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Measuring Strangeness Production From Relativistic Collisions Between Pairs of Nuclei Using a Vertex Time Projection Chamber

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Abstract

At collider energies of 200A-GeV, tracking of charged particle pairs originating from neutrals is dominated by singly-strange K_S^0 decays. Counting the number of secondary vertex pairs is a method of measuring the strangeness production. The VTX is a four-layer micro-strip gas time projection chamber being designed for use with the STAR instrument in an experiment using the Relativistic Heavy Ion Collider under construction at Brookhaven National Laboratory. Simulated pixel data generated from CERN's Monte Carlo detector-modeling program Geant were put into tables using the TAS sorting structures available from the STAR Collaboration. The response of VTX was mapped for charged pion pairs emerging from each secondary vertex resulting from the decay of a neutral kaon. Grouping each set of two charged pions of opposite sign which originate from a vertex distinct from the collider vertex is the method being presented for measuring strangeness production. This method has three steps: (1) removing all charged particles originating directly from the collider vertex using established methods, (2) identifying which ≤ 4 residual pixel tracks in the 4 micro-strip TPC planes belong to which particular individual pion, and (3) grouping these secondary pions into the appropriate pairs. Research presented will concentrate on steps (2) and (3) in identifying each K_S^0 in order to measure strangeness production. Backgrounds were generated as part of the simulation process, and to help in the elimination of backgrounds, rough-set analysis was used to fine tune algorithm parameters using exemplars which are available from simulation data in TAS Tables.

Introduction

The Relativistic Heavy Ion Collider (RHIC) is under construction at Brookhaven National Laboratory. RHIC will accelerate pairs of gold nuclei to a kinetic energy of 200A-GeV which gives each gold nucleus in a colliding pair over 100 times its rest mass energy. The Standard Model predicts pairs of colliding gold nuclei will form a Quark-Gluon-Plasma (QGP), a state in which quarks and gluons are deconfined. The emergence of a large amount of strange matter is one signature of a QGP (Schukraft, 1993; Harris and Müller, 1996). Strange quark production is found by detecting kaons and lambda particles which contain strange quarks, kaons being much more abundant in the aftermath of each central collision.

Detection of QGP by examining its decay products using the Solenoidal Tracker (STAR) Detector at RHIC is discussed by Byrd, et al. (1995). They emphasize one of six sub-detectors; the Vertex Tracker (VTX) which is a small, low-mass, high-resolution, vertex time projection chamber with a micro-strip read-out. A VTX is designed to track at smaller polar angles with more space-point pixels per track while putting less material in the path of secondaries (Angellini et al., 1990), as compared with a silicon system in this region.

A rough-set based algorithm for grouping particle tra-

jectory data in the VTX has been described, with emphases on tracking charged secondaries (Clark et al., 1995). This algorithm used artificially intelligent decision making techniques, kinematics and vector analysis to resolve and separate charged particle trajectories in the VTX. Grouping charged pion secondaries from K_S^0 decays is the focus of the present work since counting the number of K_S^0 decays will be used to measure strangeness production.

Simulation data used to develop the delayed grouper were obtained using Monte Carlo simulations run on Geant (Geant, 1994), the CERN detector modeling code, and made available to the STAR Collaboration in a convenient form called TAS, a general purpose analysis program for event-based data processing (Olson, 1993). These simulation data were generated for the VTX in the presence of a momentum-defining external magnetic field; however, for grouping purposes this external magnetic field may be ignored. TAS consists of modules containing tracking software and information about the detector geometry. Processing is a sequence of steps from raw data into physics summary data using data structures called TAS Tables. Tables are 2-D objects with columns and rows which record data at any stage of event processing.

Grouping of the delayed emission of charged pion

pairs from K_S^0 decays has three parts: (1) removing charged particles originating directly from the collider vertex using established methods (Prindle, 1993), (2) identifying which of ≤ 4 residual pixel tracks in the 4 micro-strip TPC planes belong to any particular individual pion, i.e., which hits in the multiple pad planes belong to particular charged-pion track, and (3) grouping these secondary pions into appropriate pairs consistent with charged pions emerging from K_S^0 decay. These delayed-grouping decision processes have been implemented in a rough-set-based decision module where rough set theory provides a method for the automated generation of a compact rule base from a set of exemplars which is subsequently optimized using the developmental data set (Clark et al., 1995).

Materials and Methods

The VTX design consists of a 20-cm long cylindrical gas-filled drift volume with an electric field in the center parallel to the magnetic field of the detector solenoid (Angelini et al., 1990; Wieman and Gong, 1994; Wieman et al., 1995). The read-out endplate is silicon substrate with thin metal anode and cathode strips. When a charge particle passes through the detector it ionizes the gas. These ionization electrons drift up towards the 4 pad-rows on each end of the VTX, and their signals are channeled into the data acquisition system. Each pixel's z-coordinate measurement is provided by a timing measurement, with **r** and **phi** coordinates provided by an array of crossing strips on the micro-strip endplates. This approach allows tracking at small polar angles with up to four space-point measurements per track.

Pixels from different vertex tracker planes associated with individual charged particles promptly emerging from the (primary) collider vertex are not interesting in this study as they do not come from secondary vertices. Prompt charged particles emerge from the collider vertex at constant (θ, ϕ) in spherical coordinates. Figure 1 shows the geometry of a VTX with four pad planes for use in a high track density environment (Angelini et al., 1992; Weiman et al., 1995). Most of the pixel activity in a vertex tracker will come from prompt charged particles and a conventional prompt particle grouper will be used to remove them. Removing them dramatically reduces the effort needed in subsequently grouping the charged particles from secondary vertices.

Figure 1 shows four sets of (x, y, z) pixels associated with each prompt charged particle. Each of these four data points form a similar triangle which is the foundation for the established method for grouping charged particles (Prindle, 1993). For purposes of grouping the sec-

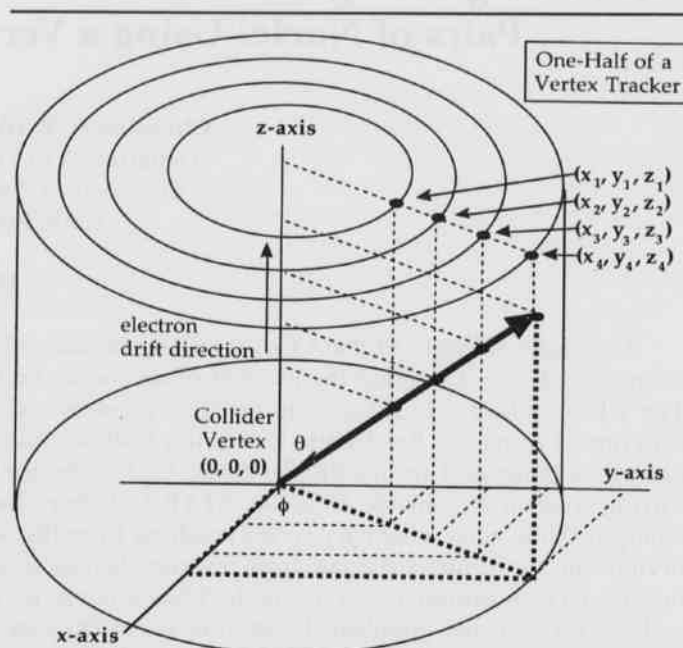


Fig. 1. A Schematic of half a Vertex Tracker with readout pads at one end of four concentric cylinders.

ondary particles, the small geometry of the VTX results in each charged particle having a negligible path curvature in the momentum-defining external magnetic field (STAR, 1992). The prompt charged-particle grouper identifies pixels from the four different tracker planes caused by the same charged particle by associating those four pixels with nearly equal values of (θ, ϕ) . Before beginning to look for secondary vertices, all pixels from prompt charged particle emission are removed by application of the prompt grouping technique.

Identifying each individual pion from events in adjacent pad planes.— Before beginning the reconstruction of a K_S^0 vertex one needs to identify which pixel set in adjacent pad planes belongs to which individual charged pion. Identifying an individual charged pion track from a determination of the colinearity of hits for each set of pixel groups in adjacent VTX pads must be carried out without apriori knowledge of the location of the charged pion's point of origin, i.e., the secondary vertex. This point of origin (the secondary vertex) occurs at whatever point the K_S^0 happens to be when it decays, which is a place distinct from collider vertex. A cross-product colinearity test is possible since the point of origin of each individual pion is distinct from the collider vertex. (If individual pions came directly from the collider origin terms like $\mathbf{r}_2 \times \mathbf{r}_1$, $\mathbf{r}_3 \times \mathbf{r}_2$, and $\mathbf{r}_1 \times \mathbf{r}_3$ would all give zero.)

The K_S^0 vertex must occur at a position before the second pad plane for the following individual (delayed) pion grouping scheme to succeed. The idea for grouping an individual charged pion is to attempt to associate a pixel

in pad 4 with a second pixel in pad 3 and a third pixel in pad 2 using two different sets of colinearity tests. The first test is between $\mathbf{r}_1 - \mathbf{r}_3$ and $\mathbf{r}_3 - \mathbf{r}_2$; the second test is between $\mathbf{r}_1 \times \mathbf{r}_3$ and $\mathbf{r}_3 \times \mathbf{r}_2$. Success will group three pixels in pads 4, 3, 2. If successful, this set of two colinearity tests is repeated. The K_S^0 vertex must occur at a position before the first pad plane for the following pion grouping scheme to succeed. Now the first test is between $\mathbf{r}_3 - \mathbf{r}_2$ and $\mathbf{r}_2 - \mathbf{r}_1$; the second test is between $\mathbf{r}_3 \times \mathbf{r}_2$ and $\mathbf{r}_2 \times \mathbf{r}_1$.

Figure 2 shows the aggregation of results from a number of these two different colinearity tests for grouping pixels with a particular individual charged pion from one side of a K_S^0 decay. Figure 2 (a.) uses difference angles between two normalized difference-vectors connecting pixels in adjacent pad planes, e.g., $\mathbf{r}_4 - \mathbf{r}_3$ and $\mathbf{r}_3 - \mathbf{r}_2$; and Figure 2 (b.) uses difference angles between normalized cross products connecting pixels in adjacent pad planes, e.g., $\mathbf{r}_4 \times \mathbf{r}_3$ and $\mathbf{r}_3 \times \mathbf{r}_2$. These two methods use two different measures of the angular dispersion between vectors connecting pixels in adjacent pad planes. In each method an angular dispersion value is calculated and used as the figure of merit in associating pad row pixel data with an individual pion passing through the VTX. Geometry for each pion from K_S^0 decay is shown in Figure 3.

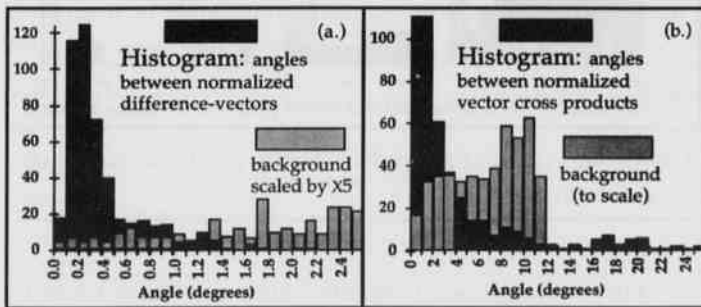


Fig. 2. Two methods of individual pion track identification in adjacent VTX pads.

Once all the individual charged-pion tracks are determined, most of the pixel groups in the VTX pads should have been assigned apart from known backgrounds. The next step is to associate pairs of charged pions as coming from a common secondary vertex (which occurs at what ever point the K_S^0 happens to be when it decays). There are many charged pion tracks, but at most only two are related to the same K_S^0 decay, and the correct pair must be determined from the know physics of the decay process: $K_S^0 \rightarrow \pi^+ + \pi^-$.

Results and Discussion

Two different ideas were used to test whether a pair

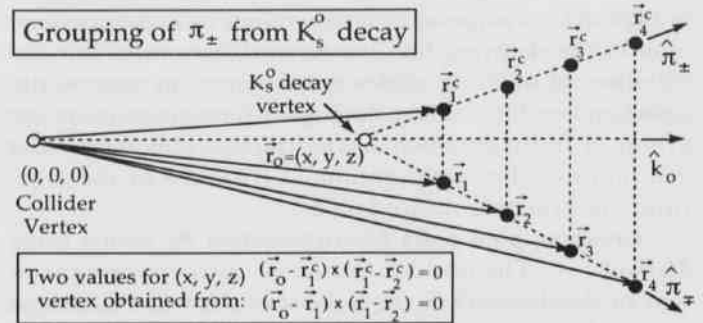


Fig. 3. Reconstruction of a K_S^0 vertex from its charged pion decays.

of individual pions come from the same $K_S^0 \rightarrow \pi^+ + \pi^-$ decay, and these ideas will be developed below. Figure 3 shows the geometry of a K_S^0 decay described in terms of each pixel-coordinate position vector in each pad plane for both charged pions, using the collider vertex as the common coordinate origin. Apart from small distortions due to the solenoidal magnetic field, these two pions emerge from a common point, the decay vertex, with these pion pairs forming a plane containing both the decay vertex and the collider vertex. The direction of the original K_S^0 is given by a unit vector pointing directly away from the collider vertex and pointing in the direction of decay vertex at position (x, y, z) .

Opening angles between pion pairs were calculated using TAS data from Geant with the solenoidal magnetic field turned on, and realistic pixel data files were generated for pion pair emission from K_S^0 decay. TAS data files are used to provide coordinates in a format consistent with pixel data from the VTX detector. These data were used to generate the histogram of pion opening angles from K_S^0 decays in Figure 4.

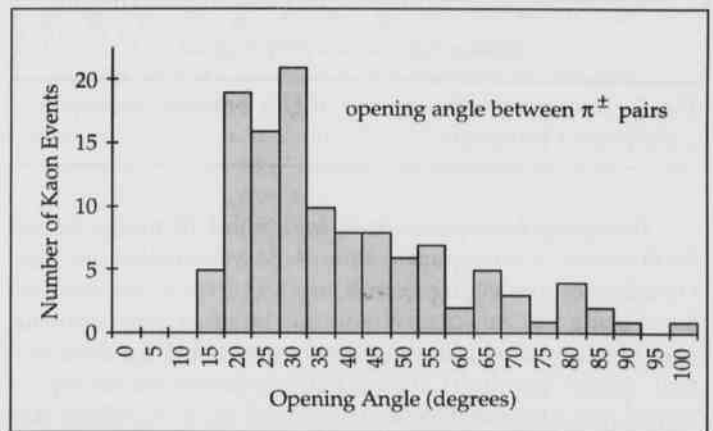


Fig. 4. Histogram of pion opening angles from K_S^0 decays.

On the average the smaller π^\pm opening angles shown in Figure 4 correspond to larger values of linear momentum for the decaying K_S^0 . The general features of this distribution of opening angles may be used to narrow the search space for finding conjugate pion pairs from the group of individually-identified pions. This narrowing can improve the computational efficiency of the algorithm for grouping delayed pions.

Grouping pion pairs from individual K_S^0 decays using Method 1.— The position vector for each emerging pion may be described in (x_k, y_k, z_k) rectangular coordinates in terms of each pixel coordinate point in each VTX pad plane for the collider vertex at $(0,0,0)$. If a pion comes directly from the collider vertex then its (x_k, y_k, z_k) pixel coordinates all fall along the same line, and they cannot form a plane with the collider vertex. However, the direction of each pion emerging from a secondary K_S^0 decay vertex will form a plane with the collider vertex, and if two pions come from the same K_S^0 decay then they must be in the same plane with each other and with the collider vertex. Figure 5 is a histogram of the number of pion pairs versus the coplanar angle between them in degrees. Figure 5 gives a histogram of a figure of merit (coplanar angle) in the test for coplanarity between any two candidate pion pairs, formulated as a single number, by recasting the coplanarity test as a colinearity test between the vector cross-products of candidate pion pairs.

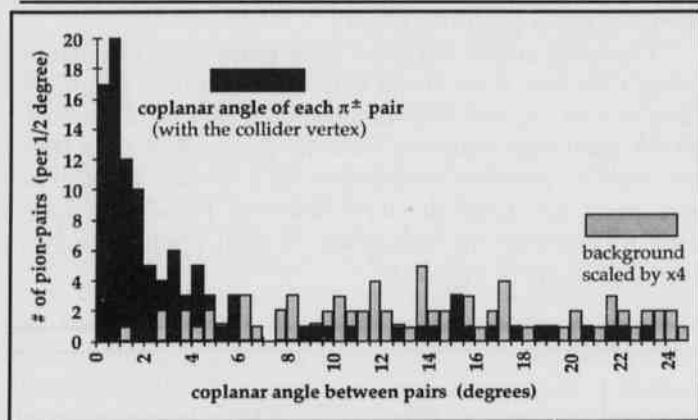


Fig. 5. Histogram of coplanar angles between pion pairs, each from a K_S^0 decay.

Grouping pion pairs from individual K_S^0 decays using Method 2.— Two separate sets of (x, y, z) values for the coordinates describing each K_S^0 decay vertex may be calculated using the position vectors of the emerging pions to provide the basis for a consistency test. Figure 3 shows two (cross product) vector equations (six scalar equations) providing two separate sets of (x, y, z) values for the same (x, y, z) coordinate describing a particular K_S^0 decay vertex. Although no one set of cross-product vector

equations can provide a unique (x, y, z) position for the vertex, a mix between these two sets of scalar equations will allow two (x, y, z) positions to be calculated for the same K_S^0 decay vertex (Braithwaite and Braithwaite, 1995). Thus, an alternate grouper approach for associating a candidate pion pair with K_S^0 decay uses a consistency test: the distance between the two calculated (x, y, z) secondary vertex points. This distance is used as a figure of merit in deciding whether to group any two individual candidate pion tracks as originating from the same K_S^0 decay. The histogram in Figure 6 shows most of the pion pairs from K_S^0 decay are consistent with a small distance between the two independent calculations of the same decay vertex (x, y, z) , despite small magnetic field distortions.

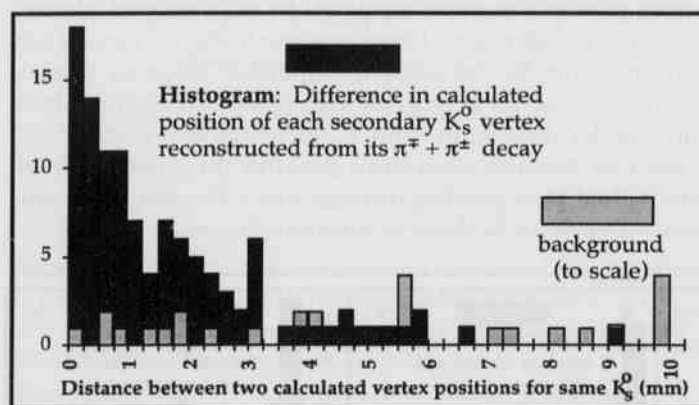


Fig. 6. Two (x, y, z) secondary vertex positions are calculated for each K_S^0 decay.

The two methods described above promise to contribute a qualitative but accurate grouping of candidate pion pairs as arising from a K_S^0 decay and provide its 'first-pass' momentum direction vector from its pion decay pairs: from $(0,0,0)$ to the average (x, y, z) decay point.

Two different methods have been presented for grouping individual pions with particular choices of pixels and two different methods have been presented for grouping pion pairs arising from a single K_S^0 decay. As shown in Figure 4, additional information such as the probability of events versus opening angles was obtained from the Monte Carlo simulations. Since a number of choices were possible in the classification schemes, an optimal choice using existing information should reduce the adverse effects from backgrounds, so rough-sets theory was employed in constructing rule-based grouping algorithms. Rough sets optimize decision rules by examining reference decision processes, and like artificial neural networks, rough sets provide a completely data-driven

technique which may be used with inconsistent data (Pawlak, 1982). The group/no group decision was included for each candidate group and was set to one for complete tracks and zero for background tracks. Rough set software can then generate a set of if-then rules which approximate the function of the reference decision process (Clark et al., 1995).

The validation set consisted of more of this same type of data with the decision attribute omitted but available elsewhere for validation of the model. The developmental data set contained 138 candidate pairs; the validation set contained 98. The individual pion grouper correctly classified candidate tracks in 97% of the cases in the validation sample using six rules. The pion-pair grouper correctly classified 91% of candidate pairs in its validation set using sixteen rules.

Effects of rough set rule generation parameters were investigated using the pion pair data sets. Figure 7 shows how rule complexity depends on the size of the roughness parameter. Roughness may vary between zero and one with a large value resulting in a small number of very general rules, but when roughness is small many more local rules result. Figure 7 shows roughness had only a small impact on the classification efficiency for this data. However, if larger backgrounds occur in the data acquisition than in these simulations, optimizing using rough sets may be more helpful.

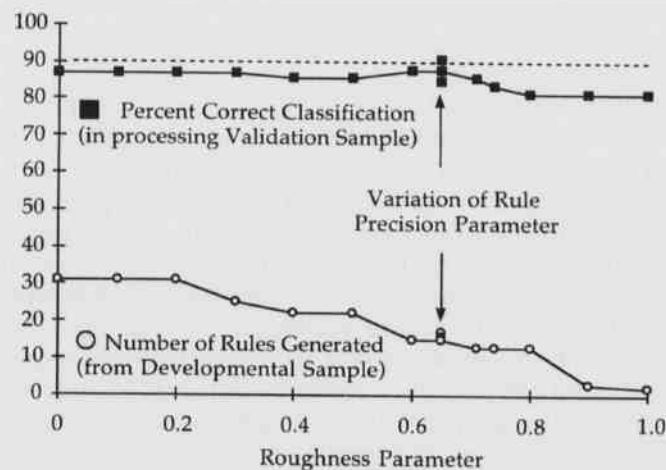


Fig. 7. Effect of the roughness parameter on rule-base generation for pion pairs.

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