Simulations of Positron Source at 120 GeV

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Outline

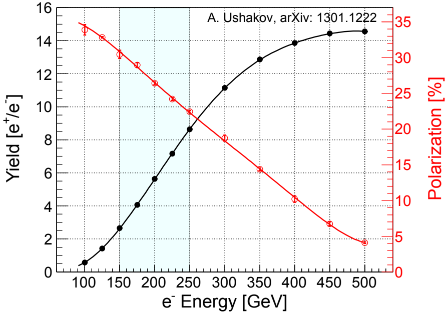
- What is a working (drive beam) energy range of e^+ source with RDR undulator?
- Generation of positrons at 120 GeV e^-
- e^+ capture of source with pulsed Flux Concentrator (FC)
- Achievable e^+ polarization
- Radiation damage of target
- Thermal stress in target

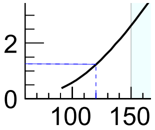
Positron Source Parameters

- Source has to deliver 1.5 e^+/e^- to Damping Ring (DR)
- DR acceptance:
  - Tranverse emittance: $\epsilon_{nx} + \epsilon_{ny} \leq 70$ mm rad
  - Max. energy spread: ± 37.5 MeV
  - Longitudinal bunch size: ≤ 34 mm
- SC helical undulator with period of 11.5 mm and $K \leq 0.92$ has been developed for operation with $150 \div 250$ GeV e^- beams
- At 150 GeV and Quarter-Wave Transformer (QWT) the required total length of undulator magnets is 231 m
- Pulsed FC has better capture efficiency than QWT

Can source with FC and max. 231 m undulator be used at ***120 GeV?***

Dependence on e^- Energy





231 m undulator with $K = 0.92$

0.4 X_0 Ti6Al4V target

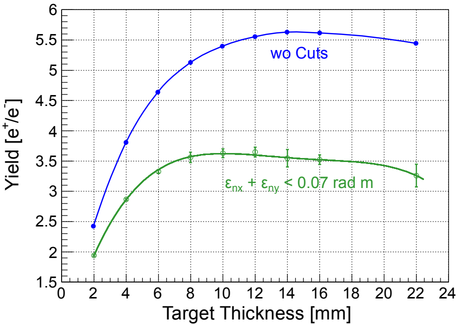
FC: 3.2 T to 0.5 T in 12 cm and smallest aperture radius of 6 mm

Can yield be improved to get 1.5 e^+/e^- at 120 GeV?

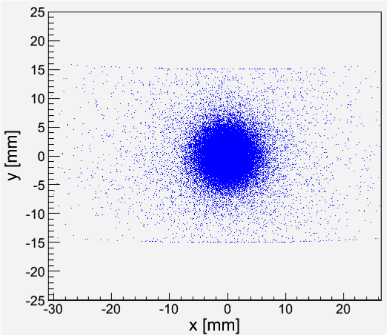
Positron Production

120 GeV e^-, 231 m undulator with $K = 0.92$, 412 m space to target

e^+ Yield after Target



Positron Distribution after Target



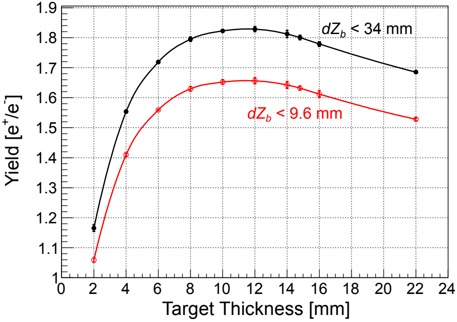
Target thickness = 14 mm

$\epsilon_{nx} = 24.5$ mm rad

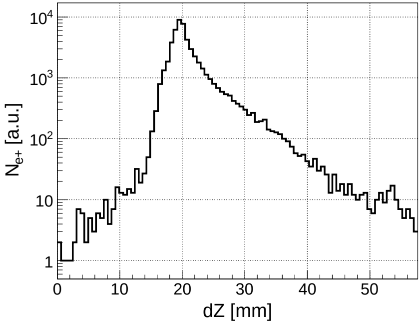
$\epsilon_{ny} = 20.4$ mm rad

Captured Yield vs Target Thickness

Yield at 125 MeV and DR "Cuts"*



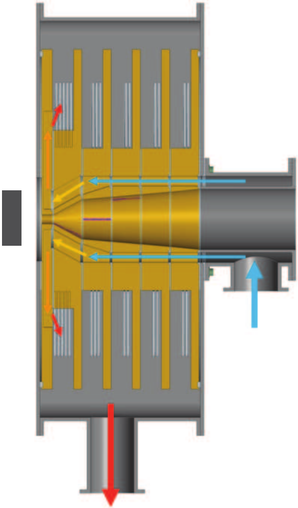
e^+ Density along Bunch



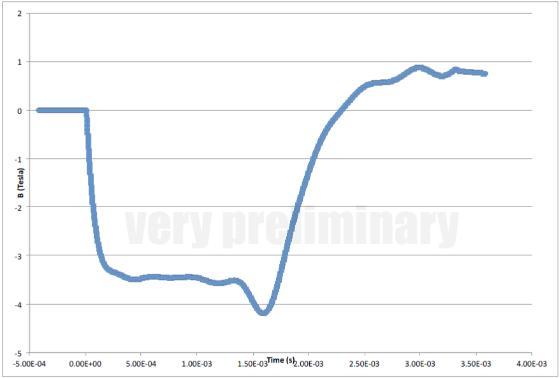
* Note: these are results for “re-optimized” capture section and improved implementation of DR acceptance into our simulation tool

Pulsed Flux Concentrator (LLNL, Jeff Gronberg)

Scheme of Pulsed FC



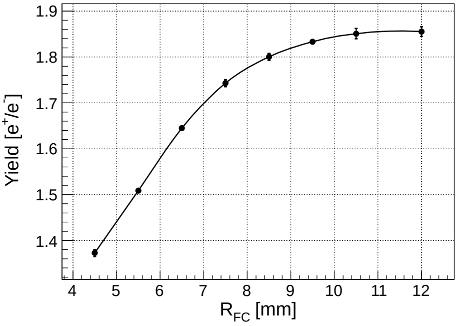
Magnetic Field vs Time



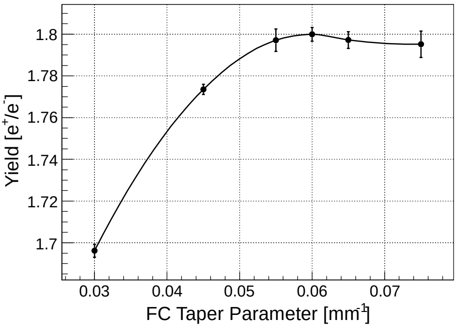
J. Gronberg, LCWS 2012

Aperture Size and Taper Parameter of FC

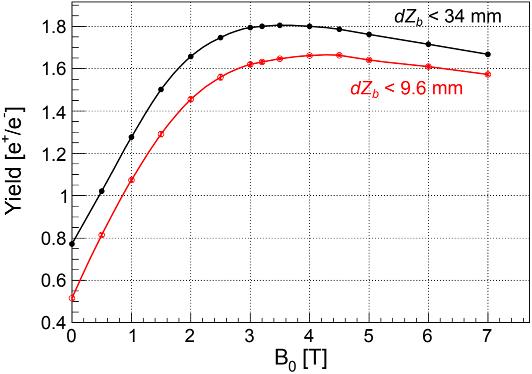
Yield vs Aperture Radius of FC



Yield vs Taper Parameter of FC



Max. B-field of FC



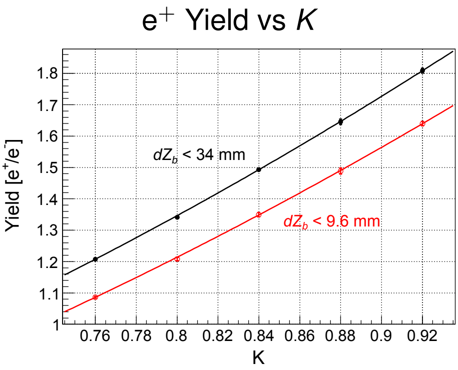
$E_{e^-} = 120$ GeV

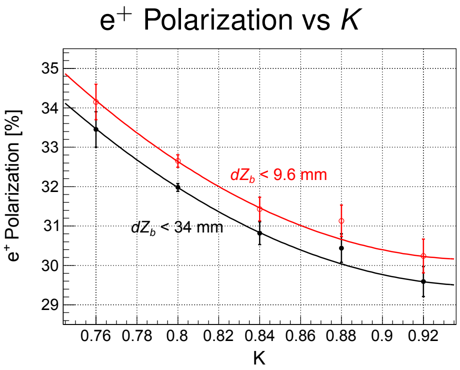
$R_{FC} = 8.5$ mm

$g = 0.06$ mm^{-1}

FC with max. field of 3.2 T is a good choice for source at 120 GeV

Undulator K Value

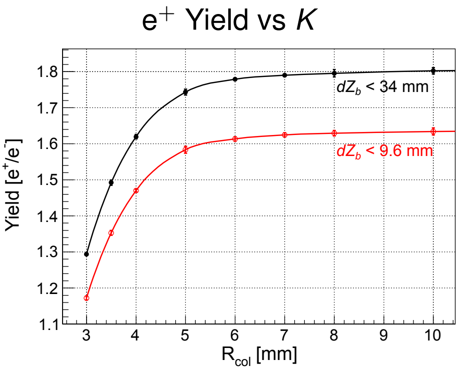


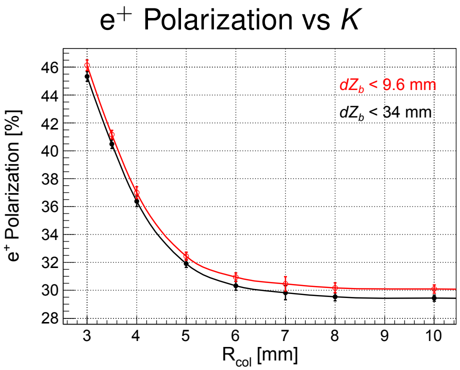


Max. e^+ polarization of source at 120 GeV (without collimator):

$\simeq$31%

Aperture Size of Photon Collimator



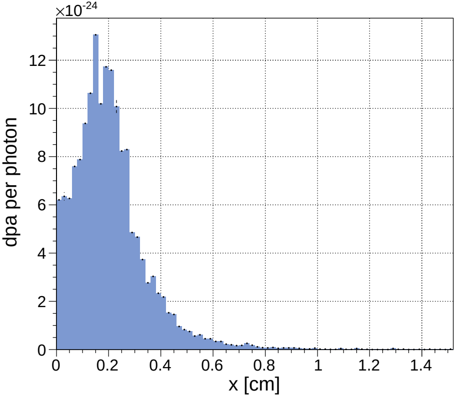


Max. e^+ polarization of source at 120 GeV (with photon collimator):

$\simeq$**40%** for $R_{col} = 3.5$ mm

Radiation Damage of Target

dpa Profile along X-Axis*



*dpa calculated in FLUKA ver. 2011.2b (last respin May 2013)

- 120 GeV e- beam
- 192.5 m undulator
- K = 0.92

$dpa_{\text{max}} \simeq 1.3 \cdot 10^{-23}$ dpa/photon

1 Year (5000 h): $\simeq 9 \cdot 10^{23}$ photons

Damage of *stationary* target:
$\simeq$ 11.7 dpa

Damage of ∅1 m *rotated target*:
$\simeq 9.2 \cdot 10^{-3}$ dpa

(250 GeV e$^-$: $dpa_{\text{max}} \simeq 2.2 \cdot 10^{-2}$ dpa)

Damage of rotated target is small

Simulations of collimator damage are ongoing

Energy Deposited in Target

Source Parameters

- 120 GeV e^- beam
- $K = 0.92$
- 192.5 m undulator active length
- 266.5 m undulator lattice length
- 412 m between undulator and target

Photons on Target

- $E_{1\,\mathrm{ph}} = 6.4$ MeV
- $\langle E_{ph} \rangle = 6.8$ MeV
- $\langle P_{ph} \rangle = 54.1$ kW

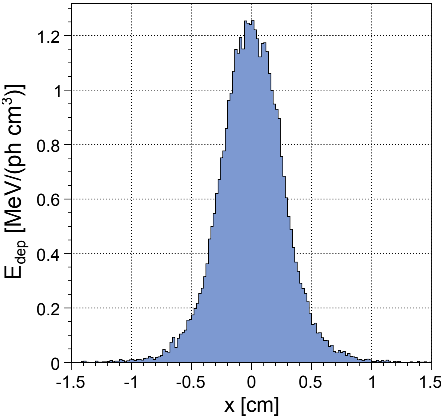
Energy Deposited in Target:

$$\langle E_{dep} \rangle = 9.2\% \text{ (5 kW)}$$

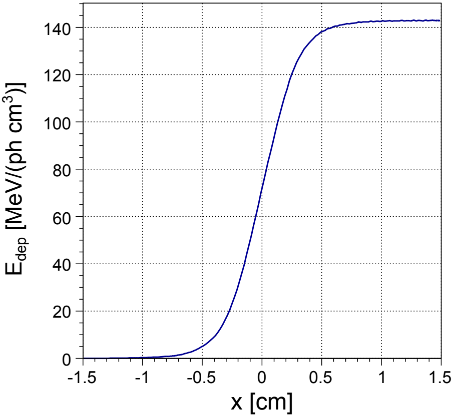
- rotated target with 100 m/s tangential speed
- 554 ns bunch spacing

Deposited Energy in Target

Deposited Energy by **Bunch**



Deposited Energy by **Bunch Train**



$\sigma_x \simeq$ 2.5 mm; Bunch Shift = 55.4 μm

Bunch Overlapping Factor = **114**

Simplified ANSYS Model

- "Instantaneous" spacial distribution of $E_{MeV/ph}(x, y, z)$
  max $E_{MeV/ph} = 1.2$ MeV/(ph·cm^3)
- Bunch Overlaping Factor (BOF): 114 bunches/train

- $N_{ph/\text{"train"}} = N_{e^-/bunch} \cdot Y_{ph/(e^- m)} \cdot L_u \cdot BOF = 8.5 \cdot 10^{14}$
- PEDD = max $E_{MeV/ph} \cdot N_{ph/\text{"train"}} \simeq 44$ J/g
  $\Delta T_{max} \simeq 84$ K
- $\Delta t_{\text{"train"}} = 554$ ns * BOF = 63.2 μs
- Heat Rate $\dot{Q}(x, y, z) = E_{MeV/ph}(x, y, z) \cdot N_{ph/\text{"train"}} / \Delta t_{\text{"train"}}$
  $\dot{Q}_{max} = 3.1 \cdot 10^{12}$ W/m^3

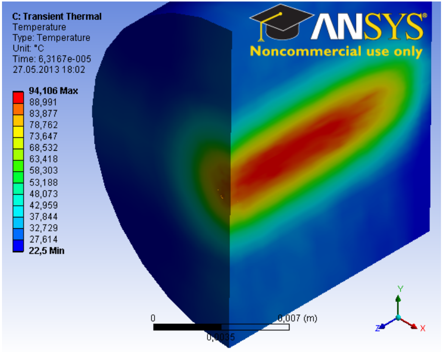
ANSYS Heat Source:

$\dot{Q}(x, y, z)$, for $t \leq \Delta t_{\text{"train"}}$
0, for $t > \Delta t_{\text{"train"}}$

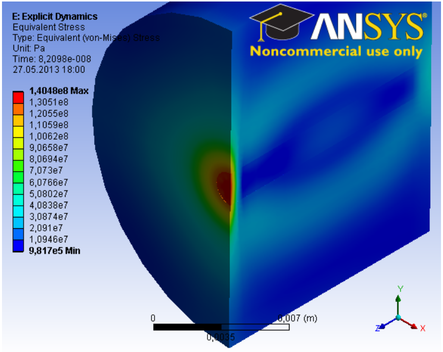
Task: to find max. stress shortly after the end of bunch train

ANSYS Results

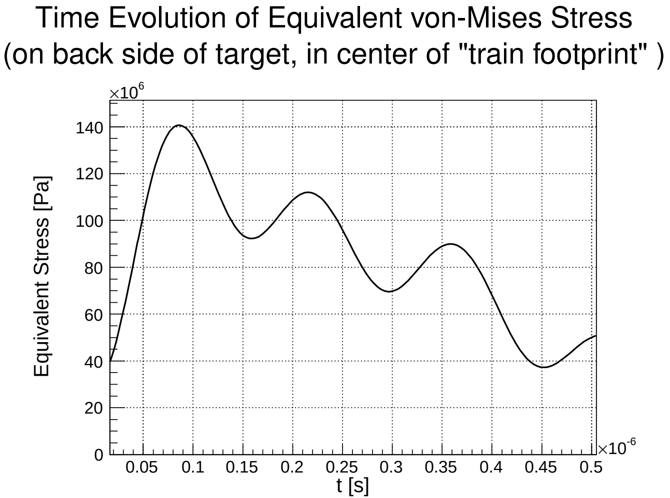
Temperature after Bunch Train



Maximal Stress



Time Evolution of Stress in Target (ANSYS)



Max. Equivalent Stress: $\simeq$ 140 MPa

Ti6Al4, Fatigue Strength (Unnotched 10M Cycles): 510 MPa

Summary

- Positron source with 231m RDR undulator can provide required yield of 1.5 e^+/e^- at 120 GeV
- Polarization of positrons is 31% for source without photon collimator and undulator $K = 0.84$
- 40% polarization can be achieved with 3.5 mm aperture radius of photon collimator
- Radiation damage of target is small
- Peak thermal stress in target during source operation with 120 GeV e^- beam is approx. 140 MPa

Final remarks: Bigger photon spot size on target at low drive beam energies makes a bigger entry aperture of FC desirable. A width of target rim may be also need to increase.