EUDET-Memo-2007-12

Constraints on the Electronic Readout for the Luminosity Detector of the ILC

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

On behalf of the FCAL collaboration †

June 2007

Abstract

A study was preformed to define the constraints on the electronic readout for the proposed luminosity detector of the International Linear Collider. The required dynamical range was studied by simulating the passage of minimum ionizing particles and of electrons at nominal energy of 250 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 longitudinal part of the detector consists of layers, each composed of 0.34 cm of tungsten and a 0.31 cm gap. 500 μm of the gap consists of a silicon sensors plane, and the rest contains electronics. For simulation purposes, the electronics was replaced by silicon.

The detector is subdivided into 29 longitudinal layers. Each tungsten layer is called a ring. An additional silicon sensor plane was placed in front of the first 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 10 cylinders each. The middle 15 sensor planes are subdivided into 60 cylinders each. All 30 sensor planes are subdivided into 24 sectors each. This detector design is referred to as the shower peak design, and is shown schematically in Figure 1.

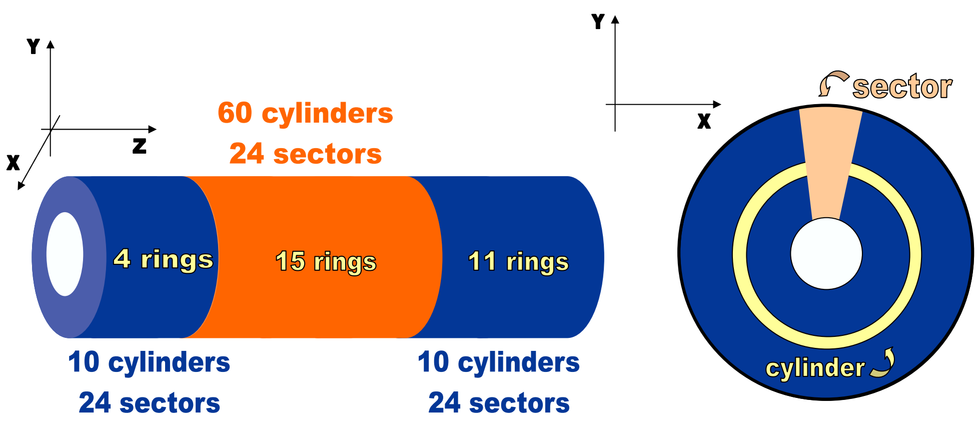

Figure 1: The design of LumiCal. **Left:** The first four and the last 11 sensor planes are subdivided into 10 cylinders and 24 sectors each. The middle 15 sensor planes are subdivided into 60 cylinders and 24 sectors each. **Right:** Subdivisions in the xy-plane.

The purpose of this study is the determination of 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 500 GeV, the maximal energy to be absorbed in LumiCal is 250 GeV, and so 250 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.

When a high-energy electron or photon is incident on a thick absorber, it initiates an electromagnetic cascade as pair production and bremsstrahlung generate more electrons and photons with lower energy [5]. The energy eventually falls below the critical energy, and then the charged particles dissipate their energy by ionization and excitation rather than by the generation of more shower particles.

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's band gap structure. For silicon the energy to create an electron-hole pair is 3.67 eV. The most probable value 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 500 μm thick sensor we expect a MIP signal of 150 keV.

The response of LumiCal to muons and electrons was simulated with the GEANT3.21 general purpose detector simulation package [6]. The output of GEANT3.21 is in terms of lost energy. In order to translate the energy signal into units of charge, the following formula was used:

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

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 500 μm of silicon is 6.6 fC[I].

2 Charge Distribution for Muons

The properties of the longitudinal electron shower development and the granularity of LumiCal are such that the amount of charge collected per sensor cell will differ in the various regions of the detector. While for electrons this is certainly important, for muons, which do not create showers in the detector, no difference in the measured signal is expected. This is indeed the case, as is demonstrated in Figure 2. There, the distribution of the deposited charge per sensor cell is shown for two different subdivisions

[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.

of LumiCal. In one case, the whole detector was assumed to have the granularity of the front and back rings of the shower peak design, while in the second case the granularity of the middle rings was used. With the exception of tails for large charge deposits, which may be due to catastrophic energy losses, the two distributions are in good agreement.

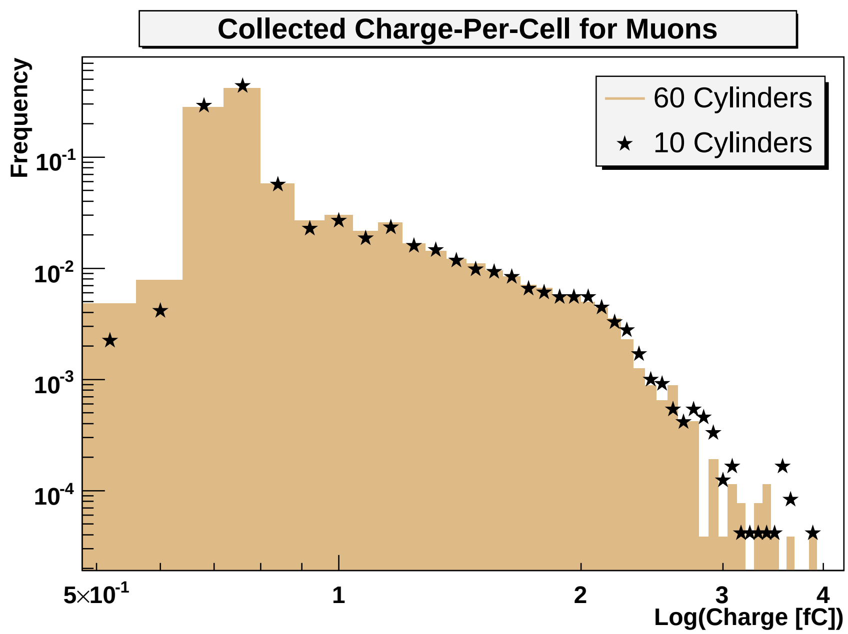

Figure 2: Distribution of the collected charge per sensor cell for 250 GeV muons. Two LumiCal subdivisions in the xy-plane were used, as described in the figure.

3 Charge Distribution for Electrons

The distribution of collected charge per cell in the shower peak design is presented in Figure 3. The value of the collected charge extends up to $2 \cdot 10^4$ fC, as opposed to the case of muons, where the collected charge extends up to $7.8 \cdot 10^3$ fC.

4 Dynamical Range

The most commonly used ADCs, and therefore the cheapest, are 8-bit ADCs. Taking this into consideration, an 8-bit digitization scheme was considered. 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 [7]. In the high-gain region of amplification one would like to have a resolution better

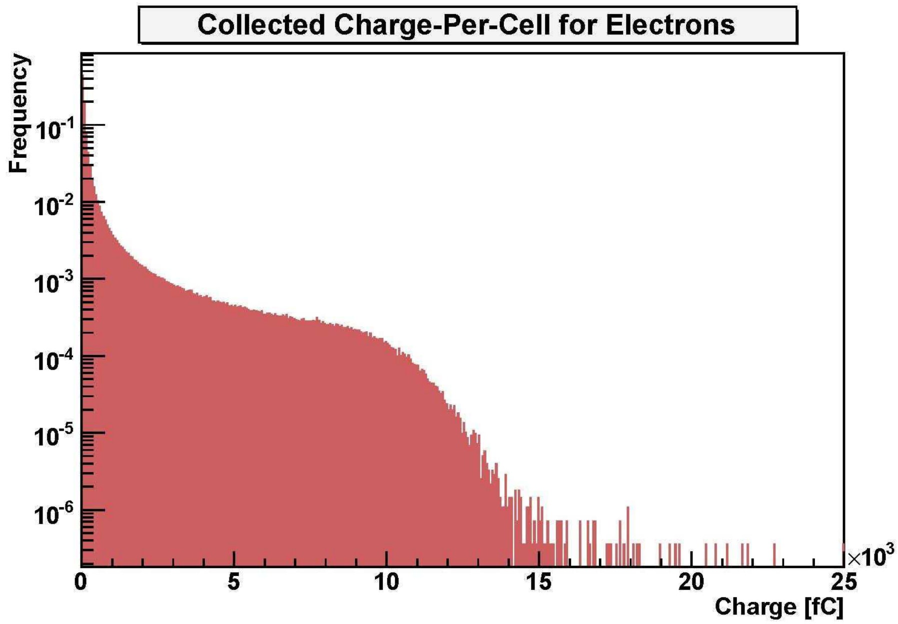

Figure 3: Distribution of the collected charge per sensor cell for 250 GeV electron showers and the shower peak design.

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 to 6.6 fC (Section 1), the minimal charge that will be measured in the high gain region of amplification will be 2.2 fC (0.3 MIPs). Taking into account that an 8-bit ADC has 256 channels, one would than be able to measure up to 563.2 fC (85 MIPs). This would allow to measure 82% of the sensor signals for the case of a 250 GeV electron shower, as derived from the distribution in Figure 3.

The requirement on the low gain was determined by studying the maximal charge collected in a single cell per shower, using 250 GeV electron showers. The distribution is shown in Figure 4. Approximately 100% of the events fall below 17.5×10^3 fC (2652 MIPs), and 93% of the events fall below 12×10^3 fC (1818 MIPs). Assuming this 7% limit, the low gain amplification, covering the range of collected charge above 563.2 fC, will set the resolution to 44.7 fC (6.8 MIPs). The ratio of low to high gain will therefore be 20.3.

Using an 8-bit ADC does not degredate the energy resolution, as is shown in Figure 5.

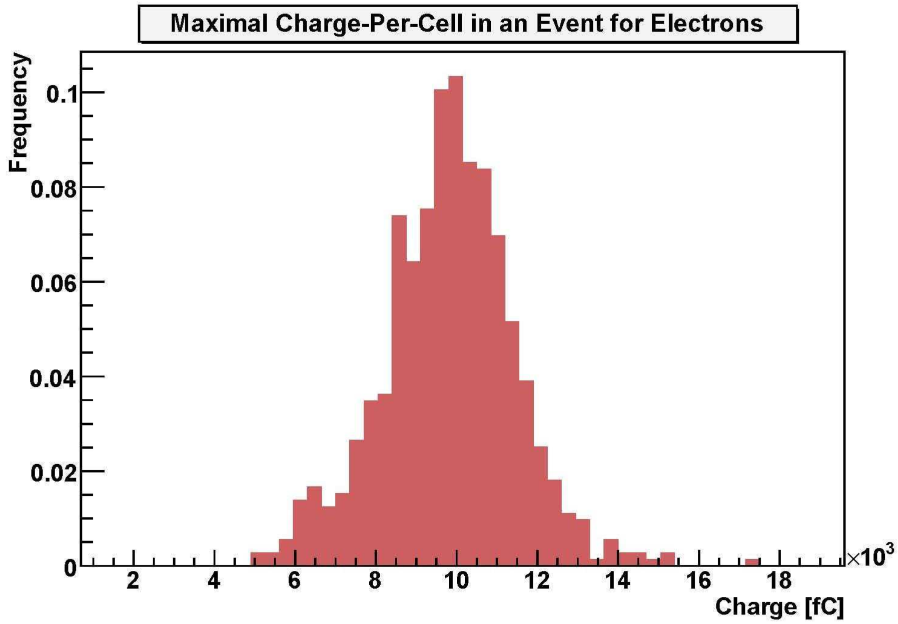

Figure 4: Distribution of the maximal charge collected in a single sensor cell for 250 GeV electrons and the shower peak design.

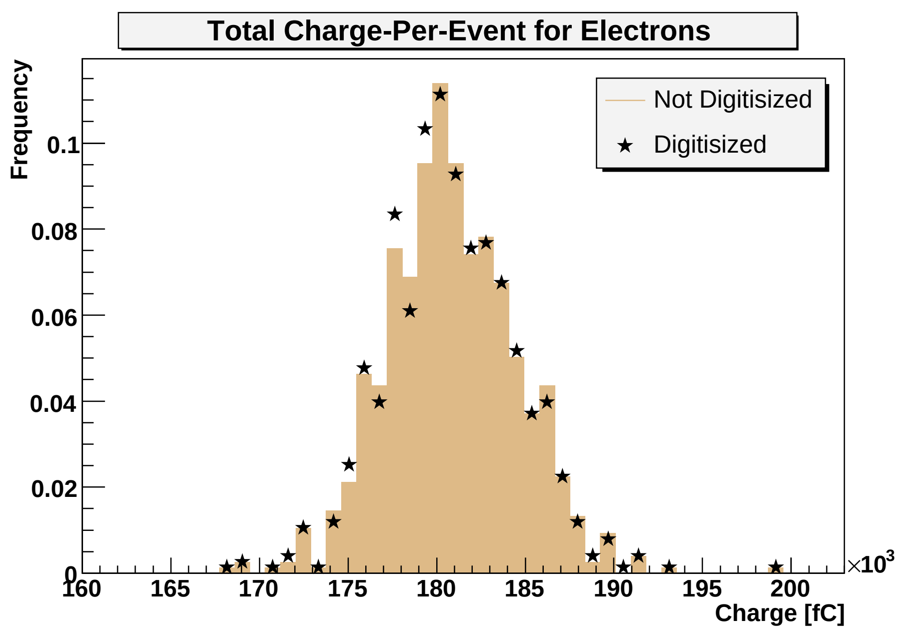

Figure 5: Distribution of the total charge collected in an event for 250 GeV electrons and the shower peak design. A digitized and a non-digitized detector was used, as described in the figure

5 Summary

The LumiCal response to the passage of MIPs and of electrons was investigated. The shower peak design was used, assuming that an 8-bit ADC is utilized for digitization. One would than be able to measure 82% of the sensors for the case of a 250 GeV electron shower with an accuracy of 2.2 fC (0.3 MIPs). The rest of the hits will than be measured with an accuracy of 44.7 fC (6.8 MIPs), with a 7% limit on events. It was shown that using an 8-bit ADC does not degredate the energy resolution. The ratio of low to high gain in this case is 20.3.

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] R. Brun, F. Bruyan, M. Maire A. C. McPherson and P. Zanarini, GEANT3, 1984.

[7] 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.