Physics Background as a Systematic Effect in Luminosity Measurement at ILC

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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 machine background originating from pairs converted from beamstrahlung and the beam-beam interaction effects, physics background from 2-photon processes is one of the main systematic effects. Properties of these processes, as well as their separation from the Bhabha signal have been studied.

1 Introduction

The International Linear Collider is anticipated to be used to make precision measurements of the properties of particles related to physics beyond the Standard Model. 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, GigaZ).

2 Method

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.

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

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

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

Background to signal ratio is the bias to correct the measured total luminosity, as can be derived from (2).

Luminosity calorimeter has been designed [2] for the precise determination of the total luminosity. 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. Layout of the forward region as in the 'Large Detector Concept' (LDC) [3] has been assumed. Luminosity calorimeter is centered along the outgoing beam in order to avoid azimuthal angle dependence of $\Delta L/L$.

3 Results

Bhabha scattering at small angles is precisely calculable in QED ($\Delta\sigma_{th} \approx 10^{-4}nb$) [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 centre-of-mass energy and the nominal luminosity of $2 \cdot 10^{-34} cm^{-2} s^{-1}$ about 10^9 events will be collected per year, corresponding 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 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 one of the main sources 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 ($2\gamma \rightarrow e^+e^-$), using Vermasseren generator [8], found occupancy in the luminosity calorimeter acceptance region of 10^{-3} particles per bunch crossing. These are rates comparable to the signal. The maximal occupancy of a sensor plane is given per train, for signal and background, in Figure 1. In terms of the detector occupancy, physics background contributes approximately 10 times less then the signal.

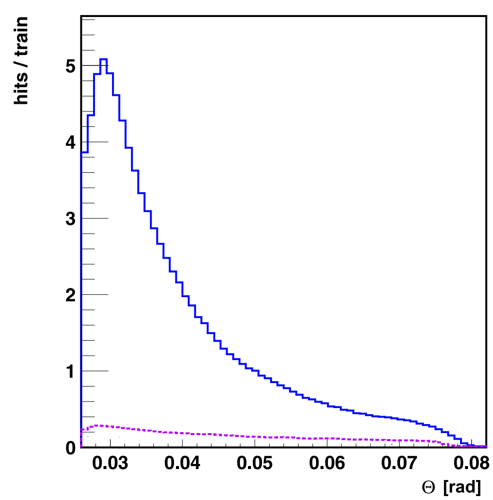

Figure 1: Occupancy in the sensors of the luminosity calorimeter for signal (solid line) and total background (dashed line).

To simulate physics background, the sample of 10^6 four-lepton events $e^+e^- \rightarrow e^+e^-l^+l^-$

($l = e, \mu$) and corresponding 10^5 hadronic events $e^+e^- \rightarrow e^+e^- q\bar{q}$ ($q = u, d, s, c, b$) have been generated with WHIZARD multiparticle event generator [9], with the total cross section of (1.68±0.03) nb, assuming event generation through contributions of all neutral current tree-level processes. 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 exploiting these symmetries of Bhabha topology [10]:

- Acolinearity cut $\mid \Delta\theta \mid \leq 0.06\ deg$,
- Acomplanarity cut $\mid \Delta\phi \mid \leq 5\ deg$,
- Energy balanance cut $\mid E_R - E_L \mid \leq 0.1\ E_{min}$, $E_{min} = min(E_R, E_L)$,
- Relative energy cut $E_{rel} > 0.75$, $E_{rel} = (E_R + E_L)/2 \cdot E_{beam}$,

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, and assuming 100% reconstruction efficiency.

As illustrated in Table 1, starting from the comparable presence of signal to background, physics background can be reduced to the level of 10^{-4}, with the loss of signal efficiency of $\sim$ 20%.

	ε_s		R_l	R_h
1. $\mid \Delta\theta \mid < 0.06$ deg	81.87%		95.20%	95.27%
2. $\mid \Delta\phi \mid < 5$ deg	97.96%		89.53%	90.42%
3. E_{bal}<0.1$\cdot$ E_{min}	90.61%		94.58%	95.45%
4. $E_{rel} > 0.75$	99.08%		88.73%	95.96%
5. $E_{rel} > 0.8$	98.50%		90.74%	96.57%
6. 30 <θ <75 mrad	64.99%		42.11%	41.95%
$B/S(1,2,3)$	$1.3 \cdot 10^{-4}$	80.60%	99.38%	99.78%
$B/S(1,2,4)$	$2.6 \cdot 10^{-4}$	80.80%	99.26%	99.47%
$B/S(5,6)$	$1.8 \cdot 10^{-3}$	64.33%	93.69%	97.48%

Table 1: Selection and rejection efficiency for signal and background, where ε_s denotes Bhabha selection efficiency, R_l - leptonic background rejection efficiency, R_h - hadronic background rejection efficiency.

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, resulting in the total suppression of the Bhabha cross-section (BHSE) of order of 4.4% [11]. In order to minimize the effect ofthe beam-beam interaction, the following set of cuts can be applied [11]:

- $E_{rel} > 0.8$
- 30 <θ <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 beamstrahlung. Alternation of this cut largely reduces the sensitivity of the luminosity measurement to the longitudinal position of the interaction point [4].

As shown in Table 1, asymmetric cuts are cutting-off more than one third of the signal, with the presence of background ten times larger then with symmetric cuts. In principal, annual Bhabha statistics of 10^9 events should allow a flexibility for 30% loss of the signal to still keep the statistical error of order of 10^{-4}. Uncertainty of background to signal ratio will influence the luminosity measurement as a component of the total systematic error. If the only of this ratio comes from the (generated) cross-section, the corresponding systematic error is of order of 10^{-6}, for colinearity based cuts, and 10^{-5} for asymmetric cuts.

4 Summary

The background to Bhabha events from the four-fermion NC processes has been studied for the luminosity calorimeter designed for ILC. It is shown that, due to the characteristic topology, Bhabha processes can be separated from physics background at the level of 10^{-4}. In the luminosity measurement, background to signal ratio will introduce 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, the 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} for symmetric and 10^{-5} for asymmetric cuts.

Considering that beam-beam effects in the luminosity measurement are of order of 10^{-2} (BHSE) and that, in addition, uncertainty of the bias from beam-beam deflection is not known, a holistic study of systematic effects in luminosity measurement is needed in order to optimize selection of the signal in the presence of various sources of systematic error.

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