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The impact of BeamCal performance at different international linear collider beam parameters and crossing angles on $\tilde{\tau}$ searches

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Abstract. The ILC accelerator parameters and detector concepts are still under discussion in the world-wide community. As will be shown, the performance of the BeamCal, the calorimeter in the very forward area of the ILC detector, is very sensitive to the beam parameter and crossing angle choices. We propose here BeamCal designs for small (0 or 2 mrad) and large (20 mrad) crossing angles and report about the veto performance study done. As an illustration, the influence of several proposed beam parameter sets and crossing angles on the signal-to-background ratio in the stau search is estimated for a particular realization of the supersymmetric model.

Keywords. BeamCal; electron veto; two-photon background; accelerator beam parameters; crossing angle; stau analysis.

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1. Introduction

The TESLA machine parameters were chosen to achieve a high peak luminosity with only little room for operational optimization. As a more flexible approach, [1] defines a number of different machine configurations achieving similar peak luminosities. We consider here the impact of these schemes on the pair depositions in the BeamCal. The pairs, stemming from the beamstrahlung photon conversions, deposit several TeV of energy in the BeamCal (see figure 1) with large local energy density fluctuations from bunch to bunch. Identification of single electrons on top of these depositions is challenging at the inner part of the BeamCal even at the highest electron energies [2].

For a 2 mrad crossing angle the depositions of the pairs in the BeamCal are very similar to the ones of the head-on scheme (figure 1a). The only change required for the BeamCal is a slightly larger inner radius.

The 20 mrad crossing angle geometry is proposed with several possible arrangements for the magnetic field inside the detector. In the DID (detector integrated

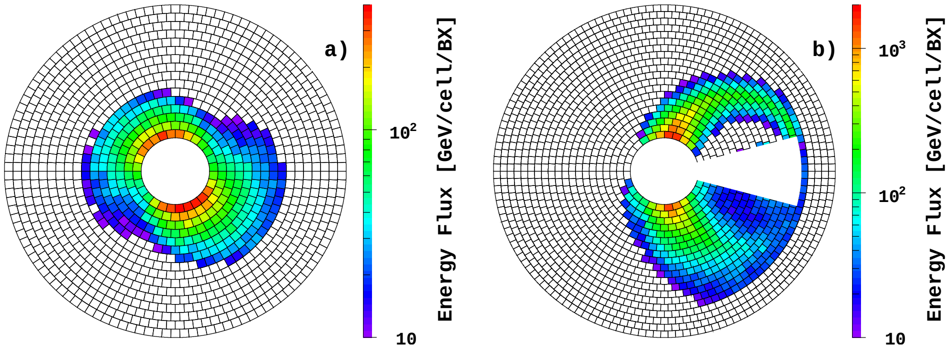


Figure 1. The energy density of beamstrahlung remnants per bunch crossing as a function of position in the r–φ plane at (**a**) 2 mrad and (**b**) 20 mrad with DID field crossing angles.

dipole) [3] field configuration, the magnetic field is directed along the incoming beam lines with a kink at the transverse plane containing the IP. Hence the incoming beams will not emit synchrotron radiation and their spins will not precess before they collide. However, the amount of beamstrahlung deposited in the BeamCal rises considerably (figure 1b), causing also higher background in the tracking detectors due to backscattering. Conversely, if the magnetic field is directed along outgoing beam lines with a kink at the IP plane (a configuration referred to as anti-DID), the depositions on the BeamCal and background in the central detector are very similar to the head-on case.

The BeamCal is an important tool to identify two-photon events by detecting either electrons or positrons with an energy near the beam energy. Two-photon events constitute the most serious background for many search channels which are characterized by missing energy and missing momentum. In most cases lepton pairs produced in photon–photon processes have significantly different topology and kinematics in comparison to the search channel and can be rejected by simple cuts. However, since the two-photon cross-section is typically several orders of magnitude larger, events in the tails of the kinematic distributions become important.

The electron veto performance, obtained from simulations, is used to estimate the suppression of the two-photon background in the different ILC schemes. The search for a $\tilde{\tau}$ supersymmetric particle is taken as a benchmark process, following the approach described in [4]. In the particular realization of the supersymmetric model, which is considered here (point 3 in the list of SUSY benchmark points for the ILC detector [5]), the $\tilde{\tau}$'s are the second lightest supersymmetric particles which are pair-produced in e^+e^- annihilation and decay into lighter neutralinos, which escape undetected, and regular τ's. In the context of this model, the $\tilde{\tau}$'s and neutralinos could combine to provide a plausible, quantitative explanation for the amount of dark matter in the Universe. The amount is directly related to the mass difference between $\tilde{\tau}$ and neutralino and is assumed here to be equal to 5 GeV.

Table 1. Beam and IP parameters for various beam parameter configurations at $\sqrt{s} = 500$ GeV.

	Nominal	Low Q	Large Y	Low P
Bunch charge (10^{10})	2	1	2	2
Number of bunches	2820	5640	2820	1330
$\gamma\epsilon_x/\gamma\epsilon_y$ (10^{-6} mrad)	10/0.04	10/0.03	12/0.08	10/0.035
β_x/β_y (mm)	21/0.4	12/0.2	10/0.4	10/0.2
σ_x/σ_y (nm)	655/5.7	495/3.5	495/8.1	452/3.8
σ_z (μm)	300	150	500	200
Luminosity (10^{34} cm^{-2} s^{-1})	2.03	2.01	2.00	2.05

2. Simulation and results

Single electrons and beamstrahlung pairs were simulated for the four proposed accelerator parameter sets (table 1) at zero crossing angle and for the nominal set at 20 mrad crossing angle with the DID magnetic field configuration. Beamstrahlung was generated using GUINEA-PIG [6]. The detector was simulated in GEANT4 [7].

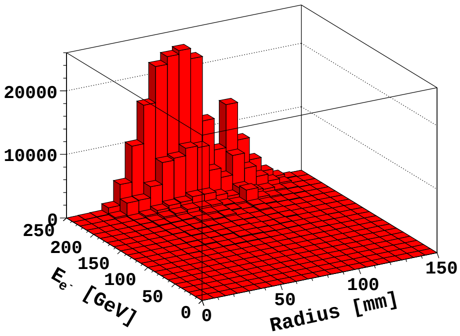
The BeamCal is located 370 cm from the interaction point. The inner radius is 1.5 cm for 0 mrad crossing angle and 2 cm for 20 mrad. The outer radius is 16.5 cm. For the 20 mrad crossing angle area of 30° in r–ϕ plane between the beam pipes for the incoming and outgoing beams is assumed to be 100% inefficient for particle detection, in anticipation of the practical difficulties to instrument this area.

Fine granularity is necessary to identify the depositions from high energy electrons and photons on top of energy depositions from beamstrahlung remnants. The simulated sampling calorimeter is longitudinally divided into 30 disks of tungsten, each one radiation length (3.5 mm) interleaved by diamond active layers (0.5 mm). The sensitive planes are divided into pads with a size of about half a Molière radius (5 mm) in both dimensions, as shown in figure 1.

The energy depositions from pairs and the single electron depositions are superimposed in the sensor pads. A reconstruction algorithm is applied to the output. The reconstruction procedure is described in more details in [8].

To evaluate the ability to suppress two-photon processes, we used the energy and polar angle distributions of the two-photon background events remaining in the analysis described in [4] after application of all selection cuts other than the electron veto [9]. At this stage of the analysis, 20 stau events are left, while the number of surviving two-photon background events is about 2.7×10^5. Figure 2 shows the energy and spatial distributions of these electrons. Most of them have nearly the beam energy and hit the BeamCal outside the area affected by pairs, though the distribution has tails down to the smallest angles and energies. It is important to notice that this distribution depends on the particular stau-neutralino mass difference considered. In this study it is 5 GeV, if it would be larger (smaller), for example the polar angle distribution would broaden (sharpen) and shift to larger (smaller) values.

The average efficiency to veto electrons is shown in figue 2 for several electron energies for head-on collisions and nominal beam parameters. An electron of 250 GeV



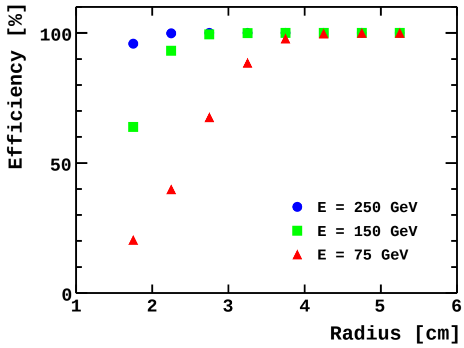


Figure 2. Left: Electron energy and spatial distribution of the two-photon background events passed all selection cuts except the BeamCal veto. Right: The efficiency to veto an electron of energy 75, 150, 250 GeV as a function of the radius in the BeamCal.

Table 2. The number of un-vetoed background events. The number of $\tilde{\tau}$ events is 20.

Energy cut (GeV)	75	50
Nominal, 0 mrad	45	5
Low Q, 0 mrad	40	0.1
Large Y, 0 mrad	50	9
Low P, 0 mrad	364	321
Nominal, 20 mrad, DID	396	349

is vetoed even in regions with high background with almost 100% efficiency. The efficiency drops near the innermost radius, partly due to shower leakage. Electrons of 75 GeV are identified with high efficiency only at larger radii.

Depending on the cuts in the reconstruction algorithm, fake electron candidates can also be found. This can be either high energy particles from tails of the incoherent pair production process or background fluctuations which mimic the electron signal. In this study, the reconstruction algorithm was tuned for a misidentification rate of 10%.

For each beam parameter set in table 1, veto efficiencies are estimated from simulations in the instrumented area of the BeamCal (see figure 1). These efficiencies were used to determine the number of remaining non-vetoed two-photon background events in the stau analysis (see table 2). Results are given for energy cuts of 50 and 75 GeV, showing that a relatively low energy cut of 50 GeV reduces this background contribution considerably. For the chosen benchmark physics scenario the chances to see $\tilde{\tau}$ particles are very good for most of the accelerator designs, except the low P scheme in which this remaining background completely dominates the selected event sample. By far the best situation is obtained for the low Q scheme.

In the cases of 2 mrad or 20 mrad with the anti-DID field configuration we expect the BeamCal performance to be similar to that in the head-on scheme, as the corresponding pair deposition distributions are similar. In the case of 20 mrad crossing angle with a DID field configuration, we would have no chance to see $\tilde{\tau}$ production for this benchmark scenario.

For the 20 mrad crossing angle geometry, an additional reduction in the expected signal-to-background ratio arises independent of choosing a DID or anti-DID magnetic field configuration, because removing events with electrons missed in the larger un-instrumented part of the BeamCal (see figure 1) requires additional special selection cuts [4] and because of the increased fake veto rate from Bhabha processes with only a single electron seen [2]. Estimations have shown that these additional effects would amount to about 30–50% in total for the present supersymmetric scenario, which could be compensated for with additional luminosity.

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