Undulator-based Positron Source for ILC

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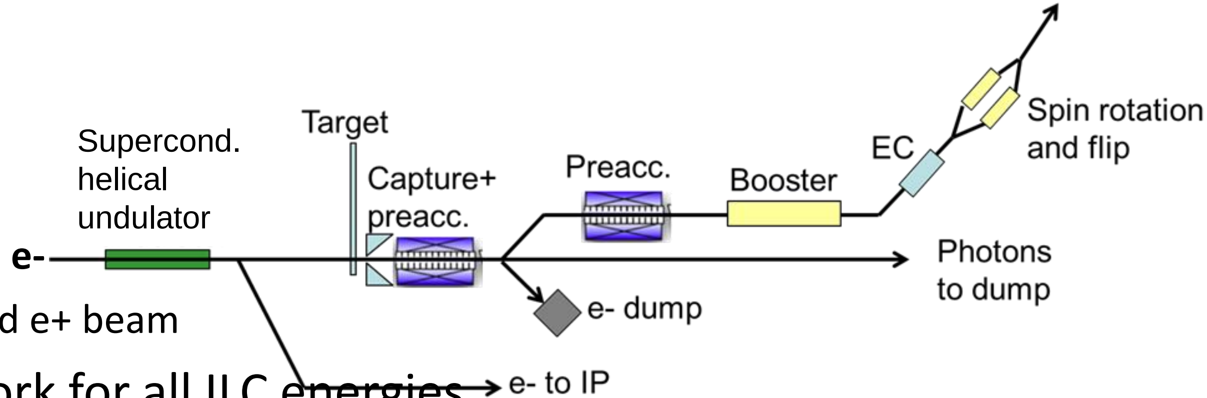
Overview



ILC e+ source (TDR)

polarized photon beam → polarized e+ beam

production scheme must work for all ILC energies

	ILC250	ILC350	ILC500	GigaZ
Final energy of e± [GeV]	125	370	250	45.6
e per bunch	2x10^10			
Bunches per pulse	1312			
Pulse rep. rate	5 Hz			3.7 Hz
Yield e+/e- at DR	1.5 e+/e-			
e+ polarization	~30%			

Challenge: ~2x10^{14} e+/sec at DR

Key activities:

- Undulator
- Rotating target
- Magnetic focusing system

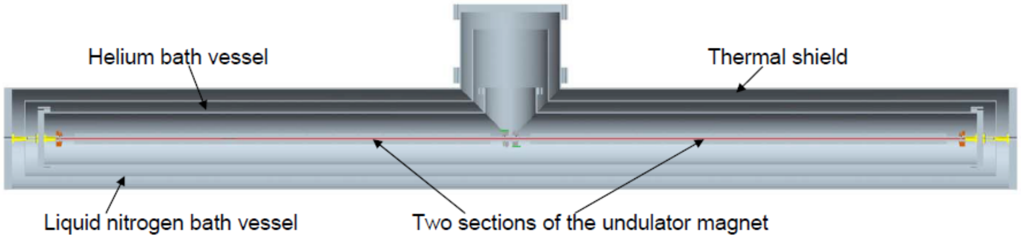
Work packages	Items
WP-5: Undulator	Simulation (field,errors, alignment) √
WP-6: Rotating target	Design finalization, partial laboratory test, mock-up design
	Magnetic bearings: performance, specification, test
	Full wheel validation, mock-up
WP-7: Magnetic focusing system	Design selection (pulsed solenoid, plasma lens), with yield calculation
	OMD with fully assembled wheel, prototype

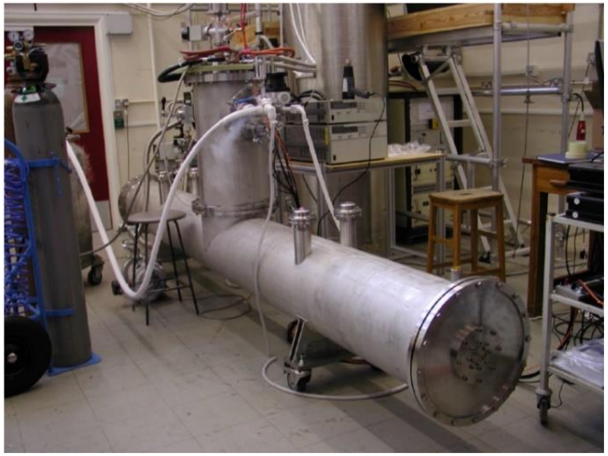
Superconducting helical undulator

D.Scott et al.,
Phys. Rev. Lett. 107, 174803

- Prototype developed at RAL

  2 unduator modules of 1.75m in 4m cryomodule

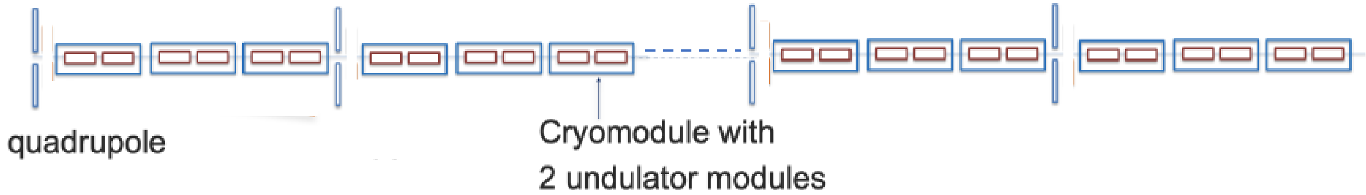




→ ILC Undulator Parameters: Undulator period, λ_U =11.5mm
Undulator strength $K \leq 0.92$ ($B_{max} \leq 0.86T$)
Beam aperture (diam.) 5.85mm

Max 231m active undulator length: 132 undulator modules ⇔ 66 cryomodules
Quadrupoles every 3 cryomodules

→ total length of undulator system is 320m



Helical undulator – parameter 'choice'

Prototype → K_{max} = 0.92 (B_{max}=0.86T) and λ_u = 11.5mm

Parameter optimization to achieve Y = 1.5e+/e- at DR

- efficiency of e+ generation depends on photon energy; photon energy depends on electron energy, λ_u and K:
- first harmonic: $E_{1\gamma} \sim \frac{E_e}{\lambda_u(1+K^2)}$ → low K increases photon energy
- Number of photons $N_\gamma \sim L \cdot \frac{K^2}{\lambda_u}$ → low K gives less photons

→ Optimize K and active undulator length L to achieve 1.5e+/e-

	ILC250	**ILC350**	**ILC500**
K	0.85	0.75	0.45
L [m]	231	147	

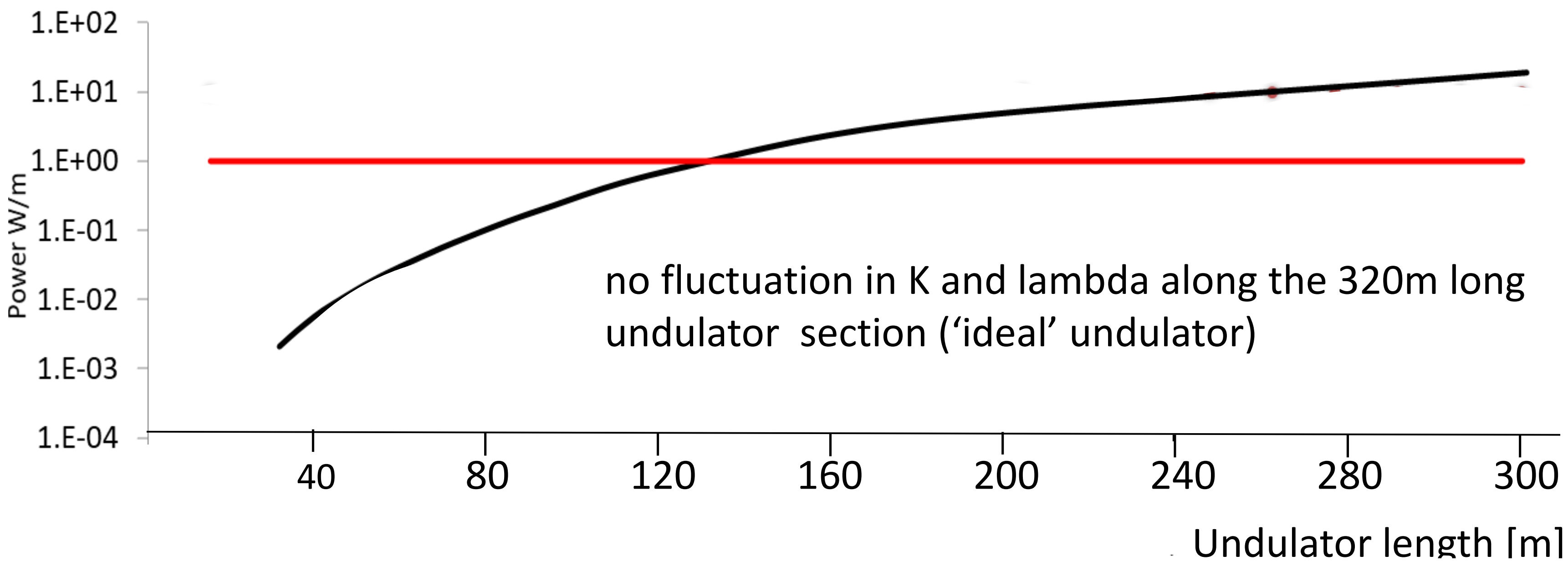
Opening angle of photon beam $\sim\sqrt{(1+K^2)}/\gamma$

- Spot size on target is determined by electron energy and is small even at ~400m distance between undulator and target
- Small part of undulator radiation hits undulator wall ⇔ this power deposition in wall must be <1W/m

Energy deposition in undulator wall

Photon beam deposits power in undulator wall; limit of 1W/m

Consider **ILC250** – largest photon beam opening angle



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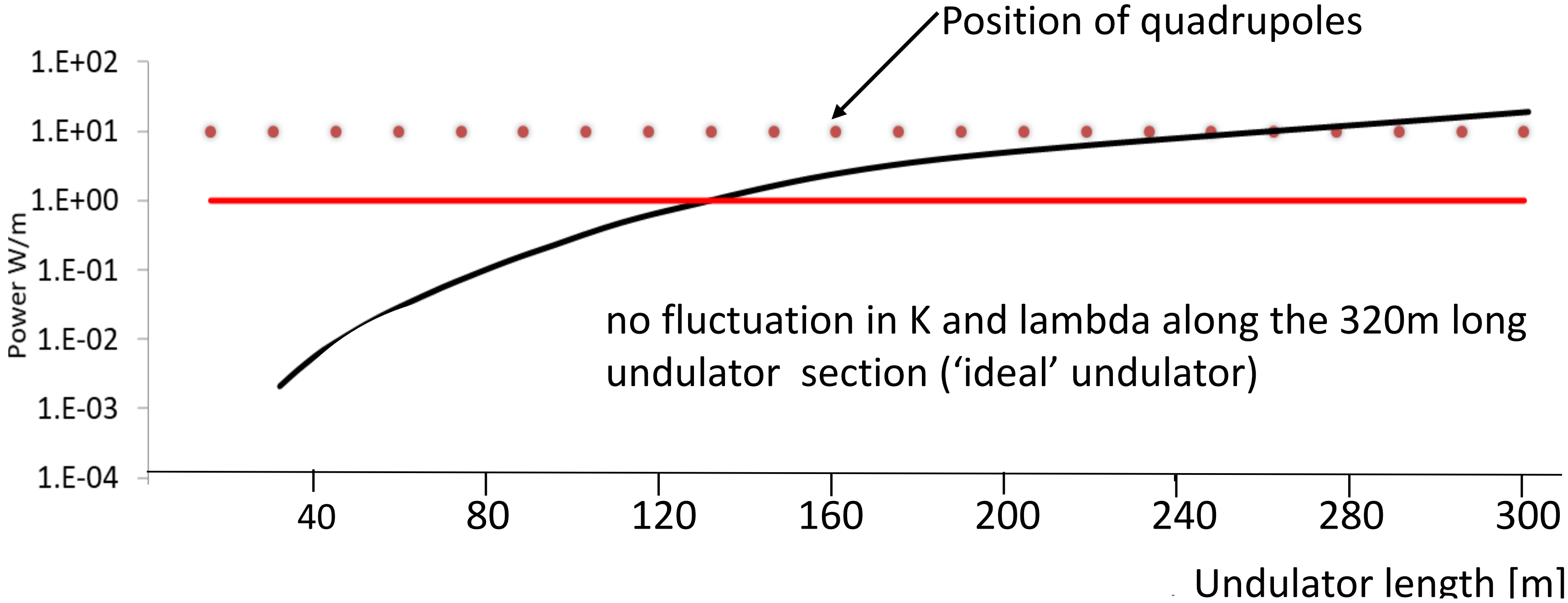
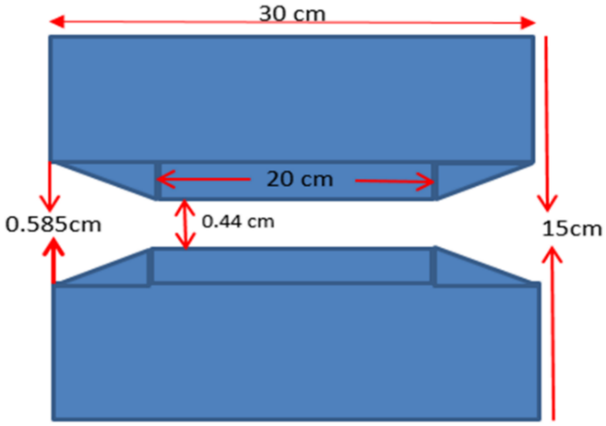
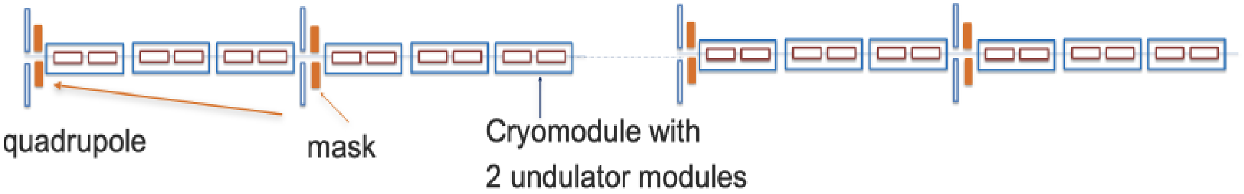
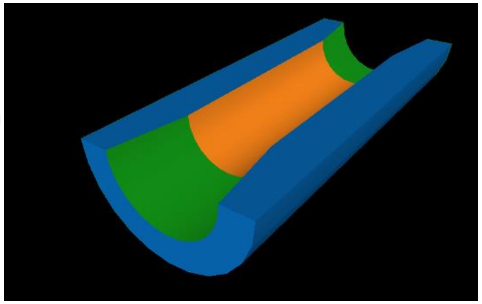


→Need masks to absorb these photons;
mask are inserted after quadrupoles

Masks to protect the undulator wall

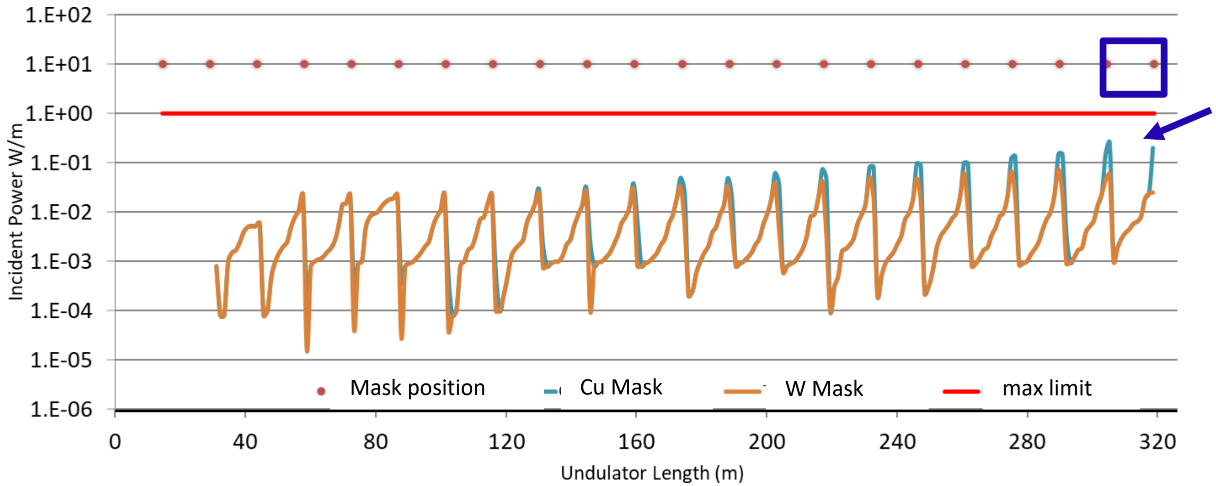






Mask material: Fe, Cu, W studied

Take into account fluctuation in K and period along the undulator (ILC250):



Maximum power deposited at the undulator wall of the last three cryomodules

Average energy E_{ave}^{γ} of photons impinging on the **last mask in the undulator**, and power P_{mask} deposited in this mask

E_{CM} (GeV)	250		350		500	
Undulator Case	Ideal	Realistic	Ideal	Realistic	Ideal	Realistic
E_{ave}^{γ} (MeV)	1.77	2.00	2.54	2.74	1.75	1.86
P_{mask} (W)	**270**	**320**	186	205	21	23

ILC250:

Undulator Case	Mask Material	P_{max} at wall (W/m)	P_{stop} (%)	PEDD (J/g/pulse)	ΔT_{max} (K/pulse)
Ideal	Cu	0.22	98.3	6.9	18
	W	0.03	99.6	9.8	73.4
Realistic	Cu	**0.26**	97.6	7.6	19.9
	W	0.04	98.4	11.0	81.9

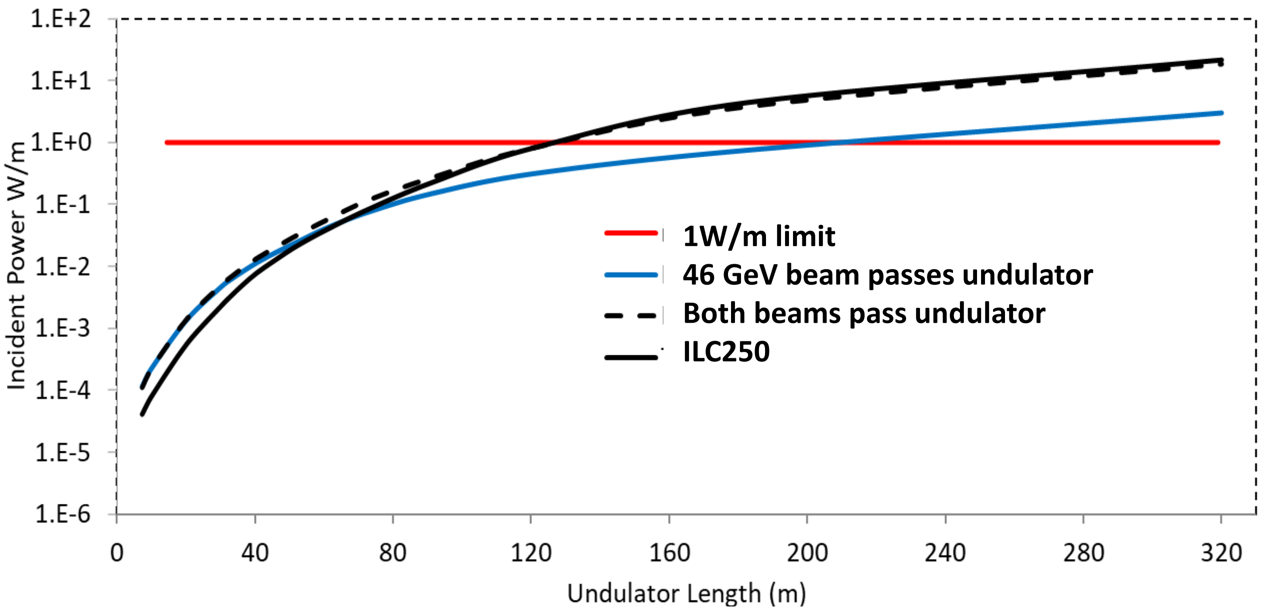
- Masks keep the SR deposition in the undulator wall below 1W/m; this holds also for luminosity upgrade
- ‘realistic’ undulator increases slightly the energy deposition in the mask

ILC GigaZ Option - Running at the Z boson pole

- Using the ILC undulator, the 46GeV electron beam cannot generate the photons for positron production
- Need 2 e- beams:
  - 46 GeV for physics collisions
  - 125 GeV for positron production

Parameters	Unit	ILC-250	ILC GigaZ option	
			e^+ production beam	collision beam
Final beam energy	*GeV*	125	125	45.6
Repetition rate	*Hz*	5	3.7	3.7

- Question: can both beams, 46GeV and 125GeV pass the undulator without exceeding the 1W/m limit? Or do we need a bypass for the physics beam?



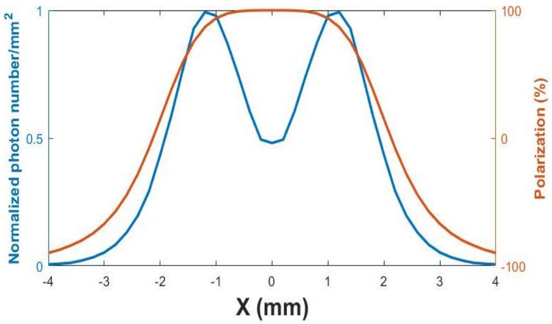
Without masks, both e- beams together deposit almost the same power in the undulator wall as the ILC250 e- beam does
→ Masks are sufficient for GigaZ; no bypass needed

Polarisation of the photon beam

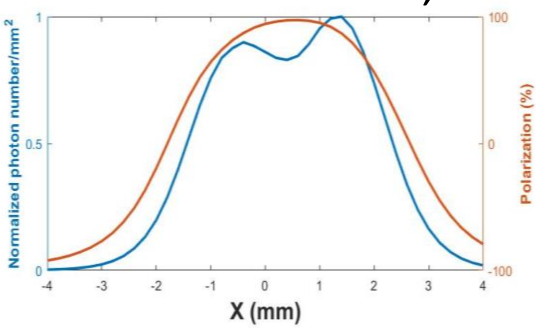
Consider photon beam profile in the target plane for **ILC250**

One undulator module only

Ideal undulator, Y=0

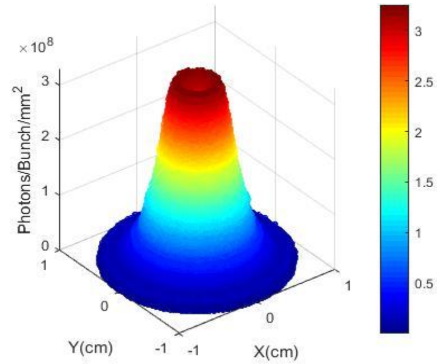


Realistic undulator, Y=0

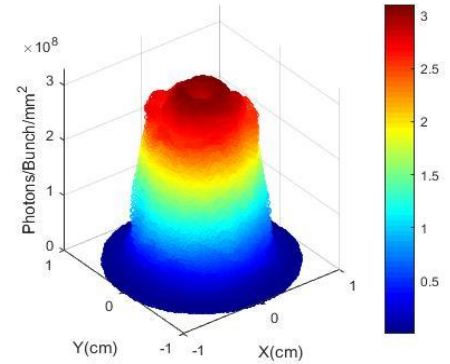


Full undulator length

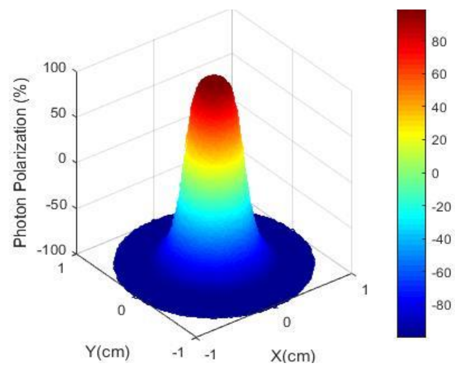
Ideal Photon Distribution



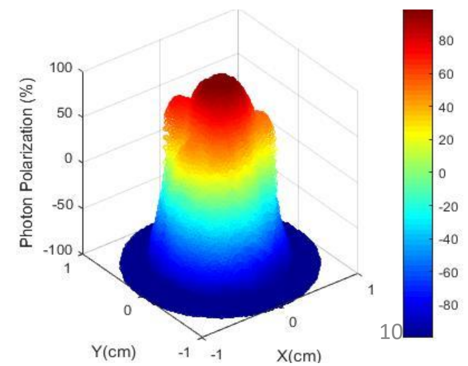
Realistic Photon Distribution



Ideal Polarization Distribution



Realistic Polarization Distribution

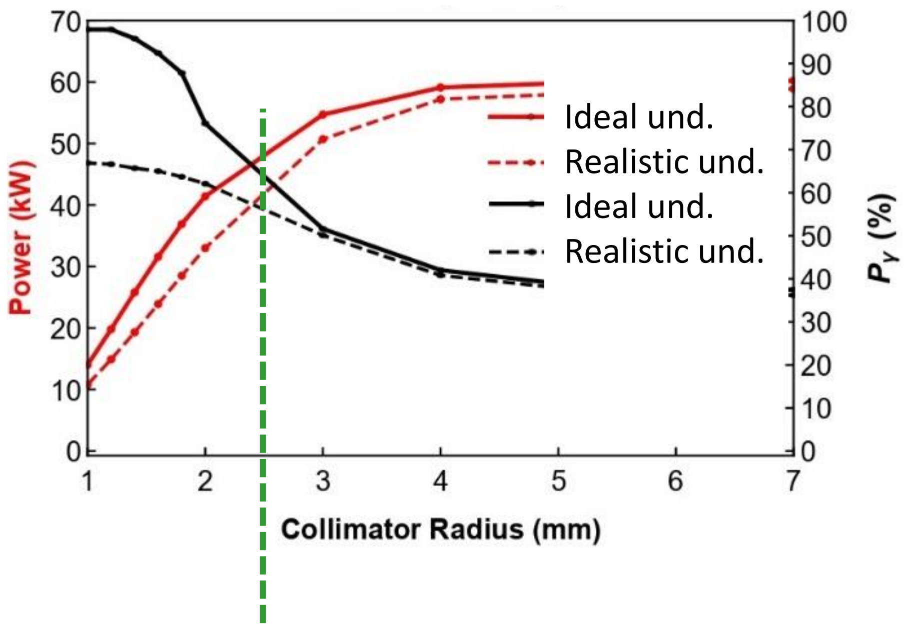


In case of a realistic undulator, i.e. fluctuation in K and λ, polarisation of photon beam is slightly reduced - and hence also the polarization of the e+ beam

Photon beam polarization

Consider ‘artificial’ photon collimation to understand the difference of photon beam polarization for ideal and realistic undulator

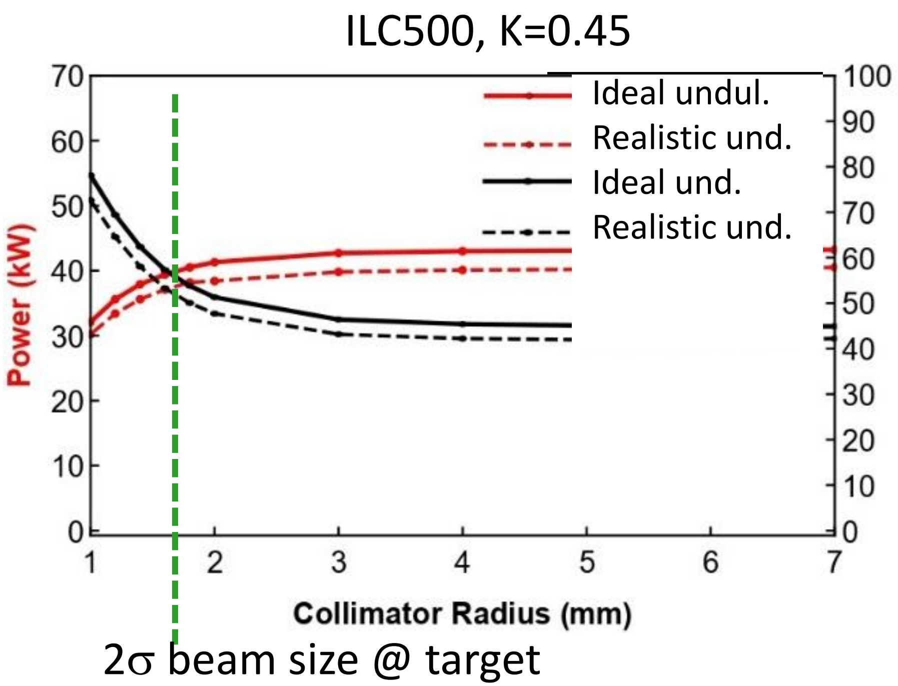
ILC250, K=0.85



2σ beam size @ target

Photon beam polarization decreases slightly for realistic undulator

Photon beam polarization



With smaller K value the photon polarization seems less sensitive to δK along undulator

Polarization upgrade so far (TDR):

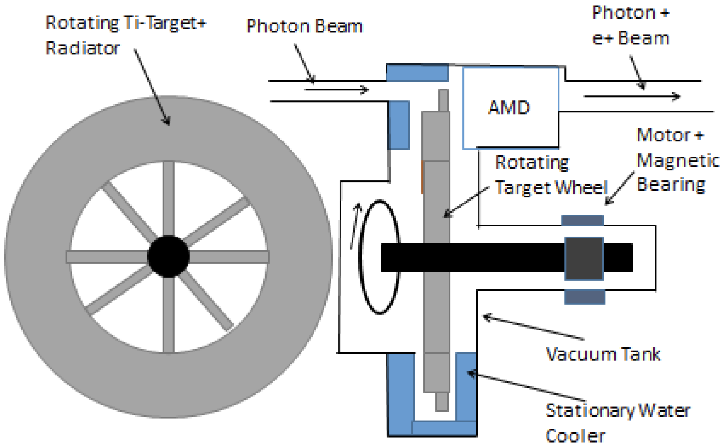
- Insert photon collimator
- Increase K to compensate intensity loss
- ILC500: K= 0.92, active undulator length 70m

→ Study should be repeated for realistic undulator to optimize e+ polarization (to be done based on new pulsed solenoid/OMD performance)

The positron target

- narrow photon beam of ~60kW power
- target wheel spinning in vacuum with ~2000rpm; photon beam impinges target at radius of 50cm
- Power deposition in target ~2kW
- material Ti6Al4V, thickness 0.2-0.4 X_0 (0.7-1.48cm) depending on E(e-)
- Design and technical specification of target wheel must include capture system

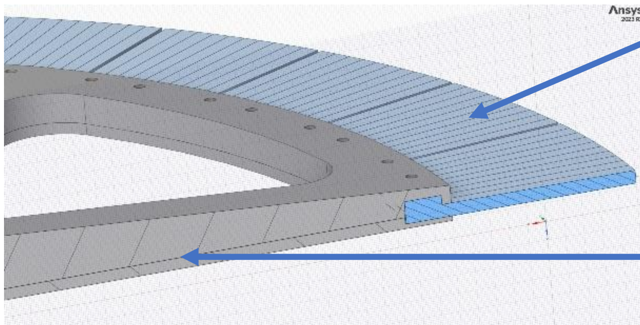
Principle layout:



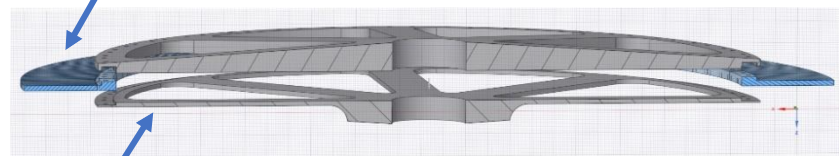
- T^4 radiative cooling from spinning hot target to stationary water cooled absorber.
  - highest temperature along the beam path, hot area is concentrated in region ~15cm around it
  - Max. target temperature should be below 600 C, must not exceed 700 C (T. Lengler)
  - Irradiation tests using electrons at microtron in Mainz show that Ti6Al4V stands high load. Tests are ongoing to evaluate the effect of high cyclic load at high temperatures (see T. Lengler et al., IPAC2024 (2024) TUPC81, T. Lengler et al. arXiv:2308.15916)

Vacuum chamber with target wheel, magnetic bearing system, and pulsed solenoid

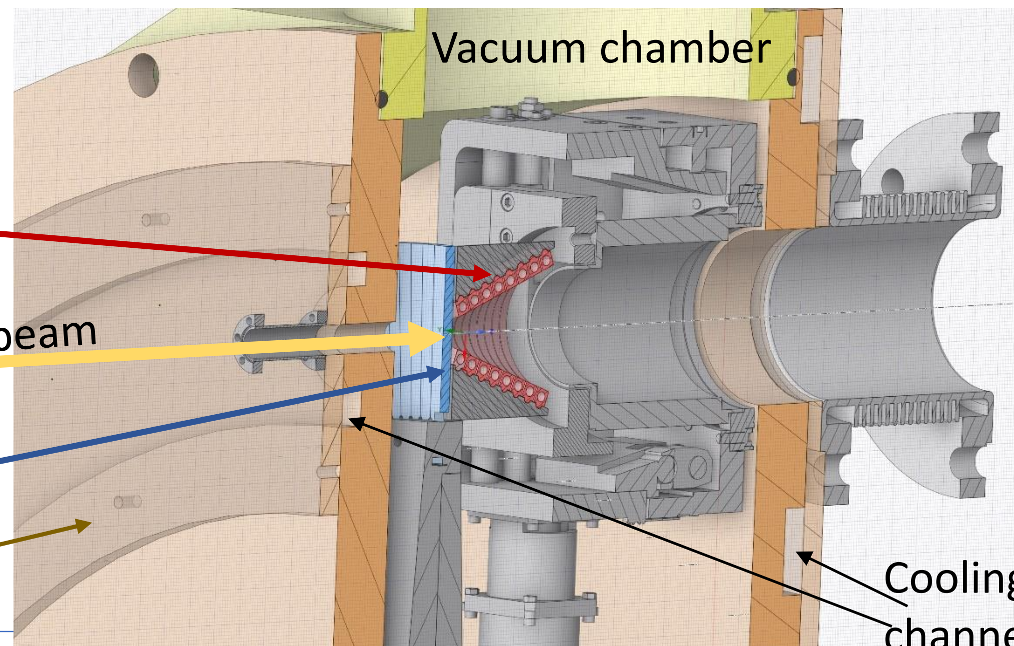
- Diameter of wheel: 120 cm
- Weight of the wheel: 50kg



Target material



Wheel: carrier of the target material



Pulsed solenoid

Photon beam

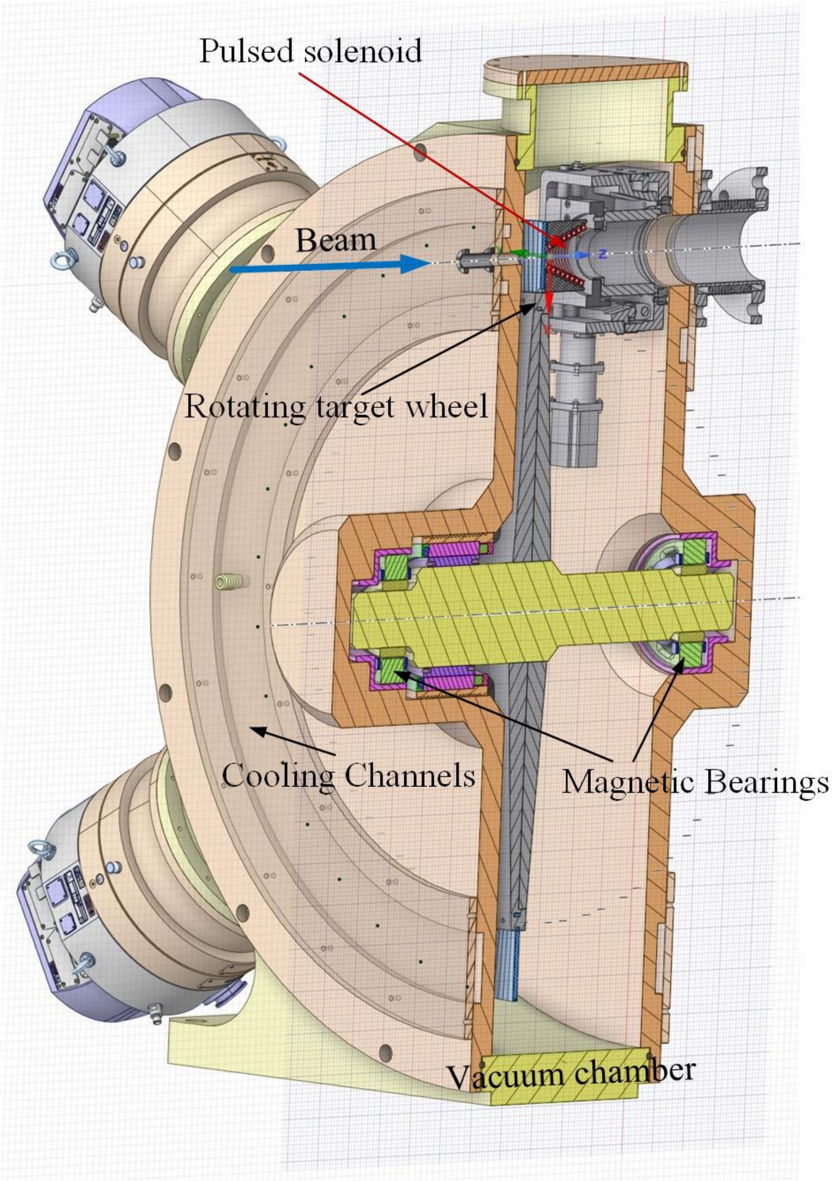
Rotating target

Stationary cooler

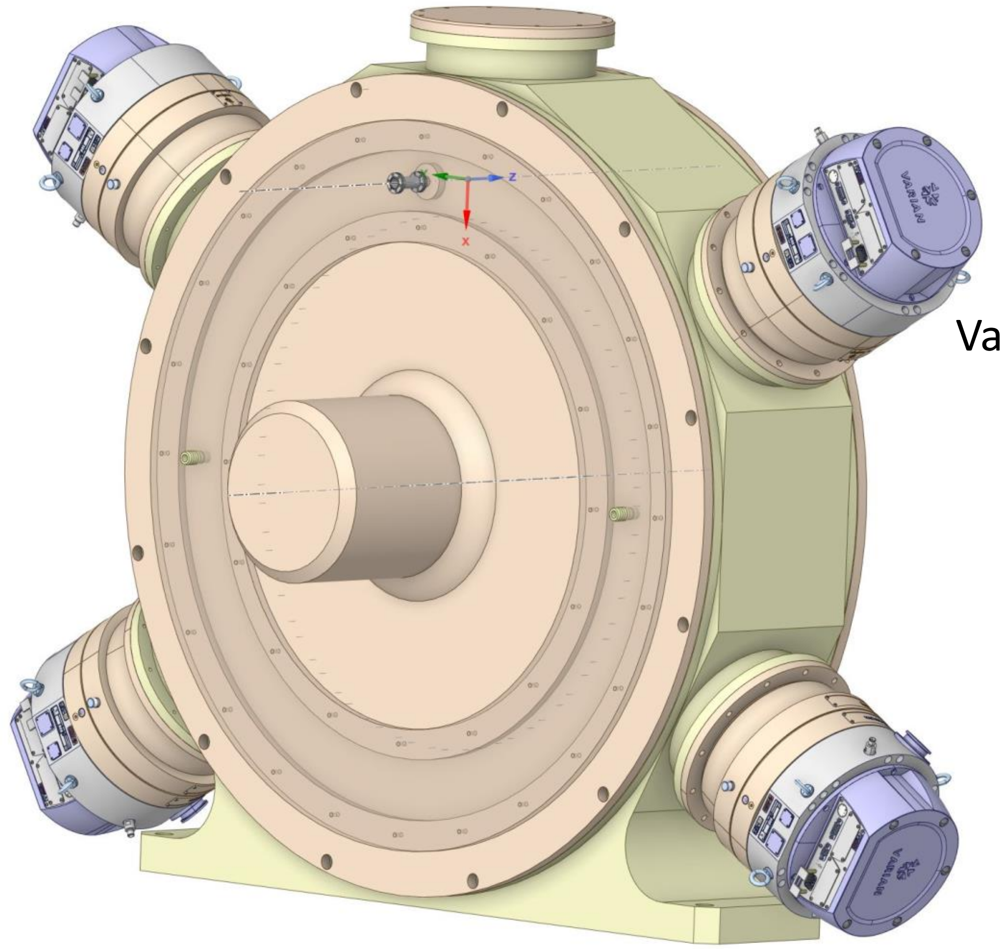
Cooling channels

Vacuum chamber with target wheel, magnetic bearing system, and pulsed solenoid

- Radiative cooling ⇔ magnetic bearings for rotation in vacuum
- Technical specification started, will be updated based on simulation studies
- Feasibility studies: Contacts with SKF (Canada):
  - — There is no ready-technical solution that meets our requirements
  - — They think about design of the magnetic suspension and simultaneously they seek government funding for R&D



Target station ('closed')

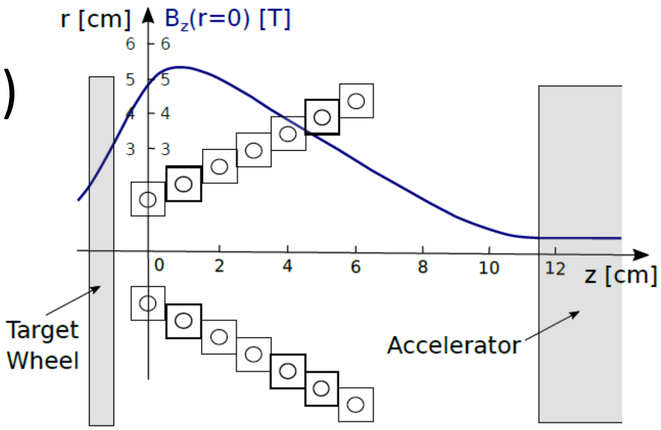


Focusing system: pulsed solenoid

The focusing system right after the target is a critical item; decisive for the positron yield

- ILC TDR: Flux concentrator (FC) or QWT
  - QWT: required e+ yield not reached for ILC250
  - FC: B field distribution is not constant during pulse (~1ms)
- Pulsed solenoid
  - Higher capture efficiency (B field on target)
  - load by eddy currents is small, ~100W
  - Pulsed breaking forces almost negligible

→ Strongest candidate for focusing system



- R&D for the pulsed solenoid
  - Detailed simulations are already on-going
  - Principal design and engineering work for a prototype pulsed solenoid; tests

Details and status see talk on Thursday

Summary

- Undulator based e+ source offers an efficient way to produce an intense polarized e+ beam for high energy e+e- colliders
- Experience at FELs and XFEL: achieved extremely stable operation, and all the ILC studies since more than 30 years tell us that the helical undulator is not a problem. Better materials will provide even better performance
- Work concentrates on the pulsed solenoid and the design of the spinning target
- ITN initiative: we are very happy that we got support. This will allow design and engineering work for a prototype of the pulsed solenoid
- Depending on the performance of the focusing system and target design a detailed simulation should optimize the final undulator K values to achieve high e+ yield and best e+ polarization

Thank you!