# First Measurements of Pion Correlations by the PHENIX Experiment

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First identical-pion correlations measured at RHIC energies by PHENIX are presented. Two analyses with separate detectors, systematics, and statistics provide consistent results. The resulting HBT radii are moderately larger than those measured at lower energies. The $k_t$ dependence of the Bertsch-Pratt HBT radii is also similar to previous measures and is consistent with the conjecture of an expanding source.

## 1. INTRODUCTION

One predicted result of a first order phase transition to a quark gluon plasma in heavy ion collisions is a long lived state due to the large latent heat and corresponding reduction in pressure of the created system [1]. The primary method for measuring the space-time extent of heavy-ion collisions is two particle interferometry, which has been utilized in hadronic interactions from proton induced to nuclear collisions. For an incoherent source ($S$) of identical bosons, the normalized probability of detecting two particles with relative momentum $q = p_1 - p_2$ and average momentum $k = (p_1 + p_2)/2$ is given by the correlation function ($C_2$):

$$C_2(\vec{q}, \vec{k}) = 1 + |\int dx S(x, \vec{k}) e^{iqx}|^2 \tag{1}$$

where $x$ is the four-position, and the integral is taken over all space-time. The direct utilization of this technique is hindered in principle because equation 1 is uninvertible: the source has 7 independent variables while the measured correlation function has 6. Furthermore, due to limited statistics most recent heavy ion experiments have chosen to plot and fit the correlation function in only three of the six dimensions versus the Bertsch-Pratt [2] projection of $\vec{q}$ in the out-side-long directions:

$$C_2(\vec{q}, \vec{k}) = 1 + \lambda \exp(-{q_{Tout}}^2 {R_{Tout}}^2(\vec{k}) - {q_{Tside}}^2 {R_{Tside}}^2(\vec{k}) - {q_{Long}}^2 {R_{Long}}^2(\vec{k})) \tag{2}$$

where $q_{Long}$ is the momentum difference in the beam direction, $q_{Tout}$, in the pair momentum direction, and $q_{Tside}$, the corresponding orthogonal direction. A benefit of such a fit

*For the full PHENIX Collaboration author list and acknowledgements see the contribution by W.A. Zajc (K. Adcox *et al.*) in this volume.

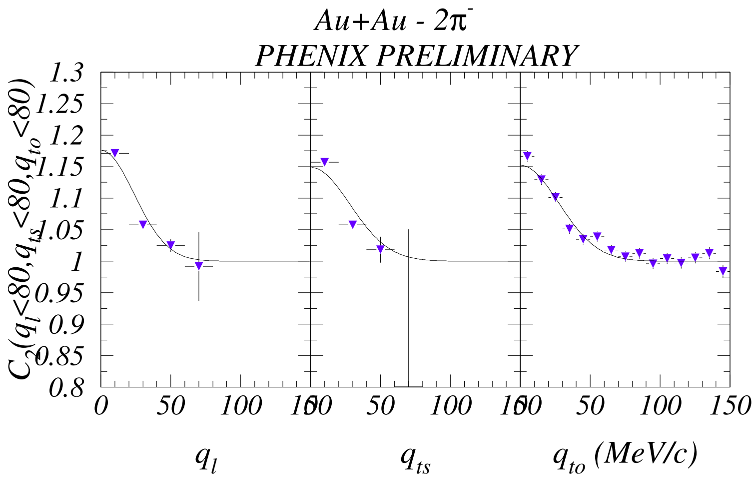


Figure 1. Correlation function for $\pi^-$ pairs from the EMC analysis. The one-dimensional projections of the three-dimensional correlation function is averaged over the lowest 80 MeV/c in the other momentum differences.

is that, for a well-behaved, gaussian source with no position-momentum correlations or resonances, the lifetime is simply determined by the difference between $R_{Tside}$ and $R_{Tout}$: $\beta^2\tau^2 = {R_{Tout}}^2 - {R_{Tside}}^2$ [3]. In such studies the k-dependence of the HBT radii is usually explored by repeating the fitting procedure with a subsample of the entire dataset of pairs.

## 2. PHENIX DETECTOR AND ANALYSIS

The PHENIX experiment is described in detail elsewhere [4]. For the analysis described in this article we use the data collected in the summer of 2000. After all offline analysis cuts, the data sample was approximately 1.5 million events.

This analysis used a subset of all of the detectors in the experiment. For vertex information and centrality definitions we rely on a pair of Cerenkov beam counters and zero-degree calorimeters; the beam counters also act as the start of the time of flight measurements. The two drift chambers measure the deflection of particles through the magnetic field and, hence, their momentum, while the velocity is measured by either the time-of-flight wall (TOF) or the electromagnetic calorimeter (EMC). The TOF timing resolution is approximately 115 ps [5], while the EMC resolution is 700 ps. As a result, the TOF analysis provides $\pi$-$K$ separation to 1.5 GeV/c; the EMC analysis, to 0.7 GeV/c. Due to geometric and acceptance effects the TOF analysis consists of $\sim 500,000$ ($\sim 300,000$) pairs of identified $\pi^+$ ($\pi^-$) while the EMC analysis consists of approximately five times as many pairs.

The particle identification algorithm is similar in both analyses. A pion is defined as being within $2\sigma$ of the pion mass-squared peak but $3\sigma$ away from the kaon peak. Backgrounds from long lived resonances (e.g. $\Lambda$'s) are reduced by intradetector association cuts. Energy deposition cuts in the TOF slat or EMC tower further reduce backgrounds due to accidental misassociations. Systematic studies have shown that the background contamination to the EMC analysis is at least double that in the TOF analysis leading to artificially lower $\lambda$ values in the former. Ongoing studies of the backgrounds in the analyses aim to resolve these differences. However, the introduction of background from accidental hits or electron contamination tend to only affect the resulting $\lambda$ in the fits and

| Data Set | $R_{Tout}$ (fm) | $R_{Tside}$ (fm) | $R_{Long}$ (fm) | $\lambda$ |
|---|---|---|---|---|
| EMC $\pi^+\pi^+$ | $4.4 \pm 0.2$ | $5.1 \pm 0.6$ | $5.9 \pm 0.4$ | $0.27 \pm .02$ |
| TOF $\pi^+\pi^+$ | $6.2 \pm 0.5$ | $7.9 \pm 1.1$ | $4.0 \pm 1.2$ | $0.49 \pm .05$ |
| EMC $\pi^-\pi^-$ | $5.1 \pm 0.2$ | $5.0 \pm 0.6$ | $5.9 \pm 0.4$ | $0.30 \pm .02$ |
| TOF $\pi^-\pi^-$ | $5.5 \pm 0.5$ | $5.8 \pm 1.5$ | $6.7 \pm 0.9$ | $0.49 \pm .06$ |

Table 1
Results of the Bertsch-Pratt fits to the identical pion pairs in the EMC and TOF analyses. Errors shown represent statistical uncertainties only; current systematic uncertainties are $< 1$ fm.

do not change the measured radii.

A number of systematic studies have been performed to ensure that the resulting correlation function does not include any artificial, experimentally induced correlations from inefficiencies in either the detector or tracking algoithms. To remove these inefficiencies, pairs of particles within 2 cm of each other in the drift chamber are removed. Further, pairs that share the same TOF slat or EMC cluster are also removed in both the signal and mixed background. For the Coulomb correction, the source is parameterized as a gaussian in $R_{inv} = \sqrt{\delta r^2 - \delta t^2}$, as determined by an iterative procedure [6].

## 3. RESULTS

Figure 1 shows the Coulomb corrected correlation function for $\pi^-$ pairs measured in the EMC analysis overlayed with the resulting fit. While the fit is performed in the full three dimensional space, we plot here projections of the correlation function into each of the standard momentum difference variables ($q_{Tout}$, $q_{Tside}$, and $q_{Long}$). The results of the fit are shown in Table 1 along with the results from the $\pi^+$ analysis from the EMC and the $\pi^+/\pi^-$ analyses utilizing the TOF. The mean transverse momentum ($\langle k_t \rangle$) of the pairs is 350 MeV in the TOF analysis and 340 MeV in the EMC analysis while the rapidity coverage in both analyses is centered about mid-rapidity, $|y| < .35$. The mean centrality of all pairs in the analysis is 15% and is strongly biased towards central collisions.

Within the current statistical and systematic error bars, the EMC and TOF analyses for both pion sets are consistent with one another. The results of the fits are moderately larger than identical measurements for Au+Au and Pb+Pb collisions at lower energies and comparable $\langle k_t \rangle$ [7]. The results do not indicate an especially large source compared to measurements at lower energies and the resulting naively calculated lifetime deduced from these measurements is consistent with zero. However, a stronger collective flow will shorten the effective source and lifetime measured by HBT.

Plotted in Fig. 2 is the $\langle k_t \rangle$ dependence of the radii in the EMC $\pi^+$ (squares) and $\pi^-$ (triangles) analyses. The sample is split into three approximately equal subsets of pairs and the correlation analysis is performed on each subset. The $k_t$ bins are $k_t < 250$ MeV, $250 < k_t < 350$ MeV and $k_t > 350$ MeV corresponding to $\langle k_t \rangle = 188$ MeV, $\langle k_t \rangle = 298$ MeV and $\langle k_t \rangle = 436$ MeV respectively. Data points at identical $\langle k_t \rangle$ are offset by 10 MeV for clarification.

The radii follow trends familiar from lower energy measurements at lower beam energies

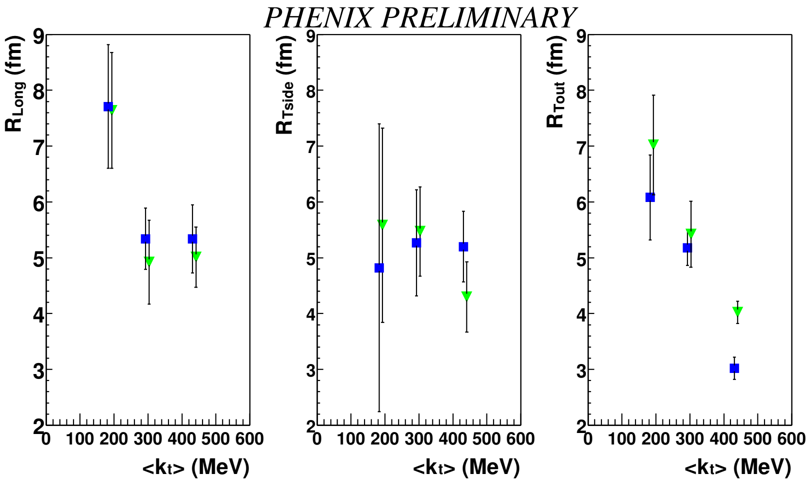


Figure 2. $k_t$ dependence of the Bertsch-Pratt radii for $\pi^-$ (triangles) and $\pi^+$ (squares) pairs in the EMC analysis. Error bars correspond to statistical errors only.

[7]: $R_{Tside}$ has a mild, if any, dependence on the transverse momentum of the pair, while $R_{Tout}$ varies strongly with $\langle k_t \rangle$. Such dependencies have been described by collective motions, though temperature gradients and decays of short-lived resonances could also contribute to such dependencies [8].

## 4. CONCLUSION

We have shown first measurements of identical pion correlations measured by PHENIX at RHIC. The resulting Bertsch-Pratt radii are moderately larger than those measured at lower energies. The $k_t$ dependence of the radii is consistent with the conjecture of a system with a large degree of collective motion.

An extension of these measurements over an wider range in $k_t$ with a larger data sample will be available following the upcoming 2001 data collection. During this second run the additional PHENIX acceptance and integrated luminosity should lead to approximately a factor of a hundred in pair statistics. The resulting data sample will lead to much stricter constraints on models of the collision and allow for comparisons to identical kaon and proton HBT analyses.

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