The Optimized Sensor Segmentation for the Very Forward Calorimeter

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This is a report on a segmentation optimization study of the BeamCal (Beam Calorimeter) for the ILC. Results of a Monte Carlo simulation are presented for the diamond-tungsten structure. The reconstruction efficiency of high energy electrons, which is particularly important for new particle searches, is limited by pair background from beamstrahlung. It is shown that 5 mm sensor cell size in $r-\phi$ plane gives the best identification efficiency of high energy electrons on top of the background at small radii. Relatively large cell sizes (10 mm) are acceptable for radii above 55 mm.

1. LAYOUT OF THE BEAMCAL

There are two calorimeters proposed for the forward region for the ILC detector: BeamCal and LumiCal (Luminosity Calorimeter). The BeamCal is positioned just adjacent to the beampipe. Its tasks are beam diagnostic using the distribution of energy deposited by beamstrahlung remnants and the identification of high energy electrons down to small polar angles. The LumiCal covers larger polar angle than BeamCal. It will provide a high precision ($O(10^{-4})$) luminosity measurement using Bhabha scattering. Here we consider BeamCal only.

Several technologies have been proposed for the BeamCal: silicon-tungsten or diamond-tungsten sandwich calorimeter or $PbWO_4$ crystal calorimeter with fiber readout. The present study is based on the diamond-tungsten design. The distance between interaction point and front face of the BeamCal is 370 cm covering polar angle in the range between 4 and 28 mrad which correspond to $R_{min} = 15$ mm and $R_{max} = 100$ mm. The thickness of the sensor is 0.5 mm and of the absorber is 3.5 mm. The BeamCal consists of 30 diamond-tungsten layers. For such a structure the radiation length is $X_0 = 4$ mm and the molier radius is $R_{molier} = 10$ mm.

2. IMPACT OF THE BEAMSTRAHLUNG ON THE BEAMCAL PERFORMANCES

The BeamCal will be hit by beamstrahlung remnants carrying about 20 TeV of energy per one bunch crossing. The distribution of this energy is shown in Fig. 1. The areas around 90 and 270 are strongly subjected to the beamstrahlung pairs. The energy deposition becomes very large for small radii. Therefore the beamstrahlung produces a severe background for electron identification in the BeamCal which is particularly important for new particle searches. For example, the signature for the production of smuons decaying into muons and neutralino ($e^-e^+ \rightarrow \tilde{\mu}^-\tilde{\mu}^+ \rightarrow \mu^-\mu^+\chi^0\chi^0$) would be a muon pair plus missing energy. The background for this process will be two-photon interactions ($e^-e^+ \rightarrow e^-e^+\gamma^*\gamma^* \rightarrow e^-e^+\mu^-\mu^+$) if electrons are not tagged.

3. PARTICLE IDENTIFICATION IN THE BEAMCAL AND OPTIMIZED SEGMENTATION

3.1. Motivation for the Optimization Study

The total number of readout channels strongly depends on the $r-\phi$ segmentation. It ranges from 7920 for 10 mm cell size to 49800 for 4 mm. We studied the electron identification efficiency for 5 different segmentations: 4 mm, 5 mm, 6.5 mm, 8 mm and 10 mm.

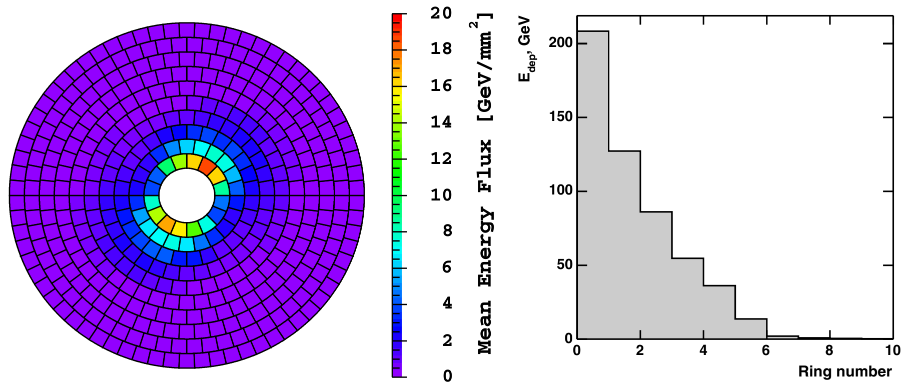

Figure 1: The energy density of beamstrahlung remnants per bunch crossing as a function of position in the $r-\phi$ plane (left) and the energy deposition in diamond rings as a function of ring number (right).

3.2. BeamCal Simulation and Particle Identification Algorithm

To simulate pairs from beamstrahlung we use GuineaPig [1] with accelerator parameters proposed for TESLA-500 [2]. Electrons were generated parallel to the beam axis and uniformly distributed in $r-\phi$. Output of the generators that contain four-momenta and vertex positions of the particles was sent to the BeamCal simulation program based on Geant-4 [3]. This program collects information about every hit (G4Step) in the BeamCal sensors. To get the energy deposition per each sensor according to the chosen segmentation a separate C++ code was used. This approach saves CPU-time since there is no need to rerun Geant-4 simulation for every particular segmentation.

The electron reconstruction algorithm was developed by V.Drugakov and is described in Ref. [4]. It is based on the following steps. The mean value and RMS of the background energy distribution for each pad in the event with an electron signal are defined from previous 10 bunches. The average background is subtracted from the total energy deposition in the pad. Only pads with a remaining energy deposition larger than $5 \cdot RMS$ are kept. Then a search is performed along segment. Cluster is found if there are more than 7 pads in the segment and more than 4 pads within at least one neighbour segment.

3.3. Energy Reconstruction and Applied Cuts

We determine the energy resolution for electrons in range between 100 GeV and 250 GeV. The intrinsic resolution (without any background) of the BeamCal is $\sim \frac{23\%}{\sqrt{E}}$. On top of beamstrahlung the resolution amounts to $\sim \frac{130\%}{\sqrt{E}}$. Therefore the energy resolution of the BeamCal is strongly dependent on the background.

For every electron found by the reconstruction algorithm we apply cuts on the energy and the position. Reconstructed energy must satisfy 3 sigma condition. The difference between reconstructed and simulated r and ϕ must be smaller than half size of the segmentation.

3.4. Particle Identification Efficiency

Figure 2 shows the efficiency to reconstruct electrons of 200 GeV in the low ($\phi \approx 0$) and high ($\phi \approx 90$) background regions for cell sizes 5 mm, 8mm and 10 mm. For radii above 55 mm the efficiency is 100% even with 10 mm pads. We calculate now the inefficiency to identify electrons in the region below 55 mm. The results for 200 GeV electrons are shown on Fig. 3

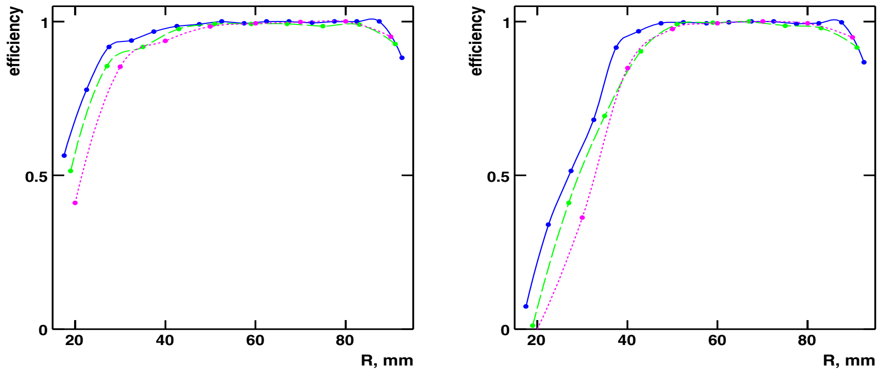

Figure 2: Efficiency to identify 200 GeV electrons as a function of radius in the low (left) and high (right) background regions. Blue full line is for 5 mm cell size, green broken line is for 8 mm and red dotted line is for 10 mm.

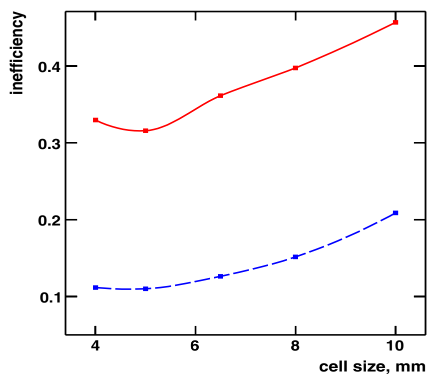

Figure 3: Inefficiency of reconstruction 200 GeV electrons as a function of cell size for the radii below 55 mm. Red full line is for high and blue broken line is for low background region.

4. SUMMARY

We have a full simulation chain for the BeamCal: a Geant-4 based simulation program and reconstruction tool. A segmentation optimization study has demonstrated that 5 mm is the best size of the sensors from the electron identification point of view. Larger segmentation up to 10 mm seems to be acceptable for radii above 55 mm.

Acknowledgments

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References

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