# STAR Note 162
# Momentum Resolution Studies in the SVT
# Part II

C. Pruneau, R. Bellwied, J. R. Hall, G. Roger,
V. Rykov and W. K. Wilson
Department of Physics and Astronomy
Wayne State University
Detroit MI 48201

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**Abstract**

The SVT detector in STAR can be used as a stand-alone tracker to extend the acceptance of the apparatus in the low $p_\perp$ region ($p_\perp < 300MeV/c$) and to improve the vectoring capabilities of the TPC tracking. In this note, we present simulations of the performance of the SVT as a stand-alone tracker under two different thickness conditions. The momentum resolution of the SVT is considered both in the Multiple Coulomb Scattering (MCS) limit and with finite detector resolution. As results have already been presented for secondary tracks in STAR Note 152, this note focuses on primary tracks only. The simulations show that the resolution is dominated by MCS effects in the bulk of the detector and beam pipe rather than the electronics. The $p_\perp$ resolution for primary pions and kaons ranges from 15 to 20% for the standard SVT configuration. Effects of the finite position resolution in the drift detector are found appreciable for position resolution larger than 50 microns. The resolution obtained with four space point fits is significantly better than the resolution reported in note 152 for three space point fits.

## 1 Introduction

This note examines the momentum resolution of the SVT as a stand-alone tracker. The SVT is expected to complement the TPC acceptance at low transverse momenta. The performance of the SVT in this regard depends on its momentum resolution, its vectoring capacity and on the track reconstruction efficiency. The momentum resolution for secondary tracks has been addressed in a previous note[1] where three space point fits to the tracks were considered. This note therefore focuses on momentum resolution for primary tracks only. Track reconstruction efficiency using the so-called "grouper" approach has been discussed in Star Note 153[2]. Notes on Track reconstruction using an alternative approach, particle pair momentum resolution and track impact parameter resolution, secondaries tracking efficiency and related quantities are in preparation[3, 4, 5].

In this note, at variance with what was done in Note 152, we include an estimate of the main vertex position as well as 3 SVT space points in the reconstruction of the momentum vector of the tracks. The inclusion of the primary vertex (or an estimate of it) results in a much better momentum resolution than a 3 space point fit as reported in Note 153. We emphasize that such a procedure, obviously adequate for primary tracks, may also be reasonable for a large fraction of the secondary tracks.

We briefly describe the fitting method in section 2. Section 3.1 compares resolution obtained with the standard SVT geometry relative to the so called No-Electronics version of the SVT where only the Si-wafers and a support structure are included in the GEANT simulation. Section 3.2 presents simulations including the finite position of the detectors. Section 4 discusses the impact of finite momentum resolution on the SVT's capacity to measure pion cross-section enhancement at low transverse momenta.

# 2 Method

Complete $Au + Au$ ($\sqrt{s} = 100 GeV/u$) Fritiof events were tracked with the STAR Geant package. For most of the results presented here, 20 different Fritiof events were used. All detector hits were stored in files from which the primary vertex position and the SVT hits were fetched and analyzed with a TAS based analysis program.

The SVT hits were extracted from the GEANT Zebra files using the standard mct package. The data points thus read were treated in two different ways. In one, only Multiple Coulomb Scattering (MCS) was included and the SVT space points were transferred to the svt_spt table without alteration (see star note#145 for more details on how this is done). The second approach includes in-plane Gaussian smearing of the space points and uses the SRS package[6].

Only primary tracks are considered here. Helix fits are done with the STK package and include an estimated primary vertex location obtained by Gaussian smearing of the actual vertex location.

As this note focuses on the resolution of the SVT as a stand-alone tracker, we consider the optimal case in which all tracks are reconstructed perfectly (ideal tracking). The SVT track fitting package (STK) assumes the magnetic field is uniform along the beam axis and has negligible (if any) transverse components. It does not correct for particle energy losses in the different media on the track's radius of curvature. The charged particles trajectories are treated as perfect helixes parameterized with the following expressions:

$$
\begin{aligned}
x(s) &= x_0 + R_H[\cos(\Phi_0 + \frac{hs\cos\lambda}{R_H}) - \cos\Phi_0] && (1)\\
y(s) &= y_0 + R_H[\sin(\Phi_0 + \frac{hs\cos\lambda}{R_H}) - \sin\Phi_0] && (2)\\
z(s) &= z_0 + s\sin\lambda && (3)
\end{aligned}
$$

These are easily decoupled into "independent" circular motion in the transverse plane and linear motion in the s vs z plane. The circular motion fit is done first using a conformal mapping technique and produces the coordinates $(x_H, y_H)$ of the center of the circular orbit and its radius, $r_H$. The linear motion fit is based on the expression

$$z(s) = a + b\Phi \tag{4}$$

where $\Phi$ is a phase obtained from the knowledge of the circle parameters

$$\Phi = arctan(\frac{y(s) - y_H}{x(s) - x_H}) \tag{5}$$

# 3 Resolution Studies

## 3.1 MCS Effects

We first investigate the effect of Multiple Coulomb Scattering on the momentum resolution and compare estimates of the tracking resolution for the standard SVT geometry and electronics with a thinner version which does not include any electronics nor its carrier. The drift detectors are assumed to have perfect (0 micron) position resolution.

The results presented below include resolution figures for pions and kaons separately although no apriori knowledge of the track particle identity is actually required or used in the helix fit. We consider the resolution in transverse momentum $p_\perp$, total momentum $p_{tot}$ and direction using the polar and azimuthal angles $\theta$ and $\phi$. Figure 1 shows scatter plots of the reconstructed (fitted) $p_\perp$, $p_{tot}$, $\theta$ and $\phi$ as a function of the initial values (inputs to GEANT) for the standard SVT configuration. The standard configuration includes the 300 micron thick Si wafers, Be supports, electronic carriers, a realistic representation of the electronic chips, water channels (cooling system) and 1 cm thick Si end cap used as a simplified representation of the end caps support structure.

These results are contrasted in Figure 2 and 3 with those of a lean, somewhat unrealistic, SVT where the electronics and its associated carrier have been removed from the GEANT simulation. Fig. 2 presents results for primary pions whereas Fig. 3 shows similar results for kaons. We plot the estimated resolution for $p_\perp$, $p_{tot}$, $\theta$ and $\phi$ as a function of the particles transverse momenta. Relative errors are plotted for

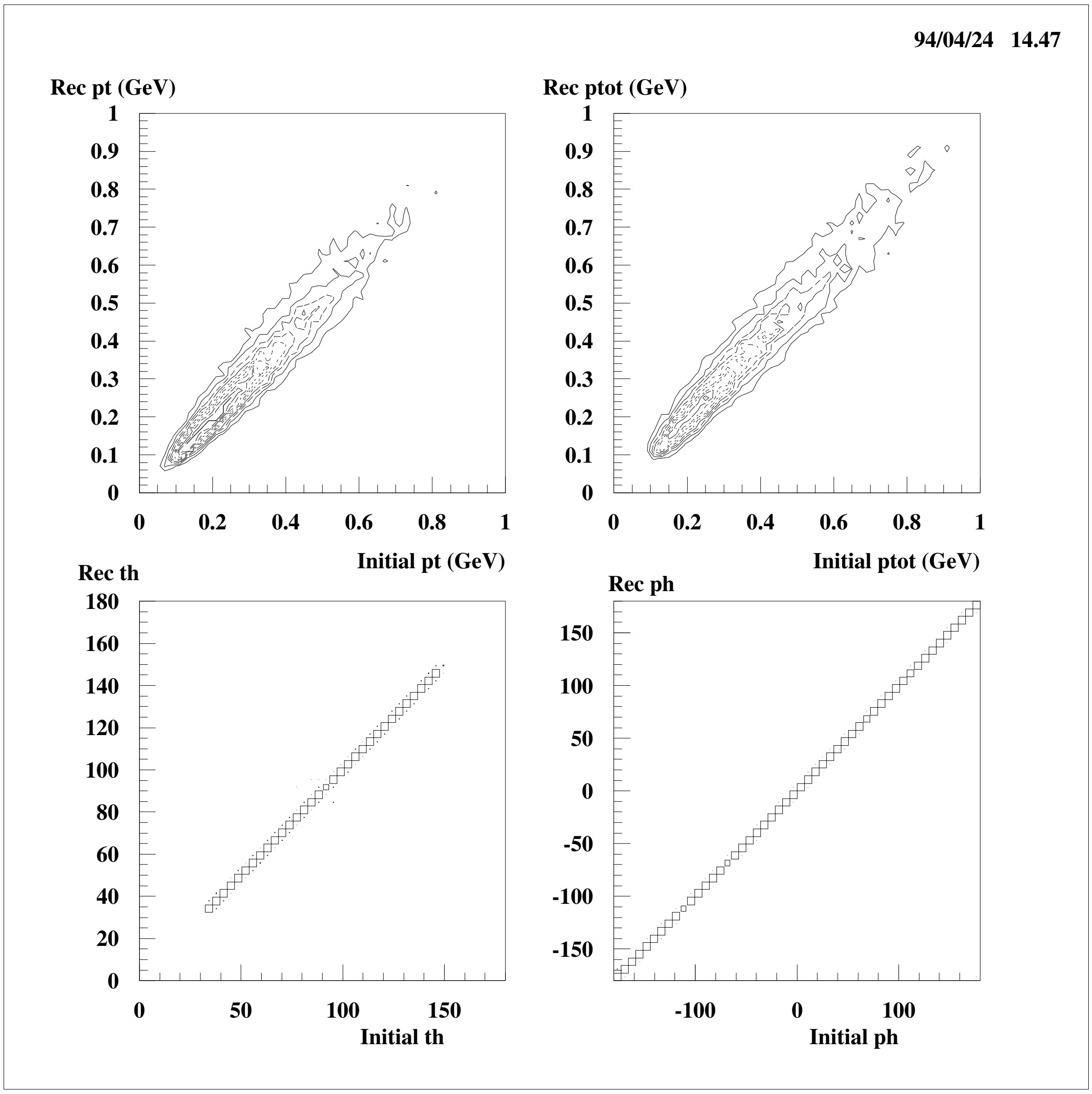


Figure 1: Standard SVT Geometry. Reconstructed track parameters vs Initial values: a) Transverse Momentum (GeV/c), b) Total Momentum (GeV/c), c) Polar (°) and d) Azimuthal Angles(°).

$p_\perp$ and $p_{tot}$:

$$\delta p_\perp = \frac{p_\perp^{rec} - p_\perp^{initial}}{p_\perp^{initial}} \tag{6}$$

whereas absolute errors (in degrees) are used for the angles. A similar analysis for protons yields results comparable to the kaon's.

The above results correspond to standard deviations (Gaussian widths) obtained with Gaussian fits in $p_\perp$ slices of 50 MeV/c and 100 MeV/c for pions and kaons respectively. The $\delta p_\perp$ distributions, generally fairly Gaussian, have low-side tails only for the lowest transverse momenta. The standard deviations plotted in Figure 2 and 3 therefore constitute a reasonable estimate of the expected resolution. No data is shown below 50 MeV/c as pions range out in the first layer at about 40 MeV/c and few particles below 50 MeV/c are obtained even with 20 Au+Au events. The transverse and total momentum resolution is of the order of 20% at 50 MeV/c and improves to 14% or so above 200 MeV/c. As expected the angular resolution is worst at the lowest momenta also. The polar angle resolution (from $tan\lambda$) is of the order of 0.4 degrees at 50 MeV/c and quickly improves to values smaller than a tenth of a degree above 200 MeV/c. The resolution in azimuthal angle determination ($\phi$) is slightly worse as one would expect from the strong correlation (in the fitting of the data) between the azimuthal angle and the (inverse) transverse momentum. The $\phi$ resolution is of the order of one degree at 50 MeV/c and decreases rapidly to less than 0.2 degrees for transverse momenta above 200 MeV/c.

The momentum resolution for kaons appears poor at first sight for momenta below 300 MeV/c. One should bear in mind however that kaons with their larger mass (relative to the pion) loose more energy in the three layers of the SVT and are also more susceptible to straggling effects. As we did not correct for energy losses in the detector, the momentum resolution reported here for kaons is bound to be worse that that for pions.

The data indicate that both the momentum and angular resolutions are dominated by Multiple Coulomb Scattering in the beam pipe and the bulk of the Si-drift detectors rather than the accompanying electronics. The incremental broadening of the distributions due to the electronics and its carrier accounts for only 30% of the total estimated errors. Although it is obviously desirable to reduce such a contribution, we feel that the presence of the electronics should not appreciably degrade the performance of the SVT as a stand-alone tracker.

## 3.2 Effects of Finite Detector Position Resolution

Next we examine the impact of finite drift detector position resolution on the reconstruction of the track kinematics. The same four parameters are plotted in figure 4 for the reconstruction of pion tracks assuming the position resolution of the drift detector is $0\mu m$ ($\square$), $20\mu m$ ($\triangle$), $50\mu m$ ($\diamond$) and $100\mu m$ ($+$).

Clearly, for position resolutions better than 50 microns, broadening of the $\delta p_\perp$ and $\delta p_{tot}$ distributions is non negligible only above 800 MeV/c and signals the fact that MCS effects are indeed quite large at the lowest momenta. However, it is also quite clear that even with a position resolution as good as 50 microns, the momentum resolution deteriorates quite rapidly above 800 MeV/c. With 100 microns position resolution, considerable broadening is seen for $p_\perp$ as low as 400 MeV/c. Even though such a deficiency would be well compensated by the excellent momentum resolution and tracking efficiency of the TPC in this momentum range, such a broadening is likely to limit the momentum resolution of the combined TPC and SVT trackers at very high momenta. The polar angular resolution seems rather insensitive to the finite position resolution of the SDD (within the resolution range so far considered). At 1 GeV/c, the 100 microns smearing results in a 30% increase only of the polar angle standard deviation. The effect of the finite position resolution is much more dramatic on the azimuthal angle as can be seen in figure 4 d). At 1 GeV/c, the standard deviation increases by nearly a factor of 10 for the 100 microns position resolution. Although a much less dramatic deterioration is calculated for 50 microns, the azimuthal angle accuracy is decreased by nearly a factor of two and would certainly impact also the tracking resolution achievable by combining the TPC and SVT space points.

# 4 Impact of the finite momentum resolution on the study of low-$p_\perp$ enhancement.

In this section, we consider the impact of the momentum resolution derived in the previous section on our ability to determine the presence or absence of a low-$p_\perp$ enhancement at RHIC in Au+Au collisions.

The magnitude and the origin of the enhancement is model dependent and should not concern us at this stage. To investigate the performance of the SVT in this regard, we therefore select arbitrarly the model reported by Bellwied and Welke[7]. We consider two pion spectra with a Bose-Einstein distribution.

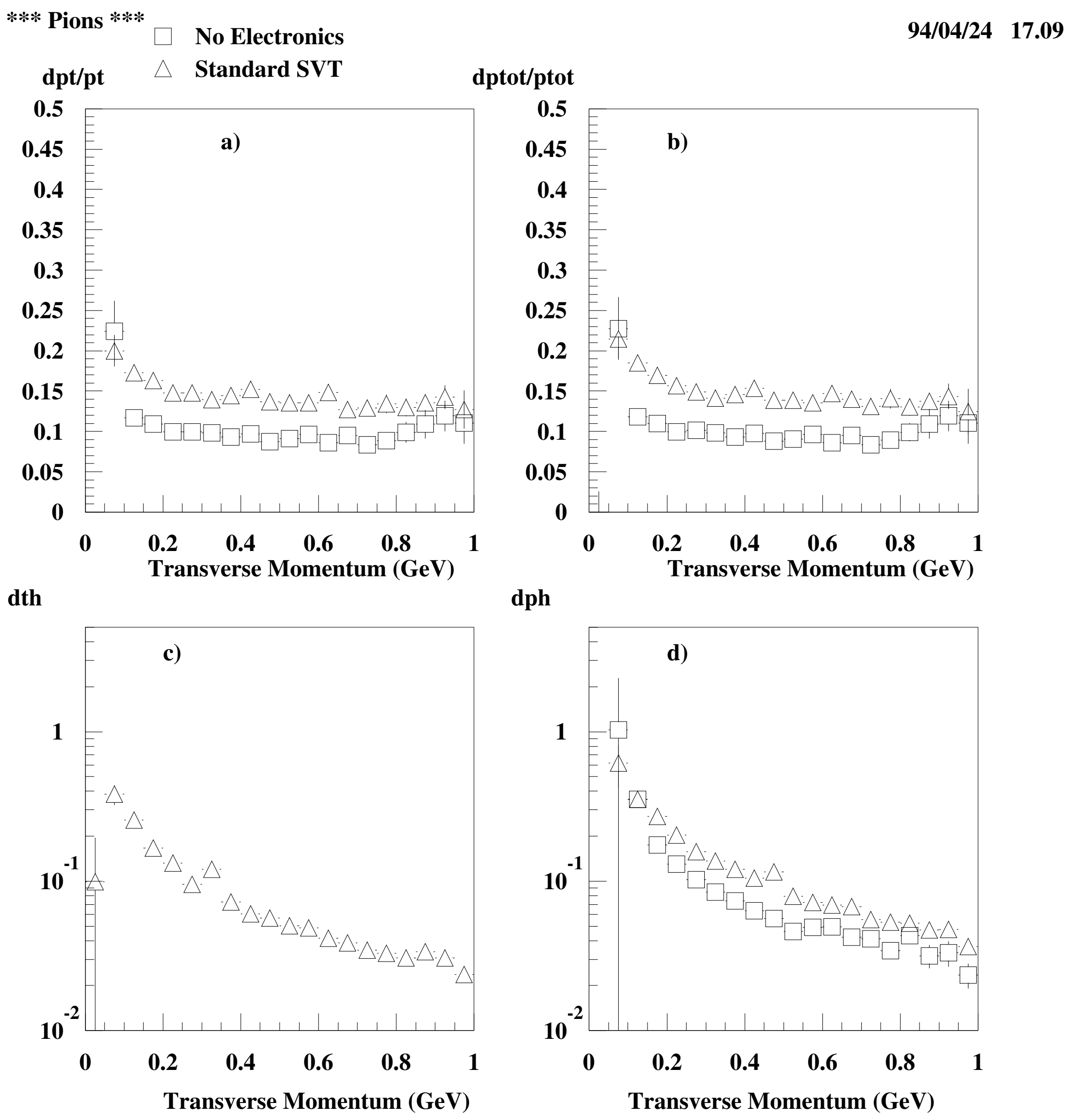


Figure 2: Track Reconstruction Resolution for Pions. Standard SVT Geometry vs No Electronics Configuration. a) Transverse Momentum (GeV/c), b) Total Momentum (GeV/c), c) Polar (°) and d) Azimuthal Angles(°).

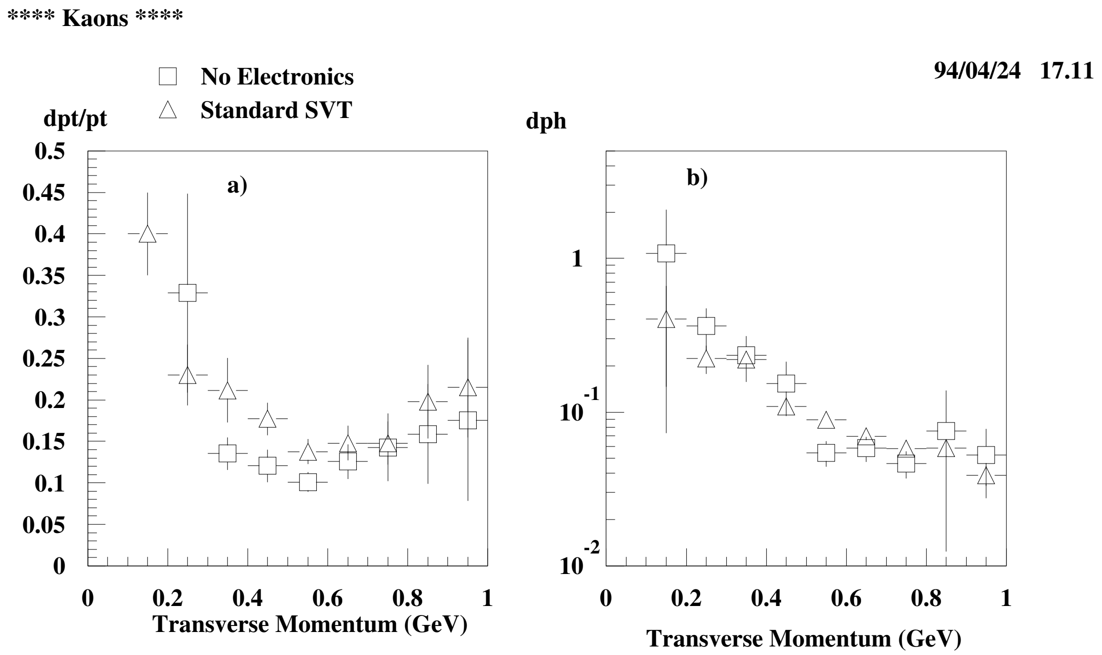


Figure 3: Track Reconstruction Resolution for kaons. Standard SVT Geometry vs No Electronics Configuration. a) Transverse Momentum (GeV/c), and b ) Azimuthal Angles (°) .

$$dN/dp \quad = \quad 4\pi g \frac{V}{h^3} \frac{p^2}{e^{\beta(\epsilon-\mu)} - 1} \tag{7}$$

where

$$\begin{aligned}
\epsilon &= \sqrt{p^2 + m^2} \\
m &= \mathrm{mass} = 139 MeV/c \\
p &= \mathrm{momentum} \\
\beta &= 1/\tau \\
\tau &= \mathrm{temperature} = 150 MeV \\
V &= \mathrm{freeze-out\ volume} \\
g &= \mathrm{spin\ degeneracy} \\
\mu &= \mathrm{chemical\ potential}
\end{aligned}$$

Following reference [7], we use $\mu = 10MeV$ and $\mu = 138MeV$ to calculate the two “typical” distributions plotted in Fig. 5a) with arbitrary units. We use these two distributions as a basis for two random number generators to calculate mo-

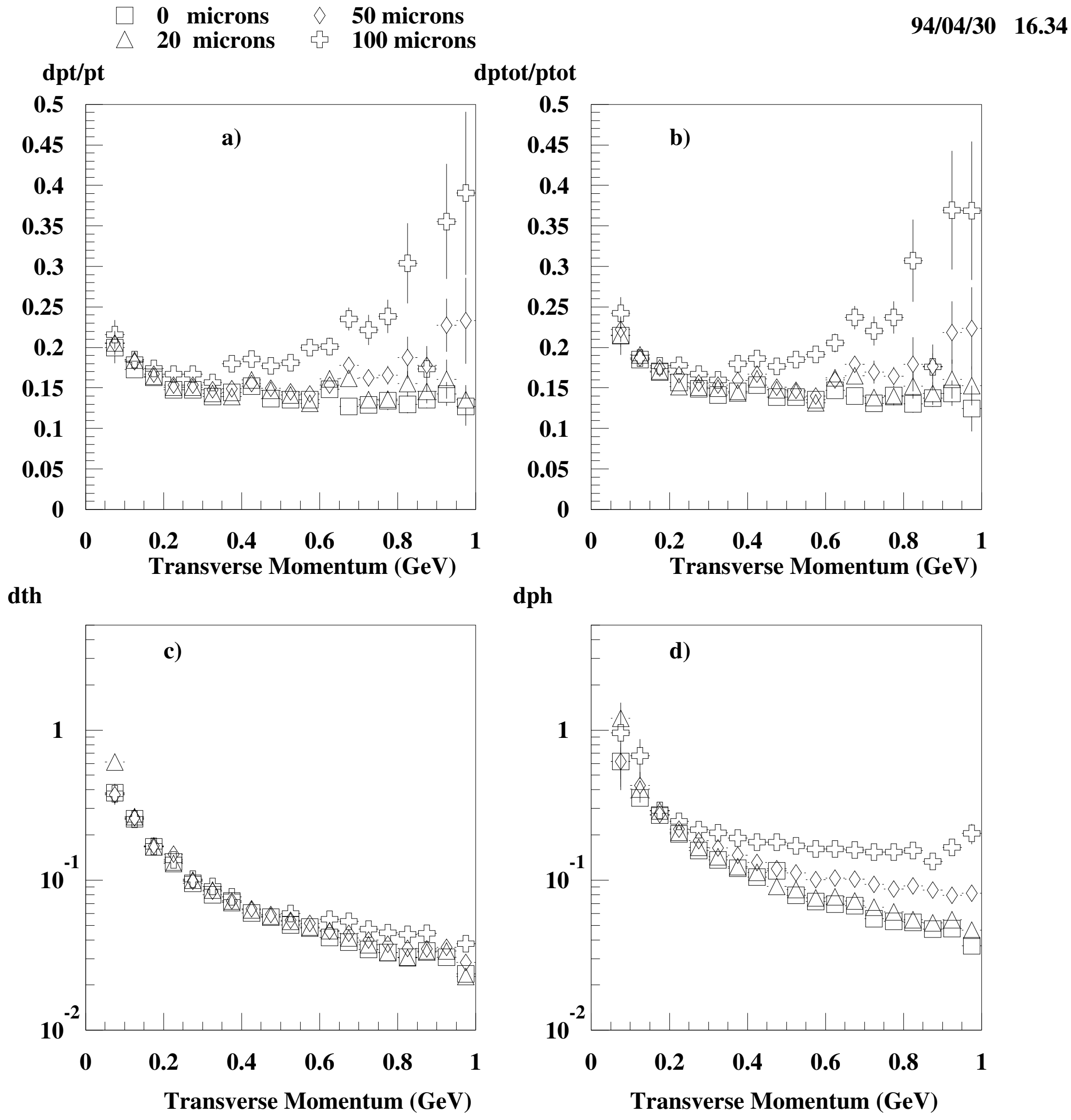


Figure 4: Effect of the drift detector finite position resolution on pion track reconstruction resolution. a) Transverse Momentum (GeV/c), b) Total Momentum (GeV/c), c) Polar (°) and d) Azimuthal Angles (°).

mentum spectra. For simplicity, we smear the momenta with a Gaussian random number generator using, as a worst case scenario, a unique value of standard deviation $\delta p/p = 20\%$ for all values of momenta. The spectra displayed in Fig. 5a) ($\Box : \mu = 138 MeV$, $\triangle : \mu = 10 MeV$) were generated with 200 events of 1000 pions each. A 50 MeV/c detector cut off has been applied on the data. Clearly, the shape and position of the maxima is not disturbed significantly by the finite momentum resolution and one can easily recognize the difference between the two spectra. The "normal" B-E distribution peaks at about 250 MeV/c whereas the low-$p_\perp$ enhanced distribution peaks right above the SVT threshold. With the TPC alone however, the tracking threshold is likely to be of the order of 200 MeV/c or higher and it could be difficult to disentangle the presence/absence of an enhancement from effects resulting from a finite tracking efficiency in that momentum range.

The large pion multiplicity expected in central Au+Au offers the interesting possibility of selecting or studying events on the basis of the strength of the low-$p_\perp$ enhancement. Fig.5c) obtained with the same distributions for 1 event (1000 pions) and plotted with a coarse binning suggests it might be feasible to distinguish the two extremes considered above on an event-by-event basis. To examine this possibility in more detail, we plot, for 200 events, in Fig.5d) and e) the means and widths of the two distributions calculated on an event-by-event basis. The standard deviation calculated event-by-event do not show any significant or useful differences and therefore do not constitute good selection observables. The event-by-event means, however, are 395 and 460 MeV/c for the low-$p_\perp$ enhanced and "normal" distributions respectively and are clearly separated making it easy to distinguish between the two types of distributions. The momentum distribution mean could therefore be used to classify or even possibly trigger (third level) on events with various levels of low-$p_\perp$ enhancement.

To emphasize the importance of a low energy threshold, we show in Fig.6 calculations of the mean and sigma of the same two distributions for thresholds of 50, 150 and 250 MeV/c. The standard deviations of the two distributions are more or less indistinguishable and are therefore not an interesting indicator of the low-$p_\perp$ enhancement. The clear mean difference seen with a low threshold is completely lost as the detector threshold approaches the peak of the B-E "normal" distribution. The mean consequently appears as a valid selection criteria only if the tracking threshold is well below the peak of the "normal" B-E distribution.

The selection of events on the basis of the $p_\perp$ distribution mean as suggested above presupposes that the temperature (or slope) is a fixed quantity. In practice, it may also vary significantly event-by-event and the use of the momentum distribution mean as a selection criteria may become somewhat ambiguous. To alleviate this ambiguity, one could possibly calculate two values of mean: one obtained with a low threshold to include the low $p_\perp$ effects and another with a larger threshold to estimate the slope of the spectra. Such a two parameter based selection criteria is likely to be more successful with a low 1st threshold well below the peak of the normal distribution and reaffirms the crucial role to be played by the SVT in the study of low $p_\perp$ physics.

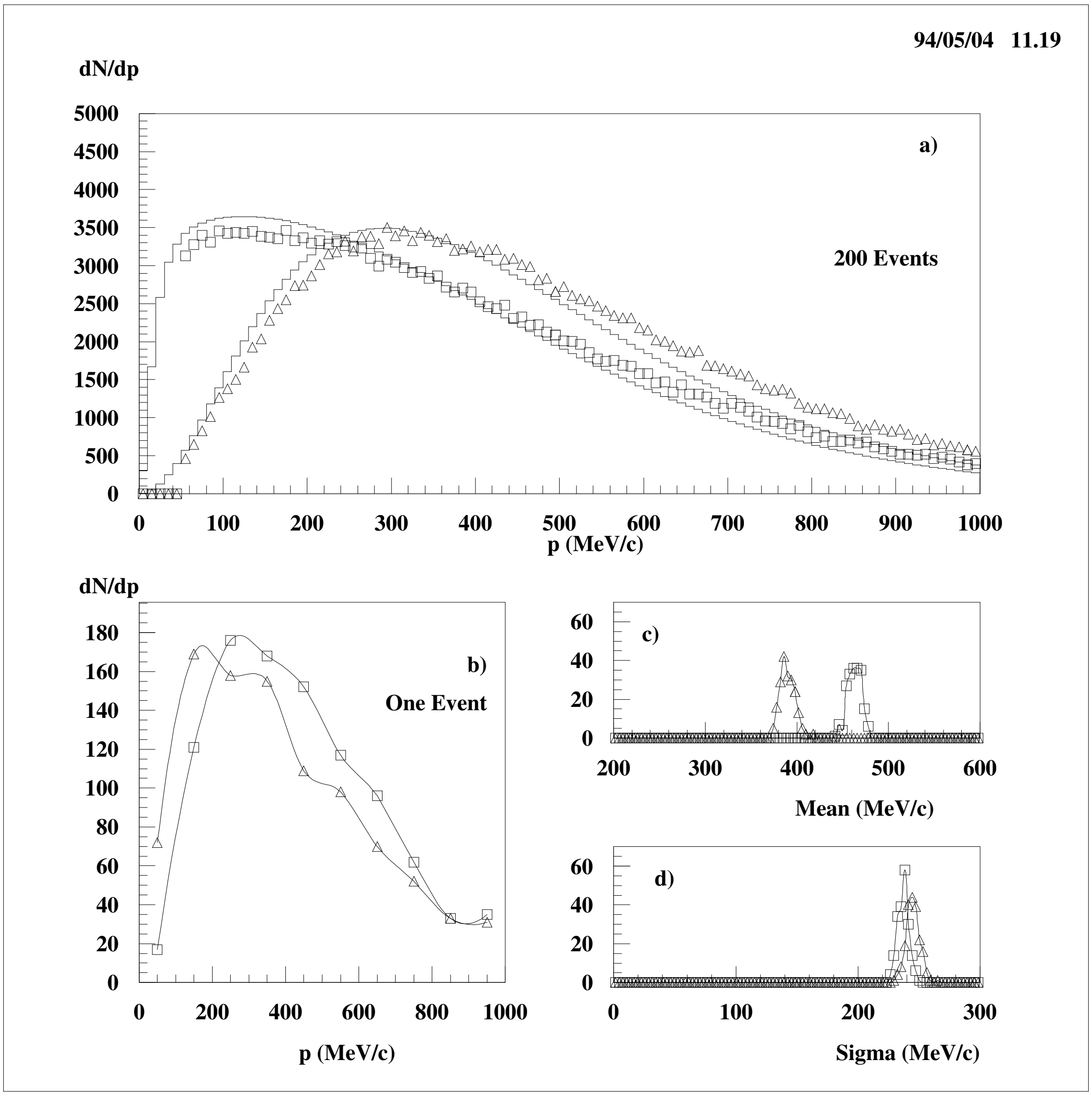


Figure 5: Measure-ability of the low-$p_\perp$ enhancement with finite momentum resolution (20%) in the SVT. a) Bose-Einstein distributions with $\mu = 10MeV$ and $\mu = 138MeV$ (solid lines) and Reconstructed distributions assuming a momentum resolution of $\delta p/p = 20\%$. ($\Box$) $\mu = 138MeV$, ($\triangle$) $\mu = 10MeV$ , b) Same distributions for one event (1000 pions), c) Distributions Mean calculated on an event by event basis for 200 events and d) Distributions Standard Deviation (sigma) as in c).

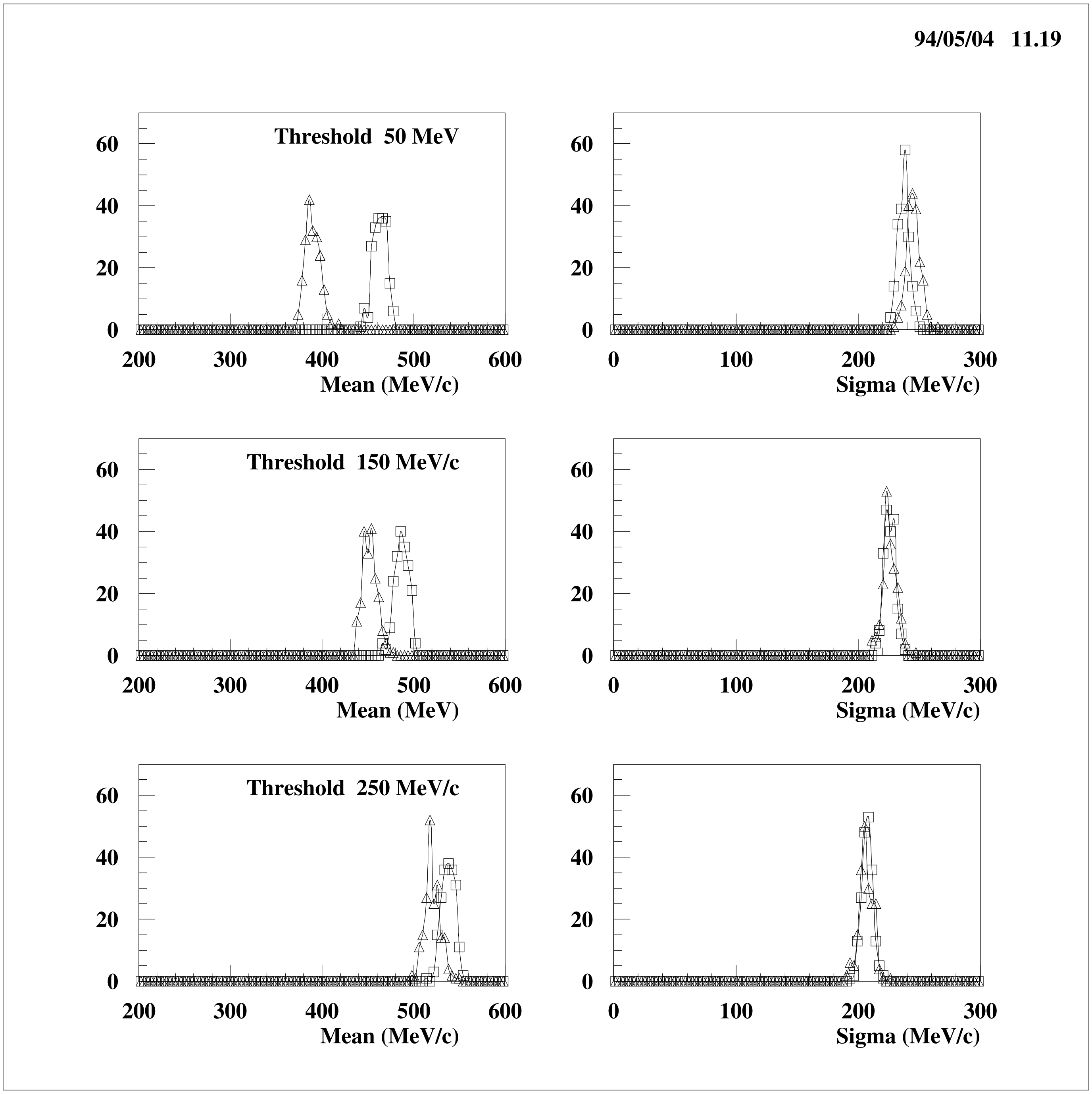


Figure 6: Bose-Einstein Distribution mean and sigma calculated for three detector thresholds 50, 150 and 250 MeV/c. Triangles - $\mu = 138 MeV$, Squares - $\mu = 10 MeV$. The distributions are calculated on an event-by-event basis assuming a multiplicity of 1000 pions per event.

# 5 Conclusion

We have completed momentum and angular resolution studies for the SVT as a stand-alone tracker using 20 Au+Au events analyzed with the SRS and STK packages. This note focuses on primary particles only and compares the estimated performance of the standard SVT geometry with that of a reduced, thin, unrealistic SVT. The estimated incremental broadening of the resolution amounts to 30% for the standard SVT relative to the reduced SVT. As such a thin SVT is unlikely to be achievable given the technological limits and the huge number of electronics channels (preamps, shapers, cables, etc) involved, the resolution of the standard SVT operated as a stand-alone tracker is considered to be acceptable although not ideal. Additionally, calculations of the effect of finite position resolution of the drift detector indicate that all efforts should be made to achieve position resolution better than 50 microns as significant deterioration of the tracking resolution performance is expected beyond 50 microns. We also emphasize that the momentum resolution achievable with four space point fits, i.e. including the main vertex in the fit rather than using three SVT space points only, significantly improves the momentum resolution, Finally, simulations discussed in section 4 show that the 20% momentum resolution foreseen for the lowest transverse momenta does not impair the crucial determination of the presence or absence of a low $p_\perp$ pion enhancement. In fact, with the foreseen pion multiplicity, our simulation indicates it might be feasible to study the presence or absence of a low-$p_\perp$ enhancement on an event-by-event basis.

# References

[1] Margetis et al, STAR Note 152, "Momentum Resolution Studies in the SVT, Part 1

[2] D. Prindle, STAR Note 153, "SVT Event Reconstruction Algorithms.

[3] Pruneau etal, SVT Tracking Efficiency, in preparation.

[4] Wilson etal, Track Impact Parameter Resolution and Secondary Reconstruction Efficiency with the SVT, in preparation.

[5] Pandai etal, SVT Resolution and Acceptance in HBT studies, in preparation.

[6] W.K.Wilson, SVT Resolution Simulator, see documentation under STAR/WWW.

[7] R. Bellwied and G. Welke, "Condensation effects in the pion spectrum at RHIC", STAR Note 108, June 1993.