STUDY ON LOW–ENERGY POSITRON POLARIMETRY*

Karim Laihem, Sabine Riemann†, Andreas Schälicke‡, Andriy Ushakov (DESY, Germany)
Ralph Dollan, Thomas Lohse (Humboldt University Berlin, Germany)

Abstract

For the design of the International Linear Collider (ILC) a polarised positron source based on a helical undulator system has been proposed. In order to optimise the positron beam, i.e. to ensure high intensity as well as high degree of polarisation, a measurement of the polarisation close to the positron creation point is envisaged. In this contribution methods to determine the positron polarisation at low energies are investigated. These studies are based on simulations with an extended version of GEANT4, which allows the tracking of polarised particles taking into account the spin effects.

INTRODUCTION

The physics potential of the ILC will be substantially broadened if both beams – electrons and positrons – are polarised [1]. The degree of polarisation, P_{e^-}, P_{e^+}, 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. For the optimisation of the ILC operation an independent check of the polarisation near the creation point of positrons and electrons is recommended; but in contrast to the polarimetry at high energies the low–energy positron polarimetry turns out to be a challenging issue even if only an accuracy of a few percent is needed. An absolute polarisation measurement is preferred but at least a relative measurement is required; main criteria are the robustness and reliability combined with easy handling.

Polarised positrons are created with circularly polarised photons hitting a thin target. The spin is transferred to the pair produced electrons and positrons 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.

In the nominal design of the ILC the positron beam pulse consists of 2820 bunches with $2 \cdot 10^{10}$ positrons each; the pulse repetition rate is 5 Hz. Depending on the position of the low–energy polarimeter, the positron energy is $E_{e^+} \approx 30 - 40$ MeV behind the capture section, $E_{e^+} \approx 100 - 300$ MeV after the pre–accelerator and $E_{e^+} \approx 5$ GeV near the damping ring. The typical transverse beam size is $\sim$1 cm. In this paper we will evaluate the different options for a positron polarimeter at the positron source.

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† sabine.riemann@desy.de
‡ andreas.schaelicke@desy.de

EVALUATION OF METHODS

Different options to measure the polarisation of positrons (or electrons) have been considered: laser Compton polarimeter, Compton transmission polarimeter, Bhabha/Møller polarimeter, Mott scattering and the possibility to exploit the spin–dependence of synchrotron radiation.

Laser Compton polarimeter

A laser Compton polarimeter is the recommended option for a polarimeter close to the interaction point. Laser photons hit the positron (electron) beam and are backscattered; the angular distribution depends on the polarisation of the positrons (electrons). With this approach it is possible to achieve very high precision in the polarisation measurement [2] as has been demonstrated at SLC [3] and HERA [4]. For a low–energy polarimeter the situation is different. On one hand the asymmetry in the angular distribution of the backscattered photons is very small for energies around few GeV or below. Furthermore, the signal rate depends on both, the intensity of photon and positron (electron) beam. To achieve sufficient signal rates within an acceptable period either the size of the polarised positron beam has to be decreased substantially or a highest power laser would be needed. Hence, a Compton polarimeter is not the solution for a low–energy positron polarimeter at the source.

Compton Transmission polarimeter

For photons of a few MeV a Compton transmission polarimeter is a well established method [5]. This method can also be applied on positrons (or electrons), since positrons can be reconverted to photons in a Bremsstrahlung's target. The polarised photons pass magnetised iron and undergo Compton scattering with the two electrons in the 3d–shell of the iron atoms. The transmission of a photon beam through iron depends on the polarisation of the beam photons as well as on the polarisation of the target electrons. The latter is assumed to be 2/26≈7.6% in fully magnetized iron. Reversing the polarity of the magnetic field in iron results in an asymmetry of the transmission signal at the percent–level. The advantage of this method is the simple setup which can deal with very poor beam qualities. The method was successfully employed in the E166 experiment ($E_{e^+} \approx 3 - 8$ MeV) [6] and at ATF ($E_{e^+} \approx 30 - 40$ MeV) [7]. However, at energies higher then a few tens of MeV this method becomes inefficient, since with rising energy the pair–production cross section becomes more and

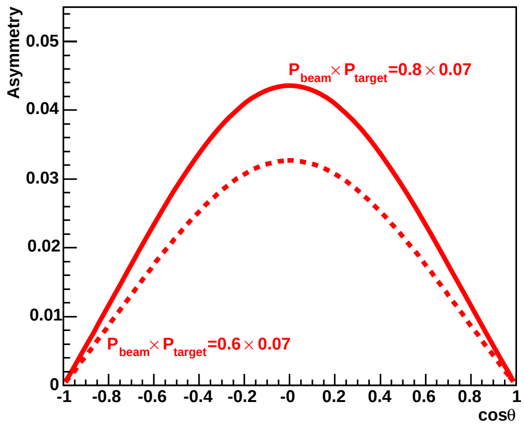

Figure 1: Angular dependence of the asymmetry in Bhabha–polarimetry in the CMS frame for different beam (positron) and target (iron electron) polarisations.

more dominant, while the cross section of the Compton–process decreases. Furthermore, the method is destructive and at least one complete bunch of a pulse will be dumped for the polarisation measurement. Even for the low energies close to the source the energy deposition into such a polarimeter is tremendous and requires special care and a short measuring time.

Bhabha/Møller polarimeter

The cross sections of Bhabha- and Møller scattering depend on the polarisation of electrons and positrons in the initial state. If both incoming particles are longitudinally polarised, an asymmetry up to $7/9 P_{e^+} P_{e^-}$ can be obtained at scattering angles $\theta \rightarrow \pi/2$, cf. figure 1. In polarimeters this is used by scattering positrons/electrons on the shell electrons of Fe–atoms in a thin magnetised iron foil. This method can be exploited in a relatively simple set–up. But operation with high beam currents is problematic, since the target is heated and possibly depolarised. In addition the electro–magnetic field of an intense beam may destroy the target polarisation. The method is not destructive, but it needs to be checked whether a continuous operation with a very thin target is possible. Møller polarimeters are widely used, e.g. in SLAC fixed target experiments and at the VEPP-3 storage ring (gas target) [8–12].

The asymmetry is measured by either reversing the magnetic field of the target or flipping the spin of the beam particles. The background is dominated by Bremsstrahlung and the Bhabha/Møller process has to be separated from Mott scattering and annihilation in flight processes. The authors of references [13–16] recommend an energy of about 250 MeV as a working point for a Bhabha/Møller polarimeter to suppress the background. Analysing only final state electrons in case of Bhabha scattering, an efficient background rejection can be achieved.

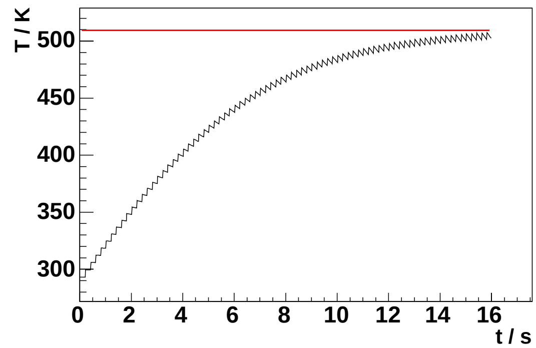

Figure 2: Time dependence of peak temperature of a 30μm iron foil, in a Bhabha polarimeter. See text for details.

Mott scattering

Elastic electron–nucleus scattering described by the Mott formula is widely used to measure the transverse polarisation of electrons. The method is destructive and requires a spin–rotation in case of longitudinal polarised electrons/positrons. In the relevant energy region (30 MeV – 5 GeV) the cross section of Mott scattering decreases more rapidly than that of Bhabha/Møller scattering. At the damping ring where the spins are rotated to the transverse direction the rates of a Mott polarimeter are too small.

Synchrotron radiation

Synchrotron radiation is spin dependent and the procedure to observe this effect was proposed in [17] and described in detail in [18, 19]. Polarisation measurements at the VEPP-4 storage ring are based on the effect that the spin magnetic moment of an electron moving in a magnetic field is a source of electromagnetic radiation (spin light). Angular asymmetries of the synchrotron radiation created in a three pole magnetic “snake” [19] could be used in the damping ring to monitor the transverse polarisation of the positrons. The method is non–destructive and non–intrusive. But the expected asymmetries are very small, $\leq 10^{-3}$. The short storage period in the damping ring makes it difficult to reduce the statistical and systematic uncertainties enough to measure this effect. Further, with a low–energy polarimeter at the damping ring the distance to the creation point of the positrons is large.

BHABHA POLARIMETRY AT LOW ENERGIES

A flexible method working at low positron energies with an acceptable signal–to–background ratio seems to be Bhabha polarimetry. Following first studies [15] it is recommended to place the polarimeter behind the positron pre–accelerator at the point where the positron beam is separated from electron and photon beam. This working point of ≈200 MeV is still close to the positron target. The main source of background to the Bhabha process is

Bremsstrahlung. With appropriate cuts its influence can be suppressed but a simulation treating the relevant scattering processes including polarisation is needed. A technical challenge could be the iron target. The critical temperature is $T_c = 1043\ K$ which will be easily exceeded if an intense beam with a small beam size hits the target. The working temperature of the target has to be stable within a certain limit to guarantee the reliable measurement of the asymmetry.

With the large size of the low–energy positron beam the temperature at the target should be within reasonable limits, and depolarisation by the electro–magnetic field of the beam is negligible. The evolution of the target temperature is shown in figure 2 assuming a beam with $\sigma = 1$ cm, $N_{e^+} = 2 \cdot 10^{10}$ particles per bunch and an energy of ≈250 MeV. A heat–up of ~ 10 K per pulse is obtained. Assuming a cooling by radiation the peak temperature in the equilibrium is ~ 500 K using all bunches of the pulse and assuming a repetition rate of 5 Hz for the polarisation measurement. This temperature rise in the target does not destroy the polarisation of the electrons in the iron foil, its slight reduction by approximately a factor 0.93 is acceptable. The variation of the polarisation within a pulse is well below 1%, which is sufficient for the envisaged accuracy of the polarisation measurement.

GEANT4 WITH POLARISATION

Polarisation extension to GEANT4

The development of polarimeters for electrons or positrons requires reasonable simulations and modelling to evaluate the analysing power. Often the absolute measurement of the polarisation is based on the "theoretical" sensitivity: for instance, at the E166 experiment the polarisation of positrons has been determined by deriving the analysing power from simulations.

The spin dependence of Compton scattering, Bhabha/Møller scattering, annihilation into photons as well as the polarisation transfer via Bremsstrahlung and pair–production are needed for a complete simulation of all processes relevant for tracking particles through matter as targets and polarimeters. Therefore the GEANT4 package, "a toolkit for the simulation of the passage of particles through matter" [20], has been extended by an independent polarisation library that provides all relevant polarised QED processes [21]. If needed a polarisation can be assigned to each logical volume. Currently this extension package is checked against data from the E166 experiment. It is envisaged to include the library for polarised processes and a corresponding example user code in the upcoming December release of GEANT4.

An important application of the GEANT4 extension with polarisation is the design optimisation of the positron production target, and a realistic simulation of a low–energy polarimeter.

SUMMARY & OUTLOOK

The low–energy polarimetry of the positron beam at the ILC provides a real challenge, due to high anticipated beam intensity, the stringent time structure, as well as the large beam spread close to the source. As one possible candidate a Bhabha polarimeter is under current investigation. Detailed simulations will provide insight into the experimental conditions. Therefore a polarisation extension to GEANT4 has been developed.

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