LINEAR COLLIDER COLLABORATION

Designing the world's next great particle accelerator

The ILC positron source target using cooling by thermal radiation

LCWS 2017, Strasbourg

October 26, 2017

Sabine Riemann, DESY

outline

- Target cooling issues focused to E_{cm} = 250GeV
- Target cooling test module
- Next steps

In collaboration with:

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P. Sievers (CERN)

Yokoya-san's statements @ POSIPOL2017:

What is Urgent for Undulator?

- For possible experiment with a small subsector of the wheel being planned in JFY2018, we first need a starting design of the wheel
  - **Cooling calculation**
    - This is the most urgent. Necessary before engineering design.
    - Some preliminary results presented at AWLC-SLAC
    - We need a definite model calculation by LCWS-Strasbourg
  - Ti-Cu contact
  - Magnetic bearing design
- Parameters
  - 125GeV beam, QWT, FC
- Other issues
  - Photon dump, Shielding of target region, replacement scenario

Our answer:

- There is no show stopper or even crisis of the undulator scheme but a dramatic lack of manpower

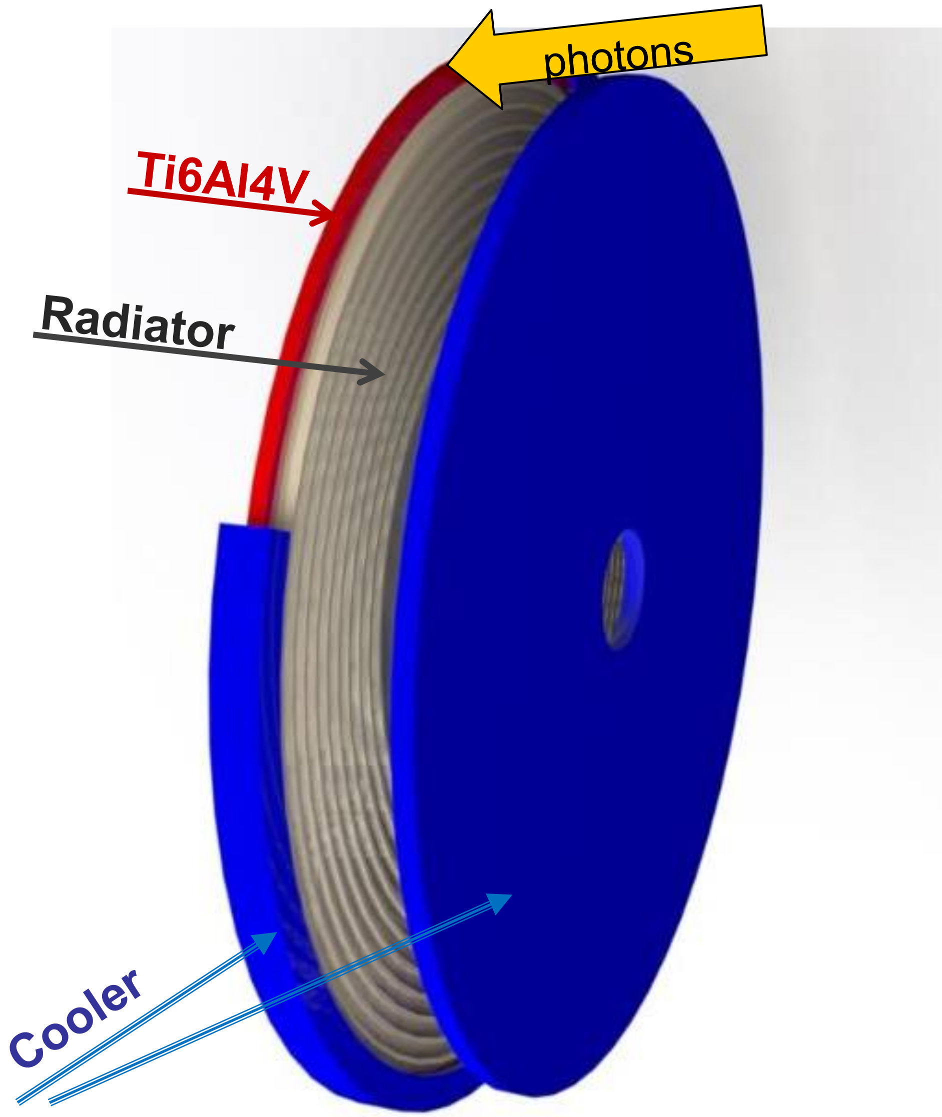
  → no definite model calculation by now
- We try our best
  - Model for the target-heating-cooling test piece has high(est) priority for DESY/Uni Hamburg group
  - To keep the manpower we apply for grant from German Ministry of science to continue our program for material test (& machine protection); see Gudi's talk

Radiative cooling model

- Heat path:
  - thermal conduction Ti → radiator
  - Thermal radiation from Ti and radiator to stationary water cooled coolers
  - Radiating area can be adjusted by fins
- Target, radiator are in vacuum
- Acceptable temperature in Ti alloy (incl. cyclic load)
  - Data sheets: ~500˚C
  - MAMI experiment: ~600˚C, may be even higher
  - Do ‘better’ target materials exist ?

We are convinced that such scheme will work

- T^4 radiation works
- Magnetic bearings are well established technology



Sketch: Felix Dietrich

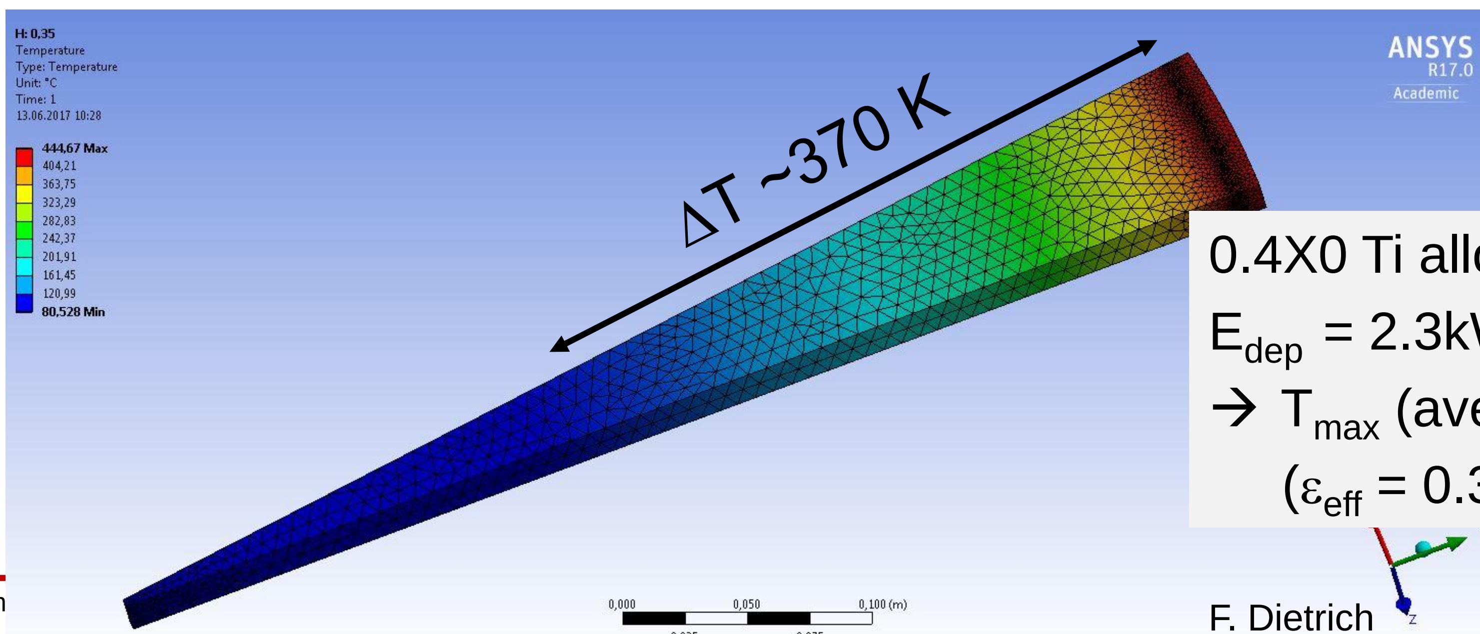
Target wheel issues

1. Temperature distribution in target

- Focused photon beam ⇔ only small part is heated instantaneously
- Low thermal conductivity in Ti and Ti alloys; Heat 'moves' $\sqrt{\lambda t/\rho c}$ ~ 0.5cm in 6.5sec

  λ = 0.065 W/(cm K), c= at RT

  λ = 0.126 W/(cm K) , c= at 500˚C
- accumulation of heat; highest T in outer region of wheel



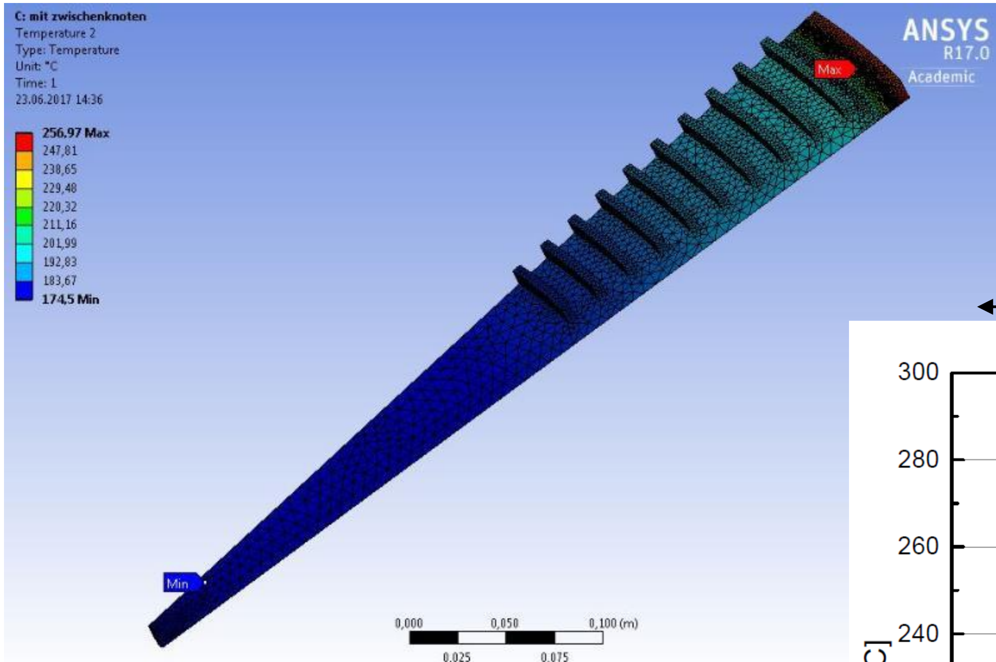
0.4X0 Ti alloy wheel,

E_{dep} = 2.3kW

→ T_{max} (average) ~ 450˚C

(ε_{eff} = 0.35)

T-distribution in wheel with Cu radiator



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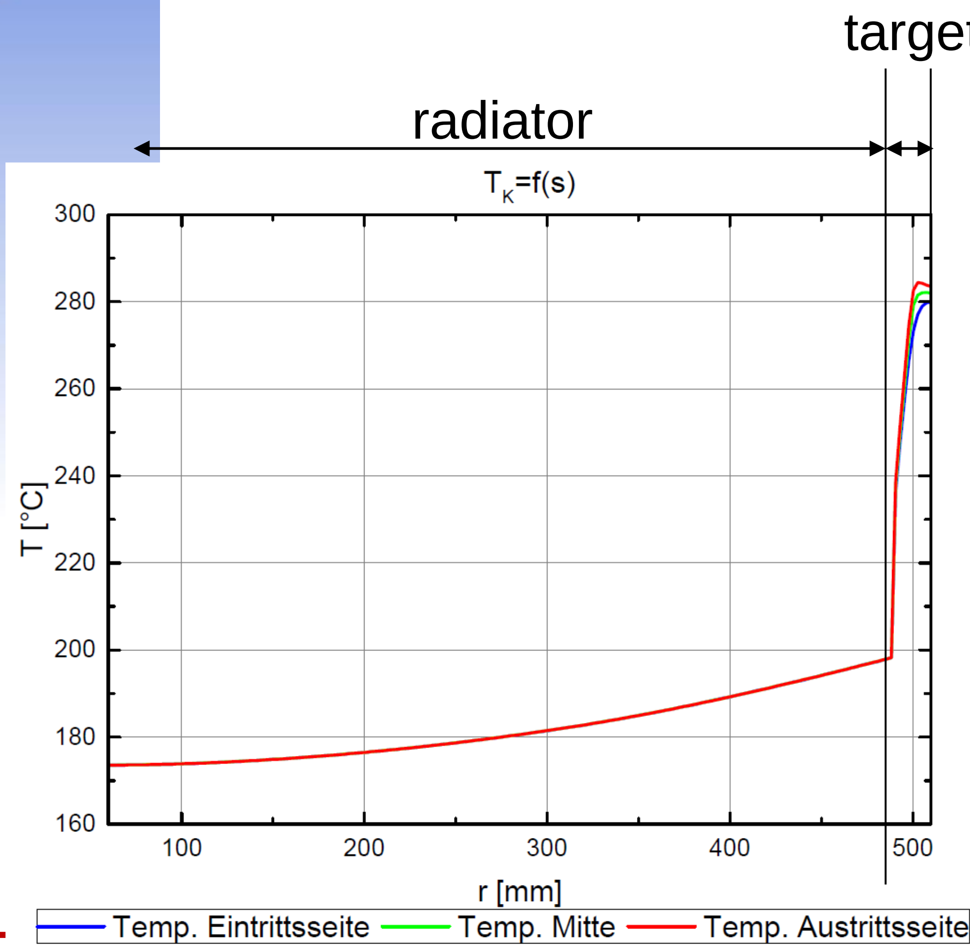
E_{dep} = 2.3kW,

0.4 X0 Ti6Al4V



Max average T in target: ~285˚C

ε_{Ti} = 0.35

ε_{Cu} = 0.8

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Target wheel issues (cont'd)

2. Radiator made of material with high thermal conductivity ⇔ contact of target and radiator must have low thermal resistance
   – Bolting, brazing, …
   – First ANSYS simulations by Felix showed too high stress values for the screws ⇔ to be checked and improved

3. Weight of the wheel
   – Ti disk, r=50cm, d=1.5cm [7mm]: ~50kg [25kg];
   – Ti rim + Cu radiator: O(100kg)

125GeV e- beam & 7mm thick target

- E_{dep} ~ 4 kW (231m TDR undulator, 2625 bunches/pulse)
- **E_{dep} ~ 2 kW (1326 bunches/pulse)**

  ΔT_{max} ~ 80 K

What do we gain concerning cooling?

- – Radiating area is almost the same, deposited power is reduced
- – Instantaneous temperature rise per pulse is almost unchanged
- – Thinner target implies lower weight – in best case a factor 2
- – Steady state T in wheel is reached in shorter time
- – Stress, stability etc to be considered in detail → under study

E_{cm}=250GeV, $0.2X_0$ target thickness

- Assume 1312 bunches/pulse, E_{dep} ~ 2 kW
- **Consider 'full' disk of Ti alloy**
  - maximum average temperature: T_{max} ~ 450˚C
  - Weight of 'full' wheel:
    - 0.7 cm thickness ~30kg
  - Stress:
    - Fatigue stress limit Ti6Al4V ~510 MPa (RT)
    - stress in outer hot region of wheel along beam path (~hoop stress in ring):

$\sigma_H = E\,\alpha\,\Delta T$ if expansion is prevented

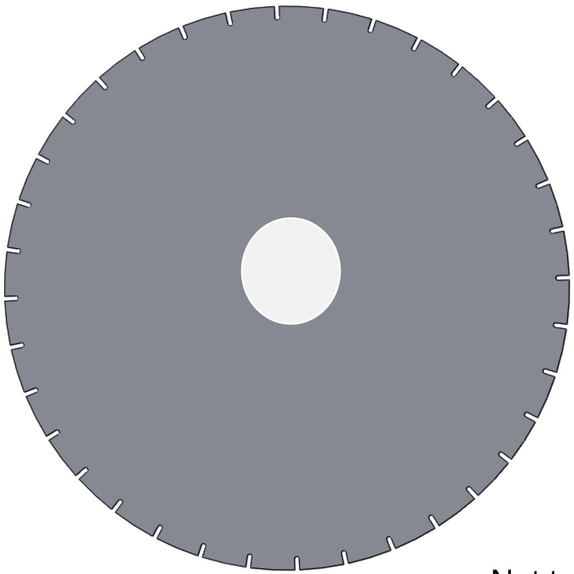
σ_H ~ 450 MPa for ΔT ~500K

- Cyclic stress due to instantaneous heating (~150MPa), eddy currents, centrifugal force etc. add to this value → too large stress value

E_{cm}=250GeV, 0.2 X_0 target thickness (cont'd)

'full' wheel made of target material:

- Hoop stress substantially reduced by sliced rim part
- such 'simple' wheel should be sufficient for E_{cm} = 250GeV, 1312 bunches/pulse
- must be studied including
  - σ_{inst}, σ_{eddy}, $\sigma_{centrifugal}$,…
  - Include other high temperature Ti alloys (M. Breidenbach et al: Ti-SF61)

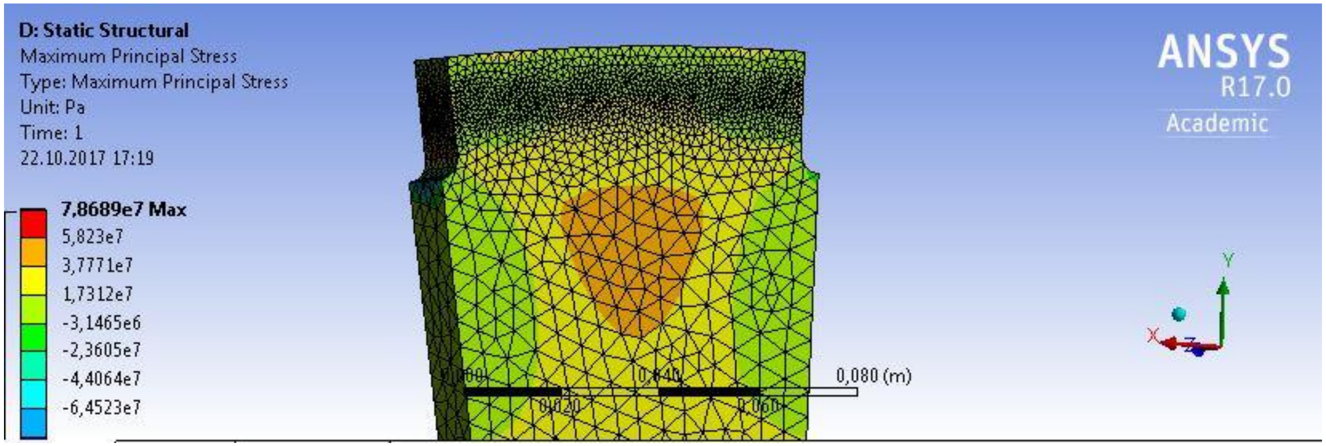


Not to scale

Full Ti alloy disk, 1.48cm thick, ε_{Ti} = 0.2 E_{dep} = 2.3kW

Shown is the piece corresponding to the sector hit by one pulse

Length of slices ~ 2cm



max. principal stress <80 MPa

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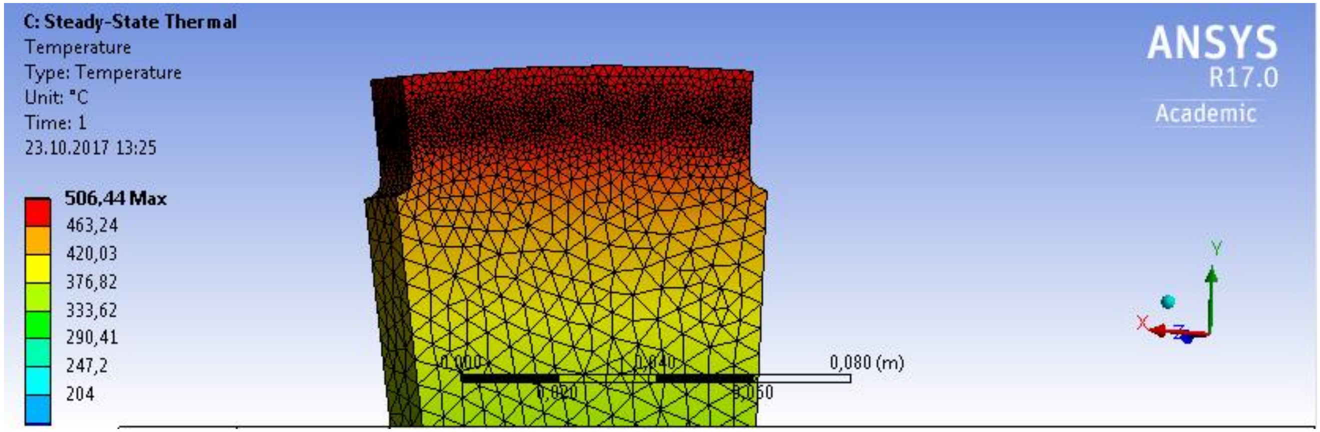
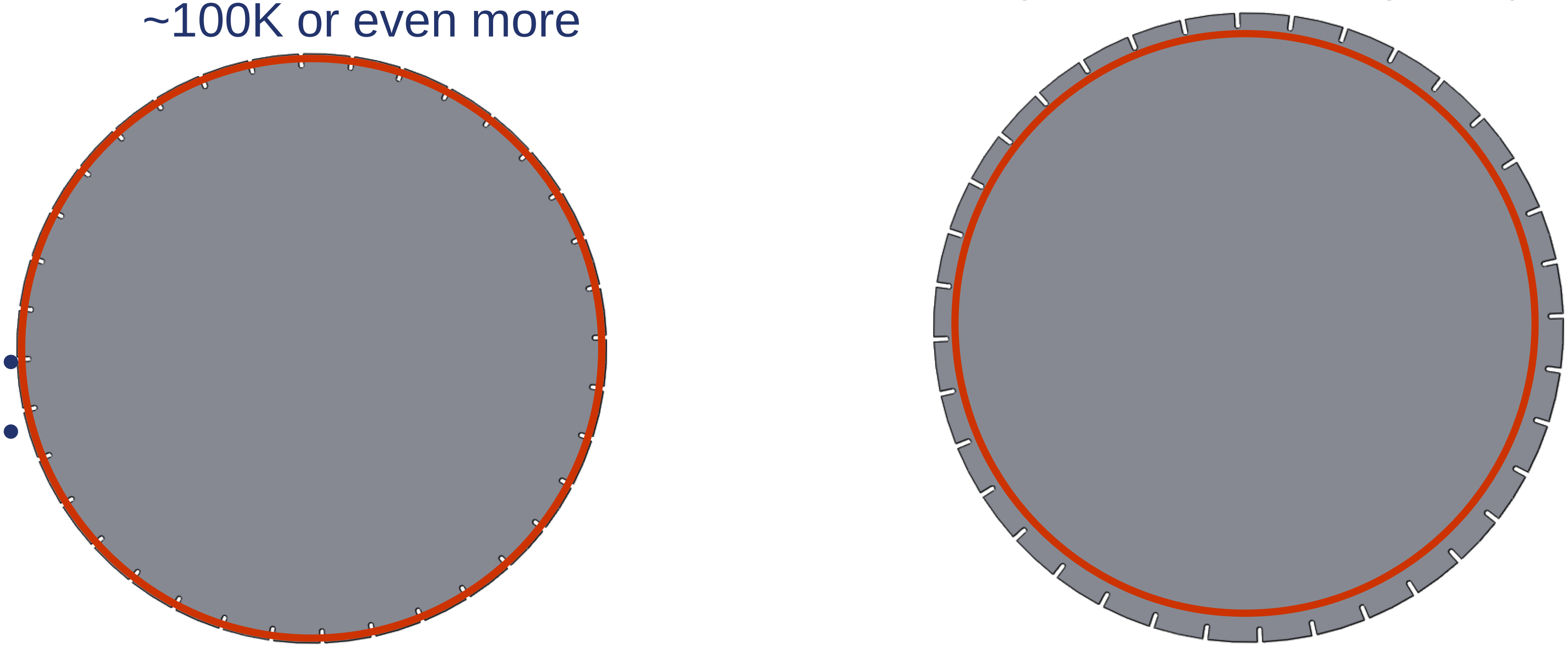


Max average temperature ~500˚C (ε_{Ti} = 0.2)

Next steps:

- Optimize slice length ⬄ stress due to heating and spinning
- Further reduction of max average temperature by increasing the outer radiation area which has high T and radiates more effectively
  - 3cm instead 1cm could reduce the average T in the hot region by ~100K or even more



Testmodule: What should we learn?

1. Temperature profile depends on surface emissivities
   - Emitted power is proportional to effective emissivity ε_{eff}

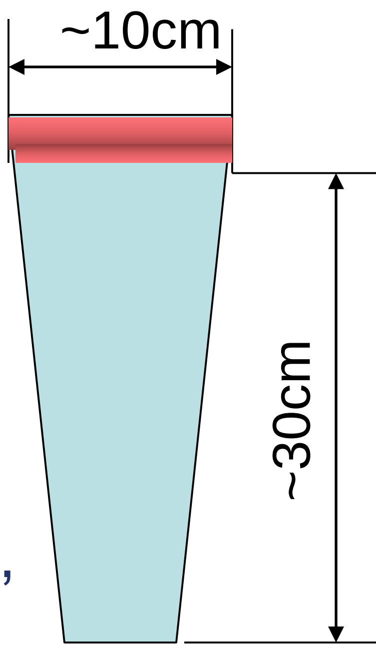
$$\dot{Q} \sim \sigma \varepsilon_{eff} A \left(T^4_{radiator} - T^4_{cool} \right)$$

$$\varepsilon_{eff} = 1 \Big/ \left(\frac{1}{\varepsilon_{rad}} + \frac{1}{\varepsilon_{cool}} - 1 \right)$$

   - surfaces of radiator and cooler are parallel:
   - Realistic effective emissivity is expected ≤ 0.5.
2. Do we reach the cooling efficiency as expected by simulations?
3. Optimize contact target ring to radiator material and effect on temperature
4. Upper limit for target cooling by thermal radiation?

Module to test radiation cooling

- Simulate energy deposition at e+ undulator source
  - Energy deposition per pulse: <1.6kJ (high L,P $_{e+}$)
    - E_{cm} = 250GeV option: ~500J
  - Max average E deposition at same area: 1.6kJ/6.5s ~ 270W
    - 250GeV option: ~80W
  - In order to reach rapidly the desired average temperature we need ‘power heating’
  - If average temperature reached, 2 options:
    - continuous heating with ~80…250W or
    - pulsed heating ($f_{heating}$ ~ 1/6.6Hz) with 0.5…1.6kJ

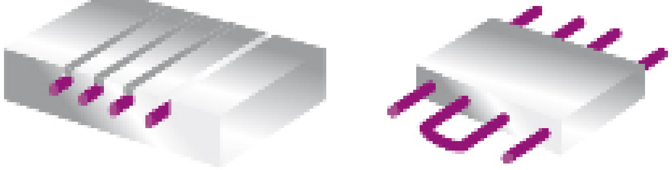


Heating options (1)

thermoexpert.de

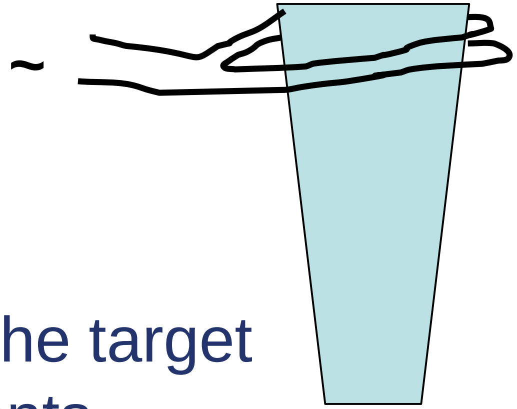
- Ohmic heating:
  - **Need heating elements**
    - with relatively high ohmic resistance
    - which are 'thin'
    - that stand high temperatures (600-1000˚C)
  - **implement the heater along the beam path.**
    - based on data sheets found so far most heat elements for our purpose are relatively thick and long
    - heat elements for high temperatures need very good contact

      → must be embedded with excellent thermal contact. Not easy; must be discussed with engineers



Heating options (2)

- inductive heating:
  - should work but details have to be considered.
  - We need a solution which only heats the target and not the cooler and other components



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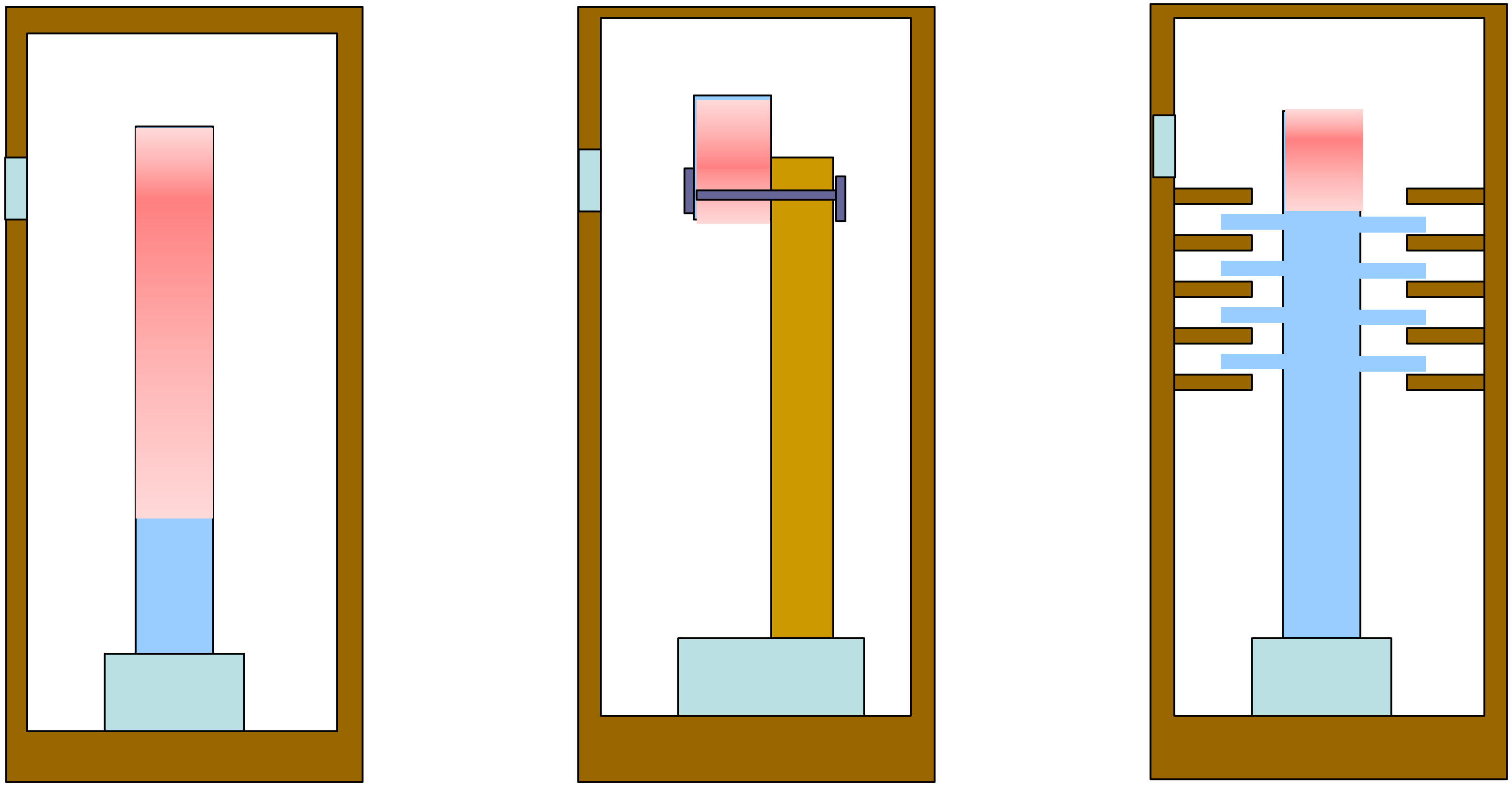
'side' view of cooler and test sample versions mounted in vacuum

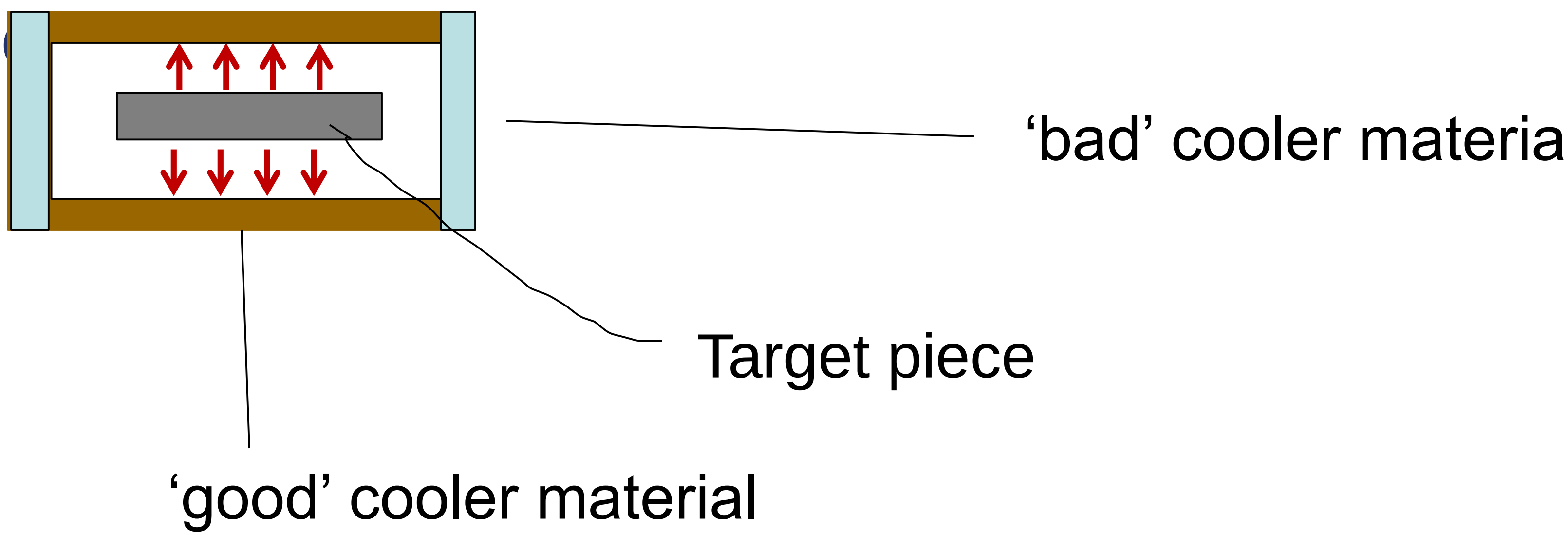


- Ohmic or inductive heating
- Thermocouples to monitor the temp. distribution target, radiator and cooler
- Windows to watch the sample
- Water cooling of copper box ; for low energy deposition a fan could be ok?

Testmodule - cooler

- Shape and cooling efficiency of the cooler surrounding the test piece must correspond to the realistic cooler in front of the target wheel surface

- T



Summary

- Radiation cooling will work; ‘only’ details have to be worked out.
  - Has high priority for the next months
- Mock-up to test cooling by thermal radiation → optimum target wheel design for all energies and luminosities
- Magnetic bearings
  - See Fukuda-san’s talk

→ Undulator source will work but manpower is a problem

- Last but not least: Undulator source provides polarized beams
  - Benefit also at E_{cm}=250GeV:
    P(e+)~30%, P(e)~90% → effective luminosity for Higgsstrahlung is increased by ~ 27%