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Kaons and Lambdas in the STAR TPC

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Abstract

Results from studies on possible strangeness reconstruction capabilities in the STAR TPC are presented. One hundred FRITIOF central Au+Au events were analyzed using the full STAR event reconstruction chain (BFC). We demonstrate that the TPC has good physics capabilities with singly strange particles.

1 Introduction

This study addresses the question whether the TPC detector in STAR is capable of performing neutral strange particle measurements (K^0_S and Λ). This would be very advantageous to STAR especially at the first year of running where the SVT is not part of the configuration. An early study trying to define strangeness reconstruction capabilities of the STAR TPC using 15 central Fritiof Au+Au events is included in Starnote # 72. Those initial results were negative (see Fig. 8 in that note), but the reader was also cautioned that further optimization might give a different answer. There are several reasons for that; the statistics were very limited, the used cuts were optimized for the SVT, and also the SVT detector material was included in the STAR geometry files in the simulations, although never used in that analysis.

A new study was performed a couple of years later. The results from that study are reported here. This time several things were improved:

- **Statistics.** One hundred central Fritiof Au+Au events were used as the data sample. Also, a pure sample of Kaons and Lambdas, filtered out from Fritiof events, was used for cut optimization.
- **Geometry.** The SVT detector was not included in the STAR geometry in order to be able to make a fair estimation for day one run conditions.
- **Simulation.** The official STAR event reconstruction chain was used. Details on the exact composition of the chain are given later in this report.

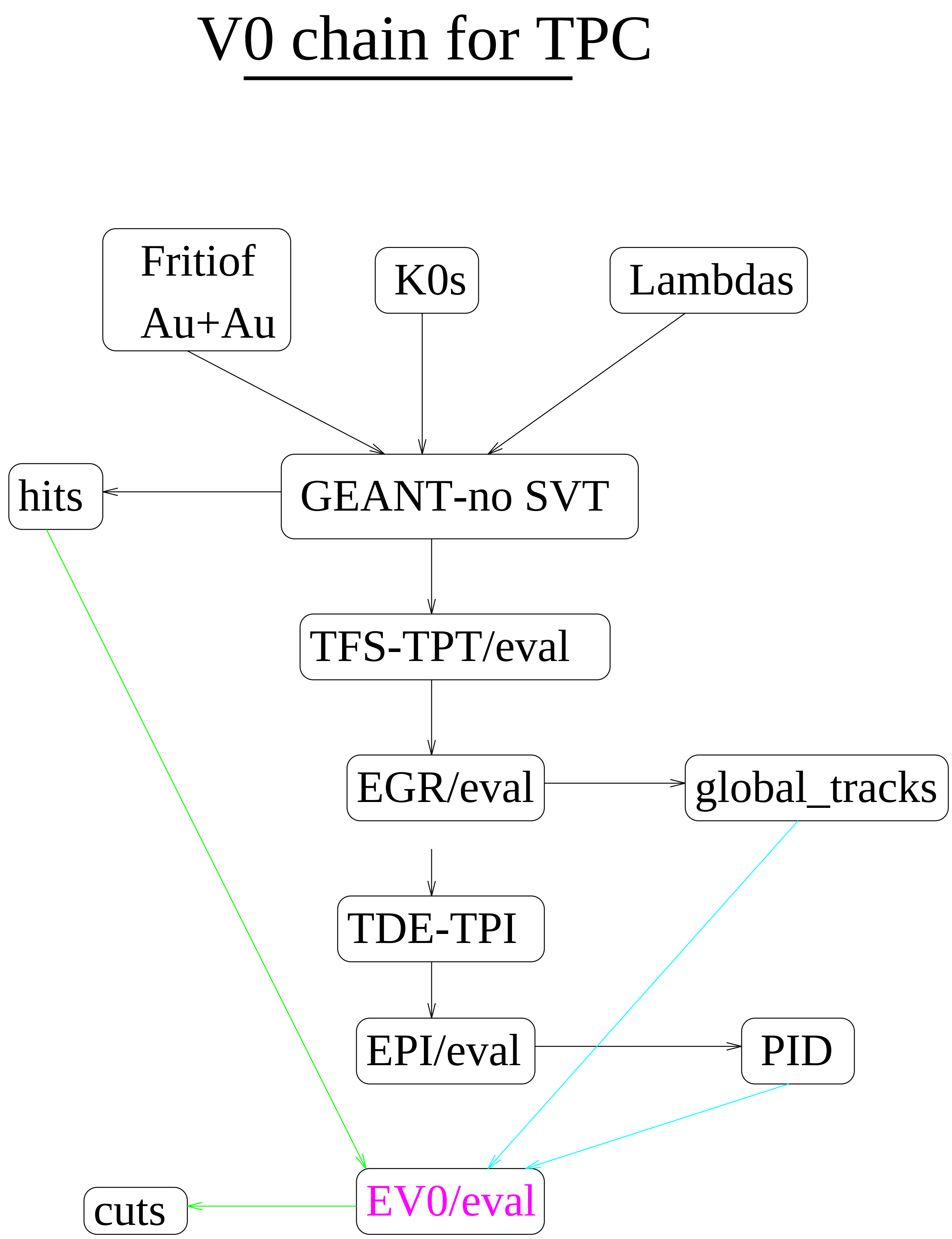

Figure 1: Analysis chain for V0 studies in TPC.

- **Cuts.** A careful study of the cut variables was done, and all cuts were tuned to the TPC features.

All resulting HBOOK ntuples as well as the analysis kumacs are saved and are available at BNL in directory /star/u2a/margetis/tas/ev0/wrk.

These changes are summarized in Fig. 1. The simulation was based on the standard GEANT TPC geometry. TFS in Fig. 1 is the TPC fast simulator, TPT the TPC tracker, EGR the global refitter (in a simple tpc-to-global track copy scenario), TDE-TPI (EPI) are the TPC dE/dx and PID modules, and EV0 is the V0 reconstruction module. The STAR analysis environment was TAS (not STAF) but this is irrelevant since the results are 'analysis framework' independent.

Only tracks with definite PID assignment were used in this analysis. This does't impact the K_S^0 analysis (most of the produced particles are pions anyway), but it greatly improved the Λ analysis. This is because EV0 was using only positively identified protons, thus avoiding looping over all positive pions. As we discuss later the protons emerging from Lambda decays are in the momentum range where dE/dx can easily identify them. There are recent studies where the PID information was not used in the Λ analysis [2]. By comparing both analyses one can estimate the impact and importance of PID information in V0 (especially Lambda) analysis.

Note in Fig. 1 that on the left side there is a direct connection of the 'hit' box to the 'EV0' box. This bypasses all the intermediate simulation boxes. In this mode, either a pure Kaon or Lambda sample was under consideration. The first (innermost) TPC hit was used and the GEANT position and momentum information was used to form pseudo- (ideal-) tracks. We did this exercise in order to define a 'best case' scenario, an ideal case where only multiple scattering and energy loss (among other physics processes in GEANT) were the only 'disturbing' factors. No hit or tracking reconstruction efficiencies, PID efficiencies etc. were considered. This allowed for an estimation of a 'best case' TPC acceptance as well as a set of 'ideal' cut-variable distributions thus defining the limits of the TPC capabilities. The only other running mode was the normal one, i.e. the simulated 'data' were analyzed as if they were real data coming from the detector.

The method of reconstruction is the standard V0 analysis method, i.e. looking for charge decays of K_S^0 and Λ particles. Figure 2 schematically shows such a V0 decay: a neutral particle emmitted from the primary vertex V travels a distance r_V and it decays into two charge daughter particles which are consequently detected in the TPC.

In the first part of the study, as we mentioned already, Kaons and Lambdas from Fritiof events were filtered out and passed through the simulation and analysis chain, (ideal case), so that the upper acceptance limits as well as the behavior of the cut variables could be mapped out. Then a set of appropriate cuts was included in the reconstruction of the full events (to avoid overflow of combinatorial background) and 100 central Au+Au events were reconstructed and then saved into HBOOK ntuple format. Using PAW as further tunning of the cuts allowed the estimation of the TPC capabilities (i.e. efficiency, acceptance estimates).

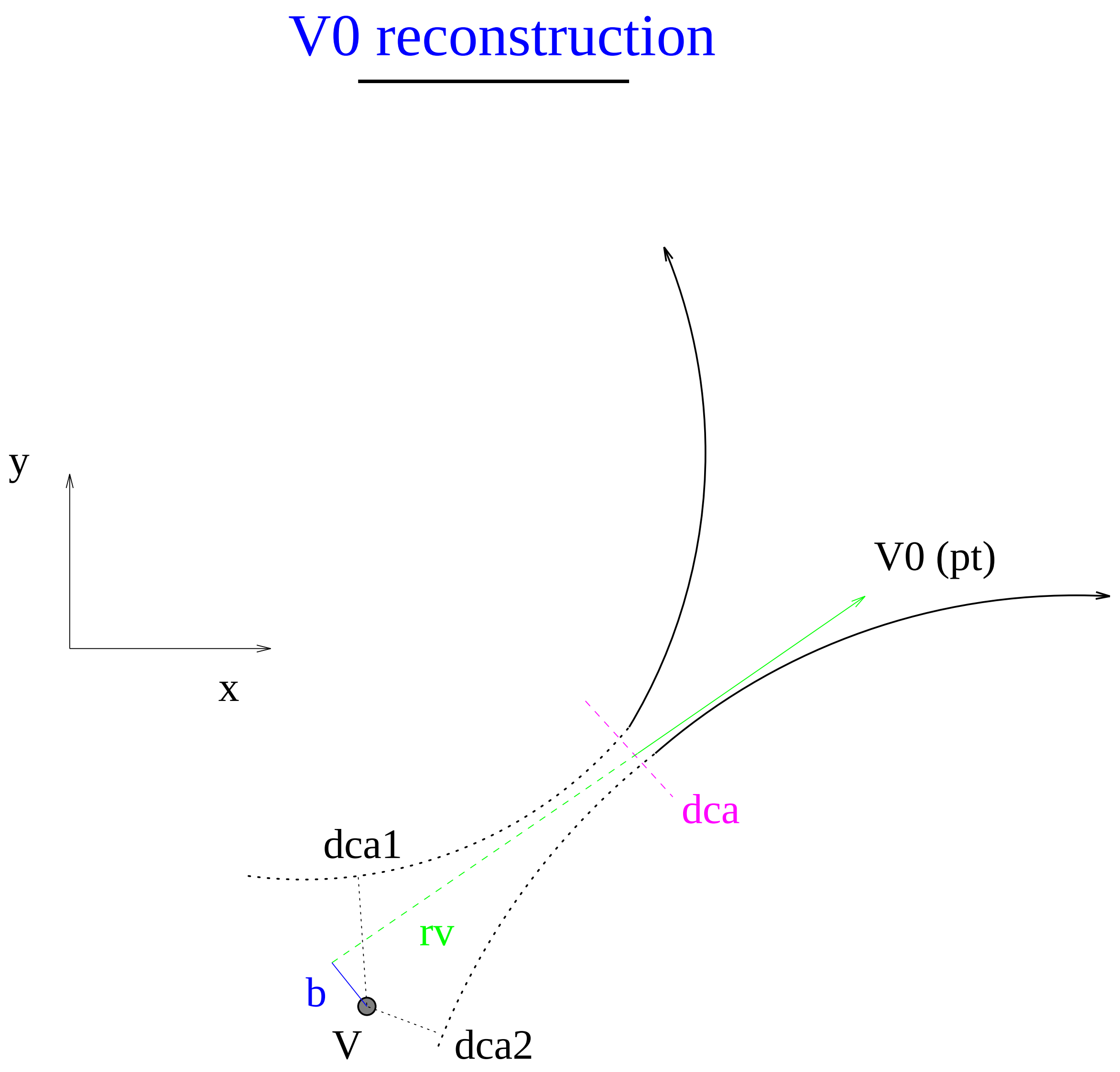

Figure 2: Characteristic V0 topology.

2 The best case scenario

Figure 3 shows the distribution of the three most important (and common) cut variables, since they are directly related to the physical model of the decay. These cuts are, the impact parameter (b) of the reconstructed V0 from the event vertex, the distance of closest approach (dca) of the two daughter tracks, and the decay distance of the V0 from the event vertex r_V (see also Fig. 2). The left column shows the distributions for real V0 particles (K_S^0 in this case), whereas the right column shows the combinatorial background. By comparing the two columns it is apparent that the behavior of b, dca and r_V in the signal is very different than in the background. From this figure we can also estimate some upper limits for these cuts, e.g. one should never try to cut on b less than about 1 mm, since the resolution of the TPC, even in this ideal case, is not sufficient. A more reasonable cut on b would be in the range of

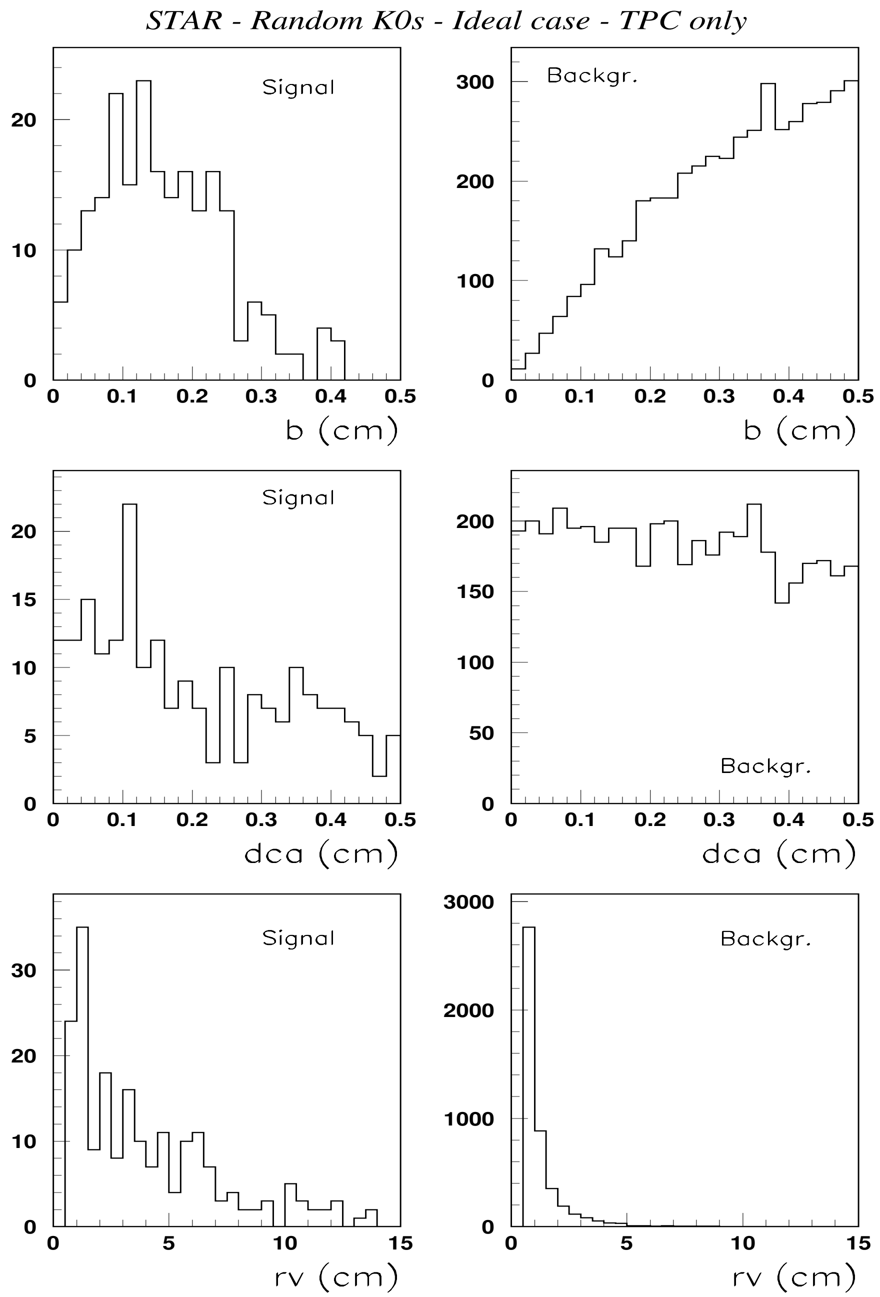

Figure 3: Characteristic cut distribution for either real (left) or fake V0 decays.

1.5–2.5 mm.

In Fig. 4 the p_T distribution of each daughter is shown for Kaon and Lambda decays. Both daughters had to reach the TPC and leave at least one hit in the chamber, in order to be included in these distributions. Looking at the mean p_T for the pions from K^0_S decays we see that it is around 400 MeV (we put c=1 everywhere in this document). For Lambdas we observe that the pion is very soft, with mean p_T of about 200 MeV and the proton with 600 MeV. The proton p_T in the region where dE/dx at its best, i.e. it should not be a problem to identify them in STAR. These figures are consistent with the rough estimations shown in Fig. 2 of Starnote #72.

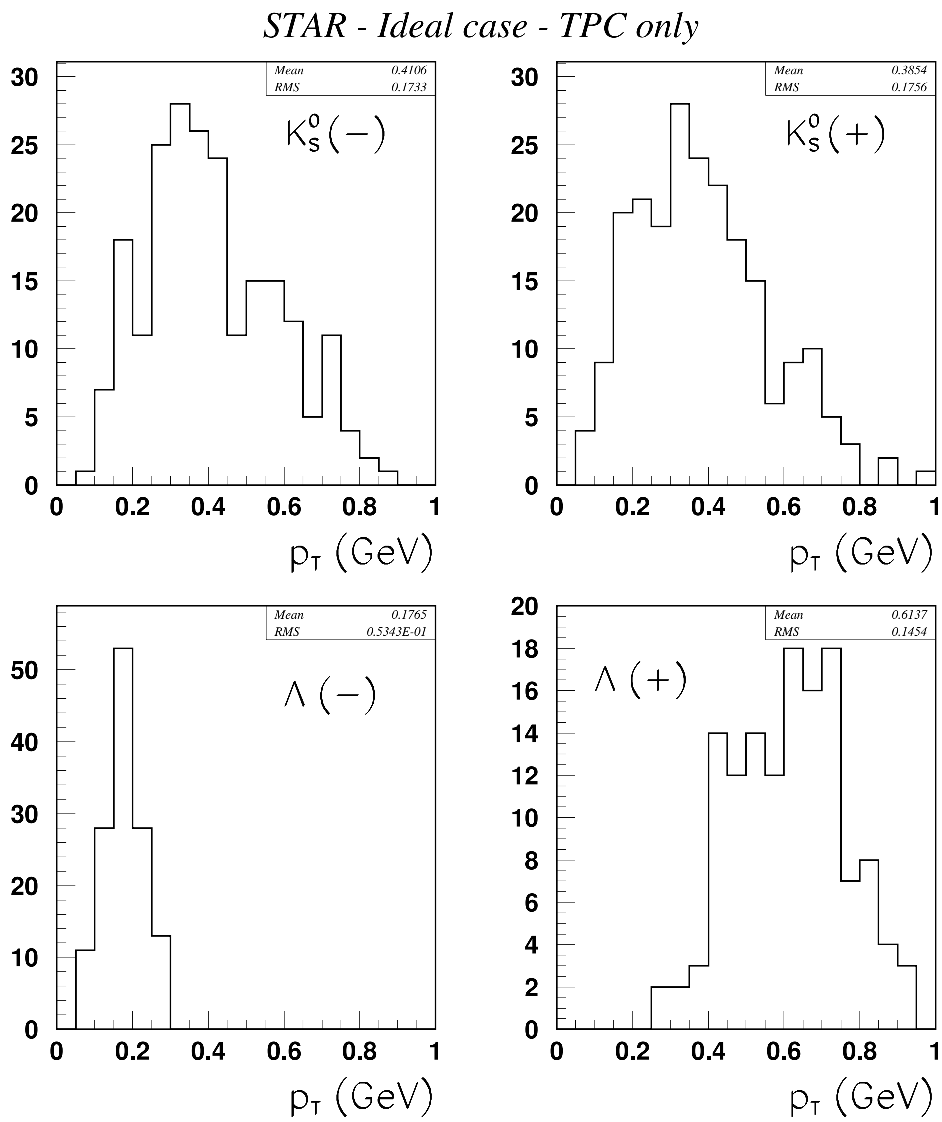

Figure 4: Transverse momentum distribution of daughter decays for K^0_S (upper) and Lambda (lower) decays.

The relatively low p_T of the daughters combined with the finite radiation length of the TPC wall (the inner field cage, IFC) lead, via multiple scattering, to the observed 'resolution' of the detector in the cut variables. Figure 5 is a schematic illustration of this effect. A 200 MeV pion coming from a V0 decay close to the event vertex first scatters at the beam pipe and then at the IFC. When extrapolated back to the main vertex, in order to be combined with other tracks to form V0 candidates, it carries with it a resolution of about half a centimeter. The scattering in the gas is neglected. One may notice that it is not so much the thickness of the IFC which produces this resolution effect but the fact that the track has to be extrapolated to a distance of about half a meter away, therefore even small scattering angles result in large extrapolation errors. The resolution depends linearly on the extrapolation distance, for fixed momentum, as one can easily see. Simulated distributions of TPC tracks extrapolated to the main vertex can be found in the STAR-CDR, page 4C-44 (TPC) and 4H-13 (SVT).

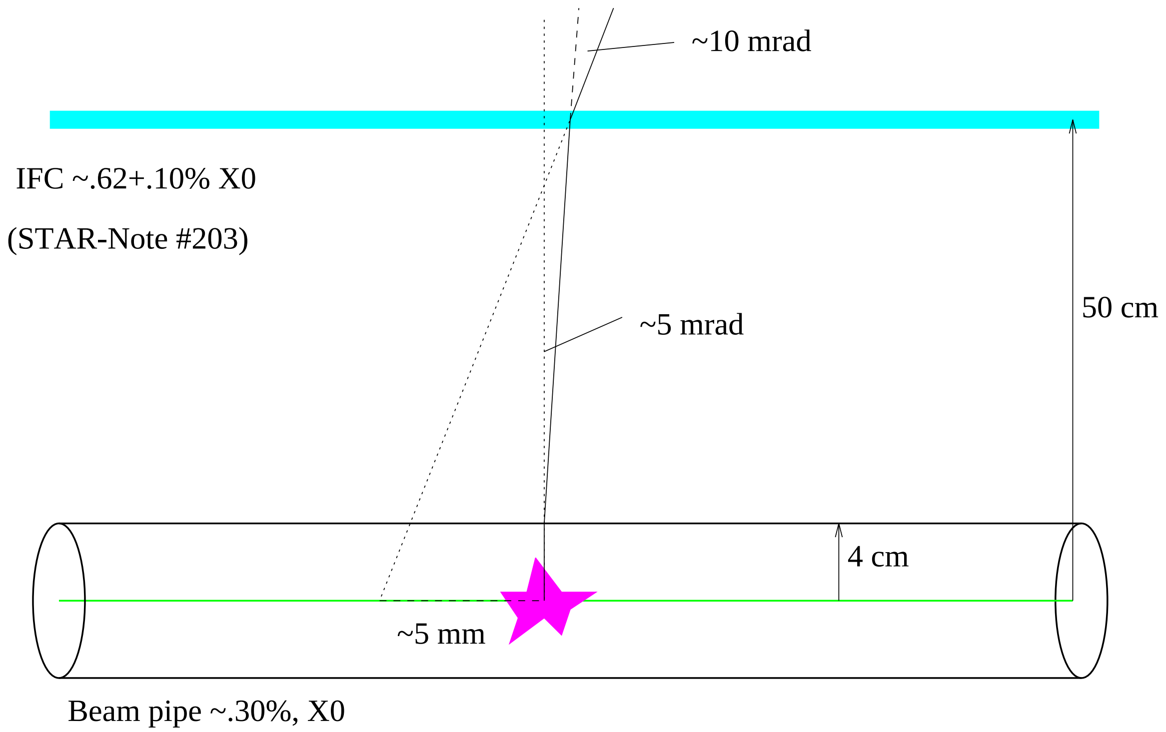

Figure 5: Illustration of the effect of the multiple scattering on the resolution of the TPC.

In this ideal case, where GEANT information instead of real pattern recognition is used, the relative efficiency for K_S^0 and Λ reconstruction is shown in Fig. 6. The relative efficiency is the percentage of the input particles that was recovered as a function of the V0 p_T. This is mainly due to geometrical acceptance since essentially no cuts or real reconstruction software was used. This puts an upper limit on STAR-TPC abilities, i.e. what is 'reconstructible'. Hit and tracking efficiencies plus the use of strong cuts for background suppression will severely impact and modify these figures. We observe that the TPC has a lower p_T cut-off of about 300 MeV for both

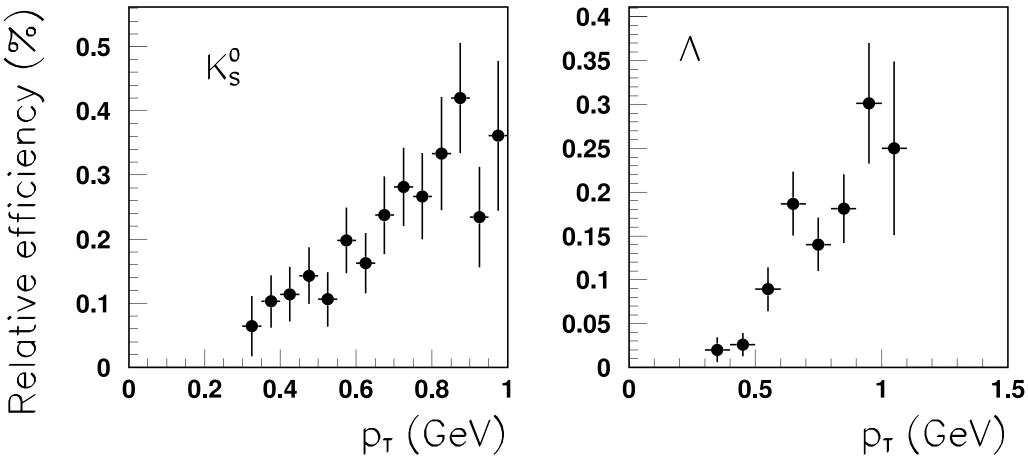

Figure 6: Relative efficiency of V0 reconstruction as a function of the V0 transverse momentum.

species. Also, at large enough values of p_T about half the K^0_S and one third of the Lambdas could be recovered.

3 Results and Discussion

In this section the results of the real STAR analysis chain are presented and discussed. Before we begin we give some background information on production rates. This can also be found in Starnote # 72.

Fritiof predicts that each central Au+Au events produces about 250 K^0_S, 60 Λ and 35 $\bar{\Lambda}$ particles (in 4π). From these, about 60 K^0_S, 10-15 Λ and 10-15 $\bar{\Lambda}$ fall into the TPC acceptance. Note that although the full event contains about twice as many Λ as $\bar{\Lambda}$, the number of particles in the TPC acceptance is about the same. This is because the $\bar{\Lambda}$ is produced predominantly around mid-rapidity, where the TPC acceptance is best.

About 2/3 of K^0_S and 1/2 of Lambdas will decay inside the beam pipe (radius of 4 cm). This is mainly because of the absence of c.m. motion relative to the laboratory system, i.e. absence of Lorentz boost in the particle life-time. Therefore, one cannot apply a large r_V cut (e.g. above 20 cm) since the recovered signal will be very small.

Figure 7 shows the invariant mass distribution of reconstructed K^0_S in 100 central Au+Au events using a set of rather relaxed cuts (listed on the figure). The solid line is all reconstructed particles and the dashed the combinatorial background. The signal to background ratio is not acceptable for physics analysis, therefore one has to further optimize the cut space.

That is done in Fig. 8 where a set of strict cuts was applied, trying to preserve

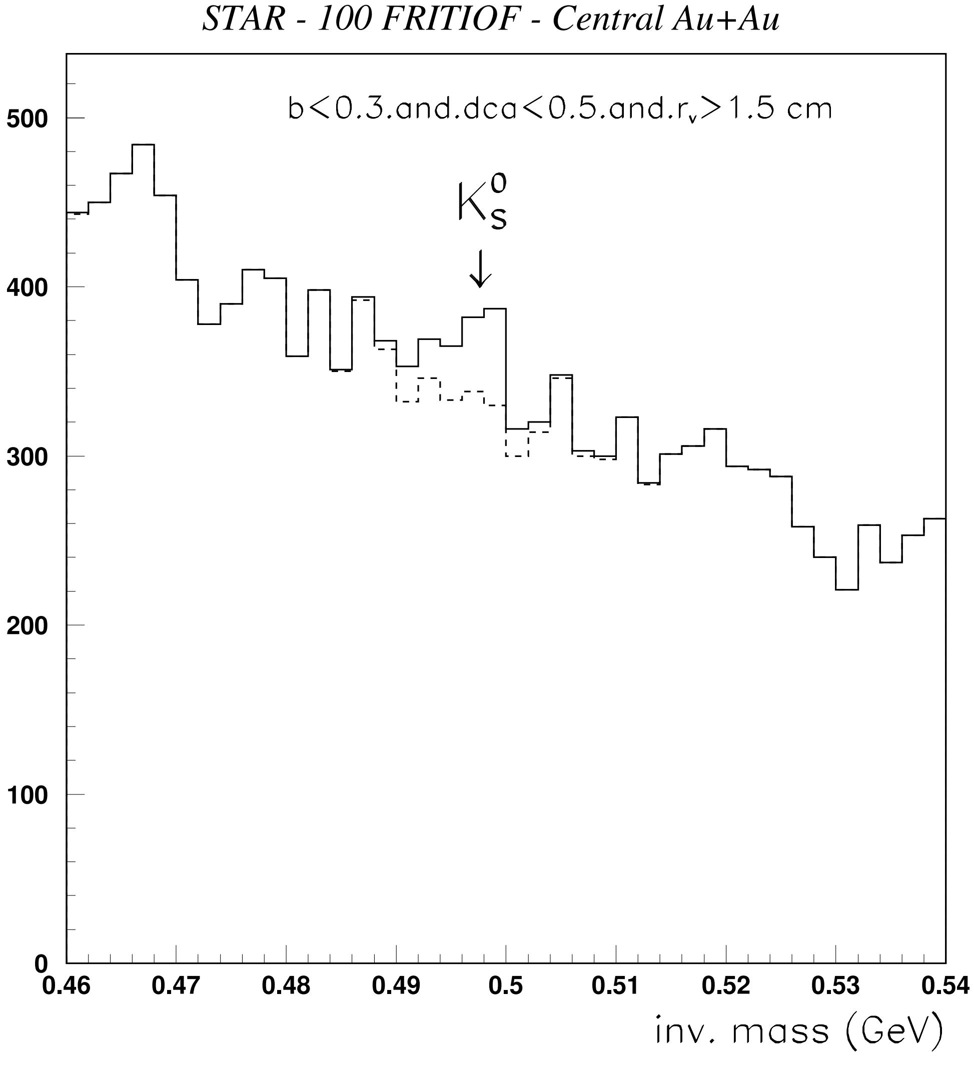

Figure 7: Invariant mass distribution of K_S^0 with 'loose' cuts.

as much signal as possible but at the same time eliminate most of the background. The cuts are again listed on the figure itself. This time a clean K^0_S signal is sitting on top of a very small background. The mass resolution has a $FWHM = 8 - 10\,\mathrm{MeV}$. This set of cuts allows the recovery of about 1 K^0_S per event. Given the statistical nature of this number we can conclude that K^0_S interferometry would be possible to a certain degree. The lower p_T cut-off for the strict set of cuts is about 400 MeV.

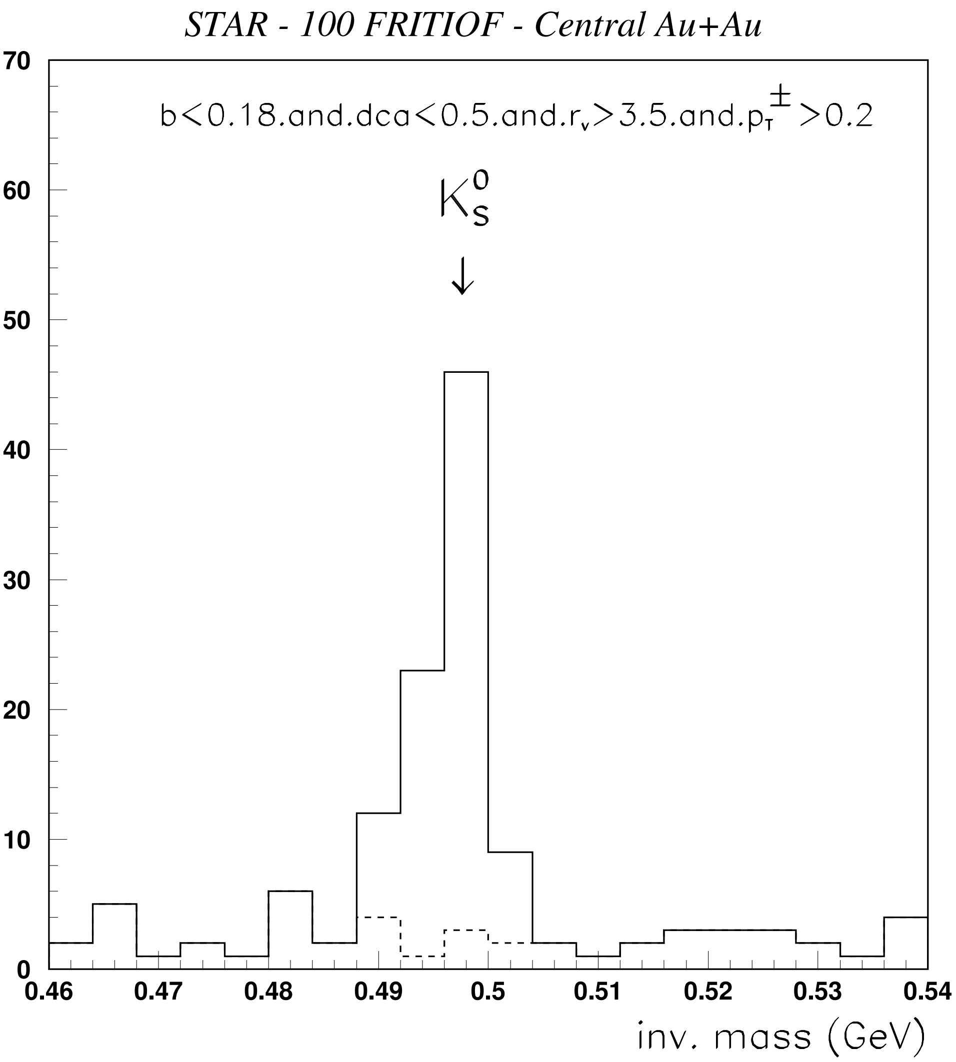

Figure 8: Invariant mass distribution of K^0_S for proper set of cuts, which eliminates most of the combinatorial background.

Figure 9 shows the invariant mass distribution of Lambdas, using a semi-optimized set of cuts (further optimization of the cuts needs higher statistics). The cuts are listed on the figure. The mass resolution has a $FWHM \approx 4\,\mathrm{MeV}$. The achieved signal to background ratio is about 1:1. With higher statistics and a better set of cuts we should be able to further improve it to more acceptable values for physics analysis. The number of Lambdas per event is about 0.5/event. This number combined with the relatively high background levels appears to be prohibiting for any Λ–Λ correlation studies. A vertex detector (SVT) appears to be an absolutely necessary addition for these kind of studies. The lower p_T cut-off for this Lambda sample was at 500 MeV.

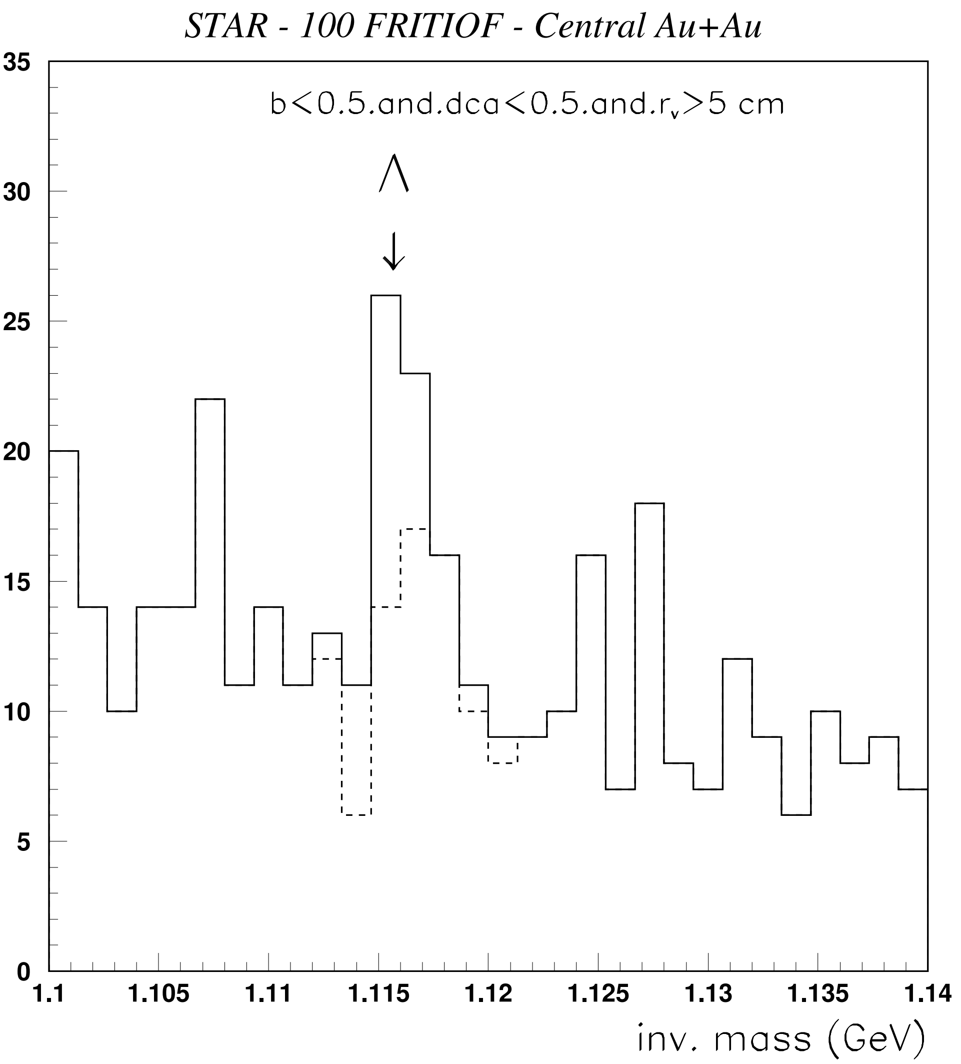

Figure 9: Invariant mass distribution of Λ with rather 'tight' cuts. Note that the background cannot be eliminated as in the K^0_S case.

We should note that Fritiof found to under-predict strangeness production at the CERN-SPS energies by almost a factor of two. Assuming that at RHIC this also might be true, the above quoted numbers about the reconstructed particles per event might have to be multiplied by a similar factor.

4 Summary

We have demonstrated that the major part of the inclusive studies of singly strange particles can be performed by the STAR TPC detector during the first year of running. About 1 K_S^0 and 0.3 Λ are anticipated to be reconstructed per central Fritiof Au+Au event, noting also that Fritiof underestimates strangeness production in nuclear collisions at CERN SPS energies.

References

[1] STAR – Geometry, Starnote-229

[2] Al Saulys, STAR Collab. meeting, LBL 1997