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Quantum Suppression of Beamstrahlung for Future Linear Colliders

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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 an 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 and the 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-mass energy 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 the advanced acceleration techniques currently under active investigation [4]. It is now becoming increasingly important to search for more feasible IP approaches at higher energy.

In this paper, we study an effect known as Quantum Suppression of Beamstrahlung (QSB). Unlike all other approaches that are aimed 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 careful investigation.

Beamstrahlung can be classified into three regimes according to the magnitude of the beamstrahlung parameter, $\mathcal{T}$. The three regimes are, respectively, the classical regime if $\mathcal{T} \ll 1$, the extreme or strong quantum regime if $\mathcal{T} \gg 1$, and in between the transition regime. According to the quantum theory, beamstrahlung scales differently in the regimes $\mathcal{T} \ll 1$ and $\mathcal{T} \gg 1$. It was shown [5] that advantage may be taken of this behavior in the extreme quantum regime to extend collider energy to multi-TeV without excessive beamstrahlung. In this paper, we examine various sources of backgrounds due to QED processes for QSB.
quantum suppression, the number of beamstrahlung photons defined in terms of $n_\gamma$ is even lower compared with most of the designs at 0.5 TeV [2].

The angle spectrum and angle-energy distribution of the photons 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 $\theta_d = D_\gamma \sigma_y / \sigma_z$. 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-energy correlation 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 $\gamma$ is the copious coherent $\pm e^-$ pairs created by beamstrahlung photons traveling in the strong field of the opposing beam. Coherent pair partners are more likely to share the 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 background problem. The angle-energy distributions of coherent pairs together with 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 fall outside 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, $n_v$, is somewhat 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 coher-
Coherent Pairs and Beam Particles

\[ \text{Coherent Pairs} \]

\[ \text{E (TeV)} \]

\[ \text{Coherent Pairs} \]

\[ \text{Angle (mrad)} \]

\[ \text{Figure 3: Scatter plot of coherent pairs and beam particles in angle-energy space (top) and in angle-} P_t \text{ space (bottom).} \]

Incoherent Pairs

\[ \text{Incoherent Pairs} \]

\[ \text{Angle (mrad)} \]

\[ \text{Figure 4: Scatter plot of incoherent pairs in angle-energy space (top) and in angle-} P_t \text{ space (bottom).} \]

different pair 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 our case, is more than 3 orders of magnitude below that of the coherent pairs. With angle 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 all be confined within a cone of reasonable opening angle. However, the detector may still be affected by the secondary particles generated by the spent beam hitting components such as quadrupole magnets 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.

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4 REFERENCES
