AZIMUTHALLY-SENSITIVE PION HBT AT RHIC

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The STAR Collaboration has measured two-pion correlation functions versus emission angle with respect to the event plane in non-central Au+Au collisions at $\sqrt{s_{NN}} = 130, 200$ GeV. In the context of a parameterized freezeout scenario, the data suggest an out-of-plane-extended freezeout geometry, and a rapid system evolution to freezeout.

Studies of nuclear collisions at the Relativistic Heavy Ion Collider (RHIC) challenge our understanding of strongly-interacting systems under extreme conditions. Momentum-space observables in the soft ($p_T < 2$ GeV) sector have been successfully reproduced by hydrodynamical models\textsuperscript{1,2,3}, which should approximate the system evolution in the high-density phase of the collision. However, two-particle correlations, which probe the space-time structure of the system\textsuperscript{4}, are not well-reproduced by most models. That theory generates the correct dynamic signatures (e.g. collective flow) in momentum space, while apparently following the wrong space-time dynamics, has been called the "RHIC HBT puzzle."\textsuperscript{5}

To model the collision more realistically than with hydrodynamics alone, groups\textsuperscript{3,6} have implemented hadronic “afterburners” to represent the dilute stage of the collision. In these calculations\textsuperscript{3}, the late hadronic stage has little effect on dynamic momentum-space observables such as elliptic flow at RHIC energies; however, discrepancies with measured HBT systematics worsen with the inclusion of the hadronic stage. This may be due to the increased timescale of particle emission\textsuperscript{3}.

If the system created at RHIC is indeed evolving/emitting on a shorter timescale than our present understanding allows, then this is important information, and it is crucial that more insight be gained on the space-time dynamics of the system. Correlating HBT measurements with the event plane in non-central collisions allows a much more detailed exploration of the system evolution and interplay between the anisotropic geometry and flow fields\textsuperscript{7,8,9,10}. It also provides a valuable (though model-dependent)
measure of the evolution time of the system until freezeout, by comparing
the final-state freezeout anisotropic geometry to that of the initial overlap
region between the colliding nuclei. Finally the role of the late hadronic
stage may be explored, as the transverse source geometry exhibits a qualita-
tive change from an out-of-plane shape as calculated by hydrodynamics\textsuperscript{3,11},
to an in-plane shape when the late hadronic stage is also considered\textsuperscript{3}.

Results and analysis details from azimuthally-integrated HBT in STAR
have been reported previously\textsuperscript{12}. The principle differences in the present
analysis are: 1) for the construction of the “background” distribution,
event-mixed pairs are formed only from events with similar event-plane
orientations in the lab; 2) separate correlation functions are formed for
cuts on pair emission angle with respect to the event plane; 3) prior to
fitting the correlation functions, the “real” and “background” distributions
are corrected\textsuperscript{10} for effects of finite event-plane resolution and binning.

The correlation functions, as a function of relative momentum in the

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{figure1.png}
\caption{Stars show measured one-
dimensional projections of the correlation
function for $\phi = 45^\circ$, for Au+Au colli-
sions at $\sqrt{s_{NN}} = 130$ GeV, integrated over
30 MeV/c in the unplotted components. Lines show projections of the Gaussian fit.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{figure2.png}
\caption{HBT parameters for Au+Au
collisions at $\sqrt{s_{NN}} = 130$ GeV. Stars (cir-
cles) show fit parameters to correlation
functions corrected (uncorrected) for finite
event-plane resolution and binning effects. Curves indicate blast-wave calculations.}
\end{figure}
Pratt-Bertsch\textsuperscript{13} “out-side-long” decomposition, were constructed in the Longitudinal Co-Moving System and fitted with the Gaussian form\textsuperscript{4}

\[ C(q_o, q_s, q_l, \Phi) = 1 + \lambda(\Phi) e^{-q_o^2 R^2_o(\Phi) - q_s^2 R^2_s(\Phi) - q_l^2 R^2_l(\Phi) - 2q_o q_l R^2_{ols}(\Phi)}, \]  

(1)

where the HBT parameters depend on \( \Phi \), the pair emission angle with respect to the 2\textsuperscript{nd}-order event plane\textsuperscript{14} estimated from the elliptic flow signal. Since the 2\textsuperscript{nd}-order event plane is used, the HBT radii \( R^2_ol \) and \( R^2_sl \) vanish by symmetry and the remaining radii must show even-order oscillations\textsuperscript{10}.

Correlation functions for Au+Au collisions at \( \sqrt{s_{NN}} = 130 \) GeV were constructed from \( \sim 10^5 \) minimum-bias events which passed quality cuts\textsuperscript{15}. For statistical reasons, \( \pi^- \) and \( \pi^+ \) data were combined. One-dimensional projections of the correlation function for \( \Phi = 45^\circ \pm 22.5^\circ \) are shown in Figure 1, together with fits using Eq. 1. Fig. 2 shows the fit parameters as a function of \( \Phi \), both with and without the correction for event-plane resolution and finite \( \Phi \)-binning. The correction increases the amplitude of the oscillations \( R^2_o, R^2_s, \) and \( R^2_{ols} \) by \( \sim 2 \times \), and \( R^2_l \) significantly more; the average values of the radii are negligibly affected.

A simple “blast-wave” parameterization\textsuperscript{16} of the freezeout distribution has proven quite successful at reproducing \( p_T \) spectra\textsuperscript{17}, the \( p_T \)-dependence of HBT radii\textsuperscript{18}, elliptic flow\textsuperscript{2}, and correlations between non-identical particles\textsuperscript{16,19}. In particular, the fit to elliptical flow at \( \sqrt{s_{NN}} = 130 \) GeV\textsuperscript{2} suggested a spatial anisotropy for the average source created in minimum-bias collisions. Indeed, blast-wave fits to the azimuthally-sensitive HBT data require an out-of-plane spatial deformation of the source, in agreement with the elliptic flow fits. It is impossible in this parameterization to simultaneously reproduce the measured elliptical flow and azimuthally-sensitive HBT measurements, without an out-of-plane-extended source. Superimposed on the transverse HBT radii in Fig. 2 are blast-wave calculations with a 5\% larger source radius out of the event plane than in-plane, and a short (\( \sim 2 \) fm/c) emission duration. In addition, the out-of-plane extension of the freezeout distribution points to a short evolution timescale (\( \sim 8 - 11 \) fm/c), in agreement with simple fits\textsuperscript{20} to of \( R_l(m_T) \).\textsuperscript{5,18}

STAR’s higher statistics dataset for \( \sqrt{s_{NN}} = 200 \) GeV collisions will allow more detailed exploration of the centrality and \( k_T \) systematics of azimuthally-sensitive HBT, which encode important information on the interplay between anisotropic geometry and flow in the collision dynamics\textsuperscript{11}. In Figure 3 are plotted preliminary HBT parameters vs. \( \Phi \), for three event centralities. With 12 \( \Phi \)-bins, the oscillations are especially convincing, and we observe the expected result of reduced oscillations for central collisions.
Figure 3. Preliminary HBT fit parameters for Au+Au collisions at √s_{NN} = 200 GeV. Stars, triangles, and squares indicate the results for central, midcentral, and peripheral collisions, respectively. Lines are fits to the allowed 2nd-order oscillations of the radii. No correction for event-plane resolution has been applied.

A combined analysis of spectra, elliptic flow, and HBT data is underway, to fully characterize the freezeout distribution at RHIC.

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