Laser treatments for SEY reduction

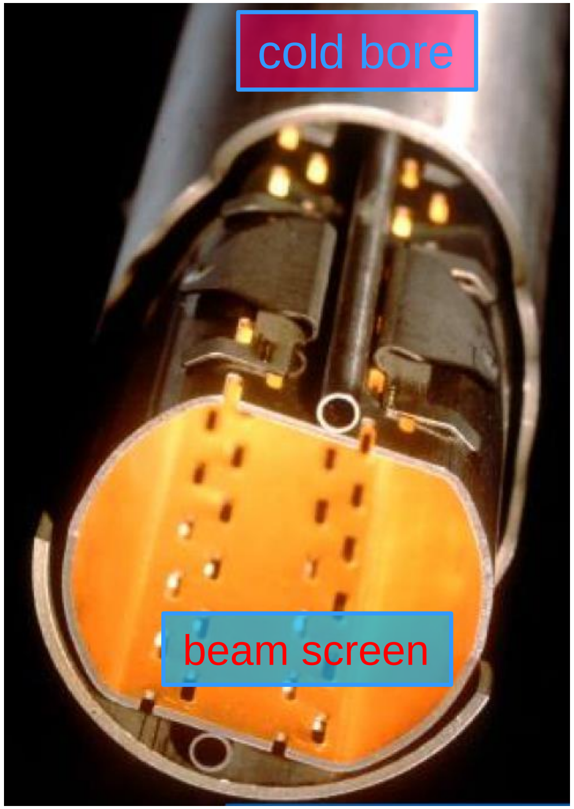
Marcel Himmerlich on behalf of TE-VSC

LESS = laser engineered surface structuring

Possible Applications

Laser surface treatment:

- Low secondary electron yield (<1) of metals and ceramics for electron cloud mitigation
- surface blackening to reduce light reflection or increasing the emissivity of metallic surfaces
- surface cleaning and coating removal
- recrystallization of surface layers to improve vacuum compatibility
- artificial patterning of surfaces



Advantages compared to thin film technology:

- selective and precise treatment of accelerator components in air or inert gas

History of LESS for low SEY

APPLIED PHYSICS LETTERS **105**, 231605 (2014)

Low secondary electron yield engineered surface for electron cloud mitigation

Reza Valizadeh,[1] Oleg B. Malyshev,[1,a)] Sihui Wang,[1] Svetlana A. Zolotovskaya,[2]
W. Allan Gillespie,[2] and Amin Abdolvand[2]
[1]*ASTeC, STFC Daresbury Laboratory, Daresbury, Warrington, Cheshire WA4 4AD, United Kingdom*
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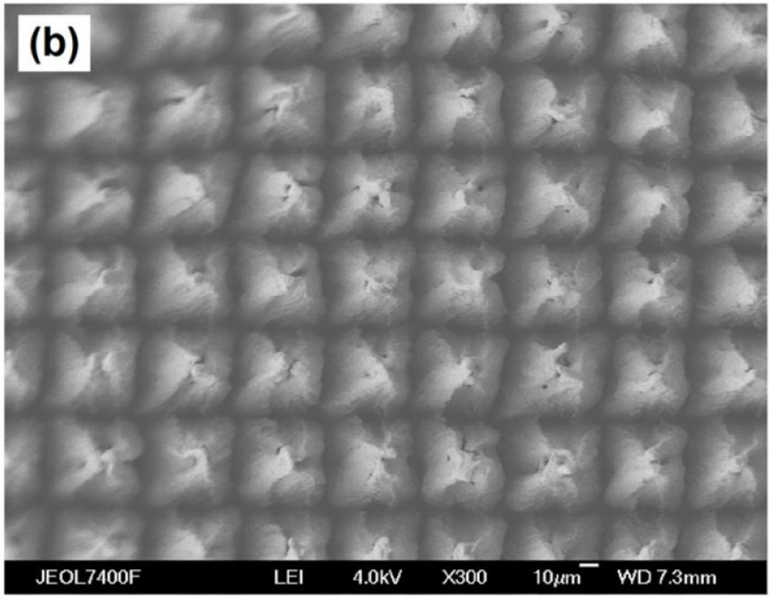

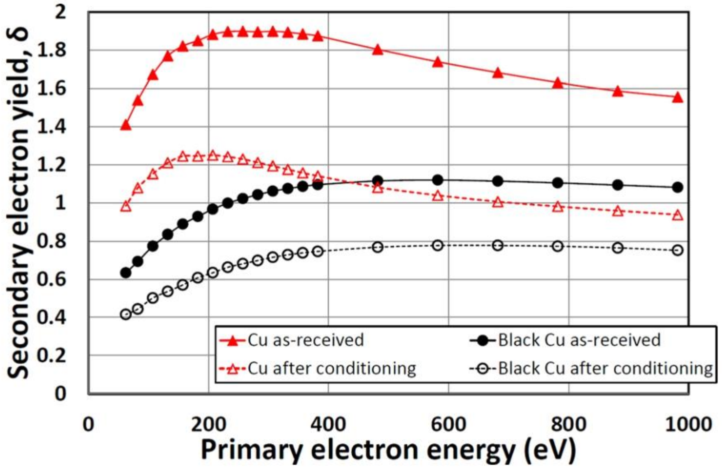

FIG. 3. SEY for Cu as a function of incident electron energy: Cu—untreated surface, black Cu—laser treated surface, and conditioning—electron bombardment with a dose of 1.0×10^{-2} C·mm^{-2} for Cu and 3.5×10^{-3} C·mm^{-2} for black Cu.

History of LESS for low SEY

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Low secondary electron yield engineered surface for electron cloud mitigation

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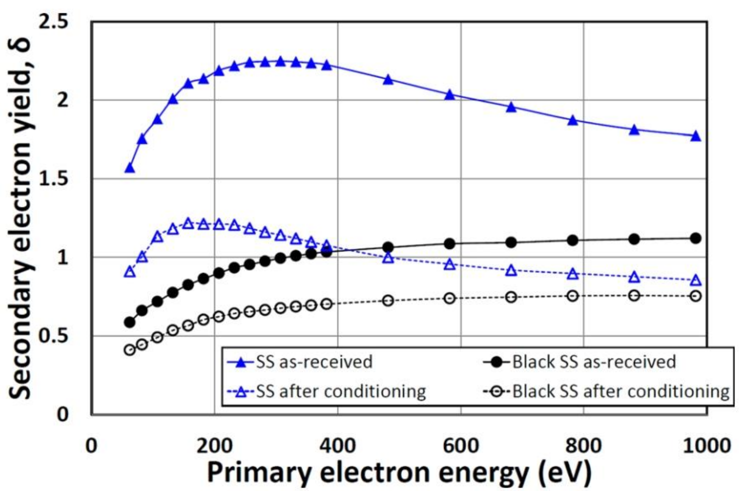


FIG. 4. SEY for 316L stainless steel as a function of incident electron energy: SS—untreated surface, black SS—laser treated surface, and conditioning—electron bombardment with a dose of 1.7×10^{-2} C·mm^{-2}.

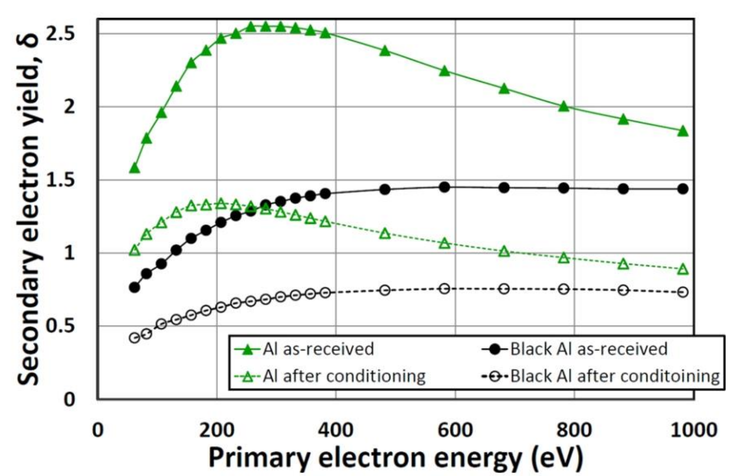
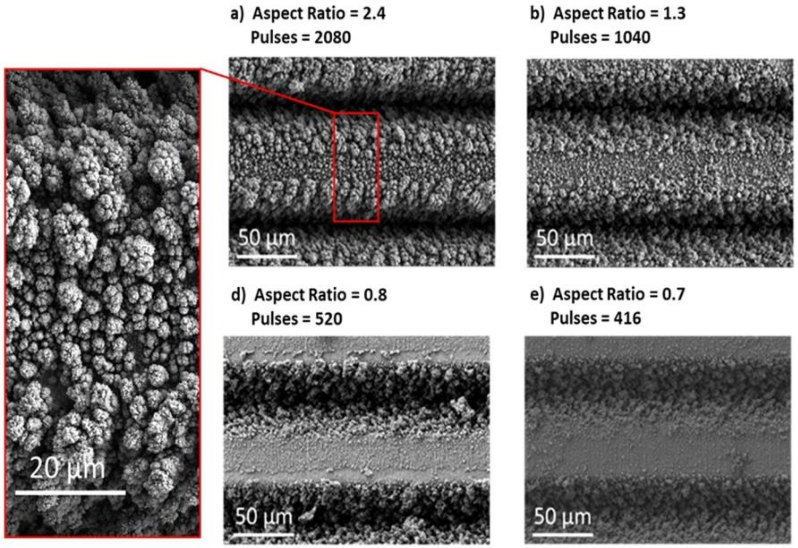
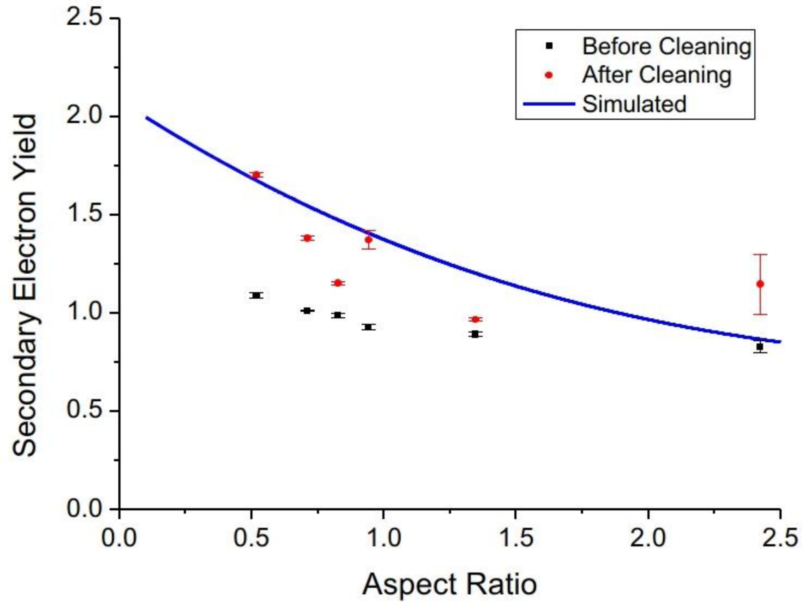


FIG. 5. SEY for Al as a function of incident electron energy: Al—untreated surface, black Al—laser treated surface, and conditioning—electron bombardment with a dose of 1.5×10^{-2} C·mm^{-2} for Al and 2.0×10^{-2} C·mm^{-2} for black Al.

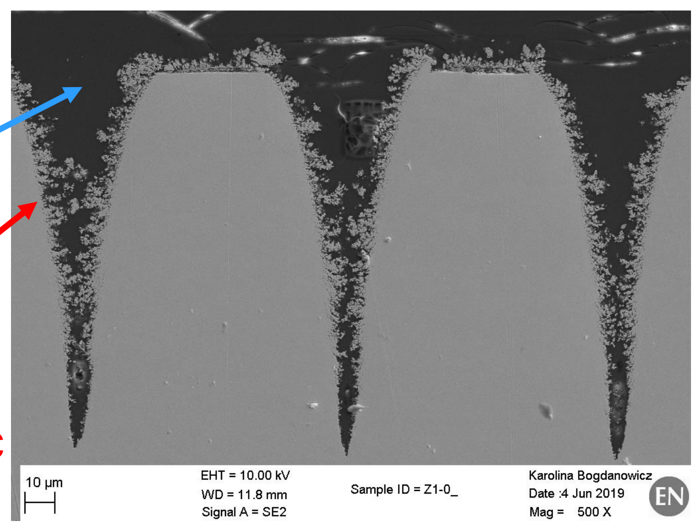
LESS studies





ablated region

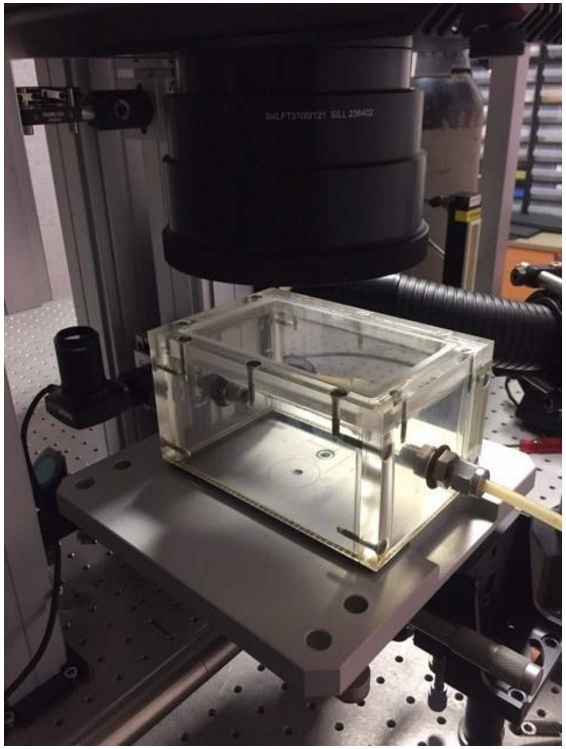
redeposited dendritic surface layer



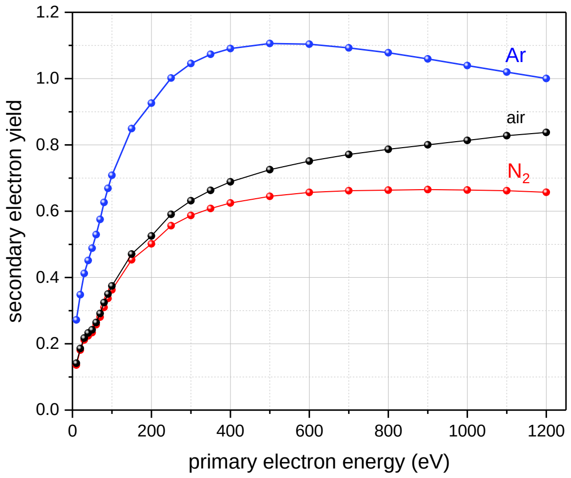
Ablation depth, trench distance and SEY can be tuned via laser parameter adjustment

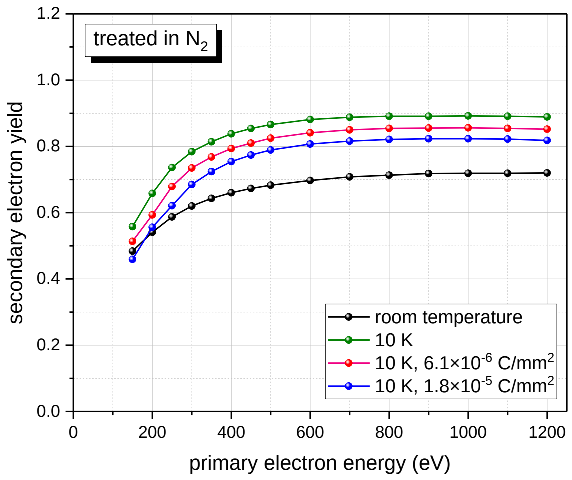
D. Bajek et al., Sci. Rep. 10 (2020), 250

Influence of ambient gas during laser treatment



Inert gas box for laser treatment



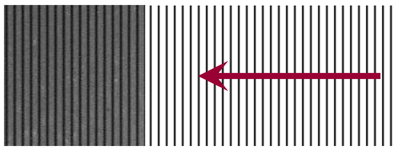


- treatment in air results in strong surface oxidation (including charge up at cryogenic temperatures)
- treatment in nitrogen prevents surface oxidation

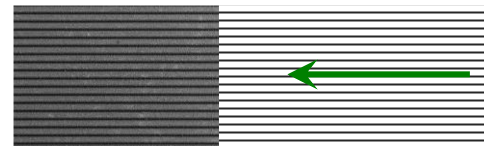
→ all setups are designed to blow N_2 blowing into the reaction zone

- all test samples are made on planar scanning stage and optimized laser focus

Impedance aspects of formed trenches



trenches ⊥ to beam



trenches ∥ to beam

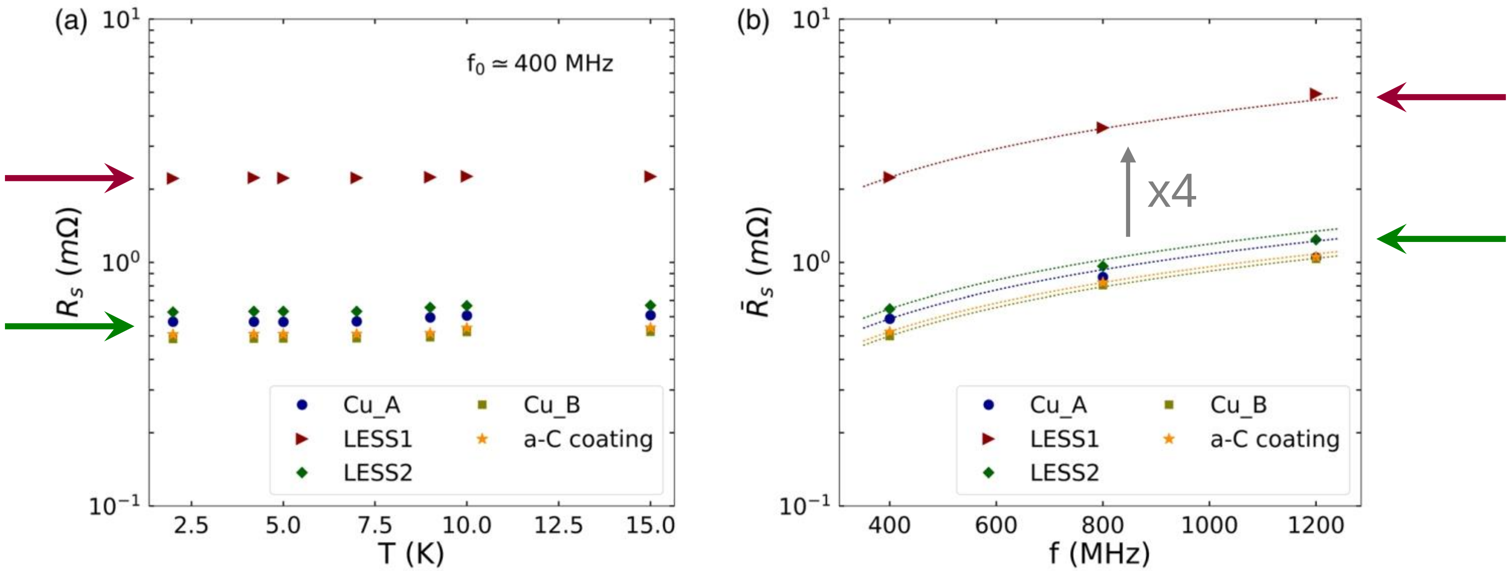
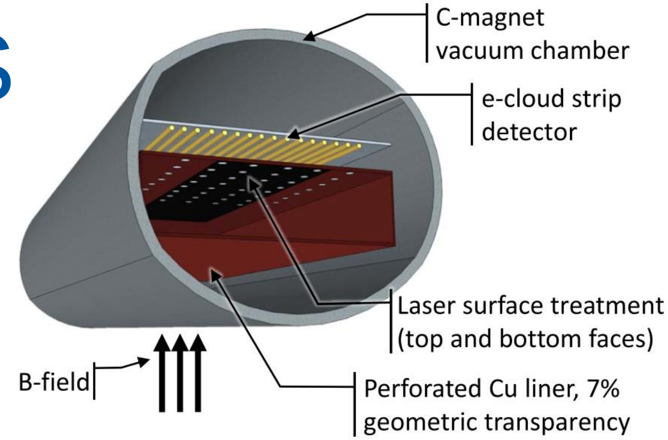


FIG. 5. (a) Surface resistance as a function of the sample temperature for pristine copper and for the different surface treatments. (b) Surface resistance averaged over the temperature as a function of the QPR mode frequency for pristine copper and for the different surface treatments. The curves show the functional dependence $f^{2/3}$, having the data points at 400 MHz as a reference. Error bars are not shown for a better visualization of the different data points (measurement uncertainty $\delta R_s/R_s \approx 10\%$).

S. Calatroni et al. Phys. Rev. Accel. Beams 22, 063101 (2019)

E-cloud monitoring in SPS



a-C coating and LESS of Copper enable electron cloud suppression

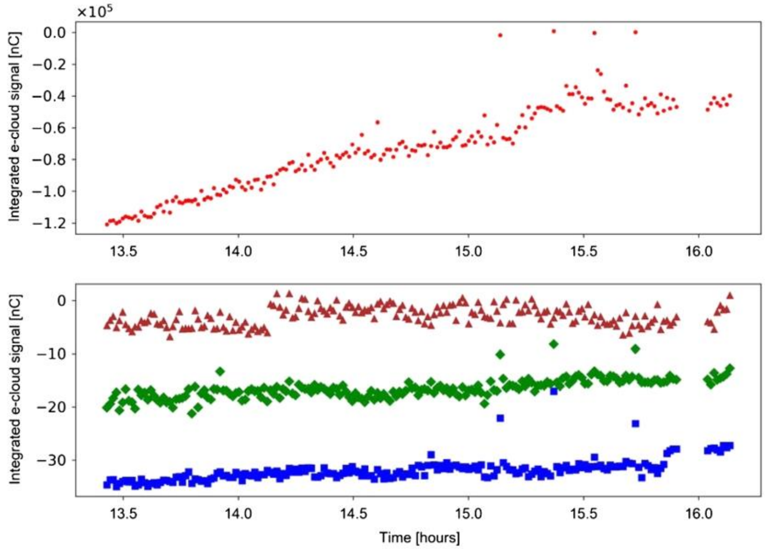


FIG. 12. Integrated signals from the ECMs during the total duration of the experiment in the SPS. (top) Reference copper liner; (bottom) liners with e-cloud mitigation: blue squares—treated by ASTeC, brown triangles—treated at the University of Dundee and green lozenges—a-C coating. Note the difference in vertical scales.

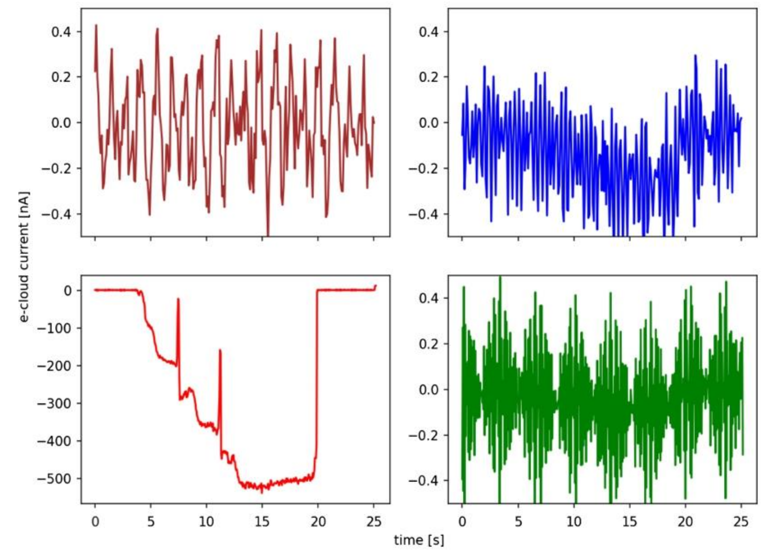


FIG. 13. Progressive e-cloud development in the four batches of 72 proton bunches. Clockwise from top left: liner treated at the University of Dundee, liner treated by ASTeC, a-C coated liner and Cu liner. Note the difference in vertical scale for the latter.

S. Calatroni Phys. Rev. Accel. Beams 20, 113201 (2017)

Potential applications

- Low SEY treatment of metals and ceramics
- Alternative method to a-C coating for inner triplets and matching section magnets in-situ treatment during LS3 & for dipole beams screens with cryosorbers
- Ex-situ beam screen treatment, baseline for FCC
- Selective and precise treatment of accelerator components, such as BPMs, for electron cloud mitigation
- Surface blackening to reduce light reflection, e.g. for Hollow Electron Lens (HEL)
- Deoxidation of beam screens of high heat-load sectors (CuO)

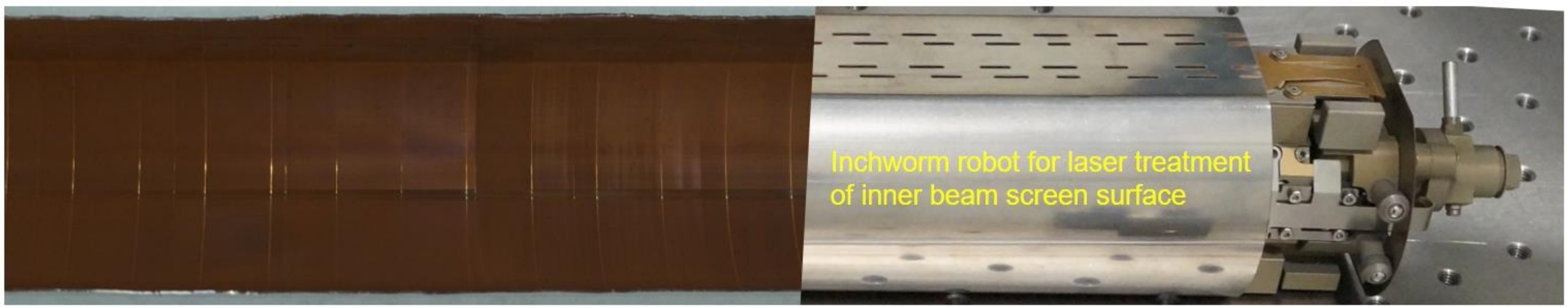
Internal treatment of beam screens

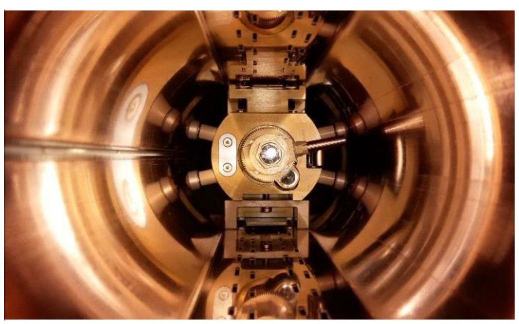
University of Dundee

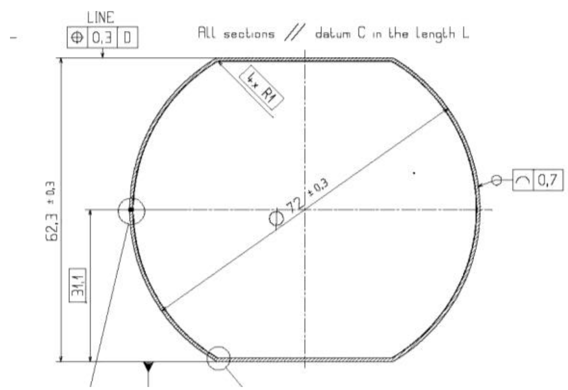
CERN

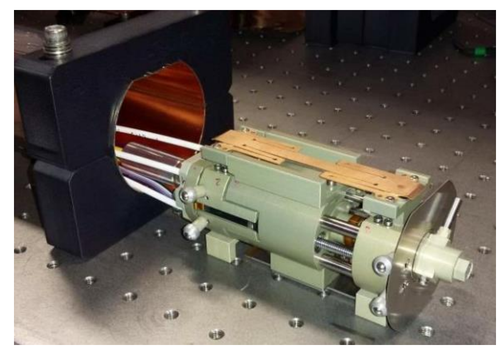
Science & Technology Facilities Council

- (In-situ) treatment of Triplet Beam screens

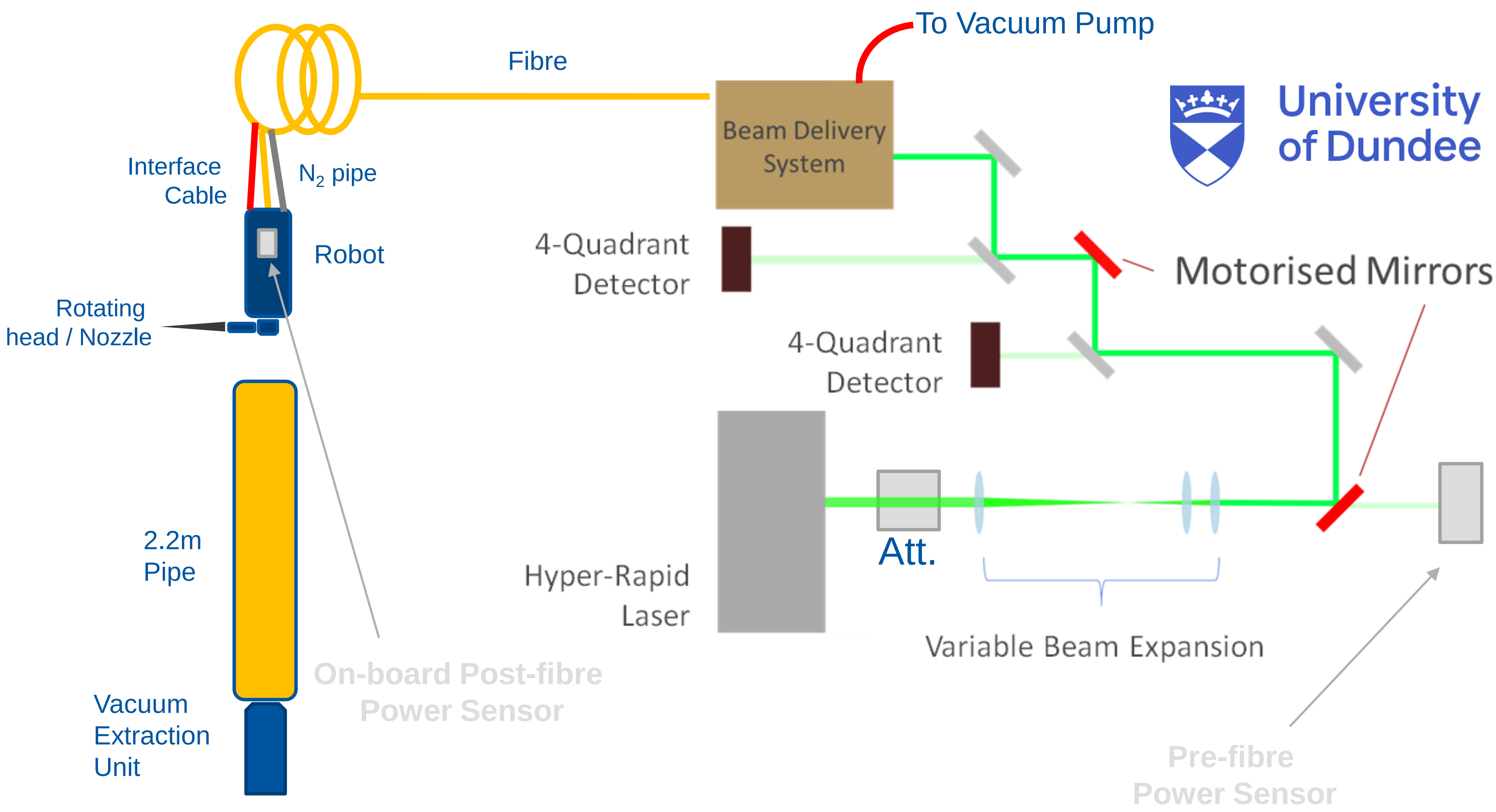




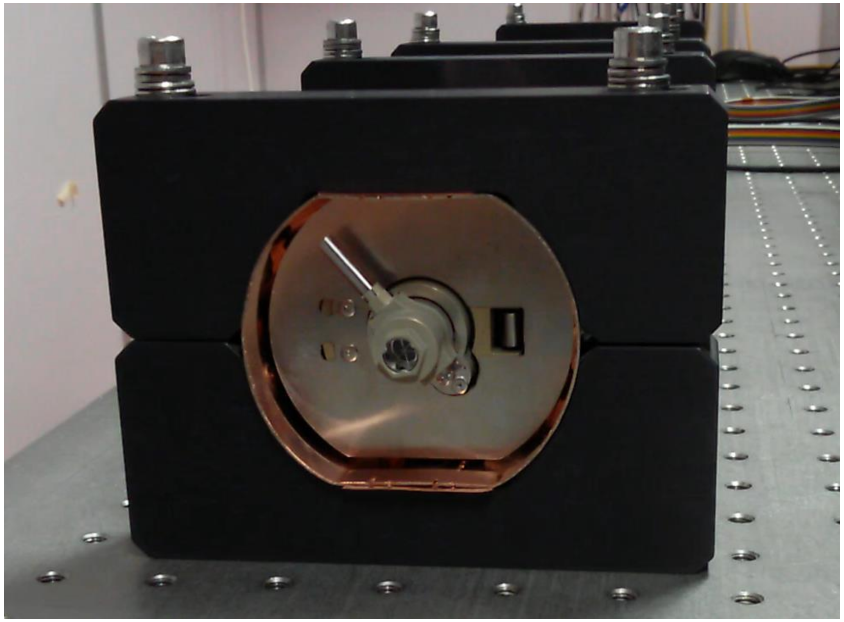


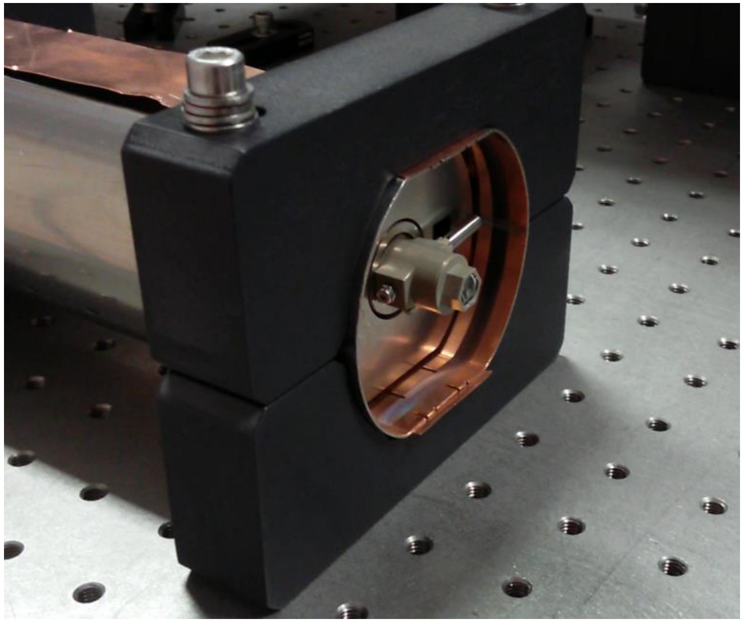


Experimental setup for laser treatment



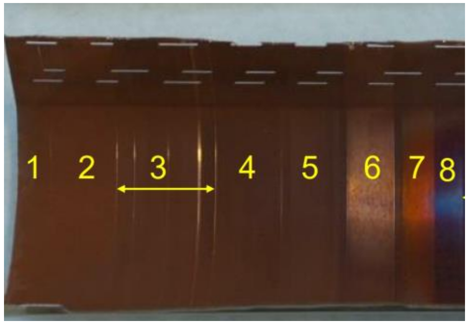
Internal treatment of beam screens

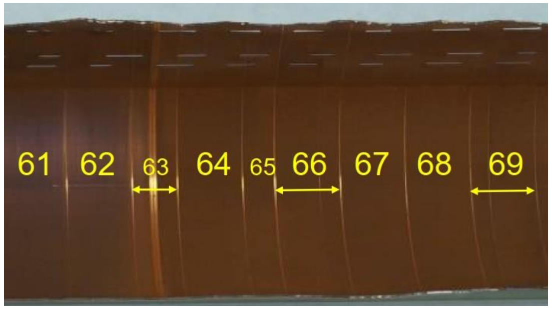


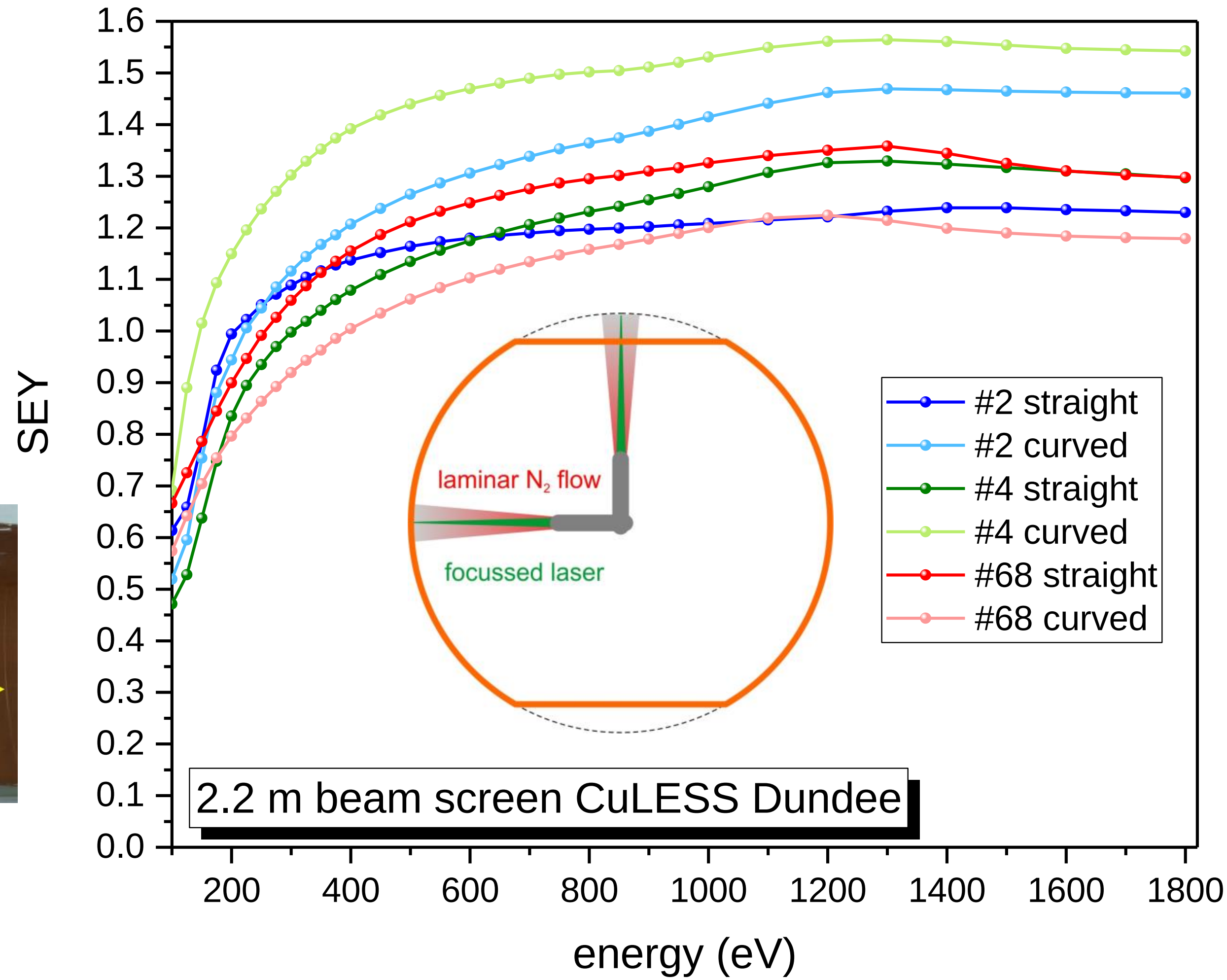


University of Dundee

SEY Analysis of laser-treated beam screen

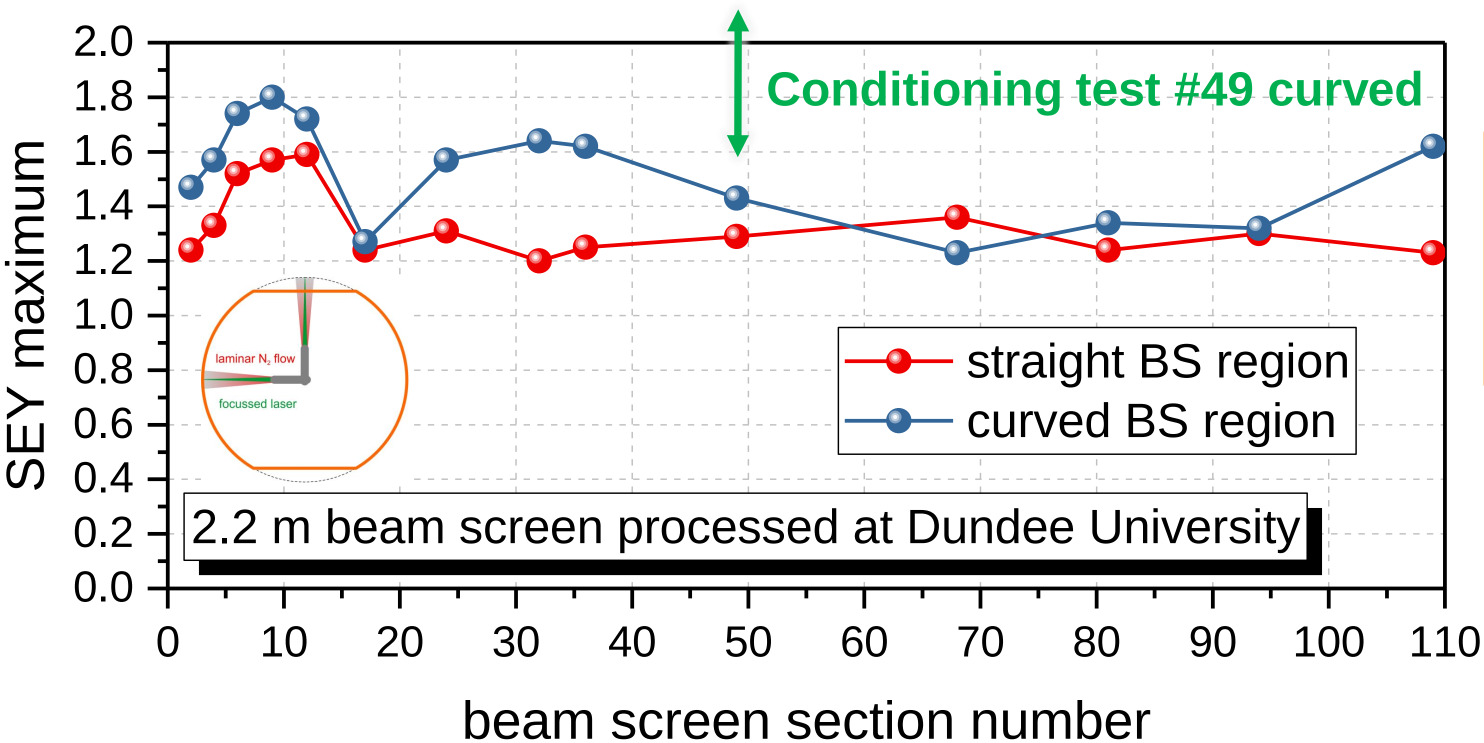






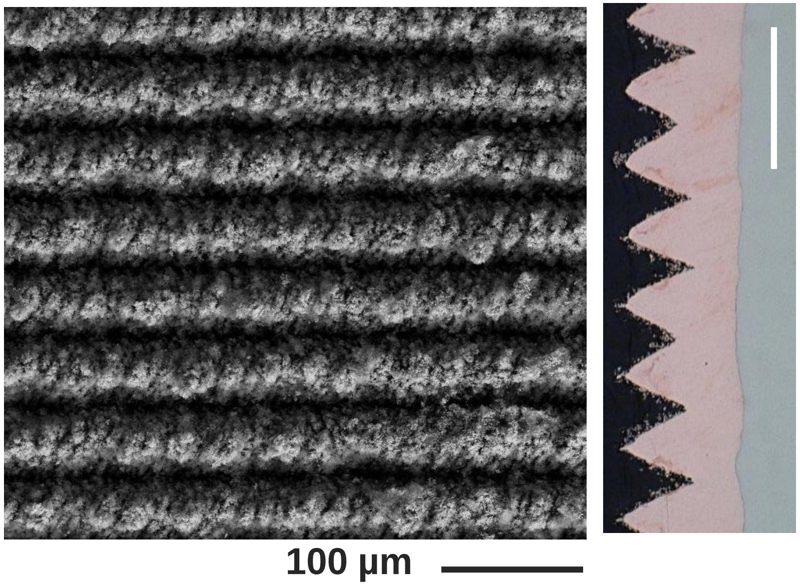
SEY Analysis of laser-treated beam screen

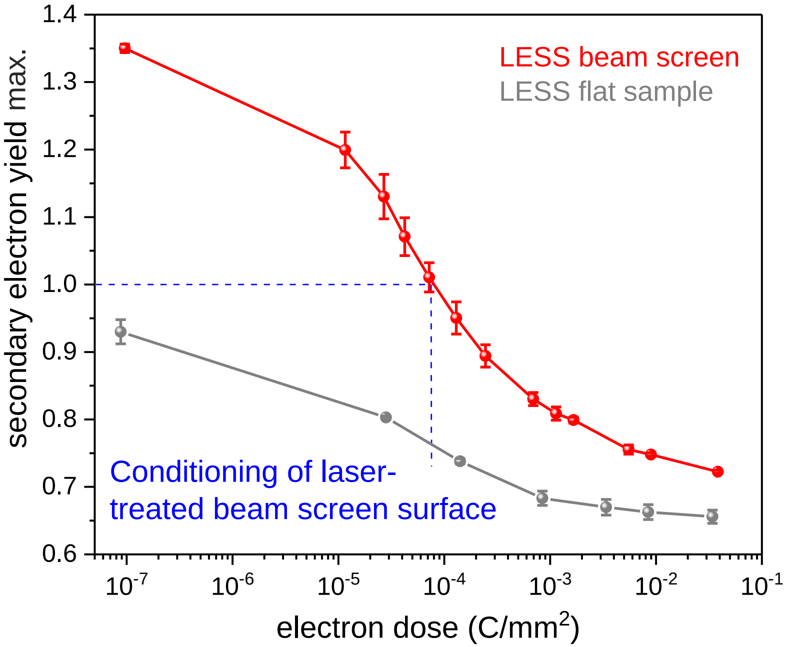
timeline of treatment including, focus & parameter optimization



Beam screen SEY after LESS: **1.2 – 1.6**

LESS beam screen characteristics





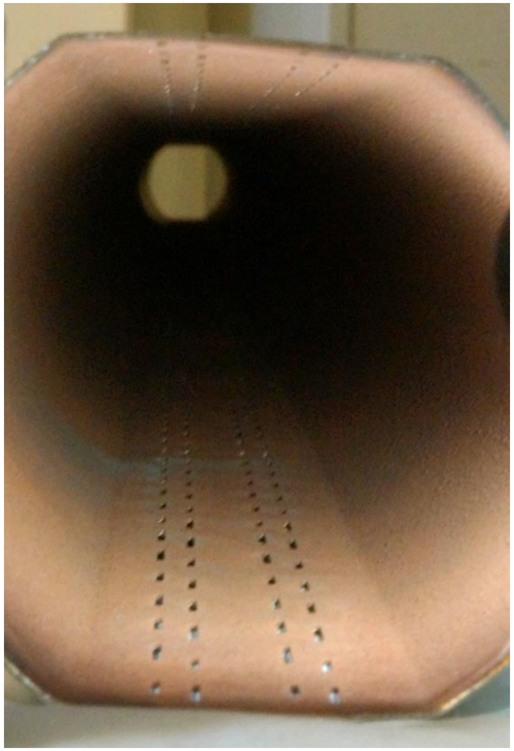
- homogeneous stripe pattern achieved
- inhomogeneities in curved regions
- ablation depth too high (< 25 µm)

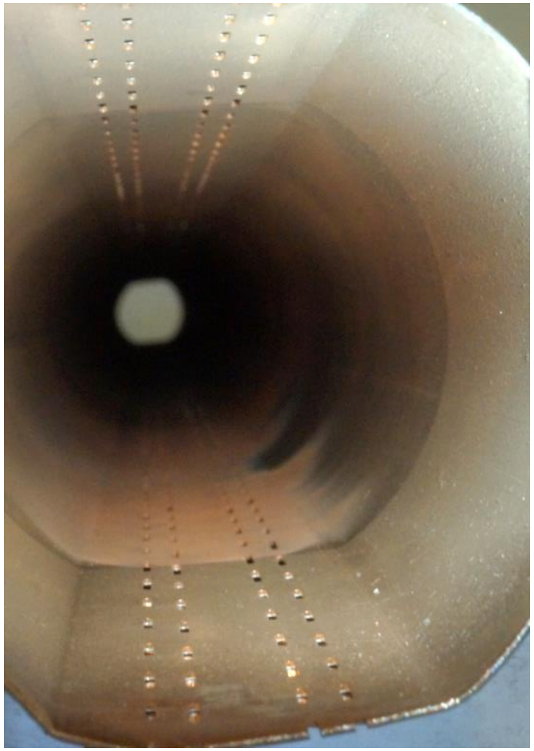
- SEY higher compared to lab LESS samples
- surface conditions to SEY<1 for electron doses $<10^{-4}$ C/mm^2

→ promising to find optimized conditions in terms of treatment speed, ablation depth and final SEY after conditioning

Particle Generation and Dust in Beam Screen

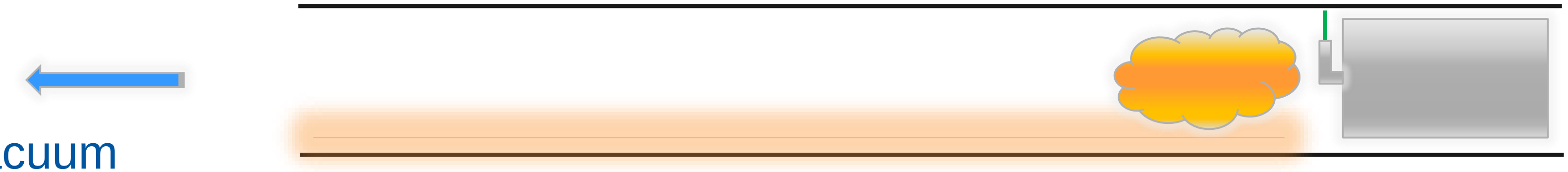
Vacuum
Extraction
Unit

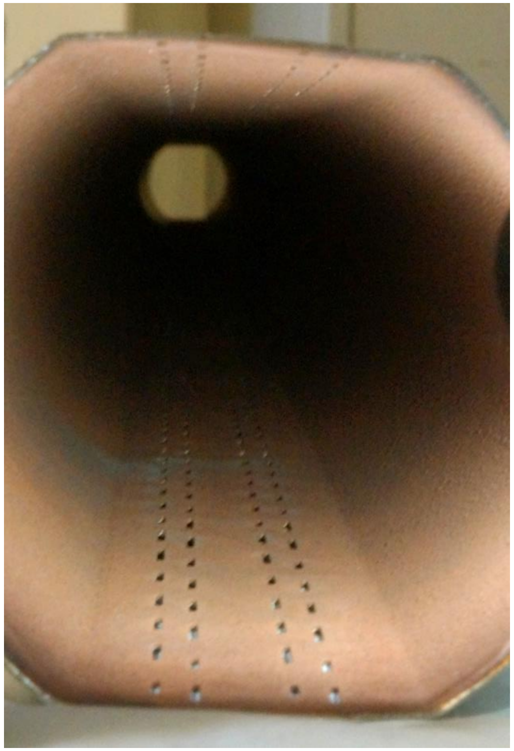


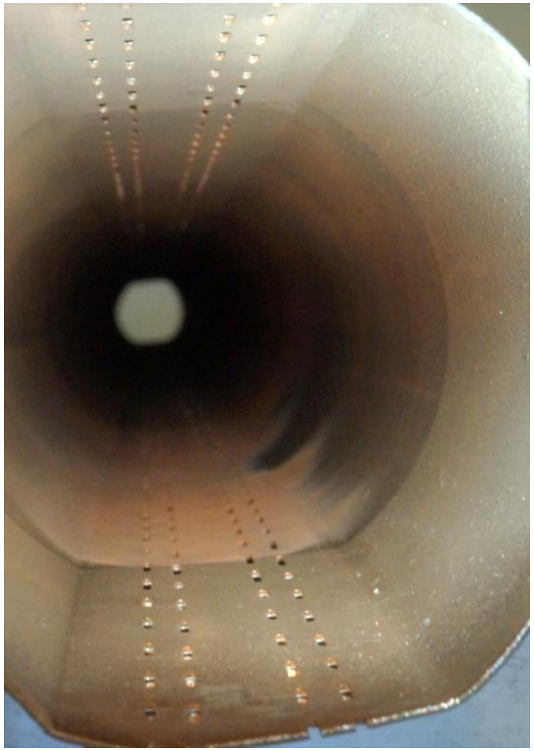


Particle Generation and Dust in Beam Screen

Vacuum Extraction Unit

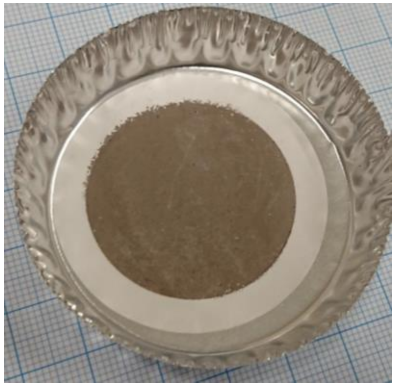




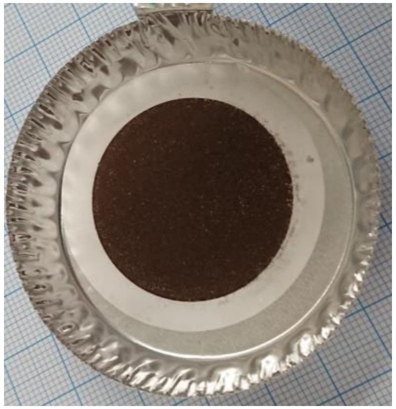


Extracted particles

Particles mass (mg)	Origin
12.0	external particles
7.4	ultrasonic cleaning of polymer bag
14.6	rinsing of beam screen



Extraction of loose particles has to be improved for treatment of long, confined spaces such as beam screens or tubes.



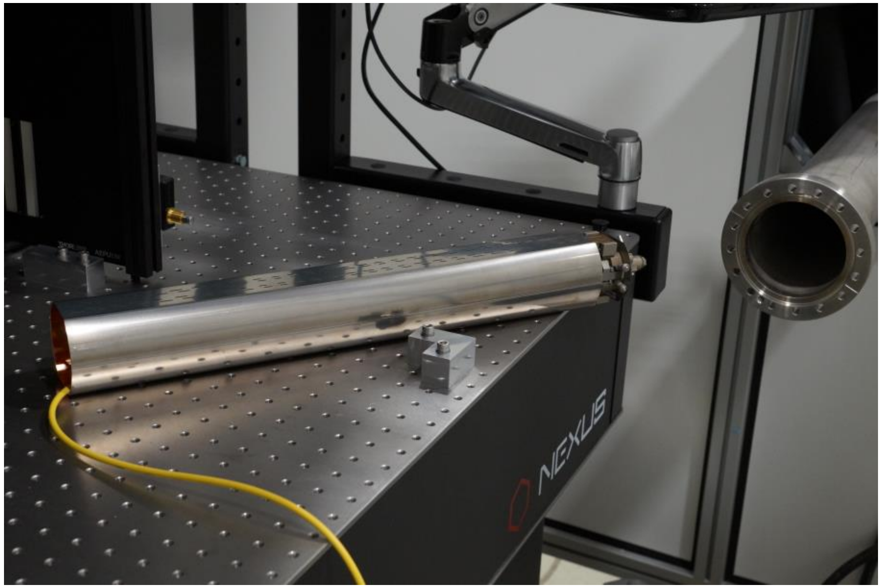
Challenges for the development of reliable beam screen treatments (towards in-situ processes)

Aim: homogeneous, low SEY surface

Requirement: robust and stable light delivery to the robot and the beam screen surface

- Laser – Fibre coupling is instable and causes down-time
  → installation of a remotely controlled beam delivery system is required including fibre upgrade to 15 m and fibre-handling
- Extraction of loose particles & cleaning processes are essential
- Process speed-up having SEY < 1 after conditioning and ablation depth < 25 μm as targets including adaptable focus
- Is green laser best solution – IR-technology (1064 nm) possible?

Installation of laser test bench in SMA 18

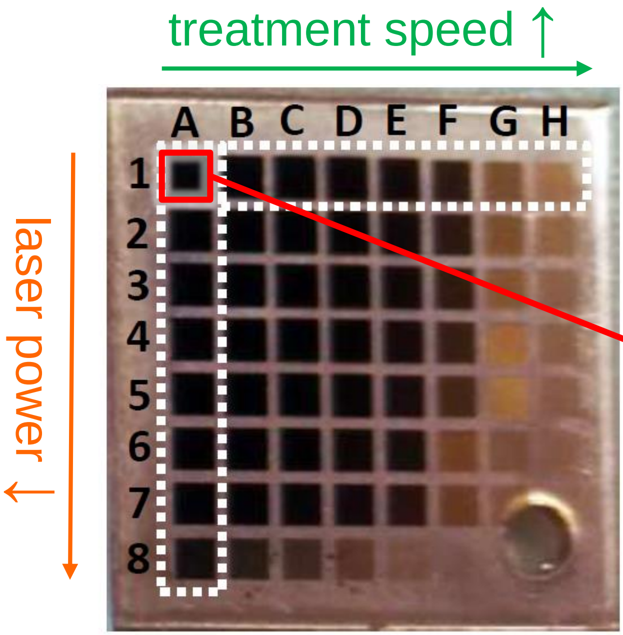


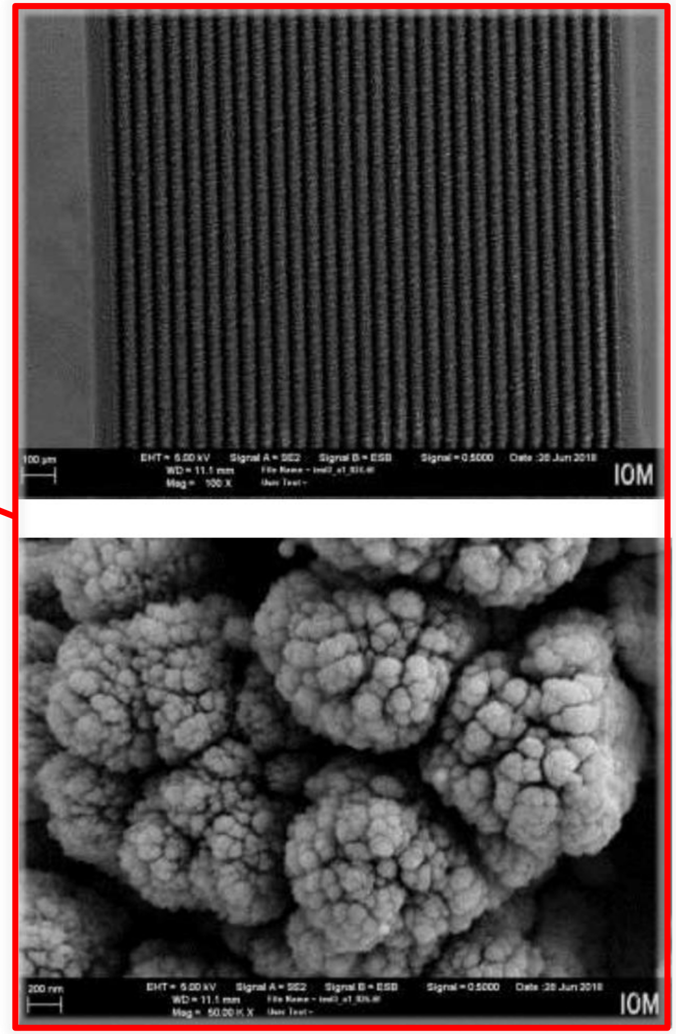
01-02/2020 installation of laser & robot
03-05/2020 upgrade of BDS
01-06/2020 control software development

- The current setup needs further technical development and the robot is currently only capable to operate in triplet beam screens.
- Modifications to treat circular cross-sections at different focal lengths or complex shapes are envisaged, but not yet available.

Laser parameter screening with IOM

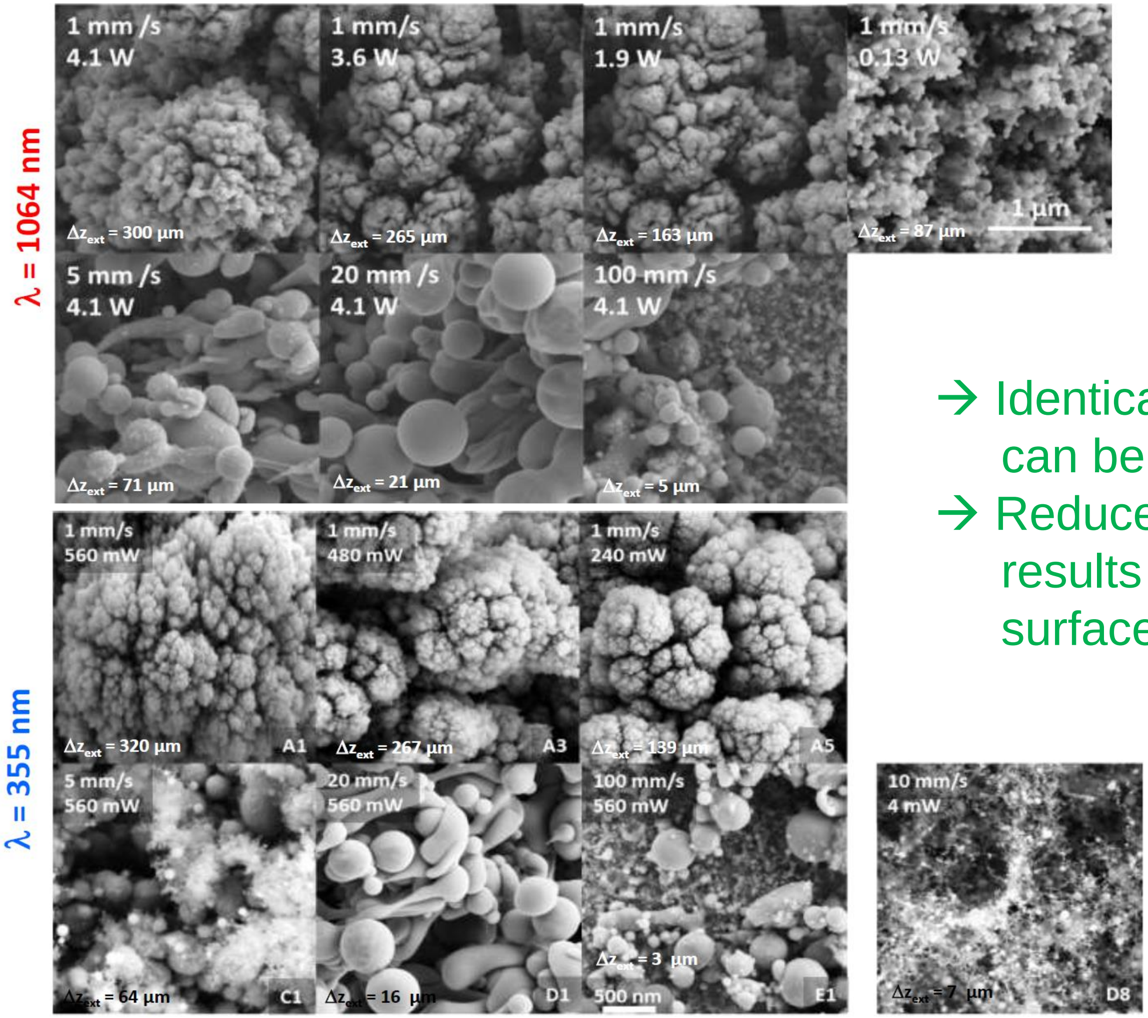
Leibniz-Institut für Oberflächenmodifizierung e.V.





IR (λ = 1064 nm)
picosecond laser
f = 100kHz, 50 µm

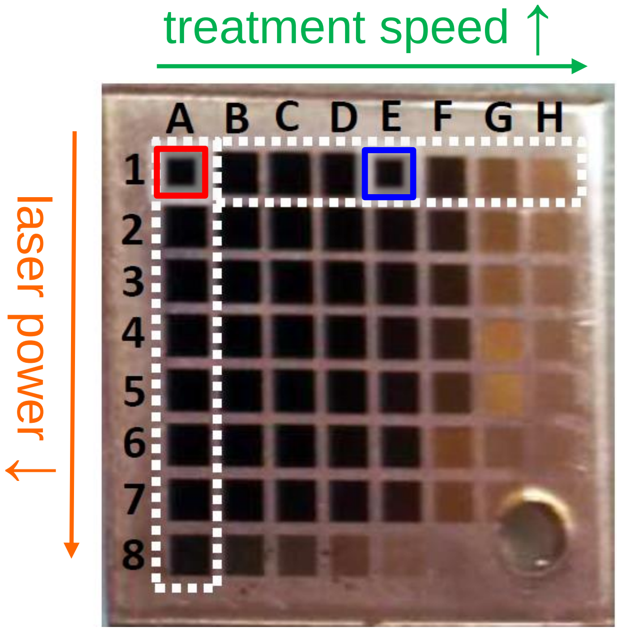
Laser parameter screening – wavelength

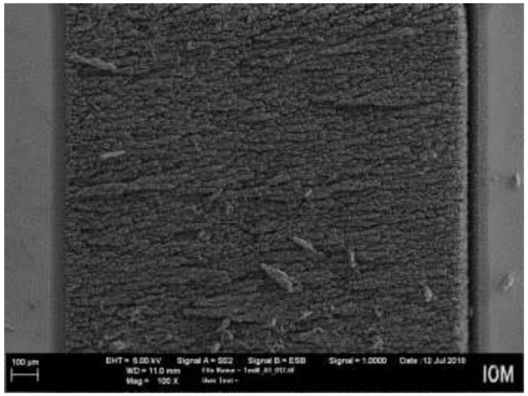


→ Identical surface structures can be obtained

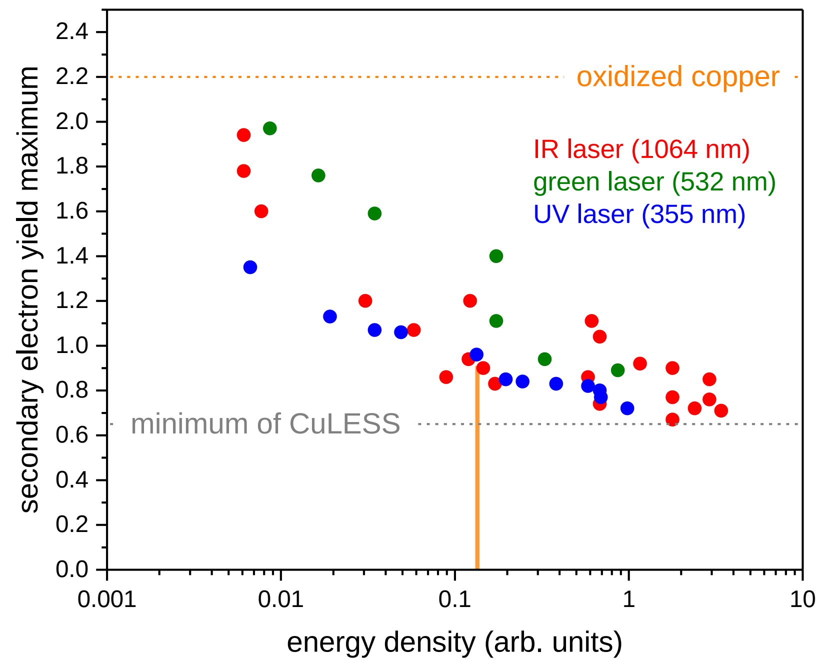
→ Reduced hatch distance results in trench-free surfaces

Laser parameter screening – energy density





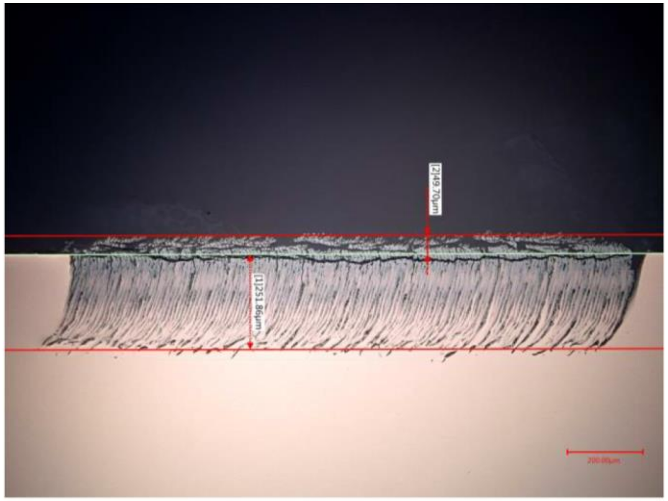
Parameters: power, wavelength, pulse duration, pulse frequency, scan velocity, line spacing, laser focus, ambient gas

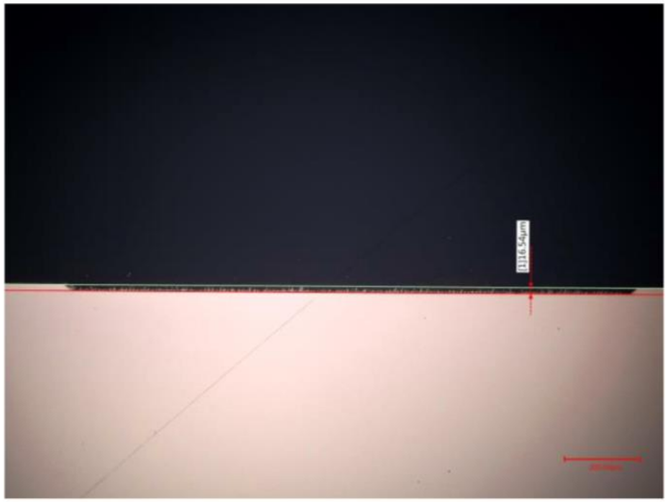


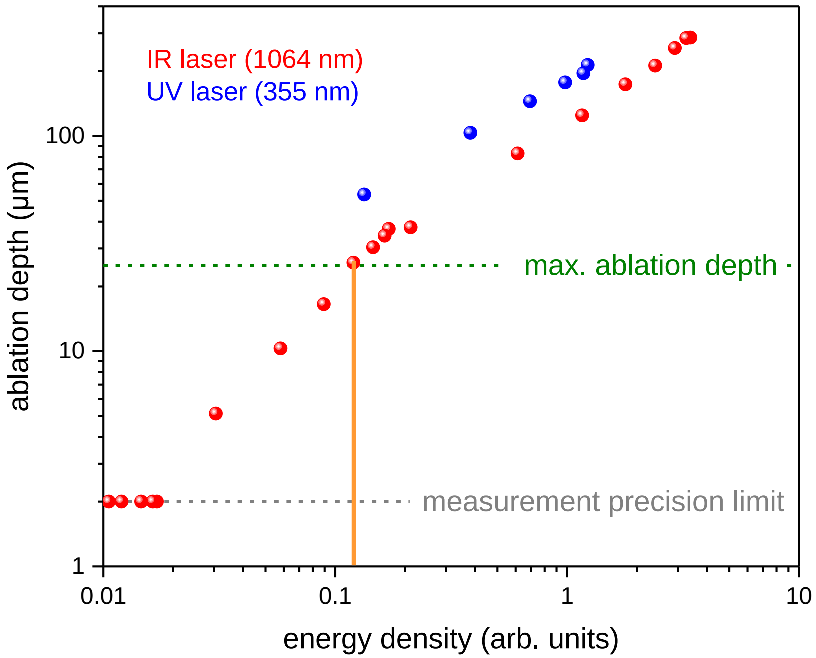
➢ LESS processing is possible from UV to IR !

532 nm is more sensitive and technologically challenging

Laser parameter screening – ablation depth





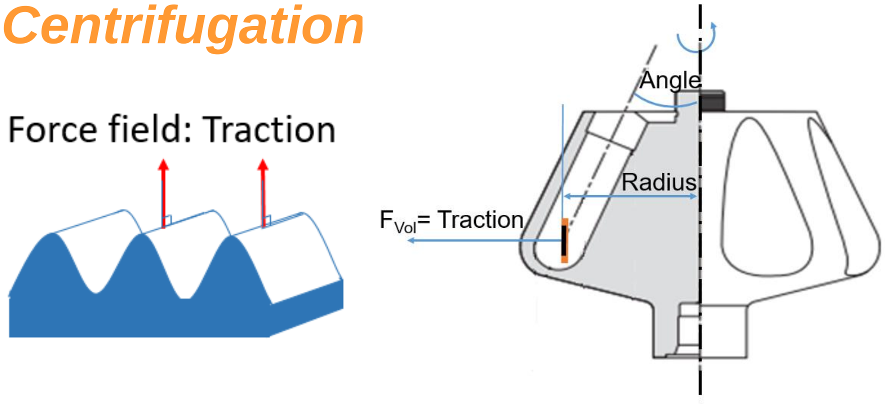


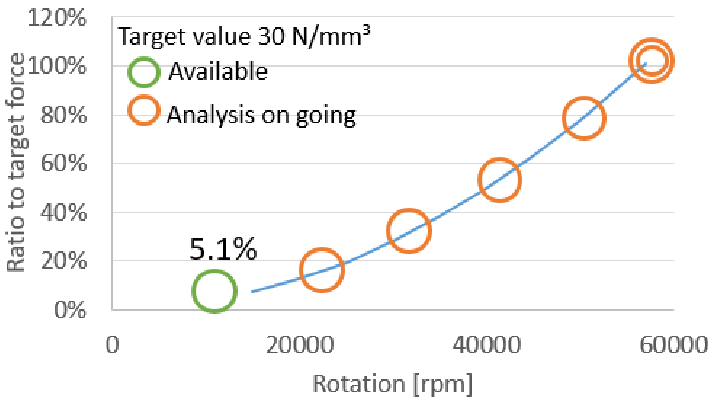
In the laboratory, it is possible to minimize the ablation depth while still obtaining SEY ~1

→ Upscaling and large-area processing to be evaluated

Evaluation of quench-induced particle release

Centrifugation





@ EPFL and Geneva University

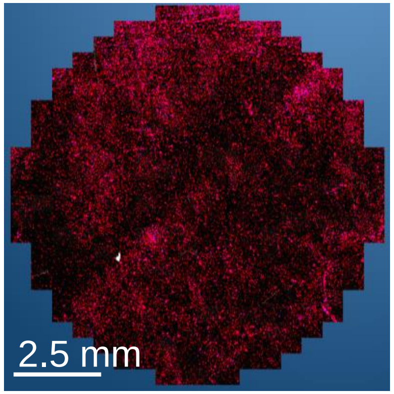
Mechanical stress on the particles during magnetic quench

$$F_{Vol\ Quench} = \frac{r_{BS} B \dot{B}}{\rho_{elec}} = 29\ N/mm^3$$

Use inertia forces to reproduce the electromagnetic forces

$$F_{Vol\ Centrif} = \rho * R * \omega_{\frac{rad}{s}}{}^2$$

Equivalent acceleration a_{eq}= 328 000 g

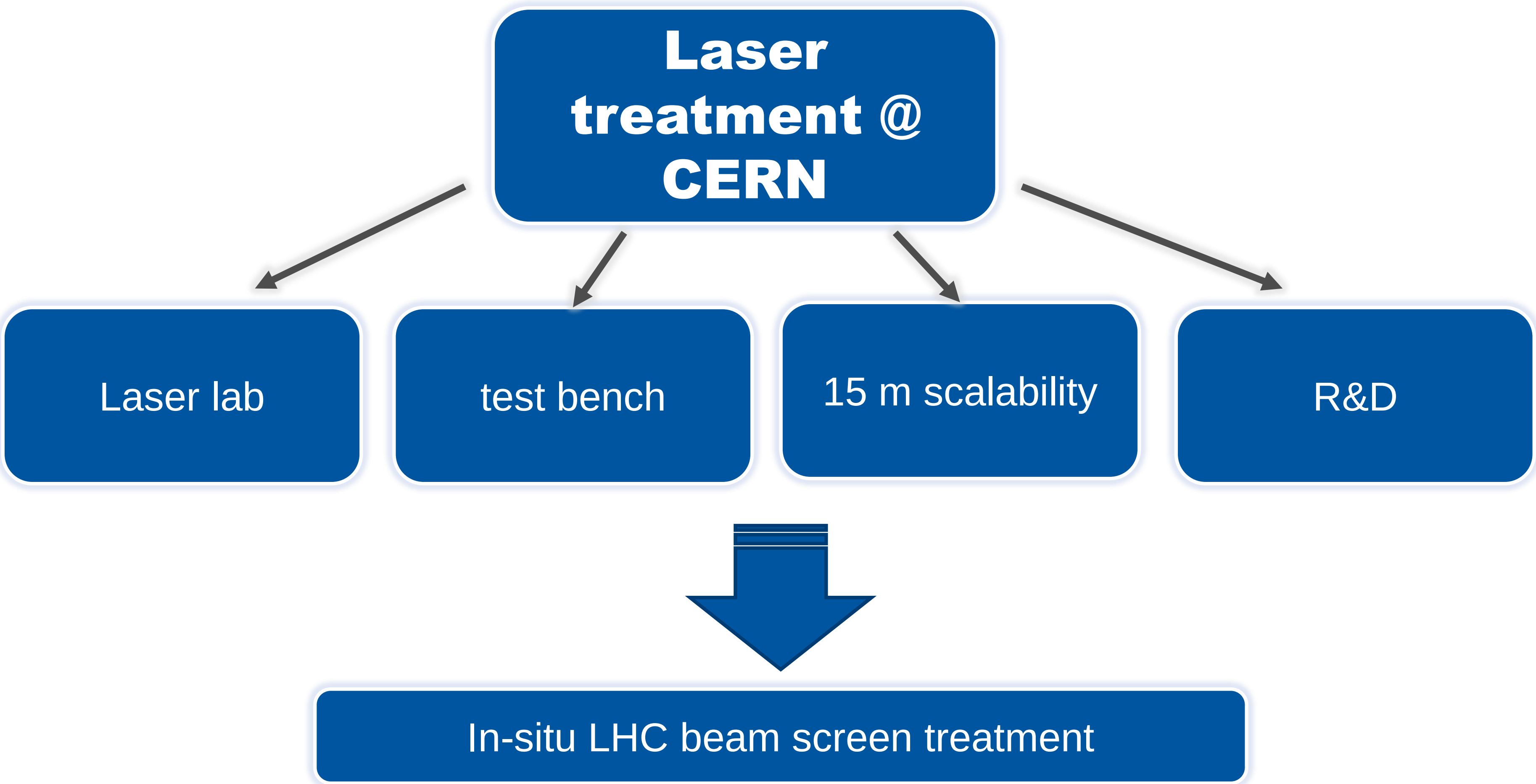


Particle counting detached from the LESS surface

Weight removed at 5.1%: 0.020 mg/cm²

courtesy of L. Baudin

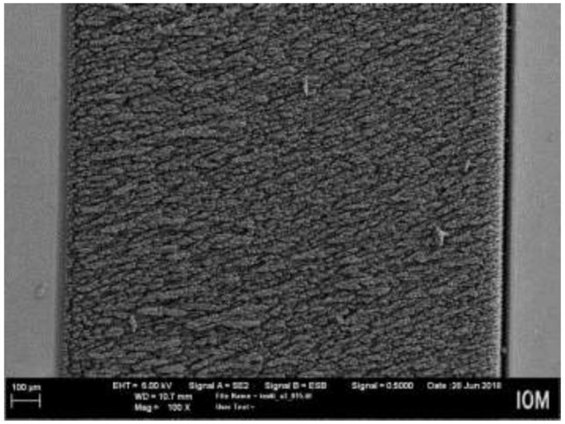
CERN laser treatment development project

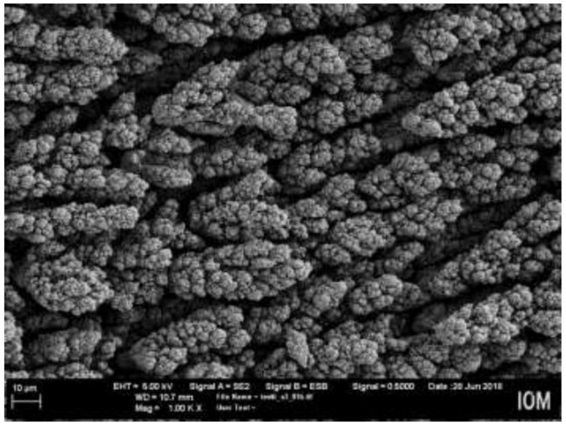


CERN

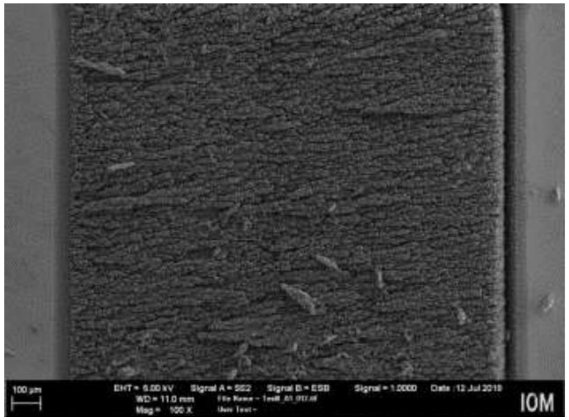
Laser parameter screening – wavelength

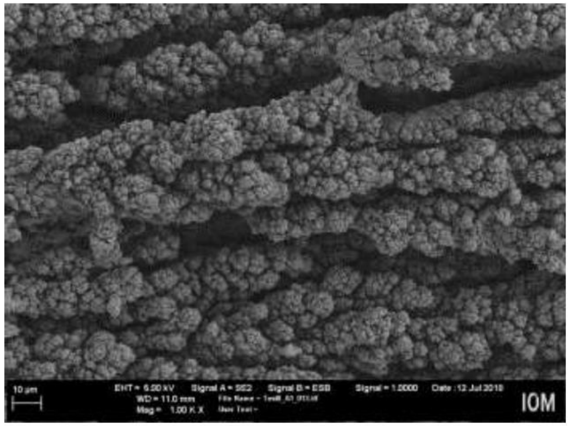
UV (λ = 355 nm)
picosecond laser
f = 100kHz, 10 µm





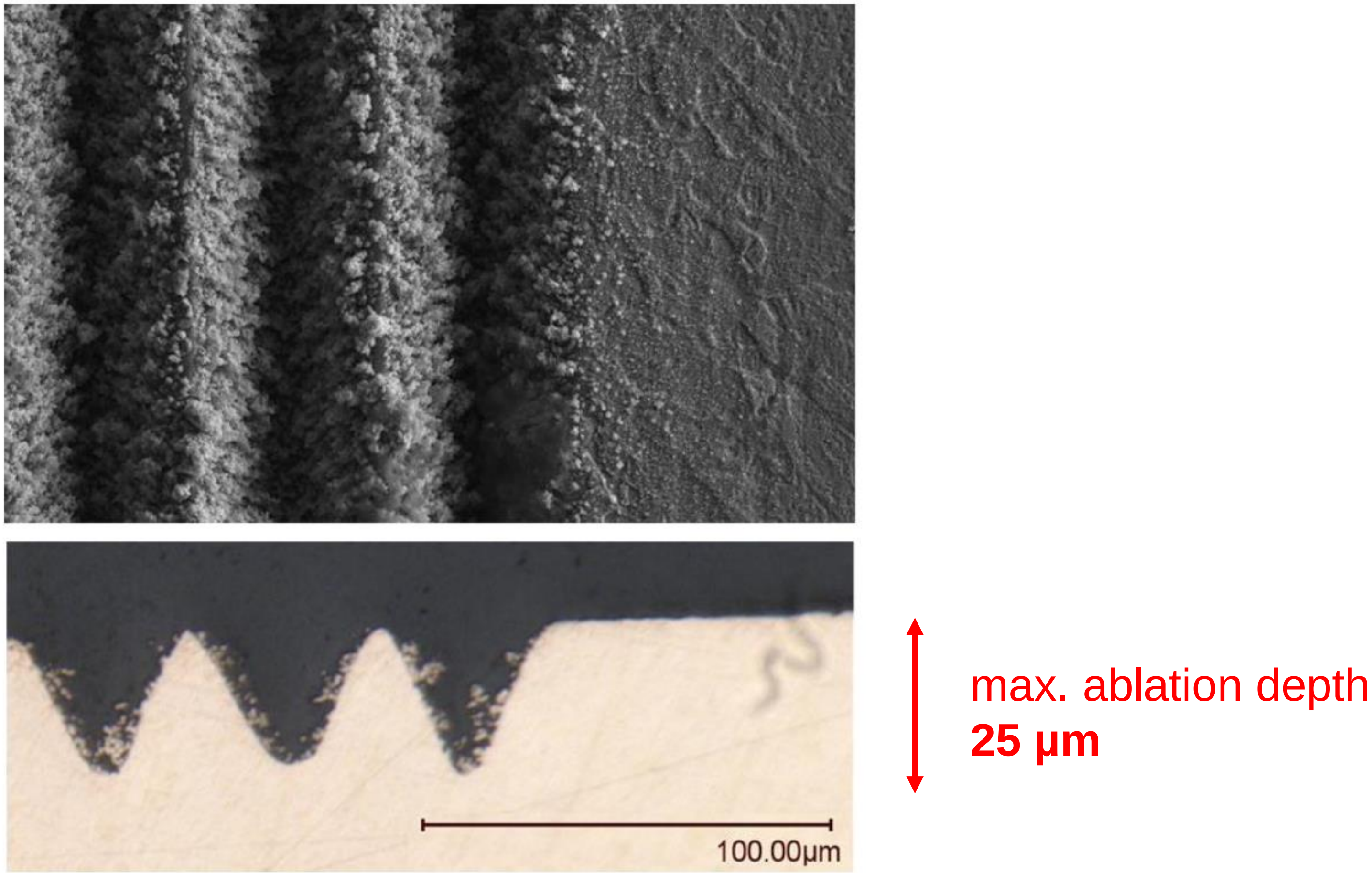
IR (λ = 1064 nm)
picosecond laser
f = 100kHz, 10 µm

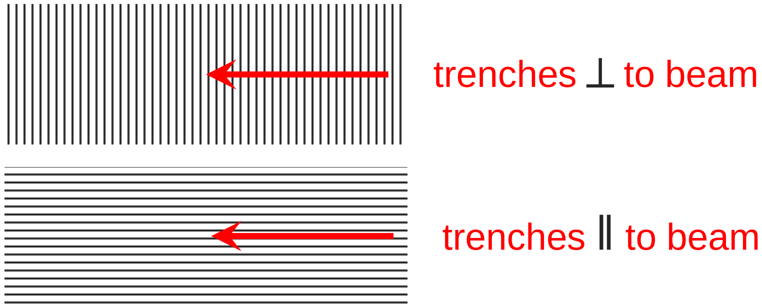




IOM

Cross section of laser treated surfaces





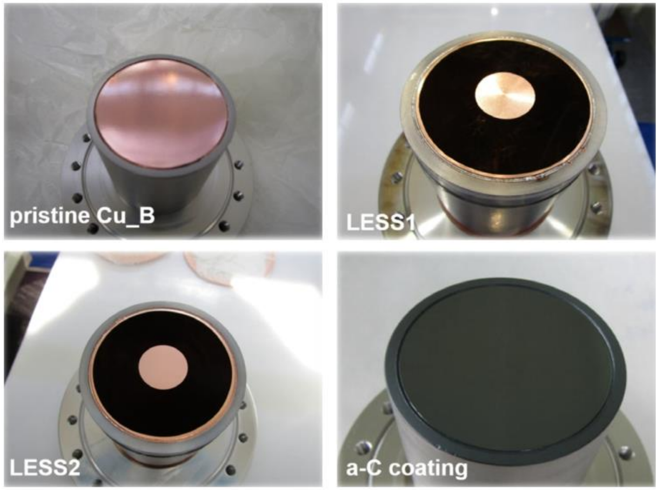
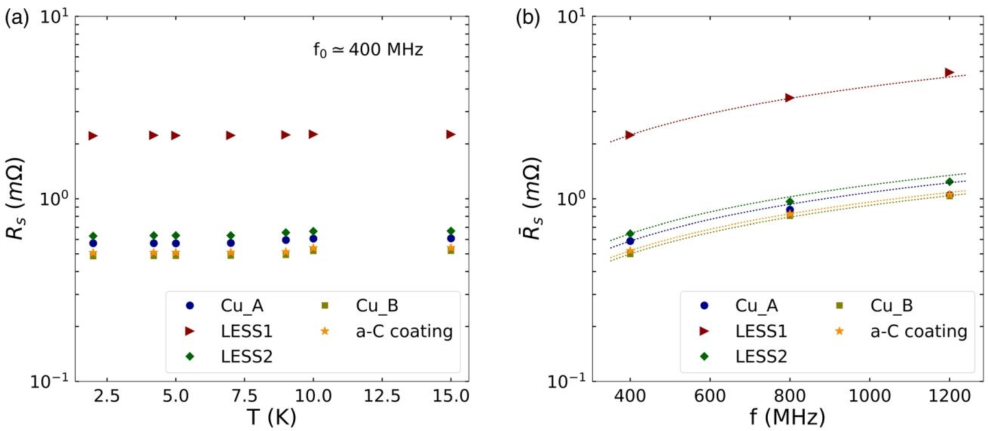


FIG. 2. The four characterized sample surfaces. Cu_A or Cu_B, pristine OFE copper; LESS1, copper with a radial laser pattern; LESS2, copper with a circular laser pattern; a-C coating, copper with an amorphous carbon coating.



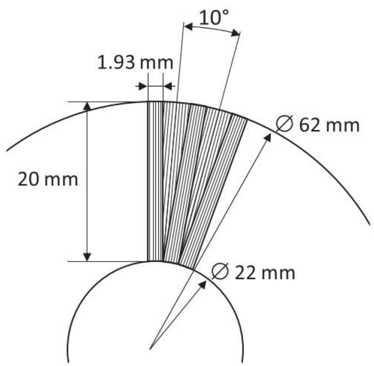
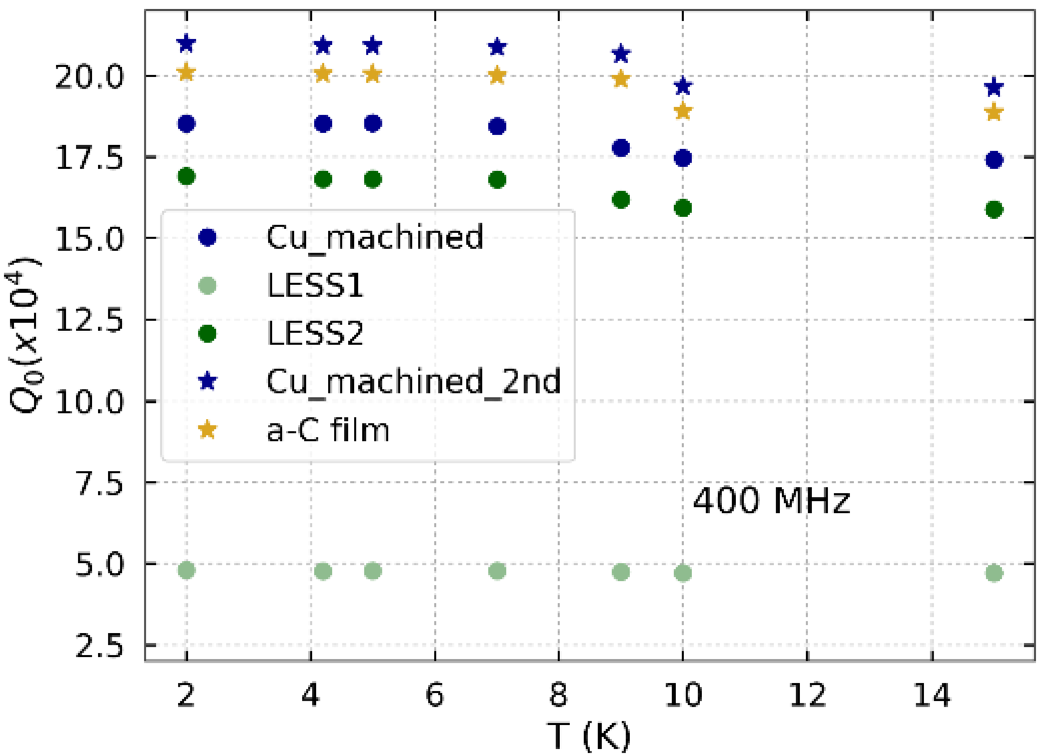


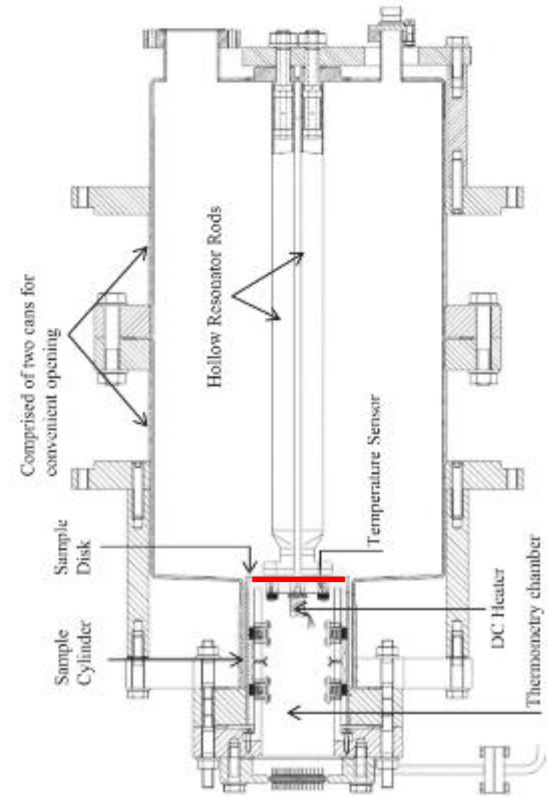
FIG. 5. (a) Surface resistance as a function of the sample temperature for pristine copper and for the different surface treatments. (b) Surface resistance averaged over the temperature as a function of the QPR mode frequency for pristine copper and for the different surface treatments. The curves show the functional dependence $f^{2/3}$, having the data points at 400 MHz as a reference. Error bars are not shown for a better visualization of the different data points (measurement uncertainty $\delta R_s/R_s \approx 10\%$).

FIG. 4. Schematic pattern for the laser treatment of the QPR sample LESS1, repeated along the entire annular surface.

S. Calatroni et al. Phys. Rev. Accel. Beams 22, 063101 (2019)

Quadrupole resonator at 400 MHz: Q0 vs Temperature MHz

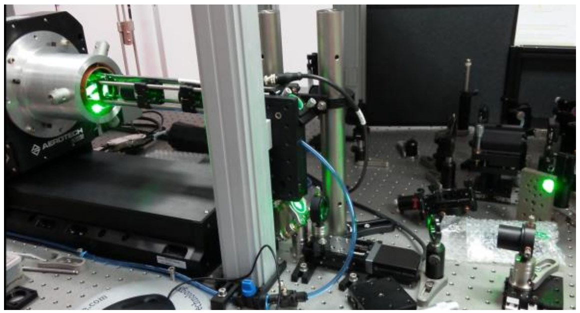




Courtesy M. Arzeo, S.Calatroni

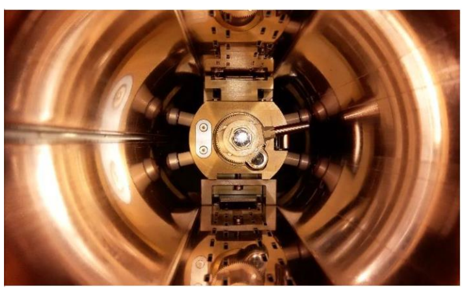
Status of Cu laser treatment development

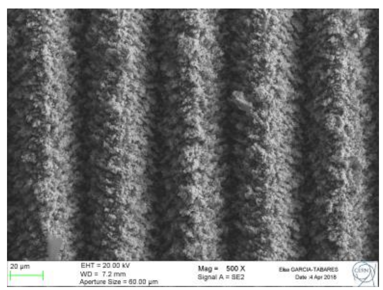
- ❑ COLDEX treatment

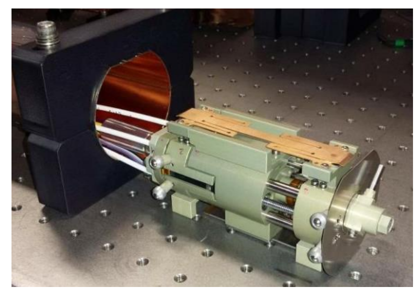


9 segments x 24 cm

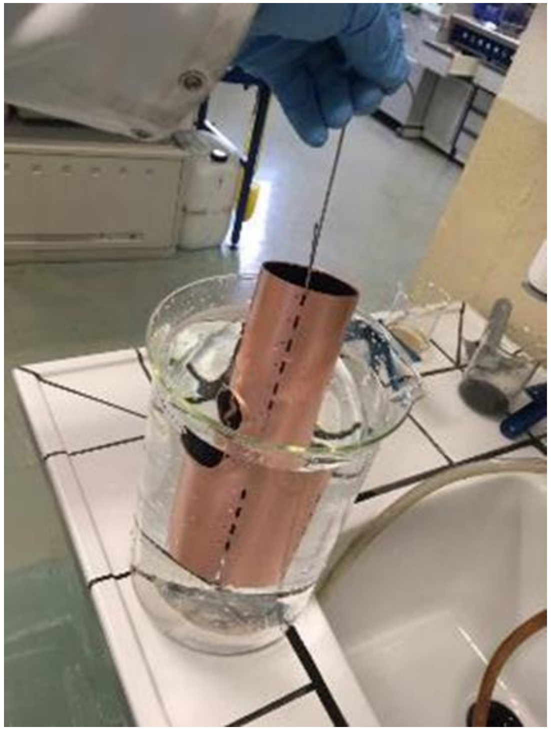
- ❑ In-situ Beam screen treatment



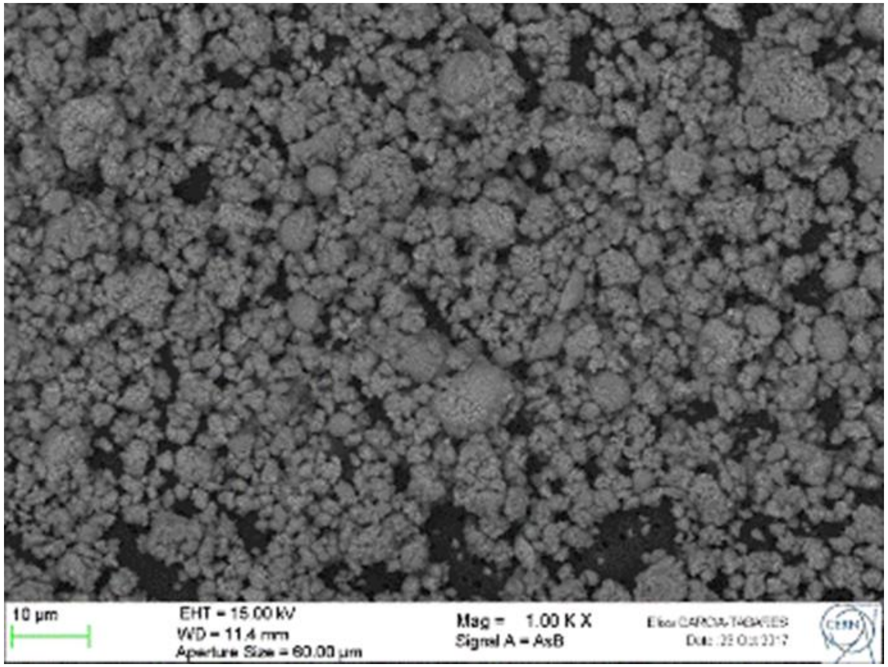


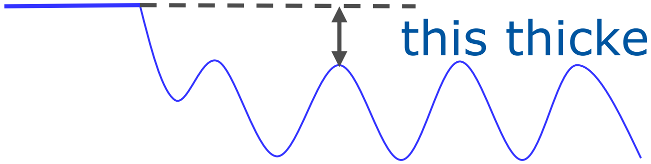


Possible issue: loose particles



Loose particles detached by rinsing and agitation

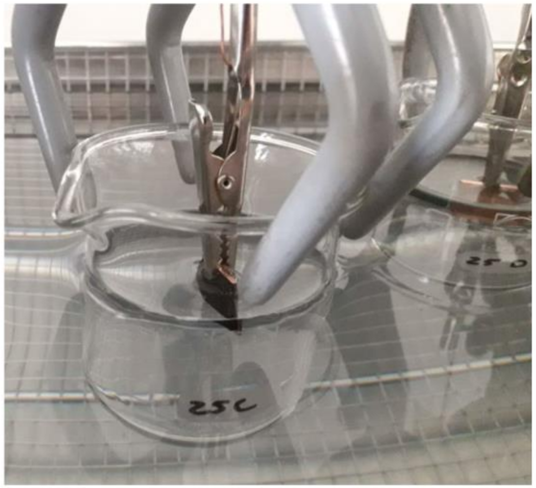




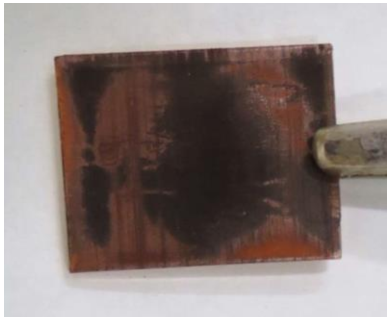
this thickess is “ablated”

Evaluation of quench-induced particle release

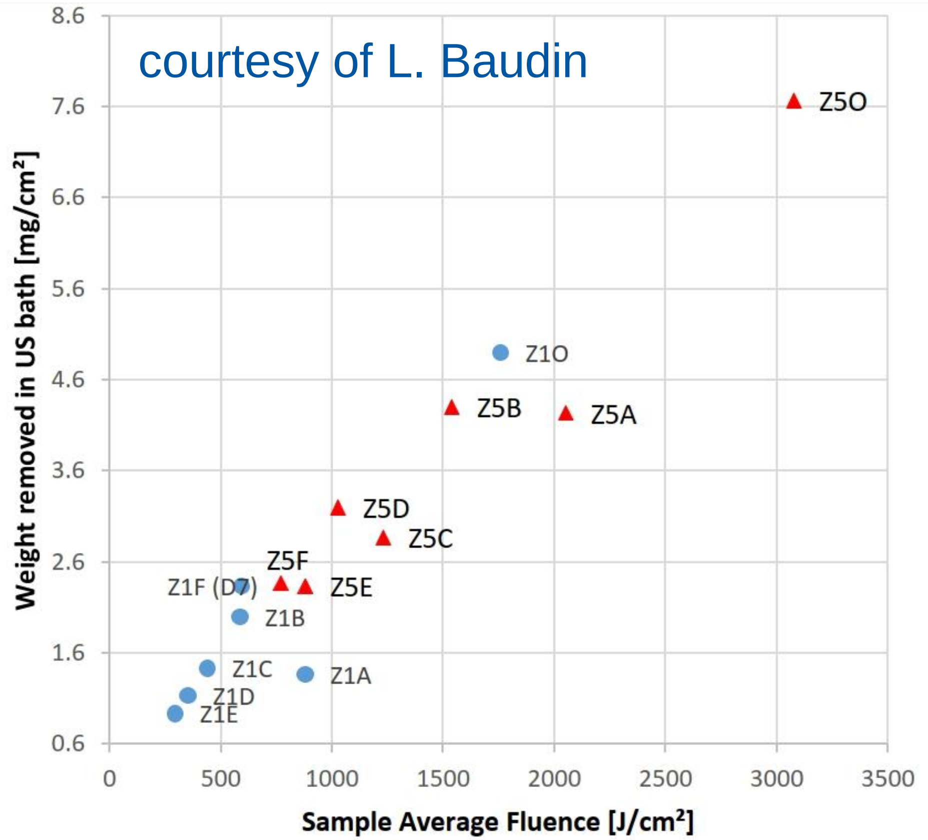
Ultra-sonic bath treatment



extracted particles



surface after cleaning



→ Proportionality between laser fluence and particle release allows minimization but no complete prevention

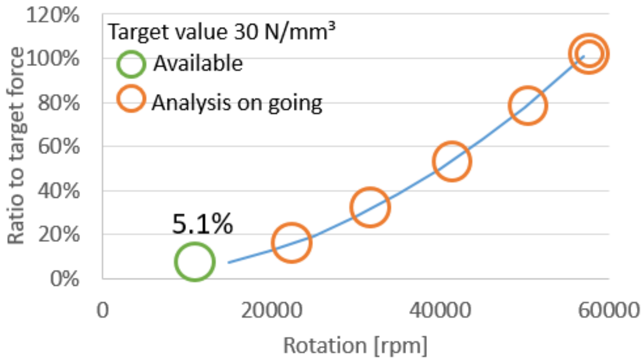
Mechanical stress on the particles during magnetic quench

$$F_{Vol\ Quench} = \frac{r_{BS} B \dot{B}}{\rho_{elec}} = 29\ N/mm^3$$

Use inertia forces to reproduce the electromagnetic forces

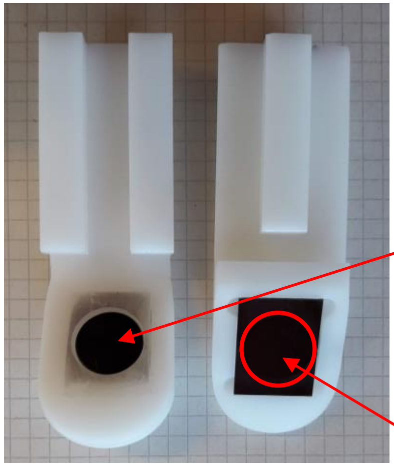
$$F_{Vol\ Centrif} = \rho * R * \omega_{\frac{rad}{s}}{}^2$$

Equivalent acceleration a_{eq}= 328 000 g



Centrifugation: apply centrifugal force on the treated surface

At EPFL and Geneva University



Sample holder made at CERN

Courtesy of H. Kos

Particles collected on carbon sticker: SEM Particles counting

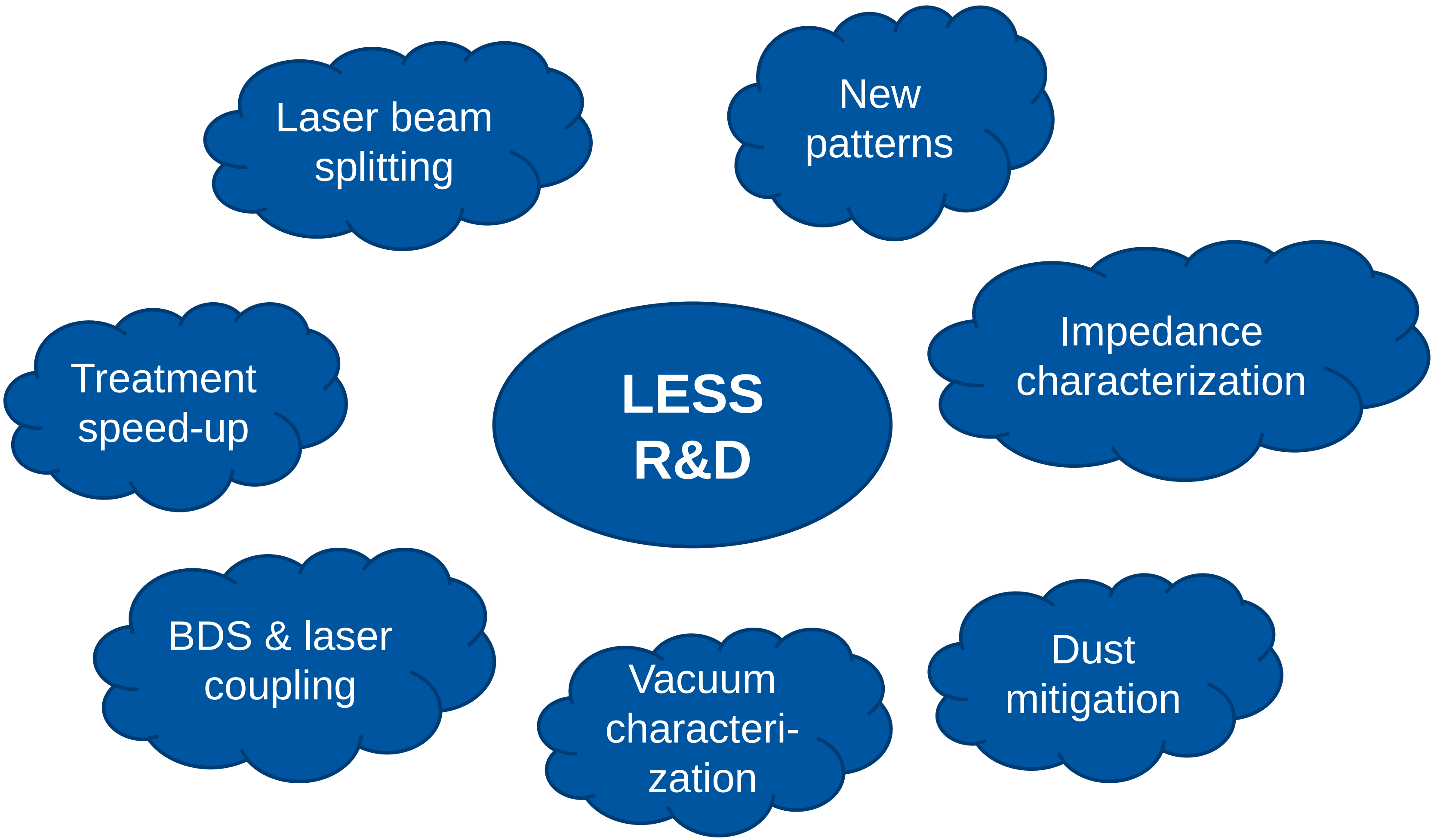
Surface submitted to centrifuge force to be analyzed: SEM, SEY

$$ch = \frac{r_{BS} B \dot{B}}{\rho_{elec}} = 29$$

Observation and counting of the copper particles detached from the treated surface

Weight removed at 5.1%: 0.020 mg/cm²

R&D of LESS


Laser beam splitting
New patterns
Treatment speed-up
LESS R&D
Impedance characterization
BDS & laser coupling
Vacuum characteri-zation
Dust mitigation