First results of Pion Interferometry in Cu+Cu collisions at $\sqrt{s_{\rm NN}}$ = 22.4 GeV

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Introduction

Numerous experimental observables have been proposed as signatures of Quark Gluon Plasma(QGP) creation in heavy ion collisions [1]. The increased entropy is expected to lead to an increased spatial extent and duration of particle emission, thus providing a significant probe for the QGP phase transition [2]. The information about the space-time structure of the emitting source can be extracted with intensity interferometry techniques. This method, popularly known as Hanbury-Brown Twiss (HBT) correlations, was originally developed to measure angular sizes of distant stars [3]. Previous femtoscopic measurements at RHIC in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 130 GeV, 200 GeV [4] and comparative studies of Au+Au and Cu+Cu in 62.4 GeV and 200 GeV [5] provided various interesting insights. However, detailed comparisons with smaller colliding systems like Cu+Cu and energies like 22.4 GeV are required in order to understand the dynamics of the source during freeze-out. In this paper we present a systematic analysis of two-pion interferometry in Cu+Cu collisions at $\sqrt{s_{\rm NN}}$ = 22.4 GeV using the Solenoidal Tracker at RHIC (STAR) detector at the Relativistic Heavy Ion Collider (RHIC).

The STAR detector [5], which has a large acceptance and is azimuthally symmetric, consists of several detector sub-systems and a solenoidal magnet. In the present study, the central Time Projection Chamber (TPC) provided the main information used for track reconstruction.

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Analysis Method and Correlation function in π interferometry

Experimentally, the two-particle correlation function is obtained from the ratio,

$$C(\vec{q},\vec{k}) = \frac{A(\vec{q},\vec{k})}{B(\vec{q},\vec{k})} \quad , \qquad (1)$$

where $A(\vec{q},\vec{k})$ is the distribution of particle pairs with relative momentum $\vec{q} = \vec{p_1} - \vec{p_2}$ and average momentum $\vec{k} = (\vec{p_1} + \vec{p_2})/2$ from the same event, and $B(\vec{q},\vec{k})$ is the corresponding distribution for pairs of particles taken from different events [4, 5]. The correlation function is normalized to unity at large $\vec{q}$. In the mixed events, each particle in a given event is mixed with all particles from other events, within a collection of 10 similar events. Similar events are selected within the centrality bin and further binned to have primary vertex z positions within 10 cm of the collisional vertex of 30 cm. With the availability of high statistics data and development of new techniques, it has become possible to have a three-dimensional decomposition of $\vec{q}$ [5], providing better insight into the collision geometry.

The relative momentum $\vec{q}$ can be decomposed according to the Bertsch-Pratt (also known as "out-side-long") convention [5]. The relative momentum $\vec{q}$ is decomposed into the variables along the beam direction ($q_{\rm long}$), parallel ($q_{\rm out}$) to the transverse momentum of the pair $\vec{k}_T = (\vec{p}_{1\rm T} + \vec{p}_{2\rm T})/2$, and perpendicular ($q_{\rm side}$) to $q_{\rm long}$ and $q_{\rm out}$. In addition to the correlation arising from quantum statistics of two identical particles, correlations can also arise from two-particle final state interactions. For identical pions, the effects of strong interactions are negligible, but the long range Coulomb repulsion causes a suppression of the measured correlation function at small $\vec{q}$.

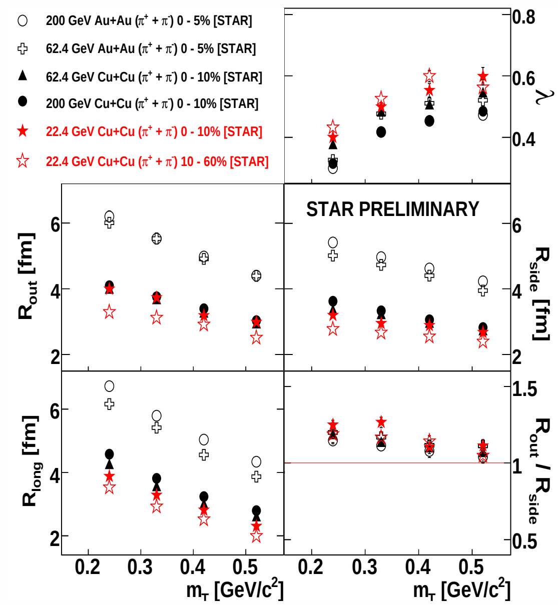

FIG. 1: (Color Online) Femtoscopic parameters vs. m_T for two centralities 0-10% and 10-60% for Cu+Cu collisions at $\sqrt{s_{\rm NN}} = 22.4$ GeV. Only statistical errors are shown. Compared with Au+Au and Cu+Cu results of 200 and 62.4 GeV.

In this analysis, we follow the same procedure as was used in the previous analysis of Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [4]. For an azimuthally-integrated analysis at midrapidity in the longitudinal comoving system (LCMS), the correlation function in Eq. (1) can be decomposed as [5]:

$$C(q_{\rm out}, q_{\rm side}, q_{\rm long}) = (1-\lambda)+$$

$$\lambda K_{\rm coul}(q_{\rm inv})(1+e^{-q_{\rm out}^2 R_{\rm out}^2 - q_{\rm side}^2 R_{\rm side}^2 - q_{\rm long}^2 R_{\rm long}^2}), \quad (2)$$

where $K_{\rm coul}$ is to a good approximation the squared nonsymmetrized Coulomb wave function integrated over a Gaussian source (corresponding to the LCMS Gaussian radii $R_{\rm out}$, $R_{\rm side}$, $R_{\rm long}$). Assuming particle identification is perfect and the source is purely chaotic, λ represents the fraction of correlated pairs emitted from the collision.

We assume a spherical Gaussian source of 3 fm [5] for Cu+Cu collisions at $\sqrt{s_{NN}} = 22.4$ GeV. For the pion interferometry analysis, the particle identification conditions are $|n\sigma_\pi| < 2$, $|n\sigma_p| > 2$, and $|n\sigma_K| > 2$, and the average transverse momentum ($k_T = (|\vec{p}_{\rm 1T} + \vec{p}_{\rm 2T}|)/2$) is required to fall in one of 4 bins corresponding to [150,250] MeV/c, [250,350] MeV/c, [350,450] MeV/c and [450,600] MeV/c. The results are presented and discussed as a function of $k_{\rm T}$ as well as $m_{\rm T}$ ($= \sqrt{k_{\rm T}^2 + m_\pi^2}$) in each of those bins for 0-10% and 10-60% centrality. The estimated systematic errors are less than 10% for all radii in the 0-10% and 10-60% centrality bin for all $k_{\rm T}$ bins, similar to those in Refs. [4, 5].

Figure 1 gives the results for $R_{\rm out}$, $R_{\rm side}$, $R_{\rm long}$, λ and the ratio, $R_{\rm out}/R_{\rm side}$. The three femtoscopic radii increase with increasing centrality for Cu+Cu 22.4 GeV as expected, whereas the values of the λ parameter and the $R_{\rm out}/R_{\rm side}$ ratio exhibit no clear centrality dependences in the two centralities of Cu+Cu 22.4 GeV and ratio $R_{\rm out}/R_{\rm side} \sim 1$ for all other RHIC energies.

References

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