Radiation damage of ILC positron source target

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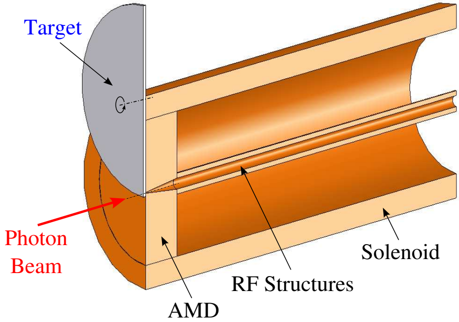
Outline

- Positron source model
- Positron production and capture
- Generation of secondary particles
- Radiation damage of positron source target
- Summary

Positron Source Model

Source Model



Helical Undulator

e^- drive beam energy, GeV	150
Undulator K-value	0.92
Undulator period, cm	1.15
Undulator-target distance, m	500

Target

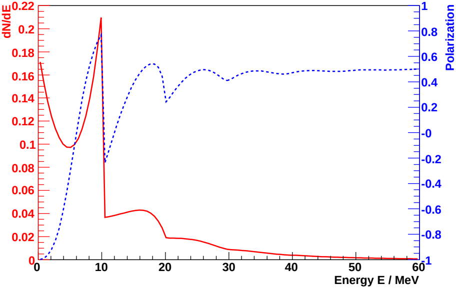
Material	Ti6Al4V
Thickness	0.4 X_0

AMD

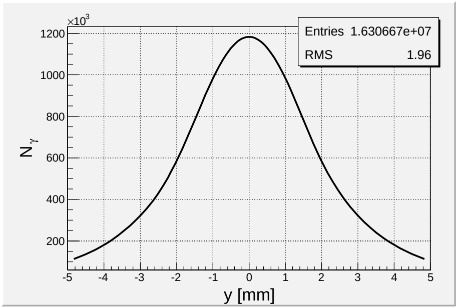
B_0 (z = 0)	6 T
B_0 (z = 20 cm)	0.5 T
∅ (z = 0)	12 mm
∅ (z = 20 cm)	46 mm

Photon Beam

Energy Distribution, Polarization

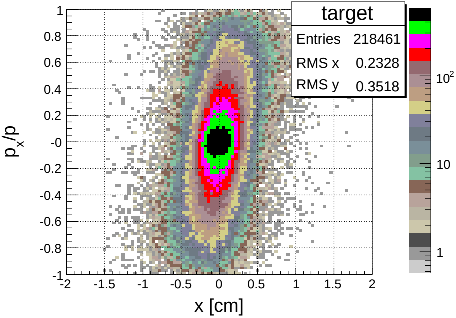


Beam Size



Positron Beam

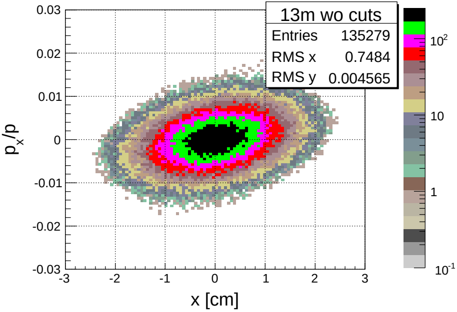
Positron x-x' Phase Space after Target



Positron yield is $2.18 \cdot 10^{-2}$ e^+/γ

Positron beam has a big divergence

Positron x-x' Phase Space after Pre-accelerator (125 MeV)

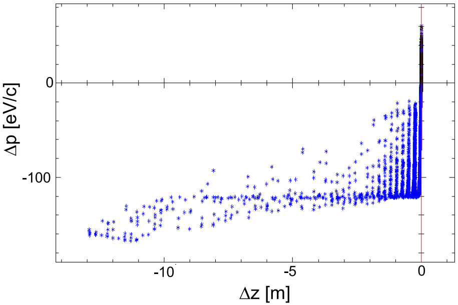


$\sim$ 30% of positrons are lost in the capture section and pre-accelerator

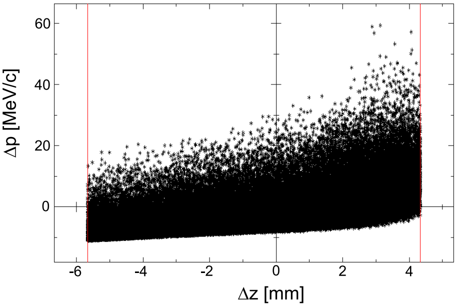
Acceptance of DR

Applying of Bunch Length Cut (Longitudinal Cut) after Pre-Accelerator (at 125 MeV)

Before Cut



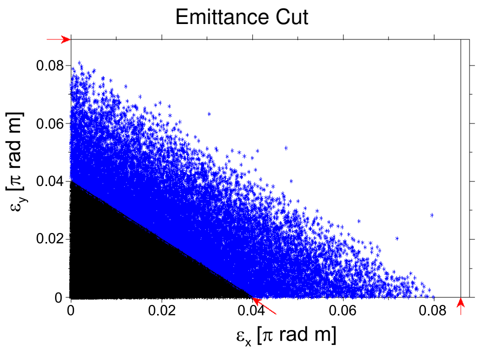
After Cut

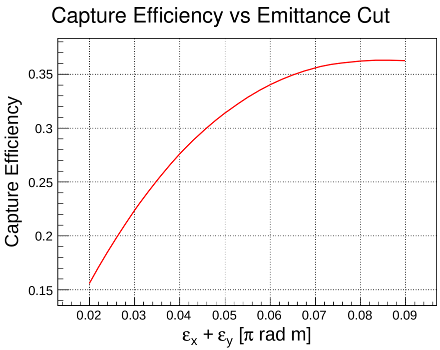


$\sim$ 34% of positrons are discarded due to
10 mm bunch length cut (phase: $\pm 7.5^\circ$, energy: 1%)

Acceptance of DR

Applying of Transverse Cut after Pre-Accelerator





$\sim$ 42.5% of positrons are discarded due to both
10 mm bunch length cut and
0.04 π rad m emittance cut

Required Photon Beam

Positron Yield: $2.18 \cdot 10^{-2}$ e^+/γ

Capture efficiency: 27.65 %

Required number of photons per e^+ at IP:
248.3 γ/e^+

Positron beam at IP: $2 \cdot 10^{10}$ e^+/bunch,
2820 bunch/pulse,
5 Hz

Required photon beam:
$7.0 \cdot 10^{16}$ γ/s or 116.8 kW

Accumulating photon beam flux after 5000 hours:
$\sim 1.26 \cdot 10^{24}$ γ

Target density:
$5.79 \cdot 10^{22}$ atoms/cm^3

Secondary Particle Production

FLUKA can provide information about

- position where interaction took place
- number generated secondaries (photons, protons, neutrons) and number heavy secondaries (deuterons, ^{3}H, ^{3}He, ^{4}He and other "Heavy" fragments)
- energy and direction cosines of the secondaries
- recoil atoms atomic and mass numbers, energies and directions

FLUKA does not transport the recoil atoms

How radiation damage can be estimated?

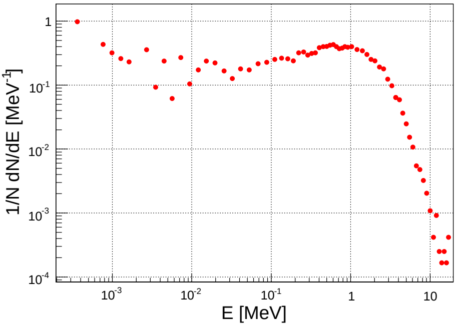
- Use FLUKA to create spatial and energy distributions for all secondary particle
- Calculate damage due to neutrons using SPECTER code calculations
- Calculate damage due to protons, deuterons, etc. and recoil atoms using Lindhard model

Damage by Neutrons

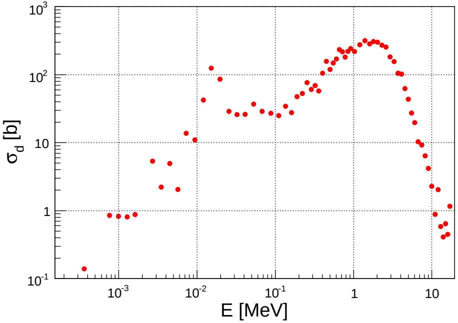
$$dpa_n = \langle \sigma_d(E_n) \rangle \; \phi_n$$

$\langle \sigma_d \rangle$ is the average damage cross-section
ϕ_n is the neutron fluence

Neutron Energy Distribution

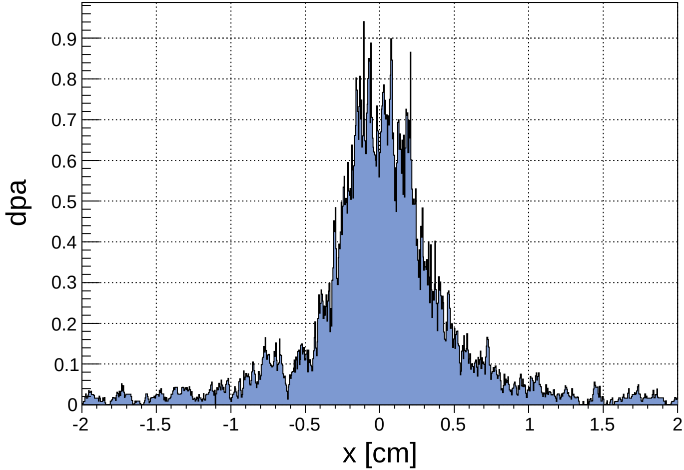


Damage Cross Section (SPECTER)



$$\langle \sigma_d \rangle = 941.3 \text{ [b]}$$

dpa by Neutrons



Damage by ions

Simplified Model

(Lindhard Model)

$$dpa = \frac{\hat{E}}{L}\frac{\phi}{N_a}$$

ϕ is the fluence of projectiles

N_a is the number atoms per cm^2

$\hat{E}$ is the damage energy
($\hat{E}/E$ is the damage efficiency)

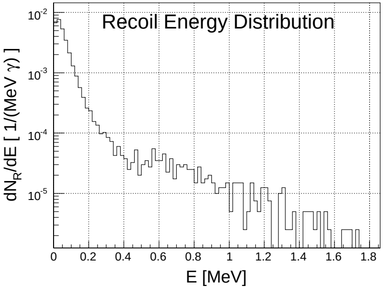
L is the cascade multiplication threshold

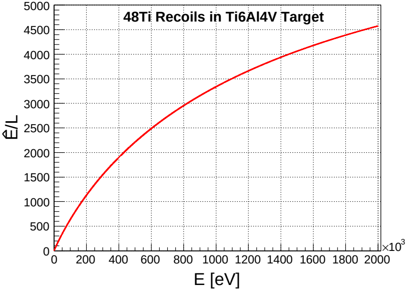
$$L = E_b + E_c + E_d$$

E_b is the energy binding an atom to its lattice site

E_c is the capture energy of slow projectile by a vacant lattice site

E_d is the energy for displacing an atom permanently from its lattice site

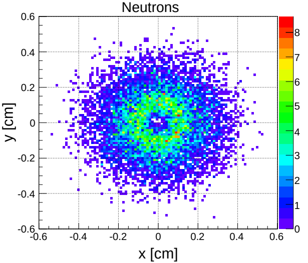


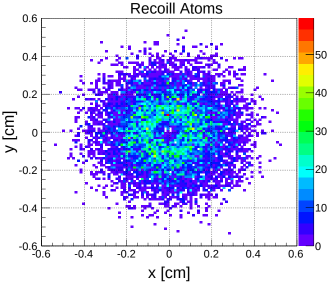


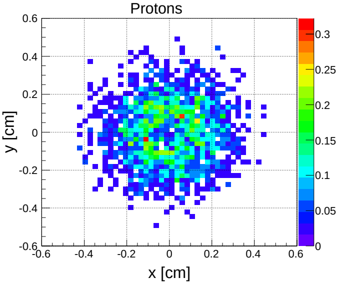
M. Robinson, Journal of Nuclear Materials **216**, 1-28 (1994)
B. Wirth, Technical Report, UCB-NE-5015 (2005)

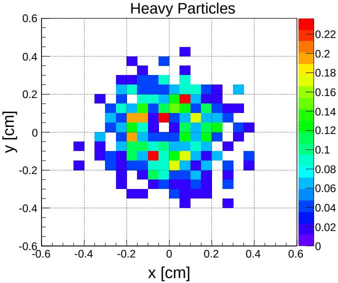
dpa by n, p, Heavy Particles and Recoil Atoms

Without taking into account particle transport



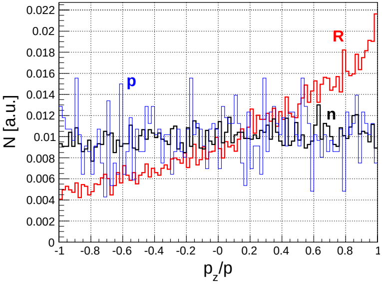


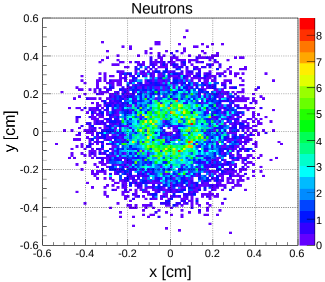


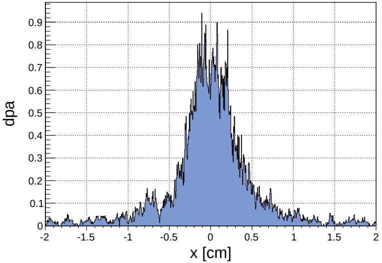


Influence of particle direction

Taking into account of secondary particle direction (particle transport) will distribute same number of displaced atoms over bigger volume!







Summary

- Max dpa in target is about 7 dpa (after 5000 hours of positron source operation)
- Neutron contribution in total dpa is about 12.5 %

Further investigations
and
more accurate/precise simulations are required!