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SIMULATIONS FOR THE BEAMCAL AT THE ILC

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Abstract

This work presents simulation studies for the Beam Calorimeter (BeamCal) of a detector which will be installed at the International Linear Collider (ILC). Studies of the Moliere radius have been performed for a diamond-tungsten calorimeter. We compare our results with theoretical calculations of the above mentioned quantity.

1. Introduction

The beam calorimeter, called in the following the BeamCal, of the International Linear Collider (ILC) detector is designed by the FCAL collaboration [1] to detect high energy electrons and photons produced in low momentum transfer QED processes, as for instance two-photon events. These processes form a very serious background for e.g. several SUSY physics studies which are characterized by missing energy and missing momentum. The background can be vetoed by tagging the electron or the positron that emerges at small angles with respect to the beam line.

The BeamCal will cover polar angles θ from 5 to 45 mrad. The calorimeter will be composed of 30 modules which contain layers of segmented sensors, interleaved with tungsten disks. Each layer will consist of a radiation-hard sensor plane (in the following we consider sensors made of diamond) of 300 μm thickness and a 0.35 cm tungsten plate and the respective read-out electronics. The sensor planes are subdivided into pads of 5 x 5 mm size. The resulting module thickness is 0.40 cm and corresponds to one radiation length.

In this paper we report on the results of the simulation studies of the transverse electromagnetic shower profiles generated by electrons in the BeamCal. The lateral extension of the electromagnetic showers is mainly due to multiple scattering of electrons that do not radiate but have enough energy to travel away from the shower axis. Shower extension is limited by the range of these low energy electrons. The radial spread of the showers is often expressed in Moliere radius units:

$$R_M = \frac{E_S}{E_c} X_0 ,$$

with E_S being the scale energy, a constant appearing in multiple scattering theory [2],

$$E_S = \sqrt{\frac{4\pi}{\alpha}} m_e c^2 = 21.2\,\mathrm{MeV} .$$

In this formula α is the fine structure constant, m_e is the electron mass and X_0 the radiation length (0.35 cm for tungsten). E_c is called the critical energy and equals the energy of an electron that loses as much energy in ionization as in radiation. Depending on the way the radiation loss is calculated, several estimations of E_c can be found in the literature. The approximate formula of reference [2] gives for the critical energy for a chemical element with the atomic number Z,

$$E_c = \frac{610\,\mathrm{MeV}}{Z + 1.24} .$$

In reality our calorimeter represents a complex structure of various materials and it is necessary to know the effective radiation length (X^{eff}_0) and the effective Moliere radius (R_M^{eff}).

The effective radiation length X^{eff}_0 can be calculated with the formula

$$\frac{1}{X_0^{eff}} = \sum_j w_j \frac{1}{X_{0j}} ,$$

where w_j are the different material fractions and X_{0j} the radiation length of each material *j*.

The above formula for the critical energy leads to the value E_c = 8.15 MeV for an effective atomic number of the BeamCal material Z_{eff} = 73.59 . Here we calculated Z_{eff} using the formula of reference [3],

$$Z_{eff} = \sqrt[2.94]{f_1(Z_1)^{2.94} + f_2(Z_2)^{2.94} + f_3(Z_3)^{2.94} + ...} ,$$

where f_i is the fraction of the total number of electrons associated with each element, and Z_i the atomic number of each element. We assume each calorimeter layer to be compound of 87.5% tungsten (3.5 mm), 7.5% diamond (0.3 mm), 3.75 % Kapton for the PCB (0.15 mm) and finally 1.25 % air gaps.

Using the formulae given above we obtained for the effective Moliere radius of our calorimeter the value $R_M^{eff} = 10.3$ mm.

2. Simulation of the Moliere radius

Simulations of the effective Moliere radius of the BeamCal were done using single electrons with energies between 30 and 250 GeV. The detector response is generated using BeCaS [4], a program which uses the GEANT 4 [5] detector simulation package. The incident particle interacts with the material of the calorimeter and a shower is initiated. Particle showers in calorimeters are simulated by tracking all secondary particles of the shower down to some minimum energy. We consider the case when the electron hits the central part of the calorimeter in order to avoid shower leakage. The coordinate system we used in the following is based on the electromagnetic shower direction. The axis of the shower, defined by the track of the incident particle, forms the z axis, with $z = 0$ at the calorimeter front face.

We determine the energy depositions in each of the calorimeter pads. For pad *ijk*, having the coordinates (x, y, z), the energy deposition is E_{ijk} and the radius r is the closest distance to the shower axis. Figure 1 shows a typical electromagnetic transverse shower profile for an electron of 200 GeV as a function of the radius r, summed over all calorimeter depths. The distribution is strongly peaked towards $r = 0$ and the obtained spread of the lateral shower dimensions is more than 30 mm.

The distribution of the electromagnetic shower profile is integrated to yield the shower containment as a function of the radius r. Figure 2 shows the fraction of deposited energy inside the radius of the electron shower as a function of r for the overall calorimeter.

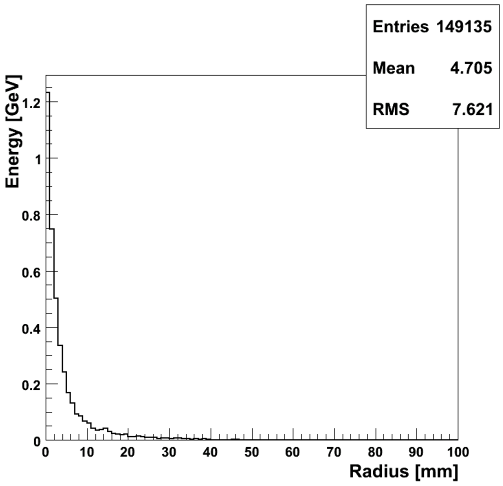

Figure 1: The deposited energy is shown as a function of the radius for a 200 GeV electron.

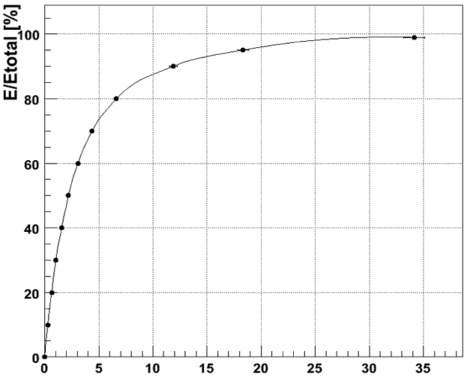

Figure 2: The transverse containment of the shower as a function of radius for the overall calorimeter.

In table 1 the radii of cylinders containing a fraction of 90%, 95% and 99% of the shower energy extracted from Figure 2, are shown for the overall calorimeter and different conditions: with and without a graphite brick in front of the calorimeter to reduce the backscattered particles, with and without magnetic field, and for the case we consider only the deposited energy in the calorimeter sensors, or when we include the energy deposited in the absorber material.

	Sensors		**Sensor and tungsten**			
			with graphite		without graphite	
	B = 0 T	B = 4 T	B = 0 T	B = 4 T	B = 0 T	B = 4 T
E/Etotal	**Radii (mm)**					
90%	11.86 ± 0.47	11.78 ± 0.45	13.04 ± 0.15	13 ± 0.12	13.01 ± 0.14	13 ± 0.15
95%	18.3 ± 0.68	18.14 ± 0.53	19.65 ± 0.25	19.65 ± 0.25	19.64 ± 0.25	19.67 ± 0.27
99%	34.09 ± 1.19	34.25 ± 1.12	35.16 ± 0.36	35.18 ± 0.34	35.09 ± 0.35	35.11 ± 0.33

Table 1: The radii of cylinders containing 90%, 95% and 99% of the shower energy at different conditions: with and without a graphite brick in front of the calorimeter, with and without magnetic field, considering only the deposited energy in the calorimeter sensors, or including the energy deposited in the absorber material.

One usually assumes [6] that 90% of the shower is contained in a cylinder with one Moliere radius, R_M. From Figure 2 we compute $R_M = 11.86 \pm 0.47$ mm for our calorimeter.

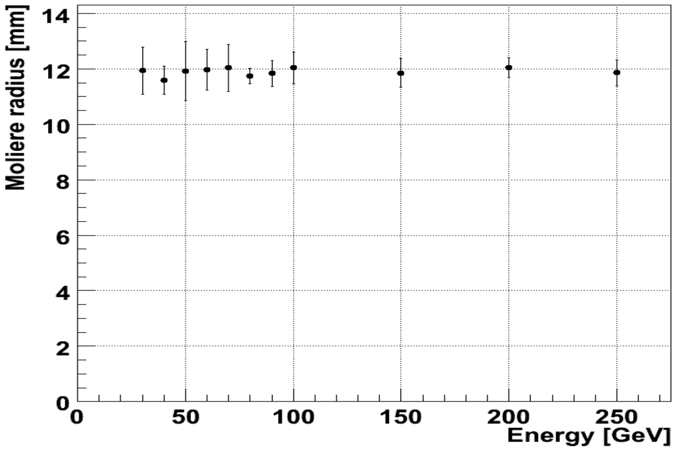

Figure 3: Dependence of the Moliere radius on the energy of the incident electron.

We have checked that the shower transverse profile does not change with the incoming electron energy. Our results are presented in Figure 3, for energies of the incoming particles between 30 GeV and 250 GeV.

3. Influence of the magnetic field

We have studied the effect of the magnetic field on the radial spread of the electromagnetic showers created in BeamCal. The development of the shower could be influenced by the interaction with an external magnetic field by the fact that the charged secondary particles will be forced to move along helices. The results we obtained are presented in table 1. No change of the Moliere radius has been observed.

4. Influence of the cut-off parameter

We investigated whether our results depend on the minimum energy to which the secondary particles in the shower are tracked in GEANT4. To do this we determined the radii of cylinders for 90%, 95% and 99% shower containment for several values of the cut-off parameter, namely for the values 0.001 mm, 0.01 mm, 0.1 mm and 2 mm. The results are presented in Figure 4. We do not observe a dependence on the cut-off parameter.

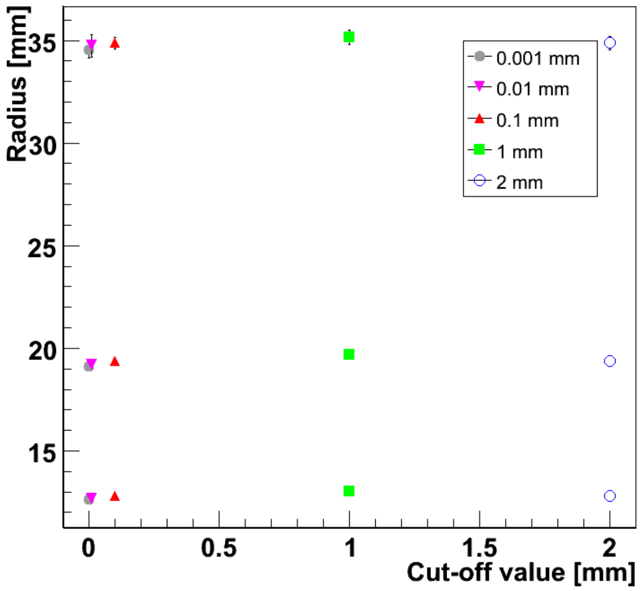

Figure 4: Radii of cylinders that contain 90% (lower points), 95% (middle data) and 99% (upper points) of the electromagnetic shower, as a function of the GEANT4 cut-off parameter

6. Conclusions

We studied the transverse dimensions of the electromagnetic showers initiated by single electrons in the beam calorimeter of the ILC detector. We found that a sampling calorimeter made of tungsten/diamond layers would have a small Moliere radius of 11.86 ± 0.47 mm. The electromagnetic shower transverse profiles and consequently the Moliere radius does not change in the energy range 30 - 250 GeV and neither depends on the magnetic field, nor the minimum energy down to which secondary particle in the showers are tracked by GEANT4.

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