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Polarised Geant4 – Applications at the ILC

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Geant4 is a Monte Carlo simulation framework for the description of interactions of particles and matter. Starting with version 8.2 a new package of QED physics processes is available, allowing for the studies of interactions of polarised particles with polarised media dedicated to beam applications. In this contribution some details about the implementation are presented and applications to the linear collider are discussed.

1 Introduction

Programs that can simulate the complex interaction patterns of particles traversing matter are indispensable tools for the design and optimisation of particle detectors. A major example of such programs is Geant4 [2, 3], which is widely used in high energy physics, medicine, and space science. Different parts of this tool kit can be combined to optimally fulfil the users needs. A powerful geometry package allows the creation of complex detector configurations. The physics performance is based on a huge list of interaction processes. Tracking of particles is possible in arbitrary electromagnetic fields. However, polarisation has played only a minor role so far[a].

The new extension in the library of electromagnetic physics is dedicated to polarisation effects in beam applications [4]. It aims for a proper treatment of longitudinal polarised electrons/positrons or circularly polarised photons and their interactions with polarised matter.

Polarised versions of Bhabha/Møller scattering (B/MS), electron-positron annihilation (EPA), Compton scattering (CS), pair creation (PC), and bremsstrahlung (BS) are already part of the polarisation library. A polarised version of the Photoelectric Effect is in preparation.

Two basic problem classes are addressed:

- *Polarisation transfer* from initial beam particles to secondaries created in material interactions can be investigated. For instance, in the context of the ILC positron source a detailed study of the production mechanism of polarised positrons from photons emitted from a helical undulator is now possible.

- Interactions of polarised particles with polarised matter can be simulated. In general, asymmetries may be observed if beam and target particles are polarised. They manifest themselves in total cross sections as well as in differential distributions, which provides the basis of applications in *polarimetry*.

[a] Compton scattering of linearly polarised photons is available since Geant4 version 3.1. Polarised Rayleigh scattering and Photoelectric effect of linearly polarised photons have been addressed recently.

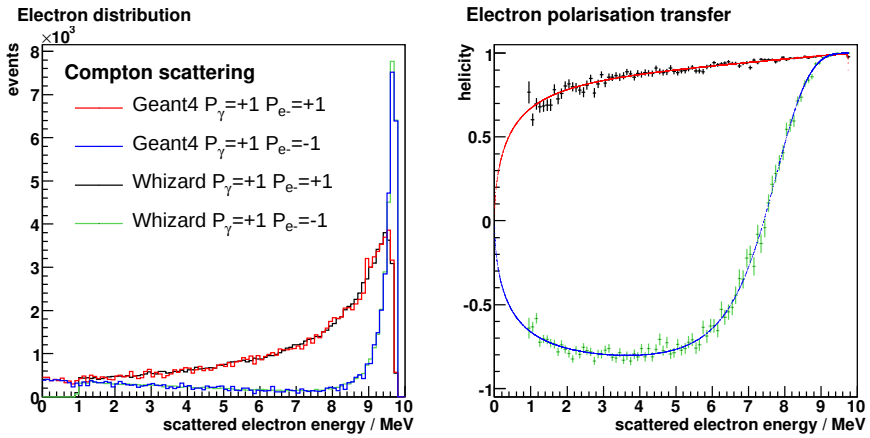

Figure 1: Compton scattering. Distribution (left) of electrons and their degree of polarisation (right) are compared with results from Whizard/O'mega for different initial state helicities [15].

These new features have already been exploited in the analysis of data from the E166 experiment [5], and are also used in studies for an anticipated low energy polarimeter [6] as well as in design and performance optimisation studies for an ILC positron source [7].

2 The new polarisation library

Several simulation packages for the realistic description of the evolution of electromagnetic showers in matter have been developed. A prominent example is EGS (Electron Gamma Shower)[8]. For this simulation framework, extensions with the treatment of polarised particles exist [9, 10]; the most complete has been developed by [11]. It is based on the matrix formalism [12], which enables a very general treatment of polarisation. However, the Flöttmann extension concentrates on evaluation of polarisation transfer, i.e. the effects of polarisation induced asymmetries are neglected, and interactions with polarised media are not considered. Another important simulation tool for detector studies is GEANT3 [13]. Here also some effort has been made to include polarisation [5, 14], but these extensions are not publicly available.

In general, the implementation of polarisation in the library in Geant4 follows very closely the approach by [12]. A *Stokes vector* is associated to each particle and used to track the polarisation from one interaction to another.

Five new process classes for CS, BS, B/MS, PC, EPA with polarisation are now available for physics studies with Geant4. The implementation has been carefully checked against existing references, alternative codes, and dedicated analytic calculations. Figure 1 shows exemplarily a comparison of electron distribution and polarisation transfer in Compton scattering using Whizard/O'mega[b] [15]. Further details can be found in [16, 17].

[b] Whizard/O'mega is a multipurpose matrix element generator allowing for polarisation in the initial state. It is dedicated to high energy collision with many particles in the final state, but can also be used to calculate polarised $2 \to 2$ cross sections, like e.g. Compton scattering.

3 Applications to the ILC

A key feature of the ILC will be that both beams – electrons and positrons – are polarised. With the new polarisation extension it is now possible to investigate details of the production mechanism and polarimetry options for electrons and, in particular, for positrons.

The degree of electron and positron polarisation should be known at least to an accuracy of a few per mill at the collision point to take full advantage of measurements with polarised beams.

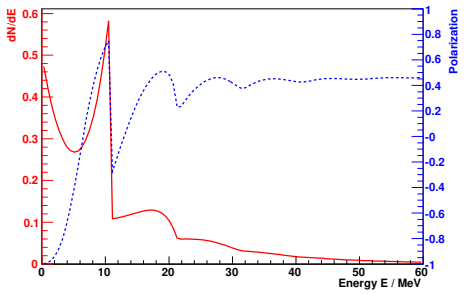

Figure 2: Energy (red) and polarisation (blue) of photons created in a helical undulator.

3.1 Polarised positron source

In the baseline design of the ILC [19] polarised positrons are produced from circularly polarised photons created in an helical undulator hitting a thin Ti target. The spin of the photon is transferred to the electron-positron pairs produced resulting in a net polarisation of the particles emerging from the target. The positrons are captured just behind the target in a dedicated capture optics, i.e. an adiabatic matching device, and their degree of polarisation has to be maintained until they reach the collision point.

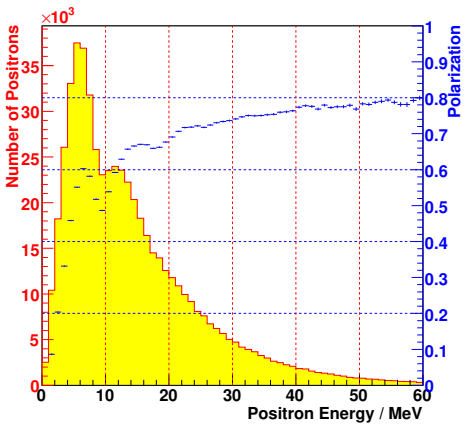

Figure 3: Energy (red) and polarisation (blue) of positrons after the production target of thickness $d = 0.4X_0$.

Figure 2 pictures energy distribution of photons and their degree of polarisation as expected from an ideal helical undulator with strength $K = 1$ and period $\lambda = 1\,\mathrm{cm}$. The resulting positron energy and polarisation distributions after the production target are shown in Figure 3.

3.2 Low energy polarimeter

For commissioning and optimisation of the ILC operation, an independent check of the polarisation near the creation point of positrons is recommended. A Bhabha polarimeter [6] is a promising candidate to realise a low energy positron polarisation measurement. There, a thin magnetised iron foil (few 10μm think) is placed in the positron beam. A few of the positrons hitting the foil undergo Bhabha scattering. Rate and distribution of the scattered electrons and positrons depend on the polarisation of the beam, and can be exploited for polarimetry. The dominating background are bremsstrahlung positrons, which can be substantially reduced by looking at the electron distribution only.

The left part of Figure 4 shows an energy vs. angle distribution of electrons emerging from a 30μm iron foil hit by a beam with $2 \cdot 10^{10}$ positrons of 200 MeV. The right part of

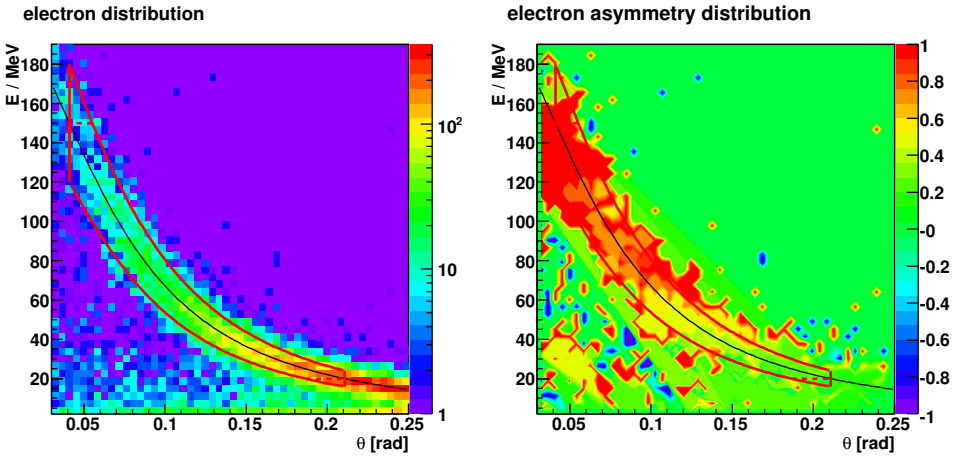

Figure 4: Angular distribution of electrons (left) and analysing power (right).

Figure 4 gives the corresponding analysing power. In the central acceptance approx. 10^4 electrons per positron bunch are expected with an analysing power of about 40%.

3.3 The E166 experiment

A proof-of-principle experiment has been carried out at SLAC to demonstrate the production of polarised positrons in a manner suitable for implementation at the ILC [5]. A helical undulator of 2.54 mm period and 1 m length produced circularly polarised photons, with a first harmonic endpoint energy of 8 MeV, when traversed by a 46.6 GeV electron beam. The polarised photons were converted to polarised positrons in a 0.2-radiation-length tungsten target. The polarisation of these positrons was measured at several energies using a Compton transmission polarimeter.

Geant4 simulations using the polarisation extension have been employed in the determination of the expected polarisation profile. These simulations also provided the basis for the determination of the analysing power needed to determine the polarisation of the produced positron beam. Further details may be found in [1, 16, 18].

4 Summary

Starting with version 8.2 a new package of QED physics processes has been added to the Geant4 framework, allowing studies of polarised particle interactions with polarised media. Applications include design and optimisation of a polarised positron source and beam polarimetry for a future linear collider facility.

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