LINEAR COLLIDER COLLABORATION

Designing the world's next great particle accelerator

Status radiation cooled target for the undulator-based e+ source

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outline

- What is new since LCWS 2017?
  Simulation studies for the ILC250 target wheel:
  - Temperature distribution for 7mm thick Ti6Al4V target
  - Stress distribution in 7mm thick Ti6Al4V target
  - Discussion whether the load is acceptable
- Next steps & plan

All results

- are included in the WG report
- Should be cross-checked

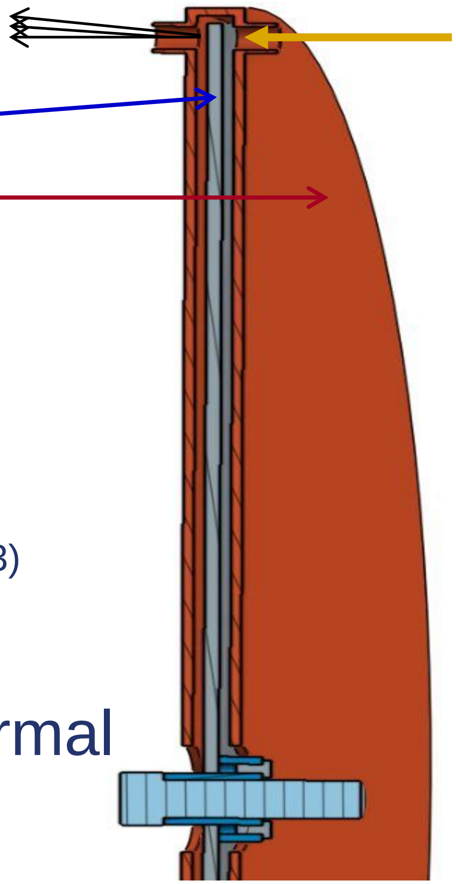
Source parameters – 1312 bunches/pulse

Electron beam energy	GeV	126,5	125	150	175	250
Active undulator length	m	231		147		
Undulator K		0.85		0.8	0.66	0.45
Photon yield	γ/e-	393		224	157	76.1
Photon energy (1st harmonic)	MeV	7.7	7.5	11.3	17.6	42.9
Average photon beam power	kW	62.6	60.2	48.8	45.2	42.9
Distance target – middle undulator	m	401	570	500		
Target (Ti6Al4V)thickness	mm	**7**	14.8			
Average power deposition in target	kW	1.94	5.4	3.9	3.3	2.3
Photon beam spot size on target (σ)	mm	1.2	1.72	1.21	0.89	0.5
Peak Energy Deposition Density (PEDD) in spinning target per pulse	J/g	61.0	43.7	41.0	42.4	45.8
Polarization of captured positrons	%	29.5	30.7	29.4	30.8	24.9

Used for current target simulations

A. Ushakov

Cooling by thermal radiation



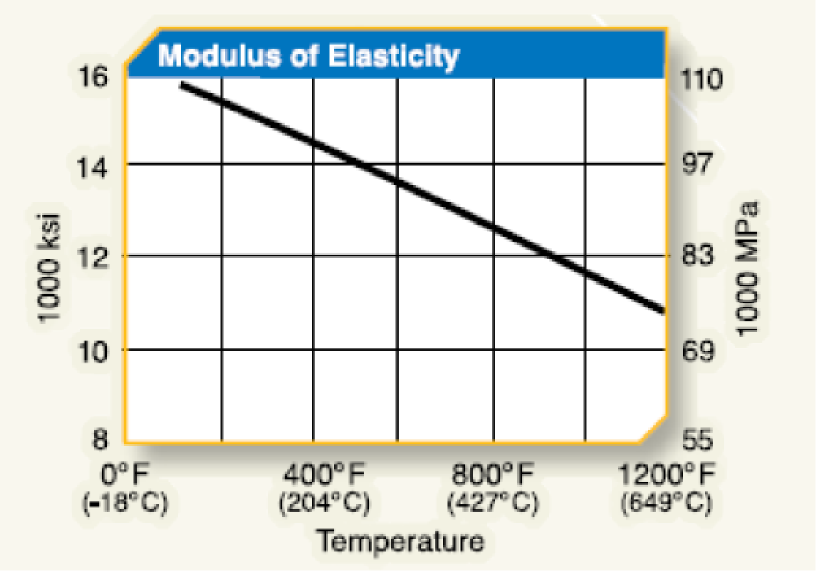
- heat is radiated from spinning target wheel to stationary water-cooled cooler
  - Rough estimate: for 2kW power deposition about 0.6 m^2 are needed to keep material at 400C average temperature (effective surface emissivity ~0.3)
- But: high-temperature Ti alloys have low thermal conductivity (λ = 0.06 – 0.15 K/cm/s)
  - heat dissipation ~ 0.5cm in 7sec

  → heat accumulates in the rim near to beam path

Temperature dependence of Ti6Al4V parameters

Important for the simulation of target load: all parameters depend strongly on temperature

- So far, we took into account temperature dependence of specific heat, thermal conductivity and thermal expansion (see arXive 1801.10565) .
- Values given in data sheets depend slightly on vendor
- New: also modulus of elasticity E(T) used
  - E is important for stress evaluation: Stress ~ E α ΔT
  - At ~500C E≈83GPa about 75% of E(RT)
  - Material response at higher T is more relaxed



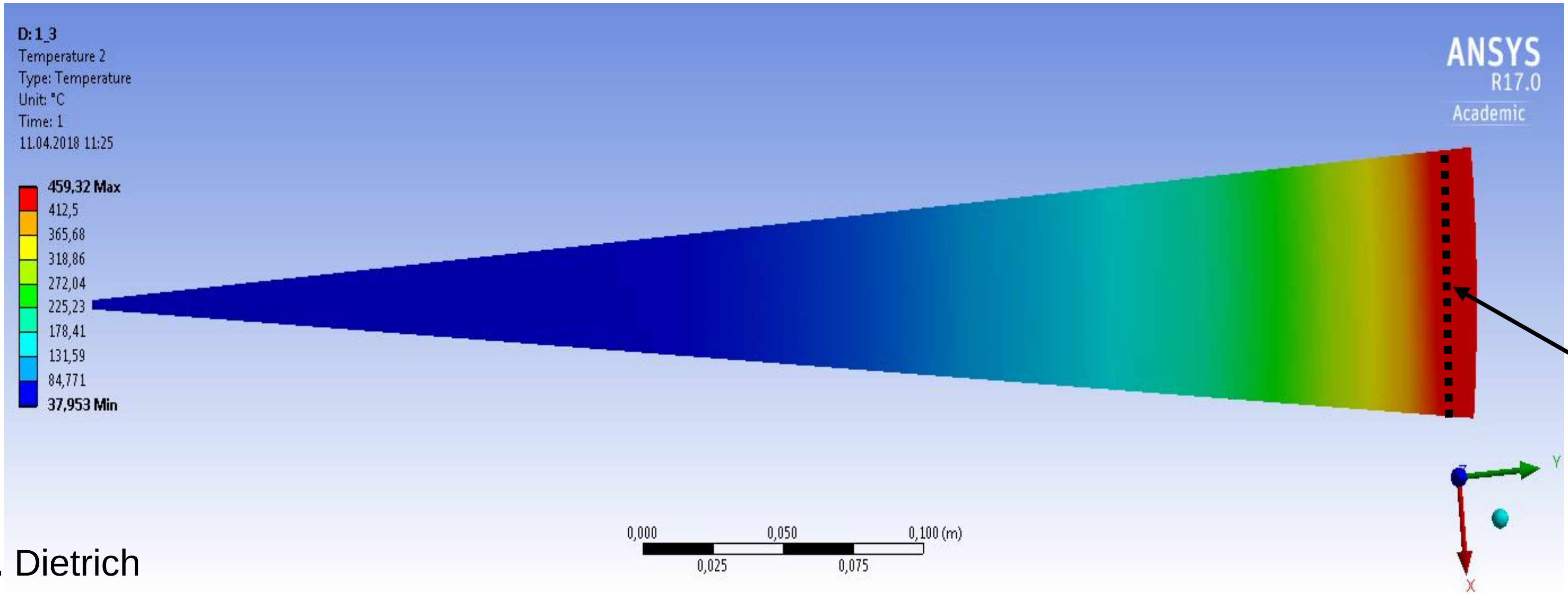
Taken from ATI data sheet Ti Grade 5

Temperature distribution in target wheel

- Average energy deposition in target ~2kW (ILC250, ILC500)
- ANSYS simulations for radiative cooling of target wheel
  - Efficiency of cooling depends on emissivity of surfaces of wheel and cooler (ε_{Ti} and ε_{Cu})

Temperature distribution in target piece corresponding to 1 pulse length; ILC250

(ε_{eff}= 0.33; ε_{Ti} = ε_{Cu}=0.5)

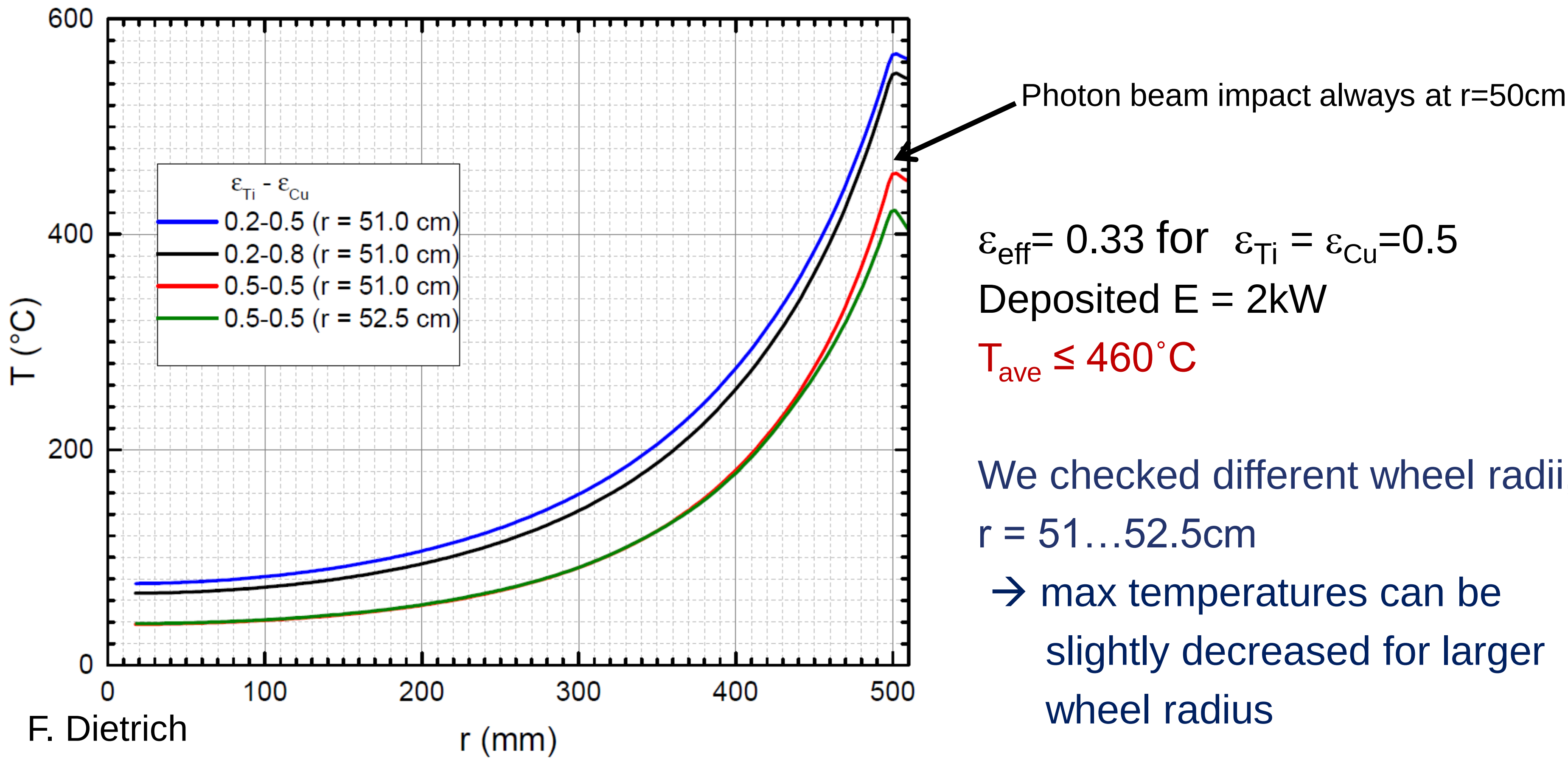


Photon beam pulse

F. Dietrich

Temperature on target, ILC250

Average temperature in wheel as function of radius r for different surface emissivities of target and cooler (Cu)



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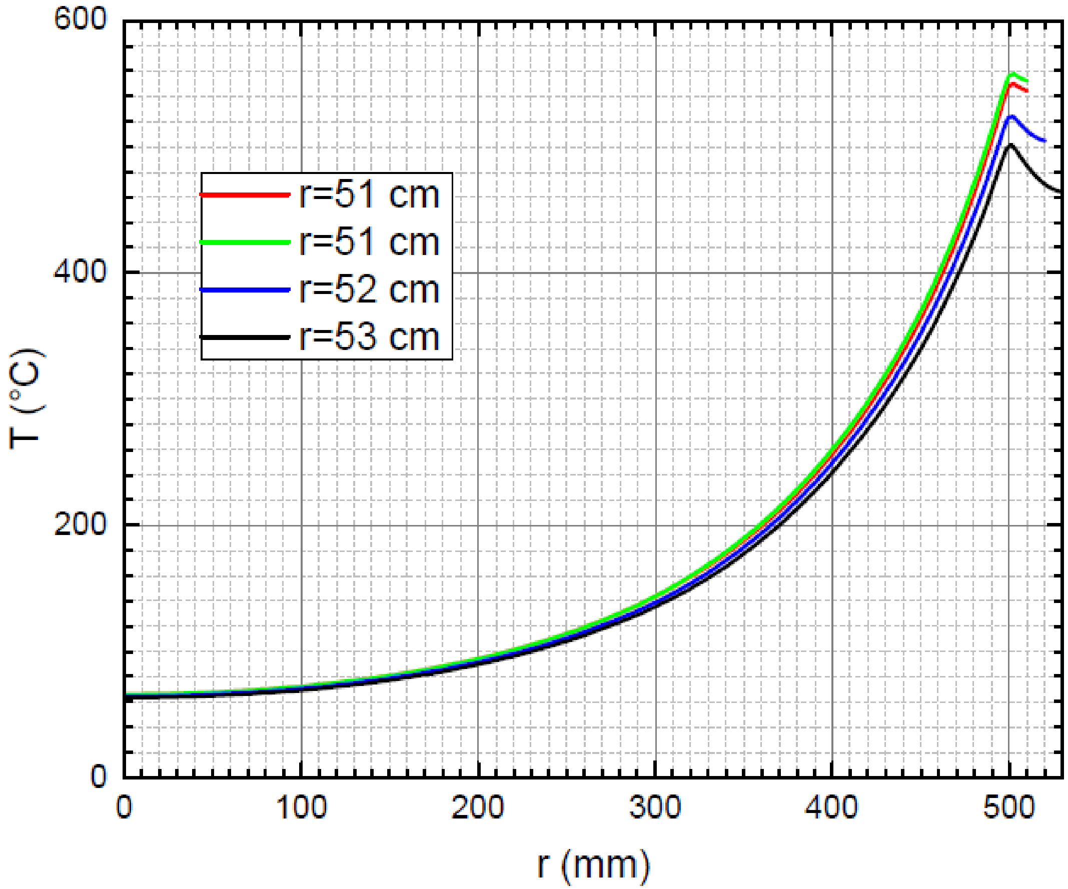
ε_{eff}= 0.33 for $\varepsilon_{Ti} = \varepsilon_{Cu}$=0.5

Deposited E = 2kW

$T_{ave} \leq 460^{\circ}C$

We checked different wheel radii, r = 51…52.5cm

→ max temperatures can be slightly decreased for larger wheel radius



Radial temperature distribution in target wheel

Red: no expansion slots

Green, blue, black: wit 20cm long expansion slots

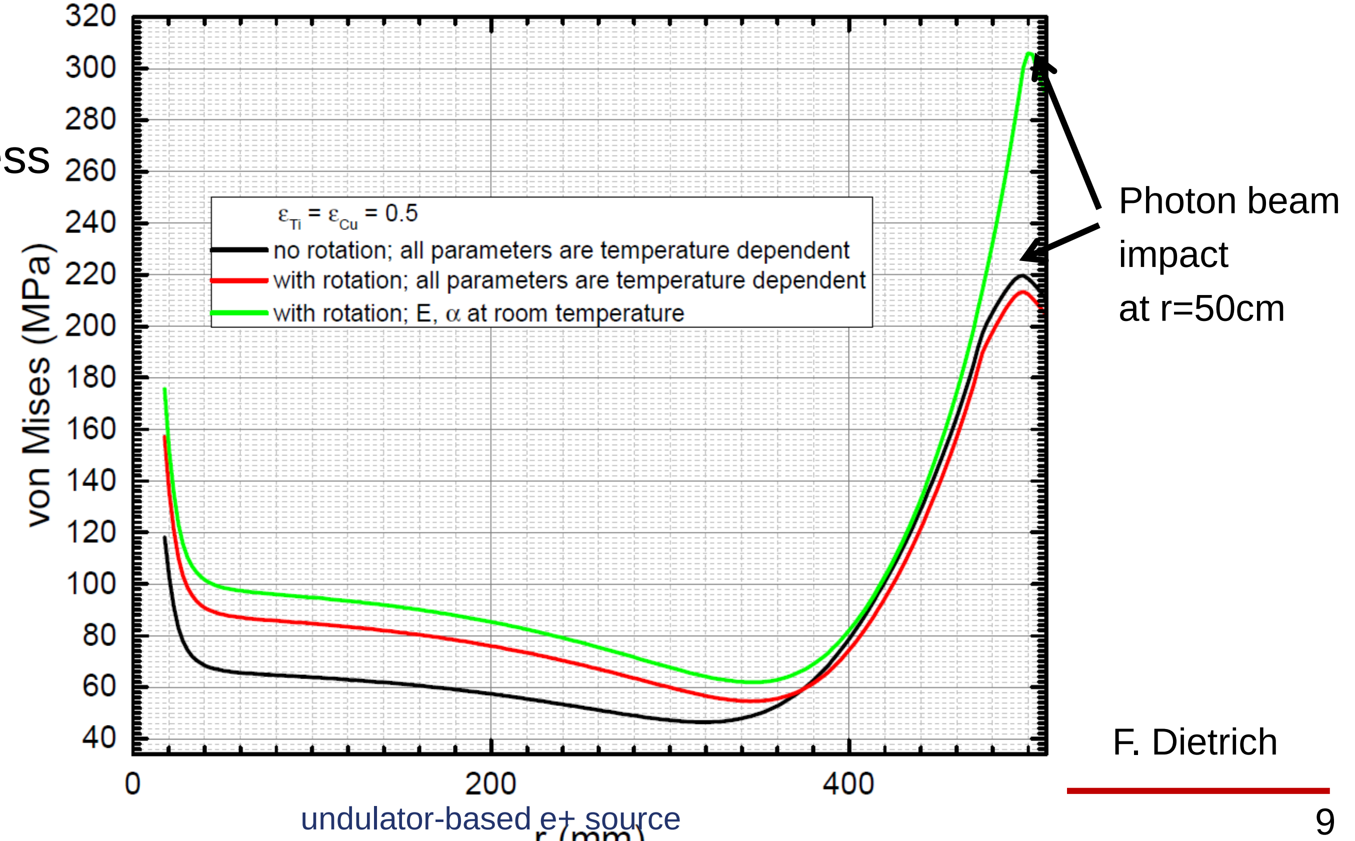
Stress in target (ILC250)

Consider target disc, thickness 7mm, r_{out}= 51cm (…53cm), beam hits target at r=50cm

- Material expansion ⬄ high thermal stress in beam impact region
- Stress due to rotation (hoop and radial) is <50MPa, in the rim region <10MPa

Average von Mises stress along wheel radius r

σ_{vM} < 220MPa



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- Dynamic stress at radius r

$$\sigma_{\mathrm{H}} = \frac{3+\nu}{8}\rho\omega^2\left(1-\frac{r^2}{r_o^2}\right)\left(1-\frac{r_i^2}{r^2}\right)$$

$$\sigma_{\mathrm{r}} = \frac{3+\nu}{8}\rho\omega^2\left(1+\frac{r_i^2}{r_o^2}+\frac{r_i^2}{r^2}-\frac{1+3\nu}{3+\nu}\frac{r^2}{r_o^2}\right)$$

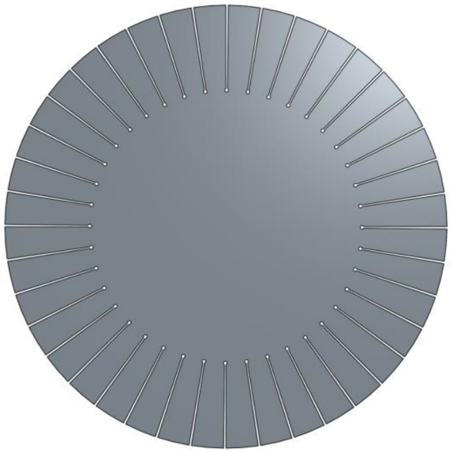
r_o = outer wheel radius, r_i = inner radius at shaft

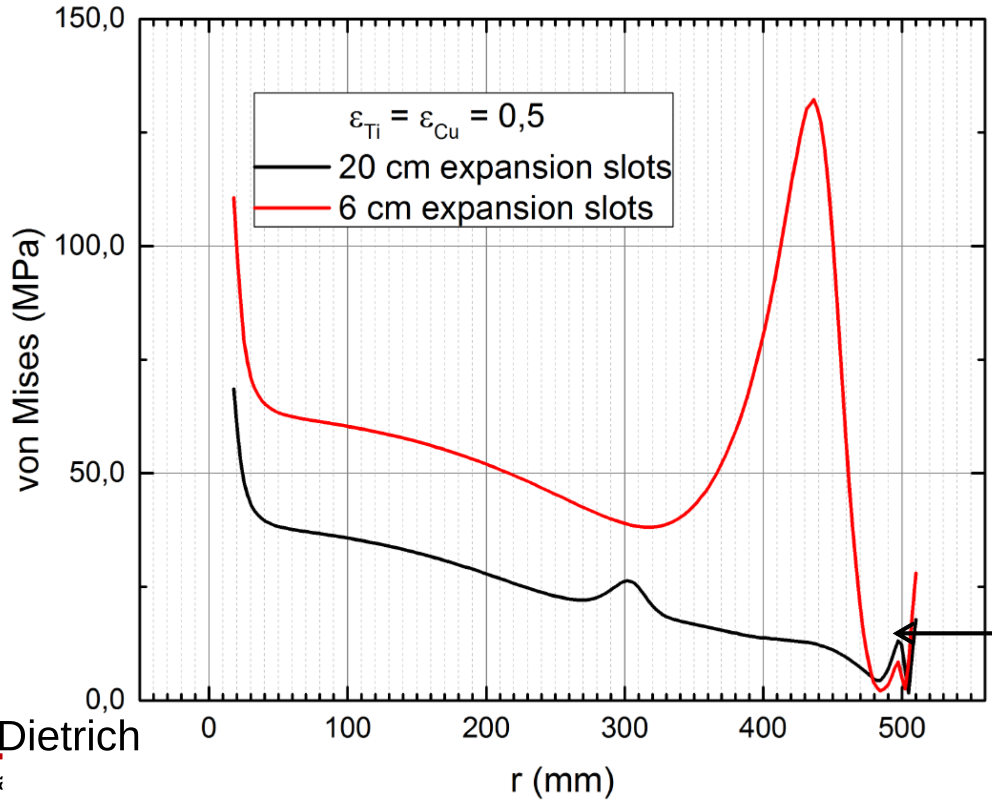
- Max radial stress is located at $\sqrt{r_o r_i}$, i.e. more in the inner region where the T is low (assuming full disc)
- Hoop stress from rotation at the beam path (highest T) is low, ~ 9MPa
- ANSYS calculations for detailed stress evaluation

Stress in target (ILC250)

Consider target disc, thickness 7mm, r_{out}= 51cm (…53cm), beam hits target at r=50cm

- Expansion slots (6cm and 20cm long)
  static stress substantially reduced, $\sigma_{vM} \leq$ 20MPa in rim region



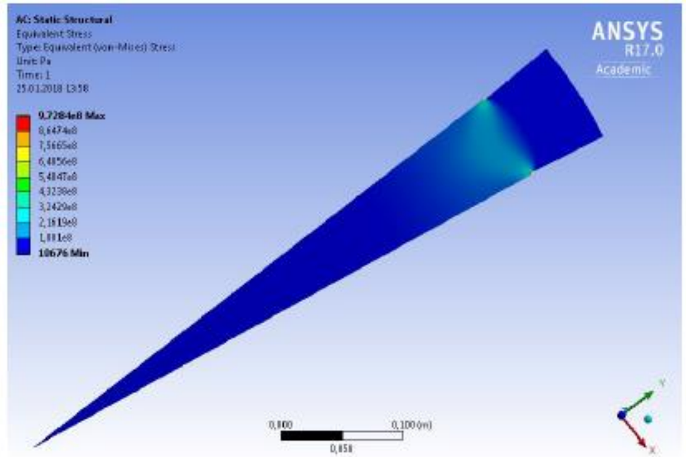


Expansion slots require synchronization with beam pulses!!

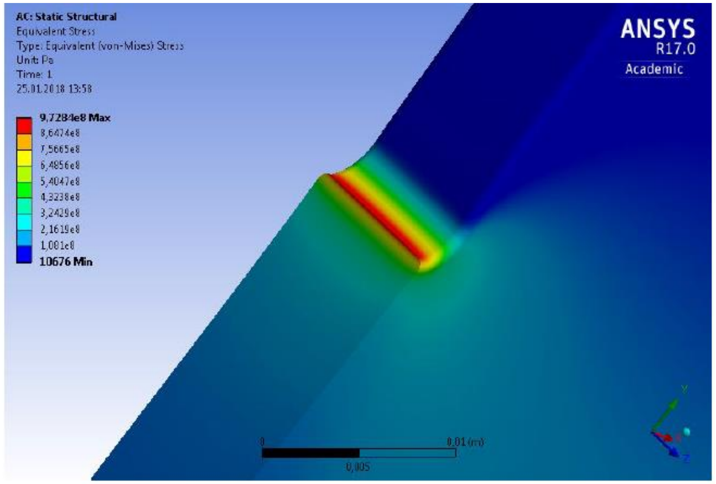
F. Dietrich

Expansion slots

- stress around the bore of the expansion slots;
  - Stress can be reduced with optimized bore shape
- Results on this page are still with E(RT), see 1801.10565



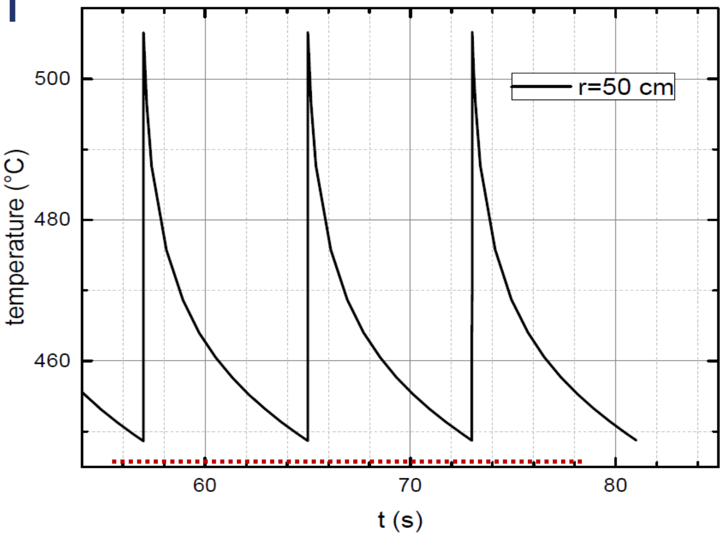
cm long



		full disc	expansion slots	
			20 cm	6 cm
von Mises	[MPa]			
	r = 50 cm	348	7.39	2.71
	r = 45 cm	192	4.43	125
	r = 30 cm	67.66	47.4	44.5

Cyclic load at the target - peak temperature

- Max temperature evolution along rim
  - if wheel has equilibrium temperature distribution reached, pulse increases temperature up to ~510C (2kW, ε_{eff}= 0.33 for ε_{Ti} =ε_{Cu}=0.5)

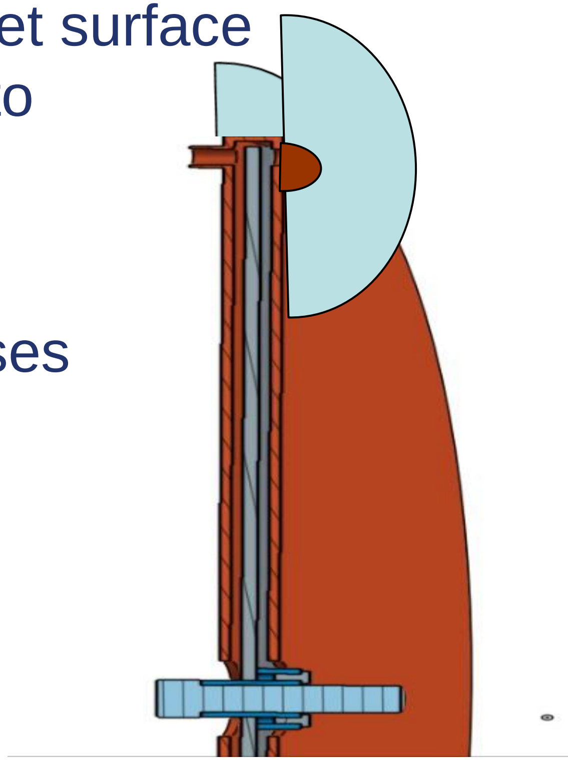


- Resulting peak stress at beam path:
  - detailed ANSYS simulations are still running
  - Time of energy deposition is to slow, intensity to small to create shock waves
  - Estimate: σ_{peak} ~ E α ΔT
    σ_{peak} <150 MPa
  - In total: σ_{peak} < 220MPa+150MPa = 370MPa in case of no expansion slots
  - The stress is compressive

Cyclic load – what does the target material stand?

- Material limits depend on
  - temperature
  - type of load (compressive or tensile)
  - Duration of load and cyclic load, …
- References for Ti6Al4V give no clear answer; we concluded to be safe if cyclic stress amplitudes are below 300 MPa for temperatures up to ~500C.
- We performed tests with the e- beam at the Microtron in Mainz: We simulated cyclic load similar as expected at ILC e+ target.
  - Ti6A4V samples were radiated with pulses that create stress amplitudes similar as expected at ILC e+ target
  - Number of load cycles corresponded to 1-2 years ILC operation,
  - The material Ti6A4V was heated up to ~900C
  - Material survived well (see IPAC2017, TUPAB002)
    - Structure in beam area was changed to larger grains
    - Max dimensional change was below ≤3% in the centre of the beam spot

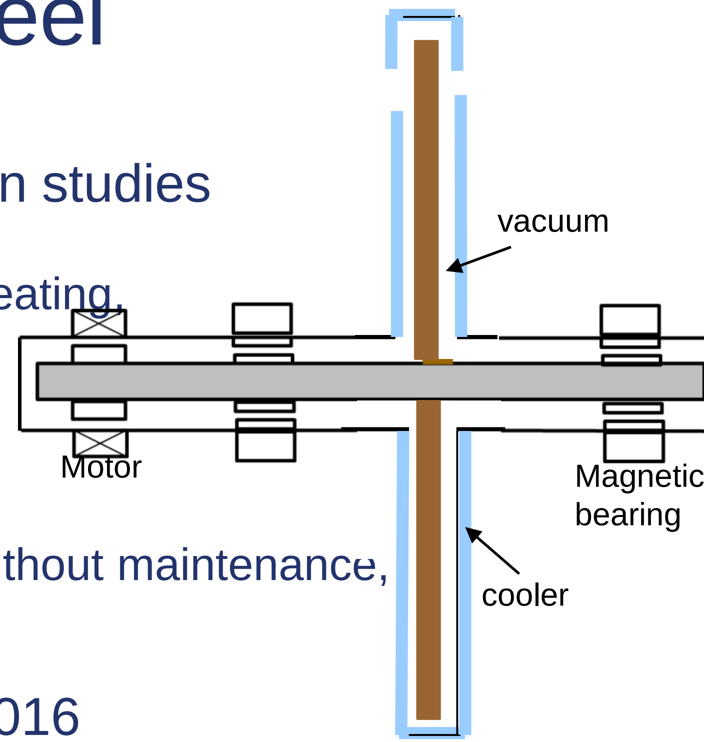
Target + optical matching device (OMD)

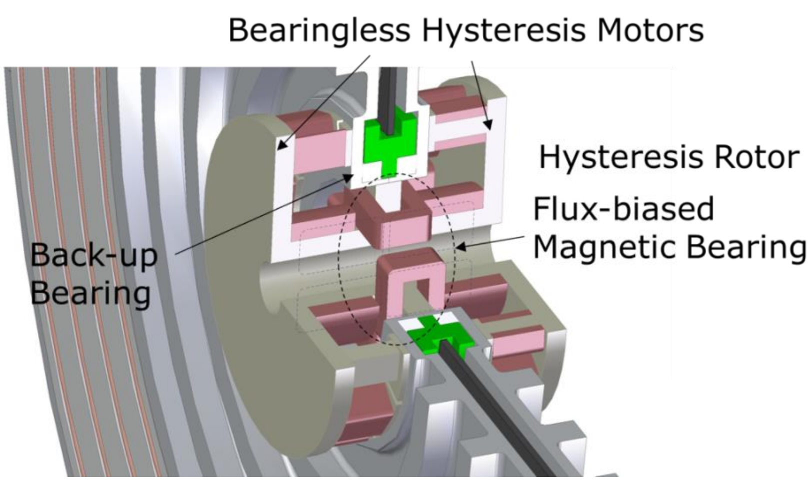


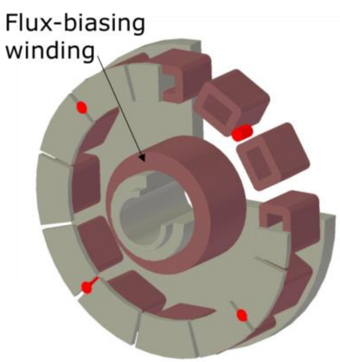
- The OMD occupies part of the radiating target surface
  → surface for effective cooling is reduced up to ~25% for the QWT (~13% for the Flux concentrator)
- Assuming no cooling → max average T[K] rises by factor ~1.075 (460C → 515C)
- In reality, the OMD acts a 'cooler'
  - 500W would radiate to QWT surfaces (~250W at front and 250W at back)
  - About 250W would radiate to the FC front
- This additional heat load for the OMD has to be taken into account for its engineering design

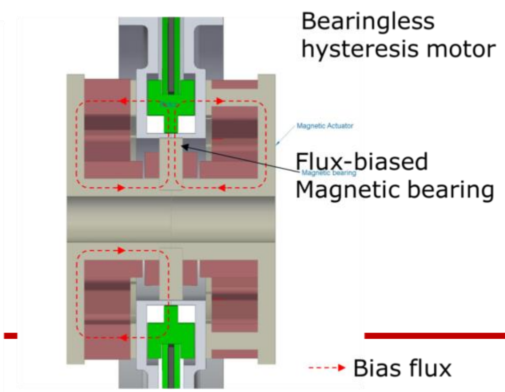
Drive and bearing for the wheel

- Nothing new – status unchanged
- Specification to be done based on simulation studies for the target wheel
  - response of rotating wheel to the beam load, heating, stress, cooling, imbalances, etc
  - Weight of the Ti alloy disc for ILC250: ~25kg
  - Eddy currents
- Magnetic bearings, drive motor etc:
  - are widely used and operated over long time without maintenance,
  - Companies: Rigaku, Juelich, SKF …
- Proposal by M. Breidenbach et al, ICHEP 2016









Upgrade to high luminosity (2625 bunches/pulse)

- Doubled energy deposition in target increases average T [K] by $\sim 2^{1/4}$
  - **460 C → ~ 600 C**
- Peak temperature rises by factor ~1.5 ⇔ $\Delta T < 100K$
- Possible options to handle the higher temperatures
  - Design with increased radiation area near the beam path (fins) is required. First studies exist (see former workshops)
  - Expansion slots are recommended
  - connection of the Ti alloy target with a cooler material of high heat conductivity to increse cooling efficiency.
    The design of the contact target-cooler has to be optimized and tested

Upgrade to higher energies

- For nominal luminosity the energy deposition and max temperatures are no problem:
  - 500GeV → E_{dep} in target ~2kW
  - Optimize target thickness for the CM energy
- Luminosity upgrade at higher energies:
  - change the wheel geometry with fins for more efficient radiation (larger radiating area)
  - Connect the rim of the wheel with material of higher heat conductivity → wheel consisting of target rim + radiator → increased cooling efficiency

General remark:

- Think about materials/Ti alloys which are designed for high load at working temperatures up to 700-800C
- M. Breidenbach, LCWS 2015, ICHEP 2016: use Ti-SF 61

Summary target disc

- Target wheel could be designed as disc; following the simulation studies the load is below the limits even in a disc wheel without expansion slots
- With expansion slots the stress due to average heating and cyclic load is safely below the material limits but the wheel rotation must be synchronized with the beam pulses
- target heating and cooling efficiency should be tested with a module consisting of a target piece corresponding to the sector which belongs to one pulse.
  - Such sector is located in vacuum, heated on one side → check temperature distribution in the target piece and radiation to a test cooler
  - Check cooling efficiency for different surface parameters, geometry etc.

R&D work for the next years

- Finalize the specifications for a target wheel (250 GeV collision energy)
- test in the lab the cooling by thermal radiation for a target piece
  - There is no doubt that radiative cooling will work, but details and optimization should be tested.
  - Test also performance beyond the desired operation temperatures of the target. This is essential for the safety margins

  → Design for such cooling-test-module
- Test load limits for target materials

- Study of the response of the spinning target wheel to the beam pulses, stress due to transient and average heating and thermal expansions are under way; (currently performed at DESY Zeuthen and University Hamburg)

- Develop a full-size mock-up for the target to test the target rotation in vacuum
  - it includes the full set-up of the target including motor,
  - bearings
  - full-size wheel

→ Target wheel for e+ production

Thank you!