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Studies on a Silicon Intermediate Tracker for the TESLA Detector

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Abstract

The performance of a TESLA detector can be increased by a Silicon Intermediate Tracker (SIT) between the high resolution vertex detector and the TPC. This note gives an overview of the effect of a SIT on pattern recognition, momentum resolution and reconstruction of secondary vertices. The optimal solution is shown to be a SIT constisting of two layers of silicon strip detector at radii of 16 cm and 30 cm and 10 μm resolution.

1 Introduction

The TESLA detector, depicted in fig. 1 is designed for redundant pattern recognition to be able to handle high multiplicity events produced at energies of 800 GeV, good quark flavour identification for example for efficient b-tagging to select Higgs candidates, and very high momentum resolution, which allows the mass of a muon pair from Z-decay to be measured with a width dominated by the Z-width.

However, the high granularity of the TPC cannot be exploited completely, because due to the longitudinal spread of electron clouds drifting through the TPC volume and the segmentation of the cathode plane double hits cannot be resolved down to the spatial resolution of the TPC. The loss of information at small radii, where the density of tracks is higher than at larger distances from the beampipe, can be compensated to some amount by a SIT inside the TPC.

The required momentum resolution of $\sigma(p_T)/p_T^2 = 0.6 \cdot 10^{-4}\,\mathrm{GeV}^{-1}$ in the central region ($|\cos\theta| < 0.7$) cannot be reached with the combination of vertex detector and TPC alone, assuming a detector magnetic field of $B = 3\,\mathrm{T}$. A SIT at large radius $R = 30\,\mathrm{cm}$ with high azimuthal resolution $\sigma_{r\varphi}$ is necessary.

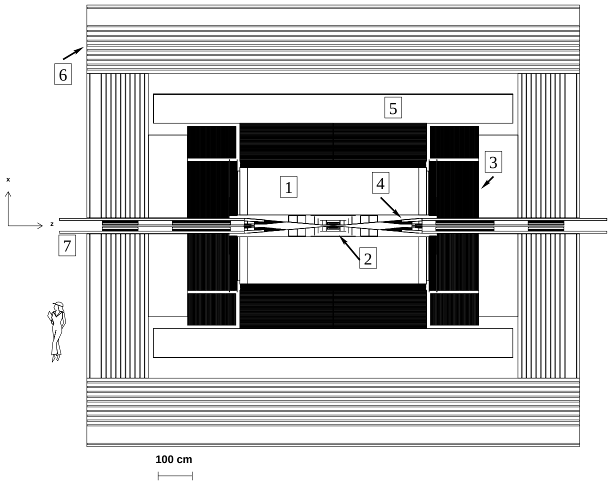

Figure 1: Cut of the TESLA detector. $\boxed{1}$ TPC $\boxed{2}$ Silicon detectors VTX, FTD and SIT, $\boxed{3}$ ECAL+HCAL, $\boxed{4}$ Mask, $\boxed{5}$ Coil, $\boxed{6}$ Instrumented return yoke, $\boxed{7}$ Beampipe.

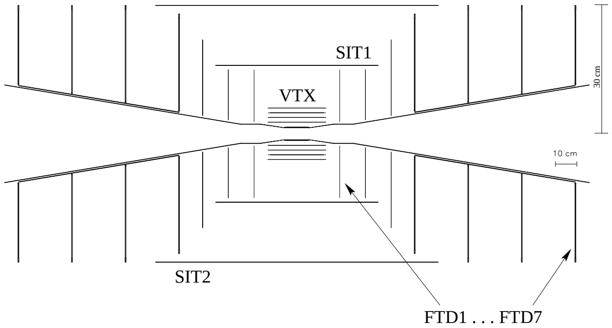

Figure 2: Cut of the silicon detectors.

Finally the two SIT layers improve the reconstruction of long lived particles decaying outside the vertex detector, but inside the TPC.

Fig. 2 shows the SIT together with the other silicon detectors. The dimensions of the SIT are limited by the outer radii of the first FTDs and the inner radius of the TPC. The pattern recognition profits most from a SIT layer at $R \approx 16\,\mathrm{cm}$ in contrast to the momentum resolution, which makes a SIT radius as large as possible desirable.

Some simplifications are made in the simulation used for this study. The detector is modeled in Brahms 1.03 based on Geant 3 [1], which in principle allows for detailed analysis. At present the concept of the TPC readout system is not complete, so that the simulation of the double hit resolution of the TPC is simpified in the sense that hits inside the TPC, which don't differ from each other by more than 14 mm and 3.3 mm [2] [3] [4] in longitudinal and azimuthal directions, are excluded from the reconstruction. A second inaccuracy concerns the SIT readout, which is implemented as a pixel device here, although general agreement is that it would be built as a strip detector.

2 Track merging

As mentioned above, the double hit resolution has to be considered for track merging studies. Extrapolating track segments from the TPC with missing hits leads to larger extrapolation errors. The process $e^+e^- \to d\bar{d} \to X$ (generated at $\sqrt{s} = 500\,\mathrm{GeV}$) is quite a difficult case for pattern recognition because of the large boost of the fragmentated d-quarks. About 9% of the tracks cannot be completely resolved, as derived from fig. 3.

In order to study the effect of additional detector components between vertex detector and TPC on the pattern recognition, a reconstruction efficiency must be defined. It is given by

$$\varepsilon = \frac{N_{corr}}{N_{tot}},$$

where N_{tot} is the number of tracks with at least one hit on the fifth vertex detector layer (VXL5) and N_{corr} is the amount of tracks which are extrapolated from the TPC via the SIT layer(s) onto VXL5 correctly, which means, that on each extrapolation surface the hit belonging to the extrapolated track is closer to the extrapolation than any other hit.

The efficiency plotted in fig. 4 is maximal for a SIT radius of about 16 cm. A larger radius increases the efficiency of the extrapolation from the TPC onto the SIT, whereas the extrapolation from the SIT onto VXL5 is easier for smaller radii. The effect of the limited double hit resolution is strengthened with decreasing SIT radius. Fig. 5 shows that the reconstruction efficiency is nearly independant from the point resolution of the SIT, as far as it is small compared to the TPC resolution.

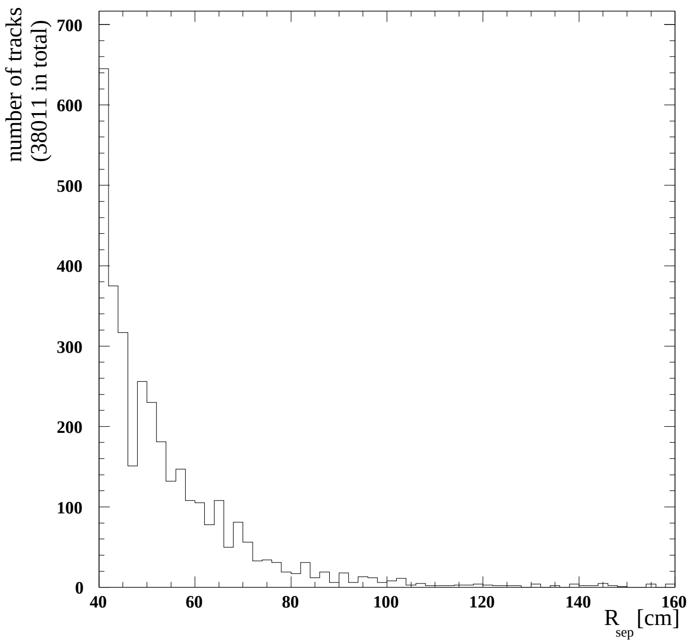

Figure 3: Radius of the innermost, resolved hit in the TPC ($d\bar{d}$ at $\sqrt{s} = 500\,\mathrm{GeV}$)

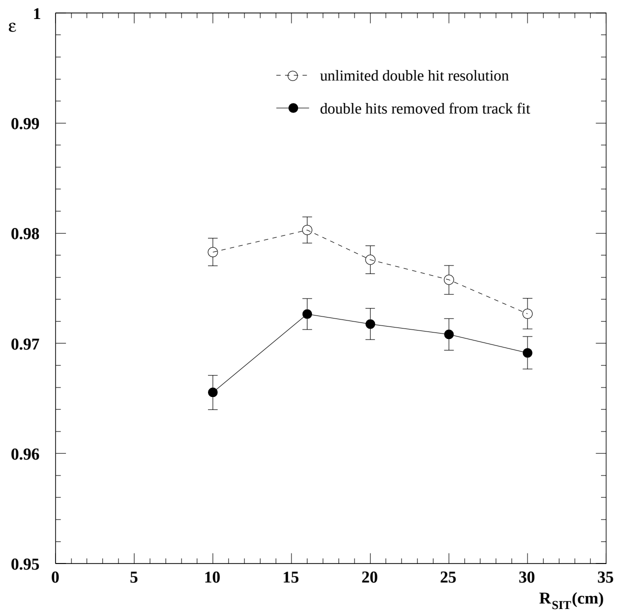

Figure 4: Efficiency of assigning the correct hits on VXL5 to track segments in the TPC versus the radius of a single layer SIT ($10\,\mu$m resolution).

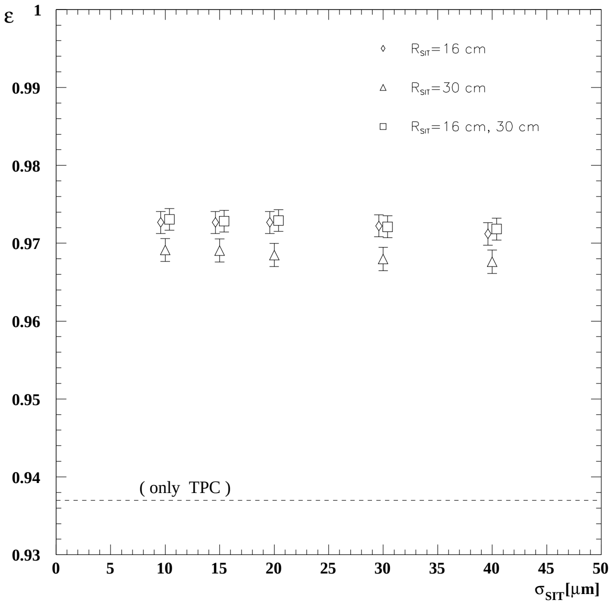

Figure 5: Efficiency (cp. fig. 4) versus the SIT point resolution.

3 Momentum resolution

Two terms contribute to the momentum resolution of a detector

$$\left(\frac{\sigma_{p_t}}{p_t}\right) = \sqrt{\left(\frac{\sigma_{p_t}}{p_t}\right)_{ms}^2 + \left(\left(\frac{\sigma_{p_T}}{p_T^2}\right)_{geom} \cdot p_T\right)^2},$$

a constant term due to multiple scattering and one proportional to the transverse momentum, which is defined by the detector geometry. Only the asymptotic contribution $\left(\frac{\sigma_{p_T}}{p_T^2}\right)_{geom}$ is examined in the following.

The excellent momentum resolution of $\sigma(p_T)/p_T^2 = 0.7 \cdot 10^{-4}\,\mathrm{GeV}^{-1}$ is necessary for example for the model independant selection of higgs candidates in the channel $e^+e^- \to HZ$ with $Z \to l^+l^-$ [5]. From this process the higgs mass can be calculated as the recoil mass

$$M_{rec} = (s - 2\sqrt{s}E_Z + M_Z^2)^{\frac{1}{2}}.$$

Efficient background reduction requires a mass resolution of the l^+l^- pair, which is significantly better than the width of the Z boson. Fig. 6 shows the error of the reconstructed Z mass as a function of the momentum resolution $\sigma(p_T)/p_T^2$ simulated with Simdet.

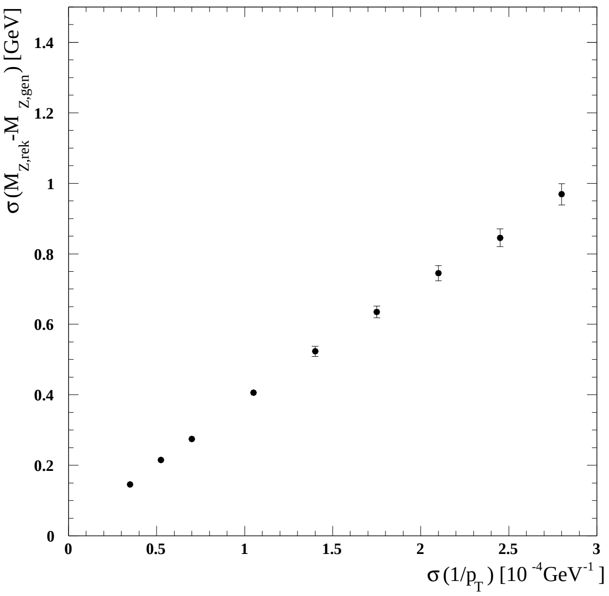

Figure 6: Width of the error on the reconstructed Z mass in the Higgsstrahlung process as a function of the momentum resolution.

Fig. 7 compares the reconstructed Z peak for two different resolutions. The detector effect on the measured width $\Gamma = 1.07\,\Gamma_Z$ $(1.75\,\Gamma_Z)$ for a momentum resolution of $\sigma(p_T)/p_T^2 = 0.7(2.8) \cdot 10^{-4}\,\mathrm{GeV}^{-1}$ can be decreased to less than 10% at the high resolution.

At a magnetic field of $B = 3\,\mathrm{T}$ this resolution cannot be achieved without additional detector components between vertex detector and TPC. As plotted in fig. 8, the largest improvement comes from a SIT layer just inside the TPC. A SIT with two layers at $R = 16\,\mathrm{cm}$ and $30\,\mathrm{cm}$ make a momentum resolution $\sigma(p_T)/p_T^2 = 0.63 \cdot 10^{-4}\,\mathrm{GeV}^{-1}$ possible, if the point resolution can be as accurate as $\sigma = 10\,\mu\mathrm{m}$. If the detector works in a magnetic field of $4\,\mathrm{T}$ the momentum resolution is scaled by a factor $3/4$ to $\sigma(p_T)/p_T^2 = 0.48 \cdot 10^{-4}\,\mathrm{GeV}^{-1}$.

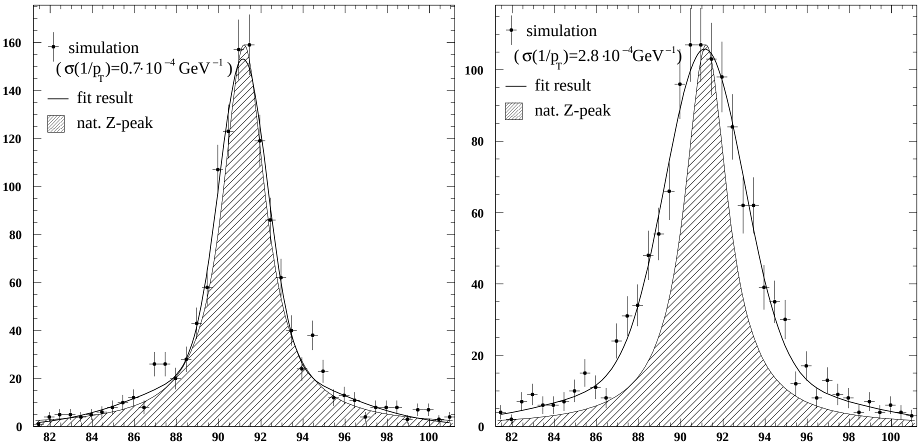

Figure 7: Reconstructed Z peak for a momentum resolution of $\sigma(p_T)/p_T^2 = 0.7 \cdot 10^{-4}\,\mathrm{GeV}^{-1}$ and $2.8 \cdot 10^{-4}\,\mathrm{GeV}^{-1}$.

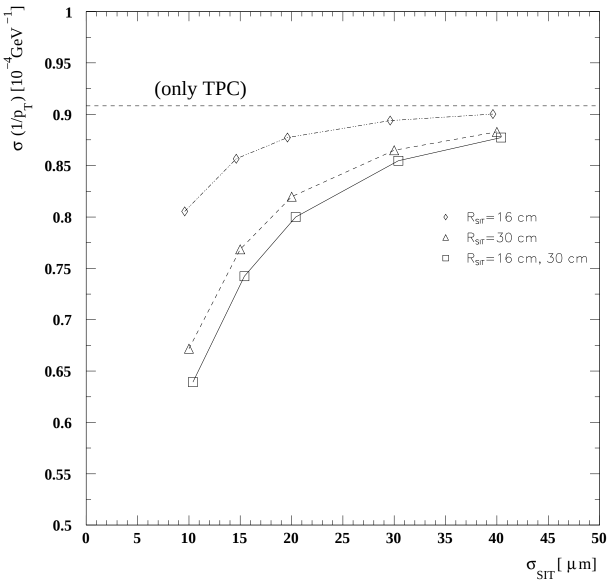

Figure 8: Momentum resolution versus the spatial resolution of the SIT for some SIT radii and magnetic field $B = 3\,\mathrm{T}$.

4 Reconstruction of secondary vertices

Some SUSY models predict neutral, long lived particles for certain regions of their parameter space. Their lifetime could be comparable to the lifetime of K^0_S mesons. In the GMSB model [6] processes of the type $\tilde{N}_1 \to S\tilde{G} \to f\bar{f}\tilde{G}$ ($S = \gamma, Z, h, H$ or A) they could produce a pair $f\bar{f}$ of charged fermions at secondary vertices outside the vertex detector, but inside the TPC. The SIT will facilitate the reconstruction of such particles.

The influence of the SIT on the reconstruction of long lived particles is studied by means of the decay $K^0_S \to \pi^+\pi^-$ [7]. The K^0_S mesons are reconstructed in events $e^+e^- \to s\bar{s} \to K^0_S$ containing at least one K^0_S decaying in the relevant region between 6 cm and 30 cm.

Each pair of opposite charged tracks is regarded as a possible pion pair. Those pairs delivering no reconstructed vertex at a radius $R > 1.2\,\mathrm{cm}$ are rejected. Furthermore the impact parameters of both pions are required to be $d_0 > 100\,\mu\mathrm{m}$ and the angle, at which the reconstructed K^0_S momentum deviates from the direction from the IP to the secondary vertex, has to be $\alpha < 3\,\mathrm{mrad}$. The background from photon conversion or Λ decays is suppressed by a cut on the mass of the two particles assumed to be an e^+e^- pair ($M(ee) > 300\,\mathrm{GeV}$) or $p\pi$ pair ($M(p\pi) > 1.12\,\mathrm{GeV}$).

After this selection all track pairs with an invariant mass $M^0_K \pm 50\,\mathrm{GeV}$ are accepted as K^0_S mesons at an efficiency and purity plotted in fig. 9.

The improvement which is reached with the additional SIT is most obvious at small vertex radii. In the first bin of fig. 9 the efficiency is increased from 73% to 86%.

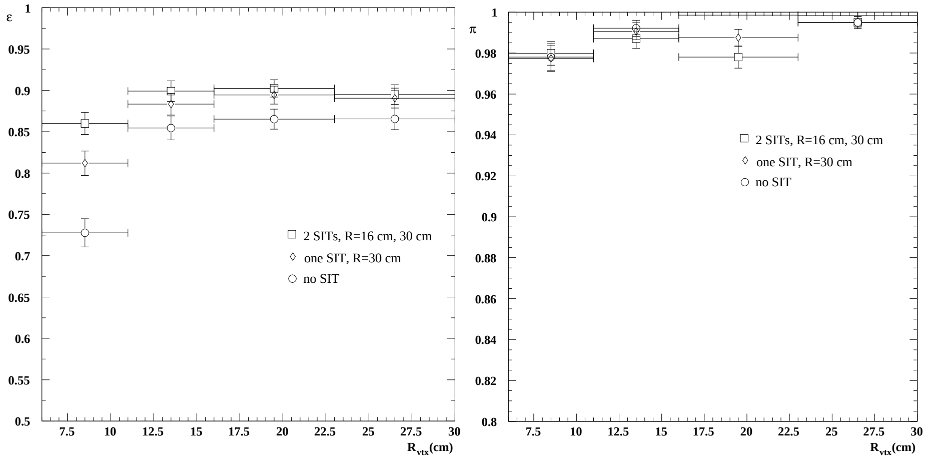

Figure 9: Efficiency ε and purity π of the $K_S^0 \rightarrow \pi^+\pi^-$ reconstruciton with 0,1 or 2 SIT layers.

5 Conclusions

Some advantages of a SIT with two cylindrical layers of silicon strip detector at radii $R = 16\,\mathrm{cm}$ and $30\,\mathrm{cm}$ were discussed. The results aim at an ambitious design with a point resolution of $10\,\mu\mathrm{m}$.

- The **momentum resolution** will improve from $\sigma(p_T)/p_T^2 = 0.91 \cdot 10^{-4}\,\mathrm{GeV}^{-1}$ to $0.63 \cdot 10^{-4}\,\mathrm{GeV}^{-1}$. With a magnetic field of $B = 4\,\mathrm{T}$ instead of $3\,\mathrm{T}$ the improvement leads to $\sigma(p_T)/p_T^2 = 0.48 \cdot 10^{-4}\,\mathrm{GeV}^{-1}$ in contrast to $0.68 \cdot 10^{-4}\,\mathrm{GeV}^{-1}$ without a SIT. With this resolution the detector contributes to the spread of the Z mass reconstructed from $Z \rightarrow \mu^+\mu^-$ with less than 10% of the natural Z width.
- A simple method of **track merging** shows that the fraction of tracks of $d\bar{d}$-events, which get a wrong hit in the silicon detectors assigned to their TPC track segment, is reduced from 6.3% to 2.7%.
- The efficiency of the reconstruction of **secondary vertices** is increased from 73% to 86% for particles decaying at radii $R = 6 \ldots 11\,\mathrm{cm}$. Vertices at a larger radius are less affected.

References

[1] GEANT Detector Description and Simulation Tool, CERN Program Library Long Writeup (1994)

[2] R. Brinkman et al., Conceptual Design Report of a 500 GeV e^+e^- Linear Collider with Integrated X-ray Laser Facility (1997)

[3] C. Bowdery et al., ALEPH Handbook Vol. 1 (1995)

[4] M. Gruwé, Gas Studies for a TPC of a detector for the future linear collider TESLA, LC-DET-1999-003-TESLA (1999)

[5] M. Sachwitz et al., e^+e^- Linear Colliders: Physics and Detector Studies Part E, DESY 97-123E (1997), 349

[6] S. Ambrosanio, G.A. Blair, Measuring gauge-mediated supersymmetry breaking parameters at a 500 GeV e^+e^- linear collider, Eur. Phys. J. C12 (2000), 287-321

[7] OPAL Collaboration, G.Alexander et al., "A study of K^0_S production in Z^0 decays", Phys. Lett. B264 (1991), 467

[8] 2nd Joint ECFA/DESY Study on Physics and Detectors for a Linear Electron-Positron Collider, `http://www.desy.de/conferences/ecfa-desy-lc98.html`