STAR Note # 47
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STAR capabilities for K_S^0 interferometry

1 Theoretical motivation

The good efficiency of the STAR SVT/TPC combination for finding and reconstructing short-lived neutral kaons offers an unprecedented opportunity to study Hanbury-Brown–Twiss correlations for K_S^0. 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[1, 2] and resonance formation[3, 4] must be well-understood, and especially at RHIC energies, additional distortions arise because the collision dynamics induce strong correlations between momenta and spatial coordinates.[5] Kaons offer significant advantages over pions in these regards[3, 4, 6, 7, 8, 9, 10]; in particular, resonance production increases the apparent size and lifetime of the source, and this distortion is less severe for charged and neutral kaons.[3, 10] Moreover, independent HBT measurements for K^+ and K_S^0 can in principle remove the resonance distortion.[10]

On the other hand, Coulomb repulsion[1] 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.[11, 12] 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_S^0 is not a strangeness eigenstate. The $K_S^0 K_S^0$ correlation includes a unique interference term that provides additional space-time information,[10] as well as insight into possible strangeness distillation effects, [6, 13, 7, 10] in cases where the baryon density of the source is appreciable. If the kaons come from a baryon-free region, the expected K_S^0 correlation function has the conventional form.[10]

2 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_S^0 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 measured 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[14] along the direction of the average pair momentum — the direction associated with the lifetime of the source.[15, 16, 17] However, even for two K^0_S at exactly zero relative momentum, the decay pions are 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 greatly reduced statistics.

3 Simulations

The strategy followed in this note for simulating the performance of STAR for K^0_S HBT involves imposing a "pseudo-Bose" enhancement on the neutral kaons from a sample of 1000 central ($0 < b < 1$ fm) Au + Au events generated by HIJING.[18] When a K^0_S pair is found at a relative momentum $\mathbf{Q}$ where the desired correlation function C lies above 1, then there is a probability $C(\mathbf{Q}) - 1$ that a duplicate of that pair of kaons will be incorporated in the *next* event in the file. For a source radius of 10 fm, this algorithm increases the average K^0_S multiplicity by only a few percent.

These events have not yet been processed through the full STAR simulation chain which includes TPC track finding and reconstruction, but have been analyzed using a simpler and much faster simulation. The latter incorporates parametrizations of the efficiencies and resolutions of the SVT/TPC, obtained from relatively small samples subjected to the full simulation. The principal features of the current calculation are

- random decay of each K^0_S — both decay pions must lie within the geometrical acceptance of the TPC;
- the decay pions are filtered by the SVT–TPC matching efficiency as a function of $p_\perp$[19];
- the decay pion momenta are smeared according to multiple scattering + an additional TPC momentum resolution: $\Delta p/p = 1.5\%$;
- K^0_S are reconstructed according to current finding efficiencies as a function of $p_\perp$ in the appropriate rapidity range;
- combinatoric background is added using pion pairs whose invariant mass lies by chance within the designated interval (see Fig. 1); all reconstructed particles outside this interval are discarded.

This simulation errs on the pessimistic side of the most probable STAR performance in several important respects: it neglect the improvement in TPC momentum resolution that will result from incorporating SVT hits in the momentum fitting, it neglects the improved K_S^0 momentum resolution that can be obtained by constraining the reconstructed particles to have the exact mass of the neutral kaon, and it uses an SVT–TPC matching efficiency based on an early design of the inner TPC field cage with 4 times the radiation length of the current design.

Some inefficiencies do not vary with any of the parameters in this simulation (e.g. loss of K_S^0 via decay to $\pi^0\pi^0$), and in order to improve statistics, these have not been incorporated explicitly. If these losses were included, it is estimated that about 10^4 central events would yield the same HBT statistics as presented in this note.

Fig. 2 shows the simulated STAR performance (points with error bars) for $C(Q_{\perp out})$ and $C(Q_{\perp side})$[16, 17] with the condition that the K_S^0 rapidity lies in the range $-0.5 < y < 0.5$.

A completely incoherent spherical source of radius 10 fm is assumed; considering that kaons can be expected to freeze-out earlier than pions, this radius is plausible. The intercept at $Q = 0$ is mostly determined by the binning and the condition imposed on the other two dimensions of $\mathbf{Q}$. The solid line shows the symmetrized HIJING without any detector distortions but with the same binning; statistical fluctuations are removed for $Q_\perp > 0.06$ GeV/c. The dashed line in Fig. 2 was calculated by assigning a charge to the kaons represented by the solid line, and applying the standard Gamow factor[1]; the width of this "Coulomb hole" underlines the benefit of neutral particle HBT when the particle is relatively heavy and the source radius is large.

Fig. 2 indicates that to extract useful information on the space-time dimensions of a 10 fm kaon source in central Au + Au collisions, several times 10^5 events are needed. The large Poisson fluctuations associated with the relatively small sample in Fig. 2 can in part be circumvented by comparing the simulated $C(Q_\perp)$ to the undistorted correlation function $C_{ideal}(Q_\perp)$ for the subset of kaon pairs that lies within the acceptance. Fig. 3 shows the ratio of these two quantities, plotted using the same scales as in Fig. 2. Smearing from the combinatoric background is neglected in Fig. 3, but the amount of distortion of the correlation function caused by multiple scattering and TPC resolution can now be seen.

Overall, the simulations shown in Figs. 2 and 3 suggest that K_S^0 interferometry offers substantive advantages over charged-particle HBT, and the K_S^0 enhancement is a robust signal with comparatively good immunity to the most important detector distortions.

4 Staging scenarios

To date, it has not been demonstrated that K_S^0 can be found and reconstructed with an acceptable background using the TPC alone. Therefore, the only staging scenarios that preserve any HBT capability for K_S^0 involve partial TPC instrumentation, and/or partial SVT coverage. Fig. 4 shows the detected number of neutral kaon pairs within the HBT enhancement region ($Q_\perp < 0.06$ GeV/c) as a function of kaon transverse momentum, for the full sample of HIJING events. The shaded region of the upper panel corresponds to a scenario in which half the SVT is removed by cutting along a diameter; the shaded region of the lower panel corresponds to shortening the length in the z direction by half.

The requirement to detect all 4 decay pions in order to reconstruct one K^0_S pair results in a substantial loss of statistics, especially at low $p_\perp$ where the opening angle at the decay vertex is larger. The fact that the "half length" scenario is favored over the "half shell" is partly a consequence of the relatively narrow rapidity gate, and possibly the neglect of the z-fluctuations of the primary vertex.

References

[1] M. Gyulassy, S. K. Kauffmann, L. W. Wilson, Phys. Rev. C **20**, 2267 (1979).

[2] M. G. Bowler, Z. Phys. **C39**, 81 (1988).

[3] S. S. Padula and M. Gyulassy, Phys. Lett. **B217**, 181 (1989).

[4] M. Gyulassy and S. S. Padula, Phys. Rev. C **41**, R21 (1989).

[5] S. S. Padula, M. Gyulassy, and S. Gavin, Nucl. Phys. **B329**, 357 (1990); Nucl. Phys. **B339**, 378 (1990).

[6] C. Greiner, P. Koch and H. Stöcker, Phys. Rev. Lett. **58**, 1825 (1987).

[7] C. Greiner, D.-H. Rischke, H. Stöcker, and P. Koch, Phys. Rev. D **38**, 2797 (1988).

[8] C. Greiner and B. Müller, Phys. Lett. **B219**, 199 (1989).

[9] S. Pratt, P. J. Siemens, and A. P. Vischer, Phys. Rev. Lett. **68**, 1109 (1992).

[10] M. Gyulassy, Phys. Lett. **B286**, 211 (1992).

[11] Y. M. Liu, D. Beavis, S. Y. Chu, S. Y. Fung, D. Keane, G. VanDalen, and M. Vient, Phys. Rev. C **34**, 1667 (1986).

[12] J. Cramer, Phys. Rev. C **43**, 2798 (1991).

[13] U. Heinz, K. S. Lee, and M. J. Rhoades-Brown, Phys. Rev. Lett. **58**, 2292 (1987); Mod. Phys. Lett. **A2**, 153 (1987).

[14] K. Kadija *et al.*, original STAR LOI, LBL-29651 (1990).

[15] S. Pratt, Phys. Rev. Lett. **53**, 1219 (1984).

[16] G. Bertsch, M. Gong, and M. Tohyama, Phys. Rev. C **37**, 1896 (1988).

[17] G. Bertsch and G. E. Brown, Phys. Rev. C **40**, 1830 (1989).

[18] X. N. Wang and M. Gyulassy, LBL-29390.

[19] G. Odyniec *et al.*, LBL-31773 (1992).

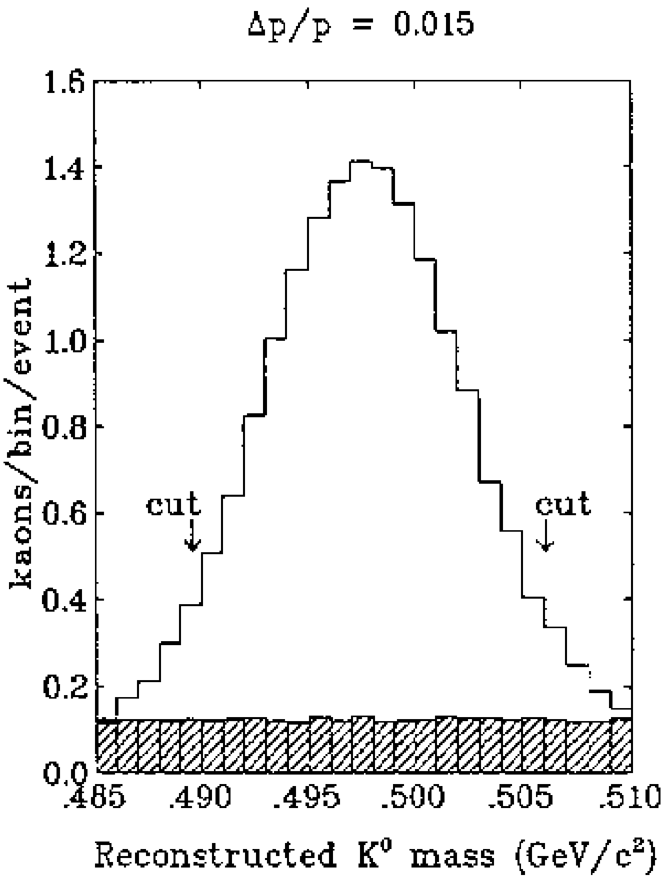

Figure 1: Reconstructed K_s^0 invariant mass spectrum after application of detector distortions. The shaded histogram denotes the level at which combinatoric background has been added.

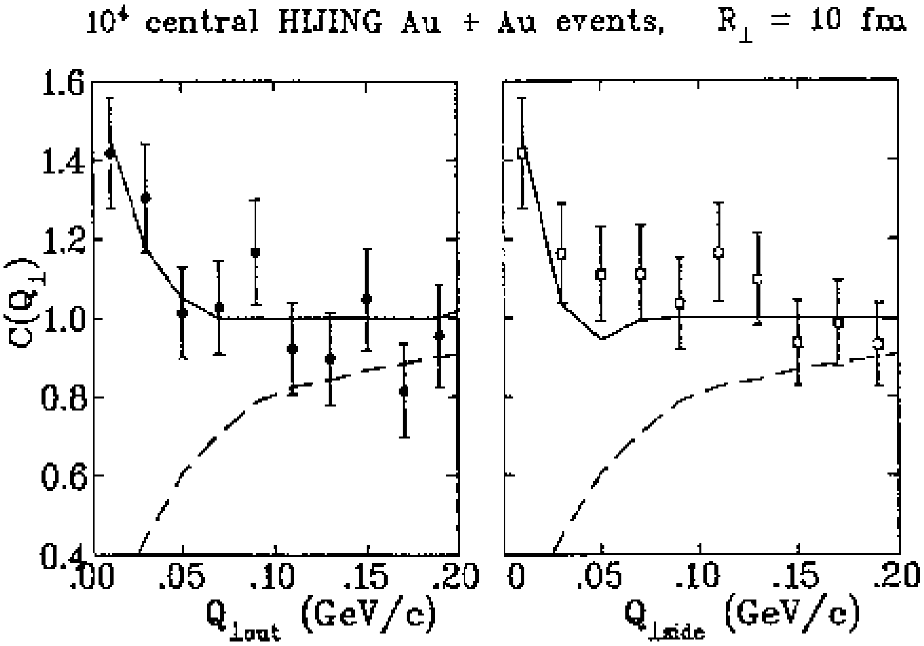

Figure 2: Simulated STAR performance (points with error bars) for $C(Q_{\perp out})$ and $C(Q_{\perp side})$ with the condition that the K_s^0 rapidity lies in the range $-0.5 < y < 0.5$. The solid line shows the HIJING data without any detector distortions but with the same binning; statistical fluctuations are removed for $Q_\perp > 0.06$ GeV/c. The dashed line is the undistorted correlation function for $K^\pm K^\pm$ from the same source with the same binning.

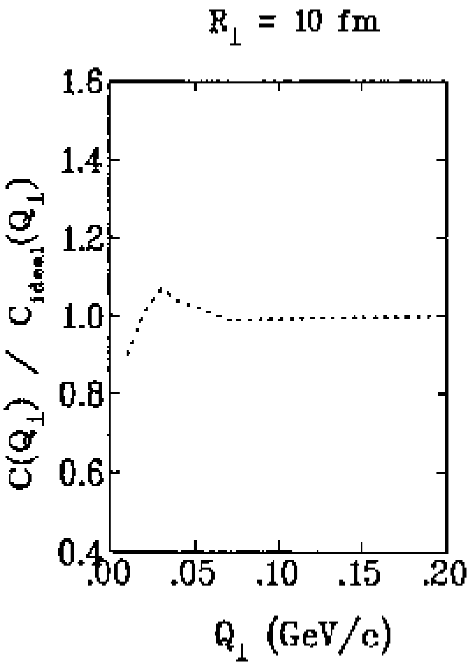

Figure 3: The simulated $C(Q_\perp)$ divided by the undistorted correlation function $C_{ideal}(Q_\perp)$ for the same set of kaon pairs as went into the calculation of $C(Q_\perp)$.

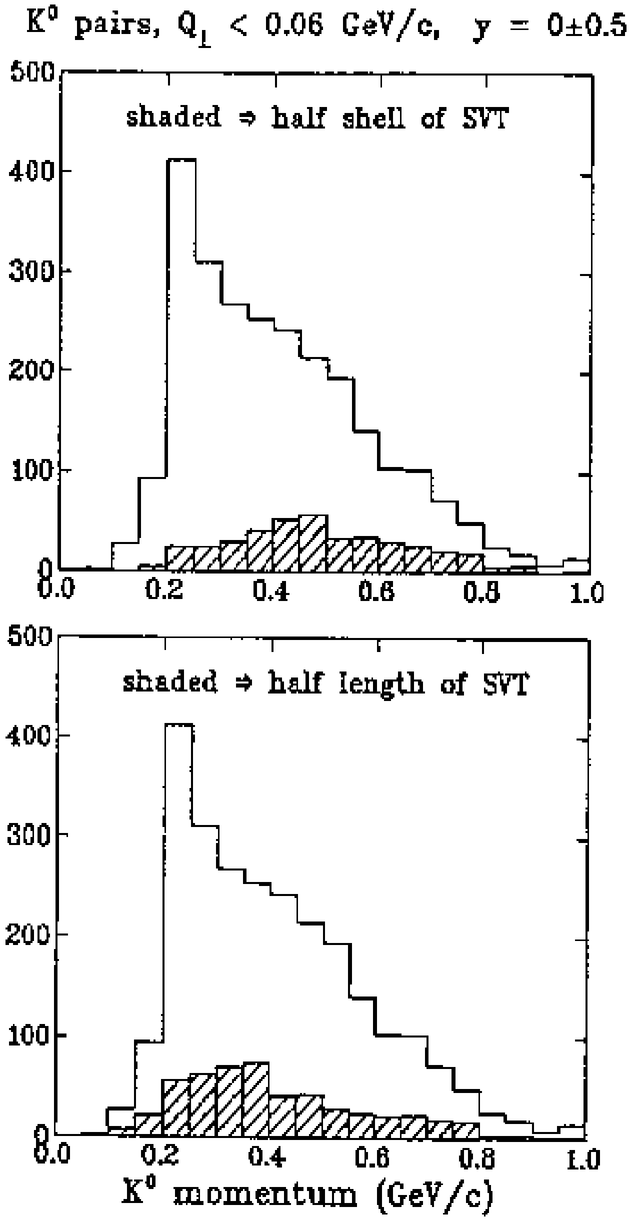

Figure 4: The detected number of neutral kaon pairs within the HBT enhancement region ($Q_\perp < 0.06$ GeV/c) as a function of kaon momentum, for the full smaple of HIJING events. The shaded region of the upper panel corresponds to a scenario in which half the SVT is removed by cutting along a diameter; the shaded region of the lower panel coresponds to shortening the length in the z direction by half.