# SIMULATIONS OF POSITRON POLARIZATION IN THE UNDULATOR-BASED SOURCE*

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*Abstract*

The generation of an intense and highly polarized positron beam for a future Linear Collider is a challenge. The design for the International Linear Collider proposes a positron source based on a helical undulator located at the end of the electron linac. This design allows to achieve a high energy linear collider with high luminosity and both electron and positron beams polarized [1]. The polarization degree of the positron beam can be enhanced using a photon collimator. In this paper, the optimization of both the positron yield and polarization for a wide energy range has been studied for different undulator parameters and collimator designs, taking into account realistic parameters for the capture section. In particular, the effects of misalignment and tolerances are considered.

## INTRODUCTION

For the production of polarized positron beams an undulator-based scheme has been chosen as baseline design of the future International Linear Collider [2]. In this scheme, the electrons with energies in a range between 150 GeV and 250 GeV generate circularly polarized photons in the magnetic field of a helical undulator.

To achieve the required intensity of the positron beam, the length of the undulator has to be long enough. In the ILC design, up to 231 meters active length of undulator is planned to provide a yield of 1.5 positrons per electron (50% safety margins).

These undulator photons are converted into longitudinally polarized positron (and electron) beams in a fastly rotated titanium-alloy target placed 412 meters downstream the undulator. The high energy of electrons results in a very small opening angle of the undulator radiation, and a long distance to the target is needed to increase the photon beam spot size at the conversion target. However, such a long distance between the point where the photons are generated and the target or photon collimator results in a high sensitivity to any "misalignments" as electron beam trajectory errors that are caused by initial off-axis injection into the undulator modules and magnetic field errors of the undulator.

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In this paper, the impact of electron beam position and direction errors on the positron yield and polarization has been estimated for a 250 GeV electron beam energy and two different undulator $K$-values: $K = 0.45$ without a photon collimator and $K = 0.92$ with collimator (ILC polarization upgrade option).

## POSITRON SOURCE MODEL

For the positron source modeling the code PPS-Sim (Polarized Positron Source Simulation) has been used. PPS-Sim is a Geant4-based tool [3] that includes the main positron source features as the undulator photon spectra, photon collimator, conversion target, magnetic focusing system, and capturing RF system [4, 5].

The simulations have been performed for a source with titanium-alloy (Ti6Al4V, grade 5) target of 0.4 radiation length thickness, a 120 mm long pulsed flux concentrator with 3.2 Tesla maximal field and approximately 10 m long capturing RF cavities embedded into 0.5 Tesla solenoid and accelerating the beam up to 125 MeV. The damping ring acceptance has been taken into account as two cuts applied to the positron beam: 34.6 mm longitudinal bunch length cut and 0.07 rad·m sum of $x$- and $y$-emittances.

The helical undulator has been developed and successfully tested by the Helical Collaboration group in UK [6]. The 4.116 meter long cryo-module includes two undulator sections with a total active undulator length of 3.5 m. The undulator period is 11.5 mm, the maximal field on axis is 0.86 T (maximal undulator $K$-value is 0.92). In the ILC design 66 undulator modules are used. In addition to such modules, the undulator lattice includes 22 quadrupoles. The quadrupoles will be placed after every third undulator cryo-module, so that the quadrupole spacing is 14.538 m. The total active undulator length is 231 m and the total space (including quadrupole) is about 319 m.

We did not calculate the electron trajectories in a real measured field of undulator, since such simulations have been performed already earlier [6, 7]. These calculations showed that at the end of a module the expected radial deviation from the nominal trajectory at 150 GeV is about 20 $\mu$m in an "over-pessimistic" scenario [6] and that with a special system of correctors the rms deviation can be reduced to a few microns [7].

Our (PPS-Sim) model of undulator radiation is based on Kincaid's model [8]. In this model, it is assumed that the field does not have any errors; the beam is mono energetic;

the beam has no offsets, no divergence and is perfectly aligned to field axis.

In order to estimate the real "misalignment" effects, a random trajectory deviation at the end of the undulator module has been added. A simplified model for every generated photon has been applied: all photons inside an undulator module get in addition to Kincaid's angle of undulator radiation also the angle of electron trajectory (constant over the whole module) defined as the ratio of deviation at the module end to the module length.

## SIMULATION RESULTS

### *Source with undulator $K$-value of 0.45*

Without taking into account any "misalignment" effects, the polarization of the positron beam for the source with the highest undulator field and a 250 GeV electron energy is about 22%. Reducing of the field helps to increase the positron polarization [9]. Therefore, an undulator with $K$-value of 0.45 is a possible way to enhance the positron polarization to about 30%. The polarization upgrade scenarios of ILC undulator-based source have been considered in Ref. [10].

The expected radial deviation of the beam at the end of the undulator module at 250 GeV is not known precisely. Therefore, this deviation has been chosen randomly and varied in wide range up to 40 $\mu$m (rms value) for every of 42 modules (the total active length of undulator was 147 m).

The calculations for $2 \cdot 10^6$ photons incident on the target have been repeated five time. The random offsets have been generated at the beginning of every run.

The positron yield and polarization, shown in Fig. 1, have been estimated for the "uncompensated" misalignment model. It means that at the beginning of the next undulator module the electron beam offset and the angle related to this offset are equal to the offset and angle at the end of previous one.

The reduction of the yield due to trajectory errors up to $5-6\,\mu$m can be compensated by using the full active undulator length (231 m). The polarization is changed only by few percent.

Figure 2 shows the yield and polarization for the "compensated" misalignment model in which the offsets and angles are set to zero at the front of every module.

If the misalignments can be completely corrected, the trajectory errors up to several tens of microns should not be a problem.

### *Source with undulator $K$-value of 0.92 and photon collimator*

To increase the polarization of positrons up to 60% more efforts is needed. The photon collimator placed upstream the target and absorbing the outer part of the photon beam with lower (or negative) polarization could be a possible solution. The resulting positron polarization of undulator-based sources with different photon collimator apertures has been studied in Ref. [9, 10]. 60% $e^+$ polarization can be achieved for an undulator with $K = 0.92$ at 250 GeV and the collimator aperture radius of 0.7 mm [10]. The reduction of the $e^+$ yield due to the photon collimator is still acceptable. The source having an higher $K$-value generates positrons more efficiently. To get the yield of 1.5 $e^+/e^-$ in the source with $K = 0.92$ without collimator needs only 42 meters of active undulator. For the case of using a photon collimator with 0.7 mm aperture radius, 41 undulator modules (143.5 m active undulator length) are required. The possible design for a photon collimator is considered in Ref. [11, 12].

Figures 3 and 4 show the impact of electron trajectory offsets for the uncompensated and compensated misalignment models with a photon collimator of 0.7 mm aperture radius.

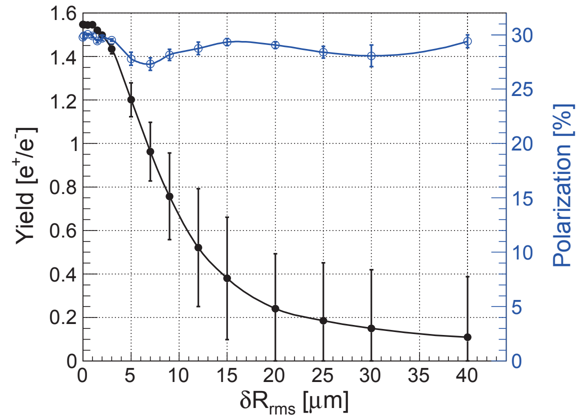


Figure 1: Positron yield and polarization versus rms value of electron beam radial shift at the end of undulator module. Offsets are not corrected. 250 GeV $e^-$, $K = 0.45$, 147 m active undulator length.

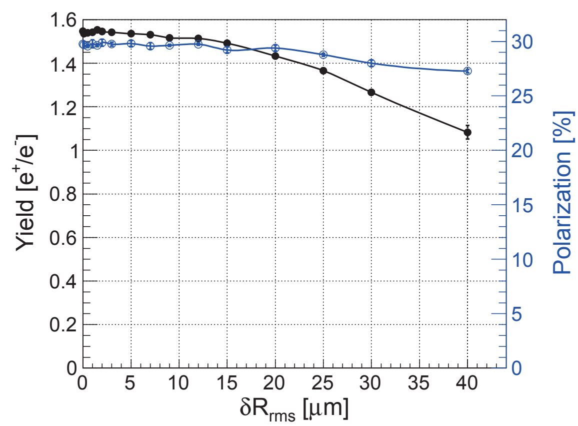


Figure 2: Positron yield and polarization versus rms value of electron beam radial shift at the end of undulator module. Offsets are corrected (compensated) at the front of every module. 250 GeV $e^-$, $K = 0.45$, 147 m active undulator length.


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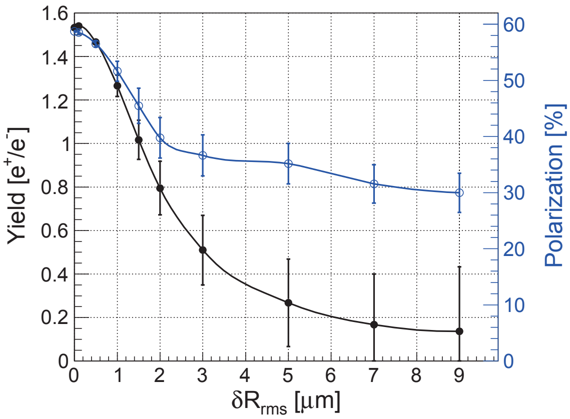


Figure 3: Positron yield and polarization versus rms value of electron beam radial shift at the end of undulator module. Offsets are not corrected. 250 GeV e$^-$, $K$ = 0.92, 143.5 m active undulator length.

In case that no correctors are placed between undulator modules, the tolerance to e$^-$ trajectory errors is about 1 $\mu$m. If a correction system for electron beam trajectories can be applied, the several $\mu$m errors are acceptable.

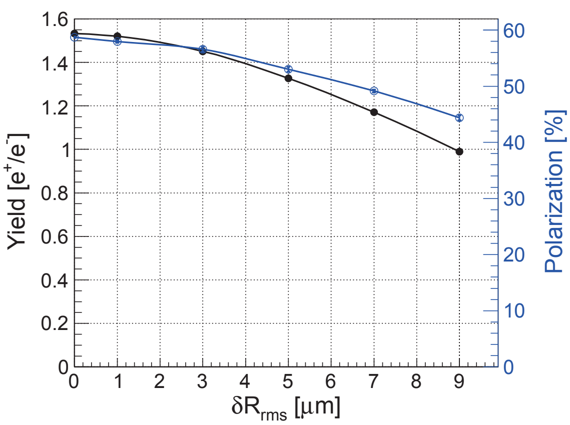


Figure 4: Positron yield and polarization versus rms value of electron beam radial shift at the end of undulator module. Offsets are corrected. 250 GeV e$^-$, $K$ = 0.92, 143.5 m active undulator length.

## SUMMARY

Electron trajectory errors in the undulator can significantly effect the $e^+$ yield and polarization in an undulator-based positron source. The long distance between the radiation point and the target amplifies the effect of any trajectory errors. Without corrections the tolerable level of these errors is in the range of $5 - 6$ $\mu$m for a source without photon collimator. In order to improve the positron polarization by photon collimator, a suppression of the trajectory errors up to 1 $\mu$m is needed. The role of trajectory errors in the presence of an ideal system that fully corrects the errors between the undulator modules has been studied, too.

Our used model of "misalignments" is not considering the real electron movement in the field of helical undulator. The trajectory error at the end of each module was taken as given fact without analyzing the reasons. Therefore, the comparison with other codes considering the electron trajectories and radiation in undulator is desired.

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