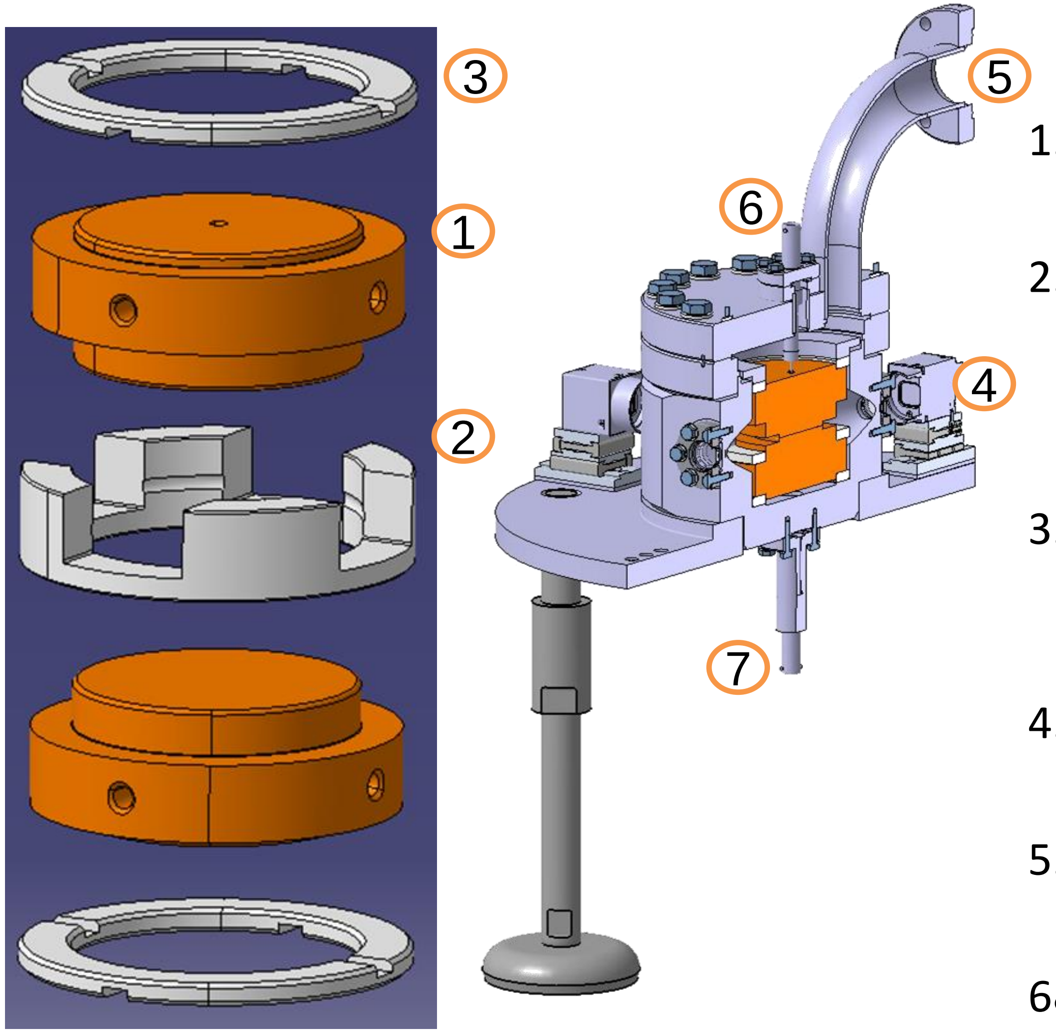
Recent Test - CERN Pulsed DC Large Electrode System

Ruth Peacock

2^{nd} September 2021

Contents

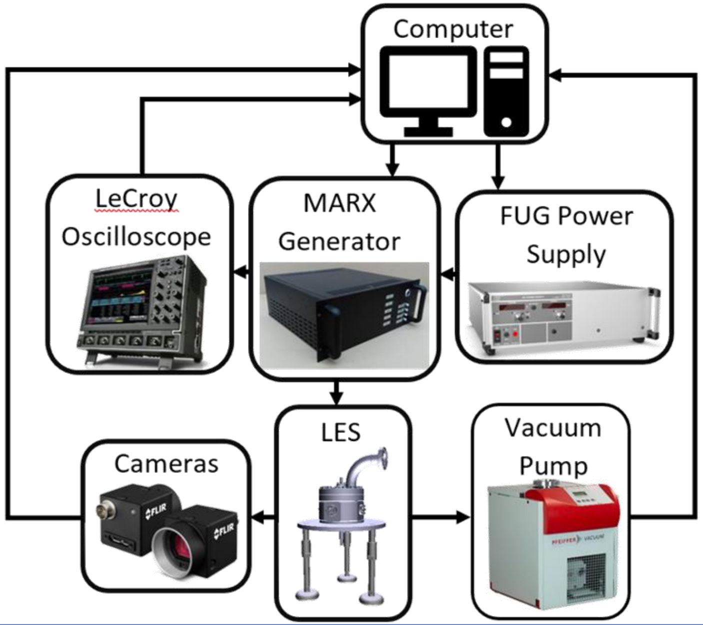
Pulsed DC Large Electrode System



1. 2 high precision machined electrodes
2. High tolerance ceramic spacer between electrodes providing a gap of 20µm, 40µm, 60µm, or 100µm
3. Ceramic spacers to isolate electrodes from the chamber
4. 4 Windows and 2 perpendicular cameras
5. Vacuum pump output (5x10^-9)

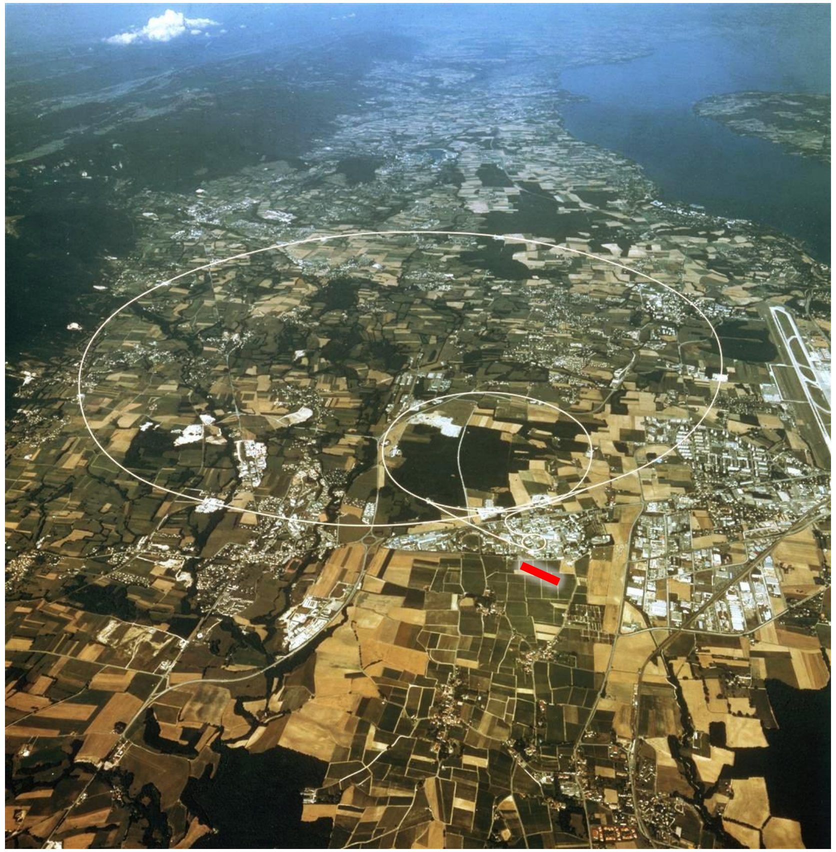
6&7. High Voltage Feedthroughs

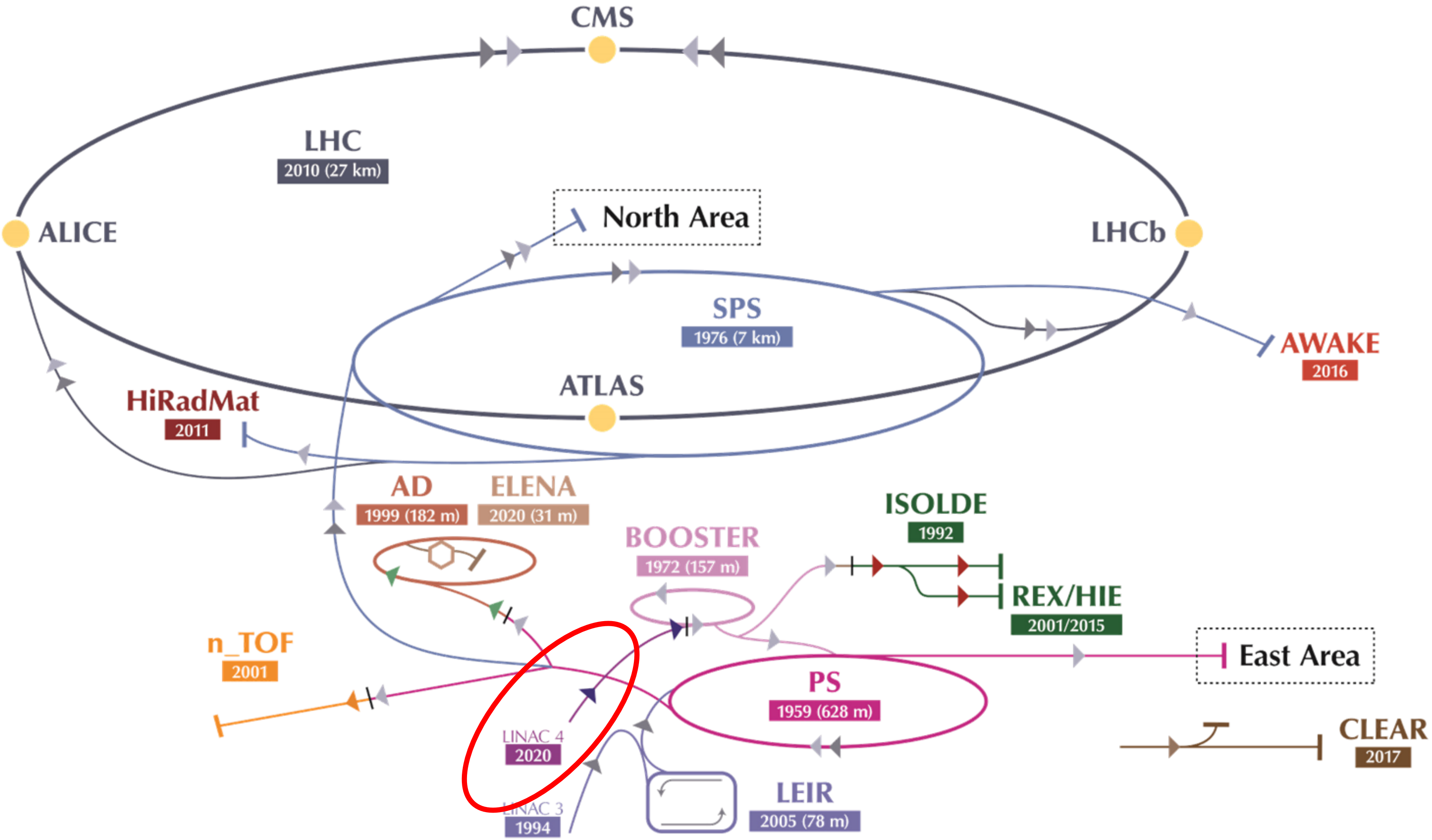
The MARX generator can pulse up to a rep rate of 6kHz and a minimum pulse length of 1µs.
Measurements of the voltage and current supplied during a breakdown are measured whenever a breakdown is detected.



L4 RFQ Irradiated Samples for DC Tests

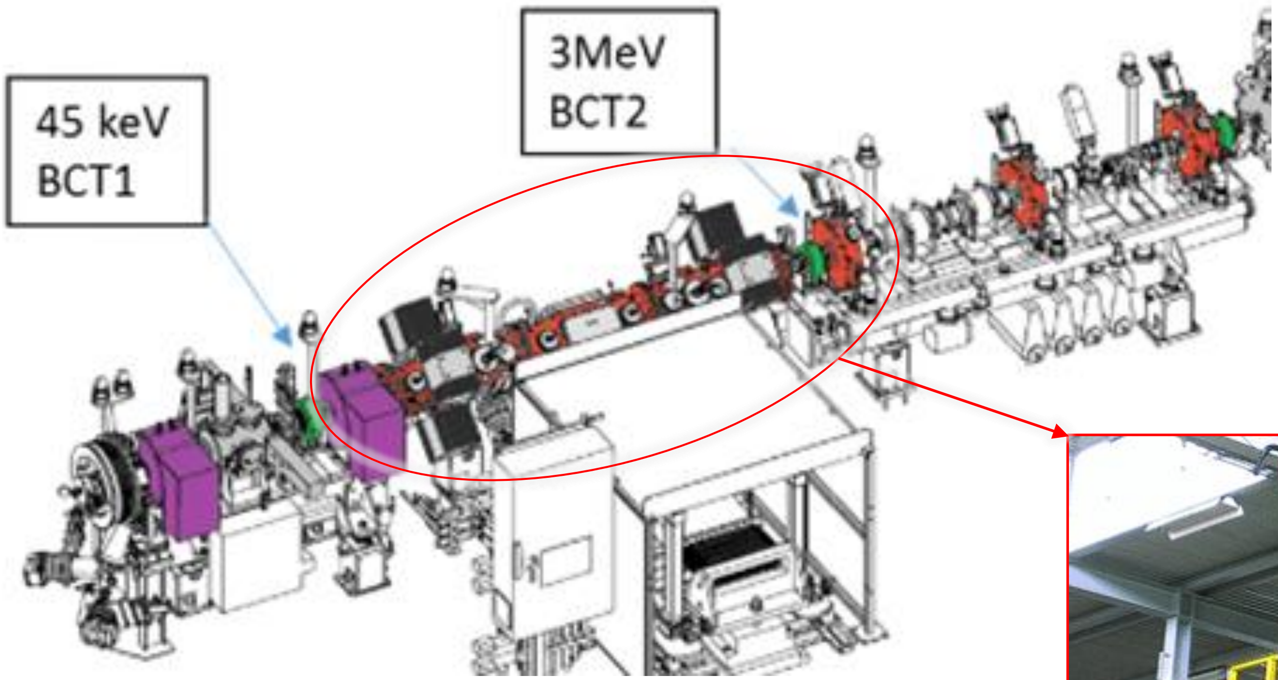
CERN Accelerator complex





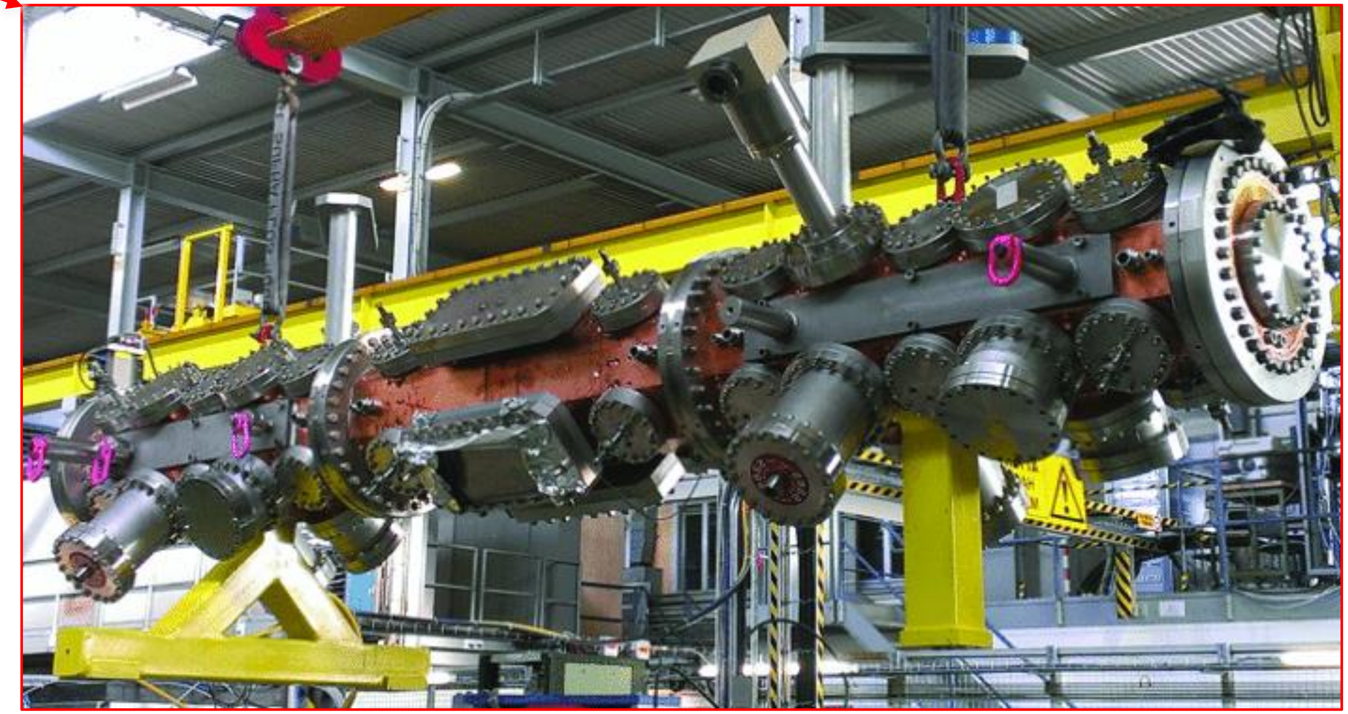
LINAC4, a new linear accelerator as injector for the HL-LHC

The radiofrequency quadrupole (RFQ) of LINAC4



Richard Scrivens

- RFQ properties
- 0.6 ms pulses
- 1 Hz rep rate
- 30 mA pulse current

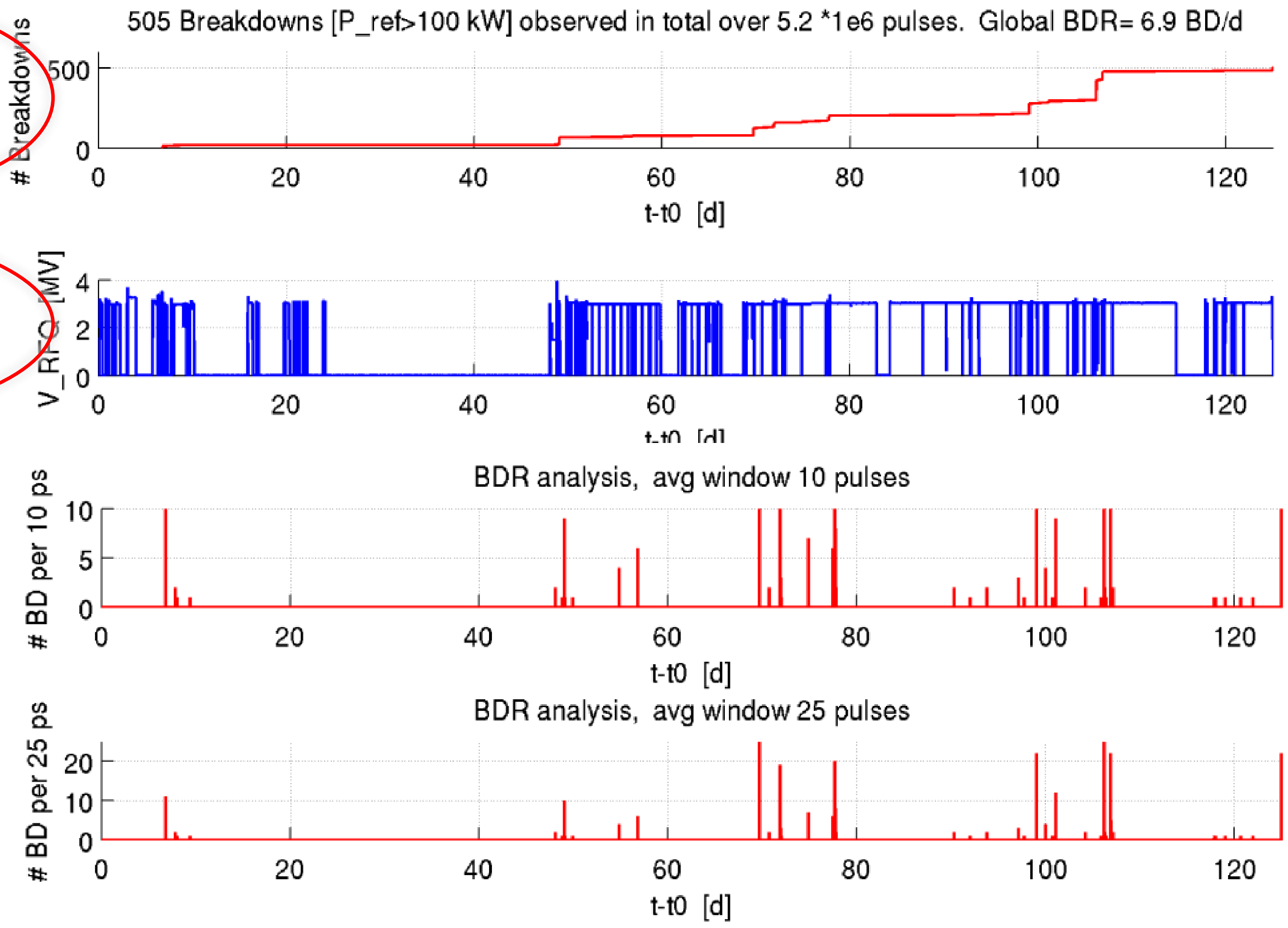


- Increased brightness
- Increased energy (160 MeV for LINAC 4)
- H^- beam
- RFQ as first-stage accelerator

Breakdown rate (BDR) in RFQ

BDR: ~10^{-4}

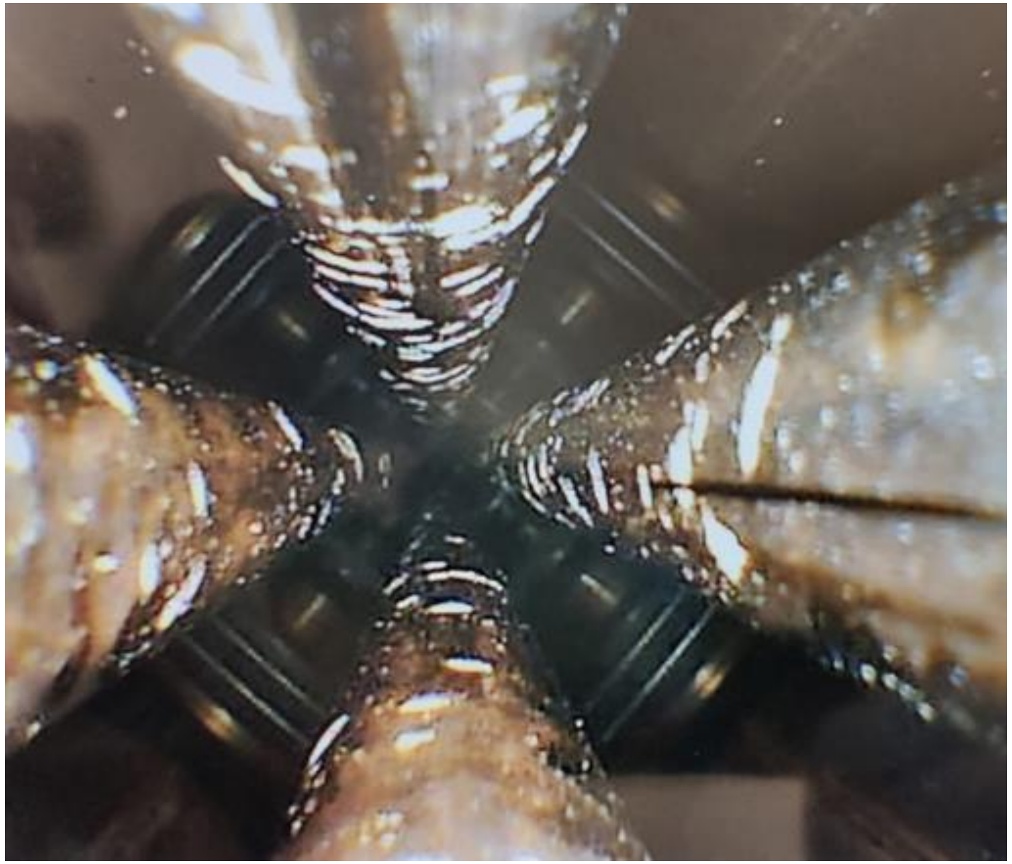
Surface field: ~35 MV/m



RF pulse 1 ms
Rep rate 1 Hz

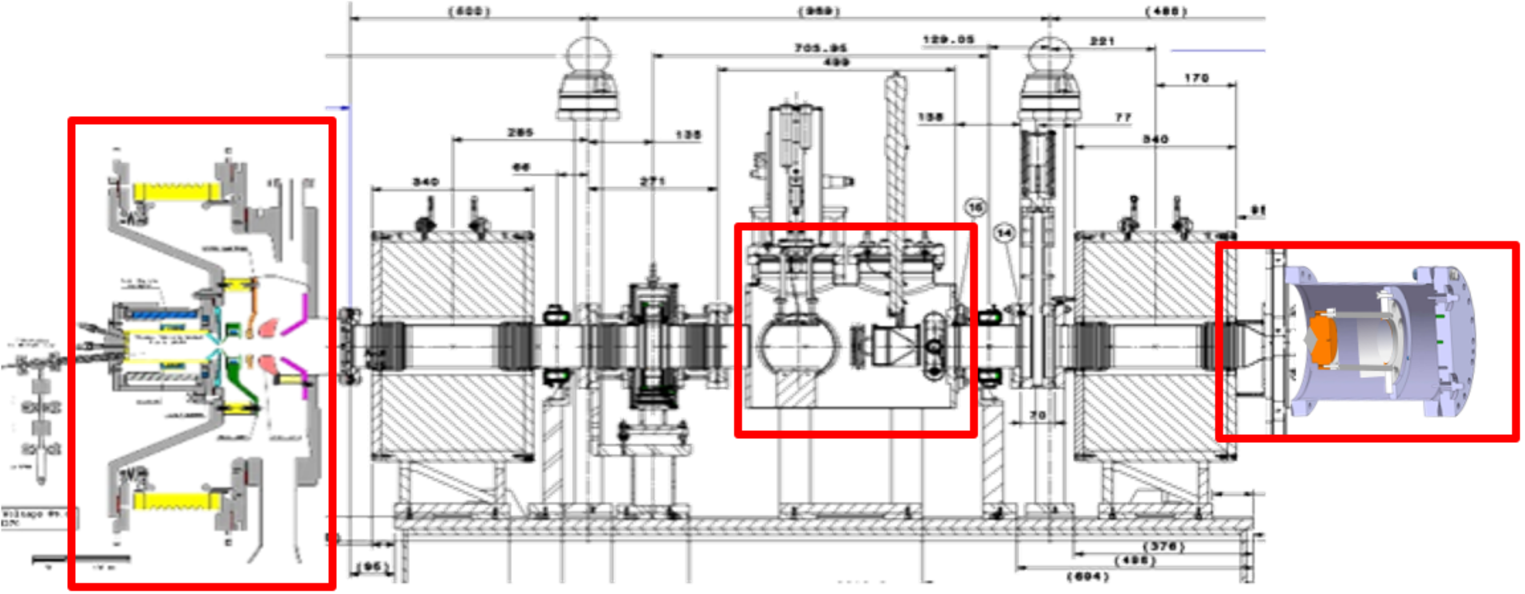
Rolf Wegner

Damage from breakdowns



- A replacement RFQ is being manufactured
- Need to understand origin of enhanced breakdown rate, and find a mitigation
- Could breakdowns be correlated with beam losses ?

Electrode Irradiation



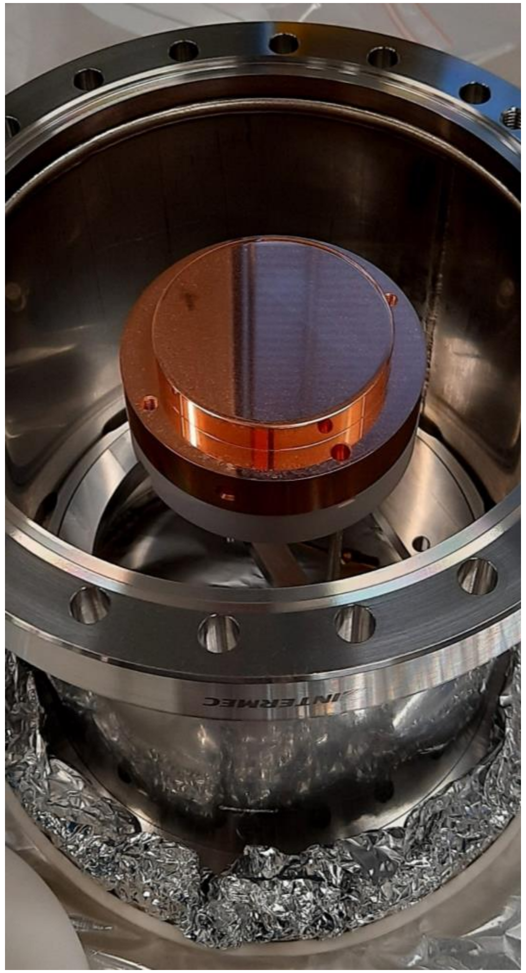
H^- Source 45 keV

Low-energy beam transport

2 Steerers, 2 Solenoids

Sample holder

Before Irradiation



After Irradiation

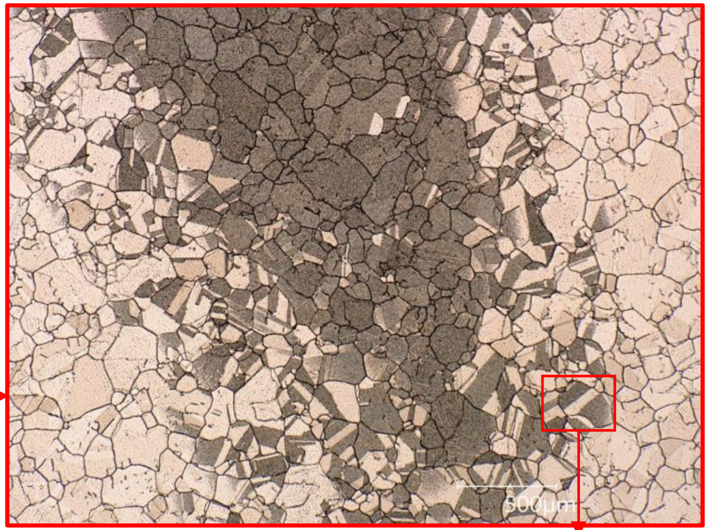
Irradiated with 10^19 H- on the target electrode

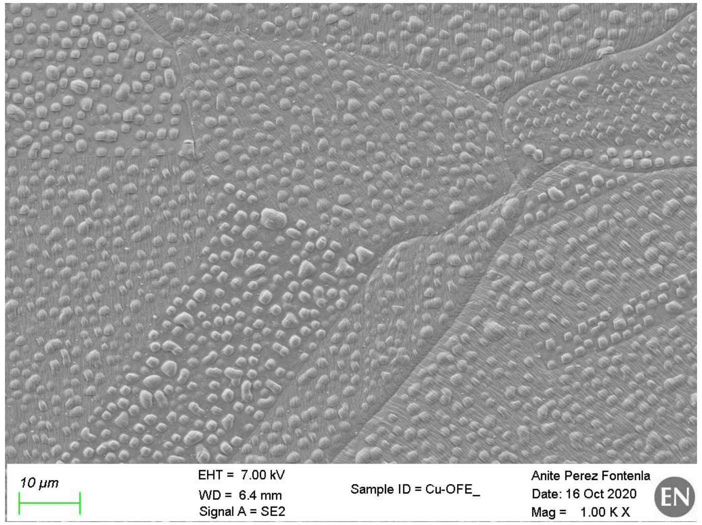
Alessandra Lombardi

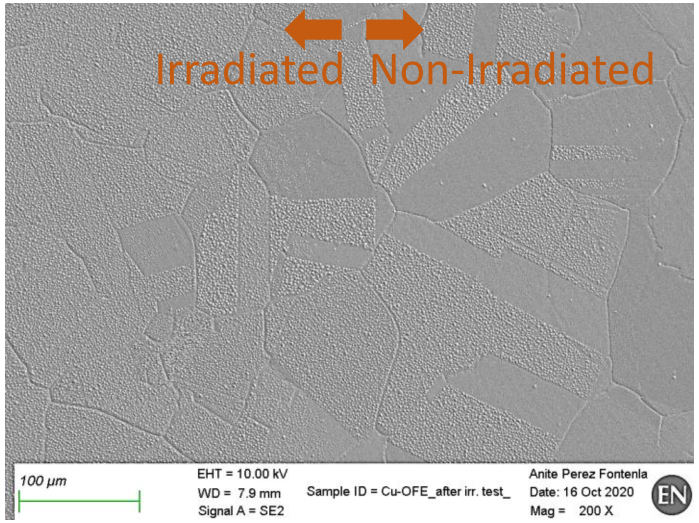
Copper OFE Tests

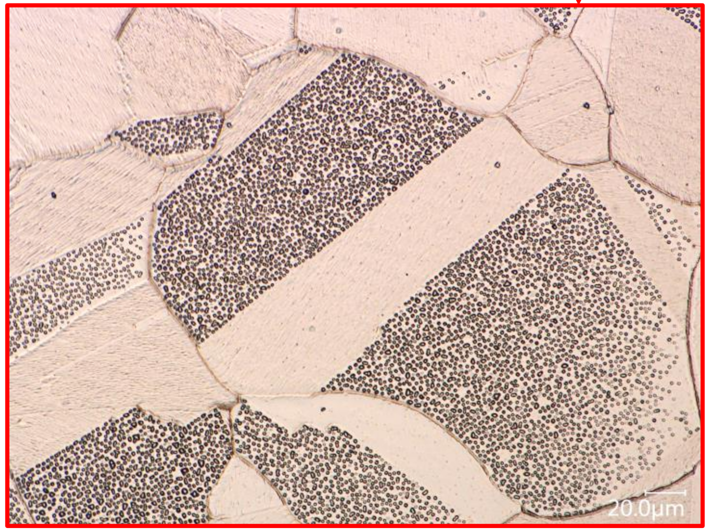
Pre-Test Scanning Electron Microscope (SEM) Analyses

SEM analyses of the surface displayed clusters of blisters in the ‘C’ shape of the beam and a visible transition between the irradiated and non-irradiated areas.





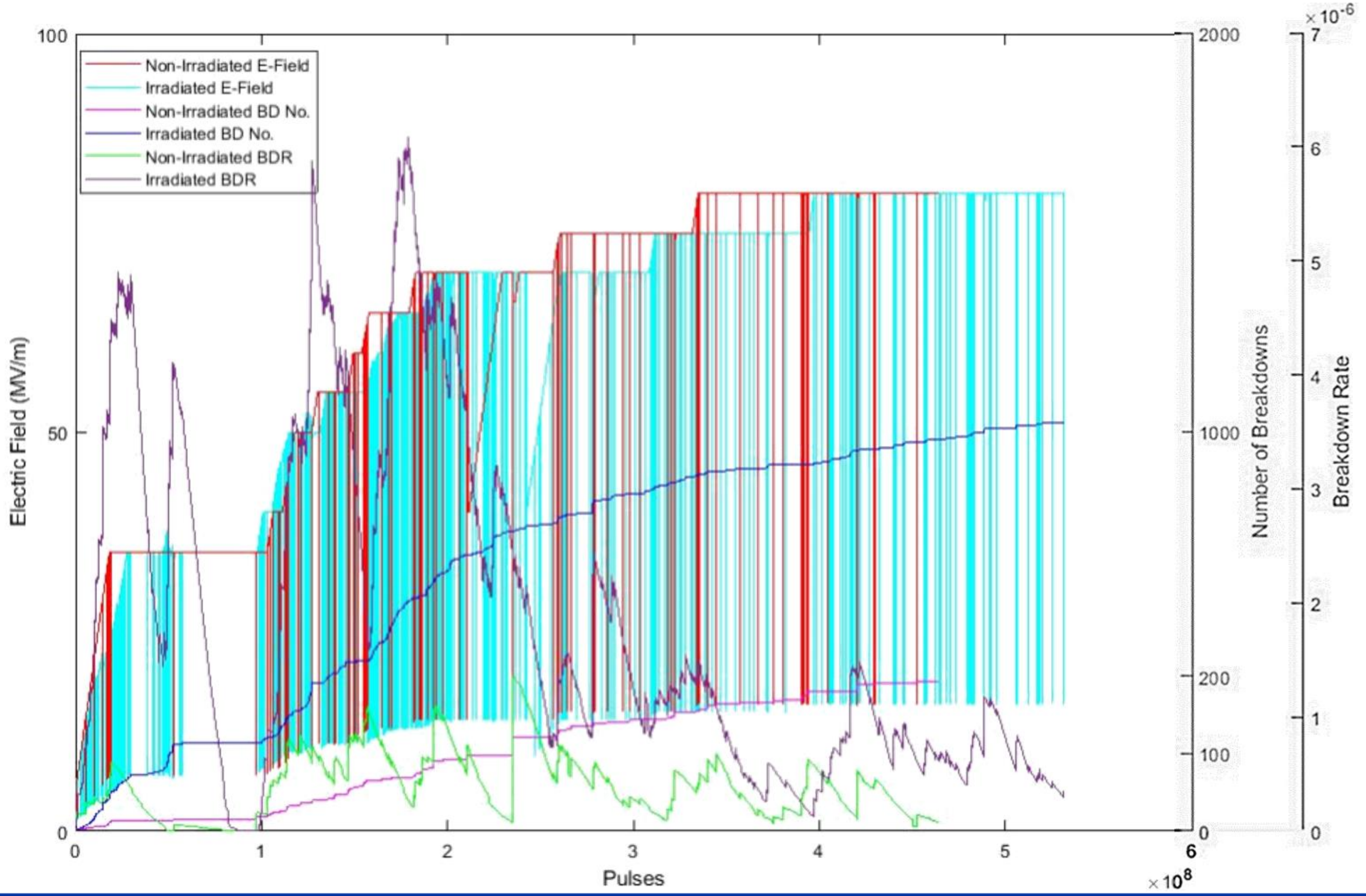




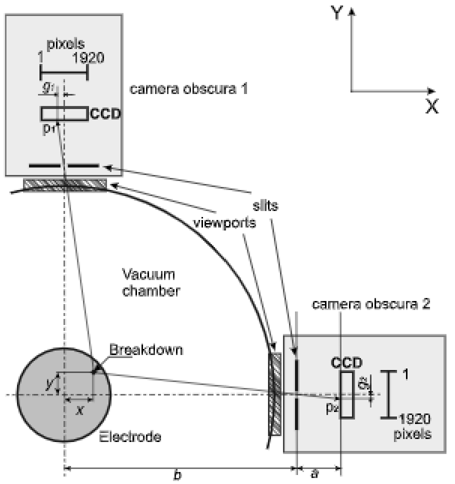
Images - Ana Teresa Perez Fontenla (CERN)

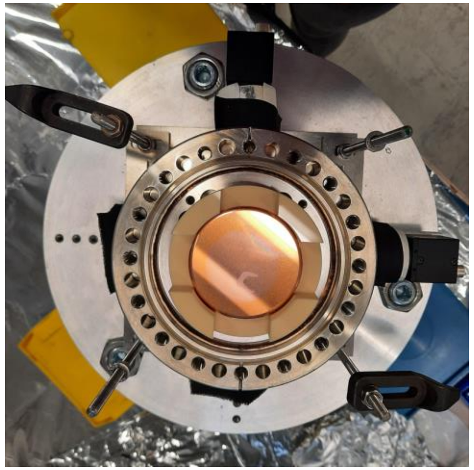
Irradiated vs. Non-Irradiated Cu BD Locations Conditioning

- Conditioning is a process where the electric field is gradually increased to achieve a higher operating field.
- 2 pairs of electrodes were tested, one with an irradiated electrode and the other without.
- Conditioning was done as similarly as possible.
- There is a large number of breakdowns in the initial stages of conditioning with the Irradiated cathode.
- The Irradiated electrodes appeared to have a reduced breakdown rate at higher voltages suggesting that the imperfections had been conditioned away.
- **Maximum stable E-Field 80MV/m**



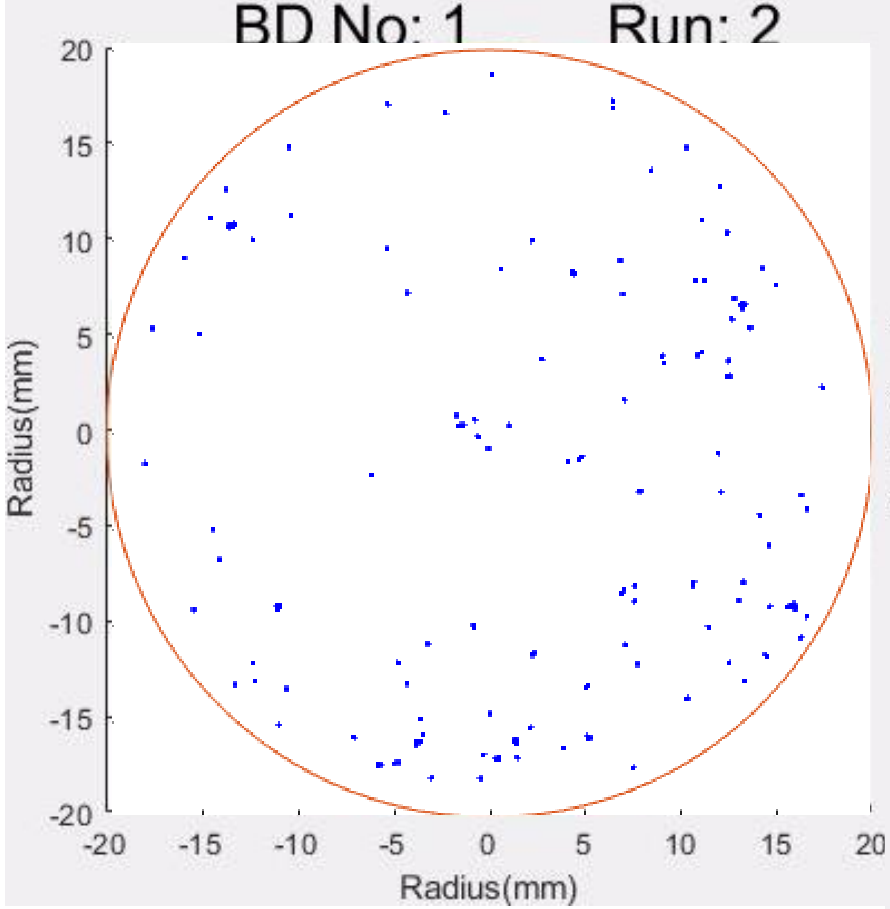
Irradiated vs. Non-Irradiated Cu BD Locations





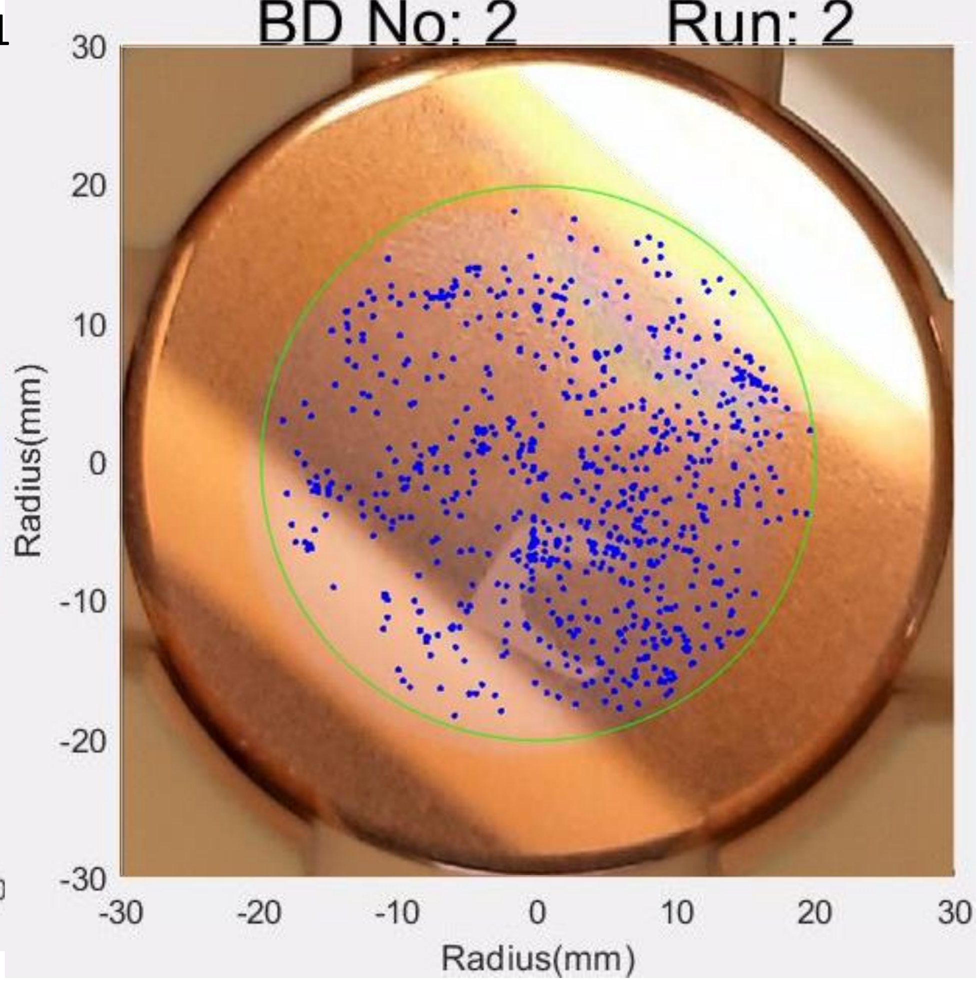
Non-Irradiated Electrode

Total BD = 191



Irradiated Electrode

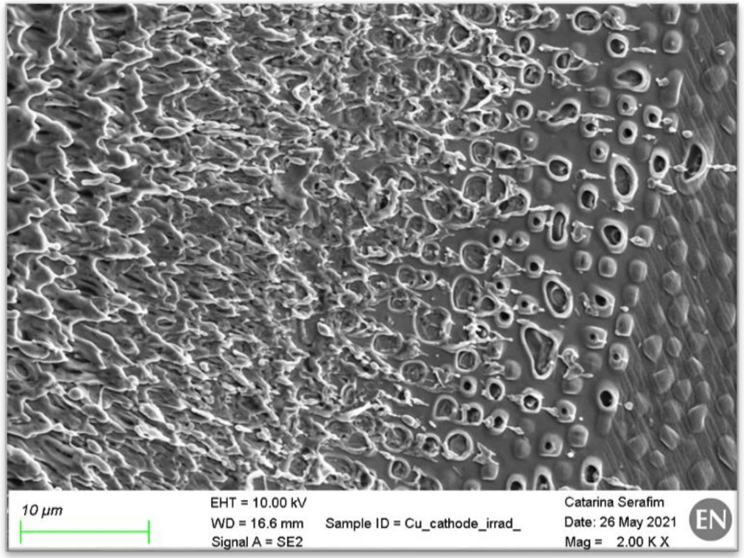
Total BD = 939

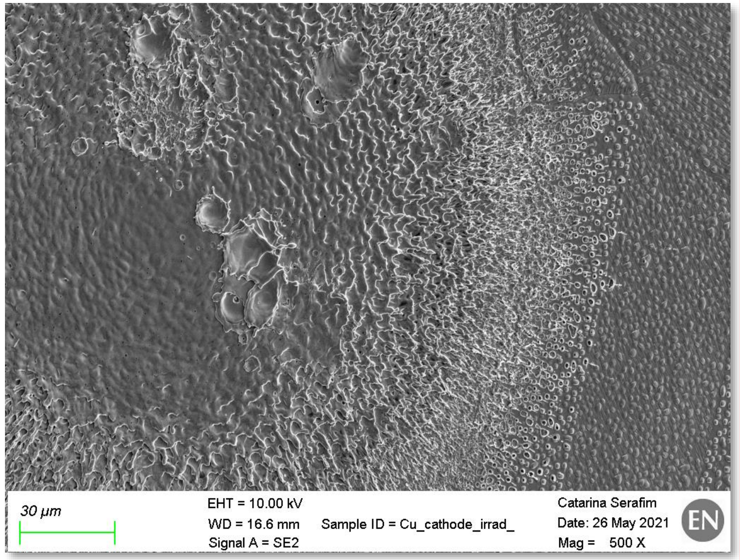


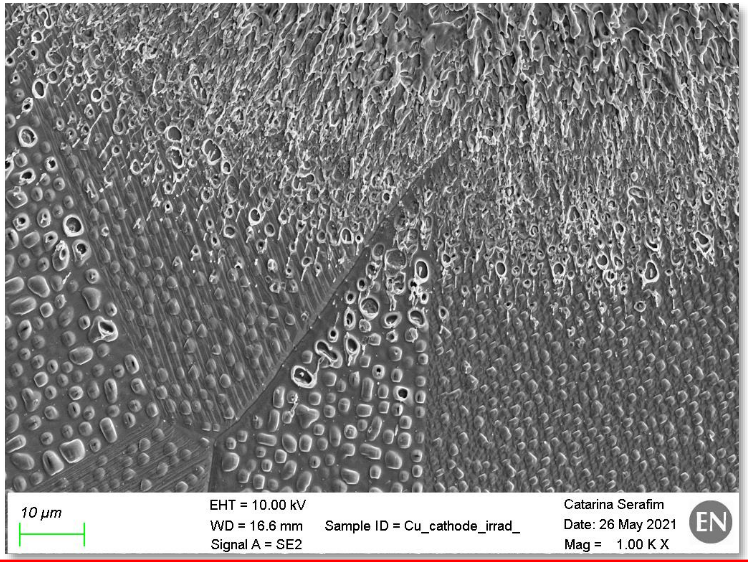
Post Test - SEM Images After Testing (Irradiated Cu)

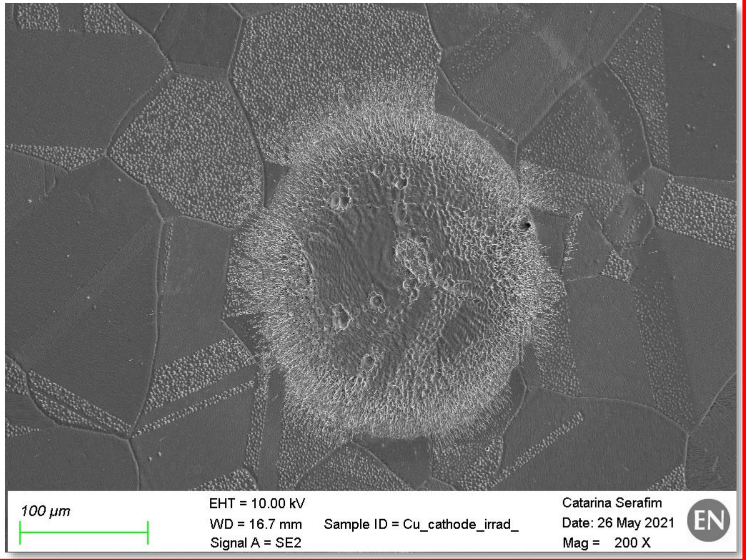
Images - Ana Teresa Perez Fontenla & Catarina Serafim (CERN)

Irradiated Area

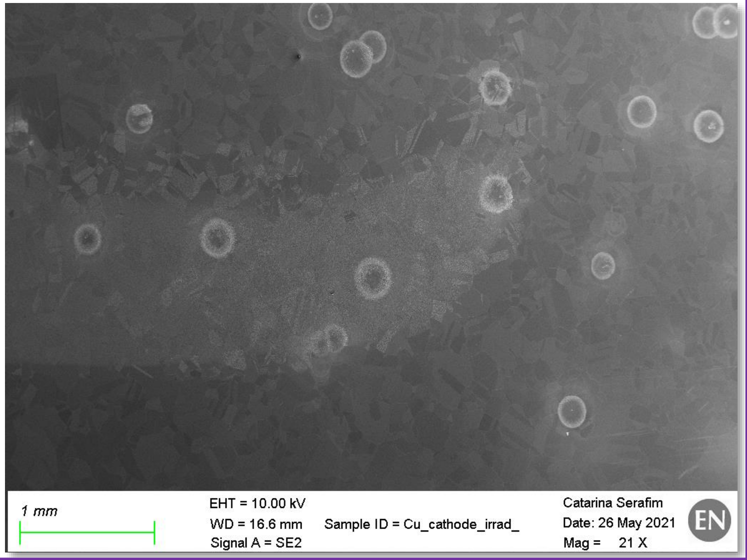




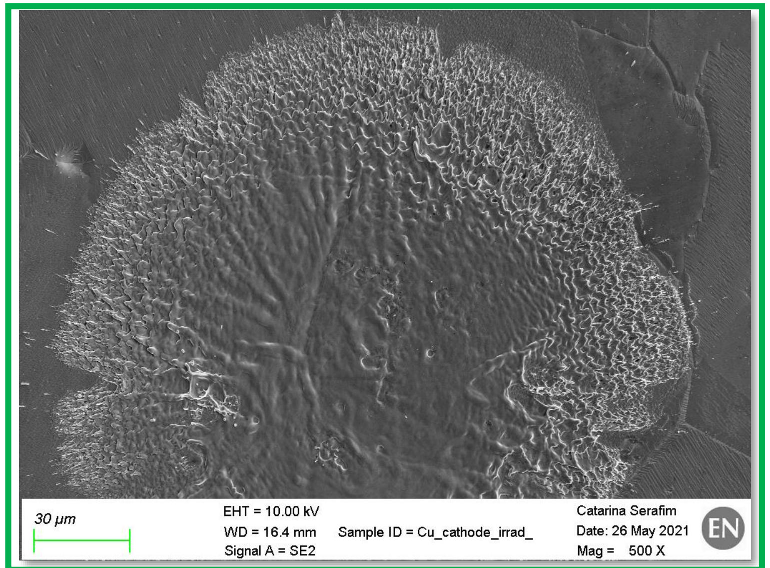




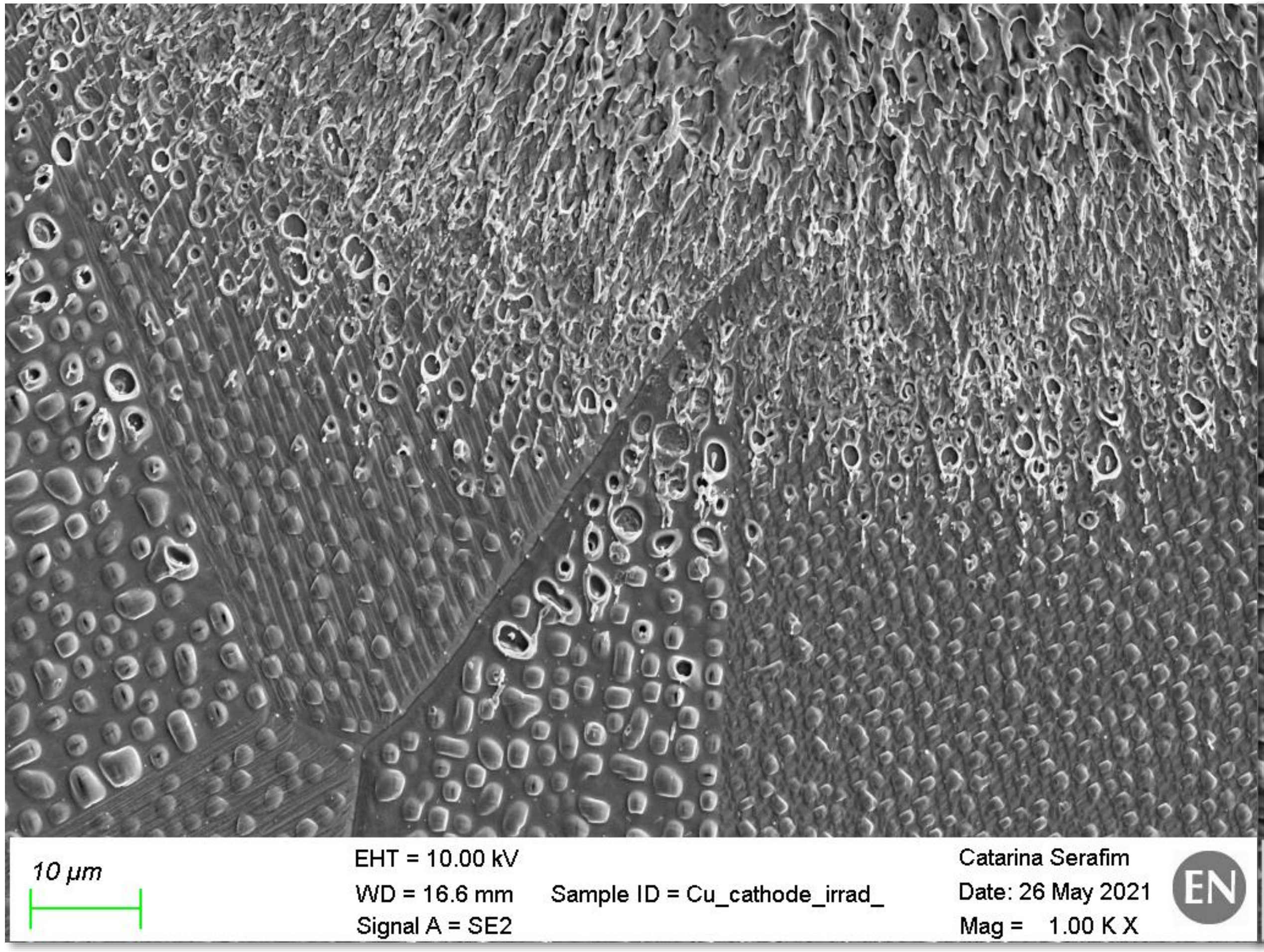
Irradiated and Non-Irradiated Area

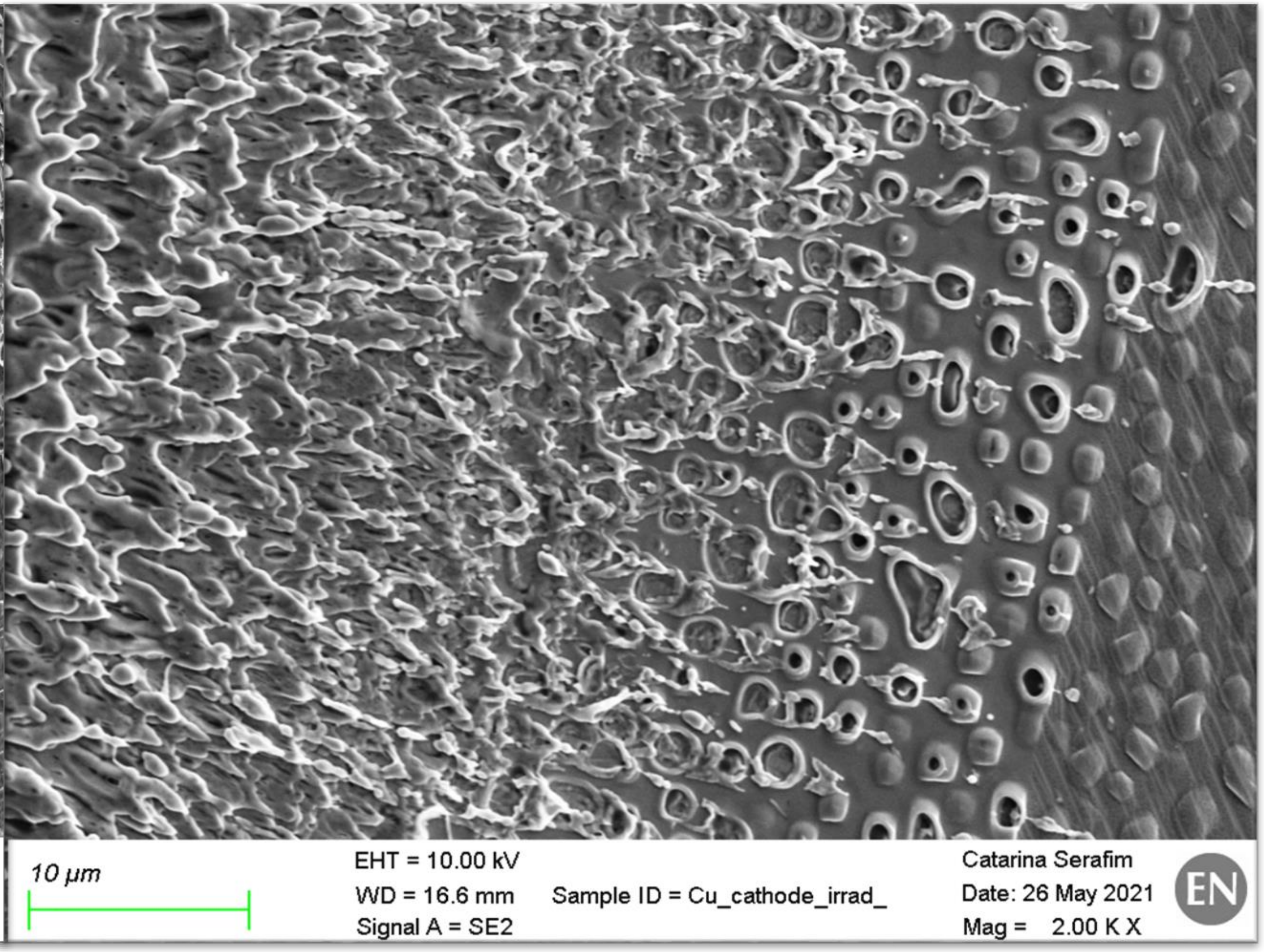


Non-Irradiated Area



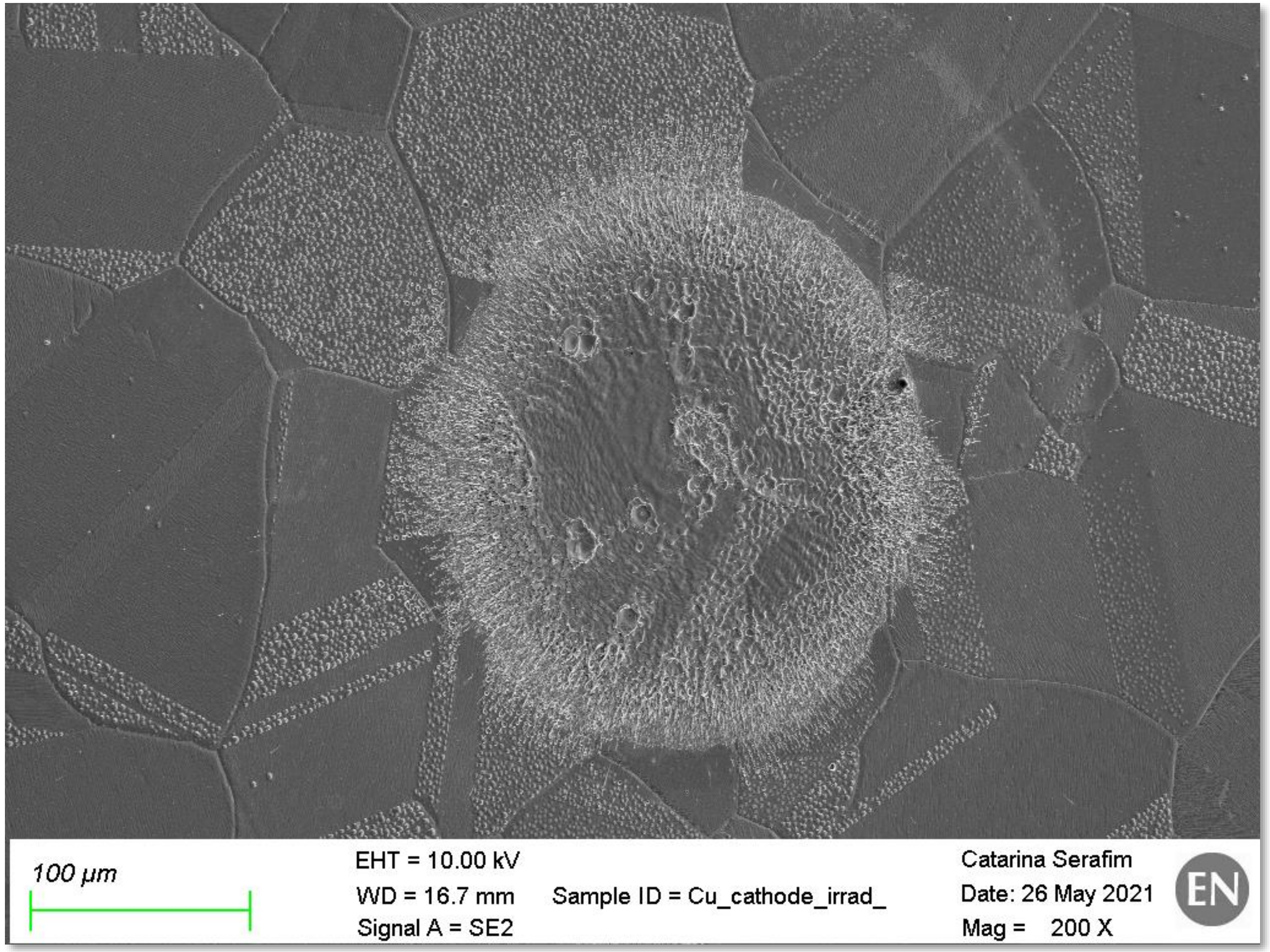
Post Test - SEM Images After Testing (Irradiated Cu)

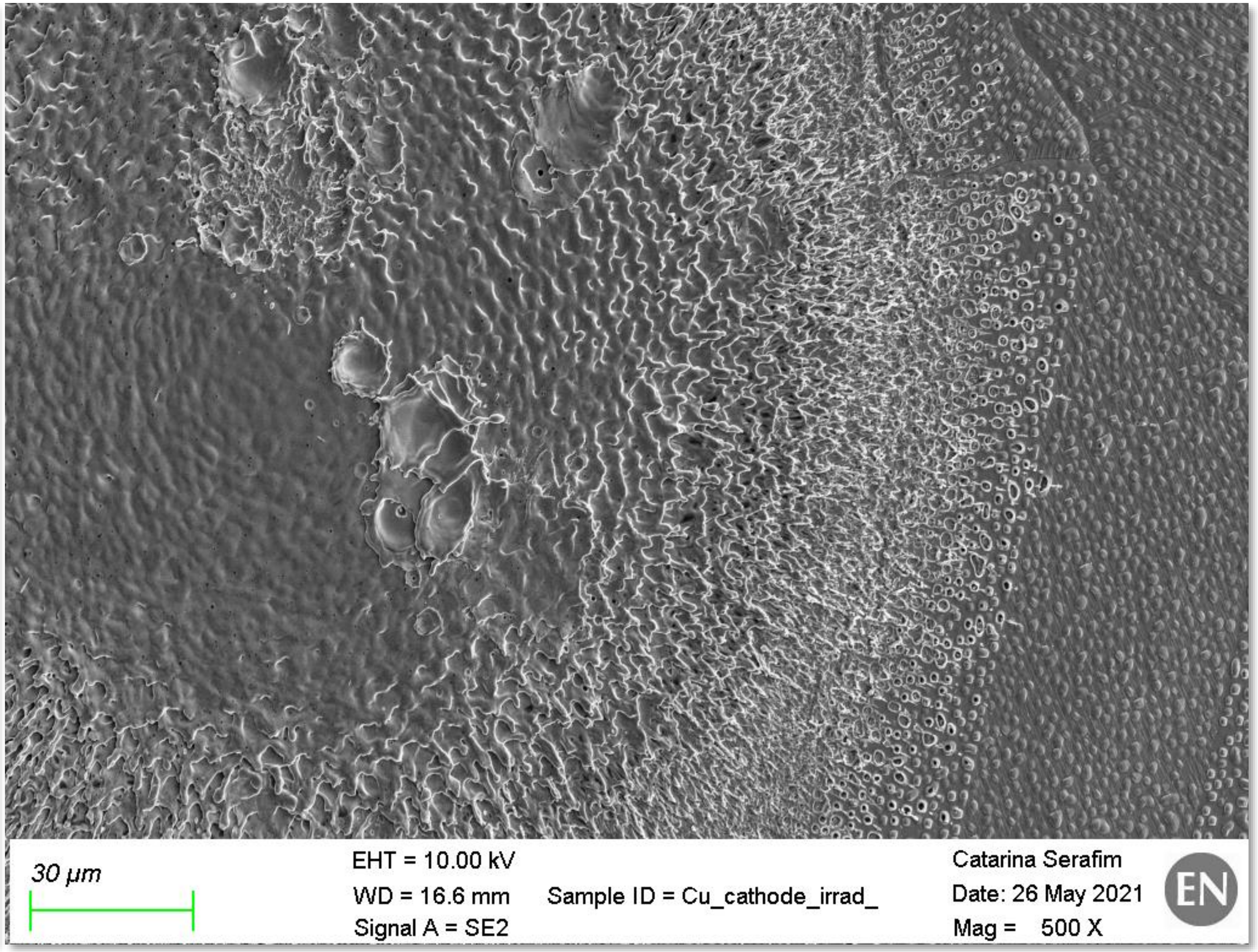




Images - Ana Teresa Perez Fontenla & Catarina Serafim (CERN)

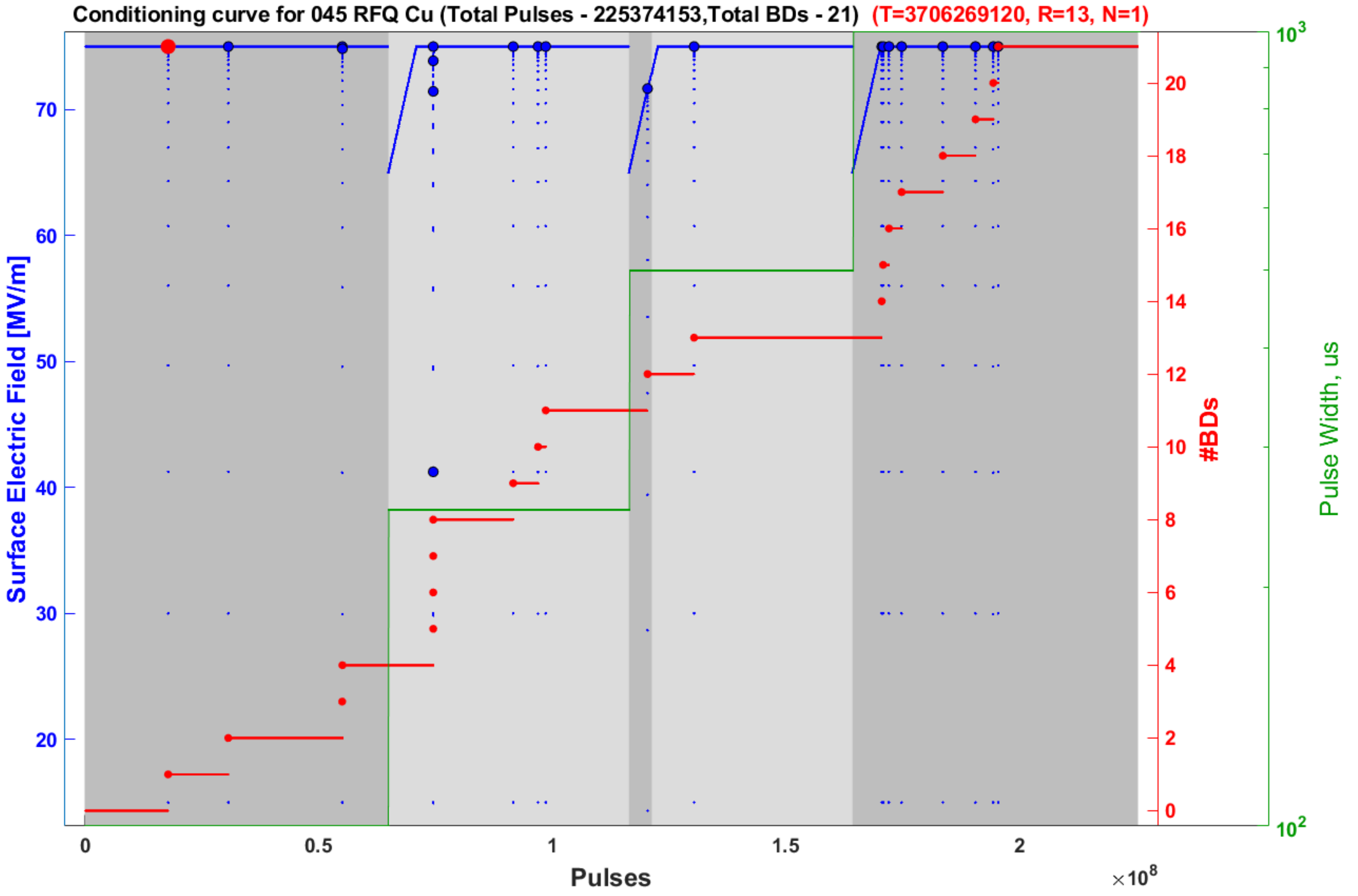
Post Test - SEM Images After Testing (Irradiated Cu)



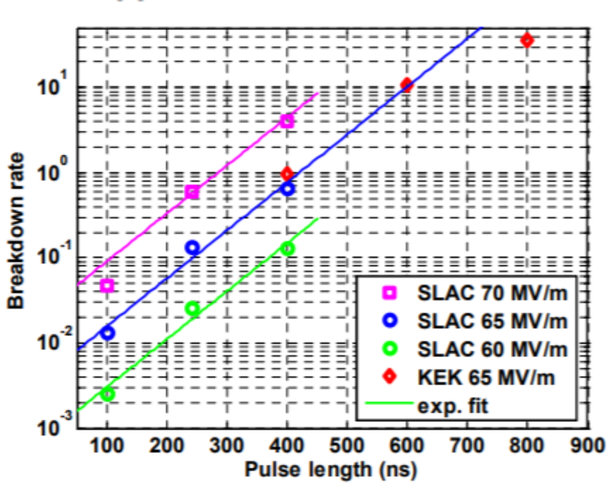


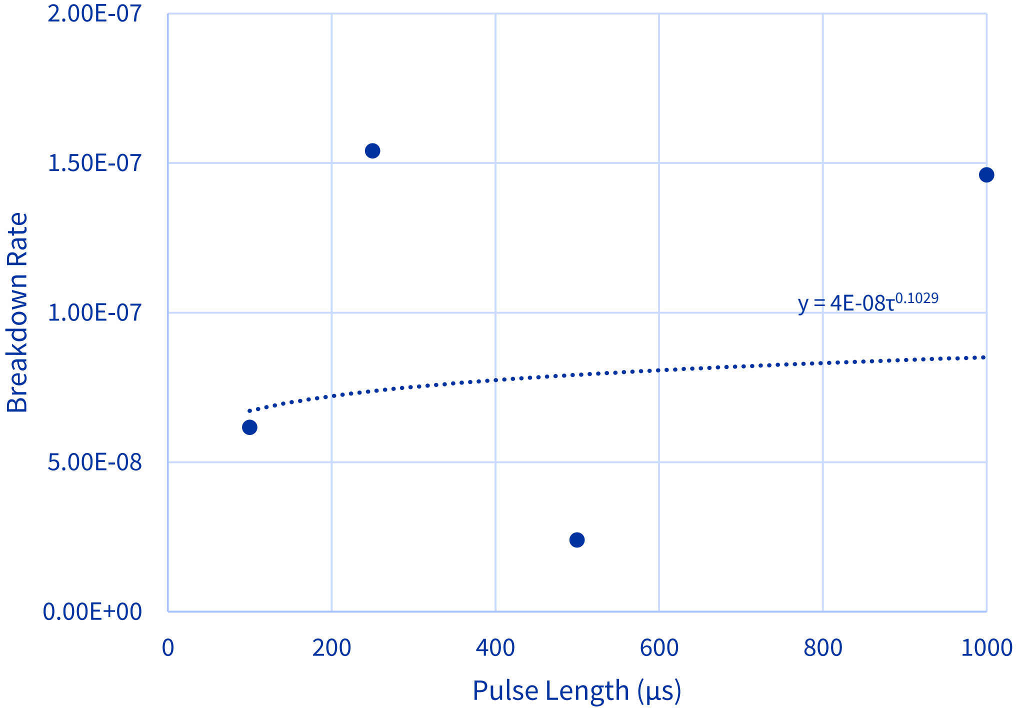
Images - Ana Teresa Perez Fontenla & Catarina Serafim (CERN)

Pulse Length Dependence in the 1us to 1ms range



S. Doebert et al., in Proceedings of the 21st Particle Accelerator Conference, Knoxville, 2005 (IEEE, Piscataway, NJ, 2005), p. 372.





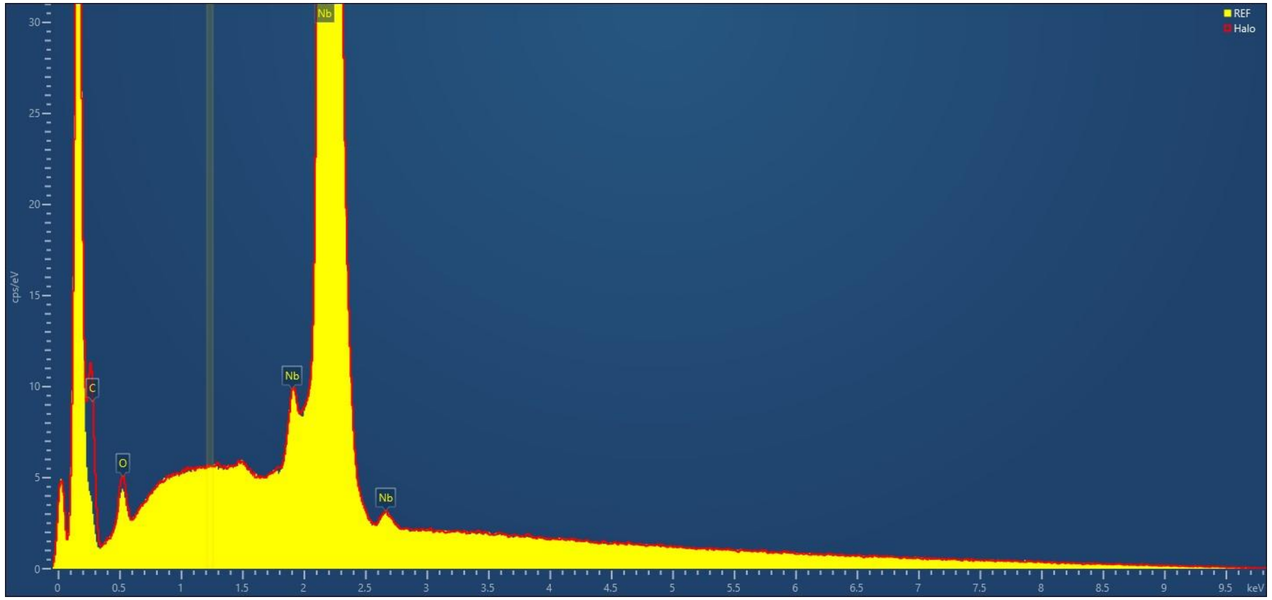
For small pulse lengths (50-800ns) the dependence is τ^5

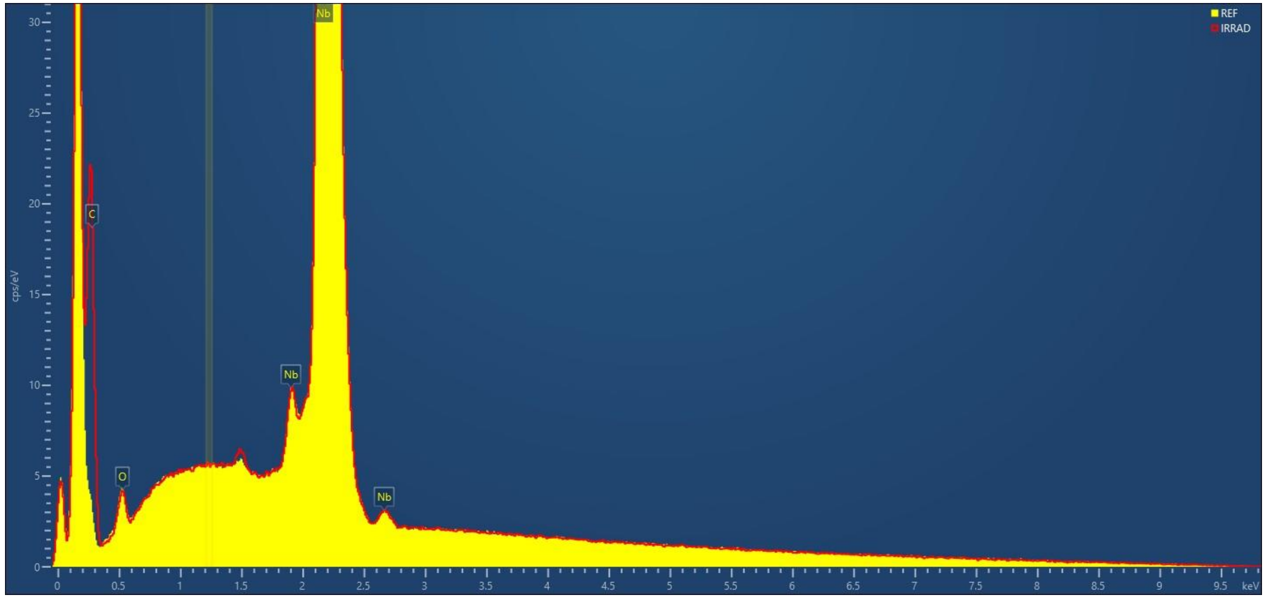
Niobium Tests

Irradiated Niobium

- 2 irradiation spots due to issues with measuring current during the first attempt.
- No physical changes to the surface from irradiation (e.g. no blisters or melting).
- Increased amounts of carbon in the halo and further increase the irradiated areas.
- Possibly cutting fluid contamination causing the discoloration during irradiation

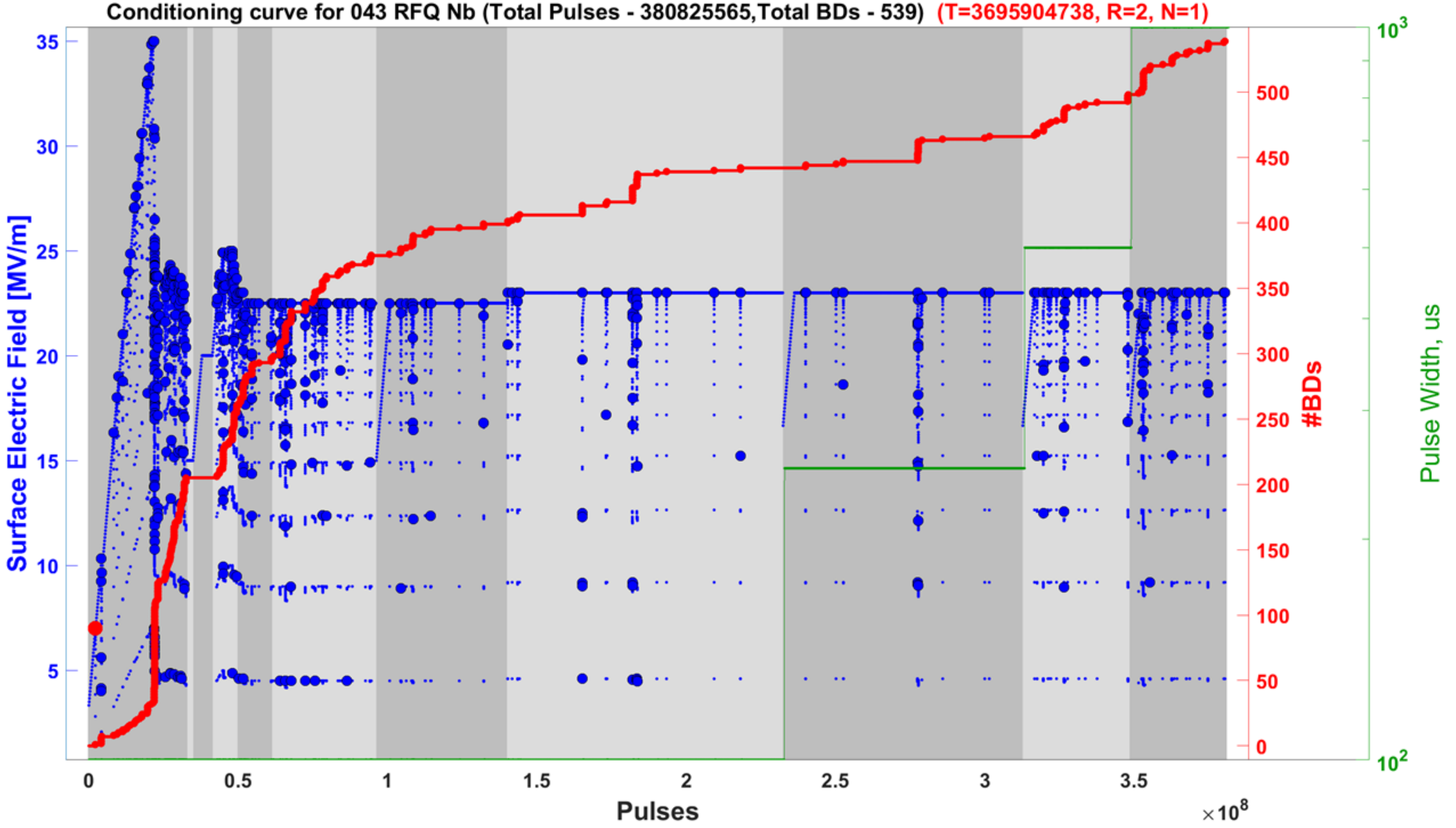
	REF	HALO	IRRAD
Element		Wt%	
C	2.7	10.4	18.9
O	1.0	1.4	0.9
Nb	96.3	88.2	80.2

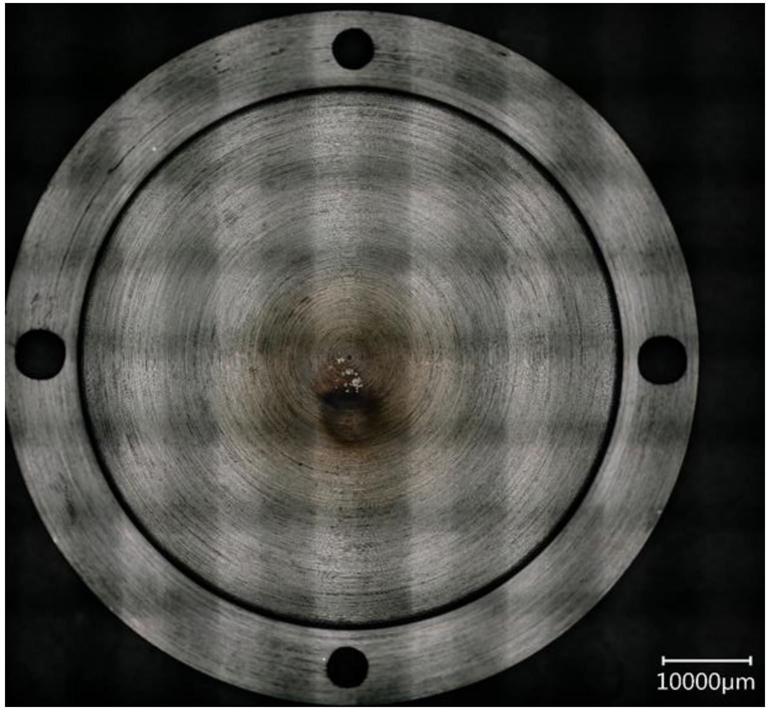




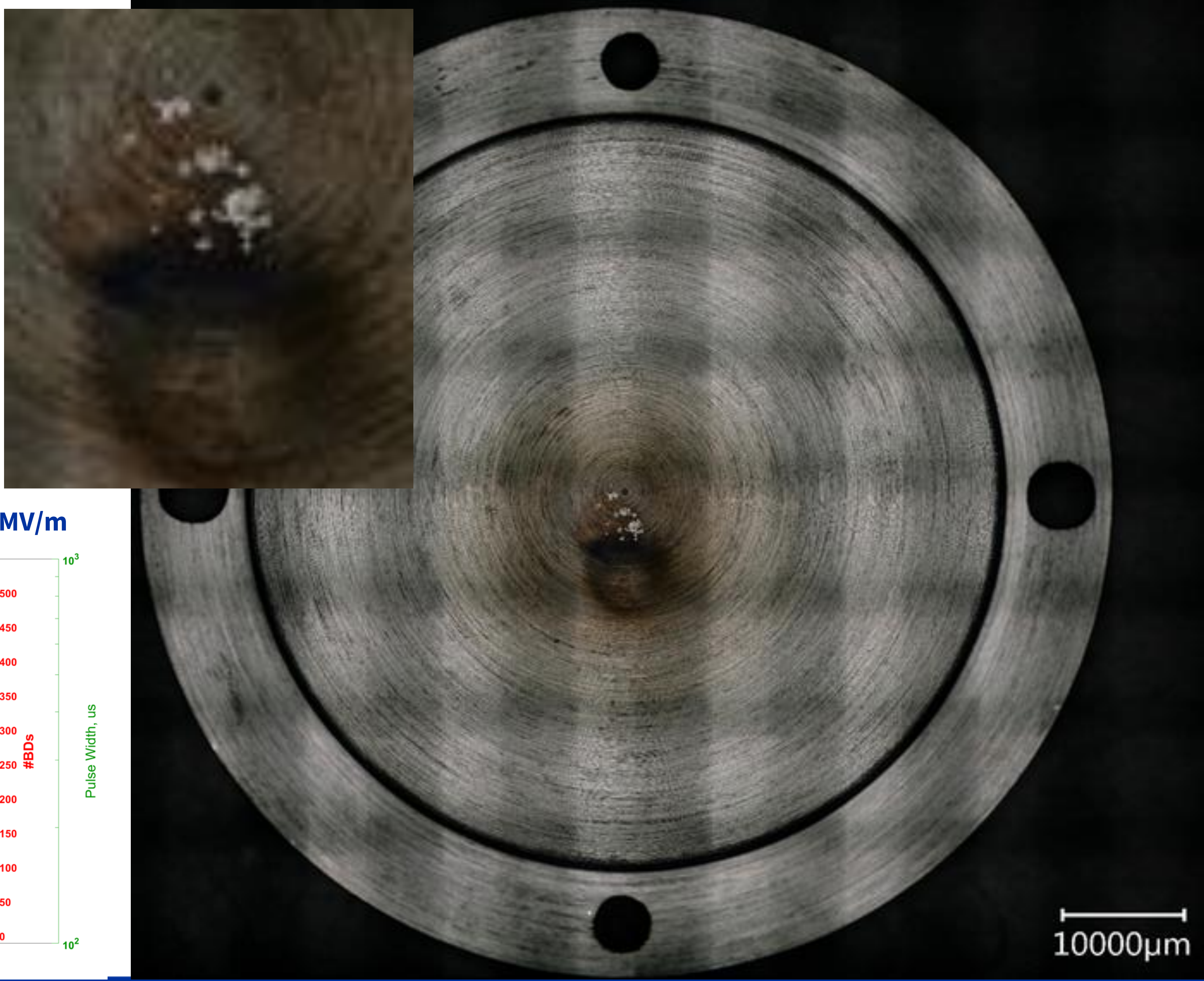
Irradiated Niobium

Max stable E-Field – 23MV/m

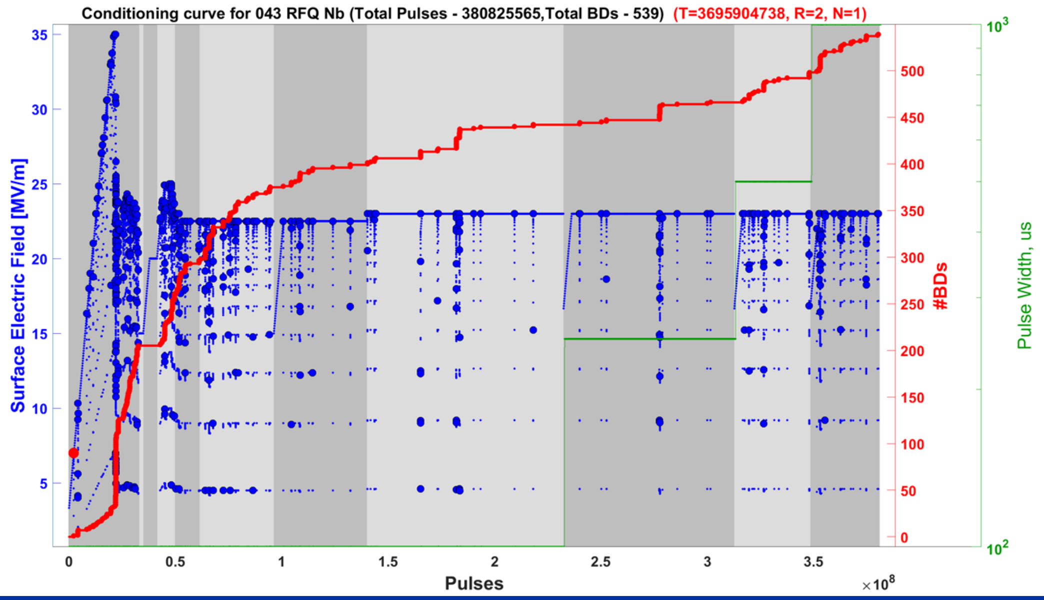




Irradiated Niobium



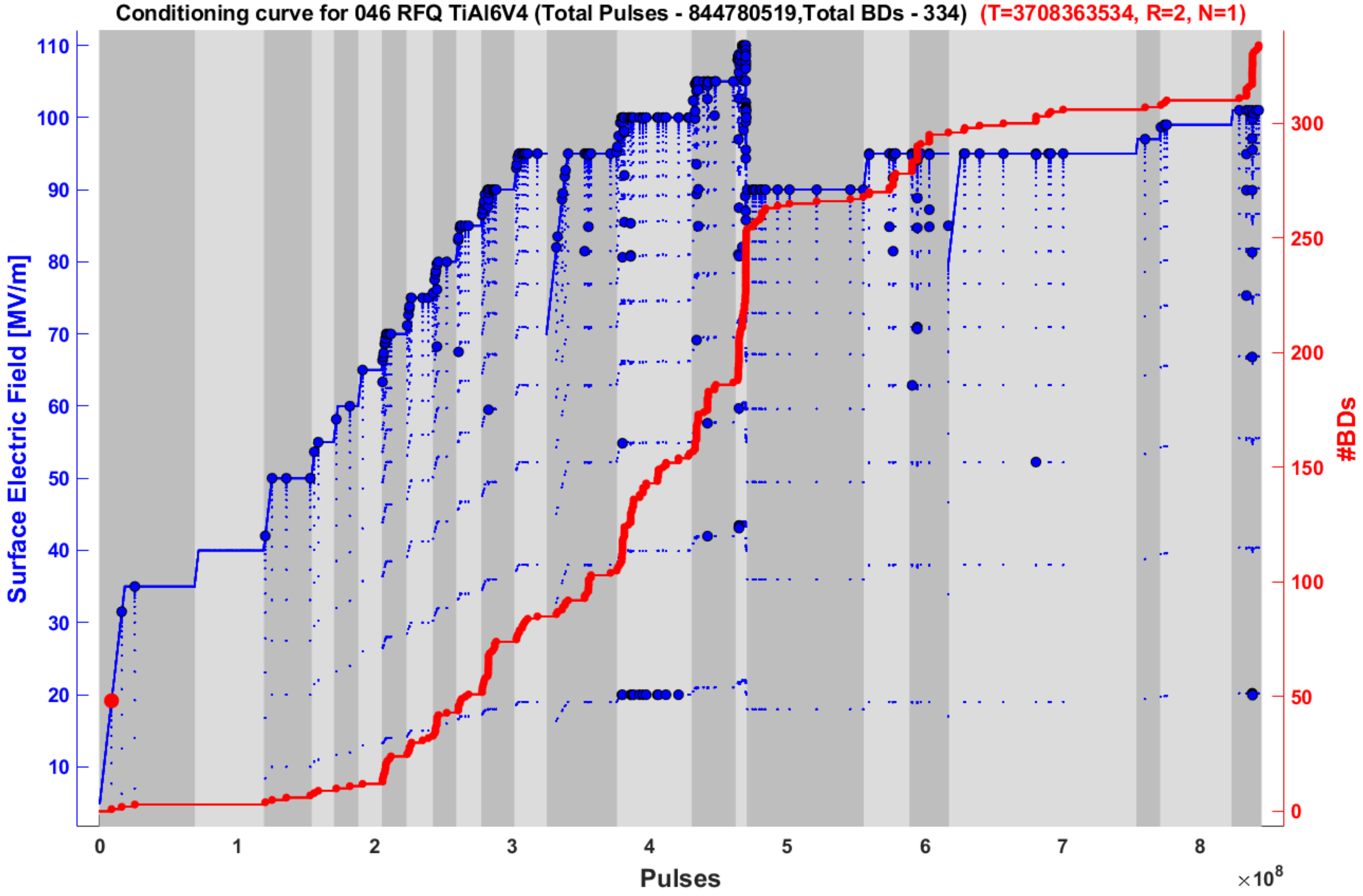
Max E-Field – 23MV/m

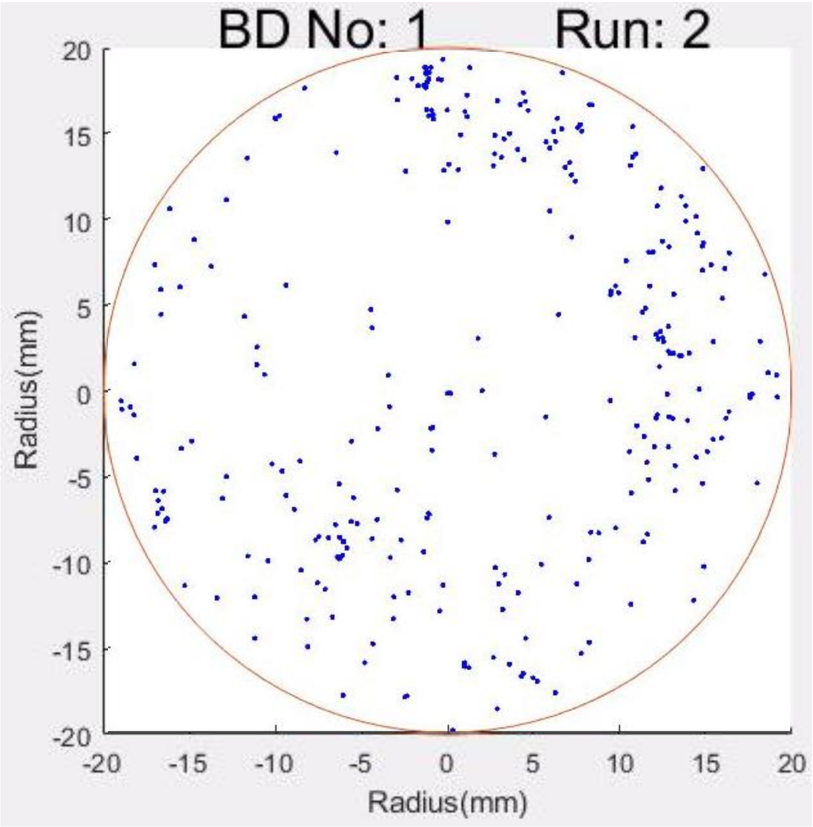


Titanium (TiAl6V4) Tests

Non-Irradiated Titanium (TiAl6V4)

Max E-Field – 105MV/m



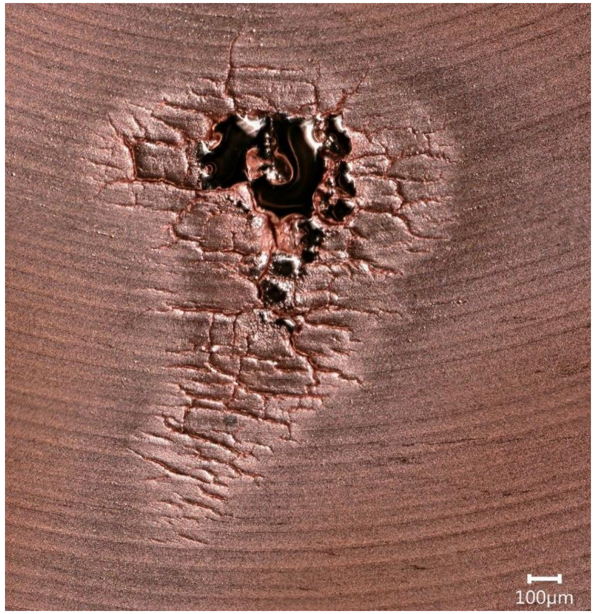


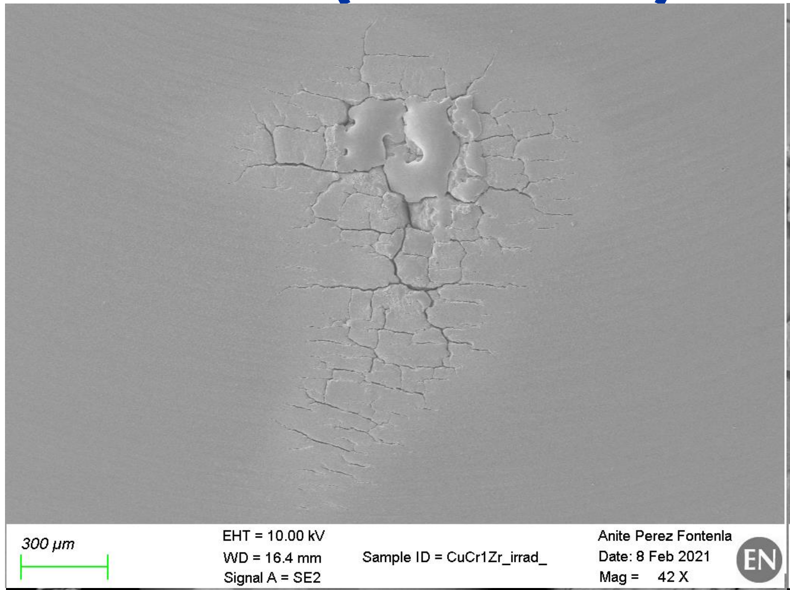
Copper Chromium Zirconium (CuCrZr)

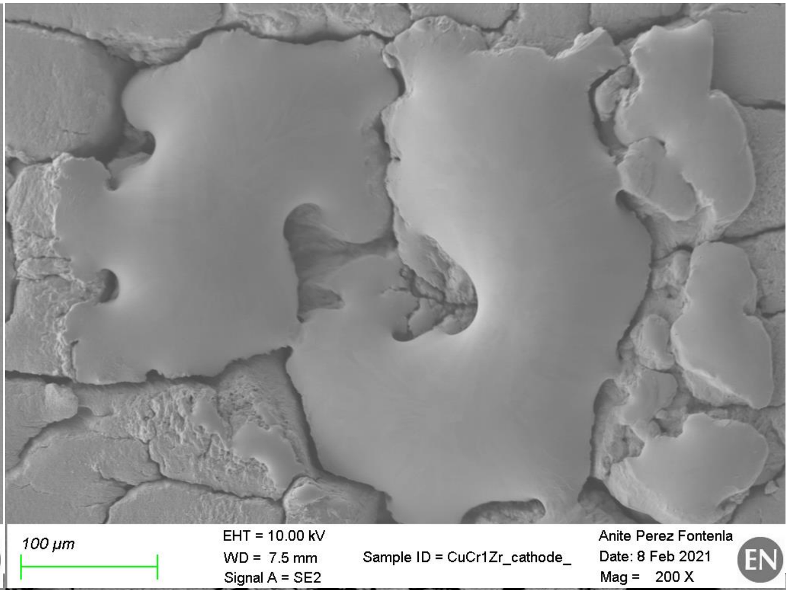
SEM Images after Irradiation (CuCrZr)

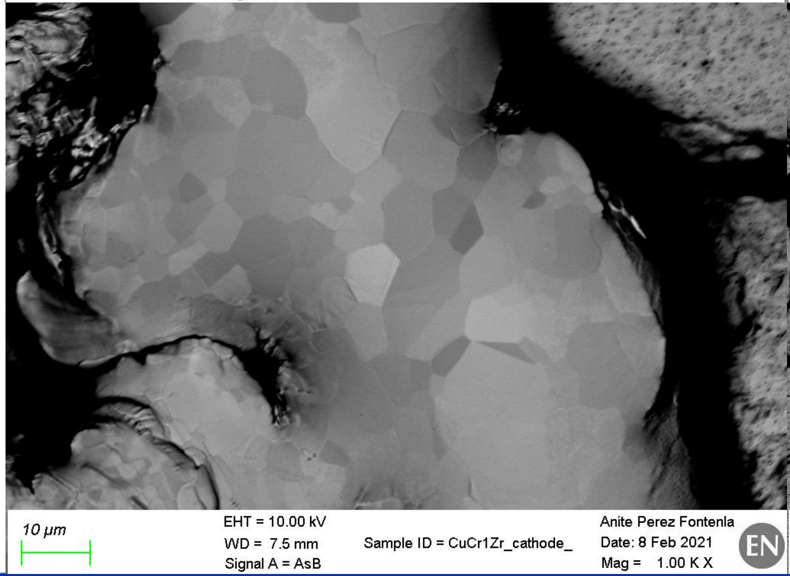
- Melting in the area of the beam spot during irradiation
- No tests done as the electrode was sent for re-machining
- Testing copper disks to determine beam parameters for next irradiation

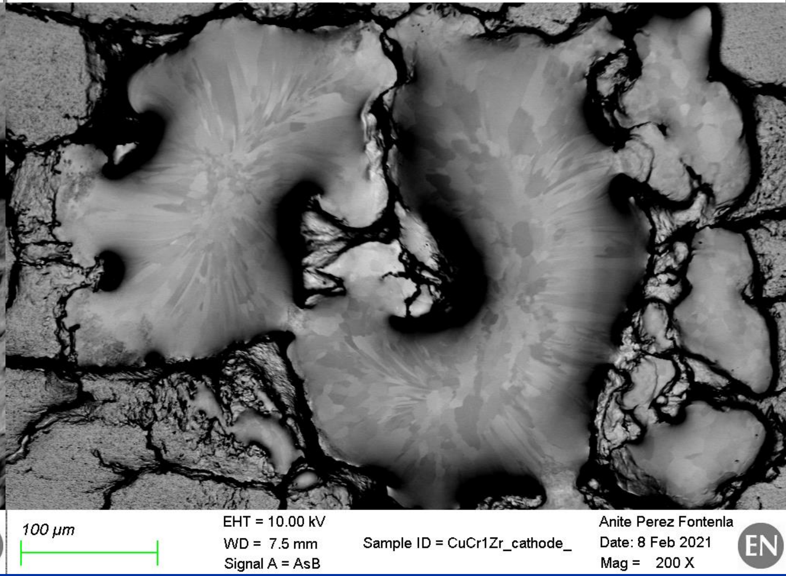
Images - Ana Teresa Perez Fontenla (CERN)



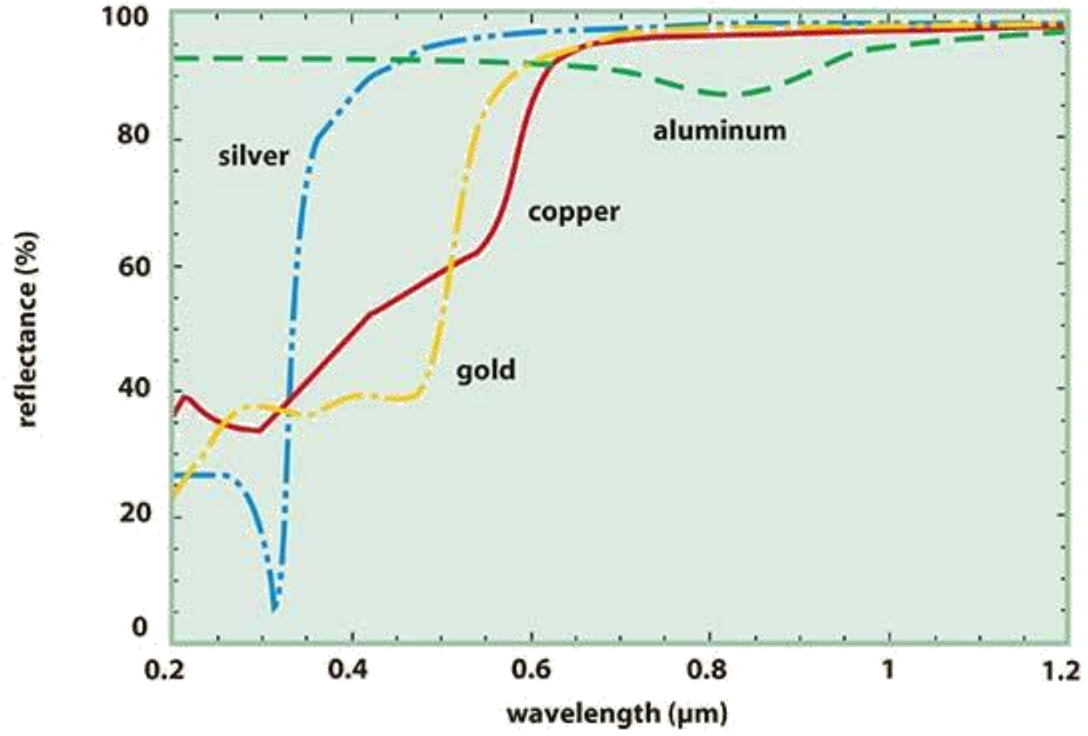




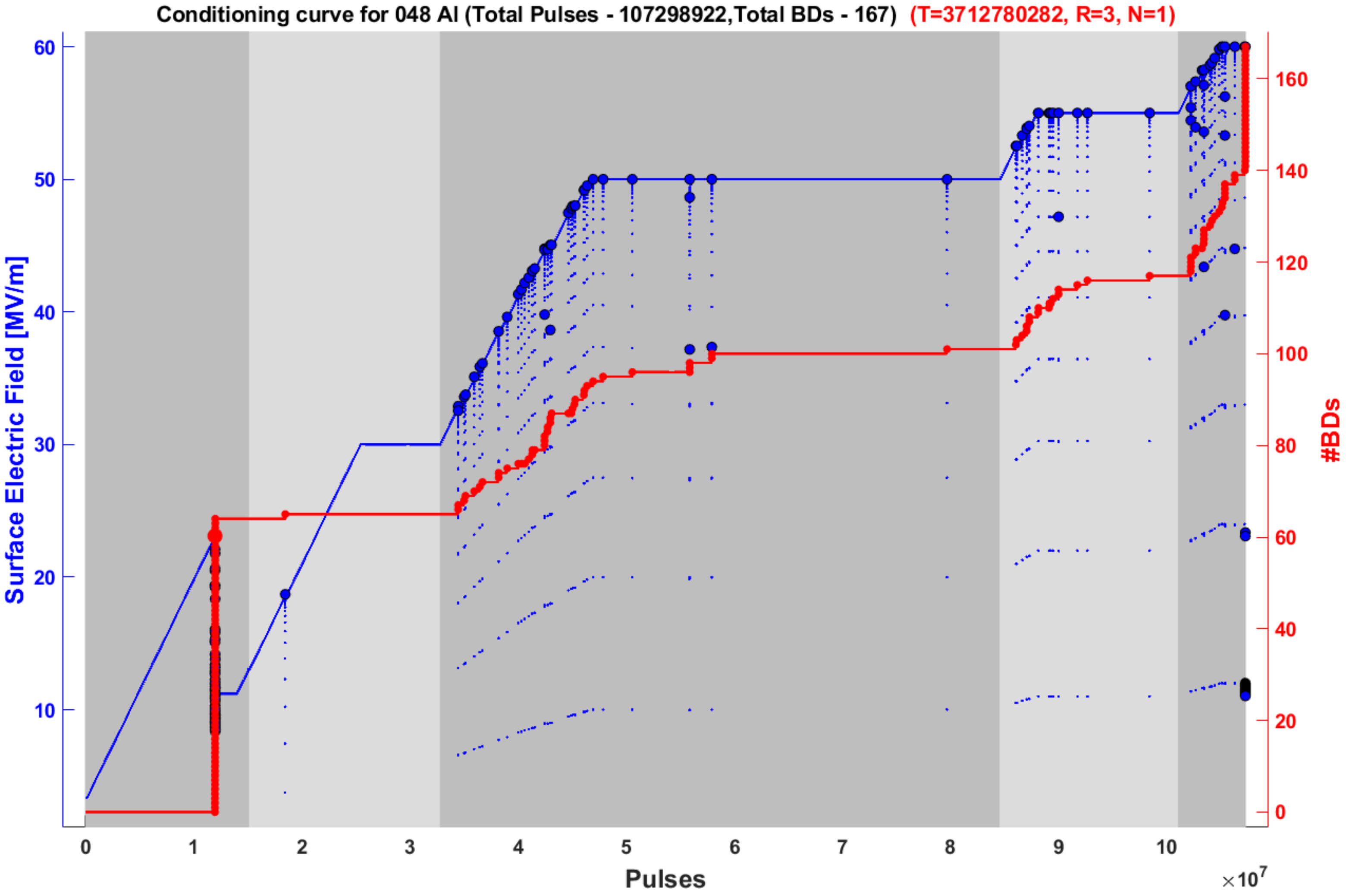


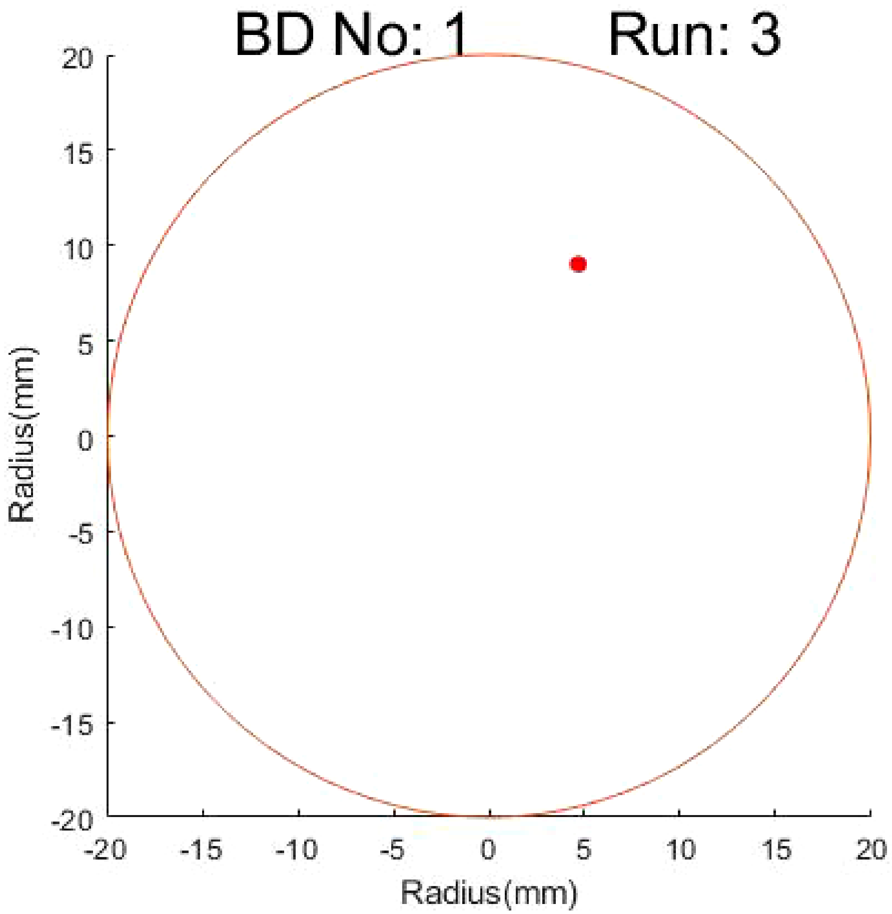


Aluminium for Spectroscopy



Aluminium Conditioning





Results Summary

Material	Non-Irradiated Max E-Field	Comments	Irradiated Max E-Field	Comments
Cu OFE	80MV/m	Tested 2 times	80MV/m	`C` shape beam spot
Nb	8MV/m	Limited by machining	23MV/m	`D` shape beam spot (possible contamination)
TiAl6V4	105MV/m		-	To be Irradiated
CuCrZr	-	To be tested	-	Melted - To be Irradiated
Ta	-	To be tested	-	To be tested
CuBe2	-	Machining	-	Machining

Results Summary

- H- Irradiation can cause blisters in pure copper that cause additional breakdowns during initial conditioning

- Possibly fixing defects during conditioning allowing it reach similar voltages - this differs from the RFQ with constant irradiation during operation

- Holding at intermediate voltages reduces probability of clusters and allows observations of decay in BDR before increasing field

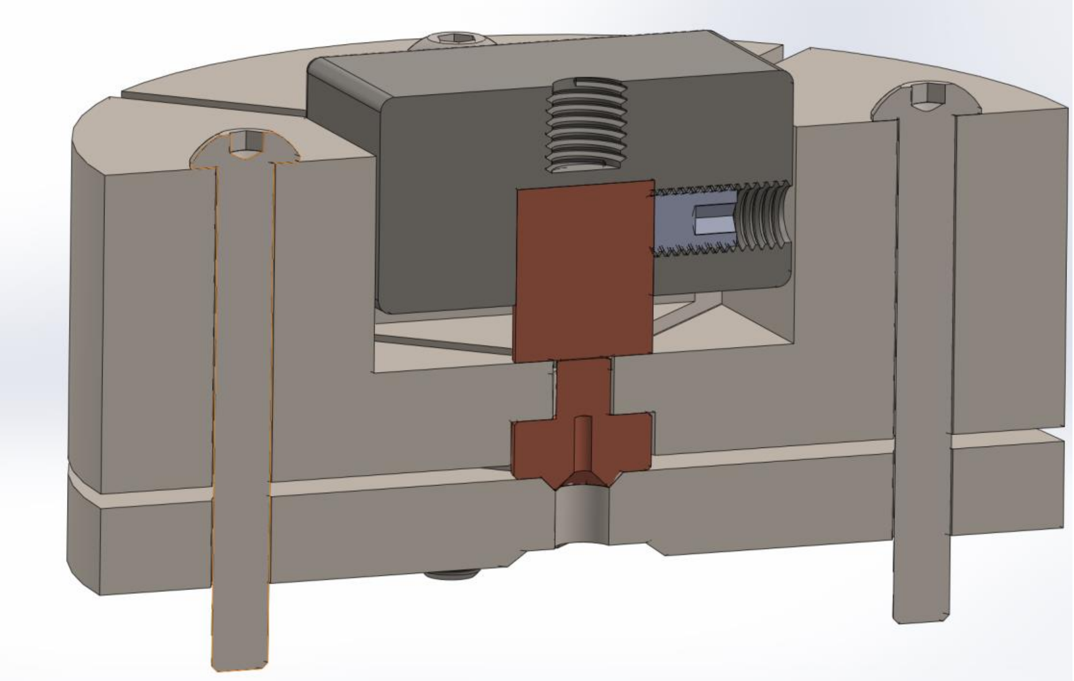
- Areas around the beam spot with higher carbon and H-neutrals also cause breakdown clusters

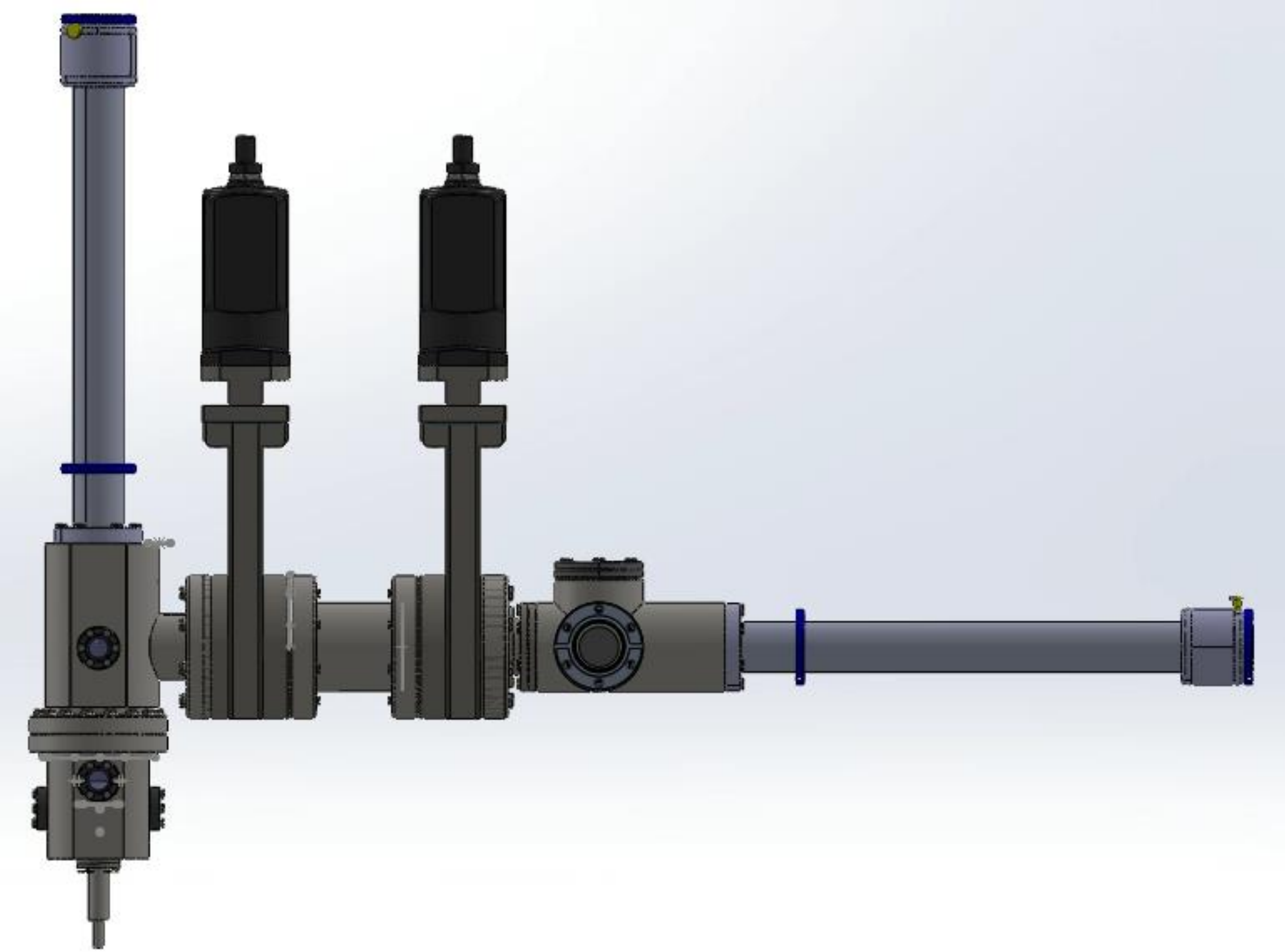
- Irradiation of niobium does not produce blisters but appears to cause breakdowns

- Initial tests of titanium allow for significantly higher E-fields for the same pulse length compared to copper – Irradiation dependence to be tested

Load Lock Pulsed DC System

Load Lock Pulsed DC System (Small Electrode)





Load Lock Pulsed DC System