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SYSTEMATIC EFFECTS IN LUMINOSITY MEASUREMENT AT ILC

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Abstract
In order to achieve required precision of luminosity measurement at the International Linear Collider (ILC), that is of order of 10^{-4}, systematic effects have to be understood at the level of this precision. Apart from systematic effects originating from hardware design and precision of the detector alignment, physics processes also contribute either as a background or additional interaction effects. Properties of physics background, its separation from the Bhabha signal, as well as the influence of selection criteria on the overall systematics of the measurement have been studied.
Keywords: International Linear Collider, luminosity, precision measurements.

1. Introduction

The International Linear Collider is a high-energy particle electron-positron accelerator. It is designed [1] to achieve an initial centre-of-mass (cms) energy up to 500 GeV with the ability to upgrade to 1 TeV, and the nominal luminosity of $2\cdot 10^{34}\ cm^{-2}\ s^{-1}$. The full $\sqrt{s}$ will be available at ILC, with defined initial state, including helicity. The full final state can be reconstructed employing energy-momentum conservation. Due to the small background, practically all process of interest will be visible at the ILC. Hence it is anticipated that ILC will be used to make precision measurements of the properties of particles discovered at LHC.

Error on luminosity affects many precision measurements, and limits some of them, as the additional component of a systematic error. 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), limiting relative error on luminosity to 10^{-4}-10^{-3}.

Integrated luminosity at ILC will be determined from the total number of Bhabha events N_{th} produced in the acceptance region of the luminosity calorimeter and the corresponding theoretical cross-section σ_B .

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

The number of counted Bhabha events N_{exp} has to be corrected for the number of background events misidentified as Bhabhas N_{bck} , and for the selection efficiency ε .

$$L_{\text{int}} = \frac{N_{\text{exp}} - N_{bck}}{\varepsilon \cdot \sigma_B} \tag{2}$$

Luminosity calorimeter has been designed [2] for the precise determination of the total luminosity, in the framework of 'Large Detector Concept' (LDC) [3]. This is compact electromagnetic sandwich calorimeter consisting of 30 longitudinal layers of silicon sensor followed by tungsten absorber and the interconnection structure. 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. Luminosity calorimeter is centered along the outgoing beam in order to avoid azimuthal angle dependence of ΔL/L.

2. Method and samples

Small angle Bhabha scattering is precisely calculable in QED. □□$_{th}$□$\tilde{\imath}$□ nb) [4]. At 500GeV centre-of-mass energy and the nominal luminosity, with the cross-section of ~ 4 nb in the luminosity calorimeter angular range, a yield of ~ 10^9 events per year is expected, which corresponds to the statistical error of order of 10^{-5}.

Bhabha events are characterized by the two electromagnetic clusters, with the full beam energy, that are back-to-back in azimuthal and polar angle. Based on this topology, separation criteria for signal from background will be derived. Signal of 10^5 Bhabha events has been generated with BHLUMI [5] small angle Bhabha generator, integrated into BARBIE V4.1 [6] detector simulation package. Both s and t channels have been included, vacuum polarization, as well as the initial state radiation. We assumed head-on collisions, with luminosity detector that is axially symmetric around beam axis, and the corresponding detector acceptance between 26 and 82 mrad. Sensor planes of the luminosity calorimeter are segmented into 120 azimuthal sectors and 64 radial strips, alternately.

Four-fermion NC processes $e^- e^+ \rightarrow e^- e^+ f^- f^+ \; (f = l, q)$ are considered to be the main source of physics background for luminosity measurement. They are dominated by the multiperipheral processes (2-photon exchange). Both this study and an independent study [7] of two-photon processes ($2\gamma \to e^- e^+$), using Vermasseren generator [8], found occupancy in the luminosity calorimeter acceptance region of 10^{-3} particles per bunch crossing.

To simulate physics background, the sample of 10^6 four-lepton events $e^- e^+ \to e^- e^+ l^- l^+ \; (l = e, \mu)$ and 10^5 corresponding hadronic events $e^- e^+ \to e^- e^+ q \, \bar{q} \; (q = u, d, c, s, b)$ have been generated with WHIZARD multiparticle event generator [9], with the total cross section of (2.68±0.03) nb, assuming event generation through contributions of all neutral current tree-level processes.

3. Results and Discussions

Though rates of signal and background are comparable in the luminosity calorimeter, well known characteristics of Bhabha events (colinearity, complanarity, energy distribution) allow isolation cuts to be applied. Discrimination of the signal from physics background is based on the set of cuts established to optimize detector performance [10]:

1. Acolinearity cut $|\Delta\theta| < 0.06$ deg
2. Acomplanarity cut $|\Delta\varphi| < 5\,\mathrm{deg}$
3. Energy balance cut $|E_R - E_L| < 0.1 \cdot E_{\min}$, $E_{\min} = \min(E_R, E_L)$
4. Relative energy cut $E_{rel} > 0.75$, $E_{rel} = (E_R + E_L)/2E_{beam}$

E_R, E_L being the total energy deposited on the right (front) and left side (back) of the luminosity calorimeter, respectively, and E_{beam} is the energy of the beam. All isolation cuts are applied assuming ideal reconstruction, since detector resolution does not affect the suppression of background [11], and assuming 100% reconstruction efficiency.

As illustrated in Table 1, physics background is reduced to the level of 10^{-4}, with the loss of signal efficiency of ~20 %. Background to signal ratio is the bias to correct the measured total luminosity. However the uncertainty of that bias gives the component of the systematic error of luminosity measurement. Thus with the given B/S ratio, one could tolerate a factor of 10 uncertainty of physics background.

Table 1. Selection and rejection efficiency for signal and background

	Bhabha selection efficiency		Leptonic background rejection efficiency	Hadronic background rejection efficiency
1. $\|\Delta\theta\| < 0.06$ deg	81.87%		95.20%	95.27%
2. $\|\Delta\varphi\| < 5$ deg	97.96%		89.53%	90.42%
3. $E_{bal}<0.1.E_{min}$	90.61%		94.58%	95.45%
4. $E_{rel} > 0.75$	99.08%		88.73%	95.96%
B/S(1,2,3)	$1.3\cdot10^{-4}$	80.60%	99.38%	99.78%
B/S(1,2,4)	$2.6\cdot10^{-4}$	80.80%	99.26%	99.47%

Beamstrahlung are the pairs converted from irradiated photon either form e^+ or e- in the field of opposite bunch. Due to energy depositions of electron and positron, which are typically of order MeV, and the number of converted pairs per bunch crossing, beamstrahlung dominantly affects the occupancy of the readout system rather then reconstruction of the signal.

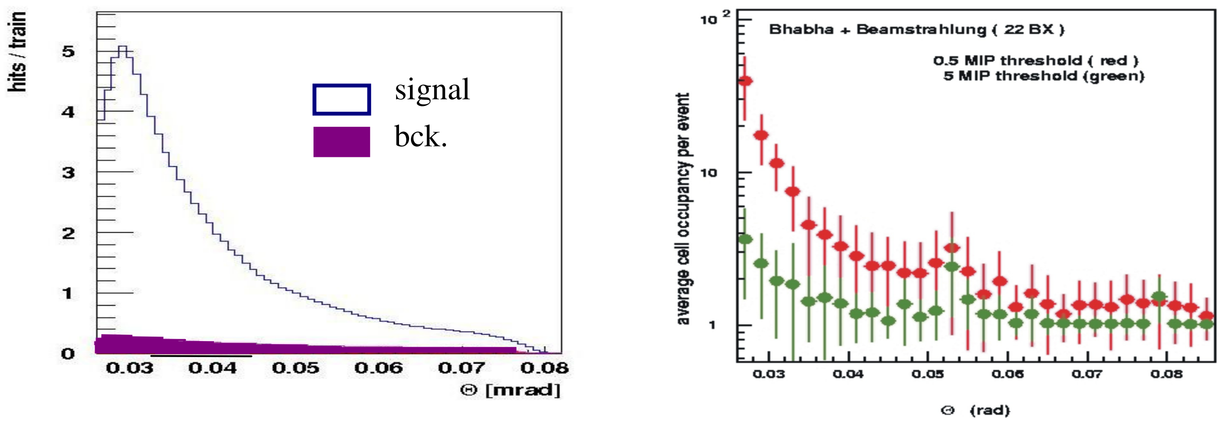

Figure 1. Occupancy of the readout system of LumiCal a) for the signal and background separately and b) signal and beamstrahlung

Occupancy of the luminosity calorimeter is dominated by the machine backgound. In terms of the detector occupancy physics background contributes approximately 10 times less then the signal.

Due to topology of this process the reduction of beamstrahlung pairs is mainly achieved by enlargement of inner radius LumiCal. In the analysis, the remaining pairs are being clearly cut of by Erel cut.

Signal and background will be additionally affected by the beam-beam interaction effects. They will modify both initial state, through beamstrahlung, and the final state through electromagnetic deflection. This leads to enhanced accolinearity of Bhabha events reflecting in large biases in the counting rate of Bhabha events and thus to luminosity measurement, resulting in the total suppression of the Bhabha cross-section of order of 4.4% [12].

Applying the following “asymmetric” cuts results in suppression of the effect (BHSE) to the order of 1.5 %:

- $E_{rel}>0.8$
- 30<|□|<75 mrad

where the second cut has been subsequently applied to forward and backward side of the detector, allowing tolerance for the enhanced acolinearity of Bhabha tracks, due to the beam-beam interactions.

Table 2. Selection and rejection efficiency for signal and background for cuts optimized to beam-beam interaction.

	Bhabha selection efficiency	Leptonic background rejection efficiency	Hadronic background rejection efficiency
1. 30 <|□|<75 mrad	64.99 %	42.11 %	41.95 %
2. Erel>0.8	98.50 %	90.74 %	96.57%
All cuts 1,2	64.33 %	93.69 %	97.48 %
B/S	1.87×10^{-3}		

The total systematic error is dependent uncertainty of the BHSE that has to be corrected to the level of 10^{-2}, which is a nontrivial task in real experimental conditions, especially for electromagnetic deflection part of BHSE.

Concerning the physics background, if the only uncertainty of this ratio comes from the (generated) cross-section, the corresponding systematic error is of order of 10^{-6}-10^{-5}, for both selections of the signal.

4. Conclusions

Background to Bhabha events from the four-fermion NC processes has been studied for the luminosity measurement at ILC. In luminosity measurement, background to signal ratio will be introduced as a bias to be corrected for. Contribution to the systematic error of luminosity comes from the uncertainty of that bias. Under the assumptions used in this study, uncertainty of background to signal comes from the error of the generated background cross-section, leading to the uncertainty of the bias of 10^{-6} - 10^{-5} , well below the required 10^{-4}. A holistic study of systematic effects in luminosity measurement is needed to accomodate other sources of systematic error, such as ones coming from positioning and mechanical alignment of the detector.

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