PRODUCTION OF HIGHLY POLARIZED POSITRON BEAMS*

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Abstract

Using polarized electron and positron beams significantly increases the physics potential of future linear colliders [1]. The production of an intense and highly polarized positron beam is a challenge. The posittron source for the International Linear Collider is based on a helical undulator located at the end of electron linac. In case of a 250 GeV drive beam energy, an helical undulator with $K = 0.92$, an undulator period $\lambda = 11.5$ mm and a titanium alloy target of 0.4 radiation length thickness, leads to a relatively low average polarization of the generated positrons (of about 22 percent). In this contribution, the possibilities for increasing the positron polarization have been considered by adjusting the undulator field and selecting only those photons and positrons that yield a high polarization. The detailed simulations have been performed with the developed Geant4-based application PPS-Sim [2].

INTRODUCTION

For the production of polarized positron beams an undulator-based scheme has been chosen as baseline design of the future International Linear Collider [3]. In this scheme, the electrons with an energy up to 250 GeV generate circularly polarized photons in the magnetic field of a helical undulator. These photons are converted into longitudinally polarized positron (and electron) beams in a relatively thin solid target. The resulting positron yield and polarization depend, for instance, on the undulator parameters, properties of positron capturing optics. For the positron beam generation and capture modeling the code PPS-Sim (Polarized Positron Source Simulation) has been developed [2, 4] and is based on Geant4 [5]. The source features as the undulator photon spectra, photon collimator, conversion target, magnetic focussing system, and first part of the capturing RF system have been implemented in PPS-Sim. In this paper the main factors that have impact on polarization will be analyzed.

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ENERGY OF THE UNDULATOR DRIVE BEAM

The higher energy of the electron beam results in the generation of more energetic photons and increases the positron yield. But the polarization of the photon beam is decreasing. The impact of the drive beam energy on yield and on polarization of the e^+-beam is shown in Fig. 1. These results have been obtained for an ILC source [3]: 231 m undulator with $K = 0.92$ and $\lambda = 11.5$ mm, titanium-alloy (Ti6Al4V) target of 0.4 radiation length thickness placed at 500 m downstream to undulator, quarter-wave transformer (QWT) with 1 Tesla maximal field and approximately 10 m long capturing RF cavities accelerating the beam up to 125 MeV. The damping ring acceptance [3] has been taken into account.

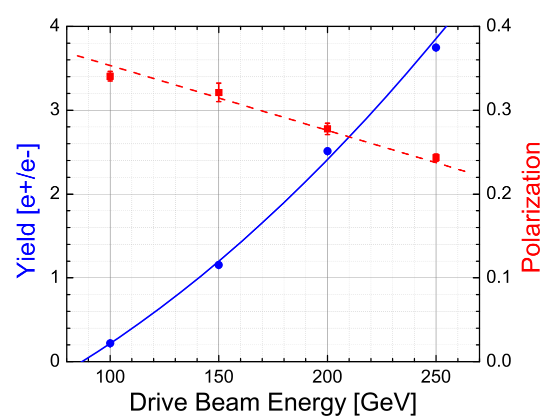

Figure 1: Yield and polarization versus drive beam energy for source with QWT (max 1 T) and without photon collimator.

For the ILC design center-of-mass energy 500 GeV, the positron polarization after the capturing section is about 24 percent. This might not be high enough to achieve the full physics potential open for collisions with polarized beams. Therefore, the factors that have impact on the polarization are analyzed below.

CORRELATIONS

The e^+ energy distribution and the dependence of the polarization on the energy are shown in Fig. 2. Selecting of positrons in a certain energy window could not increase the polarization significantly.

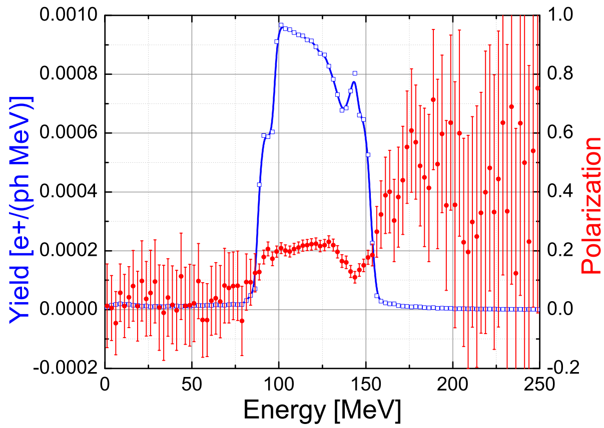

Figure 2: Positron yield and polarization versus positron energy after the capture RF (approx. 10 m long).

To estimate the distribution of polarization along the bunch, the average polarization has been calculated for different bunch length cuts that start from the bunch head. In addition to this polarization, Figure 3 shows also the fraction of positron coverred by the cut. Only about 15% of positrons have a polarization above 30% that are close (less than 2.5 mm) to the bunch head.

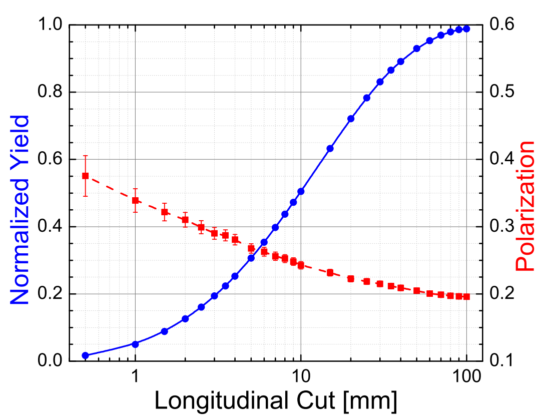

Figure 3: Positron yield and polarization versus longitudinal bunch length cut. Yield has been normalized on it's value without cut.

The polarization depends also on the beam radius. Applying a collimator can increase the polarization. The collimator could either be placed before the target (photon collimator) or after the target (e^+ collimator). The advantage of collimator before the target is reduction of power deposited in target. The photon beam radius is inverse proportional to the electron energy. The small photon spot size on target for high drive beam energies is one of the more critical issues. Therefore, only the photon collimator has been considered here.

The typical energy spectrum of undulator photons can be found in [2]. The angular distribution of polarized photons for an ILC undulator at 250 GeV is shown in Fig. 4. There is a clear angular separation between photons with different helicities. The polarization of different harmonics of undulator photons for small angles only (positive helicity) is shown in Fig. 5.

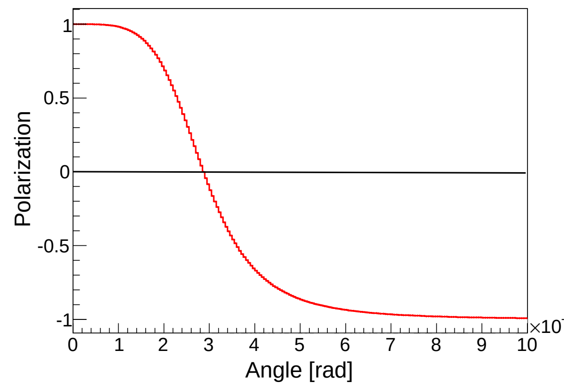

Figure 4: Photon polarization (mean value of z-component) versus angle for undulator with $K = 0.92$ and $\lambda = 11.5$ mm placed at 250 GeV.

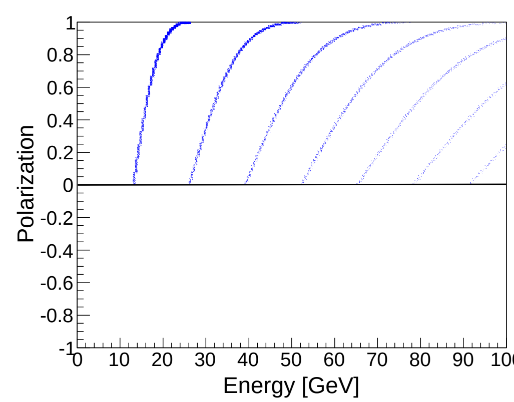

Figure 5: Polarization of photons in different harmonics (starting from 1st – left curve to 7th – right) for the angles less then 2.8 μrad.

Figure 6 shows the resulting e^+ polarization for different apertures of photon collimator. These calculations have been done also for 250 GeV position of the undulator and 500 meters distance between middle of undulator and target. The positron yield normalized on it's value without collimator also shown in this Figure. To achieve 60% polarization the collimator with radius of about 1 mm is required. The details of energy absorption in particular collimators and target requires careful consideration and is not considered in this paper.

UNDULATOR FIELD

An undulator-based source have to deliver the same intensity of positrons within a wide energy range. For instance, the ILC source must provide $3 \cdot 10^{10}$ e^+/bunch in an energy range of the electron drive beam between 150 GeV and 250 GeV. There are two possible scenarios to keep the

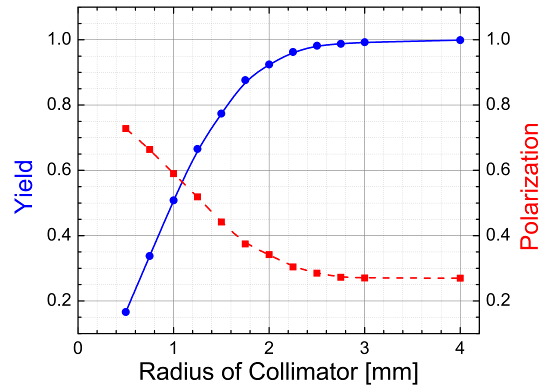

Figure 6: Positron polarization and yield normalized on yield in case of no collimator has been used versus collimator radii.

positron yield at the same level: either keeping the undulator field at its maximum and changing the "active length" of the undulator (i.e. switching on or off some undulator modules) or using the full undulator length and adjusting the magnetic field. Changing the field results in changing of the undulator K-value. This has impact on the photon yield, the angle (Figure 7) and the energy (Figure 8). PPS-Sim uses the Kincaid model of undulator spectra [6].

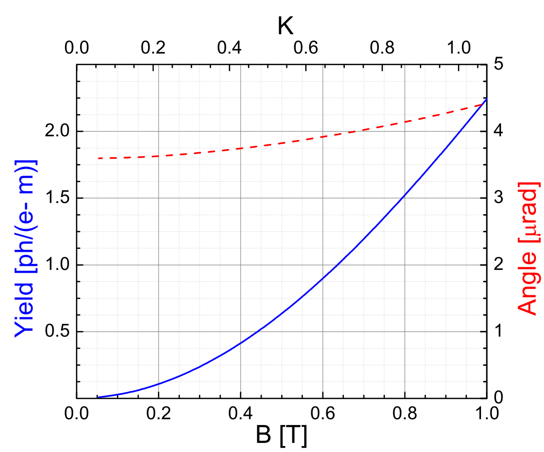

Figure 7: Average angle of photons (red dash line) and undulator photon yield per electron and one meter of undulator (blue solid line) versus B-field on axis and K-value. Undulator period is 11.5 mm.

Figure 9 shows the impact of the undulator field on the polarization and the number of captured positrons normalized per undulator photon. The lower K-value is preferred for getting a high polarization. In order to keep a high positron yield per electron, the undulator should be sufficiently long.

SUMMARY

The factors effecting the e^+ polarization in an undulator-based source have been analyzed. The beam optics that

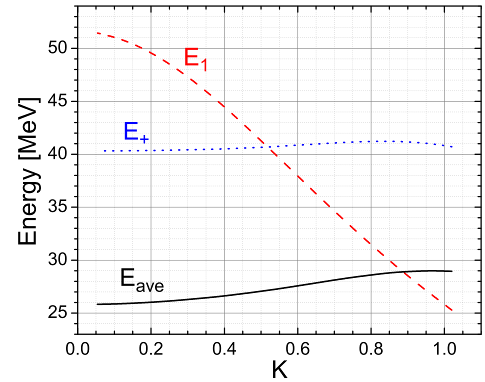

Figure 8: Average photon energy (black solid curve), energy cut-off of 1st harmonic (red dash line) and mean energy of photon with "positive helicity" only (blue dot line) vs K-value.

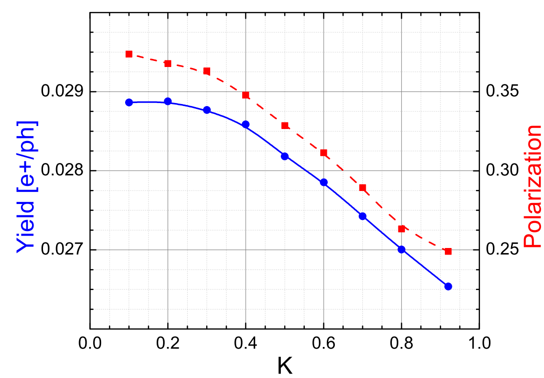

Figure 9: Positron yield and polarization vs undulator K-value.

allows a selection of highly polarized positrons along the beam axis close to the bunch head increases the polarization. Placing the photon collimator in front of the target increases the polarization: for ILC source from about 20% up to 60% with an aperture size of 2 mm. Low-K undulators can lead to a higher polarization in case they are sufficiently long.

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