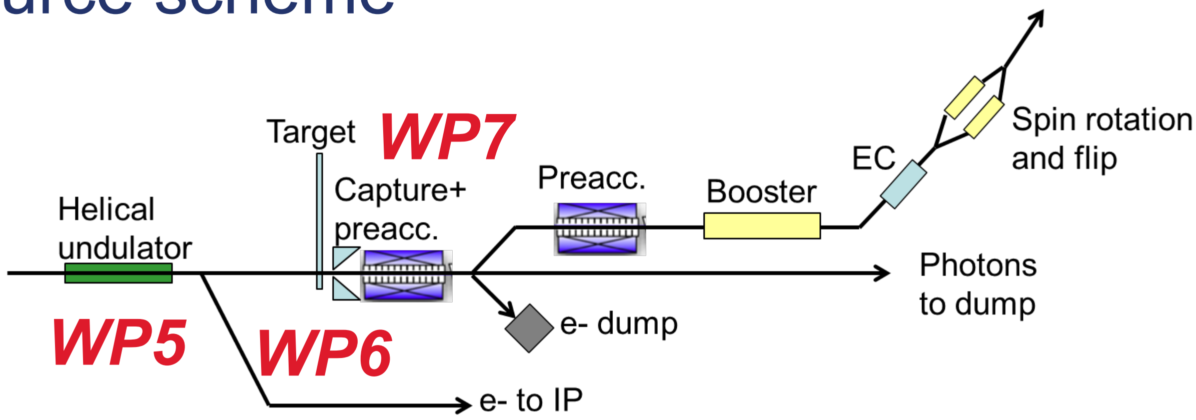
WPP undulator-based positron source

- **Overview WPP**
- **Ongoing work:**
  - **Undulator Simulations**
  - **Pulsed Solenoid**
  - **Plasma Lens**
  - **Rotating Wheel Design**
- **Conclusion**

Gudrid Moortgat-Pick et al.

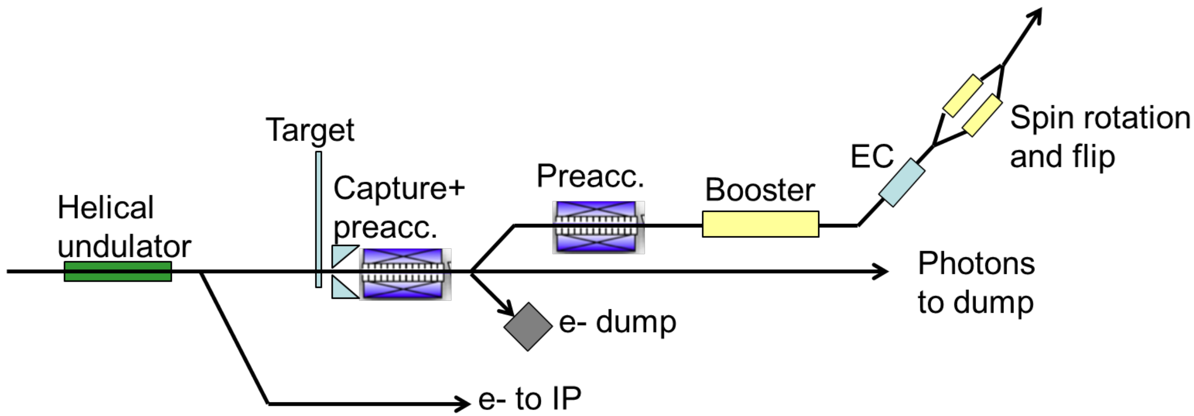
Overview: WPPs baseline positron source

The polarized e+ source scheme



Work package	Items
WP-5: Undulator	Simulation (realistic field, alignment, masks) **DONE** √
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	Pulsed solenoid, plasma lens, including with yield calculation
	OMD with fully assembled wheel

WPP-7: Focusing System for Undulator Scheme



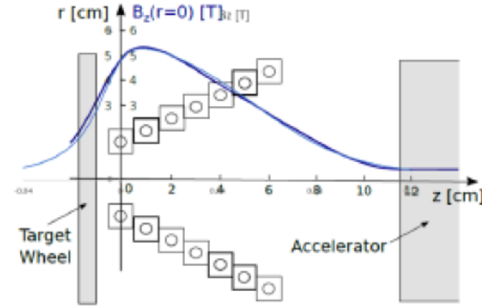
- The critical item for the undulator scheme is the magnetic focusing system right after the target
- Possible candidates are: (a) Pulsed solenoid, (b) Plasma lens
- The strongest candidate is (a) pulsed solenoid.
- R&D items to under work as WP-prime
  - Detailed simulations together in combination with design & engineering for a prototype pulsed solenoid (on-going)
  - Field measurements with 1kA (pulsed and DC) and with 50kA both in a single pulse mode and finally with pulse duration of 5ms at 5 Hz
  - Prototype plasma lens (funded study, measurements on-going)

M. Mentink, C, Tenholt, G. Loisch, M. Fukuda

OMD Design: Pulsed Solenoid

‘Baseline’: Pulsed Solenoid:

- Yield of e+ (OMD&capture Linac): 1.64-1.81
- Within ITN initiative: manufacturing & drawings at DESY
- Planned: prototype tests 2024



	Beamloss Power				Positron Yield	
	@dogleg	**@booster**	**@EC**	**@DR**	**@capture (|Z|<7mm)**	**@DR**
QWT	0.677 kW	0.014 kW	4.01 kW - 5.56 kW	13.15 kW - 14.3 kW	1.07	**~1.1**
Pulse solenoid w/o shield	0.927 kW	0.055 kW	5.86 kW - 7.93 kW	17.39 kW - 16.01 kW	1.81	**1.91**
Pulse solenoid with shield	0.871 kW	0.064 kW	5.58 kW - 7.90 kW	17.73 kW - 16.24 kW	1.64	**1.74**

G. Moortgat-Pick et al, ITN, 12/‘23

OMD Design: Pulsed Solenoid

Tenholt, Loisch, Lemke,Sievers

- ITN Funding available for prototype design of pulsed solenoid
- Mechanical design department at DESY: available manpower for design
- Close iteration between CAD, magnetic field simulations & mechanical stress simulations planned
- Goal of development is a prototype solenoid to demonstrate
  - Magnetic field strength & distribution
  - Magnetic field stability
  - Mechanical stability of solenoid
  - Thermal stability (i.e. manageable heat load)
- Vacuum vessel not foreseen in first prototype design
- Start of mechanical design after summer
- still to be seen where tests will be done (DESY,CERN)

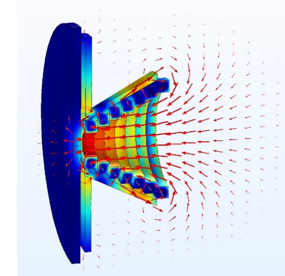
→ Overall goal: resolve open questions on mechanical feasibility

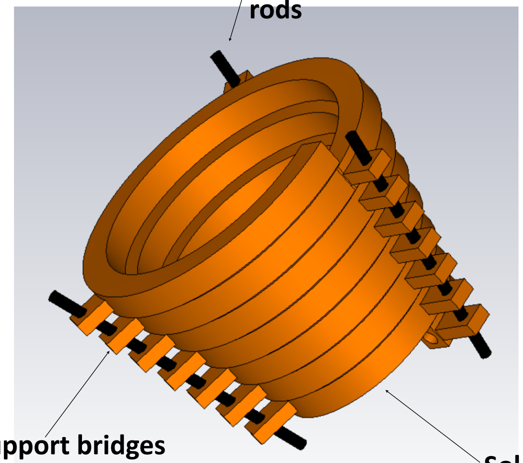
Solenoid construction

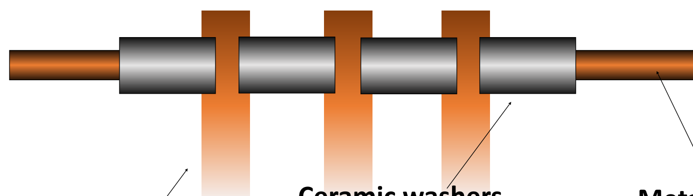
Tenholt, Loisch,Lemke,Yakopov

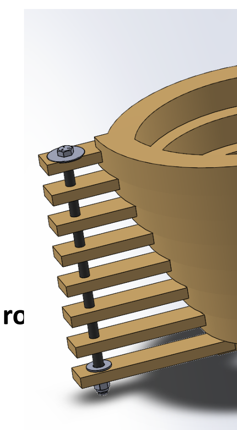
Possible mechanical design

- Solenoid coil
  - Tapered winding
  - 7 planar windings with interconnections
  - Conductor cooled from inside
- Metal supports to hold coil
- Support rods insulated from support bridges
  - Washers e.g. of SiN ceramics
- Magnetic shielding cut at support locations
  - Influence on field to be determined
  - Main shielding to target unaffected







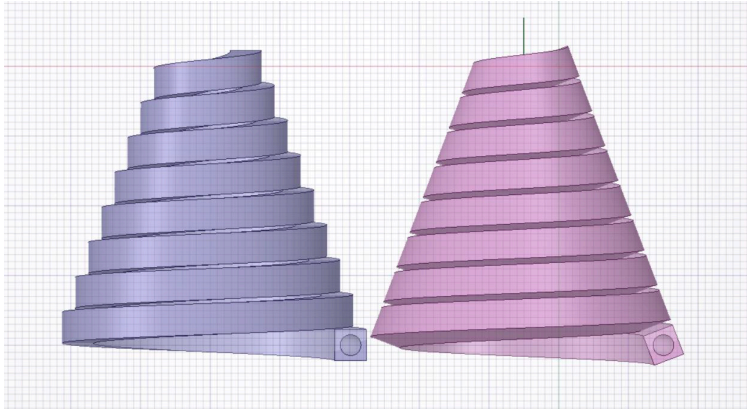


Solenoid construction

Tenholt, Loisch,Lemke,Yakopov

Possible mechanical design

- Standard stocks material
- Copper conductor with a cross-section of 9x9 mm
- Cooling channel with a diameter of 6 mm
- Two designs currently under work: depending on ease of manufacturing, mounting support, possibility of ferrite shielding
- Concerning magnetic fields: both designs practically identical
- Conductor made either by extrusion or by 3D printing



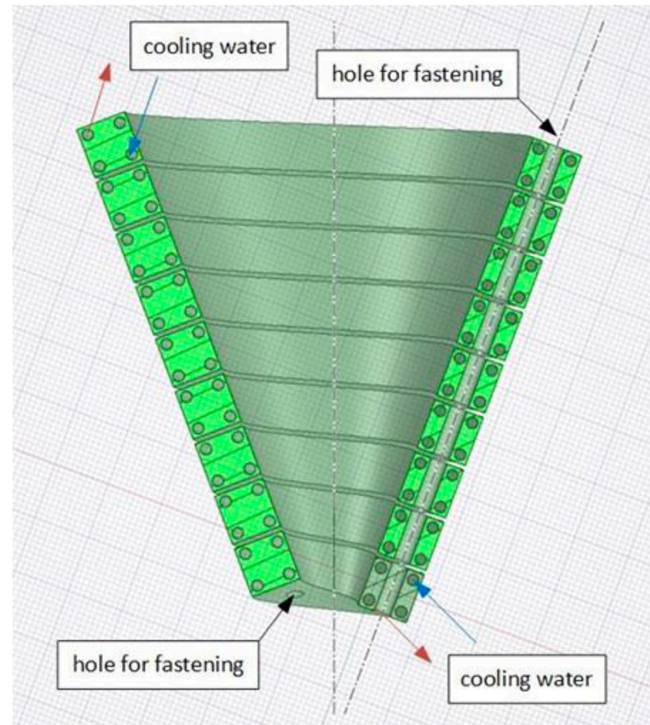
Solenoid construction

Tenholt, Loisch,Lemke,Yakopov

Possible mechanical design

- Four separate channels
- Drill through holes in the solenoid body to secure the turns together
- Channels can be fed in opposite directions, enabling more uniform cooling

Grigory Yakopov



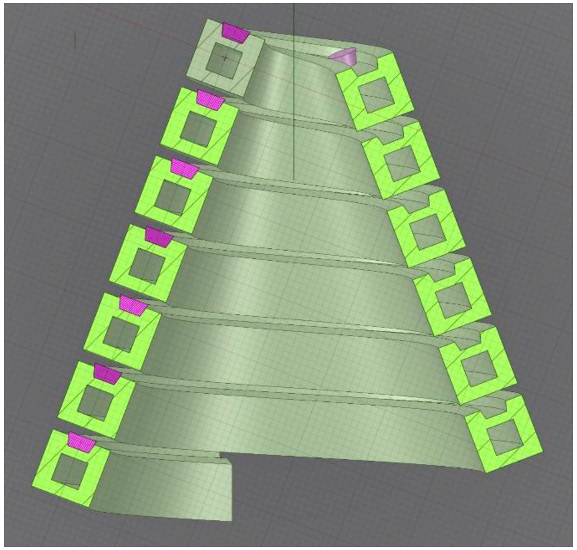
Solenoid construction

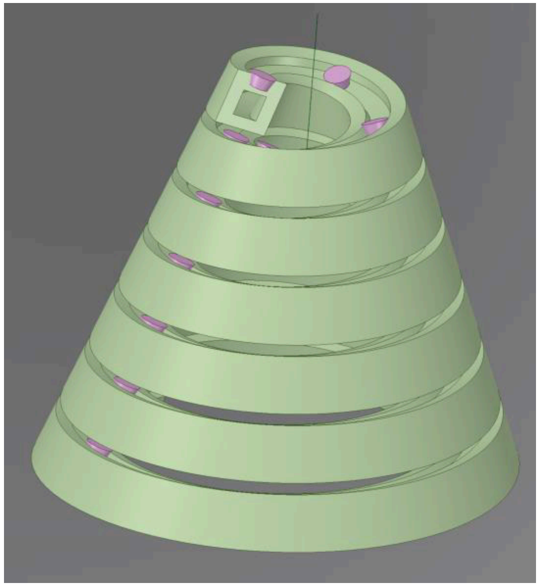
Tenholt, Loisch,Lemke,Yakopov

Possible mechanical design

- Square needs smallest area for given perimeter
- Saved space made serve as groove for insulator holders between the ewindings
- Material discussions: for prototype maybe Teflon, for final design maybe PEEK or Torlon

Grigory Yakopov



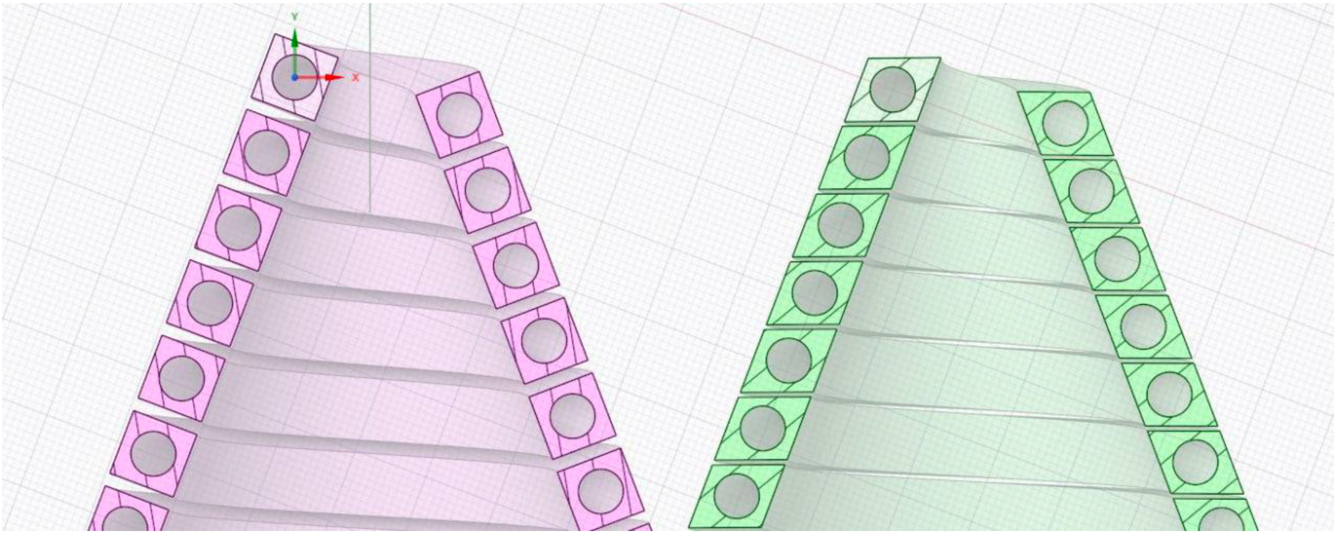


Solenoid construction

Tenholt, Loisch,Lemke,Yakopov

Possible mechanical design

Grigory Yakopov



- Solenoid can be mounteds close to target wheel, since first turn is in a parallel plane to wheel
- All discussions in close contact between simulation/construction/workshop people
- For final design: final design of target wheel also envisaged

OMD Design: Plasma Lens

‘Future’: Plasma Lenses

- increases e+ yield but increases load at target only slightly
- advantages in matching aspect
- downscaled prototype designed and produced

Formela, Hamann, Loisch

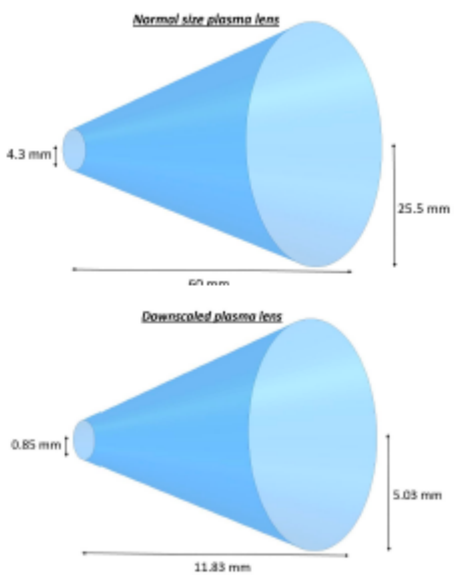
Plasma lens parameters

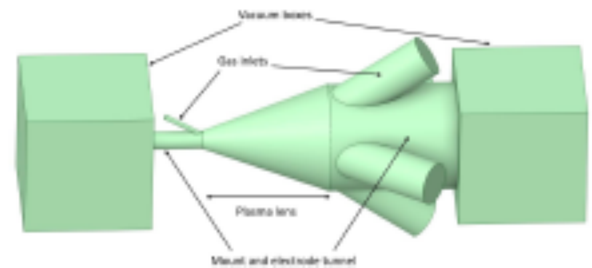
Normal size

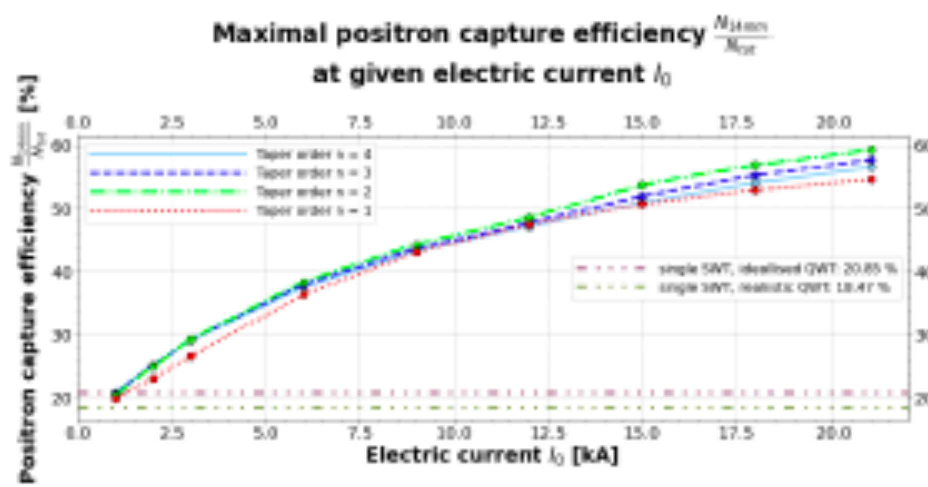
- Starting radius: 4.3 mm
- Exit radius: 25.5 mm
- Taper strength: 0.082 mm⁻¹
- Length: 60 mm
- Taper order: 2
- Total current: 9000 A
- Phase of SWT: 225 deg

Downscaled

- Starting radius: 0.85 mm
- Exit radius: 5.03 mm
- Taper strength: 0.416 mm⁻¹
- Length: 11.83 mm
- Total current: 350 A







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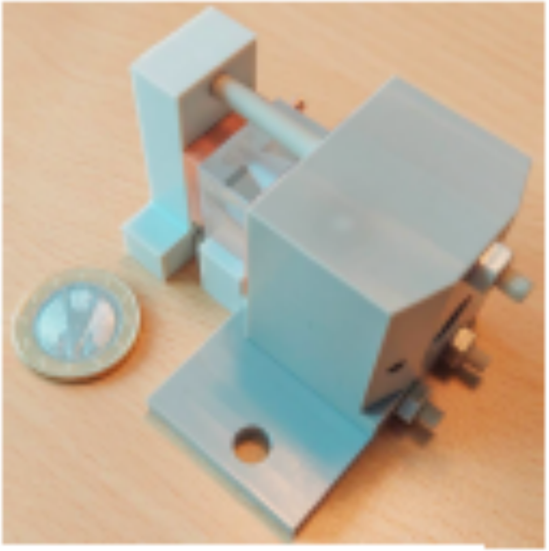
OMD Design: Plasma Lens

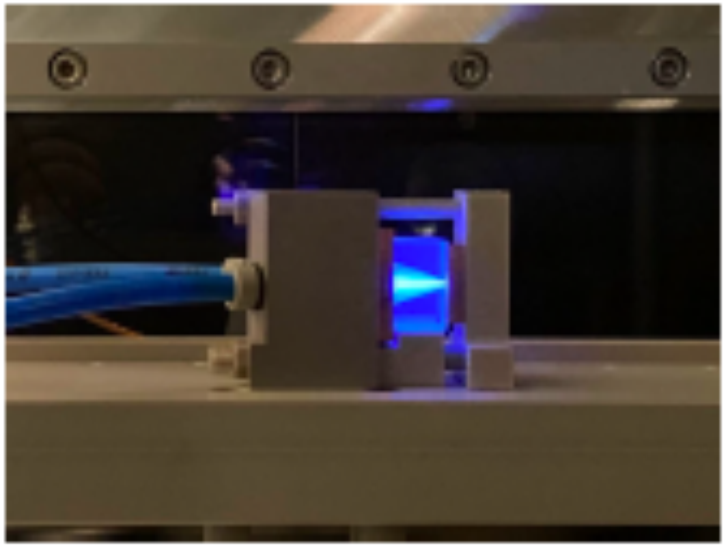
Formela, Hamann, Loisch

Prototype design

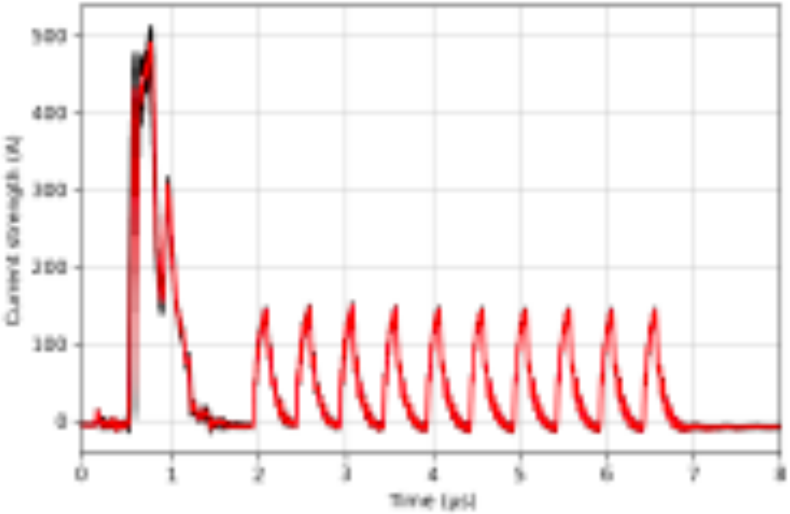
- Principle: lens is pressed in between mounts with threaded rods and sealed with O-rings
- Mounts made out of PEEK
- Electrodes made out of copper
- Plasma lens made out of sapphire block

Finished Prototype





Produced plasma

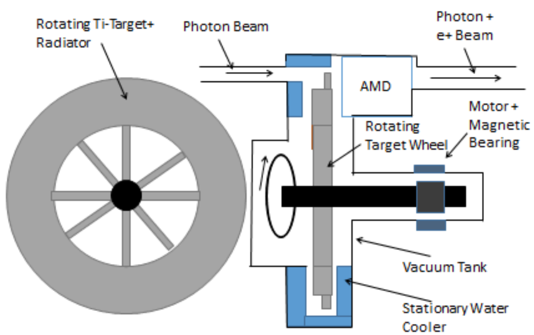


Ingoing current measured

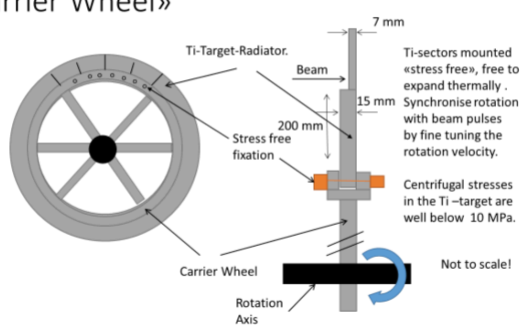
WPP-6: Rotating Target for Undulator Scheme

- Target specification
  - ➢ Titanium alloy, 7mm thick (0.2 X0), diameter 1m
  - ➢ Rotating at 2000 rpm (100 m/s) in vacuum
  - ➢ Photon power ~60 kW, deposited power ~2 kW
  - ➢ Radiation cooling
  - ➢ Magnetic bearings
- R&D to be done as WP-prime
  - ➢ Design finalization, partial laboratory test, mock-up design (in the first 2 yers)
  - ➢ Magnetic bearings: performance, specification, test (in the remaining years)

Principal Layout: Ti-Wheel with a Diameter of 1.0 m, rotating at 100 m/s, 2000 rpm.

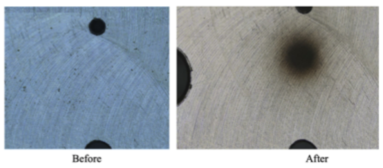


Ti-Target Sector Modules, mounted onto a «Carrier Wheel»

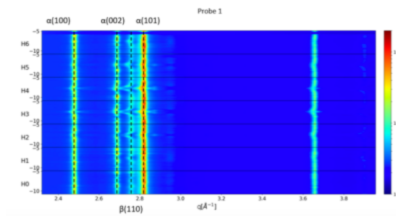


Target material test

Target before and after radiation:



α/β phase transitions in Ti-6Al-4V:



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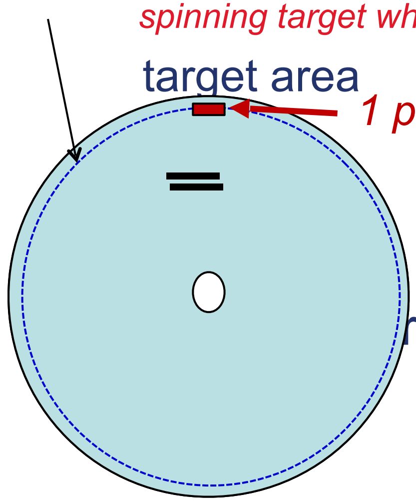
The positron target

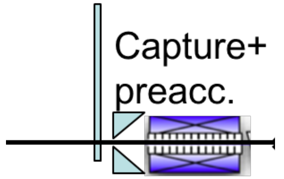
- Photon beam hits wheel at 1m diameter, spinning in vacuum with 2000rpm (100m/s tangential speed) → distribute the heat load
  - One pulse with1312 (2625) bunches occupies ~7 (~10)cm
  - Every ~7-8sec load at same target position
  - in 5000h roughly 2.5×10^6 load cycles at same target area



- ILC250, GigaZ: E(e-) = 125GeV
  - Photon energy is O(7.5 MeV);
  - target thickness of 7mm to optimize deposition and e+ yield
- Target cooling

S. Riemann, P.Sievers

  - T^4 radiation from spinning wheel to stationary water cooled cooler
    - Peak temp in wheel ~550˚C for ILC250, 1312bunches/pulse
      ~500˚C for GigaZ, 1312bunches/pulse
      assuming the wheel is a full Ti alloy disk (~simple design solution).

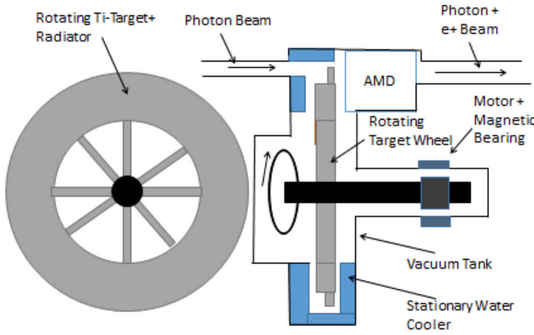


WP6: R&D activities rotating wheel

Drive and bearings

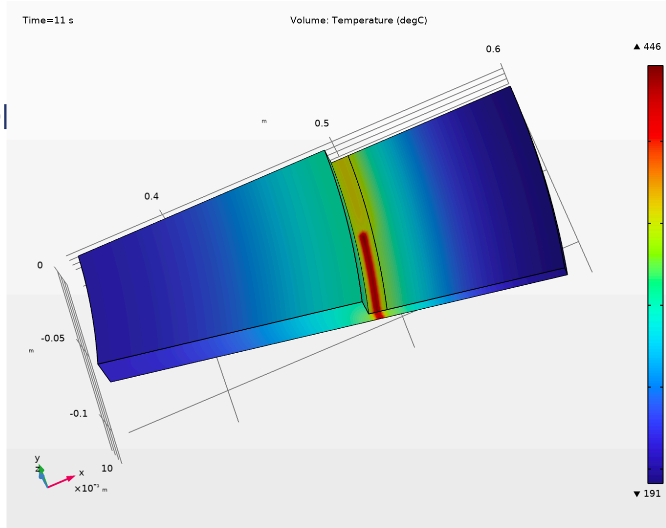
- Radiation cooling allows magnetic bearings
  - A standard component to support elements rotating in vacuum.
  - The axis is «floating» in a magnetic field, provided by permanent or electro magnets

Principal Layout: Ti-Wheel with a Diameter of 1.0 m, rotating at 100 m/s, 2000 rpm.



- For the specific ILC-application, a technical specification of for performance and boundary conditions required
  - Specification to be done based on simulation studies
  - New simulations studies under work in close collaboration with pulsed solenoid simulations
  - Discussion started with construction people at DESY

S., Patra 2022



Revive of rotating wheel activities

Try to reactivate rotating wheel effort:

- Several meetings took place
- In principle, the plan is to construct a 'new' prototype
- Needed: one lab that puts the hand up
- maybe some ITN money for the wheel available…..
- would fit perfectly well in time since pulsed solenoid is on the way…….
- Maybe even something at DESY possible

➡ might be also needed for a HALHF-like e+ source…..

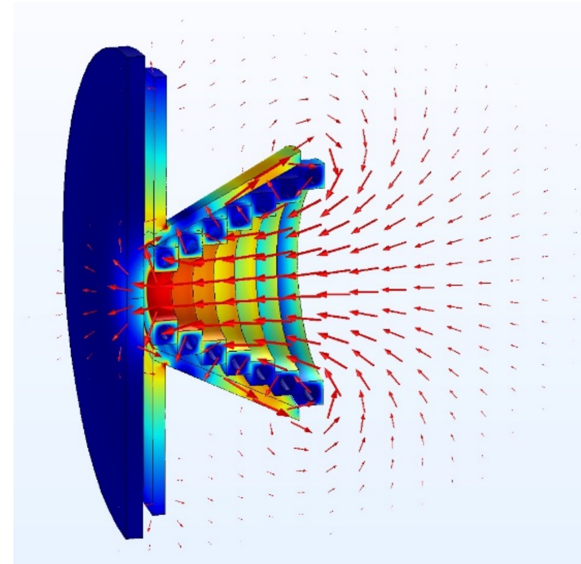
Status and Outlook

- Undulator-based positron source mature design
  - offers in addition polarized e+
- Advanced and active work on mask designs, OMD prototypes (pulsed solenoid, Plasma lens) and material target tests
  - Prototype pulsed solenoid@DESY ongoing
  - efforts&simulations ongoing on rotating wheel prototype design
  - Grant applications (BMBF) submitted for full prototype plasma lens, and pulsed solenoid&rotating wheel
- Contracts between KEK-CERN and DESY 'signed'

➡ ***Would be perfect timing now for the rotating wheel***

OMD Design: Pulsed Solenoid

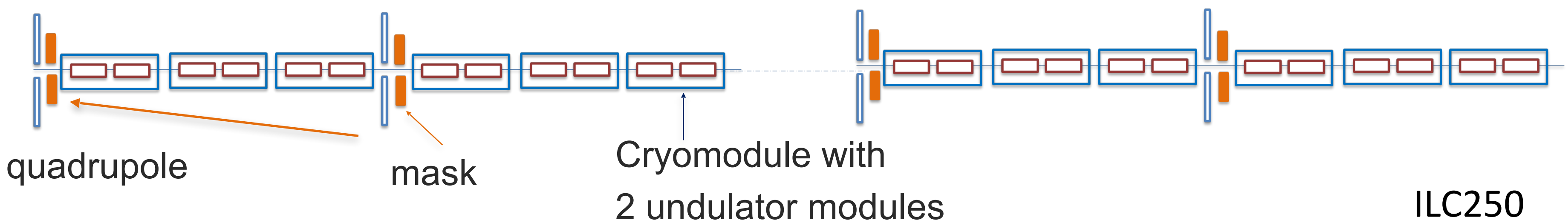
Tenholt, Loisch, Lemke,Sievers



- Design parameters:
  - ~50 kA peak current
  - 4 ms half-sine pulse + 1ms flat-top
  - 7 turns, linear taper (∅ 20mm → 80mm)
  - Peak field ~5 T
  - Average heat load on target: 73 W + 711 W
  - Peak force on wheel 612 N
  - Yield improvement compared to quarter-wave transformer
    - w/o shielding → ~70%
    - w/ shielding → ~ 55%
  - <1% focusing field variation in 1ms
  - Mechanical prototype design pending

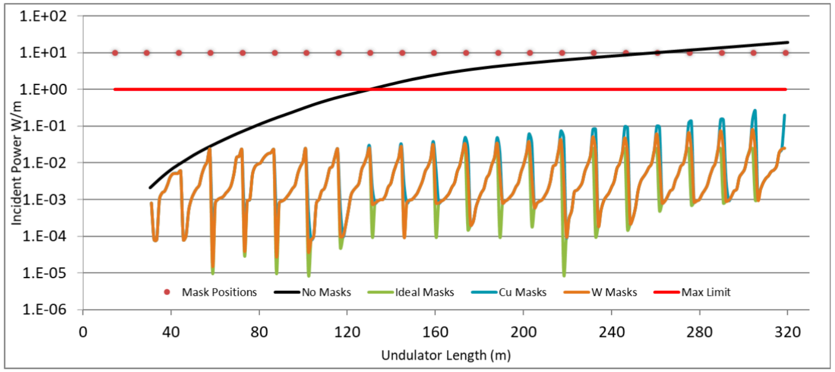
WP5 Undulator: Simulation (field errors, alignment)

- Misalignments:
  - beam spot increases slightly, yield decreases slightly *(**see A.Ushakov, AWLC18**)*
- Realistic undulator with B field (K) and period (λ) errors
  - Results consistent with previous works — ***Alharbi, Thesis 23***
  - provides beam size, polarization, target load — ***S. Riemann***
- Synchrotron radiation deposit in undulator walls
  - Masks protect wall to levels below 1W/m
  - ILC250: power deposition in 'last' mask near undulator exit: ~300W



- ***Result: Masks substantial but sufficient in all cases!***

- Studied for ILC250, ILC350, ILC500 and GigaZ !



WP5: GigaZ operation

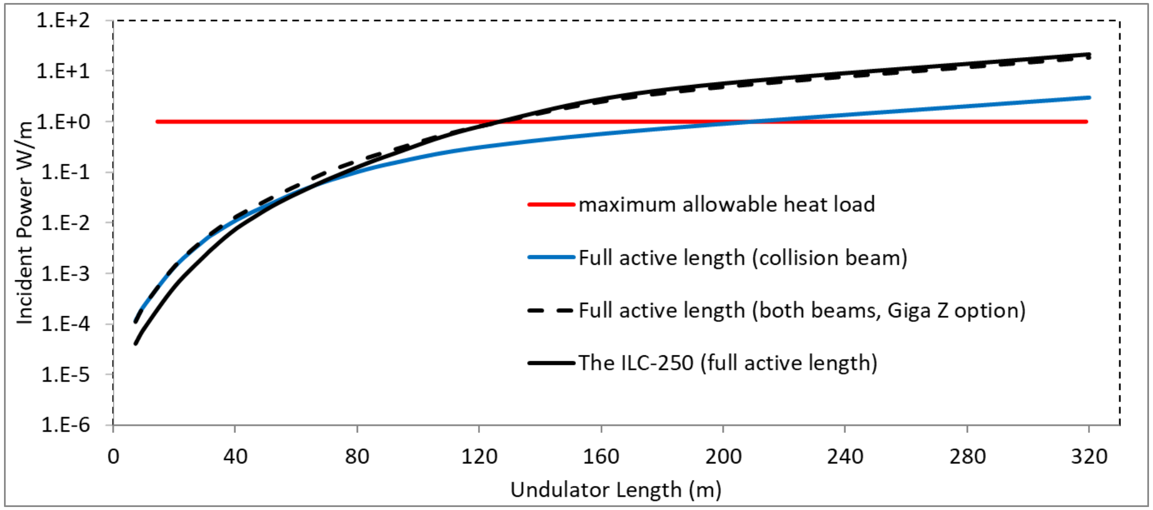
- Parameters for GigaZ operation

  Yokoya-san, 1908.08212

Parameters	e^+ production	collision	Unit
Final beam energy	125	45.6	GeV
Average accelerating gradient	31.5	8.76	MV/m
Peak power per cavity	189	77.2	kW
Beam pulse length	0.727	0.727	ms
RF pulse length	1.65	1.06	ms
Repetition rate	3.7	3.7	Hz

- Incident power at undulator walls: Compare GigaZ and ILC250

power deposition in wall without masks



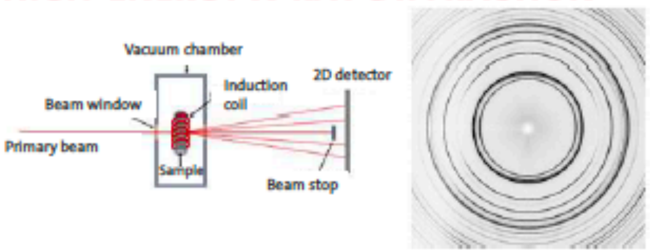
➡ Incident power at GigaZ below /comparable with ILC250

➡ Mask protection will also be sufficient for GigaZ running

Analyses of ILC targets

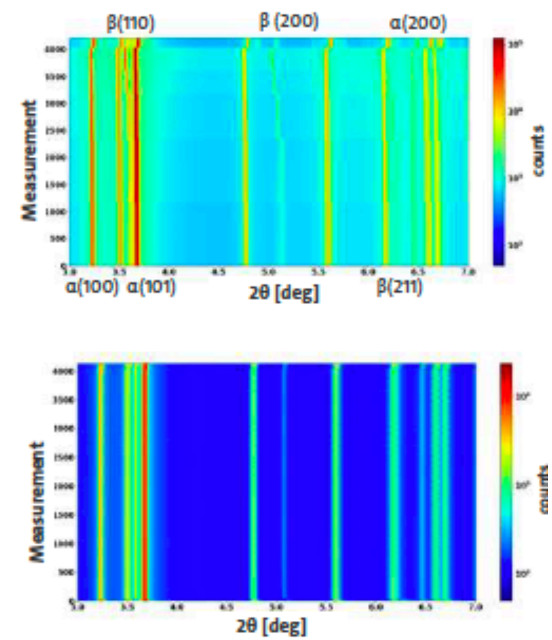
EXPERIMENT

HIGH-ENERGY X-RAY DIFFRACTION



Radial integration of all diffraction patterns →

SYNCHROTRON DATA



DILATOMETER

- **HEMS beamline** at DESY operated by HEREON
  - High-energy XRD
  - Transmission geometry
  - Destruction free analysis of the targets
- **Dilatometer**
  - Cyclical heating and cooling
  - Temperatures in accordance with previous irradiation experiments
  - Peak and base temperatures varied
  - Cooling rates varied

- **Irradiation experiments** in Mainz
  - Realistic beam parameters for the ILC
  - Build upon previous tests
- For high temperatures
  - similar results as with heating experiments

- Low temperatures:
  - Different effect for the studied material
  - Potentially effects due to local heating or displacement of lattice atoms
- Further analysis to get accurate temperatures

Analyses of ILC targets

- **target material tested at Mainz Microtron (MAMI) using e-**

  A. Ushakov

  - **Done: electron-beam on ILC target materials, generating cyclic load with same/ even higher PEDD at target than expected at ILC**
  - **Several successful tests performed on Ti-Alloy** — T. Lengler, BThesis 2020

  ➡ **Result: ILC undulator target will stand the load**

  - **Further tests in 22 and 23**

- **Ongoing: disentangling target damage originating from thermal vs radiation load**
  - **with dilatometer: targets at high temperature**
  - **fast and cyclic stress in the range of 400^0-800^0C** — T. Lengler, MThesis 2023
  - **variation of T_{max} , heating rate, fixed T**
  - **very interesting results with α- and β- phase of Ti-alloy**

- **Result: ILC undulator target will stand the load**

Why is helicity flipping required?

- **With both beams polarized we gain in**
  - Higher effective polarization (higher effect of polarization)

$$P_{eff}:=(P_{e-}-P_{e+})/(1-P_{e-}P_{e+})$$

  - Higher effective luminosity (higher fraction of collisions)

$$L_{eff}/L=1-P_{e-}\,P_{e+}$$

$\sqrt{s}$	$P(e^-)$	$P(e^+)$	$P_{\rm eff}$	$\mathcal{L}_{\rm eff}/L$	$\frac{1}{x}\Delta P_{\rm eff}/P_{\rm eff}$
total range	$\mp 80\%$	0%	$\mp 80\%$	1	1
250 GeV	$\mp 80\%$	$\pm 40\%$	$\mp 91\%$	1.3	0.43
$\geq$350 GeV	$\mp 80\%$	$\pm 55\%$	$\mp 94\%$	1.4	0.30

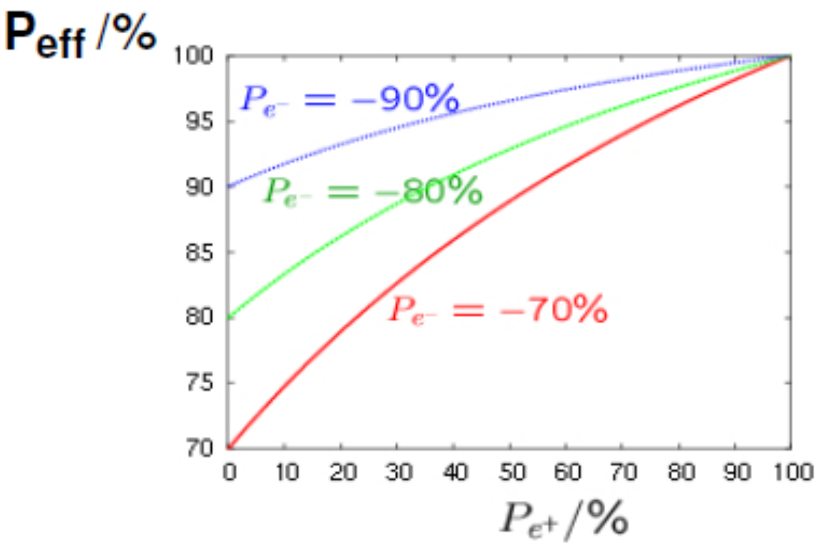
- **Applicable for V,A processes (most SM, some BSM)**

$$\sigma\,(Pe-,Pe+)=(1-Pe-\,Pe+)\,\sigma_{unpol}\,[1-P_{eff}\,A_{LR}]$$

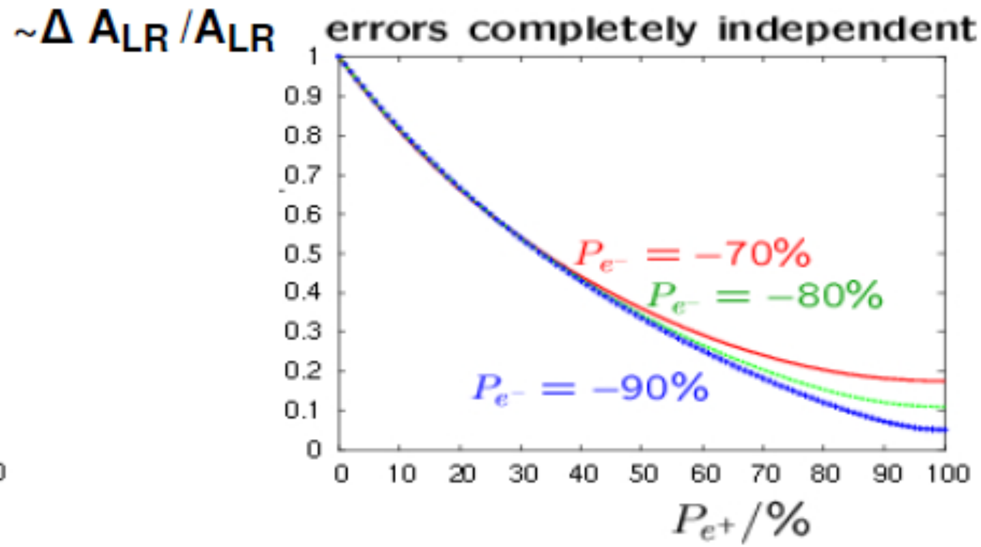
G. Moortgat-Pick et al, ITN, 12/'23

Impact of P(e+)

- **Statistics**



- **And gain in precision**



- (80%,60): P_{eff} = 95% | (90%,60%): P_{eff} =97% | (90%, 30%): P_{eff} =94 %

  $\Delta A_{LR}/A_{LR} = 0.3$ | $\Delta A_{LR}/A_{LR} = 0.27$ | $\Delta A_{LR}/A_{LR} = 0.5$

  gain: factor~3 | factor>3 | factor~2

- NO gain with only pol. e- (even if '100% ') !

Cooling of the target wheel

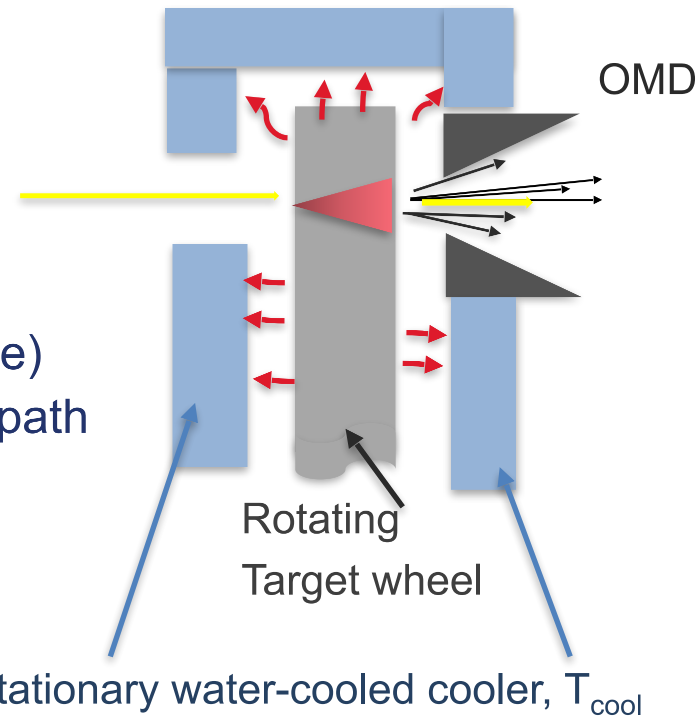
- Water cooling (TDR design) does not work
- Few kW heat deposition can be removed with thermal radiation:
  - heat radiates from spinning target to a stationary water-cooled cooler

$$P \sim \sigma \varepsilon A \left(T_{radiator}^4 - T_{cool}^4 \right)$$

ε = effective emissivity

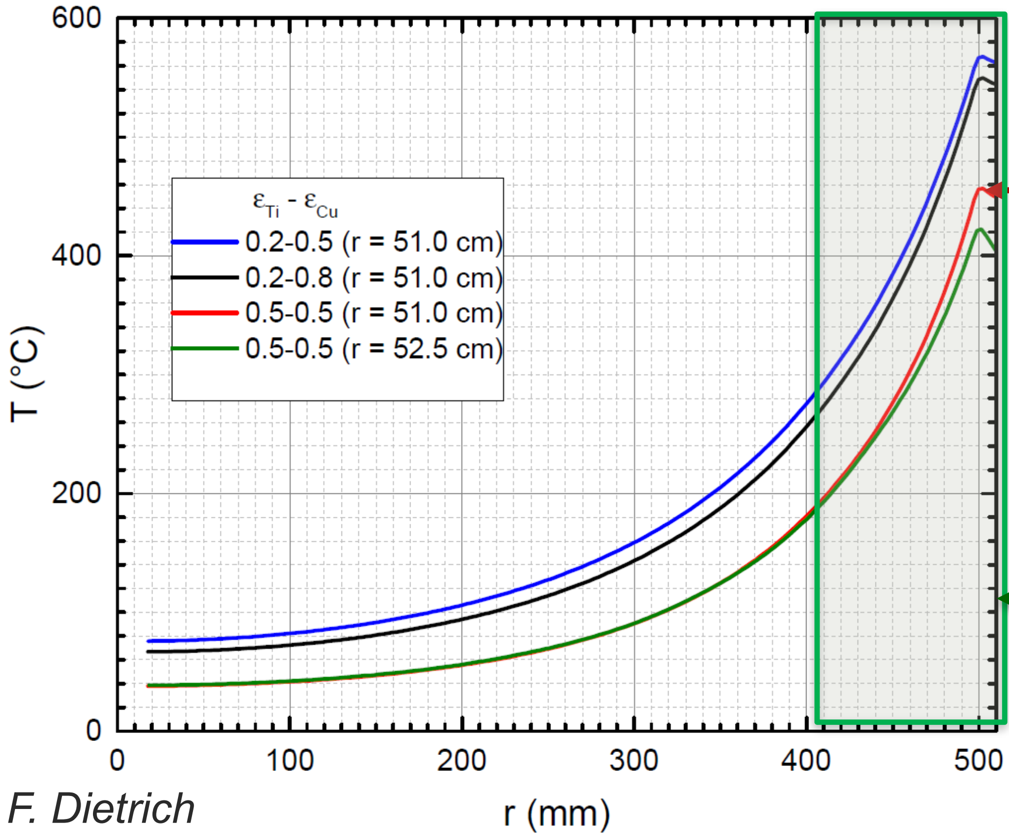
- Ti alloys have low thermal conductivity
  (λ = 0.06 – 0.15 K/cm/s)
  - heat propagation ~ 0.5cm in 7sec (load cycle)
  - heat accumulates in the rim near to beam path

Side view cutout e+ target



Temperature distribution in target

Average temperature in Ti6Al4V wheel as function of radius r for different surface emissivity of target and cooler (Cu); Target wheel assumed as disk



F. Dietrich

Photon beam impact at r=50cm

Deposited power = 2kW

ε_{eff}= 0.33 for $\varepsilon_{Ti} = \varepsilon_{Cu}$=0.5

$T_{ave} \leq 460$˚C

max average temperatures can be decreased for larger wheel radius

Main cooling power from area with r_0 ±5cm

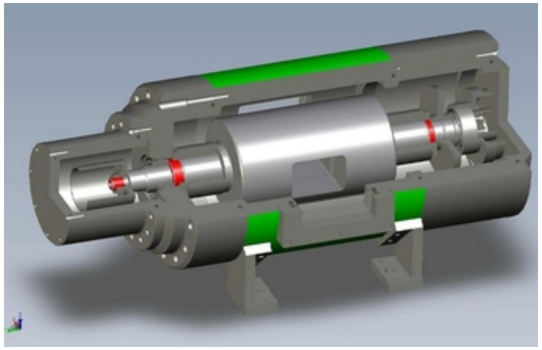
Studies (FLUKA, ANSYS) show that such spinning disk stands heat and stress load

Towards the rotating wheel

JÜLICH
FORSCHUNGSZENTRUM

Drive and bearings

- Radiation cooling allows magnetic bearings
  - A standard component to support elements rotating in vacuum.
  - The axis is «floating» in a magnetic field, provided by permanent or electro magnets
  - Allows long time operation at high rotation speed without maintenance
  - Among other things,magnetic bearings are used as Fermi-choppers in Neutron Physics and Spallation Sources.
  - Breidenbach et al. (SLAC) presented at ICHEP2016 a design proposal using magnetic bearing (see backup) for the undulator target
- For the specific ILC-application, a technical specification of the required performance and boundary conditions has to be negotiated with the supplier.
  - Specification to be done based on simulation studies



Fermi-Choppers für BRISP
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