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Simulation of polarized positron sources for linear colliders

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Simulation of polarized positron sources for linear colliders

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Abstract. It is a challenge to provide an intense polarized positron source for future linear colliders. The positron yield, polarization and spin transport have to be optimized taking into account the energy deposition in the positron target and the activation of the source area. The Geant4-based simulation tool PPS-Sim has been developed for this purpose. Different production schemes, target options and matching devices can be configured and simulated. All source components and field parameters can be chosen easily. The main features of PPS-Sim as well as some selected simulation results are presented.

1. Introduction

The development of positron sources for the future electron-positron colliders requires detailed design studies. To perform simulations of positron beam generation and beam transport, a reliable software tool is needed that should include the variety of different source components.

For instance, for International Linear Collider (ILC) a helical undulator is planed as generator of circular polarized photons, that hit a titanium-alloy conversion target, and a pulsed flux concentrator as optical matching device will be used to collect the positrons. Additionally, an "auxiliary" conventional source will provide a positron beam with 1% intensity of the undulator-based source. For the CLIC positron source the so-called "hybrid-target" scheme is under discussion. First, the electron beam goes through a single crystal and generates photons via channeling effect. Then these photons are used to produce positrons in a second amorphous target. The Compton scheme is also considered as alternative option for the ILC and CLIC polarized positron sources.

Usually, the combination of two kind of tools are used to simulate the positron source. First, the interaction of the beam with the target is simulated (positron production). For this purpose Geant4 [1], EGS [2] or FLUKA [3] are used. The simulation of different positron source options (undulator-based, conventional, Compton source etc.) requires separate models for each kind of the source. In the second step the positrons are tracked through the electro-magnetic fields using codes as ASTRA [4], MAD-X [5], Bmad [6], BEAMPATH [7] etc.

The Geant4-based application "Polarized Positron Source Simulation" (PPS-Sim) is being developed to combine the simulation of different positron source options and the beam transport in a single software tool.

2. Description of PPS-Sim

PPS-Sim is based on the Geant4, ROOT and Qt4 libraries. Geant4 is used to simulate the electro-magnetic shower in the target, the polarization transfer, and the particle and spin tracking in electro-magnetic fields. ROOT is used to import external data, to store and analyse the simulation results. Qt4 libraries are used for development of the Graphical User Interface (GUI).

The positron source parts included in PPS-Sim are schematically shown in Fig. 1. The main source elements are the primary beam, the conversion target, the Optical Matching Device (OMD) and the accelerator cavity (RF).

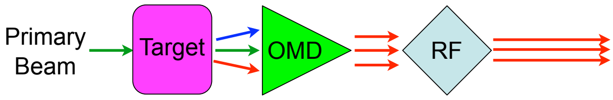

Figure 1. Schematic diagram of main source parts included in PPS-Sim.

The primary beam can be chosen between a photon beam generated in an undulator (undulator-based source), an electron beam (conventional source) or using an external ROOT-file representing the particle spectra of a Compton or hybrid-target source. PPS-Sim generates the undulator photons internally based on Kincaid's equations [10]. The necessary parameters for the generation of undulator photons are the energy of the drive electron beam, the undulator K-value, the undulator period λ, and the distance between undulator and target. The undulator-photon spectra (number photons generated by one electron passing one meter of undulator) and the polarization are shown in Fig. 2 for the ILC positron source with an undulator placed at 150 GeV (RDR design [8]) and the 250 GeV (SB2009 design [9]) electron beam energy.

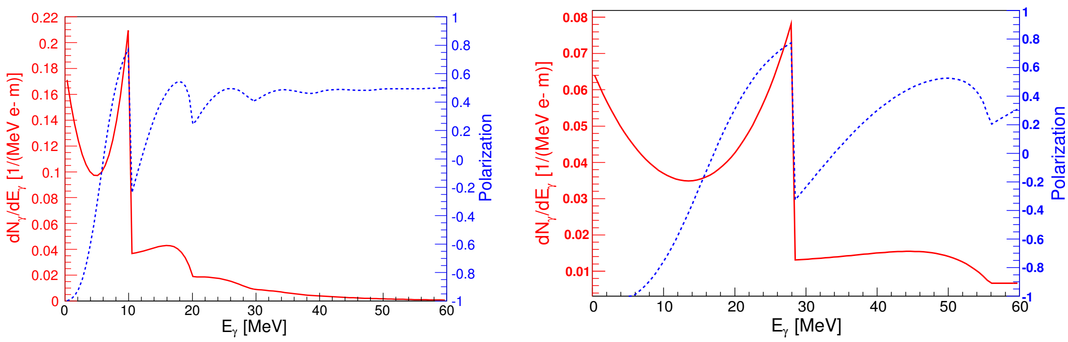

Figure 2. Energy spectra and polarization of photons generated in a helical undulator by 150 GeV electrons (left) and 250 GeV electrons (right). Undulator: $K = 0.92$, $\lambda = 11.5$ mm.

To enhance the polarization, a photon collimator can be placed between undulator and target. The collimator acts as a radial cut on the photon distribution and is not implemented as a real geometrical object.

Two kinds of conversion targets can be used: a solid wheel or a "liquid" target. The target material, thickness and other geometrical dimensions as well as the window parameters for the liquid target can be set by the user.

Three options of OMD have been implemented: adiabatic matching device (AMD), Lithium lens, and quarter-wave transformer (QWT).

The AMD is a tapered solenoid with high field strength at the beginning and low field strength at the end. The field along the beam (and solenoid) axis B_0 can be described as

$$B_0(z) = \frac{B_{ini}}{1+gz},$$

where B_{ini} is the initial field and g is the taper parameter. The dependence of the positron yield defined as number of captured positrons that fulfil the damping ring (DR) requirements, and the dependence of the positron polarization on B_{ini} are shown in Fig. 3 for the ILC source (RDR design).

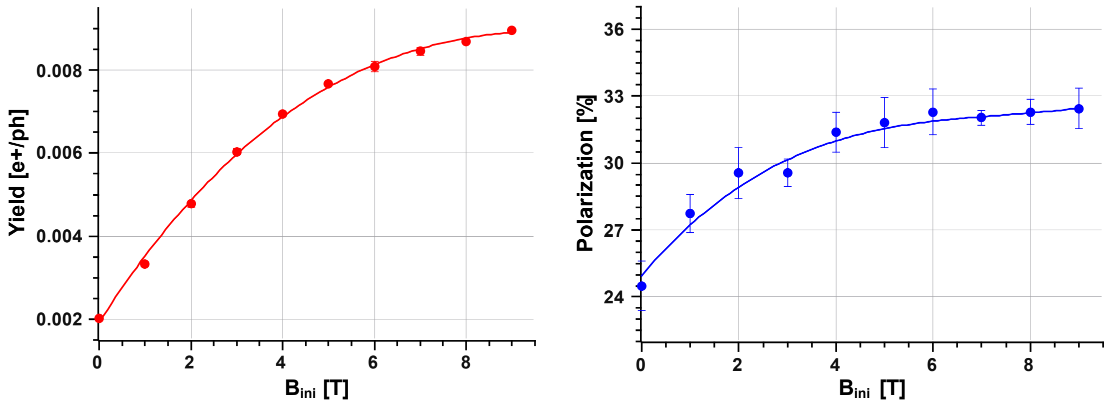

Figure 3. Dependence of yield (left) and polarization (right) on the initial field of the AMD (B_{ini}) for the ILC positron source (RDR design).

PPS-Sim does not include the whole beam line up to the DR. In order to estimate the number of positrons out of the DR acceptance, PPS-Sim applies cuts on the longitudinal bunch size and on the sum of x- and y-emittances (so-called diagonal emittance cut). By default, PPS-Sim applies a 10 mm longitudinal cut that corresponds to about 15° change of the electric field phase for 1.3 GHz.

The field of the Lithium lens implemented in PPS-Sim is described by an analytical function. Assuming that the current I in the lens has only a z-component and an equal density everywhere inside the lens, it is in cylindrical coordinates B_z, $B_r = 0$ and

$$B_\vartheta(r) = \frac{\mu_0 I r}{2\pi a^2}, \quad \text{for } r \leq a,$$

where μ_0 is the permeability of free space, and a the radius of the lens. A more realistic model of the lens is described in [11]. The focusing effect of the lens is shown in Fig. 4. In case of the ILC source (RDR undulator design), the optimal lens current, I_{LL}, is about 120 kA for a lens with 5 mm thickness and 8.5 mm radius.

The QWT consists of two solenoids. The first one has a higher and the second a lower field. Currently, PPS-Sim assumes that the field inside the solenoids is constant and in the region between them it is changed linearly. Figure 5 shows yield and polarization as function of the field strength of the first 2 cm long solenoid. The second 0.5 Tesla solenoid is placed 1 cm downstream the first one.

The E-field of the RF cavity embedded into a solenoid with constant B-field is modeled as harmonic function. The frequency, amplitude and phase of the E-field can be adjusted.

All parameters necessary to describe the fields, dimensions and the relative positions of the source parts can be configured in PPS-Sim via macro-files in batch mode or interactively in a GUI session. Figure 6 shows PPS-Sim running in interactive mode.

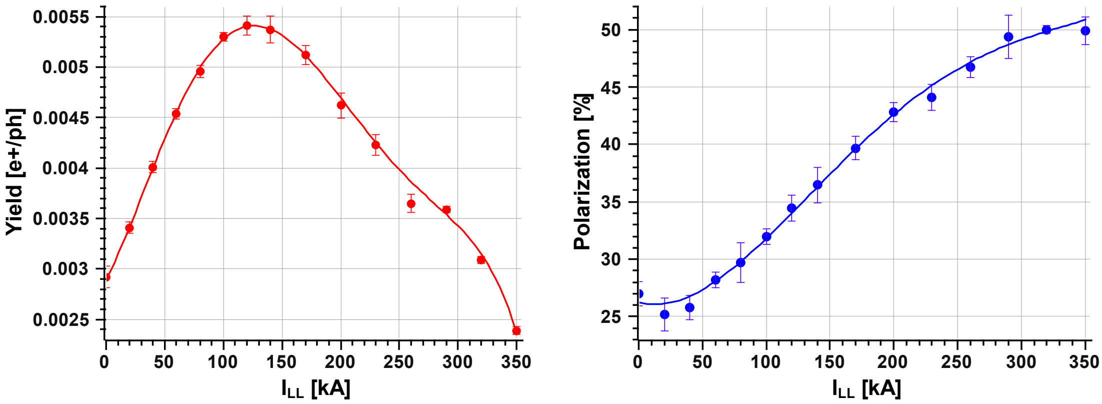

Figure 4. Dependence of yield (left) and polarization (right) on the Li-lens current (I_{LL}) for the ILC positron source (RDR design).

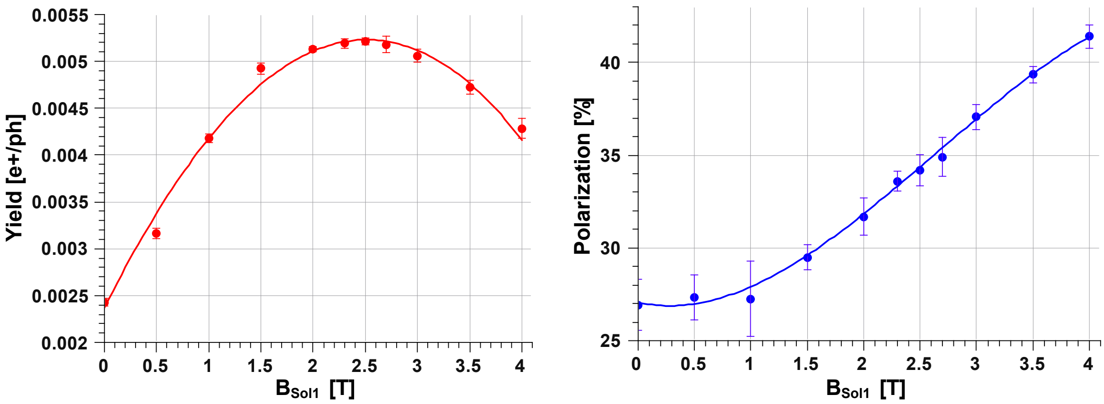

Figure 5. Dependence of yield (left) and polarization (right) on the field of the first solenoid (B_{Sol1}) of the QWT for the ILC positron source (RDR design).

Geant4 has a powerful geometry package and different possibilities to visualize the geometry of the model, particle trajectories and energy deposition in the positron source components. The 3D source model with liquid target and QWT is shown in Fig. 7. The user friendly visualization (OpenGL-based) of the geometry and particle trajectories is very useful for model development and debugging.

The ILC positron source should deliver $3 \cdot 10^{10}$ positrons in each of the 2625 bunches per pulse. To generate the required number of positrons, a photon beam with an average power of more than hundred kilowatt is required. The problem of energy deposition in a relatively small volume of the conversion target, development of shock-waves and radiation damage of the target have to be studied carefully in order to ensure a reliable lifetime of the target.

For the Peak Energy Deposition Density (PEDD) analysis, PPS-Sim provides a special running mode. The energy deposition inside the titanium target is shown in Fig. 8 for the ILC source with OMD yielding about 35% positron capture efficiency.

3. Summary

The development of Geant4 applications for positron source simulations allows to combine the positron production and tracking in one single tool. PPS-Sim is a flexible tool that includes a variety of source options. The undulator-based, conventional, Compton and hybrid-target

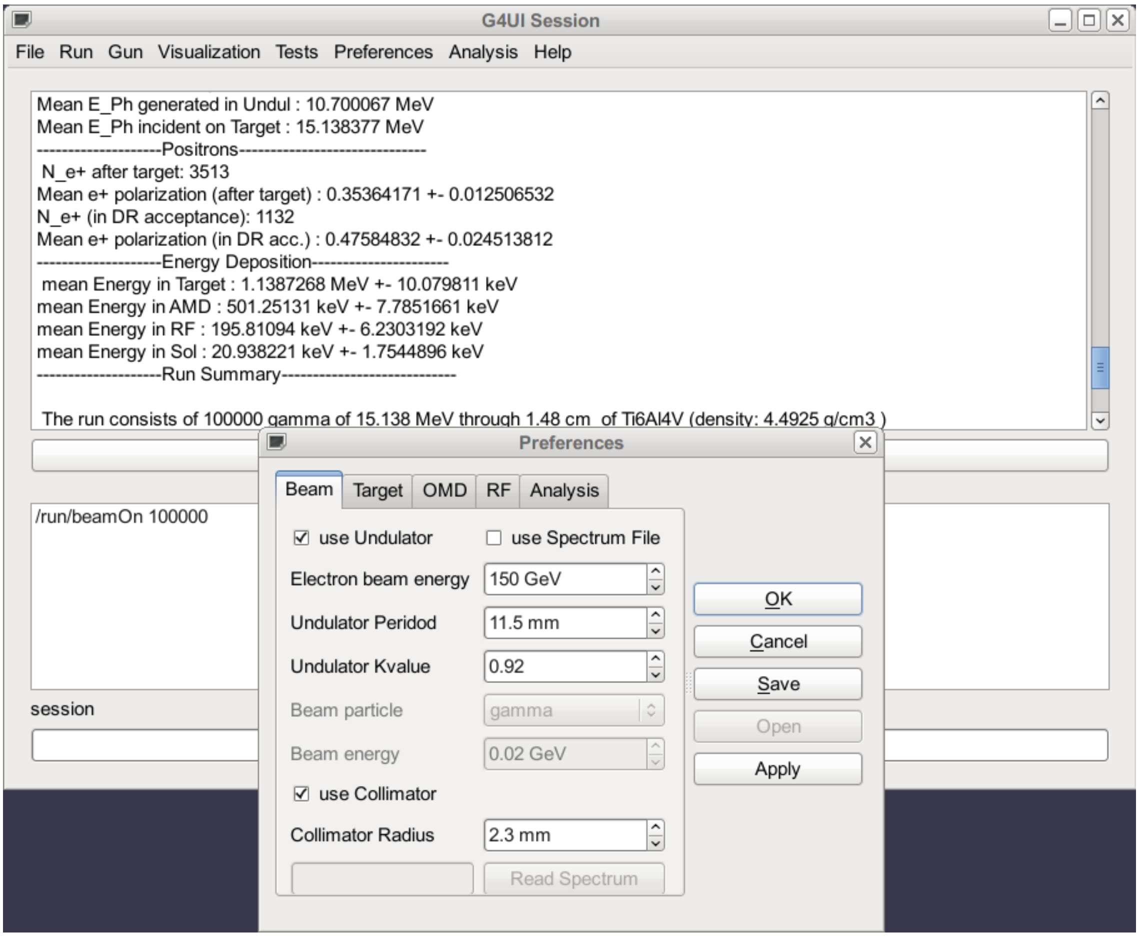

Figure 6. Examples of PPS-Sim windows: the window "Preferences" with opened tab for primary beam settings is placed over the main window "G4UI Session".

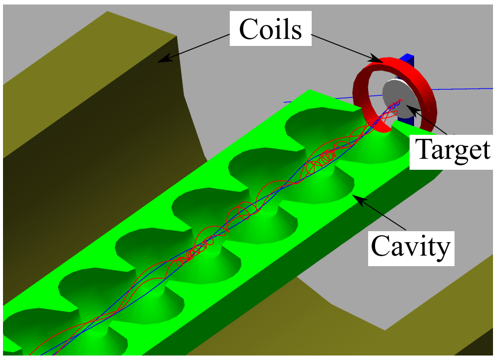

Figure 7. 3D view of the source model with liquid target (only liquid flow channel and windows are shown) and QWT (two coils). The electron trajectories are shown in red, positron trajectories in blue.

schemes of positron generation can be simulated and optimized. The different primary beams, conversion targets and OMD's can be selected. The graphical user interface is easy to use and to extend. The visualization of the geometry is useful for development and debugging. PPS-Sim

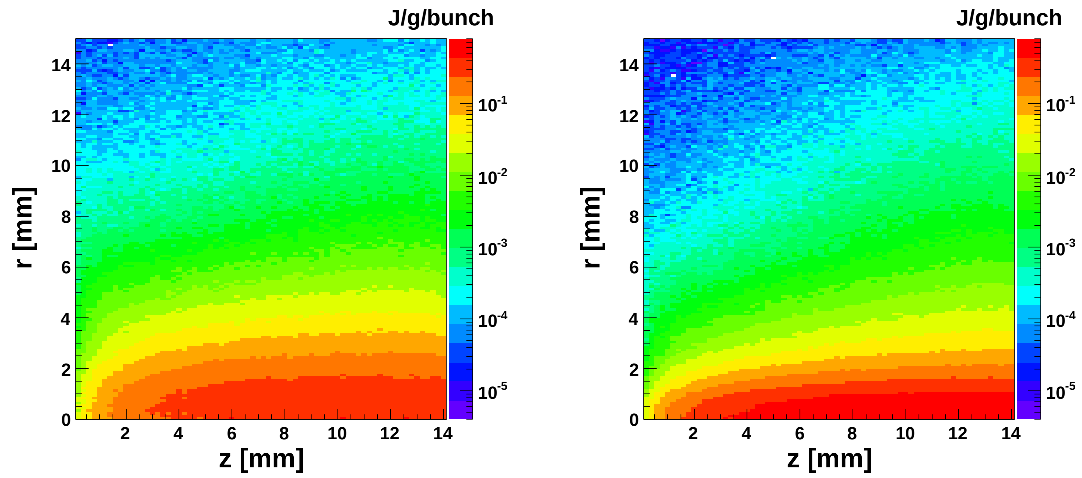

Figure 8. Spatial distribution of deposited energy in the titanium target of the ILC source: RDR design (left), SB2009 design (right).

is an open-source code and available for download from [12].

References

[1] Agostinelli S et al. 2003 *Nucl. Instr. and Meth.* A **506** 250
[2] http://www2.slac.stanford.edu/VVC/egs/
[3] Ferrari A, Sala P R, Fassò A and Ranft J 2005 CERN 2005-10
[4] http://wwww.desy.de/∼mpyflo/
[5] http://mad.web.cern.ch/mad/
[6] http://www.lns.cornell.edu/∼dcs/bmad
[7] Batygin Y K 2005 *Nucl. Instr. and Meth.* A **539** 455
[8] "International Linear Collider Reference Design Report: Volume 3: Accelelator" edited by Phinney N, Toge N and Walker N 2007
[9] http://ilc-edmsdirect.desy.de/ilc-edmsdirect/file.jsp?edmsid=D00000000900425
[10] Kincaid B M 1977 *J. Appl. Phys.* **48** 2684
[11] Mikhailichenko A 2010 *Cornell University Report* CBN 10-3
[12] http://pps-sim.desy.de/