Physics Background in luminosity measurement at 1 TeV at ILC

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In this paper we present the results of the investigation of the influence of two-photon processes on luminosity measurement at future linear collider ILC at center-of-mass energy of 1 TeV. The overall choice of selection criteria for the luminosity measurement with the respect to leading sources of systematic error is discussed. The potential of individual selection criteria to suppress physics background is discussed and comparison with the 500 GeV case is presented.

Key words: ILC, luminosity measurement, two-photon background

Introduction

The measurement of luminosity at ILC will proceed by using standard candle process: Bhabha scattering. Luminosity will be determined from the measurement of the event rate of Bhabha scattering in the luminosity calorimeter (LumiCal), which is located in the very forward region of the ILC. At ILC, a possibility of an upgrade to 1 TeV center-of-mass energy is foreseen. Since the measurement of integral luminosity at 500 GeV is discussed in detail in [1] and [2], here we present possible event selections leading to the required physics background suppression in luminosity measurement at 1 TeV center-of-mass energy. In comparison to the 500 GeV case, the Bhabha scattering cross-section scales as 1/s, still being of order of a nb. Effects from the beam-beam interaction can be compensated by the proper choice of the detector 'counting region' as shown in [3]. Four-fermion processes, representing the main source of possible miscounts, are reviewed in the light of that newly proposed selection.

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 $\sigma_B$.

$$L_{int} = \frac{N_{bha}}{\sigma_{bha}}$$  \hspace{1cm} (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 $\epsilon$.

$$L_{int} = \frac{N_{exp} - N_{bck}}{\epsilon \cdot \sigma_B}$$  \hspace{1cm} (2)

Luminosity calorimeter has been designed 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. In the ILD concept assumed here [4], it is located at \( z = 2573 \, \text{mm} \) from the IP, covering the polar angle range between 31 and 78 mrad. It corresponds to the inner radius of the LumiCal of \( r_{\text{min}} = 80 \, \text{mm} \), and outer radius of \( r_{\text{max}} = 195 \, \text{mm} \).

Bhabha events, with cross-section of \( \sigma_{\text{bha}} = (1.197 \pm 0.005) \, \text{nb} \), are simulated with BHLUMI [5] event generator, implemented in BARBIE V5.0 [6], a GEANT3 [7] based detector simulation of LumiCal.

Four-fermion NC processes \( e^-e^+ \to e^-e^+ff \) are characterized by the large cross-section scaling with \( \ln^2(s) \) and the typical topology where electron spectators are emitted at small polar angles carrying the most of the beam energy and thus can be miscounted as the Bhabha signal. In Figure 1, polar angle distribution of particles from four-fermion processes with energy greater than 60\% of the beam energy, at the center-of-mass energy of 500 GeV and 1 TeV, are given.

As can be seen from the Figure 1 the polar angle distribution of high energetic particles becomes steeper with the rise of the center-of-mass energy, meaning that these particles (primary electrons) would be emitted at at smaller polar angles than the LumiCal. This change in event topology will compensate the rise of the cross-section of these processes with the center-of-mass-energy.

In this study, fourfermion processes are simulated using WHIZARD V1.2 event generator [8]. \( 10^6 \) leptonic and \( 2 \times 10^5 \) hadronic events are simulated including contribution of all neutral tree-level processes in the angular range \([0.05, 179.95] \, \text{deg}\) and at centre-of-mass energy of 1 TeV. Total cross-section \( \sigma_{\text{tot}} = (0.78 \pm 0.05) \, \text{nb} \) is obtained, with following assumption on event generation:

- invariant masses of the outgoing lepton pairs are greater than 1 GeV/c^2
momentum transferred in photon exchange is greater than $10^4 \text{ GeV/c}$.

**EVENT SELECTION**

Two electromagnetic clusters carrying the full beam energy, originating from collinear and coplanar Bhabha particles, identify signal events. Based on these topological characteristics of the signal several selection criteria can be employed:

- relative energy, defined as a fraction of beam energy, $E_{\text{rel}} = \frac{E_L + E_R}{2 \cdot E_{\text{beam}}}$  \hspace{1cm} (3)
- energy balance:
  \[ E_{\text{bal}} = |E_L - E_R| \]  \hspace{1cm} (4)
- colinearity and coplanarity, defined as the difference in polar (azimuthal) angles of Bhabha particles:
  \[ \Delta \theta = |\theta_L - \theta_R| \quad \Delta \phi = |\phi_L - \phi_R| \]  \hspace{1cm} (5,6)

Colinearity of Bhabha events is to small extent distorted due to the beam-beam interaction effect [9]. This leads to the effective reduction of the Bhabha cross-section in the detector fiducial volume (BHSE). It has been shown [9],[3] that the effect is more pronounced with rise of the center-of-mass energy. Beam-beam interaction is accommodated by using: asymmetric cuts on particle polar angle as proposed for the 500 GeV case in [9], or by the proper choice of the detector counting volume that downscales the BHSE effectively to zero [3]. In the later case the regions within $\delta \theta$ squares are excluded (Figure 2 [3]). For $\sqrt{s} = 1\text{ TeV}$, $\delta \theta$ is found to be 3.6 mrad [3].

Effects of various combinations of the selection criteria on the background to signal ratio are given in the Table 1, assuming the center-of-mass energy of 1TeV. In the same table, the comparison with the 500GeV [1] case is presented. Relative statistical error of B/S estimation is also given.

<table>
<thead>
<tr>
<th>Selection criteria</th>
<th>B/S 1TEV</th>
<th>$\Delta$(B/S) [%]</th>
<th>B/S 500 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[\theta_{\text{min}}+4\text{mrad}, \theta_{\text{max}}-7\text{mrad}];\ E_{\text{rel}};\</td>
<td>\Delta\phi</td>
<td>&lt;5^\circ$</td>
<td>$1.4 \cdot 10^{-3}$</td>
</tr>
<tr>
<td>$[\theta_{\text{min}}+4\text{mrad}, \theta_{\text{max}}-7\text{mrad}];\ E_{\text{rel}};\</td>
<td>\Delta\phi</td>
<td>&lt;5^\circ$</td>
<td>$1.1 \cdot 10^{-3}$</td>
</tr>
<tr>
<td>$</td>
<td>\delta \theta</td>
<td>&lt;0.06^\circ;\ E_{\text{rel}};\</td>
<td>\Delta\phi</td>
</tr>
<tr>
<td>$</td>
<td>\delta \theta</td>
<td>&lt;0.06^\circ;\ E_{\text{bal}};\</td>
<td>\Delta\phi</td>
</tr>
<tr>
<td>$E_{\text{rel}};\ \text{Exclusion region (}\delta \theta=3.6 \text{ mrad)}$</td>
<td>$1.3 \cdot 10^{-3}$</td>
<td>$\pm 29.4$</td>
<td>\</td>
</tr>
</tbody>
</table>
Also, for the reason of completeness two-photon systems of beamstrahlung photons taking part into $e^+e^-\gamma\gamma \rightarrow X$ processes are simulated with the GUINEAPIG generator [10] and analyzed before hadronization in the full polar angle range. Acquiring only that total energy of the system is 80% of the $\sqrt{s}$, with no angular criteria applied, the upper limit from this source of background in the LumiCal is estimated to be less than $2 \cdot 10^{-3}$ with respect to the signal.

CONCLUSION

The rise of the cross-section of two-photon processes with the center-of-mass energy, poses no fundamental restriction on the precision of the luminosity measurement. This is mainly due to the change in topology of the primary electron-positron pair being emitted at lower polar angles bellow the LumiCal. For all the selection discussed, physics background can be in suppressed to the permille level with respect to the signal. In particular, the selection that effectively reduces BHSE to zero does not compromise the suppression of physics background.

REFERENCES

[6] Pavlik B., BARBIE V5.0, Simulation package of the TESLA luminosity calorimeter, available from Bogdan.Pavlik@ifj.edu.pl