POLARIZED POSITRON PRODUCTION AND TRACKING AT THE ILC POSITRON SOURCE*

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Abstract

The positron source planned for the future International Linear Collider (ILC) is based on a helical undulator system. Depending on the accelerator design it will be possible to get polarized positrons at the interaction point. A source performance with high positron yield and high polarization is the aim of our design studies. We focus on the optimization of target and capture section by combining the advantages of the simulation codes FLUKA, Geant4 and ASTRA.

INTRODUCTION

The operation with polarized electron and positron beams will significantly extend the physics potential of the future ILC. Already a positron polarisation of approximately 30% will improve the precision of measurements substantially.

In this work the polarization of the positron beam produced by the undulator based positron source [1] with Ti- and W-alloy targets is examined using Geant4. The new release of Geant4 includes the spin dependence of all QED processes and allows to perform a helicity-dependent tracking of particles through target and capture section. The ASTRA code is used to calculate the positron capture efficiency into the optical matching device and preaccelerator. Parameters as positron yield, capture efficiency and deposited energy obtained from Geant4 and FLUKA simulations are compared; activation aspects have been considered in earlier FLUKA studies [2].

POSITRON PRODUCTION

The undulator based system uses a helical undulator placed at the 150 GeV point of the ILC electron linac. The electron beam passing through the undulator generates circularly polarized photons [3]. The energy distribution and polarization of the photons radiated in helical undulator with period of 1.15 cm and undulator K value of 0.92 are shown in Fig. 1. Each electron passing one meter of the undulator produces 1.94 photons.

The distance between end of undulator and target is 500 meters. No photon collimator has been placed between the undulator and the target. The rms photon beam spot size on the target is 3.9 mm.

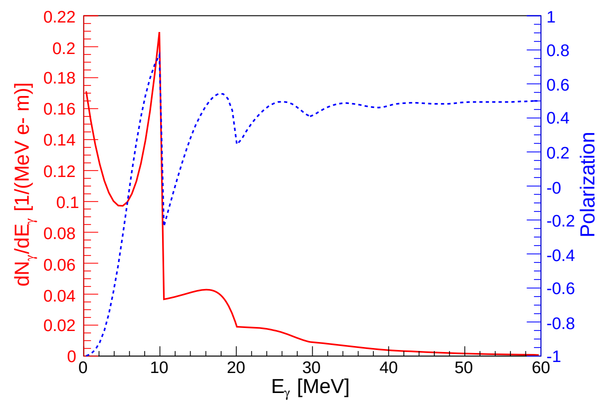

Figure 1: Energy distribution and polarization of photons generated by an electron passing one meter of the undulator (period is 1.15 cm and K value is 0.92).

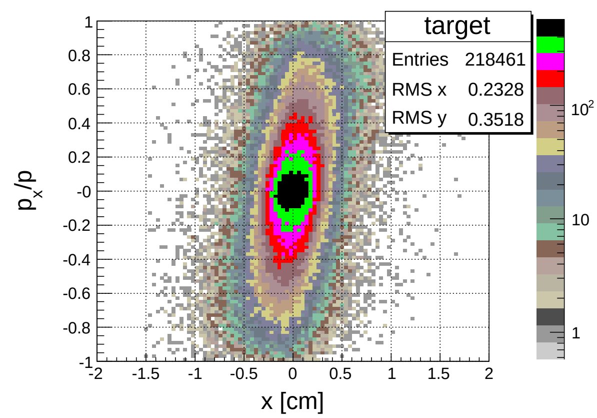

Figure 2: The positron xx' phase space after the target calculated by FLUKA for 10^7 primary photons.

The photons hit a thin Ti6Al4V alloy target (6% of Al and 4% of V) of 0.4 radiation length and produce electron-positron pairs.

The positron production in the target has been calculated with FLUKA [4] and Geant4 [5]. The positron xx' phase space after the target calculated by FLUKA for 10^7 primary photons is shown in Fig. 2. According to FLUKA simulation, the positron yield defined as number positrons per incident on the Ti6Al4V target photon is $2.18 \cdot 10^{-2}$. The positron yield of $2.19 \cdot 10^{-2}$ calculated with Geant4 is in very good agreement with the FLUKA result.

The density distribution of the power deposited in the target by the 117 kW photon beam is shown in Fig. 3. The average energy deposited in the target by one photon is 847.7 keV (FLUKA) and 854 keV (Geant4) correspond-

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ing to 8.14% (FLUKA) or 8.2% (Geant4) of photon mean energy.

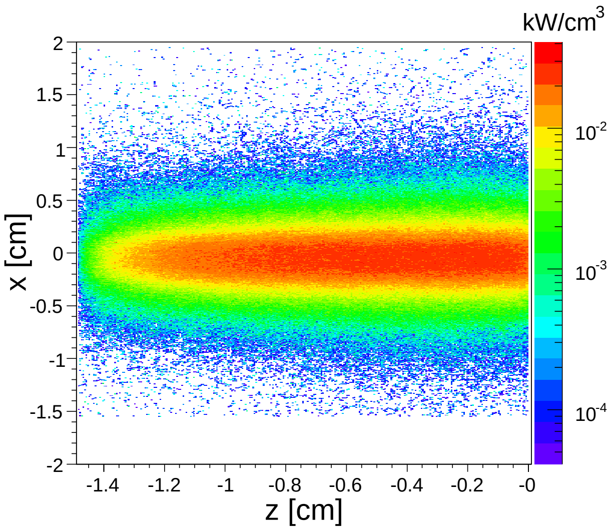

Figure 3: The power deposited in the target by 117 kW photon beam (FLUKA).

It should be remarked that it is not yet possible to implement electric fields into particle tracking simulations with FLUKA. Hence, ASTRA and Geant4 were used to model the capture section for tracking. In addition, with Geant4 the positron beam polarization can be determined. The average longitudinal polarization of positrons escaping the target is 27%. The positron energy distribution and the polarization of the positrons immediately after the target are shown in Figs. 4 and 5.

The simulations were also performed for the same photon beam hitting a W25Re target. A tungsten or tungsten alloy target has a high positron yield and is therefore also considered as possible material for the target.

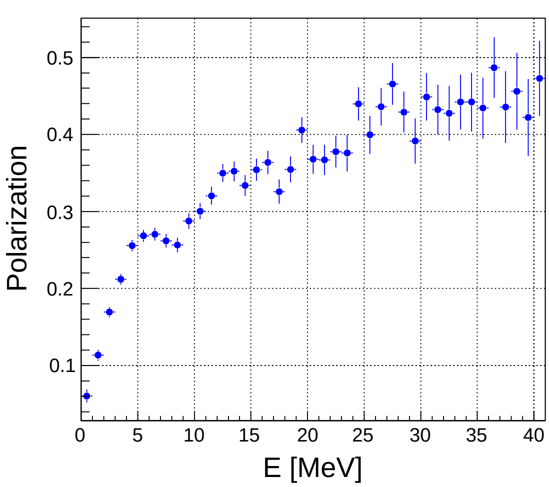

Figure 4: The positron polarization after the target.

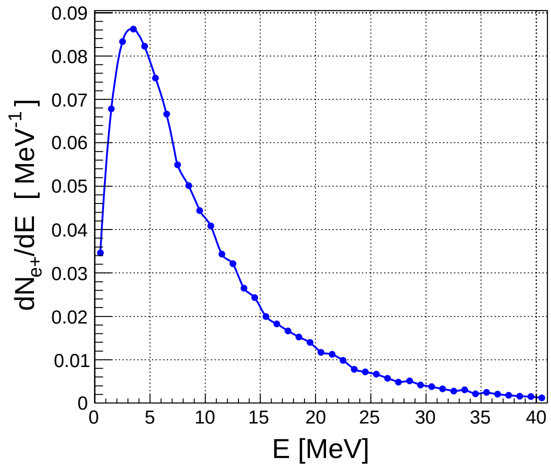

Figure 5: The positron energy distribution after the target.

POSITRON CAPTURE

Due to the very high divergence of the positron beam after the target (rms p_x/p is 0.35, see Fig. 2), the positron beam has to be focused in a capture section. In the positron source model considered here, the capture section consists of the adiabatic matching device (AMD) and a RF structure embedded in a focusing solenoid [6, 7, 8]. The AMD allows to match the positron beam emerging with small spot size and large divergence from the target to the acceptance of the solenoid. The AMD is a 20 cm length tapered solenoid starting with an initial field of 6 T which is reduced adiabatically down to a constant field of 0.5 T. The AMD has a conical aperture increasing from 12 mm at the target side to 46 mm at the RF cavity side. The cavities have also 46 mm iris diameter. The positron capture section and preaccelerator consist of two 11-cell cavities with 14.5 MeV/m average gradient and two 17-cell cavities with 8.5 MeV/m average gradient [9]. No space is left between target and AMD as well as AMD and accelerator cavities. More details about the simplified positron source model used for simulations could be found in [2].

The program ASTRA [10] has been used to track the positrons through the capture section. Figure 6 shows the capture efficiency (defined as ratio of captured positrons to the number of positrons after the target) versus the transverse component of momentum at the 125 MeV position of the positron preaccelerator. The average capture efficiency is 68.4%. 30.3% of the positrons are lost in the AMD and the first 2 m of RF structures, 0.9% in the remaining part of the preaccelerator and 0.4% of positrons turn back into the target.

The captured positron beam must satisfy the dumping ring acceptance requirements. A longitudinal cut of the bunch length to 10 mm yields 34% reduction of the number of positrons with 1% energy spread (or $\pm 7.5^\circ$ of field phase). The dependence of the positron capture efficiency on the tranverse emittance cut ϵ_{edge} (diagonal edge emittance $\epsilon_{edge} = \epsilon_x + \epsilon_y$) is shown in Fig. 7.

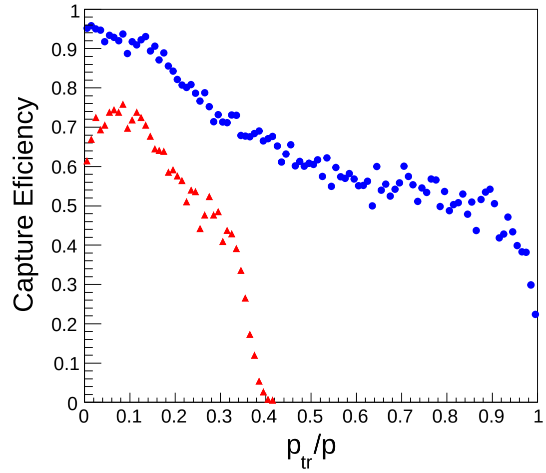

Figure 6: Positron capture efficiency vs normalized tranverse momentum p_{tr}/p at the 125 MeV point of positron preaccelerator: blue circles – without cuts; red triangles – with a longitudinal bunch length cut of 10 mm and a tranverse diagonal emittance cut of $0.04\ \pi$ rad m.

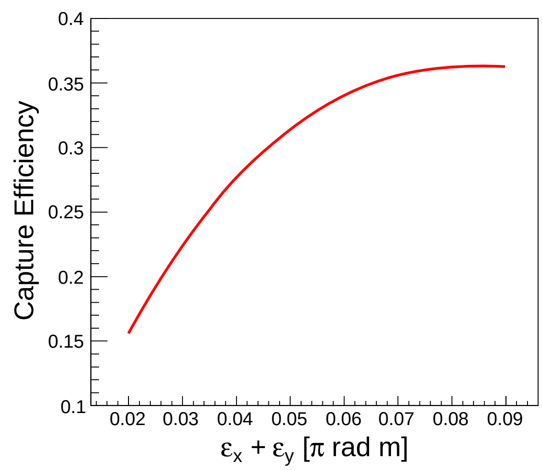

Figure 7: Positron capture efficiency vs cut on tranverse edge emittance (after applying 10 mm longitudinal bunch length cut) at the 125 MeV point of positron preaccelerator.

The capture efficiency is 26.7% after applying the 10 mm longitudinal bunch length cut and the 0.04π rad m tranverse cut (details shown in Fig. 6). The average positron polarization at 125 MeV is 38.6% neglecting polarization degradation during the transport through the capture section.

Simulations for the W25Re target (75% of W and 25% of Re) using the same procedures as for the Ti6Al4V target give a slightly lower capture efficiency and significantly lower positron polarization. The results for both target materials are summarized in Table 1.

SUMMARY

The simulations of polarized positron production and capture have been performed. A capture efficiency of 26% for Ti6Al4V target and a positron polarization of 38.6% has been found if an AMD is used as positron beam focusing device. The simulations have been done using FLUKA, Geant4 and ASTRA to cover power dissipation, capture efficiency, particle tracking in the accelerator structures and polarization yield. The positron yields calculated by FLUKA and Geant4 are in good agreement. In contrast to previous studies a helicity-dependent tracking of particles through target and capture section is possible applying the new release of Geant4 which includes the spin dependence of all QED processes. Additional effort is necessary to achieve a detailed simulation of different positron capture devices using Geant4 including the particle and spin tracking. This is also the focus of our ongoing work. The synergy of all three codes will allow to specify and optimize the the parameters of a polarized positron source.

Table 1: Comparison of the target materials Ti6Al4V and W25Re.

	Ti6Al4V	W25Re
e^+ yield, e^+/γ	$2.19 \cdot 10^{-2}$	$3.34 \cdot 10^{-2}$
$E_{deposited}$, keV/γ	854	455
Capture efficiency, %	26.7	23.0
e^+ polarization, %	38.6	25.1

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