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Rapidity and k_T dependence of HBT correlations in Au+Au collisions at 200 GeV with PHOBOS

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Abstract. Two-particle correlations of identical charged pion pairs from Au+Au collisions at $\sqrt{s_{_{NN}}} = 200$ GeV were measured by the PHOBOS experiment at RHIC. Data for the most central (0–15%) events were analyzed with Bertsch-Pratt (BP) and Yano-Koonin-Podgoretskii (YKP) parameterizations using pairs with rapidities of $0.4 < y < 1.3$ and transverse momenta $0.1 < k_T < 1.4$ GeV/c. The Bertsch-Pratt radii decrease as a function of pair transverse momentum. The pair rapidity $Y_{\pi\pi}$ roughly scales with the source rapidity Y_{YKP}, indicating strong dynamical correlations.

Identical-particle correlation measurements (Hanbury-Brown and Twiss, HBT) yield valuable information on the size, shape, duration, and spatiotemporal evolution of the emission source in heavy ion collisions. Experimentally, the correlation function $C(\mathbf{q})$ is defined as

$$C(\mathbf{q}) = \frac{P(\mathbf{p}_1, \mathbf{p}_2)}{P(\mathbf{p}_1)P(\mathbf{p}_2)} \tag{1}$$

where $P(\mathbf{p}_1, \mathbf{p}_2)$ is the probability of a pair being detected with relative four-momentum $\mathbf{q} = \mathbf{p}_1 - \mathbf{p}_2$, and $P(\mathbf{p}_1)$ and $P(\mathbf{p}_2)$ are the single particle probabilities. The numerator is determined directly from data, while the denominator is constructed using the standard event-mixing technique.

The data reported here were collected using the PHOBOS two-arm magnetic spectrometer during RHIC Run II (2001). Details of the setup have been previously described in [1]. The spectrometer arms are each equipped with 16 layers of silicon sensors, providing charged particle reconstruction both outside and inside a 2 T magnetic field. The primary event trigger was provided by two sets of 16 scintillator paddle counters, which covered a pseudorapidity range $3 < |\eta| < 4.5$. Details of event selection and centrality determination can be found in [2, 3]. The 0–15% most central events were used in this analysis, equivalent to $\langle N_{part}\rangle = 310$ as determined by a Glauber model.

The details of the track reconstruction algorithm can be found in [4]. Events with a reconstructed primary vertex position between -12 cm $< z_{vtx} <$ 10 cm along the beam direction were selected in order to optimize vertex-finding precision, track reconstruction efficiency, and momentum resolution. Only particles which traversed the entire spectrometer were used in the analysis. A 3σ cut on the distance of closest approach with respect to the primary vertex ($dca_{vtx} <$ 0.35 cm) was then applied. The final track selection was based on the χ^2 probability of a full track fit, taking into account multiple scattering and energy loss. The momentum resolution is $\Delta p/p \sim 1\%$ after all cuts. To identify pions, a cut three RMS deviations away from the expected mean value of the specific ionization $\langle dE/dx\rangle$ for pions was applied. Contamination from other particle species was studied using HIJING 1.35[5] and a GEANT 3.21 simulation of the full detector. The contamination from $\mathrm{K}^{\pm}\mathrm{K}^{\pm}$, pp, and $\overline{\mathrm{p}}\,\overline{\mathrm{p}}$ pairs is less than 1%; non-identical pairs contribute less than 10% throughout the entire k_T range. To reject ghost pairs, only one shared hit in the weak-field region and two shared hits in the strong-field region were allowed per pair. A two-particle acceptance cut was applied to both data and background; the criterion for pair acceptance was defined by $\Delta\phi + 2\Delta\theta > 0.05$ rad, where $\Delta\phi$ and $\Delta\theta$ are the relative pair separation in azimuthal and polar angle, respectively. About 7.3 million $\pi^+\pi^+$ and 5.5 million $\pi^-\pi^-$ pairs survive all cuts.

Systematic errors were determined by changing two-particle acceptance cuts, cuts in azimuthal separation, random seeds used in mixed-event background generation, as well as varying the definition of “event class” to create background events from pairs within narrow and broad vertex ranges.

Because the event-mixed background is the product of tracks from different events, it does not *a priori* include any multiparticle correlations. In order to study the HBT correlation, it is necessary to apply a weight to account for the Coulomb effect. The Coulomb correction can be expressed solely as a function of relative 4-momentum q,

$$F_R(q) = \frac{F_c(q)}{F_{pl}(q)} = \frac{\int d\vec{r}\,|\psi_c(\vec{r})|^2 S(\vec{r})}{\int d\vec{r}\,|\psi_{pl}(\vec{r})|^2 S(\vec{r})} \qquad (2)$$

where $S(\vec{r})$ is the relative separation of the particle pair, and ψ_c and ψ_{pl} are the Coulomb and plane wave-functions, respectively. A closed-form approximation and numerical correction for this relation was derived in [6] for $\lambda = 1$. For a variable λ,

$$F_R(q,\lambda) = \frac{(1-\lambda) + \lambda(1 + e^{-q^2R^2})F_R(q)}{1 + \lambda e^{-q^2R^2}} \qquad (3)$$

This prescription is nearly equivalent to the corrections applied by the CERES, STAR, and PHENIX experiments [7, 8, 9]; our results showed no significant change using either correction method. The method is applied iteratively, successively fitting distributions of the correlation function $C(q)$ and iteratively applying the fit value R to a new $S(\vec{r})$. Typically 2 or 3 iterations are sufficient for convergence.

$C(\mathbf{q})$ is typically fit to a Gaussian source in three dimensions, the so-called Bertsch-Pratt parameterization [10],

$$C(\mathbf{q}) = 1 + \lambda e^{-(q_o^2 R_o^2 + q_s^2 R_s^2 + q_\ell^2 R_\ell^2 + 2 q_o q_\ell R_{o\ell}^2)} \tag{4}$$

The correlation function was also fit to the YKP parameterization [11],

$$C(\mathbf{q}) = 1 + \lambda e^{-(q_\perp^2 R_\perp^2 + \gamma^2 (q_\parallel - \beta q_\tau)^2 R_\parallel^2 + \gamma^2 (q_\tau - \beta q_\parallel)^2 R_\tau^2)} \tag{5}$$

where β is the longitudinal velocity of the source and $\gamma = 1/\sqrt{1-\beta^2}$, $q_\perp$ and $q_\parallel$ the relative 3-momentum difference projected in the transverse and longitudinal directions respectively, and q_τ the relative difference in energy. In order to compare with lower energy, the data presented was fit in the longitudinal co-moving system (LCMS) frame.

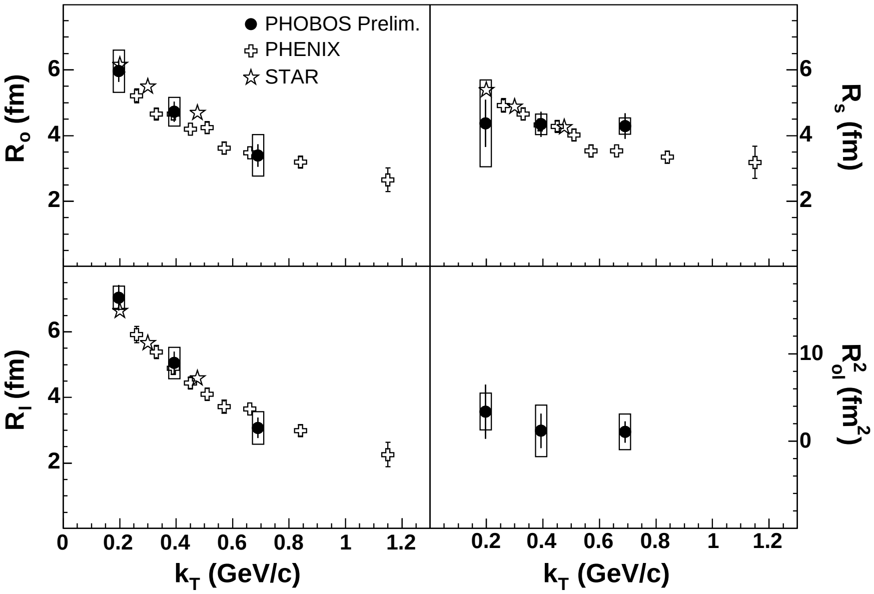

Figure 1. Bertsch-Pratt radii as a function of pair transverse momentum k_T for Au+Au at 200 GeV from PHOBOS, STAR [8] and PHENIX [9]. The boxes represent PHOBOS systematic error.

In Fig. 1, the Bertsch-Pratt radii are presented as a function of pair transverse momentum k_T for $\pi^-\pi^-$ pairs. For comparison, data from STAR [8] and PHENIX [9] at $\sqrt{s_{NN}} = 200$ GeV are also shown. The PHOBOS data were analyzed in the LCMS frame within the rapidity range $0.4 < y < 1.3$, while the other data are at mid-rapidity ($-0.5 < y < 0.5$). The three-dimensional correlation functions were fit to Eq. (4) using the log-likelihood method. R_s weakly varies as a function of k_T, while R_o and R_ℓ decrease rapidly with increasing k_T.

In Fig. 2, the extracted value of the source rapidity Y_{YKP} is plotted as a function of pair rapidity for $\pi^+\pi^+$ pairs with $0.1 < k_T < 1.4$ GeV/c. The data from NA49 [12] at lower energy is also plotted; however, it should be noted the presented NA49 data covers only $0.1 < k_T < 0.2$ GeV/c. The pair rapidity strongly scales with source rapidity, indicating the presence of strong position-momentum correlations. The solid line at $Y_{YKP} = Y_{\pi\pi}$ represents a class of models including, but not limited to, boost invariance.

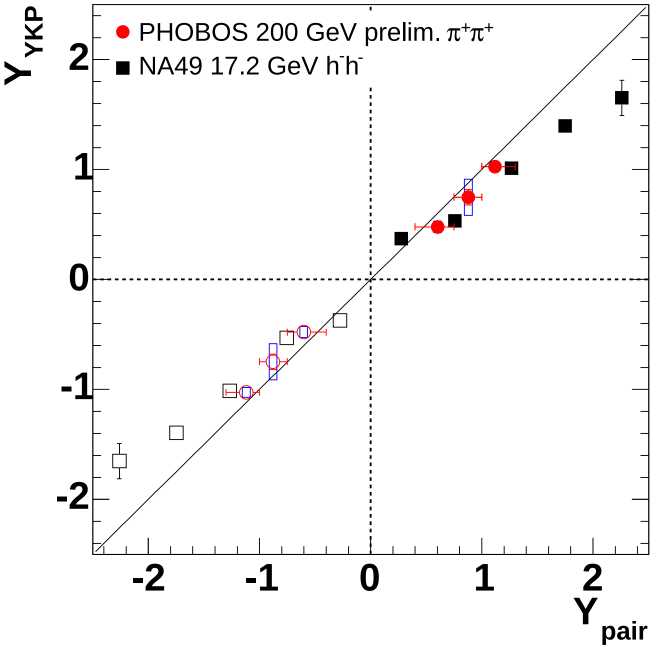

Figure 2. Source rapidity (Y_{YKP}) as a function of pair rapidity ($Y_{\pi\pi}$) for PHOBOS (circles) and NA49 (squares) [12]. The line at $Y_{YKP} = Y_{\pi\pi}$ is drawn to guide the eye. The boxes represent PHOBOS systematic error.

In conclusion, we have extracted HBT parameters from Au+Au collisions at $\sqrt{s_{NN}} = 200$ using two different parameterizations of the correlation function. The Bertsch-Pratt parameters show good agreement between three experiments with very different acceptances. From the YKP analysis, the pair rapidity scales strongly with the source rapidity, indicating a source with strong position-momentum correlations.

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References

[1] Back B B *et al* 2003 *Nucl. Instrum. Methods* A **499** 603
[2] Back B B *et al* 2000 *Phys. Rev. Lett.* **85** 3100
[3] Back B B *et al* 2002 *Nucl. Phys.* A **698** 555
[4] Back B B *et al* 2004 *Phys. Lett.* B **578** 297
[5] Gyulassy M and Wang X N 1994 *Comput. Phys. Commun.* **83** 307
[6] Ahle L *et al* 2002 *Phys. Rev.* C **66** 054906
[7] Adamova D *et al* 2003 *Nucl. Phys.* A **714** 124
[8] Adams J *et al* 2003 *Preprint* nucl-ex/0312009
[9] Adler S S *et al* 2004 *Preprint* nucl-ex/0401003
[10] Bertsch G 1989 *Nucl. Phys.* A **498** 173; Pratt S 1986 *Phys. Rev.* D **33** 1314
[11] Yano F and Koonin S 1978 *Phys. Lett.* B **78** 556; Podgoretskii M 1983 *Sov. J. Nucl. Phys.* **37** 272

[12] Appelshäuser H *et al* 1998 *Eur. Phys. J.* C **2** 661