Detailed HBT measurements with respect to the event plane and collision energy in Au+Au collisions at PHENIX

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Abstract

The azimuthal dependence of 3D HBT radii relative to the event plane gives us information about the source shape at freeze-out. It also provides information on the system's evolution by comparing it to the initial source shape. In recent studies, higher harmonic event planes and flow have been measured at RHIC and the LHC, which result primarily from spatial fluctuations of the initial density across the collision area. If the shape caused by initial fluctuations still exists at freeze-out, the HBT measurement relative to higher order event plane may show these features.

We present recent results of azimuthal HBT measurements relative to 2^{nd}- and 3^{rd}-order event planes in Au+Au 200 GeV collisions with the PHENIX experiment. Recent HBT measurements at lower energies will be also shown and compared with the 200 GeV result.

1. Introduction

HBT measurements provide information on the space-time evolution of the particle emitting source in relativistic heavy ion collisions. The azimuthal dependence of 3D HBT radii with respect to an event plane gives us information on the source shape at freeze-out. It also provides information on the system's evolution by comparing it to the initial source shape. The higher harmonic flow (v_3, v_4, etc) of particles has recently been measured at RHIC and the LHC. It is primarily due to the spatial fluctuation of the initial density of the collision area. A hydrodynamic model calculation [1] reports that the shape of the initial fluctuations resulting in a triangular component of the initial shape may be preserved until freeze-out. HBT measurements relative to a higher-order event plane may reveal this feature.

2. Azimuthal HBT with respect to the 2^{nd}-order event plane

Azimuthal HBT radii with respect to the 2^{nd}-order event plane have been measured for charged pions and kaons in $\sqrt{s_{\rm NN}}$ = 200 GeV Au+Au collisions at PHENIX [2]. It was found that the final eccentricity of kaons, which is defined as $\varepsilon_{2,final} = 2R^2_{s,2}/R^2_{s,0}$ [3], is larger than that of pions and almost the same as the initial eccentricity. However, since HBT radii show a transverse mass (m_T) dependence and the average m_T of pions and kaons are different, the m_T dependence needs to be considered in the comparison of the final eccentricities. Figure 1 shows the relative

[1] A list of members of the PHENIX Collaboration and acknowledgements can be found at the end of this issue.

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amplitude of the azimuthal HBT radii for charged pions and kaons as a function of $\langle m_T \rangle$ for two centrality bins. The left top panel corresponds to the final eccentricity; there is still a difference between pions and kaons in non-central collisions even at the same $\langle m_T \rangle$. This difference may be due to different cross-sections of pions and kaons. The relative amplitudes of R_o and R_{os} at low m_T in the most central collisions have finite values although the final eccentricity is almost close to zero. This result may indicate a temporal variation of the emission duration of particles because R_o and R_{os} contain temporal information in addition to geometrical information.

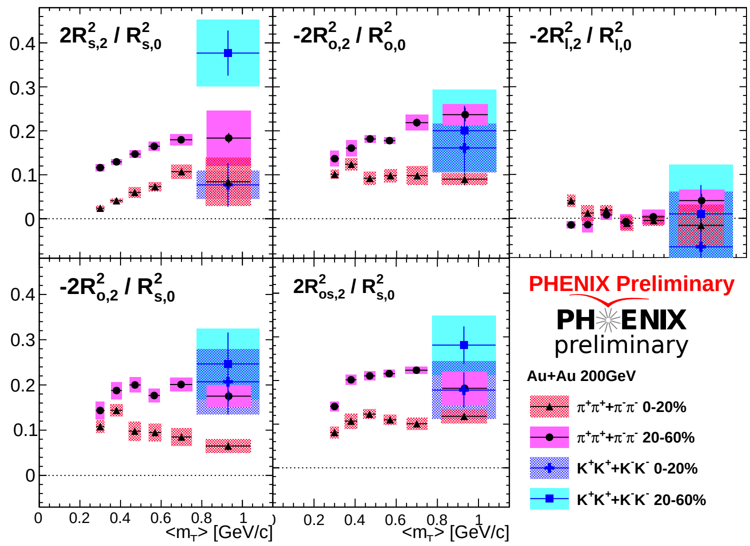

Figure 1: Relative amplitude of azimuthal HBT radii for charged pions and kaons with respect to 2^{nd}-order event plane in Au+Au 200 GeV collisions.

3. Azimuthal HBT with respect to 3^{rd}-order event plane

Fluctuations in the initial geometry of the heavy ion collisions, which is considered to be the origin of higher harmonic flow, may be preserved until freeze-out. Triangular flow, v_3, is known to have a weak centrality dependence, while the initial triangularity calculated within a Glauber model has a pronounced centrality dependence [4]. Triangularity at freeze-out is determined by the initial triangularity, v_3, the expansion time, and so on, and will provide detailed information on the space-time evolution.

Figure 2 shows R_s and R_o for charged pions as a function of the azimuthal angle with respect to 2^{nd}- and 3^{rd}-order event planes (Ψ_2 and Ψ_3) in 0-10% in Au+Au 200 GeV collisions, where the averages of the radii with respect to Ψ_2 and Ψ_3 are set to 10 and 5 fm^2 respectively. Filled symbols show measured data points, and open symbols are the same data points reflected around $\phi - \Psi_n = 0$. The solid lines depict the fit functions $R_{\mu,0}+2R_{\mu,n}\cos(n(\phi - \Psi_n))$ ($\mu = s, o$). The values of R_s show a very weak oscillation with respect to both Ψ_2 and Ψ_3, while R_o clearly exhibits stronger oscillation. The oscillation strength of R_o relative to Ψ_3 is comparable to that relative to Ψ_2. The oscillation of R_o may carry information about the duration of the emission.

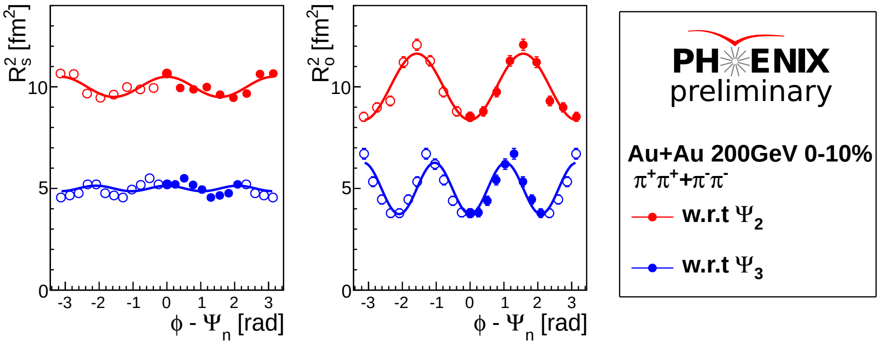

Figure 2: The azimuthal dependence of R_s and R_o for charged pions with respect to 2^{nd}- and 3^{rd}-order event plane in Au+Au 200 GeV collisions, where the averages of radii with respect to Ψ_2 and Ψ_3 are set to 10 and 5 fm^2 respectively.

The Ψ_2 dependence may indicate that the emission duration is different in-plane versus out-of-plane since R_s shows a weak oscillation and the source shape is thought to be close to a circle. The Ψ_3 dependence may be also due to the difference of emission duration between different azimuthal directions. However, the flatness of R_s doesn't necessarily mean that the source shape is not triangular but circular [1]. It may be difficult to imagine that the emission duration has such strong variations in azimuth relative to different event planes. The oscillation of R_o may reflect not only the emission duration but also the depth of the elliptical or triangular source.

As mentioned before, the final eccentricity is defined as $\varepsilon_{2,final} = 2R^2_{s,2}/R^2_{s,0}$. Here, we define $\varepsilon_{3,final}$ as $2R^2_{s,3}/R^2_{s,0}$. Figure 3 shows $\varepsilon_{n,final}$ as a function of $\varepsilon_{n,initial}$, where $\varepsilon_{n,initial}$ is calculated using a Glauber model. Note that $\varepsilon_{3,final}$ doesn't represent the final triangularity because there is no higher harmonic anisotropy in the Gaussian approximation for a static source. However, it will mean any triangular component of homogeneity region in a expanding source. The observed $\varepsilon_{3,final}$ doesn't seem to exhibit any centrality dependence and is zero within systematic uncertainties.

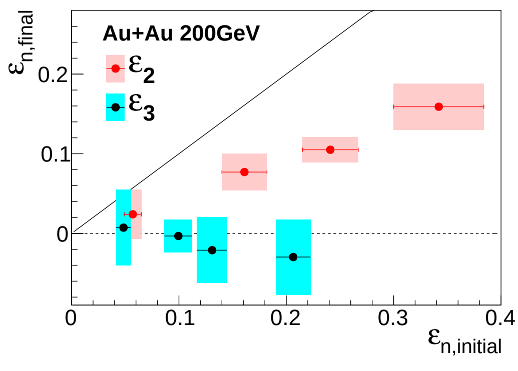

Figure 3: Final ε_n as a function of initial ε_n in Au+Au 200 GeV collisions. Initial ε_n is calculated in a Glauber model.

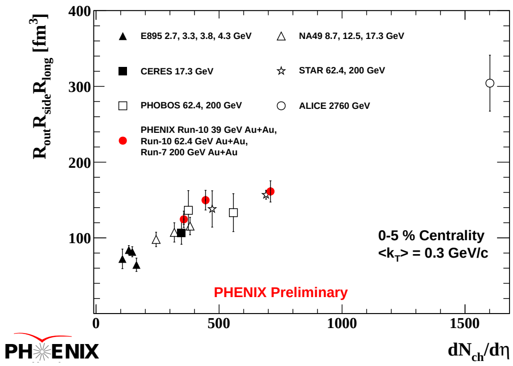

Figure 4: The product of pion 3D HBT radii as a function of charged particle multiplicity density.

4. Low energies at PHENIX

The RHIC beam energy scan program has been conducted in order to explore the critical point between the QGP and hadron gas phases in the QCD phase diagram, The centrality and m_T dependence of HBT radii were measured for 39, 62 and 200 GeV collision energies. We observe no significant change beyond systematic errors across the three energies. Figure 4 shows the product of 3D HBT radii for charged pions as a function of charged multiplicity density. PHENIX results are compared with results at different energies and collision species at AGS[5], SPS[6, 7], RHIC[8, 9] and LHC[10]. The product of 3D HBT radii, which represents the volume of the homogeneity region, from PHENIX is consistent with the global trend.

5. Summary

The latest results of azimuthal HBT measurements with respect to the 2^{nd}- and 3^{rd}-order event planes are presented. The difference of final eccentricity for charged pions and kaons is seen even in the same m_T region, which may indicate a shorter freeze-out time of kaons due to a lower cross section. The azimuthal dependence of pion HBT radii relative to Ψ_3 has been measured and the oscillation of R_o is clearly seen. This may be indicative of the temporal variation of the emission duration or the depth of the source with triangular shape. These results will provide new constraints on theoretical models and new insight into the space-time evolution of the system.

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