Design of LumiCal

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This paper presents the status of Monte Carlo simulation of one of the luminosity detectors considered for the future e^+e^- International Linear Collider (ILC). The detector consists of a tungsten/silicon sandwich calorimeter with a pad or strip readout. The study was performed for Bhabha scattering events assuming a zero crossing angle for the beams.

1. INTRODUCTION

The linear collider community has set a goal to achieve a relative precision of 10^{-4} on luminosity measurement. Traditionally luminosity is determined through the rate of Bhabha scattering events, $e^+e^- \to e^+e^-$. Presently the Forward Calorimetry Collaboration (FCAL) [1] is considering two possible designs for the luminosity detector (LumiCal). Both designs are based on a tungsten/silicon calorimeter. They differ in the readout design, pad or strip. The LumiCal [2] consists of two identical calorimeters positioned along the beam line, symmetrically with respect to the interaction point (IP), 3.05 m away from the IP.

Each calorimeter covers polar angles θ from 26 to 92 mrad with respect to the beam line. Longitudinally, it consists of 30 layers composed each of 500 μm thick silicon sensors and a tungsten-silicon mixture of 0.34 cm of tungsten and 0.31 cm of silicon and electronics. Each layer corresponds to a depth of about one radiation length.

In the pad design, the calorimeter with an inner radius of 8 cm and an outer radius of 28 cm, is subdivided radially into 15 cylinders and azimuthally into 24 sectors. In the strip design, a readout plane subdivided into 64 concentric strips alternates with a plane consisting of 120 radial strips.

2. MONTE CARLO SIMULATION AND EVENT SELECTION

The performance of the LumiCal was studied with samples of Bhabha scattering events generated with BHWIDE [3], a Monte Carlo multi-photon event generator, coupled to the CIRCE program [4] to include the distortion of the beam energy spectrum due to beamstrahlung. In addition, two different values of a Gaussian beam spread, 0.05% and 0.5%, at the nominal center of mass energy ($\sqrt{s}$), were investigated in the range of beam energy between 50 and 400 GeV. The typical spectrum obtained at $\sqrt{s} = 500\,\mathrm{GeV}$ for beam spread of 0.05% is shown in figure 1. The detector simulation was performed using the BRAHMS [5] package based on the standard GEANT 3.21 simulation program [6].

The events are selected based on the containment of the shower. For the pad readout, the signal collected within three layers located close to the shower maximum is subdivided into the signal contained within two cylinders at the outer edge of LumiCal and two cylinders at its inner edge, E_{out}, and the remaining signal, E_{in}. If the variable

$$p = \frac{E_{\mathrm{out}} - E_{\mathrm{in}}}{E_{\mathrm{out}} + E_{\mathrm{in}}} \tag{1}$$

is less then zero, then the shower is well contained in the calorimeter and the event is accepted for further analysis. The cut on p corresponds to a fiducial cut on the polar angle θ such that $\theta > 33\,\mathrm{mrad}$. Events with a reconstructed $\theta > 80\,\mathrm{mrad}$ are also rejected.

In the strip readout, events are accepted if the reconstructed energy $E > 0.8E_{\mathrm{beam}}$, where E_{beam} is the nominal beam energy, and the reconstructed angle $28 < \theta < 80\,\mathrm{mrad}$.

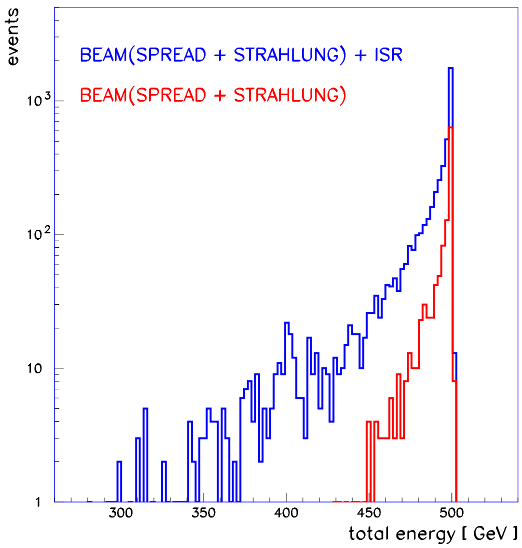

Figure 1: Energy spectrum of the e^+e^- using BHWIDE and CIRCE at $\sqrt{s} = 500GeV$ with a beam spread of $0.05\%\sqrt{s}$, with (outer histogram) and without initial state radiation (inner histogram).

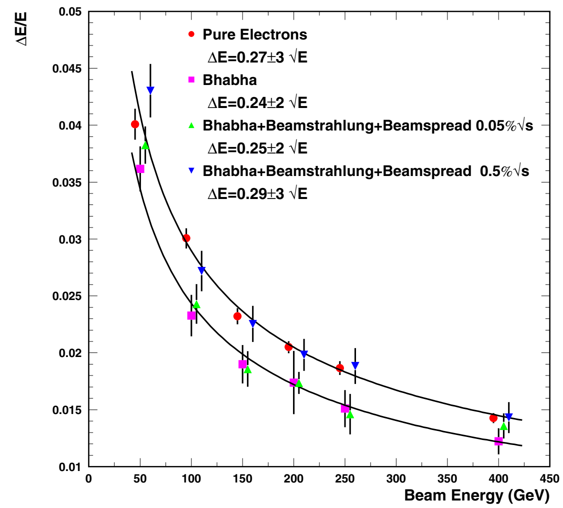

Figure 2: Energy resolution, $\Delta E/E$, as a function of beam energy for different physics cases, as denoted in the figure.

3. DETECTOR PERFORMANCE

The energy resolution was studied for various event samples, with and without radiative effects, with and without beam spread effects. The results are shown in figure 2.

In the best case scenario the resolution $\Delta E/E = 0.24/\sqrt{E}$. For large beam-spreads as well as for pure electron beams the resolution visibly deteriorates. In the latter case it is most likely due to longitudinal leakage. While not impressive, the energy resolution will not affect the uncertainty on luminosity measurements as long as it is known to within 10% (see [7]).

The effect of possible dead areas around the pads and electronic noise on the energy resolution at $E_{\rm beam} = 250\,\rm GeV$ was also investigated. A marked deterioration is observed if the margins around the pads exceed $10^{-3}\,\rm mm$ or if the noise level in each cell exceeds 0.5% of the average cell signal.

The position is reconstructed as the weighted average of signals in pads (strips) which are above a certain threshold and the weight of cell i with energy E_i, w_i, is given by

$$W_i = \max\{0, [C + \ln \frac{E_i}{E_{\rm tot}}]\}, \tag{2}$$

where $E_{\rm tot}$ is the total energy deposited. The constant C determines the threshold and is obtained in an iterative procedure to minimize the resolution in θ. This method is known to minimize both the resolution and the bias due to granularity effects [8]. As it turns out the same constant C optimizes both the resolution and the bias.

The bias comes out to be compatible with zero within the statistical error, while at $E_{\rm beam} = 250\,\rm GeV$ the angular resolution is $\sigma_\theta = 1.3 \cdot 10^{-4}$ mrad for the pad readout and $\sigma_\theta = 0.3 \cdot 10^{-4}$ mrad for the strip readout.

The resolution in the pad readout may be improved by increasing the granularity in the region of the shower maximum. If after the first 11 layers (with 10 cylinders), the next 15 layers are subdivided into 60 cylinders instead of 15, σ_θ of the pad readout is the same as for the strip readout. By then, the pad structure has 25200 readout channels to be compared to 3720 (13320 without bonding) channels of the strip readout. In the strip readout the azimuthal resolution, σ_ϕ is the same as for the polar angle, while for the pads $\sigma_\phi = 0.63^o$. In its maximum shower design, the pad readout option is similar in performance to the OPAL luminosity detector [9].

The inclusion of possible dead areas and noise has the same influence on the deterioration of the angular resolution as for the energy resolution.

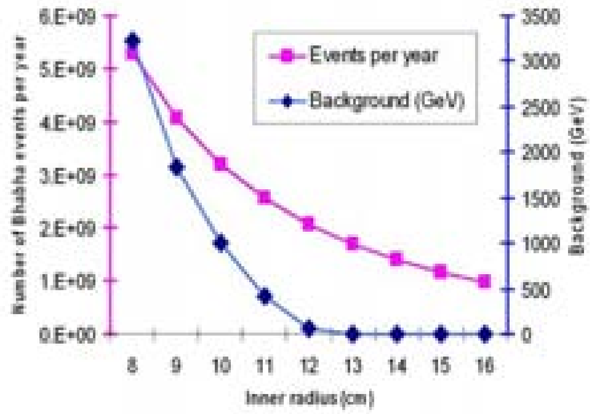

Figure 3: The dependence of the yearly Bhabha event rate (left vertical scale) and of the integrated energy deposited by beamstrahlung pairs created per bunch crossing for a 20^o crossing angle (right vertical scale) as a function of the inner radius of LumiCal .

4. EFFECT OF BEAM CROSSING ANGLE

For a crossing angle of 20^o and a DID magnetic field, the background originating from beamstrahlung pairs hits the inner surface of the LumiCal . The integrated background around the beam hole of LumiCal may be as high as 3 TeV per bunch crossing. As shown in figure 3, above a radius of 13 cm, the background dies out and the yearly rate of Bhabha scattering events remains still high enough to allow a precision measurement of luminosity.

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