STATUS REPORT

Incoherent and coherent beamstrahlung at the ILC

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Collaborators None.

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Project Overview

This is a continuation proposal for two beam-beam interaction (BBI) monitoring devices, that use low energy beamstrahlung component.

The purpose of this work is to develop devices beyond the existing ones, first developed at the SLC, that use the beam-beam deflection or the high energy beamstrahlung components. The interest of these alternative devices is that they have different sensitivity to parameters such as the beam-beam vertical offset, and they also have sensitivity to BBI parameters beyond that of the existing devices. The new BBI information stems from the available polarization and spectral information in the low energy components.

It is commonly agreed that a detailed understanding of the BBI is fundamental to the successful operation of the ILC. Unfortunately the BBI has a large number of degrees of freedom, of order at least eleven and up to twenty or more depending on assumptions. Our goal is to measure as many of these parameters as possible. The new devices have been pursued in a number of papers, in the visible and near infrared $[1-4]$, which is termed incoherent beamstrahlung (IB) and in the far infrared and microwave region [5], where coherent beamstrahlung (CB) is expected to arise.

IB detector. The IB detector has been developed for CESR, thanks to a NSF-MRI grant (NSF-PHY-0116058). It is completely installed if only partially operational (all parts have been operated at least once). It consists of four optical telescopes, with angular acceptance of 1mrad^2 each, each beam being observed by two of them. The primary mirrors are located respectively at $\theta =$11.5 mrad (inner edge) and $\phi =$-72.5 degrees, or $\theta =$12 mrad and $\phi =$-50 degrees. The radiation for each telescope is divided into a visible and infrared component by a set of hot/cold mirrors, and split into $x-$ and $y-$ polarization components by a calcite beam splitter. Each radiation is counted in a separate phototube, totaling 16 phototubes for the whole system.

Visible radiation is mostly in a band $350 < \lambda < 650$nm where there is little signal (less than 3 Hz on a background usually exceeding 3000 Hz), contributing a precise evaluation of the background.

Infrared radiation can further be observed in the band $650 < \lambda < 800$nm, termed 'red', and in the band $750 < \lambda < 1000$nm, termed 'IR'. This is done by using a visible phototube with a filter in front, for the 'red' band, and by using an infrared phototube (Hamamatsu R316-02) for the IR band. The IR phototubes are very noisy at room temperature, and are operated at temperatures below -45C, which can be kept for about 24 hours running after CESR access, until the liquid nitrogen used in the cooling of the device runs out.

The purpose of taking different infrared bands is to use to advantage intensity dependence on wavelength. A simplified expression for the large angle electron beamstrahlung power is given, which stresses various testable properties of IB

$$P_{-}(\lambda,\theta) \propto \frac{I_{-}I_{+}^{2}}{\gamma^{2}\theta^{3}} \exp -(\pi\sigma_{z}\theta^{2}/2\lambda)^{2}.$$

σ_z is the beam length, $I_{\pm}$ are the positron and electron currents, and γ the relativistic parameter. At our angles, the term within parentheses is approximately equal to 3, and the exponent approximately equal to -9. The signal rises sharply when the wavelength increases, a feature inconsistent with common synchrotron radiation (SR). Likewise, the decreasing signal intensity with increasing beam energy ($1/\gamma^2$) is not a feature to be expected from common synchrotron radiation.

Data were taken on numerous occasions in 2005 (34 full days). Of these, the last 16 full days (approximately 200 machine runs) are data of high quality, and contain both red and IR data. The results have convinced us that a signal is present in the CESR data. The pieces of evidence are listed in the Status Report Section.

CESR program. Assuming a first publication in spring 2006, the device will be made fully self-running and completely operational by connecting to a continuous source of liquid nitrogen (Summer 2006). The device will then be turned over to graduate student E. Wisniewski, who will produce his thesis using the continuously produced CESR data. The minimal tests to be performed include several specialized Machine Studies measurements. These are:

- single bunch data taking (after a suggestion from D. Rice). Operating CESR with only one bunch per beam allows one to change the beam horizontal angle by up to 2 mrad, in the process changing the expected signal by two orders of magnitude. Single bunch also allows one to increase the bunch charge by up to a factor of two, effectively testing the $I_{-}I_{+}^{2}$ dependence of beamstrahlung.
- Short bunch data taking. The CESR beam length can be shortened by up to 20%, increasing the signal and allowing one to test the σ_z dependence. The SR background should be unchanged.
- Beam-beam scanning. As with all beamstrahlung phenomena, the radiation increases when the beams are offset. For a 3σ offset in y, the $y-$polarization yield increases by a factor of 2.5, and the $x-$ polarization yield decreases by 40%. Fig. 1 shows this effect (also known as "camelback effect") for the total yield. Our telescopes have a somewhat

decreased sensitivity to this phenomenon, due to their azimuthal location. This test will be best done with a fully operational detector, so that the sensitivity can be maximal.

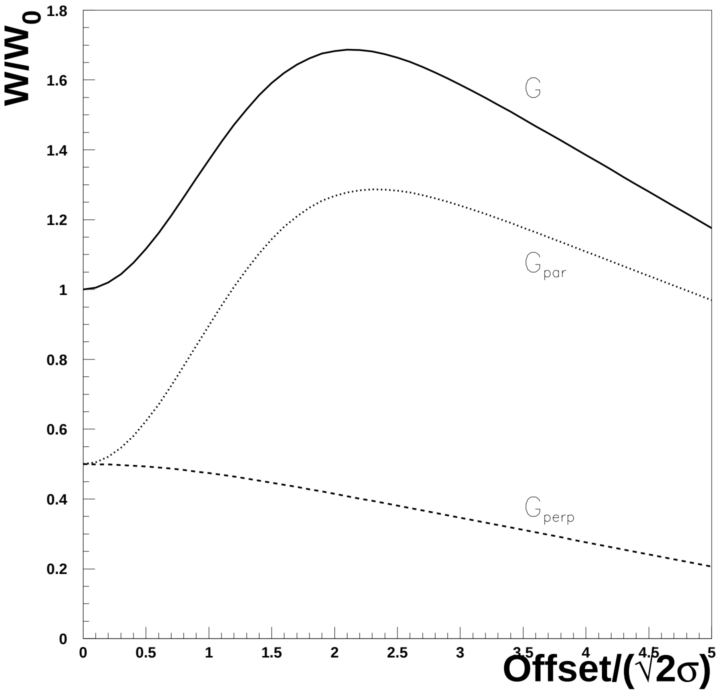
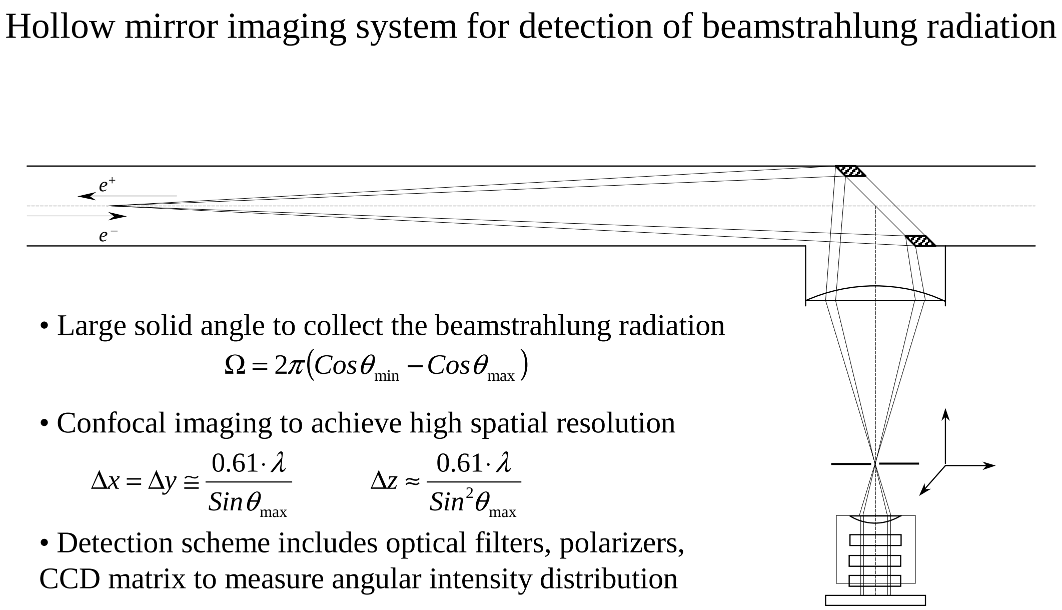


Figure 1: $y-$polarization (dotted), $x-$polarization (dashed), and total large angle beamstrahlung yield as a function of the beam-beam offset.

It is hoped that, once the device runs continuously whenever CESR is running at close to maximum luminosity, the analysis of plentiful data will further elucidate the usage and possibilities of this device.

ILC program. The CESR device is expected to be completely under the responsibility of graduate student E. Wisniewski as soon as it is completely operational and continuously running, and it is very likely that it will happen in 2006.

The next step is to finalize a design for the ILC IB detector. No changes have been made to our baseline design, Fig. 2, which consists of a ring-like primary mirror, covering $1 < \theta < 2$mrad (a window of only 0.5 mrad should be sufficient, if there are real estate issues). Following the mirror, one will have a collimating device (shown schematically in Fig. 2), similar to the CESR one but much longer, because of the much smaller angular resolution. The ring is then divided into two polarizations (not shown in Fig. 2) and projected onto two fast CCD cameras. The major advantage of this design is that the diffraction limit for the mirror is



Hollow mirror imaging system for detection of beamstrahlung radiation

- Large solid angle to collect the beamstrahlung radiation

$$\Omega = 2\pi\left(Cos\theta_{\min} - Cos\theta_{\max}\right)$$

- Confocal imaging to achieve high spatial resolution

$$\Delta x = \Delta y \cong \frac{0.61\cdot\lambda}{Sin\theta_{\max}} \qquad \Delta z \approx \frac{0.61\cdot\lambda}{Sin^2\theta_{\max}}$$

- Detection scheme includes optical filters, polarizers, CCD matrix to measure angular intensity distribution

Figure 2: ILC IB conceptual design.

much smaller than in the case of the 7X7mm^2 mirrors in CESR, and is of order 0.06 mrad. To compare, at CESR the angle of observation is 11 mrad, the collimation angle 1 mrad, the diffraction limit 0.16 mrad, and the typical background angular spread 1 mrad. At the ILC, the observation angle is 1 mrad, the collimation angle is 0.06mrad, the diffraction limit 0.06 mrad, and the typical background angular spread of order 0.01 mrad. These numbers are encouraging enough (and also not easy to improve upon). At ILC nominal conditions, the setup of Fig. 2 would collect some 0.5X10^6 visible photons per BBI (for each bunch-to-bunch collision, not for each train).

As with CESR, the extreme tails of the beam angular and spatial distribution need to be simulated well before one commits to building such a device for the ILC. CESR simulation show virtually all background to be coming from certain spatial regions within the final quadrupoles, about 3 to 5 σ from the central axis. A simulation, as accurate as possible, of the ILC backgrounds will be performed in the second part of 2006, and the results of the final design presented in the appropriate forum (such as a ILC workshop). There appears to be no particular need to buy and test the IB hardware at this time. It is fairly expensive, and CCD technology is advancing fast enough that a device bought now may well be obsolete once the ILC becomes a reality.

Having accumulated experience with the CESR device, we have come to grasp some of the advantages that this device provides. First, some of the lower quality data at CESR show rate fluctuations in the background. Our devices see only a small window in azimuth, and any small change in the beam direction will be reflected in a change in the observed rate. This effect will be minimized if the whole azimuth is observed the whole time. If one part of the ring is overwhelmed by backgrounds, one can always use the part opposite to it in azimuth. Ref. [1] shows that one only needs to monitor $\pi/8$ radians to recover full information. The two polarizations also distribute in azimuth according to $(\sin^2 2\phi, \cos^2 2\phi)$ distributions. If all four azimuthal modulations are observed, disentangling signal and background will be much easier. Ref. [1] also discusses how this device becomes fully powerful when each polarization is measured to 1% or better. A clean way to disentangle signal from background will help.

Second, backgrounds at all beam energies (from 1.5 to 5 GeV) have shown strong $x-$ polarization (90% or more, depending on energy). That will almost certainly be true at the ILC as well. The usage of particular polarizations in particular azimuthal segments may reject the bulk of the background while preserving most of the signal information.

Finally, at CESR it has become clear that the effect of the beam angular distribution is important. No agreement between data and expectations could be had without convolution of the signal with the calculated beam angular distribution. This effect is certainly going to be very important at the ILC, as the beams get disrupted in the BBI, with the maximal deflection of order of a fraction of 1 mrad. Different parts of the detector will be illuminated differently if, for example, the beams are not colliding exactly head-on. Preliminary estimations show that this is indeed a large effect. One can reasonably expect that this device might give ultimately provide more information than just the four quantities described in Ref, [1], and also that the device will relatively weigh the beam tails than the beam core. Detailed calculations are needed and will be performed in 2008.

In conclusion, the two important parts for the ILC are a thorough calculation of the backgrounds, to determine final feasibility, and also important is to have a sense of what is the sensitivity of this device in the ILC environment, where the disruption angle is of the same order of the observation angle. These calculations can almost certainly be completed by the end of 2008.

Coherent beamstrahlung. The microwave concept, presented in Ref.[7] has been criticized due to the lack of any viable calculation. Coherent synchrotron radiation is subject to the coherence condition of Ref.[6],

$$\sigma_z < \lambda < d\sqrt{d/R},$$

where d is the beam pipe diameter and R the typical radius of curvature. Given the typical magnetic field near a beam,

$$B \sim \frac{2N_2 r_e mc}{e\sigma_z\sigma_x} \sim 10^4 T,$$

the beam-beam curvature radius at the ILC is of order 1 meter. A coherent enhancement is therefore expected for $0.3 < \lambda < 4$mm.

The coherence condition is satisfied over a fairly large wavelength window and the existence of such a phenomenon at the ILC is not in doubt. Also the qualitative features shown in Ref.[5] should be correct. These include a rapidly increasing CB yield with beam-beam offset, sensitivity to the beam length σ_z (which provides the lower CB cutoff) and sensitivity to at least one other beam-beam mismatch.

However, the calculations of Ref.[5] were performed in vacuum and for perfectly overlapping angular radiation pattern from each part of the beam. Neither of these conditions are true in reality. In particular preliminary calculations show that when the angular patters do not overlap, the coherent radiation decreases by two orders of magnitude.

A fairly robust, if not very precise, calculation is badly needed. If the coherent beamstrahlung yield is at the level of even a few Watts, the ILC sensors downstream of the interaction point will be affected. And of course such a large signal has tremendous monitoring potential.

Recent work by Agoh and Yokoya [7] show that it is indeed possible to evaluate coherent beamstrahlung in a way that is only limited by the mesh size. This is a difficult calculation that will be initiated in the second part of 2007.

Status Report

CESR IB monitor. In 2005 the IB CESR detector was retrofitted with a cooling system, to try and solve recurring cooling problems with the IR phototubes. Parts were fabricated in the WSU Machine Shop and installed between May and July. Now the IR phototubes can be kept to -40C for close to 24 hours. The highest quality data were taken with phototubes at -50C, for up to 14 hours. Data were taken on numerous occasions. After it was decided, in October, that there is a signal both in the red and IR data, final data analysis started in early november.

A typical day of CESR data taking is shown in Fig. 3. The effect sought (and repeatedly seen) is that of a monitor rate falling faster in time than the beam intensity, and the discrepancy being consistent with a $I_- I_+^2$ effect.

As mentioned above, there is strong indication that a signal has been seen each and every time quality data were taken. What is observed is that there is a non-zero signal in the red or IR that is not seen in the visible. Other evidence includes

- all runs in all quality days, from January 2005 to October 2005, show a signal, with no exceptions. For red data, the minimum effect was measured to be 2.2σ, and the largest 5.3σ. For IR, the significance ranges from 5.0 to 9.2σ.

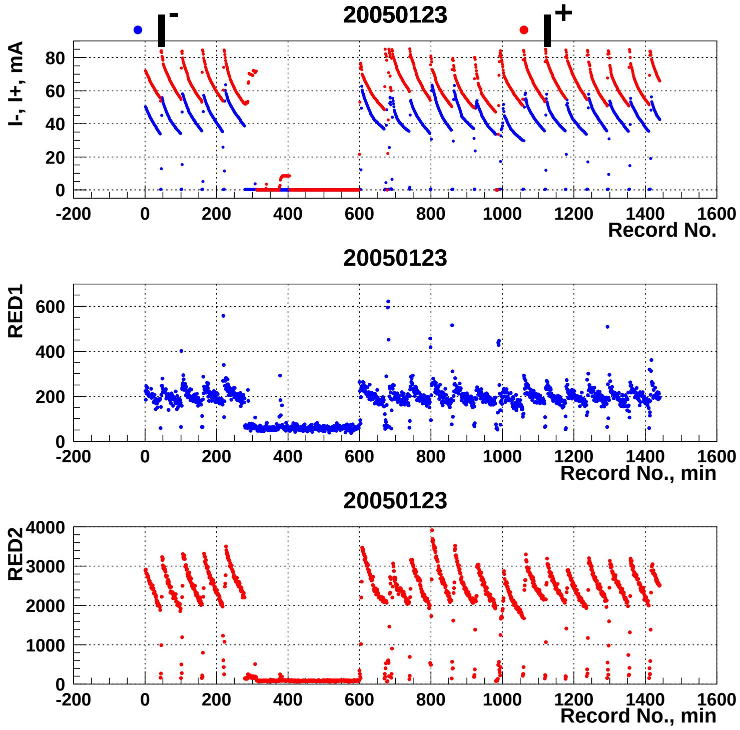


Figure 3: CESR currents and RED1/RED2 rates for Jan. 23, 2005.

- the red raw signal (before convolution with the photoefficiency curve) is about one order of magnitude smaller than the IR signal. This is consistent with expectation and inconsistent with SR backgrounds.
- the signal sizes are consistent with expectations, given the known beam parameters.

We are refining our fitting procedure, to quantify correlations between free parameters, for the purpose of minimizing the number of free fit parameters, evaluate in-run beam fluctuations, and generally improve the goodness-of-fit. With the exception of special runs, the body of available data should be more than enough for first publication.

The special runs are performed to produce a more complete matrix of tests. Such special tests include data taking with the shutters closed, to measure directly the Cherenkov background in the phototube windows (done on Nov. 16, 2005), and to take red data at 2.1 GeV beam energy. Due to our running in mostly parasitic mode with CESR, all red data were taken at beam energy 1.9 GeV, and all IR data were taken at 2.1 GeV. A single day of quality data taking, therefore, should allow both the spectral cross check at the same energy and the $(1/\gamma^2)$ cross check for the same band.

Coherent beamstrahlung. In 2005 the possibility of detecting CB at existing accelerators was studied. Graduate student E. Wisniewski studied the waveguide transmission of the CESR beam pipe near the CLEO IP, to see if two possible experiments devised by M. Billings could be performed. These consisted of a time-separated measurement for the Beam Position Monitors (CB reaches them out of time with the beam, due to waveguide delay), and a frequency analysis of their signal (to disentangle the frequencies corresponding to the beam length from those of a normal BPM response).

However, it appears that the coherent SR limit applies to CB as well, and that therefore there is no chance to observe CB at existing accelerators. If this topic is to progress, we will have to compute CB properly. This will be done starting in the second half of 2007.

FY2006 Project Activities and Deliverables

In the first part of 2006 the first beamstrahlung paper will be published, and the system will obtain its final configuration (with a continuous liquid nitrogen supply). In the second part of 2006, graduate student E. Wisniewski will study CESR data extensively. In the second part of 2006, a new graduate student will start to calculate the backgrounds for the ILC IB detector.

FY2007 Project Activities and Deliverables

While CESR data continue to be analyzed, the ILC IB background calculations should be finished by May 2007. In May 2007, the CB calculations for the ILC will be started. Being a new project, with many uncertainties, we can only assign a 18 months window to this project.

Budget justification: Institution 1.

In 2006, we request support for one graduate student, and some travel money to Cornell. The support is for the student that analyzes the CESR data. Material and supplies expenses cover for costs involved in making the liquid nitrogen supply continuous. This involves building some piping with insulation from the CLEO main nitrogen supply. Tuition is listed under “Other”.

In 2007, we request support for two graduate student, and some travel money to Cornell. The support is for the student that analyzes the CESR data, and for the new student (starting in 2006) who will help perform the ILC calculations. One undergraduate student is also requested to help with the expected high volume of calculations. Tuition is listed under “Other”.

Two-year budget, in then-year K$

Institution: Institution 1

Item	FY2006	FY2007	Total
Other Professionals	0	0	0
Graduate Students	17	36	53
Undergraduate Students	0	5	5
Total Salaries and Wages	17	41	58
Fringe Benefits	5	10	15
Total Salaries, Wages and Fringe Benefits	22	51	73
Equipment	0	0	0
Travel	5	5	10
Materials and Supplies	5	0	5
Other direct costs	13	26	39
Total direct costs	45	82	127
Indirect costs(1)	16	28	44
Total direct and indirect costs	61	110	171

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