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Azimuthal HBT measurements for charged pions and kaons in Au+Au 200 GeV collisions at RHIC-PHENIX

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Azimuthal HBT measurement with respect to reaction plane is the way to measure the source shape at freeze-out and give information about the system evolution in relativistic heavy ion collisions. We report the recent results of azimuthal HBT measurement for charged pions and charged kaons in Au+Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV. The oscillation of azimuthal HBT radii was seen for charged kaons as well as charged pions. PHENIX result of final eccentricity for charged pion is consistent with STAR result, while there was a difference of final eccentricity between pions and kaons.

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1. Introduction

The HBT measurement provides the information of the source size and the particle emission duration in relativistic heavy ion collisions. In non central collisions, the overlap region of nucleus-nucleus is like elliptical shape (initial eccentricity). The larger pressure gradient in the direction of reaction plane by initial eccentricity leads to the elliptical anisotropy in momentum space, resulting in stronger expansion of the source toward in-plane direction than to out-of-plane direction. Azimuthal HBT measurement with respect to reaction plane is the way to measure the source shape at freeze-out (final eccentricity) and give information about the system lifetime by the comparison of initial and final eccentricity. Also, kaon HBT measurements[1] have been performed so far because charged kaons have smaller cross section than charged pions and not so affected by long-lived resonance decay. Significant difference between both species in the traditional HBT measurements have never been reported.

We present the recent PHENIX results of azimuthal HBT measurement for charged pions and charged kaons in Au+Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV. The result of charged pions and charged kaons is compared and discussed. We also compare our result to the result of STAR.

2. Data Analysis

We used the data collected by the PHENIX experiment in Au + Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV. Event centrality was determined by Beam-Beam Counter (BBC). Event plane was measured by Reaction plane detector (RXNP) which covered full azimuth and $|\eta|$ from 1.5 to 2.8, and the resolution of the event plane is $< \cos(2(\Psi_2 - \Psi_{\rm rp})) >\sim 0.75$ at centrality 20%. Tracking was done by the PHENIX central arm spectrometer. Charged particle identification is performed by Electromagnetic Calorimeter (EMC) using the time-of-flight technique.

The experimentally measured correlation function is defined as $C_2 = A(q)/B(q)$, where A(q) is the pair distribution with relative momentum q in the same event and B(q) is that in the different event. In this analysis, C_2 is measured by the Bertsch-Pratt parameterization[2], in which "side-out-long" frame is used. "Long" is parallel to the beam direction, "out" is parallel to the transverse momentum of the pair $k_T = (p_{1T} + p_{2T})/2$ and "side" is perpendicular to "out" and "long". As a fit function, we used the Sinyukov's fit function[3] to deal with the coulomb interaction for charged particle pairs, which is described as the following.

$$C_2 = C_2^{core} + C_2^{halo} = [\lambda(1+G)F_C] + [1-\lambda] \quad (2.1)$$

$$G = \exp(-R_{side}^2 q_{side}^2 - R_{out}^2 q_{out}^2 - R_{long}^2 q_{long}^2 - 2R_{os}^2 q_{out} q_{side}) \quad (2.2)$$

where F_C is the coulomb factor calculated by the coulomb wave function assuming a spherical gaussian source. $R_i(i = side, out, long)$ is HBT radii obtained by fitting the experimentally C_2, which represent the spatial lengths of the source in each direction at freeze-out. R_{os} is a cross term between "side" and "out" directions. HBT radii are measured for the azimuthal angle $\Delta\Phi$ between event plane and the direction of the average momentum of the pair. It is known that finite reaction plane resolution reduces the oscillation amplitude of HBT radii as a function of $\Delta\Phi$. Therefore a model independent correction was applied in this analysis as described in [4]. This method also corrects the effect of azimuthal angular binning.

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3. Results

Figure 1 shows correlation functions of charged pions measured for $0.2 < k_T < 2.0$ GeV/c and 8 azimuthal bins at 30-60% centrality without the correction of event plane resolution. These correlation functions for different q parameters in the right three raw of Figure 1 are projection of the 3 dimensional correlation functions. Figure 2 shows correlation functions of charged kaons for $0.2 < k_T < 2.0$ GeV/c. Red solid lines show fit function in both Figure. Figure 3 shows 3D HBT radii of charged pions as a function of azimuthal pair angle with respect to reaction plane $\Delta\Phi$ for different centrality. We can see the oscillation for R_{side}, R_{out}, R_{os}. The oscillation strength of R_{side} increases with increasing centrality, which corresponds to the elliptical shape of the source. In centrality 0-10%, R_{side} is almost flat, while R_{out} has oscillation. It may indicate that there is the different emission duration between in-plane and out-of-plane. Figure 4 shows 3D HBT radii of charged kaons as a function of $\Delta\Phi$. The oscillation for R_{side}, R_{out}, R_{os} can be seen as well as charged pions.

The oscillation amplitude in Figure 3, Figure 4 is related to the source shape at freeze-out. To obtain the strength of the amplitude, we used the following function as described in [4].

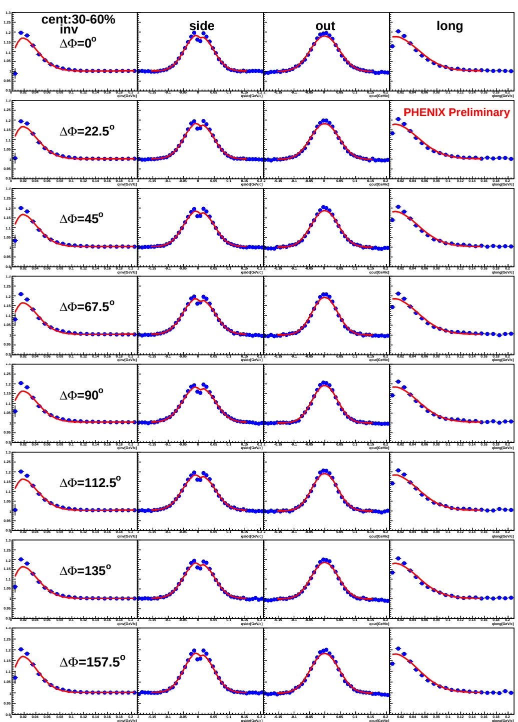

Figure 1: 1D and 3D correlation functions of charged pion pairs for each azimuthal bins at 30-60% centrality with no correction of the event plane resolution. Correlation functions for 3D parameters are projected along each q directions with $q_{other} < 40$ [MeV/c]. Solid lines show the fit functions.

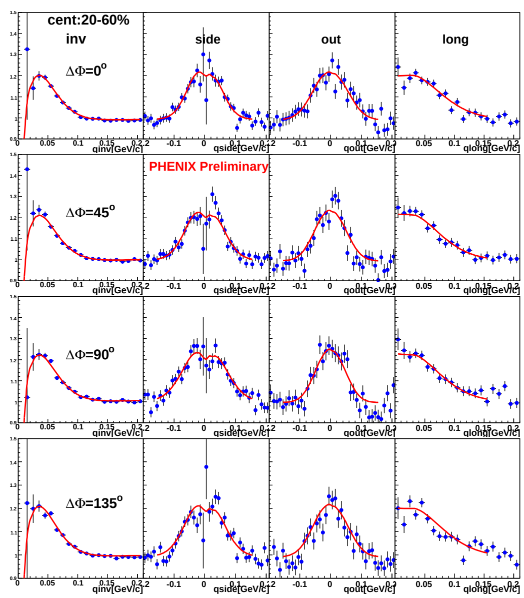

Figure 2: 1D and 3D correlation functions of charged kaon pairs for each azimuthal bins at 30-60% centrality with no correction of the event plane resolution. Correlation functions for 3D parameters are projected along each q directions with $q_{other} < 40$ [MeV/c]. Solid lines show the fit functions.

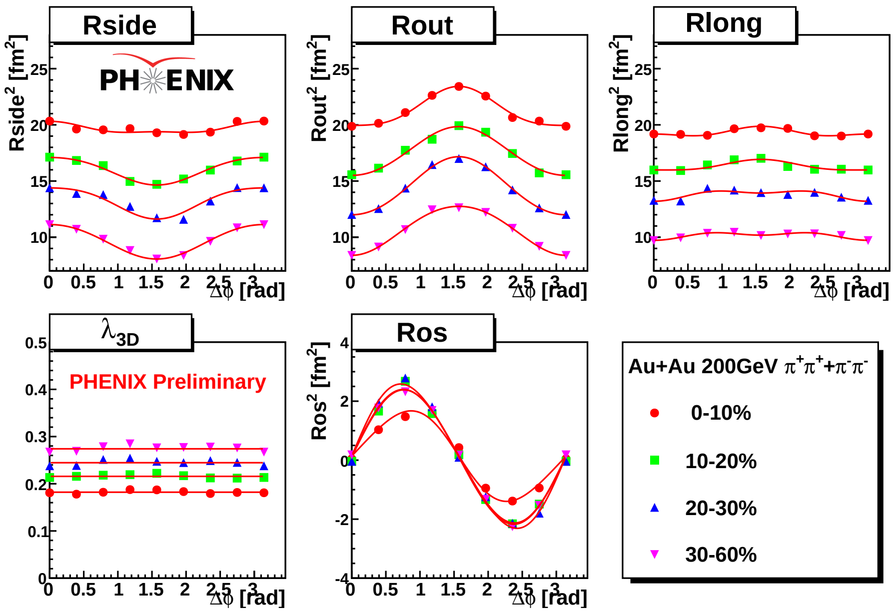

Figure 3: 3D HBT radii of charged pions as a function of azimuthal pair angle with respect to reaction plane for four centrality class. The data point at $\Delta\Phi = \pi$ is same value at $\Delta\Phi = 0$.

$$R_\mu^2 = R_{\mu,0}^2 + 2 \sum_{n=2,4,6,\ldots} R_{\mu,n}^2 \cos(n\Delta\phi) \quad (\mu = side, out, long) \tag{3.1}$$

$$R_\mu^2 = R_{\mu,0}^2 + 2 \sum_{n=2,4,6,\ldots} R_{\mu,n}^2 \sin(n\Delta\phi) \quad (\mu = os) \tag{3.2}$$

where $R_{\mu,n}^2$ is n^{th} order Fourier coefficient for each q parameter. 0^{th} order Fourier coefficient corresponds to HBT radii in the azimuthally integrated analysis. The solid lines in Figure 3, 4 show the above fit function.

Figure 5 shows realative radius of 2^{nd} and 4^{th} order Fourier coefficient to 0^{th} order for charged pions as a function of the number of participant N_{part} calculated by Glauber model. Relative 2^{nd} order radius has N_{part} dependence, which is discussed as final eccentricity in Figure 6. Relative 4^{th} order radius seems to have negative value, but it is consistent with zero within systematic error. Figure 6 shows final eccentricity for charged pions and charged kaons as a function of initial eccentricity. Here, final eccentricity is defined as $\varepsilon_{final} = 2R_{s,2}^2/R_{s,0}^2$[5] and initial eccentricity is calculated by Glauber model. PHENIX and STAR[6] results for charged pions are consistent with each other within systematic error. Final eccentricity for charged pions increases with increasing initial eccentricity, that is with going from central collision to peripheral one, while the value of final eccentricity is less than that of initial eccentricity. It indicates that the source expands to in-plane direction and still have elliptical shape at freeze-out. And final eccentricity for charged kaon is larger than that for charged pions and close to initial eccentricity, but we don't consider the difference of average m_T between pions and kaons. Therefore its difference may be due to the different average m_T or be related to the different cross section between both particle species.

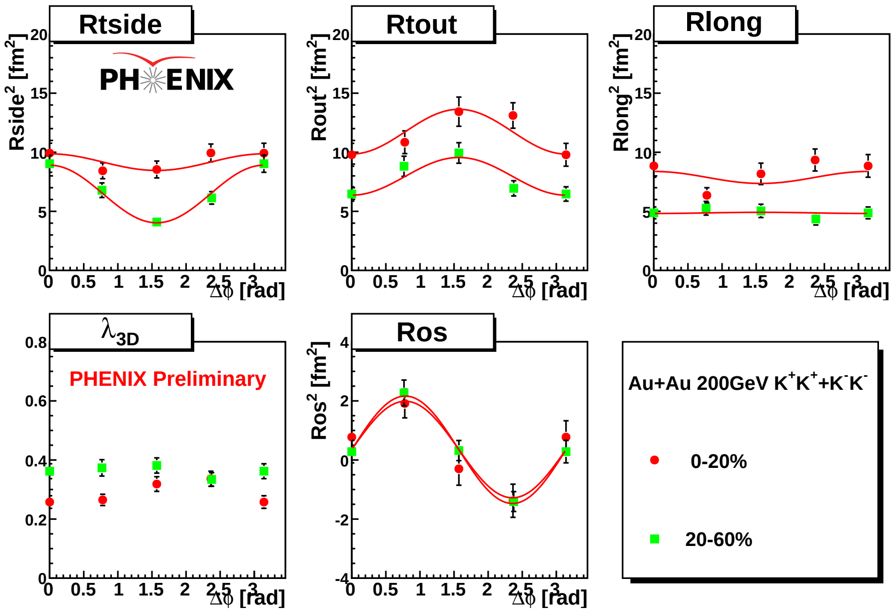

Figure 4: 3D HBT radii of charged kaons as a function of azimuthal pair angle with respect to reaction plane for two centrality class. The data point at $\Delta\Phi = \pi$ is same value at $\Delta\Phi = 0$.

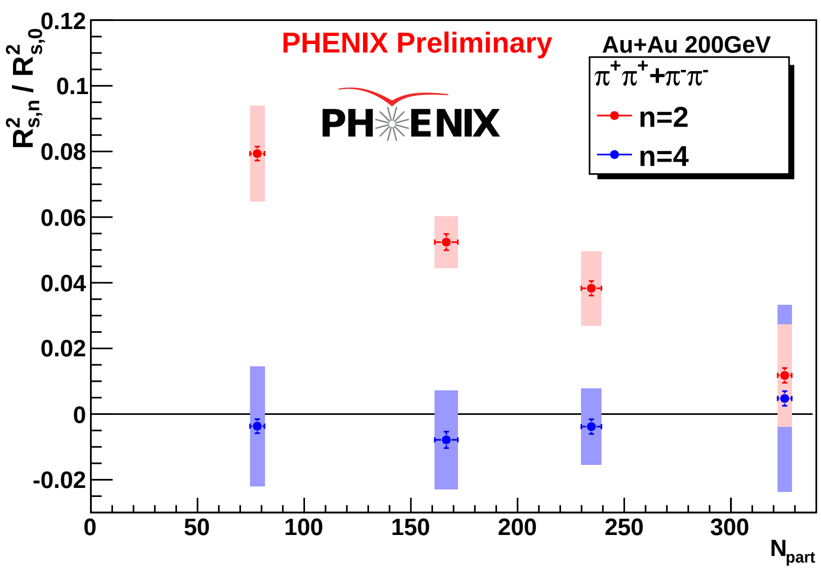

Figure 5: Realative radius of 2^{nd} and 4^{th} order for charged pions as a function of the number of participant N_{part}

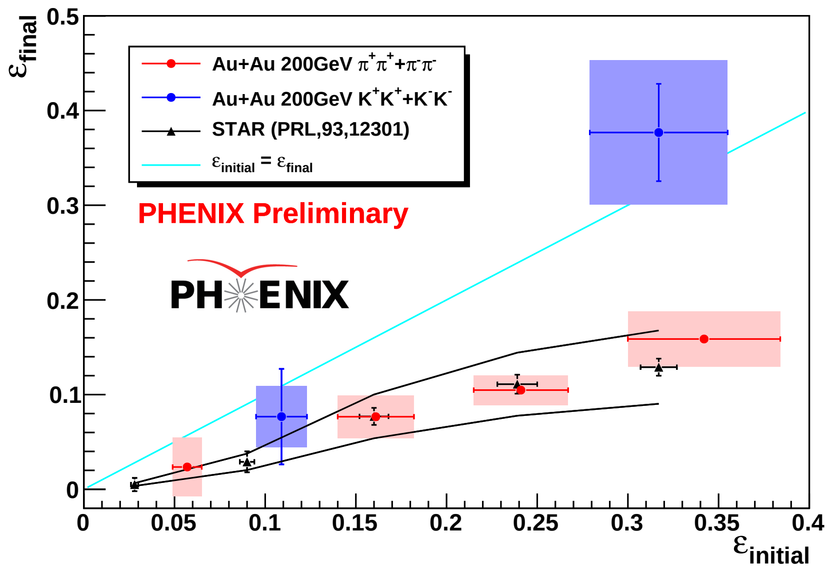

Figure 6: Initial eccentricity vs final eccentricity for charged pions and charged kaons. Result for pion measured by STAR[6] is also shown.

4. Conclusion

We have measured azimuthal HBT radii with respect to reaction plane for charged pions and charged kaons in Au+Au 200 GeV collisions at RHIC-PHENIX. We observed the oscillation of azimuthal HBT radii for charged kaons as well as charged pions. PHENIX and STAR result of final eccentricity for charged pions was consistent with each other. Larger final eccentricity at more peripheral collision indicates the elliptical shape of the source at freeze-out, and its smaller value compared to the initial state indicates that the source expands strongly to in-plane direction. On the other hand, final eccentricity for charged kaons was larger than that for charged pions at peripheral collision and almost same to initial eccentricity. A further study will be needed to interpret this result.

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