GamCal - A Beam-strahlung Gamma Detector for Beam Diagnostics

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The ILC bunches experience intense electro-magnetic fields during the collision which produce a prodigious number of beam-strahlung gammas. A small fraction of the gammas convert into pairs. We discuss the use of the beam-strahlung gamma detector GamCal and the pair detector BeamCal as Luminosity Feedback Detectors to optimize the ILC luminosity. These two detectors provide complimentary information. Both have adequate statistical significance at full ILC beam current, but only the GamCal has adequate statistical significance if the ILC starts up at low beam currents.

1 Introduction

The ILC beams experience intense electro-magnetic fields due to the other bunch as they pass each other. The maximum equivalent magnetic field is 1KT. This causes a large amount of beam-strahlung gamma radiation. The power radiated by a beam electron is

$$P_e = \frac{2}{3}\frac{e^2}{m^2c^3}\gamma^2 F^2 \tag{1}$$

where $F = e(E + c\beta B)$. A small fraction of the gammas convert into pairs, mainly by the Bethe-Heitler process [2] $\gamma e \rightarrow eee$. These pairs spiral in the magnetic field and some strike the BeamCal, about 3m away from the IP [1]. There are a smaller number of pairs from the Landau-Lifshitz ($ee \rightarrow eeee$) process [2]. The beam-strahlung gammas continue un-deflected by magnetic fields to a converter $10^{-4} - 10^{-5} X_0$ thick, about 180m from the IP. The conversion positrons are then deflected by a dipole magnet into the GamCal detector. Table 1 gives some of the ILC beam-strahlung parameters. The GamCal converter thickness is 10^{-5} X_0 for this calculation. The BeamCal calculation is for the small crossing angle, or the 14mrad crossing angle with the anti-DiD.

2 GamCal Detector

Beam-strahlung	Number	E
ee	94K	180 TeV
BeamCal	7K	14 TeV
γ	2.5×10^{10}	110 MTeV
GamCal	10^5	300 TeV

Table 1: Number and energy per beam crossing of beam-strahlung gammas and pairs with the nominal ILC parameters.

Figure 1 shows the GamCal concept. The converter could be a gas jet or a foil. The acceptance of the GamCal for the converted positrons is large: about half for the nominal ILC parameters. The main background is Landau-Lifshitz pair production by the electron beam: $eZ \rightarrow eZee$. This background is about 6% of the beam-strahlung signal for the nominal ILC parameters. Furthermore, the background from the electron beam can be measured by accelerating only one beam, and thus it can be subtracted. At the ILC we get only about 10^4 Higgs events per year at the nominal luminosity of $2 \times 10^{34} cm^{-2} s^{-1}$. Attaining the design luminosity will be challenging. The nominal ILC beam height is only 5nm; two orders of magnitude less than the SLC beam height. We need to find a signal for feedback which is proportional to the instantaneous luminosity and has statistical precision of $\sim 1\%$ for each beam crossing.

The instantaneous luminosity is proportional to:

$$L_i \propto \frac{N_o^2}{A_o} \tag{2}$$

where A is the effective area and the o subscript denotes the overlapping part of the distribution. The production of Bethe-Heitler pairs at the IP is proportional to:

$$N_{BH} \propto \frac{\sigma_{BH} N_\gamma N_o}{A_o} \tag{3}$$

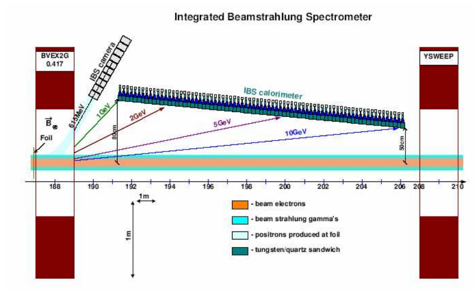

Figure 1: Concept for the GamCal.

For the above equation, N_o is the number of overlapping positrons for the left BeamCal and GamCal detectors, and the number of overlapping electrons for the right detectors. Thus the ratio of the number of produced pairs divided by the gammas gives us the information needed to evaluate equ.2. This analytical result works remarkably well, as can be seen in the Guniea Pig based simulation results [3] shown in Figures 2 and 3. The bunch electric fields cancel when the bunches overlap perfectly, while the bunch magnetic fields add, giving a local minimum in the average Lorentz force, and thus a local minimum in the gamma beam-strahlung (see equ. 1). Thus GamCal and BeamCal detectors provide complementary information, and the ratio tracks the instantaneous luminosity.

3 Luminosity Feedback Detectors

The ILC Reference Design Report describes the luminosity feedback process: "Because the luminosity may be extremely sensitive to bunch shape, the maximum luminosity may be achieved when the beams are slightly offset from one another vertically, or with a slight nonzero beam-beam deflection. After the IP position and angle feedbacks have converged, the luminosity feedback varies the position and angle of one beam with respect to the other in small steps to maximize the measured luminosity".

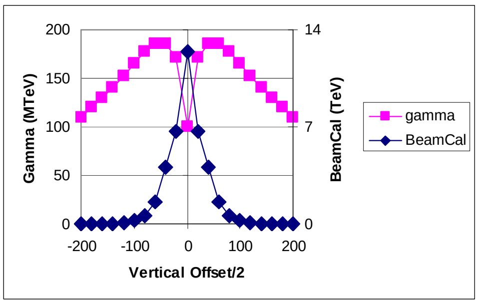

Figure 2: Beam-strahlung gamma energy and energy deposited in the BeamCal vs. vertical offset of the bunches.

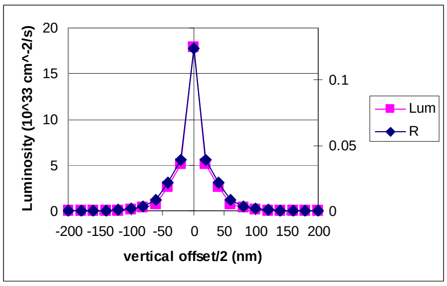

Figure 3: Luminosity and the ratio R of the BeamCal energy to the gamma energy.

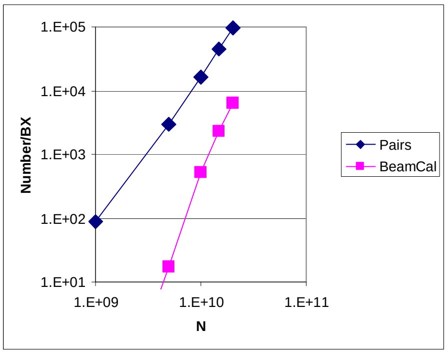

Figure 4: Number of Beam-strahlung pairs produced per beam crossing and the number hitting the BeamCal vs. the number of beam electrons N.

The BeamCal and GamCal detectors provide the instantaneous luminosity feedback, as discussed above. The BeamCal statistical accuracy is $\simeq 1\%$ per beam crossing at the ILC nominal parameters; however, it becomes statistically marginal if the ILC starts up with lower beam currents. Figure 4 shows the number of pairs produced and those hitting the BeamCal from a simulation program [3] vs. N. Both the number of produced pairs and the BeamCal acceptance drops rapidly as N is reduced by an order of magnitude. A simple simulation program [4] shows that the GamCal acceptance drops by about a factor of two when N is reduced by an order of magnitude. The background from the electron beam hitting the GamCal converter will rise from $\simeq 6\%$

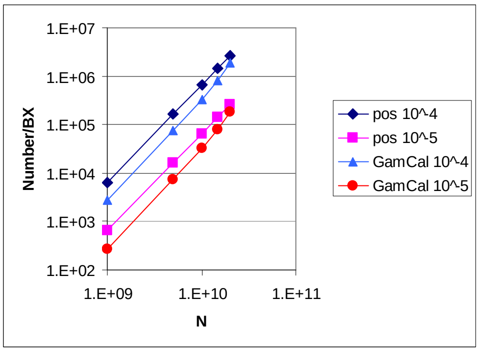

Figure 5: Number of positrons from the GamCal converter and the number hitting the GamCal vs the number of beam electrons N.

to $\simeq$ 60% of the beam-strahlung signal, but this can be subtracted, as discussed above. Figure 5 shows the number of conversion positrons produced, and those hitting the GamCal vs. N for a converter of 10^{-4} and $10^{-5}X_0$. It appears that the damage issues for this foil of $10^{-5}X_0$ ($10^{-4}X_0$) are less challenging than for the SNS stripping foil at full (10%) ILC beam current. We would plan to have several foils remotely controllable in vacuum, as the SNS does.

4 Conclusions

The BeamCal and GamCal detectors will be used to optimize the ILC instantaneous luminosity. The BeamCal will be statistically challenged at low beam currents, but the GamCal has good statistical validity even at 10% nominal beam current.

References

[1] http://www-zeuthen.desy.de/ILC/fcal/.

[2] C. Rimbault *et al.*, Phys. Rev. Special Topics - Acc. and Beams **9** 034402 (2006).

[3] M. Ohlerich et al., *Monitoring the ILC Luminosity with Beam-strahlung Measurements*, FCAL Report in Prep.

[4] W. Morse and T. Rao, submitted as an ILC Note.