Simulations of the Polarized Positron Source with PPS-Sim

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Outline

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

- Status of PPS-Sim development
- Impact of electron beam energy for undulator-based source with AMD on:
  - positron yield
  - energy deposited in target
  - polarization
- Yield and polarization of source at 250 GeV and photon collimator
- Summary

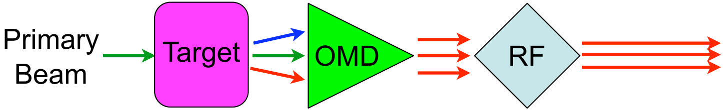
What is PPS-Sim?

PPS-Sim: Polarized Positron Source Simulation

PPS-Sim is **Geant4-based application**

- Electromagnetic and hadronic shower development in target
- Single particle tracking in electro-magnetic fields
- 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)

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

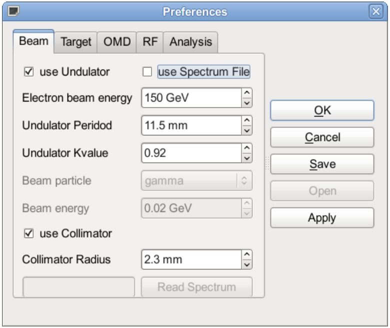
Acceptance of Damping Ring

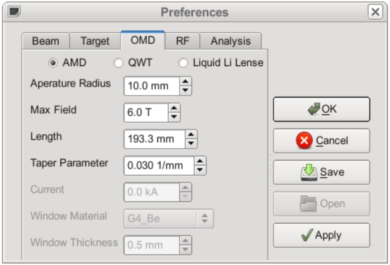
Photon Collimator (optionally)

PPS-Sim: Source Configuration

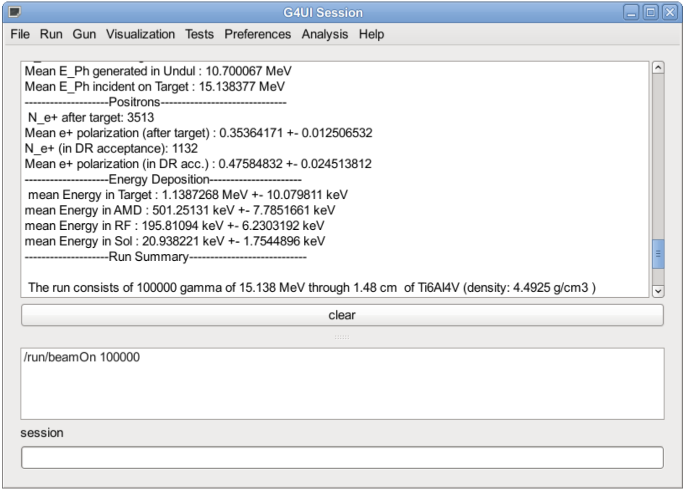
Source can be configured via macro-commands (Geant4) or dialog “Preferences”

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





PPS-Sim: Main Window



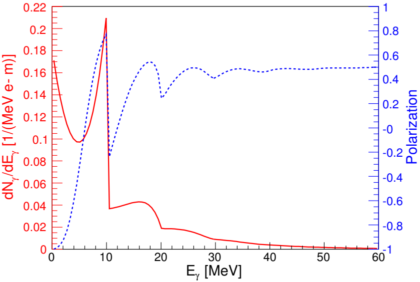
Photon Energy Distribution and Polarization

<u>Helical Undulator:</u>

$K = 0.92$, Period = 11.5 mm

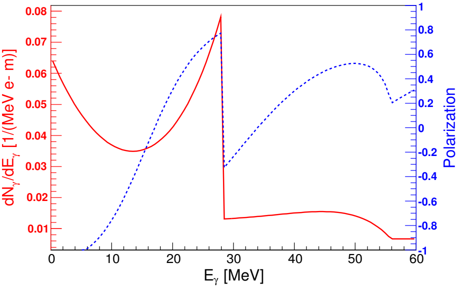
Field on axis = 0.86 T, Aperture = 5.85 mm

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



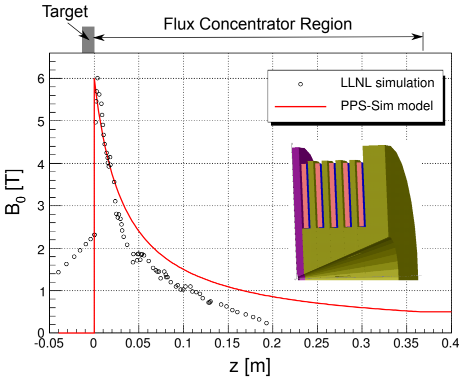
$E_1 \simeq 10$ MeV

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



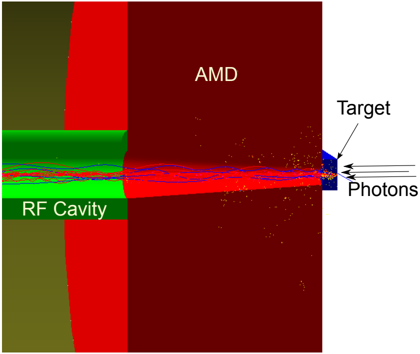
$E_1 \simeq 28$ MeV

Flux Concentrator (AMD) Model

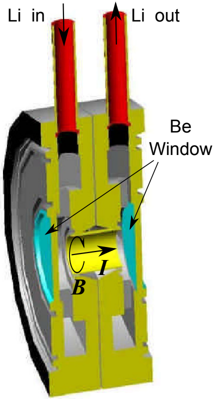


$$B_0(z) = \frac{B_{ini}}{1+gz}$$

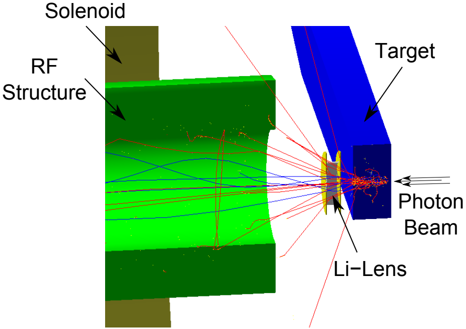
Initial B-field, T	6
End B-field, T	0.5
Taper parameter g, m^{-1}	30



Li-Lens Model

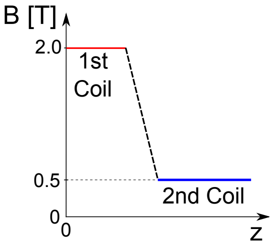


$$B_\theta(r) = \frac{\mu_0 Ir}{2\pi a^2}$$



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

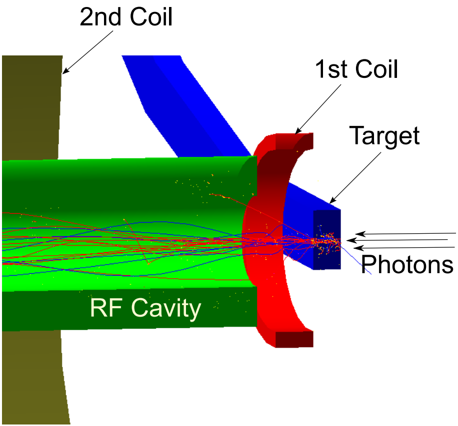
QWT Model



Parameters of 1st Coil

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

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



Performance of AMD, Li-Lens and QWT (RDR Design)

- Undulator at 150 GeV, $K = 0.92$, $\lambda = 11.5$ mm
- 0.4 X_0 Ti6Al4V Target

	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 [%]

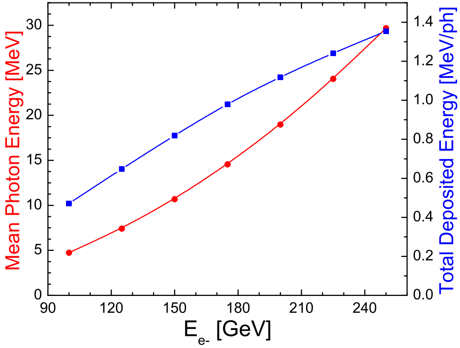
OMD	ANL[1]	PPS-Sim
AMD, immersed target	~ 30	35.8
Li-Lens (50 MV/m)	~ 29	31.2
QWT (1 T, 2 cm)	~ 21	18.5
0.5 T Solenoid	~ 10	10.7

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

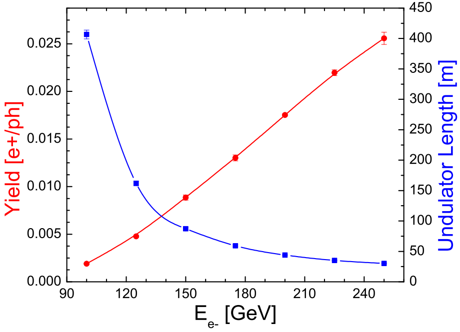
Impact of Electron Beam Energy

RDR Undulator; Ti-target, 0.4 X_0; AMD 6T to 0.5 T, taper parameter = 60 m^{-1};
E_{max} = 28.8 MeV/m, DR acceptance: 1 % energy spread, $\epsilon_x + \epsilon_y < 0.09$ rad m

Mean Photon Energy and
Total Deposited Energy in Target



Captured e^+ Yield and
Required Undulator Length



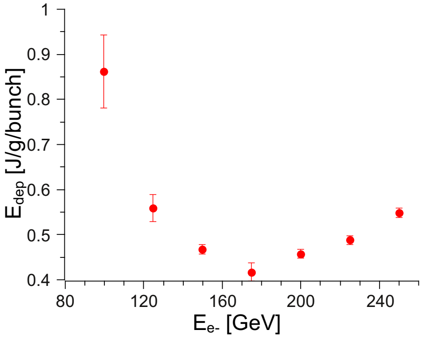
Undulator length required for 1.5 captured e^+ per e^-

Energy Deposition vs Electron Beam Energy

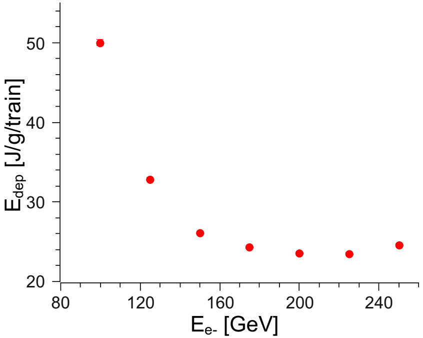
- $2 \cdot 10^{10}$ e^-/bunch
- 1.5 e^+/e^-

- 1312 bunches/train, 1.5 MHz
- 100 m/s rotation speed

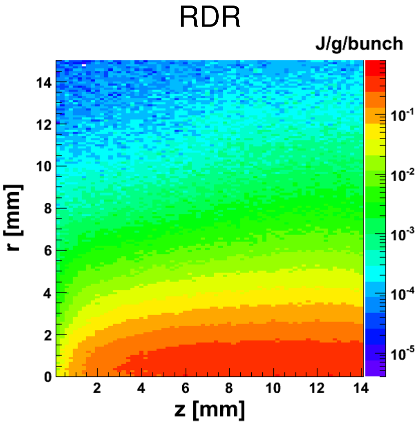
Peak Energy Deposition per Bunch



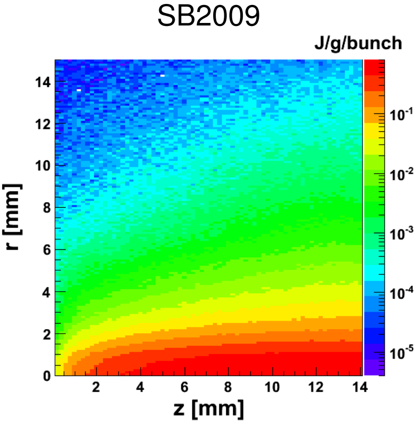
Peak Energy Deposition per Train



Energy Deposition in Target: RDR Design and SB2009



PEDD: 0.47 J/g/bunch (1.5 e^+/e^-)



PEDD: 0.74 J/g/bunch (2 e^+/e^-)

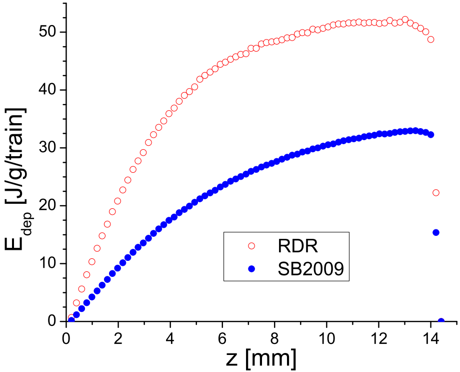
PEDD - Peak Energy Deposition Density

Energy Deposition in Rotating Target

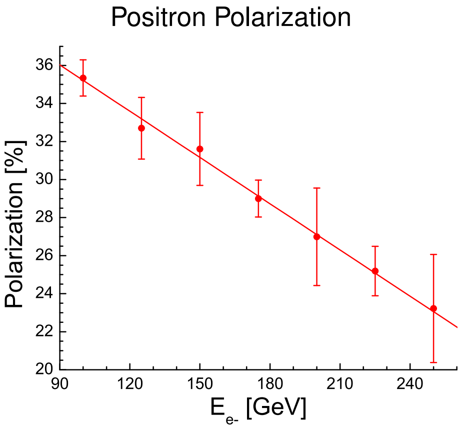
Rotation Speed: 100 m/s
Target Diameter: 1 m
1900 RPM

RDR: 2625 bunches/train
SB2009: 1312 bunches/train

Energy Deposition (per Train)

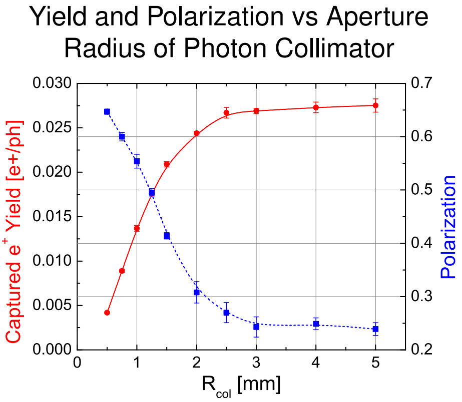


Positron Polarization vs Electron Beam Energy



To increase beam polarization
a photon collimator
can be used

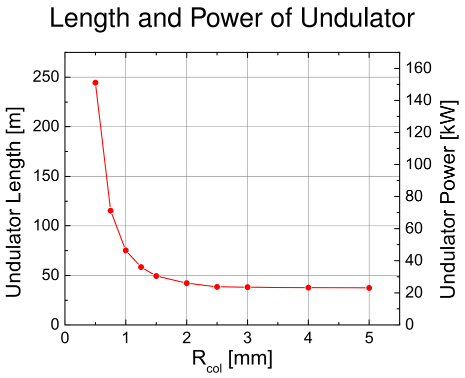
Photon Collimator for Positron Source at 250 GeV: Yield and Polarization vs Collimator Aperture Size

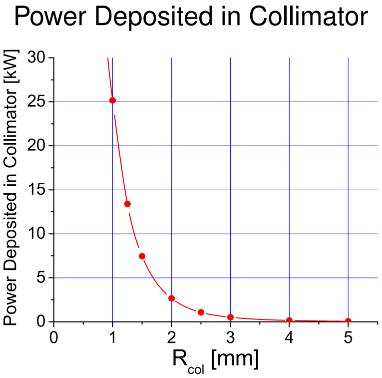


Collimator with 2 mm aperture radius:

- increases polarization to ≈30%
- results in ≈12% yield reduction

Undulator Length and Power. Energy Deposited in Collimator





Summary and Outlook

- Geant4-based tool PPS-Sim for polarized positron source simulations is being developed
- A variety of e^+ source options (different primary beams, targets, OMD's) are included
- Impact of e^- beam energy on source efficiency, e^+ polarization and heat load in target has been analyzed
- Photon collimator with 2 mm (1.5 mm) aperture radius increases polarization up to 30% (40%) without significant reduction of yield for source at 250 GeV

Plans:

- Beam tracking up to DR (including spin rotator) in PPS-Sim + Bmad

PPS-Sim is open-source code and available for download:
http://pps-sim.desy.de