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TWO PARTICLE CORRELATIONS AT MID-RAPIDITY IN SI+A AND AU+AU FROM E859/E866

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ABSTRACT

Two particle correlation measurements for *Si-A* and *Au-Au* collisions from Brookhaven E859 and E866 are discussed. These measurements allow us, with some interpretation, to deduce the size of the participant region in a heavy ion collision. We show that various source parameterizations yield consistent results and we explore the dependence of the apparent source size on the pion yield.

1. Introduction

Two-pion correlations allow us to measure the size of the participant region in a heavy ion collision as the pions decouple from the surrounding matter (freezeout), as well as the duration of the freezeout process. Interesting physics, such as the formation of a quark-gluon plasma, can show up as a sudden increase in the size or lifetime parameters with increasing centrality.

In this writeup, we present recent two-particle correlation results from Brookhaven experiments E859 and E866. We will compare a few different source parameterizations to show that they are consistent and we will compare the source size for various systems, ranging from peripheral *Si-Al* up to central *Au-Au*, as a function of the peak $(dN/dy)_\pi$.

2. Apparatus

Experiments 859 and 866 at the BNL AGS were fixed target, spectrometer-based experiments with good acceptance for pions at midrapidity [1]. The data presented here are from the Henry Higgins, or wide-angle, spectrometer of E866, which was the only spectrometer available in E859. The data samples used in this analysis were centrality-selected using two global detectors: a zero-degree hadronic calorimeter (ZCAL) which selects events according to the number of projectile participants and a multiplicity array surrounding the target (TMA) which selects events according to the multiplicity of produced particles.

Expt.	Year	Species	p_{beam}/A	Use
E802	1988	$Si+A$	14.6 GeV/c	dN/dy
E859	1991/2	$Si+A$	14.6 GeV/c	$2\pi^{\pm}$
E866	1992	$Au+Au$	11.45 GeV/c	$2\pi^{-}$
E866	1993	$Au+Au$	11.1 GeV/c	dN/dy
E866	1994*	$Au+Au$	11.7 GeV/c	$2\pi^{\pm}$

Table 1: E802/E859/E866 (Henry Higgins) data used in this analysis.
*- The 1994 analysis is very preliminary and currently only includes a subset of the available statistics.

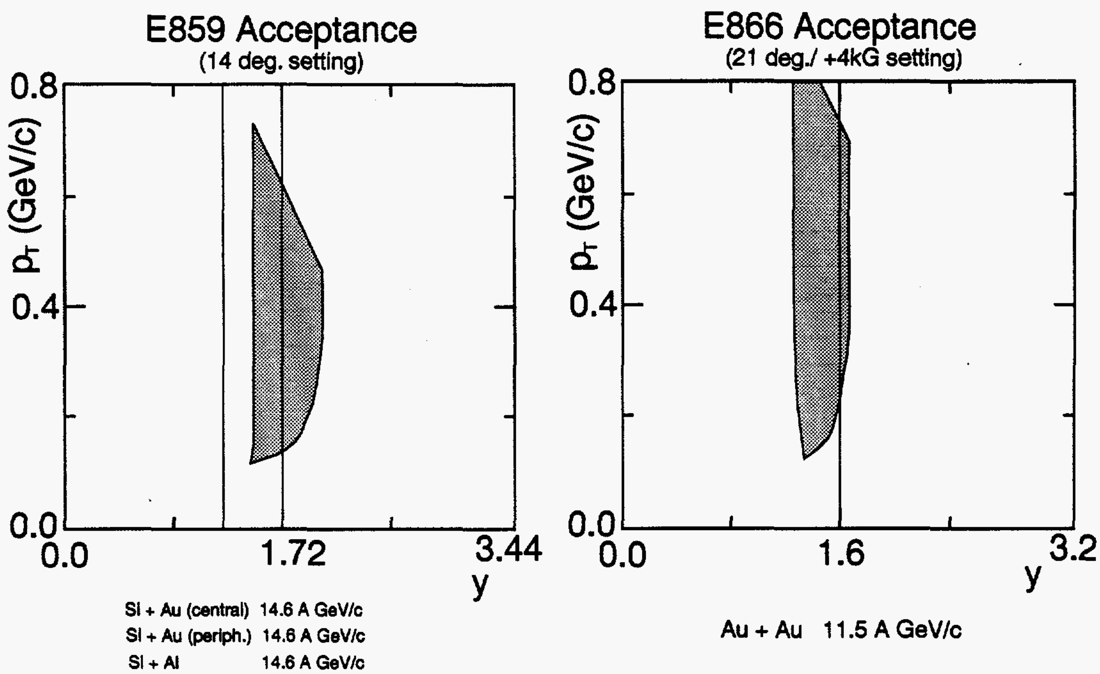

Figure 1: Acceptance for Mid-Rapidity Pions.
The acceptance for negative pions in the E866 Henry Higgins spectrometer for the angle setting used in taking the a) *Si-A* and b) *Au-Au* $2\pi^-$ data discussed in this writeup. Mid-rapidity is at a) $y = 1.72$ for $Si+Al$ and peripheral $Si+Au$, at $y = 1.5$ for central $Si+Au$, and at b) $y = 1.6$ for *Au-Au*. $2\pi^+$ acceptances are similar to the $2\pi^-$ acceptances.

Table 1 lists the various data samples to be discussed in this writeup. The data sets consist of charged pion pairs from narrow slices near mid-rapidity (see Figure 1). This allows us to examine the participant region with minimal confusion from spectator matter and longitudinal expansion.

3. HBT correlations

Two-pion correlation functions for bosons, called Hanbury-Brown Twiss (HBT) or Bose-Einstein correlations, provide information about the length and time scales which charac-

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terize the pion source. In the simplest cases, we can directly relate the correlation function to the Fourier transform of the source distribution and therefore the rms geometric size and lifetime of the source. In practice, this simple interpretation is complicated by final state interactions and dynamical correlations.

3..1 Coulomb Corrections and Dynamical Correlations

Final state interactions, dominated by the Coulomb repulsion between like-sign pions, distort the desired correspondence between the measured correlation function and the Fourier transform of the source. Since we are primarily interested in the properties of the source, we "correct" the data to remove the Coulomb effect, plotting the correlation function as it would appear in a world without Coulomb repulsion between the pions. The simplest method of Coulomb correction is the Gamow correction which assumes a point source. A more accurate method of Coulomb correction was used for some of the results discussed herein [2].

Correlations between the spacetime position of pion emission and the pion momentum, known as dynamical correlations, also complicate the interpretation of the source parameters. HBT correlations measure the shortest length scales available, not necessarily the geometric length scale in which we are most interested. When interpreting the results, we must keep in mind that this measurement, while well-defined, measures only a part of the source and may be an underestimate of the full source size. It should be noted that there is no reason to expect this effect to depend strongly on centrality for mid-rapidity particles.

3..2 HBT Fit Functions

Given a set of correlation data, we have a wide choice of fit functions available to us. In this writeup, we will discuss only four fit functions, all of which take the form:

$$C_2(q^\mu) \equiv \mathcal{N}(1 + \lambda e^{-X^2}). \qquad (1)$$

Various choices of X^2 are given in Table 2. The 3D fit allows us to separate out the geometrical size, the duration of freezeout, and the longitudinal extent at freezeout. The 2D fit measures an average radius and a duration of freezeout in the participant rest frame (at midrapidity in a symmetric collision). The R_{inv} fit measures the size of the source as seen in the pion-pair center-of-mass frame; this is primarily useful in determining the proper Coulomb correction rather than for making physics measurements directly. Finally, the one-dimensional variable $R_{R=\tau}$ measures a weighted average of R and τ, in quadrature, in the participant center-of-mass frame [2]. Interesting physics could show up as an increased geometric size or a longer lifetime; $R_{R=\tau}$ is sensitive to either or both signals.

Dim.	X^2	Params.	Meaning
3D:	$q_{Tside}^2 R_{Tside}^2 +$	R_{Tside}	Transverse radius of the source.
	$q_{Tout}^2 R_{Tout}^2 +$	R_{Tout}	Transverse radius of the source $\oplus$ "lifetime"
	$q_L^2 R_L^2$	R_L	Longitudinal radius of the source at freezeout
2D:	$\lvert\vec{q}\rvert^2 R^2 + q_0^2\tau^2$	R	"Average" radius R
		τ	lifetime
1D:	$(\lvert\vec{q}\rvert^2 + q_0^2)R_{R=\tau}^2$	$R_{R=\tau}$	$\approx \sqrt{0.8R^2 + 0.2\tau^2}$ (for E866 acceptance at small q).
1D:	$(\lvert\vec{q}\rvert^2 - q_0^2)R_{inv}^2$	R_{inv}	avg. R in PAIR-CM frame

Table 2: Four different parameterizations of the correlation function.

Species	R_{Tside}	R_{Tout}	R_L
$Si + Al \rightarrow 2\pi^+$	2.58 ± 0.17 fm	3.53 ± 0.11 fm	3.47 ± 0.15 fm
$Si + Au \rightarrow 2\pi^+$	3.38 ± 0.25 fm	3.87 ± 0.17 fm	2.62 ± 0.17 fm
$Si + Au \rightarrow 2\pi^-$	2.96 ± 0.14 fm	3.74 ± 0.09 fm	2.50 ± 0.09 fm
$Au + Au \rightarrow 2\pi^-$	3.57 ± 0.52 fm	4.53 ± 0.33 fm	3.43 ± 0.40 fm

Table 3: E859/E866 source size parameters for various central collisions, taken from Ref. [3]. These data were analyzed using the Gamow correction. These can be compared to 1d rms radii for Si and Au of 1.76 fm and 3.08 fm as explained in the text. All quoted errors are statistical only.

4. Results

The measured 3D fit parameters are tabulated in Table 3. These results were obtained using a Gamow correction, and we estimate that the full Coulomb correction will increase them by about 7% for the *Au*-*Au* sample and about 1–4% for the Si beam samples. In all cases, we see a significant difference between R_{Tside} and R_{Tout}, which implies a finite source lifetime. It should be noted that the 3d rms radii for Si and Au are 3.04 fm and 5.33 fm [4], yielding 1d rms values of 1.76 fm and 3.08 fm respectively. This means that the measured source sizes for these central collisions are larger than the original projectile radii. Given the presence of dynamical correlations, the true source sizes might be even larger.

Figure 2 shows a comparison of various fit parameters over a broad range of system sizes, ranging from peripheral *Si*-*Al* to central *Au*-*Au*, including some $2K$ correlation data [5] as well as 2π. Since all of the sources except *Si*-*Al* (peripheral) are nearly spherical, with aspect ratios between 3:4 and 4:3 [3,5], we expect the two-dimensional fit parameter R to be a good measure of the geometric size. Figure 2a shows that the correspondence of R_{Tside} and R is quite good. Similarly, Figure 2b shows that the one-dimensional fit parameter $R_{R=\tau}$ is well described as a simple mixture of R and τ.

Since the source sizes are larger than the initial participant region, we expect the pions to freeze out at a fixed density. It is unclear exactly how this translates into a dependence on dN/dy in the presence of longitudinal expansion. Insofar as the peak dN/dy reflects the multiplicity seen at mid-rapidity, we expect the freezeout radius to grow like $(dN/dy)^{1/3}$ if nothing interesting is going on. If τ is constant or is growing proportionally to R, then we expect $R_{R=\tau}$ to also grow like $(dN/dy)^{1/3}$ or perhaps even more slowly.

Figure 3 shows a comparison of the Gaussian $R_{R=\tau}$ fit parameters from pion pairs near midrapidity for *Si*-*Al*, *Si*-*Au*, and *Au*-*Au* collisions. The Si beam data, from E859, has been

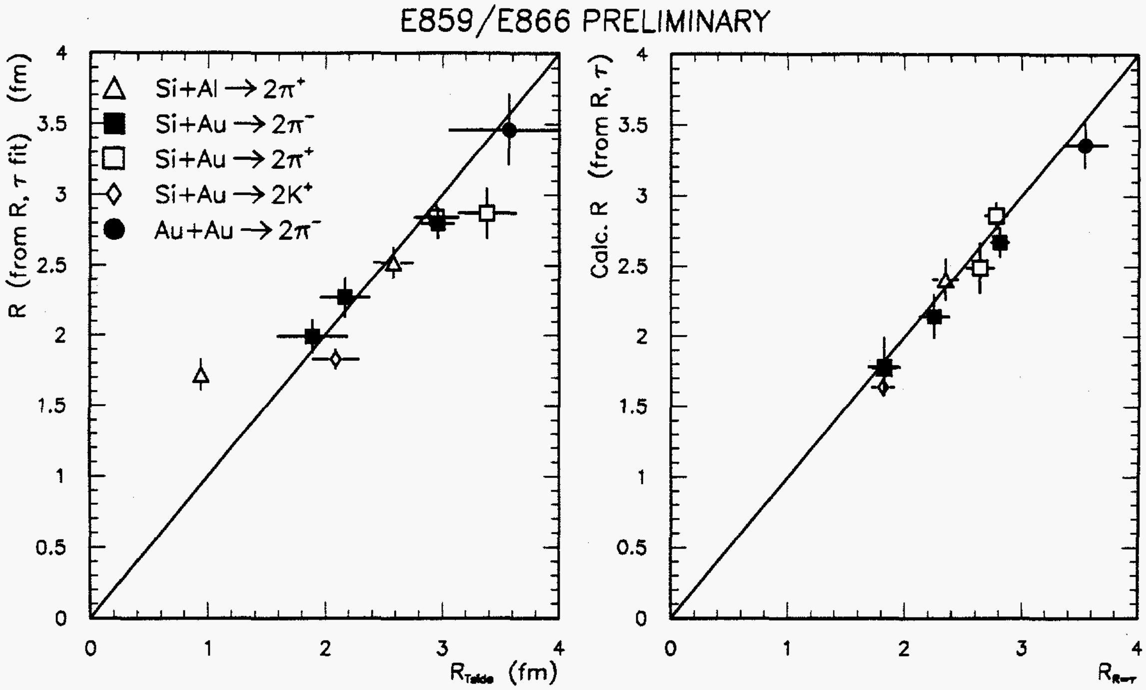

Figure 2: Comparison of various source parameterizations.
This plot shows that the various parameterizations are consistent. The Gamow correction was used in the fits for this particular comparison. a) R_{Tside} from the 3D parameterization compared with R of the 2D parameterization. The line corresponds to equality. b) Calculated R from the 2D parameterization vs. the 1D parameterization $R_{R=\tau}$. The line corresponds to equality.

reanalyzed, since previous fits used two-dimensional fit functions and a Gamow correction, rather than one-dimensional fit functions and a full Coulomb correction. The data have been plotted versus the pion dN/dy at the peak. In each case, the pion yields come from the same-charge pion as that used in the corresponding HBT sample. The results are tabulated for R_{inv} and $R_{R=\tau}$ in Reference [2].

In Figure 3a, we see that the *Au-Au* data seem to be showing a different behavior than the *Si*-beam data, raising the intriguing possibility that the pion source in the most central *Au-Au* data has an anomalously large size and/or lifetime. The problem with this result, as mentioned previously [2], is that the error bars are large and the range in centrality (here dN/dy) is rather narrow.

In Figure 3b, we see the same results with the addition of some very preliminary *Au-Au* data from the 1994 run. The new data have a broader coverage in centrality and ultimately will have better statistical precision. In the region where the two *Au-Au* datasets overlap, they are consistent. The new data, however, are also consistent with a simple extrapolation from the *Si* data. The simplest explanation, therefore, is that the source size is a universal function of dN/dy at AGS energies, independent of the system and the centrality. Better

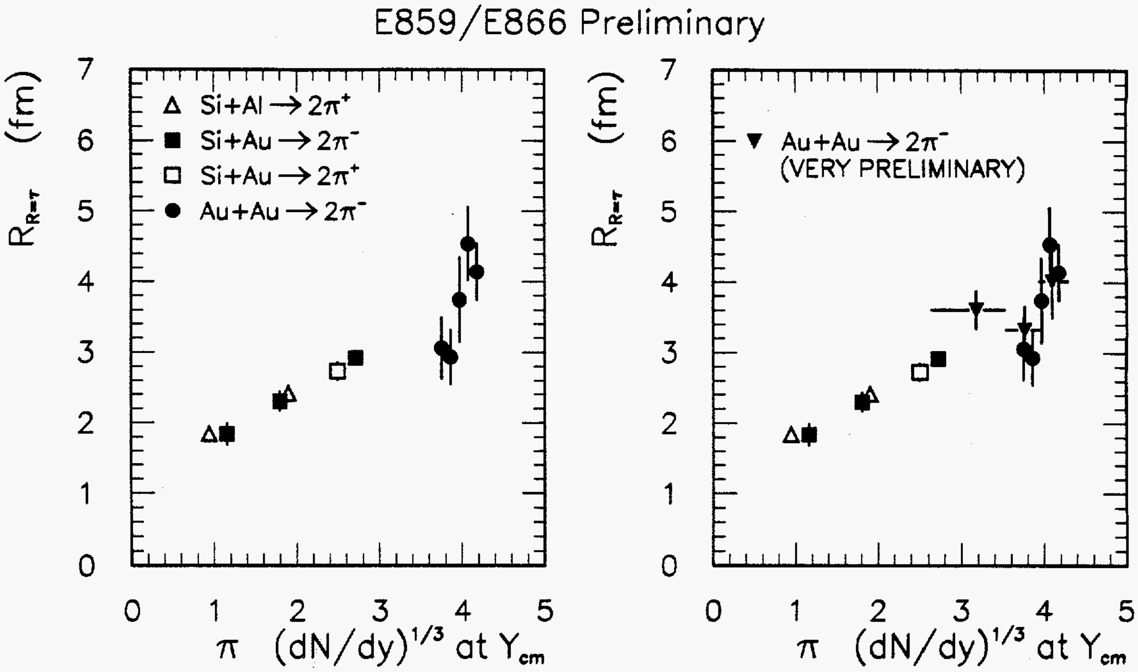

Figure 3: Dependence of the source size on the pion yield.
Preliminary E859/E866 HBT results are shown vs. the peak pion dN/dy at mid-rapidity for a) the data taken during and before 1992 which has undergone a full standard analysis with many cross-checks [3,2,5], and b) all of the data analyzed so far including the very preliminary analysis of a subset of the 1994 data. The error bars are statistical only. See Ref. [6] for details on the measurement of dN/dy.

statistical precision would be helpful, however, in order to confirm or fully rule out the possibility of an unusual shape in the *Au-Au* data.

5. Summary

We have shown that the sources observed at AGS energies are larger than the initial projectile size and that the various source parameterizations are consistent with each other. We have seen a hint of unusual behavior in the variable $R_{R=\tau}$ versus centrality (dN/dy) for mid-rapidity pions for the most central events. However, the newest, very preliminary data imply that there is a universal behavior with dN/dy and that nothing interesting is going on.

The E866 data set currently being analyzed should allow us to examine multidimensional fits versus both centrality and $m_{T_{pair}}$. This data set also includes three global event characterization measurements: forward energy, multiplicity, and forward-particle reaction plane. Furthermore these pion pairs will cover a broad range in centrality. This data set should allow us to more fully rule out the possibility of unusual behavior in the central *Au-Au* system.

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