Such "soft hot spots" are the likely candidate mechanism for the observed back-to-back dihadron correlation in heavy-ion collisions at the SPS energy [6], where jet production is insignificant. Without jets in AMPT, one can further randomize the polar angle of transverse coordinates of soft partons and therefore eliminate the "soft hot spots". The dihadron correlation from such "smoothed" initial condition becomes almost flat (dotted).

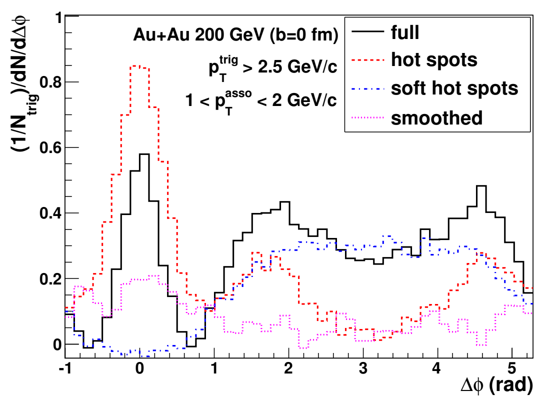

Fig. 5. (Color online) Dihadron correlations (with harmonic flow background subtracted) from AMPT with different initial conditions. See the text for details on the different initial conditions.

However, because the results in Fig. 5 include both short and long range dihadron correlations($|\Delta\eta| < 2$), it is necessary to compare short and long range dihadron correlations to study the pseudorapidity range dependence of dihadron correlations. Figure 6 shows the background removed dihadron correlations for $p_T^{\rm trig} > 2.5\,{\rm GeV}/c$ and $1 < p_T^{\rm asso} < 2\,{\rm GeV}/c$ from AMPT calculations with full initial condition. It can be seen that dihadron azimuthal correlation is very sensitive to the pseudorapidity range between trigger and associated hadrons ($\Delta\eta = \eta_{\rm asso}-\eta_{\rm trig}$). The remaining short range dihadron correlations ($|\Delta\eta| < 3$) can carry the information about hot spots and jet-medium interactions beyond harmonic flows. However, harmonic flows basically can account for the very long range dihadron correlations ($|\Delta\eta| > 3$).

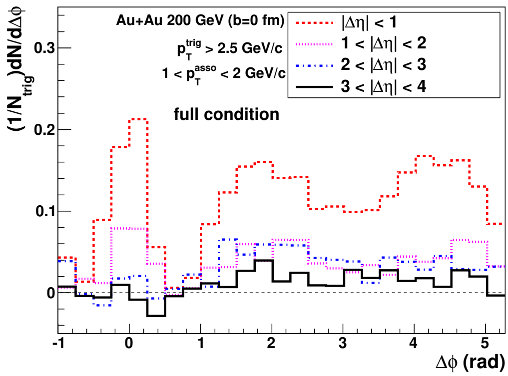

Fig. 6. (Color online) Dihadron correlations with different pseudorapidity ranges (with harmonic flow background subtracted) from AMPT calculations with full initial condition.

5. γ-triggered azimuthal correlations

Compared with dihadron correlations, γ-hadron correlations have their own unique advantages [7]. Because direct (prompt) photons, produced isotropically, have neither strong interactions with medium nor harmonic flows, the background for γ-hadron correlation is flat. Therefore, γ-hadron correlation is a golden probe to study jet-medium interactions. Any structures in γ-hadron correlations with large p_{T}^{γ} should be only due to jet-medium interactions. Figure 7 shows that γ-hadron correlation ($p_{\mathrm{T}}^{\mathrm{trig}}(\gamma) \sim 15\,\mathrm{GeV}/c$ and $1 < p_{\mathrm{T}}^{\mathrm{asso}} < 2\,\mathrm{GeV}/c$) is comparable with dihadron correlation in magnitude but with a less pronounced double-peak, which can be attributed to additional dihadron correlations from hot spots, geometric bias toward surface, and tangential emissions that enhance deflections of jet showers and jet-induced medium excitations by radial flow [4].

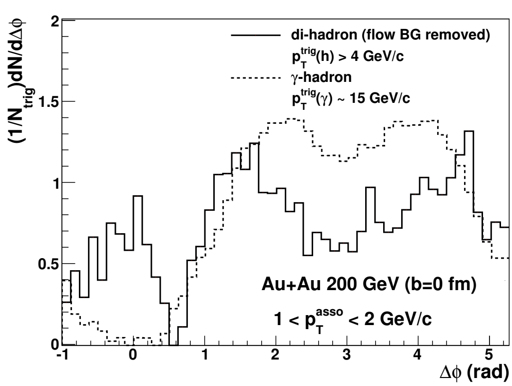

Fig. 7. Dihadron correlation (solid) compared with γ-hadron correlation (dashed) from AMPT model calculations.

6. Summary

Harmonic flows are not just the elliptic flow (v_2), because odd orders of flows arise from large initial fluctuations. The harmonic flow background significantly affects dihadron correlations, especially due to odd orders of harmonic flows. Hot spots and jet-medium interactions support short-range dihadron correlations up to $\Delta\eta \sim 3$, while harmonic flows account for longer range dihadron correlations. A comparative study between γ-hadron and dihadron correlations can help us to approach a whole picture about jet-medium interactions.

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