

Luminosity Measurement at ILC

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The FCAL Collaboration joins effort of more than twenty institutes studying a design of the very forward region of a detector for ILC and CLIC. Of particular importance is an accurate luminosity measurement to the level of 10^{-3} , the requirement driven by the potential for precision physics at a future linear collider. In this talk, the method for luminosity measurement, requirements on luminometer and its integration in the forward region are presented. The impact of several effects contributing to the systematic uncertainty of luminosity measurement is given.

1 Introduction

Physics requirements like production cross-sections measurements, anomalous gauge boson couplings, EW physics and new physics searches impose precision of luminosity measurement at a future linear collider. Luminosity will be measured from Bhabha scattering that is dominantly QED process at ILC energies. Achievable precision is limited both by the reconstruction of scattered Bhabha particles as well as by physics effects (collective space charge effect, presence of physics background) that have to be experimentally controlled. At the same time, there is an on-going theoretical effort to complete NLO corrections of the Bhabha cross-section.

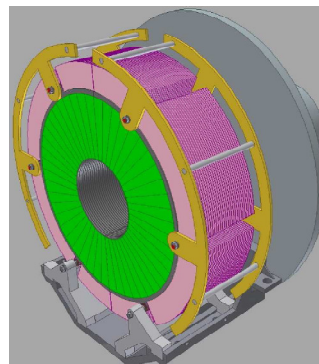


Figure 1: Mechanical structure of the luminosity calorimeter.

2 Luminometer at ILC

Luminosity calorimeter is foreseen as a sampling Si/tungsten calorimeter consisting of 30 one radiation length thick absorber planes followed by segmented silicon sensor planes. To keep the Moliere radius of 1.5 cm, 1 mm sensor gaps are provided. As illustrated in Figure 1,

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tungsten disks are precisely positioned using 4 bolts additionally stabilized by steel rings. Reconstruction of the polar angle of electron is influenced by sensor segmentation that is optimized to 48/64 azimuthal/radial divisions. Luminosity calorimeter is positioned 2.5 m from the IP, with the geometrical aperture between 31 mrad and 78 mrad. Sufficient statistics corresponding to the 2.1 nb of integrated cross-section of the signal is provided in the detector fiducial volume [41,69] mrad [1]. By restricting the signal for luminosity measurement onto the detector fiducial volume, only events with no shower leakage through the edges of luminosity calorimeter are selected. In this volume, a stable sampling term α_{res} (2.1), usually referred to as ‘energy resolution’ is obtained (Figure 2).

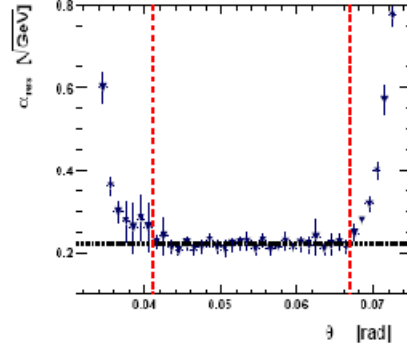


Figure 2: Energy resolution for 250 GeV electrons as a function of the polar angle. Dashed lines mark fiducial volume of the luminosity calorimeter.

In (1.1), the usual parameterization of energy resolution σ_E corresponding to the standard deviation of an energy distribution with a mean E , deposited by electron beam E_{beam} is given:

$$\frac{\sigma_E}{E} = \frac{\alpha_{res}}{\sqrt{E_{beam}[GeV]}} \quad (2.1)$$

Simulating only electron showers inside luminometer’s fiducial volume, α_{res} is estimated to be: $\alpha_{res} = (0.21 \pm 0.02)\sqrt{GeV}$, within statistical error. Parameter α_{res} is found to be independent of shower energy in the range from 50 GeV to 300 GeV. In the same range, response of luminosity calorimeter is linear with respect to the shower energy [1]. The position of an EM shower in the detector is reconstructed by performing a weighted average over the depositions on individual pads. The weight W_i , of a given detector pad i , is determined by logarithmic weighting [2], for which $W_i = \max\{0, C + \ln(E_i/E_{tot})\}$. The symbol E_i refers to the individual pad energy, E_{tot} is the total energy in all pads, and C is a constant. In this way, only pads which contain a sufficient fraction of the shower energy contribute to the reconstruction. The polar angle resolution σ_θ , and a polar angle measurement bias $\Delta\theta$, are defined as the Gaussian width and the central value of the distribution of the difference between the reconstructed and the generated polar angles. They are found to be $(2.2 \pm 0.01) \cdot 10^{-2}$ mrad and $(3.2 \pm 0.1) \cdot 10^{-3}$ mrad, respectively. Uncertainties of α_{res} , σ_θ and $\Delta\theta$ will be considered in Chapters 3.2.3 and 3.2.4 as sources of systematic uncertainty for luminosity measurement.

3 Luminosity measurement an ILC

3.1 Method

At ILC, integrated luminosity will be determined from the counted number of Bhabha events reconstructed in the detector fiducial volume N_{exp} , corrected for the number of miss-counted

events due to various effects. As in (3.1), measured luminosity will also depend on the selection efficiency ε and theoretical cross-section for Bhabha scattering σ_B .

$$L_{\text{int}} = \frac{N_{\text{exp}} - \sum_i N_i^{\text{cor}}}{\varepsilon \cdot \sigma_B} \quad (3.1)$$

In order to exploit characteristic topology of Bhabha events with two back-to-back showers deposited almost full beam energy in forward and backward arms of the detector and, at the same time, to minimize effective suppression of the Bhabha cross-section due to collective space charge effects [3], the following empirical selection is applied: the polar angle of the reconstructed shower must be within the detector fiducial volume $[\theta_{\text{min}}, \theta_{\text{max}}]$ at one side and within $[\theta_{\text{min}}+4 \text{ mrad}, \theta_{\text{max}}-7\text{mrad}]$ at the other, and the total energy deposited in the luminometer must be more than 80% of the center-of-mass energy. Polar angle criterion is subsequently applied at forward and backward side of the detector in order to avoid systematic uncertainty from the longitudinal position of the interaction point.

3.2 Systematic uncertainties

3.2.1 Beam-beam effects

The acceleration of electrons and positrons towards the bunch center when bunches are crossing changes their momentum direction and, more important, electron and positron radiate beamstrahlung prior to Bhabha scattering. In addition, final state Bhabha particles get focused by the electromagnetic field of the opposite space charge. The result is effective reduction of the Bhabha cross-section in the detector fiducial volume, where the dominant contribution comes from the beamstrahlung. Size of the Bhabha Suppression Effect (BHSE) is found to depend on selection criteria for luminosity measurement, amounting to $1.51\% \pm (0.05\%)_{\text{stat}}$ [3]. for nominal beam parameters at 500 GeV center of mass energy, for the proposed event selection. BHSE can be taken as a correction, once its experimental uncertainty is known. Data-driven method to measure beamstrahlung component of BHSE is proposed, based on reconstruction of the luminosity spectrum [3]. Experimental uncertainty is resulting from the precision to which bunch sizes σ_x and σ_z are measured. In this paper, BHSE experimental uncertainty corresponding to 5% relative error of bunch sizes is assumed (Table 1).

3.2.2 Background from physics processes

Four-fermion production via Neutral Current is known to be of large cross-section with maxima at low polar angles. It is dominated by the multiperipheral Feynman diagram where two virtual photons are exchanged between electron spectators. The spectators remain at high energy. Less than 1% of spectators hits the luminosity calorimeter and manifests a background for Bhabha events. The cross-section amounts to $(12.0 \pm 0.5) \text{ nb}$ at 500 GeV allowing photons with momentum larger than 0.1 GeV/c to be exchanged. We used WHIZARD [4] event generator to obtain sample of events for final states with leptons in the inner legs. Event generator is tuned to reproduce LEP data for charm production in two-photon processes [5] by further reduction of minimal exchanged momentum to 10^{-4} GeV/c . A Bhabha sample of 5 pb^{-1} has been generated with the cross-section of $(4.70 \pm 0.03) \text{ nb}$, at 500 GeV, using BHLUMI [6] event generator. As said in 3.1, selection is optimized to reduce

Bhabha suppression from space charge effects. After selection is applied, overall impact of four-fermion events on luminosity measurement saturates with background to signal ratio $B/S=2.3 \cdot 10^{-3}$ at 500 GeV. The Bhabha event selection efficiency is sufficient to maintain statistical error below 10^{-3} for annual high energy run at nominal luminosity. Projection of background hits on the front plane of the luminosity calorimeter is given in Figure 3, before and after event selection.

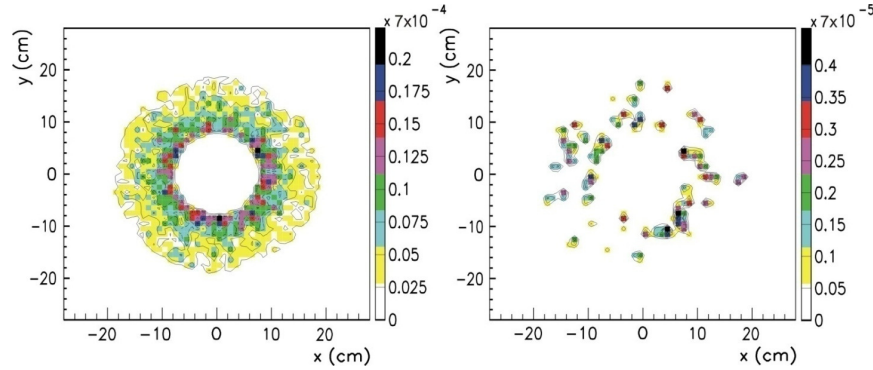


Figure 3: Projections of background hits in the luminometer front plane before (*left*) and after selection (*right*).

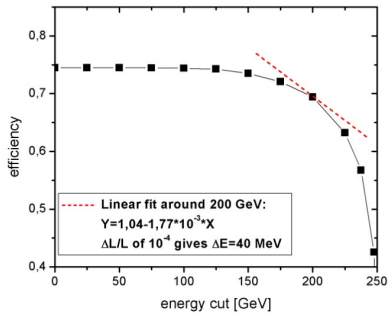


Figure 4: Selection efficiency dependence on the cut-off energy.

fit (Figure 4) at the energy cut-off, with the slope of $-1.77 \cdot 10^{-3}$. Detector energy resolution must be understood to $\Delta\alpha_{\text{res}}=2.5\%$ to contribute to the relative uncertainty in luminosity of 10^{-4} , as proven also in [10]. In both cases, photons irradiated from the final state are excluded from the simulation. If radiative photons, emitted by Bhabha particle within cone of one Moliere radius, would be taken into account, ΔE and $\Delta\alpha_{\text{res}}$ would be relaxed to 67 MeV and 4.3%, respectively [11].

3.2.3 Effects from energy resolution and bias of energy scale

Event selection for luminosity measurement is based on criterion that total deposited energy in the fiducial volume of the luminosity calorimeter is more than 80% of the center of mass energy. A possible uncertainty of Bhabha selection efficiency due to the bias of measured energy, or uncertainty of the stochastic term α_{res} in (2.1), will result in corresponding uncertainty of luminosity measurement.

To keep contribution to the luminosity uncertainty below 10^{-4} , absolute uncertainty of measured deposited energy in the luminosity calorimeter (ΔE) have to be 39 MeV. This is obtained from the linear

3.2.4 Effects from polar angle resolution and bias in polar angle reconstruction

The existence of the bias in polar angle reconstruction may cause a shift in the luminosity measurement, since events may be pushed in or out of the detector fiducial volume. With the present bias of the polar angle reconstruction, relative uncertainty of the luminosity measurement of $1.6 \cdot 10^{-4}$ is expected as the upper bound. In practice, it is possible to measure bias of the polar angle in a test beam. Once this is done, uncertainty of this measurement will contribute to the luminosity uncertainty. The same order of contribution to the relative uncertainty of luminosity measurement can be expected from the resolution of polar angle reconstruction [11].

Source of uncertainty	$\Delta L/L$
Bhabha cross-section σ_B	$5.4 \cdot 10^{-4}$
Polar angle resolution σ_θ	$1.6 \cdot 10^{-4}$
Bias of polar angle $\Delta\theta$	$1.6 \cdot 10^{-4}$
Energy resolution α_{res}	$1.0 \cdot 10^{-4}$
Energy scale	$1.0 \cdot 10^{-4}$
Physics background B/S	$2.3 \cdot 10^{-3}$
BHSE	$1.5 \cdot 10^{-3}$
Beam polarization	$1.9 \cdot 10^{-4}$
Σ	$3.0 \cdot 10^{-3}$

Table 1: Summary on systematic errors in luminosity measurement. Errors are assumed to be uncorrelated. Uncertainty of the theoretical cross-section for Bhabha scattering is taken to be as at LEP energies.

3.2.5 Polarization of beams

If polarization of electron and positron beams is available at ILC as foreseen, it will suppress the Bhabha cross section in the acceptance range of the luminometer up to a few per cent [8]. In the current design, the maximum values for electron and positron polarization are 0.8 and 0.6, respectively, with an uncertainty of 0.0025 [9], producing relative reduction of the Bhabha cross section of $2.3 \cdot 10^{-2}$ with an uncertainty of $1.9 \cdot 10^{-4}$ that translates into relative uncertainty of measured luminosity.

4 Conclusion

At the present level of understanding of the detector performance and physics effects in luminosity measurement it has been shown that it will be possible to measure integrated luminosity at ILC with the total systematic uncertainty of $3 \cdot 10^{-3}$. The largest uncertainty due to two-photon background can clearly be reduced by correcting for it and using its uncertainty from NLO corrections as a true source of uncertainty of luminosity measurement. As well, effects from the polar angle reconstruction taken at present at full sizes can be replaced by their uncertainties once they are known.

5 Bibliography

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