Chapter 1

HBT STUDIES WITH E917 AT THE AGS: A STATUS REPORT

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Abstract  Two-particle correlations between pions in Au+Au collisions have been measured at beam kinetic energies of 6, 8, and 10.8 GeV/u at the Alternating Gradient Synchrotron (AGS) over a wide range of rapidities using a magnetic spectrometer. The data have been analyzed in the Hanbury-Brown and Twiss (HBT) framework to extract source parameters. The event-by-event orientation of the reaction plane has also been measured using a scintillator hodoscope at far forward rapidities, and beam vertexing detectors upstream of the target. A preliminary analysis of the dependence of the source parameters on the reaction plane is presented.

Keywords: AGS, HBT, reaction plane

1. INTRODUCTION

Identical particle correlations have previously been used to determine source sizes and lifetimes of the emission regions formed in heavy-ion collisions [1, 2, 3, 4]. In the case of non-central collisions, such measurements usually integrate over the reaction plane of the collision and therefore obscure physics which depends on the relative orientation of the two colliding nuclei.

In this report we discuss preliminary results from our investigations of the dependence of HBT source parameters on the reaction plane. This approach should eventually give us another perspective into the source dynamics. Together with other HBT dependencies of the source geometry and dynamics, we may thus be able to form a more complete picture of the nature and evolution of the emission region.

1.1 THE HBT CORRELATION FORMALISM

Quantum statistics require that the amplitudes for identical particles be added together before interpreting the square modulus as a probability. Specifically, identical bosons, such as pions, are required to have symmetric two-particle amplitudes, and the HBT correlation arises from the cross-term in the square of the symmetrized amplitude.

For a pair of identical bosons, emitted by an extended source $\rho(x)$ with four-momenta $p_1$ and $p_2$, detected at space-time coordinates $x_1$ and $x_2$, assuming that the bosonic wavefunctions can be described by plane waves, the symmetrized amplitude of this process is:

$$\Psi_{12}(x_1, x_2, p_1, p_2) = \frac{1}{\sqrt{2}}(e^{i(p_1 \cdot x_1 + p_2 \cdot x_2)} + e^{i(p_1 \cdot x_2 + p_2 \cdot x_1)}) \quad (1.1)$$

Which leads to the probability of detecting a pair with relative four-momentum $q = p_1 - p_2$: 
\[ C_2(q) = \frac{1}{N(q)} \int d^4x_1 d^4x_2 \rho(x_1)\rho(x_2)|\Psi_{12}|^2 = \frac{1 + |\tilde{\rho}(q)|^2}{N(q)} \]  

(1.2)

where the two-particle correlation function \( C_2(q) \) is simply related to the Fourier transform of the source density. The normalization \( N(q) \) is discussed below in Section 1.4.

The above formulation is only strictly valid for completely incoherent sources. To account for partial coherence effects, as well as contamination from long-lived resonances, an empirical variable \( \lambda \) is added to the definition of the correlation function as a coherence scaling parameter:

\[ C_2(q) = 1 + \lambda|\tilde{\rho}(q)|^2 \]  

(1.3)

### 1.2 HBT PARAMETERIZATIONS

In practice, the source \( \rho(r) \) has usually been assumed to be Gaussian in configuration-space. In this case, the momentum-space distribution is also Gaussian:

\[ \rho(r) \sim e^{-|\vec{r}|^2/R^2} \Rightarrow \tilde{\rho}(q) \sim e^{-|q|R^2} \]  

(1.4)

For multi-dimensional HBT analyses, the relative momentum variable \( q \) can be expressed in terms of a variety of orthogonal components, each of which has model-dependent significance [5, 6].

In the preliminary analysis presented here, a simple 3-D Cartesian parameterization is chosen: \((Q_x, Q_y, Q_z)\), with conjugate source parameters \((R_x, R_y, R_z)\). \( R_z \) is taken along the beam axis; \( R_x \) is lies in the reaction plane; and \( R_y \) is orthogonal to both.

In this case, \( C_2(q) \) has the following form:

\[ C_2(q) = \frac{1}{N(q)}[1 + \lambda e^{-(q_x R_x)^2-(q_y R_y)^2-(q_z R_z)^2}] \]  

(1.5)

### 1.3 REACTION PLANE DETERMINATION

The reaction plane is determined using the relative orientation of two axes: the direction of the incoming beam particle, \( \hat{z} \), and the direction of the impact parameter \( \hat{b} \). In our experiment, the beam axis is defined by a beam vertexing detector (BVER). The BVER detector consists of four planes of scintillating fibers each read out by a multi-anode photomultiplier tube. The fiber planes each consist of \( \sim 150 \times 200 \mu m^2 \)
fibers, situated 5.84 m and 1.72 m upstream from the target [7]. The position of the projection of \( \hat{z} \) onto the hodoscope can be determined with an accuracy of 1.5 mm at 11.4 m downstream from the target.

Charged projectile spectator fragments are detected in a hodoscope (HODO), and their charge centroid calculated for each event. HODO consists of two orthogonal planes of 38 plastic scintillator slats with 1 cm\(^2\) cross-sections, centered on the beam line, and situated 11.4 m downstream from the target. The response of individual scintillators to deposited charge was calibrated on a run-by-run basis and this information was used to find the charge-weighted centroid \( \vec{Q} = Q_x \hat{i} + Q_y \hat{j} \) for each event, where

\[
Q_x = \frac{\sum Q \cdot x}{\sum Q}
\]  

(1.6)

The direction of the impact parameter \( \hat{b} \) is then \( \hat{Q} \), defined with the origin at the projected beam position on HODO, and the reaction plane is defined as the plane spanned by \( \vec{Q} \) and \( \hat{z} \). \( \hat{z} \) is then redefined to lie along \( \vec{Q} \). Implicit in this definition of the impact parameter is the assumption that the direction of proton flow – the deflection of the spectator fragment – is along the reaction plane.

An estimate of the reaction plane resolution is determined by randomly dividing each event into two sub-events and looking at the \( (\phi_1 - \phi_2) \) difference distribution for the two reaction planes calculated from each sub-event (see Fig. 1.1). The actual resolution for the reaction plane determined using the full event statistics is roughly half this value [8], and in this manner we obtain an estimate of \( \delta \phi \approx 32^\circ \).

Figure 1.1  Distribution of the reaction plane angle difference for angles \( \phi_1 \) and \( \phi_2 \) determined by splitting each event into two sub-events. The angle resolution for the full event is roughly half this value (\( \delta \phi \approx 32^\circ \)).
1.4 NORMALIZATION

The correlation function is, by definition, a normalized quantity. To find the proper normalization \( N(q) \), a background is generated which creates two-particle “events” out of single tracks from different events. \( C_2(q) \) is then simply the ratio between real data and the event-mixed background.

1.5 CORRECTIONS TO THE CORRELATION FUNCTION

The shape of the measured two-particle correlation function mainly depends on three effects: the Coulomb repulsion between the two particles, the two-particle resolution of the detector, and the HBT correlation itself.

For the Coulomb effect, a correction \( f_C \) is numerically calculated for a simple extended source [9, 10] of size \( R_0 \). This correction is applied iteratively to the background until the value of \( R_{\text{inv}} \) obtained from the one-dimensional correlation function converges to that of \( R_0 \).

The two-particle resolution arises from the finite resolution of the tracking detectors in the spectrometer. Two close tracks are, at some point, indistinguishable from single tracks, and do not, therefore, appear in the measured two-particle correlation. A two-dimensional cut in relative coordinate space, \( f_{\text{TPR}} \), is applied to both signal and background events. The separation between two tracks, projected onto the first plane in the spectrometer, is shown in figure 1.2, together with \( f_{\text{TPR}} \).

![Figure 1.2](image)

*Figure 1.2* Separation between two tracks on T1. The \( f_{\text{TPR}} \) cut is the solid line.

The final correlation function is fitted from a spectrum in \( q \), which is generated by dividing signal events by background events.
nal and background have been corrected by $f_{TPR}$; the background has additionally been corrected by $f_{C}$.

2. RESULTS

The reader is reminded that the following results and analysis are preliminary, and only contain a limited subset of the E917 data. Thus far, only about 10% of the data has passed through the HBT analysis. By December 1999, we expect at least another 50% will have been analyzed.

The measured correlation for identical pairs of pions is shown in Fig. 1.3, plotted as a function of $Q_{x}$ and $Q_{y}$, where $x$ and $y$ are defined relative to the reaction plane of the event as discussed in Section 1.3. To improve the statistics, all of $Q_{z}$ has been integrated over. In addition, since the radii for $\pi^{+}\pi^{+}$ and $\pi^{-}\pi^{-}$ pairs are similar [10], both datasets were combined in the present analysis.

\[
R_{x} = 2.95 \pm 0.26 \\
R_{y} = 3.34 \pm 0.19
\]

Figure 1.3 $|Q_{y}|$ vs. $|Q_{x}|$

Figure 1.4 $|Q_{x}|$, $|Q_{y}| < 30$ MeV

Figure 1.5 $|Q_{y}|$, $|Q_{x}| < 30$ MeV
Central slices are shown in Figures 1.4 and 1.5 along with the projections from the two-dimensional fit. These data have been fit with the function in Eq. 1.5, and values for $R_x$ and $R_y$ obtained. We find that $R_x = 2.95 \pm 0.26 \text{ fm}$ and $R_y = 3.34 \pm 0.19 \text{ fm}$, the latter value being larger than the former. The error bars are solely from the fitting procedure and do not include systematic errors.

To establish a baseline for comparison, the data were also analyzed in the same fashion, but with $\hat{x}$ chosen along a random direction rather than along the reaction plane (Figs. 1.6, 1.7, 1.8). In this analysis, the values of $R_x$ and $R_y$ obtained are consistent with each other, indicating that the observed difference relative to the reaction plane is a real effect.

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{figure16.png}
\caption{$|Q_y|$ vs. $|Q_x|$ – systematic check}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{figure17.png}
\caption{$|Q_x|$, $|Q_y| < 30 \text{ MeV}$}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{figure18.png}
\caption{$|Q_y|$, $|Q_x| < 30 \text{ MeV}$}
\end{figure}
3. CONCLUSIONS

In a naive geometrical model of the source, we would expect $R_y$ to be larger than $R_x$. This is consistent with the simple overlap of two non-centrally colliding spheres for which the overlap region resembles an almond in shape, with $R_y > R_x$.

Other data and analyses [11, 12], however, indicate that the emission region is not a simple static source at these energies, with $dN/dy$ distributions and flow studies indicating both longitudinal and transverse expansion. The shape of the source may also be obscured by particle absorption by spectator matter.

Future analyses with better statistics will allow the investigation of the source asymmetry with respect to the reaction plane and its dependence on collision centrality, pair $m_T$, and rapidity. These, taken together with $dN/dy$ distributions and flow studies, may be able to further disentangle expansion and absorption effects from the source shape and size, and thus assemble a more complete picture of the collision dynamics. This work is in progress.

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