STAR NOTE 299: The Impact of the SVT Material on the TPC Environment

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Abstract

The results of a search for negative aspects of the impact of the SVT material on the TPC tracking environment are reported. The geometry of the SVT and its support structures are described and the radiation length of the SVT material is explained. Particle generation by the SVT and other materials in STAR are evaluated. The effect of the SVT material on the lower limit of the STAR transverse momentum acceptance is investigated. We conclude that the negative impact of the SVT is generally within reasonable bounds, although there is a need for further simulations at high rapidities.

1 Introduction

The Silicon Vertex Tracker (SVT) and Time Projection Chamber (TPC) measurements play complementary roles in the STAR experiment. Due to its position close to the main vertex and its excellent position resolution, the SVT provides high precision directional information for the tracks it reconstructs. However, since the SVT is comprised of only three layers, its momentum resolution is rather limited. On the other hand, the TPC can provide much better momentum resolution since it samples a longer path length. However, due to the long distance between the TPC and the beam axis its vectoring information near the main vertex is poor. Both detectors provide dE/dx measurements which help to identify low momentum particles.

Because of the complementarity of these detectors, the addition of the SVT enhances the performance of the STAR detector. The nature of these enhancements has been described on many occasions, see the SVT proposal for a detailed discussion[1]. The measurements for which the SVT contribution is most helpful includes reconstructing secondary decay vertices which occur a few cm from the main vertex and tracking particles with low transverse momentum.

In this report we will search for *negative* aspects of the SVT material in STAR. Such an investigation can be useful if it points out problem areas which may be addressed before construction begins. It may also provide some new perspectives on the limitations of STAR's tracking capabilities.

2 AGI SVT model

A model of the SVT in STAR was created using the STAR advanced geometry interface (AGI) package, a fortran preprocessor for GEANT geometry code[2].

2.1 Geometry

The SVT group has developed a highly detailed description of the SVT geometry and materials in GEANT. This includes the silicon drift detectors, their support ladders, front end electronics, water cooling, end rings, water manifold, cabling, and support cones. The constituents of each of these elements are individually described and placed. This level of detail provides a wealth of information about the impact of different aspects of the SVT on the TPC environment.

In Fig. 1 a transverse cross section of the mid-rapidity region of the SVT (beam axis out of the page) is displayed. Six rings of silicon drift detectors are paired into three "super"

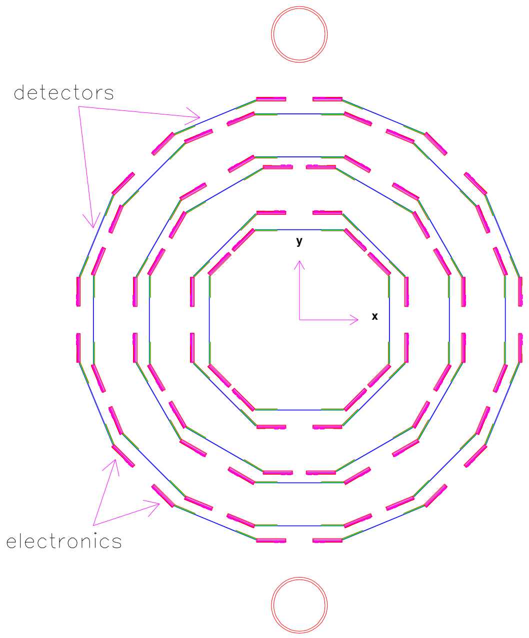

Figure 1: GEANT description of the SVT at mid-rapidity. The beam (z) axis is normal to the page

layers. The circles appearing above and below the SVT are hollow Beryllium support rods. The actual configuration of these rods around the SVT is yet to be determined. Note that a high transverse momentum (straight) track with zero momentum in either the x or the y direction passes through only three silicon wafers when escaping the SVT. The layers of the SVT are arranged to provide these relatively "thin" windows in radiation length for a subset of the data.

The longitudinal cross section of the SVT is shown in Fig. 2. In this figure the projective nature of the SVT geometry is apparent; the length of the active area of the SVT increases as the distance from the beam axis increases. The active area of the SVT covers ± 1.0 unit of pseudo-rapidity (η) while allowing for a ± 3.0 cm variation in the z position of the main

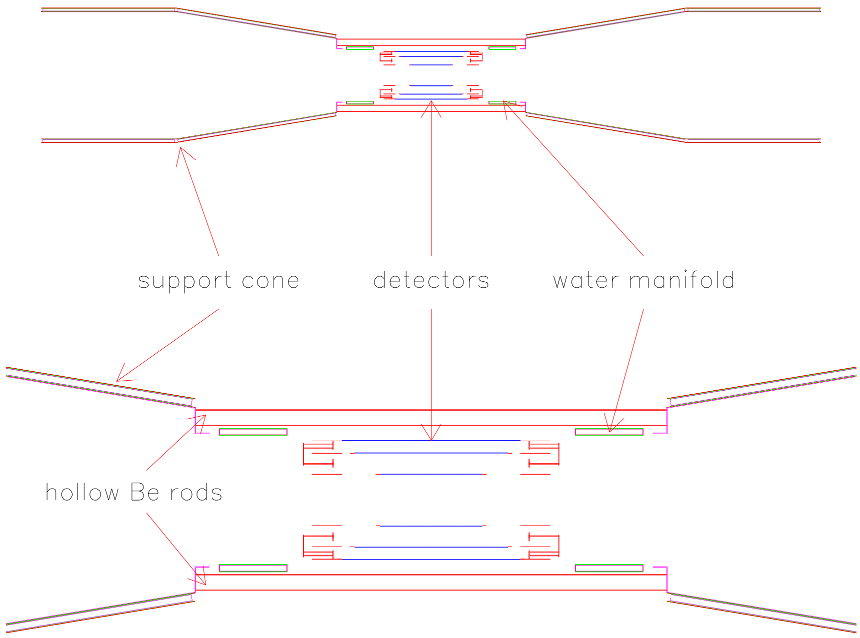

Figure 2: GEANT description of the SVT.

vertex. The water manifold goes from 1.5 to 1.9 in η, and the support cone goes from 1.5 to 2.5 in η.

2.2 Radiation length

Since the SVT is the innermost layer of the STAR detector it should be as thin as possible. Multiple Coulomb scattering of tracks within the SVT will degrade the momentum resolution of the SVT[3] and make it more difficult to match tracks between the SVT and TPC. The SVT is designed to contribute approximately 4.5% of a radiation length at mid-rapidity. For comparison, the 1.0 mm thick Be beam pipe contributes only 0.28% of a radiation length. Note that it is crucial for the radiation length of the pipe to be held to a minimum since it degrades the ability of the SVT to project tracks back to the main vertex.

The radiation length contributions of the various SVT elements to the 4.5% total at mid-rapidity is shown in Fig. 3. The SDD wafers, cables, and the Be support make up about half of the total and the remainder comes from the front-end electronics and their water cooling. There is some uncertainty in these numbers. The AgPd fraction is for 2 layers, 15 μm thick each, and additional layers may be required. However, the numbers used for the radiation thickness of the AgPd material are likely to be an overestimate since the actual material will not be a pure alloy but will be mixed with other substances with lower radiation lengths. The dielectric is taken as a generic glass, and could be higher or lower by as much as a factor of two. The final form of the cabling has not been established.

The electronics are placed on the ladders rather than on endcaps outside the active region of the SVT. They cannot be placed on the end caps due to difficulties in driving the signal over such long cables. However, placing the electronics adjacent to the detectors allows multiplexing of signals, reducing the number of cables by a factor of 216. The resulting

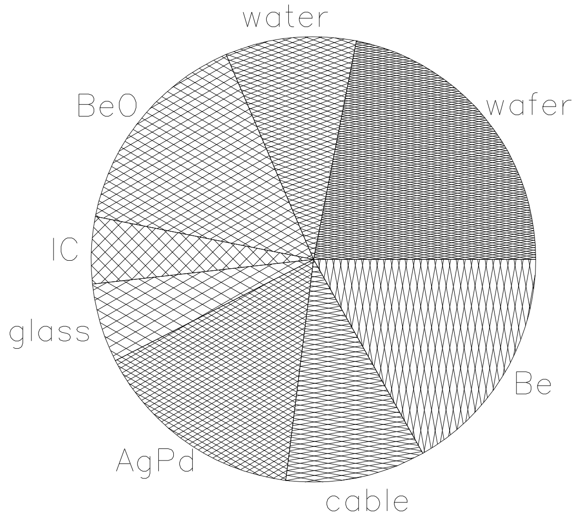

Figure 3: Contributions to the SVT 4.5% radiation length at mid-rapidity.

Table 1: Percentage radiation length of the SVT. The calculation averages over $\eta = \pm 1$ in $6°$ azimuthal bins.

less than 3% radiation length	6.6% of SVT
less than 4% radiation length	13.3% of SVT
greater than 6% radiation length	13.3% of SVT
greater than 7% radiation length	none of SVT

savings in radiation length offset the increase due to the addition of the electronics to the active region.

The radiation length of the SVT as a function of pseudo-rapidity is shown in Fig. 4. Note that the radiation length is presented as a fraction, not a percentage, so this figure is consistent with a 4.5% radiation length at mid-rapidity. The radiation length is calculated in GSTAR assuming straight line trajectories from the main vertex. Low momentum tracks will strike the SVT at angles and see a larger radiation length.

In the active region of the SVT the radiation length increases with the pseudo-rapidity due to the increasing angle of incidence. At large pseudo-rapidities the radiation length exceeds 40%. The dramatic increase in the radiation length above η=1.5 is primarily due to the water manifold. This pseudo-rapidity region is outside the SVT region of interest, but it does shadow the edge of the TPC and the endcap calorimeter.

The radiation length as a function of azimuthal angle (ϕ) is shown in Fig. 5 for the mid-rapidity region. The radiation length exhibits minima at ϕ=0 and π radians due to the angular alignment of the wafers shown in Fig. 1. This alignment was chosen to provide radiation "thin" windows for a subset of the tracks as opposed to attempting to evenly distribute the radiation thickness. The range of radiation length values is shown in Tab. 1 averaged over $\eta = \pm 1$ in $6°$ azimuthal bins. The mean value is about 5.5% of a radiation length rather than 4.5% since this calculation extends to $\eta = \pm 1$ where the angle of incidence increases the effective radiation length.

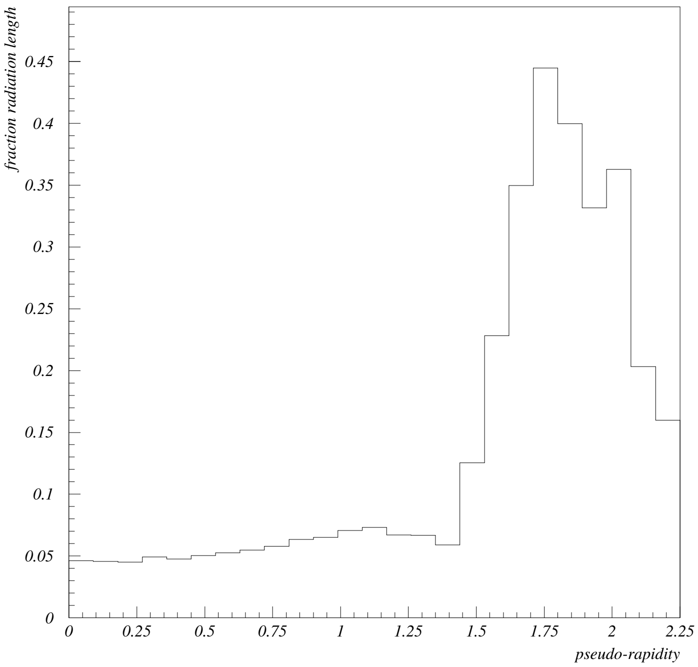

Figure 4: SVT radiation length as a function of pseudo-rapidity. Note that the radiation length is presented as a fraction, not a percentage.

3 Particle Production

Tracks fall into three broad categories: primaries, secondaries produced by decays, and secondaries produced in interactions within the apparatus. The dividing line between primaries and decay products follows from the relationship between the event generator (ie. HIJING) and GEANT. All of the particles input by the event generator are considered primaries by GEANT, and only those particles which result from decays during GEANT tracking are labeled as secondaries. In general, the event generator decays all particles with lifetimes shorter than the π°, the rest are decayed in GEANT. This means that particles produced by decays of very short lived resonances in the event generator are labeled primaries as far as GEANT is concerned.

Produced particles include electron pair production by photons, hadronic interactions between tracks and the nuclei of GEANT materials, and so on. The hits in the TPC due to produced particles are a concern for two reasons. First, they increase the occupancy of the TPC and may reduce tracking efficiency. Second, they may be confused with primaries or decay products. In order to gauge the impact of particles produced by the SVT we must not only examine the role of the SVT but we must also compare it to other sources of background tracks.

3.1 Beam pipe contribution

Background from the beam pipe has been under investigation for some time in order optimize the beam pipe design[4]. The standard beam pipe in STAR consists of a 1.0 mm thick Be

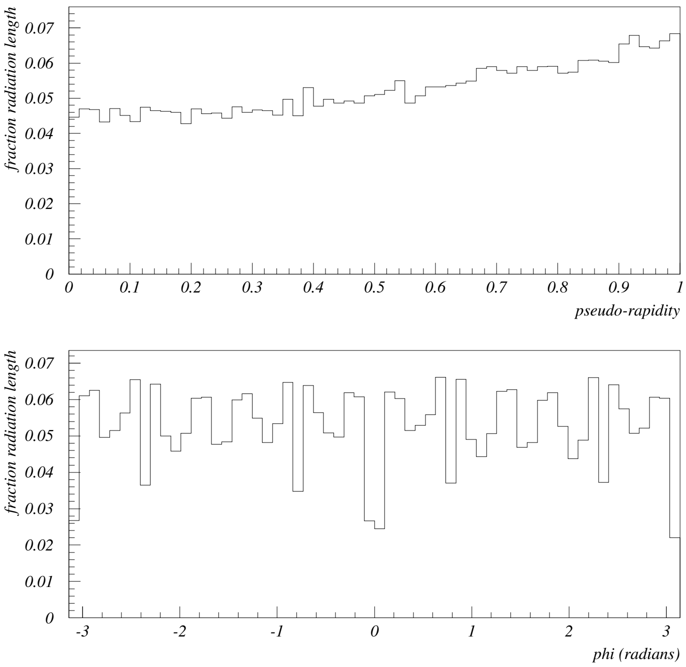

Figure 5: SVT radiation length as a function of azimuthal angle (ϕ) in the mid-rapidity region. The top panel shows the pseudo-rapidity region for the simulation. The bottom panel shows the azimuthal angle dependence. Note that the radiation length is presented as a fraction, not a percentage.

which extends to $\pm$76.2 cm of the mid-plane of the detector, at which point the material changes to steel. According to our simulations, the TPC sees 17$\pm$2% more hits with the standard beam pipe than with no beam pipe at all. For comparison, a beam pipe made only of Be increases the number of TPC hits by 5.6$\pm$1.6%. Obviously, the steel section of the beam pipe is a very significant source of background for the TPC. See Ref.[4] for a full discussion of the various beam pipe options.

3.2 GSTAR methodology

The increase in the number of TPC hits that results from adding the SVT was found to be 5.0$\pm$2.3% using 5 central Au+Au 100 GeV/nucleon HIJING events. However, the raw number of TPC hits is not a very useful indicator of the impact of particle production on the TPC. Some particles may actually be stopped in material placed in front of the TPC, decreasing the total number of TPC hits. In order to carefully investigate the impact of particles produced in various materials on the TPC we have performed a series of new GEANT simulations.

We employed the recently created table operations (TOP) package in the STAR Analysis Facility (STAF) to join GEANT track and vertex tables, creating new tables which combined information about where a track was produced with momentum information and particle identification. Since the track table contains pointers to both the starting vertex and the stopping vertex for each track, we were able to successively build up information about the parentage a track. This is important since it is possible for tracks produced by one material in STAR to interact in another section of the detector, producing additional tracks which ultimately leave hits in the TPC. For example, a primary hadron may create a shower in the steel section of the beam pipe, which generates a photon that travels to the endcap of the TPC where it creates conversion electrons which spiral through the TPC active region.

In order to obtain full parentage information, it is necessary to force GEANT to save all tracks. This is in contrast to the standard STAR philosophy of saving only tracks which leave hits and perhaps decay products. Saving all the tracks produced in showers in dense media in an Au+Au event results in very large track tables. The process of joining track entries to those of their parents and children with TOP creates tables which quickly grow to an unmanageable size.

This problem was solved by leaving out some dense materials such as the calorimeter and the magnet (but not the field). Leaving out these materials can produce an additional problem by allowing tracks to spiral back into the TPC again and again, artificially increasing the number of TPC hits. We eliminated this problem by shrinking the STAR CAVE (the mother of all volumes) to a radius just larger than the TPC. Whenever a track leaves the TPC it exits the CAVE and is no longer tracked by GEANT. Note that by using this approach, we loose any backscatter into the TPC, so our estimates of the percentage of TPC hits due produced particles are slightly underestimated.

It was also necessary to restrict the event size in order to keep the table size manageable. The results presented here are thus based on 100 central C+C events at 100 GeV/nucleon. For this reason we will present all of our results as percentages which should be similar for Au+Au and C+C collisions. For example, from the Au+Au study we found that the all Be version of the beam pipe increased the number of TPC hits by $5.6\pm1.6\%$, and according to the C+C study described below 4% of the TPC hits come from tracks created in the all Be beam pipe. In any case, the results presented here will be model dependent and can not be considered precise predictions. They can only provide a qualitative impression of the relative contirbutions of different processes to the background. The yield of the 100 C+C events at mid-rapitidy is equavalent to that of 2.5 Au+Au events.

The process which created a particle is not (at present) explicitly recorded in the GEANT output, but the medium in which its vertex of origin occurs is available from the geant medium variable[1]. In the results that follow we will use that information to determine the origin of a track.

We chose to use the all Be beam pipe in these simulations. Should the STAR collaboration elect to use the old standard beam pipe with steel at 76.2 cm, the beam pipe contributions presented below will be tripled. The GSTAR model of the TPC includes additional "shadow" pad rows in the TPC which are used by the slow simulator module. The artificial pad rows were suppressed in these simulations in order to obtain an accurate count of the TPC hits generated by a track.

3.3 Sources of particle production

The pie chart in Fig. 6 shows the point of origin of tracks which leave hits in the TPC. Primary tracks are those that were passed to GEANT directly from the event generator. We take all vertices that occur in vacuum or gas to be decay vertices. The endcap is the Al endcap of the TPC. The fraction from the SVT includes all the tracks originating from the

[1]This variable is correctly filled only when all of the GEANT tracks are saved

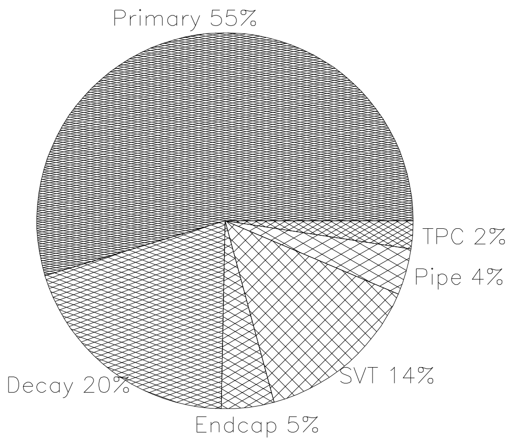

Figure 6: The point of origin of tracks which leave at least one hit in the TPC.

dense material of the SVT and its support structures. The pipe is the all Be version of the beam pipe discussed earlier. The remaining fraction from the TPC includes all of the dense material of the TPC other than the endcap (inner field cage, central membrane, etc.). .

The SVT is the main scattering source between the TPC and the main vertex, so it is not surprising that it is the major source of background tracks. However, the SVT is not the dominant source of background *hits*. The pie chart in Fig. 7 shows the sources of GEANT hits in the TPC. Note that the beam pipe used is the all Be version, the percentage from the standard beam pipe was found to be $\approx 17\%$ in Au+Au collisions. Although the SVT is the most significant source of background tracks, the TPC endcap produces a slightly larger fraction of hits. This is because the tracks produced by the SVT are primarily hadrons which travel approximately radially through the TPC, while the tracks produced by the endcaps are primarily electrons which spiral through the TPC entire volume parallel to the beam axis. Almost 90% of the hits coming from the endcap are due to electrons, while only 34% of the hits coming from the SVT are electrons.

The SVT could also contribute to the TPC hits indirectly. For example, the SVT might generate photons which go on to produce electrons in the endcap. In order to find out if this is a significant contribution, we have investigated the processes which lead to the production of endcap electrons. About 90% of the photons which convert to electrons which leave hits in the TPC are also produced within the endcap. These photons are predominantly backward going in the z (beam axis) direction, meaning that they are traveling back towards the central membrane of the TPC. Photons produced by π° decay at the main vertex or by interactions with the SVT are not a significant source of endcap generated hits since they travel away from the central region, and the electrons they produce in the endcaps tend to continue in the same direction.

The backward photons generated within the endcaps are due to neutron interactions (65%), π° decay (25%), and e^+ annihilation (10%). Almost all of the neutrons, pions, and positrons producing backward traveling photons were generated within the endcaps. The

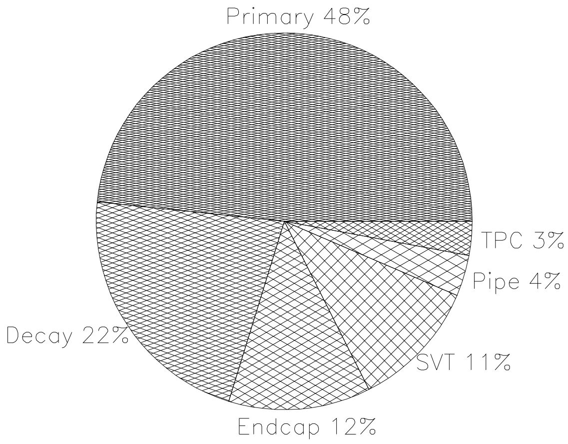

Figure 7: The sources of TPC GSTAR hits. Note that the beam pipe used is the all Be version, the percentage from the standard beam pipe was found to be $\approx 17\%$.

primary culprit is hadronic interactions. Primary hadrons are the most significant source of hadronic interactions in the endcap. The SVT contribution is only $\approx 10\%$ since only a small fraction of the hadrons in a given rapidity region are due to interactions with the SVT material.

We conclude that the SVT contributes background hits to the TPC at a rate similar to the TPC endcaps and the standard (not all Be) beam pipe.

3.4 Impact of produced particles on the TPC

Increasing the number of hits in the TPC will increase the number of merged clusters and create a more difficult tracking environment in general. However, it is unlikely that TPC tracking would be sensitive to the modest increase in hits caused by the addition of the SVT. In fact, according to a study by Jones et al.[5], even a doubling of the number of tracks in the TPC only resulted in a 5% loss of tracking efficiency and an insignificant loss of momentum resolution.

A more serious question is whether or not the additional tracks created by the SVT might impact the physics signals in STAR. One example would be the misuse of SVT generated tracks in the search for secondary decays such as $\Lambda \rightarrow \pi^- + \mathrm{p}$. There are several reasons to believe that tracks generated in the SVT material should not substantially increase the combinatoric background for strangeness reconstruction.

First of all, note that the combinatoric background is formed from the sample of both secondary and primary tracks which hit the TPC. There is no practical way to remove the primary tracks from the sample without a major loss of efficiency since both secondaries and primaries point roughly back towards the main vertex. Since only about 14% of the total TPC tracks are created by the SVT, the potential increase in the combinatoric background is small.

However, the actual contribution of the SVT should be even smaller. Consider the central

± 1 unit of pseudo-rapidity which is within the active region of the SVT. In all the simulations that have been done up till now[6], the candidate tracks for V0 reconstruction have been formed of matched SVT and TPC tracks. In order to be a candidate, the background track would therefore have to be generated before or within the first layer of the SVT in order to create an SVT track. This requirement severely restricts SVT contribution to the combinatoric background.

The issues considered above only deal with the role of SVT generated tracks in increasing total track sample. Since the generated tracks originate in hadronic interactions which typically produce several tracks simultaneously, the production vertex itself could be mistaken for a decay vertex. As discussed above, this contribution to the reconstructed vertices could only be significant when one was not using complete SVT tracks. It might be significant when reconstructing vertices outside of the SVT active region. For example, a hadronic interaction in the SVT water manifold could produce secondary tracks in the TPC which would not be expected to match to SVT tracks. One might then mistake the reconstructed production vertex as a decay vertex. Of course, only a fraction of these vertices would reconstruct to the correct invariant mass of the parent particle. Ultimately, all of these can be removed by excluding vertices which occur within dense material. We can conclude that the modest increase in TPC tracks due to tracks generated in the SVT should not impact secondary vertex reconstruction in any substantial way.

4 Low Momentum Acceptance

The position of the SVT near the beam axis allows it to access very low momentum particles. The maximum distance (D) of a point on a primary track from the main vertex in the plane normal to the magnetic field is

$$\mathrm{D} = 2.0 \times \mathrm{R} = 2.0 \times \frac{\mathrm{p}_\perp}{1.5} \tag{1}$$

with the transverse momentum ($\mathrm{p}_\perp$) in MeV/c and the radius (R) in cm. The outer radius of the SVT at 14.9 cm corresponds to a 11 MeV/c minimum track momentum. If we require that a track make it to 81.6 cm, crossing at least the fifth pad row on the inner sector of the TPC[2], the required momentum is 61 MeV/c. However, since energy is lost in the material between the detectors and the main vertex, the minimum momenta is lower than indicated by these calculations.

4.1 Stopping within the SVT

At mid-rapidity, a pion must have 25-30 MeV/c just to make it out of the 1.0 mm thick Be beam pipe. The SVT is a composite structure composed of many different materials, each with its own particle stopping properities. However, it is reasonable to model the SVT and beam pipe as 4.5 + 0.3% of a radiation length of Al to simplify the calculation since Al is near the middle of the range of elements found in the SVT material. In this approximation, the punch-through momenta of pions, kaons, and protons are 62, 155, and 240 MeV/c respectively[7]. From Fig. 5 we saw that the radiation length of the SVT is unevenly distributed, so some of the pions punch through the SVT at lower momenta.

[2]This distance is midway between the fifth and sixth pad row

According to GEANT, a few percent of 50 MeV/c pions punch out of the final layer of the SVT, so it is possible that the SVT will be able to say something about the shape of the pion momentum spectrum down to 50 MeV/c in an ensemble average over many events. It will, however, be a challenge for the SVT software to recognize these tracks using only 3 space points and the main vertex. On an event by event basis it appears that it will be very difficult to say anything below the 65 to 75 MeV/c range where the majority of the particles punch through the third layer.

4.2 TPC acceptance

It is interesting to investigate which particles reach the TPC with and without the SVT in place. In Fig. 8 we show the results of a GEANT simulation in which a flat momentum distribution of pions from 50 to 100 MeV/c at mid-rapidity were tracked with and without the SVT present. The solid and dashed histograms represent the fraction of tracks which

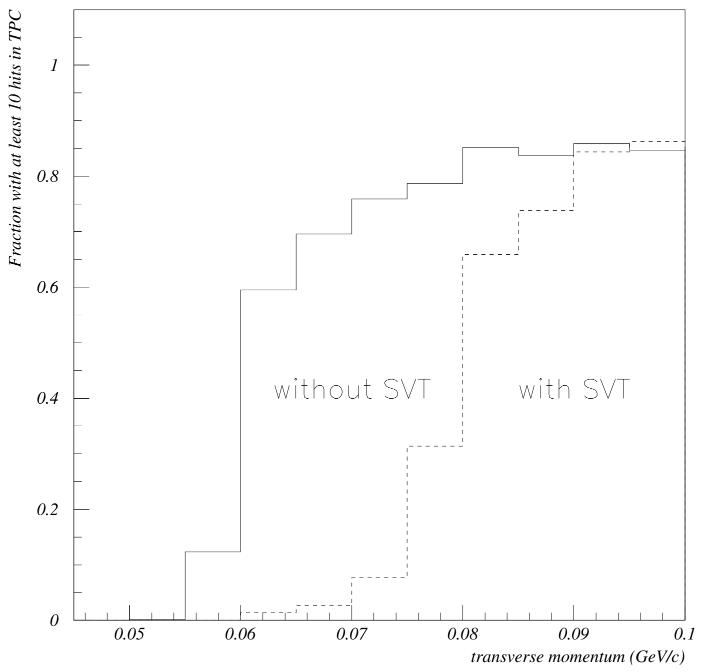

Figure 8: Fraction of pions at mid-rapidity which leave 10 or more GEANT hits in the TPC. The solid and dashed histograms result when the SVT material is excluded or included. The transverse momentum on the horizontal scale is the initial transverse momentum of the pion.

leave at least 10 GEANT hits in the TPC when the SVT material is excluded or included. The number of GEANT hits is generally equivalent to the number of TPC pad rows crossed. The effect of the SVT material is significant when the transverse momentum drops below 90 MeV/c. For reference, about 4% of the charged pions within $\eta = \pm 1$ are below 90 MeV/c in a central Au+Au event according to HIJING, or about 100 pions per event. Note that leaving 10 GEANT hits in the TPC is a necessary but not sufficient condition for the track to be trackable in the TPC. Tracking is difficult in the inner pad rows of the TPC due to the large occupancy, and these low momentum tracks leave very short paths which only travel a few pad rows into the TPC before turning around. Those below 65 MeV/c do not pass the fifth pad row and are not expected to be trackable by the TPC group[8]. In fact the TPC group has never attempted to track below 70 MeV/c due to these difficulties. Once the fast simulator has been tuned to reproduce the results of the TPC sector cosmic ray tests, the issue of low momentum track recognition in the inner pad rows should be explored in detail.

The relatively large radiation length at higher rapidities due to the water manifold and the support cone is a cause for concern since it affects the active region of the TPC ($1.5 \leq |\eta| \leq 1.7$). The full impact of this material on the quality of TPC tracking at the edges of its acceptance is beyond the scope of this report. However, we note that it does not have a large impact on the acceptance of pions with transverse momenta above 100 MeV/c. In Fig. 9 we show the results of a GEANT simulation in which a flat pseudo-rapidity distribution of 100 MeV/c pions were tracked with and without the SVT present. The solid and dashed

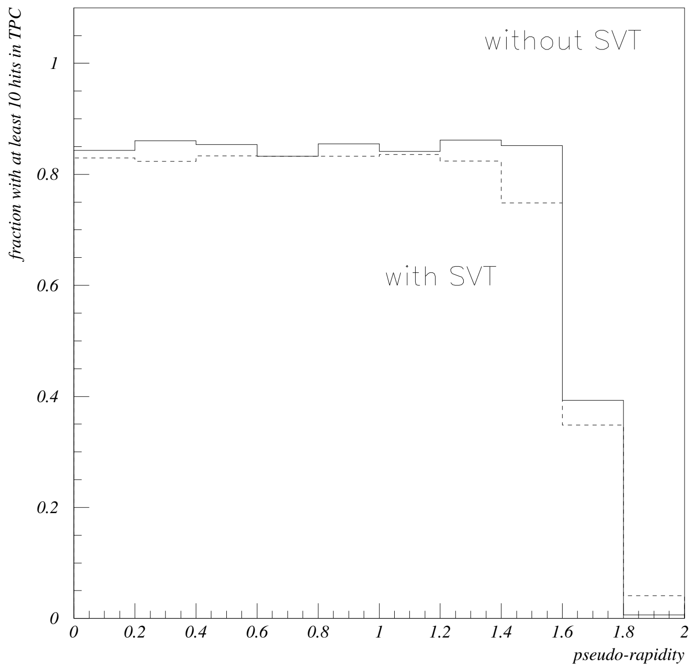

Figure 9: Fraction of $p_\perp$=100 MeV/c pions which leave 10 or more GEANT hits in the TPC. The solid and dashed histograms result when the SVT material is excluded or included.

histograms are defined as before in Fig. 8. The effect of the SVT material on the TPC acceptance is not very strong for 100 MeV/c $p_\perp$ pions. Effects on track resolution deserve further study.

5 Conclusions

We have examined the impact of the SVT material on the TPC. A highly detailed description of the SVT geometry is available in GSTAR. The overall radiation length of the SVT at mid-rapidity is 4.5%, but it is unevenly distributed in azimuth. As a function of pseudo-rapidity the radiation length increases as we move out of the active area of the SVT to quite large values at the edge of the TPC acceptance. Although particles are generated in interactions with the SVT material, these are not expected to be a major problem for the TPC. The SVT material generates TPC hits at a rate similar to or less than the standard beam pipe and the TPC endcap. The TPC has already been shown to be able to withstand much larger increases in multiplicities with little degradation in performance. It appears that the SVT should not be a significant source of background combinatoric background in reconstructing secondary vertices when matched tracks are used. When the SVT information is not used, it will be possible to eliminate false vertices by excluding any "decays" which appear to occur within a dense material such as the SVT water manifold. The SVT extends the acceptance of the STAR detector to low transverse momentum, but energy loss in the material of the SVT places strong limitations on the SVT acceptance in this regime. A very preliminary look at the effect of the SVT material at the edge of the TPC acceptance at high pseudo-rapidity did not reveal a major impact on 100 MeV/c $p_\perp$ pions, but the effect on TPC resolution requires more detailed investigation.

References

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