STAR NOTE 232: Results From Four Layer SVT Simulations

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Abstract

The potential benefits of increasing the number of SVT layers from three to four are explored with full GEANT simulations and back-of-the-envelope calculations. The addition of a fourth layer is found to produce only moderate improvements in tracking efficiency and resolution. The benefits of a fourth SVT layer to the STAR physics program are discussed.

The current design of the STAR Silicon Vertex Tracker (SVT) calls for three layers of silicon drift detectors (SDD). The number of layers is partially determined by the requirement that the SVT perform stand-alone tracking of low momentum particles which are not trackable by the TPC. Three space points is the minimum number which will allow SVT stand-alone tracking. However, one may speculate that many improvements might result from the addition of a fourth layer. This report explores the advantages and disadvantages resulting from the addition of a fourth layer to the SVT design. In the introduction we will define the tracking evaluation terminology and discuss aspects of the SVT performance which might be improved by the addition of a fourth layer. Next, we will compare the results of a series of three and four layer SVT simulations. Finally, we will look at the possible impact of adding a fourth layer on the reconstruction of short lived strange particles.

1 Introduction

The SVT will be constructed of SDDs and their front-end electronics mounted on ladders which lie parallel to the beam direction. In this document we will refer to the beam/B-field as the z direction. The x-y projection of the three layer SVT design is shown in Fig. 1 with the edge-on SDDs appearing as thin lines lines and the electronics appearing as thick lines. Note that within each layer, the SDD's active areas overlap slightly in the azimuthal direction. This is an important feature since it reduces gaps which would otherwise allow tracks to escape from the SVT without leaving the required three points. However, it is not possible to overlap in the z direction due to mechanical constraints, so there is a small percentage of dead area in each layer in this design. The dead area amounts to 3.8 % per layer in the current GEANT representation of the SVT[1]. Therefore, a track within the SVT rapidity region will leave between 0 and 6 hits, but three hits is the most likely outcome.

The SVT software allows the user to add an additional point by forcing the helices through the measured position of the main vertex. This option is only appropriate when tracking

[1] The amount of dead area in the final design will depend on the outcome of current R&D efforts to maximize the percentage of active area on the individual silicon wafers.

primary particles, and is referred to as "main vertex tracking". For the simulations presented in this note, the position of the main vertex was randomly assigned using a Gaussian distribution with $\sigma = 5\,\mu$m to reproduce the uncertainty in the main vertex position. When one is interested in secondary tracks which may originate some centimeters away from the main vertex, the vertex is not included in the fit. This mode of tracking will be referred to as "unconstrained tracking".

The dead areas in each layer imply that the efficiency for obtaining three hits on three separate layers from a single track is:

$$P(\text{three hits from three layers}) = (1.000 - 0.038)^3 = 0.890$$

We will refer to this figure as the "hardware efficiency" of the three layer SVT design. Even if a track produces three hits, the tracking algorithm may fail to recognize the hits as a track. We will refer to track loss due to the tracking algorithm as the "software efficiency" of the SVT. In addition, the algorithm may group together hits which do not belong to the same track. Since the number of available SVT hits is so small, even one incorrect hit assignment will significantly degrade the accuracy of the helix parameters for a reconstructed track. Therefore, we will refer to any track which is made up of hits belonging to more than one GEANT track as a "ghost track".

Main vertex tracking finds primary tracks with a high efficiency and produces only a small number of ghost tracks. However, main vertex tracking misses many of the secondary tracks. Unconstrained tracking finds both primary and secondary tracks, but it produces a larger number of ghost tracks than main vertex tracking. The momentum resolution is poorer for unconstrained tracking than for main vertex tracking because both the path length and the number of points being fit are larger when the main vertex is included.

Tracking is performed independently in the SVT and the TPC. Next, the tracks are extrapolated to a cylinder midway between the two detectors and matched together to form global tracks. The "matching efficiency" is the number of correctly matched tracks divided by the number of tracks which had segments correctly reconstructed in both the SVT and the TPC. The matching efficiency is higher for main vertex tracking than for unconstrained tracking, partially because the helix parameters resulting from the four point fit are more accurate. However, one must also remember that the track sample found in unconstrained tracking is different than that found in primary vertex tracking. Since secondary tracks generally have lower momenta, they leave fewer points in the TPC and are more susceptible to multiple coulomb scattering, making matching more difficult for secondaries than for primaries.

One can expect that adding a fourth layer to the SVT will improve all of the efficiencies described above. The fourth layer will provide four chances to obtain three hits, improving the hardware efficiency. The number of ghost tracks should be reduced since each track will be tested four rather than three times. Since the algorithm allows each SVT point to be used only once, this should translate into an improved software efficiency as the number of points swallowed up into ghost tracks is decreased. The increased number of points for each track and the extended path length will improve the accuracy of the extracted helix parameters and may thereby improve the matching of SVT tracks to TPC tracks. There is a downside to adding a fourth layer, however. The radiation length of the SVT would be increased by 33 %, reducing the quality of the tracking information from the TPC.

2 Simulation Results

In order to address these questions about the impact of a fourth layer on efficiency and resolution, we have placed a fourth SVT layer in our GEANT simulations. The projection of the four layer SVT onto the x-y axis is shown in Fig. 2. The number of wafers required to fill in each layer is shown in Tab. 1. The standard SVT tracking algorithms were modified to search for hits in four layers rather than in three. In all the simulations presented here, the position resolution of the SDDs was assumed to be 20 microns for all hits. The efficiencies and resolutions were evaluated using central Au+Au events from the FRITIOF event generator.

As the simulations progressed, it became apparent that a major modification of the software would be necessary in order to get the full benefit of the addition of the fourth layer. It was expected that the addition of a fourth layer would reduce the number of ghost tracks, but the number of ghost tracks was found to be greater for the four layer SVT than for the three layer version. The reason for this effect is illustrated in Fig. 3. In the figure, the actual paths of the tracks are shown by the arrows and the hits they produce are represented by the circles. The ghost track indicated by the three hits enclosed within the dashed line would not have existed for the three layer SVT, demonstrating that the addition of a fourth layer increases the possibilities for forming ghost tracks. Since hits are used only once, there will also be a degradation of the software tracking efficiency as more hits are taken up into ghost tracks in the four layer design. Of course, it would be possible to reject candidate tracks which pass through the active areas of the SVT without leaving hits, and thus eliminate ghost tracks such as the one indicated in the figure. A routine which would check the tracks in this way would be fairly complex to write, and was deemed to be beyond the scope of this study. As a result, the software efficiencies reported here for the four layer SVT configuration should be considered as lower limits.

The hardware tracking efficiency for the four layer SVT is determined by the probability of getting three or more hits from four layers. To first order, this is:

$$\begin{aligned} P(\text{three hits from four layers}) &\approx \\ 1.0 - \text{probability of missing 2 layers} &= \\ & 1.0 - 0.038^2 \approx 1.0 \end{aligned}$$

Thus we expect a 12 % increase in the hardware tracking efficiency.

The software efficiency for primary tracks using main vertex tracking was found to be 92 % for both the three layer and the four layer SVT. However, the four layer SVT produced about 12 % more tracks overall than the three layer SVT, reflecting the increase in the hardware tracking efficiency. For unconstrained tracking, going from three to four layers nearly doubled the number of ghost tracks and seriously degraded the secondary tracking software efficiency. As stated earlier, we believe that this trend could be eliminated with the proper software.

The inverse transverse momentum ($1/p_\perp$) resolution obtained from the full GEANT simulations is shown in Tab. 2. We are presenting the resolution in the variable ($1/p_\perp$) because it is more accurate than extracting the resolution from $p_\perp$. This is because the resolution in ($1/p_\perp$) is well characterized by a gaussian function, while the resolution in $p_\perp$ contains a significant non-gaussian tail. The entries for the primary particles in the table were obtained using main vertex tracking, while the entries for the secondaries were obtained using unconstrained tracking. From the statistics of the simulations, the uncertainty in the resolution reported for primaries is on the order of a few tenths of a percent, while for secondaries it is a couple of percent. Because main vertex tracking for three layers already uses four points, the improvement in the resolution obtained from adding a fourth layer is marginal for primaries. The improvement is significant for secondaries since then the comparison is really between three point and four point tracking.

A calculation performed outside of GEANT which included a rough approximation of the effects of detector resolution and multiple coulomb scattering predicted that, for unconstrained tracking, the resolution for 300 MeV/c particles should go from 21 % for three layers to 12 % for four layers. However, the entries in the table for four hits include tracks in which the four hits occurred on only three layers due to the small overlap of active areas within a layer. The factor of two improvement in the resolution would only hold true for tracks that leave hits in all four layers, a subset of the total track sample. The hardware efficiency for obtaining four hits is only about 85 %, and the software efficiency for finding all four hits would also reduce the size of this subset. For the full set, summing over all momenta and hit configurations, we obtained an overall ($1/p_\perp$) resolution for secondaries of 26 % for three layers and 22 % for four layers.

Next we will consider the efficiency for matching SVT track segments to the corresponding track segments in the TPC. For three layers, the matching efficiency for main vertex tracking is 85 % and for unconstrained tracking it is 72 %. The differences between the two tracking modes can be attributed both to differences in SVT momentum resolution and differences in the SVT track sample, since the additional tracks found by unconstrained tracking are typically low momentum secondaries. Simulations of the four layer design did not produce statistically significant improvements in these efficiencies.

A preliminary exploration of the effect on impact parameter resolution was also performed. The impact parameter is defined as the closest approach of a track to the main vertex in the x-y (bending) plane. One use of the impact parameter information would be to distinguish secondary from primary tracks following unconstrained tracking. We compare the impact parameter distributions of primary kaons obtained with unconstrained tracking in the three and four layer configurations in Fig. 4. The top panel displays the distribution using a linear scale and the bottom panel uses a logarithmic scale. The tails of the distributions are very similar, although the shape of the peaks are different. The difference in the total number of tracks is due to the improved hardware efficiency in the four layer configuration. These plots included kaons of all momenta, so the tails are dominated by the effects of multiple coulomb scattering. It may be that high momentum kaons would have different impact parameter distribution tails for the two configurations.

3 Physics Impact

The SVT significantly enhances STAR's capability to reconstruct decays of strange mesons and baryons. It has already been demonstrated that a strangeness signal can be extracted from an ensemble of events with the present three layer SVT design[1]. The time periods needed to obtain significant samples of K°_s and Λ particles are small compared to the total running time of STAR, ie. one day of running at 1.0 Hz would result in a sample of more than 40 thousand reconstructed Λ baryons. Since a Λ is reconstructed only once per two central FRITIOF Au+Au events, it is not possible to say anything about the event to event variation in the Λ production with the three layer design. The relevant question for the four layer design would be whether or not it opens the possibility of doing event-by-event strangeness reconstruction.

We can obtain a rough answer to this question by considering the efficiencies for a Λ produced with $y = 0$ and a $p_\perp = \langle p_\perp \rangle = 0.77$ GeV/c. The Λ has a $c\tau$ of 7.89 cm, so 72 % decay before the first layer of the SVT. In the three layer design, the rest of the Λs are lost since their decay products are not able to leave three hits in the SVT. The addition of the fourth layer would allow the SVT to reconstruct Λs which decay between the first and second layers, an additional 15 % of the total sample. For three layers, the hardware efficiency gives a detection probability:

$$\begin{aligned} &\mathrm{P(decay\ before\ first\ layer)} \times [\mathrm{P(three\ hits\ from\ three\ layers)}]^2 \\ &\qquad = 0.72 \times (0.89)^2 = 0.57 \end{aligned}$$

For four layers we have to include the possibility that the Λ decays between the first and second layers:

$$\begin{aligned} &\mathrm{P(decay\ before\ first\ layer)} \times [\mathrm{P(three\ hits\ from\ four\ layers)}]^2 + \\ &[\mathrm{P(decay\ between\ first\ and\ second)}] \times [\mathrm{P(three\ hits\ from\ three\ layers)}]^2 \\ &\qquad = 0.72 \times (1.00)^2 + 0.15 \times (.89)^2 = 0.84 \end{aligned}$$

Thus, the improvement in the hardware efficiency allows the four layer design to reconstruct 0.84/0.57=1.5 times as many Λs as the three layer design. This would boost the number of Λs reconstructed per event from 0.5 to 0.8, which is still falls short of the range where event-by-event physics would be possible.

The addition of the SVT to STAR also allows the study of low transverse momentum particles which do not reach the TPC. The main physics observable here is the shape of the momentum spectra on an event by event basis at the lowest $p\perp$ obtainable. The addition of a fourth layer would aid in studying this kinematical region by improving the momentum resolution, but we have not investigated the degree of improvement in detail.

4 Conclusion

We have investigated the impact of an additional SVT layer on the SVT performance with GEANT simulations. We have quantified the improvements in the momentum resolution, the hardware efficiency, and the matching efficiency. The advantages of a four layer SVT for strange particle reconstruction are found to be modest. These observations should provide guidance when the SVT is weighing the merits of various upgrade proposals.

References

[1] "Measurements of Strangeness Production in the STAR Experiment at RHIC" W.K. Wilson for the STAR collaboration, Workshop on Physics with the Collider Detectors at RHIC and LHC, Proceedings of the Pre-Conference Workshop, Quark Matter 95, UCRL-ID-121571 (1995).

Layer	Number of ladders	Number of wafers	radius (cm)	azimuthal offset
1 A	4	4	6.10	0.0°
1 B	4	4	7.16	45.0°
2 A	6	6	10.16	0.0°
2 B	6	6	11.05	30.0°
3 A	8	7	13.97	0.0°
3 B	8	7	14.91	22.5°
4 A	11	8	20.60	0.0°
4 B	11	8	21.60	16.36°

Table 1: SVT four layer configuration. The number of wafers is the number on a ladder. Super layers are denoted by numbers 1-4, sub-layers are denoted by the letters A and B.

Track Type	Three layers Three Hits	Four layers Four Hits
Primaries ($p_\perp \geq 300$ MeV/c)	14.6	13.5
Primaries ($p_\perp \leq 300$ MeV/c)	15.6	15.0
Secondaries ($p_\perp \geq 300$ MeV/c)	24.4	18.1
Secondaries ($p_\perp \leq 300$ MeV/c)	25.4	19.0

Table 2: Percent resolution of $(1/p_\perp)$ for SVT pion tracks Note that the 4 hit case includes tracks which have 4 hits on three layers. See the text for further details

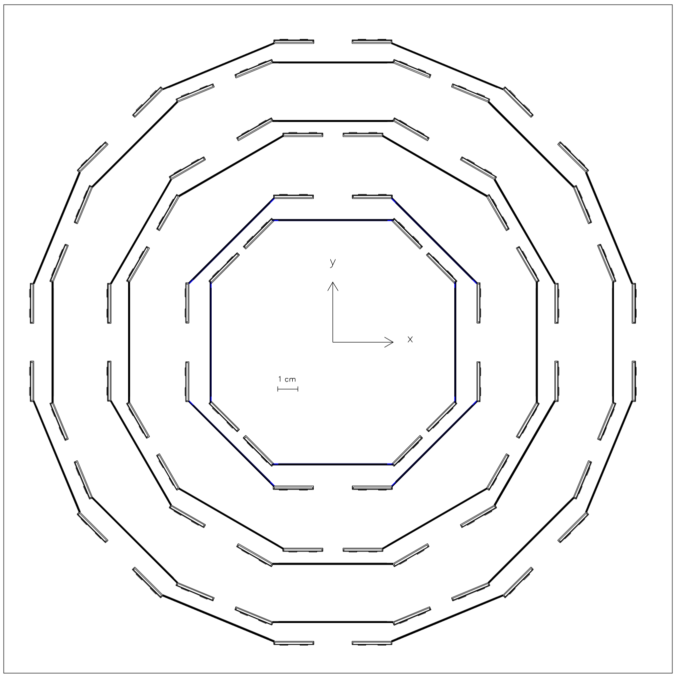

Figure 1: The three barrel structure of the baseline SVT.

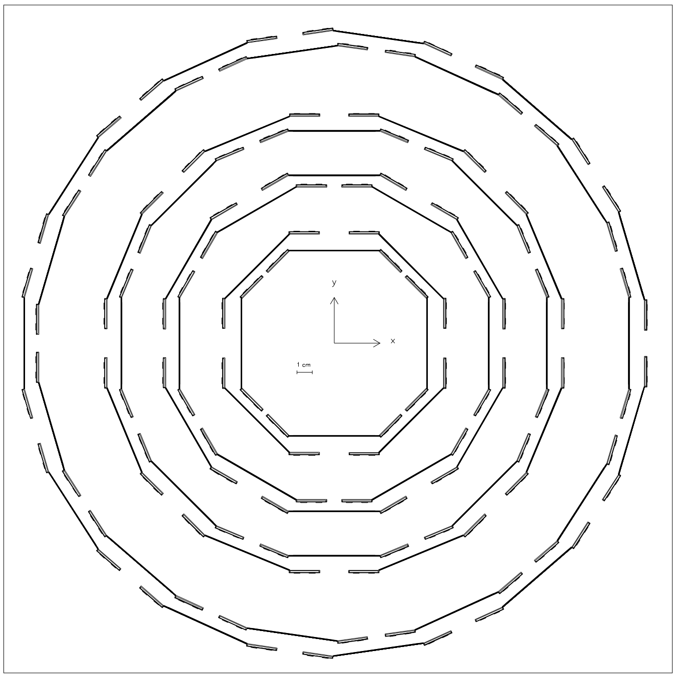

Figure 2: The four barrel structure studied in this note.

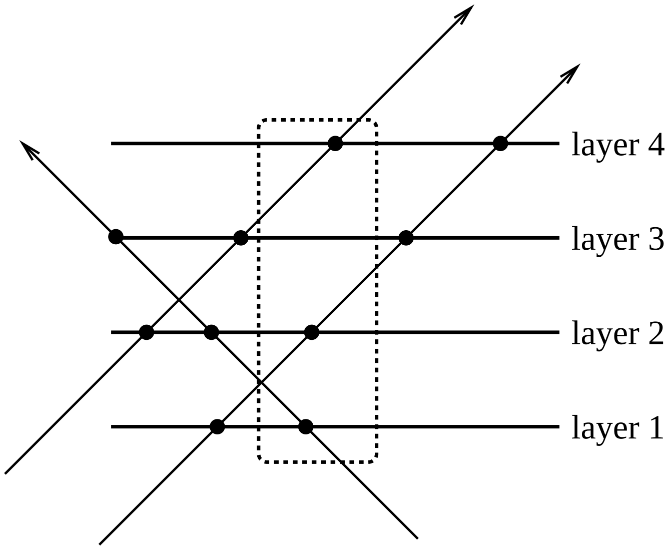

Figure 3: Ghost track production in a four layer geometry.

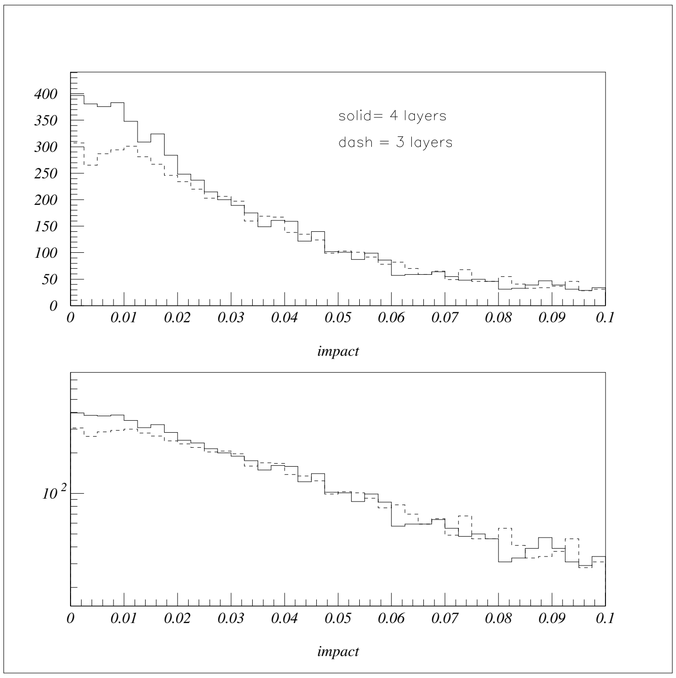

Figure 4: Impact parameter distributions for the SVT 3 and 4 layer configurations.