STAR Note # 0224
November 6, 1995

Updated Simulations for Neutral Kaon Interferometry

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Abstract

We revisit the topic of K^0_S interferometry in STAR using the latest simulation infrastructure. The new simulations show no evidence of detector-induced distortion of the K^0_S correlation functions in either the *outward* or *sideward* transverse direction, and the expected relative momentum resolutions are such that source dimensions as large as about 20 fm might be resolved. Given that we expect an average multiplicity of about 2.5 reconstructed neutral kaons in central Au + Au events, we project that several million events will provide enough statistics for a useful HBT analysis if transverse source dimensions are on the order of 10 fm.

1 Introduction

Star Note 0047 described a simulation of K^0_S interferometry in STAR dating back to 1992, in which the equivalent of about 10^4 central HIJING events was processed through a dedicated stand-alone simulation program which used parametrizations of the main features of STAR's acceptance and distortions. The latter were determined from samples of up to five events processed via the best GEANT-based simulation then available. The STAR simulation infrastructure is now in a much more advanced state, with much better statistics, with fully-operational tracking in both TPC and SVT, and with realistic track matching between the two subsystems. We begin this K^0_S HBT update by reproducing below the sections on theoretical and experimental motivation from SN0047. The most noteworthy development in the literature since 1992 has been the publication of a K^0_S HBT analysis by the OPAL collaboration [1]. Among other things, their study provides evidence that resonance decays do not pose a serious problem in interpreting K^0_S pair correlation functions.

2 Theoretical motivation

The expected space-time structure of the particle-emitting source at RHIC differs according to whether or not a quark-gluon plasma is formed, and the HBT effect has the potential to probe this space-time structure. Before such information can be extracted, final state interactions [2, 3] and resonance formation [4, 5] must be well-understood, and especially at RHIC energies, additional distortions arise because the collision dynamics induce strong

correlations between momenta and spatial coordinates [6]. Kaons offer significant advantages over pions in these regards [4, 5, 7, 8, 9, 10, 11]; in particular, resonance production increases the apparent size and lifetime of the source, and this distortion is less severe for charged and neutral kaons [4, 11]. Moreover, independent HBT measurements for K^+ and K^0_S can in principle remove the resonance distortion [11].

On the other hand, Coulomb repulsion [2] between a $K^{\pm}K^{\pm}$ pair is larger than for a $\pi^{\pm}\pi^{\pm}$ pair at the same momentum difference, and strongly suppresses the entire region of the HBT enhancement for a source with a radius on the order of 10 fm or more (see below). For multiplets of higher order than pairs, Coulomb repulsion is even more dominant, and is much more difficult to understand theoretically [12, 13]. Neutral particles thus enjoy an important advantage over their charged isospin partners for HBT analyses.

Finally, some interesting and potentially important consequences arise from the fact that the K^0_S is not a strangeness eigenstate. The $K^0_S K^0_S$ correlation includes a unique interference term that provides additional space-time information [11], as well as insight into possible strangeness distillation effects [7, 14, 8, 11], in cases where the baryon density of the source is appreciable. If the kaons come from a baryon-free region, the expected K^0_S correlation function has the conventional form [11].

3 Experimental motivation

Neutral kaons enjoy some experimental advantages over charged pions and kaons in HBT analyses. The most important of these is the fact that K^0_S interferometry is immune to two-track resolution effects, whereby the efficiency for separately resolving two charged particles with closely-spaced momenta decreases with decreasing momentum difference. In charged particle HBT analyses, this efficiency typically begins to drop in precisely the region where the Bose-Einstein enhancement occurs, and is a source of systematic uncertainty to the extent that it can only be simulated and corrected for with limited accuracy. Below some ultimate limit in relative momentum, two-track resolution renders charged particle data unusable for HBT. Two-track resolution is particularly troublesome [15] along the direction of the average pair $p_\perp$ (the $Q_{\perp\mathrm{out}}$ direction) — a component which must be measured in order to probe the lifetime of the source [16, 17, 18]. However, even for two neutral kaons at exactly zero relative momentum, the decay pions are as likely as ever to be well-separated in momentum space, and the neutral kaons can be found and reconstructed with the same efficiency as if the relative momentum of the kaons was large. Furthermore, multiple scattering in the beam pipe sets a lower limit to the usable particle momentum for HBT analyses in some scenarios; by selecting neutral kaons that decay outside the beam pipe, this source of multiple scattering can be avoided, albeit at the expense of reduced statistics.

4 Event Statistics Needed for K^0_S HBT

In the 1992 simulation, the reconstructed K^0_S multiplicity in central Au + Au collisions averaged about 3 times higher than the current estimate of 2.5, while 10,000 HIJING events resulted in $Q_{\perp\mathrm{out}}$ and $Q_{\perp\mathrm{side}}$ correlation functions having 2 to 3 bins within the Bose-Einstein enhancement region for a 10 fm Gaussian source radius, each bin having typically $\sim \pm 0.15$

error bars. We now project 10^5 central Au + Au events as the sample needed to generate correlation functions resembling those in SN0047, while a further increase to several million central events would be needed to obtain "useful" statistics for a determination of source dimensions — say, determining a 10 fm source dimension with better than 10% statistical uncertainty. Of course, cuts on variables like pair $p_\perp$ could greatly increase the desired sample size, as would an increase in source dimensions above 10 fm.

5 Distortion of K^0_S Correlation Functions

Using the current simulation infrastructure, it is feasible to process up to about 50 central Au + Au events, yielding a total sample of about 130 reconstructed neutral kaons when cuts are adjusted for a low level of combinatoric background. This sample is too small by far to probe the region of parameter space where the Bose-Einstein enhancement occurs. If all particle species other than K^0_S are removed from the events, then it becomes feasible to process up to about 1000 central Au + Au events. When the K^0_S-only events are subjected to the same cuts and conditions as used to process the complete events, the multiplicity of accepted neutral kaons increases to about 6. This increase results from the greater tracking and SVT-TPC matching efficiency in the low multiplicity environment of K^0_S-only events. This sample is still much smaller than a useful data set for an experimental analysis as discussed in the previous section, but it *is* sufficient to explore $Q_{\perp\mathrm{out}}$ and $Q_{\perp\mathrm{side}}$ resolution and pair reconstruction efficiency in the vicinity of the HBT enhancement. (Note: we define an rms Q resolution as the root-mean-square of $Q_{\mathrm{input}} - Q_{\mathrm{recon}}$ for all possible K^0_S pairs.)

Fig. 1 illustrates the capability of STAR to resolve the HBT enhancement for neutral kaons with minimal distortion; in particular, it is significant that the efficiency for detecting pairs, plotted in the left-hand panel and normalized to unity at large Q, shows no sign of dropping as a function of decreasing relative momentum, as normally observed for charged particles. The dashed line in this panel is the effective efficiency for K^+K^+ or K^-K^- pairs, which is dominated by Coulomb repulsion. If the standard Gamow correction factor for Coulomb repulsion is applied, a smaller drop in charged kaon pair efficiency persists at low Q because of two-track efficiency effects.

Also in contrast to what is typically observed for charged particles, the right-hand panel of Fig. 1 demonstrates that the resolution for $Q_{\perp\mathrm{out}}$ is at least as good as the $Q_{\perp\mathrm{side}}$ resolution. This ~ 5 MeV/c $Q_{\perp\mathrm{out}}$ resolution is about a factor two better than the same for charged pions in STAR, as quoted in in the CDR [19], while the $Q_{\perp\mathrm{side}}$ resolution for K^0_S is about the same as the CDR number for charged pions. These resolutions translate to the maximum resolvable source dimension being about 20 fm for both $R_{\perp\mathrm{out}}$ and $R_{\perp\mathrm{side}}$, assuming the CDR criterion of at least two bins within the inflection point of the correlation function [19].

A caveat surrounding the above-described simulations is the replacement of complete events by K^0_S-only events processed using the same cuts and conditions as complete events. We have used a sample of 50 full events with 130 reconstructed neutral kaons to explore this issue as far as possible. Averaging over a wide Q region (0 to 500 MeV/c), we find

$$\langle Q_{\perp\mathrm{out}}\ \mathrm{resolution}\rangle = 4.9 \pm 2.0\ \mathrm{MeV}/c \quad \text{and} \quad \langle Q_{\perp\mathrm{side}}\ \mathrm{resolution}\rangle = 5.7 \pm 2.8\ \mathrm{MeV}/c\,.$$

The same quantities for 1000 K^0_S-only events are 5.0 MeV/c and 7.3 MeV/c. These results

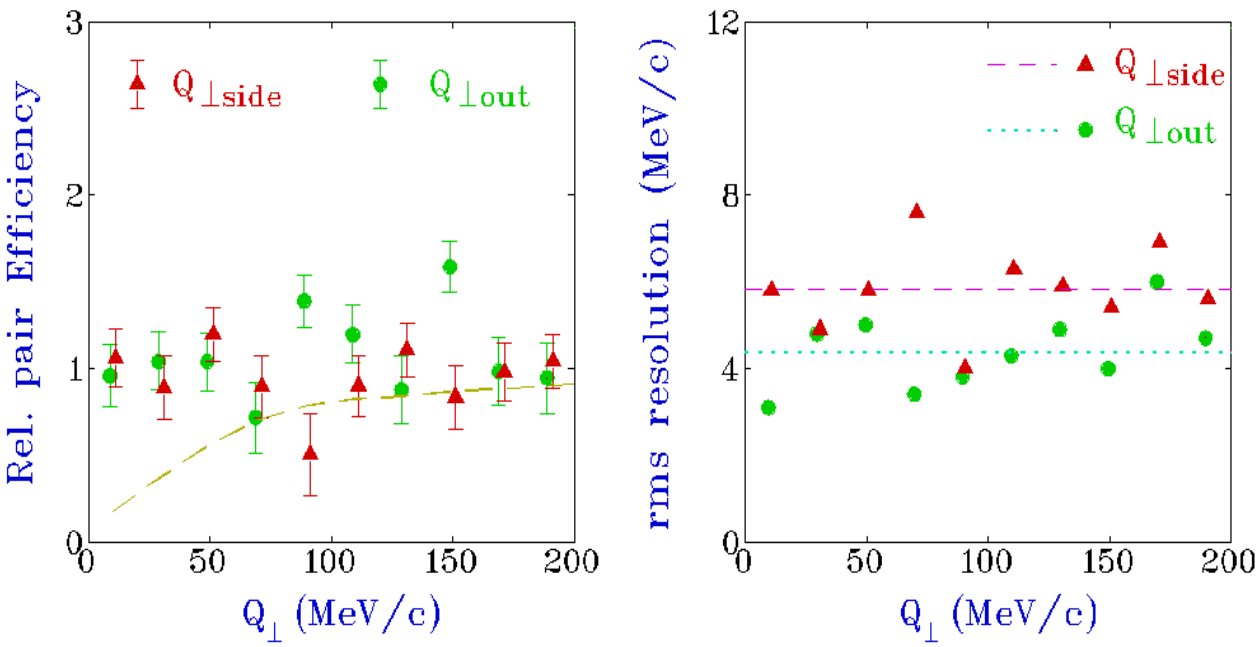

Figure 1: Simulated efficiency and relative momentum resolution for K^0_S pairs as a function of relative momentum. The original color version of this figure can be accessed in GIF format at http://cnr2.kent.edu/~ keane/star/k0.gif

are suggestive that our use of K^0_S-only events has not caused the simulated HBT performance to be biased in the optimistic direction.

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