ILC Positron Source: Concepts and Status

A. Ushakov

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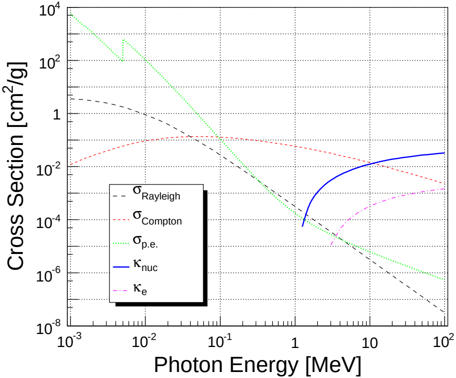
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

LINEAR COLLIDER COLLABORATION

Positron Production

Photon Cross Sections in Ti6Al4V Target



$\sigma_{\text{Rayleight}}$: coherent scattering

σ_{Compton}: incoherent scattering

$\sigma_{\text{p.e.}}$: atomic photoelectric effect

κ_{nuc}: pair production in nuclear field

κ_{e}: pair production in electron field

- Photons with energies $E_\gamma > 2$ MeV **are required** for e^+ generation
- Higher E_γ is better

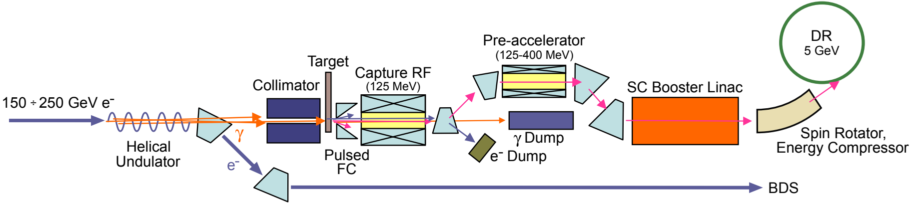
Types of e^+ Sources

	Undulator-Based Source	**Conventional Source**
Primary Beam	Main e^- Linac	Additional (Independent)
e^- Drive Beam Energy Bunch Spacing; Pulse Length	150 ÷ 250 GeV 554 ns ; 0.727 ms	6 GeV ∼6 ns / 3.3 ms ; 63 ms
Generation of γ	Helical Undulator	W25Re Target **4.0 X_0**
Generation of e^+	Ti6Al4V Target **0.4 X_0**	
Target Heat Load and Rotation Speed	∼ 5 kW* 100 m/s	35 kW 5 m/s

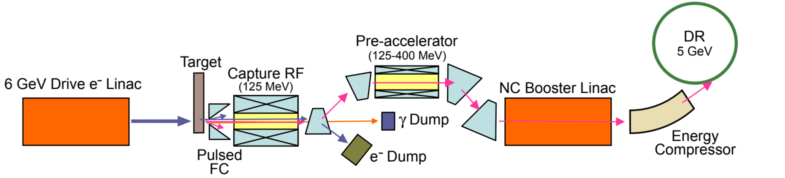
* *depend on CM energy*

Scheme of ILC e$^+$ source

ILC undulator-based source (30% up to 60% e$^+$ polarization)



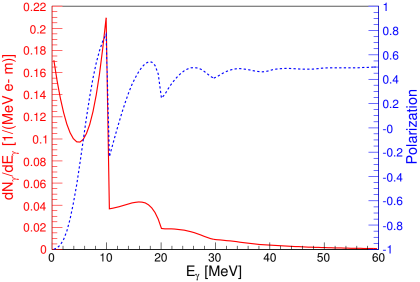
ILC conventional source (no e$^+$ polarization)



Energy and Polarization of Undulator Photons

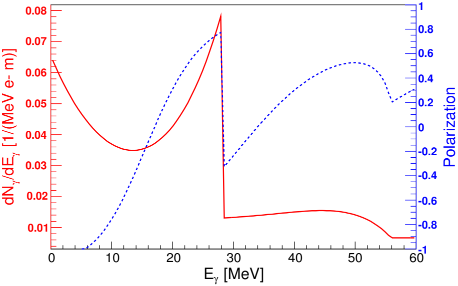
ILC base-line undulator: $K = 0.92$, λ = 11.5 mm

150 GeV e$^-$ Beam



$E_1 \simeq 10$ MeV

250 GeV e$^-$ Beam



$E_1 \simeq 28$ MeV

Photon yield: $\approx$ 2 ph/(e$^-$ m)

Conversion Efficiency ($\gamma \to$ e$^+$):

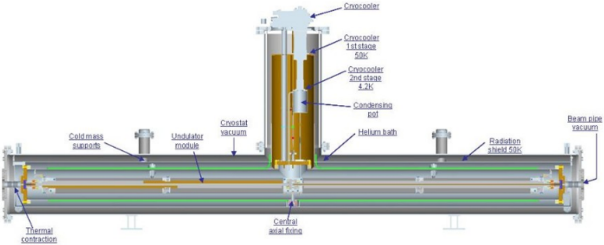
$\approx$ 0.006 e$^+$/ph | $\approx$ 0.018 e$^+$/ph

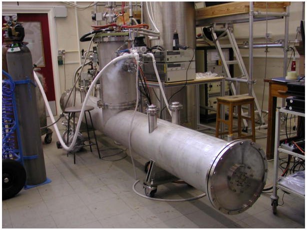
Required Undulator Length (1.5 e$^+$/e$^-$ at DR):

$\approx$ 130 m | $\approx$ 40 m

Undulator Cryomodule

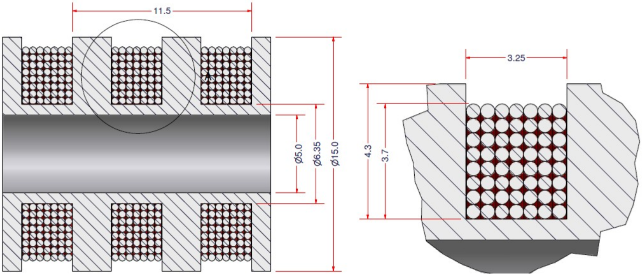
Superconducting helical undulator has been developed and tested by STFC, UK (Daresbury Laboratory & Rutherford Appleton Laboratory)

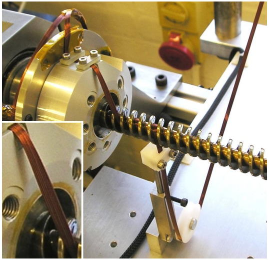




- Effective magnet length: 3.5 m (2 magnets)
- Cryomodule length: 4.1 m
- 66 undulator cryomodules (231 m total effective magnet length)
- 23 quadrupoles, 14.5 m quad spacing
- 320 m total lattice length

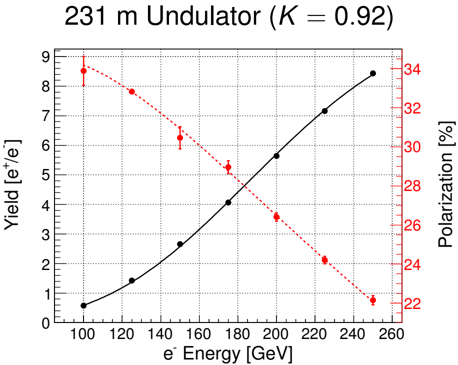
NbTi Winding





- ⌀0.4 mm NbTi wire, 7 wire ribbon, 8 layers, square packing
- **11.5 mm period**, winding ID: 6.35 mm
- 215 A
- 2.7 T peak field in conductor
- 0.86 T max field on axis, **K = 0.92**

Positron Yield and Polarization vs e^- Beam Energy

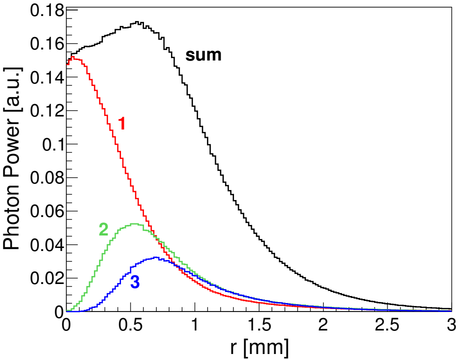


- Source should provide 1.5 e^+/e^-
- To increase e^+ polarization up to 30% at high energies a lower field (K-value) is needed (250 GeV e^-: $K = 0.45$)
- To increase e^+ polarization up to 60% a photon collimator can be used (undulator K-value must be optimized)

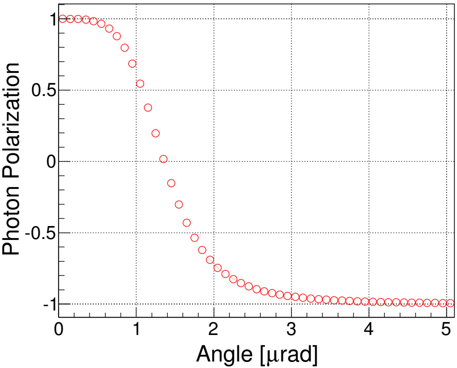
Photon Polarization vs Angle and Energy (250 GeV e^-)

500 m space between middle of undulator and target

Photon Power on Target vs Radius



Photon Polarization vs Angle

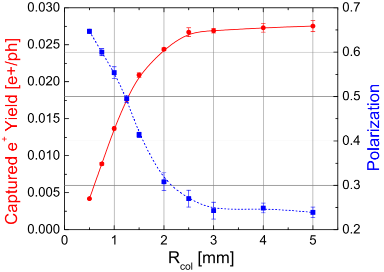


1, 2, 3 — harmonics numbers

Absorbing (in collimator) photons having high angles increases e^+ polarization

Photon Collimator for Positron Source at 250 GeV

Yield and Polarization vs Aperture Radius of Collimator

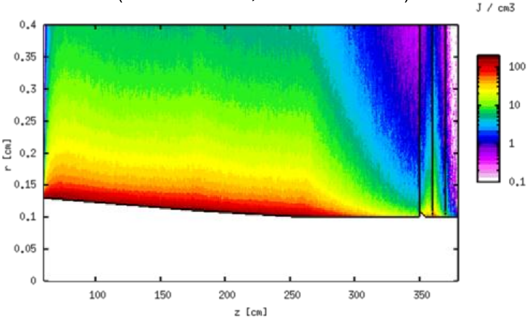


- $P_{e^+} = 30\%$ for R_{col}= 2 mm
- $P_{e^+} = 59\%$ for R_{col}= 0.7 mm,

80% of photons are absorbed in collimator, **132 kW**

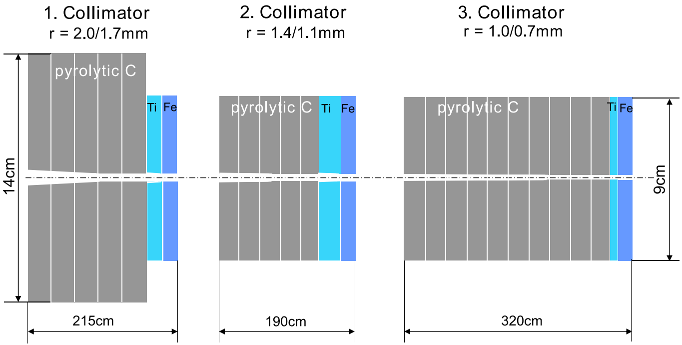
Energy Deposition in Photon Collimator

(F. Staufenbiel, DESY Zeuthen)



Design studies and calculations of thermal stress in multistage collimator have been done in Zeuthen

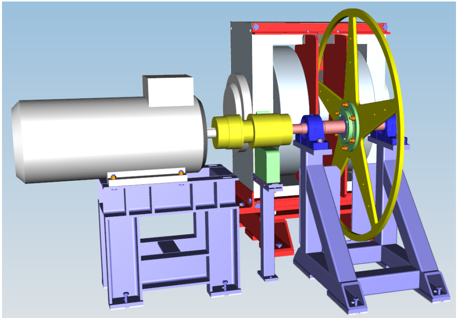
Photon Collimator (S. Riemann and F. Staufenbiel, DESY Zeuthen)



- The multistage design has been chosen to be flexible:
  1. Col. at 150 GeV e^-;
  1.+2. at 175 GeV;
  1.+2.+3. at 250 GeV.
  It allows to increase e^+ polarization up to $\simeq 50 \div 60\%$
- Heat loads and thermal stress are at acceptable level

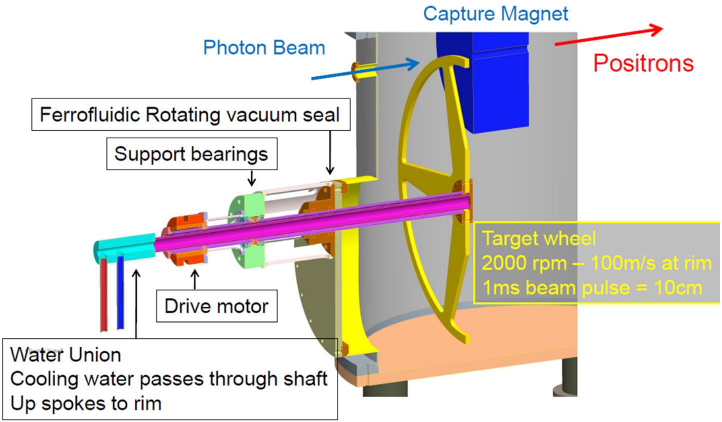
S. Riemann et al., DESY Report 14-232 (2014), arXiv:1412.2498

Target Prototype



- Cockcroft Institute: Full-scale Ti-alloy target wheel has been built (wo water channels) and eddy-current issue has been studied (2008).
- Pulsed magnetic field induces a torque $\sim$ 50 N m/pulse and additional average heat in target $\sim$ 50 W.
- Moderate instantaneous temperature rise of cooling water (a few degrees) induces high pressure, danger of water leeks in radiation damaged target and etc.
- Alternative target cooling options: cooling by sliding contacts (ANL, USA and IHEP, China); cooling by radiation (DESY and University of Hamburg).
- Target material aging under irradiation and cyclic thermal load will be studied and tested (Mainz University, University of Hamburg and DESY).

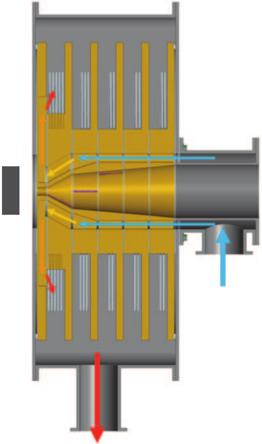
Ferro-Fluidic Vacuum Seal Test

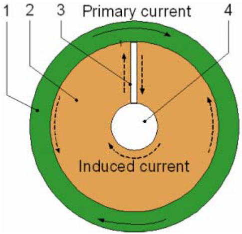


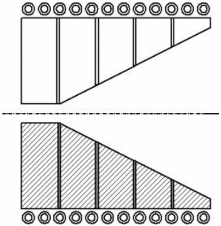
- Off shelf vaccum seal (Rigaku, FerroTec) have been tested.
- Rigaku seal fails after 15 min. at 2000 rpm (heating problem, grinding). Rigaku agreed to rework the pieces. FerroTec seal ran several hours at 2000 rpm without significant problem, outgassing rate was falling, but the seal burps regularly. [J. Gronberg, KILC 2012]
- Current status at LLNL: pending funding.

Pulsed Flux Concentrator (LLNL, Jeff Gronberg)

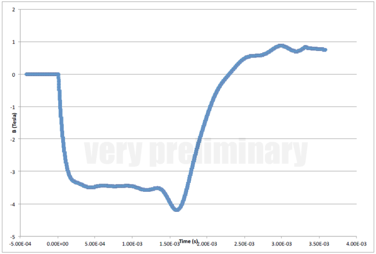
Pulsed FC (LLNL)







Magnetic Field vs Time

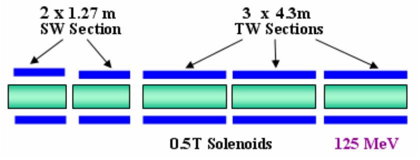


- Transverse component of field is relatively small, but $\neq 0$
- Longitudinal field profile is changed in time (FC for CS)

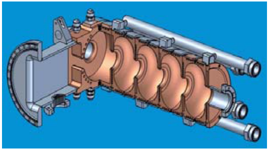
J. Gronberg, LCWS 2012

Capture RF System (SLAC)

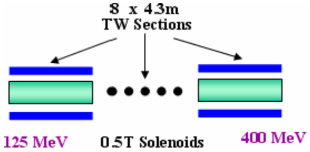
Schematic Layout of Capture Section



Structure Type	Simple π Mode
Cell Number	11
Aperture 2a	60 mm
Q	29700
Shunt impedance r	34.3 MΩ/m
E_0 (8.6 MW input)	15.2 MV/m



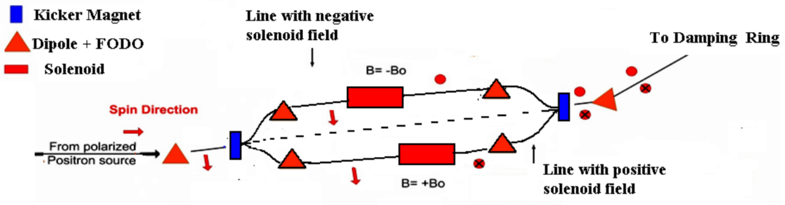
Layout of Pre-Accelerator



Structure Type	TW 3π/4 Mode
Cell Number	50
Aperture 2a	46 mm
Attenuation τ	0.98
Q	24842 - 21676
Group velocity Vg/c	0.62% – 0.14%
Shunt impedance r	48.60 – 39.45 MΩ/m
Filling time T_f	5.3 μs
Power Dissipation	8.2 kW/m
E_0 (8.6 MW input)	8.0 MV/m

J. W. Wang et al. APAC2007, SLAC-PUB-12412 (2007)

Schematic Layout of Spin Rotator/Flipper

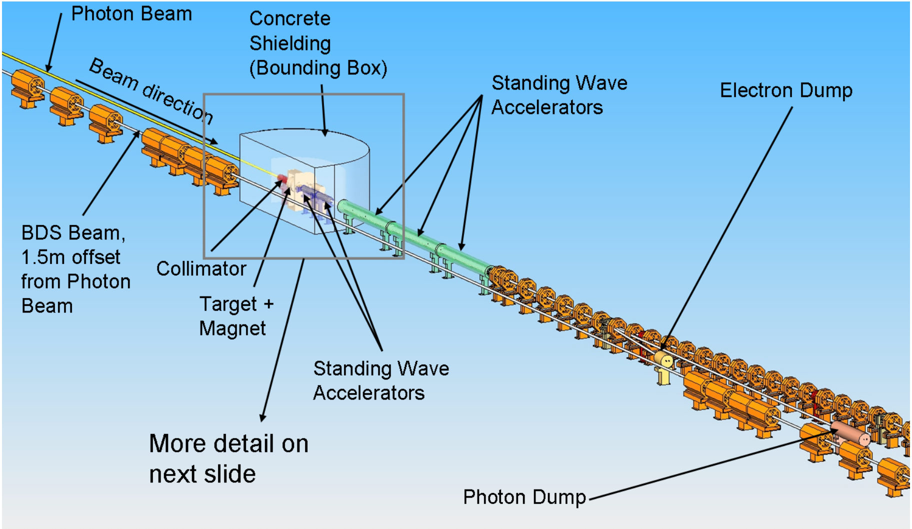


L. Malysheva et al., IPAC2012, TUPPR001

- Horizontal bend of 23.795° (spin is rotated 3x90°).
- Splitter/merger sections $\sim$ 26 m, 2 m separation between two horizontal branches.
- Integrated field of solenoid required to rotate spin up (or down) is 26.18 T·m.

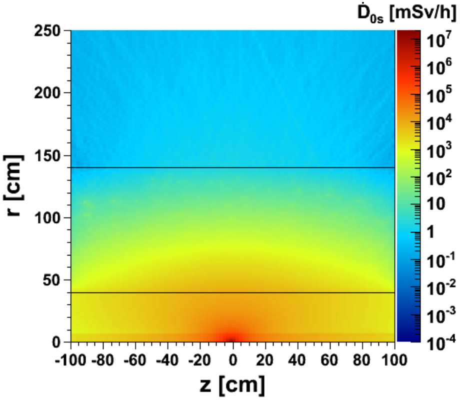
Provisional Target Area Sketch

provided by Norbert Collomb, Neil Bliss (STFC, UK)



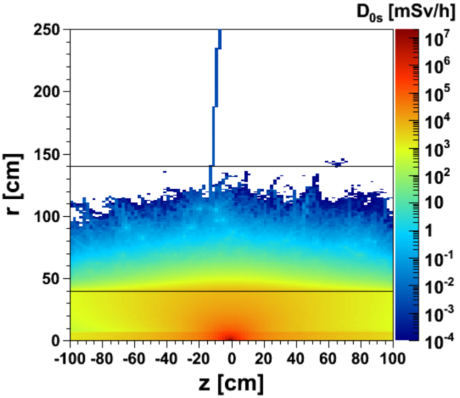
Dose Rates for Ordinary and Heavy Concrete Shielding (RDR. QWT)

Ordinary Concrete
($\rho = 2.3$ g/cm^3)



$\dot{D}_{0s}$(r = 140 cm) $\approx$ 1.5 mSv/h

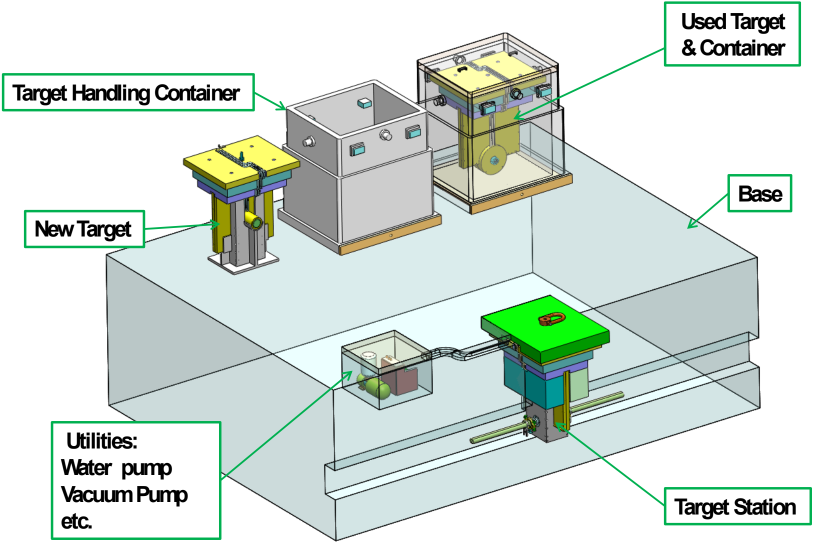
Heavy Concrete
($\rho = 4.68$ g/cm^3)



$\dot{D}_{0s}$(r = 140 cm) $\lesssim 10^{-5}$ mSv/h

Target Remote Handling

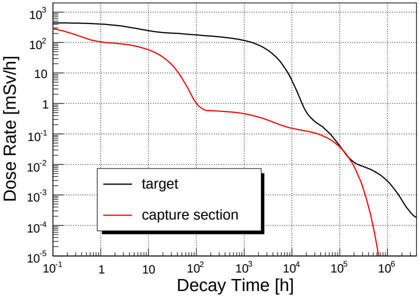
Jia Xuejun, IHEP, China (KILC 2012)



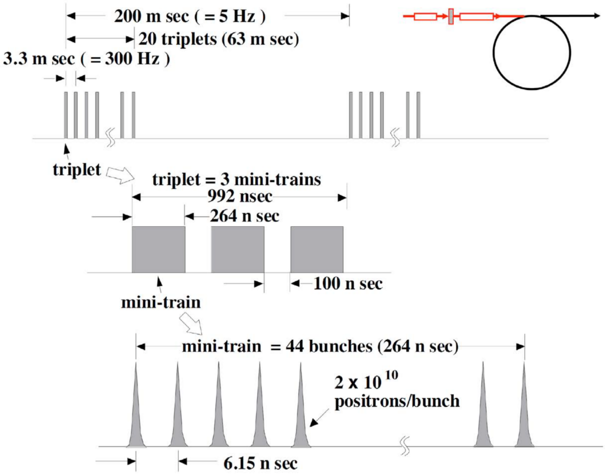
Activation Decay Times

Nuclei	A	$T_{1/2}$, h	$\dot{D}_{+1h}$, mSv/h	%
Ti	45	3.1	104.4	42.09
Sc	46	**2011.9**	86.7	34.96
Sc	44	3.9	21.3	8.59
Sc	48	43.7	19.1	7.71
Sc	47	80.4	13.6	5.47

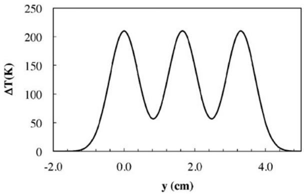
Ambient Dose Rate Equivalent vs Decay Time



Beam Time Structure of Conventional Source



ΔT in Target after 3 Triplets
for 5 m/s rot. speed



Conventional Source Parameters

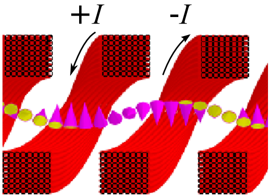
T. Omori et al., NIM 672, 52 (2012)

Parameters for target and captures		Parameters for the 300 Hz scheme	
Drive beam energy	6 GeV	#Drive e-/bunch	2×10^{10}
Beam size	4.0 mm (rms)	#Bunches/triplet	132 (in 996 ns)
Target material	Tungsten	#Bunches/train	2640 (in 63 ms)
Target thickness	14 mm	Repetition of the trains	5 Hz
Max. AMD field	7 T	Results numbers in () are for the 300 Hz scheme	
Taper parameter	60.1/mm	e+yield	$1.6/e^-$
AMD length	214 mm	PEDD in the target	$1.04\ \mathrm{GeV/cm^3}/e^-$ (22.7 J/g)
Const. field	0.5 T	Energy deposit in the target	$823\ \mathrm{MeV}/e^-$ (35 kW)
Max. RF field	25 MV/m	Energy deposit in the AMD	$780\ \mathrm{MeV/e^-}$ (33 kW)
RF frequency	1.3 GHz	Energy deposit in the RF section	$470\ \mathrm{MeV}/e^-$ (20 kW)

Backup Slides

Field of Helical Undulator

Magnetic field on axis of a double-helix-wound with equal and opposite current in each helix



$$B_\perp = \frac{8\pi I}{10\lambda}\left[\frac{2\pi a}{\lambda}K_0\left(\frac{2\pi a}{\lambda}\right) + K_1\left(\frac{2\pi a}{\lambda}\right)\right]$$

λ: period of magnet

a: radius of helix

K_0 and K_1: modified Bessel functions

- If $2\pi a/\lambda$ increases, the $B_\perp$ on axis decreases exponentially.
- Using superconducting technology, it is possible to make 1 Tesla magnet with $\lambda \cong a \cong 1$ cm

Angle and Power of Undulator Radiation

The orbit of an electron in a helical field is also a helix, with the same period λ.

$$r = \left(\frac{\lambda}{2\pi\rho}\right)^2 \rho\left[1 - \left(\frac{\lambda}{2\pi\rho}\right)^2\right]^{-1/2} \approx \frac{\lambda^2}{4\pi^2\rho}$$

$$\rho = \gamma\beta mc^2/eB$$

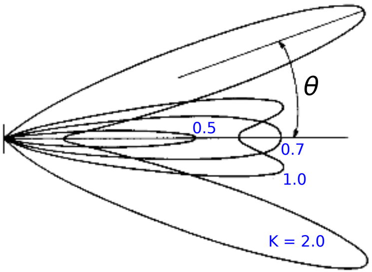
$$\theta_{pitch} \approx 2\pi r/\lambda$$

$$\theta_{pitch} \approx \frac{\lambda eB}{2\pi\gamma mc^2} = \frac{K}{\gamma}$$

$$K = \frac{\lambda eB}{2\pi mc^2}$$

Opening angle of synchrotron radiation $\theta \simeq 1/\gamma$

- $K < 1$ (weak-field case): $\theta \simeq 1/\gamma$
- $K > 1$ (strong-field case): $\theta \simeq K/\gamma$



- Power of radiation is proportional to B^2 and photon yield does not depend on e^- energy