Kaon and Proton Interferometry from PHENIX at RHIC

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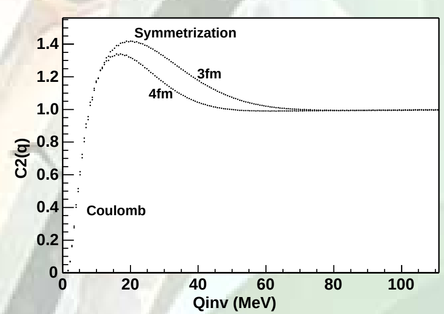
Introduction

Two-particle interferometry, also known as HBT, is based upon the interactions between particle pairs after the last significant scattering, and it provides information about the spatial extent of the last scattering region of a relativistic nuclear collision. This technique relies on the calculable distortion of the relative momentum (q) spectra from an emitting source of a given size, and the ability to measure the relative momentum of particle pairs from a collision to the order of a few tens of MeV. Combining these two items with a fitting package provides a method to infer the size of a nuclear collision.

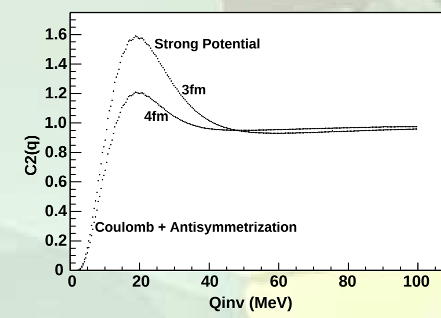
In principal, two-particle interfereomerty is possible with any particle type that is generated in these collisions provided the interactions between the emitted particles are understood. These interactions basically fall into three categories, coulomb, strong, and quantum interference of identical particles. It is not always the case that all three interactions play a role. In the case of the pions the strong interaction is quite small and the coulomb effect can be "corrected" from the data. The golden feature of the pions is that if the source is assumed to be gaussian, the correlation function is also gaussian with a radius that is inversely proportional to the source radius. This behavior stems from only having the wavefunction symmeterization in the correlation function. Other pair combinations are not as simple as the identical spinless bosons and a more general approach is needed.

The correlation function can be calculated from the Koonin-Pratt equation (see below) for any pair type. This equation states that the relative wave function squared times the two-particle source is the correlation function when integrated over the spatial components. This provides the connection from a given source to a correlation function. Utilizing a parameterized source, a numerical wave function solver and an iterative fit to the data, this equation can be used to extract a source size for any pair type, even complicated interactions with a strong potential and spin.

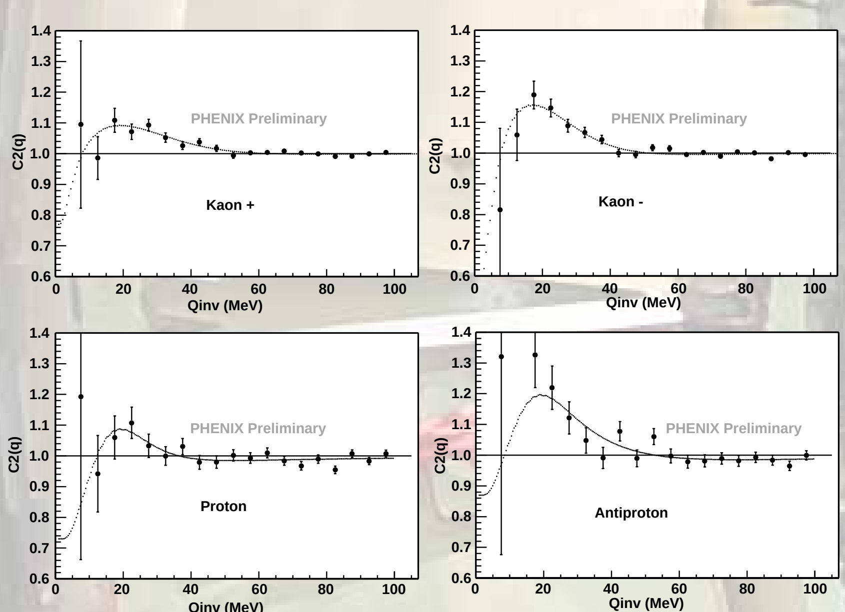
$$C_2(q) = \int d^3r \left|\Psi(q,r)\right|^2 S(r) \quad \text{(Koonin-Pratt eq.)}$$



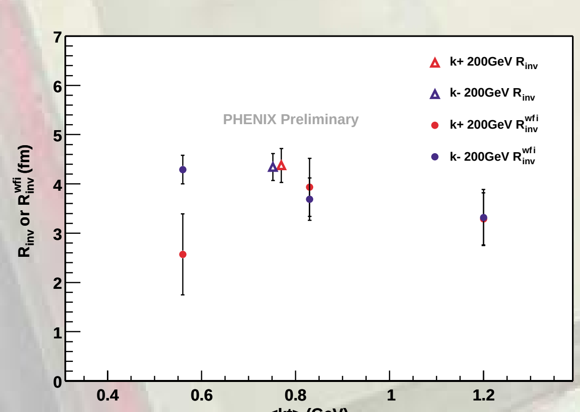
This is an example correlation calculation from the Koonin-Pratt equation for identically charged kaons. This correlation is similar to what is expected for pion correlations with the exception that the larger mass of the kaon enhances the effect of the coulomb force. As in the case of the pions, the size of the correlation in the q direction is inversely proportional to the size of the particle's source. The height of the correlation is not strongly correlated to the source size.



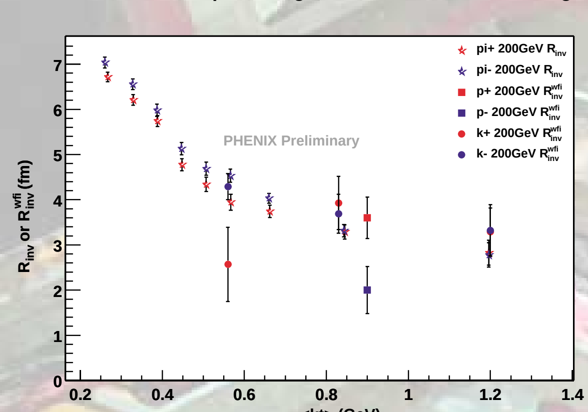
This example correlation is generated from the Koonin-Pratt equation with the proper wavefunction for a two-proton interaction. The protons not only have strong interactions, they also have spin. These effects complicate the calculation of the wave function, but it can still be calculated in a rather straightforward manner. In the case of this calculation the Ried93 potential was used. Unlike the spinless bosons, the proton correlation changes in height and width in response to a change in a source size.



The Phenix data in the plots above are fit to a calculation from the CorAL code. A parameterized gaussian source within CorAL is varied by the Minuit fitting package to obtain the best fit to the data.



The kaon correlations fit with the standard method and with CorAL agree rather well. The CorAL fits shown in solid circles are fit to bins in kt, where the radii extracted from standard HBT methods, shown in open triangles, contain the entire kt range.



This plot contains the pion, kaon, and proton fits to 1-D correlations from the Phenix experiment. The open symbols are calculated with the standard methods of HBT, and the closed symbols are calculated from CorAL. The systematic errors from two track inefficency cuts have been estimated to be K+ 0.31 fm, K– 0.52 fm, P+ 0.86 fm and P– 0.68 fm.

CorAL

CorAL is the Correlation Algorithm Library. This C++ code is in development to provide a library specifically designed for the calculation of correlations. The code has a few major classes that map onto the Koonin-Pratt equation in a rather straightforward way.

- WaveFunction

  This is the real workhorse of the package. It can generate a wave function, store it, read it back in, square it, add wave functions, or anything else wave functions do. I plan to template this class to further improve its utility. In the templated form, it could be a complex wave function, a real wave function, and possibly with enough thought, teaching it spinor math may be possible.

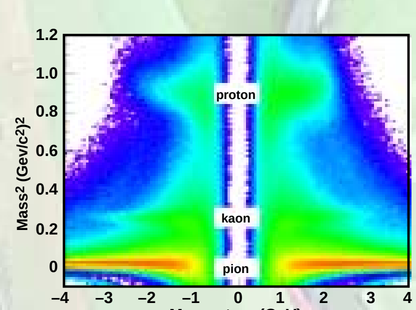
- Source

  This object characterizes the particle emitting source. This can in principle be arbitrarily complicated, but is generally is much simpler than the wave function class, and for example can just contain a gaussian.

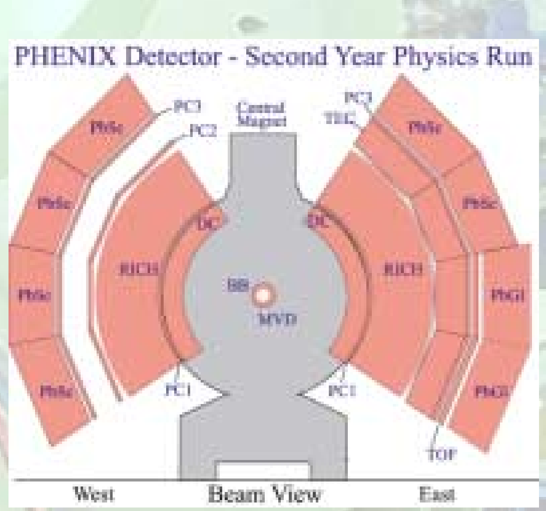
- Correlation

  The third major class is the correlation class. This takes a source object and a kernel object (essentially the wave function squared) and makes a correlation object that can be saved, read back in, queried, etc.

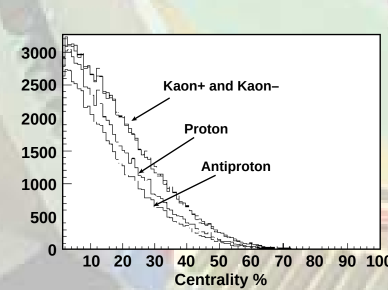
This framework allows one to easily make any correlation without having to rework the basic tasks that can be tedious and prone to error.



This is a plot of reconstructed mass^2 vs. momentum. The particle bands are clearly separated with the EMC timing resolution and 5m path length from the vertex.



This is a cross section of the Phenix detector where the beam passes in and out of the page. Shown in the picture are the two central arms that each measures 90 degrees of the azimuth and a pseduo-rapidity of +- 0.35. The inner layer labeled DC is the drift chamber where tracks are reconstructed and the momentum is measured. The particle identification is accomplished with the outer layer of electromagnetic calorimeter that is used as a time of flight. The momentum resolution of this set up is $\Delta p/p = 1.1\% \oplus 1.0\%/p$.



This is the centrality of the events that contribute to the analysis. It is clear that there is a strong central basis for events that contain either two protons or kaons in one spectrometer arm. The central bias is expected since a central event has a higher probability of getting two tracks close in phase space because there are more tracks filling the phase space.

Conclusion

Within the current errors, the protons, kaons, and pions all have radii that are consistent and lie along a curve that slowly changes slope in the region of about 0.6 to 1.0 GeV in <k+>.

Future work will include fitting all possible combinations of particles within the framework of CorAL. The common treatment of different particles within CorAL will allow us to experiment with global fits to all of the particles with the same source, and variations of that theme.

PHENIX

This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

P02267-mdh-u-001