We present preliminary results from a two-pion intensity interferometry analysis from Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV measured in the STAR detector at RHIC. The dependence of the apparent pion source on multiplicity and transverse momentum are discussed and compared with preliminary results from d+Au and p+p collisions at the same beam energy.

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 dependence of the apparent source size \[3,4\]. Extracted parameters in HBT analysis from Au+Au collisions at $\sqrt{s_{NN}}=130$ GeV at the Relativistic Heavy Ion Collider (RHIC) did not agree with predictions of hydrodynamic models that gave an almost perfect description of the momentum-space structure of the emitting source and elliptic flow \[5\].

In this paper we present two-pion correlation systematics as a function of the transverse total mass ($m_T = \sqrt{k_T^2 + m^2}$, $k_T = \frac{1}{2}(p_1 + p_2)_T$) and multiplicity in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV produced by RHIC at Brookhaven National Laboratory and measured by the STAR detector. We also discuss a fitting procedure in which the strength of the final state Coulomb interaction between the two charged pions is taking into account in the fit itself.

2. Experimental Details

Experimentally, two-particle correlations are studied by constructing the correlation function $C_2(q) = A(q)/B(q)$. Here $A(q)$ is the measured distribution of the momentum difference $q = p_1 - p_2$ for pairs of particles from the same event, and $B(q)$ is the corresponding distribution for pairs of particles from different events. For this analysis we selected events with a collision vertex position within $\pm25$ 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 5 cm. We divided our sample into six centrality bins, where the centrality was characterized according to the measured multiplicity of charged particles at midrapidity. The six centrality bins correspond to 0-5% (most central), 5-10%, 10-20%, 20-30%, 30-50% and 50-80% (most 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 \[6\].

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 \[7\]. A new procedure to take into account final state Coulomb interaction is described in the
next section.

The effect of the single-particle momentum resolution ($\delta p/p \sim 1\%$ for pions) induces systematic underestimate of the HBT parameters. Using an iterative procedure [7], 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 has been calculated in [8] and is included as systematic error.

3. Fitting procedure

The three-dimensional correlation functions were generated. The relative momentum was measured in the longitudinal co-moving system (LCMS) frame, and decomposed according to the Pratt-Bertsch [9,10] “out-side-long” parametrization. There is a Coulomb interaction between emitted particles that needs to be taken into account in order to isolate the Bose-Einstein interaction. This Coulomb interaction, repulsive for like-sign particles, causes a reduction on the number of real pairs at low $q$, reducing the correlation function. In our previous analysis [7,11] as well as in previous experiments, this was corrected by applying a pair Coulomb correction to each pair in the background [9] corresponding to a spherical Gaussian source of a given radius; we call this standard procedure. The correlation function was then fit with the functional form:

$$C(q_o, q_s, q_l) = C(0, q_s, q_l) = 1 + \lambda \exp[-R_o^2 q_o^2 - R_s^2 q_s^2 - R_l^2 q_l^2],$$

where $R$ is the source parameter.

We have implemented a new procedure, first suggested by Bowler [12] and Sinyukov [13] and recently used by the CERES collaboration [14], in which the strength of the Coulomb interaction is taken into account in the fit itself and only pairs with Bose-Einstein interaction are considered to Coulomb interact; we call this Bowler-Sinyukov procedure. The fit in this case is:

$$C(q_o, q_s, q_l) = C(0, q_s, q_l) = (1-\lambda) + \lambda K_{coul}(q_{inv})(1 + \exp[-R_o^2 q_o^2 - R_s^2 q_s^2 - R_l^2 q_l^2]),$$

where $K_{coul}(q_{inv})$ is the same as above.

In Figure 1 the measured $\pi^+\pi^-$ correlation function is compared to several calculations. Lines indicate the standard ($K_{coul}(Q_{inv})$) and Bowler-Sinyukov ($1 + (\lambda - 1)K_{coul}(Q_{inv})$) Coulomb functions; in the latter, $\lambda$ was extracted from the fit to the 3D like-sign correlation function. Clearly, the Bowler-Sinyukov function better reproduces the data. Further improvement is observed when the strong interaction (negligible for like-sign pion correlations) is included [15] into the $\pi^+\pi^-$ final state interactions.

When we use this procedure in our 3D analysis we observe an increase in $R_o$ of 10-15%. The values of $R_s$ and $R_l$ do not depend significantly on the Coulomb procedure. Consequently the increase in $R_o/R_s$ is not enough to solve the HBT puzzle.

4. HBT parameters versus centrality and transverse momentum

Figure 2 shows the $m_T$ dependence of the source parameters for pions at six centrality bins from Au+Au collisions as well as from p+p and d+Au collisions at same beam energy. The three radii increase with increasing centrality and $R_l$ varies similar to $R_o$ and $R_s$; for $R_0$ 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 [16]. In order to extract information about the $m_T$ dependence on centrality, we fit the $m_T$ dependence of each radius and each centrality to a power-law function: $R_i(m_T) = R_0 \cdot m_T^{-\alpha}$ (solid lines in Figure 2). Figure 3 shows the dependence of $\alpha$ on the number of participants; for Au+Au, $\alpha$ is constant for $R_l$ as a function of number of participants and decreases with the number of
Figure 1. Experimental (triangles) and theoretical [15] (stars) 1D $\pi^+\pi^-$ correlation functions compared with standard (discontinuous line) and Bowler-Sinyukov (continuous line) functions.

Figure 2. HBT radii for 6 different centrality from Au+Au collisions, and from p+p and d+Au collisions. The lines indicate power-law fits to each parameter and centrality.

participants for $R_o$ and $R_s$ for the most peripheral bins indicating a decrease of transverse flow for these collisions. $R_o/R_s \sim 1$ which indicates a short emission duration in a blast wave fit [17].

Assuming boost-invariant longitudinal flow we can extract an evolution time-scale by using a simple fit [17]: $R_t = < t_{fo} > \sqrt{\frac{T}{m_T} \frac{K_2(m_T/T)}{K_1(m_T/T)}}$ where T is the freeze-out temperature and $K_1$ and $K_2$ are the modified Bessel functions of order 1 and 2. For T extracted from fits to pion, kaon, and proton transverse momentum spectra (90 MeV for most central and 120 MeV for most peripheral collisions) [18] we get $< t_{fo} > \approx 9$ fm/c for central events and $< t_{fo} > \approx 6$ fm/c for peripheral events. Hence, the evolution time, in addition to the emission duration, is quite short.

For a transverse expanding, longitudinally boost-invariant source, and assuming a Gaussian transverse density profile, we can extract information about its radius, $R_{geom}$, by fitting the $m_T$ dependence of $R_s$ to: $R_s(m_T) = \sqrt{R_{geom}^2 + \rho^2}$ where T is again the freeze-out temperature and $\rho_f$ is the surface transverse rapidity [19]. For T and $\rho_f$ consistent with spectra we see an increase on this radius from $\sim 5$ fm for the most peripheral case to $\sim 13$ fm for the most central one as shown in Figure 4. We also observe a smooth transition from p+p ($N_{participants} = 2$) and d+Au ($N_{participants} = 8.3$) to Au+Au collisions.

5. Conclusion

We have presented identical pion 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. HBT radii and geometrical radius increase with increasing
centrality. HBT radii decrease with $m_T$ and we observe a stronger flow for the most central collisions. Our results indicate that both the evolution timescale (as measured by the $m_T$ dependence of $R_l$) and the emission duration (probed by comparing $R_o$ to $R_s$) are surprisingly fast. The Bowler-Sinyukov Coulomb procedure does not solve the “HBT puzzle” although increases the ratio $R_o/R_s$ by 10-15%.

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