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FORWARD CALORIMETRY AT ILC

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Abstract
The very forward region of a detector at the International Linear Collider (ILC) is particularly challenging area for instrumentation. Forward calorimeters should provide luminosity measurement with the high precision, tuning of the beam parameters, detector hermeticity at lowest polar angles and shielding of the central detectors from backscattered particles. High-energy electron identification is particularly important to veto Standard Model background to new particle searches. In addition, extreme radiation hardness in required for the innermost calorimeter due to several tens of TeV depositions of beamstrahlung remnants per bunch crossing.
Keywords: ILC, luminosity measurement, beam diagnostics

1. Introduction

International Linear Collider is a proposed future international particle accelerator. It will create high-energy particle collisions between electrons and positrons, and provide a tool for scientists to address many of the most compelling questions like ones related to electroweak symmetry breaking, unification of forces, dark matter, space-time with additional dimensions and many others. It is designed [1] to achieve an initial center-of-mass energy up to 500 GeV with the ability to upgrade to 1 TeV, and the nominal luminosity of $2\cdot10^{34}$ $\text{cm}^{-2}\text{s}^{-1}$. ILC will work in complement with the LHC (Large Hadron Collider) at CERN dedicated primarily to discover Higgs bosons and SUSY particles, while ILC will provide precise measurements of characteristics of these particles (masses, quantum numbers, couplings) since a collision between an electron and a positron is much simpler than a collision between many quarks, antiquarks and gluons confined in a proton. In 2007 the Reference Design Report of ILC has been delivered with an Engineering Design Report expected in 2010.

The very forward region of ILC (below 150 mrad) will accommodate three sub-systems in decreasing order of polar angle: the luminosity calorimeter (LumiCal) for precision luminosity measurement, the beam calorimeter (BeamCal) for beamdiagnostics and high-energy electron identification close to the beam pipe and the beamstrahlung photons monitor (GamCal) also for beamdiagnostics and instantaneous luminosity measurement.

Instrumentation of the very forward region is facing particular challenges like high precision in polar angle reconstruction, efficient particle identification, radiation hardness, high occupancies and a fast read-out. The layout of the forward region of the LDC detector, as considered in the present study, is given in Figure 1 [2].

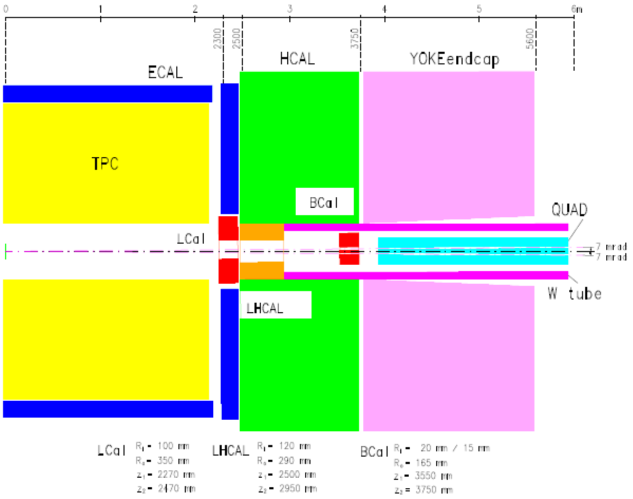


Figure 1. Layout of the very forward region of the LDC detector. BCal, LCal, HCAL, ECAL, TPC, QUAD and LHCAL are denoting Beam Calorimeter, Luminosity Calorimeter, Hadronic Calorimeter, EM Calorimeter, Time Projection Chamber, final quadrupole and a possible low-angle hadronic calorimeter.

2. Luminosity Calorimeter

A cylindrical electromagnetic calorimeter has been designed for measurement of the total luminosity. It is a compact highly granulated sandwich calorimeter (Figure 2 [2]) consisting of 30 longitudinal layers of silicon sensor followed by tungsten absorber and the interconnection structure. Each detector layer corresponds to about one radiation length. It is located at z = 2270 mm from the IP, covering the polar angle range between 44 and 155 mrad, for the 14 mrad crossing-angle between the beams. In addition, detector is placed around the outgoing beam in order to avoid phi-dependency of the luminosity relative error.

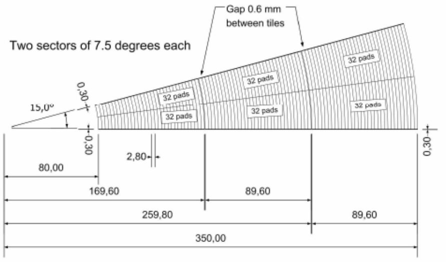


Figure 2. Silicon sensor layout for the LumiCal.

Precision of luminosity measurement is driven by physics requirements for the cross-section measurements (i.e. the total hadronic cross-section at Z^0 resonance, 2-fermion production at high energy) and precision EW measurements (EWSB - anomalous gauge boson couplings) requiring $\Delta L / L$ being of order of 10^{-4} to 10^{-3}.

Integrated luminosity at ILC will be determined from the total number of Bhabha events produced in the acceptance region of the luminosity calorimeter and the corresponding theoretical cross-section (1).

$$L_{\mathrm{int}} = \frac{N_{th}}{\sigma_B} \tag{1}$$

Bhabha scattering at small angle is precisely calculable in QED ($\Delta\sigma_{th}/\sigma_{th} \approx 10^{-4}$) and has a sufficiently large cross-section to deliver high statistics for luminosity measurement of the required precision. With the cross-section of approximately 4 nb in the luminosity calorimeter angular range, at 500 GeV center-of-mass energy and the nominal ILC luminosity of $2 \cdot 10^{34}$ $\mathrm{cm}^{-2}\mathrm{s}^{-1}$, about 10^9 events will be collected per year, corresponding to the statistical error of order of 10^{-5}. However, one has to provide precision particle reconstruction and, in addition, to control numerous systematic effects.

The cross-section is falling steeply with increasing polar angle as $1/\theta^3$, causing luminosity measurement to be sensitive to the detector aperture $\theta_{\min}$ (or corresponding inner radius of the luminosity calorimeter) (2).

$$\frac{\Delta L}{L} \approx 2 \cdot \frac{\Delta\theta}{\theta_{\min}} \tag{2}$$

Two parameters are describing quality of the position reconstruction: bias $\Delta\theta$ and resolution of the polar angle measurement $\sigma(\theta)$. Suggested design of the LumiCal sensors has been proven through simulation to provide bias and polar angle resolution better then 10^{-3} and 10^{-2} mrad respectively.

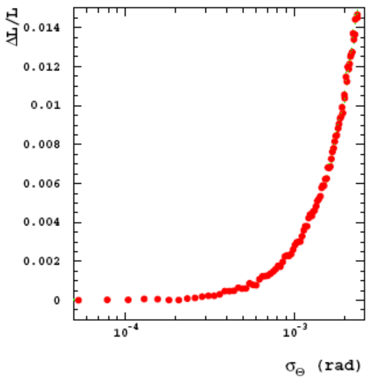
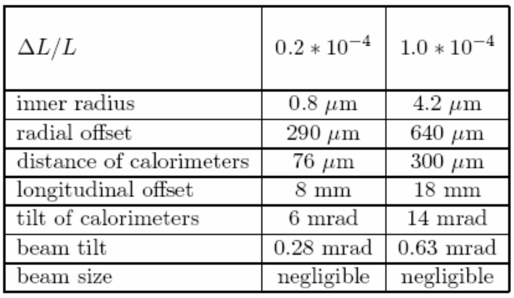


Figure 3. Relative error on luminosity as a function of polar angle resolution.

Dependence of the relative error of luminosity on polar angle resolution is given in Figure 3 [2].

At the same time, numerous sources of systematic uncertainties have to be controlled: position and alignment of the detector, background from physics processes (4-fermion production via Neutral Current), beam-beam interaction effects. Table 1 [2], summarizes requirements on detector precision and alignment parameters.

Table 1. Requirements on luminosity calorimeter position and alignment.



$\Delta L/L$	$0.2 * 10^{-4}$	$1.0 * 10^{-4}$
inner radius	0.8 μm	4.2 μm
radial offset	290 μm	640 μm
distance of calorimeters	76 μm	300 μm
longitudinal offset	8 mm	18 mm
tilt of calorimeters	6 mrad	14 mrad
beam tilt	0.28 mrad	0.63 mrad
beam size	negligible	negligible

Detailed studies [3] showed that beam-beam interaction results in effective suppression of the Bhabha cross-section of order of a percent, at 500 GeV center-of-mass energy. It also implies asymmetric selection of Bhabha events in order to accommodate for the enhanced Bhabha acolinearity due to EM deflection. As can be found in [4], with such selection it is still possible to keep the error of luminosity measurement originating from uncertainty of the number particles from physics background misidentified as Bhabhas at the level of 10^{-3}.

3. Beam Calorimeter and Gamma Calorimeter

As luminosity calorimeter, beam calorimeter is also compact silicon-tungsten sandwich calorimeter, consisting of 30, one radiation length thick, layers of sensor and absorber planes. Sensor planes are segmented into pads of 0.5-0.8 Molière radiuses. Electrons and positrons, originating from conversion of beamstrahlung photons, carrying several 10 TeV of energy per bunch crossing, will hit beam calorimeter.

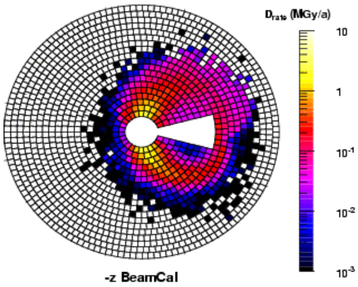


Figure 4. Annual depositions at BeamCal sensor plane from pairs converted from beamstrahlung. [5]

On the top of widely spread depositions from beamstrahlung (Figure 4), it is important to efficiently identify a high-energetic electron. Standard Model processes like $e^+e^- \to 2\gamma \to e^+e^-l^+l^-$ can fake SUSY process $e^+e^- \to \chi^0\chi^0 l^+l^-$ due to the loss of spectator electron along the beam pipe. In addition, corresponding cross-sections for SM 2-photon processes and the SUSY signal are of order of nb and fb respectively.

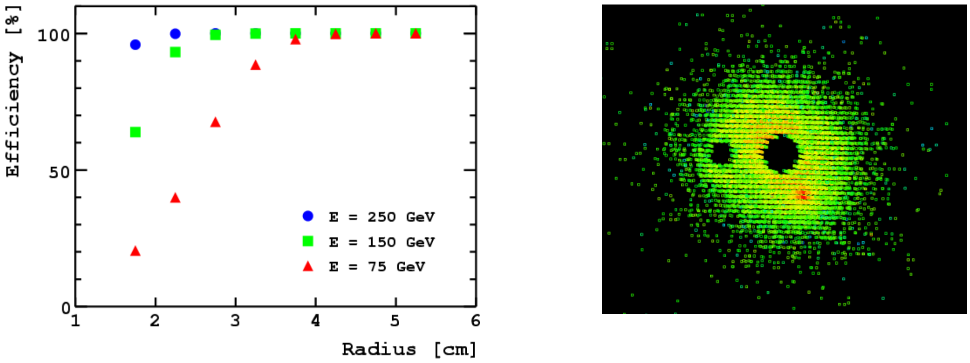


Figure 5. Electron identification efficiency and simulation on 2-photon electron in the BeamCal on the top of beamstrahlung remnants [2].

Beam calorimeter is also providing measurement of the beam parameters based on observables like total deposited energy, first radial moment, left/right and up/down asymmetries of beamstrahlung depositions, by employing (3)

$$O=O_{\mathrm{nom}}+T\cdot\Delta B \tag{3}$$

where O and O_{nom} are matrices of observables for changed and nominal beam parameters, ΔB is a change of beam parameters from its nominal values and T is a Taylor expansion matrix. Moore-Penrose Method is applied to obtain T^{-1}. This information can be used for a fast luminosity optimization by providing it to the beam delivery feedback system.

The Gamma Detector – GamCal is providing complementary information to the BeamCal on beamdiagnostics. By exploiting idea that the small fraction of beamstrahlung photons will convert into Bethe-Heitler pairs, with the ratio of BH pairs to beamstrahlung photons proportional to the number of electrons in the beam, GamCal is providing information on instantaneous luminosity. In addition, energy of Bethe-Heitler pairs and beamstrahlung gammas are sensitive to shape and offset of bunches thus serving for supplementary beamdiagnostics.

Table 2 illustrates diagnostics of the basic bunch parameters by simulation of the beamstrahlung remnants in the BeamCal [2].

Depositions of high radiation doses from converted pairs require radiation hard sensors operational, in terms of linearity of the response, CCD degradation, etc, after absorbing several MGy per year. Several materials are under study, including poly and mono CVD, GaAs and radiation-hard Si.

Table 2. Precision of determination of bunch sizes with the BeamCal.

Beam parameter	Nominal value	Precision Head-on	 2 mrad	 20 mrad
σ_x [nm]	655	1.2	3.1	2.9
σ_y [nm]	5.7	0.1	0.3	0.2
σ_z [μm]	300	4.2	4.8	8.5

4. Conclusions

The FCAL Collaboration develops detectors in the very forward region of the ILC. FCAL detectors are going to provide precision luminosity measurement (LumiCal), efficient particle reconstruction relevant for new physics searches (BeamCal), beamdiagnostics (BeamGal and GamCal) and luminosity monitoring (GamCal). MC simulations are providing clear understanding of implications of detector design on physical measurements. At the same time, systematic effects such as physics background, beam-beam effects, etc. have to be well understood.

Acknowledgements

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