Project Report
Summer Student Program 2007
Deutsches Elektronen-Synchrotron (DESY) Hamburg, Germany

Simulation Studies for a Polarimeter at the International Linear Collider (ILC)

Moritz Beckmann
Leibniz Universität Hannover, Germany

Supervisors: Oleg Eyser, Jenny List

September 14, 2007

A simulation of a magnet chicane as part of the polarimeter for the high energy electron beam at the ILC was set up in this project. The effect of another experiment put right up the beamline has been investigated and measures to reduce the background originating from that experiment have been tested.

Contents

1 Introduction

1.1 The Problem

To measure the polarization of the electron beam accelerated to 250 GeV, the polarimeter investigated here is placed in the beam delivery system of the ILC electron beam (see figure 1). A likewise polarimeter is used for the positron beam.

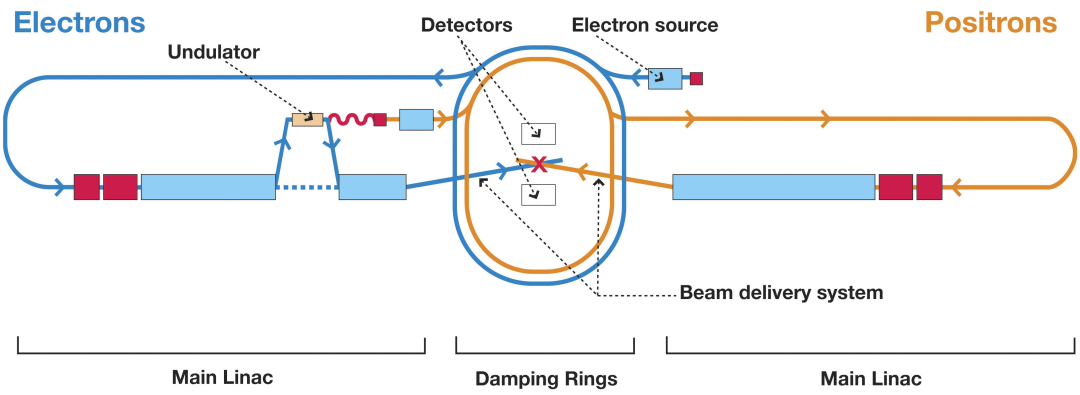

Figure 1: Sketch of the ILC. The polarimeters are located in the BDS

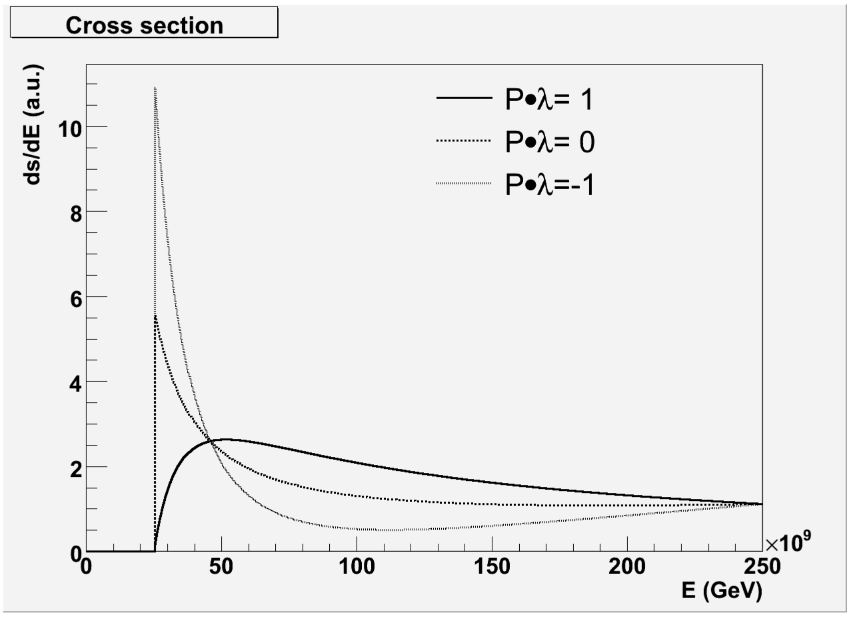

Figure 2: Compton scattering cross sections for different helicity configurations. The asymmetry between same and opposite helicity is used to measure P

The polarimeter is based on Compton scattering, where the cross section $\frac{d\sigma}{dE}$ depends on the product of electron helicity P and photon helicity λ as shown in figure 2. Colliding photons with same (+) and opposite (-) helicities on the electron beam, we obtain the the two counting rates $N^{\pm}$. Therefrom we obtain the measured asymmetry

$$\varepsilon = \frac{N^+ - N^-}{N^+ + N^-} \sim P \tag{1}$$

which is proportional to P, and we can then compute the polarization P as described in [1]. Since the overall asymmetry of the total cross section is rather small (figure 2), this has to be done as a function of the electron energy.

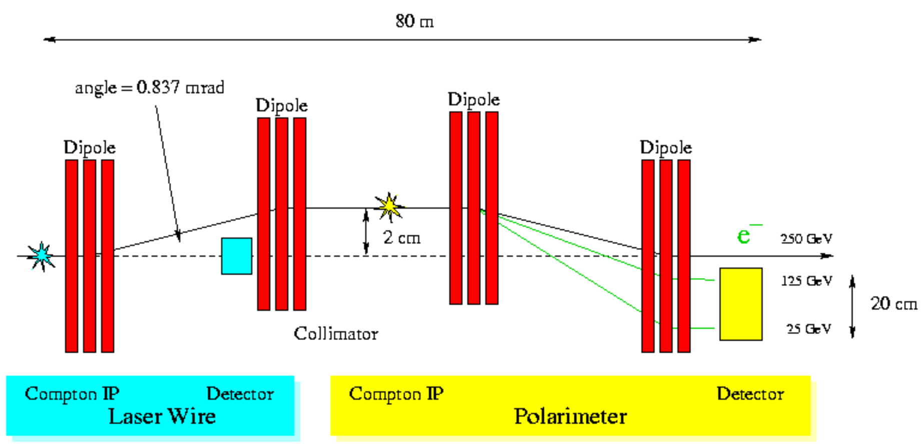

Figure 3: Top view of the polarimeter chicane

The polarimeter (right-hand side) is placed in a magnet chicane as shown in figure 3. In the middle of the chicane a laser extracts about 1000 electrons per bunch out of the beam by Compton scattering. In the scattering process these electrons lose energy to the photons. Therefore, the two latter dipoles bend the electron trajectories stronger, such that the chicane works as spectrometer. The displaced electrons generate Cerenkov light in the detector gas volume, which can then be detected, e.g. by photomultiplier tubes. From the displacement we can derive the energy of the scattered electron. The aim is to measure the polarization with a precision of 0.25%, which has not been accomplished so far.

One problem for the polarimeter might be the Laser-Wire experiment (figure 3, left-hand side) measuring the beam emittance by means of the beam size. In order to keep the ILC as short as possible to decrease the costs, this experiment might be placed into the same chicane. The Laser-Wire experiment also uses a laser for Compton-scattering of beam electrons. The photons hit a massive plate producing particle showers which are then detected also by their Cerenkov radiation. Particles from those showers or scattered electrons arriving at the polarimeter might produce some background diluting the polarization measurement. Simulations of the Laser-Wire group predict a 30% background contribution to the polarimeter yield. But that simulation assumed a one order of magnitude larger detector surface than planned at the moment. Thereupon the

FLC polarimeter group decided to cross-check with a simulation to quantify the problem properly and investigate possible solutions, which was my job during the summer student program.

1.2 The Tools

The simulation is based on GEANT4 [4], which is an object-oriented simulation toolkit developed at CERN, and done in BDSIM (Beam Delivery SIMulation) [3], which is an extension toolkit for GEANT4. Since BDSIM has only a small number of users continuously developing the program further, there were some problems with an incomplete or sketchy documentation, programming errors and yet unimplemented functions. The data analysis was performed with ROOT [5].

2 Results

2.1 Remarks on the Plots

In all simulations presented below the Laser-Wire laser was turned on and the polarimeter laser was shut off, because subject of this investigation was only the effect of the Laser-Wire experiment on the polarimeter detector. The yields for the different particle species are added up in all plots. That means, the number of photons is represented by the *visible* part of the green bars. All plots are normalized to one bunch. Since 1,000 scattering events per bunch are expected and 100,000 events were simulated, all numbers are scaled down by a factor 100. The computation of one set-up on a conventional PC takes approximately 5 hours.

2.2 Simulation of the Background due to Laser-Wire Experiment

The results of the simulation are summarized in figure 4, which shows the energy spectra at different places in the beam line. The upper left plot shows the energy spectrum directly behind the Laser-Wire laser. The axial symmetry of the total area around $E = 125$ GeV reflects the existence of a scattered photon with energy 250 GeV$-E$ for each scattered electron with energy E, neglecting the initial photon energy in the eV range. The shape of the curves corresponds to $P \cdot \lambda = 0$ (figure 2) because we assume the background at the moment to be unpolarized. The lower end of the electron spectrum is the Compton edge at about 45 GeV.

The upper right plot shows the energy spectrum behind the second set of dipoles. The explanation for the cut-off in the electron spectrum at around 105 GeV is the beam pipe wall (beam pipe radius is 3 cm). Electrons with a lower energy are bend so strongly in the first dipole that they hit the beam pipe before reaching the second dipole. The particle shower from the collision with the wall explains the increase in the number of low-energy particles, especially the positrons.

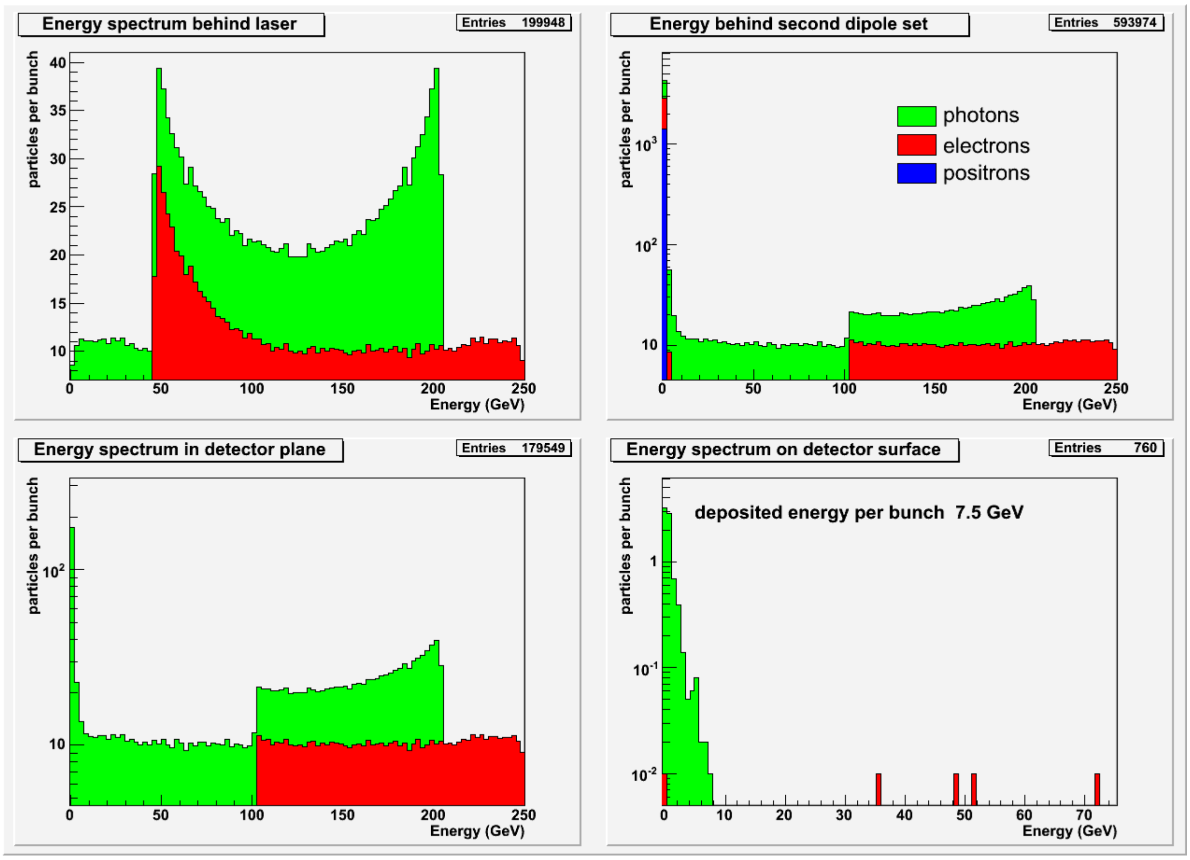

Figure 4: Energies of particles scattered by the Laser-Wire laser at different locations (curves added up)

The lower left plot contains all particles arriving at the detector plane, whereas the lower right plot contains only the particles hitting the detector itself, which is assumed to have a surface of 20 cm $\times$ 1 cm, placed 2 cm apart from the beam axis.

The high-energy electrons in the lower right plot reveal the need for a larger data sample in order to obtain more reliable results, since even the one electron with the highest energy contributes about 10% to the total energy deposit on the detector of 7.5 GeV. Although the deposit is three orders of magnitude smaller than predicted by the simulation of the Laser-Wire group (3.51 TeV), it is nevertheless undesirable due to the envisaged high precision. A counteractive measure will be presented in the next section.

2.3 Shielding against the Background

One proposal to shield the detector against particles from the Laser-Wire experiment was to insert a collimator as shown in figure 5. To find the best dimensions for the collimator, the simulation was run for different collimator lengths and aperture radii.

Figure 6 shows the energy spectra of the particles hitting the detector surface for different aperture radii with a collimator length of 1 m. One can see that the number of background photons increases generally with the aperture radius, while the number of electrons is highest for the smallest aperture. Those electrons lead to the remarkable

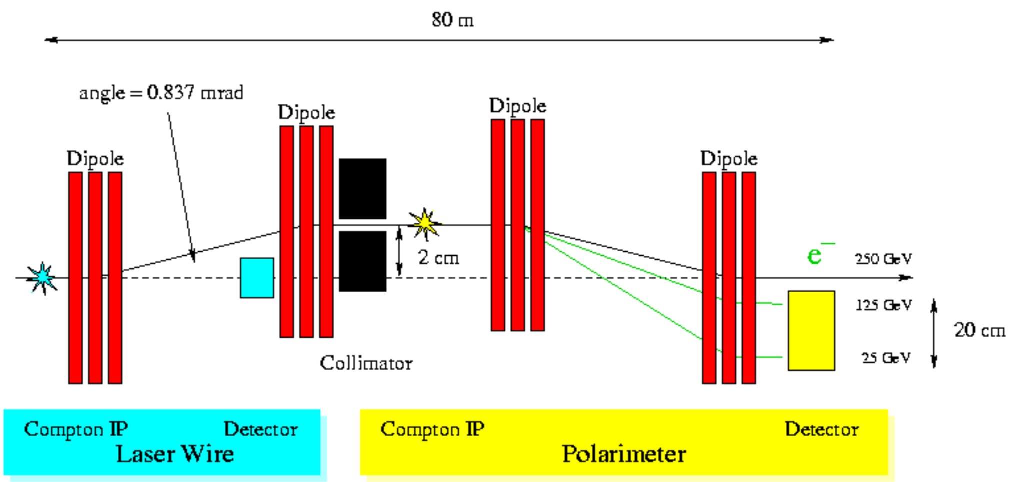

Figure 5: Top view of the polarimeter chicane with collimator

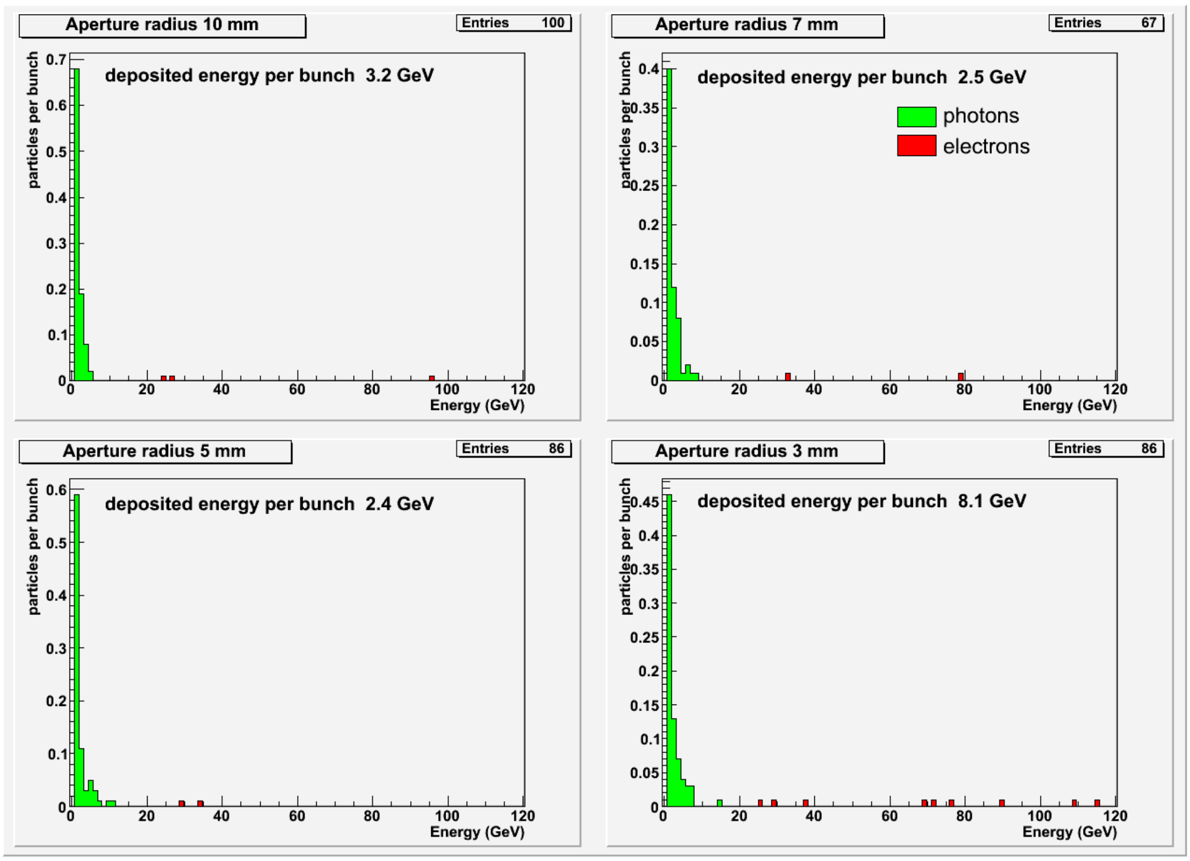

Figure 6: Energies of particles hitting the detector, collimator length = 1 m, different aperture radii

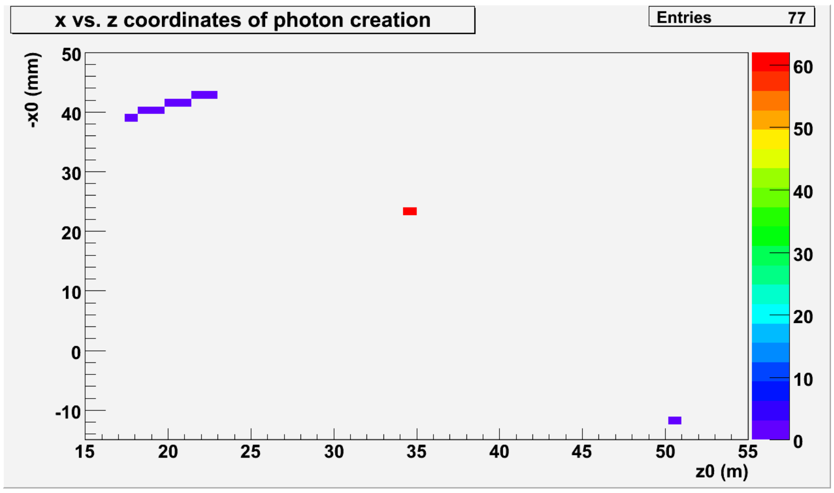

Figure 7: Origin of photons hitting the detector, collimator length = 1 m, radius = 3 mm. The row in the upper left corresponds to the low-energy electrons hitting the beam pipe. The spot at z = 35 m corresponds to the collimator, where most of the photons are produced.

energy deposit, which is even slightly larger than the energy deposit without collimator! Since BDSIM saves the coordinates of the production of photons (but unfortunately not for electrons/positrons), we can investigate the origin of the photons further using figure 7. The red dot at z = 35 m corresponds to the collimator, the sloped line between 18 m and 23 m matches the course of the beam pipe wall, that means, those photons come from the low-energy-scattered electrons mentioned earlier (section 2.2). A larger number of those photons passing a collimator with larger aperture do at least partially explain the increase in the photon background.

To explain the additional electrons for the smaller apertures, we should consider their transverse shift to the unscattered beam growing with their energy loss. A collimator with smaller aperture absorbs also higher-energy electrons producing particle showers with higher energies, such that more particles pass the collimator and hit the detector. Figure 8 shows that a longer collimator finally absorbs more particles, such that the energy deposit on the detector decreases. Again we see the photon background decreasing with smaller apertures, while the electron background increases.

3 Conclusion

From the simulations we see that a well-dimensioned collimator would be useful to confine the effect of the Laser-Wire experiment to the polarimeter. A larger aperture radius, which seems to be better for the polarimeter might also diminish bunch-bunch interaction of the beam (electromagnetic wake fields), which has not been investigated here. However, it also leads to more scattered electrons passing the chicane and reducing the beam quality or disturbing the e^--e^+ collisions further down the beam pipe.

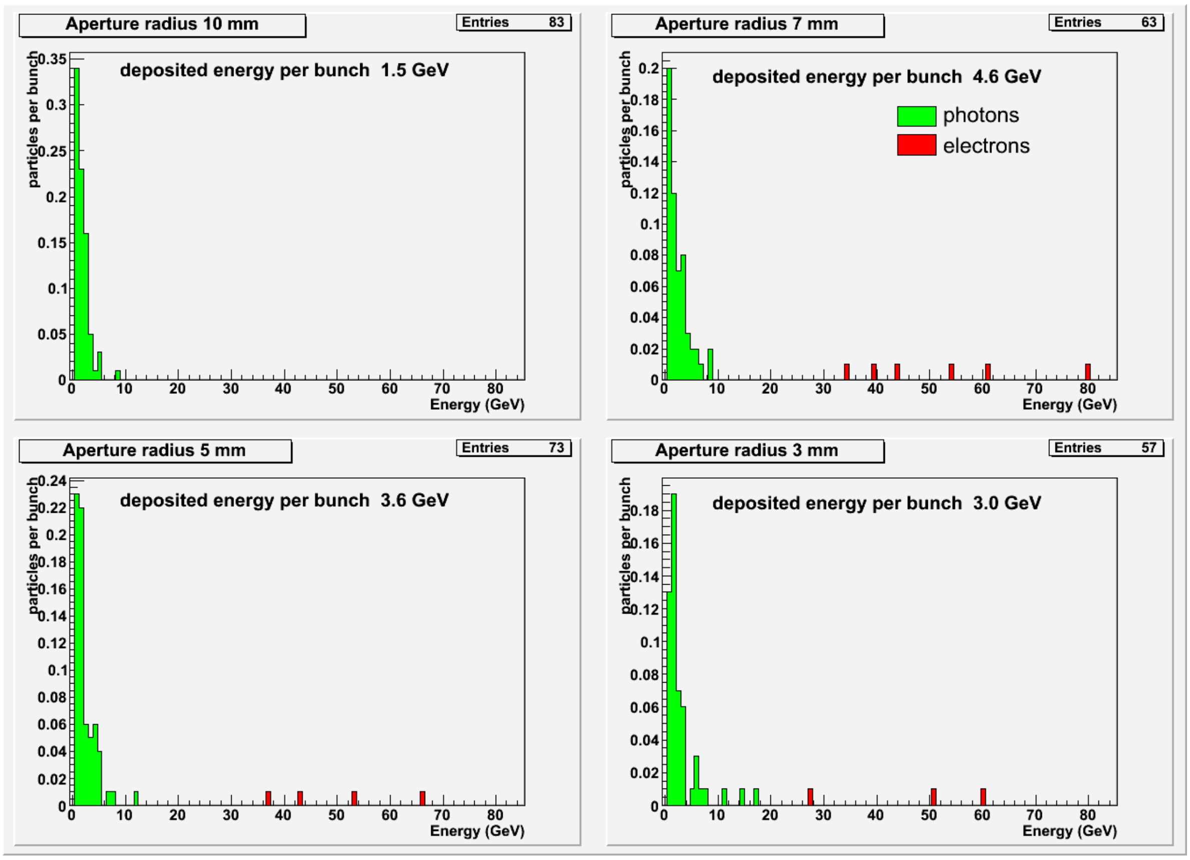

Figure 8: Energies of particles hitting the detector, collimator length = 3 m, different aperture radii

4 Outlook

To get a proper simulation of the polarimeter, there are still many more things to add or to improve, which could not be accomplished so far, are still in progress, respectively.

- More details of the beamline need to be added:
  - The Laser-Wire detector mentioned above (section 1.1) has to be inserted into the simulation to investigate the effect of particle showers originating from a possible converter plate.
  - Between the third dipole and the detector a vacuum chamber with specific dimensions will be installed as a part of the polarimeter. Due to problems with its implementation is has been replaced by a cylindric beam pipe with 20 cm radius.
  - The detector gas volume for the polarimeter has to be inserted to obtain more precise results for the planned measurements

- To find the best dimensions for the collimator, more lengths and aperture radii have to be tested. Due to the small number of particles reaching the detector this should be done with a larger number of events per simulation to get more reliable results.
- The spatial extensions of bunch and laser spot have to be considered as well as a proper normalization for the cross section. So far we assumed both to be point-like because of problems with the implementation of an extended laser spot.
- A possible polarization dependence of the background has to be investigated.

References

[1] V. Gharibyan, N. Meyners, K.P. Schüler, *The TESLA Compton Polarimeter,* `http://www-flc.desy.de/lcnotes/notes/LC-DET-2001-047.ps.gz`, 2001.

[2] ILC website, `http://www.linearcollider.org`

[3] BDSIM website, `http://ilc.pp.rhul.ac.uk/bdsim.html`

[4] GEANT 4 website, `http://geant4.web.cern.ch/geant4`

[5] ROOT website, `http://root.cern.ch`

[6] Laser-Wire group website, `http://www.pp.rhul.ac.uk/~lbbd`