LINEAR COLLIDER COLLABORATION

Designing the world's next great particle accelerator

Target material tests with the e- beam at MAMI

AWLC 2017, SLAC

26 June 2017

S. Riemann, A. Ignatenko (DESY)

A. Ushakov, G. Moortgat-Pick, A. Prudnikava, Y. Tamashevich (U Hamburg)

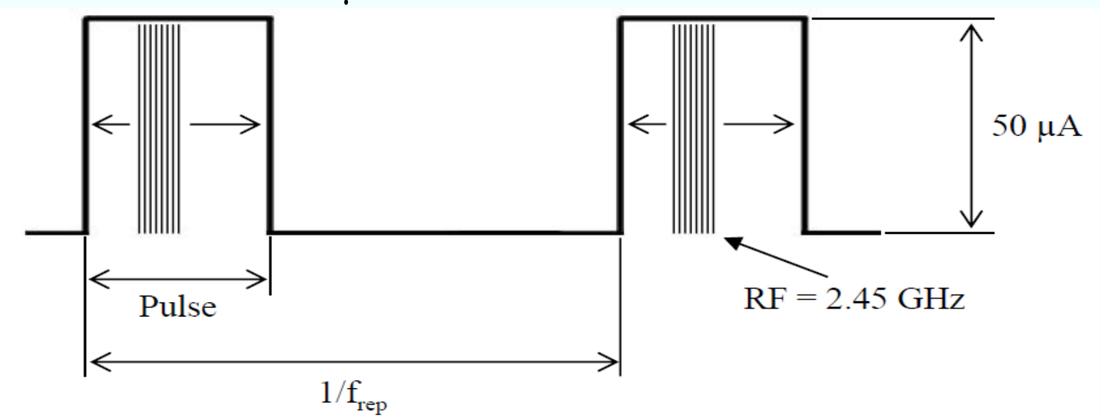
K. Aulenbacher, T. Beiser, P. Heil, V. Tioukine (U Mainz)

outline

- Idea and goal of the tests
- The experiments
  - Long-term irradiation (cyclic load) of 1mm and 2mm thick samples
  - Long- and short-term irradiation (cyclic load) of ~0.2mm thin samples
- Results
- Plans

Idea:

- Simulate ILC load on e+ target (or windows) using e- beam
- Radiation protection and availability of facilities ⇔ perform studies at the Mainz Microtron (MAMI):
  - Electron energy: 14MeV and 3.5MeV
  - cw e- beam > 20μA (polarized) or up to 100μA (unpolarized)
  - In our tests:
    - 10μA average beam current
    - f_{rep} = 100Hz
    - Pulse length: mainly 2ms (rotating ILC target: ~50μs)
    - 1.28×10^{5} e-/bunch, 4.08×10^{-10}s bunch spacing → 4.9×10^{6} bunches in 2ms, 6.25×10^{11} e- per 2ms pulse
    - Beam sizes focused below 200 μm



Aim of material tests

- Load at ILC (photon beam)
  - peak energy deposition ~50J/g ($\Delta T \sim 100K$)
  - Average temperature in target 400-500≤C
  - Few 10^6 load cycles per year
  - Estimated dpa: O(0.3-0.5) per year for spinning target in beam region

- MAMI (e- beam)
  - peak energy deposition ~50J/g
  - Average T depends on f_{rep} and cooling
  - 8.6×10^6 load cycles per day
  - Estimated dpa:
    - O(0.33) for E_{e-} = 14MeV and 24hours irradiation
    - O(0.22) for E_{e-} = 3.5MeV and 24hours irradiation

Target test run 1 (March 2016)

All targets:
50 μA during pulse

#1: 1 mm thickness — 2 ms, 100 Hz
wo thermal contact to holder — ~18.5h of irradation

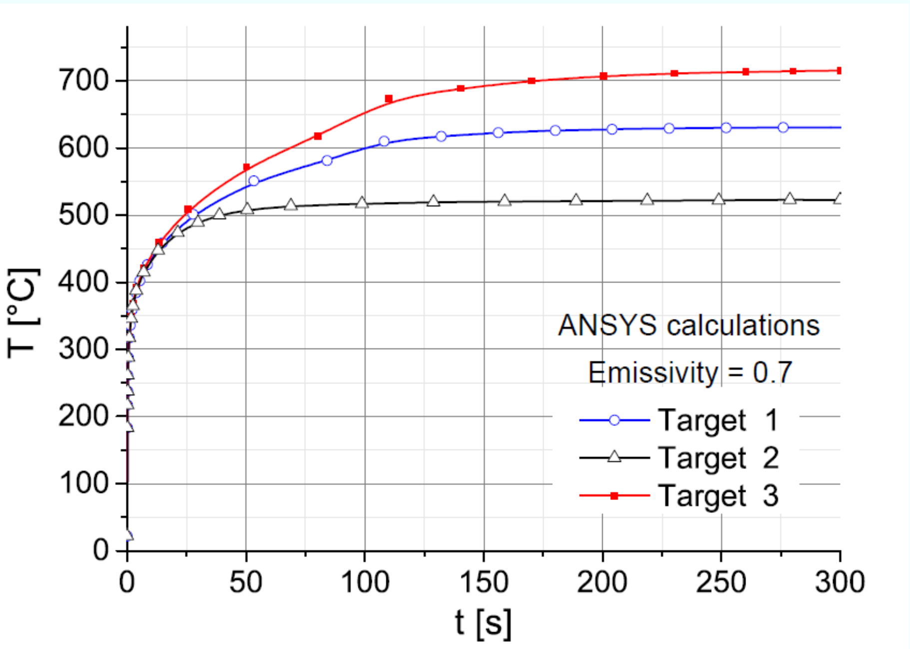
#2: 1 mm thickness — 3 ms, 67 Hz
with thermal contact to holder — ~4h of irradation

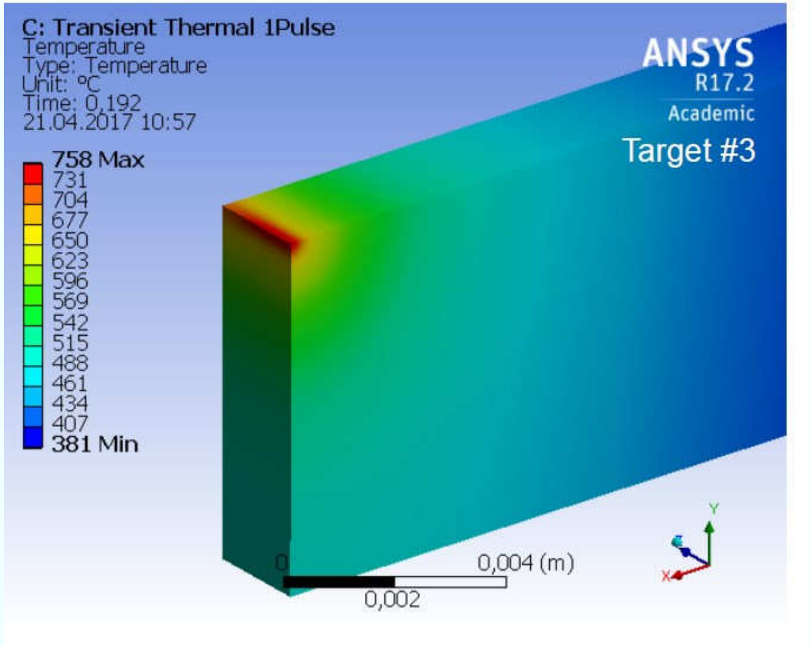
#3: 2 mm thickness — 2 ms, 100 Hz
wo thermal contact to holder — ~14.5h of irradation

#4: not used

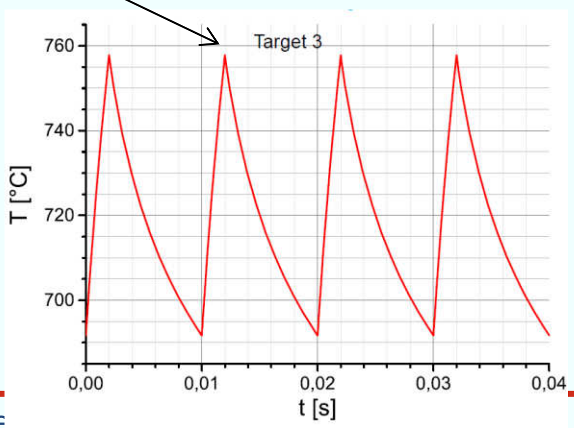
Temperature in target samples

Assumed emissivity ε = 0.7

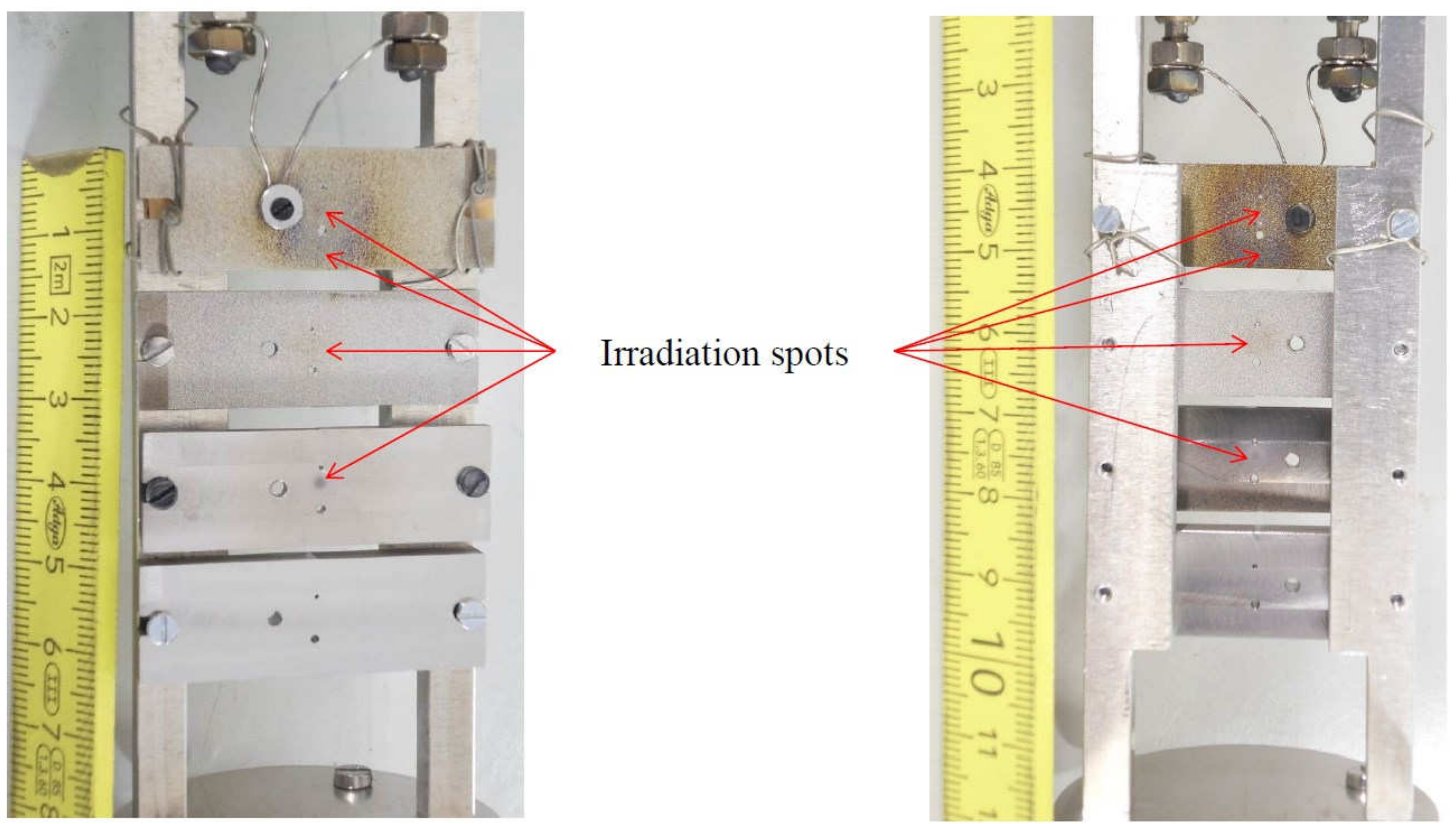




Temperature at pulse end



After irradiation



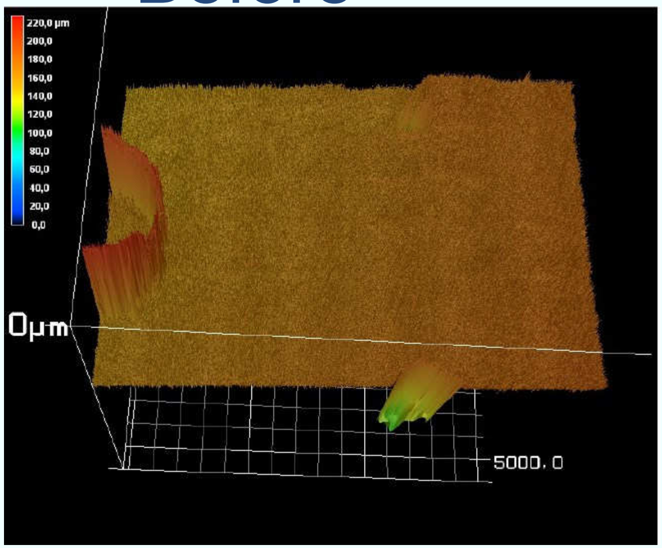
Holder with targets, entrance side

Holder with targets, exit side

Surface investigation, target #3 (2mm thick)

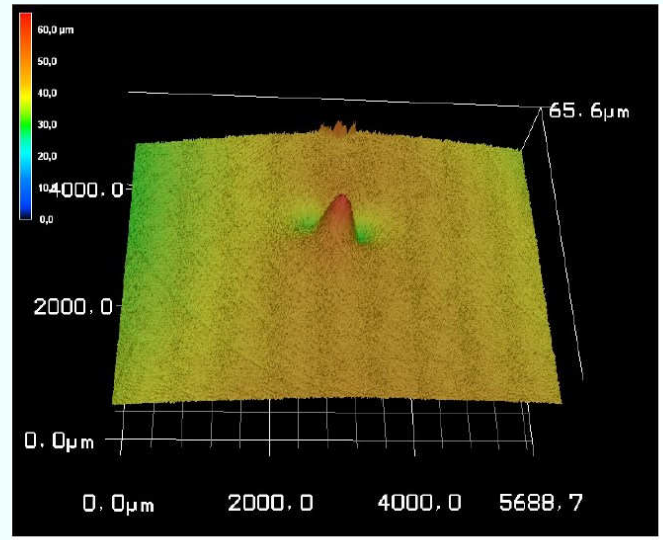
Before

Front side

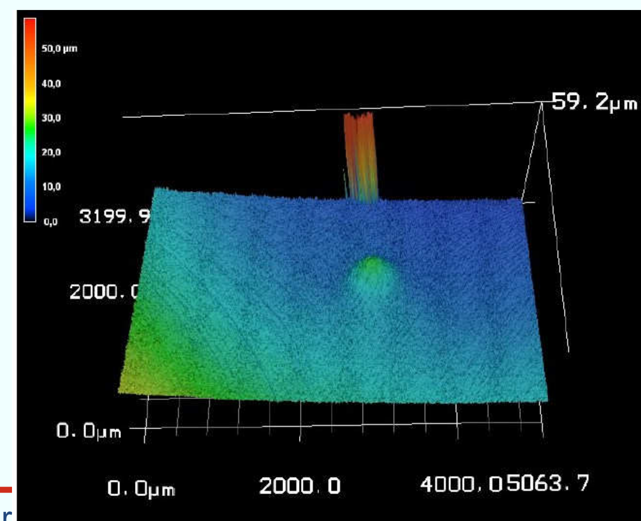


After

Front side



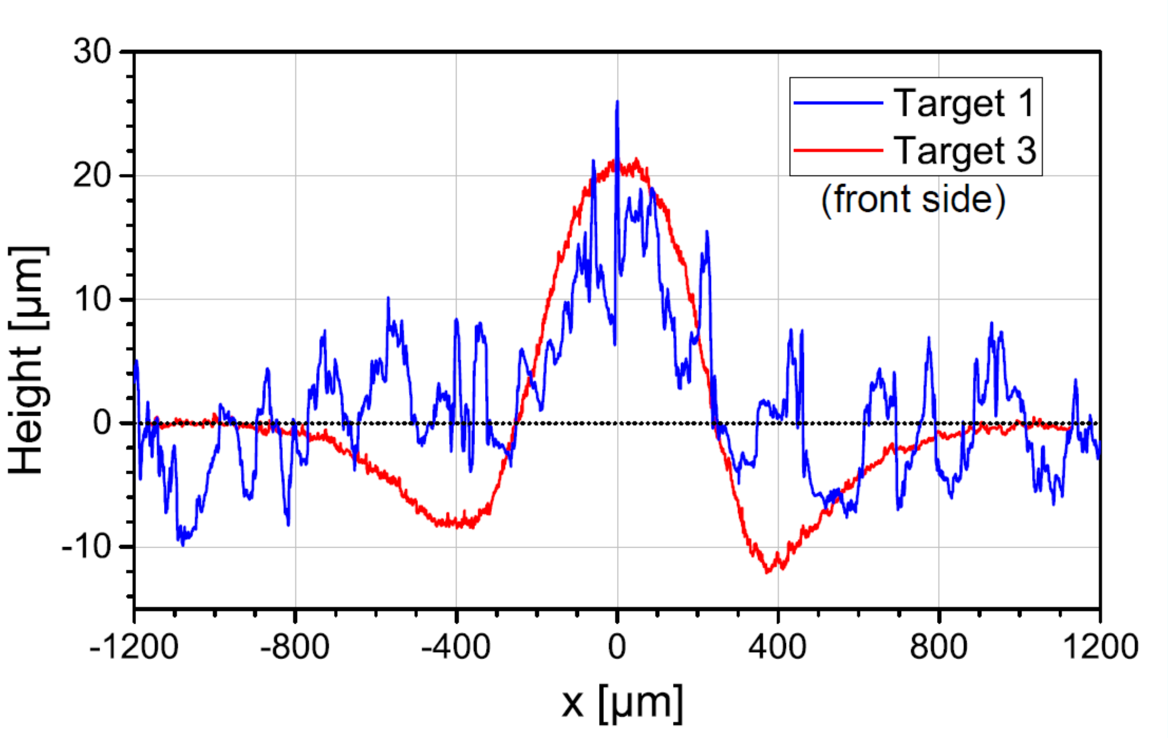
exit side

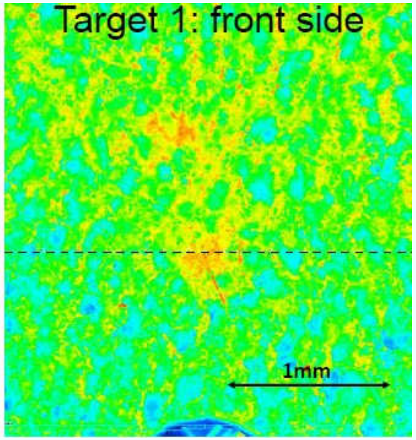


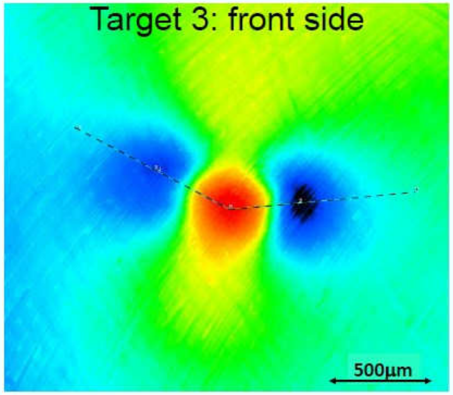
Plastic deformation after irradiation:

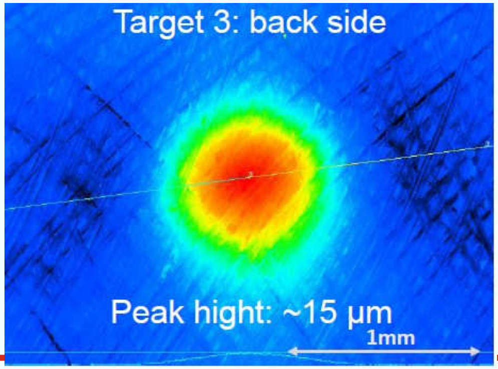
- ~35 μm at front
- ~25 μm at exit

Deformation after irradiation









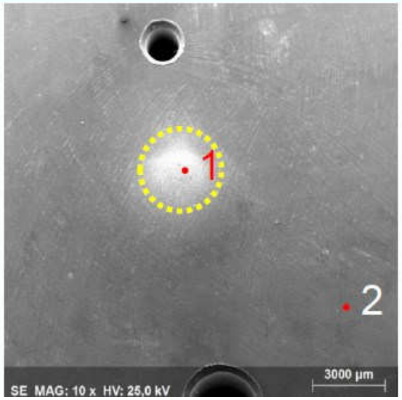
- No deformation at exit side of target #1
- No deformation at target #2 (thermal contact to holder)

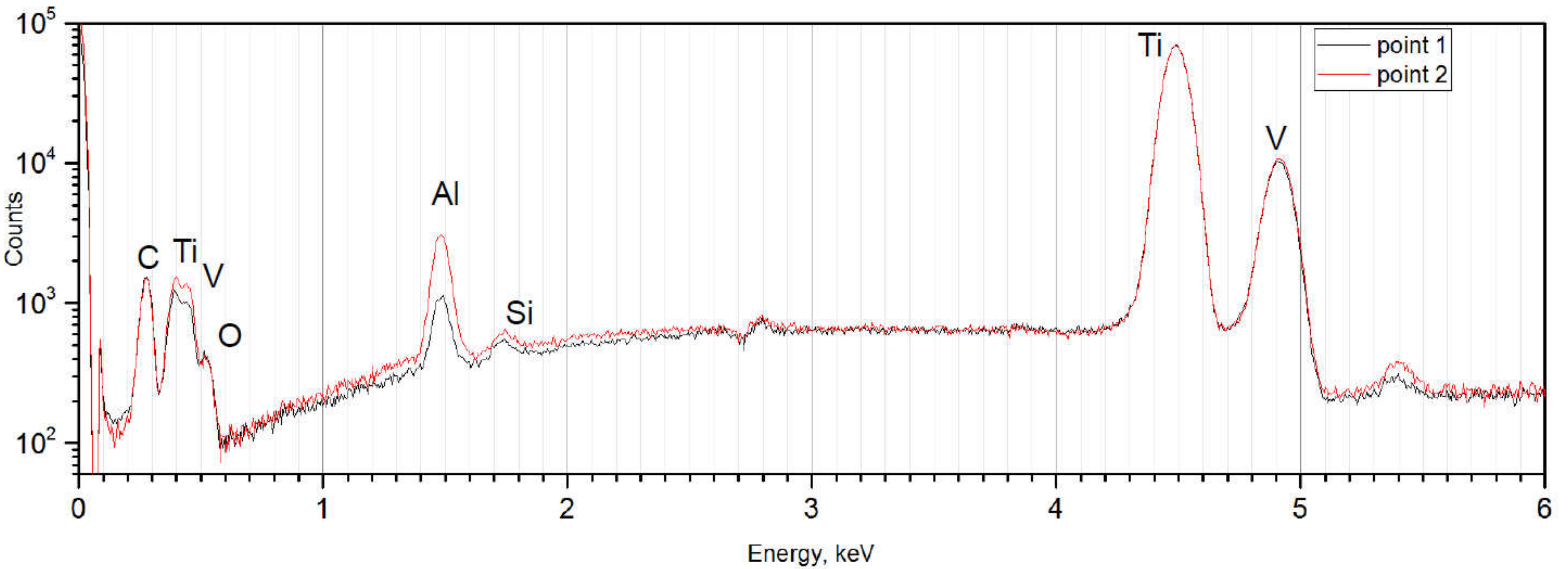
SEM result for target #3 (2mm thick)

Point 1: beam spot area

Point 2: non irradiated area

After irradiation, Al concentration was reduced in beam spot ares

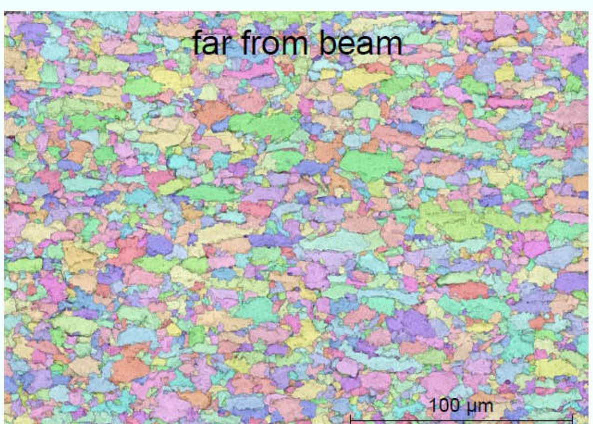




*Results are normalized to Ti (4,5 keV)

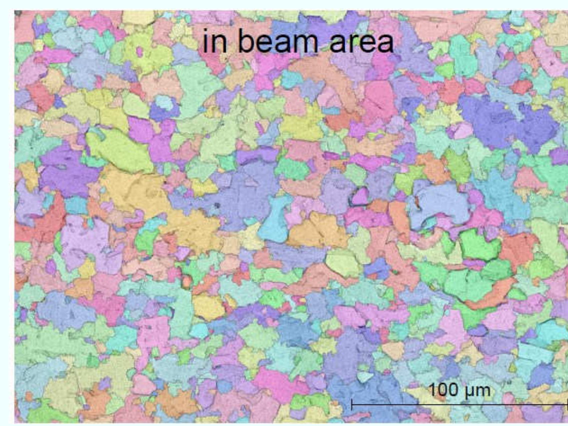
Target	Thickness	Cooling	Irradiation regime	T_{ave} [C] (sim.)	T_{peak}[C] (sim.)	#of load cycles	Deformation front/exit
1	1mm	thermal radiation	2ms 100Hz	629	690	6.8×10^6	0 / ≤15µm
2	1mm	Thermal contact +radiation	3ms 67Hz	max		1.2×10^6	0 / 0
3	2mm	thermal radiation	2ms 100Hz	713	713	5.2×10^6	≤28µm / ≤15µm

- All targets stand the long term irradiation without cracks or holes
- At temperatures above 700˚C we obtained dimensional changes and substantial grain growth in the region around beam path



main grain area [µm^2]:
19 µm^2 (far beam area)
50 µm^2 (far beam area)

main grain area [µm^2]:
291 µm^2 (far beam area)
982 µm^2 (far beam area)

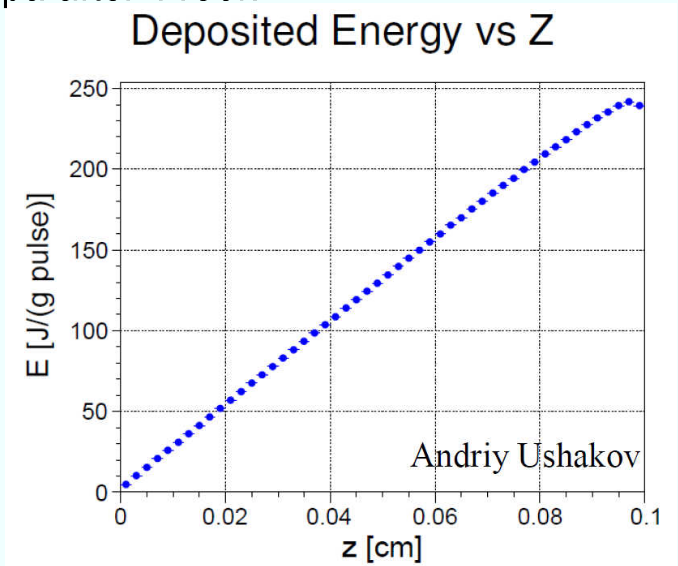


Irradiation tests with thin samples (~0.2mm)

Irradiation of thin Ti alloy samples

- Exit window to photon dump is an issue
  - See Peter Sievers' talks at ECFA-LC 2016 and LCWS 2016
  - window must be moved (low speed) and cooled to avoid overheating by sequent pulses
  - Dpa (FLUKA simulations, A. Ushakov):
    - expect 0.5dpa/56.7hours for stationary window
    - tumbling window in 1km distance to target: 0.5 dpa after 8000h
    - tumbling window in 47m distance to target: 0.5 dpa after 1150h

simulation of energy deposited in exit window to photon dump (E_{e-} = 250GeV, 1312 bunches/pulse)



→ Test what stand thin Ti (alloy) samples using the e- beam at MAMI

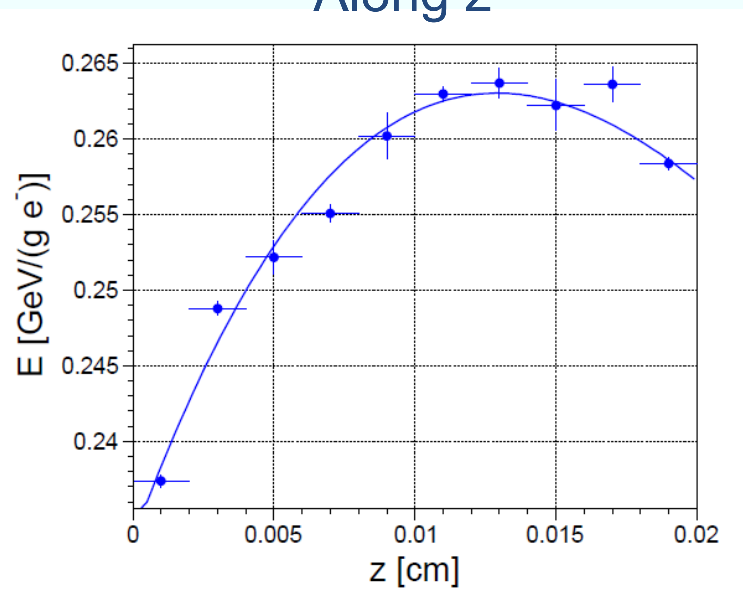
Irradiation of thin samples

- Because of radiation issues, e- beam at 3.5MeV used
- beam sizes:
  - use $\sigma_x = \sigma_y = 285\mu m$ (671μm FWHM)

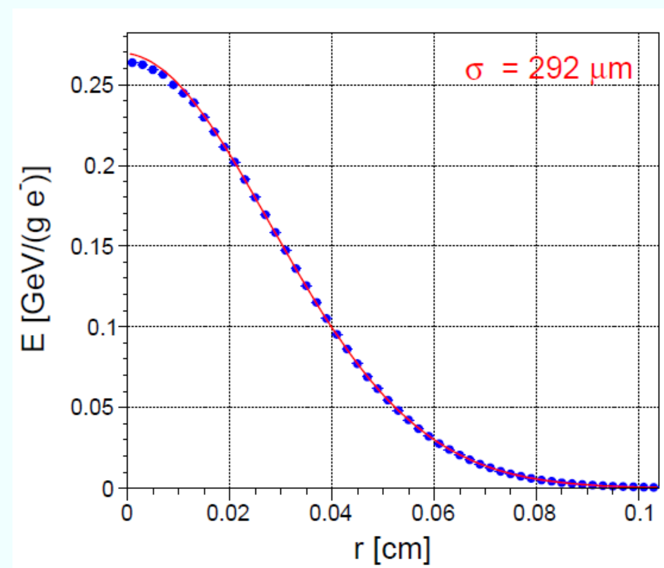
Method	σ_x [μm]	σ_y [μm]
Transition radiation	285	258
Current mesurements	319	277

- Energy deposition in Ti6Al4V:

Along z



radial



Irradiation of thin targets (Nov 2016)

Irradiation regime: 2ms/100Hz, 10uA average current

Cooling: thermal radiation + heat conduction to holder

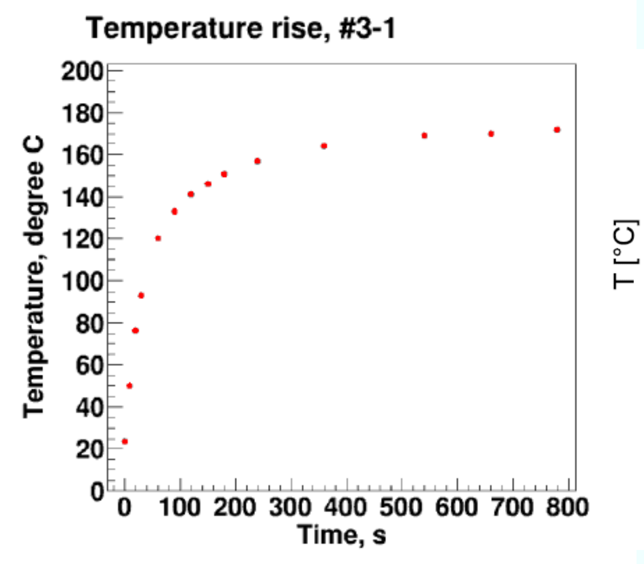
Target	material	thickness [mm]	Max T_{ave} [˚C] (sim.)	ΔT [K] @ max av T (sim.)	#of load cycles
2-1	Ti6Al4V	0.2	455	~40	6.2×10^6
3-1	Ti grade 2 (unalloyed)	0.25	420	~40	6.0×10^6
3-2	Ti grade 2 (unalloyed)	0.14	391	~40	2.9×10^6

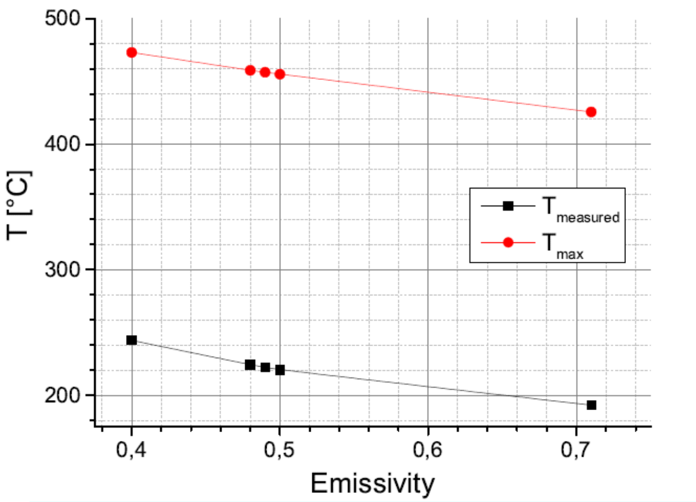
preliminary

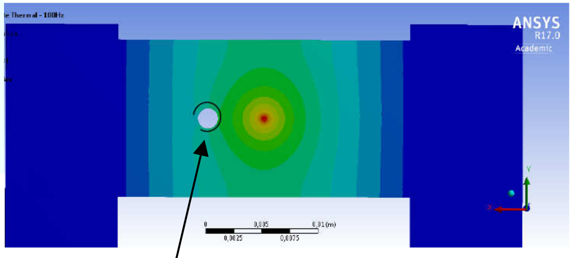
No surface change has been obtained.

Temperature distribution

- We used thermocouples mounted at ~0.5cm distance to beam position
- Heat conductivity in Ti and alloys →
  the heat reaches only after 6-10s the thermocouple;
  high temperature gradient between beam spot and thermocouple position







Thermocouple position

Emissivity ε ~ 0.5 ⇔
max av temperature ~455˚C

- based on temperature evolution at thermocouples the emissivity was estimated and the temperature profile in the samples determined,

Irradiation of thin layers (2017)

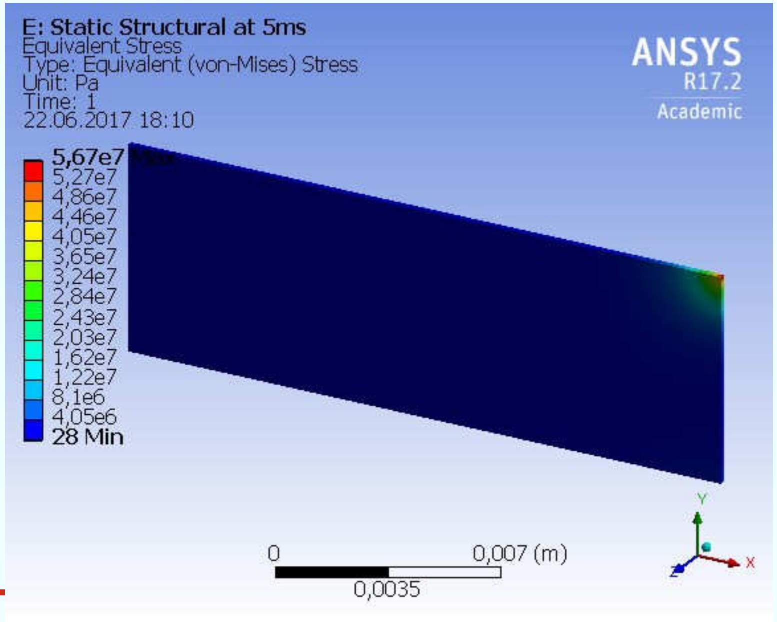
- Irradiation regime:
  - 50uA peak current, but
  - longer pulse length,
  - low rep rate
- Goal: vary the pulse length up to 5ms to achieve high peak load
- Cooling: thermal radiation + heat conduction to holder

- Analysis is still ongoing; dimensional change only at the surface of a 0.2mm Ti6Al4V sample irradiated with 5ms pulses, 1Hz

- Simulation of peak load in 5ms:
  - beam size σ = 285μm, 0.2mm Ti6Al4V, ε = 0.4:

    PEDD = 65.9 J/g/pulse ⇔ ΔT ~ 120 K

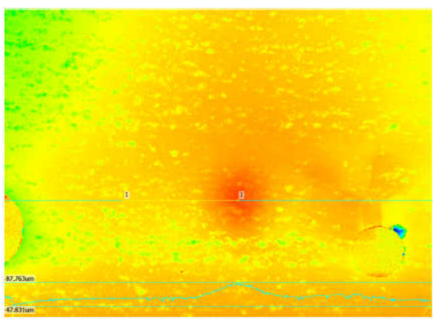
  - estimated stress: $\sigma = \frac{E\alpha\Delta T}{1-\nu} \approx 155\,\mathrm{MPa}$
  - ANSYS: v.Mises stress after 5ms ~57MPa

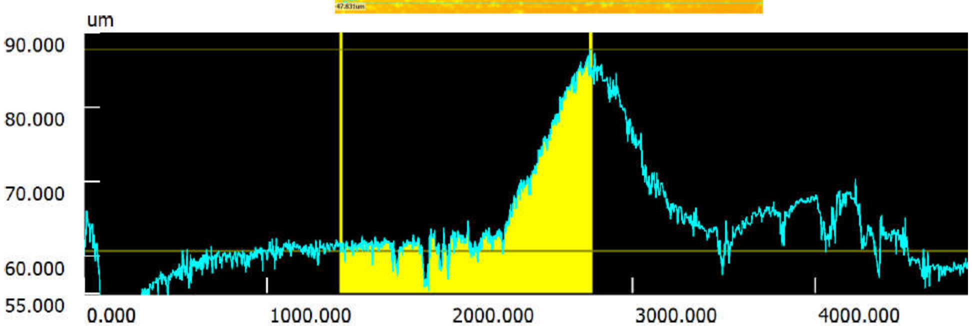


Irradiation of thin layers – preliminary result

- No changes obtained for irradiation with 2ms pulses (100Hz, 1Hz)
- Plastic deformation (27-39um) for 0.2mm Ti6Al4V, 5ms, 1Hz
  - Possible reasons:
    - beam size smaller as expected
    - Lower surface emissivity
  - analyses will be continued

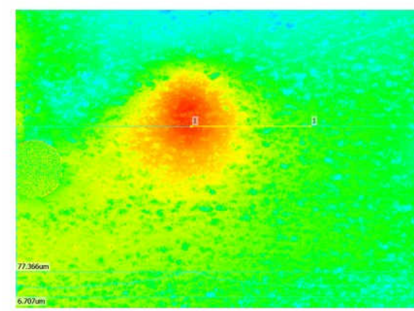
front side

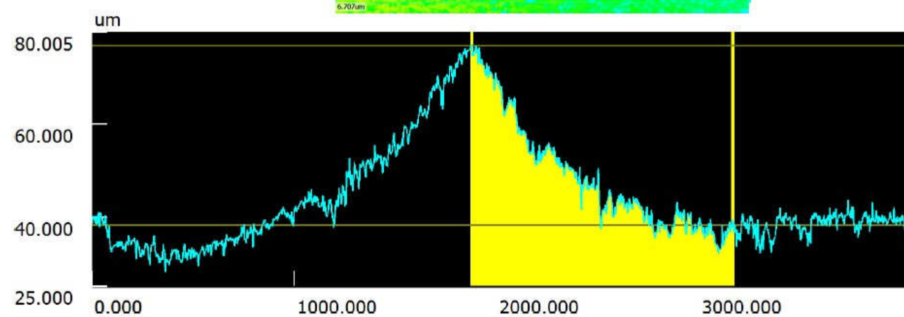




Hight difference = 27 μm

back side





Hight difference = 39 μm

Summary & outlook

- Tests using the e- beam of MAMI demonstrate that Ti6Al4V stands a long-term irradiation with high cyclic load without serious damage
- In the thicker samples, at temperatures above 700˚C dimensional changes as well as grain growth has been obtained
- The iLC e+ target design shoud ensure that the temperatures remain below 700 ˚C
- Also thin samples stand the thigh cyclic load. Further studies are required to understand the dimensional change in one on the thin samples irradiated with 5ms pulses, 1Hz
- Emissivity measurements are ongoing

Summary & outlook (cont'd)

- Plan
  - Continue analyses
  - stress calculations/considerations
    - Pulse at MAMI is substantially longer than at ILC target
    - Polarization upgrade yields high PEDD in target
  - Understand plastic deformation
  - Clarify whether dimensional changes influence creep properties and other parameters important for the construction of the spinning target wheel
  - Check alternative Ti alloys (SF61)
  - Possibility to create dpa as expected in exit window to dump ?
- The irradiation tests are supported by the German Ministry of Science (until spring 2018). Next application (2018-21) will follow in autumn '17.