Simulations of the Undulator Based e^+ Source at 120 GeV

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LINEAR COLLIDER COLLABORATION

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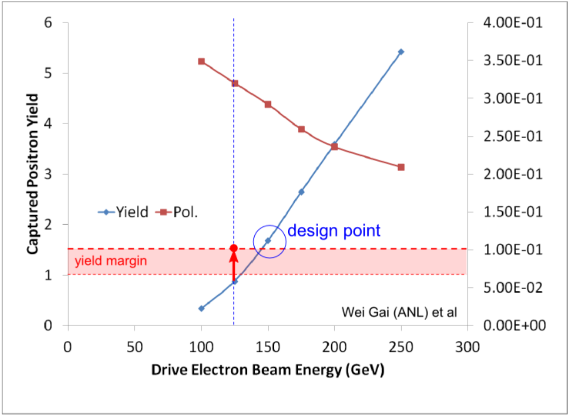
Dependence on e^- Energy
147 m RDR Undulator



e^- linac operates at 10 Hz

✓ 1st e^- pulse (at 150 GeV) makes positrons

✓ 2nd e^- pulse (at $E_{cm}/2$) makes luminosity

⇒ Collision rate is 5 Hz

Motivation: Increase e^+ yield to 1.5 e^+/e^- at low e^- energies (120÷125 GeV)

Ways to Increase e^+ Yield

1. Increase length of undulator to $\approx$ 250 m

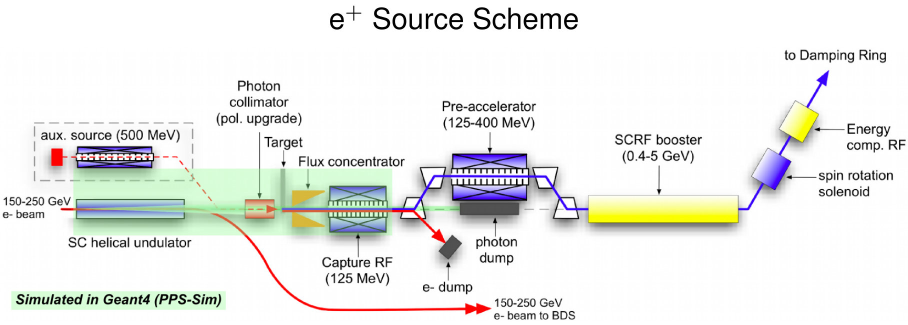
2. Use 231 m undulator

   (TDR: 231 m is reserved for polarization upgrade)

   - Optimize e^+ capture (FC, capture RF etc.)*

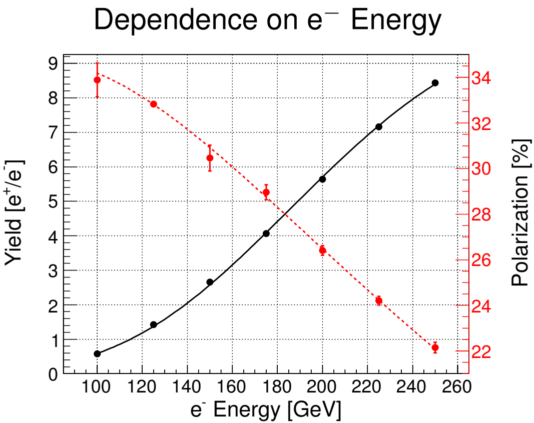
*A. Ushakov et al., LC-REP-2013-019
http://flcweb01.desy.de/lcnotes/notes/LC-REP-2013-019.pdf

e^+ Source Scheme



- DR acceptance was emulated as series of cuts at $\simeq$125 MeV:
  - Tranverse emittance: $\epsilon_{nx} + \epsilon_{ny} \leq 70$ mm rad
  - Max. energy spread: $\pm$37.5 MeV
  - Longitudinal bunch size: $\leq$ 34 mm

e^+ Yield vs e^- Energy for 231 m Undulator



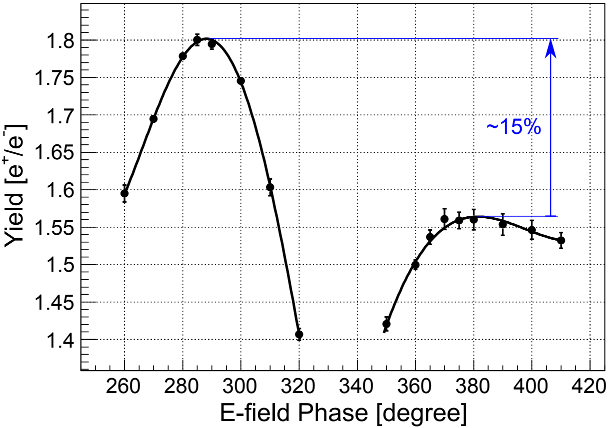
Source Parameters:

- **231 m** undulator, $K = 0.92$
- 0.4 X_0 Ti6Al4V target
- FC: 3.2 T to 0.5 T in 12 cm and $R_{ini} = 6$ mm
- ≈10 m 1.3 GHz RF structure

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

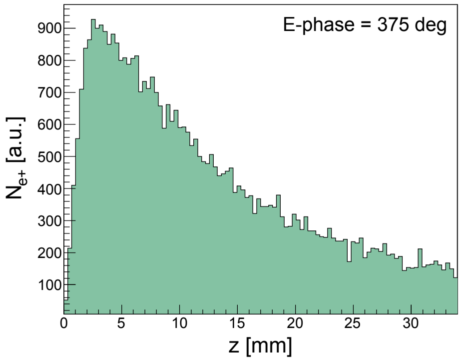
Yield vs E-Field Phase of Capture RF

$$E_z = E_0 \cos(kz + \omega t + \varphi_0)$$

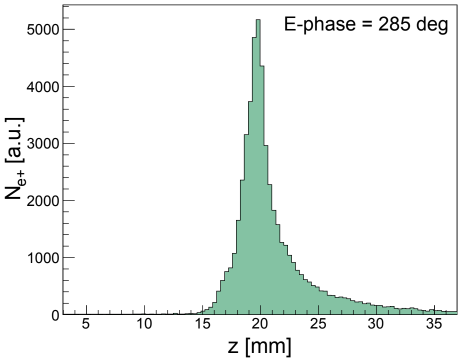


Bunch Length for Different E-Phases

Longitudinal Bunch Profile for "Acceleration" Phase



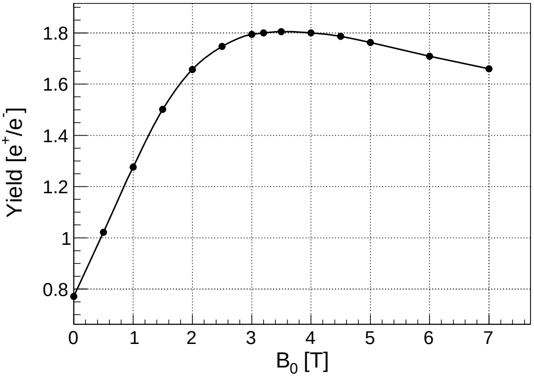
Longitudinal Bunch Profile for "Deceleration" Phase



e^+ Polarization = 33.0%

e^+ Polarization = 29.6%

Maximal B-field of FC



$E_{e^-} = 120$ GeV

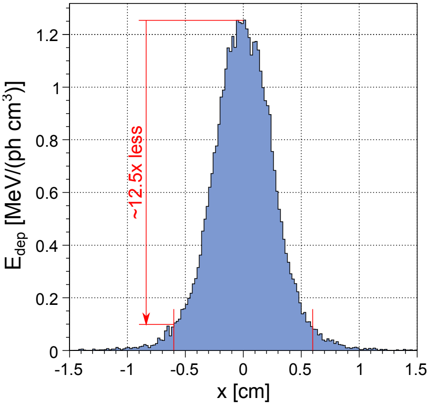
$R_{FC} = 8.5$ mm

$g = 0.06$ mm^{-1}

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

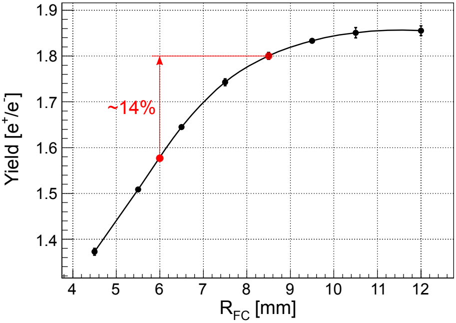
Aperture Size of FC

Deposited Energy by Bunch in Target



$\sigma_x \simeq 2.5$ mm

Yield vs Aperture Radius of FC



Lower E_{e^-} + longer undulator $\Rightarrow$ bigger beam spot size

Bigger R_{FC} (**?!**) $\Rightarrow Y \uparrow + E_{dep} \downarrow$

Taper Parameter of FC

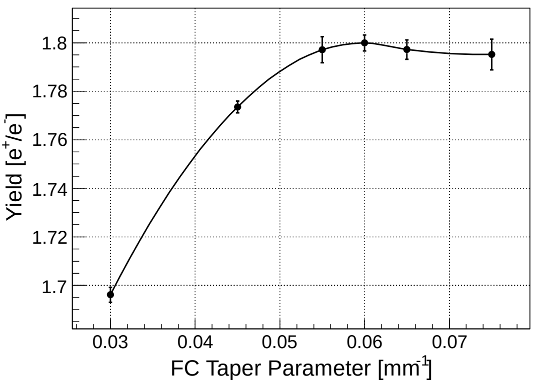
FC field on axis:

$$B(z) = \frac{B_0}{1 + g \cdot z}$$

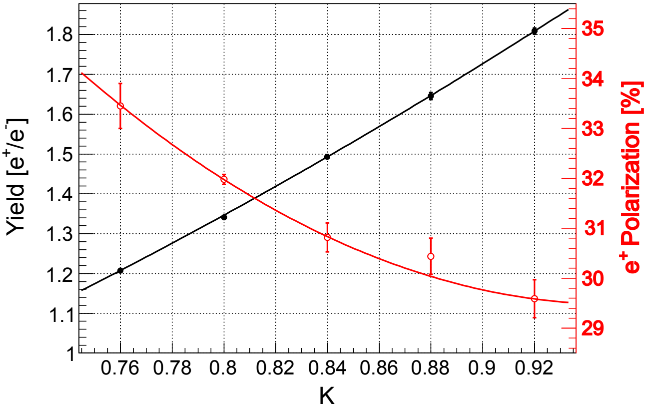
$$B(z_{\mathrm{end}}) = 0.5\ \mathrm{T}$$

g [m^{-1}]	L_{FC} [mm]
30	180
45	120
60	90
75	72

Yield vs Taper Parameter of FC



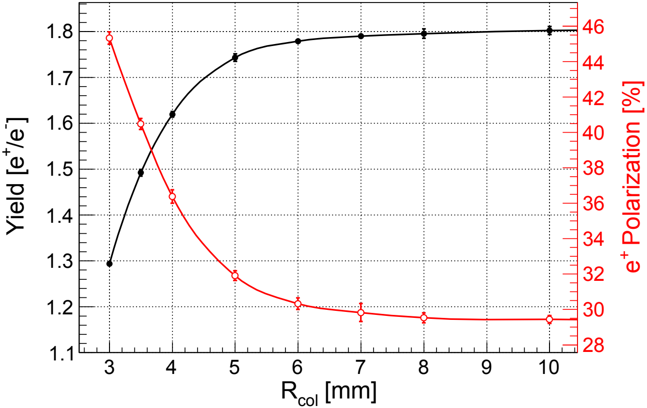
Undulator K Value



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

$\simeq$ **31%**

e^+ Polarization of Source with Photon Collimator



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

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

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

- $E_{1\,\text{ph}} = 6.4$ 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

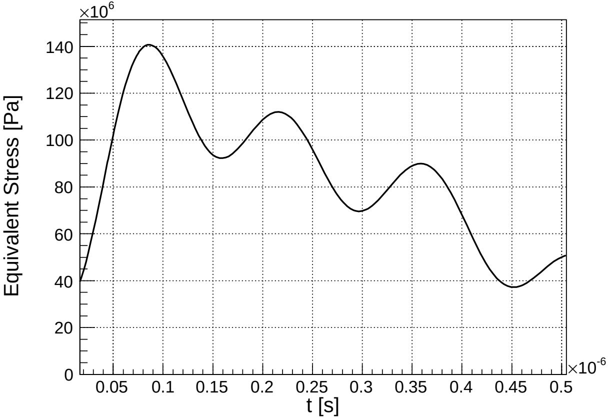
$$\text{PEDD} \simeq 44 \text{ J/g}$$

$$\Delta T \simeq 84 \text{ K per pulse}$$

*More details are in A.Ushakov et al., ECFA LC 2013 talk

Thermal Stress in Target (ANSYS)

Time Evolution of Equivalent von-Mises Stress
(on back side of target and beam axis)



Max. Equivalent Stress: $\simeq$ 140 MPa (**27.5%** of Fatigue Strength)

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

Summary

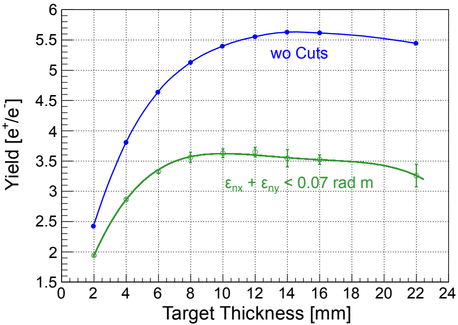
- Baseline positron source operated at $E_{e^-} =$ **120 GeV** and **231 m** active undulator length **can provide 1.5 e^+/e^-**
- Polarization of positrons is 31% for source without photon collimator and undulator $K = 0.84$
- 40% polarization can be achieved with photon collimator having 3.5 mm aperture radius
- At 120 GeV the maximal thermal stress in target induced by pulse is $\approx$ 27.5% of fatigue strength
- *Heat load and thermal stress in FC has to be checked*

Backup Slides

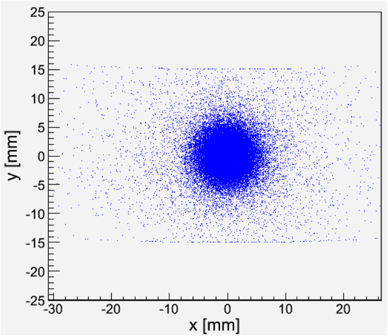
Positron Production

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

e$^+$ Yield after Target



Positron Distribution after Target

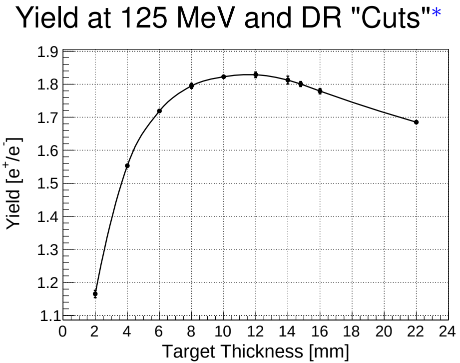


Ti6Al4V, 0.4 X_0

$\epsilon_{nx} = 24.5$ mm rad

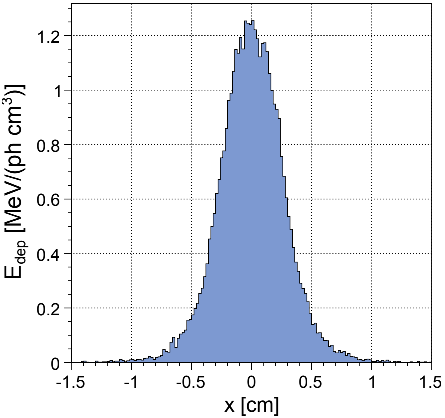
$\epsilon_{ny} = 20.4$ mm rad

Captured Yield vs Target Thickness



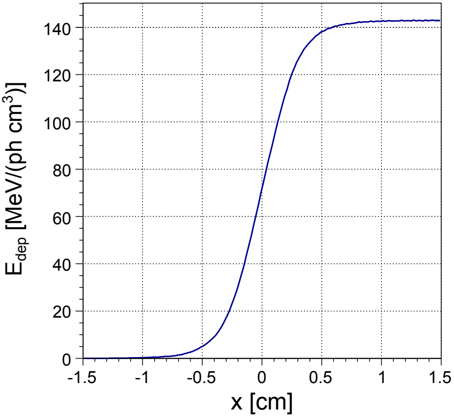
Deposited Energy in Target

Deposited Energy by **Bunch**



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

Deposited Energy by **Bunch Train**



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

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

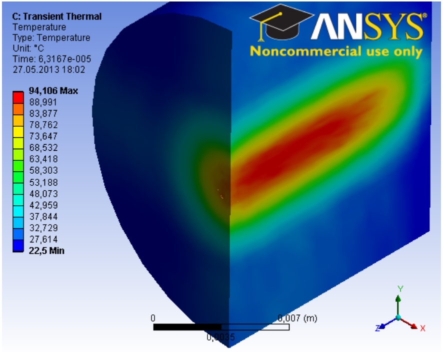
ANSYS Heat Source:

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

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

ANSYS Results

Temperature after Bunch Train



Maximal Equivalent Stress