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Instrumentation of the forward region of the TESLA detector

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Abstract. The expected beam-beam interaction at the proposed TESLA electron-positron linear collider has a significant impact on the design of the TESLA detector. Especially the instrumentation of the very forward region down to polar angles below 5 mrad will have to handle an immense background of electrons and positrons adding up to TeVs of energy deposition per bunch crossing. Instrumentation down to small angles is crucial not only for the measurement of the luminosity through Bhabha scattering, but also to maximize the hermeticity of the detector. Additionally these charged particles from beamstrahlung have to be measured as part of the feedback system of the TESLA accelerator and could also be used for beam diagnostics. The present design of the TESLA detector foresees two calorimeters in the forward region whose technologies have to meet the requirements regarding detector resolutions and radiation hardness.

PACS. 29.40.Vj Calorimeters – 29.17.+w Electrostatic, collective, and linear accelerators – 41.85.Qg Beam analyzers, beam monitors, and Faraday cups

1 Introduction

TESLA is a proposed electron-positron linear collider with a cms energy of 500 GeV (extendable to energies above 800 GeV) and with high luminosity [1]. It offers a rich physics program in the understanding of the electroweak symmetry breaking mechanism and new physics scenarios like supersymmetry. The physics potential drives the design of the TESLA detector which has to measure the final states of the collisions with unprecedented precision. A detailed design has been proposed [2] and is under permanent revision with respect to the outcomes of the ongoing refined physics studies and a detailed R&D program for the different detector technologies.

2 Beam induced backgrounds

The expected beam induced backgrounds at TESLA imply boundary conditions to the design of the TESLA detector. When the extremely focused and flat TESLA bunches collide, each of the bunches is affected by the field of the colliding bunch. As the colliding bunch is of opposite charge, this leads to a focusing effect (the 'pinch effect') which increases the luminosity by roughly 60%. The bending of the high energetic particles leads to the emission of high energetic bremsstrahlung photons, the so called 'beamstrahlung'. These photons carry a huge amount of energy ($\approx 2.5 \cdot 10^{11}$ GeV per bunch crossing BX) and are well focused to small angles. They leave the detector through the beam pipe and are sent to a dedicated beamstrahlung dump downstream. While these photons are still inside the particle bunches they can convert to e^+e^- pairs.

These pairs are emitted under larger angles from the interaction point (IP), but their trajectories are curled up inside a well defined cone around the beam pipe in the solenoidal 4 T magnetic field of the TESLA detector. They carry about 360 TeV per BX and create large backgrounds in the far forward region with polar angles of less than $\approx$25 mrad.

A large part of the pairs enters the final focus quadrupoles aperture. The typical energy of the pairs is a few GeV so that they are over-focused in the quadrupoles and eventually hit the quadrupole material and produce electromagnetic showers which are a major source of background for the detector. To prevent these secondary particles from entering the tracking and calorimetric system, a cylindrical tungsten mask has to be placed outside the quadrupoles.

3 The forward region of the TESLA detector

The design of the forward region of the TESLA detector is shown in Fig. 1. The final focus quadrupoles are surrounded by the tungsten mask. The main purpose of the mask is the shielding of the detector from the e^+e^- pairs. It will additionally be instrumented with two calorimeters: the Low Angle Tagger (LAT) and the Luminosity Calorimeter LCAL. The main task of the LAT is the precision luminosity measurement. It lies outside the cone of the pair particle trajectories while the LCAL is positioned in the very forward region and collects a significant

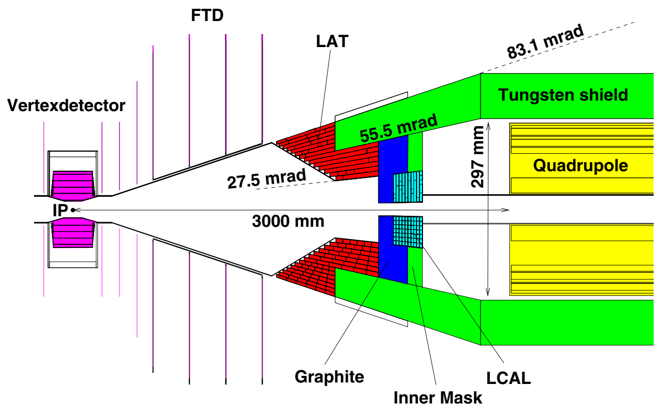

Fig. 1. Forward region of the TESLA detector. FTD: Forward Tracking Disks, LAT: Low Angle Tagger, LCAL: Luminosity CALorimeter

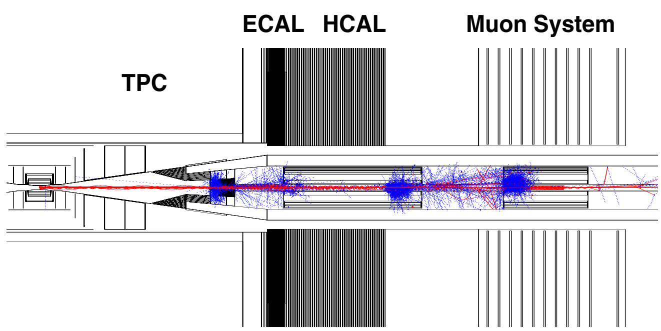

Fig. 2. Simulated tracks of 10 pair particles and their secondaries. TPC: Time Projection Chamer, ECAL: Electromagnetic CALorimeter, HCAL: Hadron CALorimeter

amount of background. The main purpose of the LCAL is beam diagnostics and to provide hermeticity by having a limited ability for the detection of high energetic particles in the very forward region.

Figure 2 shows the tracks of 10 simulated e^+e^- pair particles hitting the quadrupoles and the LCAL. About 130000 pair particles are produced in a typical BX at the TESLA collider with 500 GeV cms energy.

4 Performance simulations of the mask calorimeters

Detailed simulations have been performed to study the performance of the mask calorimeters.

4.1 LAT: The luminosity measurement

The LAT is foreseen to be a Silicon/Tungsten sandwich calorimeter at the tips of the tungsten mask covering the region of $27.5 \leq \Theta \leq 83.5$ mrad in the polar angle. As it also serves as a shield against pair background which scatters back from the LCAL, the shape of the LAT is conical. The foreseen segmentation are 14 cylinders in the polar angle Θ, 24 azimuthal sectors and 40 rings in the beam direction adding up to a thickness of 40 radiation lengths.

The main task of the LAT is the precision luminosity measurement. The precision goal of $\Delta L/L \approx 0.02\%$ is driven by the measurements of the Z-scan observables in the GigaZ option of TESLA [3]. The process under study to reach this goal is elastic and radiative Bhabha scattering. At the 500 GeV machine, the expected rate is ≈ 170 Hz so that the main errors stem from systematical uncertainties. The main expected error here comes from the steepness of the angular distribution of the Bhabhas ($\sigma_{tot} \sim \Theta^{-2}$). For the anticipated precision in the luminosity measurement this transforms to a precision in the angular resolution of a few μrad to which the position of the lower edge of the LAT has to be known.

Detailed simulations using a GEANT3 based detector Monte Carlo program have been performed to study the response of the LAT to high energetic electrons [4]. The energy response was shown to be linear in energy with a resolution of $\Delta E/E = 37\%/\sqrt{E}$. However, due to the conical face of the detector, the energy resolution is not uniform over the polar angle. This results in an angular resolution which varies between 0.2 and 0.4 mrad and does not match the anticipated resolution in the μrad range.

A flat surface of the LAT would improve the situation a lot. Studies are under way to change the optics of the TESLA beam delivery system which would allow to increase the focal length of the final focus quadrupoles so that they could be moved back by 1–2 m [5]. In that case a flat surface LAT could be realized.

4.2 LCAL: Beam monitoring and hermeticity

The Luminosity Calorimeter LCAL covers the angular region from $4.6 \leq \Theta \leq 30$ mrad. It serves also as the last collimator before the IP and protects the vertex detector from backgrounds coming from upstream. As it receives a significant amount of pair background it has to survive electromagnetic doses of up to 10 MGy/y. Technology options under study are e.g. a Diamond/Tungsten sandwich or a crystal $PbWO_4$ calorimeter.

The main purpose of the LCAL is to serve as a beam monitor device. As the number of pairs impinging on the LCAL surface is a measure for the luminosity, the LCAL signal will be used as an input for the TESLA fast feedback system [1]. The azimuthal distribution of the deposited energy of the pairs on the LCAL can in addition be used to detect beam misalignments and displacements.

In addition to being a beam monitor device, the LCAL can also be used for physics applications. Figure 3 shows for a 60 layer Diamond/Tungsten LCAL the energy deposition of the pair background of one full BX in four different layers. The pair background shows a specific azimuthal distribution which stems from the flat TESLA bunch profile. Overlayed is the signal of one 250 GeV electron which is clearly visible as the additional peak.

Detailed simulations have been performed [6] where a simple algorithm has been applied to disentangle the electron from the background signal: The pair background was

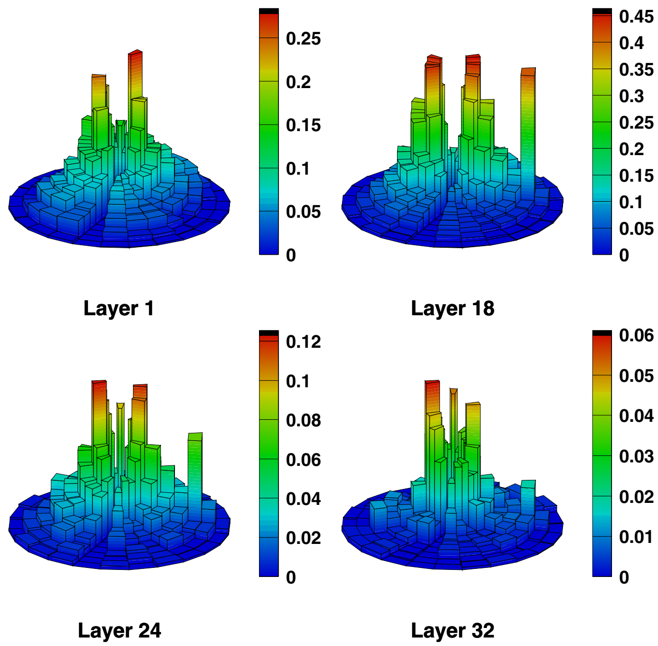

Fig. 3. Energy deposition (in GeV) on four sensitive layers of the LCAL from one 250 GeV electron superimposed to the background of e^+e^- pairs from one BX

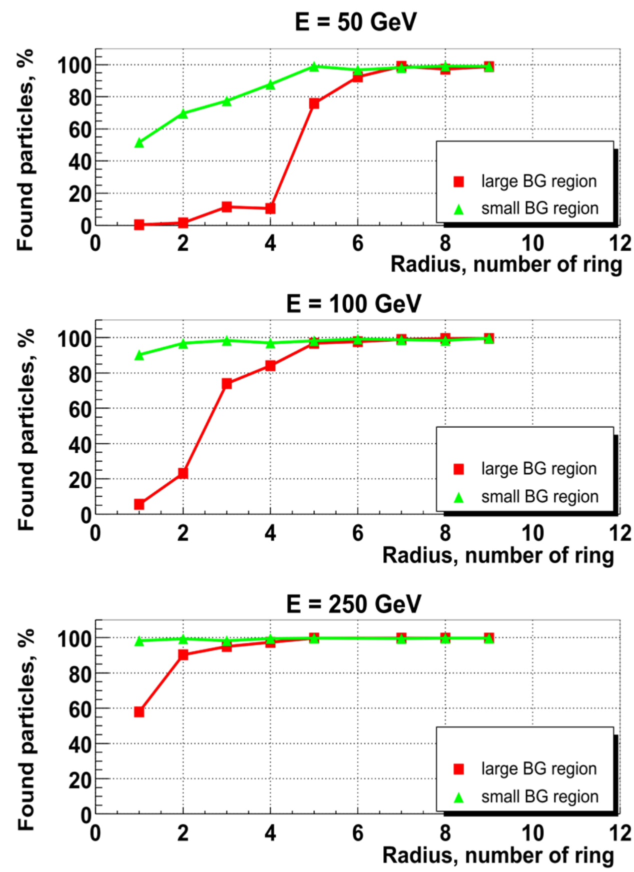

Fig. 4. The efficiency to identify and reconstruct an electron of 50, 100 and 250 GeV energy as a function of the radius in the large background region (*squares*) and the low background region (*triangles*) [6]. Ring 1 starts at $\Theta = 4.6$ mrad, Ring 9 ends at $\Theta = 30$ mrad

averaged over 10 BX and then subtracted from the energy depositions. A longitudinal chain of signal cells was required where each cell had a signal larger than three standard deviations of the background fluctuation. Figure 4 shows the efficiency to identify the high energetic electron as a function of the radius in azimuthal regions where the pair background is high (squares) and low (triangles).

The reconstruction efficiency shows that at least in the low background regions tagging of high energy electrons is possible down to angles below 5 mrad. As the energy resolution is completely dominated by the background fluctuations a precision energy measurement should not be expected in this region.

Another problem are high energetic pair particles which might be misidentified as signal events. In 500 BX a number of ≈50 pair particles is expected with energies larger than 20 GeV. About half of them would be falsely identified as a signal electron with the current algorithm.

5 Conclusion and outlook

The instrumentation of the forward region of the TESLA detector is challenging. The high pair background forces the LAT shape to be disadvantageous for the luminosity measurements via Bhabha scattering. Though the LCAL provides a quite good hermeticity down to small polar angles below 5 mrad, its technology has to stand a high electromagnetic radiation environment.

As a new TESLA optical design is under study which would allow to move the final focus quadrupoles back by 1–2m, the LAT could also be moved back to the face of the electromagnetic calorimeter. This would allow to design a LAT with a flat surface to improve the luminosity detector and measurement.

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