Polarization issues

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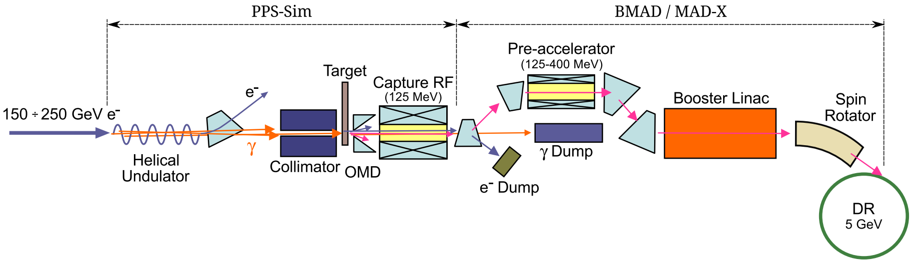
Outline

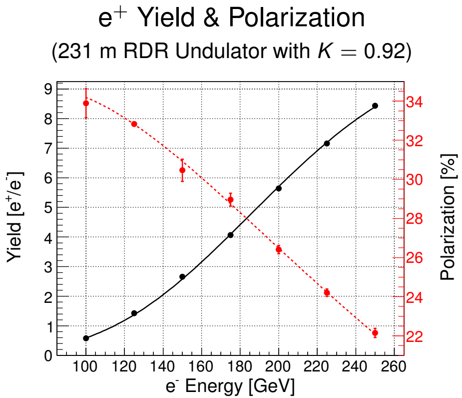
- ILC e^+ source scheme and parameters
- Simulation results for RDR undulator
  - e^+ yield and polarization
  - Energy deposition and thermal stress in target
- Source upgrade for 1 TeV CM energy
- Source upgrade for low-energy ($\sim$ 100 GeV e^-) operation
- Summary

e+ Source Model (PPS-Sim)



- RDR helical undulator (NbTi): $\lambda = 11.5$ mm, $K_{max} = 0.92$, 231 m active magnet length (3.5 m module), 320 m total lattice length, 412 m to target
- Photon collimator (optional)
- Target: Ti6Al4V, 0.4 X_0 thickness, $\varnothing$1 m, 100 m/s rot. speed
- Pulsed flux concentrator (FC): $B_0 = 3.2$ T, $B_{end} = 0.5$ T, $L_{FC} = 12$ cm
- RF Cavity: 1.3 GHz, $E_{max} = 14.5$ MeV/m
- DR Acceptance: $\Delta z \leq 34.6$ mm, $\epsilon_{nx} + \epsilon_{ny} \leq 70$ mm rad (cuts at 125 MeV)

Positron Yield and Polarization vs e^- Beam Energy



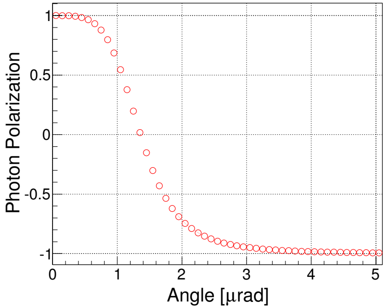
- Source should provide 1.5 e^+/e^-:

E_{e^-} [GeV]]	L_u [m]	P_{e^+} [%]	f [Hz]
100	599.6	33.9	10
125	242.9	32.8	10
150	130.3	30.5	5
175	85.3	29.0	5
250	41.1	22.2	5
500	23.6	3.9	4

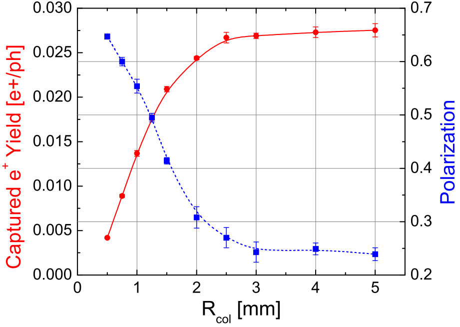
- 250 GeV: 30% e^+ polarization can be achieved by reduction of undulator field ($K = 0.45$)
- 130-250 GeV: 60% e^+ polarization can be achieved by using of a photon collimator
- 500 GeV: an other undulator is needed to improve the polarization and relax a heat load problem
- 100-130 GeV: an other short period/high field undulator (Nb3Sn) can be a good alternative

Photon Collimator for Positron Source at 250 GeV

Photon Polarization vs Angle



Yield and Polarization vs Aperture Radius of Collimator



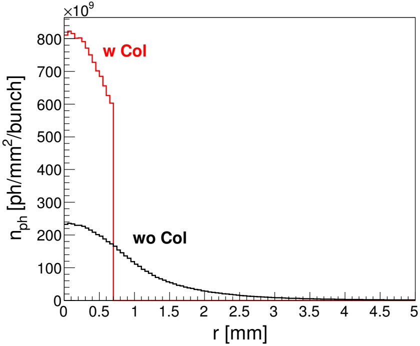
- $P_{e^+} = 30\%$ for R_c= 2 mm
- $P_{e^+} = 59\%$ for R_c= 0.7 mm, 80% of photons are absorbed in collimator, **132 kW**

Intensity and Energy of Photons on Target

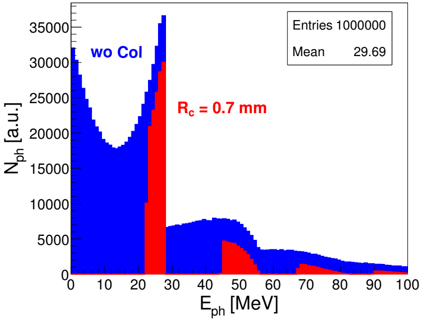
250 GeV e^-, K = 0.92

- L_u = 41.1 m wo collimator,
- L_u = 143.5 m with collimator $R_c = 0.7$ mm

Photon Density on Target after Bunch



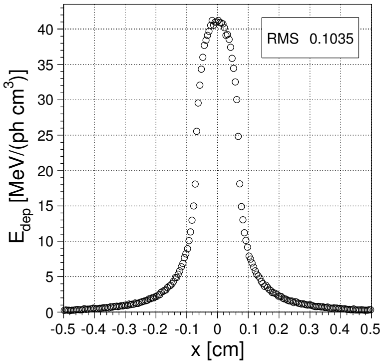
Energy Distribution of Photons



Energy Deposition in Target (FLUKA)

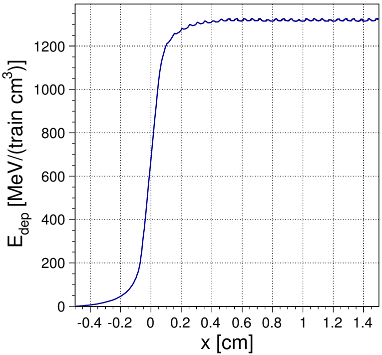
250 GeV e^-, K = 0.92, $R_c = 0.7$ mm,
554 ns bunch spacing, 100 m/s rot. speed

Energy Deposition after Bunch



E_{max} = 1.6 J/(g bunch)

Energy Deposition after Bunch Train



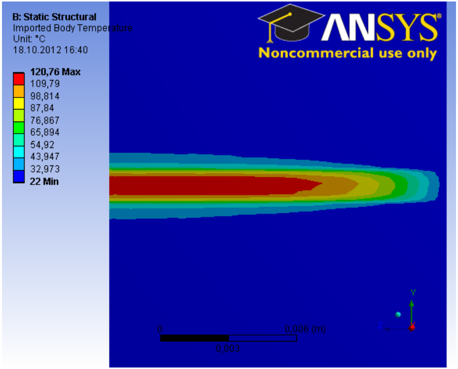
E_{max} = 52 J/(g train)

Bunch Overlapping Factor $\equiv E_{max\ Train}/E_{max\ Bunch} = 32.5$

Temperature Distribution and Stress in Target

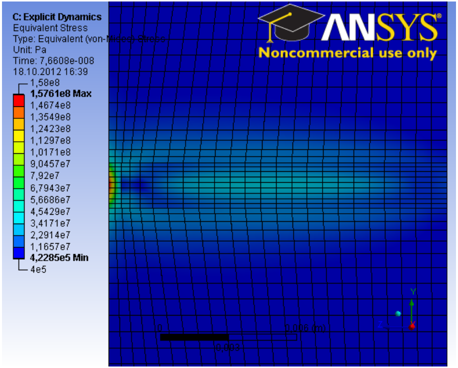
250 GeV e$^-$, K = 0.92, $L_u = 143.5$ m (active), $R_c = 0.7$ mm

Temperature Map after Bunch Train



$\Delta T_{max} \simeq 100$ K

Max. Dynamic Stress in Target



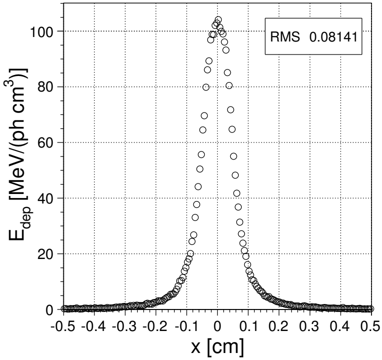
$\sigma_{max} \simeq 160$ MPa

www.matweb.com – Ti6Al4V (Grade 5), Annealed:
Tensile Yield Strength = **880 MPa**, Fatigue Strength = **510 MPa** at 10^7 Cycles

Energy Deposition in Target. K = 0.92, wo collimator

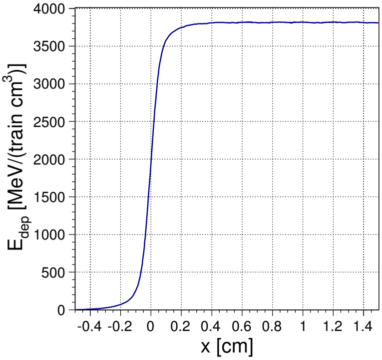
Will target withstand the heat load induced by photons generated in **RDR undulator at 500 GeV e^-?**

Energy Deposition after Bunch



E_{max} = 3.5 J/(g bunch)

Energy Deposition after Bunch Train



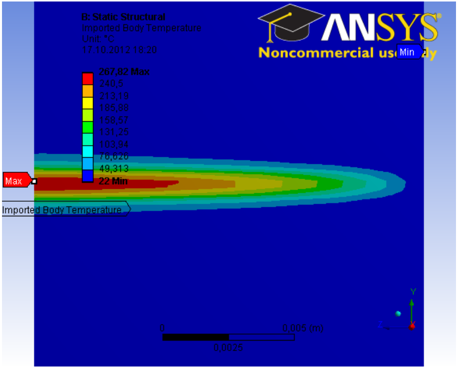
E_{max} = 129 J/(g train)

Bunch Overlapping Factor = 37.2

Temperature Distribution in Target

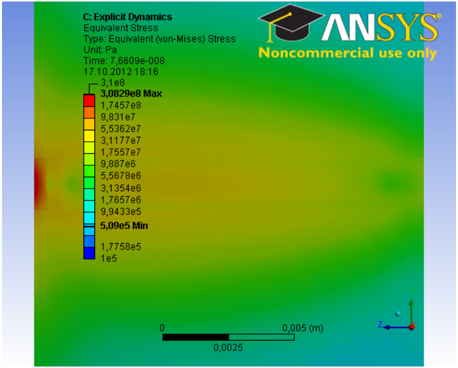
500 GeV e^-, K = 0.92, $L_U = 24.5$ m (active), wo collimator

Temperature Map after Bunch Train



$\Delta T_{max} \simeq 245$ K

Max. Dynamic Stress after Bunch Train



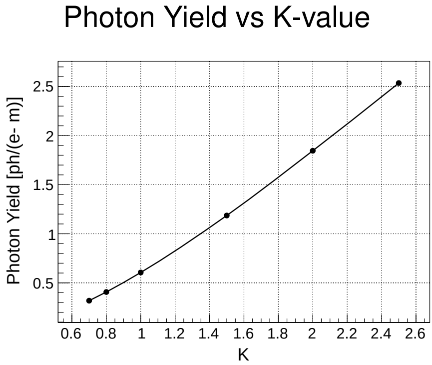
$\sigma_{max} \simeq 310$ MPa

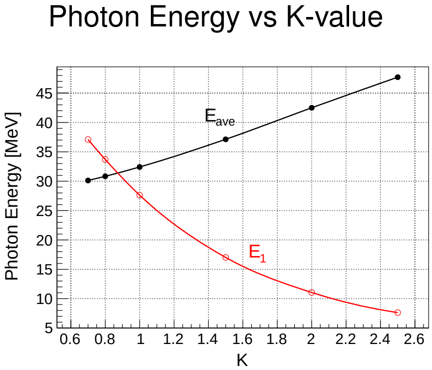
Upgrade of e^+ Source for 1 TeV Center-of-Mass Energy

- NbTi undulator with period of 4.3 cm (proposed by ANL group)
- K is varied ($K = 1$ ⇔ B-field = 0.25 T)
- Space between the end of undulator and target is 412 m
- Maximal active undulator length is 231 m
- Active length of undulator module is 11 m

- Ti6Al4V target with thickness of 0.4 X_0
- Pulsed flux concentrator: max. field on axis is 3.2 T
- DR acceptance:
  - long. bunch size $\leq$ 34.6 mm
  - $\epsilon_{nx} + \epsilon_{ny} \leq$ 70 mm rad

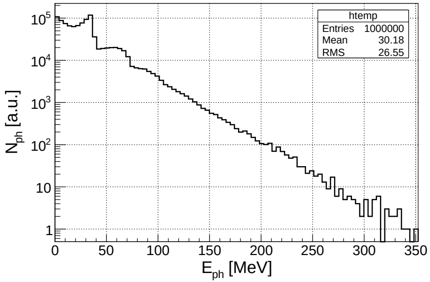
Photon Yield and Energy vs K value



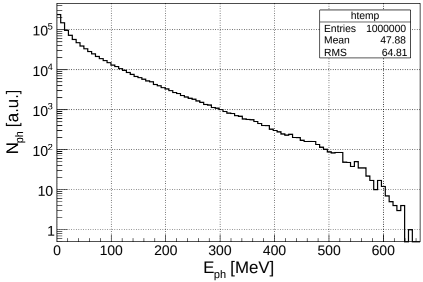


Photon Energy Spectra vs K value

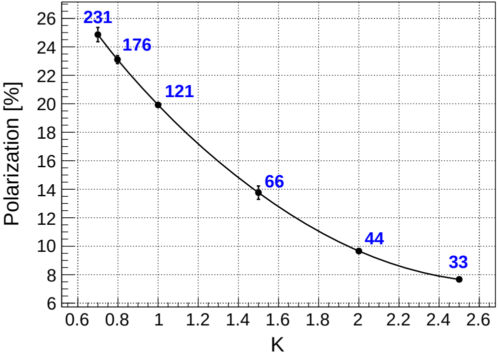
Energy Distribution for K = 0.7



Energy Distribution for K = 2.5



e^+ Polarization vs K for Source wo Photon Collimator



K	# Modules	e+ Yield [e+/e-]
0.7	21	1.564
0.8	16	1.500
1.0	11	1.521
1.5	6	1.586
2.0	4	1.655
2.5	3	1.688

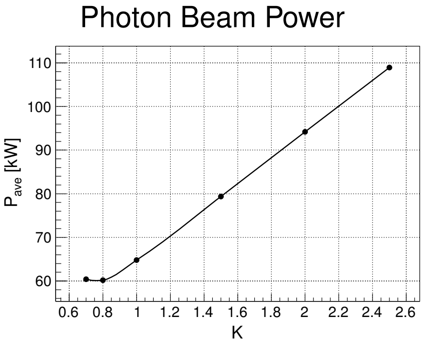
Length of undulator module is 11 m

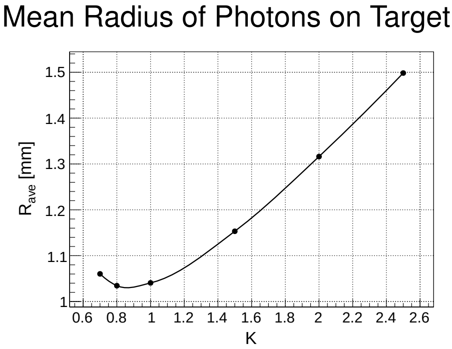
blue numbers – required active undulator length [m]

Max. polarization without collimator is about 25% for $K = 0.7$

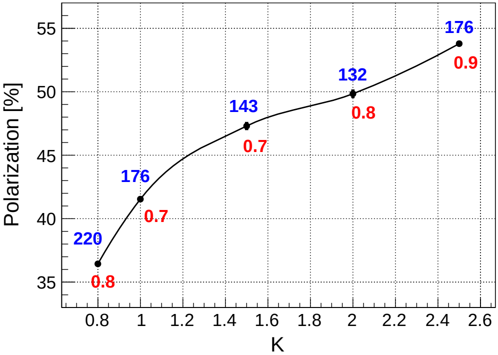
Photon Power and Spot Size on Target (wo Collimator)

$1.74 \cdot 10^{10}$ e^-/bunch, 2450 bunches/train, 4 Hz, 1.5 e^+/e^- at DR





Polarization vs K for Source with Photon Collimator



K	# Modules	e+ Yield [e+/e-]
0.8	20	1.556
1.0	16	1.507
1.5	13	1.523
2.0	12	1.499
2.5	16	1.511

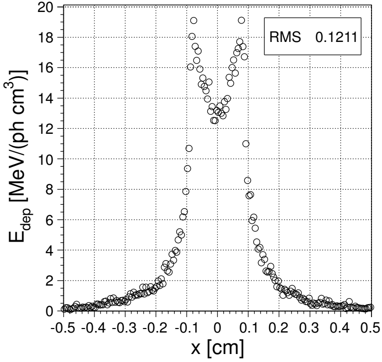
blue numbers – required active undulator length [m]
red numbers – aperture radius of collimator [mm]

54% e^+ polarization can be achieved for source with $K = 2.5$ and $R_c = 0.9$ mm

Energy Deposition in Target

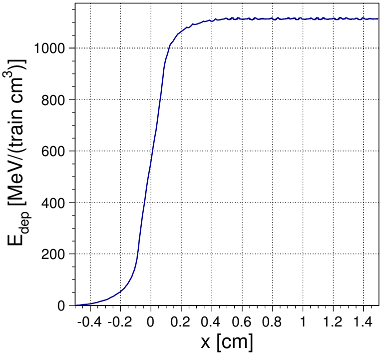
500 GeV e^-, $\lambda = 4.3$ cm, $K = 2.5$, $L_u = 176$ m, $R_c = 0.9$ mm
366 ns bunch spacing, 100 m/s rot. speed

Energy Deposition after Bunch



E_{max} = 1.2 J/(g bunch)

Energy Deposition after Bunch Train

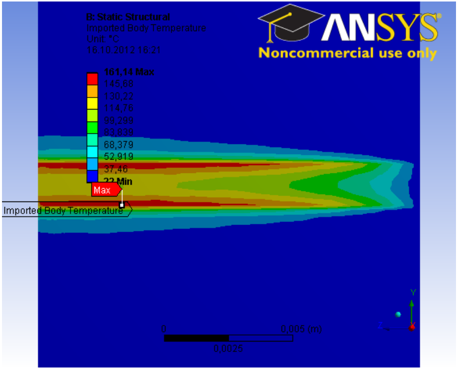


E_{max} = 73 J/(g train)

Bunch Overlapping Factor = 60.7

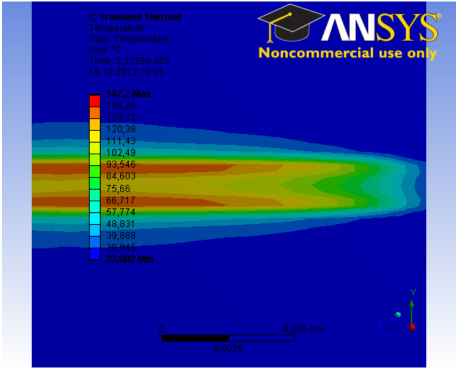
Temperature Distribution in Target

Temperature Map after Bunch Train, wo heat diffusion during the pulse



$\Delta T_{max} \simeq 140$ K

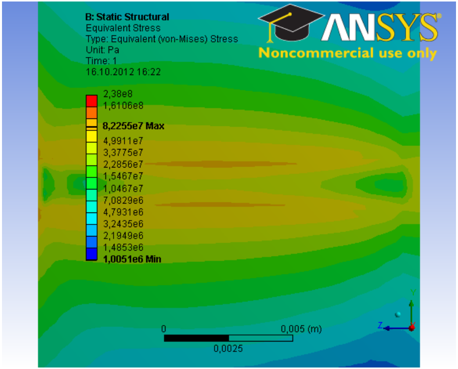
Temperature Map after Bunch Train, with heat diffusion during the pulse



$\Delta T_{max} \simeq 125$ K

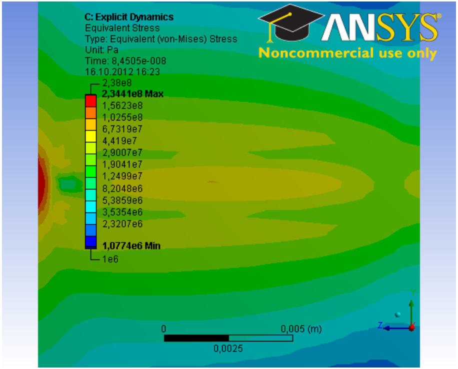
Thermal Stress in Target (Imported Temperature)

Static Stress



$\sigma_{max} \simeq 82$ MPa

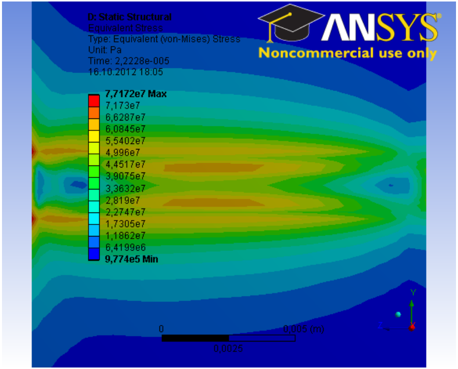
Max. Dynamic Stress



$\sigma_{max} \simeq 234$ MPa

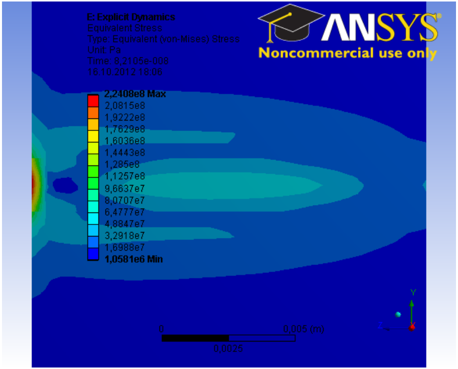
Thermal Stress in Target (Imported Heat)

Static Stress



$\sigma_{max} \simeq 77$ MPa

Max. Dynamic Stress



$\sigma_{max} \simeq 224$ MPa

e^+ Source with Nb3Sn Undulator

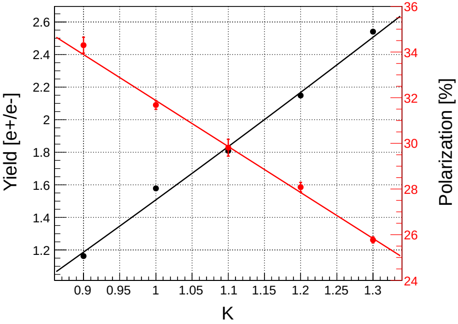
Parameters of e^+ source with a **short period, high field undulator**:

- **Nb3Sn** undulator with period of 0.9 cm (*STFC, EuCARD project)*
  Tom Bradshaw, Aug 2011: "The wire is a problem – commercially available wire is unstable at low fields ..."
- Max B-field on axis 1.54 T $\Rightarrow$ $K \simeq 1.3$
- Maximal active undulator length is 231 m
- Space between the end of undulator and target is 412 m
- Ti6Al4V target with thickness of 0.4 X_0
- Pulsed flux concentrator: max. field on axis is 3.2 T
- DR acceptance:
  - long. bunch size $\leq$ 34.6 mm
  - $\epsilon_{nx} + \epsilon_{ny} \leq 70$ mm rad

e^+ Yield and Polarization without Collimator

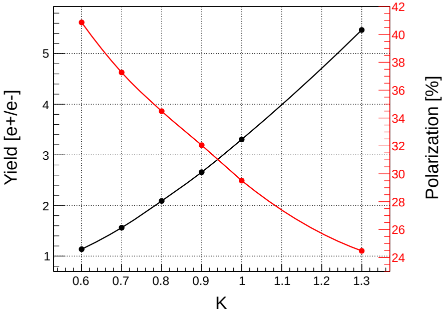
231 m Undulator

100 GeV e^-



$P_{e^+} \approx 32\%$ for $K = 1$

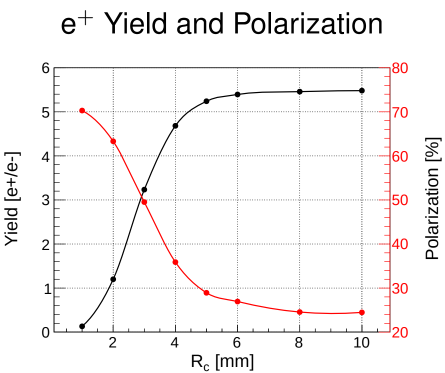
125 GeV e^-



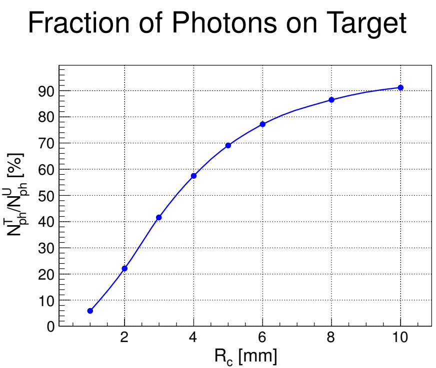
$P_{e^+} \approx 37\%$ for $K = 0.7$

e^+ Yield and Polarization with Collimator at 125 GeV

231 m Undulator Length



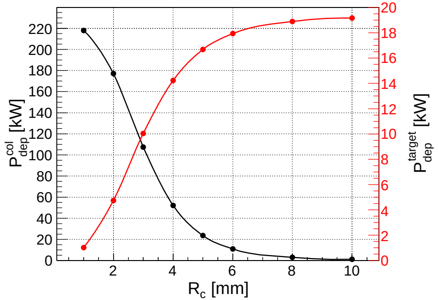
$P_{e^+} \approx 60\%$ for $R_c = 2.2$ mm



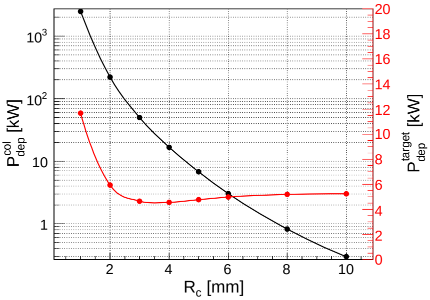
Collimator with $R_c = 2.2$ mm absorbs 75% of photons

Power Deposited in Collimator and Target at 125 GeV

Power Deposited in Collimator and Target, 231 m Undulator



Power Deposited in Collimator and Target, 1.5 e^+/e^-



Heat load in target/collimator and thermal stress have to be studied

Summary

- ILC e^+ source with 231 m RDR undulator provides 1.5 e^+/e^- in energy range between 130 GeV and 250 GeV. e^+ polarization can be kept at 30% by proper choice of undulator field.
- To increase e^+ polarization of source with RDR undulator up to 60% a photon collimator with the smallest aperture radius of 0.7 mm is needed.
  - Average deposited power in collimator is up to 130 kW.
  - Peak thermal tress in target is about 160 MPa.
- Source for 1 TeV upgrade using a 4.3 cm period NbTi undulator can generate a beam having
  - 25% polarization with undulator $K = 0.7$ and without collimator,
  - 54% polarization with undulator $K = 2.5$ and 0.9 mm apertures radius of collimator. Peak thermal tress in target is about 230 MPa.
- Source with Nb3Sn undulator having 9 mm period can
  - operate down to 100 GeV e^- energy,
  - generate e^+ beam with 60% polarization in case of using 125 GeV drive beam and collimator with 2.2 mm apertures radius.