Recent microscopy at CERN

Enrique Rodríguez Castro

Microscopy at CERN	**Introduction**	**Equipment**	OM	
			SEM	
			FIB-SEM	
Microscopy for CLIC	**Production**	**Machining**		
		Pollution		
	RF and DC Studies	**Post-mortem**	CLIC-AS	Crab cavity
				T24 Open
			LES	Materials tests
				Cameras
				Size vs Gradient

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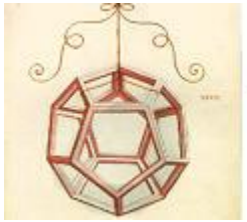
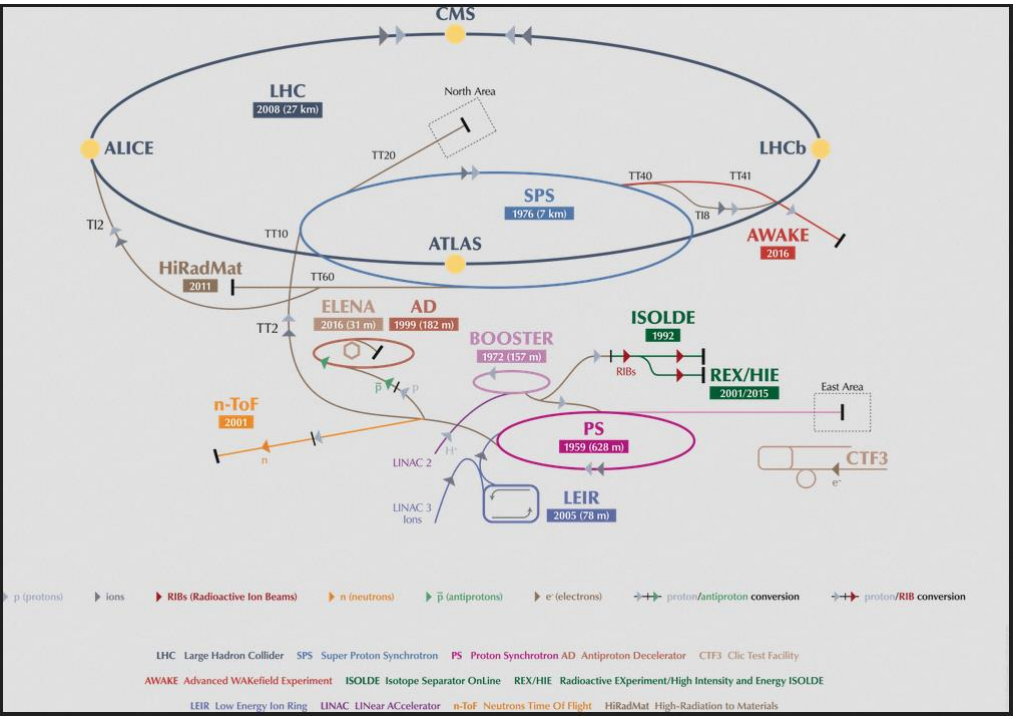
Microscopy at CERN

ENGINEERING DEPARTMENT



MME Mechanical & Materials Engineering

EN/MME MATERIALS & METROLOGY



Experiments and projects

- CERN experiments (Grey Book)
- ACE
- AEGIS
- ALICE
- ALPHA
- ASACUSA
- ATLAS
- ATRAP
- AWAKE
- CAST
- CERN Neutrino Platform
- CLIC
- CLICdp
- CLOUD
- CNGS
- CMS
- COMPASS
- DIRAC
- ELENA
- FCC
- GBAR
- HL-LHC
- HiRadMat
- ISOLDE
- LHCb
- LHCf
- LIU project
- MoEDAL
- NA61/SHINE
- NA62
- NA64
- nTOF
- PBC
- SHiP
- TOTEM
- UA9
- WLCG

Optical Microscopes

StereoMicroscope: M205C by LEICA

Objectives	
Resolution	Max. 1,050 lp/mm
Magnification	7.8×–1,280×
Object field	Max Ø 59mm
Field Optics Illumination	Bright Field (BF), Dark Field (DF), Single-Side Dark Field with Rotterdam contrast and Constant Color Intensity Control (CCIC)

Digital microscope: VHX 1000E by KEYENCE

Features	
Resolution	2-6 million pixels: 1600 (H) x 1200 (V) ≈ 1000 TV lines 8 million pixels: 3200 (H) x 2400 (V) ≈ 1600 TV lines 18-54 million pixels: 4800 (H) x 3600 (V) ≈ 2000 TV lines
High dynamic Range (HDR)	16-bit resolution through RGB data from each pixel
Magnification	1-1000x
Field Optics Illumination	*DF, *BF, *PL and *DIC

Optical Microscope: AxioImager by ZEISS

Performances	
Resolution	At 1296 X 968 Resolution of 3 Frames/S At 430 X 322 Resolution of 11 Frames/S At 258 X 193 Resolution of 16 Frames/S
Magnification	12.5 – 1,500x
Field Optics	Dark Field (DF), Bright Field (BF), Polarized light (PL), Differential Interference-Contrast (DIC)

Software
AxioVision & Zencore (New version)

Electron microscopy

Scanning Electron Microscope (SEM) ΣIGMA by ZEISS

Performance	
Resolution	1.2 nm at 30kV
Acceleration Voltage	0.1 – 30kV
Magnification	12 – 500,000x

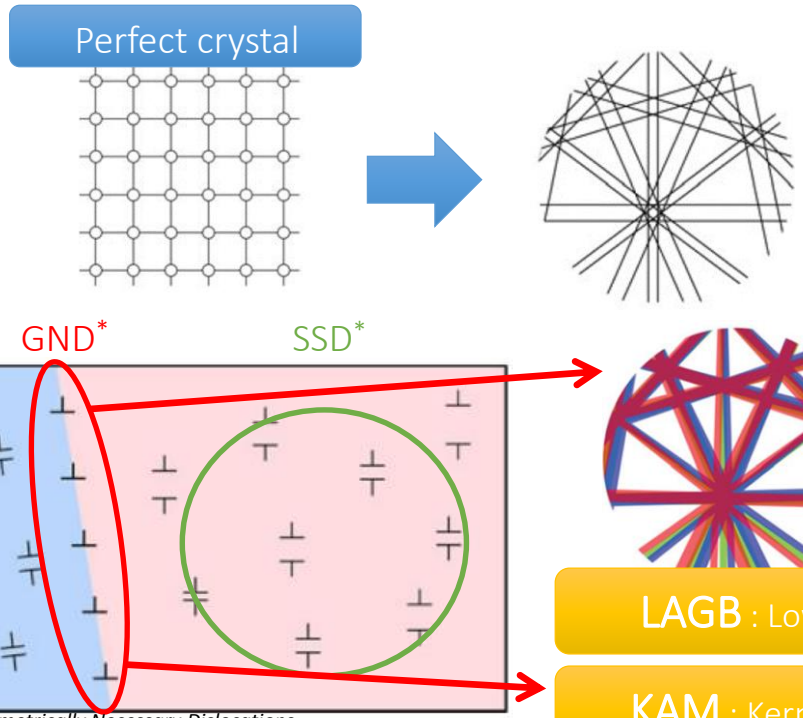
Specimen, Chamber and Stage	
Stage Movement range	5 motorized axes: X,Y,Z,T and R X and Y: ≥ 125 mm; Z: ≥ 50 mm T: 0° to 90°; R: 360°
Maximum specimen Weight	Up to 0.5 kg (tilted) and 2.0 kg (not tilted)
Chamber Internal Dimensions	365 mm diameter x 275 mm high

Focused Ion Beam (FIB) XB540 by ZEISS

SEM Performance	
Column	Crossbeam 540 (Gemini® II column)
Resolution	High resolution configuration: 0.7 nm at 30 kV
Acceleration Voltage	0.02 - 30 kV
Magnification	12x - 2,000,000x

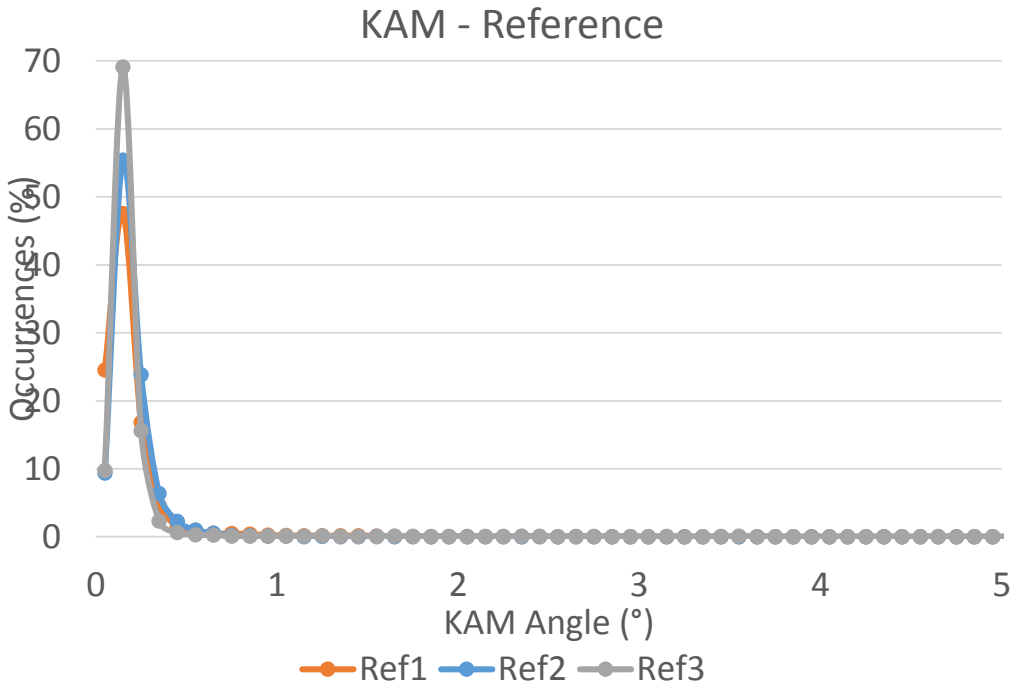
FIB Performance	
Source	Gallium Ion
Resolution	3nm at 30kV
Acceleration Voltage	0.5 – 30 kV
Magnification	300x - 500,000x

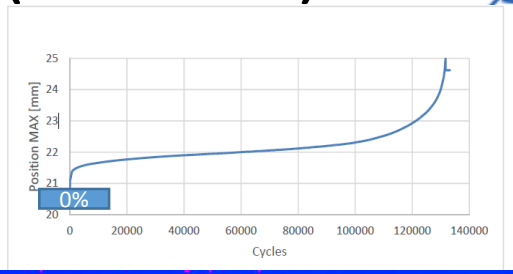
Mis-orientation and dislocation

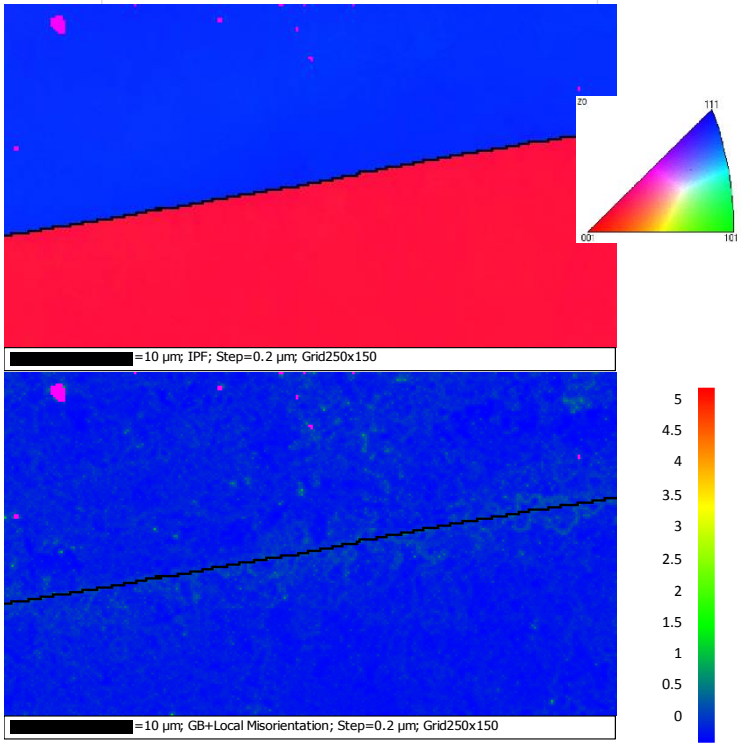


Fatigue - Reference (0% LT)

- Narrow distribution
- Low KAM values

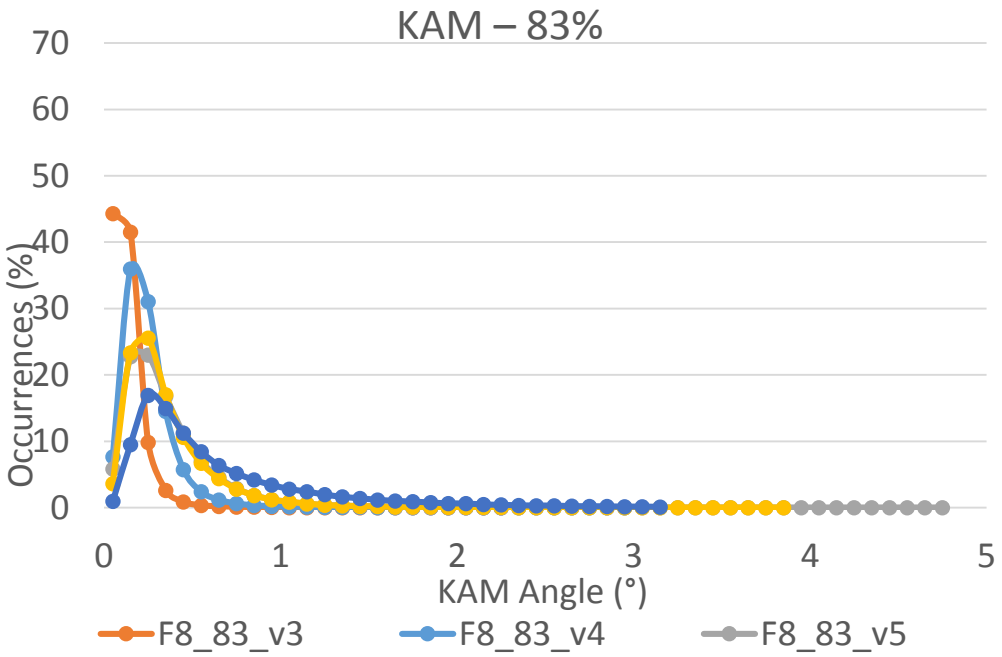


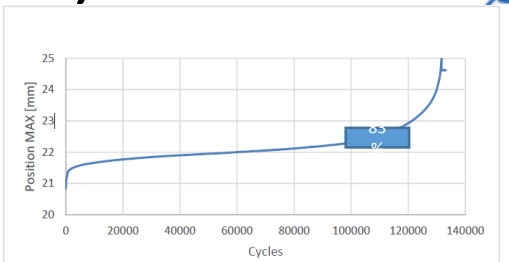


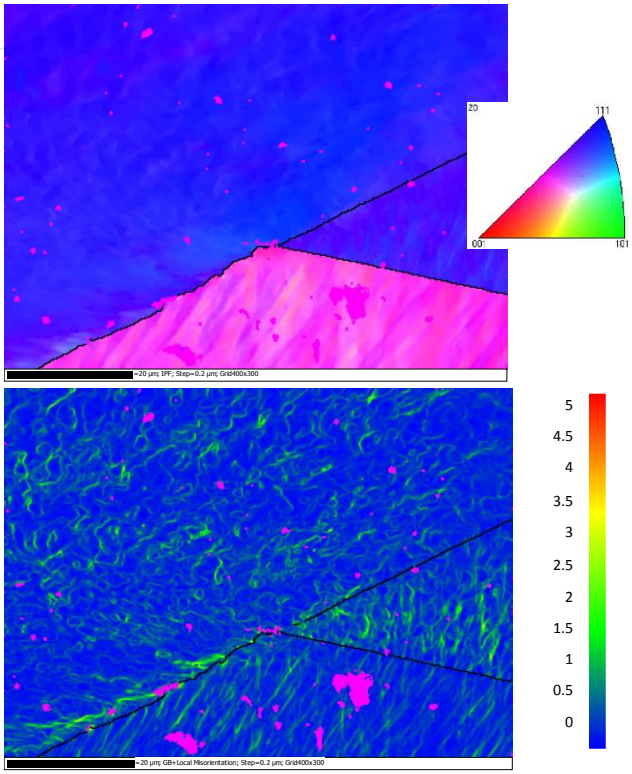


Fatigued (83% LT)

- Broadening of the distribution
- Shift to higher value
- Higher dispersion

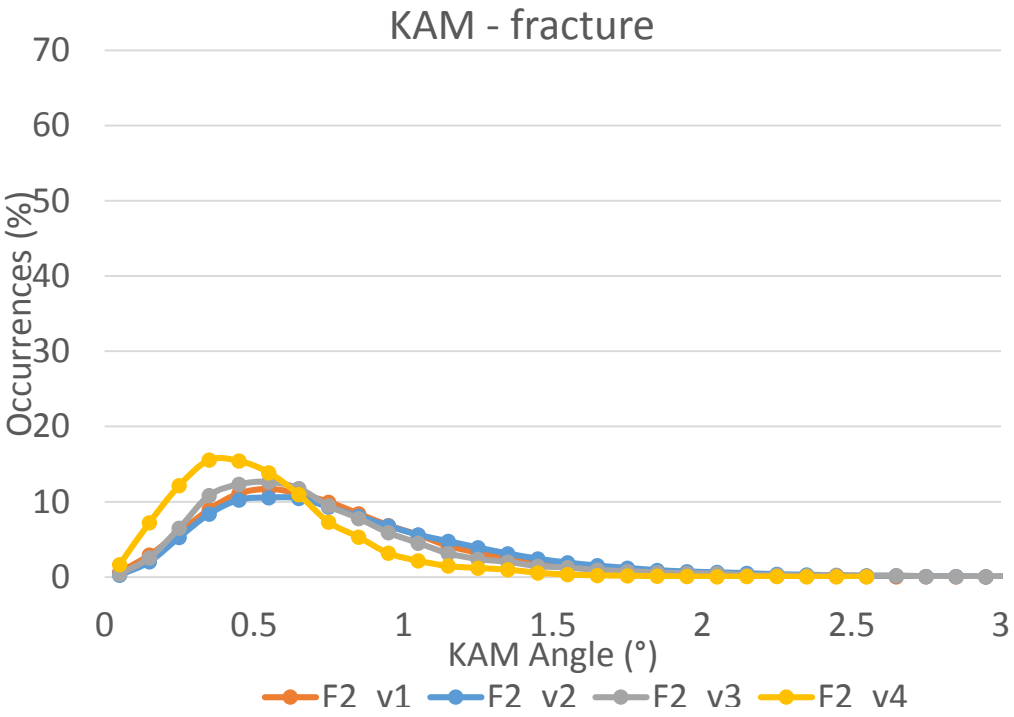


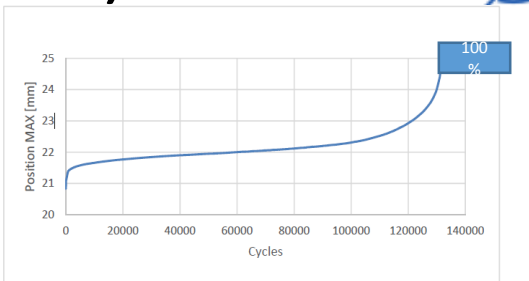


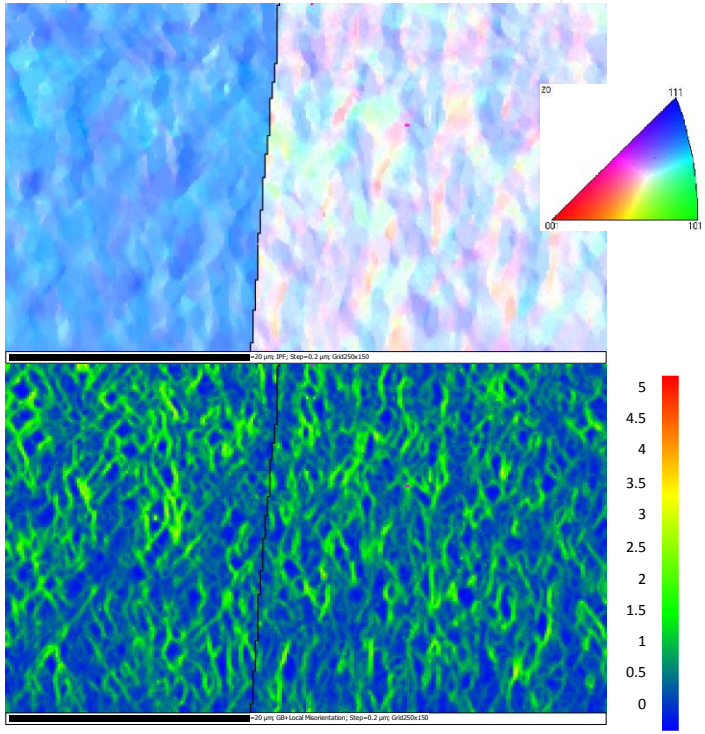


Fatigued (100% LT)

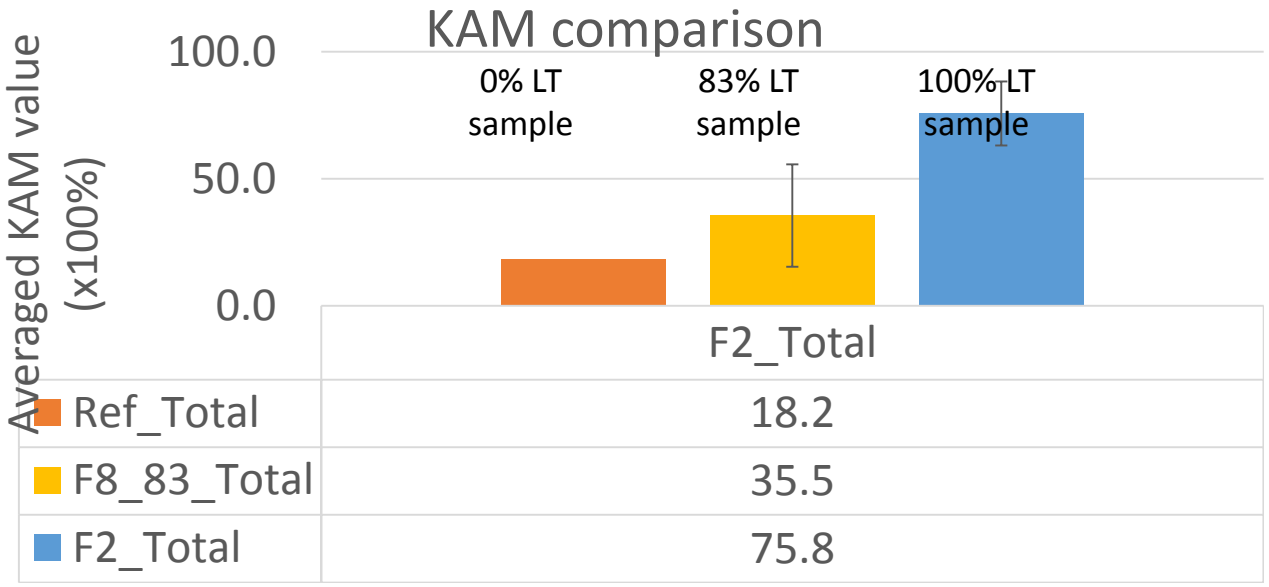
- Strong broadening of the distribution
- Shift to even higher value







Summary of EBSD observations



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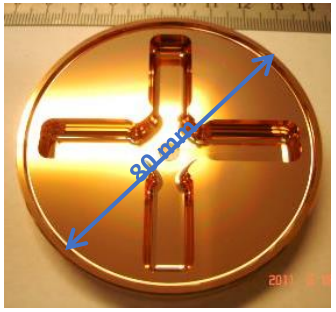
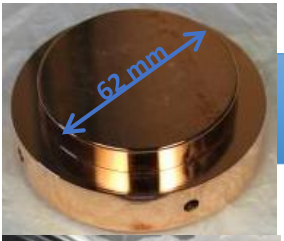
Microscopy for CLIC

UP-Diamond machining

Cleaning
Pollution analysis

SEM
(QC of the surface)



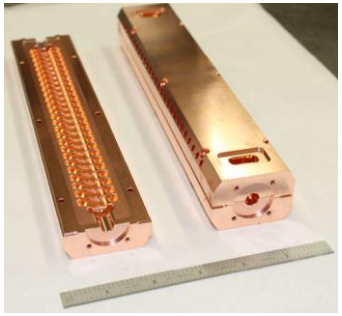


LES
HARD-Cu

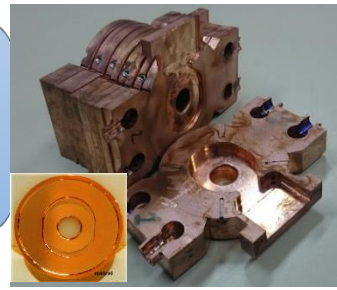
Assembly:
H_2 diffusion
bonding/brazing

LES
SOFT-Cu

Vacuum baking



High Gradient
testing



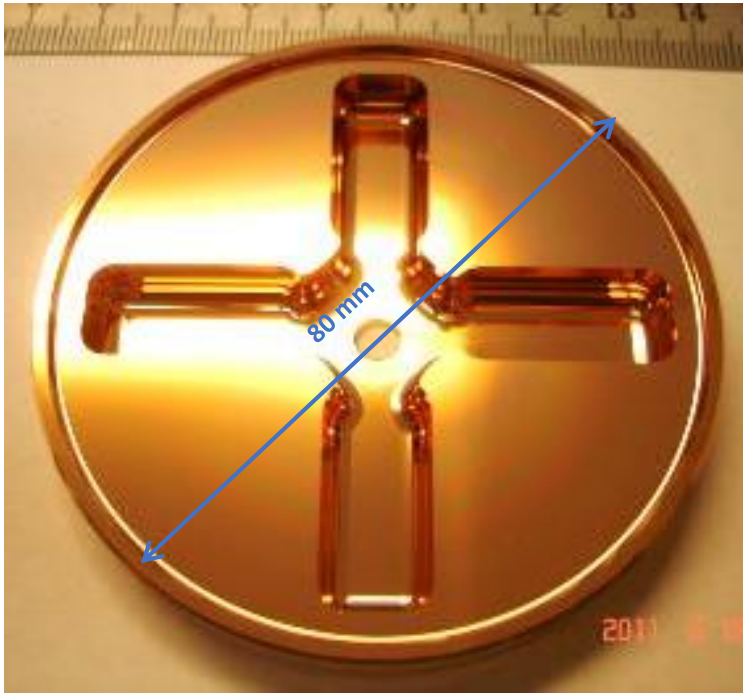
SEM
(Post-mortem)

Microscopy for CLIC

UP-Diamond machining

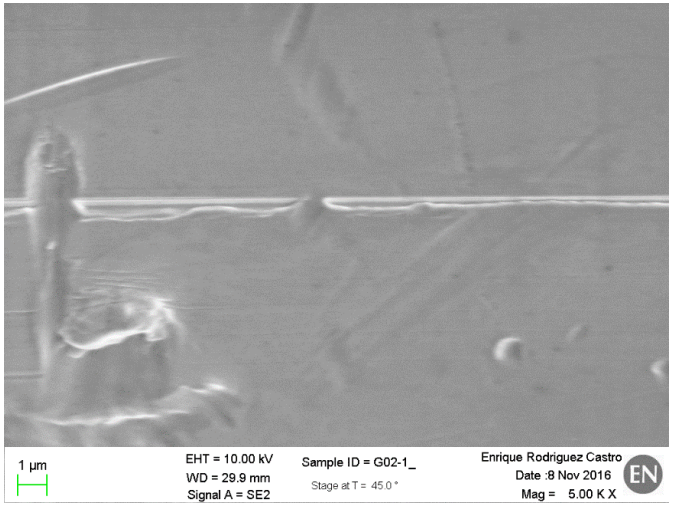
Cleaning
Pollution analysis

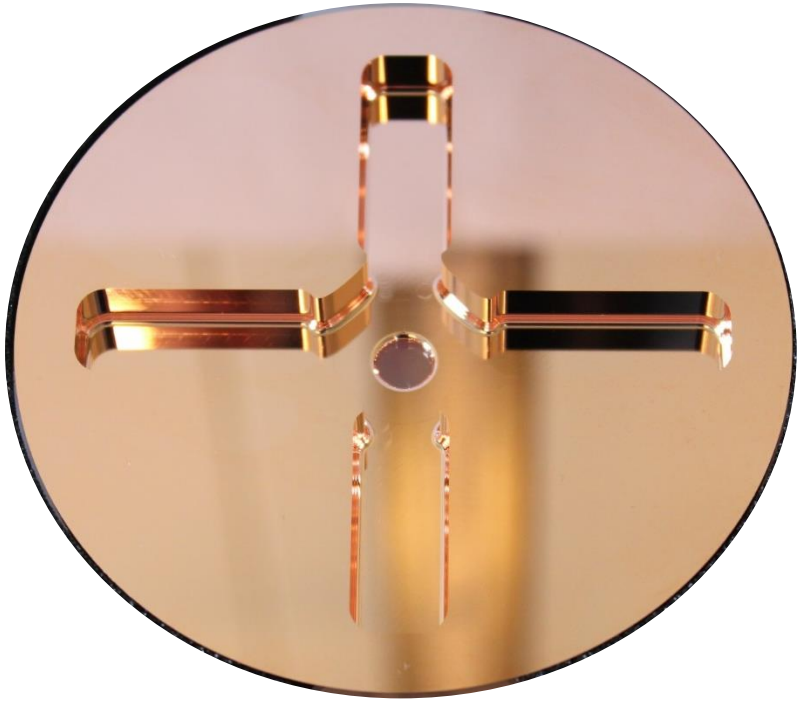
SEM
(QC of the surface)



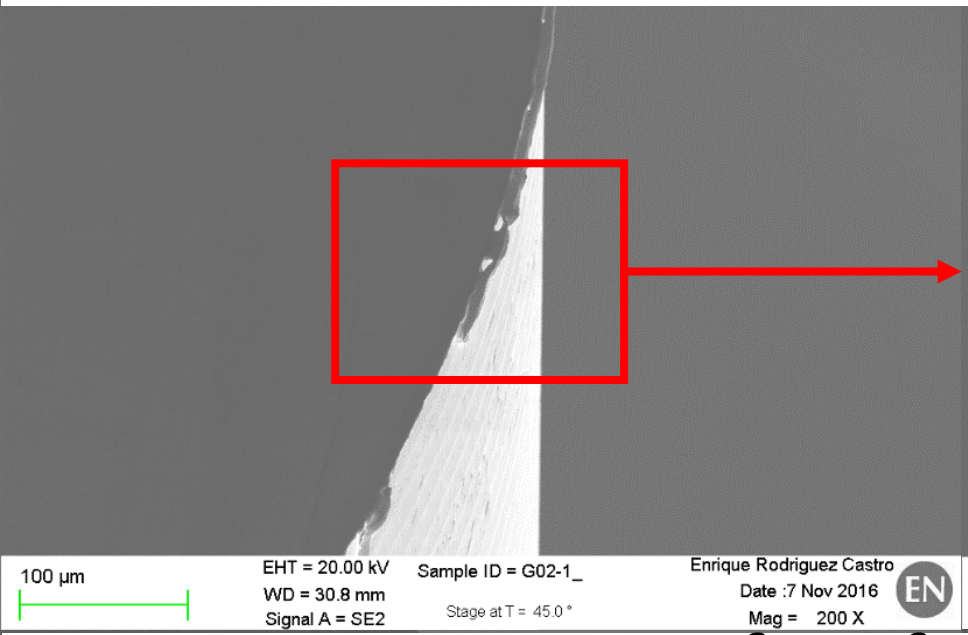
Machining qualification

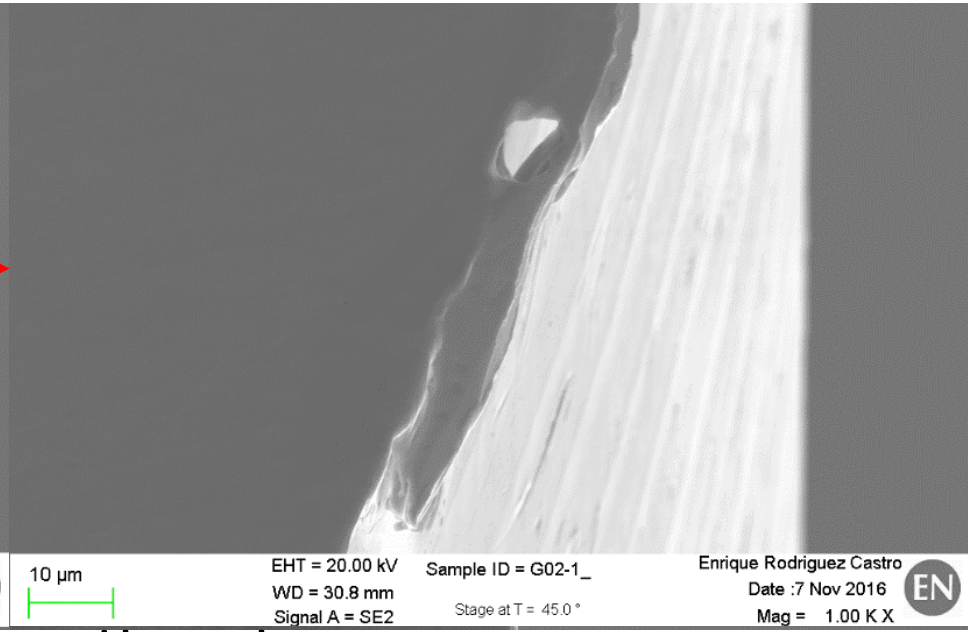
- Important to feedback company
  - Improvement on machining process
  - Correction of errors (before finishing the manufacturing)



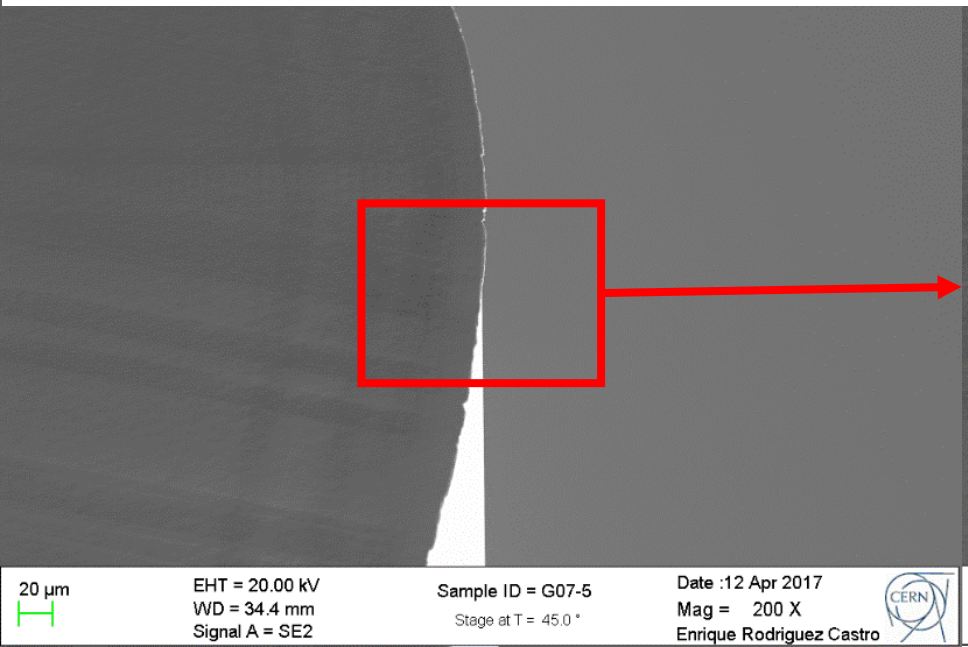


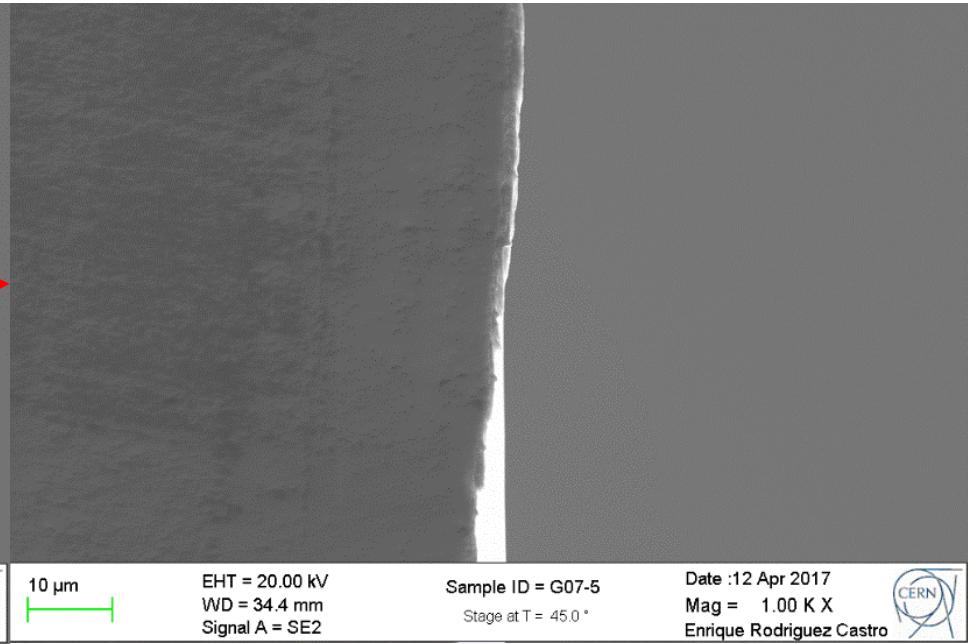
First observation





After feedback





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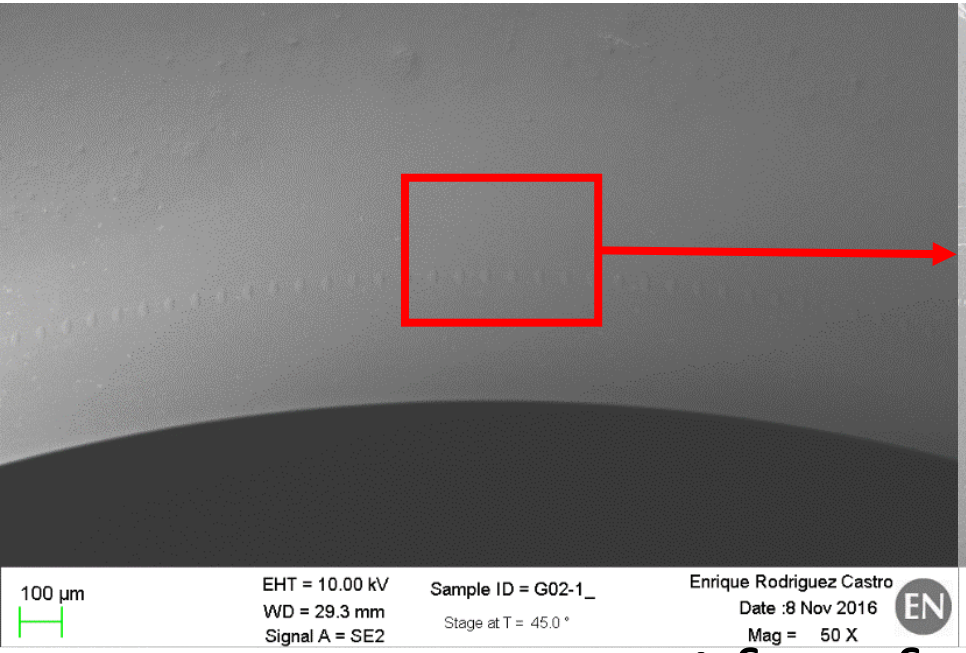
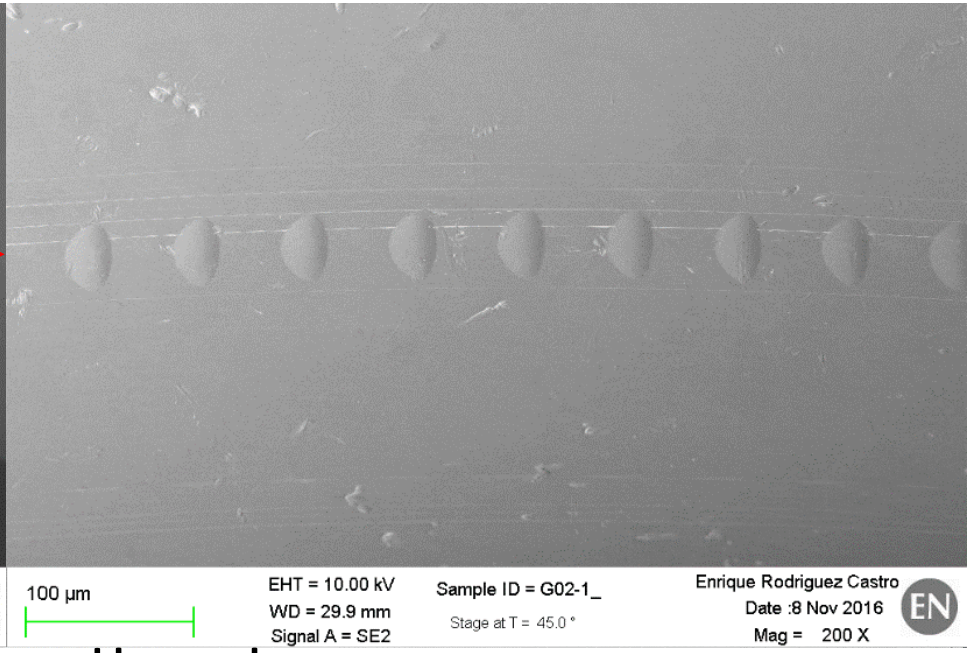
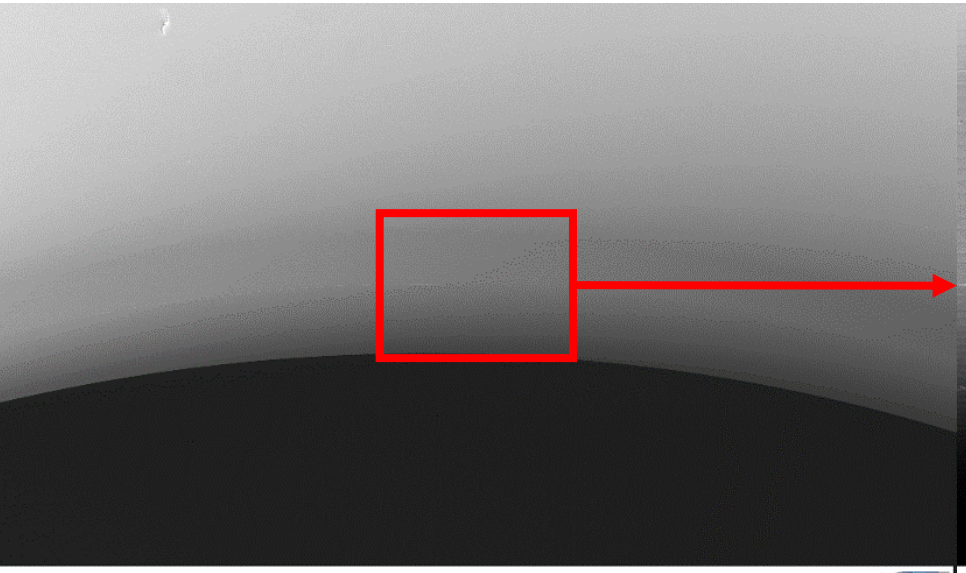
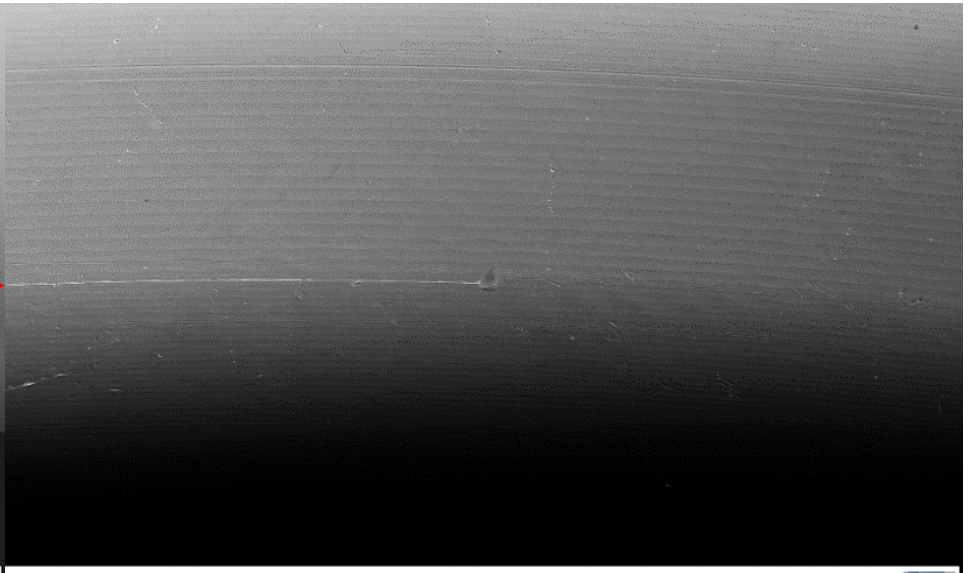




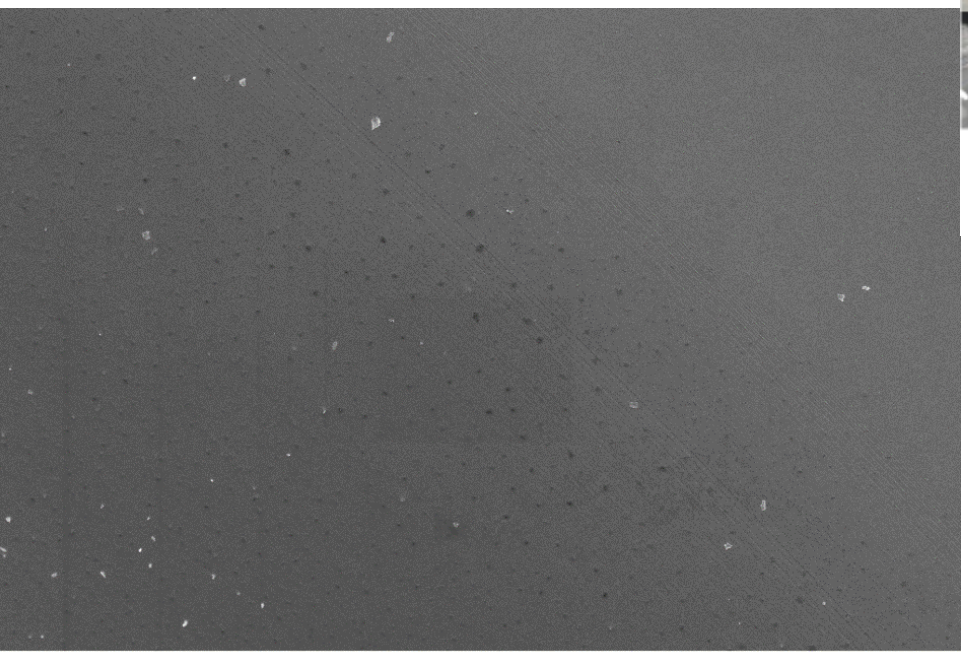
After feedback

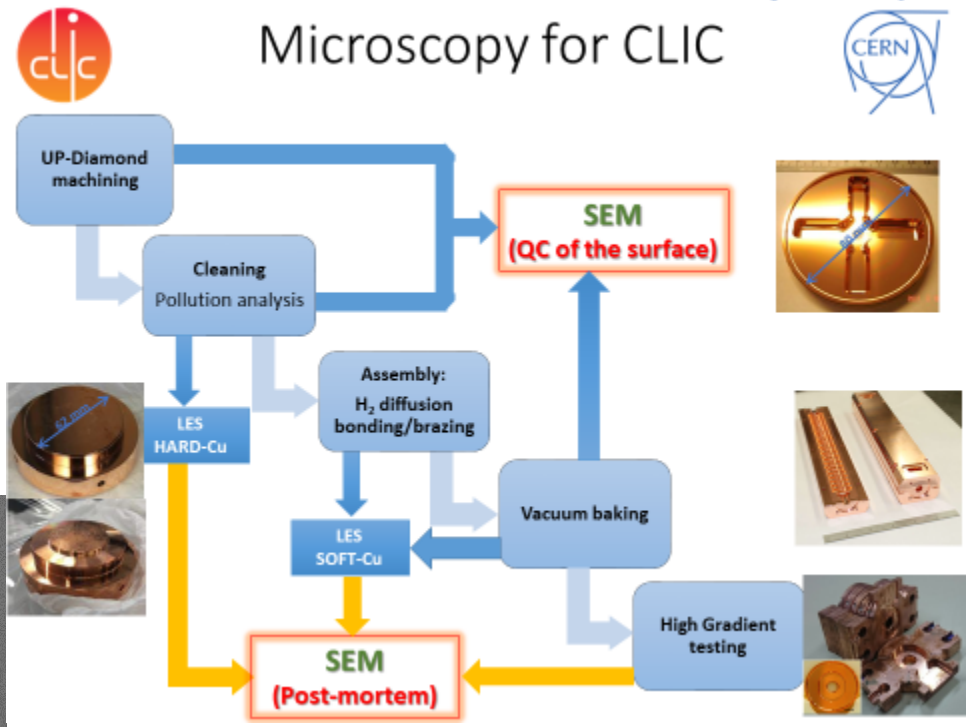




Pollution Analysis

- A particle on surface could be the origin of a BD.
- Reduce the contamination on structures is crucial.
- Procedure for furnace qualification (including CERN new oven).

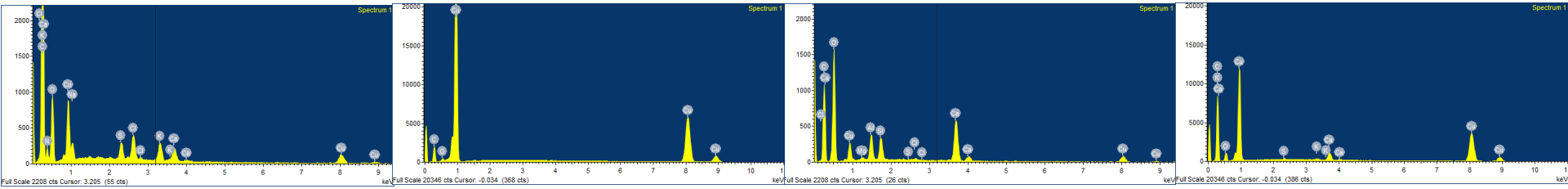




- Witness disc to trace back if any problem is encountered

APA (Automated Particle Analysis)

- Possibility to create custom classification
  - Ignore non important SOI
  - Enhance those with dangerous contaminants



- Shape recognition.
- From qualitative to quantitative

	APA	Manual
Number of analysed particles	21 290	50
Number of classified particles	20 225	/
% of fitting	95 %	/

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				T24 Open
			LES	Soft / hard Cu
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Microscopy for CLIC

UP-Diamond machining

Cleaning
Pollution analysis

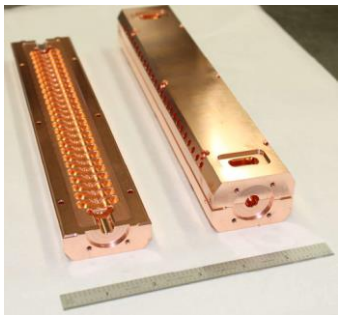
Assembly:
H_2 diffusion bonding/brazing

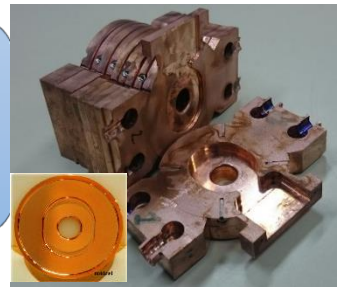
Vacuum baking

High Gradient testing

SEM
(QC of the surface)

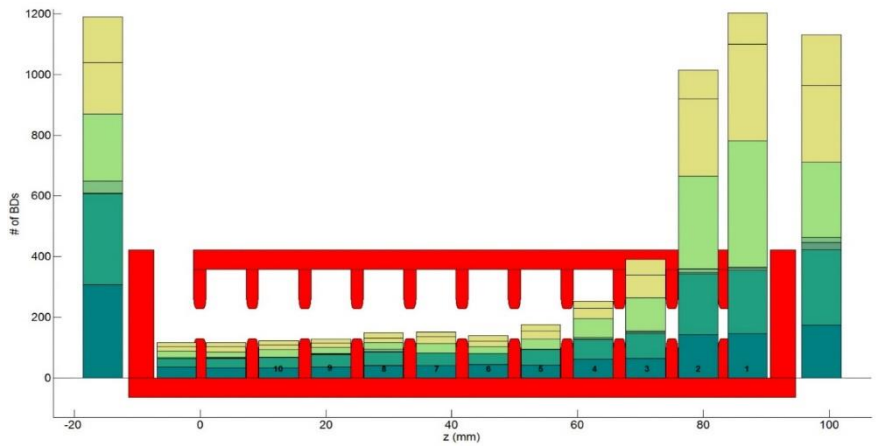
SEM
(Post-mortem)



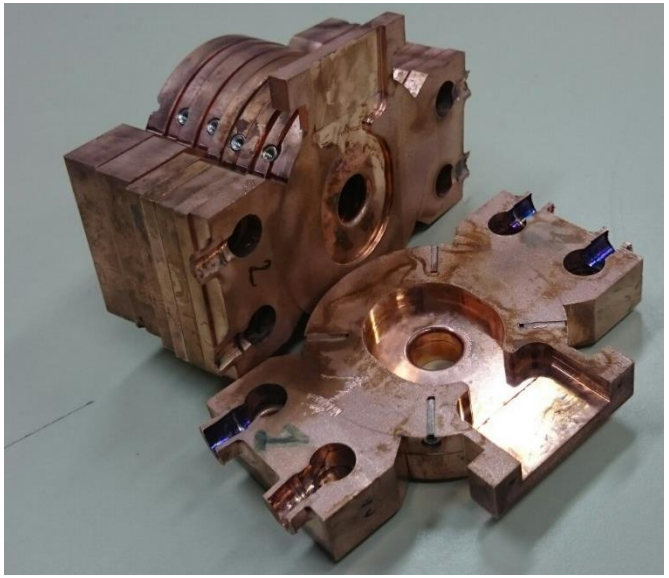


Post-mortem: CLIC-AS

- Not camera system on AS as we do have in DC
- Only solution to know the BD distribution, position and amount of affected surface

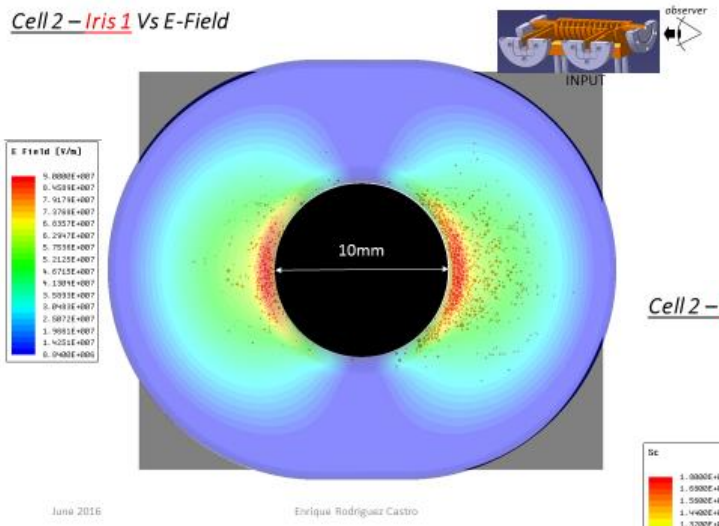


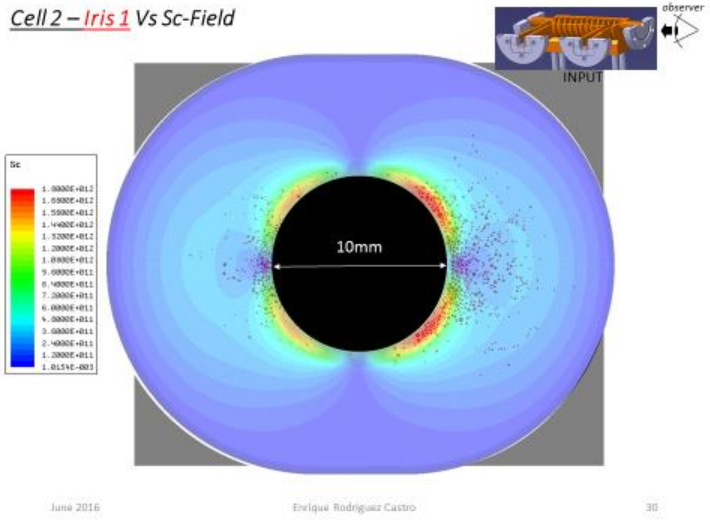
Histogram of the BD cell location, along with the month in which the BD occurred.

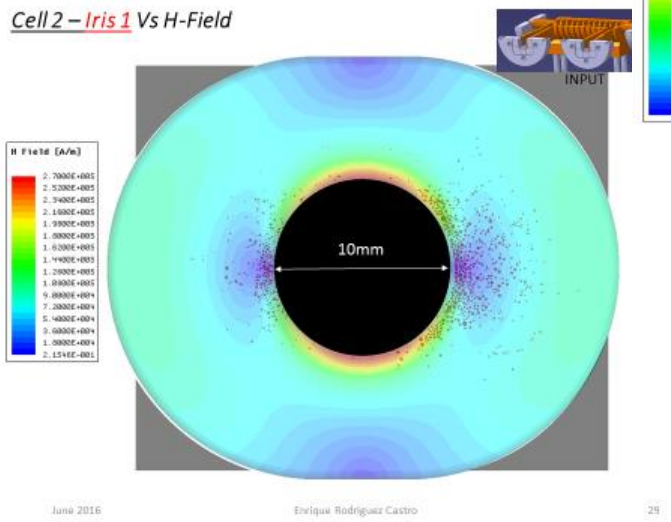


Crab cavity

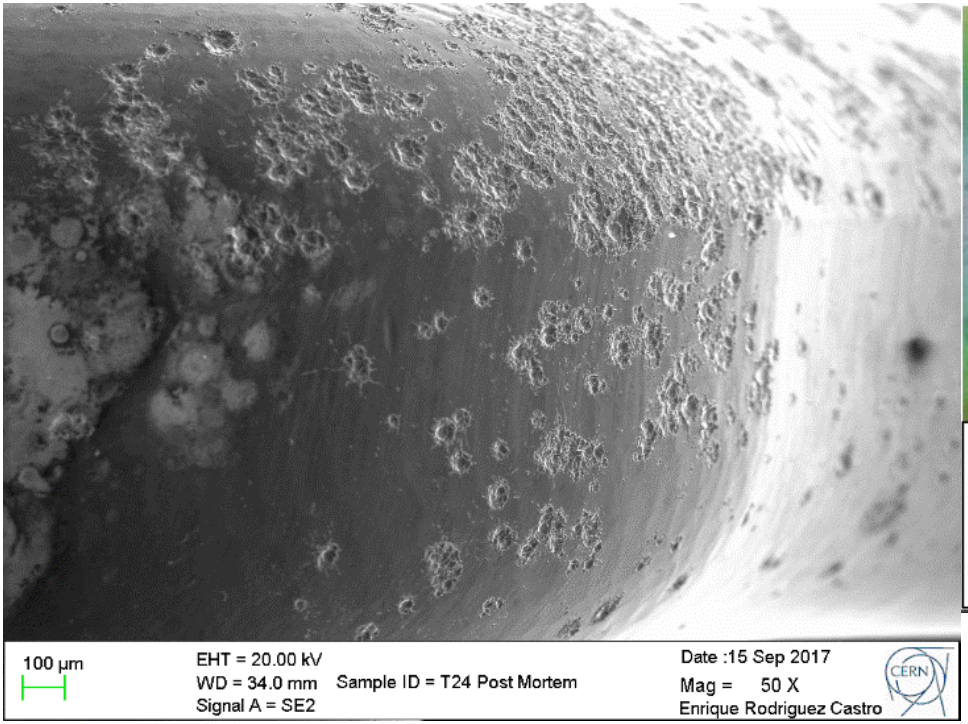
- BD correspondence with the highest E-field on the cell

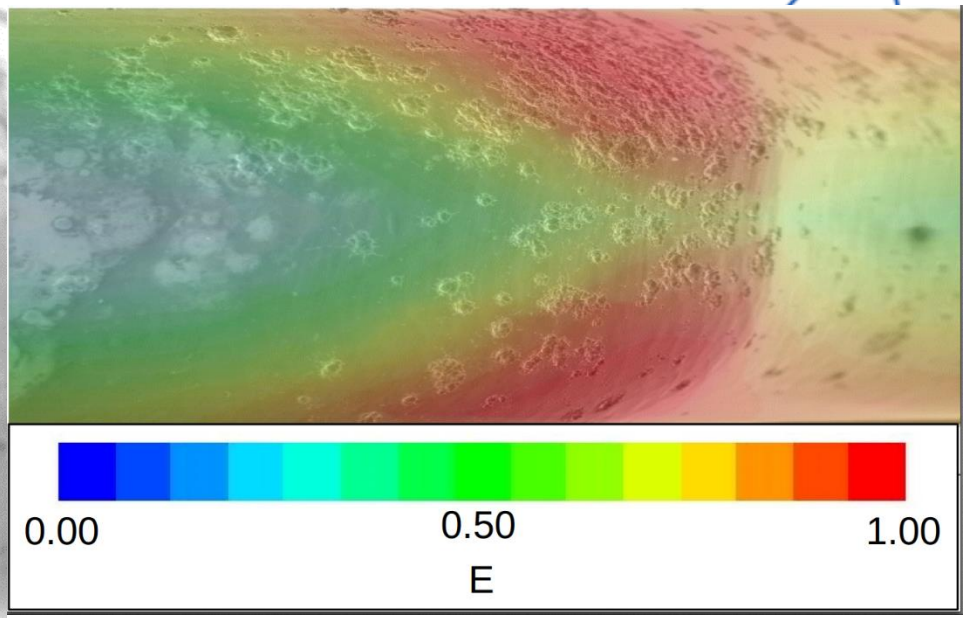




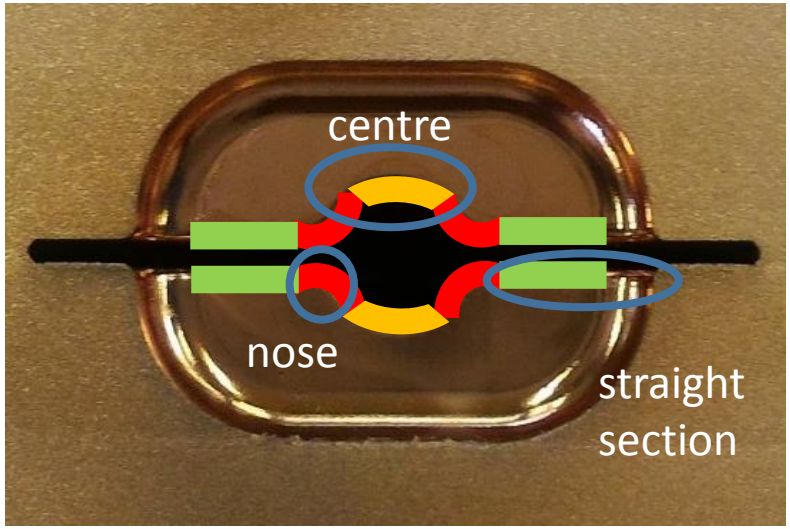


T24 Open





- More BD accumulation on nose than center or straight part of the iris, matching the E-field
- BD trend to accumulate in E_max



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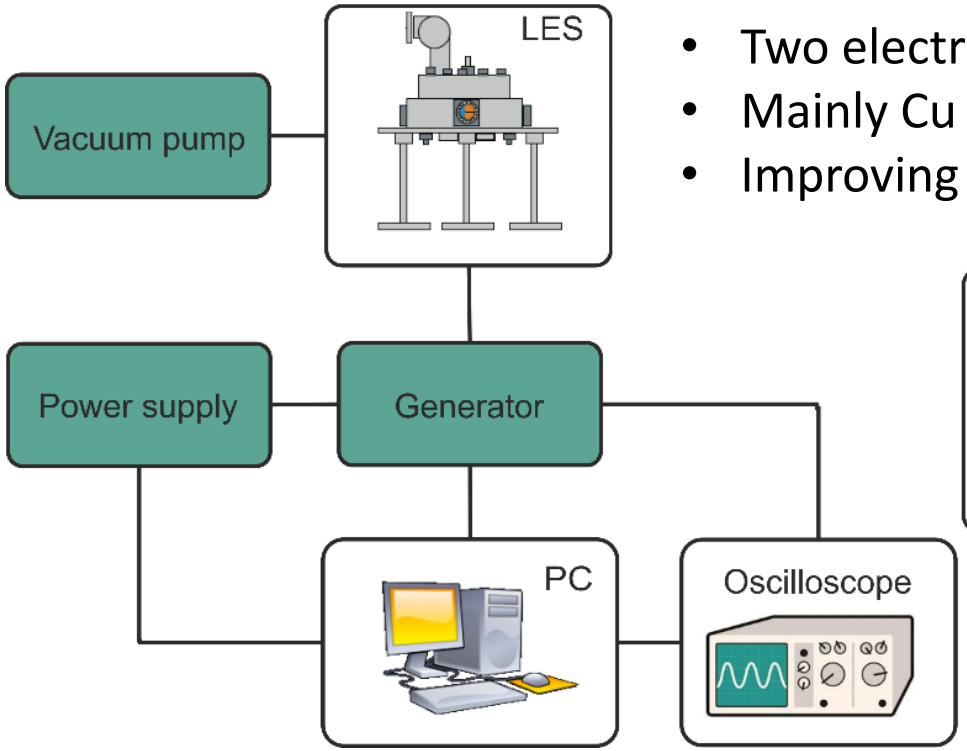
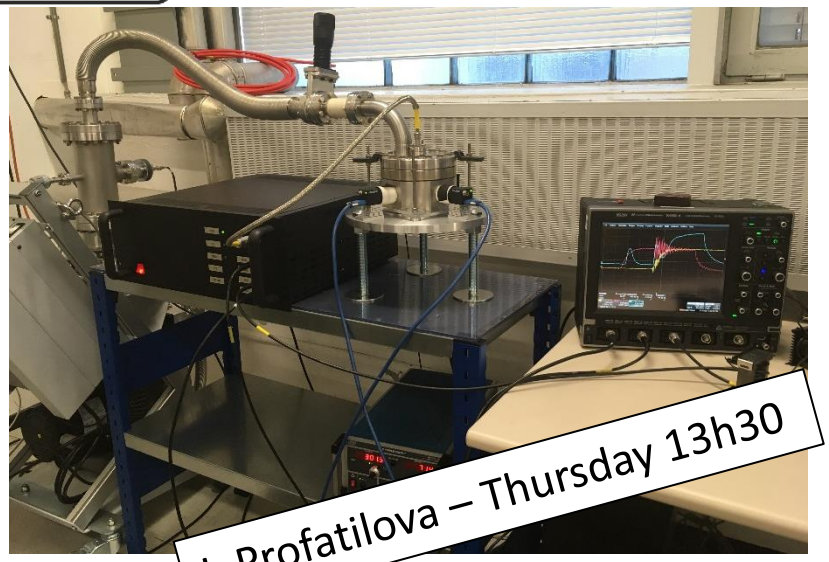
Large Electrode System (LES)



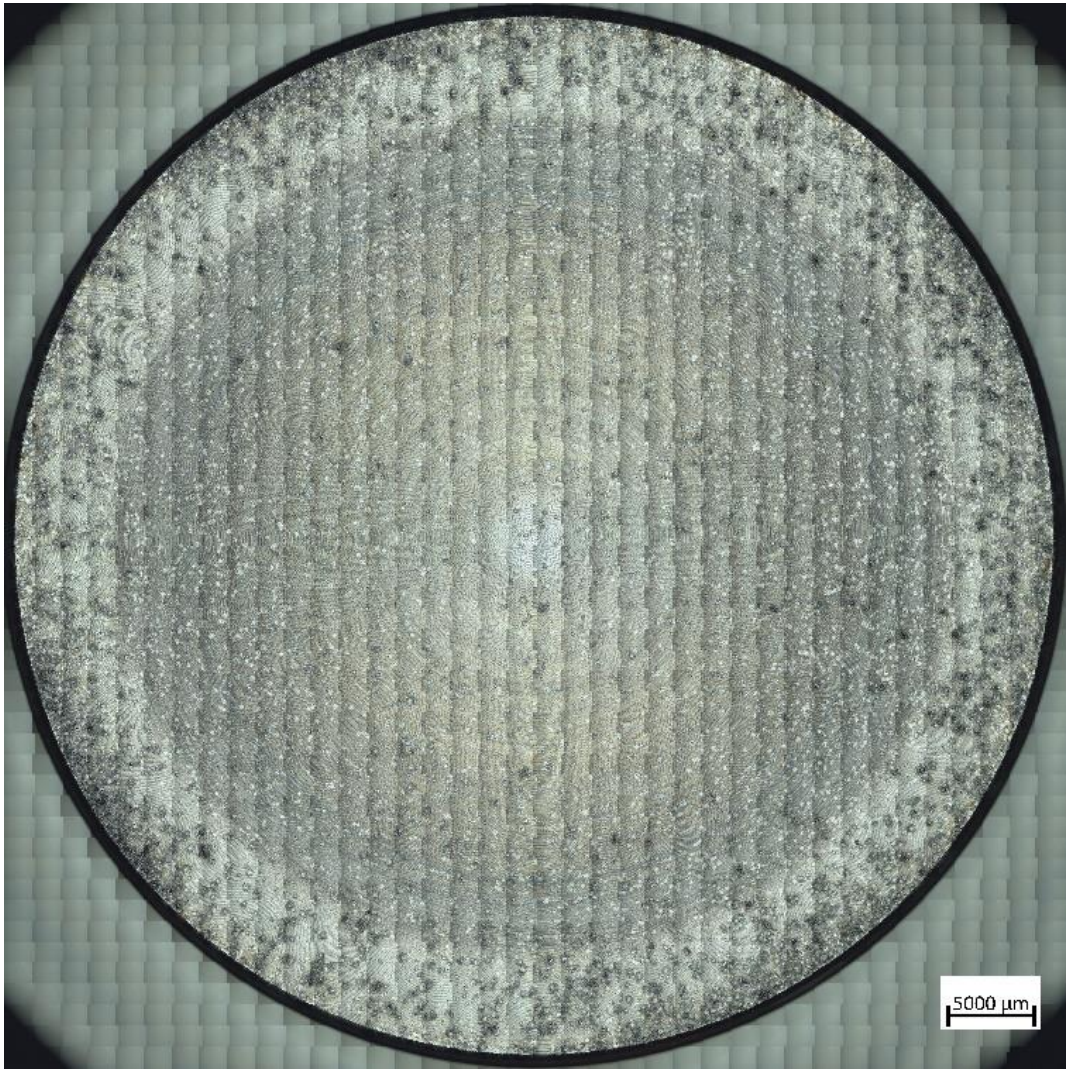
- Two electrodes tested under vacuum
- Mainly Cu but also other materials as Nb, SS, CuAg
- Improving the system and the tests

Repetition rate: 2 kHz
Pulse length: 500 ns – 1 ms.

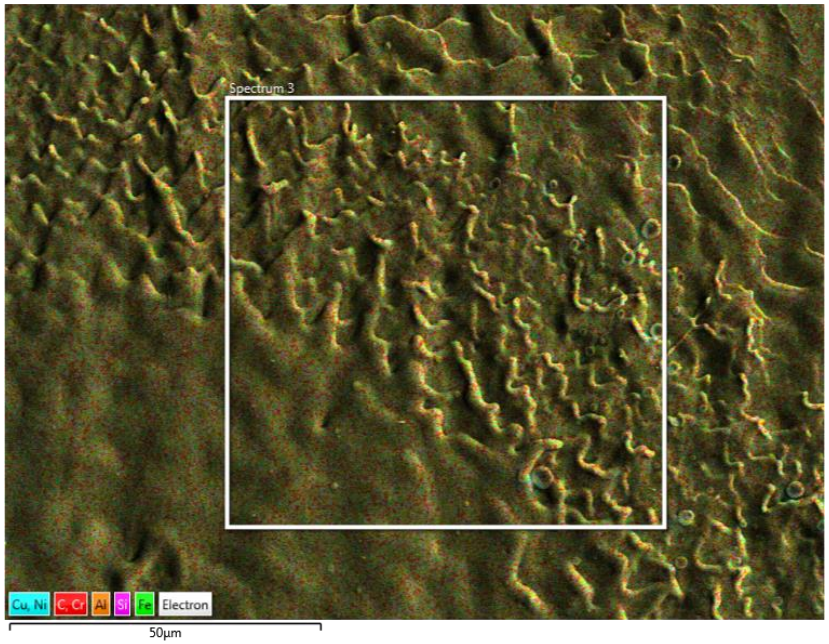


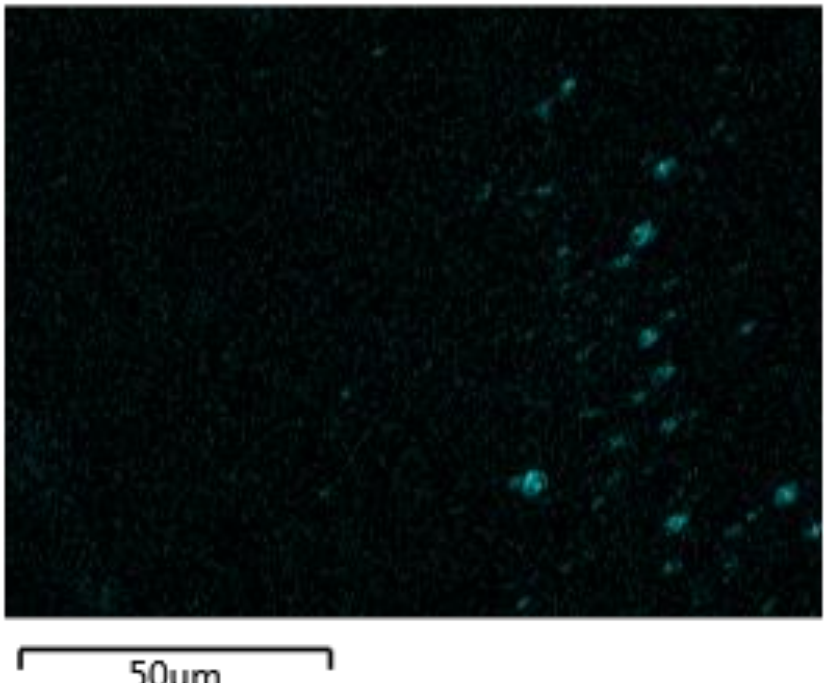
Large Electrode System (LES)

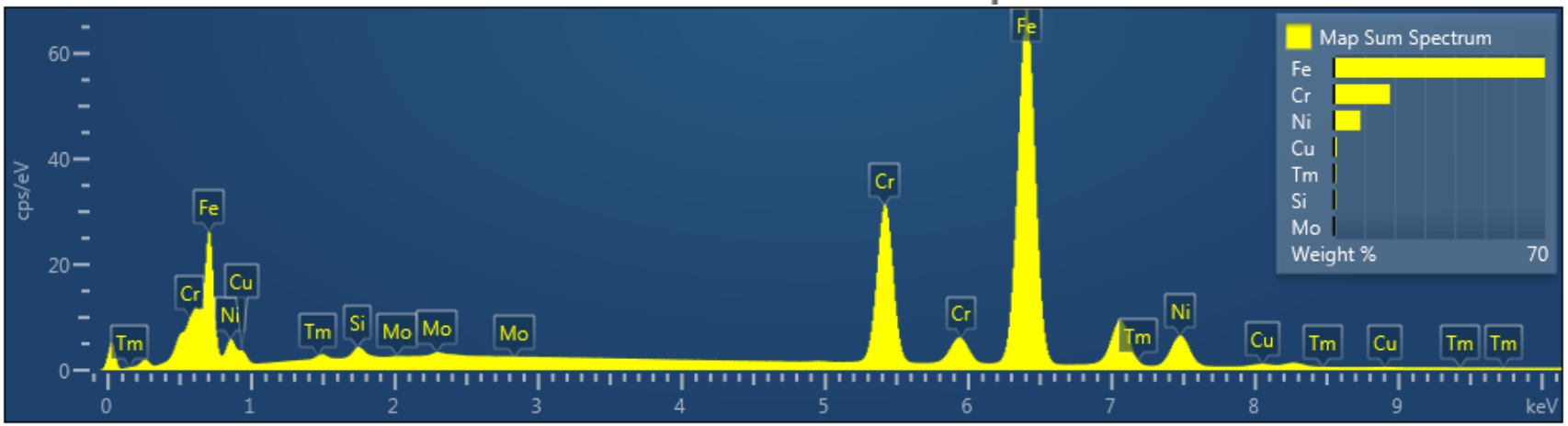
- SS anode tested against 2 different cathode:
  1. CuAg
  2. Fired vacuum Cu



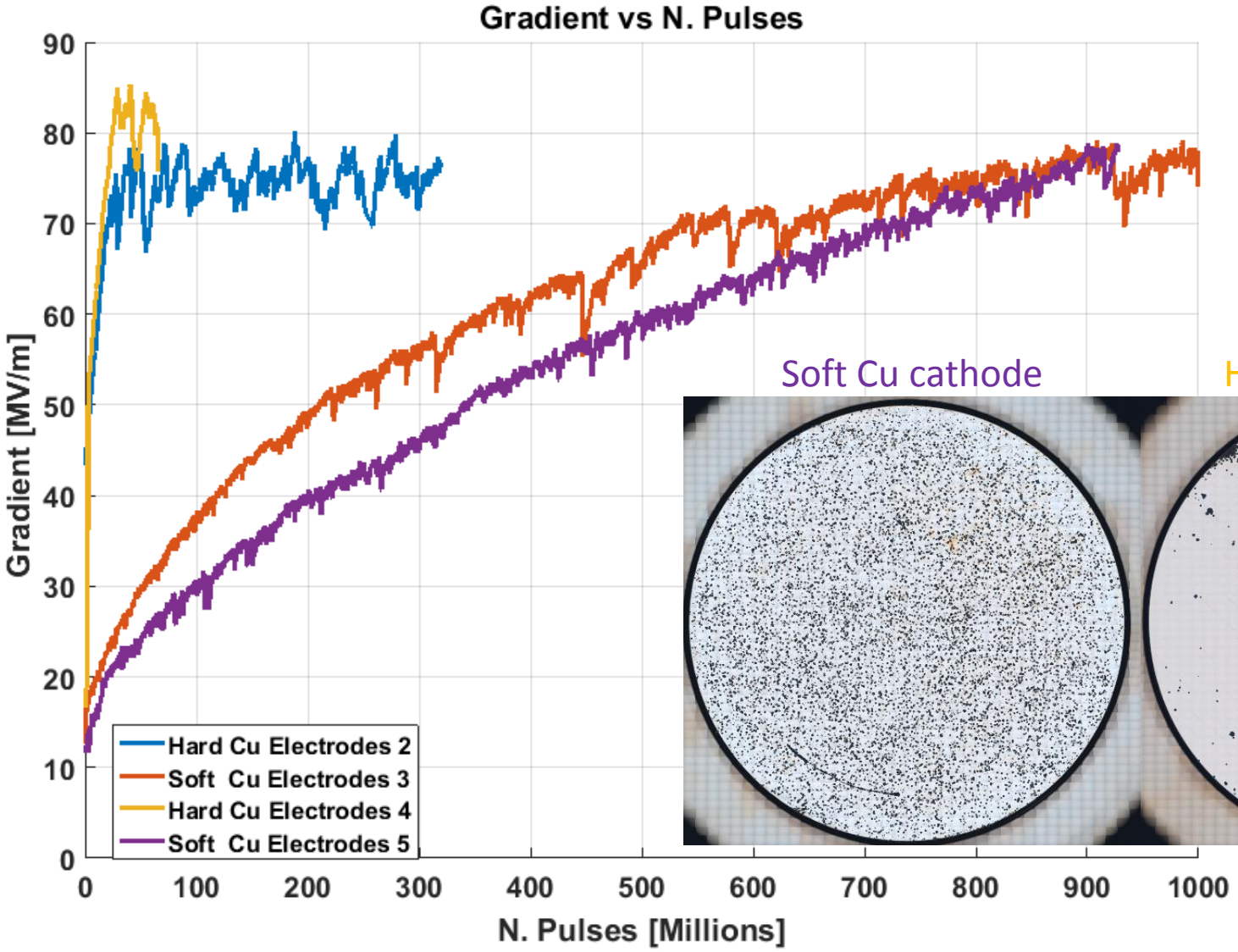
Large Electrode System (LES)







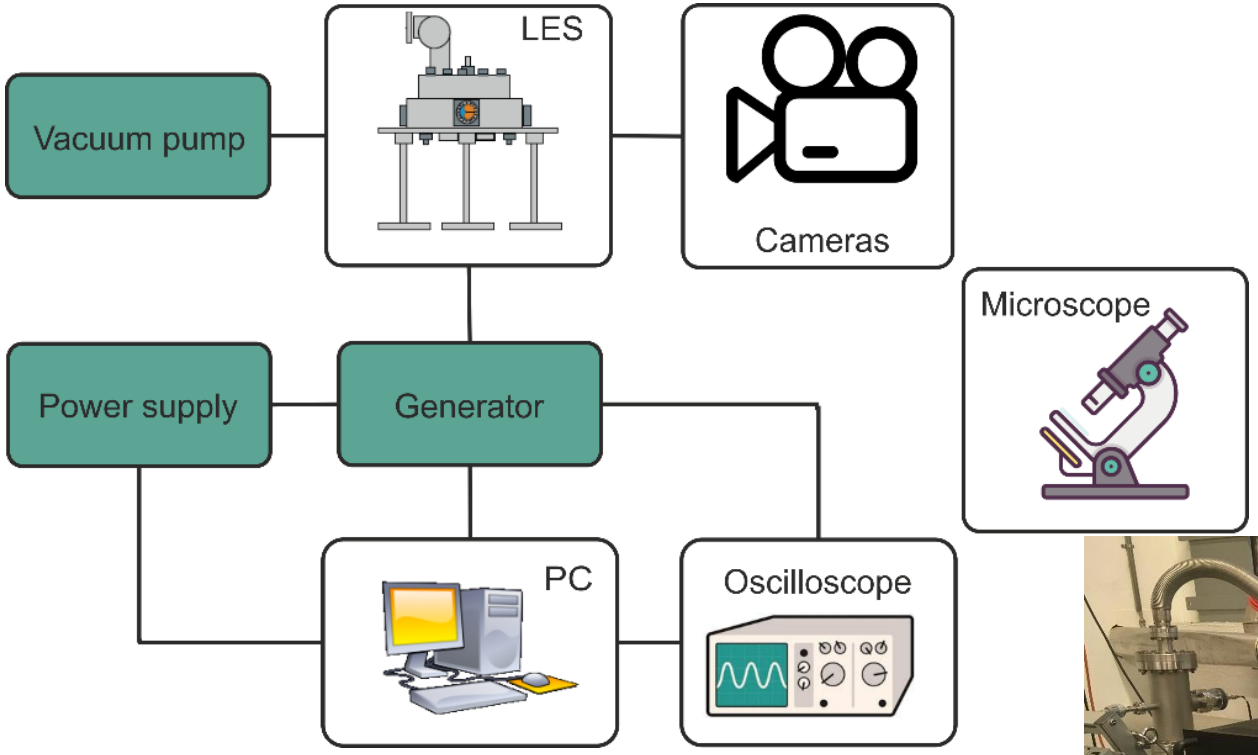
Large Electrode System (LES)



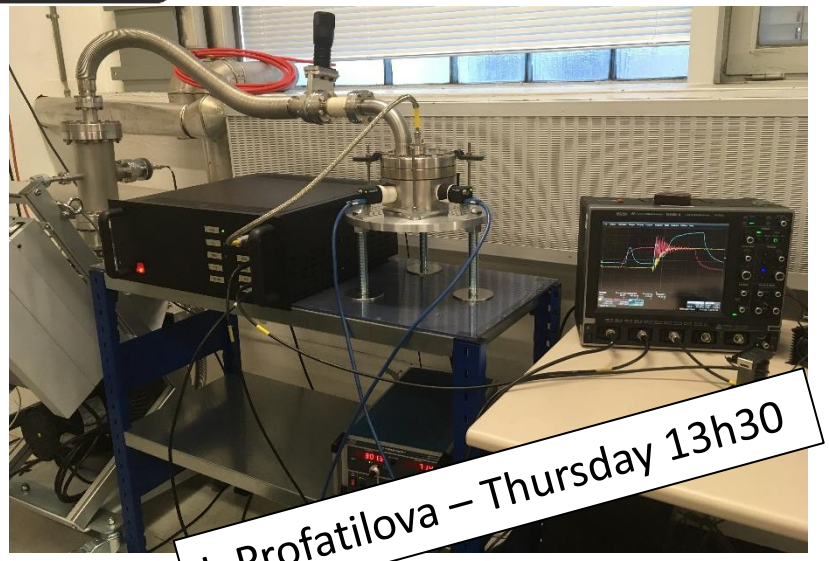
Soft Cu cathode

Hard Cu cathode

Large Electrode System (LES)

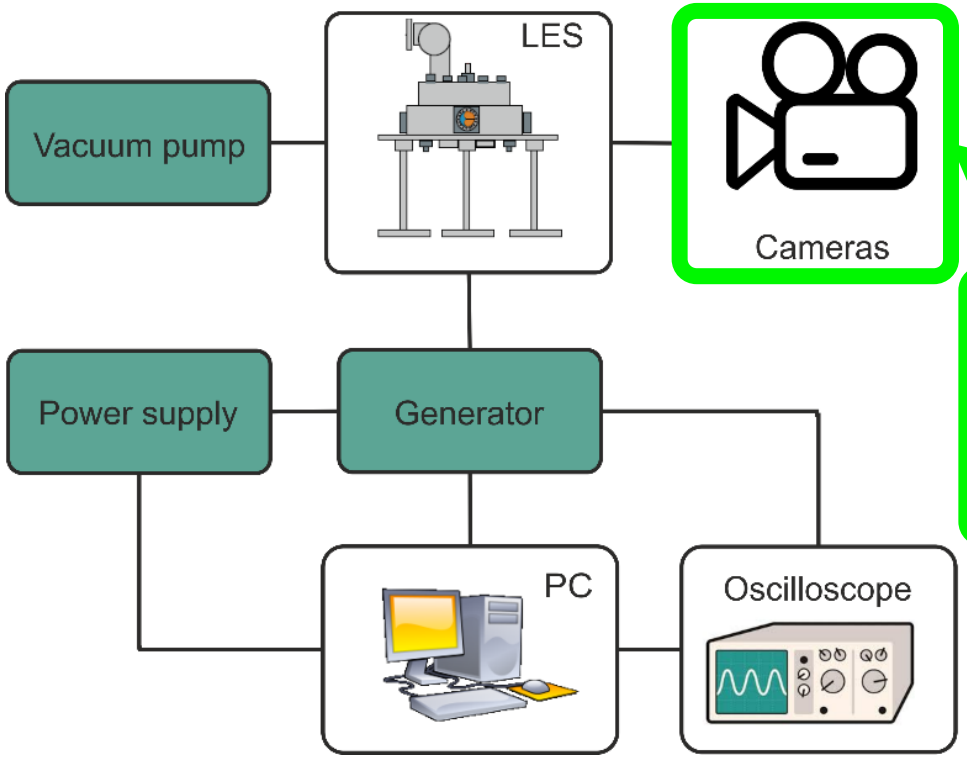


Repetition rate: 2 kHz
Pulse length: 500 ns – 1 ms.



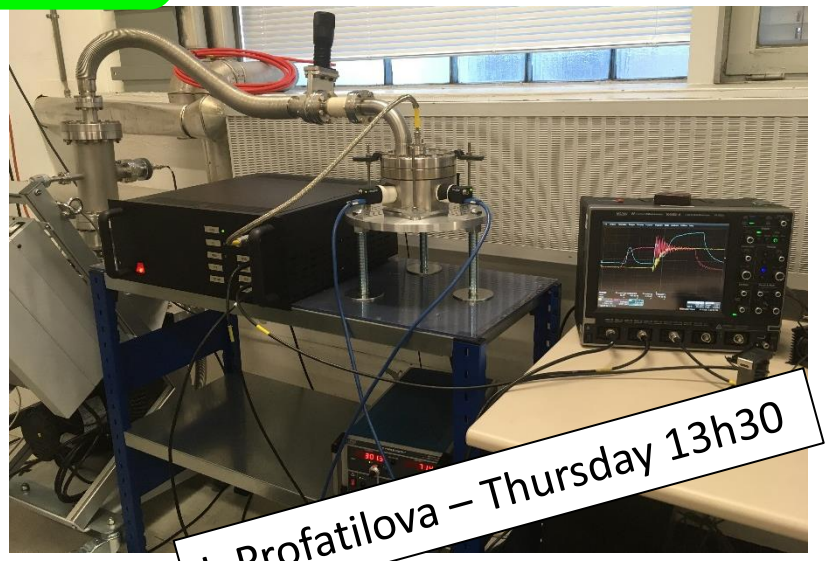
I. Profatilova – Thursday 13h30

Large Electrode System (LES)



- Relation between cameras and microscopy observation

Repetition rate: 2 kHz
Pulse length: 500 ns – 1 ms.

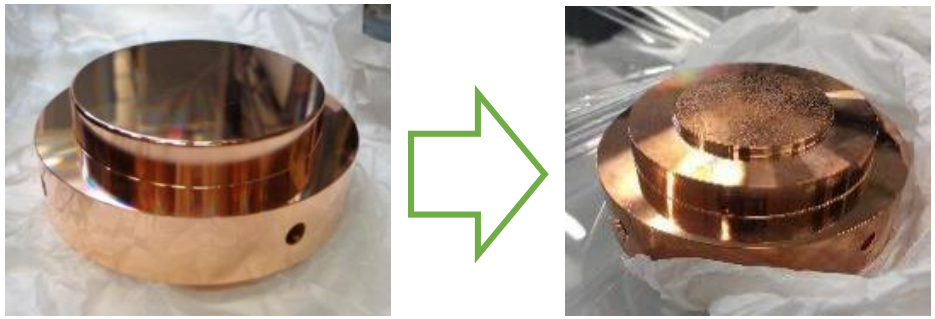


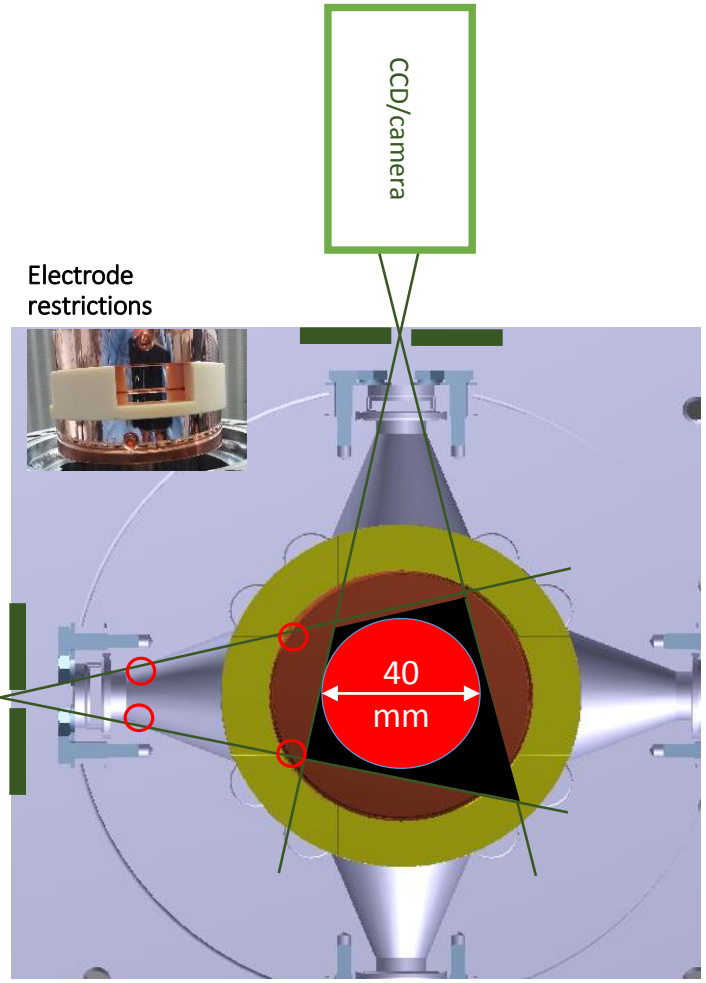
I. Profatilova – Thursday 13h30

Large Electrode System (LES)

Motivation:

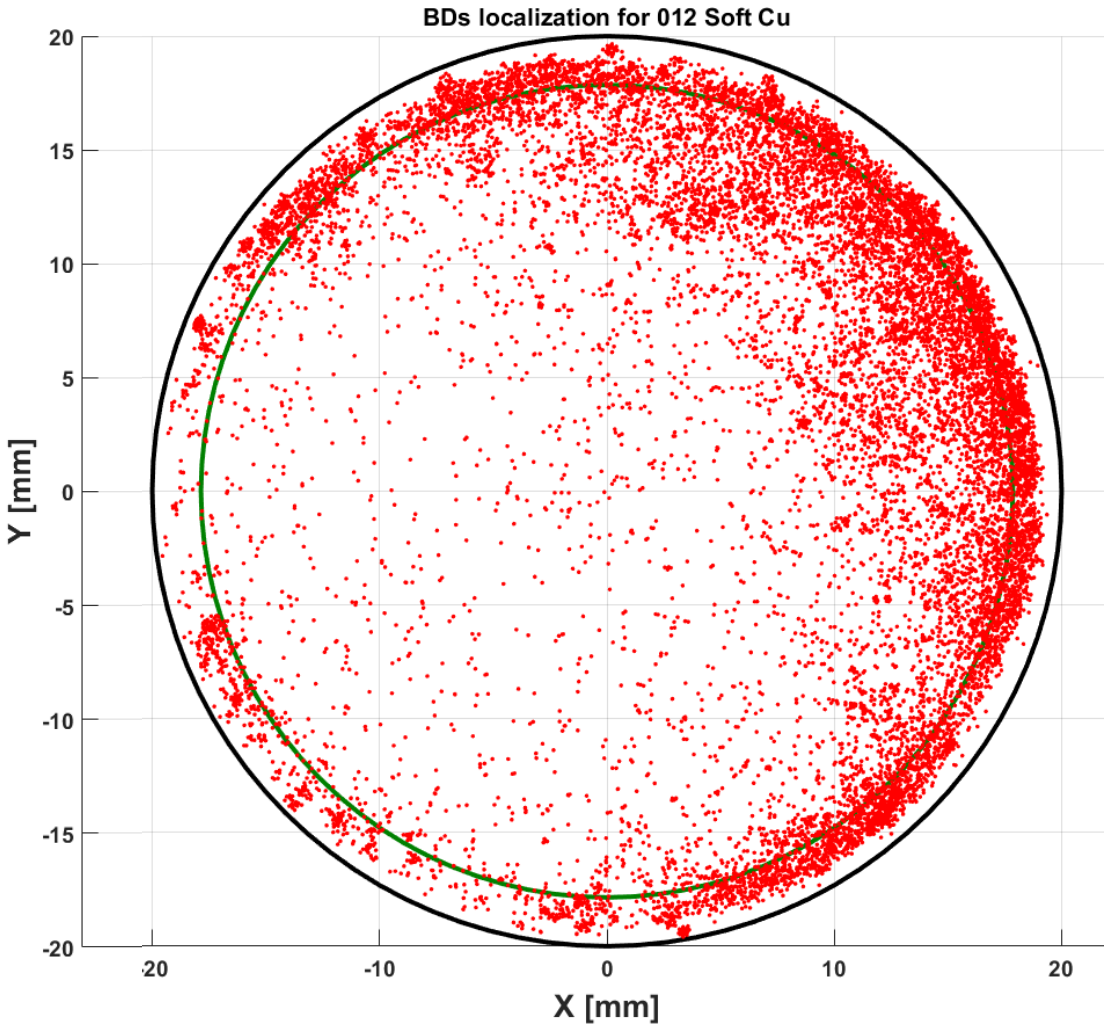
- ❑ find the position of BDs
- ❑ find how crater after BD relates to the next BD location.



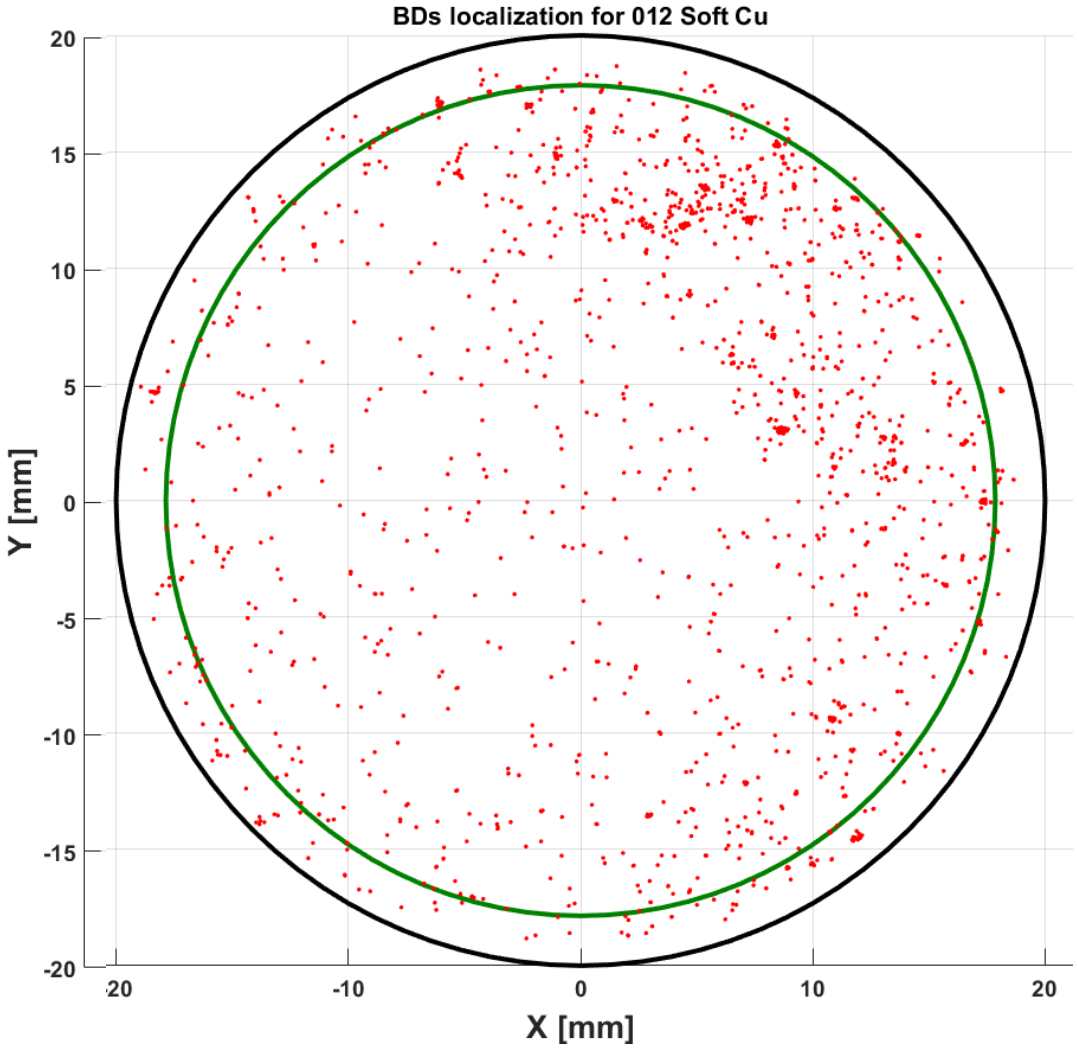


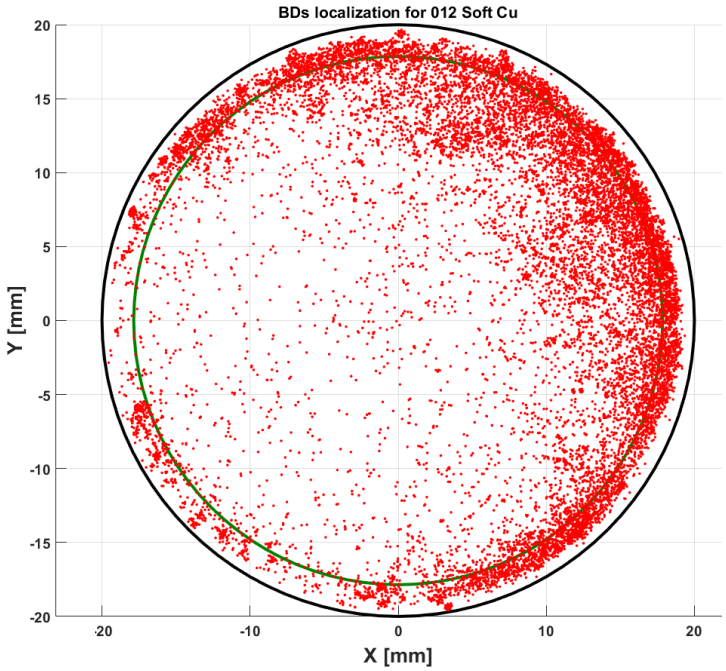
Courtesy
I. Profatilova and X. Stragier

Large Electrode System (LES)



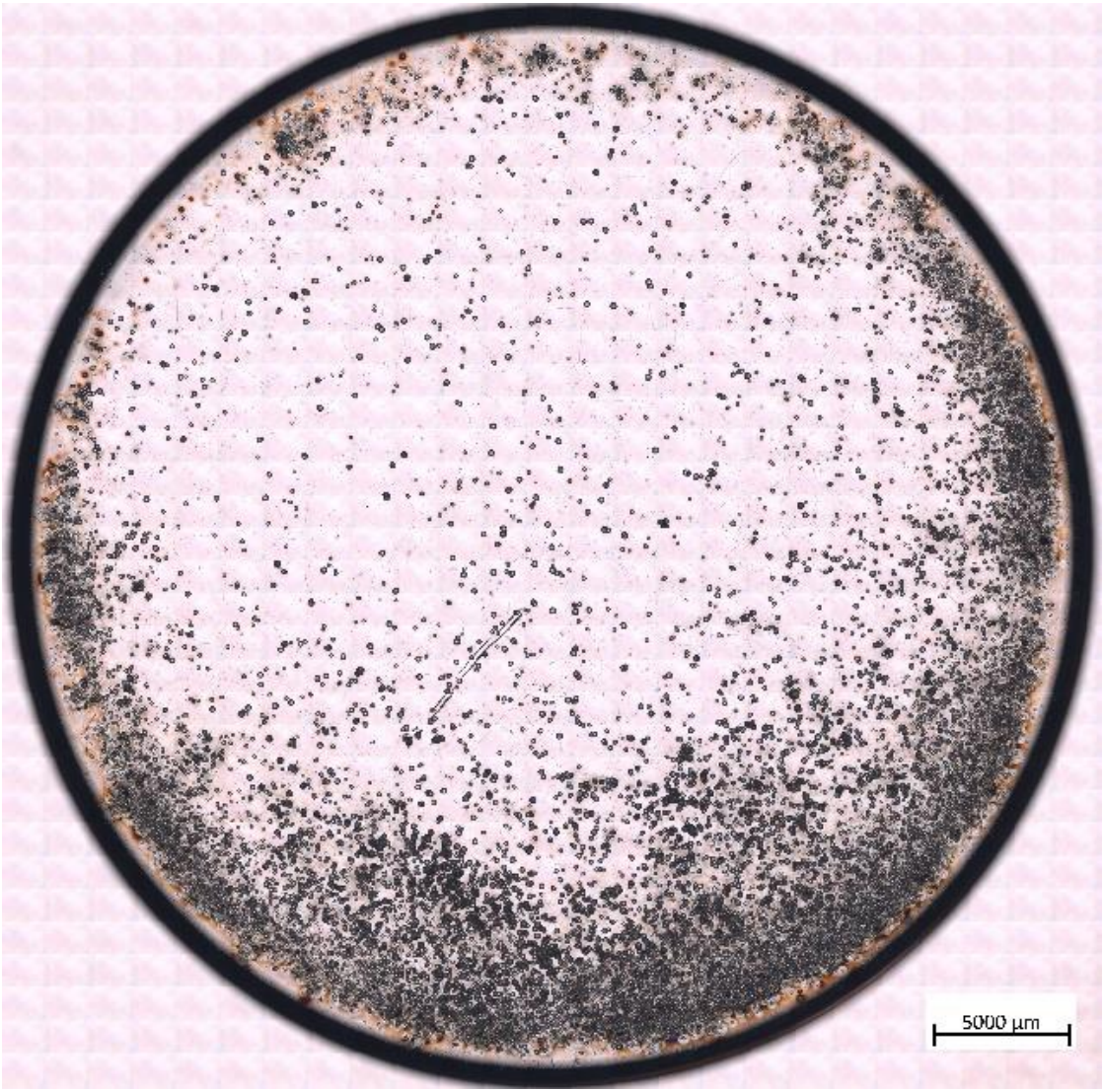
Large Electrode System (LES)



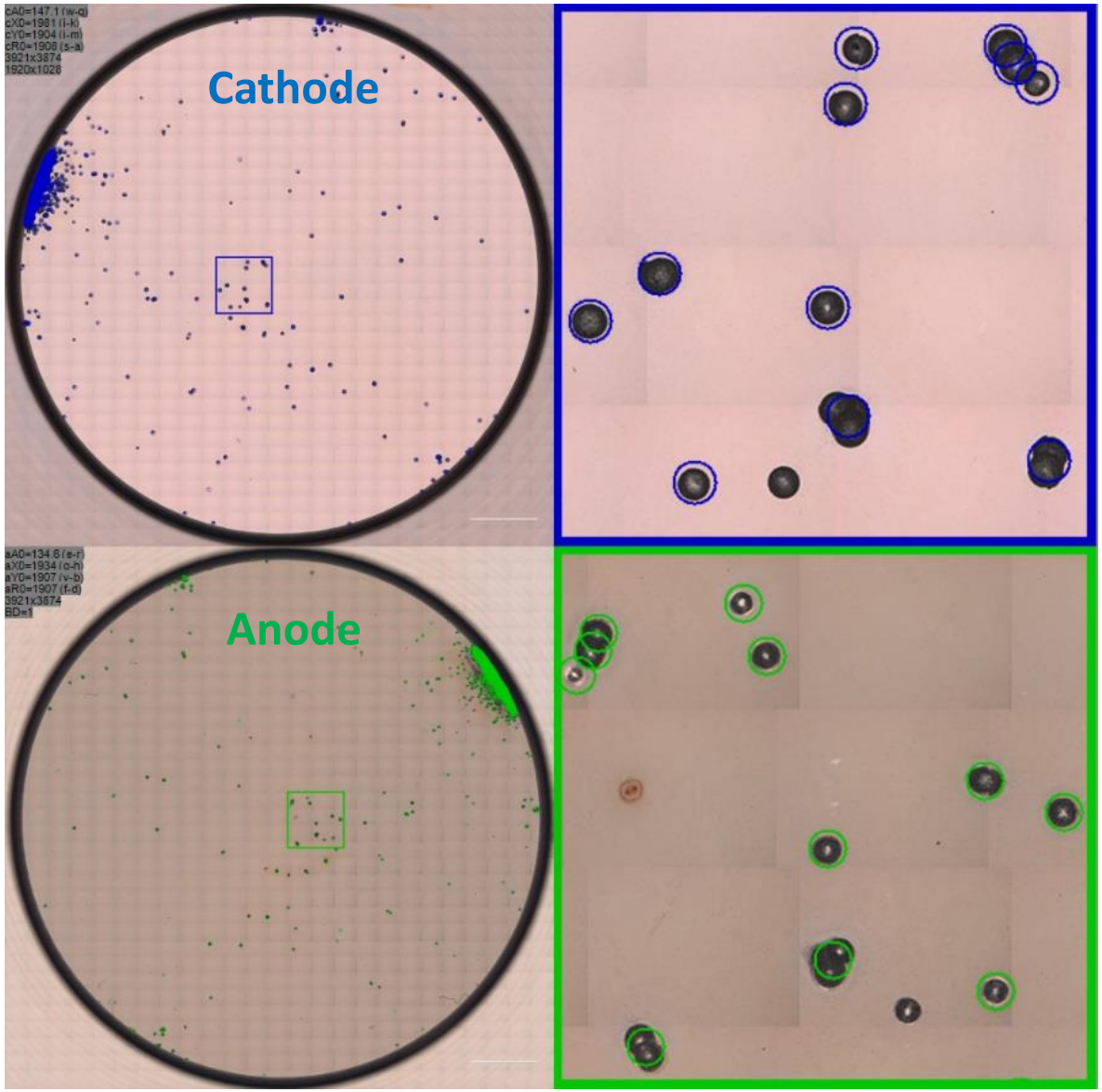


Large Electrode System (LES)

- Image compose of High Quality images



Large Electrode System (LES)

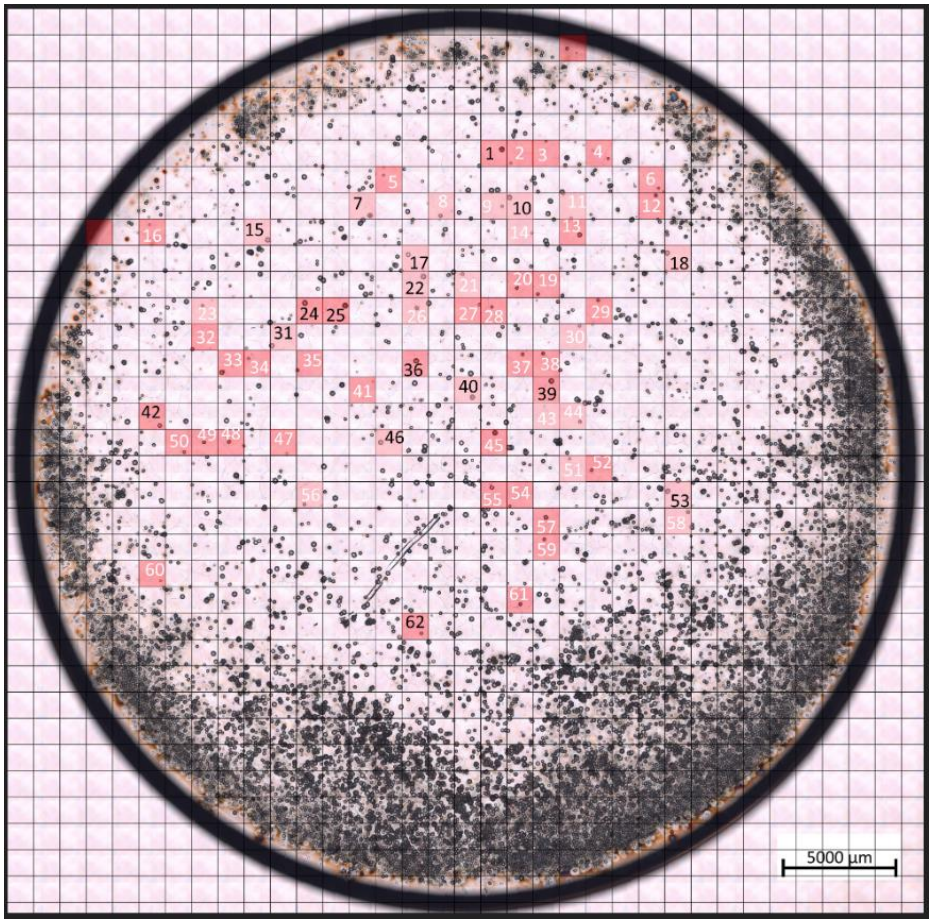


- Combining this techniques we can validate the positioning of the cameras
- Number of breakdowns detected by Marx generator: **5690**
- Number of breakdowns detected by cameras: **5665**
- Difference in data: **~0.5%.**

Conclusion

It works!

Large Electrode System (LES)

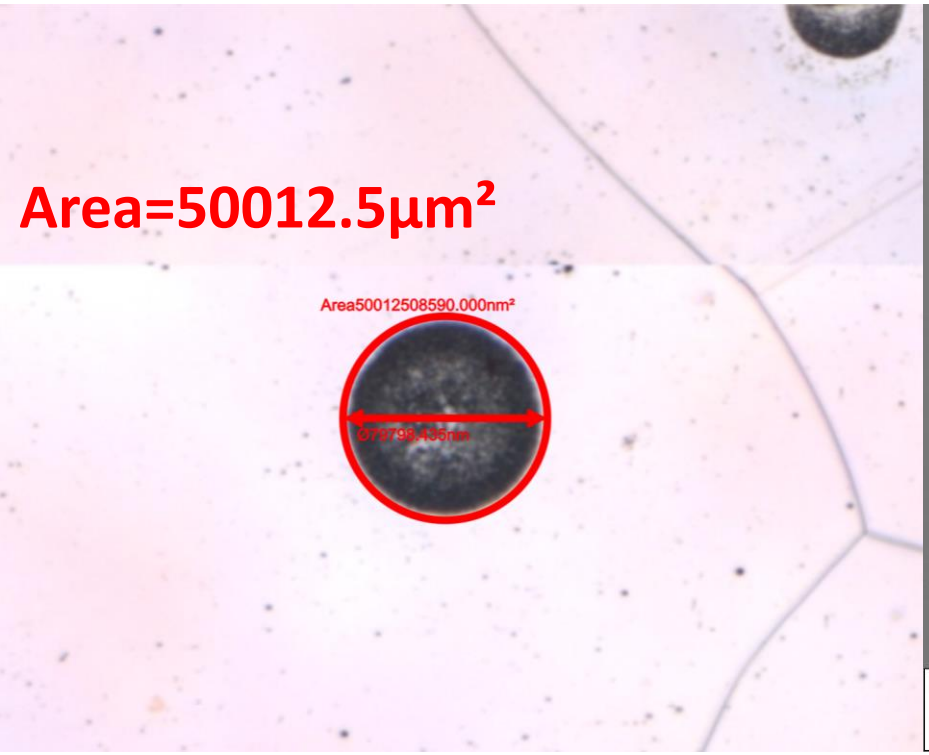


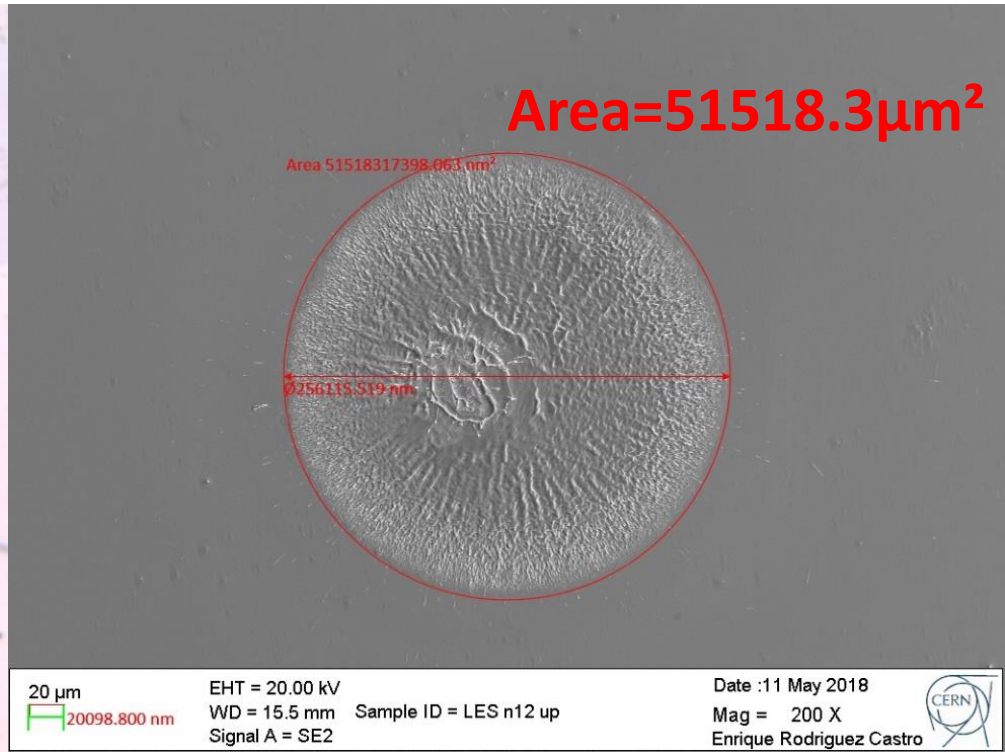
- Is there a relation between the size of the craters and the voltage supplied when they occurred?

- Data analysis:
  - **Cameras** allow to identify single breakdowns locations and voltage
  - **Microscope** to measure the size

Large Electrode System (LES)

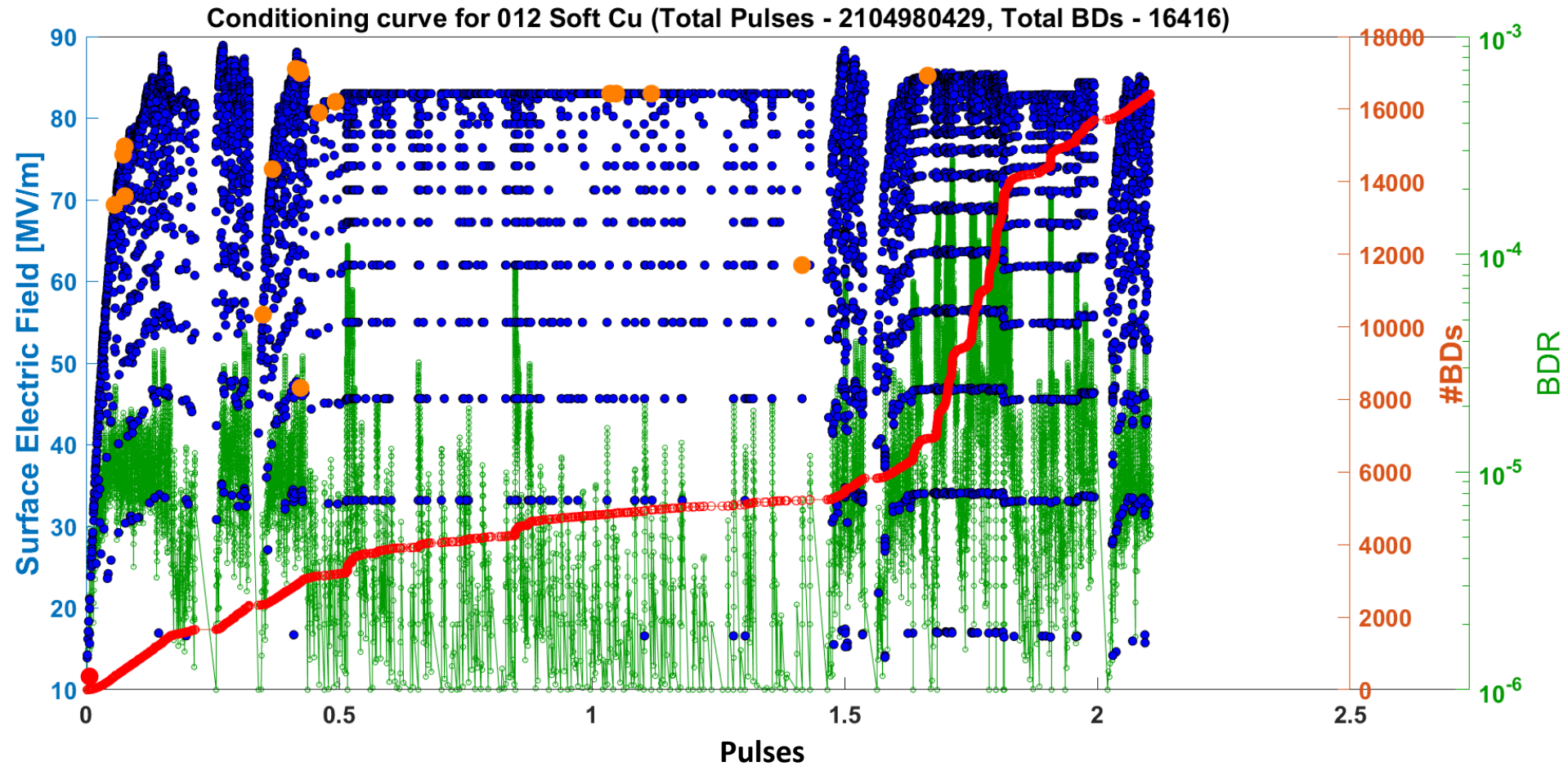
- Measure in OM and SEM
- Average of 60 µm diference in diameter



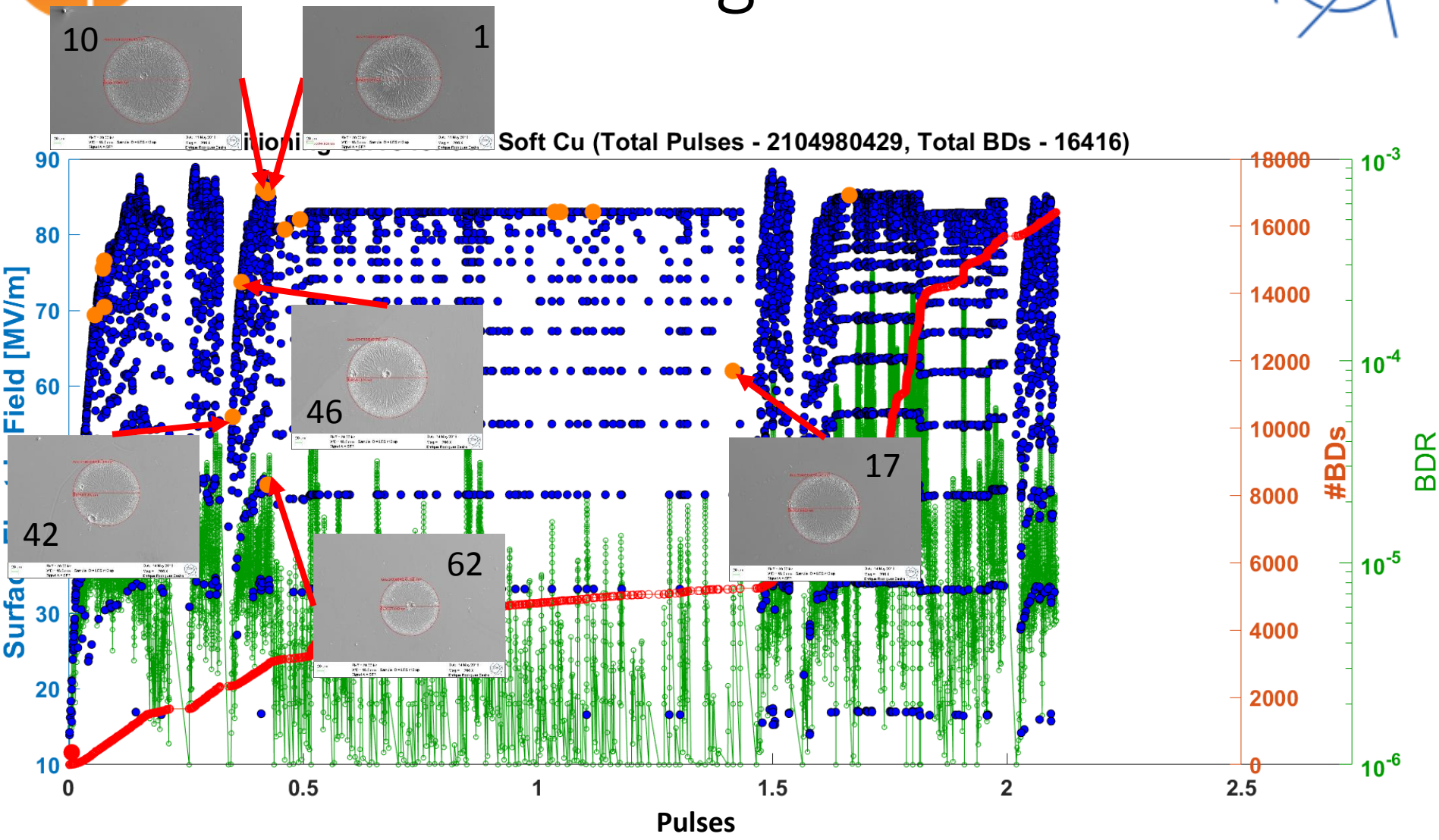


Observations and measurements by Francois-Xavier Greffoz

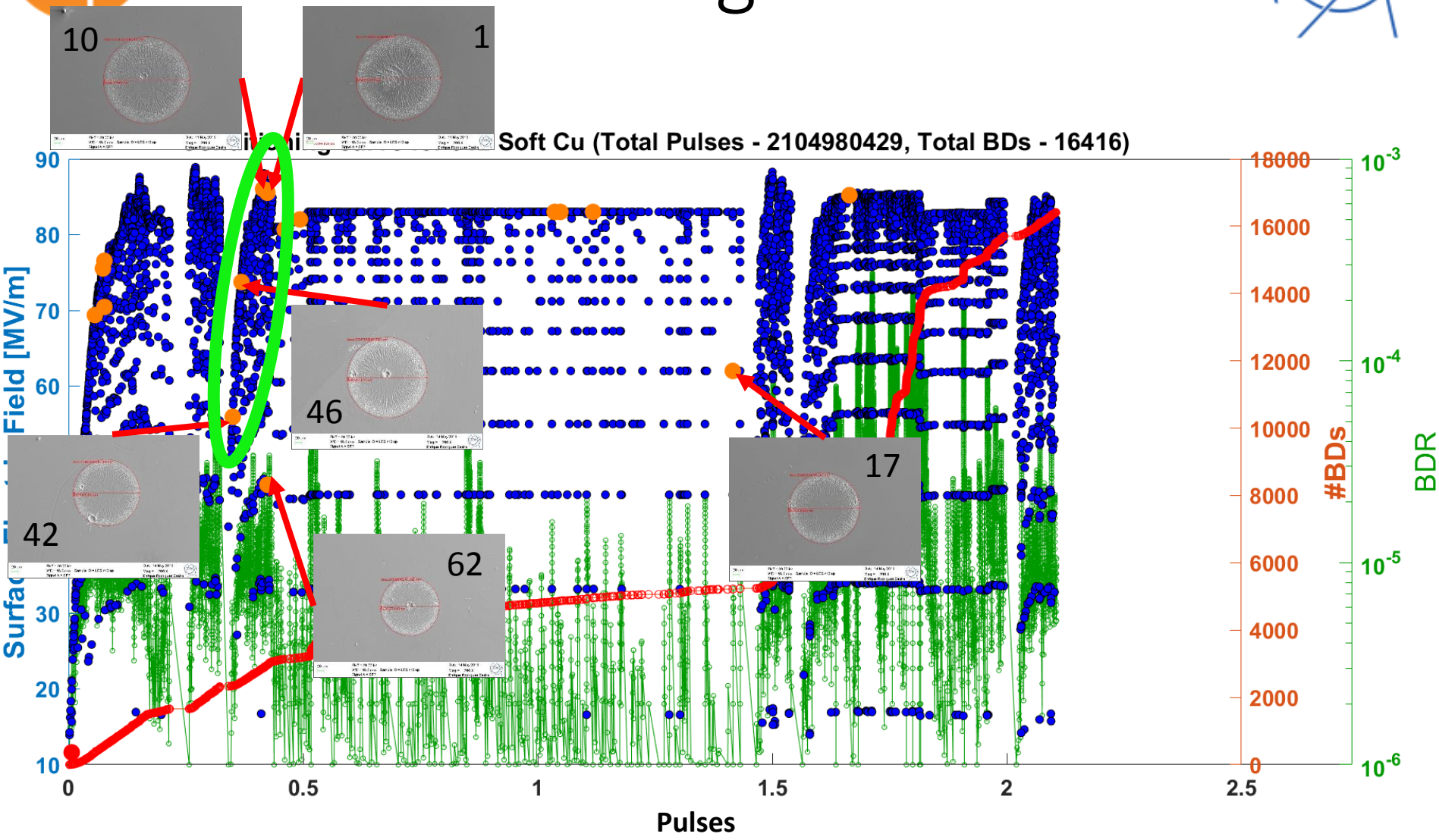
Conditioning curve n12

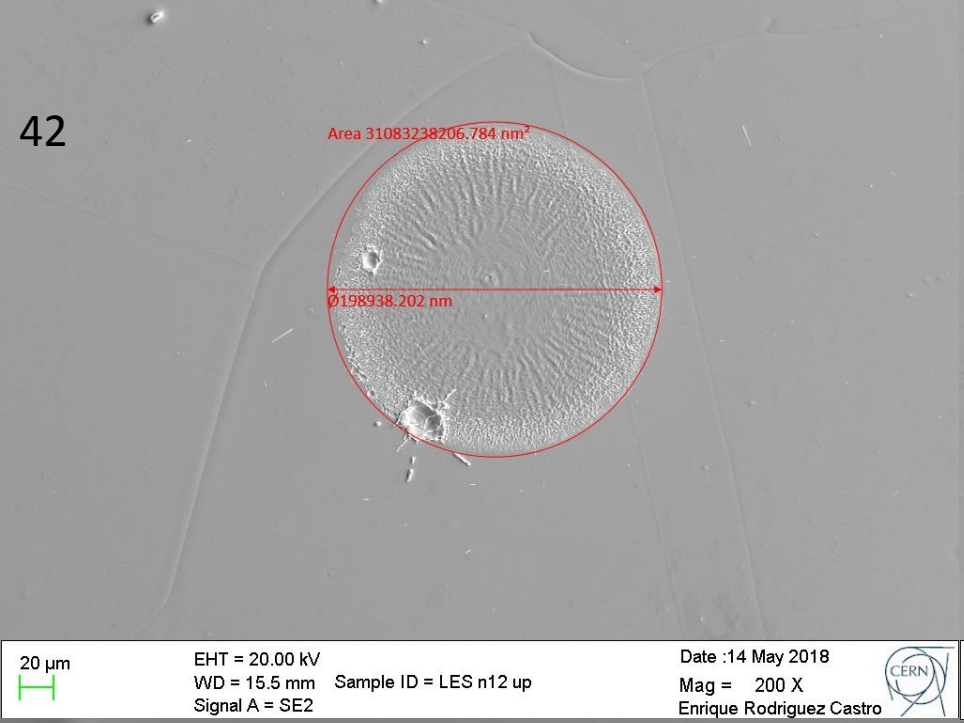


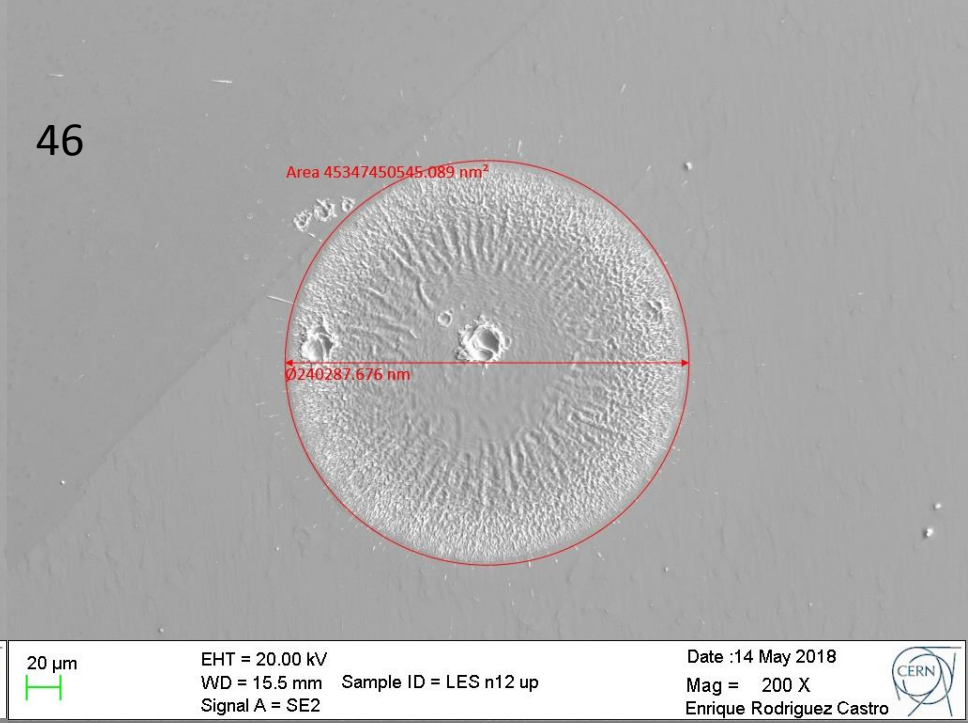
Conditioning curve n12

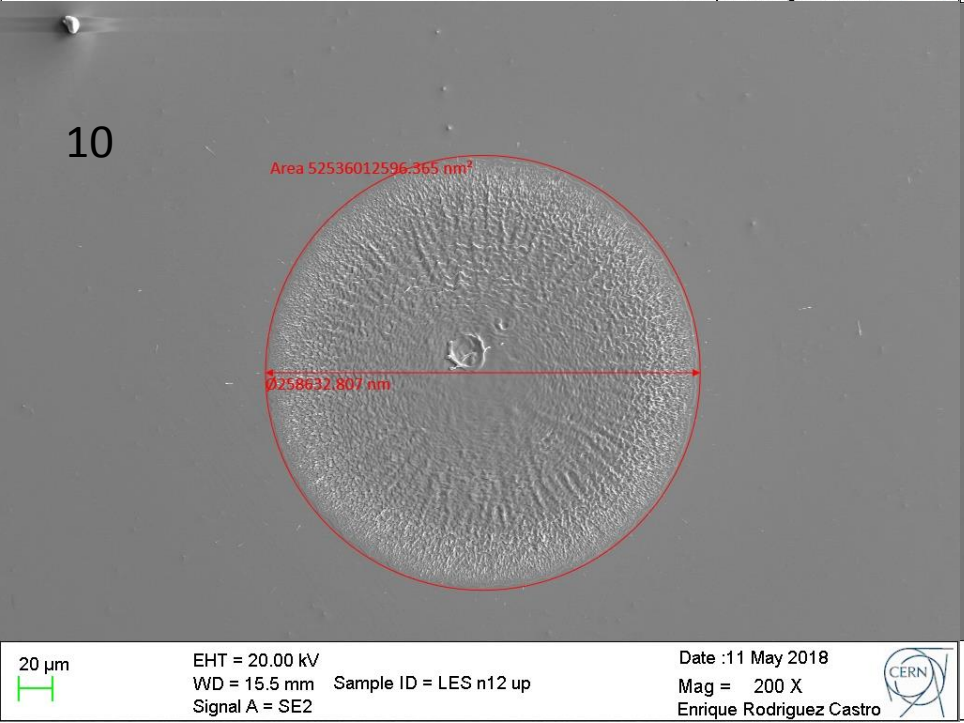


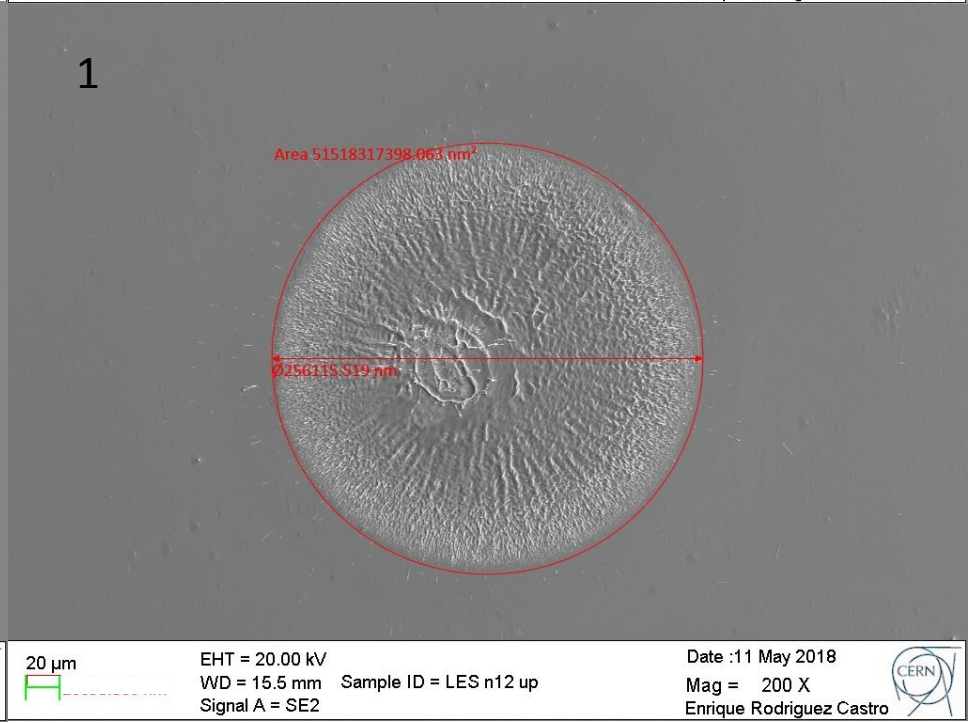
Conditioning curve n12




42
Area 31083238206.784 nm²
Ø198938.202 nm
20 µm
EHT = 20.00 kV
WD = 15.5 mm
Signal A = SE2
Sample ID = LES n12 up
Date :14 May 2018
Mag = 200 X
Enrique Rodriguez Castro
CERN

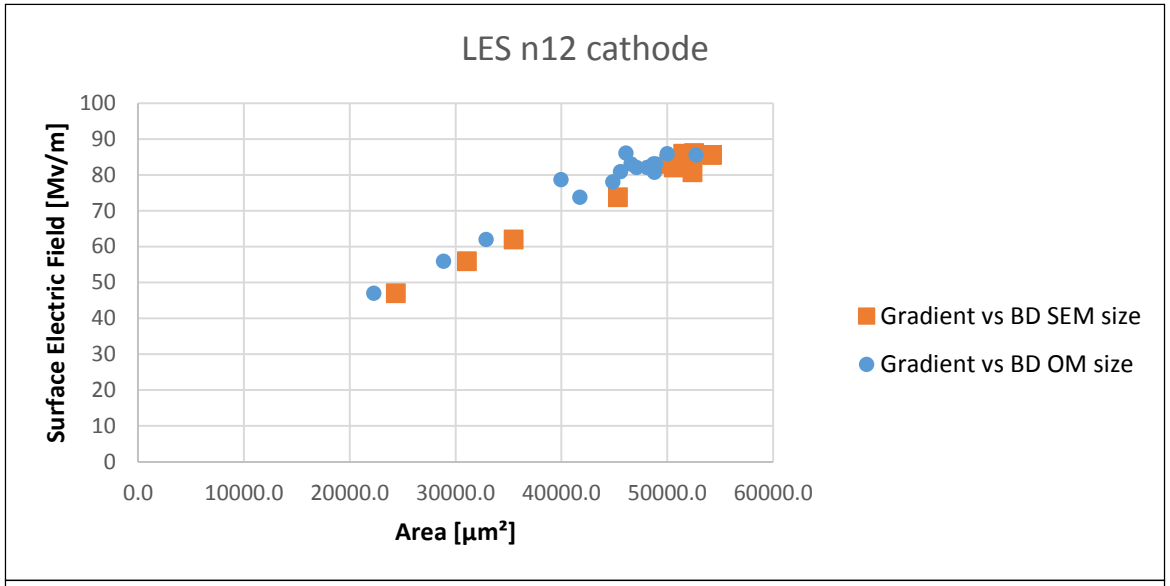

46
Area 45347450545.089 nm²
Ø240287.676 nm
20 µm
EHT = 20.00 kV
WD = 15.5 mm
Signal A = SE2
Sample ID = LES n12 up
Date :14 May 2018
Mag = 200 X
Enrique Rodriguez Castro
CERN

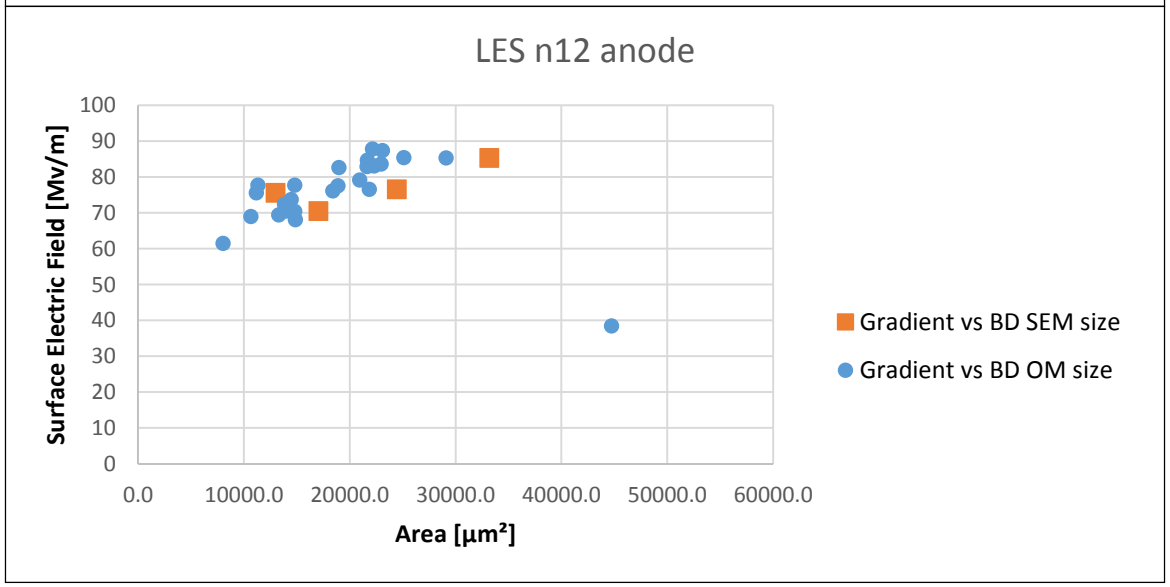

10
Area 52536012596.365 nm²
Ø258632.807 nm
20 µm
EHT = 20.00 kV
WD = 15.5 mm
Signal A = SE2
Sample ID = LES n12 up
Date :11 May 2018
Mag = 200 X
Enrique Rodriguez Castro
CERN


1
Area 51518317398.063 nm²
Ø256119.519 nm
20 µm
EHT = 20.00 kV
WD = 15.5 mm
Signal A = SE2
Sample ID = LES n12 up
Date :11 May 2018
Mag = 200 X
Enrique Rodriguez Castro
CERN

Large Electrode System (LES)

- Preliminary results show that crater size increase with surface electric field





Large Electrode System (LES)

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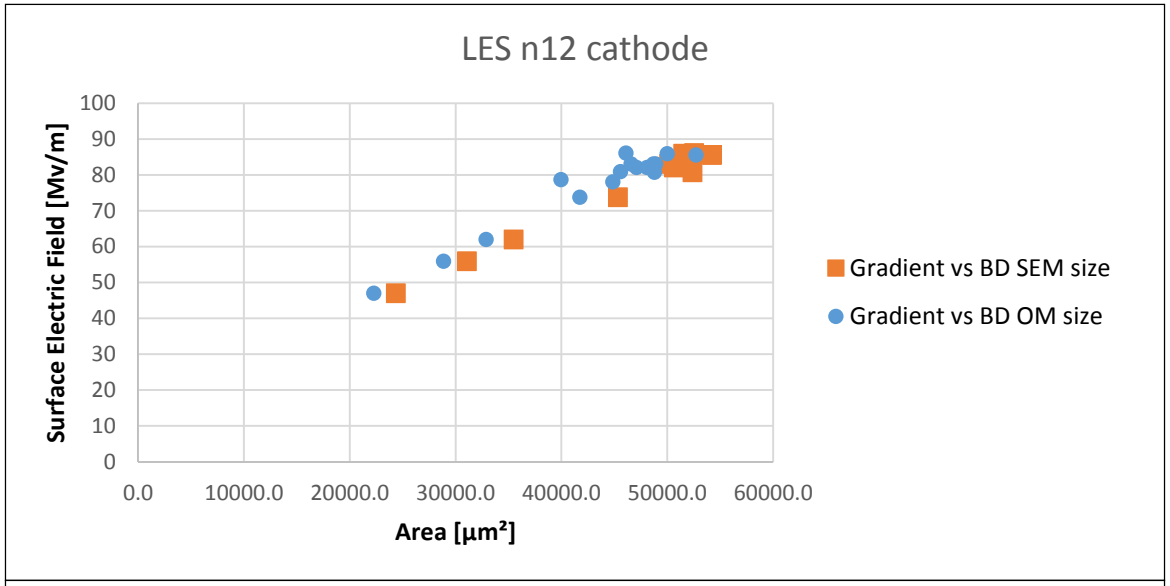
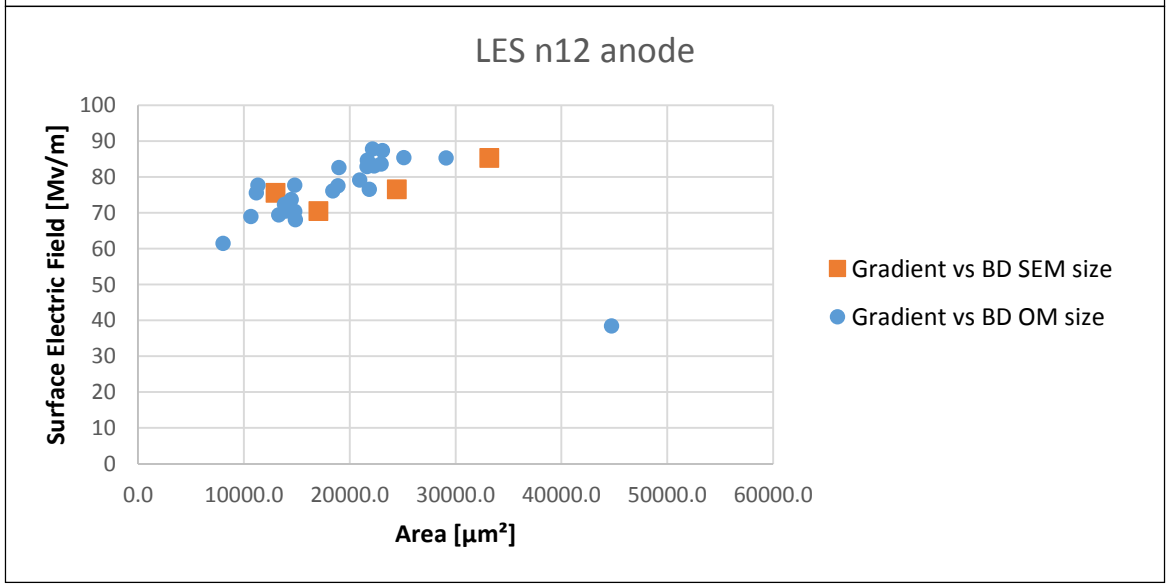
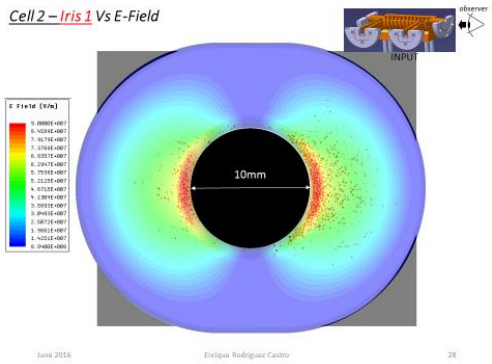
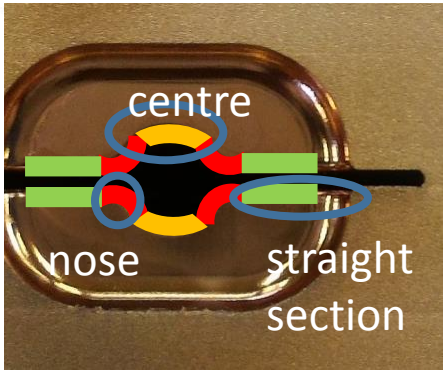


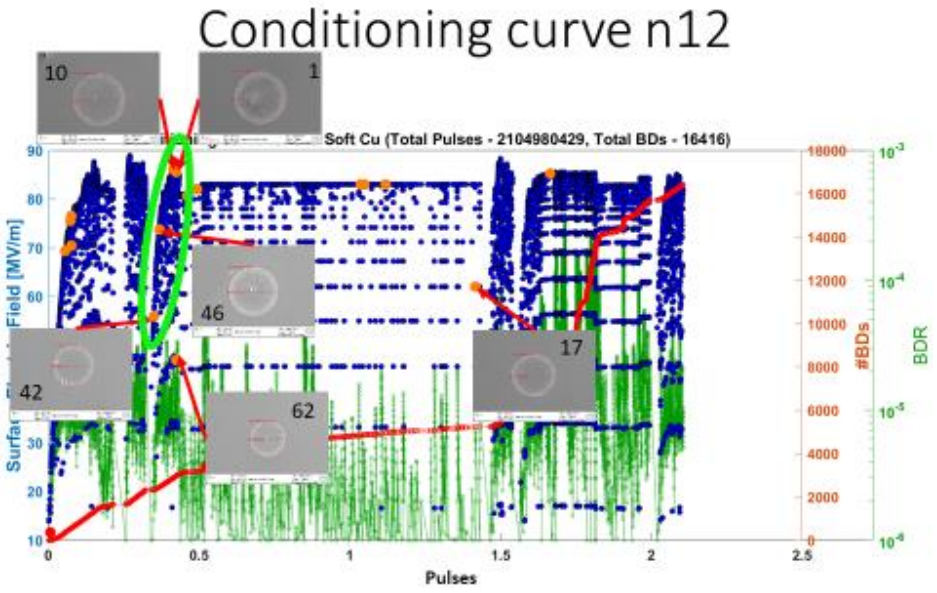


Summary

- Post mortem on RF and DC important tool on BD understanding
- Constantly adding equipment and tools
  - FIB-SEM → cross section and lamellas
  - APA → pollution analysis
  - Cameras → BD positioning not only in space but also in time
- CLIC-AS: BD accumulation on max E_field regions
- LES: BD size relation to surface electric field

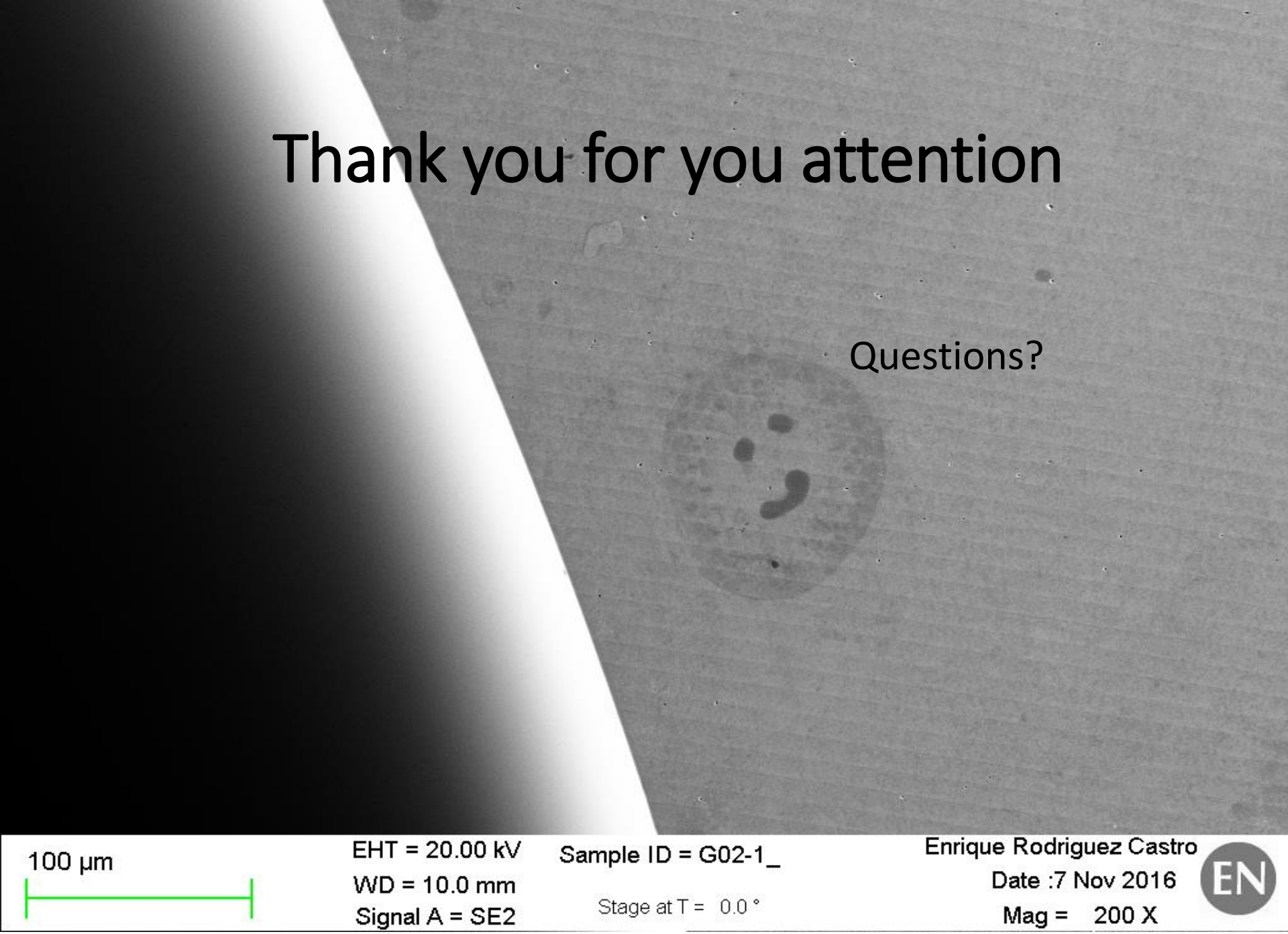






Thank you for you attention

Questions?



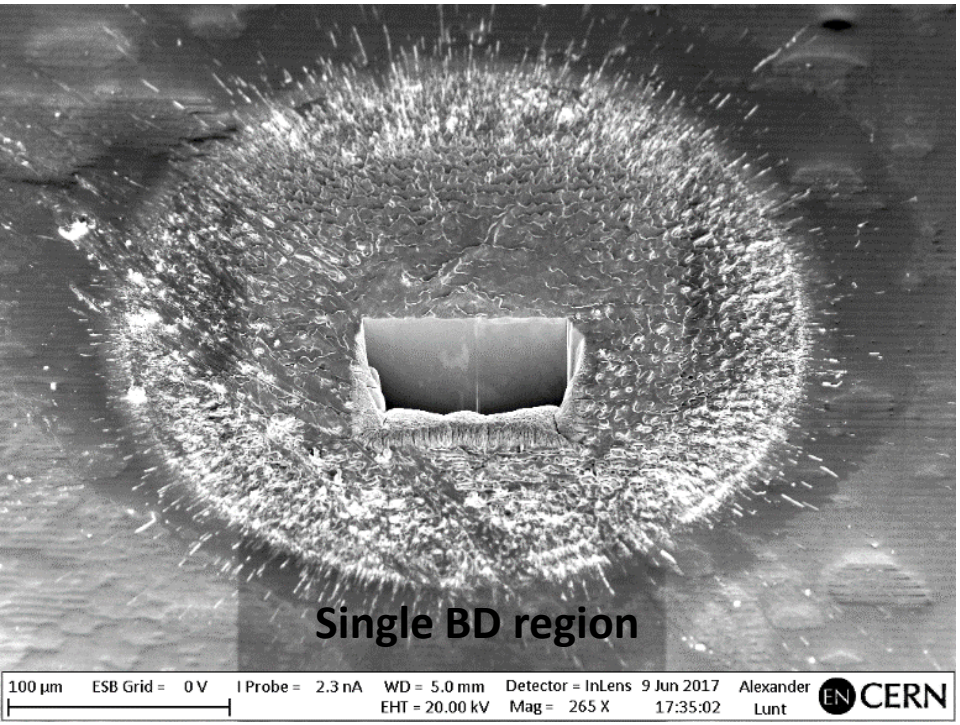
Recent microscopy at CERN

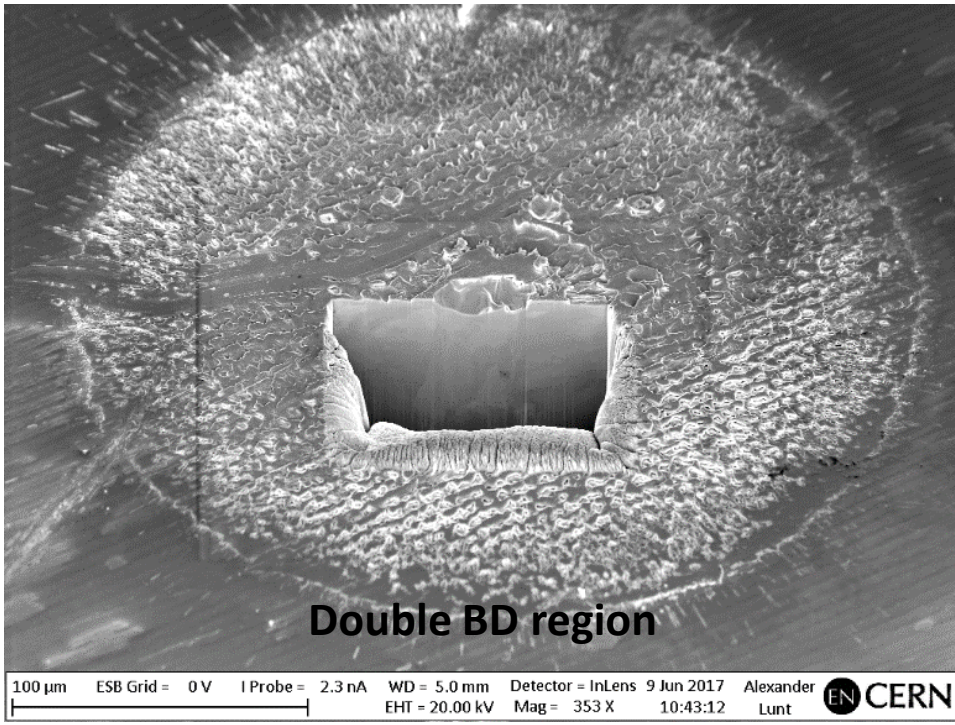
Enrique Rodríguez Castro

EXTRA SLIDES

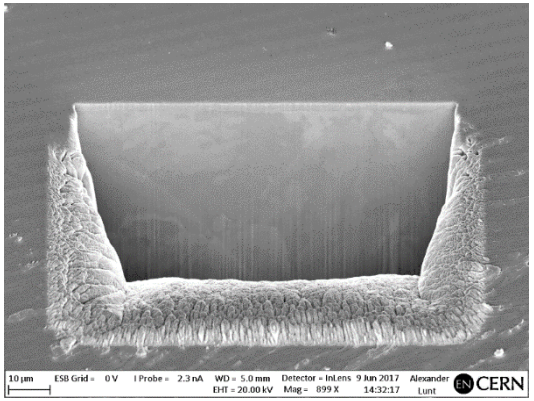
LES Post-Mortem

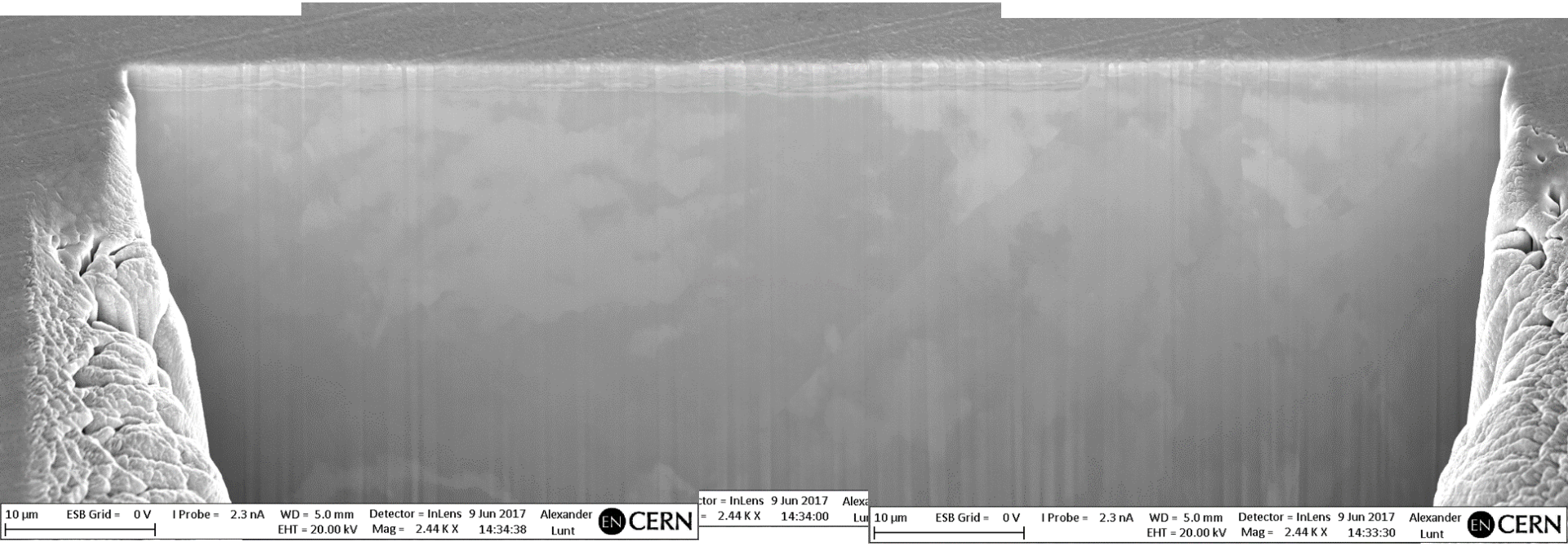
- This system allow us to FIB in well know regions
  - Reference surface → surface that has not suffer a BD
  - BD site → surface that has suffer a BD
  - Follow up site → surface that has suffer multiple BD



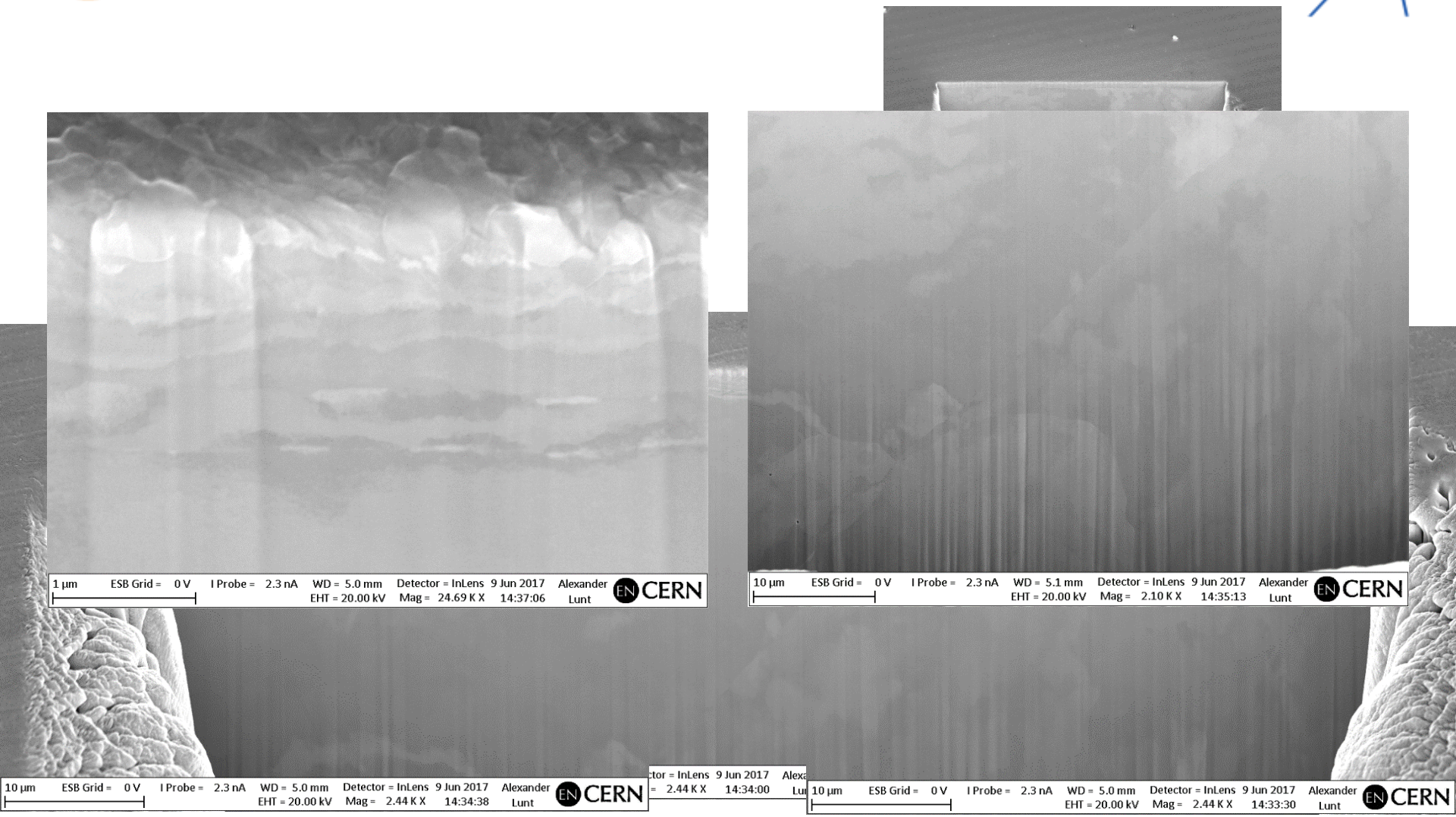


Cross-section: Hard Cu Reference

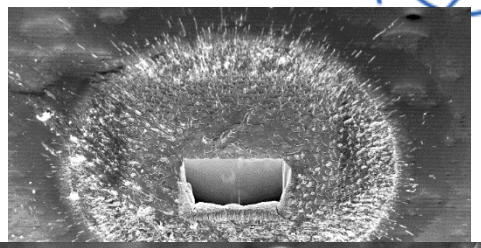


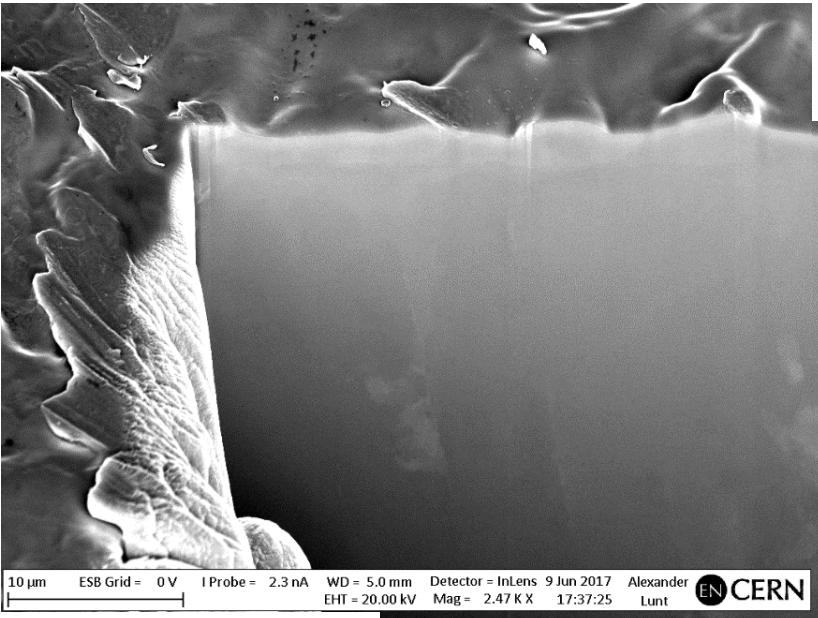


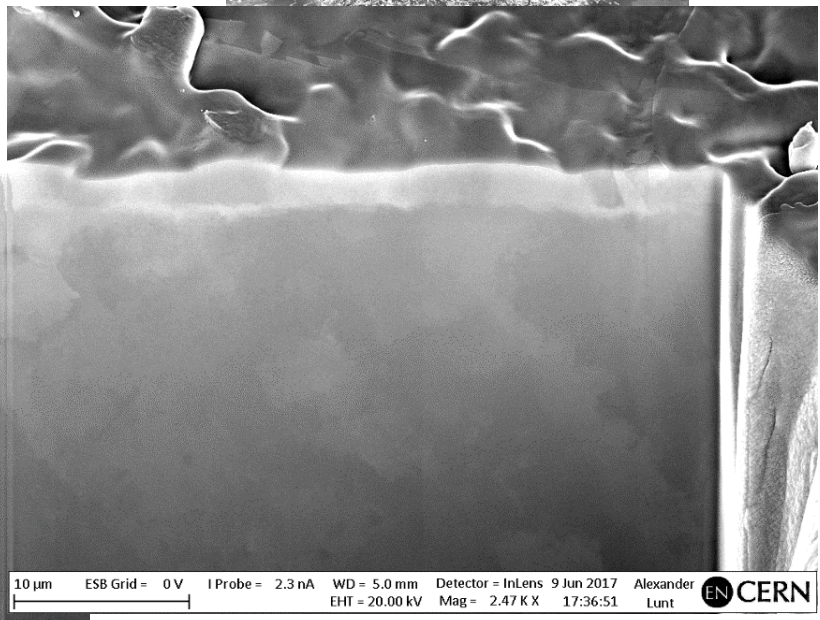
Cross-section: Hard Cu Reference

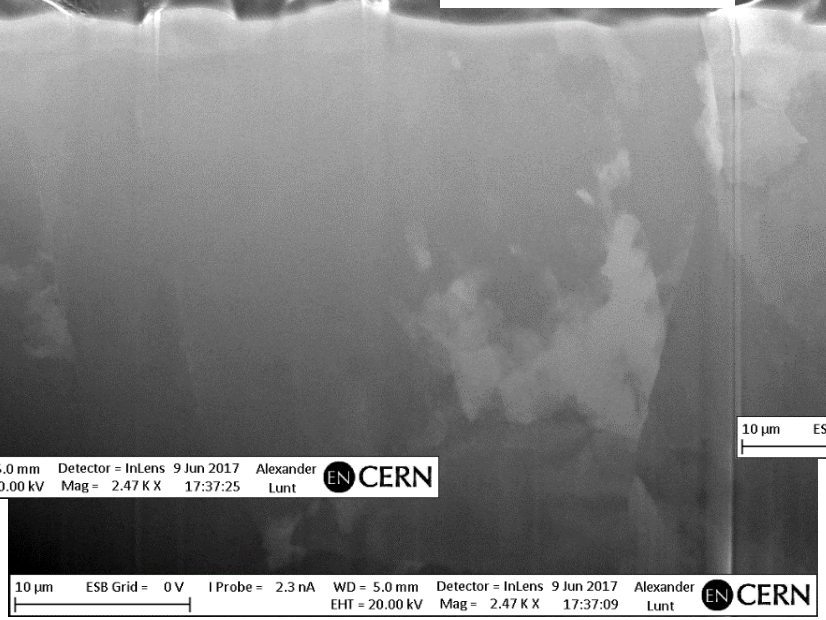


Cross-section: Hard Cu 1 BD

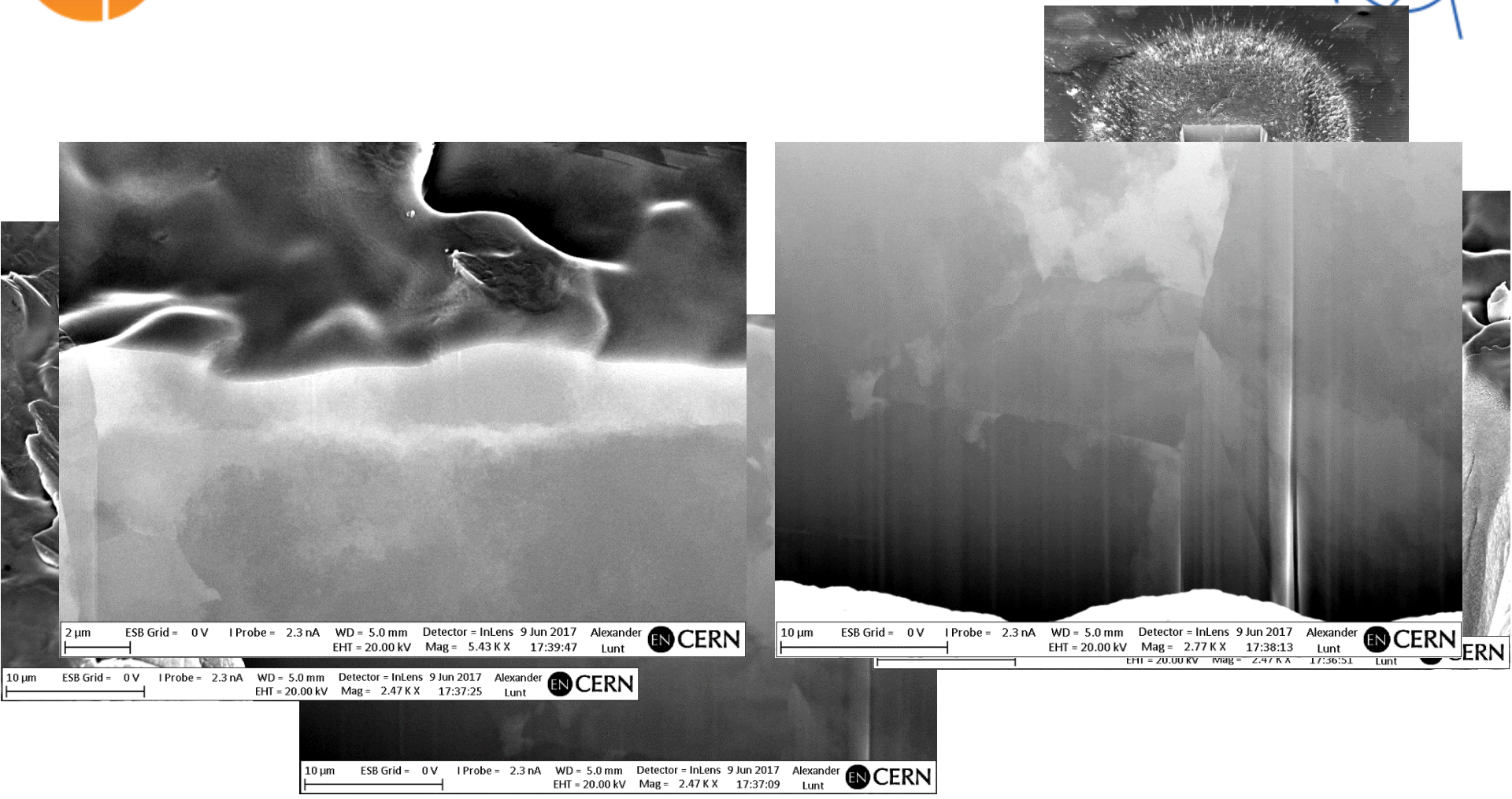




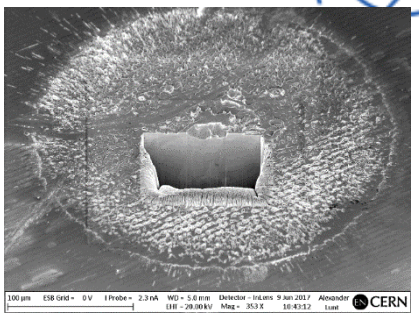


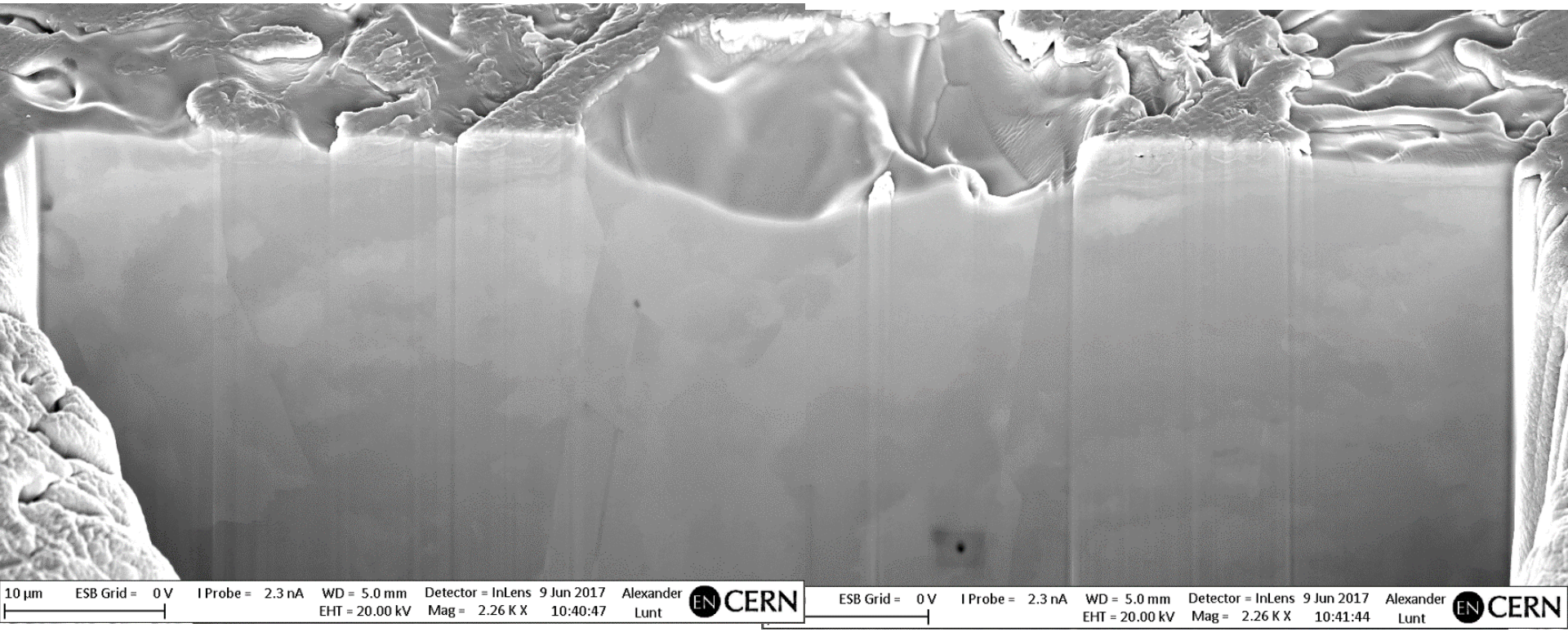


Cross-section: Hard Cu 1 BD



Cross-section: Hard Cu 2 BD





Cross-section: Hard Cu 2 BD