Simulations of Undulator-Based Positron Source with Tungsten-Alloy Target

A. Ushakov [1], G. Moortgat-Pick[1,2], S. Riemann[2], F. Staufenbiel[2], P. Sievers[3]

[1]University of Hamburg, [2]DESY, [3]CERN/ESS

International Workshop on Future Linear Colliders (LCWS13)

12 November 2013, University of Tokyo, Japan

LINEAR COLLIDER COLLABORATION

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

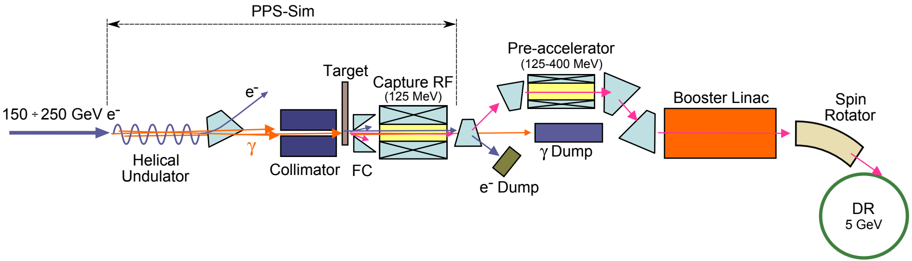
DESY

Outline

- e^+ source scheme
- e^+ yield of base-line source (3.2 T FC, 0.4 X_0 Ti6Al4V solid target)

- Source with FC and W25Re solid target
- W25Re solid target and pure Li lens
- W-doped Li lens
- Summary

Positron Source Scheme



e^- Beam Energy: 150 $\div$ 250 GeV

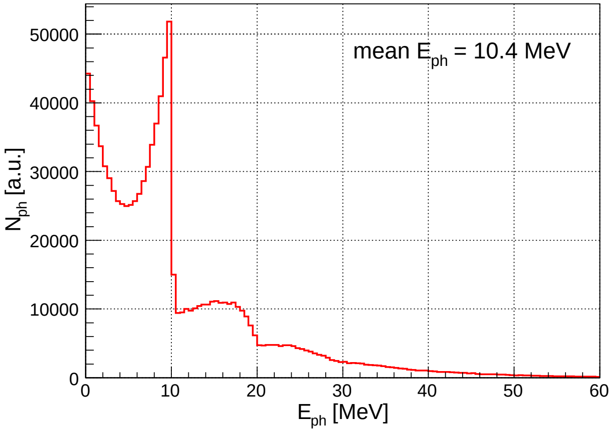
Helical Undulator: 11.5 mm period, max 0.86 T $\Rightarrow$ max $K = 0.92$

Target: solid Ti6Al4V, 0.4 $X_0 \Rightarrow$ 1.4 cm

Pulsed Flux Concentrator: tapered solenoid, 12 cm long, max 3.2 T on axis, 0.5 T at end

Capture RF: 1.3 GHz cavities embedded into 0.5 T solenoid

Photon Energy Spectrum

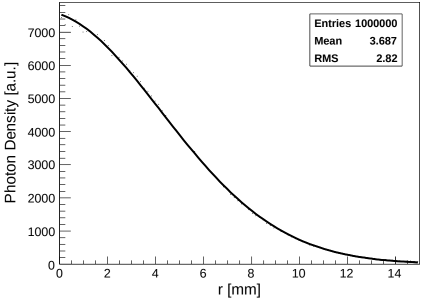


Undulator $K = 0.92$ at 150 GeV

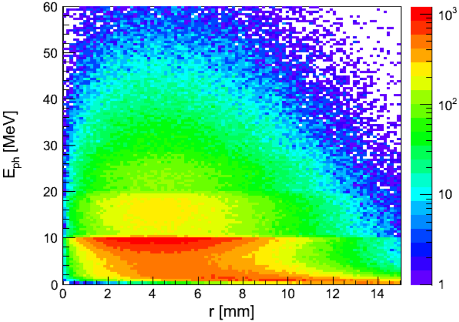
Spot Size and Power of Photons

150 GeV e^-; $K = 0.92$; 500 m between undulator and target

Photon Density vs Radius



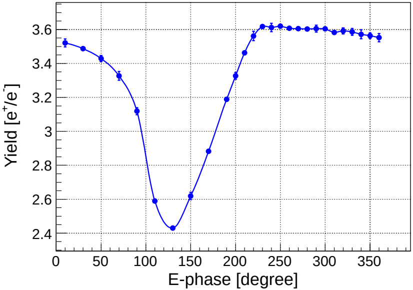
Photon Power [a.u.] vs Photon Energy and Radius



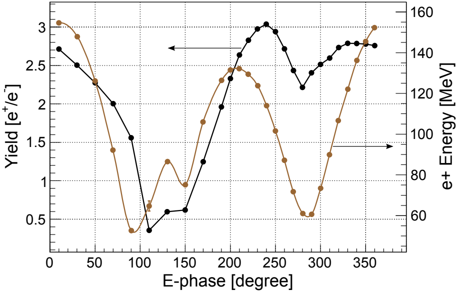
Baseline Source at 150 GeV e^-. E-Phase Scan

231 m RDR Undulator, Ti6Al4V 0.4 X_0 Target, 3.2 T FC, 10 m Capture RF

e^+ Yield at End of Capture RF vs E-field Phase



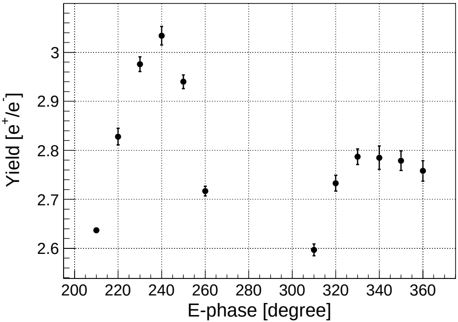
Captured e^+ Yield and Energy vs E-field Phase



Ti vs W. e^+ Yield of Source with Flux Concentrator

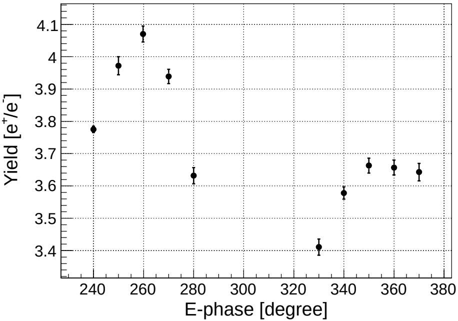
e^+ Yield vs E-field Phase

Ti6Al4V target, $0.4\ X_0$ (1.4 **cm**)



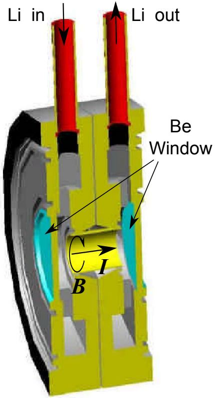
e^+ Yield vs E-field Phase

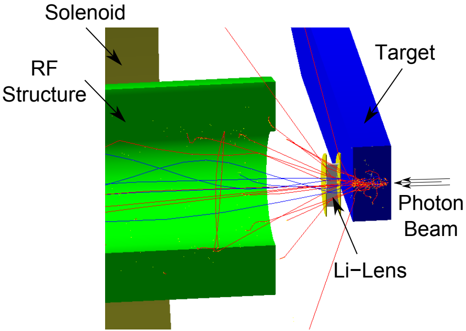
W25Re target, $0.4\ X_0$ (1.4 **mm**)



$$Y_{max}(W)/Y_{max}(Ti) \approx \mathbf{1.34}$$

Li-Lens Model





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

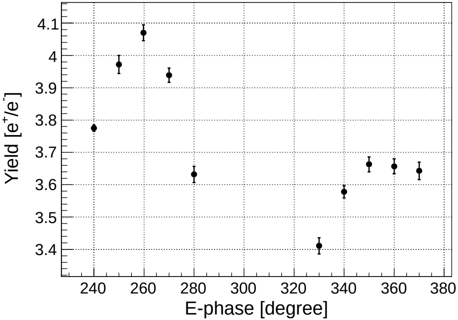
$$B_\theta(r) = \frac{\mu_0 I r}{2\pi a^2}$$

Lens thickness = 7.0 mm

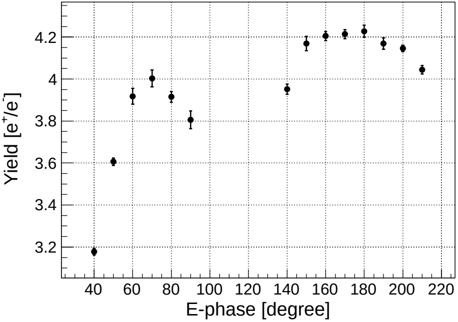
Lens radius = 8.5 mm

Li-Lens vs Flux Concentrator. E-Phase Scan

e^+ Yield vs E-field Phase
W25Re solid, **flux concentrator**

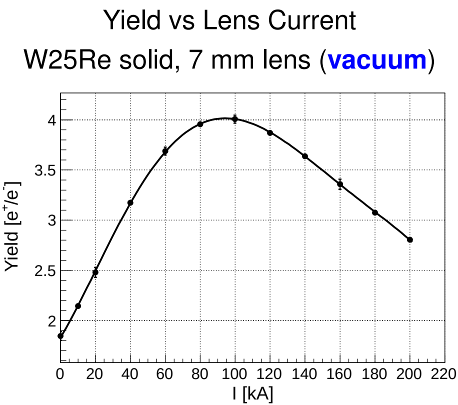


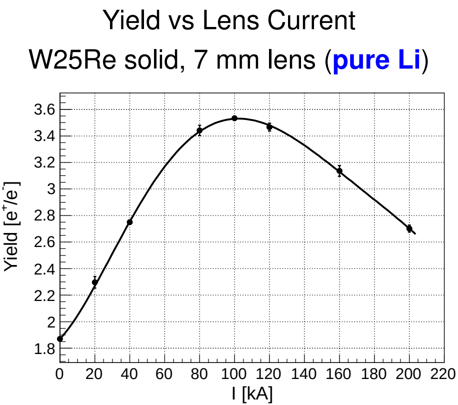
e^+ Yield vs E-field Phase
W25Re solid, **7 mm lens (vacuum)**



Efficiency of Lens $\approx$ FC

Pure Li vs Vacuum. Yield vs Lens Current



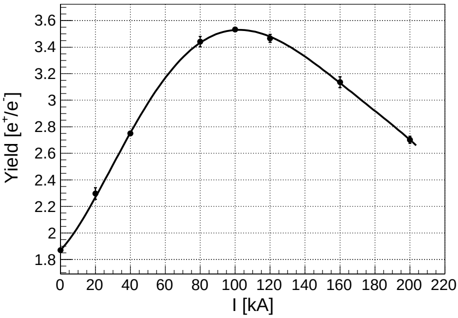


$I = 0$ kA: $\quad Y$(pure Li) $\approx$ Y(vacuum)

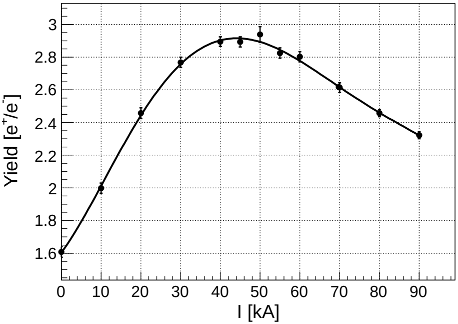
Y_{max}(pure Li) / Y_{max}(vacuum) = 0.88

20 mm vs 7 mm Pure Li Lens. Yield vs Lens Current

Yield vs Lens Current
W25Re solid, **7** mm lens (pure Li)



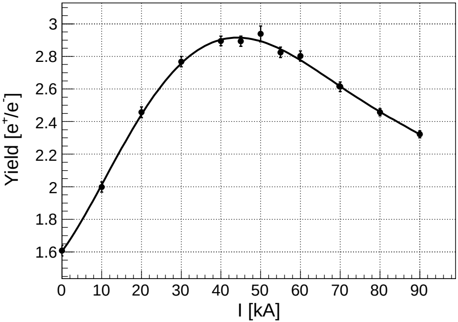
Yield vs Lens Current
W25Re solid, **20** mm lens (pure Li)



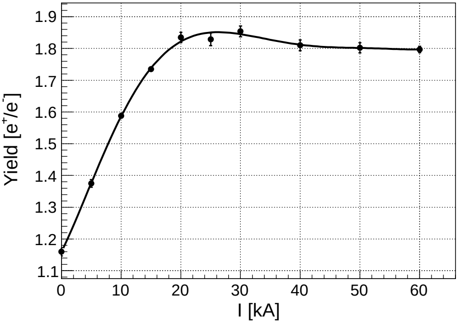
$$Y_{max}\ (20\ \text{mm})\ /\ Y_{max}\ (7\ \text{mm}) = 0.83$$

20 mm vs 7 mm Pure Li Lens. Yield vs Lens Current

Yield vs Lens Current
W25Re solid, **20** mm lens (pure Li)



Yield vs Lens Current
W25Re solid, **50** mm lens (pure Li)



Y_{max} (50 mm) / Y_{max} (20 mm) = 0.62

Density of W-Doped Lithium

Li: $X_0 = 155$ cm

W: $X_0 = 0.36$ cm $\Rightarrow 0.4X_0 = 0.144$ cm

2 cm thick W-doped lithium lens (liquid Li + W powder):

- W: 0.144 cm x 19.25 g/cm^3 = 2.772 g/cm^2
- Li: 1.856 cm x 0.512 g/cm^3 = 0.950 g/cm^2
- Total mass: 3.722 g/cm^2

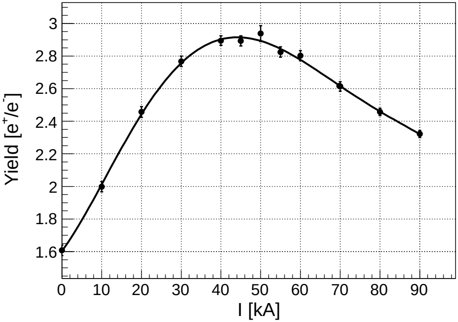
- W mass fraction: **0.745**; Li mass fraction: **0.255**
- W+Li effective mass: **1.861 g/cm^3**; radiation length: 4.75 cm

```
density = 1.861*g/cm3;
G4Material* Li75W = new G4Material(name="Li75W", density,
ncomponents=2);
Li75W->AddMaterial(Li, fractionmass=0.255);
Li75W->AddMaterial(W, fractionmass=0.745);
```

W-Doped Li vs Pure Li. 20 mm Lens

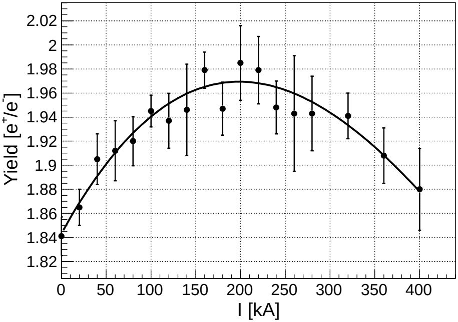
Yield vs Lens Current

W25Re solid, 20 mm lens (**pure Li**)



Yield vs Lens Current

– , 20 mm lens (**Li75W**)

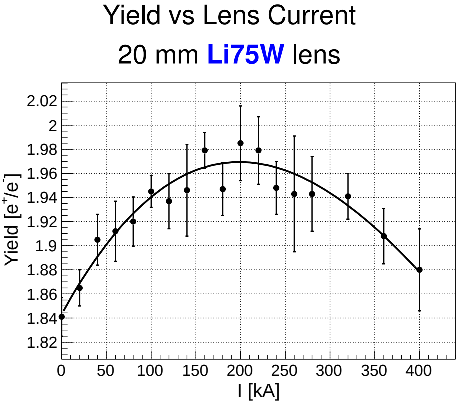


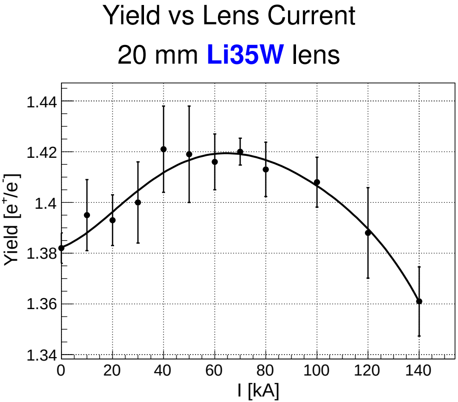
Solid W25Re + pure Li lens: $Y_{max} \ / \ Y(I = 0) \approx$ **1.83**

Li75W lens: $Y_{max} \ / \ Y(I = 0) \approx$ **1.08**

Li75W lens: higher optimal current

Li35W vs Li75W. 20 mm W-Doped Li Lens

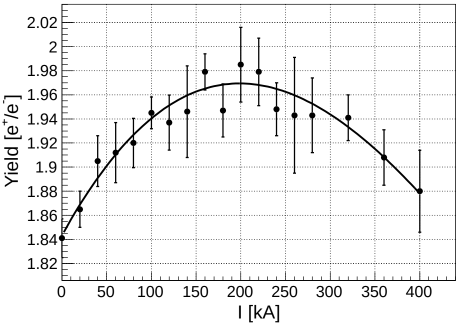




FLUKA vs Geant4. 20 mm Li75W Lens

Captured Yield at **DR**

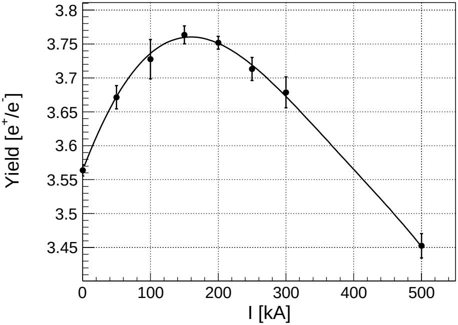
Li75W, 20 mm Lens (**Geant4**)



$Y_{max} / Y(I = 0) \approx 1.08$

Yield **before 1st RF**

Li75W, 20 mm Lens (**FLUKA***)

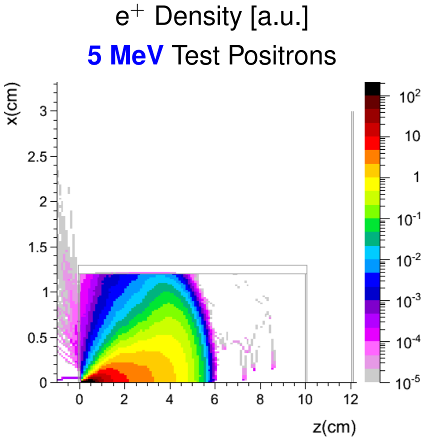


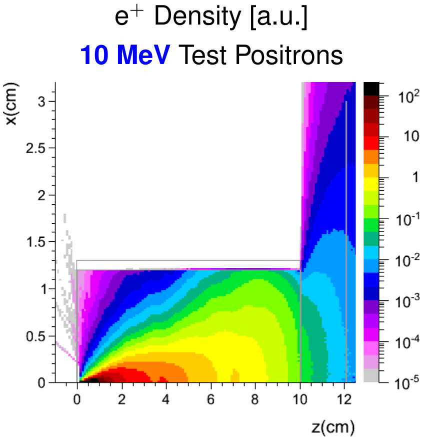
$Y_{max} / Y(I = 0) \approx 1.06$

* E-field is not implemented in FLUKA

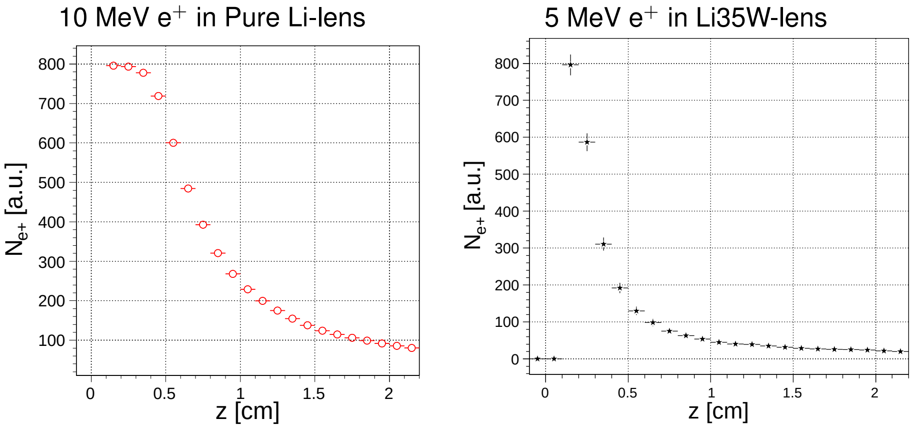
5 MeV and 10 MeV “Test” Positrons in Pure Li Lens

I = 150 kA





Number of Test Positrons vs Z Position in Target



Low Energy of e^+ ⇒ High Losses of e^+

$E_1^{ph} \simeq 10$ MeV (for 150 GeV e^-)

Summary

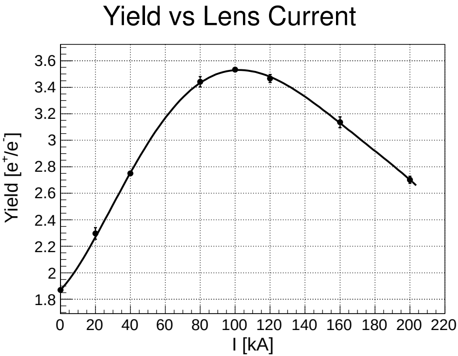
- Baseline source with (solid) **tungsten target has a better e^+ yield**: $Y_{\mathbf{W}}/Y_{\mathbf{Ti}} = 1.34$ at 150 GeV. *Issues with target cooling and thermal stress* have to be solved:
  - Can a target cooled by liquid Li (W25Re as an entry window of thin Li lens) be alternative to the fast rotating Ti-alloy target + pulsed FC*?
  - Radiative cooling?
- **Thin** (pure) **Li lens** has approx. the **same efficiency** as **pulsed FC**. *The heat load in windows* has to be studied.
- Energy of generated positrons in baseline source is too low for thick Li or **W-doped Li lenses** (low capture efficiency).

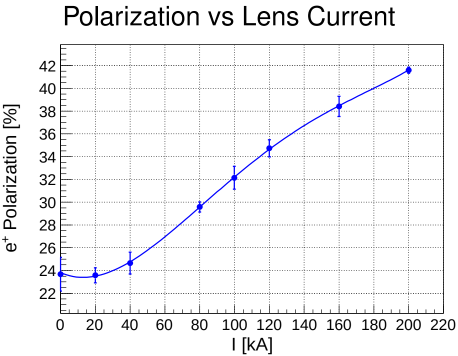
* A. Mikhailichenko, ALCPG11, March 2011

Backup Slides

Polarization vs Lens Current

Solid W25Re Target + Short (7 mm) Li Lens





Over-focusing positrons ⇒ Higher e^+ polarization