Event geometrical anisotropy and fluctuation viewed by HBT interferometry

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Abstract

Azimuthal angle dependence of the pion source radii was measured applying the event shape selection at the PHENIX experiment. The measured final source eccentricity is found to be enhanced when selecting events with higher magnitude of the second-order flow vector, as well as the elliptic flow coefficient v_2. The spatial twist of the particle-emitting source was also explored using a transport model. Results indicate a possible twisted source in the final state due to the initial longitudinal fluctuations.

1 Introduction

Higher-order flow coefficients v_n are useful observables to constrain the properties of the quark-gluon plasma, such as a shear viscosity over entropy density ratio, in heavy ion collisions [1, 2]. The v_n are found to largely fluctuate in each event even if the collision centrality is fixed [3], which is due to the initial spatial fluctuation of participating nucleons. To control such event-by-event initial fluctuations, the event shape engineering was suggested [4]. The event shape engineering can be performed by selecting the magnitude of the event flow vector Q_2:

$$
\begin{aligned}
Q_2 &= \sqrt{q_{2,x}^2 + q_{2,y}^2}/\sqrt{M}, &&(1)\\
q_{2,x} &= \sum_i w_i \cos(2\phi_i), \quad q_{2,y} = \sum_i w_i \sin(2\phi_i),
\end{aligned}
$$

where M is the particle multiplicity, ϕ_i is the azimuthal angle of particles, and w_i is a weight for particle i. The magnitude of Q_2 is proportional to the strength of event-by-event v_2 and also reflects the resolution of the second order event plane. This technique could allow us to test the effect of the initial geometry on the final state distribution of emitted particles, which help to understand the medium response through the system evolution.

The event shape engineering focuses on the fluctuations in the transverse plane. It is naturally considered that there would be the fluctuations not only in the transverse plane but also in the longitudinal direction. The presence of such fluctuations could cause a twisted source along the longitudinal direction [5]. The number of participants going to the forward and backward directions would be different, and therefore participant planes might also be different. As a result, the event plane angle in the final state could be different between the forward and backward angles. Thus the initial spatial twist may survive in the final state as well as a twisted flow [8, 9].

In this proceedings, we present results on HBT measurements using charged pions and applying the event shape engineering technique for Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV recorded with the PHENIX experiment. Also, we examine the possibility of a spatially twisted source in the final state using HBT interferometry in AMPT model.

2 The event shape engineering at the PHENIX

The flow vector was determined by the Reaction Plane Detector (RXN, $1 < |\eta| < 2.8$). In our analysis, the w_i in Eq. (2) reflects the multiplicity or energy measured in a segment i of the RXN and M is $\sum w_i$. The tracking for charged particles was performed by the Drift Chamber and the Pad Chamber, and the particle identification was done by the electromagnetic calorimeter, where they have the acceptance of $|\eta| < 0.35$ and $|\phi| < \pi/2$ in the west and east central arms.

The measured Q_2 distributions were fitted with the Bessel-Gaussian function [4], and then the events were classified with the magnitude of Q_2. Figure 1 shows charged hadron v_2 for the higher 20% and the lower 30% Q_2 events. Results without Q_2 selection are also plotted for the comparison. The effect of Q_2 selection
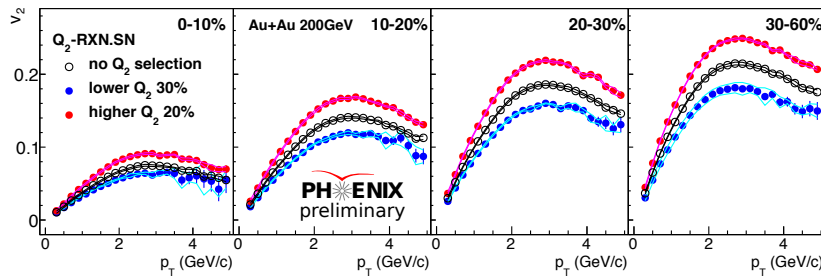

Figure 1: Charged hadron v_2 as a function of p_{T} for four centrally bins with and without the Q_2 selection in Au+Au 200 GeV collisions. The lower and higher Q_2 events were selected.

on the v_2 is clearly observed, that is, the higher (lower) Q_2 enhances (decreases)

the strength of v_2 compared to the v_2 without the Q_2 selection.

Then the Q_2 selection was applied to the HBT measurements using charged pion pairs. In the HBT analysis, pion pairs were analyzed with the out-side-long parameterization [10, 11] in the longitudinally co-moving system. The effect of the event plane resolution was also corrected for both cases with and without Q_2 selection. Figure 2(left) shows the extracted pion HBT radii, R_{s}^2 and R_{o}^2, as a function of azimuthal pair angle ϕ relative to the second-order event plane Ψ_2. Results show that the higher Q_2 selection increases the oscillation strength compared to the case without Q_2 selection.

These oscillations of HBT radii are supposed to be sensitive to the final source eccentricity at freeze-out, $\varepsilon_{\mathrm{final}}$. Blast-wave studies suggest that the quantity of $2R_{\mathrm{s},2}^2/R_{\mathrm{s},0}$ would be a good probe of $\varepsilon_{\mathrm{final}}$ in the limit of $k_{\mathrm{T}} = 0$, where k_{T} denotes a mean transverse momentum of pairs. The oscillation amplitudes of R_{s}^2 and R_{o}^2 in a form of the final eccentricity are plotted as a function of the number of participants calculated by Glauber model in Fig. 2(right). The higher Q_2 selection enhances the measured $\varepsilon_{\mathrm{final}}$ as well as v_2. It could be originating from a larger initial eccentricity, although there should be a bias from selecting the larger v_2 events because the radii modulations also depend on the anisotropy in the momentum space [6, 7].
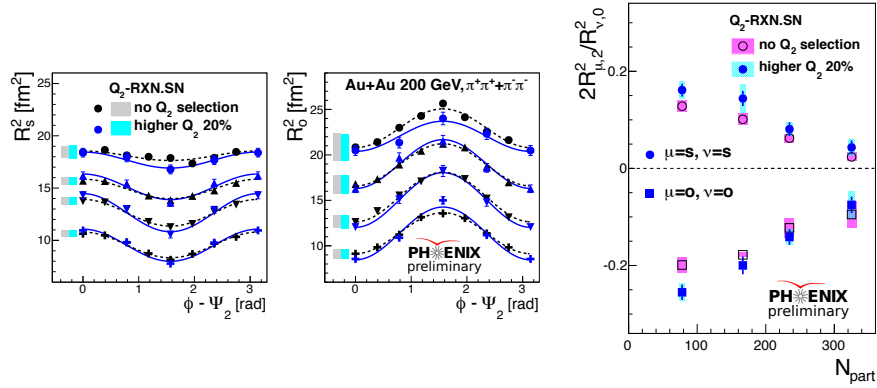

Figure 2: (Left and center) Azimuthal angle dependence of R_{s}^2 and R_{o}^2 relative to Ψ_2. (Right) 2nd-order azimuthal oscillation on R_s^2 and R_o^2. In both panels, results with and without higher Q_2 selection are shown.

3   Study on the event twist effect

The data of Pb+Pb 2.76 TeV collisions simulated using a Multi Phase Transport Model (AMPT, v2.25 with string melting) were used for the study on the twist effect of the particle-emitting source in the final state. The impact parameter was fixed to 8 fm. For the HBT study, the interference effect between two identical particles, $1 + \cos(\Delta \mathbf{r} \cdot \Delta \mathbf{p})$, was calculated and weighted to the relative pair momentum distributions. Then the correlation functions were reconstructed by taking a ratio of the distributions with and without the weight. Also, all charged pions were allowed to make a pair with each other including $\pi^+\pi^-$ to increase the statistics (the consistency between results for positive and negative pairs was checked). The event plane was determined using particles in $4 < |\eta| < 6$, where particles were

divided into two sub-groups. A set of forward and backward event planes $\left(\Psi_2^{\mathrm{F}}, \Psi_2^{\mathrm{B}}\right)$ were used for the event cut which requires finite difference between Ψ_2^{F} and Ψ_2^{B} as a event twist selection, whereas the other set of event planes was used for a reference angle of azimuthal HBT measurements. The effect of the event plane resolution was not taken into account in this study, assuming the resolution hardly affects the phase of the radii oscillations but the magnitude of the oscillations.

Figure 3 shows R_{s}^2, R_{o}^2, and R_{os}^2 as a function of azimuthal pair angle relative to the Ψ_2^{B} $(\Delta\phi)$ for four η regions, where $(\Psi_2^{\mathrm{B}} - \Psi_2^{\mathrm{F}}) > 0.6$ was required. The oscillations of the HBT radii measured in $\eta > 0$ are shifted to the direction of $\Delta\phi < 0$, which is the direction of Ψ_2^{F} in the current event cut. This phase shift can be understood to be a possible twist effect in the final source distribution. The radii oscillations measured in $\eta < 0$ have no phase shift because the negative η is closer to the backward angle used for a reference of the HBT measurement and therefore the twist effect is supposed to be small. Figure 4 shows all the extracted radii parameters measured with respect to Ψ_2^{B} and Ψ_2^{F} with the event cut of $(\Psi_2^{B} - \Psi_2^{F}) > 0.6$. The phase shift can be seen in the transverse radii (not in the longitudinal radii including the cross terms) when comparing the results for Ψ_2^{B} and Ψ_2^{F} in the same η region. It indicates the twist of the event plane angles in the backward and forward angles. These oscillations were fitted with the following functions:

$$R_\mu^2(\Delta\phi) = R_{\mu,0}^2 + 2R_{\mu,2}^2 \cos(2\Delta\phi + \alpha) \ \text{(for } \mu = o, s), \qquad (2)$$

$$R_\mu^2(\Delta\phi) = R_{\mu,0}^2 + 2R_{\mu,2}^2 \sin(2\Delta\phi + \alpha) \ \text{(for } \mu = os), \qquad (3)$$

to extract the magnitude of the phase shift (α). The phase shift parameter α obtained from the results with respect to Ψ_2^{F} and Ψ_2^{B} is plotted as a function of η in Fig. 4. The α increases going from backward to forward angle in all cases. The variation of α in the η dependence is comparable to the difference between results relative to Ψ_2^{F} and Ψ_2^{B} at the same η. The finite slope in the η dependence of α indicates the twisted source in the final state due to the initial longitudinal fluctuations, as well as the twisted event plane and flow as discussed in Ref. [8, 9]. In this study, the effect of the event plane resolution is assumed to be negligible, but there should be an uncertainty derived from the event cut of $(\Psi_2^{\mathrm{B}} - \Psi_2^{\mathrm{F}})$ and their finite event plane resolutions.
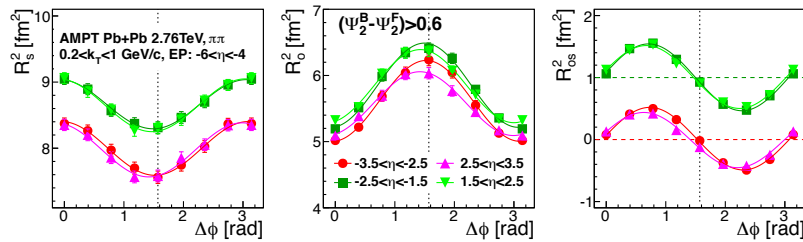

Figure 3: Azimuthal angle dependence of R_{s}^2, R_{o}^2, and R_{os}^2 relative to the backward Ψ_2 with the event cut of $(\Psi_2^{\mathrm{B}} - \Psi_2^{\mathrm{F}}) > 0.6$, where the dashed lines show $R_{\mathrm{os}}^2 = 0$ and the dotted lines show $\Delta\phi = \pi/2$.
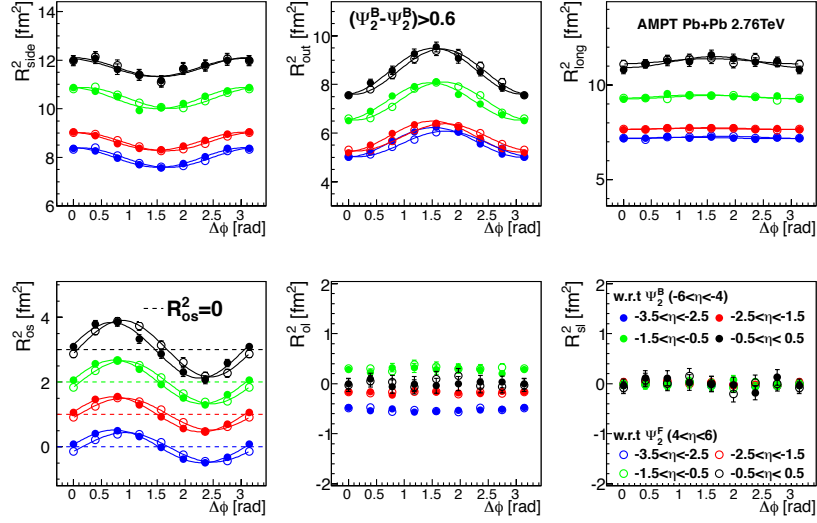
Figure 4: Azimuthal angle dependence of the radii parameters relative to the backward and forward Ψ_2 with the event cut of $(\Psi_2^{\mathrm{B}} - \Psi_2^{\mathrm{F}}) > 0.6$, where the dashed lines show $R_{\mathrm{os}}^2 = 0$.

4 Summary

We presented the results of HBT measurements using the event shape engineering for Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV at the PHENIX experiment. We found that the higher Q_2 selection enhances the measured final source eccentricity as well as v_2. Although the model comparison is needed to disentangle both spatial and dynamical effects on the HBT radii, this study would clarify the relation between the initial and final source eccentricities and constrain better the system dynamics.

We also studied the event twist effect using AMPT model. When selecting events with finite difference between forward and backward event plane angles, the oscillations of HBT radii are shifted in the phase and the phase shift increases with η. The results indicate a possible twisted source in the final state preserving the initial twist due to the longitudinal fluctuations. This effect might be measured in experiments at RHIC and the LHC.

Both techniques could be useful to probe and control initial fluctuations in transverse plane and longitudinal directions, as well as to study the response of the system to the space-time evolution.

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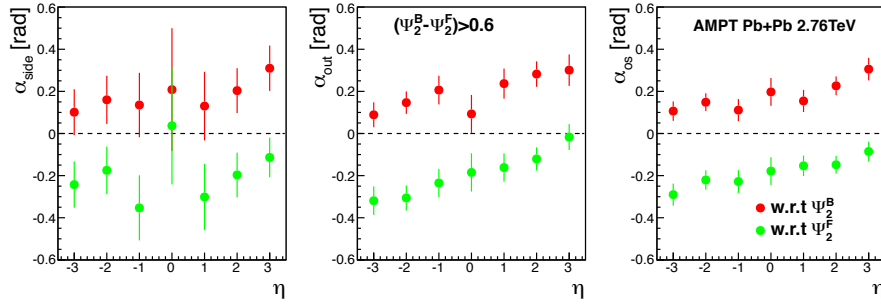[3] G. Aad *et al.* (ATLAS Collaboration), JHEP **11** (2013) 183.

Figure 5: Phase shift parameters α obtained from the R_{s}^2, R_{o}^2, and R_{os} as a function of η. Results measured with respect to forward and backward event planes (Ψ_2^{F}, Ψ_2^{B}) are shown, with the event cut of ($\Psi_2^{\mathrm{B}} - \Psi_2^{\mathrm{F}}$) > 0.6.

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