ILC Target Experiment at MAMI

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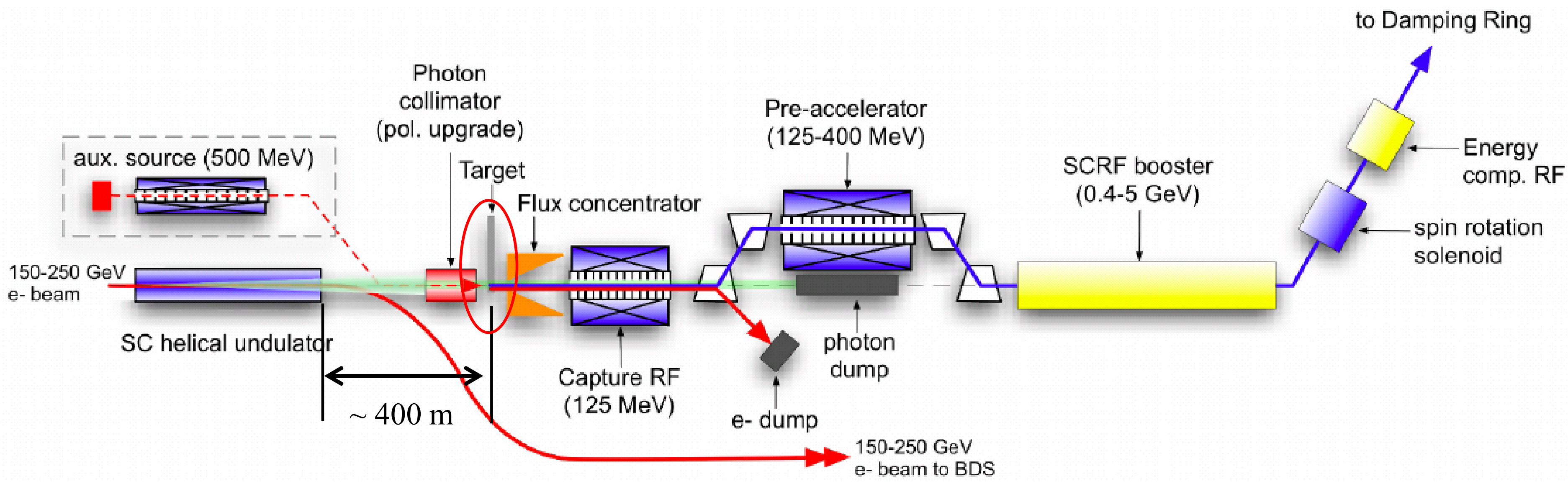
DESY

Overview

- Introduction
- Conversion target for the ILC positron source
- Target material tests
- Exit window to the photon dump
- Summary

Layout of undulator-based positron source



γ beam spot @ target location: r ≈ 1 mm (E_{beam}=250 Gev)

Issues : - Target load (T, stress) → Max. ΔT / pulse 150 ˚C; Δϭ / pulse 250 MPa; Average T in the target 500 - 600 ˚C

- Photon beam dump (window, dump core)

Stationary target will melt after the 1st pulse even with 1312 bunches

Target wheel of Ø1 m is rotated in vacuum with 100 m/s, rotation distributes heat over an arc of 10 cm

Introduction

- Idea to expose the material to high peak and cyclic load the as expected for the ILC components
- Tests using injector of MAMI
- Ti alloy for the positron conversion target

Conversion target

Positron production target

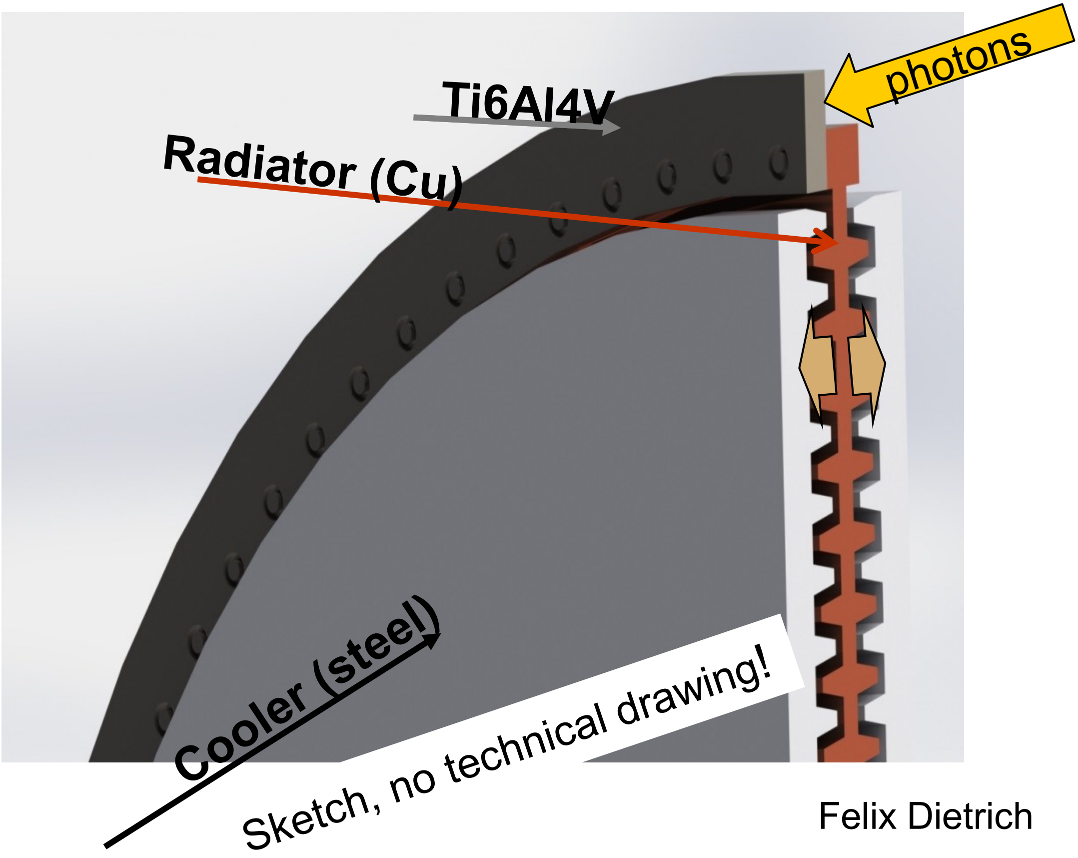
Average power in target ≈ 4.6 kW (250 GeV e-, 2625 bunches/pulse)

Radiative cooling model so far:

- Rotating wheel consists of Ti rim (target) and Cu radiator
- Heat path:
  – thermal conduction Ti → Cu
  – radiation Cu → steel, stationary water cooled coolers
- Target, radiator and cooler are in vacuum

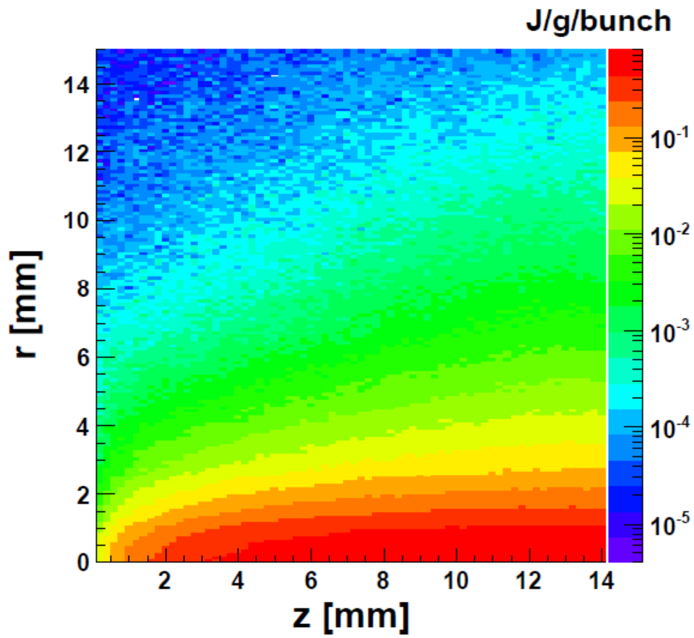
Goal:
Keep the target temperature below the failure limit of Ti 6Al4V

load cycles / year (5000 h) at the same target position ≈ $3 \cdot 10^6$

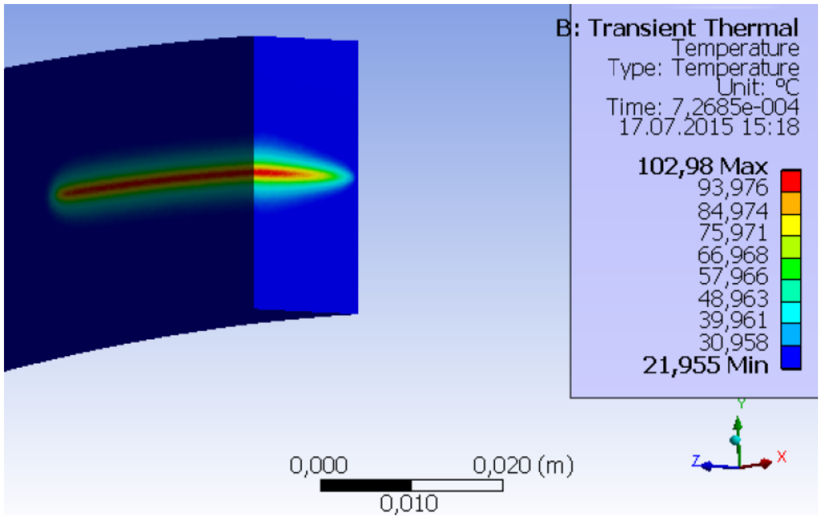


Felix Dietrich

Edep and T development in the target



Simulated energy deposition in the target from the undulator photons created by 250 GeV e^-



Typical max. temperature rise – after the first pulse for the nominal case (250 GeV, 1312 bunches)

Max. ΔT / pulse 150 ˚C

$\Delta\sigma$ / pulse 250 MPa

Average T in the target 500 - 600 ˚C

Andriy Ushakov

Material tests

Material tests, idea

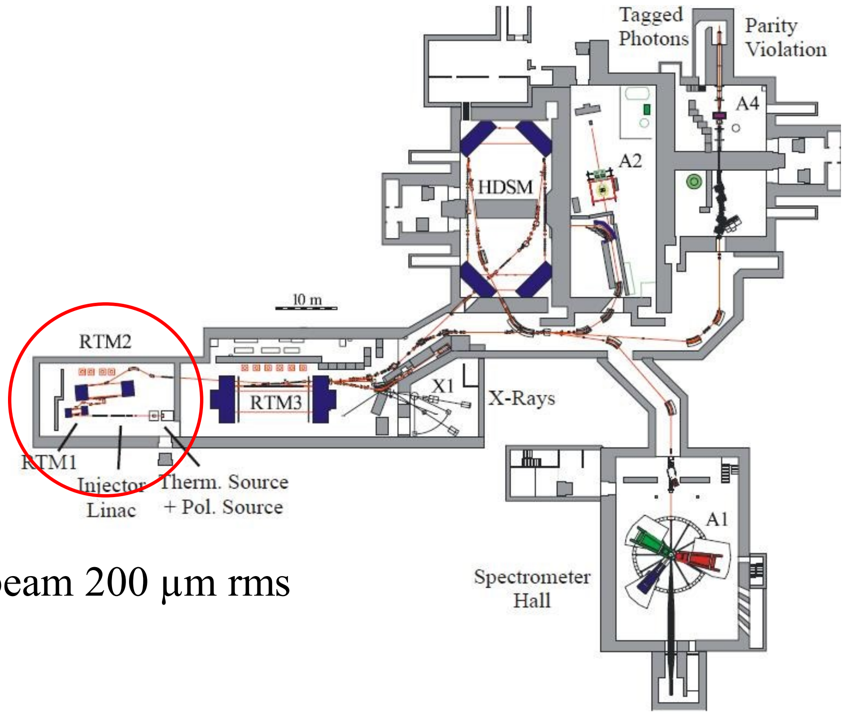
Idea:

Simulate the load to the ILC target imposed by E_{dep} from γ using e^-

At MAMI we need beam size below 200 micron rms, 2 ms long pulses with peak current of 50 µA

Mainz Microtron

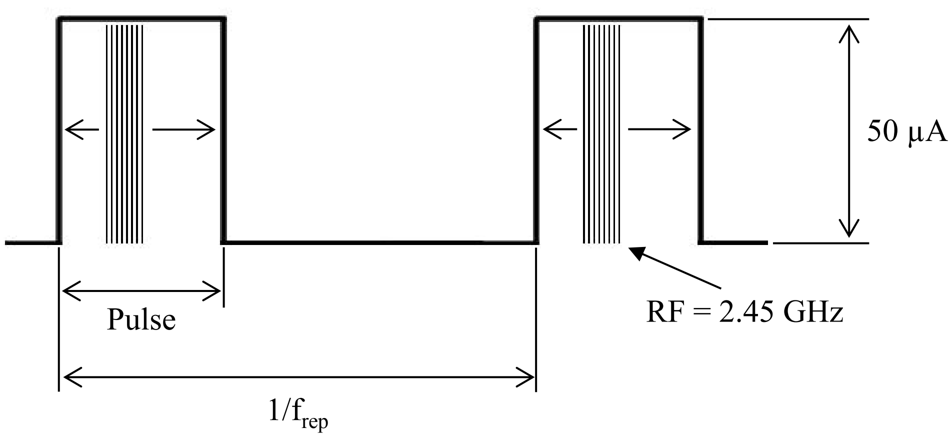
The Mainz Microtron (MAMI) is an accelerator for electron beams run by the Institute for Nuclear Physics of the University of Mainz used for hadron physics experiments



cw e^- beams > 20 μA (polarized) or up to 100 μA (unpolarized)

In our tests:
14 MeV e^-, 10 μA average beam current, Gaussian beam 200 μm rms

e- /s (cw operation) ~O(10^{14})



Collaborators in Mainz

Kurt Aulenbacher

Philipp Heil

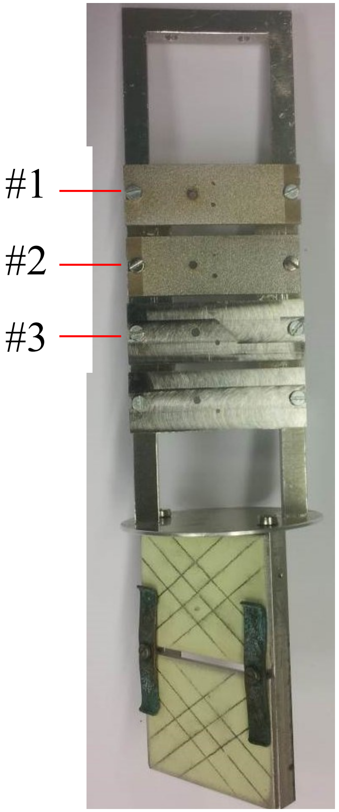
Valery Tioukine

+ Marco Dehn et al. (operators of MAMI)

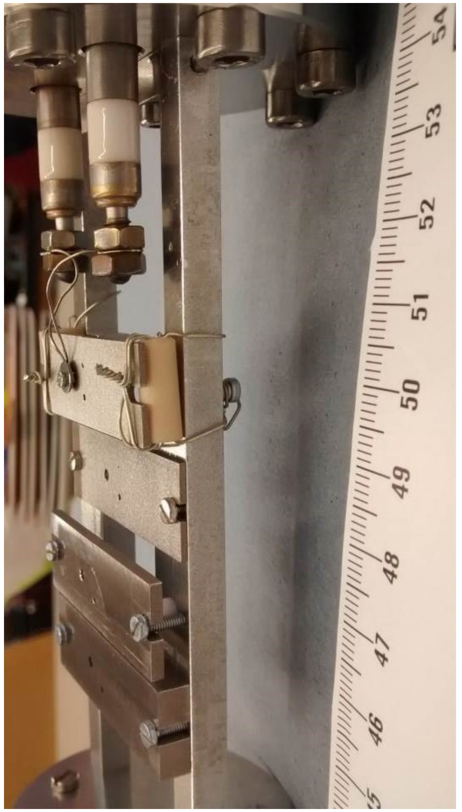
Material for the tests

Material of targets:
Grade 5 Ti – Ti6Al4V

Target	#1	#2	#3
Thickness	1 mm	1 mm	2 mm
Surface	Rough	Rough	Smooth
Fixation	Not fixed	Fixed	Fixed
Cooling	Radiation	Radiation + heat conduction to the holder	Radiation
Regime	100 Hz, 2 ms, 10 µA average	67 Hz, 3 ms, 10 µA average	100 Hz, 2 ms, 10 µA average

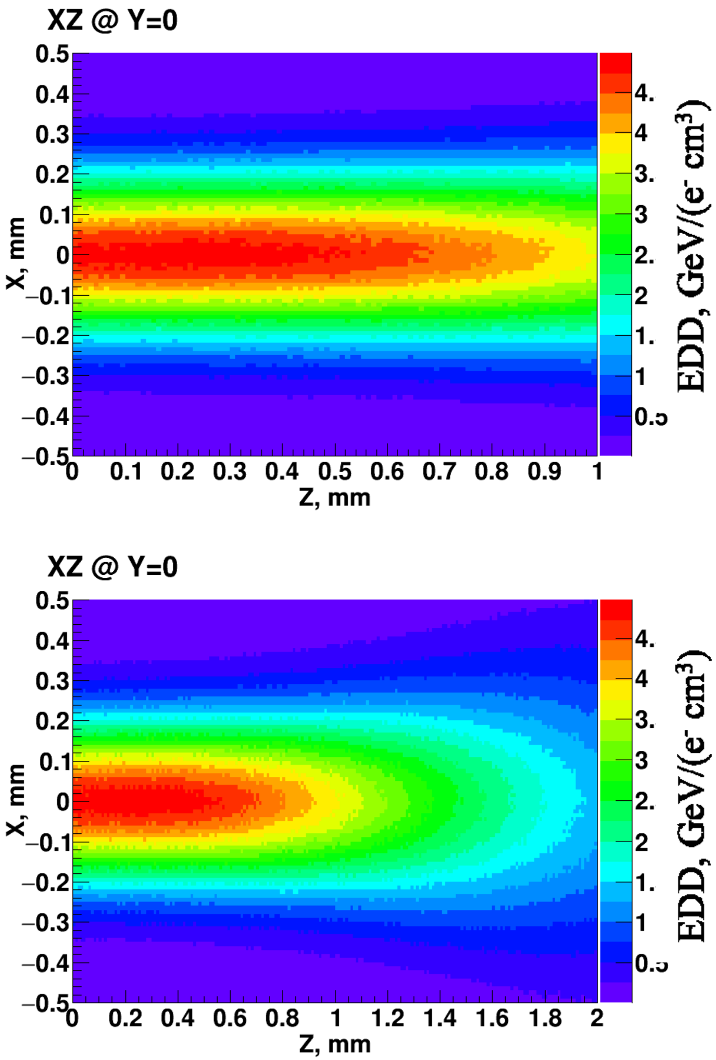


Front view to the target assembly


Side view to the target assembly

Diagnostics: temperature and current measurement for target #1

GEANT4 simulations



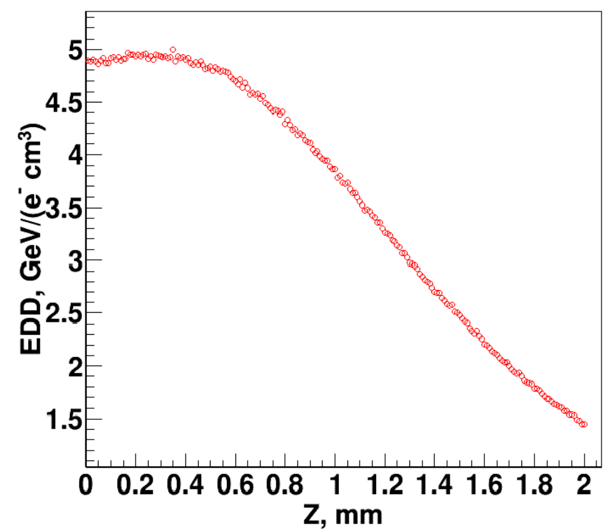
Energy deposition for 1 mm and 2 mm thick targets

Peak energy deposition (PEDD):

PEDD = 4.87 GeV/(e^- cm^3) = 4.49 $\cdot 10^{-5}$ J/(g$\cdot$bunch)

Number e^- per bunch = 2.55$\cdot 10^5$

Number of bunches per pulse = 4.9$\cdot 10^6$ (2 ms) or 7.35$\cdot 10^6$ (3 ms)



Energy deposition vs depth along the beam axis

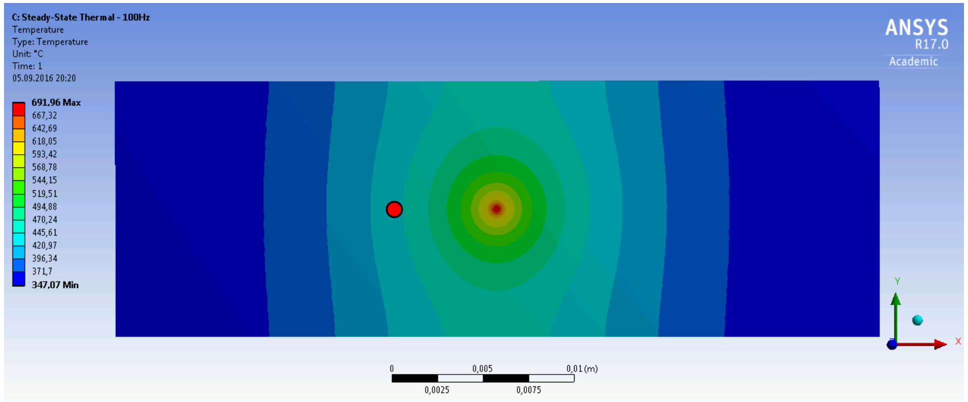
DESY

ANSYS simulation, target #1

Target	#1
Thickness	1 mm
Surface	Rough

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

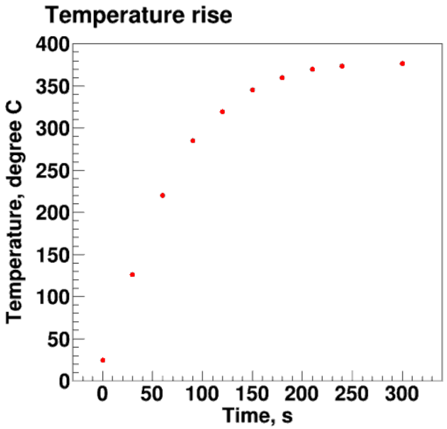
Max. T in target #**1**: **691 + 82 °C**

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



→ ε ≳ 0.5

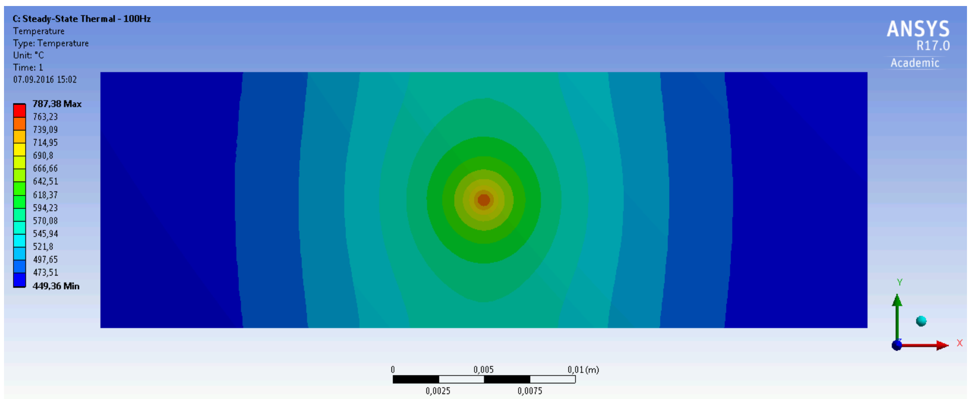
Real temperature measurement at the position ●

ANSYS simulation, target #3

Target	#3
Thickness	2 mm
Surface	Smooth
Fixation	Fixed
Cooling	Radiation

Neglect thermal conductivity to the holder via ceramics and fixation screws

Consider cooling by radiation from the surface only

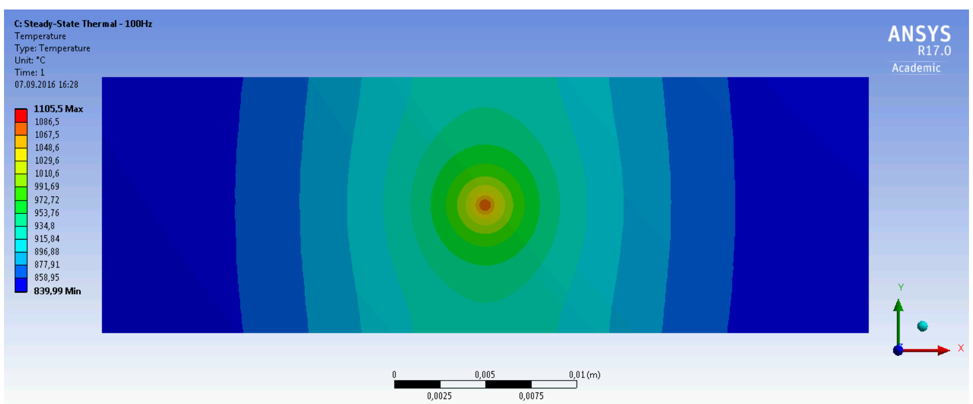


$\varepsilon = 0.5$

Max. average T = 787 °C

Max. T rise / pulse (@ 760 °C) = 88 °C

Max. T in target #**3**: **787 + 88 °C**



Although, if $\varepsilon = 0.1$:

Max. average T = 1105 °C

Results

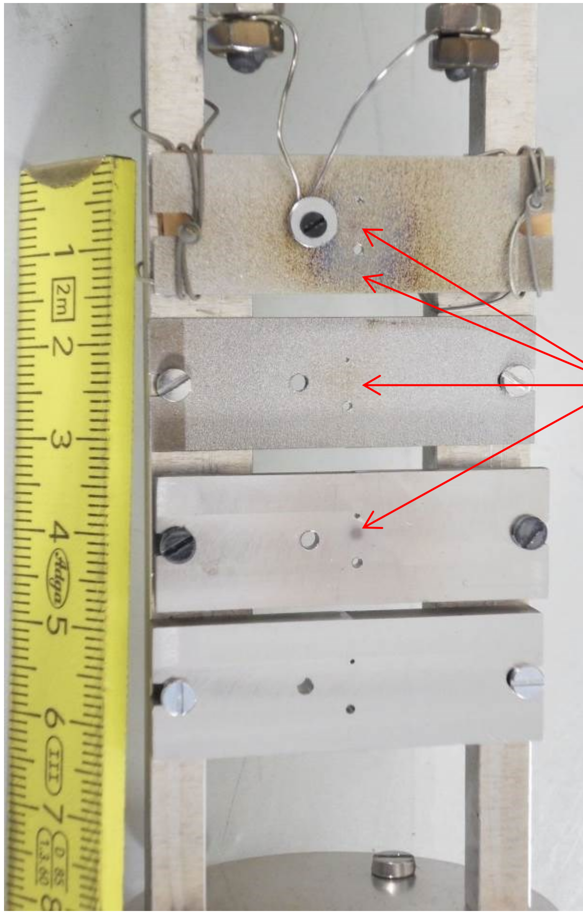
Target	Thickness	Regime	ΔT @ 20 ˚C	Load cycles	Years of ILC operation*
#1	1 mm	100 Hz, 2 ms, 10 μA average	110 ˚C	$6.82 \cdot 10^6$	2.46
#2	1 mm	67 Hz, 3 ms, 10 μA average	-	$1.24 \cdot 10^6$	0.45
#3	2 mm	100 Hz, 2 ms, 10 μA average	145 ˚C	$5.17 \cdot 10^6$	1.87

All targets survived the irradiation – no cracks or holes

Plastic deformation for the target #3 (exposed to a higher temperature)

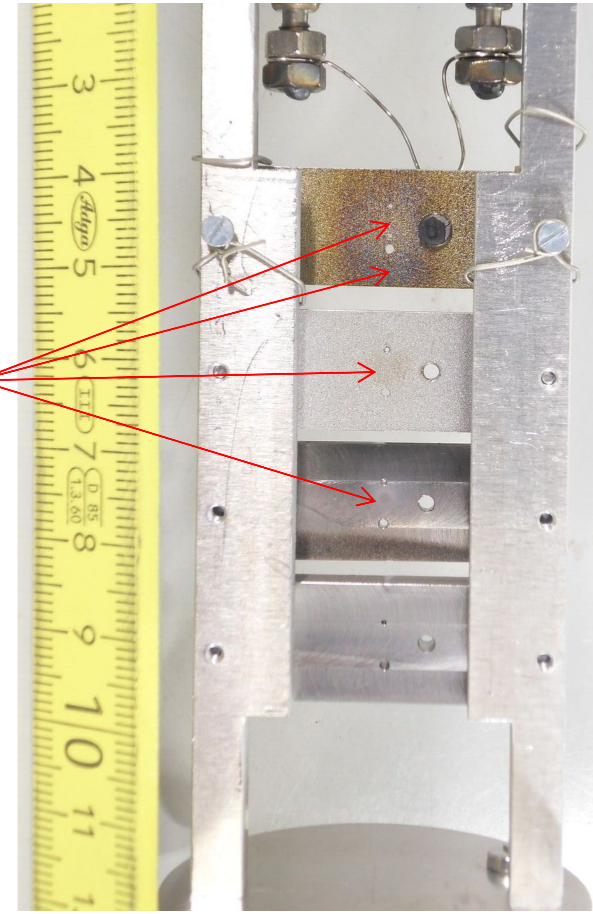
*1 year of ILC operation: 5000 h, 5 Hz, each point is irradiated every 6.5 s

Targets after testbeam



Holder with targets, entrance side

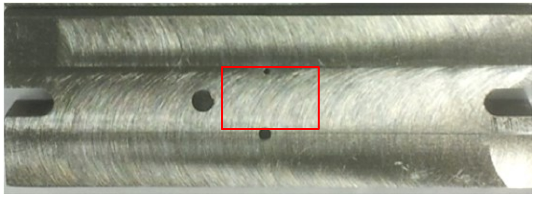
Irradiation spots



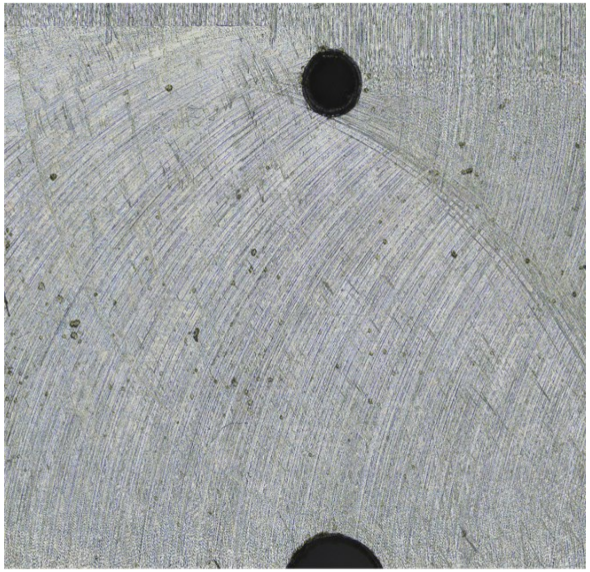
Holder with targets, exit side

Surface investigation

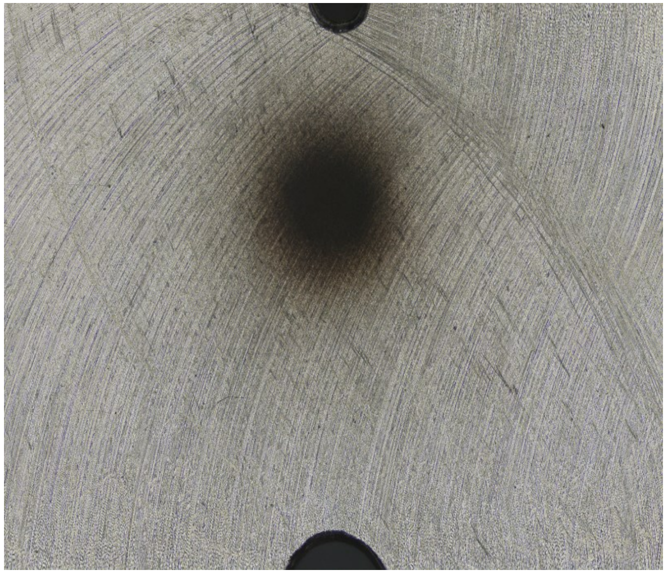
Surface investigation with 3D Laser Scanning Confocal Microscope



Target #3, 2 mm thick, entrance side



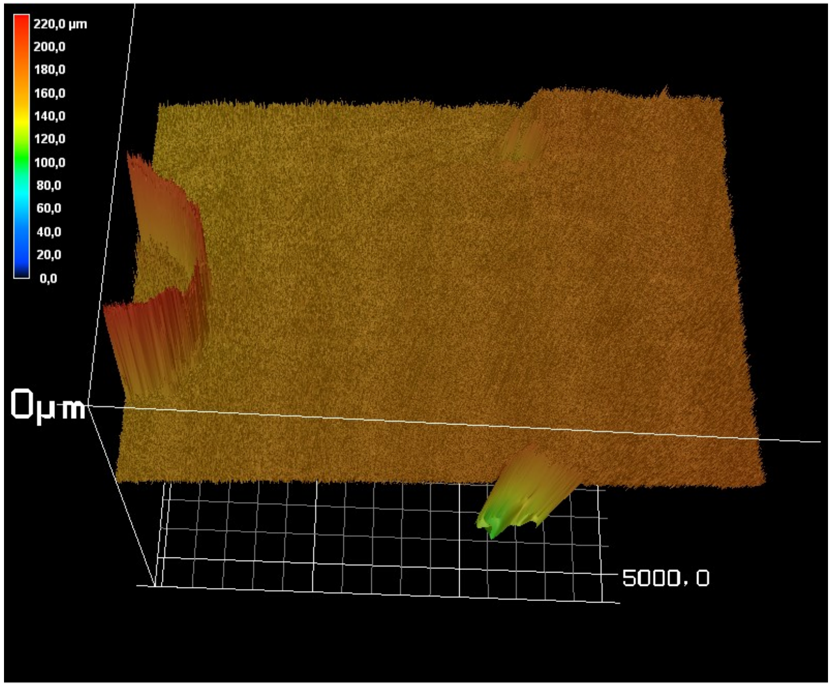
Before



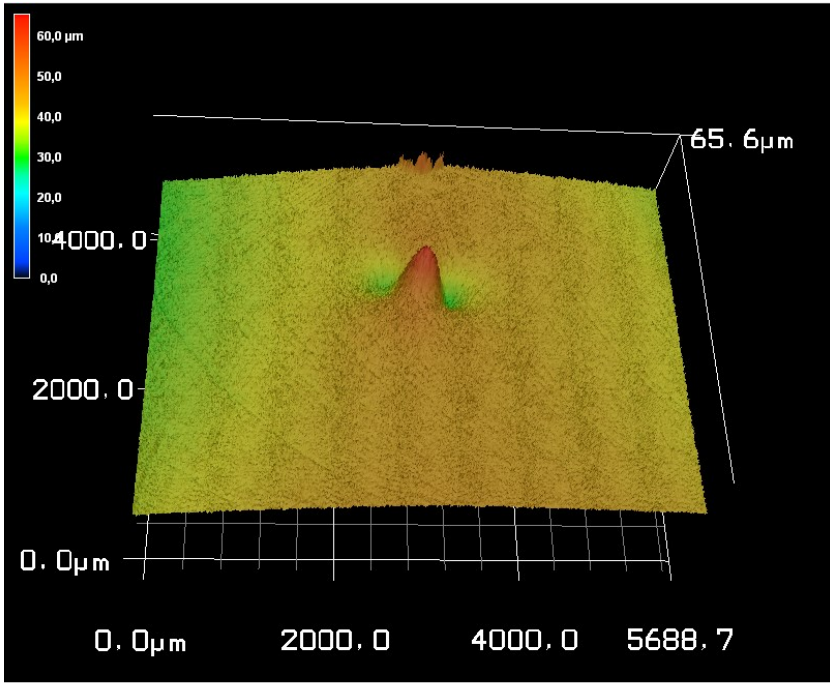
After

Beam spot clearly seen, major changes

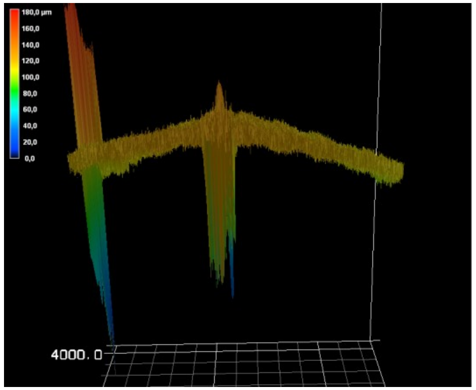
Target #3, surface investigation, entrance side



Before



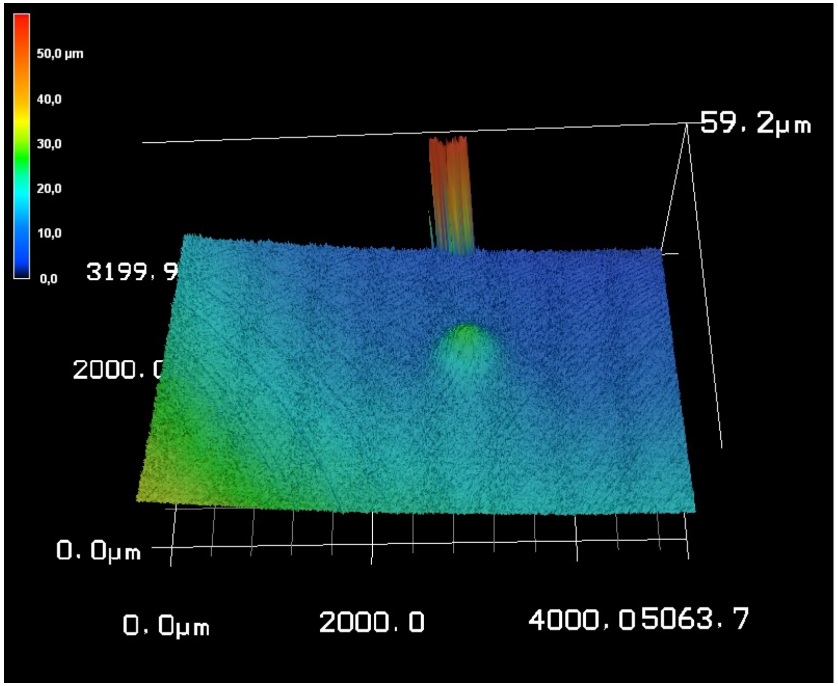
After

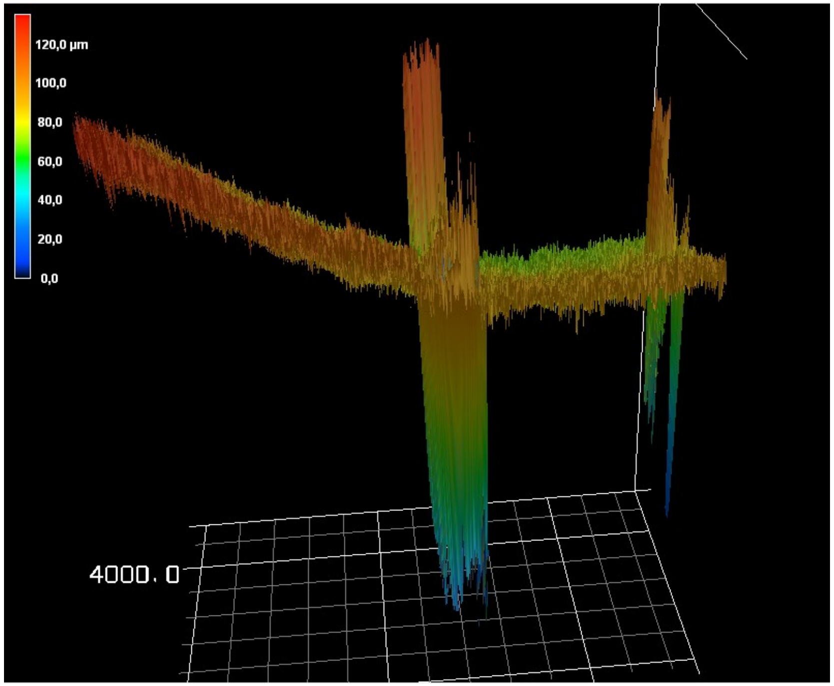


Flat surface observed before irradiation

Plastic deformation after irradiation, 1 peak and 2 deeps observed in the beam spot: ~ 35 µm from the bottom of the deep to the top of the peak

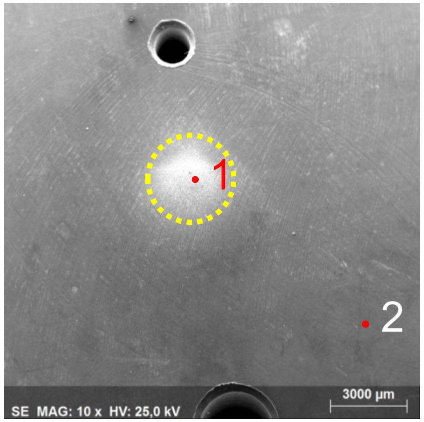
Target #3, surface investigation, exit side





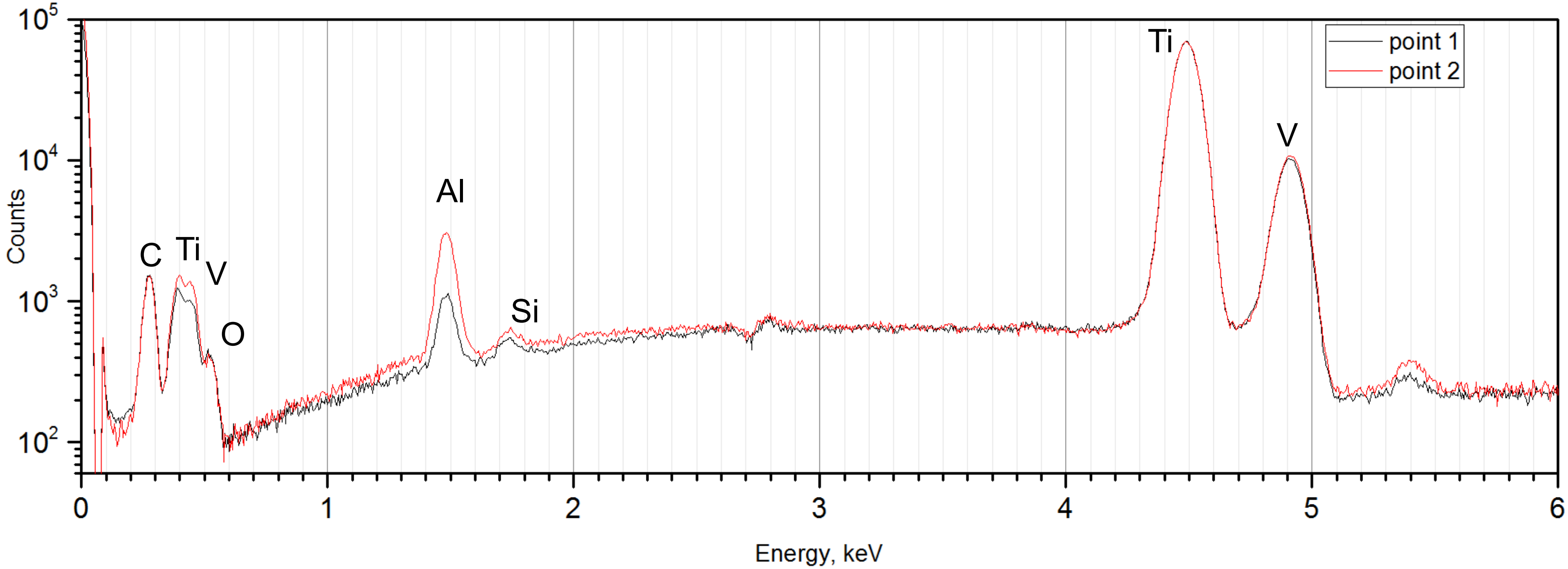
Plastic deformation after irradiation, 1 peak observed in the beam spot: ~ 25 µm from the surrounding to the top of the peak

Target #3, SEM image (Yegor Tamashevich)



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

Aluminum concentration is lower in the beam spot area



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

Photon dump

Vacuum window for the photon dump

The photon beam has to be dumped, design is still under discussion

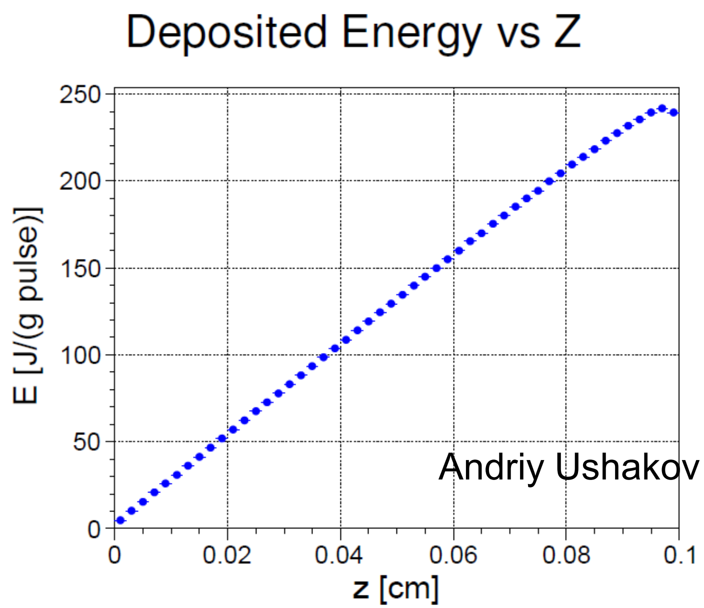
- Photon beam power: up to 200 kW
- Photon beam size on exit window: r ~1 mm
- # of photons ~ 10^{16} per second, E ~ O(40 MeV)
- Window has to be thin enough to survive the high load and rather thick to hold the pressure

Goal: find the optimal window thickness

→ Tests at MAMI with Ti foils (0.15 – 0.25 μm)

First tests started in Nov. 2016

Energy deposited by undulator photons in Ti window along Z (a pulse of 1312 bunches, 250 GeV e^-)



Summary

- Ti6Al4V targets survived high cyclic load of up to $6.82 \cdot 10^6$ cycles heated to average temperature 690 °C

- No major damage to the material after the tests at the average temperature of 690 °C

- Noticeable changes only for the material (plastic deformation, surface change) exposed to the temperatures >780 °C

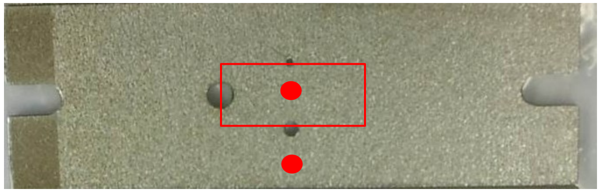
- Next steps:
  - evaluate the data for the irradiated samples (target & window)
  - analysis of the changes in the material bulk, hardness measurements
  - thermal stress calculations for irradiated targets
  - simulation of plastic deformation

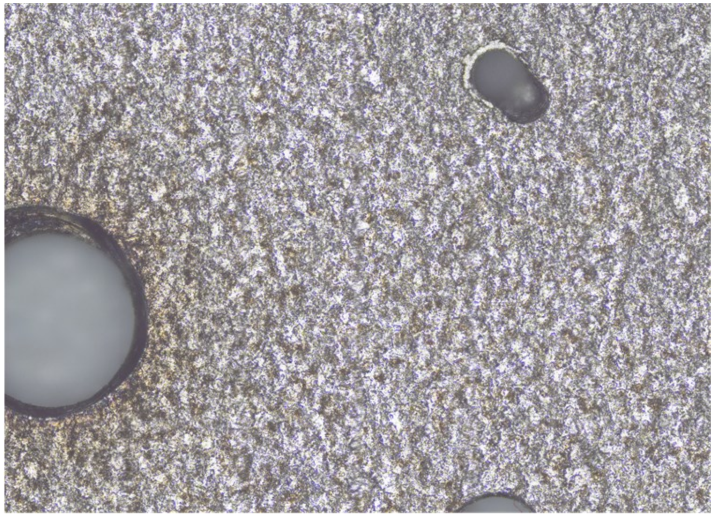
Thank you for your attention!

Backup slides

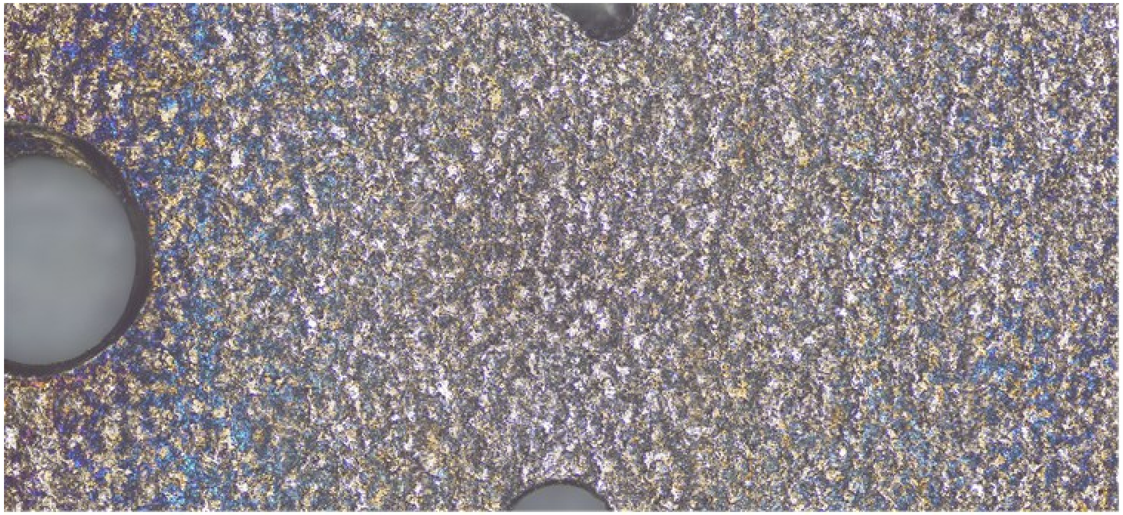
Target #1, entrance side, surface investigation

Surface investigation with 3D laser scan microscope VK-X100/X200 series





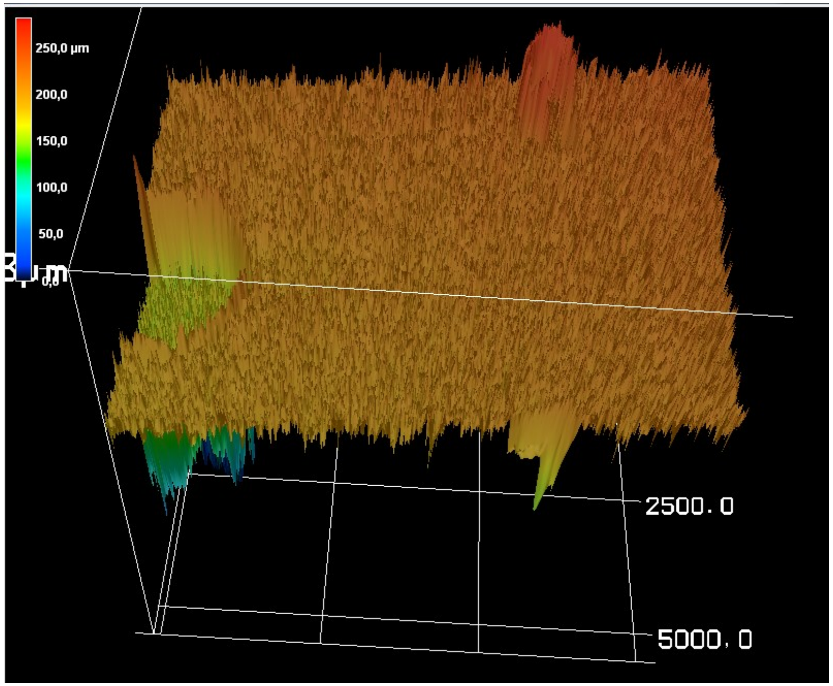
Before



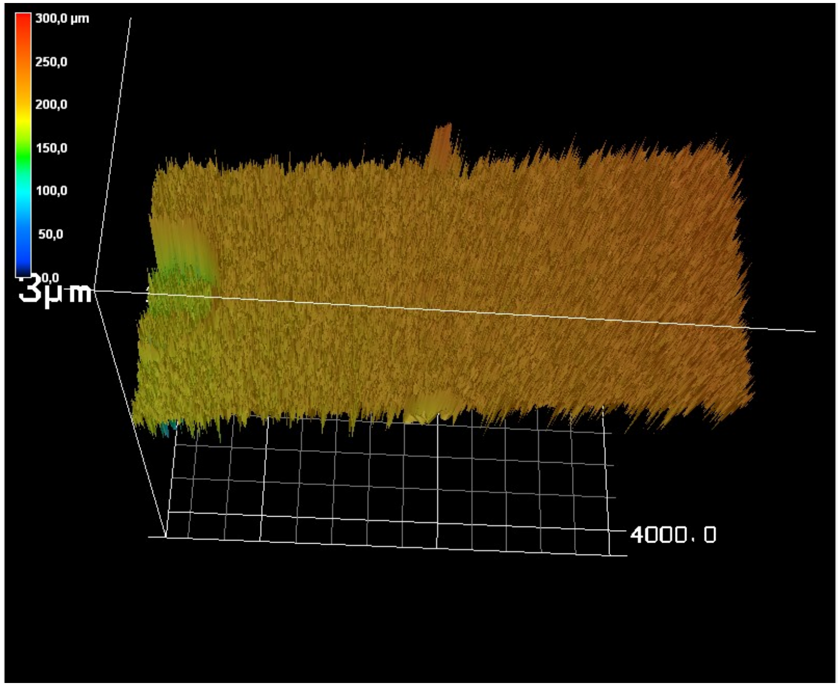
After

Color change observed, no major changes to the surface

Target #1, entrance side, surface investigation



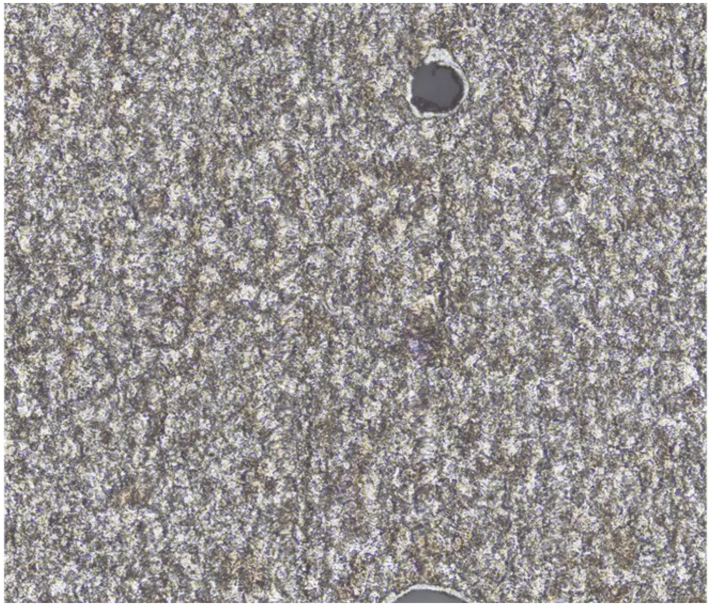
Before



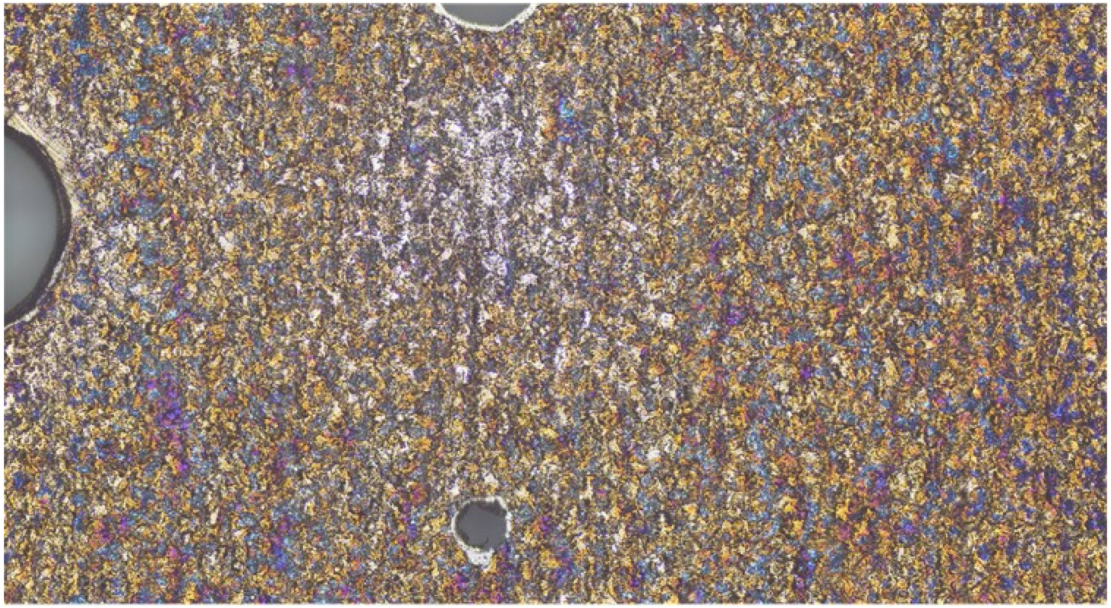
After

Flat surface observed before and after irradiation, no major changes

Target #1, exit side, surface investigation



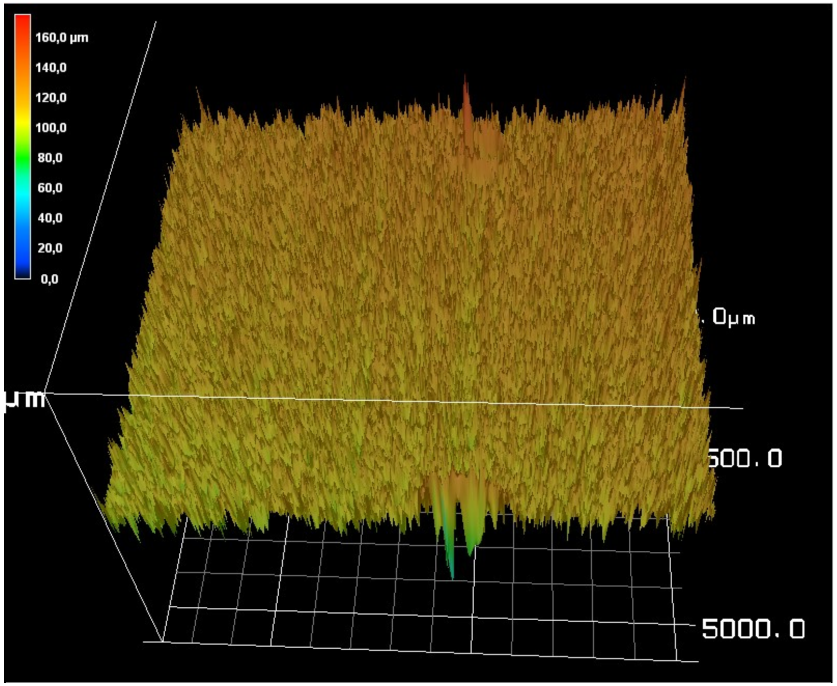
Before



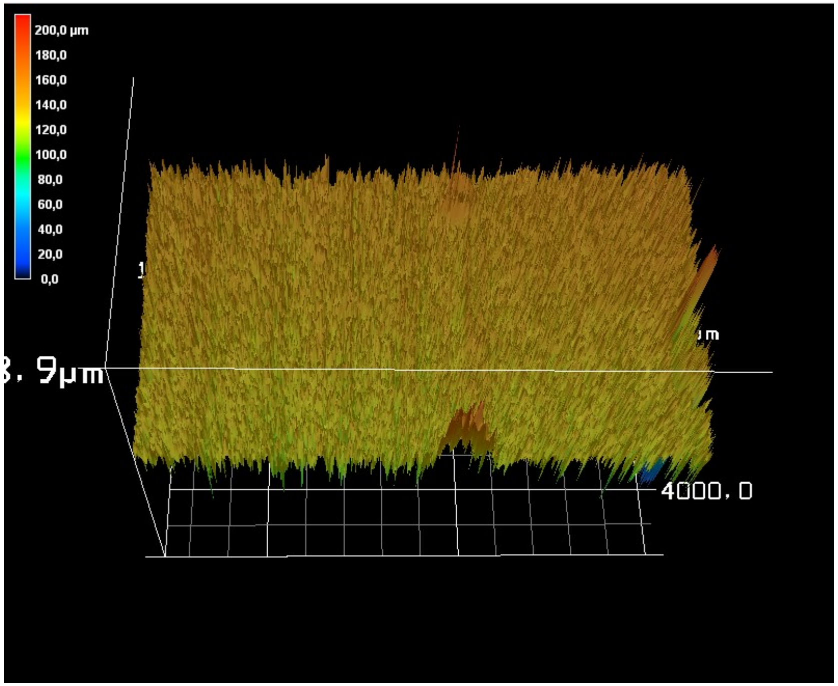
After

Color change observed, no major changes to the surface

Target #1, exit side, surface investigation



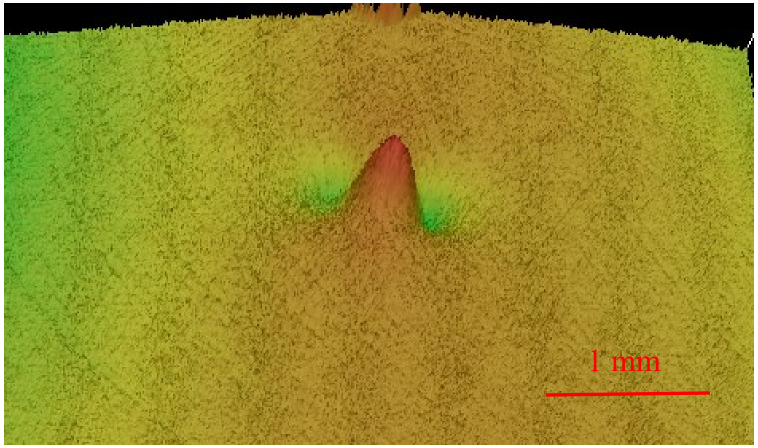
Before



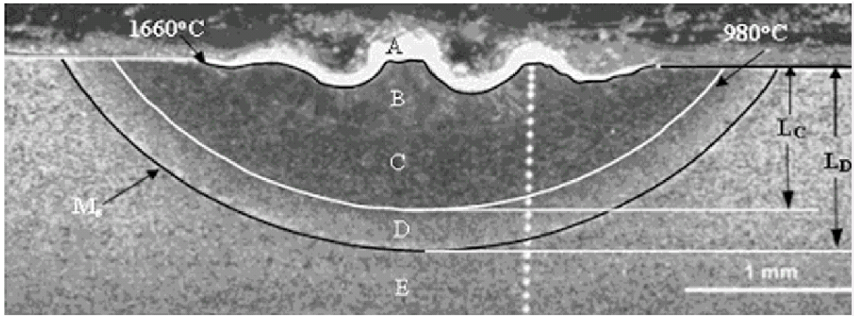
After

Flat surface observed before and after irradiation, no major changes

Target #3, entrance side



Surface of target #3

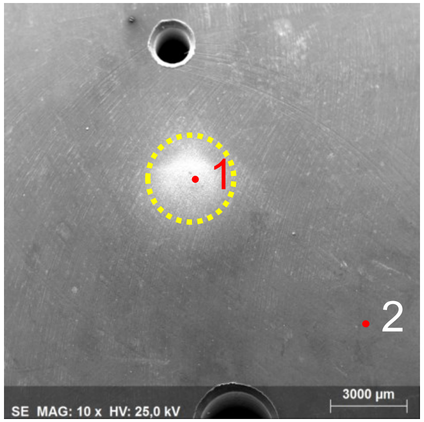


Surface of a Ti6Al4V plate heated by laser beam *

Heated up to 1660 °C ?

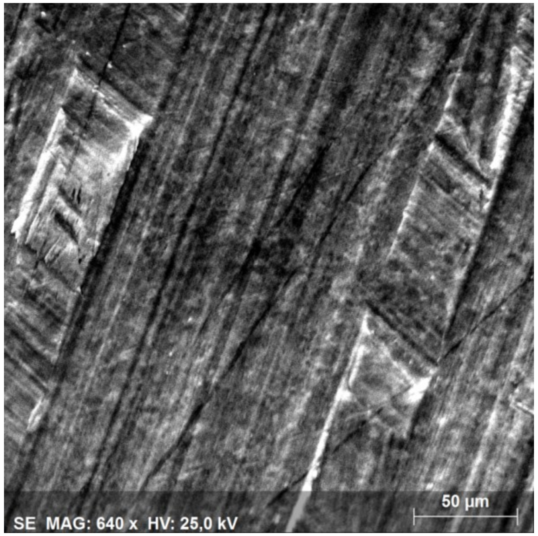
* J. Yang et al., Journal of Materials Processing Technology 210 (2010) 2215-2222

Target #3, SEM image (Yegor Tamashevich)

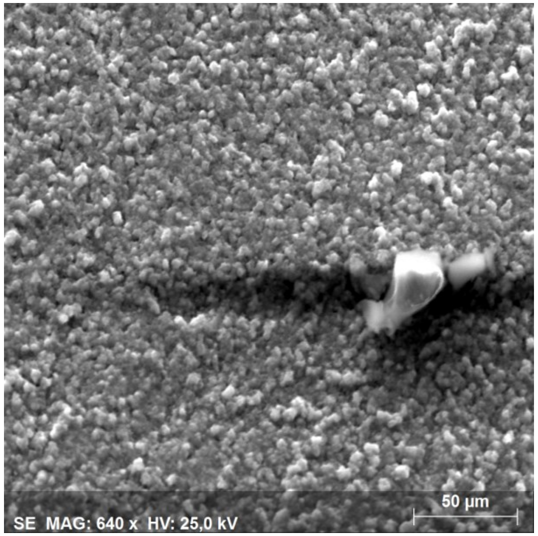


Point 1 – Beam spot area
Point 2 – Un-irradiated area

Surface outside beam spot



Beam spot area



Ablation and condensation process ?