QUANTUM SUPPRESSION OF BEAMSTRAHLUNG FOR FUTURE LINEAR COLLIDERS

MING XIE, Lawrence Berkeley National Laboratory, Berkeley, USA

Abstract

Beamstrahlung at interaction point may present severe limitations on linear collider performance. The approach to reduce this effect adopted for all current designs at 0.5 TeV will become more difficult and less effective at higher energy. We discuss the feasibility of an alternative approach, based on an effect known as quantum suppression of beamstrahlung, for future linear colliders at multi-TeV energy.

1 INTRODUCTION

One of the most important constraint on the performance of a e^+e^- linear collider is that imposed by the QED processes [1], in particular beamstrahlung, at the Interaction Point (IP). Beamstrahlung is the synchrotron radiation produced by the particles of one beam as they pass through the electric and magnetic fields of the oncoming beam. The fields can be so strong due to the extremely high charge density that colliding particles may lose significant amount of their energy, causing severe luminosity degradation. The photons generated by beamstrahlung may also turn to copious e^+e^- pairs, or even hadrons through QCD processes, causing troublesome background problem to the detectors andthe particle physics under study. Therefore a crucial task to assess the potential of future linear collider is to identify the operation regimes and the approaches with which the impact of these deleterious effects on collider performance can be minimized, taking into account other collider constraints and requirements, of course. To suppress beamstrahlung, the so called flat-beam approach has been adopted for all current designs of linear collider at a center-of-massenergy of 0.5 TeV [2]. However this approach will become more difficult technically and less effective at higher energy. Recently, high energy physics community has been emphasizing the importance of higher energy reach (up to 5 TeV) for a linear collider [3]. There is also a need to explore drastically different collider parameter regime that might potentially be reached with theadvanced acceleration techniques currently under active investigation [4]. It is now becoming increasingly important to search for more feasible IP approachesat higher energy.In this paper, we study an effect known as Quantum Suppression of Beamstrahlung (QSB). Unlike all other approaches that areaimed at reducing or eliminating the beam fields, QSB is effective only when the field is sufficiently strong. In that regard, it is compatible with the ever increasing beam density required of a linear collider at higher energy, thus deserves a carefulinvestigation.Beamstrahlung can be classified into three regimesaccording to the magnitude of the beamstrahlung parameter, Υ. The three regimes are, respectively, the classical regime if $\Upsilon \ll 1$, the extreme or strong quantum regime if $\Upsilon \gg 1$, and in between the transition regime. According to the quantum theory, beamstrahlung scalesdifferently in the regimes $\Upsilon \ll 1$ and$\Upsilon \gg 1$. It was shown [5] that advantage may be taken of thisbehavior in the extreme quantum regime to extend collider energy to multi-TeV without excessive beamstrahlung. In this paper, weexamine various sources of backgrounds due to QED processes for QSB.

2 MONTE-CARLO SIMULATION

In this section we present full-blown Monte-Carlo simulationusing CAIN developed by Yokoya and coworkers [6].The beam parameters used for simulation are taken from the CASE II by Xie et al [7]. They are listed in Table 1together with some quantities given by formulas [1].

Table 1. Beam Parameters And Results By Formulas.

P_b(MW)	20	Υ	631
$N(10^8)$	1.6	D_y	0.29
f_c(kHz)	156	n_γ	0.72
ε_y(nm)	25	δ_E	0.2
$\beta_y(\mu$m)	62	n_b	0.094
σ_y(nm)	0.56	n_v	0.026
$\sigma_z(\mu$m)	1	$\mathcal{L}_g(10^{35}\text{cm}^{-2}\text{s}^{-1})$	1

Table 2. Results By CAIN Simulations.

n_γ	δ_E	σ_e/E_b	n_b	$\mathcal{L}_{1\%}$	$\mathcal{L}_{10\%}$
0.97	0.26	0.36	0.12	0.65	0.80

Figure 1 shows the luminosity spectrum fore^+e^- and γ-γ collisions. For e^+e^- case the spectrum is characterized byan outstanding core at the full energy and a nearly flat-low energy tail two orders of magnitude below the peak. The backgroundeffect due to the tail is further suppressed, as the products frommost collisions in the tail are highly boosted thus confined within a small forward and backward angular cones. Seen from Table 2, the core itself within 1% of full energy, denoted by $\mathcal{L}_{1\%}$,accounts for 65% of the geometrical luminosity, $\mathcal{L}_g$, even though on average the beam loses 26% of its energy and has a rms energy spread of 36%. The sharpness and high peak value of the core is surprisingly encouraging. Upon careful examination, it is found that nearly half of the primary particleswent through beam crossing without having enough

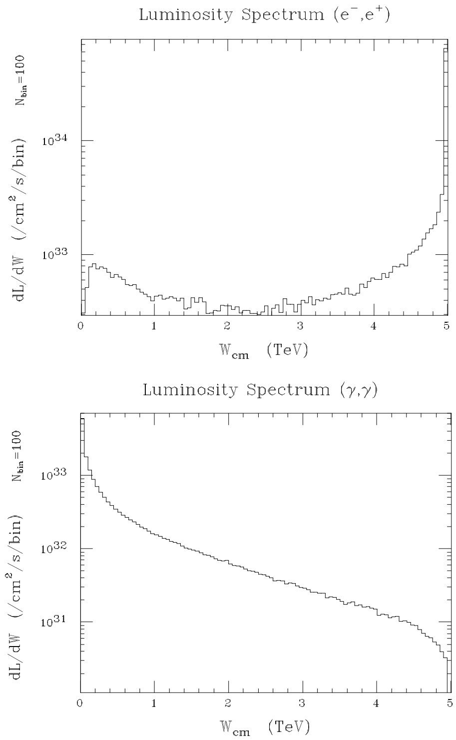

Figure 1: Luminosity spectrum for e^+e^- (top), and γ-γ (bottom), with 100 bins over full energy range.

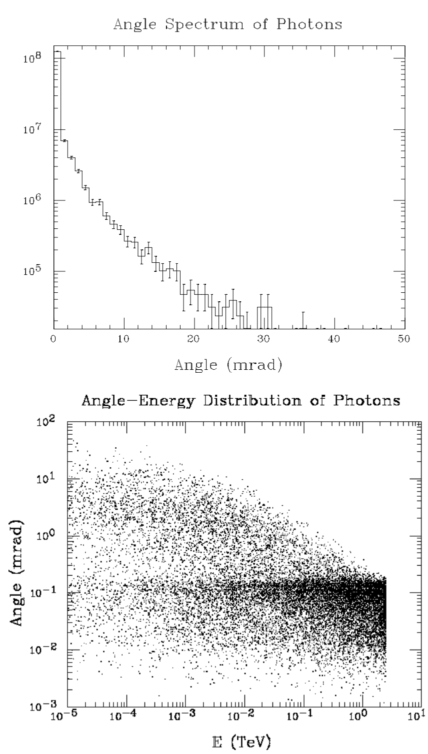

Figure 2: Angle spectrum of photons (top).Scatter plot of photons in angle-energy space (bottom).

probability to suffer energy loss through any QED process, even though their trajectories are bent significantly by the beam field.Because of quantum suppression, the number of beamstrahlung photons defined in terms of n_γ is even lower compared with most of the designs at 0.5 TeV [2]. The angle spectrum and angle-energy distribution of thephotons are given in Figure 2. In the lower plot we see features of two distinct distributions. The photons generated by primary particles at full energy occupy the band below 0.2 mrad, roughly. This number corresponds to the characteristic disruption angle of primary particles given by $\theta_d = D_y\sigma_y/\sigma_z$. The photons with angle larger than 0.2 mrad are generated either through secondary beamstrahlung or by pair particles to be discussed later. The angle-energycorrelation is due to the fact that the lower the energy of the radiating particle, the larger the angle it is deflected by the beam field, and the larger the angle of the radiated photon.Another major source of backgrounds at high Υ is the copious coherent e^+e^- pairs created by beamstrahlung photonstraveling in the strong field of the opposing beam. Coherent pair partners are more likely to sharethe photon energy asymmetrically, giving rise to particles with significantly lower energy. These low energy pair particles, if deflected to large enough angle, may enter the detector and cause backgroundproblem. The angle-energy distributions of coherent pairs together with beam particles are shown in Figure 3 (top). The beam particles are concentrated mostly inthe area near full energy. Notice the split oftwo bands in the lower energy region. The band with larger anglecorresponds to the opposite sign pair partners. The band with smallerangle corresponds to the same sign pair partners and beam particles.Because of the angle-energy correlation, the detector hits bythe charged particles may be further reduced with a solenoid magnetic field along the beam pass. In this situation, rather than particle energy, a more relevant variable is transverse momentum, P_t, which determines the radius of the helical orbit in given solenoid field. The angle-$P_t$distributions of coherent pairs and beam particles are shown in Figure 3 (bottom).On this plot, only those particles in the top right corner with large enough angle and P_t will falloutside of a given forward cone and have a chance of hitting the detector directly. The detector planned for NLC has a half angle of 100 mrad [8], seemingly large enough to swallow all coherent pairs and photons for our case.Coherent pairs can also be produced from virtual photons (as opposed to real photons from beamstrahlung) through a process known as trident cascade. The current version of CAIN does not include this process. But according to simple formulas [1], the number of pairs per primary particle due to virtual photons, n_v, issomewhat lower than the real photon pair production, n_b, seen from Table 1.Figure 4 shows the scatter plot of incoherent pairs (without beam particles)in angle-energy space(top) and in angle-P_t space (bottom). A 10 MeV cut on pair member energy is used for the simulation. Comparing with the coherentpair distribution, incoherent pairs spread much more to the lower energy region and thus are deflected to larger angles. However the total number of incoherent pairs, about 5 thousands for ourcase,

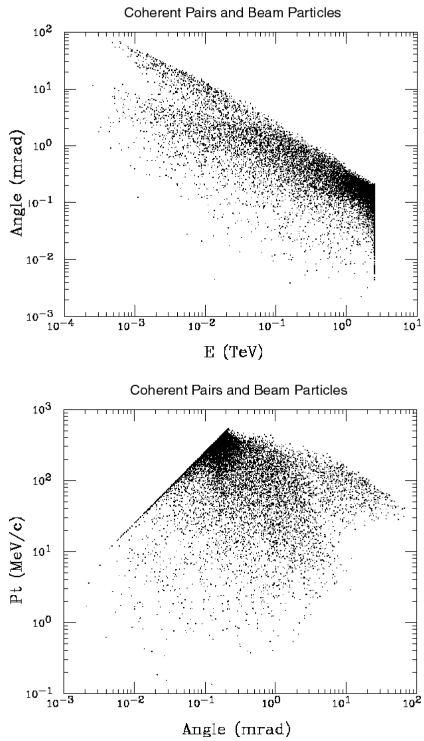

Figure 3: Scatter plot of coherent pairs and beam particlesin angle-energy space (top) and in angle-P_t space (bottom).

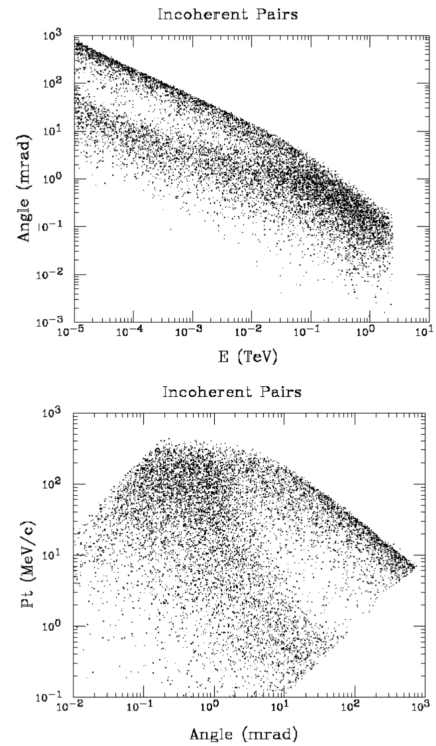

Figure 4: Scatter plot of incoherent pairs in angle-energy space (top) and in angle-P_t space (bottom).

is more than 3 orders of magnitude below that of the coherent pairs. Withangle and P_t cuts similar to NLC case [8]the situation here does not seem to be much worse than the 0.5 TeV machine.

3 DISCUSSIONS AND CONCLUSIONS

We have shown collision products from QED processes could allbe confined within a cone of reasonable opening angle. However,the detector may still be affected by the secondary particlesgenerated by the spent beam hitting components such as quadrupolemagnets within the forward cone.A detailed analysis of these issues requires more specific detector design and realistic detector simulation, which is beyond the scope of this paper. It is hoped the situation could somehow be managed with appropriate masking scheme and IR design.Collisions of beamstrahlung photons can also produce hadronic minijets through QCD interaction [9, 10], giving rise to yet another source of backgrounds. Current theories on minijet are model dependent with free parameters that need to be adjusted with input from experimental data, so far available only up 100 GeV.The cross sections based on the theories are in nowhere near converging when extrapolating to multi-TeV energy. It is the area of uncertainty, where a more definitive prediction on minijet cross section is in urgent need.Last but not least, backgrounds due to standard model processes, such as W pair production in two-photon collisions, also have to be dealt with for exploration of physics beyond the standard model.The author wishes to thank K. Yokoya, J. Siegrist, S. Chattopadhyay, T. Tajima, T. Ohgaki, H. Murayama, K.-J. Kim, B. Barletta and P. Chen for assistance, comments and discussions. This work was supported by the U.S. Department of Energy under contract No.DE-AC03-76SF00098.

4 REFERENCES

[1] For a comprehensive review and references, see K. Yokoya and P. Chen, Frontiers of Particle Beams: Intensity Limitations, Lecture notes in Physics, **400**, Springer-Verlag, (1992).

[2] International Linear Collider Technical Review Committee Report, SLAC-R-471, (1995).

[3] Conference Proceedings of Snowmass Workshop, 1996.

[4] AIP Conference Proceedings **398**, (1996).

[5] T. Himel and J. Siegrist, AIP Conf. Proc., **130**, 602(1985).

[6] P. Chen et al., Nucl. Instrum. Methods A **397**, 458 (1997).

[7] M. Xie et al., AIP Conf. Proc., **398**, 233(1997).

[8] ZDR for the NLC, SLAC-R-474, Chapter 12 (1996).

[9] M. Drees and R. Godbole, Phys. Rev. Lett. **67**, 1189 (1991).

[10] P. Chen et al., Phys. Rev. D **49**, 3209 (1994).