Summary of PosiPol2016

LINEAR COLLIDER COLLABORATION

Designing the world's next great particle accelerator

Masao KURIKI (Hiroshima University)

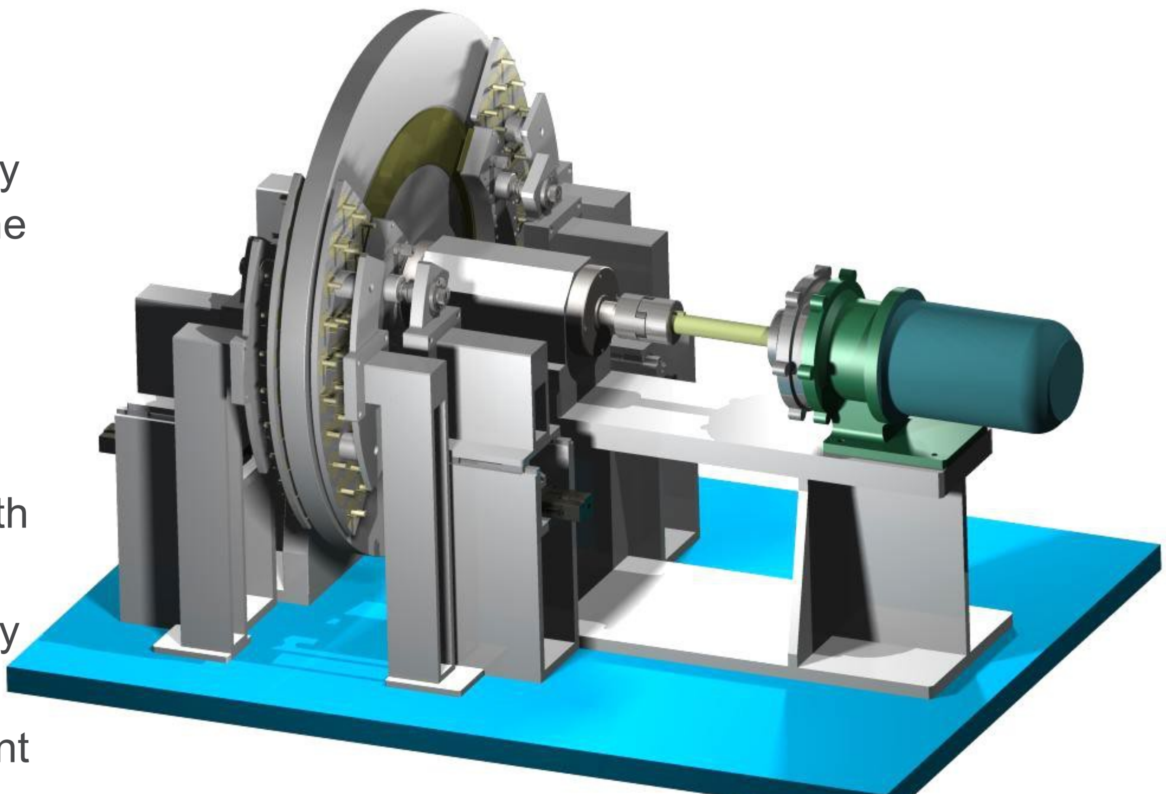
PosiPol2016

- 11th PosiPol WS
- 22 participants(16 EU, 1 US, 5 Japan) + online
- 2016/9/16-18 @ LAL-Orsay
- Laser Compton : 6
- E-Driven : 9
- Undulator : 7
- Other : 2

Active Sliding Contact Cooling Demo Conceptual Illustration

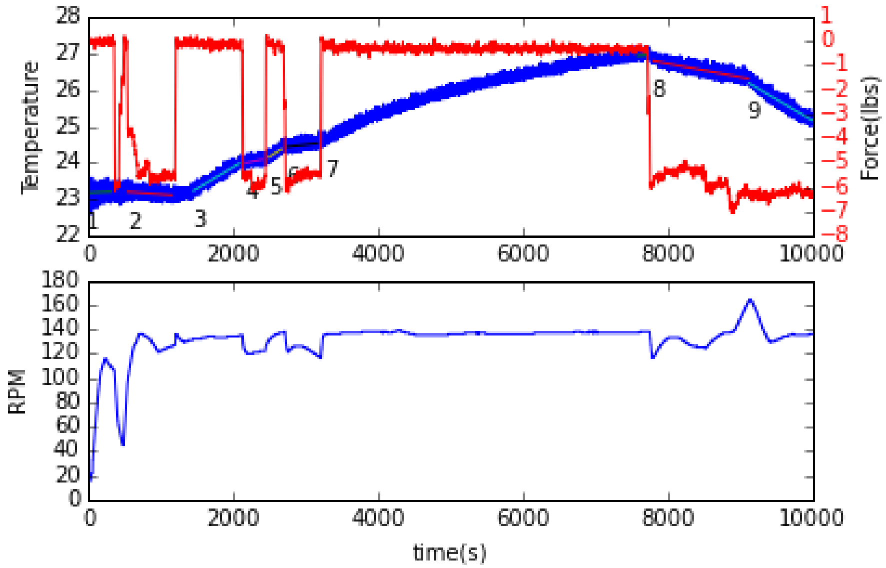
W. Liu

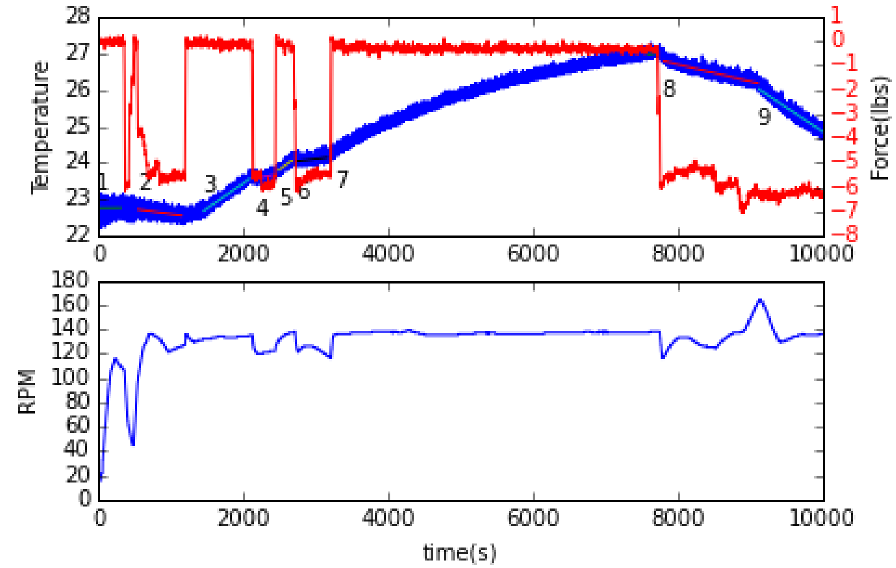
- Rotating 1meter diameter Target Wheel at 2000 rpm (100 m/s) while extracting ~10kW by using active sliding contact cooling.
- Target wheel is driven by a magnetically coupled drive motor which separates the motor from the vacuum.
- Stability of wheel controlled by heavy duty machine spindle.
- Temperature of wheel controlled by 4 Active Sliding Contact Cooling Pads with luburicant.
- Cooling Pad's temperature controlled by water/coolant.
- Heat applied to wheel using UHV radiant filament heaters.



Full Size Target Wheel Ready for Operations in Vacuum

Cooling Demonstration in Air





stage	heater	Cooling pads	dT/dt (oc/s)		Estimated cooling /heating power (W)	
			Upstream	Downstream	Upstream	Downstream
1	Off	Removed	9.36E-05	2.29E-05	---	---
2	Off	Applied	-1.51E-04	-2.83E-04	-14.6	-27.4
3	On, medium	Removed	1.17E-03	1.38E-03	113.5	133.8
4	On, medium	Applied	4.18E-04	4.40E-04	-72.9(equivalent)	-91.2(equivalent)
5	On, medium	Removed	1.26E-03	1.41E-03	122.2	136.7
6	On, medium	Applied	2.26E-04	2.51E-04	-100.3(equivalent)	-112.4(equivalent)
7	On, medium	Removed	1.01E-03	1.24E-03	97.8	120.2
8	On, medium	Applied	-3.73E-04	-4.66E-04	-36.2(net)	-45.2(net)
9	Off	Applied	-1.16E-03	-1.32E-03	-112.5	-128.0

Cooling of the ILC e+ target by thermal radiation

S. Riemann

Ecm and luminosity determine energy deposition in target

Ø = 1m; 2000rpm, 0.4X0 Ti6Al4V (Pe+ ≤30%)

Ebeam [GeV]	Edep [kW]	∞Tmax/pulse [K]	dpa	Edep [kW]	∞Tmax/pulse [K]
	Nominal luminosity			High luminosity	
120 A. Ushakov, 2015	5.0	66	0.035	-	-
175 (ILC EDMS)	3.9	125	0.06	-	-
250 (ILC EDMS)	2.0	130		4.1	195
250 A. Ushakov, Update 2015	2.3	85	0.05	4.6	128

Edep ≤ 7kW → cooling by thermal radiation is an option

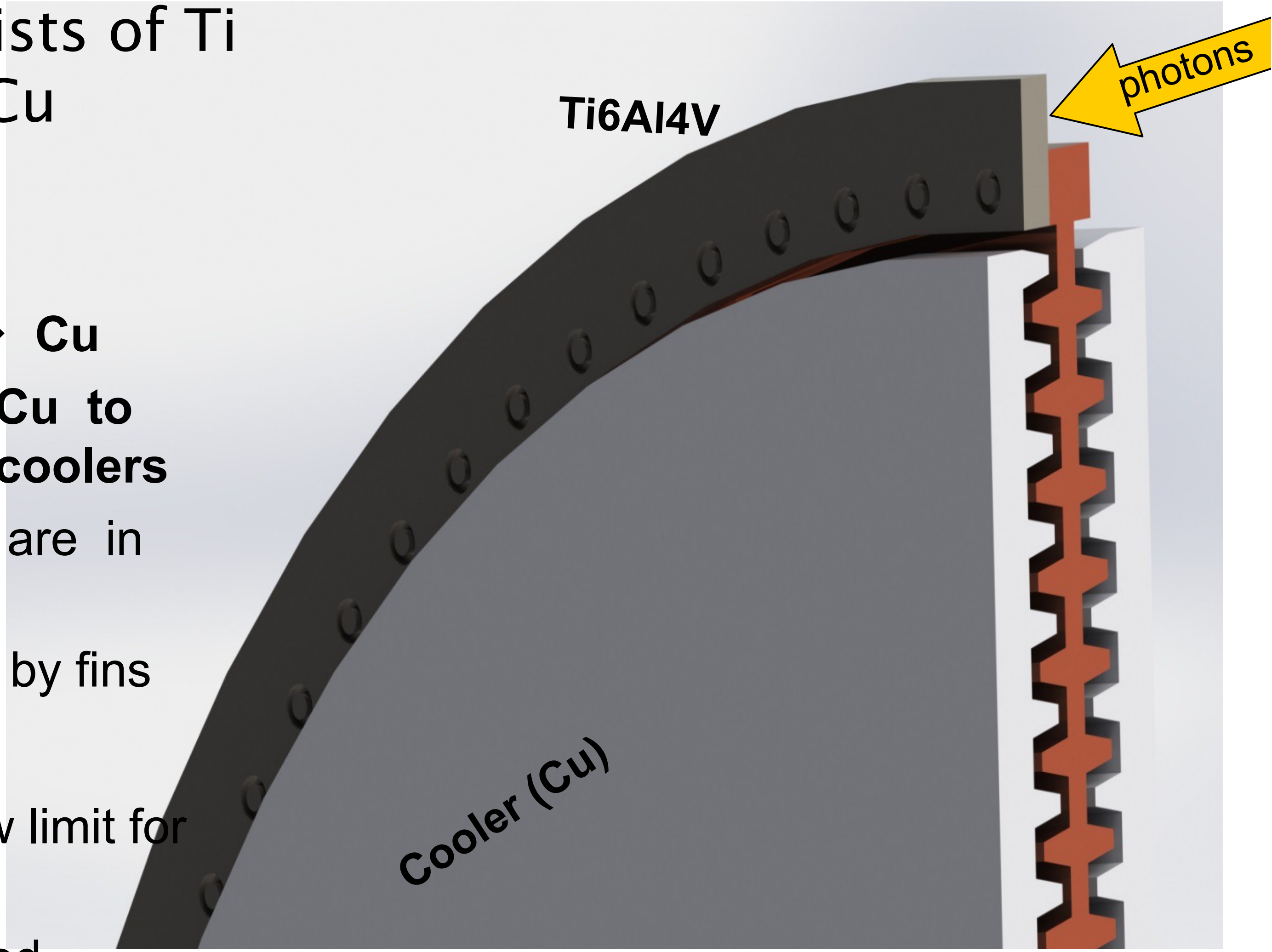
Radiative cooling model

- Rotating wheel consists of Ti rim (e+ target) and Cu (radiator)
- Heat path:
  - **thermal conduction Ti → Cu**
  - **Thermal radiation from Cu to stationary water cooled coolers**
- Target, radiator and cooler are in vacuum
- Radiating area is adjusted by fins

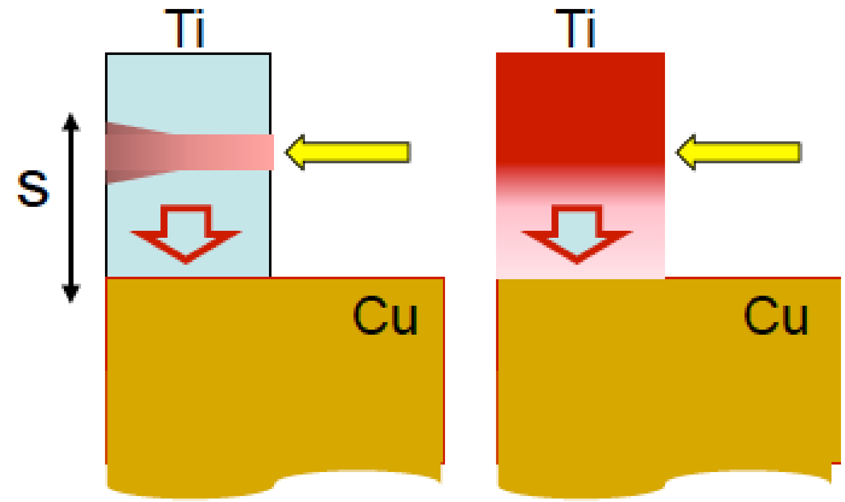
<u>Goal:</u>

keep target temperature below limit for failure of Ti6Al4V

Reliable fatigue limit at elevated temperatures?



Heat transfer target to radiator



- Spinning target⇔ ~6.5s between load cycles
  - Heat moves $\sqrt{\lambda t / \rho c}$ ~ 0.5cm in 6.5sec

  → accumulation of heat in the target
- Temperature flow to radiator depends on s
  - Average heat transfer through rim

$$\frac{dQ}{dt} = \lambda \cdot A_{contact}^{Ti-Cu} \frac{dT}{ds} \sim \lambda / s \cdot A_{contact}^{Ti-Cu} \left(T_{Ti} - T_{Cu}\right)$$

$A_{contact}$ ~470cm², λ~10W/(m K)

dQ/dt = 2.3kW: $T_{max\text{-}ave}$ (Ti) – $T_{contact}$ ~ 100K (s=1.5cm)

~ 150K (s=2.5cm)

  - Additional cyclic temperature rise by pulse (80…200K)
- Cyclic peak temperatures in target can exceed 500°C, in particular for large s

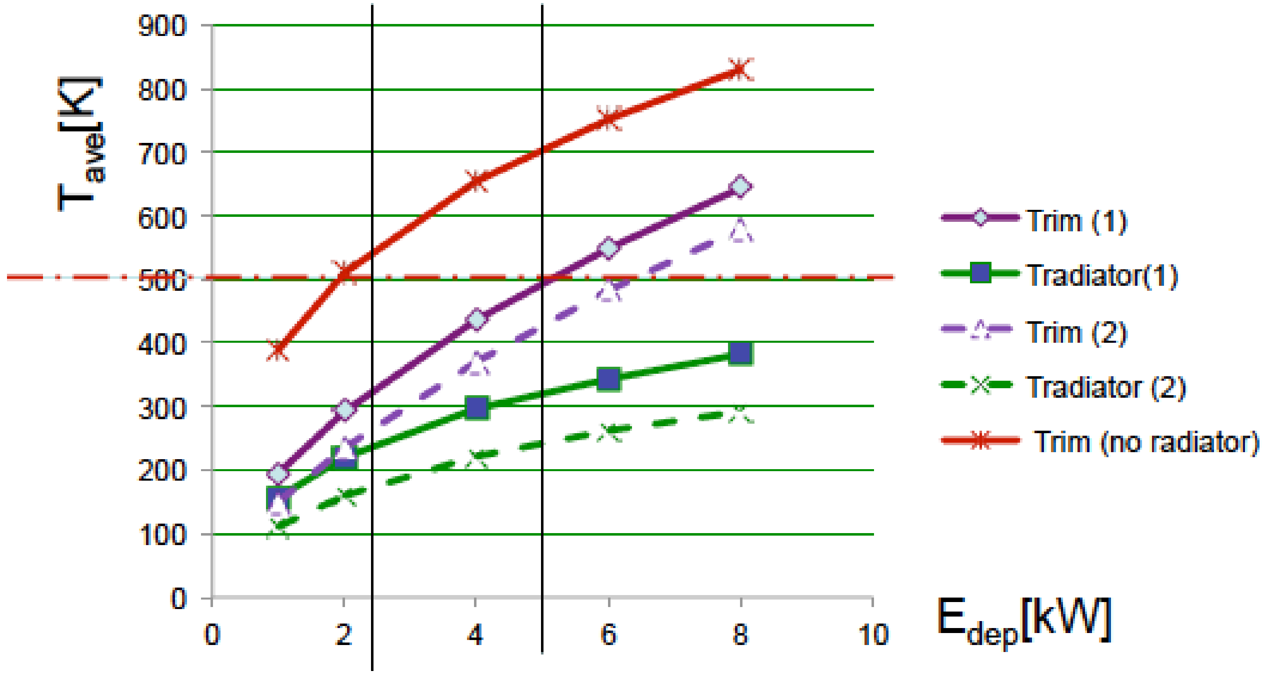
  → need design with short heat transfer path through Ti rim to keep the average T_{target} as low as possible

  → for high power deposition (⇔ high lumi) even average temperature could be >500C

Estimated average temperature in T rim and Cu radiator

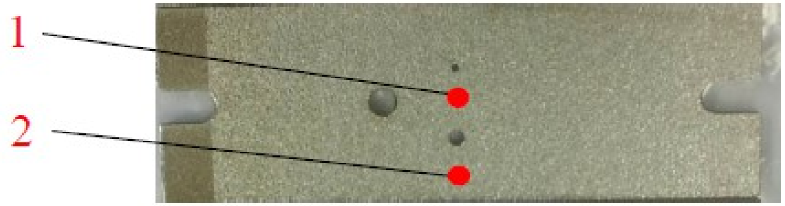
Consider thermal radiation from rim and radiator

- Case (1): rim 0.082m^2 + radiator 1m^2
- Case (2): rim 0.082m^2 + radiator 2m^2
- Case (3): Only rim, 0.16m^2; no radiator
- Emissivity ε=0.6



- Estimates give the principal behavior and only approximate temp values. Real temperatures need simulations, they depend on radiator design and Ti-Cu contact

Target Material Test at MAMI, Mainz
A. Ignatenko



Target	Hit point	Regime	Beam time	Load cycles	Years of ILC operation*
#1	1	100 Hz, 2 ms, 10 μA average	18 h 28 min	$6.82 \cdot 10^6$	2.46
#1	2	67 Hz, 3 ms, 10 μA average	5h 4 min	$1.24 \cdot 10^6$	0.45
#2	1	67 Hz, 3 ms, 10 μA average	5h 4 min	$1.24 \cdot 10^6$	0.45
#3	1	100 Hz, 2 ms, 10 μA average	14 h 22 min	$5.17 \cdot 10^6$	1.87

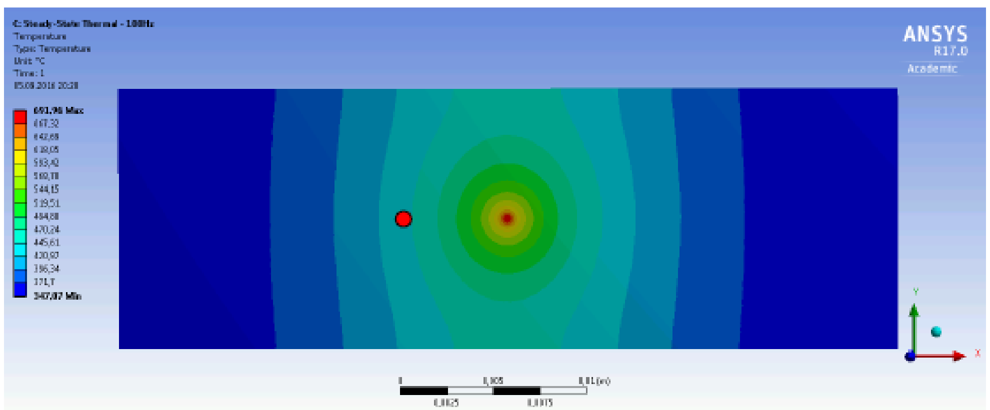
*1 year of ILC operation: 5000 h, 5 Hz, each point is irradiated every 6.5 s

ANSYS simulation, target #1

Target	#1
Thickness	1 mm
Surface	Rough
Fixation	Not fixed
Cooling	Radiation

Neglect low thermal conductivity to the holder via ceramics etc

Consider cooling by radiation from the surface only



Max. average T = 691 °C

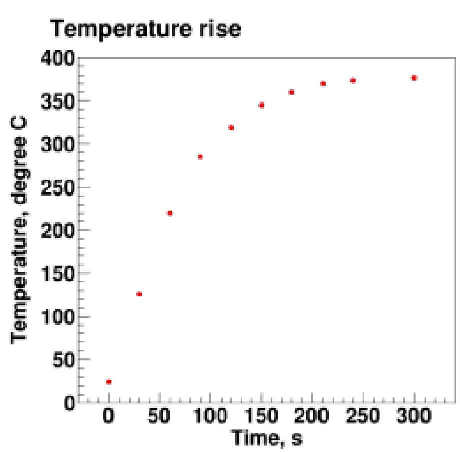
Max. T rise / pulse (@ 700 °C) = 82 °C

Max. T in target #1: **691 + 82 °C**

Distribution of the average temperature (ε=0.5)*

* Here and later:
- Ambient T = 22 °C
- Ti6Al4V properties according to

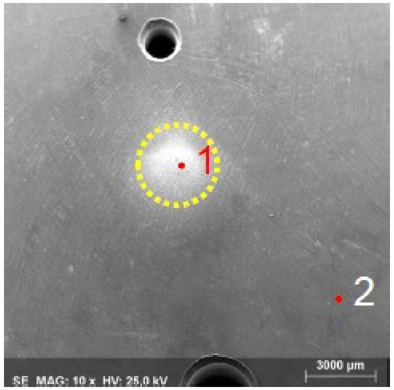
K.C. Mills, 2002, Recommended Values of Thermophysical Properties For Selected Commercial Alloys, p. 217, as referenced by J. Yang



→ $\varepsilon \gtrsim 0.5$

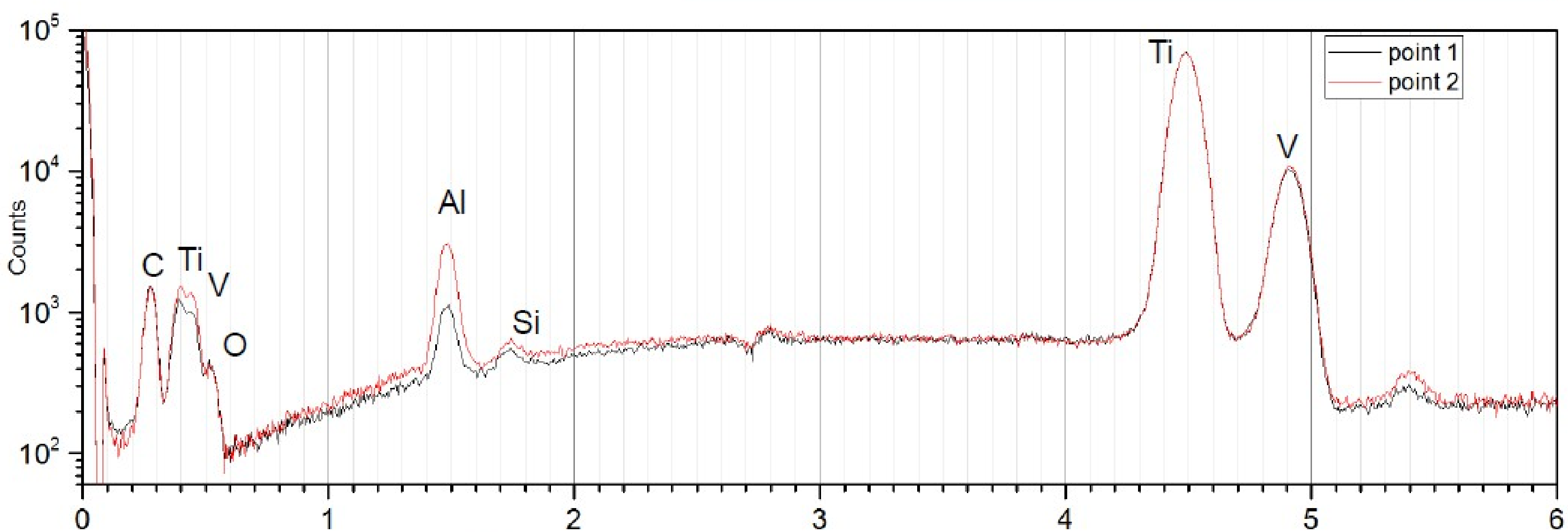
Real temperature measurement in ●

Target #3, SEM image (Yegor Tamashevich)



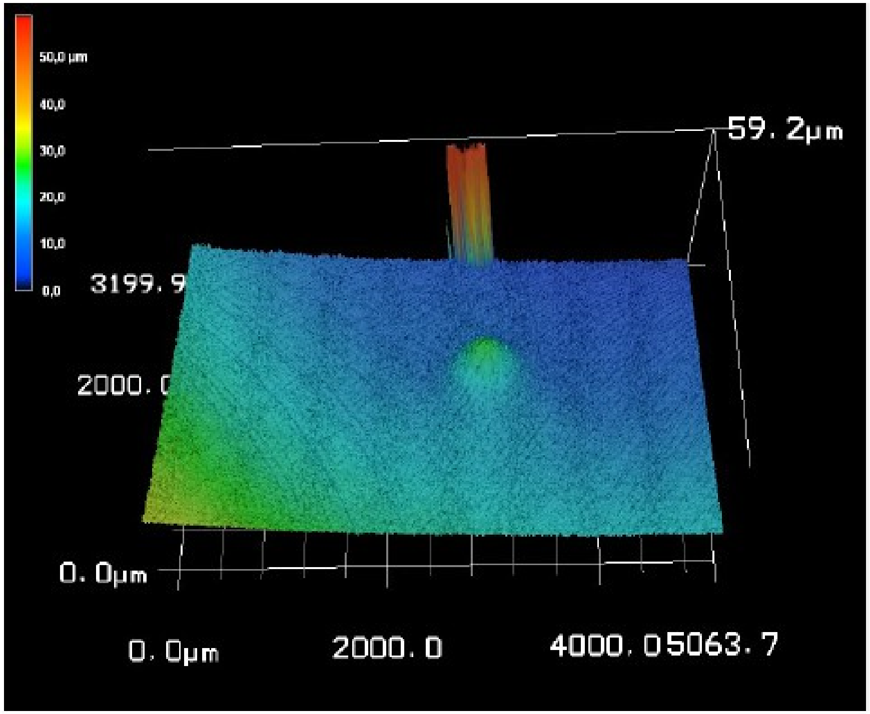
Point 1 – Beam spot area
Point 2 – Un-irradiated area

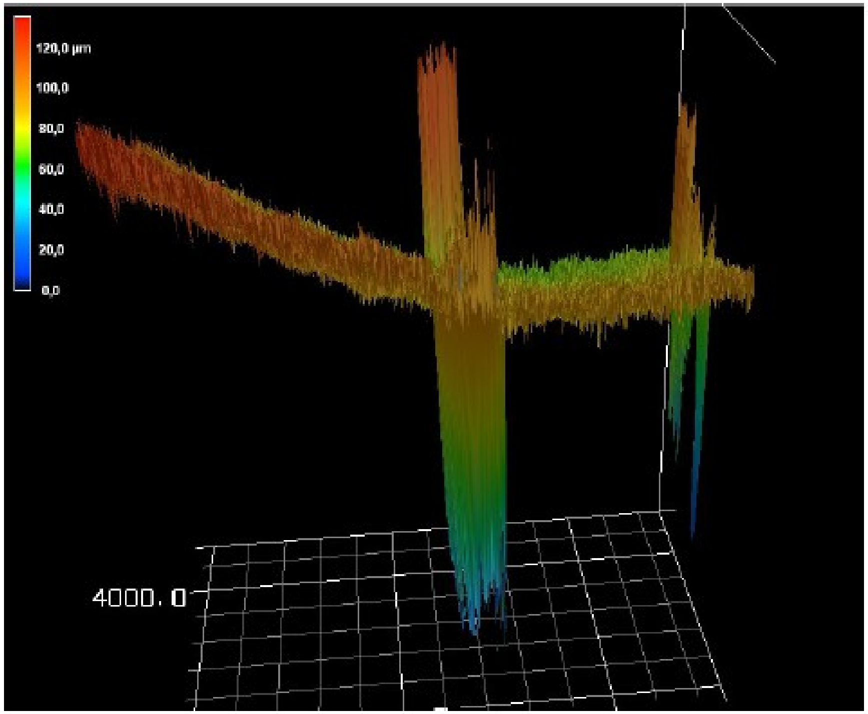
Aluminum concentration is lower in the beam spot area



*Results are normalized by Ti (4,5 keV)

Target #3, surface investigation, exit side



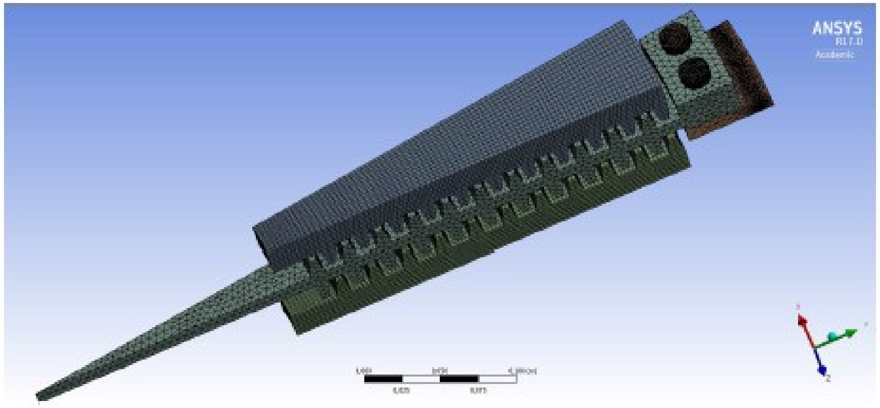


Plastic deformation after irradiation, 1 peak observed in the beam spot: ~ 25 µm from the surrounding to the top of the peak

Thermomechanicle Examination :F. Dietrich

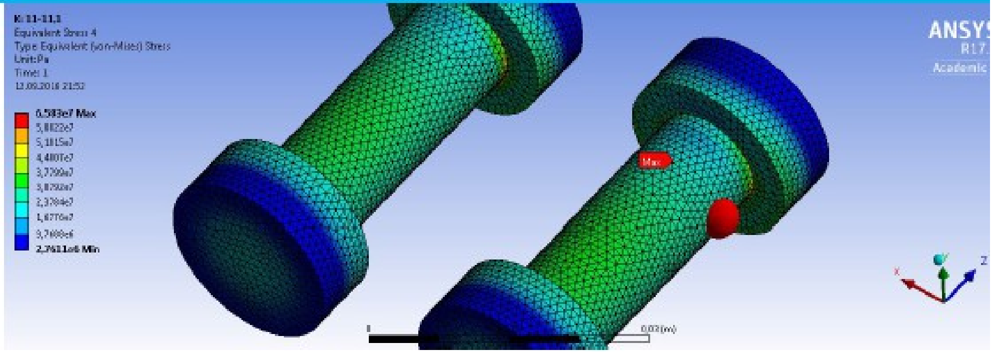
Modified Model – simulation set up

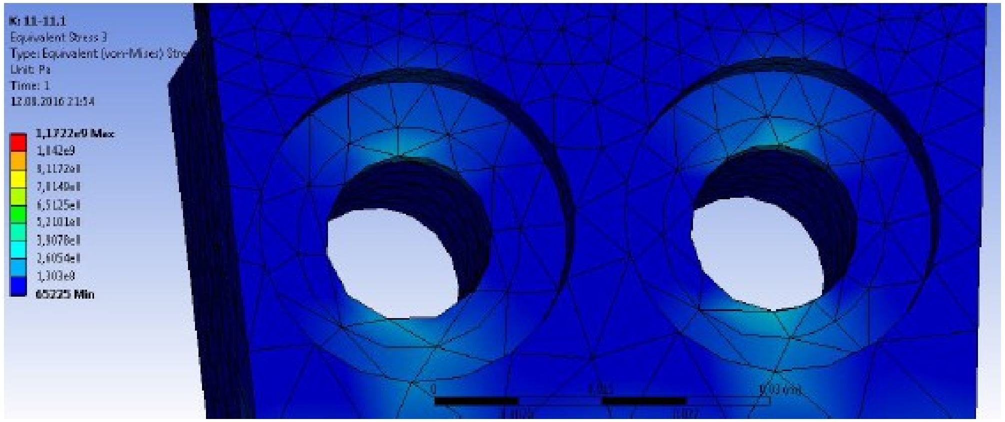
- the new Model is simulated with an energy deposition of 2.3 kW
- there is only a static thermal simulation
- there is now a static structural analysis
  - including a constant rotational force
  - the wheel has fixed faces under the fins
  - Screw were fixed with Bolt pretensions and frictional connections
- 3 Simulations were done
  - M12 with 11.1 mm thickness
  - M12 with 14.8 mm thickness
  - M5 with 14.8 mm Thickness

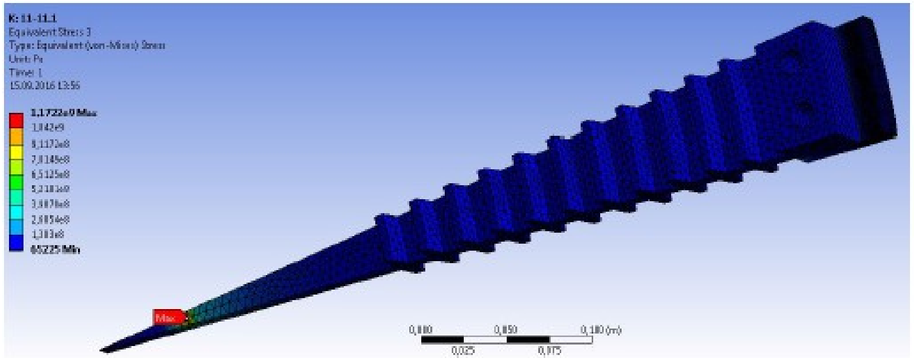


New Model – result

- Max. temperature: 282.71°C (555.86 K)
  - located in the middle of the beam spot
- Max von Mises stress: 1,17GPa
  - at the fixed surface (maybe artificial)
- Max. von Mises stress at the screws 65,83MPa
- Max. von Mises stress at the contact surface is 203,8MPa







Fire-tree-root – results

- Max equilibrium temperature is 301.31 °C (574.46K)
  - located over the fire tree ,at the exit side, in the middle of the beam spot
- Static simulation shows max. von Mises Stress of 66,08 MPa
  - locates at the bottom of the fire-tree notch