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Estimates of Hadronic Backgrounds in Future $e^+e^-$ Linear Colliders *

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†Research Fellow of the Japan Society for the Promotion of Science for Young Scientists.
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Abstract

We have estimated hadronic backgrounds for an $e^+e^-$ linear collider at a center-of-mass energy of 5 TeV. In order to achieve a required luminosity in TeV $e^+e^-$ colliders, the high beamstrahlung parameter $\Upsilon$, such as several thousands, is caused. In the high $\Upsilon$ regime, the $\gamma\gamma$ luminosities due to the collision of beamstrahlung photons are calculated by using the CAIN code. According to the $\gamma\gamma$ luminosity distribution, we have estimated the hadronic backgrounds of $\gamma\gamma \rightarrow$ minijets based on the parton distributions of the Drees and Grassie model by the PYTHIA 5.7 code. The Japan Linear Collider (JLC-I) detector simulator is applied for selection performances in the detector.

1 Introduction

For sufficient study of elementary particle physics, an $e^+e^-$ linear collider at a center-of-mass energy of 5 TeV requires a luminosity of $10^{35}$ cm$^{-2}$s$^{-1}$. In order to achieve the required luminosity at TeV $e^+e^-$ colliders, we need to more strongly focus the electron or positron beams at the interaction point. The beam field gives rise to the high beamstrahlung parameter $\Upsilon$ of several thousands. In a high $\Upsilon$ regime, the maximum energy of beamstrahlung photons achieves the energy of the initial electron. The $\gamma\gamma$ luminosity at higher cms energy with high $\Upsilon$ is much larger than that with low $\Upsilon$. Since the cross section of $\gamma\gamma \rightarrow$ minijets increases with cms energy, the number of minijet events in high $\Upsilon$ regime in TeV $e^+e^-$ colliders can be enormous. If very interesting signal and minijet events are piled up in the detector, minijets become serious backgrounds. The minijets are reviewed in [1] and several parameterizations of the parton distribution are proposed. The hadron production in $\gamma\gamma$ collisions as a background for $e^+e^-$ linear colliders at $\sqrt{s_{e^+e^-}} = 0.5$ and 1.0 TeV has been studied using the Monte Carlo simulation by Chen et al. [2].

In this paper, the $\gamma\gamma$ luminosities due to the collision of beamstrahlung photons in a high $\Upsilon$ regime are calculated by using the CAIN code [3]. According to the $\gamma\gamma$ luminosity distribution, we calculate the hadronic backgrounds of $\gamma\gamma \rightarrow$ minijets based on the parton distributions of the Drees and Grassie model by the PYTHIA 5.7 code [4], and the Japan Linear Collider (JLC-I) detector simulator [5] is applied for selection performances in the detector.

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Table 1: Beam parameters of the e^+e^- colliders at \( \sqrt{s_{e^+e^-}} = 5 \) TeV. Cases I, II, and III are laser-driven 5 TeV e^+e^- colliders [7]. Case IV is a 5 TeV linear collider based on 34 GHz normal conducting RF [8].

<table>
<thead>
<tr>
<th>CASE</th>
<th>( T ) (MW)</th>
<th>( P_0 ) (MW)</th>
<th>( N(10^8) )</th>
<th>( f_c ) (kHz)</th>
<th>( \epsilon_x/\epsilon_y ) (nm)</th>
<th>( \beta_x/\beta_y ) (( \mu m ))</th>
<th>( \sigma_x/\sigma_y ) (nm)</th>
<th>( \sigma_z ) (( \mu m ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>3485</td>
<td>2</td>
<td>0.5</td>
<td>50</td>
<td>2.2/2.2</td>
<td>22/22</td>
<td>0.1/0.1</td>
<td>0.32</td>
</tr>
<tr>
<td>II</td>
<td>631</td>
<td>20</td>
<td>1.6</td>
<td>156</td>
<td>62/62</td>
<td>25/25</td>
<td>0.56/0.56</td>
<td>1</td>
</tr>
<tr>
<td>III</td>
<td>138</td>
<td>200</td>
<td>6</td>
<td>416</td>
<td>188/188</td>
<td>310/310</td>
<td>3.5/3.5</td>
<td>2.8</td>
</tr>
<tr>
<td>IV</td>
<td>2.7</td>
<td>52</td>
<td>24</td>
<td>27</td>
<td>10^3/10</td>
<td>7820/122</td>
<td>40/0.5</td>
<td>100</td>
</tr>
</tbody>
</table>

2 Beam parameters with high \( \Upsilon \) parameters

The Upsilon parameter, which is described as the ratio of the strength of the magnetic field \( B \) (which means \( |B| + |E| \) ) in the bunch to that of the critical magnetic field \( B_c \) defined as \( B_c = m_e^2/e \approx 4.4 \) GTeslas, is [6],

\[
\Upsilon = \frac{2 \hbar \omega_c}{3 E_e} = \frac{\gamma B}{B_c},
\]

where \( \omega_c \) is critical energy, \( E_e \) the electron energy before radiation, and \( \gamma = E_e/m_ec^2 \).

The average Upsilon parameter in a linear collider is [6],

\[
\Upsilon_{avr} = \frac{5}{6} \frac{N_e e^2 \gamma}{\alpha \sigma_z (\sigma_x + \sigma_y)},
\]

where \( \alpha \) is the fine structure constant, \( N_e \) the number of particles per bunch, \( \sigma_z \) the classical electron radius, \( \sigma_x, \sigma_y \) the transverse and vertical sizes of the bunch at the interaction point. In this paper, we present the Upsilon parameter \( \Upsilon \) as the average Upsilon parameter \( \Upsilon_{avr} \) of colliding bunches in linear colliders.

Table 1 lists the beam parameters of the e^+e^- colliders at \( \sqrt{s_{e^+e^-}} = 5 \) TeV. Cases I, II, and III are laser-driven 5 TeV e^+e^- colliders [7]. Case IV is a 5 TeV linear collider based on 34 GHz normal conducting RF [8]. The \( \Upsilon \) parameters of laser-driven 5 TeV e^+e^- colliders are several thousands, because \( \sigma_z \) is much smaller than that of conventional microwaves due to typical wavelength of an accelerating wakefield for laser wakefield acceleration which is about 100 \( \mu m \). On the other hand, The \( \Upsilon \) parameter of the collider based on a 34 GHz normal conducting RF is ten times as large as that of a 500 GeV e^+e^- collider for JLC. For this paper, we calculated the beam-beam interaction in 5 TeV linear colliders by using these beam parameters by way of an example of large and small \( \Upsilon \) parameters.

3 Monte Carlo Simulation

We show the simulation results of the beam-beam interactions in 5 TeV linear colliders by using the CAIN code [3]. The \( \gamma \gamma \) luminosities of the e^+e^- colliders at \( \sqrt{s_{e^+e^-}} = 5 \) TeV are listed in Table 2. The collisions among beamstrahlung photons are included only in the \( \gamma \gamma \) luminosity, and the effect of e^+e^- pair creation is not included. The difference between the \( \gamma \gamma \) luminosities in cases II and IV is small, but
Table 2: The $\gamma\gamma$ luminosity of the $e^+e^-$ colliders at $\sqrt{s_{e^+e^-}}=5$ TeV. Only the collisions among beamstrahlung photons are included, and the effect of the $e^+e^-$ pair creation is not included.

<table>
<thead>
<tr>
<th>CASE</th>
<th>$\Upsilon$</th>
<th>$L_\gamma\gamma$ ($10^{34}$ cm$^{-2}$s$^{-1}$)</th>
<th>$L_{e^+e^-}$ ($10^{34}$ cm$^{-2}$s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>3485</td>
<td>10</td>
<td>34</td>
</tr>
<tr>
<td>II</td>
<td>631</td>
<td>2.6</td>
<td>14</td>
</tr>
<tr>
<td>III</td>
<td>138</td>
<td>0.71</td>
<td>4.4</td>
</tr>
<tr>
<td>IV</td>
<td>2.7</td>
<td>2.0</td>
<td>7.1</td>
</tr>
</tbody>
</table>

the $e^+e^-$ luminosity of case II is two times larger than that of case IV. The ratio of $L_\gamma\gamma$ to $L_{e^+e^-}$ does not depend only on $\Upsilon$ parameter and is affected by another parameter $f_c$, which is the collision frequency. Therefore, in order to achieve the required luminosity in TeV $e^+e^-$ colliders, the quantum effect to suppress beamstrahlung has the intrinsic advantage according to the table.

Figure 1 shows the luminosity distribution of a laser-driven $e^+e^-$ collider at $\sqrt{s_{e^+e^-}}=5$ TeV with $\Upsilon=3485$. The lower cms-energy collisions between electrons and positrons occurred frequently and the collisions between beamstrahlung photons at the initial 5 TeV $e^+e^-$ cms-energy appeared. The $\gamma\gamma$ luminosity especially at about 100 GeV was found to be above $10^{34}$cm$^{-2}$s$^{-1}$, as in a $\gamma\gamma$ collider.

Figure 2 shows the luminosity distribution of an $e^+e^-$ collider based on 34 GHz normal conducting RF at $\sqrt{s_{e^+e^-}}=5$ TeV with $\Upsilon=2.7$. In comparison with the large $\Upsilon$ parameter, the maximum energy transfer from initial electrons to beamstrahlung photons with $\Upsilon=2.7$ is small.

For estimation of hadronic backgrounds from minijet events, we use the parton distributions of Drees and Grassie [9] for the photon. We calculated the events of $\gamma\gamma \rightarrow$ minijets by the PYTHIA 5.7 code [4]. The cross section of $\gamma\gamma \rightarrow$ minijets with $p_t > 2$ GeV is shown in Fig. 3. From the figure, the cross section is larger than 10 $\mu$b at $\sqrt{s_{\gamma\gamma}} > 1$ TeV. Even if almost minijet backgrounds are going to the beam pipe and do not enter the detector, the cross section is enormous for the experiment.

In the simulation, the cross section of $\gamma\gamma \rightarrow$ minijets is given in principle according to the model of Drees and Godbole [10]. In reference [11] the minijets cross section is calculated by taking account of the eikonalization effects. The uneikonalized cross section, like the model of Drees and Godbole, is about three times as large as the eikonalized cross section at $\sqrt{s_{\gamma\gamma}} = 1$ TeV. The cross section calculated by the model of Chen-Barklow-Peskin [2] is similar to the eikonalized cross section which is slowly rising, increasing the $\gamma\gamma$ cms energy. Therefore, the results using the model of Drees and Godbole are overestimated compared with using two models.

Another ambiguity is the selection of parameterization of the parton distribution for the photon. There are several parameterizations, such as DG, LAC, WHIT, and GRV in the review [1]. We need to compare its model with other models of the photon parton distribution at $\sqrt{s_{\gamma\gamma}} > 1$ TeV.

Figure 4 shows the cms energy and rapidity distribution of the effective cross section of $\gamma\gamma \rightarrow$ minijets with $p_t > 2$ GeV with $\Upsilon=3485$. The effective cross section $\sigma_{\text{effective}}$ is obtained by the convolution of the differential luminosity distribution.
Figure 1: The luminosity distribution of a laser-driven $e^+e^-$ collider at $\sqrt{s_{e^+e^-}} = 5$ TeV with $\mathcal{Y} = 3485$. The bin size is 50 GeV. (a) $e^+e^-$ collision. (b) $\gamma\gamma$ collision.
Figure 2: The luminosity distribution of an $e^+e^-$ collider based on 34 GHz normal conducting RF at $\sqrt{s_{e^+e^-}}=5$ TeV with $\gamma=2.7$. The bin size is 50 GeV. (a) $e^+e^-$ collision. (b) $\gamma\gamma$ collision.
Table 3: The number of events and the effective cross section of $\gamma\gamma \rightarrow$ minijets.

| CASE | $L_{\gamma\gamma}$ (nb) | $\sigma_{\gamma\gamma,minijets}$ (nb) | $\sigma_{\gamma\gamma,minijets,|\cos\theta|<0.95}$ (nb) | Events/bunch |
|------|-----------------|----------------|-----------------|----------------|
| I    | 2.0             | 258            | 198             | 396            |
| II   | 0.12            | 263            | 207             | 24.9           |
| III  | 0.062           | 268            | 204             | 12.6           |
| IV   | 0.74            | 118            | 90.0            | 66.4           |

Here $\eta$ is the $\gamma\gamma$ rapidity in the laboratory system

$$\eta = \ln \frac{w_1}{w_2},$$

where $w_1$ and $w_2$ are the energies of left and right-moving photon beams. The effective cross section is maximum at 2.5 TeV cms energy, and the same energy photons collide frequently according to the rapidity distribution.

Table 3 lists the number of events and the effective cross section of $\gamma\gamma \rightarrow$ minijets. The effective cross sections with the large $\Upsilon$ parameters are about 260 nb and it shows that the shape of the $\gamma\gamma$ luminosity distribution with high $\Upsilon$ parameters is similar. The number of events per bunch for case I is large, such as 396. These numbers are strongly dependent on the collision frequency. The number of events per bunch for case IV is 66.4, and it seems that the number of minijet backgrounds does not rely on the $\Upsilon$ parameter.

Table 4 lists the visible energy and the transverse momentum per event. Here the JLC-I detector simulator [5] is applied for selection performances in the detector which has the acceptance $|\cos\theta| < 0.95$. The visible energy and the transverse momentum per event are small, but the energy deposition per bunch is enormous.
Figure 4: The effective cross section of $\gamma\gamma \rightarrow$ minijets with $p_t > 2$ GeV with $\gamma = 3485$. (a) The center-of-mass energy distribution. The bin size is 100 GeV. (b) The rapidity distribution. The bin size is 0.08.

Table 4: The visible energy and the transverse momentum per event.

<table>
<thead>
<tr>
<th>CASE</th>
<th>Tracking Detector</th>
<th>Calorimeter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$E_{vis}$ (GeV)</td>
<td>$P_t$ (GeV)</td>
</tr>
<tr>
<td>I</td>
<td>5.8</td>
<td>3.4</td>
</tr>
<tr>
<td>II</td>
<td>5.7</td>
<td>3.3</td>
</tr>
<tr>
<td>III</td>
<td>5.8</td>
<td>3.4</td>
</tr>
<tr>
<td>IV</td>
<td>6.0</td>
<td>3.5</td>
</tr>
</tbody>
</table>
4 Summary

We have estimated hadronic backgrounds for an $e^+e^-$ linear collider at a center-of-mass energy of 5 TeV. In high $\mathcal{Y}$ regime, the $\gamma\gamma$ luminosities due to the collision of beamstrahlung photons are calculated by using the CAIN code. According to the $\gamma\gamma$ luminosity distribution, we have estimated the hadronic backgrounds of $\gamma\gamma \rightarrow$ minijets based on the parton distributions of the Drees and Grassie model by the PYTHIA 5.7 code. The Japan Linear Collider detector simulator was applied for selection performances in the detector.

In order to achieve a required luminosity at TeV $e^+e^-$ colliders, the quantum effect to suppress beamstrahlung has the intrinsic advantage because the shape of the $\gamma\gamma$ luminosity distribution with any high $\mathcal{Y}$ parameters is similar.

The cross section of $\gamma\gamma \rightarrow$ minijets based on the parton distributions of the Drees and Grassie model is enormous at $\sqrt{s_{\gamma\gamma}} > 1$ TeV by the PYTHIA 5.7 code. In the simulation, the cross section of $\gamma\gamma \rightarrow$ minijets is given in principle according to the model of Drees and Godbole. The results from using the model of Drees and Godbole are overestimated as compared with the models of Forshaw-Storrow and Chen-Barklow-Peskin.

Another ambiguity is the selection of parameterization of the parton distribution for the photon. There are several parameterizations, such as DG, LAC, WHIT, and GRV. We need to compare its model with other models of the photon parton distribution at $\sqrt{s_{\gamma\gamma}} > 1$ TeV.

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References


