Ultrafast laser processing of inner LHC beam pipe surfaces for secondary electron yield reduction

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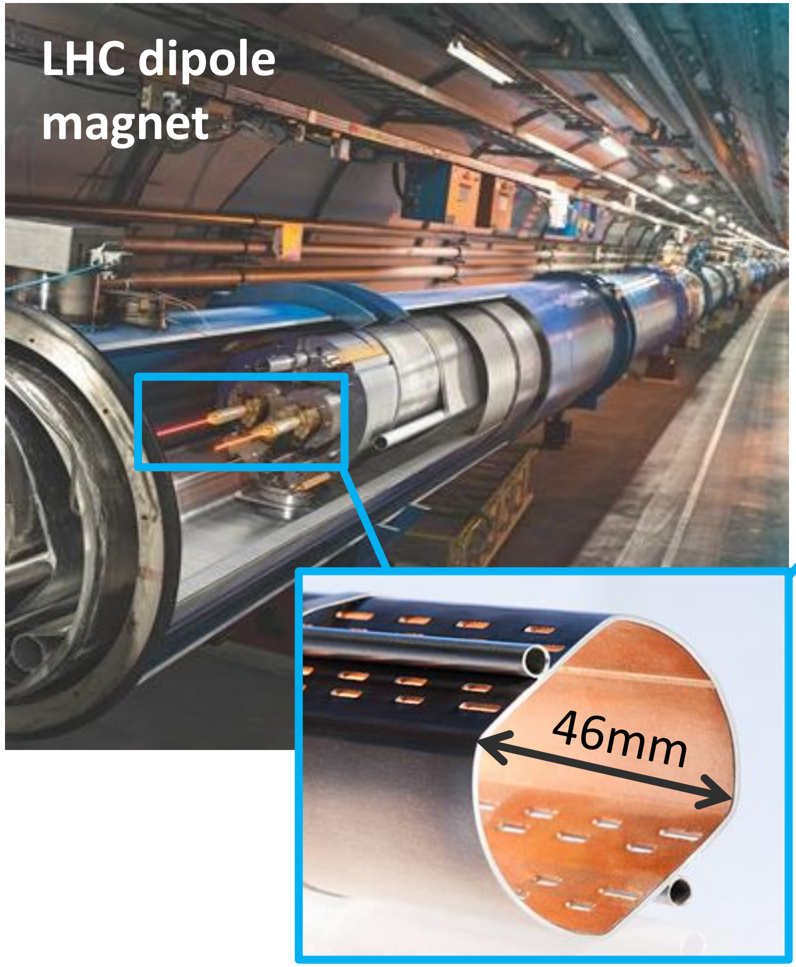
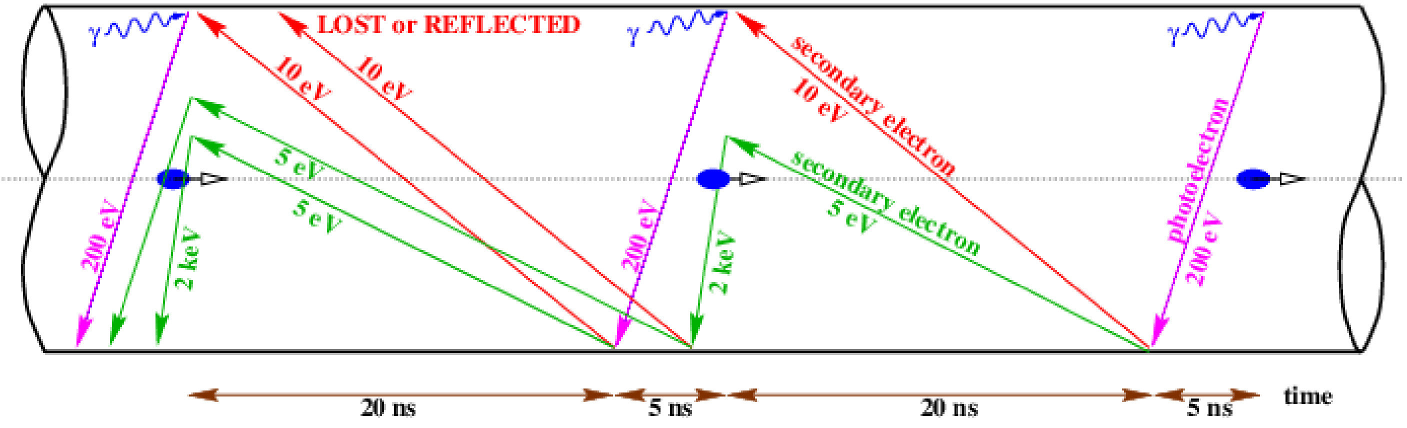
Why Secondary Electron Yield reduction?



Beam pipe

Problem: Electron clouds deteriorate proton beam quality

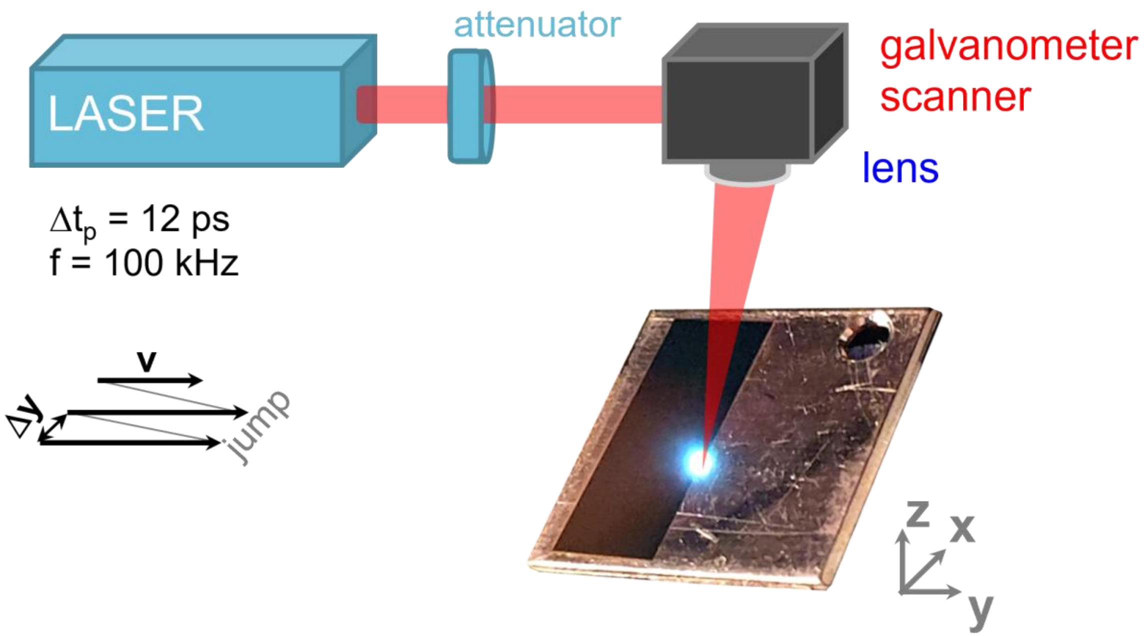


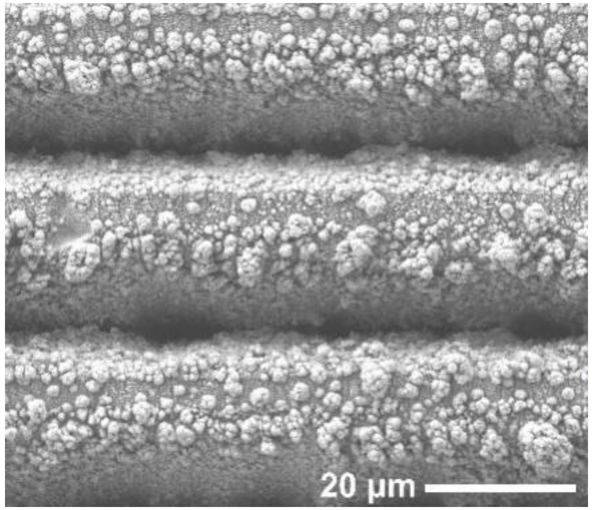
F. Ruggiero, F. Zimmermann, Possible Scenarios for an LHC Upgrade (2005).

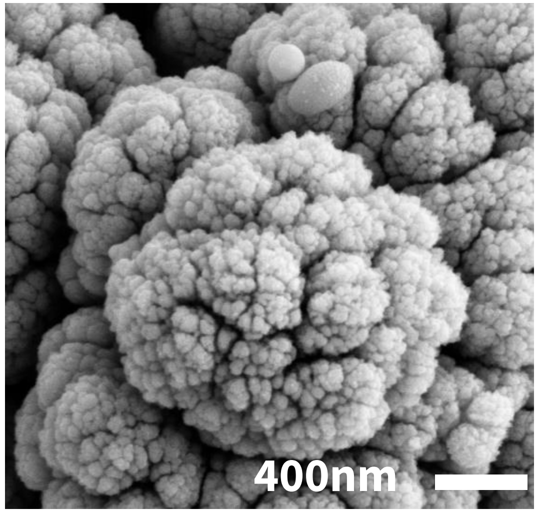
Solution: Reduction of secondary electron yield

How: laser-induced surface roughening

Laser-induced surface roughening





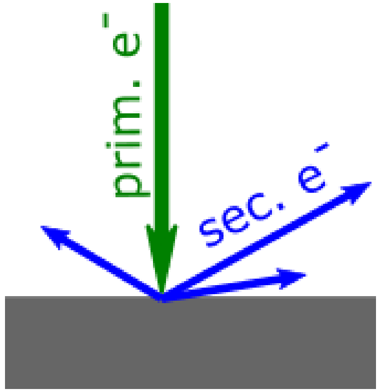


➢ **Variation of laser power, scanning speed and line distance**

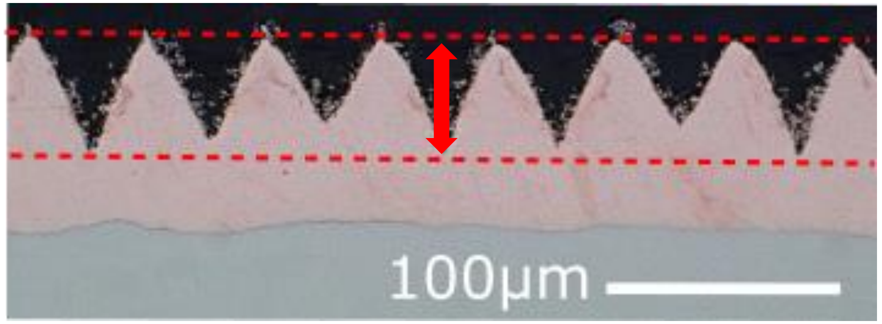
Surface requirements for implementation in LHC

1) Secondary Electron Yield ≤ 1

$$\text{SEY} = \frac{\#\text{secondary e}^-}{\#\text{primary e}^-}$$



2) Modification depth < 25 µm

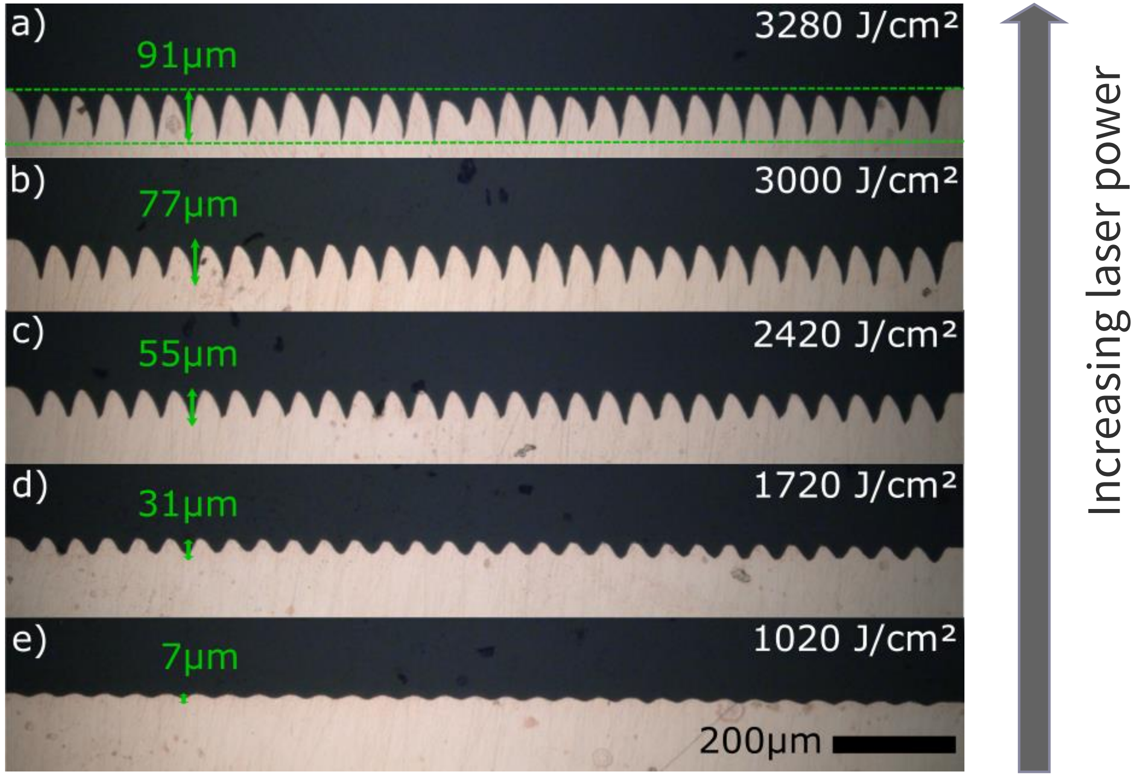


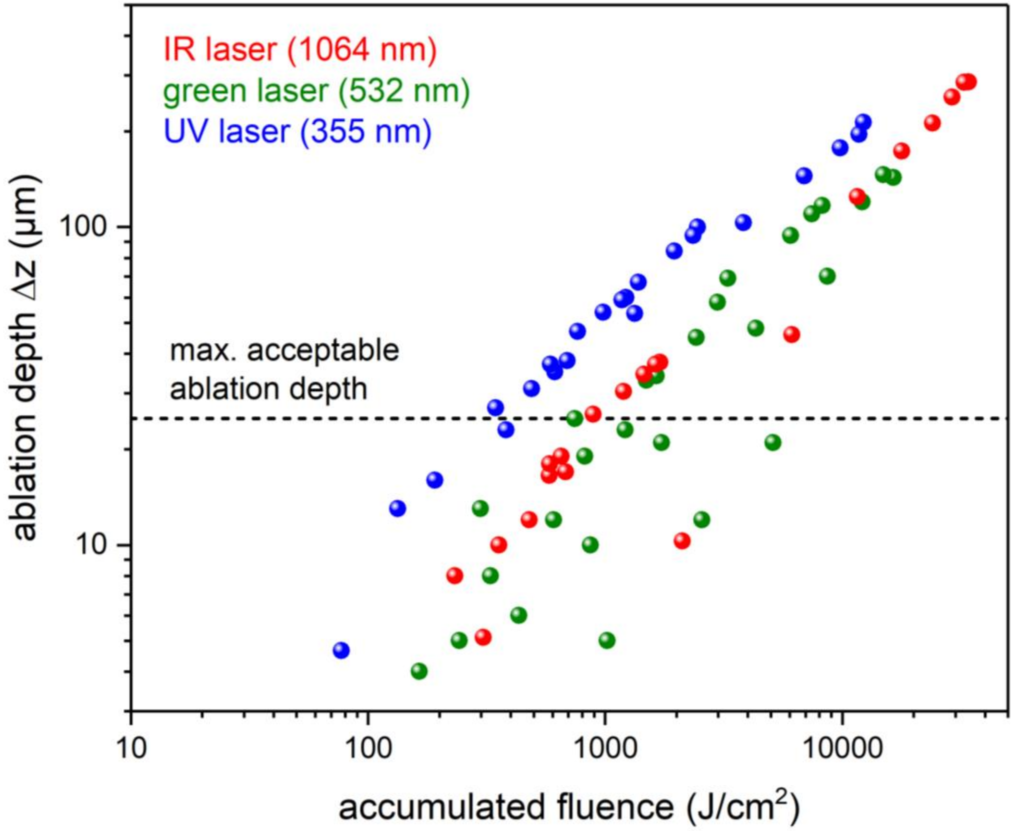
3) Limitation of loosely bound surface particles

➢ **Laser parameters must be tuned to meet surface requirements**

Microstructures

$$acc.fluence = \frac{laser\ power}{line\ distance\ \cdot\ scanning\ speed}$$





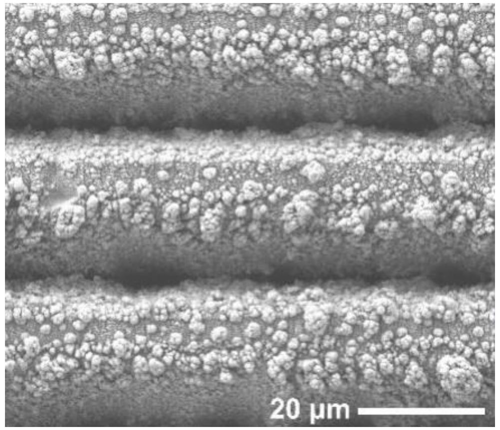
Higher accumulated fluence:

- More material removal
- Deeper trenches

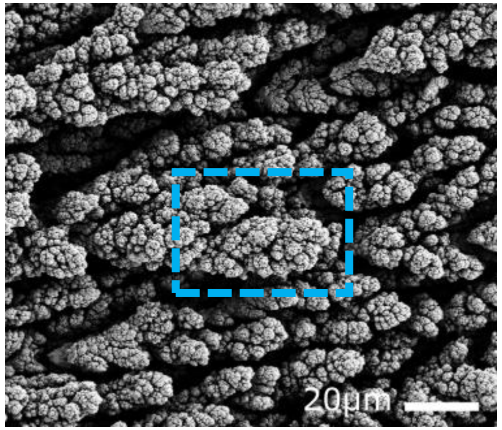
E. Bez et al., *Influence of wavelength and accumulated fluence at picosecond laser-induced surface roughening of copper on secondary electron yield*

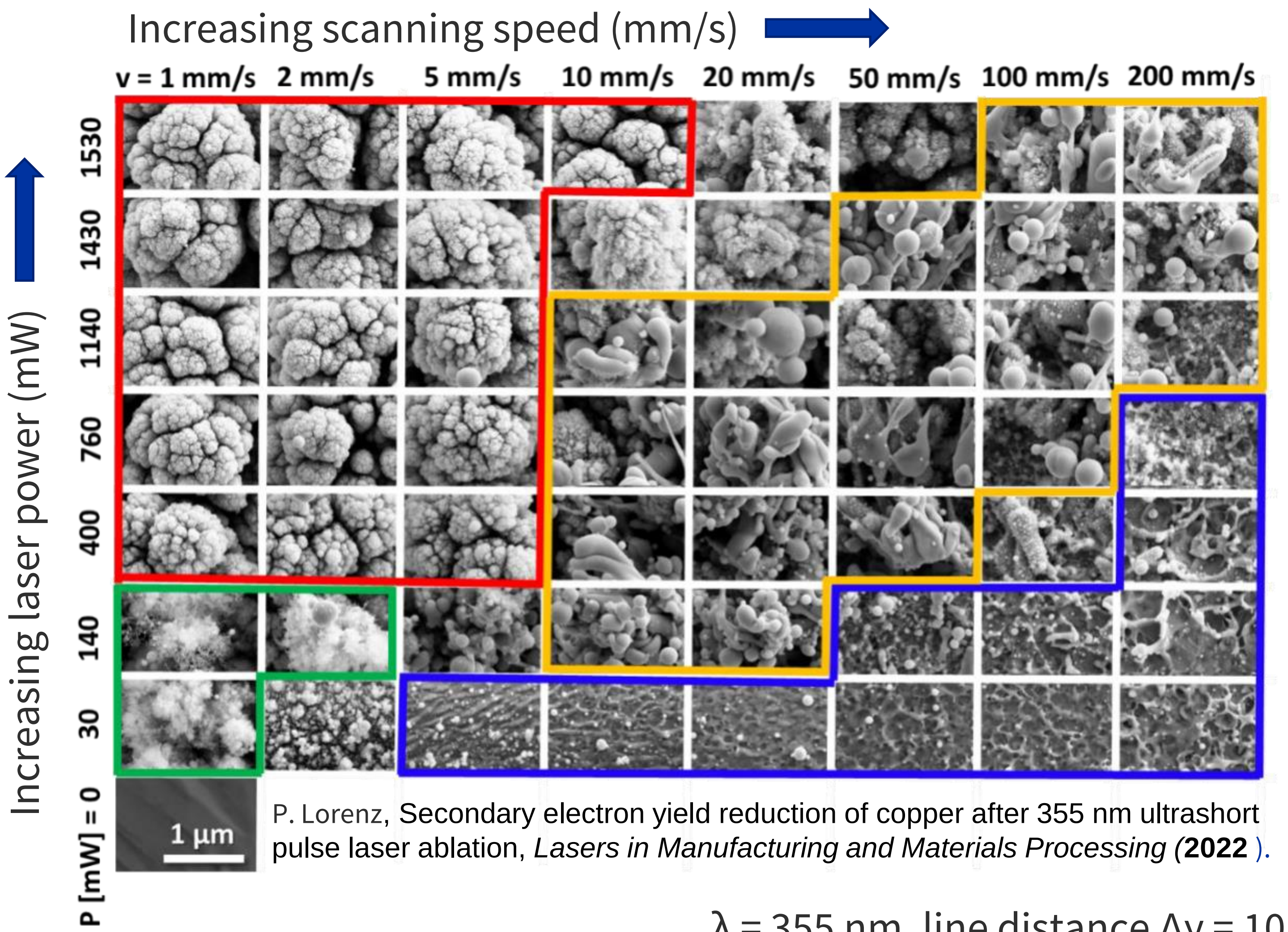
Nanostructures

Non-overlapping lines



Overlapping lines

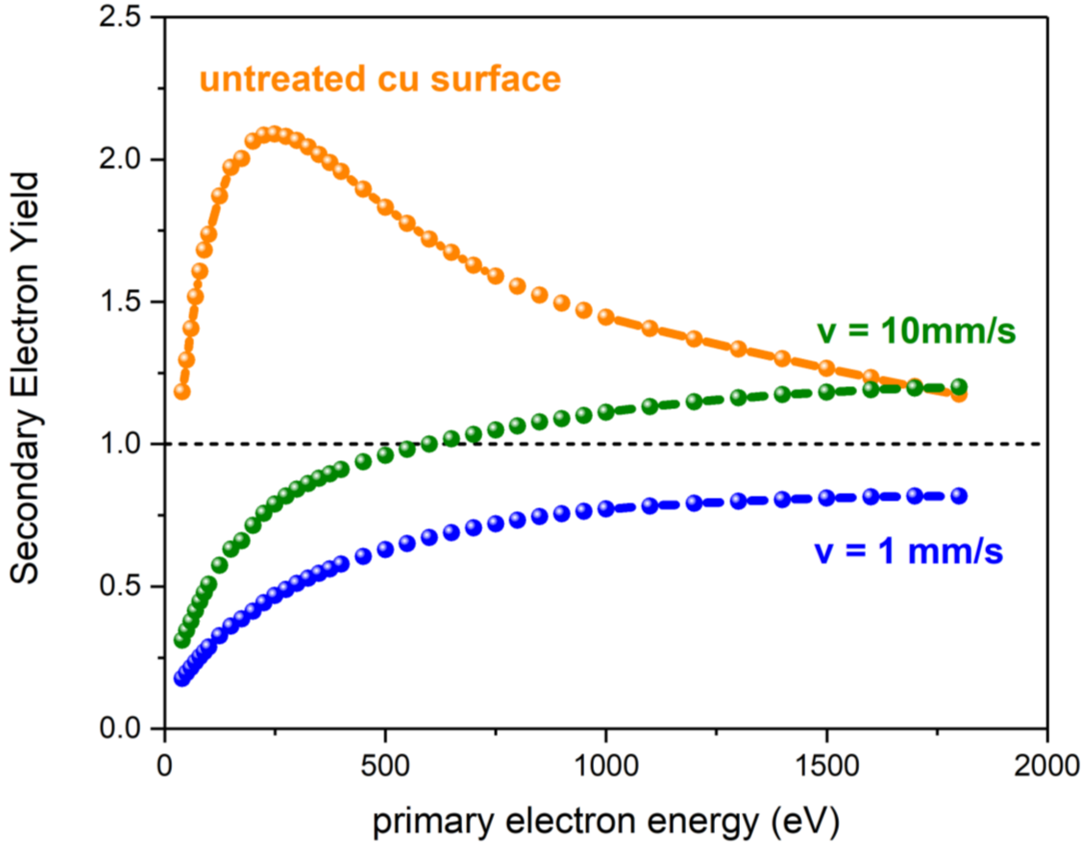


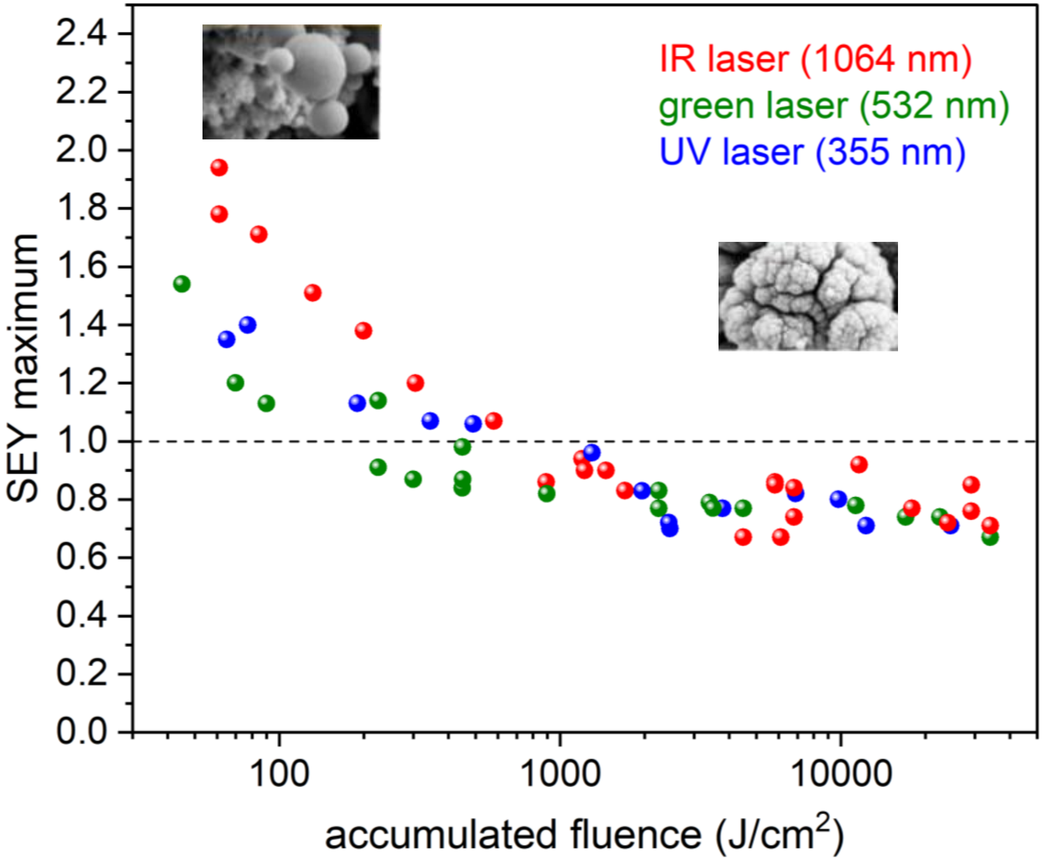


P. Lorenz, Secondary electron yield reduction of copper after 355 nm ultrashort pulse laser ablation, *Lasers in Manufacturing and Materials Processing* (**2022**).

λ = 355 nm, line distance Δy = 10 µm

Secondary Electron Yield reduction

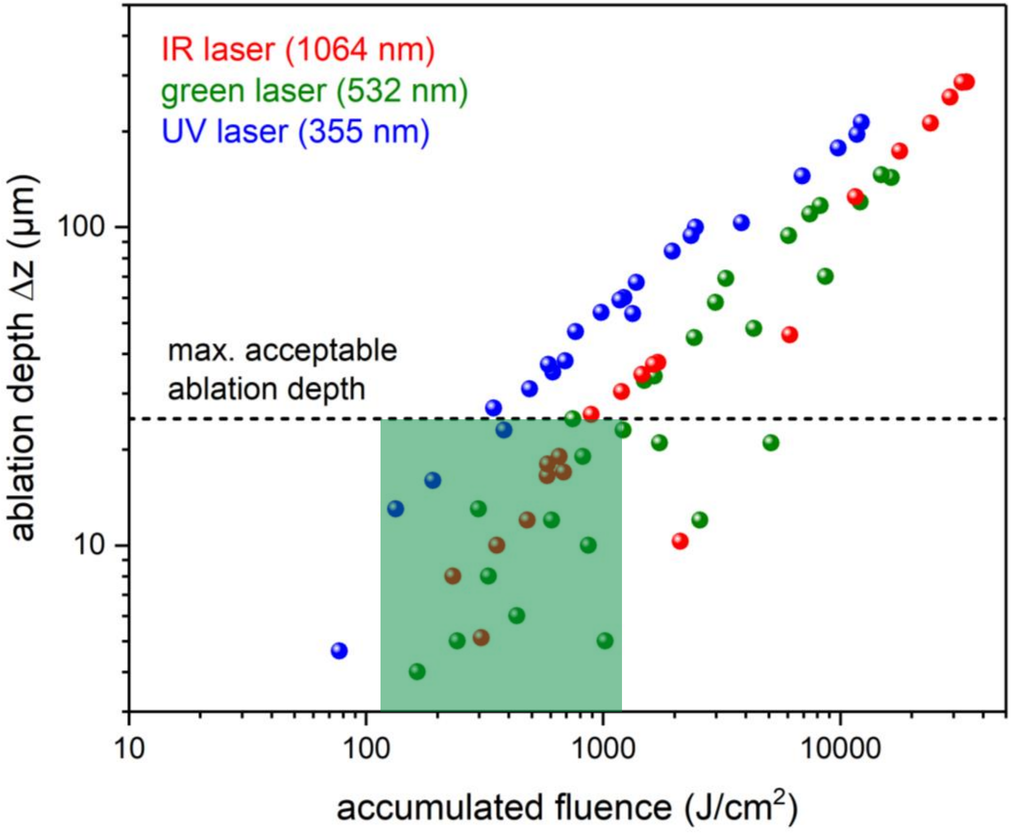


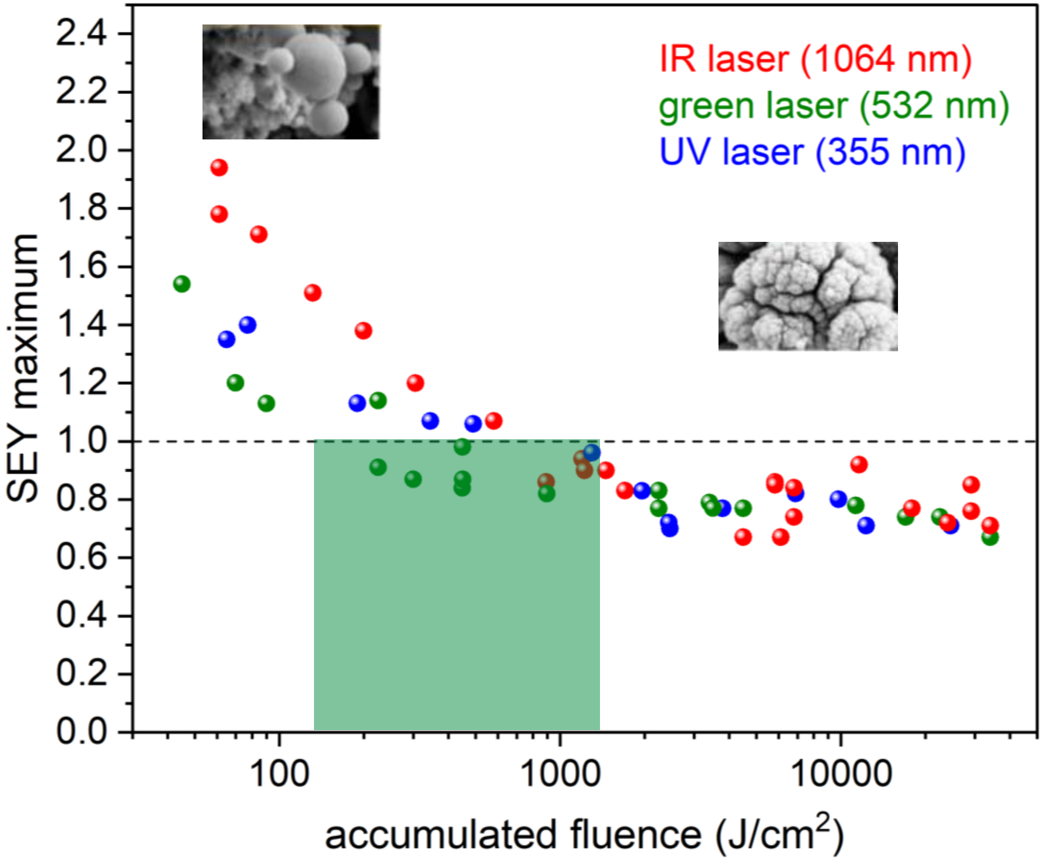


- Typical SEY measurement
- Surface structures reduce SEY

$$acc.\,fluence = \frac{laser\ power}{line\ distance \cdot scanning\ speed}$$

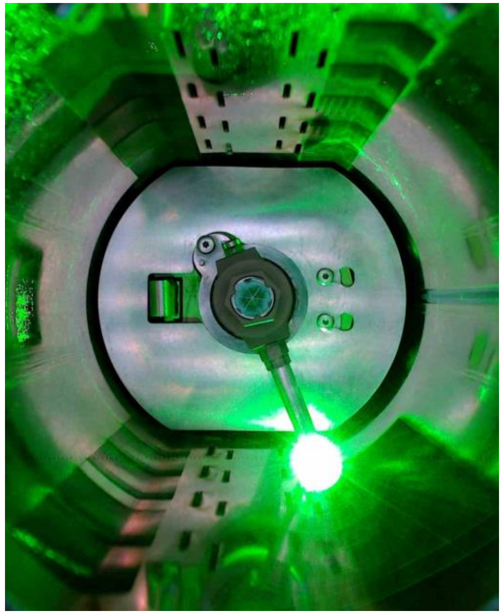
Meeting surface requirements





- Ablation depth $\Delta z < 25\ \mu m$ and SEY maximum ≤ 1
- **Strategy: lower fluences**

Implementation in LHC beam pipes



Laser
Wavelength 532nm
Pulse length 10ps

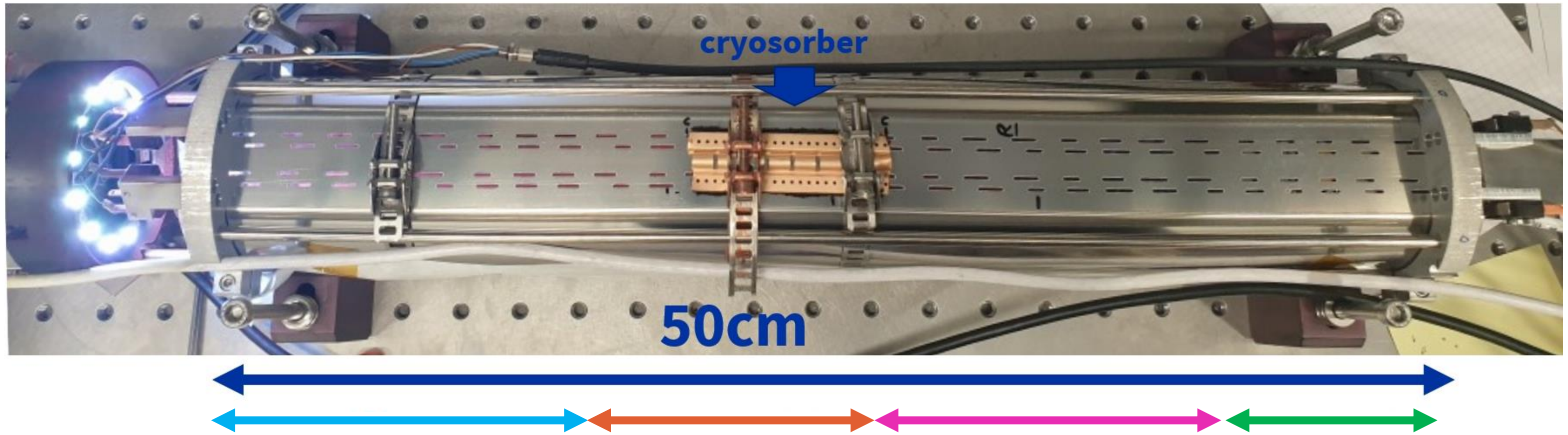
Beam Delivery System
Beam focusing
Coupling into fiber

15 m long optical fiber

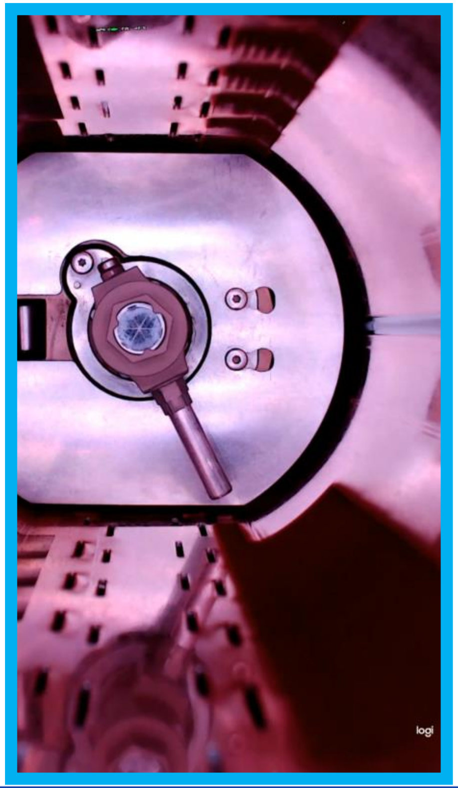
Robot

Beam pipe

Scanning strategies



Longline, 4 edges

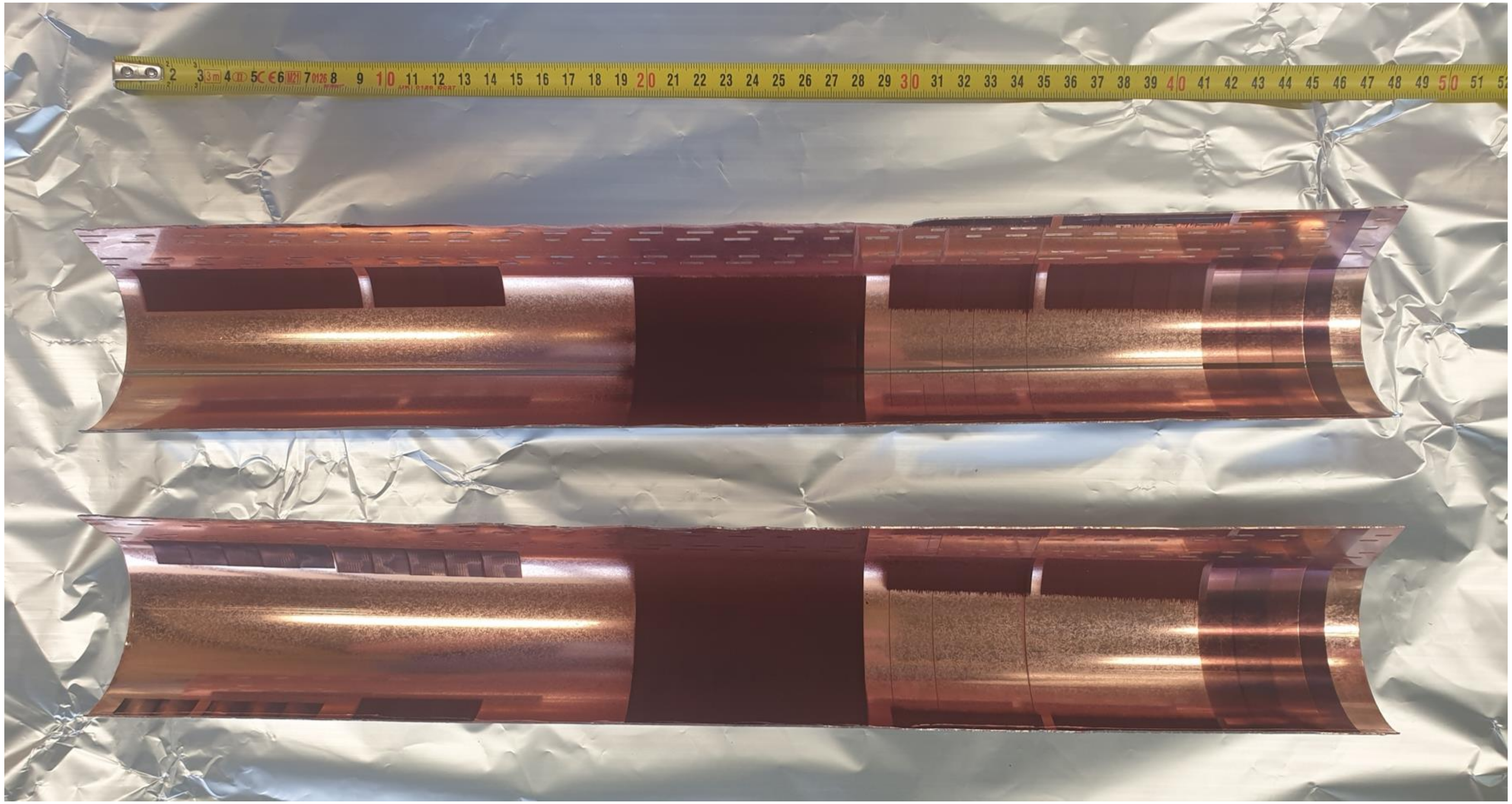


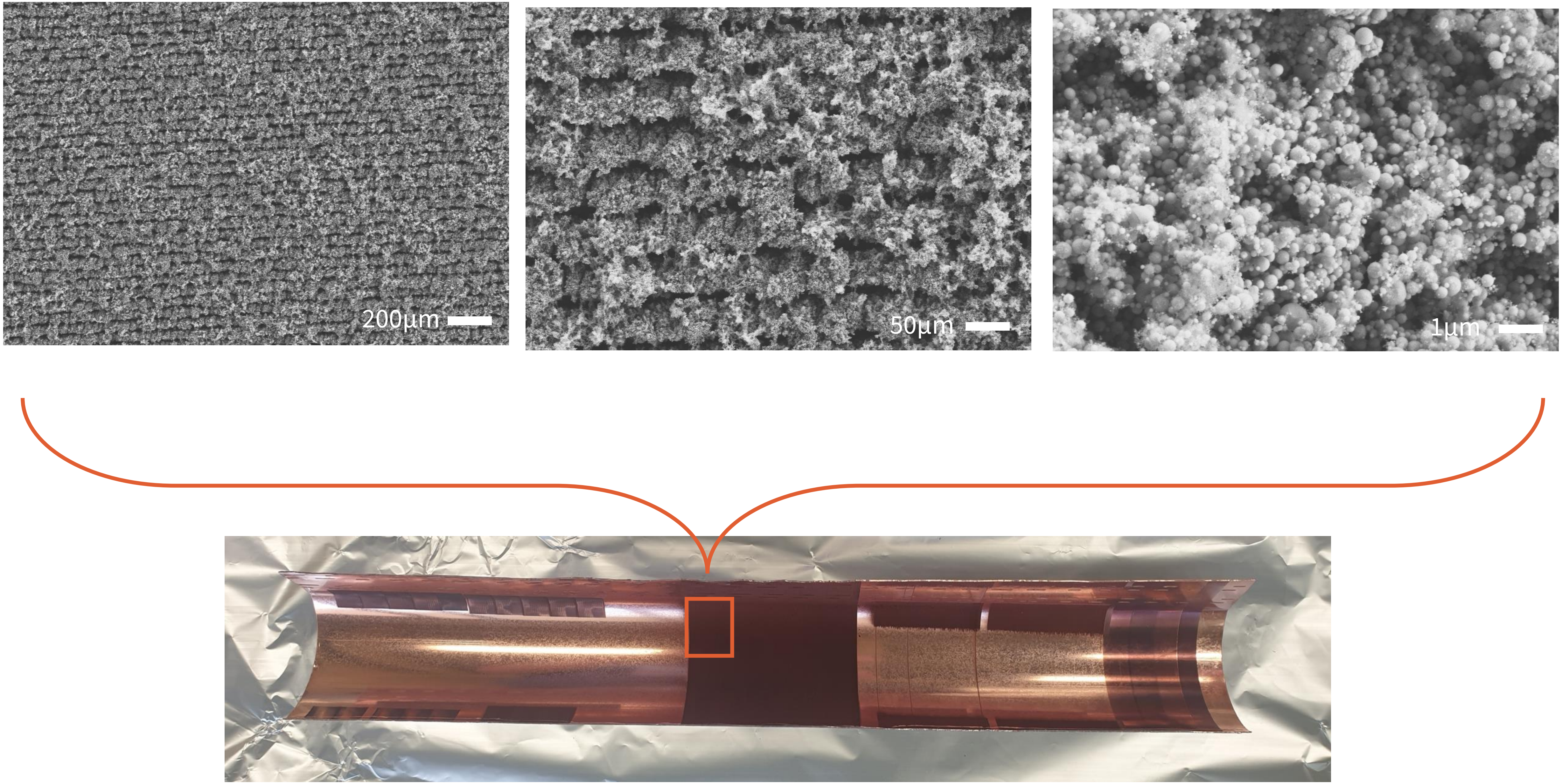
Spiral, 300°

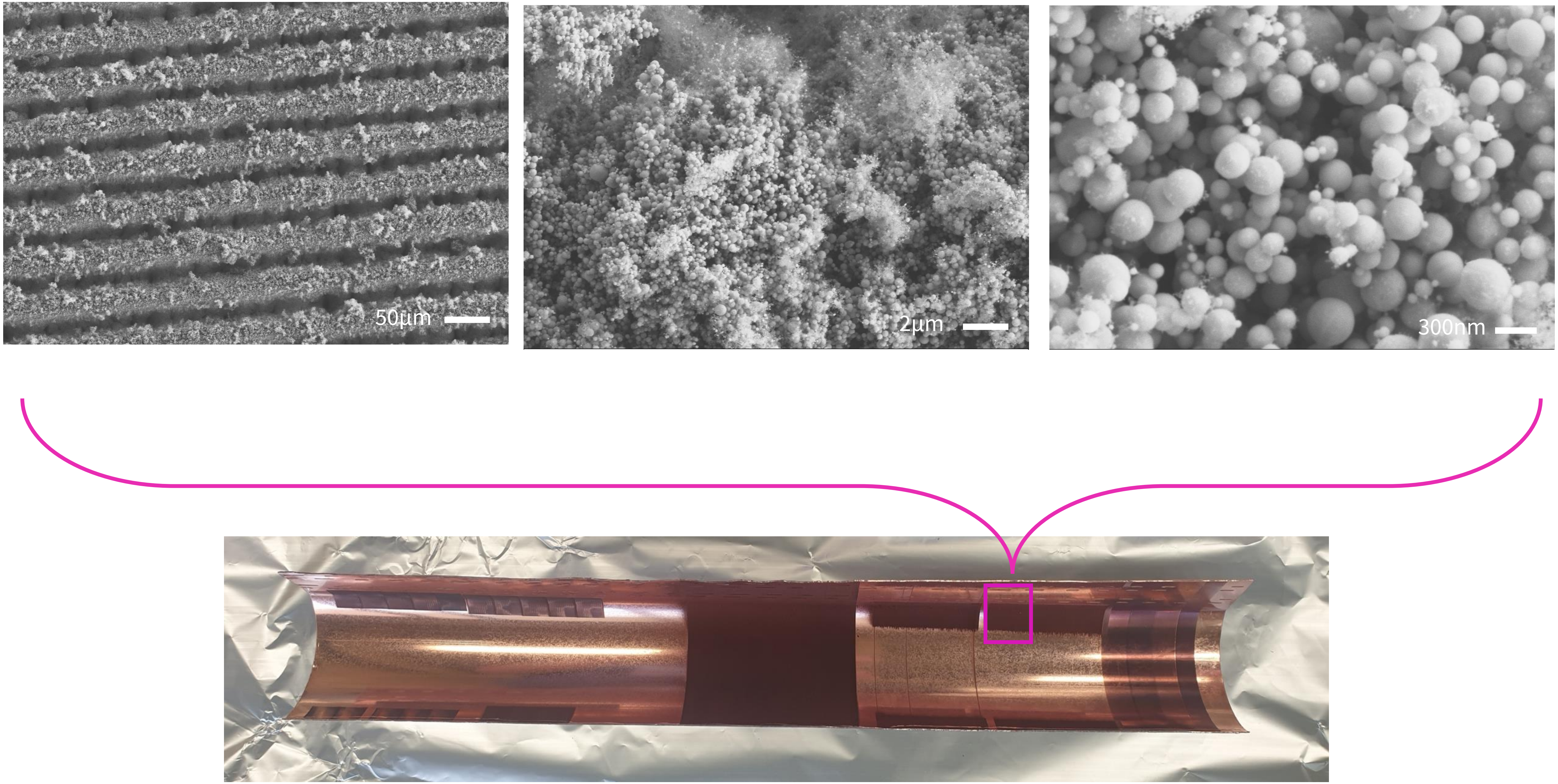
Spiral, 4 edges

Spiral, 360°

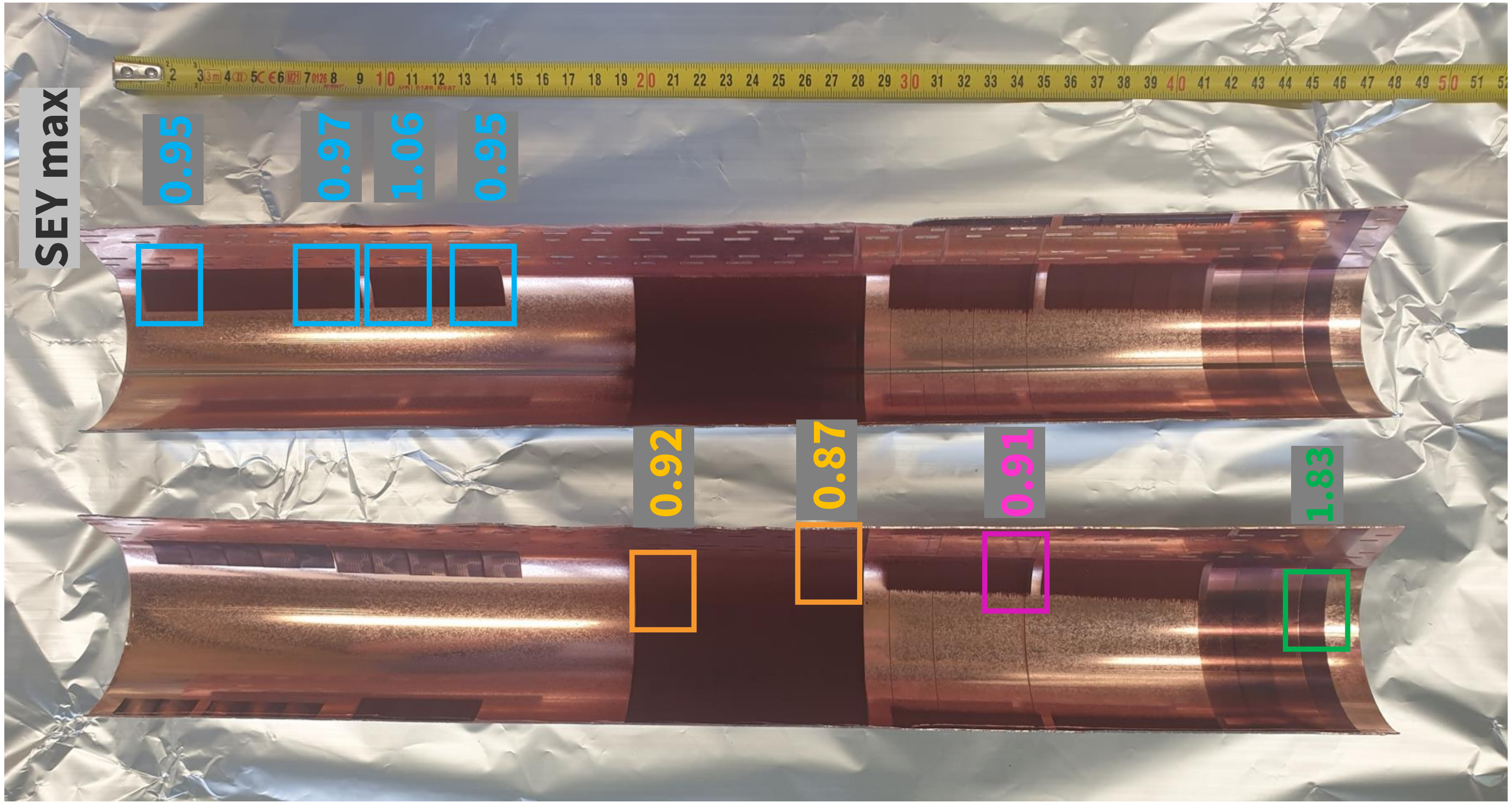
Long treatment and scanning strategies




200µm
50µm
1µm


50µm
2µm
300nm

Very low SEY ≤ 1 on beam pipe surfaces



Conclusions & Outlook

- **Combination of laser- induced micro- and nanostructures reduced the SEY from 2.2 to 0.7**

- **Higher accumulated fluence leads to:**
  - ➢ Deeper trenches
  - ➢ Higher particle density
  - ➢ Low SEY

- **Strategy: Lower acc. fluences on curved surfaces to meet surface requirements (lower particle density, lower ablation depth)**

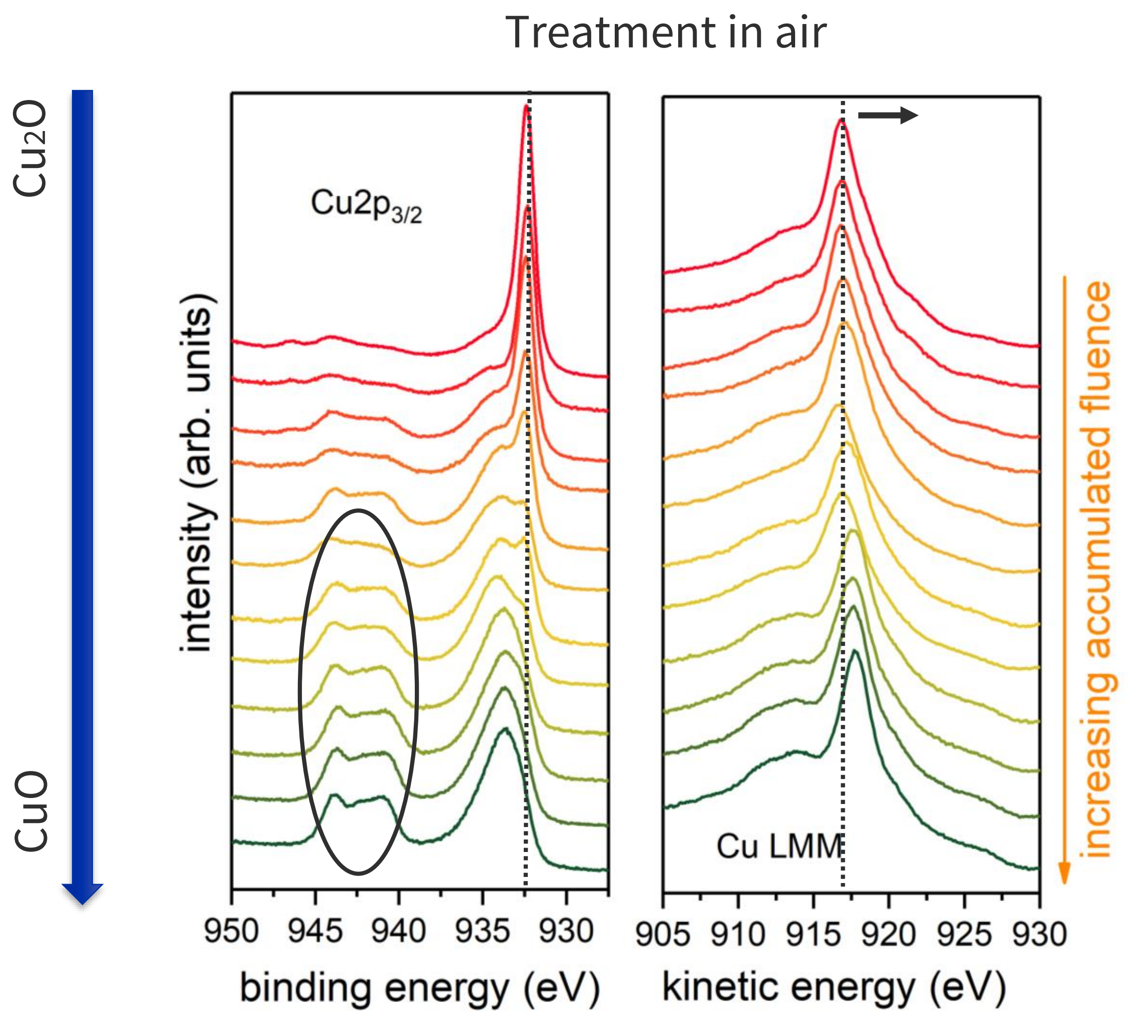
IOM

Leibniz-Institut für Oberflächenmodifizierung e.V.

CERN

UNIVERSITÄT LEIPZIG

Surface chemical properties (XPS)



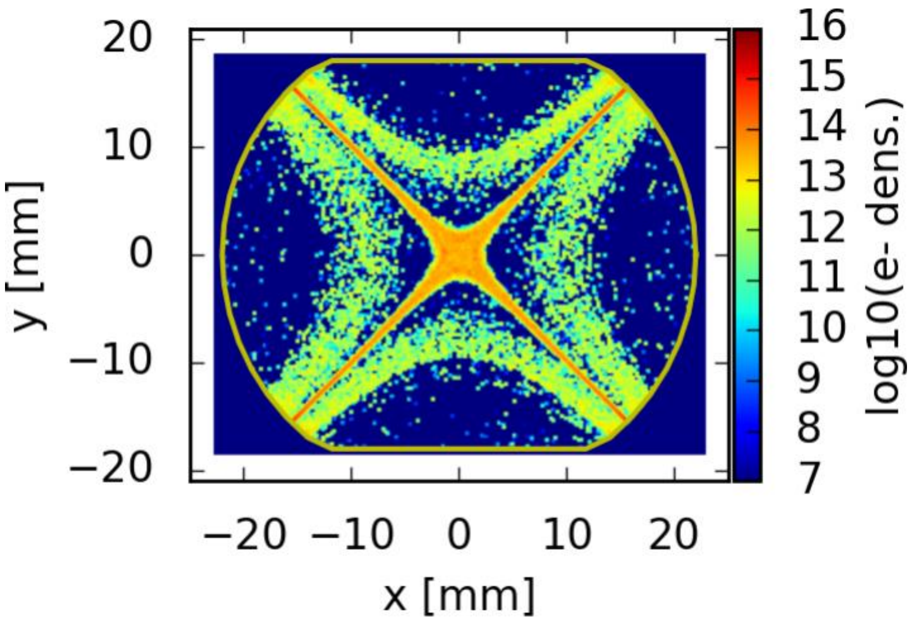
<u>Higher accumulated fluence leads to:</u>

- more surface oxidation
- Gradual transformation: Cu_2O -> CuO
  Cu_2O (native)
  CuO (forms in heated air)

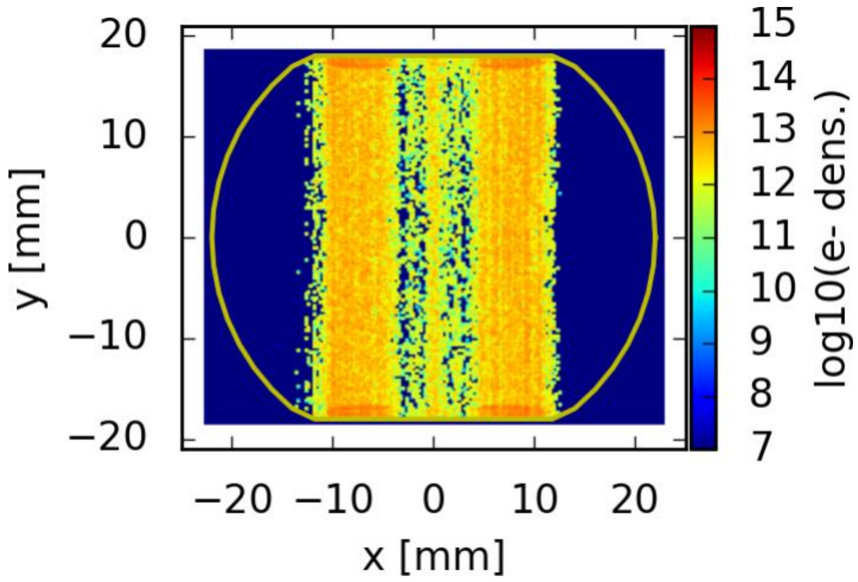
$$acc.\ fluence = \frac{laser\ power}{line\ distance\ \cdot\ scanning\ speed}$$

Scanning strategies

Ecloud formation in quadrupole

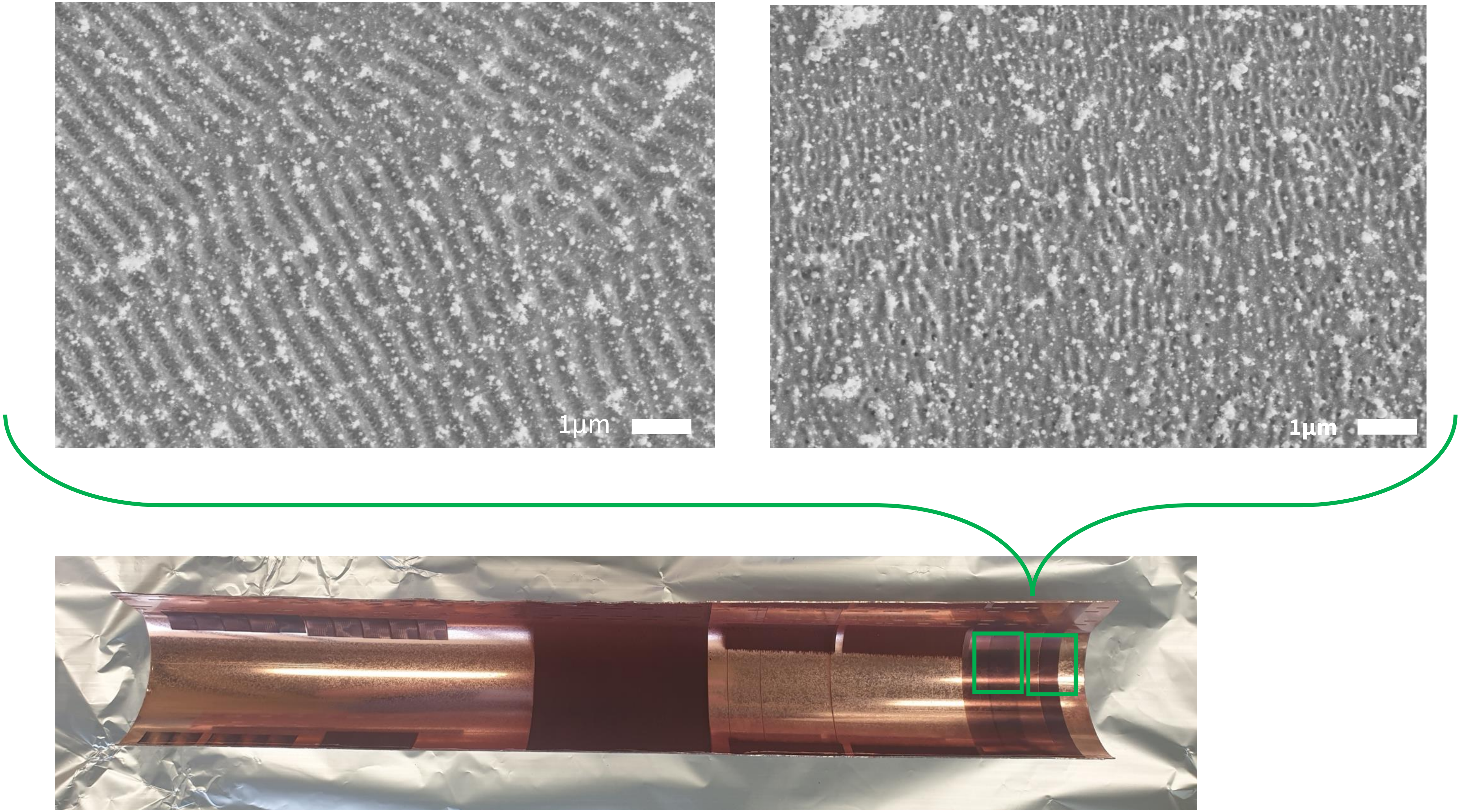


Ecloud formation in dipole



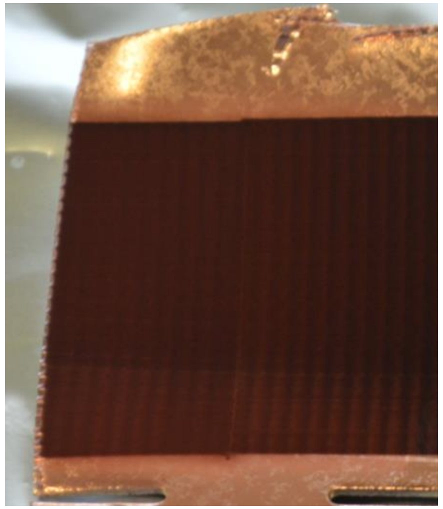
P. Dijkstal, G. Iadarola, L. Mether, and G. Rumolo, Tech. Rep. CERN-ACC-NOTE-2017-0057, CERN, Geneva, Switzerland, (2017).

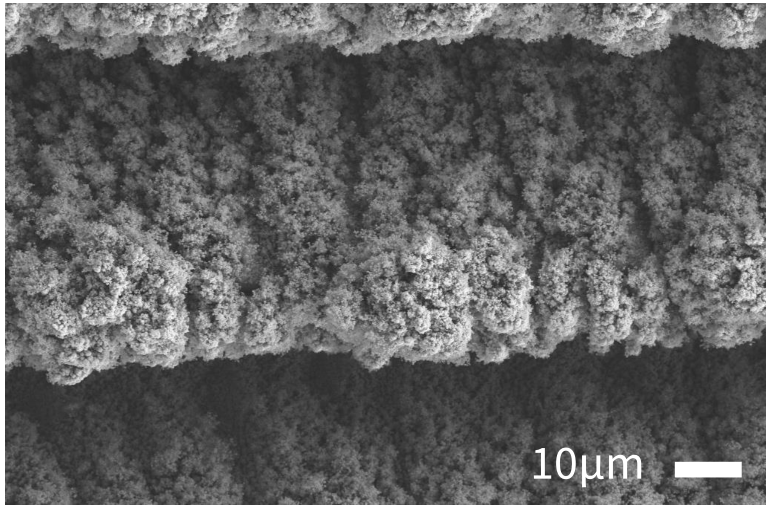
- **Idea: selective laser treatment of high intensity ecloud zones**

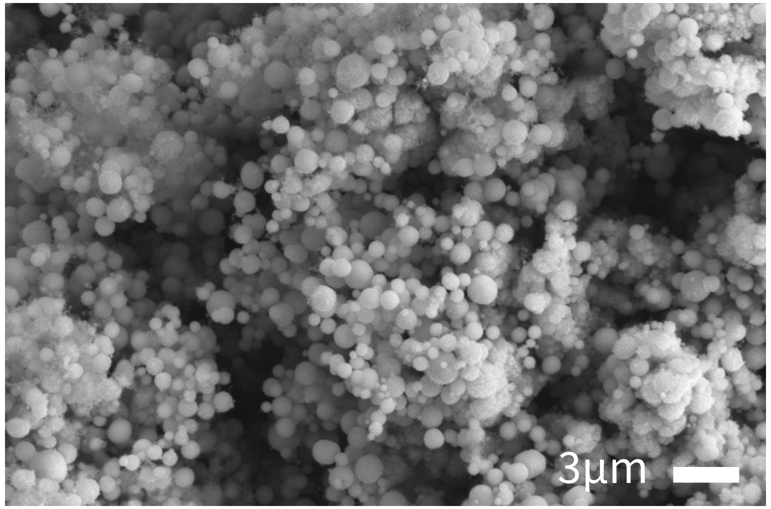

1µm
1µm

Post – treatment cleaning using gas jet

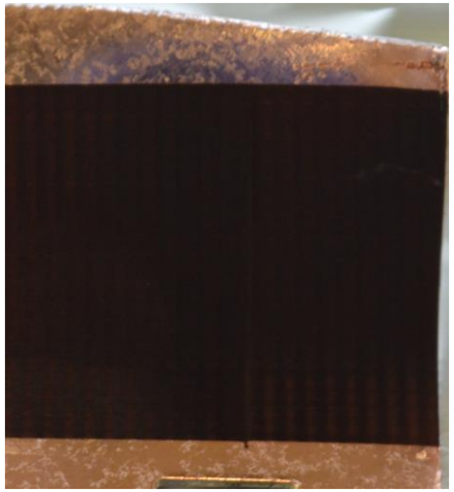
Laser treated

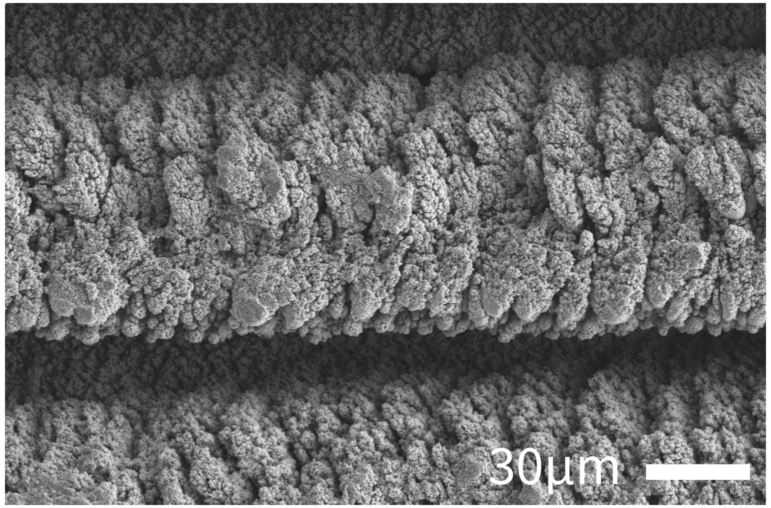


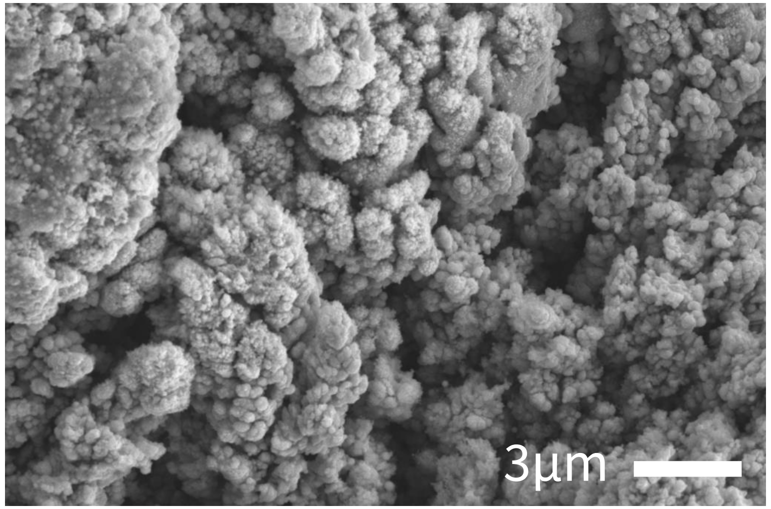




Laser treated
+ **cleaned**



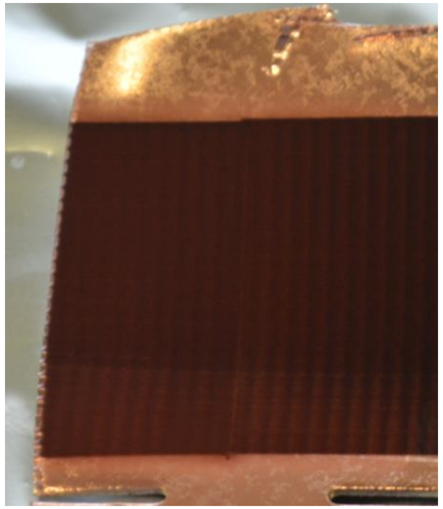




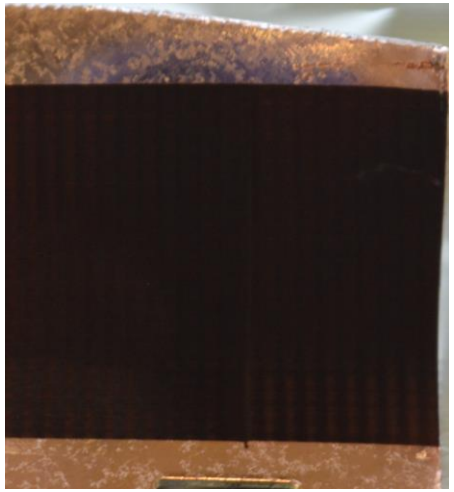
- **Loosely bound molten spheres removed with gas jet**

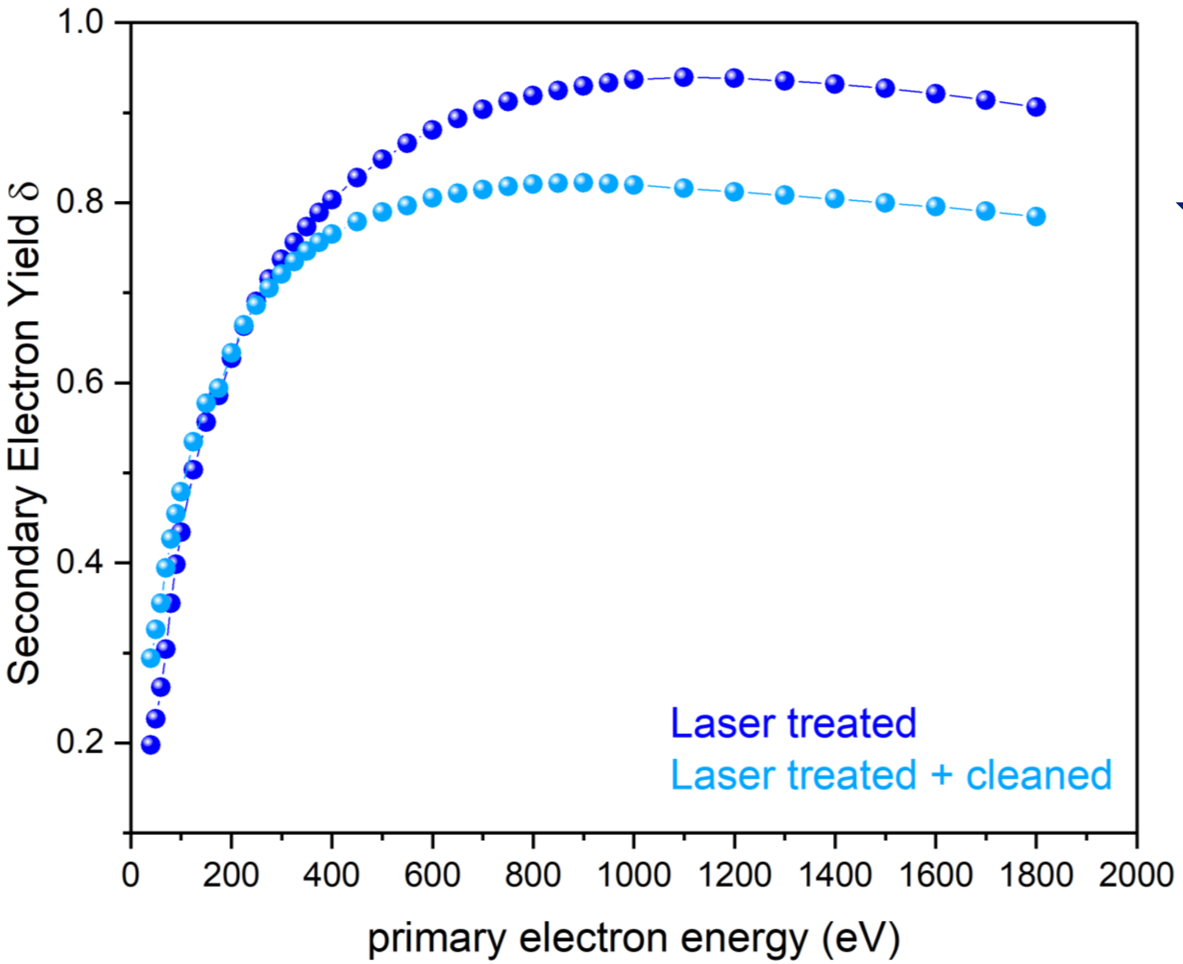
Reduced SEY after post-treatment cleaning

Laser treated



Laser treated
+ **cleaned**

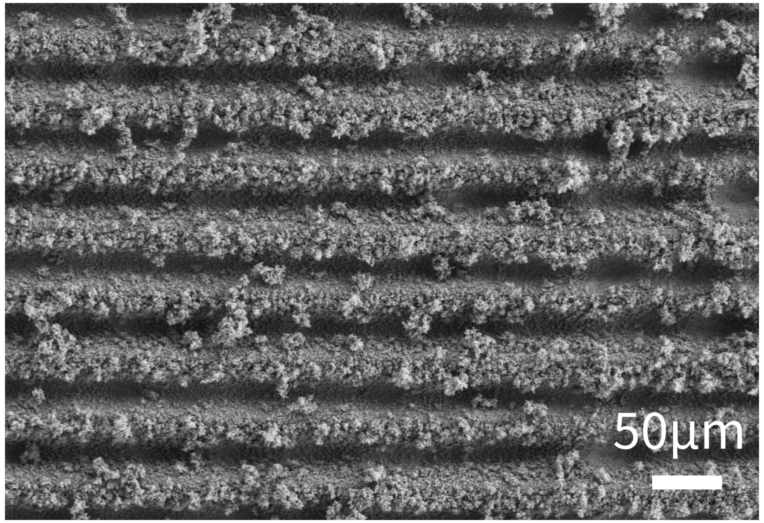


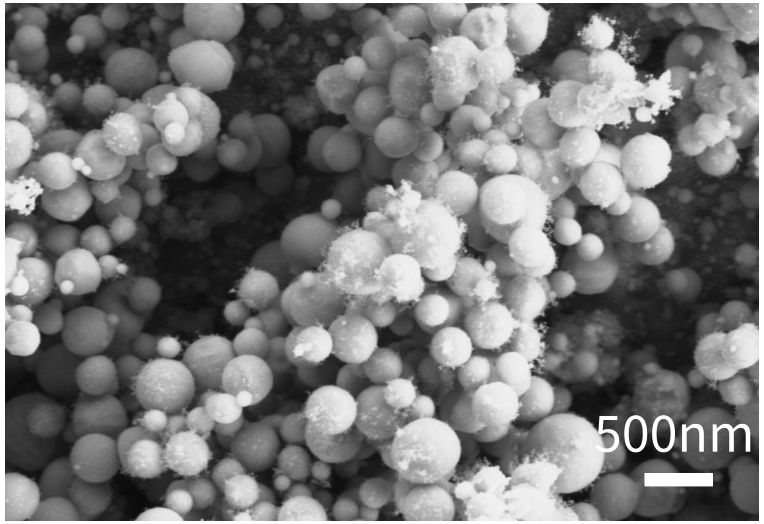


δ_{max} - 0.1

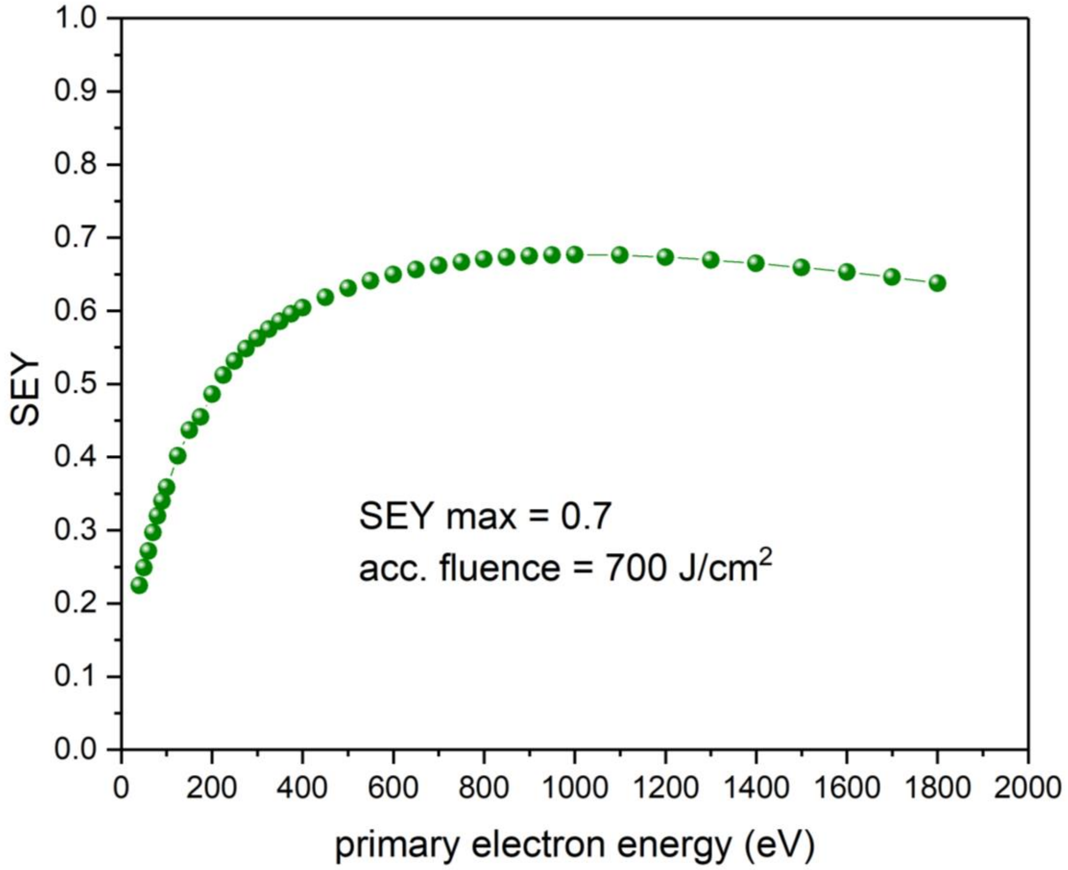
Topography on curved surfaces

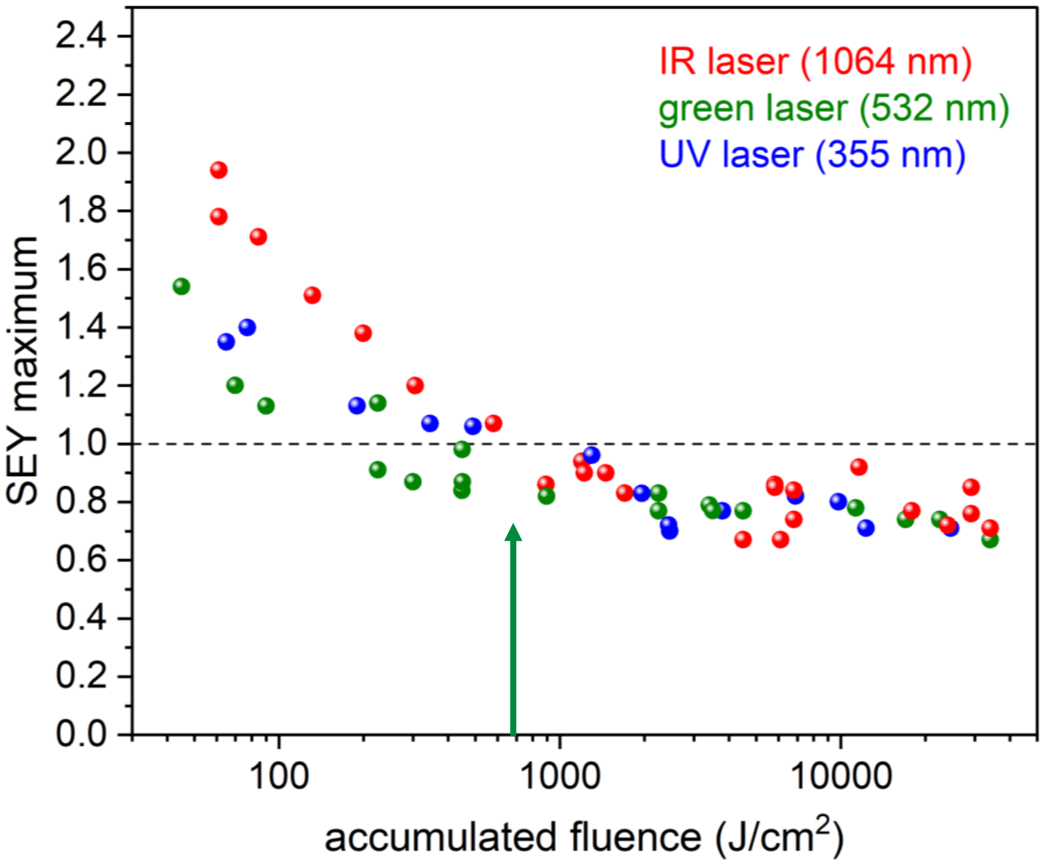
Scanning speed: 10 mm/s
Average laser power: 3100 mW
Acc. Fluence: 700 J/cm^2



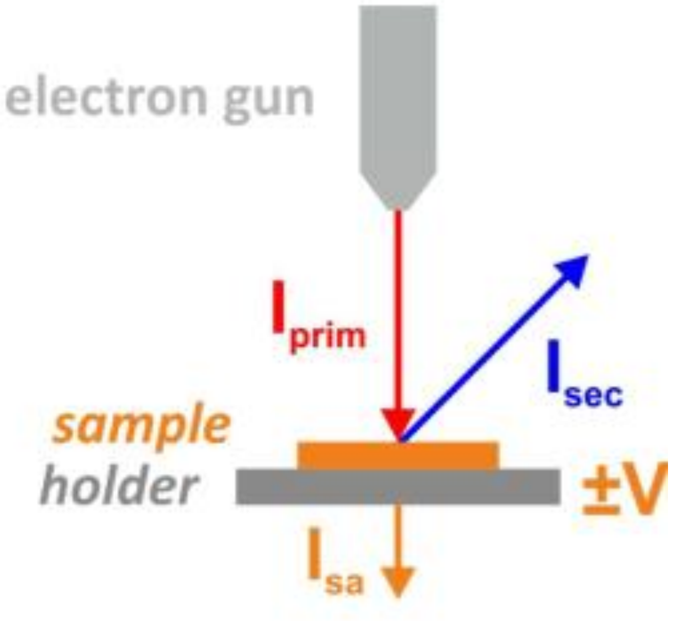


SEY on curved surface

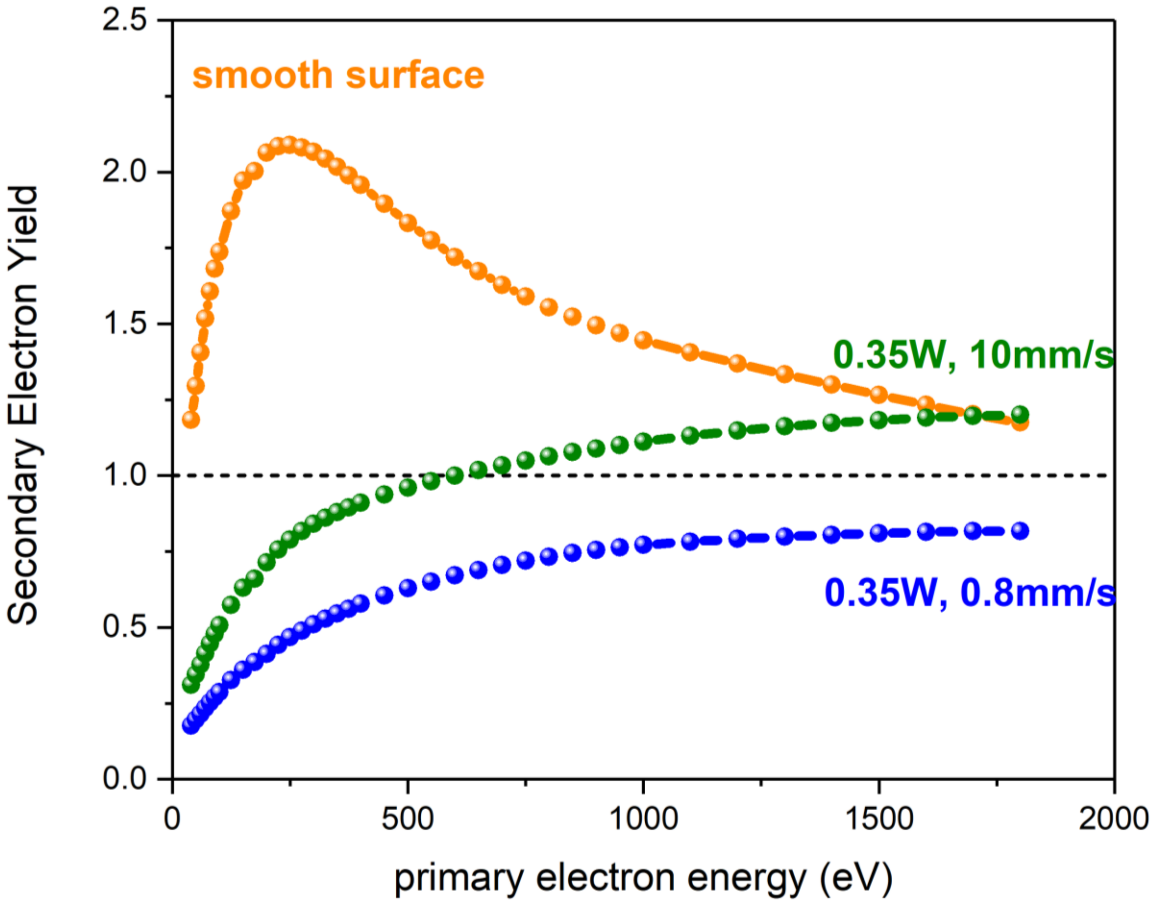




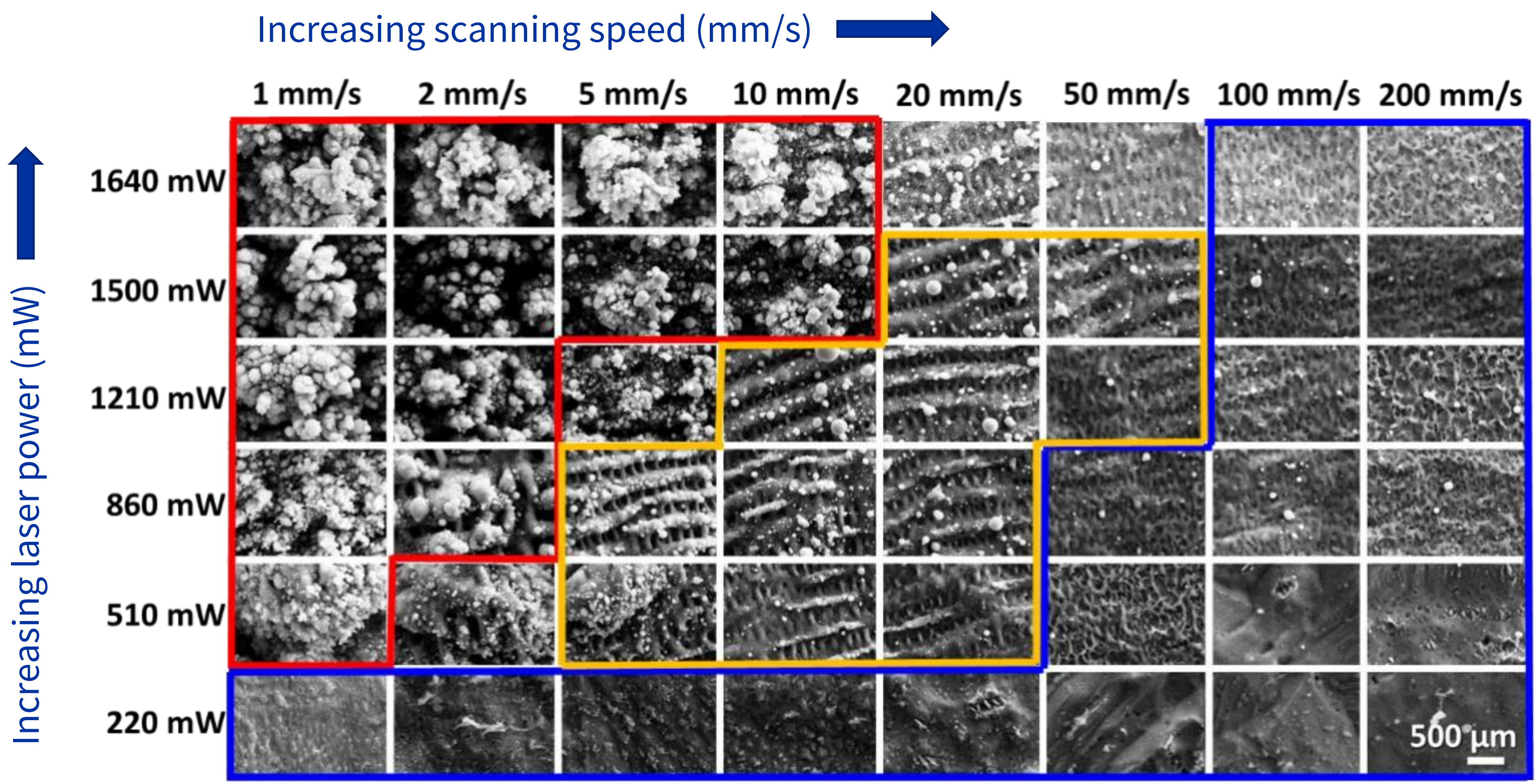
SEY measurement



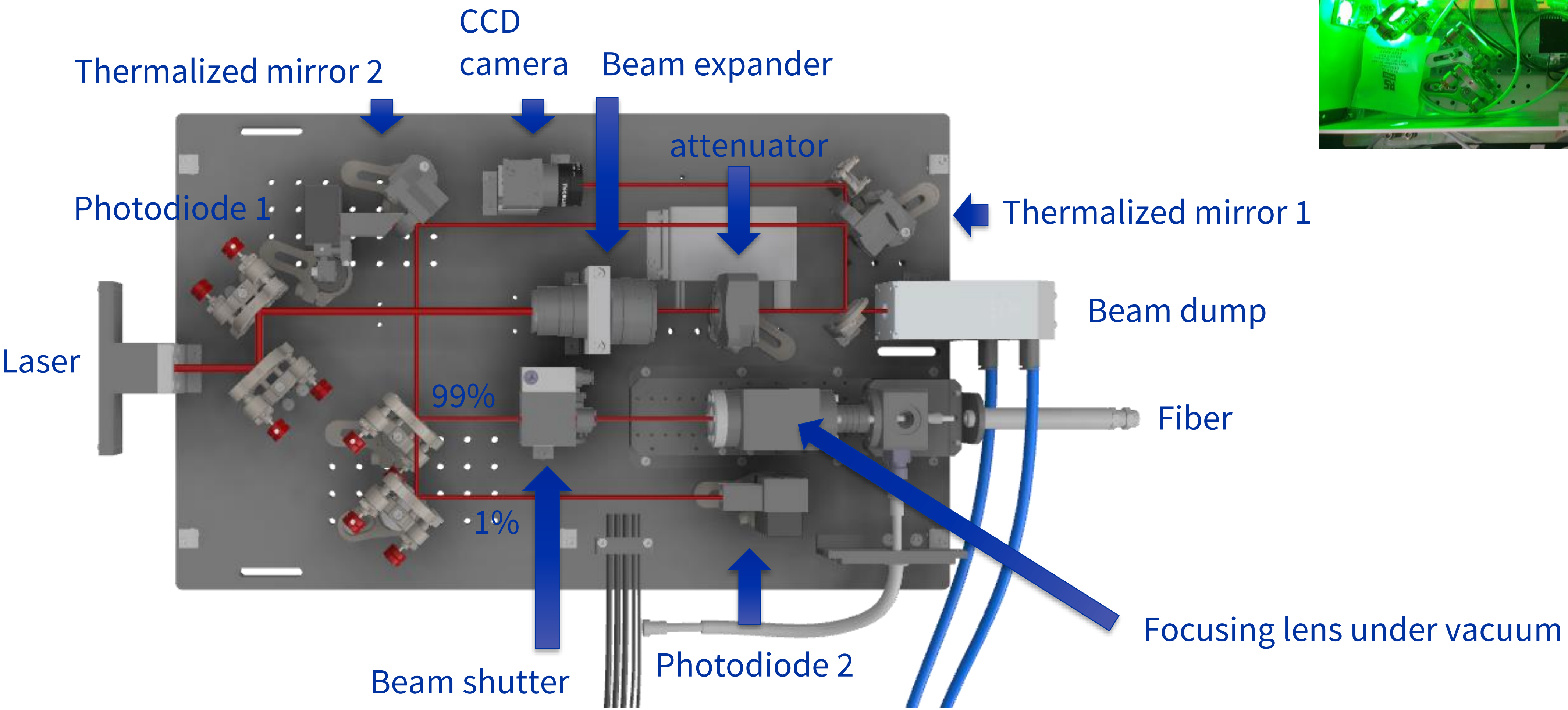
$$\delta(E) = \frac{I_{sec}(E)}{I_{prim}(E)} = \frac{I_{+V} - I_{-V}}{I_{+V}}$$

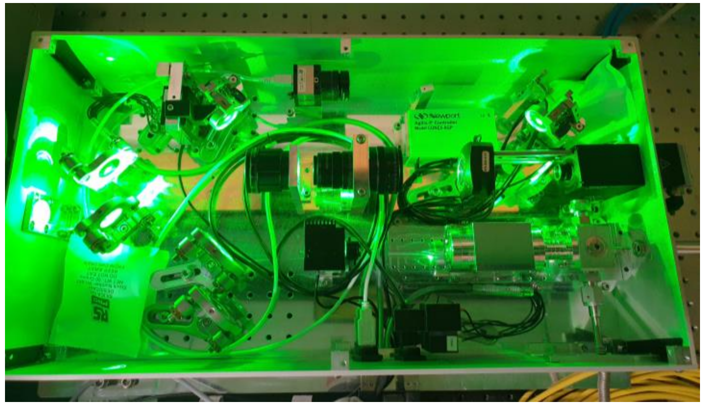


Surface morphology 532 nm



Beam Delivery System





Cross-section of the robot