

Identical Particle Interferometry at STAR

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We present preliminary results from a two-particle intensity interferometry analysis of charged pions and neutral kaons emitted from Au+Au collisions at $\sqrt{s_{\text{NN}}} = 130$ and 200 GeV measured in the STAR detector at RHIC. The dependence of the apparent pion source on beam energy, multiplicity, transverse momentum and emission angle with respect to the reaction plane are discussed.

1. Introduction

Two-particle intensity interferometry (HBT) is a useful tool to study the space-time geometry of the particle-emitting source in heavy ion collisions [1,2]. It also contains dynamical information that can be explored by studying the transverse momentum (p_T) dependence of the apparent source size [3,4]. In non-central collisions information on the anisotropic shape of the pion-emitting region can be extracted by measuring two-pion correlation functions as a function of emission angle with respect the reaction plane [11].

In this paper we present two-pion correlation systematics as a function of the collision energy $\sqrt{s_{\text{NN}}}$, transverse mass ($m_T = \sqrt{p_T^2 + m^2}$), multiplicity, and emission angle with respect to the reaction plane in Au+Au collisions produced by the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. We also present the first significant HBT measurement for neutral kaons from heavy ion collisions; besides carrying important information about the dynamics of strange particles, these measurements provide valuable cross-checks on charged kaon HBT, as complication due to various corrections (e.g. two-track efficiency and Coulomb correction) are quite different for neutral particles.

Experimentally, two-particle correlations are studied by constructing the correlation function $C_2(\mathbf{q}) = A(\mathbf{q})/B(\mathbf{q})$. Here $A(\mathbf{q})$ is the measured distribution of the momentum difference $\mathbf{q} = \mathbf{p}_1 - \mathbf{p}_2$ for pairs of particles from the same event, and $B(\mathbf{q})$ is the corresponding distribution for pairs of particles from different events.

2. Experimental Details

For this analysis we selected events with a collision vertex position within ± 30 cm measured from the center of the 4 m long STAR Time Projection Chamber (TPC), and we mixed events only if their longitudinal primary vertex positions were no farther apart than 6 cm. We divided our sample into three centrality bins, where the centrality was characterized according to the measured multiplicity of charged particles at midrapidity.

*For the full author list and acknowledgements, see Appendix "Collaborations" of this volume

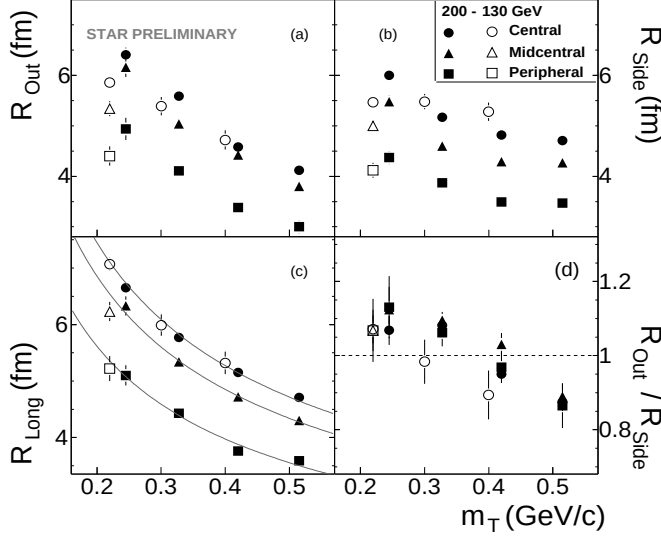


Figure 1. Centrality dependence of the m_T dependence of the $\pi^-\pi^-$ HBT radii for $\sqrt{s_{NN}}=200$ GeV in closed symbols. The error bars indicate the statistical errors only. Multiplicity and m_T dependence of the HBT radii of the $\pi^-\pi^-$ HBT radii for $\sqrt{s_{NN}}=130$ GeV in open symbols. Lines in (c) represent the Mahklin/Sinyukov fit [4].

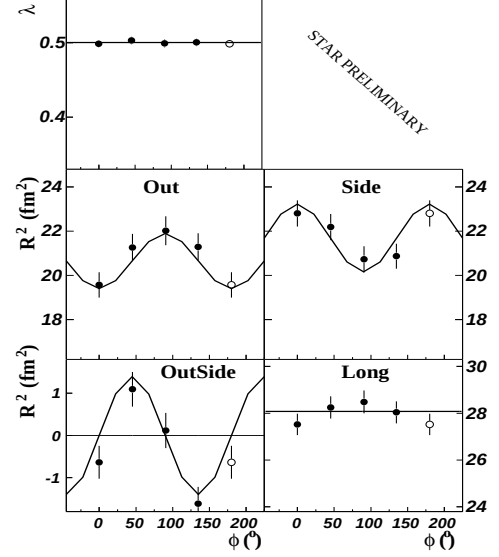


Figure 2. Azimuthal dependence of HBT parameters from peripheral Au+Au collisions at $\sqrt{s_{NN}}=130$ GeV. Bolstered statistics by summing results of π^- and π^+ analysis. Lines represent the blast wave source parameterization.

The three centrality bins correspond to 0-10% (central), 10-30% (midcentral), and 30-70% (peripheral) of the total hadronic cross section. Charged pions were identified by correlating their specific ionization in the gas of the TPC with their measured momentum. Neutral kaons were identified via topological methods [12].

For charged pions, the effects of track-splitting (reconstruction of a single track as two tracks) and track-merging (two tracks with similar momenta reconstructed as a single track) were eliminated as described in [5]. We applied to each background pair a Coulomb correction [6] corresponding to a spherical Gaussian source of 5 fm radius.

In the neutral particle analysis, the possibility of a single K_s^0 being correlated with itself was eliminated by requiring that a pair of K_s^0 's have unique daughters, and that their decay positions were spatially well-separated.

3. Pion HBT versus p_T and centrality

The three-dimensional correlation functions were generated. The relative momentum $\mathbf{q}$ was measured in the longitudinal co-moving system (LCMS) frame, and decomposed according to the Pratt-Bertsch [6,7] "out-side-long" parametrization. The correlation functions were fit with: $C(q_o, q_s, q_l) = 1 + \lambda \exp(-R_o^2 q_o^2 - R_s^2 q_s^2 - R_l^2 q_l^2)$.

The effect of the single-particle momentum resolution ($\delta p/p \sim 1\%$ for the particles

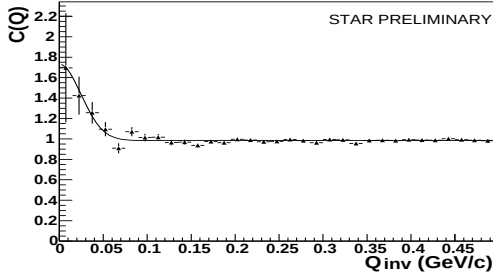


Figure 3. One-dimensional correlation function $C(Q_{inv})$ for K_s^0 candidates with invariant mass within $\sim \pm 15$ MeV/c², $0.1 < p_T < 3$ GeV/c at midrapidity from central Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV. Line represents the fit to a one-dimensional Gaussian.

under study) induces systematic underestimation of the HBT parameters. Using an iterative procedure [5], we corrected our correlation functions for finite resolution effects. The correction due to the uncertainty on the removal of the artificial reduction of the HBT parameters associated with the anti-merging cut is still being finalized; we estimate systematic errors on HBT radii at about 1 fm.

Fig.1 shows the m_T dependence of the source parameters for negative pions at three centrality bins. The three radii increase with increasing centrality and R_l varies similarly to R_o , R_s ; for R_o and R_s this increase may be attributed to the geometrical overlap of the two nuclei. The extracted radii rapidly decrease as a function of m_T , which is an indication of transverse flow [8]; interestingly the m_T dependence is independent of centrality.

While slightly larger at 200 GeV, the transverse homogeneity lengths are similar for both energies (Figs.1 (a) and (b)). These results suggest a steeper fall-off with m_T , which might indicate increased flow; finalized corrections are necessary before drawing such conclusions. R_o falls somewhat steeper than R_s with m_T and $R_o/R_s \sim 1$ (Fig. 1(d)) which indicates short emission duration, $\Delta t \sim 1$ -2 fm/c, in a blast wave fit [10].

The longitudinal radius falls along the same curve at both energies (Fig. 1(c)). Assuming boost-invariant longitudinal flow, we can extract an evolution timescale, by using a simple fit [4] (solid lines Fig. 1(c)): $R_l = \langle t_{fo} \rangle \sqrt{\frac{T_k}{m_T}}$. Taking $T_k = 110$ MeV we got $\langle t_{fo} \rangle \approx 10$ fm/c for central events and $\langle t_{fo} \rangle \approx 7.6$ fm/c for peripheral events. Hence, the evolution time, in addition to the emission duration, is quite short.

4. Pion HBT with respect the reaction plane

Azimuthally-sensitive HBT, correlated event-by-event with the reaction plane, provides information about the coordinate-space anisotropies of the emitting source [9].

We calculated the three-dimensional correlation functions with fixed pair angle with respect to the 2nd-order event plane (determined from elliptic flow) $\phi = \angle(\mathbf{K}_\perp, \mathbf{b})$, where $\mathbf{K}_\perp = (\mathbf{p}_1 + \mathbf{p}_2)_\perp$ is the total momentum of the pair perpendicular to the beam. The correlation functions for each ϕ bin were fit with the standard Gaussian parametrization $C(\mathbf{q}, \phi) = 1 + \lambda(\phi) \exp[-q_i q_j R_{ij}^2(\phi)]$, in this case the cross-term R_{os}^2 is also relevant.

Fig.2 shows the HBT parameters plotted as a function of ϕ at $\sqrt{s_{NN}}=130$ GeV. Data were corrected for event plane resolution and merging systematics. R_o and R_s show significant equal and opposite 2nd-order oscillations with phases indicating an out of plane extended source geometry. This would suggest a fast evolution, since positive v_2 will push the source from an out-of-plane extended configuration (present in the entrance

channel and caused by the partial overlap of the colliding nuclei) to in-plane extended. For comparison, the lines represent a fit with the "blast wave model" [10], corresponding to a transversely deformed (5% extended out-of-plane) source geometry with an oscillating flow field, and a short (2 fm/c) emission duration. This model successfully reproduces the details of elliptic flow measured by STAR [13].

Preliminary results for π^- and π^+ from peripheral Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV confirm the oscillations measured at 130 GeV and the higher statistics of these measurements will allow m_T and centrality systematic analysis.

5. K_s^0 Interferometry

The good efficiency of the TPC for finding and reconstructing short-lived neutral kaons gives us the opportunity to study HBT correlations for K_s^0 . This analysis should allow us to extend our systematics to higher p_T . Using the topology of the decay $K_s^0 \rightarrow \pi^+\pi^-$ we reconstructed ~ 3.8 K_s^0 candidates per event with $\langle m_T \rangle \sim 1.12$ GeV/c². Fig.3 shows the one-dimensional correlation function which exhibits a promising low-Q correlation signal. Fitting with the functional form $C(Q) = 1 + \lambda \exp(-Q^2 R^2)$ yields $\lambda = 0.76 \pm 0.29$ and $R = 5.75 \pm 1$ fm. If these results persist as the analysis is finalized, it is interesting to speculate on possible causes of such a large homogeneity length at this high m_T .

6. Conclusion

We have presented identical meson interferometry results for Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV. With respect to multiplicity and m_T dependencies, pion HBT radii are very similar to results reported at $\sqrt{s_{NN}}=130$ GeV. Our results indicate that both the evolution timescale (as measured by the m_T dependence of R_l and the out-of-plane extended source indicated by the azimuthally-sensitive HBT) and the emission duration (probed by comparing R_o to R_s) are surprisingly fast. The large acceptance and excellent tracking of the TPC has allowed for the first solid measurement of K_s^0 - K_s^0 correlations. While still preliminary, these suggest a surprisingly large homogeneity length at high m_T .

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