EUDET-Memo-2010-35

Monte Carlo evaluation of tile gap effect on energy resolution in LumiCal

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January 31, 2011

Abstract

LumiCal is the integrated luminosity calorimeter for the forward region of the future International Linear Collider. LumiCal's two identical modules on either side of the interaction point will be used to estimate luminosity by counting Bhabha scattering events, matching polar angle and energy deposition. Using Monte Carlo simulation, we have determined that uninstrumented gaps in the sensor pads cause the energy resolution it to be worse than the acceptable limit. This can only be remedied by discounting particles that impact these gaps. A second consequence is that since lower energy deposition in the gap regions no longer must be ameliorated, it seems likely that the design of LumiCal can be simplified.

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1 Introduction

1.1 LumiCal

LumiCal is a sandwich-type silicon-tungsten calorimeter made of two identical modules that will measure integrated luminosity in the forward region of the future International Linear Collider (ILC). The physics requirements of the ILC demand that the relative error in resolution be better than $\Delta L/L \leq 10^{-4}$. The luminosity will be estimated by counting Bhabha scattering events, whose cross section has been well-described theoretically [1].

1.2 Energy resolution

Accurately identifying Bhabha events depends in part on matching the energies of particles that strike the opposing LumiCal modules. Therefore, the energy resolution must be as high as possible. Fabjan [4] gives the equation for the energy resolution of a sandwich calorimeter as (ignoring noise from electronics):

$$\frac{\sigma_E}{E} = \sqrt{\frac{a^2}{E} + b^2}, \tag{1}$$

where the first term corresponds to stochastic shower processes and the second corresponds to leakage, where energy is deposited in the calorimeter but not registered, or else escapes out the sides and back. In these simulations, the contribution of this constant term to the energy resolution was investigated. This is especially important because, as can be seen from equation 1, the leakage term dominates at high energies. The energy resolution required from LumiCal to reach the physics goal of $\Delta L/L \leq 10^{-4}$ is $\sigma_E/E \leq 0.015$.

1.3 Simulation

LumiCal was simulated using the Geant4 [2] software package. Electrons were generated at nine different energies: 5, 25, 50, 100, 150, 200, 250, 500, and 1500 GeV. Both the polar and azimuthal angles of the electrons were randomly generated to cover the entire surface of one LumiCal module. The polar angle refers to the angle measured from the beam axis, and azimuthal angle is measured in the plane perpendicular to the beam axis. Electrons were generated at a point 2.5 m from the surface of the detector.

Energy resolution is determined by calculating the proportion of a particle's energy that is deposited within the sensitive regions of the detector. This proportion changes as a function of energy, but typically is around 1/100. The inverse of this proportion is called the "correction factor" (CF), and is multiplied by the deposited energy to reconstruct the original energy of the particle. For a given energy, the CF used for reconstruction is the maximum likelihood value from a histogram of all the CFs for particles at that energy.

2 Geant4 model

The design of the detector follows the specifications found in [3], and the geometric parameters are listed in table 1.

Element	Value	Units
# planes/module	30	
# tiles/plane	12	
# sectors/tile	4	
# cells/sector	64	
Length	130.1	mm
Position (z)	$\pm$ 2504.9	mm
Mech. inner radius	76.0	mm
Sensor inner radius	80.0	mm
Mech. outer radius	250.0	mm
Sensor outer radius	195.2	mm
Cell radial pitch	1.762	mm
Sector width	7.5	deg
Gap between absorber plates	0.835	mm
Air gap	0.1	mm
Tile gap	2.5	mm
Layer phi offset	3.75 or 0	deg
Electronics thickness (front)	0.66	mm
Electronics thickness (back)	0.235	mm
Sensor thickness	0.320	mm
Pad metallization thickness	0.020	mm
Tungsten thickness	3.500	mm
Total plane thickness	4.335	mm
Mass (1 module)	211.320	kg

Table 1: Geometric parameters used for simulation.

In the present LumiCal design, individual sensor pads are placed in 64 concentric rings extending out from the inner radius of the detector. Each ring has 48 pads aligned with the pads above and below it, creating 48 sectors placed azimuthally around the center of the detector, as in figure 1 (left). Mechanically, only four sectors can fit on a single tile of silicon, so between every four sectors there is an uninstrumented gap of 2.5 mm. This is show in figure 1 (right).

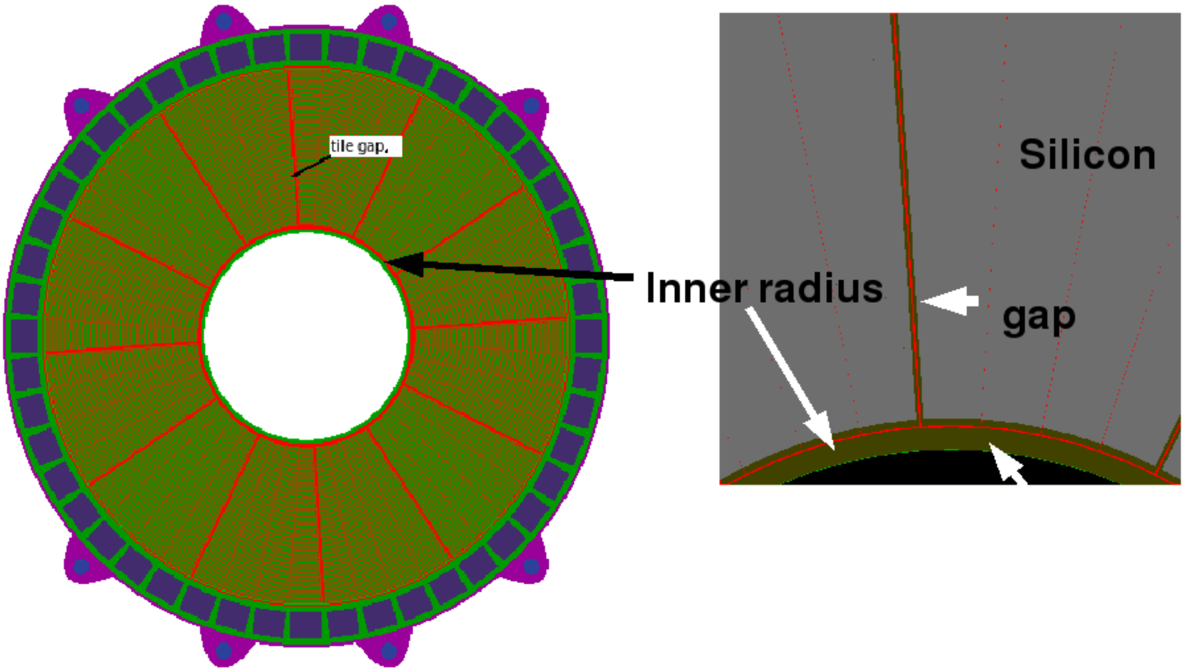
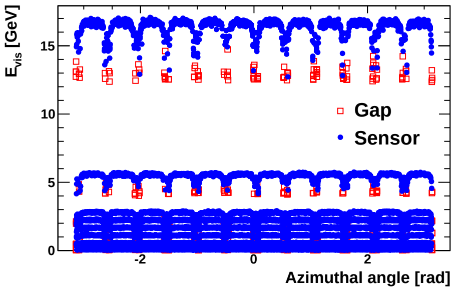


Figure 1: Image of model implemented in simulation.The left view looks down the beam axis, and the right view is a close-up image of the sensor tiles and gaps.

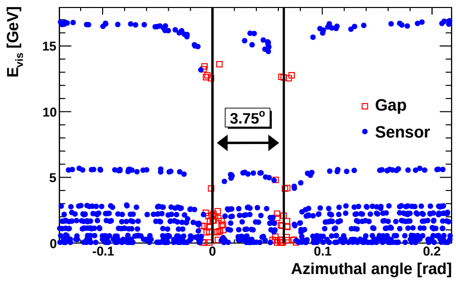
Energy deposition from electrons will not be recorded within these gaps. In order to compensate for this loss, current plans for LumiCal call for every other layer to be rotated by 3.75^o (one half of a sector). However, it will be shown that this rotation is insufficient to compensate for the energy loss in the tile gaps and that, in fact, particles that hit the gap must be thrown out in order to achieve the required energy resolution of $\sigma_E/E \leq 0.015$. Furthermore, it will be shown that leaving LumiCal layers unrotated not only achieves comparable energy resolution, but does so while losing fewer particles to the tile gaps, so the effect on statistics will be smaller.

3 Tile gaps worsen energy resolution

The effect of rotation can be seen in figure 2, which plots the energy deposition from incident electrons against their azimuthal angle. Subfigure 2(b) demonstrates that the tile gaps are clearly resolved, so rotating every odd layer does not fully compensate for the presence of the gaps.
Energy resolution was plotted for three different cases - particles in the gap were considered separately, particles that hit the sensors were considered separately, and finally the



(a) Energy deposited by incident electrons



(b) Close-up of the area surrouding a tile gap

Figure 2: Dips in energy deposition due to tile gaps

two sets of particles were combined. The selection for "gap" particles was varied from 1.2 mm (about half the gap size) to 20 mm from the center of the gaps - that is, any particle coming within this distance of a tile gap was tagged as a "gap" particle.
This plot (figure 3) of energy resolution shows the effect of the tile gaps for a cut 2 mm wide on either side of the gap (4 mm total) - about twice as wide as the tile gap itself. The bottom line, "Sensor", is the energy resolution calculated only from particles that did not hit LumiCal within 2 mm of any gap. The top line ("All particles") includes all particles. Only the "Sensor" line comes close to the required energy resolution of 0.015, marked by the dashed horizontal line. Furthermore, excluding gap particles smooths out irregularities in the energy resolution, making the fit to equation 1 better.

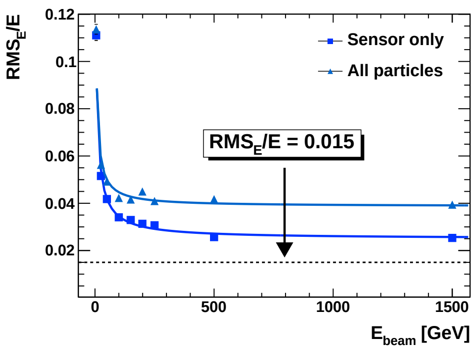
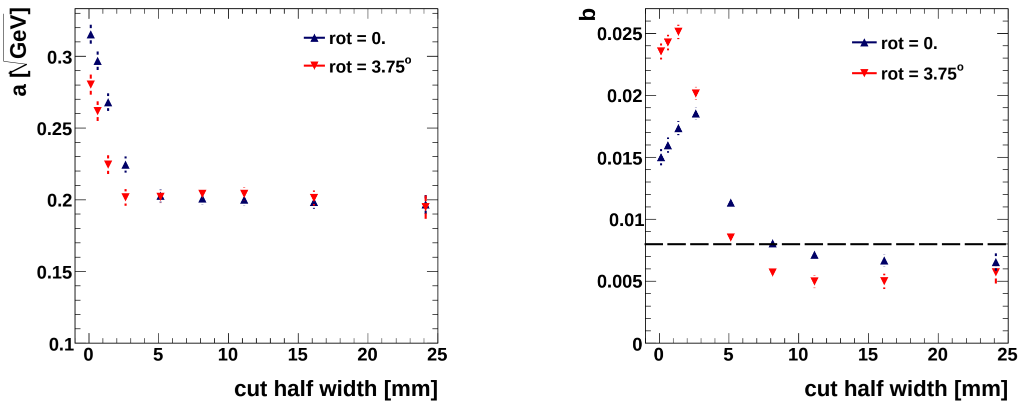


Figure 3: Energy resolution: Gap effect for a 2.0 mm-wide cut. Dashed line shows the required energy resolution.

It is important to consider how the stochastic and leakage parameters contribute to energy resolution. At high energies, the leakage parameter dominates. Using formula 1, for a=0.21 and b=0.01, the terms contribute equally at about 450 GeV. The changes in the parameter values as more particles are excluded are shown in figure. Increasing the cut size improves both parameters. At high energies, the leakage parameter is expected to dominate. This is observed in figure 3, as the curve flattens above 500 GeV.



(a) Stochasic parameter, a

(b) Leakage parameter, b

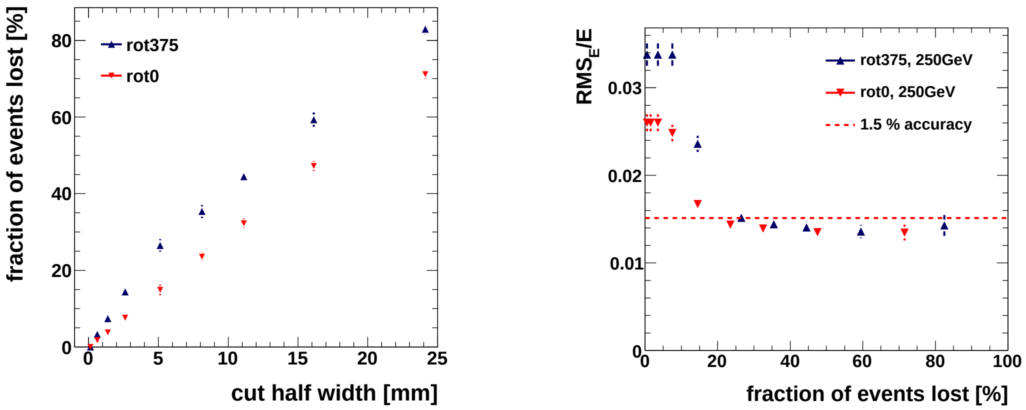
Figure 4: Variation in stochastic and leakage parameters as more particles are excluded. The error bars for the leakage parameters are too small to be seen at this scale.

4 Unrotated geometry loses fewer electrons

It is clear from figure 3 that leakage from the gap particles causes the energy resolution of the detector to be much worse than is acceptable. Figures 2 and 5 suggest that good energy resolution can be acheived if a sufficient number of particles near the gap are removed from the data set. The actual number of particles lost is more relevant to luminosity measurement than the width of the cut. Figure 5(a) gives the relationship between cut width and particle loss. Figure 5(b) shows the energy resolution plotted against particle loss for 250 GeV electrons. From this plot, for a given value for energy resolution, the unrotated geometry retains better statistics than the rotated geometry.

5 Conclusions and considerations

Rotating every odd plane by 3.75^o is insufficient to ensure energy resolution better than 1.5%, so instead it is necessary to cut all particles that are incident near the



(a) Cut width and losses

(b) Energy resolution

Figure 5: Energy resolution for different cut widths at 250 GeV. A similar plot can be obtained for 1500 GeV. Tagging and removing gap particles improves energy resolution to the required limit.

tile gap. In this situation, it seems worthwhile to consider that rotating planes may be unnecessary. An unrotated geometry would have significant advantages in terms of design simplicity. This paper demonstrated that for the case in which gap particles must be cut, an unrotated geometry performs just as well as a rotated geometry does while losing fewer particles.

Acknowledgements

This work was partially supported by the Commission of the European Communities under the 6th Framework Programme Structuring the European Research Area, contract number RII3-026126. It was also supported in part by the Polish Ministry of Science and Higher Education under contracts nr 372/6.PR UE/2007/7 and nr 141/6.PR UE/2007/7. J. Aguilar was supported by the 7th Framework Programme "Marie Curie ITN", grant agreement number 214560. The authors would also like to thank Dr. Marek Idzik and Dr. Leszek Zawiejski for many valuable discussions.

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