Luminosity Measurement

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The luminosity measurement at the future ILC will proceed via measurement of the Bhabha scattering event rates. The achievable precision will be limited by the reconstruction of the scattered particles in the luminosity calorimeter. Estimates of the required precision on the positioning of the calorimeter and on the reconstruction of the kinematics of Bhabha events are presented.

1. INTRODUCTION

At the e^+e^- colliders the luminosity is measured through the Bhabha scattering process $e^+e^- \to e^+e^-$. Luminosity is determined by

$$\mathcal{L} = \frac{\mathcal{N}_{\rm B} - \mathcal{N}_{\rm bgr}}{\varepsilon\sigma_{\rm B}} \tag{1}$$

where $N_{\rm B}$ is the number of selected Bhabha events, $N_{\rm bgr}$ is the number of estimated background events, ε stands for acceptance and smearing corrections and $\sigma_{\rm B}$ is the Bhabha scattering cross section corresponding to the phase space covered by the selection rules.

In the presently considered design the two electromagnetic calorimeters of the luminosity detector (LumiCal) [1] are assumed to be located on the opposite sides of the interaction point, IP, at a distance of 3.05 m from it. LumiCal covers a polar angle of 26.2 to 80 mrad, and the fiducial volume is assumed to extend from 30 to 75 mrad. For this coverage the estimated Bhabha cross section is $\sigma_{\rm B} \simeq 3\,{\rm nb}$.

The figure of merit for the relative precision to be achieved in luminosity measurement is at present 10^{-4}. This is comparable to the precision achieved at LEP [2, 3] and there is at present a massive theoretical effort [4] to achieve a similar precision in the calculation of Bhabha scattering cross section at ILC energies.

This presentation addresses the issue of the required precision on the LumiCal in order to achieve the goal uncertainty.

2. METHODOLOGY

The integrated Bhabha cross section is a strong function of the lower angular limit of the integration, $\theta_{\rm min}$,

$$\sigma_{\rm B} \sim \theta_{\rm min}^{-2}\,. \tag{2}$$

Therefore any misalignment of the components of LumiCal or biases in the reconstruction of the scattering angle will influence the error on luminosity measurement. Selection of Bhabha scattering events relies on the fact that the two leptons are expected to have energies close to the beam energy and to be back to back in the laboratory frame. Radiative effects and beamstrahlung introduce extra smearing, but do not change the conceptual approach.

For the purpose of this study [5] events were generated with BHLUMI 4.04 [6] in the phase space of LumiCal . In a first step the position of the e^+ and the e^- on the front face of LumiCal is calculated. The scattering angle is then deduced from these positions. The energy of the particles is taken from the tree. Simple selection as defined below is applied. In subsequent steps, the position and energy are subjected to systematic mis-reconstructions and the selection is reapplied. The change in the number of accepted events with respect to the number of originally selected events is a measure of the systematic effect induced by the particular mis-reconstruction. The size of the effects are varied in order to determine the required level of precision to achieve a goal of 10^{-4} uncertainty on the luminosity measurement. The same event sample is used for all steps so that statistical fluctuations largely cancel.

In the selection of Bhabha scattering events, the energy of the e^+, $E(e^+)$, and of the e^-, $E(e^-)$, is required to be larger than $0.8E_{\mathrm{beam}}$, where $E_{\mathrm{beam}} = 250\,\mathrm{GeV}$. In addition, the scattering angle of e^+ or e^-, θ, is required to be in the range $30\,\mathrm{mrad} < \theta < 75\,\mathrm{mrad}$. The scattering angle constraint is applied to only one of the leptons, to e^+ for even events and to the e^- for odd events. Note that for any lepton to pass the energy cut, its scattering angle θ has to be in the range of LumiCal acceptance, that is $26.2\,\mathrm{mrad} < \theta < 82\,\mathrm{mrad}$.

3. RESULTS

A detailed discussion of the results obtained in this study can be found in the note by Achim Stahl [5]. Here only a brief summary is presented in table I.

Table I: Requirements on the various parameters of the LumiCal to maintain a relative precision on luminosity measurement of 10^{-4}.

Parameter	**Constraint**
Inner radius, r	$\Delta r \leq 4\,\mu\mathrm{m}$
Radial beam offset, r_o	$\Delta r_o \leq 600\,\mu\mathrm{m}$
Distance LumiCal to IP, d_{IP}	$\Delta d_{\mathrm{IP}} \leq 100\,\mu\mathrm{m}$
Longitudinal IP offset, d_o	$\Delta d_o \leq 2\,\mathrm{cm}$
Tilt of LumiCal , θ_{tilt}	$\Delta\theta_{\mathrm{tilt}} \leq 10\,\mathrm{mrad}$
Beam tilt, θ_{beam}	$\Delta\theta_{\mathrm{beam}} \leq 0.2\,\mathrm{mrad}$
Twist between arms of LumiCal , $\Delta\phi_{\mathrm{twist}}$	$\Delta\phi_{\mathrm{twist}} \leq 0.1\,\mathrm{mrad}$
Position resolution, $\sigma_r = 500\,\mu\mathrm{m}$	$\Delta\sigma_r = \pm 20\%$
Energy calibration, ΔE	$\Delta E/E < 10^{-4}$
Energy resolution, $\sigma_E/E = a/\sqrt{E}$	$\Delta a = 2\%$ for $a = 20\%$
Center of mass energy, $\sqrt{s} = 500\,\mathrm{GeV}$	$\Delta\sqrt{s} \leq 25\,\mathrm{MeV}$

While the required precision puts stringent limits on the geometrical stability of the LumiCal , the required precision on the energy calibration seems to be particularly challenging. The requirements may be less stringent if the selection cut on the energy is relaxed. This issue requires further studies. The requirement on the knowledge of the center of mass energy may not be reachable, however if the unknown cross sections to be determined have a similar energy dependence as Bhabha scattering, the uncertainty will cancel.

4. LASER MEASUREMENT OF DISPLACEMENT

A possible way to control the position of the LumiCal is through laser monitoring of the displacements. A test has been conducted by the Cracow Group [7], with a He-Ne laser with beam diameter of 50-100 μm and a simple web camera with 640×480 pixels. The lens of the camera was removed and a gray filter was added. An algorithm was designed to find the center position of the laser spot in the CCD camera and the position of the spot was then studied as a function of the position of the camera. The correlation is shown in figure 1. With this simple set, a resolution of 0.127 pixel/μm was found. The group is now moving toward a more sophisticated equipment.

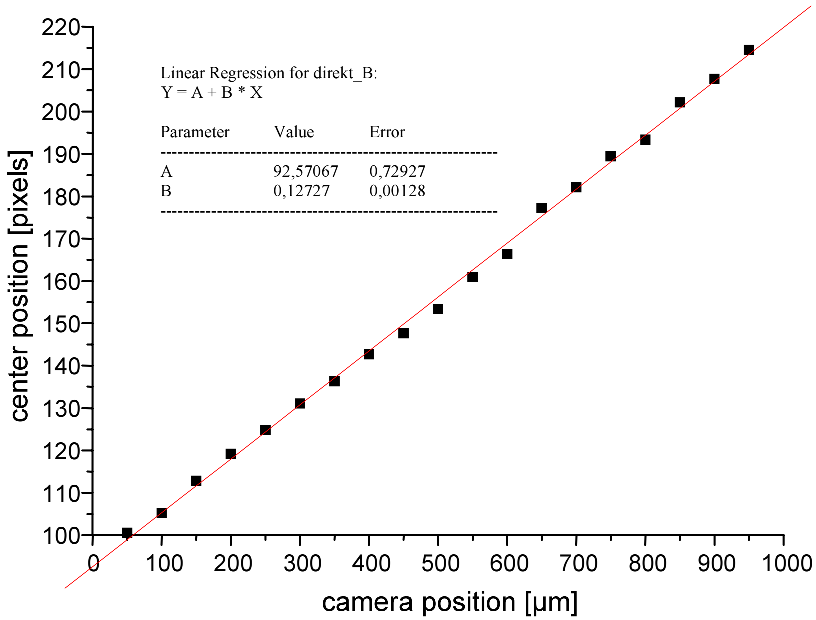

Figure 1: The position of the laser spot in the CCD camera in pixels as a function of the position of the camera. The line represents a linear fit to the observed correlation. The results of the fit are also shown.

5. CONCLUSIONS

The statistical precision of the Bhabha counting will be sufficient to reach the goal of a luminosity measurement with a relative uncertainty of 10^{-4}. The most critical systematic effect is due to the inner radius of the luminosity detector, which must be known to a precision of $4\,\mu$m. Critical is also the distance between the two arms of the detector along the beam axis and must be known to better than $200\,\mu$m on a total distance of about 6 m. The influence of the energy calibration must be studied further and some cross section measurements may be limited in precision by the knowledge of the center of mass energy.

Acknowledgments

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References

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