Measurement of Neutral Strange Particles in the FTPC

Mike Heffner*for the FTPC Collaboration

January 1999

Max-Planck-Institut für Physik, and University of California Davis

Abstract

This note presents a feasibility study to determine whether the Forward TPCs (FTPCs) can measure V0s in RHIC Au+Au events. 226 Hijing events were simulated to address issues of acceptance and efficiency, and to generate mass plots with the signal and noise. We demonstrate that the FTPCs are capable of measuring V0s with a momentum reconstruction method.

Introduction:

The STAR experiment has engaged in a strong strangeness program to glean as much information as possible from the nuclear reactions at RHIC[6][7]. The combination of the Main TPC and the Silicon Vertex detector will provide information about various strange particles in the pseudo rapidity(η) range of about +1 to -1[7]. This range represents only a portion of the total range of the collision.(see Figure 1) The Forward TPCs (FTPC) are located at a pseudo rapidity of approximately 2.5 to 4 on both sides of the collision. The natural question that arises is, can these FTPCs also measure neutral strange particles, and contribute to the STAR measurement of strangeness. This note is the product of a study to answer this question.

The FTPC has ten pad rows, so a maximum of ten position and dE/dx measurements are possible of any charged track in the active volume. This

*A University of California Davis graduate student. This work was carried out during a visit to MPI in Munich Germany with the generous support of MPI.

number of measurements in combination with the average momentum of the particles passing through the active volume make particle identification(pid) challenging.[2] In this study it is assumed that the dE/dx method of pid is unavailable. On the other hand, it has been shown that the sign of charge determination of the FTPC is rather good.[2] The charge information allows a reduction of the combinatorics (and therefore the background) and is used in this simulation.

The momentum resolution of the FTPC is less than ideal for V0 finding. Without the main interaction vertex and with a maximum of 10 position points, we see a resolution$\left(\frac{\Delta P}{P}\right)$ in the range of 14% to 30%. At the start of this study, it was not clear that a momentum reconstruction of V0s from their daughters could be done with the FTPC. It will be shown that a mass peak *is* formed and is sufficiently narrow with only the small number of hits. The reduced momentum resolution does have some clear consequences. The most notable consequence is the large width of the mass peak that will be presented later in this note.

The species studied in this note are the Λ, $\overline{\Lambda}$, and the K^0_{short}. The decay topology makes them the most likely to be separable from the background. In addition, it is expected that these species will be relatively abundant in RHIC events.(see Figure 1) The Hijing event generator was used to provide simulated events for this study. Figure 1 shows the P_t and η distributions of the above mentioned species from the generator.

Simulation Details:

The simulation used the “standard” FTPC STAR software as much as possible. Figure 2 shows how the data were processed, and the V0 classes designed for this analysis. The analysis started with 226 central Au+Au Hijing events. The tracks from this event generator are processed by geant with the geometry files that correspond to the “year2a” configuration. All physical processes in geant are turned on. The resulting hits were then passed through the FTPC fast simulator(ffs). The fast simulator smears the location of the hits, based on electron diffusion and the pad response function. The fast simulator also removes merged hits and hits on the edge on the FTPC active volume. The hits at this point are a simulation of the hits that would come from the hit finder with real data. The remaining software shown in Figure 2 was written for this study.

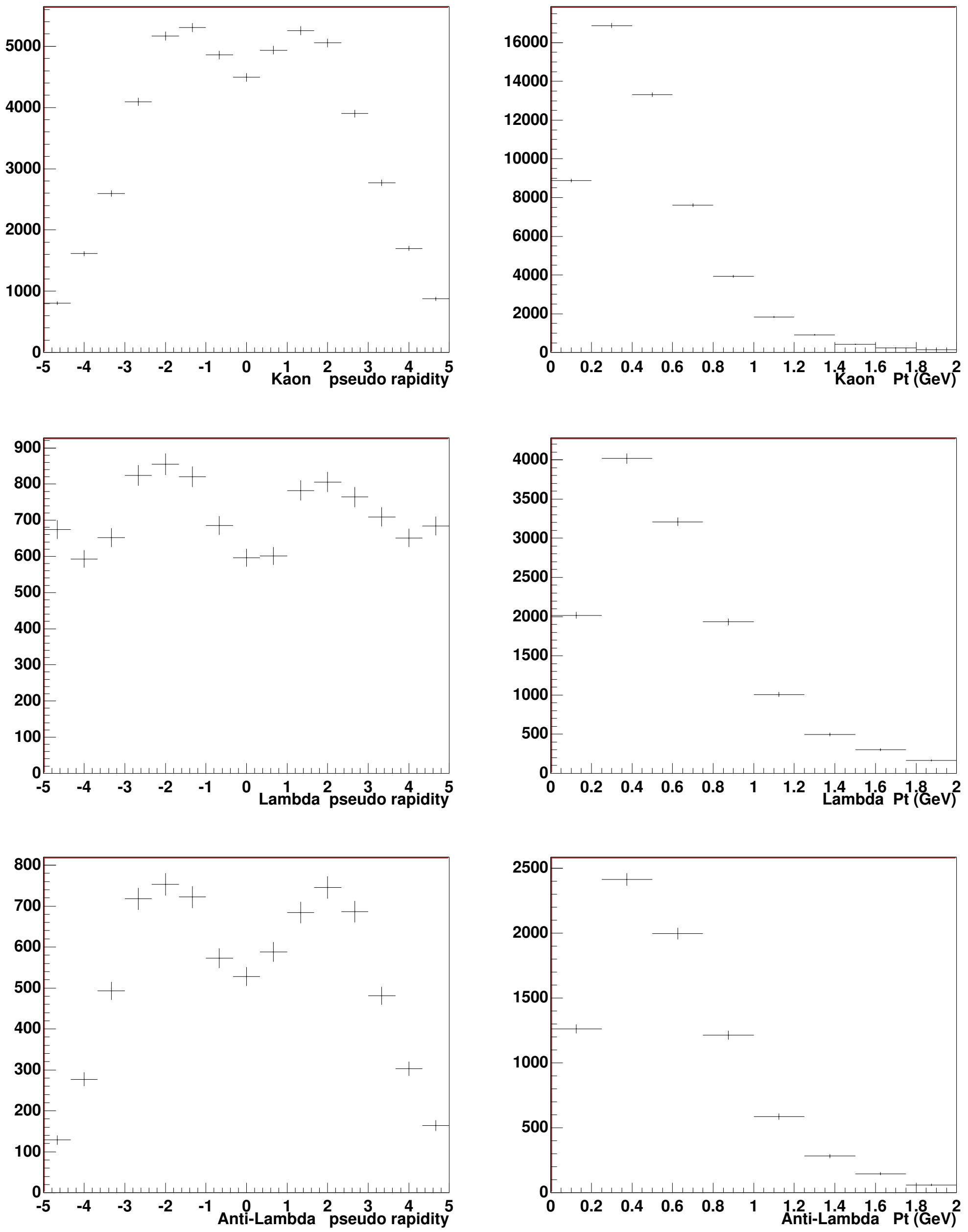

Figure 1: Pseudo-rapidity and P_t distributions from the Hijing event generator.(226 events)

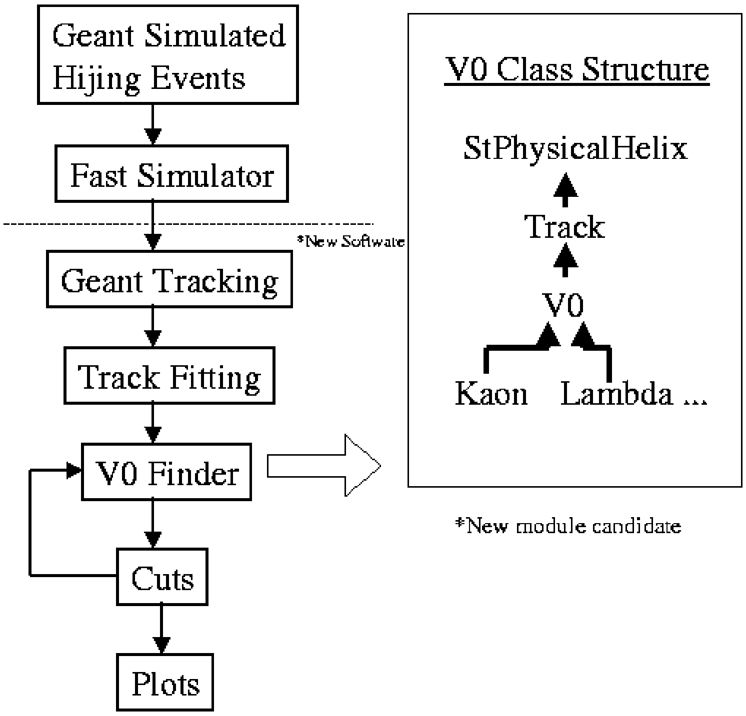

Figure 2: Data Flow and classes used in this analysis.

Tracking and Fitting

The next step is to group the hits into tracks. The current FTPC tracker uses the main vertex information to find tracks, and therefore can only find tracks that pass near the collision region. Since the tracks of the daughters from V0s do not necessarily pass near this point, the current tracker could not be used in this study. The tracking for this study was performed using geant information since it is still intact after fast simulation. The geant tracker in Figure 2 simply groups the hits by their geant track id. The only geant information used in this perfect tracker is the hit to track relationship. The pattern recognition problem of finding non vertex tracks in the FTPC is not included in the results. Part of this study is to show the need for a tracker to find tracks that do not come from the main vertex.

The hits for each track were then fit to a helix to get the momentum. Only hit coordinate information was used at this stage. Fitting of the points to a helix was carried out in two steps. The points in the xy plane were first fit with a circle. This was done with a fast and effective least squares algorithm[1]. This provided the radius of the helix and the xy position of the center. The pitch of the helix and the phase were determined by a linear fit to the z positions of the hits and projected path length in the xy plane. The parameters from these fits are then fed into the V0 finder.

It is important to note that the helix model is only valid for a uniform magnetic field. The geant geometry file at the time of the this study only had the option of a uniform field, so the helix model is the correct model for the reconstruction. We know that the field is not completely uniform, especially in the region of the FTPC furthest from the main vertex. On the other hand, the field is not rapidly changing with large amplitude. Calculations show that about 4% variation over the FTPC may be expected. The fitting of tracks in the real field could possibly be unsatisfactory with a helix model. However, the impact of this discrepancy on the results given here should be quite small since the simulation model and reconstruction model is the same.

V0 Finding

The V0 finder was written in C++ using ROOT and the StarClassLibrary(SCL). The class inheritance is shown in figure 2. This class structure worked well for this study, but problems will arise when the proper magnetic field is used. The classes inherit from the class StPhysicalHelix and this fixes the track model to a helix. As discussed above, this will have to be modified for simulations with the real field map, and real data.

The task of the V0 finder is to match pairs of tracks, and calculate parameters that can be used to evaluate the probability that the pair is from a neutral particle decay. The V0 finder starts by finding the intersection of the helices that represent the paths of the candidate pair. Possible intersection points are first identified by looking at the xy projection of the helix. In this projection the helix is a circle. It is simple to calculate the crossing of the circles. There are two crossing points. For each the z position is calculated. If only one lies in the "acceptable" region between the main vertex and the 5th pad row in the FTPC, it is the candidate crossing. If both are in the "acceptable" region then the one that minimizes the distance between the helices is used. In the case that the circles don't cross, the point closest to both circles is used.

The candidates found with this method turn out to be too imprecise. The crossing point is improved by linearizing the track model near the candidate crossing, and using a least square method in all three dimensions to find the point that minimizes the distance between the helices[4][5]. This last step can be repeated to make sure that the linear model doesn't introduce a large error. Such an iteration has been found to converge quite strongly. This is mostly due to the small curvature of the tracks. After the crossing point is found, it is a simple matter to calculate all of the physical parameters of the decay.

Results:

Acceptance

The most basic question to be answered in such a study as this is, what is the acceptance. This question was answered without the need of tracking. The acceptance is a function of the geometry of the detector and the colliding system. Acceptance for this note is defined simply as the following,

$$Acceptance = GoodV0Tracks/EventGeneratorOutput$$

A good V0 track is defined as a V0 that decayed into two charged daughters and each of the daughters has at least five hits in the FTPC. The event generator output is all of the neutral strange particles in the simulated event. The branching ratio of the strange particles into charged daughters is incorporated at the Geant simulation stage. The notable result is that the acceptance is limited to a maximum of the branching ratio. This fact should be taken into account when viewing the acceptance plots.

Figure 3 shows the acceptance in transverse momentum (P_t) and pseudo rapidity. The data used in these plots are V0s extracted from the Hijing event generator. The acceptance in P_t is rather flat, and the pseudo rapidity acceptance is about what one may hope for with such a geometry. The Λs have an η acceptance similar to the protons. This is a result of the proton carrying the major portion of the Λ momentum. The kaons have an unexpected acceptance above $\eta = 4$(unexpected because, $\eta = 4$ is the end of the acceptance for charged particles from the main interaction point), and the expected drop off at low P_t is not apparent. This is due to low momentum kaons with a small angle to the beam vector. The small angle gives them a large η. The direction of the small momentum vector is easily changed by the 206 MeV of the decay, and this puts them in the FTPC acceptance, as defined. These kaons are not explicitly cut in further analysis, but it is unlikely that these small momentum particles will be properly reconstructed. Higher statistics acceptance plots have also been created with a flat generator(uniform filling of P_t η space).[3]

The integrated yields per event in the FTPC acceptance is shown in table 1. These numbers represent the best that the FTPC can measure if the Hijing model is correct.

K^0_{short}	Λ	$\overline{\Lambda}$
9.6±0.21	4.8±0.15	3.1±0.11

Table 1: Number of particles in the FTPC acceptance per event (both FTPCs; errors are statistical).

Background

The previous section has shown that the acceptance is significant and that the signal is of reasonable size. The next step is to study the background. We must be able to reduce the background if we are to see the signal. There are two major categories of cuts used to reduce the background. The first category consists of cuts made on the individual charged tracks that are measured in the FTPC. These cuts can be made quickly, and reduce the CPU usage and storage space in addition to reducing the background. Examples of these cuts are: momentum, distance of closest approach(dca) to the main vertex, and pid, as shown in table 2. After tracks pass this first set of cuts, they are paired to form V0s. The result is again subject to cuts, but this time the cuts are related to the V0 that is formed. Important cuts at this stage are: dca of the back projected neutral strange particle to main vertex, dca of the daughters to each other, and the distance of the decay from the main vertex.

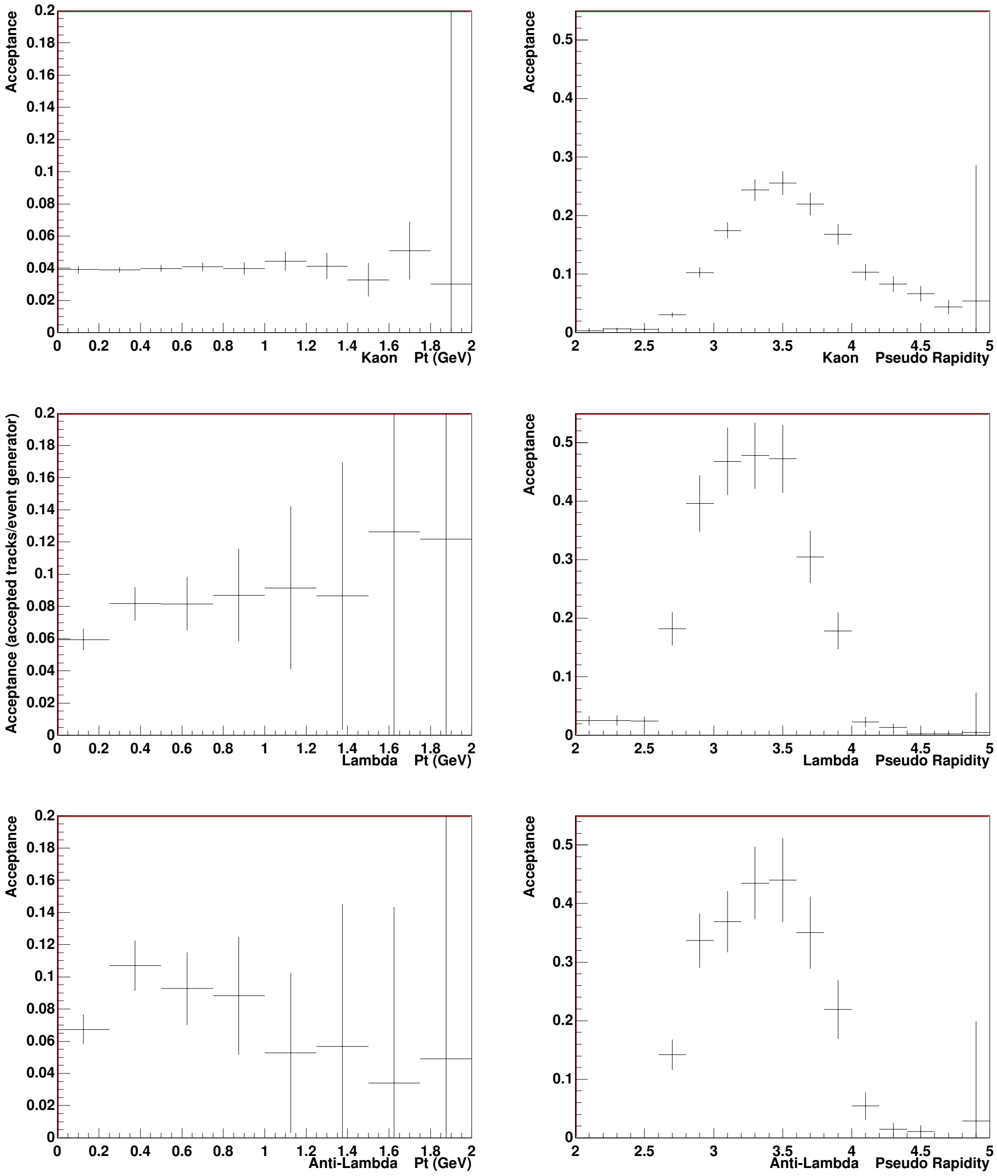

Figure 3: Strange particle acceptance of the FTPC for central Au+Au Hijing events.

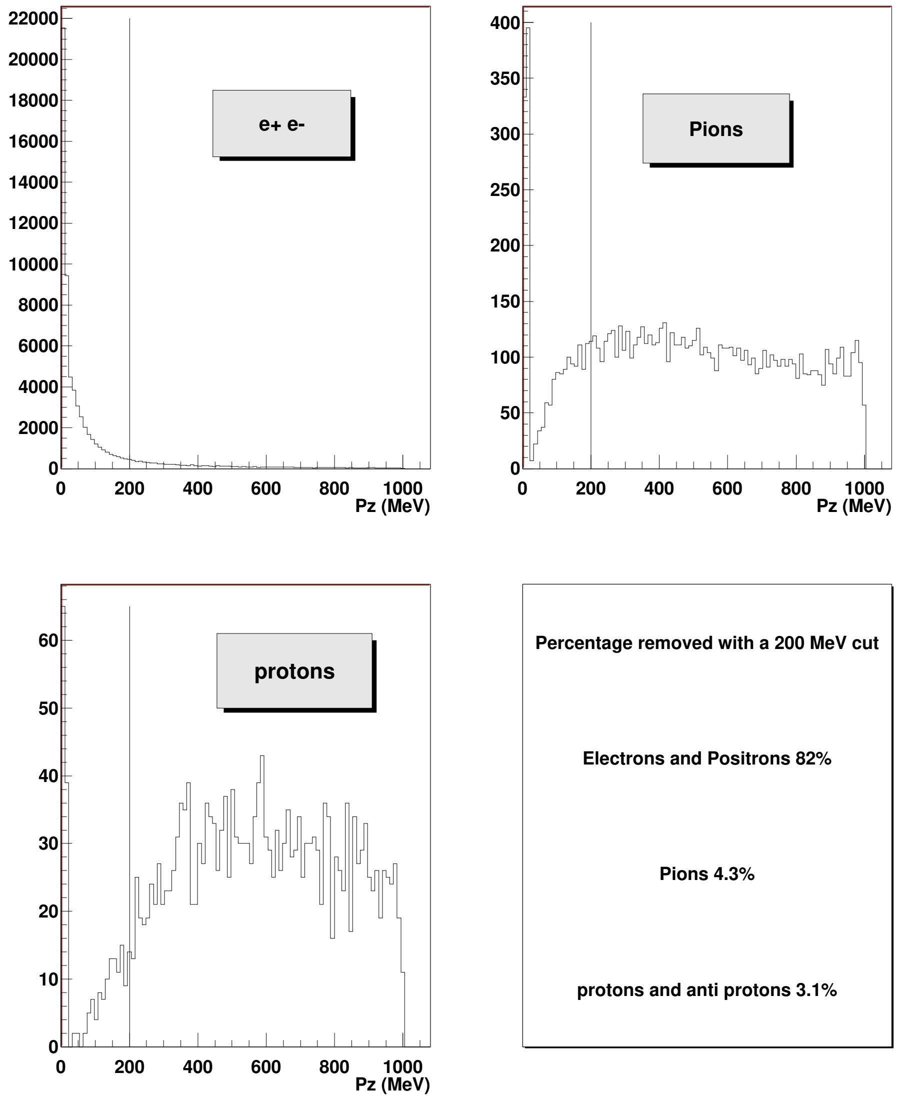

Figure 4: Longitudinal Momentum(P_z) distributions, and an example cut to remove electrons and positrons.

As mentioned before, the dE/dx pid was not used. In place of dE/dx pid it was found that momentum cuts can make a significant reduction of the background from electrons and positrons. Figure 4 shows the longitudinal momentum distribution of charged particles in the simulated events. At very low momentum we see that the electrons and positrons are very abundant, and the number of pions or protons is rather low. With a "loose" P_z cut, almost all (80-90%) of the electrons can be cut, with minimal losses in the number of pions or protons.

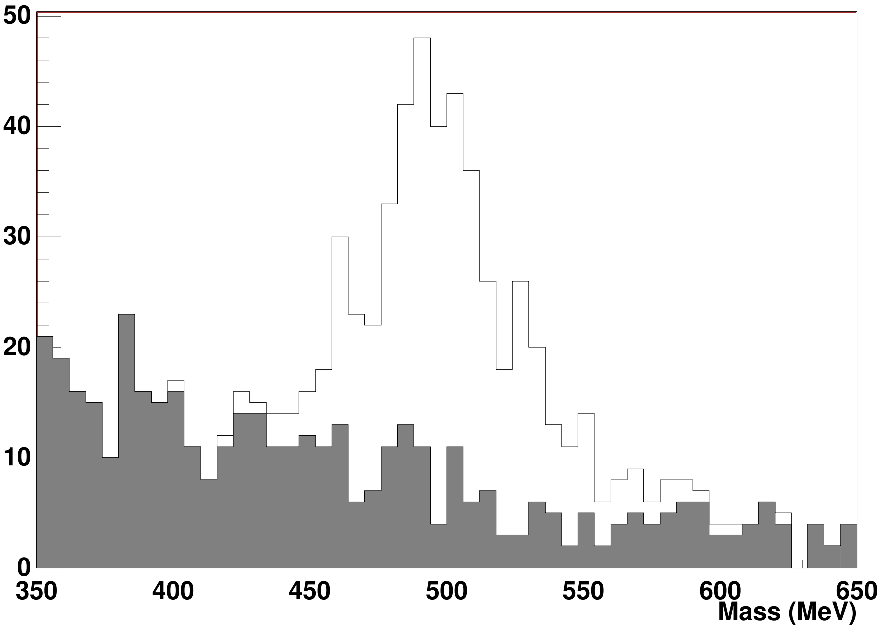

Figure 5: Kaon mass plot. The shaded histogram is the background. The open histogram is signal plus background.

The next largest source of background resulting from the non-existent pid is the ambiguity between the protons and pions. The pid situation is not much of a problem for the kaons since most of the particles in the FTPC are pions. The lambdas on the other hand are reconstructed from protons (with pions of course), and the numbers of protons are much lower. The topology of the decay and the fact that the FTPC is in the forward region gives us a possibility to pull the lambdas from the noise. In the rest frame of the lambda, the proton and pion daughters have the same magnitude of momentum. When we boost this decay into the lab, we find that the proton carries a large amount of the momentum of the original lambda. We can use this fact to our advantage. If we look at the decay in detail we find that it is a simple matter to distinguish lambdas from anti-lambdas. In the boost range that the FTPC is in, the lambda will always have a positive(proton) daughter with a larger momentum than the negative(pion). So a simple comparison of the positive and negative daughters' momentum will separate the lambda from the anti-lambda. With the lambda and anti-lambda separated, this idea can also be taken further to reduce the background. It has been found that the signal and background have a significant difference in the ratio of the daughters' momentum. This can be used to increase the signal to noise.

In order to determine how well the background can be rejected, a set of cuts was made to optimize the signal and reduce the background. The Figures 5,6,7 show the invariant mass distributions from these cuts. We see that the signal can be distinguished from the noise for all three species studied in this note. As stated in the beginning of this paper, we can see that the mass peaks are rather wide, especially the kaons. FWHM is about 40-60 MeV for the kaons, and about 15 Mev for the lambdas and anti-lambdas. The kaons have a much wider peak due to the fact that a larger proportion of the invariant mass is reconstructed from the momentum of the daughters.

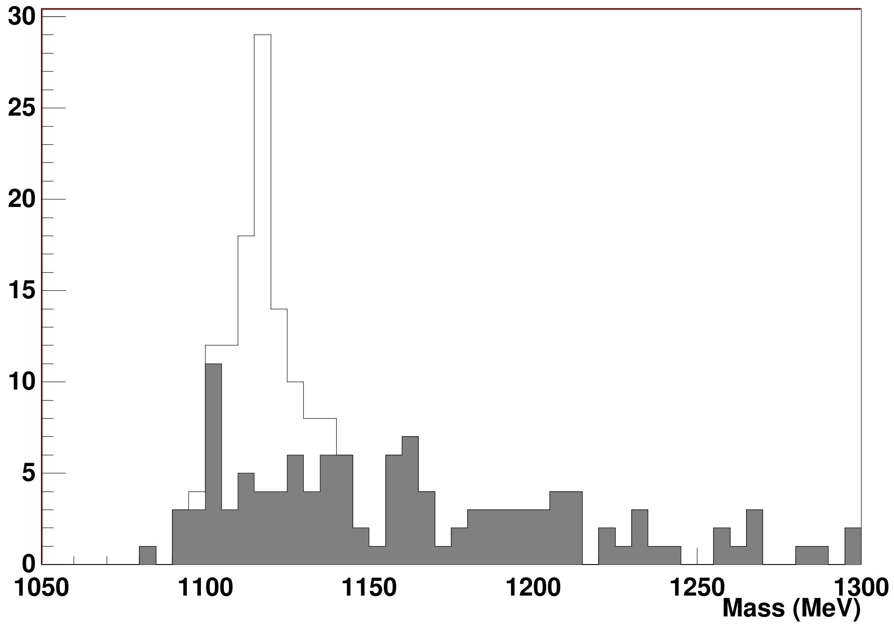

Figure 6: Lambda mass plot. The shaded histogram is the background. The open histogram is the signal plus background.

The cuts for the mass plots were determined by looking at the distribution of the cut parameters for both the signal and the background, and picking values that gave the best signal to noise. This is a complicated process that involves some trail and error, and some judgment on the part of the author. These cuts are presented as a demonstration that this type of analysis can be carried out with the FTPC. Later analysis may decide on more purity and less efficiency, or more efficiency and less purity. With the current cuts we see that the background is not completely removed. From the experience of trying different cuts, all of the background will not likely be removed. One will have to parameterize the background and subtract it. With the large statistics expected from RHIC, this should not be a problem.

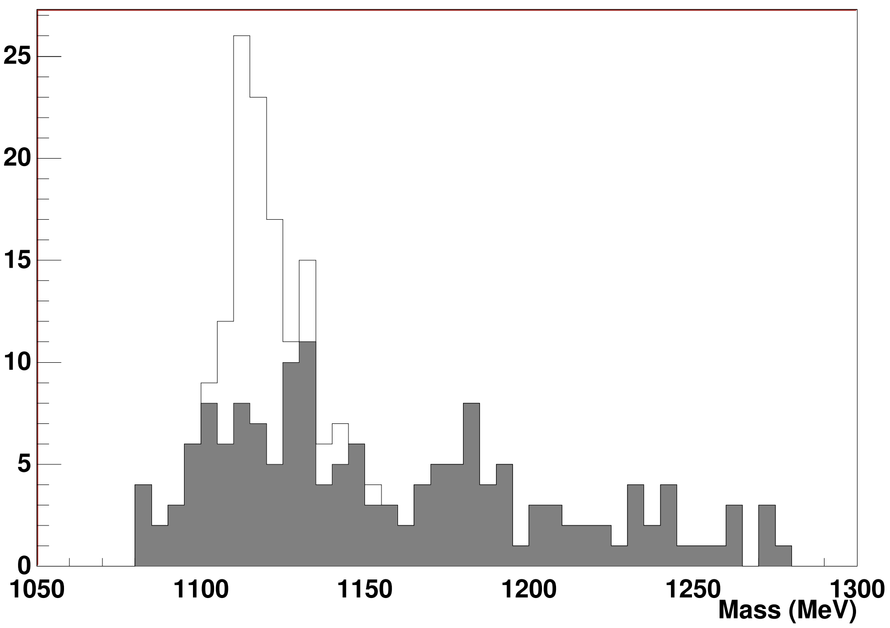

Figure 7: Anti-Lambda mass plot. The shaded histogram is the background. The open histogram is the signal plus background.

The actual values of the cuts used for these plots are shown in table 2. An explanation of the cuts is the following:

- $b^+(b^-)$ is the distance of closest approach of the Positive(Negative) daughter to the Main interaction point.
- ${P_z}^+({P_z}^-)$ is the z component of the momentum of the Positive(Negative) daughter.

- P^+/P^- is the ratio of the momenta of the Positive and Negative daughters.
- dca is the closest distance between the daughters at the decay point of the V0.
- b is the distance of closest approach of the V0 projected to the main interaction point.
- decayR is the distance from the main interaction point to the point where the V0 decayed.

	b^+	b^-	${P_z}^+$	${P_z}^-$	P^+/P^-	dca	b	decayR
K^0_{short}	>12mm	>12mm	>1GeV	>1GeV	N/A	<4mm	<5mm	>100mm
Λ	>13mm	>50mm	>2GeV	>0.6GeV	>3	<5mm	<7mm	>300mm
$\overline{\Lambda}$	>50mm	>13mm	>0.6GeV	>2GeV	<3	<5mm	<7mm	>300mm

Table 2: Cuts used to produce the mass plots in this paper.

Table 3 is the average number of particles per event that pass all of the cuts. This is provided to give a rough idea of what one might expect from this analysis with the FTPC. More detail on the efficiencies and signal to noise can be found in the FTPC Strangeness web site.[3] Taking all of this information into account, it appears that the FTPC will be able to study kaons in a range of pseudo rapidity of about 2.8 to 3.6 and the lambdas and anti-lambdas in a range of about 2.6 to 3.6. These are just rough figures from looking at the various plots, so the error on this guess is maybe ± 0.2. This is a substantial range of η, and makes the FTPC and interesting tool in the characterization of strangeness in the RHIC events.

K^0_{short}	Λ	$\overline{\Lambda}$
1.7±0.09	0.31±0.04	0.28±0.04

Table 3: Number of particles passing all cuts per event.(both TPCs, errors are statistical)

Conclusions and the Future:

This study has shown that measuring V0s in the FTPC should be possible with a reasonable efficiency. The numbers are not large enough and the background is too high to consider kaon interferometry, and event by event physics may also be too difficult, but good dN/dy and m_t spectra should be possible. This opens the possibility to put tighter constraints on the models, by extending the distributions measured by detectors in the central region.

One major item that remains outstanding is the pattern recognition problem of track finding. This study has demonstrated that there is a need for a tracker that will find non main vertex tracks. Work has started on a tracker that can perform this task. In addition, the new track fitter will also have to deal with the non-homogeneous magnetic field.

References

[1] N.I. Chernov, G.A. Ososkov, *Effective Algorithms for Circle Fitting*, Computer Physics Communications 33 (1984) 329-333

[2] The STAR FTPC Proposal

[3] rsgi01.rhic.bnl.gov/star/starlib/doc/www/html/ftpc_l/ftpc_strange/StrangeFTPC.html, The FTPC Strangeness Web Page

[4] S.Margetis, D.Cebra, *Main Vertex Reconstruction in STAR*, Star Note 89

[5] R.K. Bock, et. al., *Data analysis techniques for high-energy physics experiments*, Cambridge University Press 1990

[6] S. Margetis, *Kaons and Lambdas in the STAR TPC*, Star Note 367

[7] W.K. Wilson, *Measurements of Strangeness Production in the STAR Experiment at RHIC*, Star Note 233