Final source eccentricity measured by HBT interferometry with the event shape selection

Takafumi Niida for the PHENIX Collaboration

University of Tsukuba, 1-1-1 Tennoudai, Tsukuba, Ibaraki 305-8571, Japan

E-mail: `niida@bnl.gov`

Abstract. Azimuthal angle dependence of the pion source radii has been measured applying the event shape engineering technique at the PHENIX experiment. When events with higher magnitude of second-order flow vector are selected, the oscillation of the source radii is enhanced as well as v_2 which leads to the enhancement of the measured final source eccentricity. The event twist effect in the spatial source distribution in the final state has been also explored with AMPT model. Results indicate a possible twisted source 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 a heavy ion collision [1, 2]. The v_2 is mainly caused by the almond shape of the nuclear overlap region, but higher-order flow, v_3, v_4, $\cdots$, especially their odd components are originating from the initial spatial fluctuations of participant nucleons. Recently ATLAS experiment has presented results of event-by-event v_n [3], where v_n values show large variations even in the fixed centrality bin due to initial fluctuations. To control such an initial fluctuation, the event shape engineering was suggested [4]. This could be a useful tool to study the response of initial state to the system evolution and connect the initial and final states. In these 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.

The event shape engineering focuses on the fluctuations in the transverse plane, but the presence of fluctuations in longitudinal direction could cause a twisted source along that direction [5]. The number of participants going to the forward and backward directions is not necessarily the same, and also participant eccentricities and participant planes might be different at both angles, which leads to different event plane angles between forward and backward rapidities. Thus the initial twist may survive as a twisted flow in the final state [8, 9]. In these proceedings, we examine the possibility of a spatially twisted source in the final state using HBT interferometry in AMPT model.

2. HBT measurements with event shape selection at PHENIX

The event shape selection was performed by selecting the magnitude of 2^{nd}-order flow vectors, Q_2, which were measured by the Reaction Plane Detector (RXN, $1 < |\eta| < 2.8$). The Q_2 is

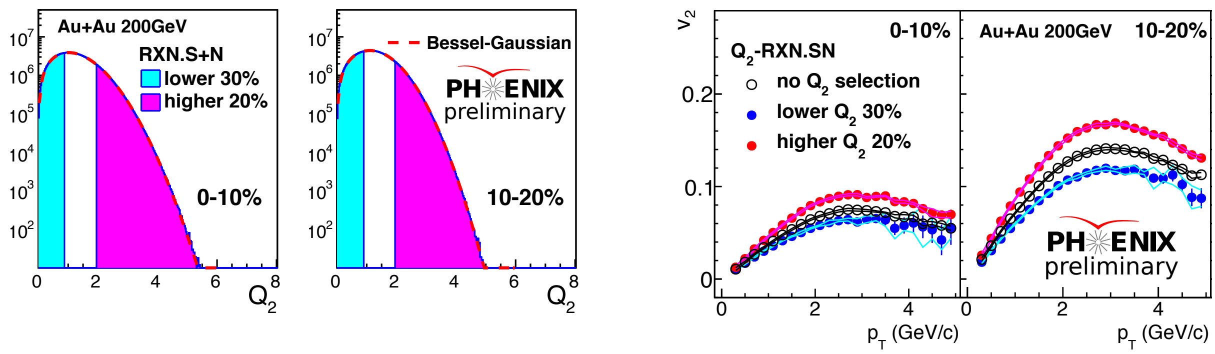

Figure 1. (Left) Q_2 distributions measured with the RXN in Au+Au 200 GeV collisions, indicating 20%(30%) higher(lower) Q_2 events. (Right) Charged hadron v_2 as a function of p_T with and without event shape selection.

defined as $Q_2 = \sqrt{Q_{2,x}^2 + Q_{2,y}^2}/\sqrt{\Sigma w_i}$, where $Q_{2,x} = \Sigma w_i \cos(2\phi)$, $Q_{2,y} = \Sigma w_i \sin(2\phi)$, and w_i reflects the multiplicity within the element i of the RXN. Figure 1(left) shows Q_2 distributions for two centrality bins, where the higher 20% and the lower 30% Q_2 events are shown filled. We have tested the effect of the Q_2 selection on charged hadron v_2 as shown in Fig. 1(right), where the v_2 is measured at mid-rapidity ($|\eta| < 0.35$) and the systematic uncertainty from different event planes of south, north, and both combined RXN is included. It is confirmed that the Q_2 selection enhances or decreases the strength of v_2. Then we have applied this technique to the HBT measurement using charged pion pairs. Charged pions were identified by the electromagnetic calorimeter (EMCal, $|\eta| < 0.35$) and the pair selection cuts at the drift chamber and EMCal were applied to remove the effects of mis-reconstructed tracks and detector inefficiency. For 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, $R_{\rm s}$ and $R_{\rm o}$, 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, $\varepsilon_{\rm final}$. Blast-wave studies suggest that the quantity of $2R_{\rm s,2}^2/R_{\rm s,0}$ would be a good probe to $\varepsilon_{\rm final}$ in the limit of $k_{\rm T} = 0$, where $k_{\rm T}$ denotes a mean pair transverse momentum. The oscillation amplitudes of $R_{\rm s}^2$ and $R_{\rm o}^2$ 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 $\varepsilon_{\rm final}$ as well as v_2. It could be originating from a larger initial eccentricity, although there should be a contribution from the selected flow itself because the radii modulations also depend on the anisotropy in the momentum space [6, 7].

3. HBT measurements with event twist selection in AMPT model

To study the twisted source in the final state, we used the data of Pb+Pb 2.76 TeV collisions simulated using AMPT model (v2.25 with string melting), where 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

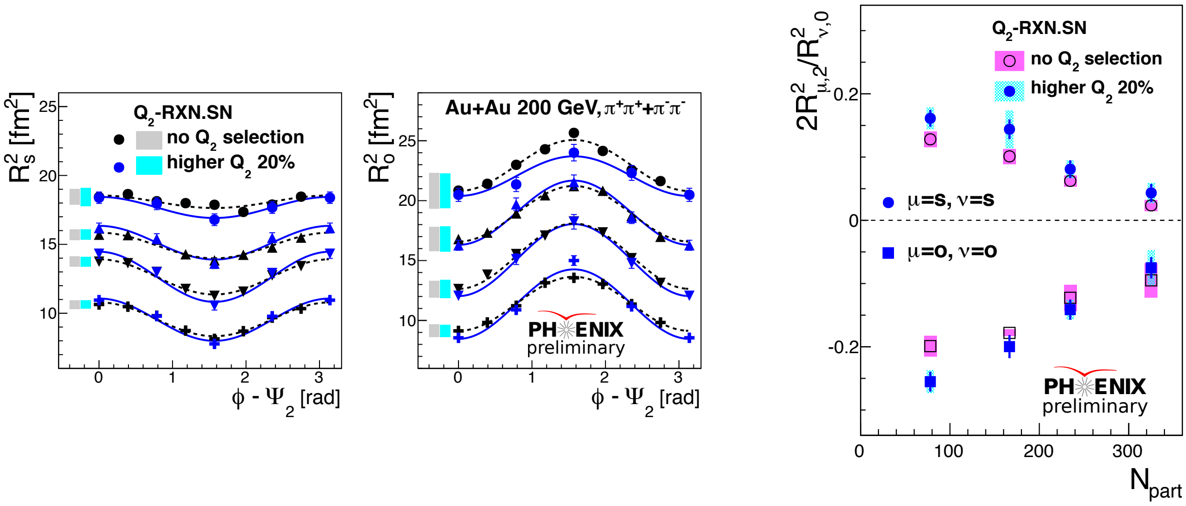

Figure 2. (Left and center) Azimuthal angle dependence of $R_{\rm s}^2$ and $R_{\rm o}^2$ relative to Ψ_2. (Right) 2[nd]-order azimuthal oscillation on R_s^2 and R_o^2. In both panels, results with and without higher Q_2 selection are shown.

were divided into two sub-groups. A set of forward and backward event planes $(\Psi_2^{\rm F}, \Psi_2^{\rm B})$ were used for the event cut which requires finite difference between $\Psi_2^{\rm F}$ and $\Psi_2^{\rm B}$ as a event twist selection, whereas the other set of events was used for a reference angle of azimuthal HBT measurement.

Figure 3(left) shows $R_{\rm s}^2$, $R_{\rm o}^2$, and $R_{\rm os}^2$ as a function of azimuthal pair angle relative to the $\Psi_2^{\rm B}$, $\Delta\phi$, for four η regions, where $(\Psi_2^{\rm B} - \Psi_2^{\rm F}) > 0.6$ was required. The oscillations of three HBT radii measured in positive η regions are shifted to negative direction, which is the direction of $\Psi_2^{\rm F}$ in the current event cut. This phase shift can be understood to be a possible twist effect in the final source distribution. These oscillations were fitted with the following functions:

$$R_\mu^2(\Delta\phi) = R_{\mu,0}^2 + 2R_{\mu,2}^2\cos(2\Delta\phi + \alpha) \quad (\text{for } \mu = o, s), \tag{1}$$
$$R_\mu^2(\Delta\phi) = R_{\mu,0}^2 + 2R_{\mu,2}^2\sin(2\Delta\phi + \alpha) \quad (\text{for } \mu = os), \tag{2}$$

to extract the magnitude of the phase shift, which is taken into account with α. The phase

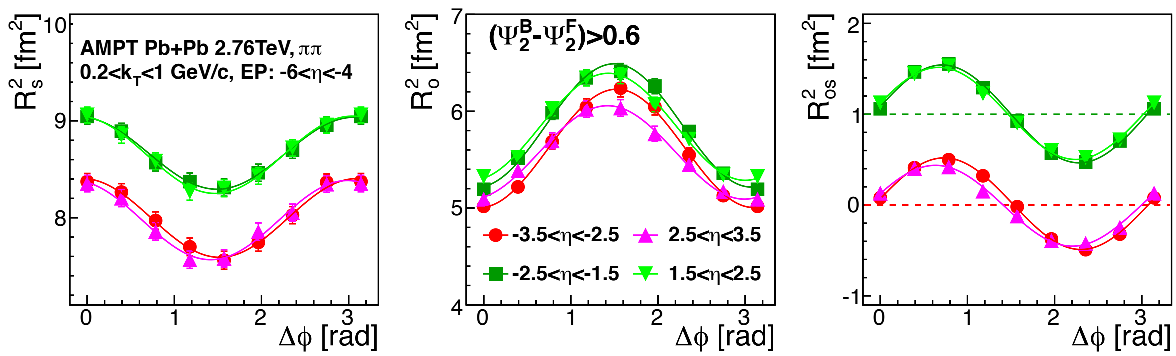

Figure 3. Azimuthal angle dependence of $R_{\rm s}^2$, $R_{\rm o}^2$, and R_{os}^2 relative to the backward Ψ_2 with the event cut of $(\Psi_2^{\rm B} - \Psi_2^{\rm F}) > 0.6$, where the dashed lines show $R_{\rm os}^2 = 0$.

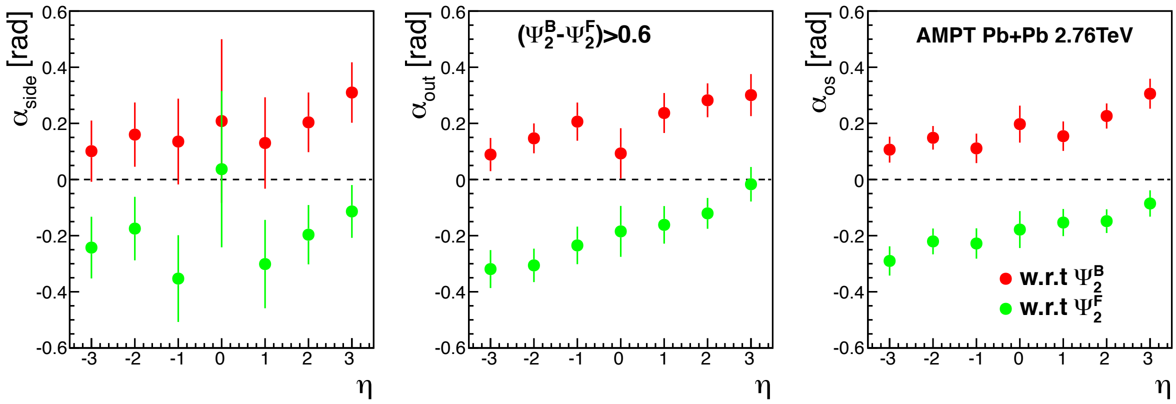

Figure 4. Phase shift parameters α obtained from the R_s^2, R_o^2, and R_{os} as a function of η. Results measured with respect to forward and backward event planes (Ψ_2^F, Ψ_2^B) are shown, with event cut of $(\Psi_2^B - \Psi_2^F) > 0.6$.

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 with 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. These results indicate that the source in the final state is also twisted due to longitudinal fluctuations in the initial state, as well as the twisted event plane and flow as discussed in Ref. [8, 9].

4. Summary

We presented the results of HBT measurements using event shape engineering for collisions recorded with 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 clarifies the relation between initial and final eccentricity and constrains better the system dynamics.

We have also studied the event twist effect using the 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 could 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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