

The TESLA Detector

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For the superconducting linear collider TESLA a multi purpose detector has been designed. This detector is optimised for the important physics processes expected at a next generation linear collider up to around 1 TeV and is designed for the specific environment of a superconducting collider.

1. Introduction

Recently the Technical Design Report for the superconducting linear collider TESLA has been completed [1]. As a proof that the proposed physics program [2] can be done with a detector of known technology and reasonable price the conceptual design of a multipurpose detector has been included [3].

The physics goals of TESLA require from the detector

- very good momentum resolution ($\delta 1/p \sim 4 \cdot 10^{-5}/\text{GeV}$) e.g. to measure the Z recoil mass in the process $e^+e^- \rightarrow ZH$, $Z \rightarrow \ell^+\ell^-$,
- high resolution of the hadronic jet energy ($\Delta E/E \approx 30\%/\sqrt{E}$) to reconstruct multi-jet events with intermediate resonances such as ZHH or $t\bar{t}H$,
- superb b-tagging to identify multi-b final states like ZHH or $t\bar{t}H$ or to separate $H \rightarrow b\bar{b}$, $H \rightarrow c\bar{c}$ and $H \rightarrow gg$,
- optimal hermeticity to reduce backgrounds in missing energy channels, especially to veto two-photon induced events.

At TESLA a bunch train consists of around 2800 bunches with a bunch spacing of more than 300 ns. The relatively long time between bunches makes bunch identification easy and no special fast detectors are needed for this purpose. The only really relevant background at TESLA are e^+e^- pairs created in the collision. These pairs are concentrated at low angle or low transverse momentum. The low angle component requires a mask in the forward direction, which can, however, to a large part be used for calorimetry. The low p_t component at large angles can be kept at low radius by a strong magnetic field. It limits the radius of the most inner detector layer to around 1.5 cm and causes a significant background in that layer of the vertex detector.

Figure 1 a) shows the principle layout of the detector. The tracking system and the calorimeters are situated inside a 4T superconducting coil. Sections 2 and 3 describe the two main subsystems, tracking and calorimetry. In section 4 the expected performance of the detector is summarised. Needed and planned R&D to build the detector presented here is described in other talks of this session.

2. The Tracking system

The layout of the tracking system is shown in figure 1 b). It consists of a precise microvertex detector, a large TPC, silicon tracking in between these two main detectors and a set of forward chambers behind the TPC endplate.

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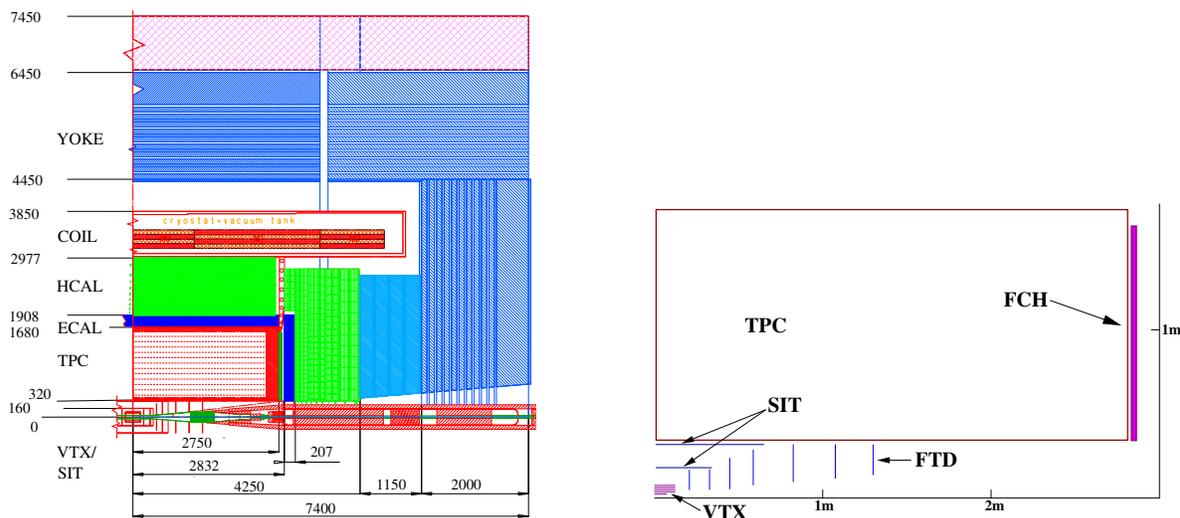


Figure 1: a) Layout of the TESLA detector b) The tracking system of the TESLA detector

The TPC is in principle similar to existing ones, such as ALEPH, DELPHI or STAR. Due to the higher photon background higher granularity and 100–200 pad rows are needed. For this reason an R&D program has been started to read out the signals with new technologies like GEMs or Micromegas. Not to compromise the momentum resolution and the calorimetric energy reconstruction also the field cage and the endplate will be designed to be as thin as possible.

For the microvertex detector (VTX) several technologies are under study, CCDs, active pixel sensors and CMOS sensors. With the CCDs a point resolution of $3.5\mu\text{m}$ and a layer thickness of 0.12% of a radiation length can be reached. The main problem of CCD detectors for TESLA is the relatively long readout time. Reading out the columns in parallel with a frequency of 50 MHz results in one complete readout every 100 bunch crossings giving a relatively high but acceptable background in the innermost layer. For the other technologies an R&D program is in progress to reach a similar performance as presented for the CCDs.

The intermediate tracking detector consists of two cylinders of silicon strip detectors in the barrel region down to 25° (SIT) and three silicon pixel and four silicon strip layers on either side in the forward region (FTD) of the detector. The SIT and FTD use only technologies that have already been used successfully in LEP so that important R&D is not needed beyond finding ways to thin the detectors. It improves significantly the momentum resolution in the full acceptance region and enables a precise angle measurement in the forward region before a lot of material is crossed, which is needed to measure the acolinearity of Bhabha events in the analysis of the luminosity spectra.

To get a reasonably precise momentum measurement below a polar angle of around 12° , where the projected tracklength in the TPC starts to limit the accuracy, at least one precise space point with a resolution around $50\mu\text{m}$ at maximal distance from the interaction point is needed. This can for example be done with a forward chamber (FCH) consisting of 12 straw tube planes with $100\mu\text{m}$ resolution. The high redundancy helps solving ambiguities in the pattern recognition. The chamber is also extended over the full TPC endplate to help mapping distortions in the TPC and possibly to serve as a preshower device.

3. Calorimetry

To measure jet energies the so called “energy flow” concept is proposed. In this scheme the energy is measured as the sum of the charged particle energies, which contribute about 60% to a typical hadronic jet, the neutral electromagnetic energy measured in the electromagnetic calorimeter, around 30% of a jet, and the energy of neutral hadrons measured in the hadronic calorimeter, representing only the remaining 10% of the energy. In principle this method allows a very good jet energy resolution, since the tracking resolution is below a few percent, while the resolution of a typical hadron calorimeter is around $100\%/\sqrt{E}$. However, in this concept one

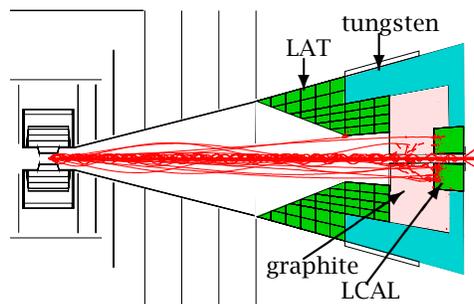


Figure 2: The mask of the TESLA detector

needs a very good spatial resolution of the calorimeters to separate showers from charged and neutral particles.

The setup of the proposed calorimeters can be seen in Figure 1. In the barrel and endcap the electromagnetic (ECAL) and hadronic (HCAL) calorimeters, which are inside the coil are followed by the instrumented iron return yoke which is used as a tail catcher and for muon identification. In the very forward region the mask is instrumented for electromagnetic calorimetry.

For the ECAL two options are under study, a SiW calorimeter and a lead scintillator sandwich with shashlik readout. The SiW option offers several advantages. Due to the high density of tungsten one can pack 25 radiation length into 20 cm thickness. The small Moliere radius of tungsten (~ 1 cm) together with a 1 cm^2 Si-pad size offers a superb lateral resolution and with around 40 layers also a very good longitudinal resolution is possible. However the detector is fairly expensive (~ 130 MEURO). For the shashlik option a readout granularity of $3 \times 3 \text{ cm}^2$ has been studied. Longitudinally a granularity of two is possible using scintillators of different decay times. The shashlik calorimeter is about a factor six cheaper than for SiW, but with worse performance which still has to be quantified.

For the hadronic calorimeter again two options have been studied. One option is a scintillating tile calorimeter with $5 \times 5 \text{ cm}^2$ tiles in the front part and $25 \times 25 \text{ cm}^2$ tiles in the back part. The granularity is limited by the possibility to get the fibres out of the detector. As an alternative a so called “digital calorimeter” has been proposed. If the granularity of the calorimeter is high enough the energy resolution using only the number of hit cells is better than by using the total amplitude. Following this observation as a second possibility a “digital calorimeter” has been proposed, consisting of $1 \times 1 \text{ cm}^2$ Geiger counters which are read out binary. The very high granularity is well matched to the SiW-ECAL allowing an almost perfect separation of showers from charged and neutral particles.

The detailed setup of the mask is shown in Figure 2. The two parts labelled “LAT” and “LCAL” are equipped as calorimeters. The LAT is reasonably clean so that it can be used at least to veto two-photon events. The LCAL receives much background from e^+e^- -pairs from beamstrahlung. Probably it is only usable for a fast luminosity measurement for machine tuning.

4. Detector performance

Figure 3 shows the momentum resolution for 250 GeV muons as a function of the polar angle and for particles at $\theta = 90^\circ$ as a function of the momentum. Over the full tracking region a unique charge identification is possible up to highest momenta and in the central region $\Delta \frac{1}{p} \approx 4 \cdot 10^{-5}/\text{GeV}$ is reached. With this resolution the Z- and Z-recoil mass resolution in $e^+e^- \rightarrow ZH$, $Z \rightarrow \mu^+\mu^-$ is dominated by the Z-width and the beam energy spread.

With the CCD vertex detector the impact parameter resolution is given by $\sigma = 2.9 \oplus 3.9/(p \sin^{3/2} \theta) \mu\text{m}$. For b- and c-tagging the SLD package ZVTOP [4] has been used. As detailed in [5] this allows in Z decays at rest to tag b-quarks with 70% efficiency at 95% purity and to tag c-quark with 40% efficiency at 85% purity.

An energy flow resolution of $\Delta E/\sqrt{E} = 30\%$ had been reached with the SiW-ECAL and the digital HCAL [6]. As can be seen from Figure 4 this resolution is needed for example to measure the

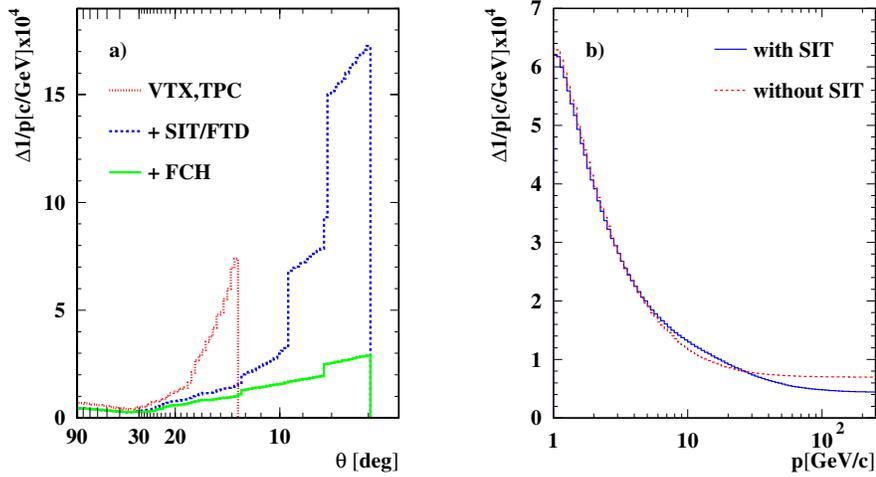


Figure 3: Momentum resolution of the tracking system, a) for 250 GeV muons as a function and b) as a function of the momentum for $\theta = 90^\circ$.

Higgs self coupling from $e^+e^- \rightarrow ZHH$. A comparable analysis for the shashlik ECAL does not exist yet.

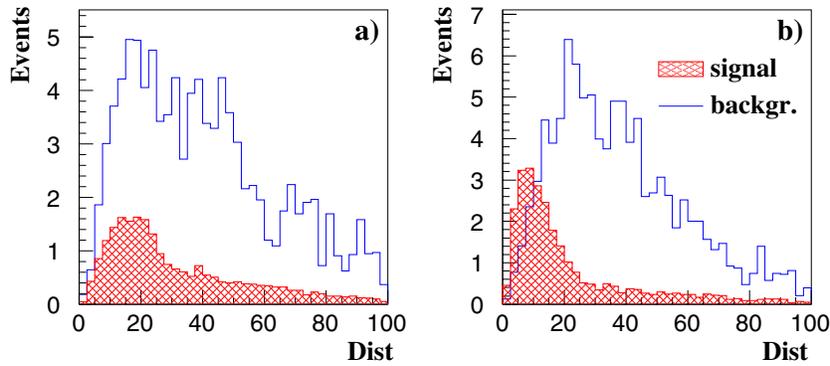


Figure 4: Mass-distance variable for $e^+e^- \rightarrow ZHH$ and background assuming a): $\Delta E/E = 60\%(1 + |\cos \theta_{jet}|)/\sqrt{E}$ or b): $\Delta E/E = 30\%/\sqrt{E}$.

5. Conclusions

For the TESLA collider a detector has been designed with which the proposed physics from $\sqrt{s} = 91$ GeV to $\sqrt{s} = 800$ GeV can be well measured. The degradation of the physics signals due to the finite resolution is minimal. The necessary R&D for the proposed detector is explained in other contributions to this session. The total cost of the detector has been estimated to be between 160 MEURO and 280 MEURO depending on the calorimeter choice.

Acknowledgments

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