EUDET-Memo-2007-17

GEANT4 Simulation of the Electronic Readout Constraints for the Luminosity Detector of the ILC

H. Abramowicz, R. Ingbir, S. Kananov, A. Levy, I. Sadeh *

On behalf of the FCAL collaboration †

September 2007

Abstract

A study was preformed to define the constraints on the electronic readout for the proposed luminosity detector of the International Linear Collider using Mokka, a GEANT4 application. The required dynamical range was studied by simulating the passage of minimum ionizing particles and of electrons at nominal energy of 500 GeV through the detector.

*School of Physics and Astronomy, The Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Tel Aviv Israel.

†List of members can be found at: http://www-zeuthen.desy.de/ILC/fcal/

1 Introduction

The Luminosity Detector (LumiCal) proposed for the precise measurement of luminosity at the international linear collider (ILC) is a tungsten-silicon sandwich calorimeter. The detector is placed 227 cm from the Interaction Point (IP). The LumiCal inner radius is 8 cm, and its outer radius is 35 cm. The longitudinal part of the detector consists of layers, each composed of 0.35 cm of tungsten, a 0.1 cm ceramic support and a 300 μm silicon sensors plane. A 0.1 cm gap for electronics between layers is also simulated.

The detector is subdivided into 30 longitudinal layers. Each layer is called a ring. The transverse plane is referred to as the xy-plane. Subdivisions in the xy-plane in the polar angle are called cylinders, and subdivisions in the azimuthal angle are called sectors. The number of cylinders depends on the ring number. The first four and the last 11 sensor planes are subdivided into 13 cylinders each. The middle 15 sensor planes are subdivided into 104 cylinders each. All 30 sensor planes are subdivided into 48 sectors each. This detector design is referred to as the shower peak design, and is shown schematically in Figure 1.

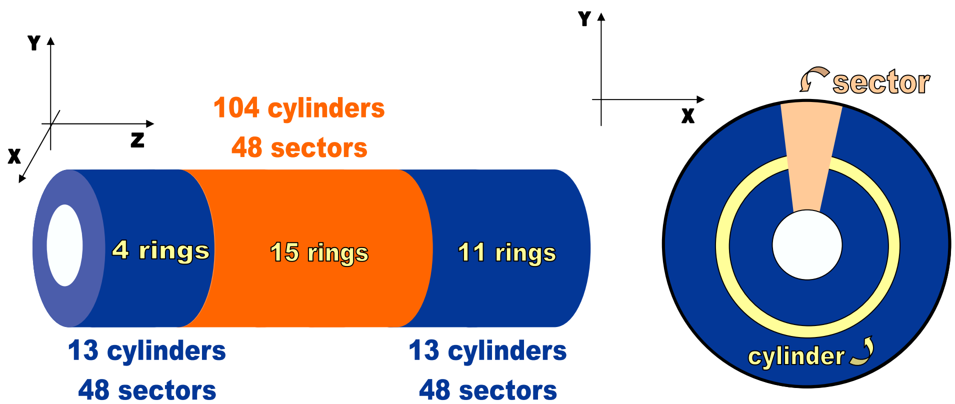

Figure 1: The design of LumiCal. **Left:** The first four and the last 11 sensor planes are subdivided into 13 cylinders and 48 sectors each. The middle 15 sensor planes are subdivided into 104 cylinders and 48 sectors each. **Right:** Subdivisions in the xy-plane.

The purpose of this study to determine the lower and upper bounds on the signal which is expected to be deposited in a sensor cell. LumiCal is intended to measure small angle Bhabha scattering events: $e^+e^- \rightarrow e^+e^-(\gamma)$ [1, 2], a theoretically well understood process, which can be calculated to very high precision [3, 4]. The signature of a Bhabha event in LumiCal is an e^+e^- pair, where the leptons are back to back and carry almost all of the initial energy. For the case of an e^+e^- collider with nominal center of mass energy of 1 TeV, the maximal energy to be absorbed in LumiCal is 500 GeV, and so

500 GeV electrons were used in order to find the upper bound on the signal. In order to determine the lower bound, the passage of muons through the detector was simulated. In the present conceptual approach, muons, which do not shower, will be used to inter calibrate the cells of the detector. Muons may also be used to check *in situ* the alignment of the detector.

2 Charge Distribution for Muons and Electrons

A charged particle passing through a semiconductor leaves a track of electron-hole pairs in its wake, which translates to a measurable current. This current is usually scaled in units of minimum ionizing particles (MIPs). A MIP looses a predictable amount of energy while passing through a given thickness of semiconductor material. The charge induced is proportional to the energy deposited in the semiconductor, as it takes a constant value of energy to create an electron-hole pair (ionization energy). This value depends on the semiconductor band gap structure. For silicon the energy to create an electron-hole pair is 3.67 eV. The most probable value (MPV) of the energy deposited by a MIP per unit length is $(\frac{dE}{dX})_{\mathrm{MPV}} \approx 0.29\frac{\mathrm{keV}}{\mu\mathrm{m}}$ [5]. Therefore, for a 300 μm thick sensor we expect a MIP signal of 94 keV, as shown in Figure 2 (top).

The response of LumiCal to muons and electrons was simulated with Mokka, version 06.03.p01 [6], using the Large Detector Concept (LDC) super-drivers. Mokka is an application of a general purpose detector simulation package, GEANT4, of which version 4.8.1.p02 was used [7]. A previous study has been preformed using version 3.21 of the GEANT package and a different geometry setup of LumiCal [8]. The results presented there are in agreement with this study.

The output of Mokka is in terms energy lost in the active material, silicon in the case of LumiCal. In order to translate the energy signal into units of charge, the following formula was used:

$$S_Q[\mathrm{fC}] = S_E[\mathrm{eV}] \times \frac{1.6 \cdot 10^{-4}}{3.67} \qquad (1)$$

where S_E denotes the signal in units of eV, and S_Q the signal in units of fC. The division by 3.67 eV gives the number of electrons induced by depositing the amount S_E of energy. The number $1.6 \cdot 10^{-4}$ fC is the charge of an electron. According to this, the induced charge for a MIP traversing 300 μm of silicon is 4.1 fC[I].

The distribution of collected charge per cell for 500 GeV electron showers is presented in Figure 2 (bottom). The value of the collected charge extends up to $1.2 \cdot 10^4$ fC, which is equivalent to $3 \cdot 10^3$ MIPs.

[I] It is assumed here that the charge collection efficiency is 100% and that there are no signal fluctuations due to electronic noise. The collected charge is therefore equal to the induced charge.

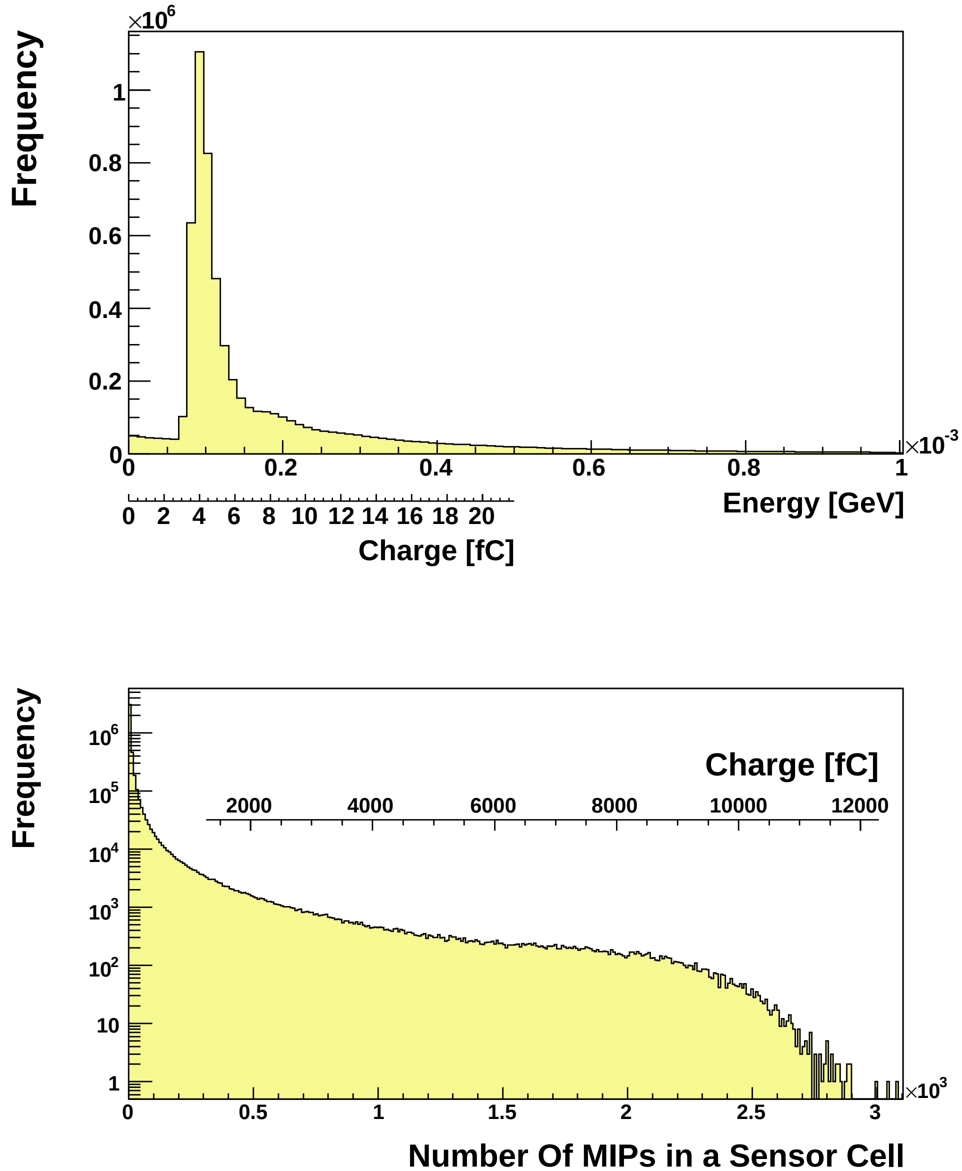

Figure 2: **Top:** Distribution of the energy lost by a muon (MIP) in a 300 μm thick silicon sensor. The corresponding scale in units of charge is shown underneath the energy scale. **Bottom:** Distribution of the signal deposited by a 500 GeV electron shower expressed in units of MIPs. A corresponding scale in units of charge is shown in the figure.

3 Dynamical Range

The electronics of LumiCal should allow the identification and measurement of MIPs as well as of high energy electrons from Bhabha scattering. To accommodate these constraints, the signal output of the detector would than have to be digitized using two separate gain amplifiers [9]. In the high-gain region of amplification one would like to have a resolution better than one MIP. For purposes of identifying the passage of a muon, and to account for electronic noise and current fluctuations, we assume that an allocation of five bins per muon will be necessary.

Assuming that the maximum of the muon charge distribution, which is in the 3rd of the five bins per MIP, will be assigned a value of 4.1 fC (Section 2), the minimal charge that will be measured in the high gain region of amplification will be 1.37 fC (0.3 MIPs). The upper bound on the high gain region will be set by the number of available channels, which is 256 for an 8-bit ADC, and 1024 for a 10-bit ADC. The percentage of the signal which could than be measured in the high gain region is derived from the distribution in Figure 2 (bottom), and is shown in Table 1.

Energy [GeV]	Signal in high gain	
	8-bits	10-bits
100	95.6%	99.3%
250	93.8%	98.3%
500	92.5%	97.4%

Table 1: The percentage of the signal which will be measured in the high gain region for different electron energies.

The requirement on the low gain was determined by studying the maximal charge collected in a single cell per shower, using 500 GeV electrons. The distribution is shown in Figure 3. Approximately 100% of the events fall below 1.2×10^4 fC (3,010 MIPs), and 95% of the events fall below 10.6×10^3 fC (2,585 MIPs). Table 2 showes the low and high gain bounds, assuming this 5% limit.

The digitization schemes discussed above were applied to the simulation of the detector response to single electrons from 50 to 500 GeV. The comparison between the energy resolution of LumiCal with an 8-bit digitization scheme and with no digitization is shown in Figure 4 as a function of electron energy. No degradation in the energy resolution is observed with an 8-bit digitization scheme. Comparable results were obtained for a 10-bit digitization scheme (not shown).

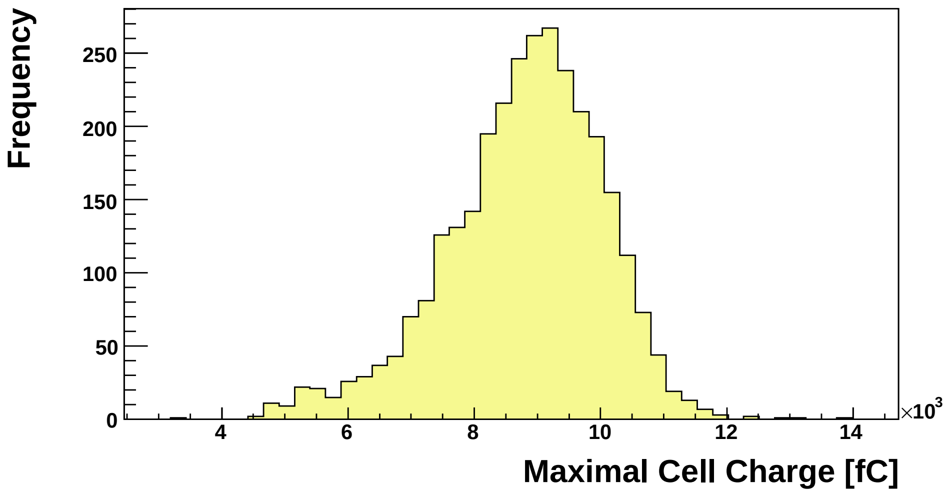

Figure 3: Distribution of the maximal charge collected in a single sensor cell for 500 GeV electron showers.

		8-bits	10-bits
High gain	range - step -	[1.37 , 349] fC 1.37 fC $\mapsto$ 0.3 MIPs	[1.37 , 1396] fC 1.37 fC $\mapsto$ 0.3 MIPs
Low gain	range - step -	[349 , 10575] fC 40 fC $\mapsto$ 9.8 MIPs	[1396 , 10575] fC 9 fC $\mapsto$ 2.2 MIPs
Ratio of low to high gain		29.4	6.6

Table 2: The low and high gain bounds of the signal.

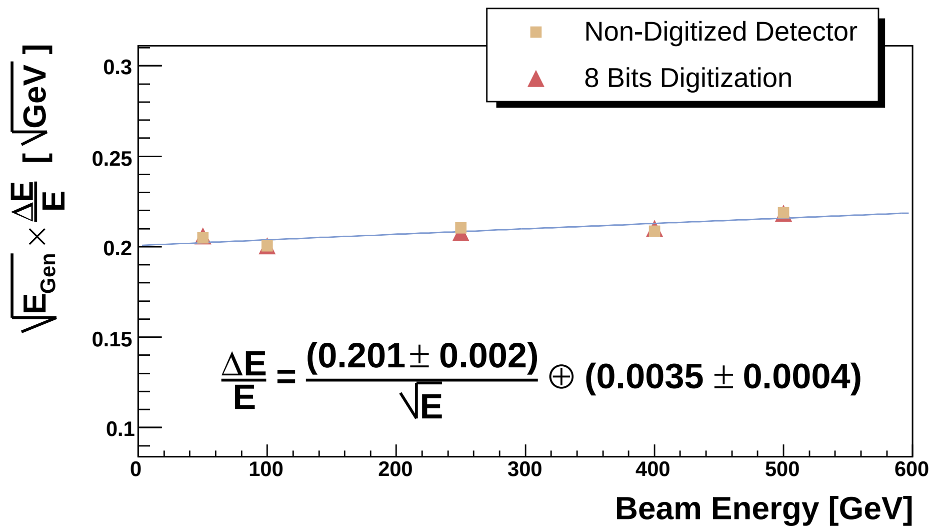

Figure 4: Energy resolution as a function of beam energy for a non-digitized LumiCal and an 8-bit digitized LumiCal, as described in the figure.

4 Summary

The response of LumiCal to the passage of MIPs and of electrons was investigated. The shower peak design was used, assuming that either an 8-bit or a 10-bit ADC is utilized for digitization. It was shown that using an 8-bit ADC does not degredate the energy resolution, and the same holds for 10-bits. For the case of a 10-bit digitization, one would be able to measure 97.4% of the sensors for the case of a 500 GeV electron shower with an accuracy of 1.37 fC (0.3 MIPs). The rest of the hits will than be measured with an accuracy of 9 fC (2.2 MIPs), with a 5% limit on events. The ratio of low to high gain in this case is 6.6.

Acknowledgments

This work is partly supported by the Commission of the European Communities under the 6^{th} Framework Programme "Structuring the European Research Area", contract number RII3-026126, and by the Israeli Science Foundation.

References

[1] H. Abramowicz, R. Ingbir, S. Kananov, and A. Levy. Monte Carlo study of a luminosity detector for the International Linear Collider. arXiv.org:physics/0508074, 2005.

[2] R. Ingbir MSc thesis. http://alzt.tau.ac.il/∼ronen/msc/msc.html, 2006.

[3] S. Jadach, Theoretical error of luminosity cross section at LEP, hep-ph/0306083.

[4] J. Fleischer, A. Lorca and T. Riemann, Automatized calculation of 2-fermion production wit h DIANA and aITALC, hep-ph/0409034.

[5] W-M Yao *et al.*, Particle Data Group- Review of Particle Physics. (2006), J. Phys. G: Nucl. Part. Phys. 33 1. http://pdg.lbl.gov

[6] MOKKA - a detailed GEANT4 detector simulation for the Future Linear Collider, http://polywww.in2p3.fr/geant4/tesla/www/mokka/mokka.html

[7] J. Allison, et al., GEANT4 Developments and Applications, in IEEE Transactions on Nuclear Science, Vol. 53, No. 1, Feb. 2006, pp. 270-278.

[8] H. Abramowicz, R. Ingbir, S. Kananov, A. Levy, I. Sadeh, Constraints on the Electronic Readout for the Luminosity Detector of the ILC, EUDET-Memo-2007-12, http://www.eudet.org

[9] R. Ingbir talk at FCAL Munich meeting, Luminosity Detector Research and Development TAU update, http://www-zeuthen.desy.de/ILC/fcal/pages/Munich06.html , 2006.