Beamstrahlung monitoring of the beam beam effects at the Linear Collider

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At the Linear Collider mismatches between the two beams will result in an intense beamstrahlung. We have studied how this beamstrahlung would evolve as a function of the offset between the two beams and we suggest ways of monitoring it.

1 Beamstrahlung at the Linear Collider.

At the Linear Collider the colliding beams will have a vertical size of less than a few nanometers. With such a small size any misalignment of the final focus magnets will lead to an offset between the two beams at the interaction point (IP). As the magnetic field in each bunch will be of the order of kilo-Teslas, the misalignment of the two beams will make that each beam will travel across the strong magnetic dipole created by the other and thus produce an intense synchrotron radiation called, in this case, beamstrahlung [1].

We have used CAIN [2] to evaluate the intensity of the beamstrahlung as a function of the offset between the two beams. The beam parameters used are those of the JLC as described [3] but our conclusions are valid for any linear collider operation around 500 GeV and would be similar at an energy of 1 TeV. In this study we have neglected the coherent beamstrahlung (CB) as the energy of the CB photons is well below the energies discussed below.

The figure 1 shows the beamstrahlung spot 200 meters away from the IP for different vertical offset between the two beams. As one can see there is a clear dependance of the beamstrahlung pattern with the beam offset.

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Figure 1: Beamstrahlung spot 200 meters away from the IP for different beam offset. For 4 different beam beam vertical offsets: (from top to bottom) 0, 0.5, 1 and 10 times the size of the beams. For each offset the leftmost figure is the beamstrahlung pattern, the figure in the middle gives the horizontal profile of the pattern and the rightmost figure gives the vertical profile of the pattern. The four different colors correspond to the four energy range (eV, KeV, MeV and GeV). When the vertical offset changes, the pattern, as well as its vertical profile change but the horizontal profile remains constant.
The figure 2 shows the total power per bunch of the beamstrahlung. As one can see the power also changes with the beams offset. It is also important to note on this figure that at high energy (MeV and above) the beamstrahlung intensity is higher than the synchrotron radiation generated by the bending of the electrons during the final focusing whereas at lower energy (KeV and below) the beamstrahlung photons are drowned in a synchrotron radiation background. A more detailed comparison of the beamstrahlung and synchrotron radiation spectrums is shown on figure 3 upper plot.

As the beam offset will have an important influence on the luminosity of the Linear Collider, monitoring the beamstrahlung pattern would provide useful information on the beam offset.

2 Possible beamstrahlung monitors

One of the main challenge faced by a beamstrahlung monitor will be the intensity of the beamstrahlung. As one can see on figure 2, the total energy of the radiations emitted by each bunch will be of the order of a dizains of joules per bunch. As there will be more than 10 000 bunch per second the total power delivered by the beamstrahlung will be a few kilowatts. A conventional imaging system would not be able to stand such power and would be instantly destroyed if it was placed in the beam line. Thus alternative solutions have to be proposed to monitor the beamstrahlung.

2.1 Using the low energy photons reflected by a mirror

The beamstrahlung radiation will be absorbed by a water tank. As the walls of the tank will be made of metal, one can imagine to polish this metal to make it reflective. The reflectivity of most metals is low for very high energy photons whereas it becomes higher for photons of a few eV. Thus the most energetic part of the spectrum would be absorbed by the water tank whereas the lower part of the spectrum would be partly reflected toward an imaging device, allowing the observation of the beamstrahlung pattern in the optical spectrum. One of the challenge faced by this imaging device would be to extract the variation of the beamstrahlung pattern from the huge synchrotron radiation background (2 orders of magnitude bigger, see figure 3 lower plot). Thus the imaging device would have to be sensitive to intensity variation of the order of a few percents. To increase the spatial resolution of the imaging device one could give a spherical shape to the mirror rather than a flat one, thus increasing the size of the beamstrahlung pattern on the imaging device.
Figure 2: Power delivered by the beamstrahlung as a function of the vertical beam beam offset. The upper plot shows the total power delivered and the lower plot shows the power delivered for each energy range. On the lower plot the power delivered by the synchrotron radiation produced by the final focusing is also shown.
Figure 3: Energy spectrum of the beamstrahlung photons and of the synchrotron radiation photons produced by the final focusing (upper plot) and ratio between these two sources (lower plot).
2.2 Using a Bragg crystal to select hard X-rays

To increase the signal to noise ratio, one may want to select hard X-rays photons (in the hundreds of KeV range) instead of optical photons. In the KeV range the signal to noise ratio is slightly better than in the optical range (as shown on figure 3, lower plot), thus detecting changes in the beamstrahlung pattern would be easier.

To select photons in the KeV range a Bragg crystal could be used. This Bragg crystal would reflect photons of different wavelength in different directions, thus allowing to easily select only one small energy range as shown on figure 5.

The main difficulty of this layout is that the Bragg crystal would have to be inserted directly in the beamstrahlung flux and thus would be exposed to a very intense radiation (a few kilowatts for a 1mm thick crystal).

2.3 Ionization Chamber

As seen in figure 2 (top), the total photon energy depends on the beam offset, especially in case of large offset where the deflection angle would be too small for the fast feedback. An ionization chamber can be a candidate detector for measurement of the photon flux. The chamber has a 1mm thick gap filled with gas such as Helium, whose pressure can be less than 1 atm. Front plate of the chamber must have enough thickness for absorption of synchrotron radiations, e.g. a few cm thick copper plate. The area covers the photon distribution shown in figure 1, e.g. 20cm diameter at 200m from IP. The photons convert into electron-positron pairs in the front plate. The electrons
and positrons ionize the gas. The ionized electrons are detected at the back plate with readout electronics. The gap thickness shall be optimized with drift time. Since typical drift velocity is \(4\text{cm}/\mu\text{sec}\) with \(\sim 2\text{kV/cm}\) electric field in the gap, the drift time is estimated to be 40nsec. Since number of ionized electrons can be \(10^9/\text{bunch}\) in this configuration, no additional amplification would be necessary. Segmented back plate must be very desired option for position measurement. The segmentation size of \(1\text{cm} \times 1\text{cm}\) seems to be enough as seen in figure 1.

2.4 Electron Wire

![Diagram of electron wire](image)

Figure 6: An electron wire could scan the radiation beam. Electrons would be scattered in different directions depending on the energy of the photons they have hit. Electron counters would be used to measure the scattered electrons’ energy and reconstruct the beam spectrum.

To measure the high energy part of the spectrum without inserting any device in the beamline, one could try to use an “electron wire” to scan the beam: a thin beam of medium energy (a few MeV) electrons would be sent across the beamstrahlung beam. The electrons of the beam would be scattered by the photons. The angle with which the electrons would be scattered would be proportionnal to the photons’ energy. By installing electrons counters at different angles one would be able to measure the photon beam spectrum at different energies. The most forward counters (observing electrons that have been scattered by highly energetic photons) would observe almost only the beamstrahlung spectrum. The observed spectrum would evolve when the beams offset changes.

3 Conclusion

The beamstrahlung radiation generated during the beam crossing at the IP will carry some information on the beam beam offset. Monitoring the beamstrahlung pattern would thus allow to extract these information. We have
proposed different setup that would allow the monitoring of the beam-strahlung pattern despite its high power and the high background.

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References


