EXPERIMENTAL ISSUES FOR HBT STUDIES AT RHIC

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The Relativistic Heavy Ion Collider at Brookhaven will begin producing colliding beams by the middle of next year. We will undoubtedly have our first preliminary HBT analysis from one or more of the RHIC detectors shortly thereafter. In this paper we will attempt to identify some experimental issues involved in carrying out HBT studies at RHIC in the context of the STAR detector and will try to address what realistic expectations we can have for these studies.

1 Introduction

RHIC should easily provide the most interesting physics yet to probe with Hanbury-Brown-Twiss (HBT) interferometry and the means to carry out HBT studies with a wide variety of particle types[1]. In addition, we have the advantage at RHIC that we can apply the lessons we have learned about extracting physics from HBT studies in extensive AGS and SPS experiments (e.g. Ref.[2,3]). All of the four main RHIC experiments (BRAHMS, PHENIX, PHOBOS, and STAR) will have the capability of carrying out HBT studies with charged pions, kaons and protons and some of the experiments will in addition be able to study more exotic probes such as K^0_S-K^0_S and Λ-Λ correlations.

The main question to be answered when the analysis of the data has been completed in an HBT experiment is "what have we measured?" This question applies to both the physical and the experimental interpretations of the data. This paper concentrates on the experimental interpretation of the data which is necessary to understand before one can move on to consider the physical implications of what was measured. The experimental issues involved

in HBT at RHIC will be studied in the context of the STAR experiment[4] which has the capability of using a broad range of HBT probes. For the present work, only charged pion pairs and K^0_S pairs near mid-rapidity in STAR will be considered.

In STAR, charged hadrons are measured at mid-rapidity ($|\eta|<1$) in cylindrical-geometry tracking detectors (whose axis is defined by the colliding beams) which are the Silicon Vertex Tracker (SVT) at smaller radii and the Time Projection Chamber (TPC) at larger radii. The SVT is composed of three barrel-geometry layers of silicon drift detectors (SDD's). The combination of the SVT and TPC form a global tracker. Matching tracks between the SVT and TPC to form global tracks allows better overall momentum resolution (very important for HBT interferometry studies) and better particle identification using dE/dx than either detector alone. Note that a fourth barrel of silicon strip detectors (SSD's) located at a radius between the SVT and TPC will also be present in STAR but at this time is not implemented in the STAR software and thus will not be included in the present study. K^0_S's are measured in the SVT+TPC detector by observing the decay channel $K^0_S \rightarrow \pi^+\pi^-$.

2 Calculational Method

The goal of the present work is to make "realistic" Monte Carlo calculations for STAR HBT capabilities for charged pion pairs and K^0_S pairs using the most recent (and available) versions of STAR software and to determine what distortions are introduced into the experimental correlation functions by the detector. The STAR software chain used is the following: a) detector Monte Carlo which takes a HIJING event and converts the output list of particles via GEANT into smeared hits in the detectors (no cluster-finding used), b) track reconstruction in the SVT and TPC from the detector hits, c) track matching in the SVT and TPC to make global tracks, d) V0 reconstruction of oppositly charged pions to find K^0_S's and e) the extraction of the "experimental" momenta of the reconstructed

particles. The HBT effect is then imposed pairwise on the reconstructed particles and correlation functions are generated (see below). Several "non-realistic" assumptions are also made in the present work which to some extent can be justified: 1) perfect charged π-K separation using dE/dx--this should be a good approximation for $p_t < 500$ MeV/c and for stringent cuts being made on dE/dx, 2) 100% purity in reconstructed K^0_S's--this limit can be approached in STAR by making stringent cuts on the ^{0} V reconstruction parameters and the invariant mass and by using neural-network pattern recognition (this purity comes at the expense of reconstruction efficiency--in the present work we get two reconstructed pure K^0_S's per event), 3) cluster finding software is not used, only smeared space points as already mentioned above--however recent cluster-finding codes have shown that almost 100% efficiency for finding space points can be obtained, and 4) silicon strip detector (fourth) layer in STAR not included in software--when included the SSD should improve dE/dx, tracking, and ^0_S K reconstruction.

The method used to impose HBT correlations on particle pairs and to assess the distortions due to the detector on the correlation function and extracted boson source parameters is now discussed. After running the STAR Monte Carlo chain on a HIJING event (as described above) one has generated a "list" of reconstructed particles for that event. Each particle in the list has associated with it a HIJING (unprimed) four-momentum (E, $\mathbf{p}$) and a reconstructed (primed) four-momentum (E',$\mathbf{p}$') which reflects the distortions due to detector effects and due to imperfect reconstruction software. From this list, an "experimental" two-boson correlation function is formed using the following four steps:

1) choose two like particles from the list and calculate their true (HIJING) and distorted momentum differences (in the LCMS frame, i.e. $p_{1z}+p_{2z}=p_{1z}'+p_{2z}'=0$)

$$\mathbf{Q}=\mathbf{p}_1-\mathbf{p}_2, \quad Q_0=E_1-E_2, \quad Q_{inv}^2=Q^2-Q_0^2$$

$$\mathbf{Q}' = \mathbf{p}_1' - \mathbf{p}_2', \quad Q_0' = E_1' - E_2', \quad Q_{inv}'^2 = Q'^2 - Q_0'^2 ,$$

2) calculate the true HBT weight (i.e. using HIJING momenta), W(Q), for the two particles assuming a gaussian boson source and assuming values for the source parameters R_{To}, R_{Ts}, R_L, λ (Bertsch-Pratt parameterization [2]) and include the final-state Coulomb effect between the two bosons using a Gamow factor, $G(Q_{inv})$

$$W(Q) = [1 + \lambda \exp(-R_{Ts}^2 Q_{Ts}^2 - R_{To}^2 Q_{To}^2 - R_L^2 Q_L^2)] G(Q_{inv}) \qquad (1)$$

where $G(Q_{inv}) = 2\pi\eta/[\exp(2\pi\eta)-1]$ and $\eta = m\alpha/Q_{inv}$ and where m is the boson mass and $\alpha = 1/137$,

3) calculate the "experimental" correlation function, $C_{exp}(Q_{bin}')$, in terms of the distorted momenta by binning pairs of bosons (weighed by Eq.1) in terms of the distorted momentum differences and make a Coulomb correction (in the denominator) also using the distorted momentum differences

$$C_{exp}(Q_{bin}') = A[R(Q_{bin}')/B(Q_{bin}')] \qquad (2)$$

where $R(Q_{bin}') = \sum_i W(Q_i)$ and $B(Q_{bin}') = \sum_j G(Q_{inv\,j}')$ and the sums over i and j extend over boson pairs whose distorted momentum differences fall into a particular momentum-difference bin such that $Q_{bin}' = \sum_i Q_i'/N$ where N is the number of boson pairs that falls in the particular bin. The quantity A is a normalization constant determined by the condition that $C(Q_{bin}') = 1$ for large Q_{bin}', and

4) fit a gaussian correlation function, C(Q') to the "experimental" correlation function calculated from Eq.2 to extract the "distorted" source parameters, R_o', R_{Ts}', R_L', λ', and compare the results with the true source parameters input into the calculation via Eq.1,

$$C(Q')=A'[1+\lambda' \exp(-R_{Ts}'^2 Q_{Ts}'^2 - R_{To}'^2 Q_{To}'^2 - R_L'^2 Q_L'^2)] \quad (3)$$

where A' is a normalization parameter determined in the fit.

In order to carry out the proceedure outlined above, it is necessary to guess reasonable values to use for the input boson source parameters, R_{To}, R_{Ts}, R_L, λ, which are to be inserted into Eq.1. For the present study two sets of input source parameters were used: 1) $R_{To}=R_{Ts}=R_L=6$ fm, $\lambda=0.6$, and 2) $R_{Ts}=R_L=6$ fm, $R_{To}=3R_{Ts}=18$ fm, $\lambda=0.6$. Set #1 represents a lower-limit or conventional physics case since it approximates measured values for CERN Pb+Pb collisions[2] and preliminary predictions for RHIC Au+Au collisions from a simple rescattering calculation[5]. Set #2 represents an upper-limit case where a phase transition to Quark Matter takes place resulting in a long-lived boson source as predicted by the hydrodynamics calculations of Rischke and Gyulassy[1]. In the present study calculations were performed for both sets of parameters whereas for $K^0_S K^0_S$ calculations only set #1 was used.

3 Results

Figures 1-5 present the results of the present study. Figure 1 shows a sample m_T distribution for pion momenta reconstructed from HIJING in the STAR tracking detectors (SVT+TPC) as described above. An exponential slope parameter of 188 MeV is extracted by fitting the expression

$$(1/m_T)dN/dm_T = C \exp(-m_T/B)$$

where B is the slope parameter and C is a normalization constant.

Figure 2 shows the momentum resolution for rectangular components for reconstructed pions in STAR and projections of the three-dimensional two-pion correlation function produced from these reconstructed pions weighted by Eq.1 for the "conventional physics" case (input parameter set #1). The difference between the "real" (unprimed) and "recon" (primed) components are plotted and a

gaussian is fitted to extract σ in each case. As is seen σ is slightly less than 5 MeV/c for each component. The distored source parameters obtained by fitting Eq.3 to the correlation function are also shown. The statistics for this correlation function corresponds to one hour of STAR running assuming a data acquisition rate of one event per second, yielding about 8 million pion pairs. The average k_T of these pions is 250 MeV/c. Error bars are statistical only. The momentum binning used in this case is 10 MeV/c for all components.

The distorted source parameters from Figure 2 are compared graphically with the input source parameters from set #1 and two other calculations in Figure 3. The dashed line at 6 on the ordinate of the plot represents both the input radius parameters and the input λ*10. The three calculation types indicated on the abcissa of the plot are the following: a) "all effects"--pion pairs weighted by Eq.3 and Coulomb corrected as described above, i.e. the parameters shown in Figure 2, b) "no Coulomb effects"--pion pairs weighted by the symmetrization part of Eq.3 but not the Gamow part and with no

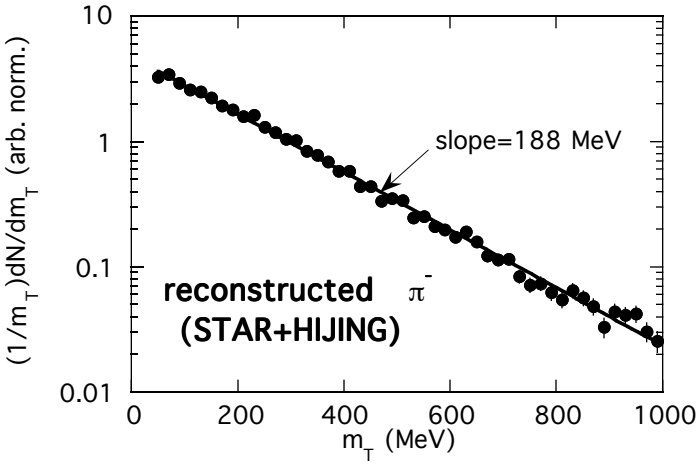

Figure 1: Sample m_T distribution for pion momenta reconstructed from HIJING events in the STAR detector (SVT+TPC).

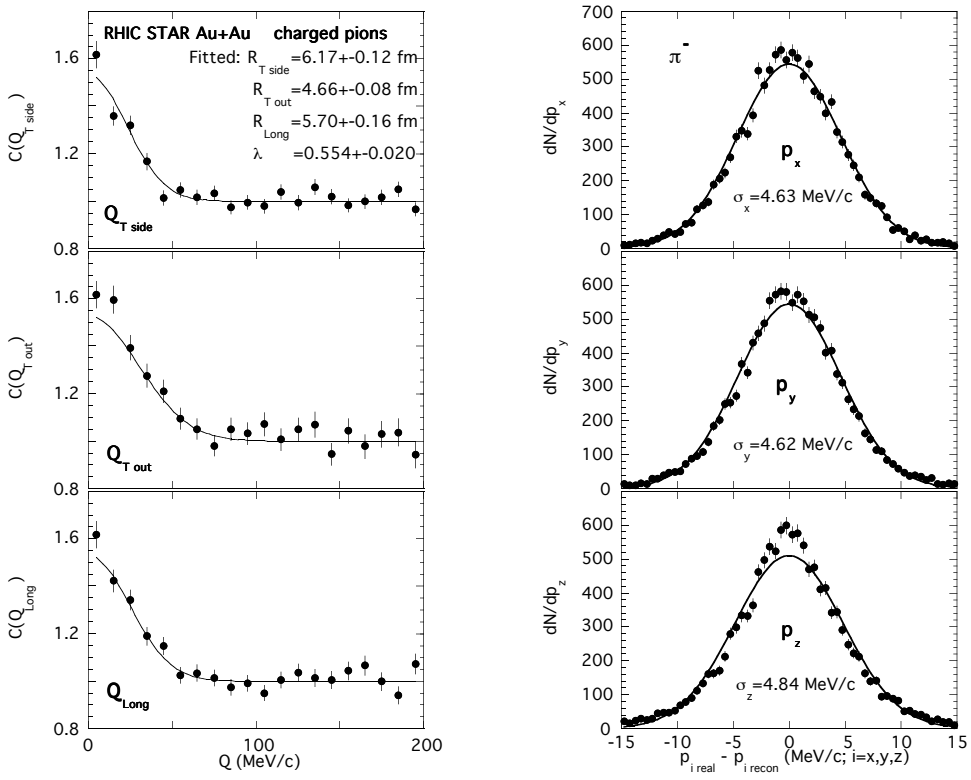

Figure 2: Momentum resolution for rectangular components for reconstructed pions in STAR and projections of two-pion correlation function from STAR for input parameter set #1 (conventional physics).

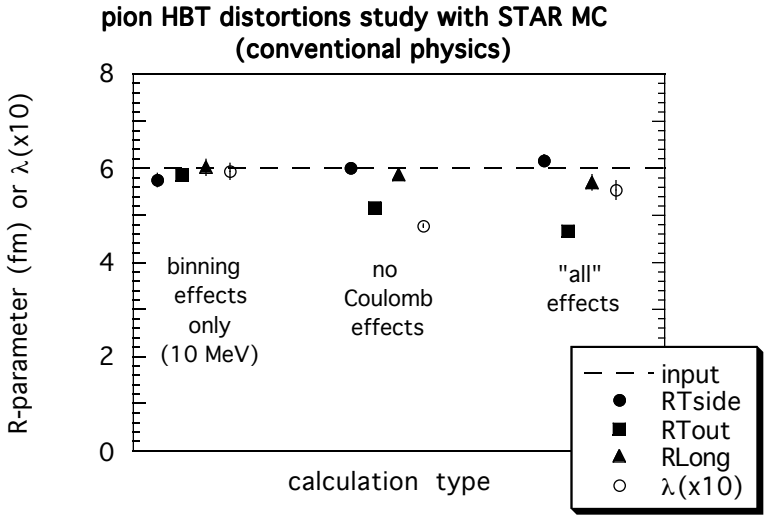

Figure 3: Distorted source parameters for conventional phyiscs input (set #1) compared for several calculations.

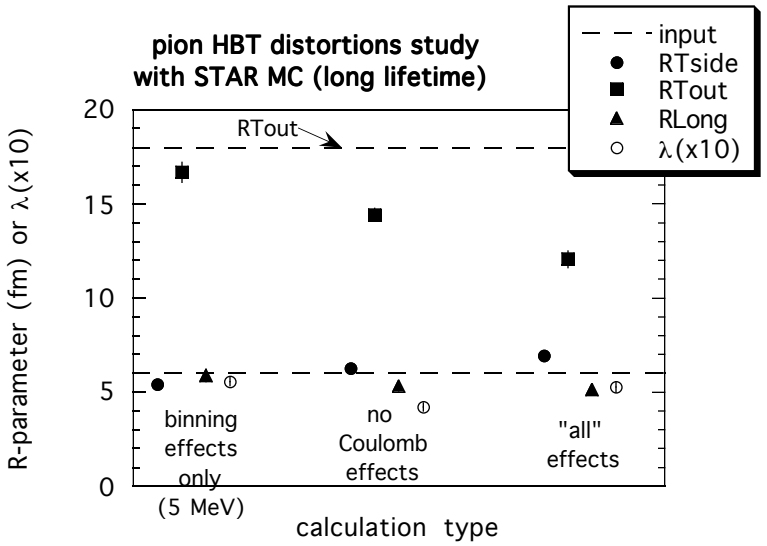

Figure 4: Same as Figure 3 except for long-lifetime input parameters (set #2).

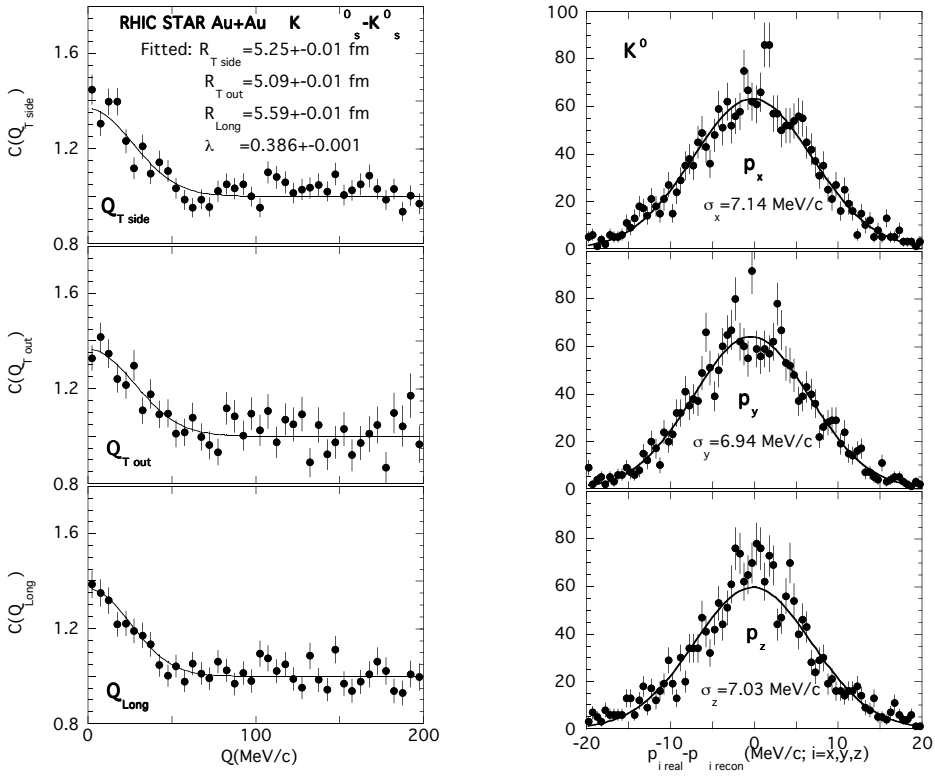

Figure 5: Same as Figure 2 except for K^0_s's.

Coulomb correction to the correlation function, and c) "binning effects only"--take out all detector effects and study the smearing introduced into the correlation function by the 10 MeV/c binning only, i.e. weight pairs with Eq.3 but form the correlation function with HIJING (unprimed) momenta. As seen in Figure 3, the "binning

effects only" calculation has a negligible effect on the source parameters and thus acts as a check on the method being used. The "no Coulomb effects" case shows some distortions in the extracted R_{out} and λ parameters due to the detector momentum smearing. Including "all effects" increases the distortion in R_{out} but making a "wrong" Gamow correction via Eq.2 using the distorted momenta compensates for the momentum smearing effect in λ. Figure 4 is similar to Figure 3 except that the long-lifetime input parameters (set #2) were used. The distortions are qualitatively similar to those seen in Figure 3 but the effect on R_{Tout} is larger.

Figure 5 shows the results of the present study for K^0_S's (Ref.[6] describes an earlier study for K^0_S's.).As seen, the momentum resolution width is about 7 MeV/c which is approximately equal to $\sqrt{2}*\sigma_{pion}$ as expected since a K^0_S is reconstructed from its decay into two pions. The correlation function with distorted source parameters using input parameters from set #1 is also shown. The statistics for this correlation function corresponds to about 100 days of STAR running and results in about 8 million pairs. The average k^* of these K^0_S's is 525 MeV/c. Comparing this calculation with the similar calculation for pions seen in Figure 2, the distortions in the radius parameters are qualitatively the same whereas the distortion in λ is significantly greater for K^0_S's. This is due to two effects: 1) the momentum resolution for K^0_S's is larger than for pions and, 2) there is no "wrong" Gamow correction to apply to compensate for the momentum resolution effects.

Summarizing the results shown above, distortions in the extracted boson source parameters induced by detector effects can be significant at RHIC. Thus, in most cases it is necessary to use an accurate detector Monte Carlo to correct the experimental correlation function, as has already been applied successfully in SPS experiments[2].

Acknowledgment

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