Simulation of Polarized Positron Sources for Linear Colliders

A. Ushakov, A. Schälicke, S. Riemann

DESY, Zeuthen

PESP2010,
Workshop on Sources of Polarized Leptons and High Brightness Electron Beams

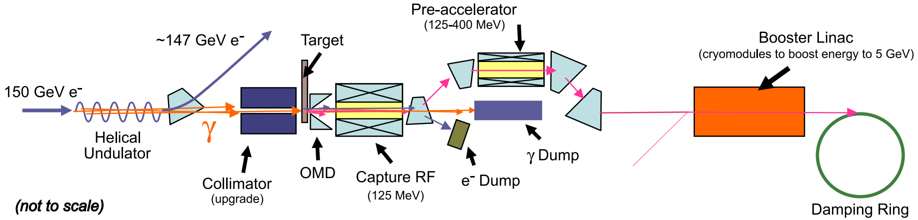
Bonn, 24 September 2010

Outline

Motivation: ***Development reliable tool for positron source simulations***

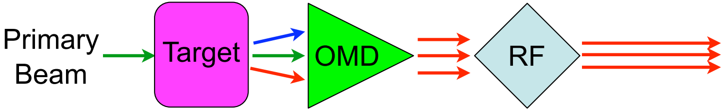
- Positron Source Components
- Simulation Tool PPS-Sim: Polarized Positron Source Simulation
- Simulation Results: Yield and Polarization
  - AMD
  - Li-Lens
  - Quarter Wave Transformer
- Energy Deposition in Target (PEDD)
- Summary

ILC Positron Source Scheme (RDR Design)



Aim: to simulate e^+ production, focusing/capturing and transport up to end of capture section (125 MeV) or up to DR

Positron of Source Components



Primary Beam

- Undulator photons
- Electrons (conventional source)
- Input file (Compton photons, channeling radiation)

Target

- Solid wheel (Ti- or W-alloy)
- Liquid Lead

Optical Matching Device (OMD) and Accelerating Cavity (RF)

- Pulsed flux concentrator (AMD)
- Lithium lens
- Quarter-wave transformer (QWT)
- 1.3 GHz cavity embedded into solenoid

Damping Ring (DR)

Photon Collimator (optionally)

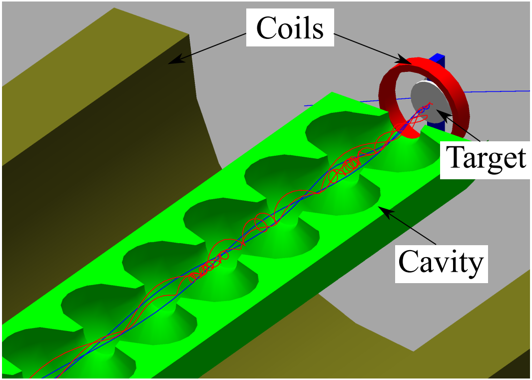
Used Simulation Tools

PPS-Sim is **Geant4-based application** for e^+ source modeling

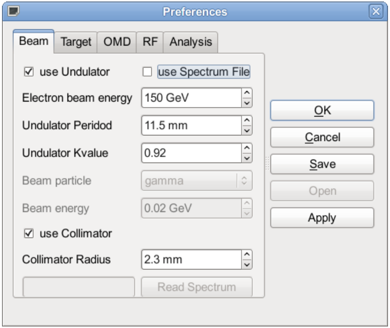
- Electromagnetic and hadronic shower development in target
- Single particle tracking in electro-magnetic fields
- Polarization transfer in physics processes
- Spin tracking in electro-magnetic fields
- Powerful geometry package
- Visualisation of geometry model, particle trajectories and energy deposition
- Qt4-based Graphical User Interface (GUI)
- ROOT: analysis of results and input data (e.g. energy spectrum of primary beam)

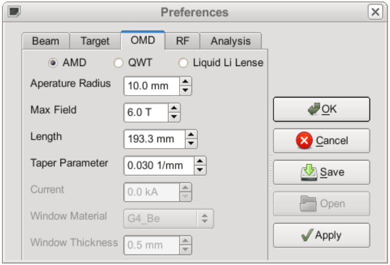
Visualization Example

Source Model with Liquid Lead Target and QWT



PPS-Sim: Source Configuration



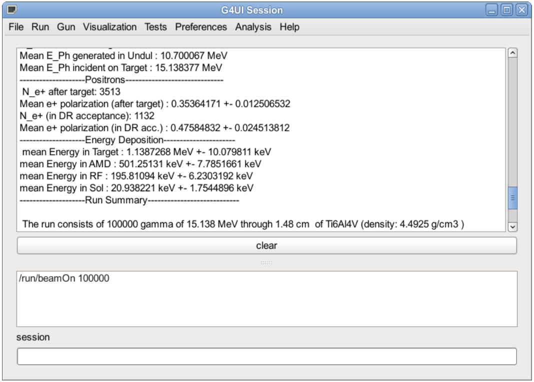


Source can be configured via macro-commands (Geant4) or dialog “Preferences”

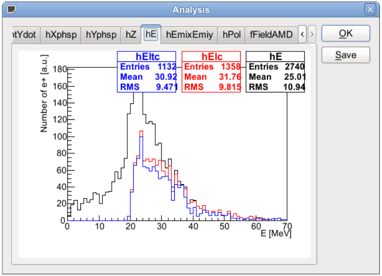
- Choice of source components
- Dimensions & relative positions
- Beam, field parameters
- ...

PPS-Sim: Main Window and On-line Analysis

Main Window



Analysis



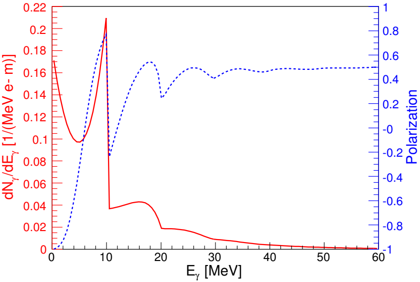
Photon Energy Distribution and Polarization

Helical Undulator:

$K = 0.92$, Period = 11.5 mm

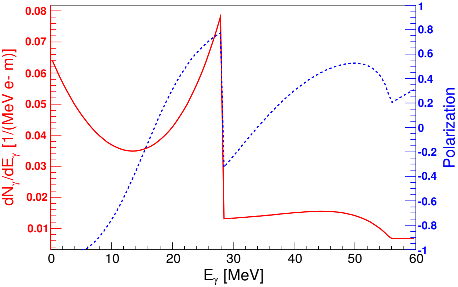
Field on axis = 0.86 T, Aperture = 5.85 mm

150 GeV e^- Beam (**RDR Design**)

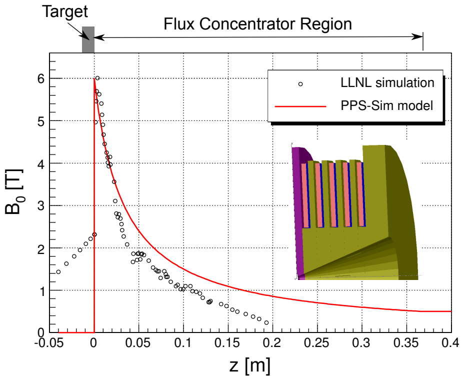


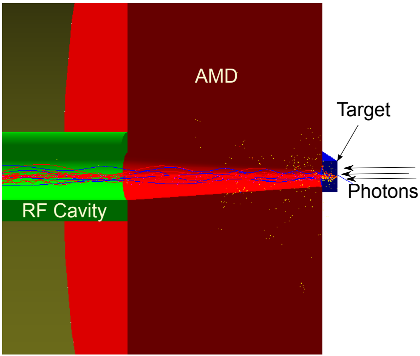
$E_1 \simeq 10$ MeV

250 GeV e^- Beam (**SB2009**)



$E_1 \simeq 28$ MeV

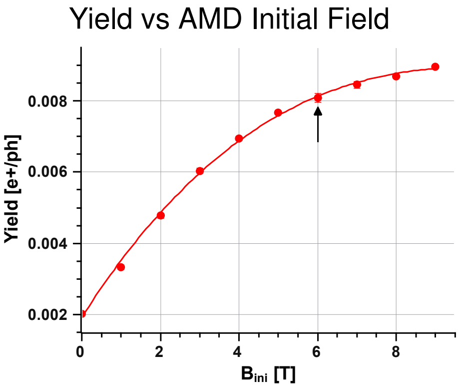


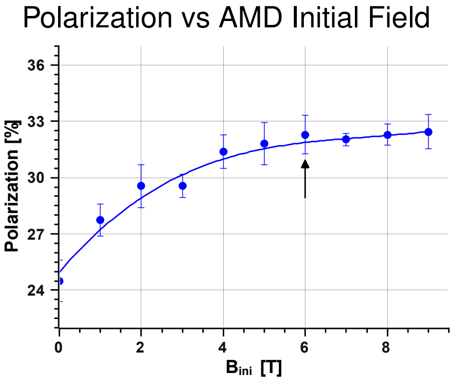


$$B_0(z) = \frac{B_{ini}}{1+gz}$$

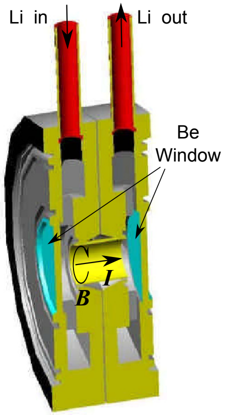
Initial B-field, T	6
End B-field, T	0.5
Taper parameter g, m^{-1}	30

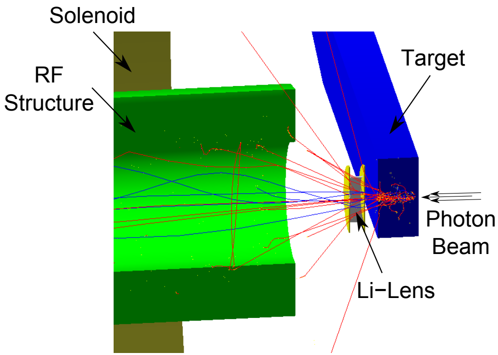
Yield and Polarization vs AMD Initial B-field





Li-Lens Model





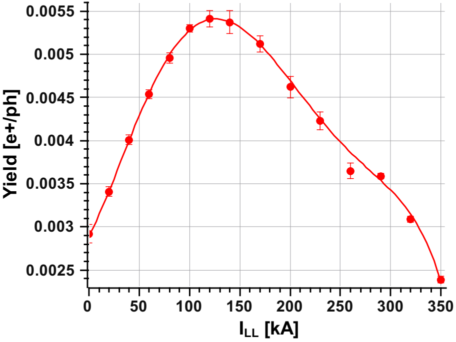
$$B_{\theta}(r) = \frac{\mu_0 I r}{2\pi a^2}$$

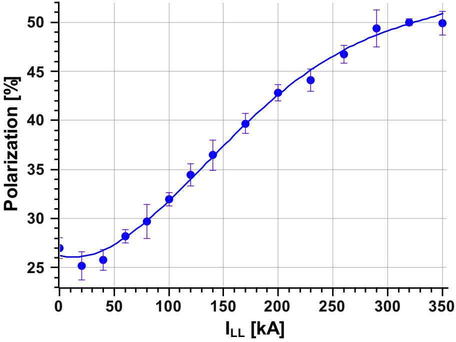
A. Mikhailichenko, Cornell University Report (2010) CBN 10-3

Issue:

Energy deposition in lens windows

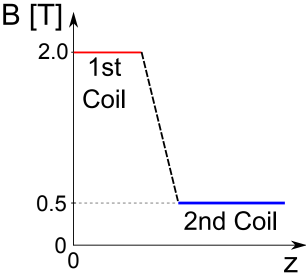
Yield and Polarization vs Lens Current



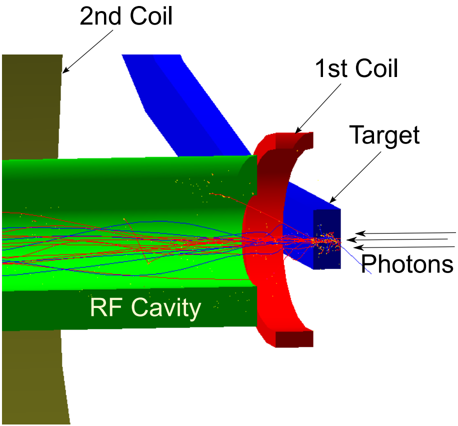


- Optimal lens current (for yield): $\simeq$ 120 kA (0.52 kA/mm^2)
- Higher lens field ("overfocussing") is better for polarization

QWT Model



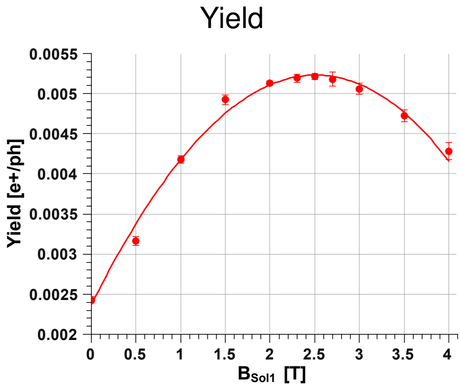
More realistic field distribution has been calculated and will be implemented in PPS-Sim

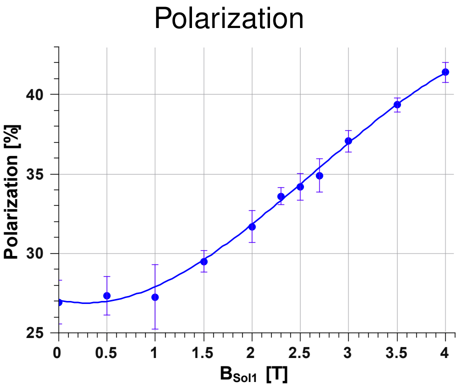


Parameters of 1st Coil

B-field, T	$1 \div 3.5$
Length, mm	20
Inner Radius, mm	46

Yield and Polarization vs Field of 1st Coil of QWT





Distance to Target, mm	0
Distance to RF, mm	10
B_{Sol2}, T	0.5

Performance of AMD, Li-Lens and QWT

	AMD (6 T $\mapsto$ 0.5 T)	Li-Lens	QWT (2.5 T)
Yield (after Target), e^+/ph	0.0226		
"Captured" Yield, e^+/ph	$8.1 \cdot 10^{-3}$	$6.4 \cdot 10^{-3}$	$5.2 \cdot 10^{-3}$
Capture Efficiency, %	35.8	28.3	23.1
Polarization, %	32.3	34.7	34.2

Comparison with other Simulation Programs (EGS+Elegant)

Capture Efficiency [%]

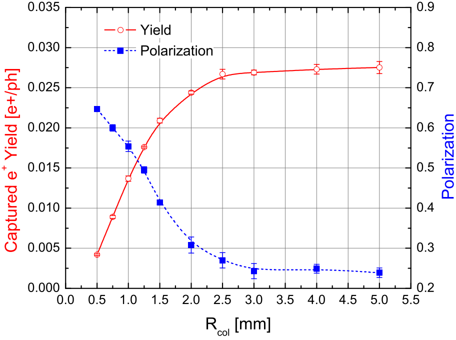
OMD	ANL[1]	PPS-Sim
AMD, immersed target	~ 30	35.8
Li-Lens (50 MV/m)	~ 29	31.2
QWT (1 T, 2 cm)	~ 21	18.5
0.5 T Solenoid	~ 10	10.7

[1] Wanming Liu, Wei Gai et al., Positron Source Collaborating Meeting, Argonne, IL, USA, Sept. 17-19, 2007

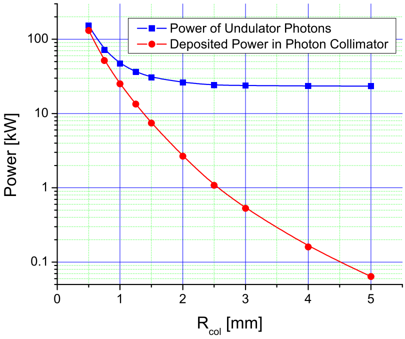
Photon Collimator for Positron Source at the End of Main Linac (250 GeV)

Positron source at 250 GeV (SB2009) provides much more (approx. 3 times) positrons that at 150 GeV (RDR) for the same undulator length, but e+ polarization is about 22% only.
To increase beam polarization the photon collimator have to be used.

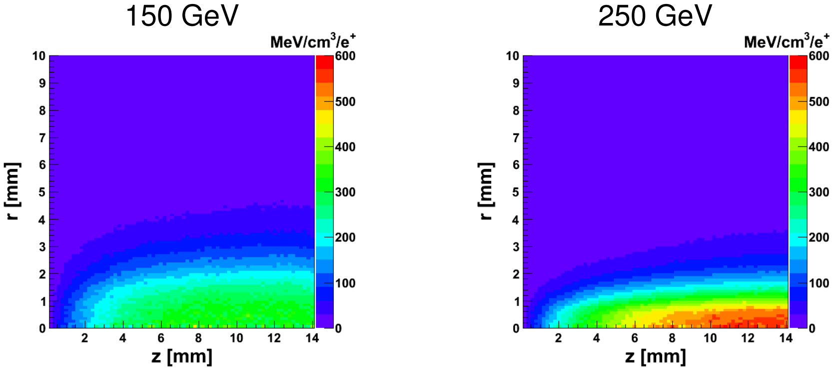
Yield and Polarization vs Aperture Size of Photon Collimator



Required Undulator Photon Power and Deposited Power in Photon Collimator



Energy Deposition in Target. AMD Field from 6 T to 0.5 T



150 GeV	250 GeV
Total Energy: 92.7 MeV/e^+	Total Energy: 60.4 MeV/e^+
PEDD: 320.8 MeV/e^+/cm^3	PEDD: 547.0 MeV/e^+/cm^3
0.34 J/g/bunch	0.58 J/g/bunch

PEDD - Peak Energy Deposition Density

PEDD: Comparison with other Programs

RDR undulator, AMD

PPS-Sim

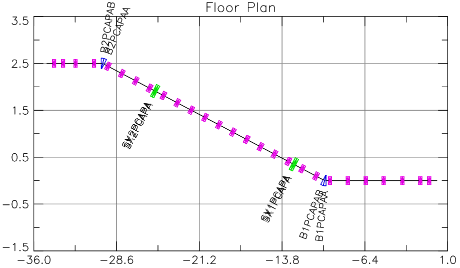
	150 GeV & 5 T	250 GeV & 6 T	
Total Deposited Energy	100.4 MeV/e^+	60.4 MeV/e^+	60%
PEDD	348.8 MeV/e^+/cm^3	547.0 MeV/e^+/cm^3	157%

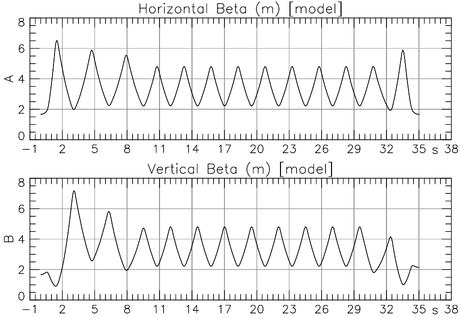
Elegant (Wei Gai, ALCPG, Albuquerque, 2009)

	150 GeV	250 GeV	
Total Deposited Energy	101 MeV/e^+	62.8 MeV/e^+	62%
PEDD			160%

BMAD simulations for ILC polarized e+ beam transport downstream 125 MeV have been started

PCAPA (Positron CAPture system A) is the beamline that separates the positrons from the electrons and photons





Summary and Outlook

- Geant4-based tool PPS-Sim for polarized positron source simulations has been developed
- A variety of e+ source options (different primary beams, targets, OMD's) are included
- Graphical User Interface simplifies usage
- OpenGL visualization of geometry provided
- PPS-Sim is open-source code and available for download: http://pps-sim.desy.de

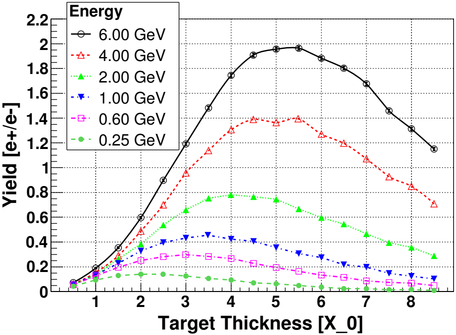
Plans:

- Adding more realistic field (field maps) into PPS-Sim
- Automatically finding of optimal electrical field phase
- Beam tracking up to DR (including spin rotator) in PPS-Sim + Bmad

Backup Slides

- Pb target, 3 mm BN window
- Pencil-like e^- beam
- AMD field: 6 T to 0.5 T
- Optimized AMD taper parameter
- E-field: 14.5 MeV/m
- DR acceptance: 0.09 m rad, 10 mm long. bunch size

“Captured” Positron Yield



PEDD for 6 GeV e^- beam

Conventional Source with Lead Target and AMD

e^- beam energy	**6 GeV**
Beam size, σ_r	4.0 mm
Target material	Lead
Target density, ρ	11.35 g/cm^3
Target thickness	5 X_0
Number of e^+	$3 \cdot 10^{10}$ per bunch
Captured Yield	0.84 e^+/e^-
PEDD	**4.54 J/g/bunch**

Energy Deposition in Target