Pulsed DC Large Electrode System Study of the effects of H- Irradiation on Breakdowns

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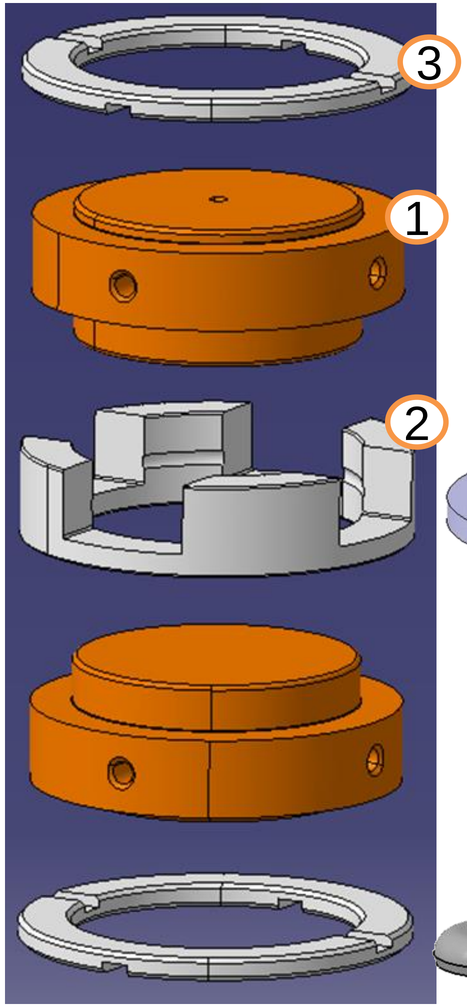
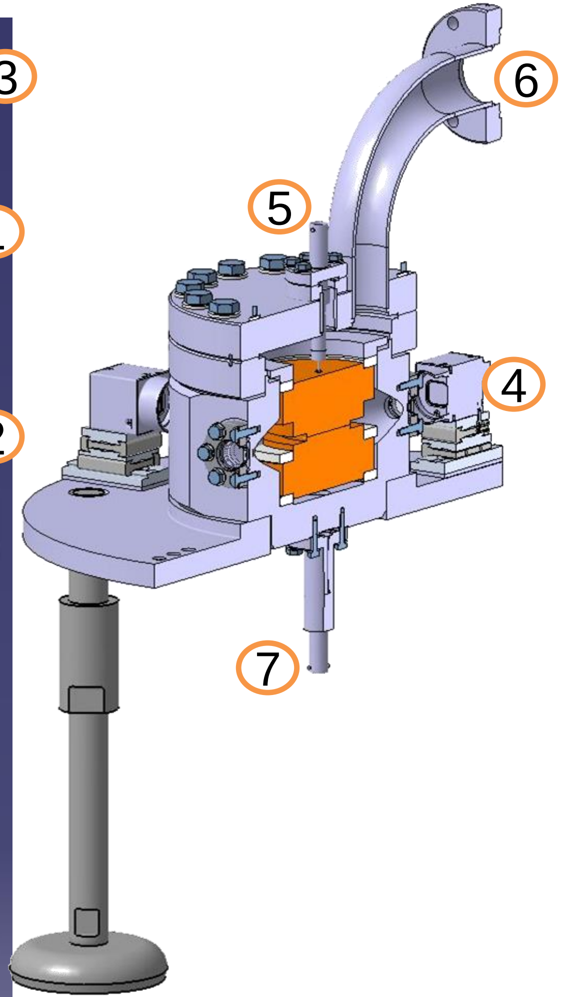
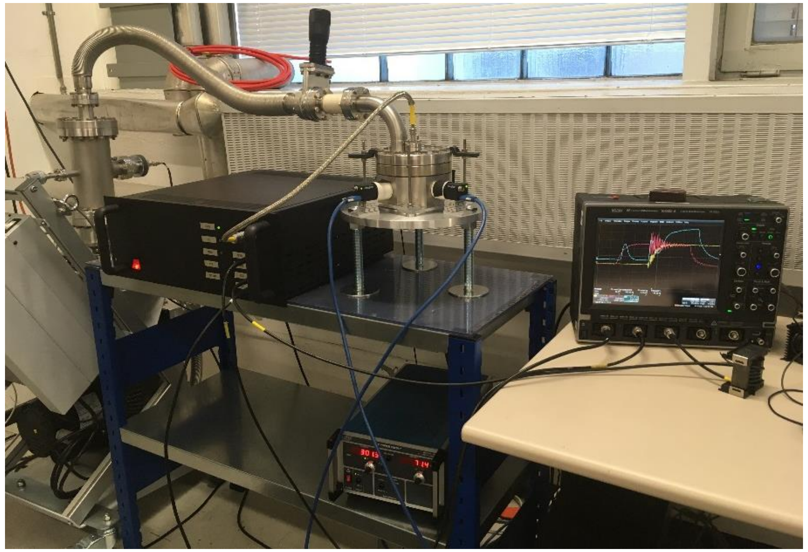
Pulsed DC Large Electrode System Chamber

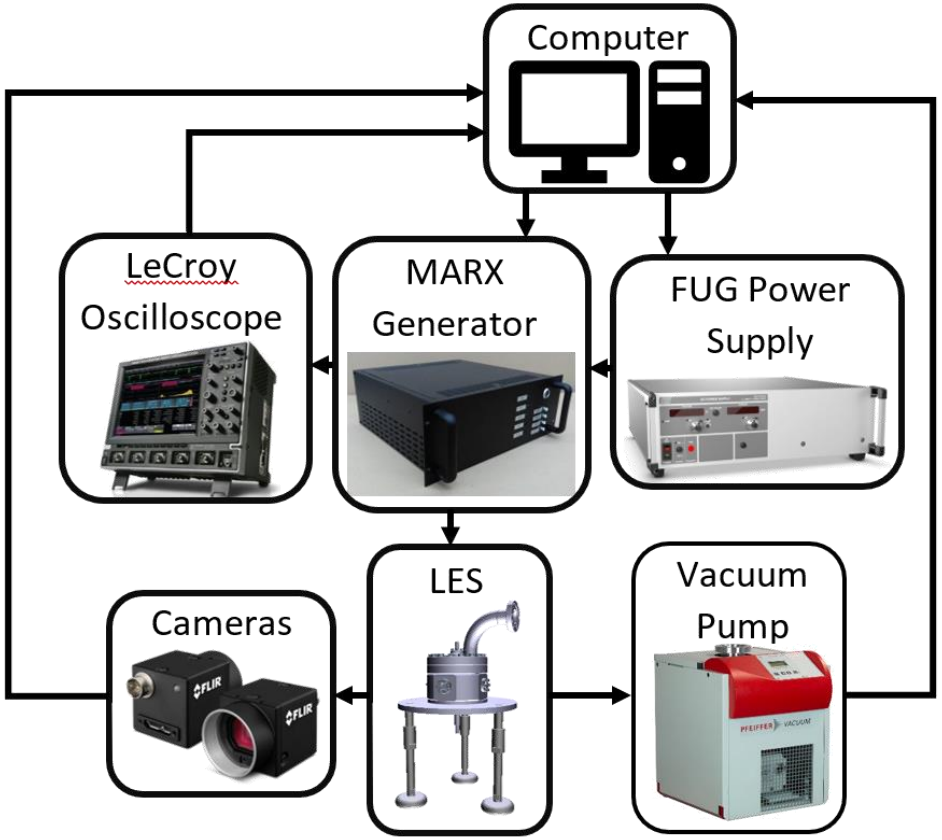
- Configuration
  1. 2 high precision machined electrodes (1µm tolerances)
  2. High tolerance ceramic spacer between electrodes providing a gap of 20µm, 40µm, 60µm, or 100µm
  3. Ceramic spacers to isolate electrodes from the chamber
  4. 4 Windows and 2 perpendicular cameras
  5. High voltage feed though
  6. Vacuum pump output (5x10^-9)
  7. Connection from the bottom electrode to ground (outside of system)





Pulsed DC Large Electrode System Setup

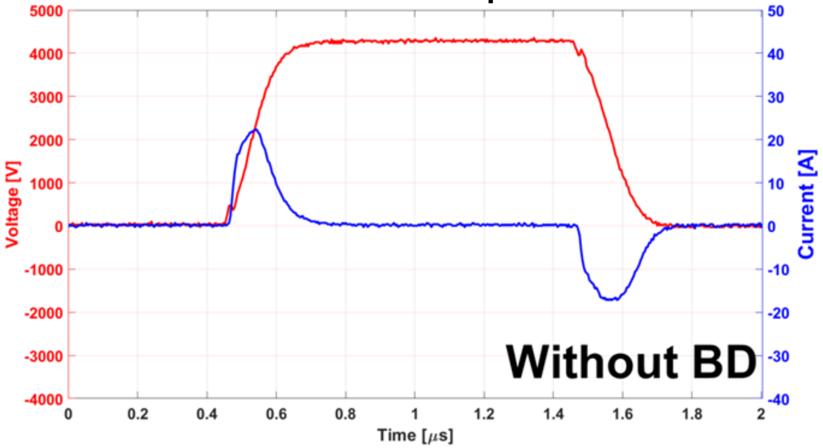


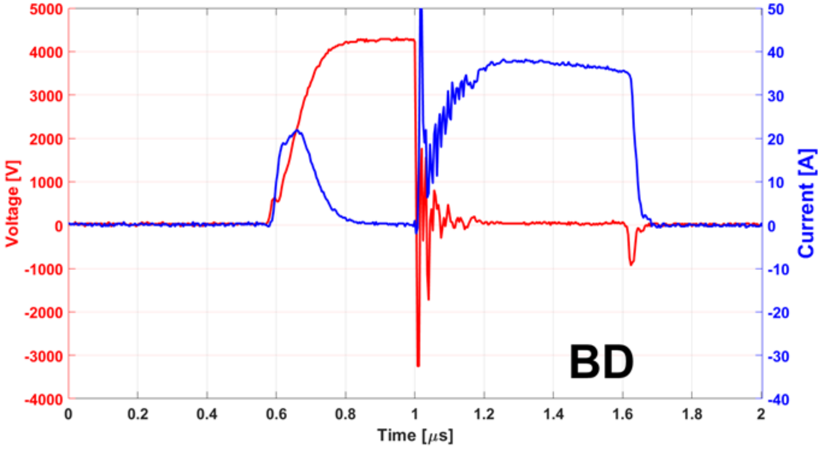


The MARX generator can pulse up to a rep rate of 6kHz and a minimum pulse length of 1μs. Measurements of the voltage and current supplied during a breakdown are measured whenever a breakdown is detected.

Breakdown Detection

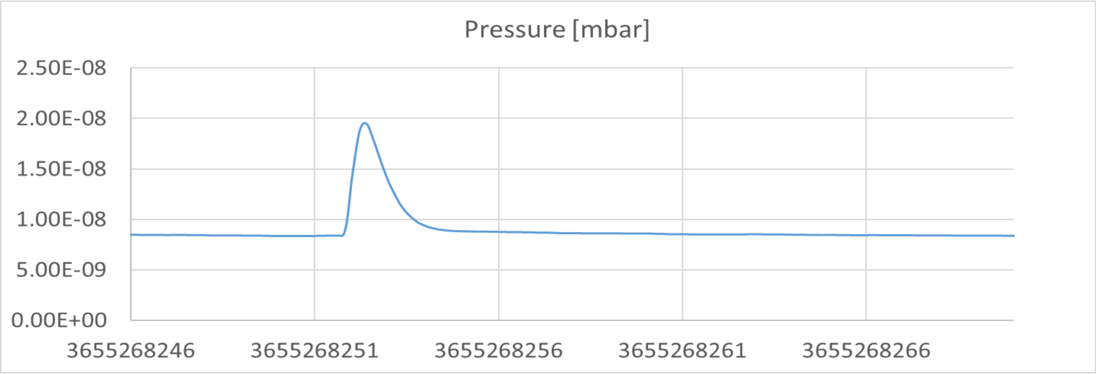
Oscilloscope





Iaroslava Profatilova

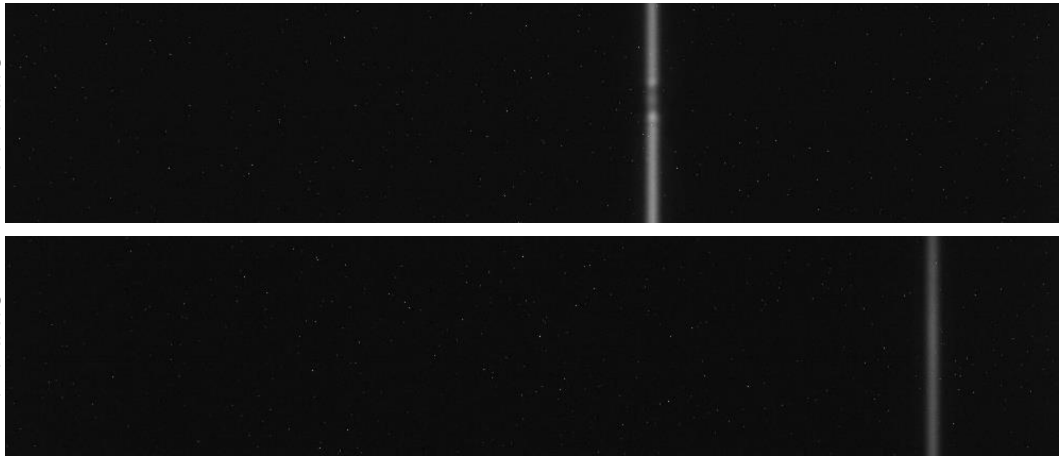
Pressure Increase



Cameras detect light

Camera 1 X-Axis

Camera 2 Y-Axis



System Operations

Conditioning Mode

- Used for conditioning using the same algorithm as the RF Structures (X-Boxes)
- Reduces voltage during conditioning if the maximum breakdown rate is exceeded else increases according to the gain voltage.

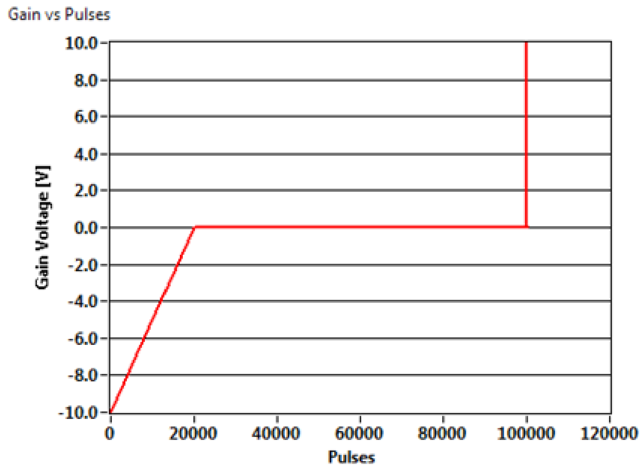
Constant Voltage Operation

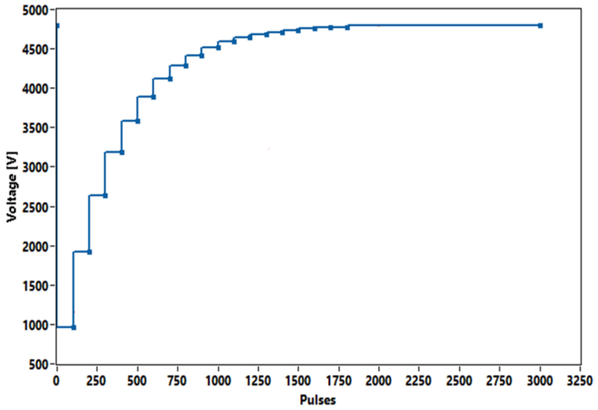
- Keeps the same voltage throughout the run

Recovery from breakdown

- After a breakdown the voltage is reduced to 20% and the increased exponentially (or linear)

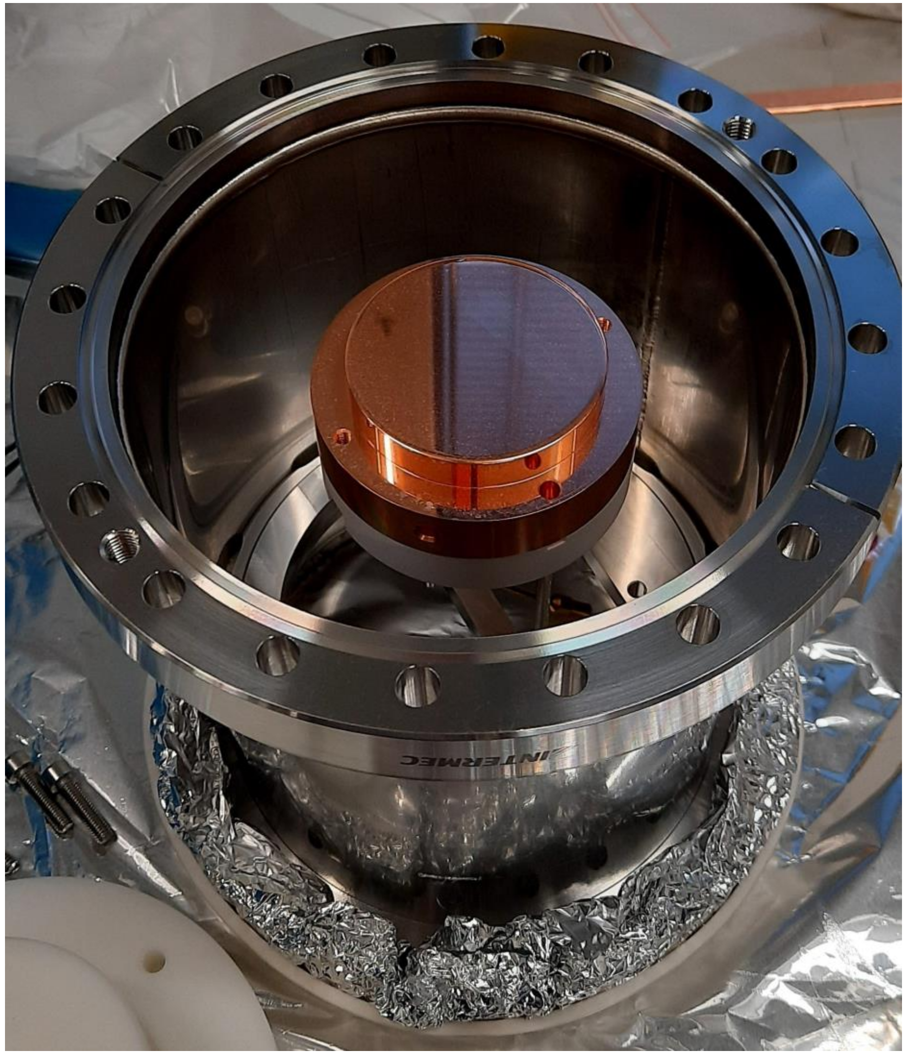
Parameter	Value
Max number of pulses per cycle	100 000
Safe pulses	20 000
Gain voltage at 0	-0.17 MV/m
Gain after timeout	0.17 MV/m
Initial voltage	(~10 MV/m)
Max BDR	1E-5

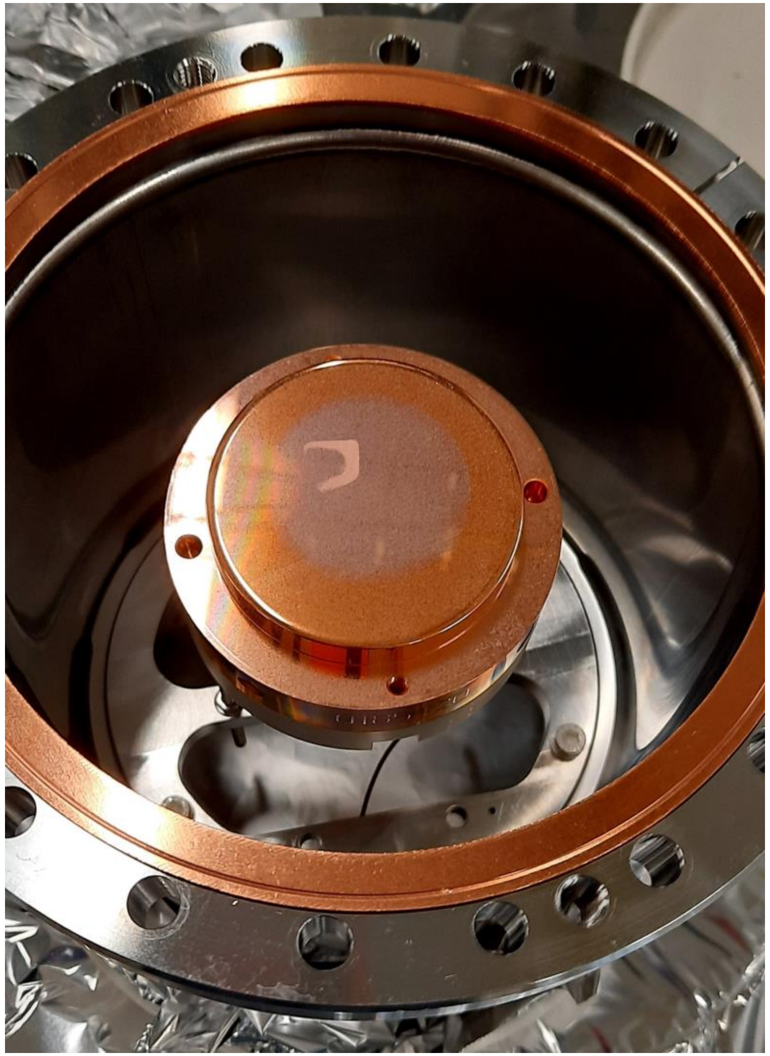




Images - Iaroslava Profatilova

Irradiation Setup





Matching to the RFQ Parameters

- Pulse lengths used for the RFQ up to 900µs and pulse lengths ranging from 100µs to 1000µs in the DC System
- A maximum repetition rate for the RFQ of 2Hz, and starting with a 20Hz repetition rate in the DC System
- Surface electric field of the RFQ of 34MV/m with a vane voltage of 78.27kV
- Due to the differences in the 2 systems there were 2 different ways considered to calculate the voltage required for a field of 34MV/m
  - The first is Electric Field(E) = Voltage(V) / Gap(d)
  - The second is using a normalised field holding calculation that takes into account the change in gap

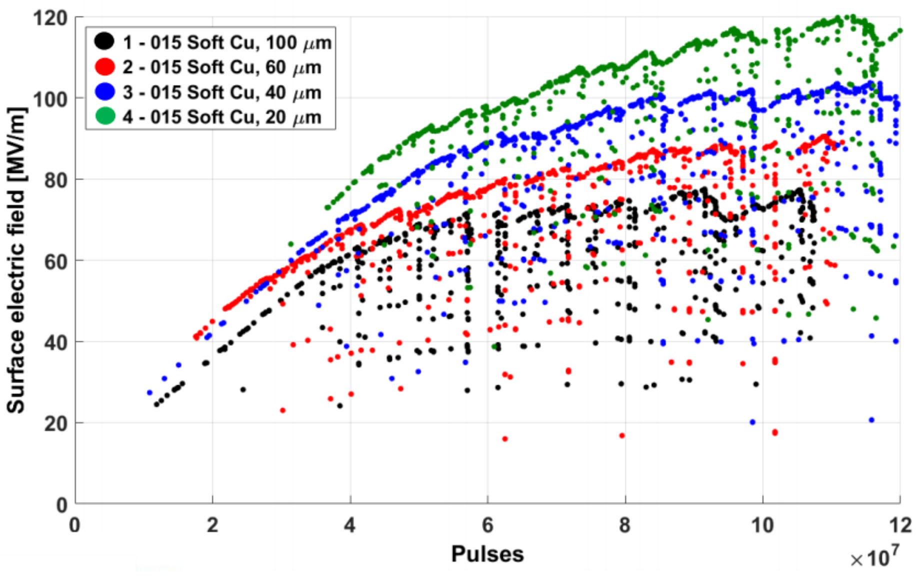
https://cds.cern.ch/record/1004186/files/ab-2006-084.pdf?fbclid=IwAR2VmyEqHN0xaQ4c7BflNKuL-ywWI3Vq88EJ6cNFSiPG9S8NkPjSYFQLx74 – page128

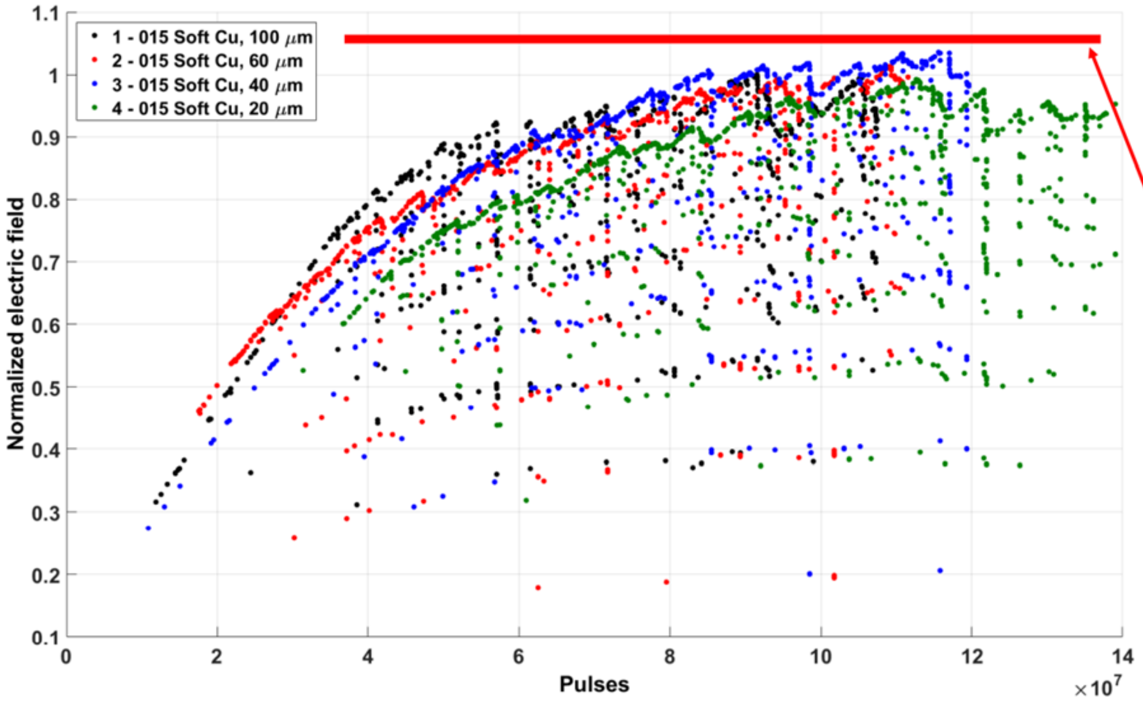
Normalised Field: Including effect of gap distance

$$Normalised\ Field\ Holding = \left(\frac{V}{V_{max}}\right) \times \left(\frac{d_{max}}{d}\right)^{0.72}$$

Making one step further gives the connection: L4-RFQ <-> DC setup

$$E = \frac{V}{d}$$





$V_{max} = 7747\ V$

$d_{max} = 100\ \mu m$

V = 78.3 kV;

Es = 34 MV/m

d = V/Es

=>

NFH = 1.05

Iaroslava Profatilova - https://indico.cern.ch/event/774138/contributions/3507941/attachments/1911936/3160618/7_IProfatilova_MeVArc2019.pdf

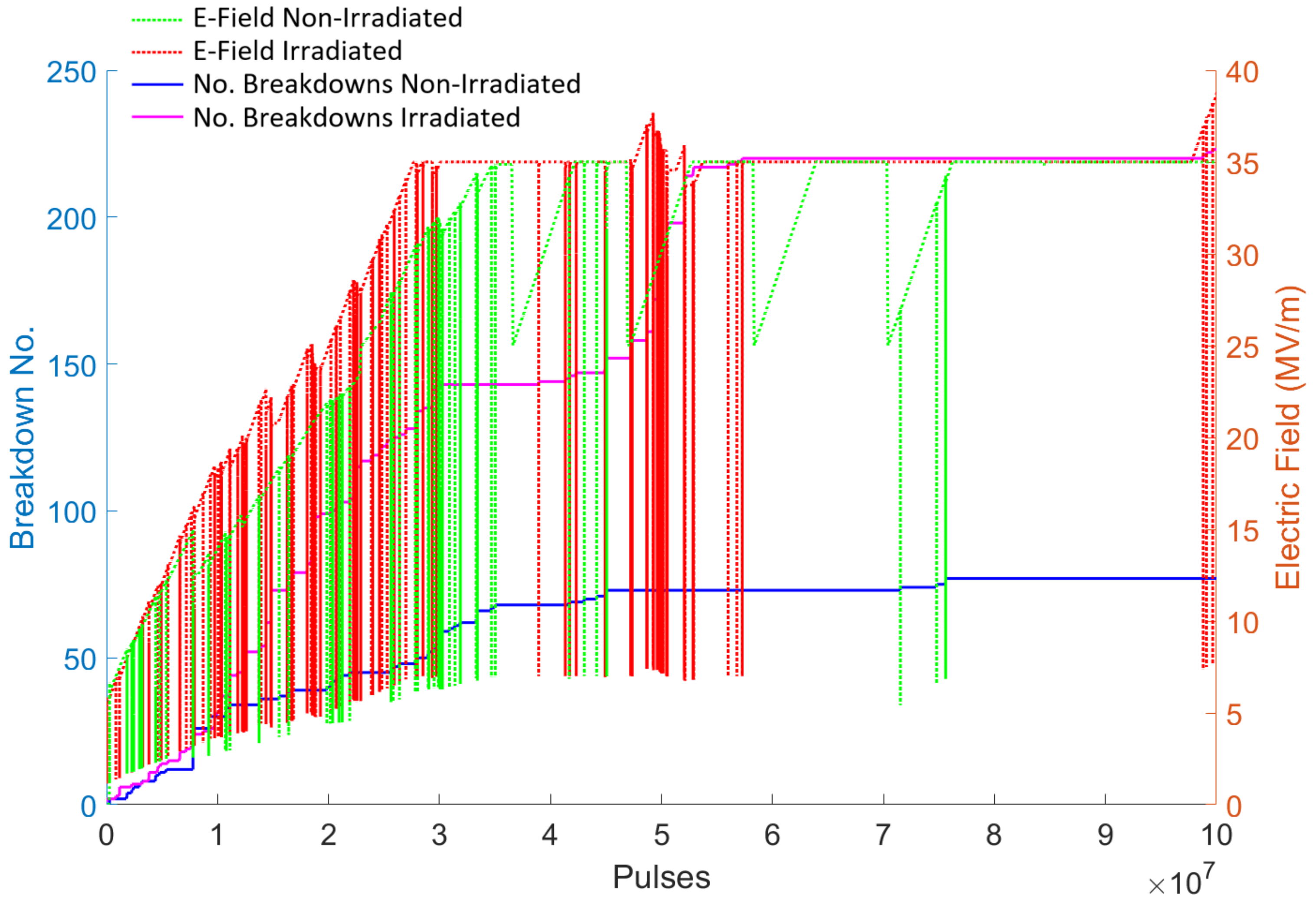
Alexej Grudiev - https://indico.cern.ch/event/925403/contributions/3889048/attachments/2050505/3436872/20200604_WP_RFQ3_design_Introduction.pdf

Normalised Field Holding Calculations

- The surface field in the RFQ is 34MV/m, the target surface electric field for this electrode test was 35 MV/m
- 35MV/m with a gap of 60μm gives a voltage of 2100V and a normalised field holding of 0.3915
- The normalised field holding of the RFQ is 1.0563 giving a voltage of 5664.9V and surface electric field for a 60μm gap of 94MV/m
- Assuming the gap size scaling holds we would need to reach a field of 94MV/m in the Pulsed DC System
- We first went to a field of 35MV/m then attempted to increase to 94MV/m

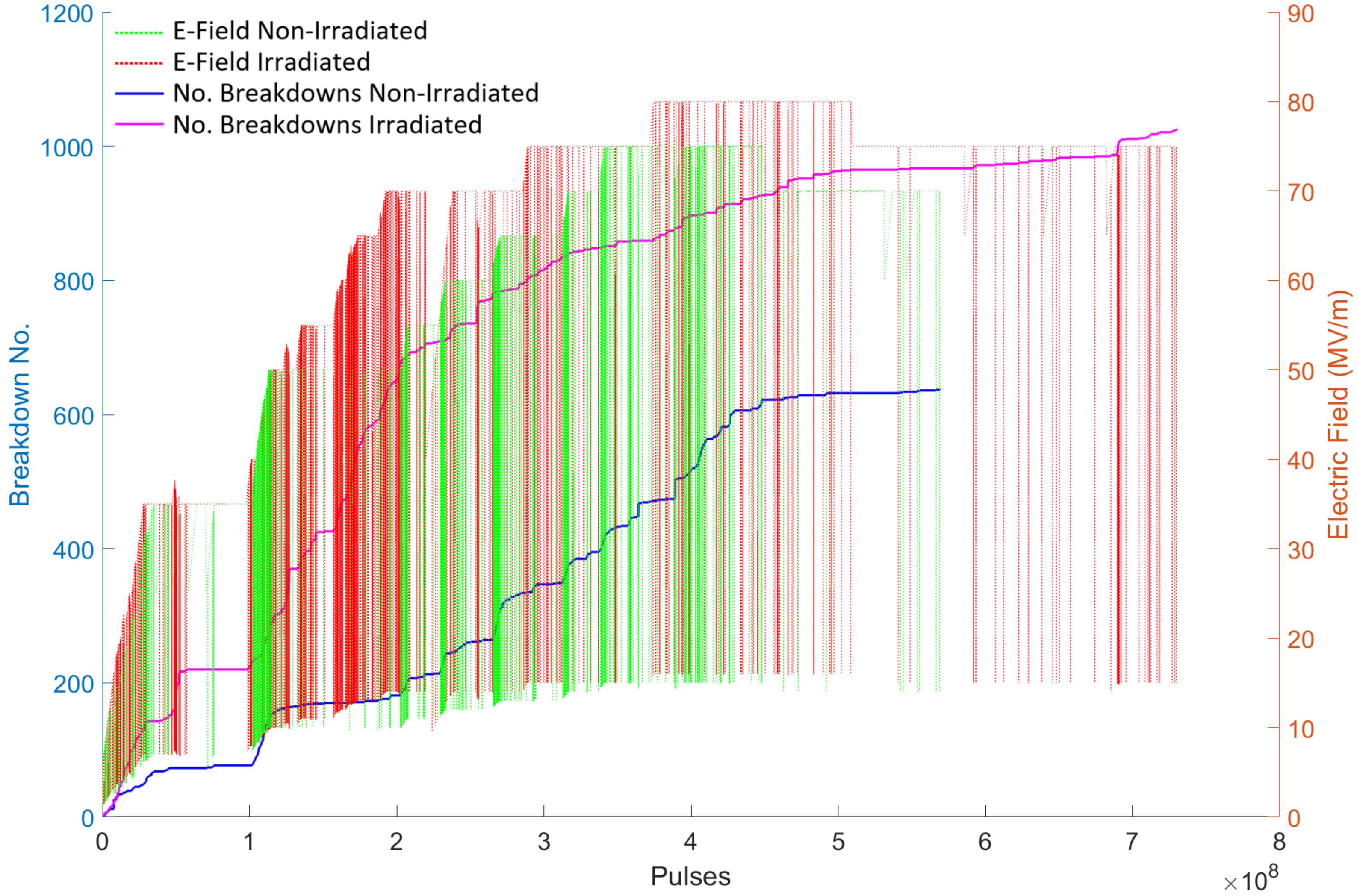
Conditioning Comparison

- Non- Irradiated Initial conditioning up to 35MV/m
  - Pulse Length 100µs
  - Repetition Rate 20Hz
  - Increase Pulse length
- Irradiated Initial conditioning up to 35MV/m
  - Pulse Length 100µs
  - Repetition Rate 100Hz
  - Set target to 50MV/m – cluster of breakdowns

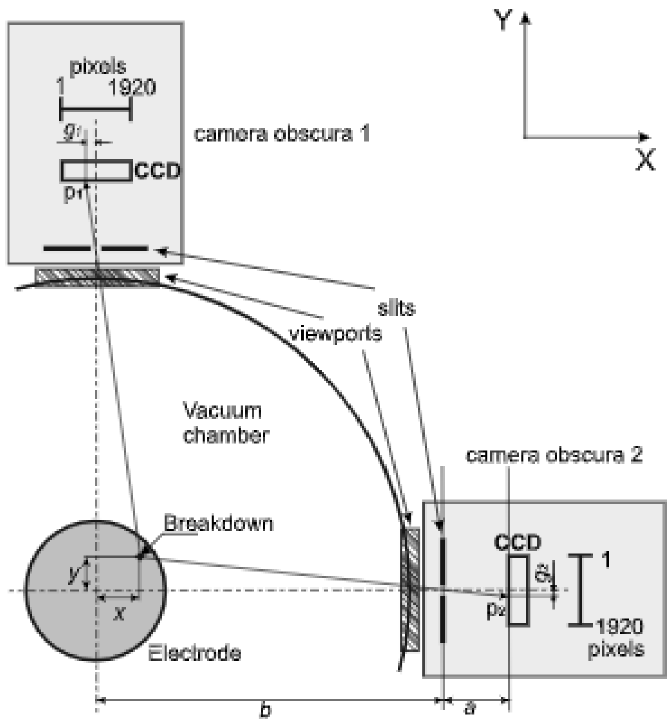


Conditioning Comparison

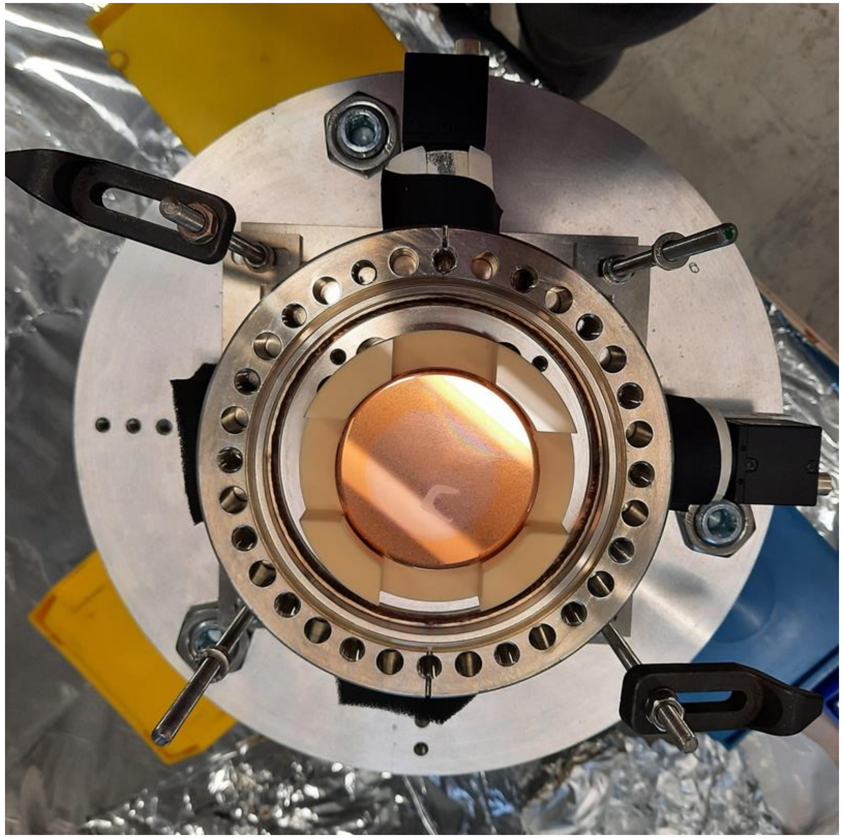
- Non-Irradiated
  - Increase to 50MV/m
    - Pulse Length 100µs
    - Repetition Rate 100Hz
    - Increase Pulse Length
  - Increase in 5MV/m Steps to 75MV/m
  - Increase pulse length at 70MV/m
- Irradiated
  - Increase to 40 then 50
  - Target as 55MV/m – cluster of breakdowns
  - Increase in 5MV/m Steps to 80MV/m
  - Increase pulse length at 75MV/m

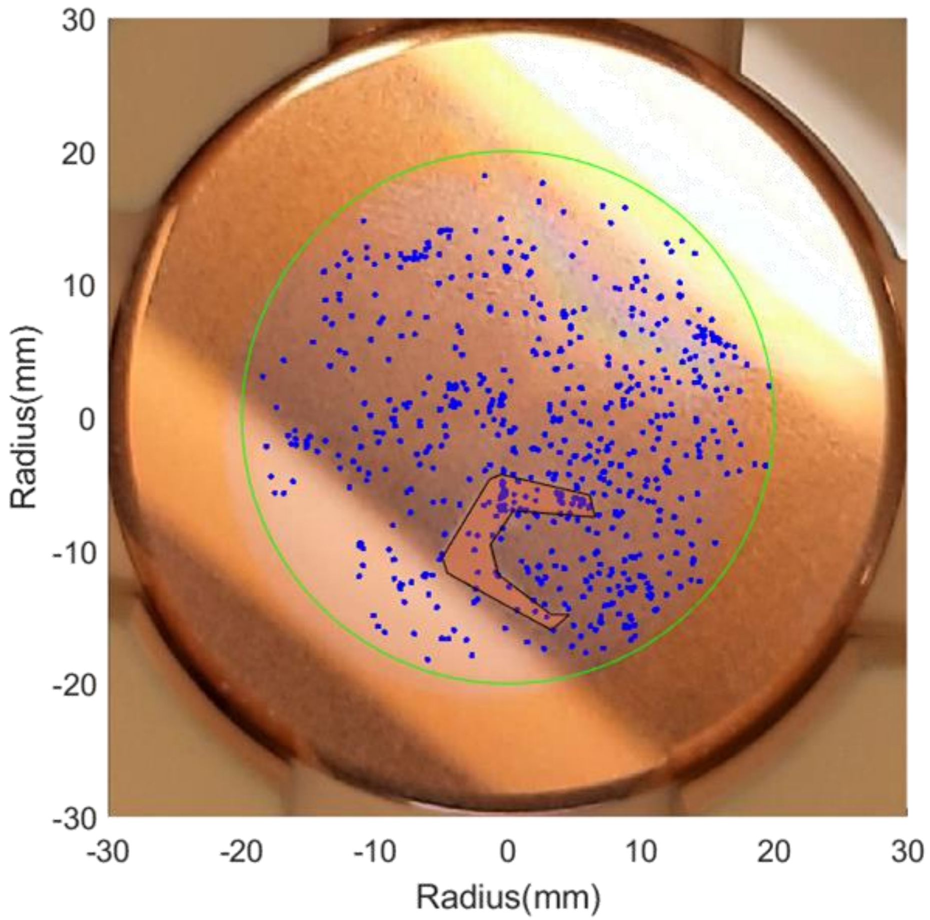


Breakdown Localisation



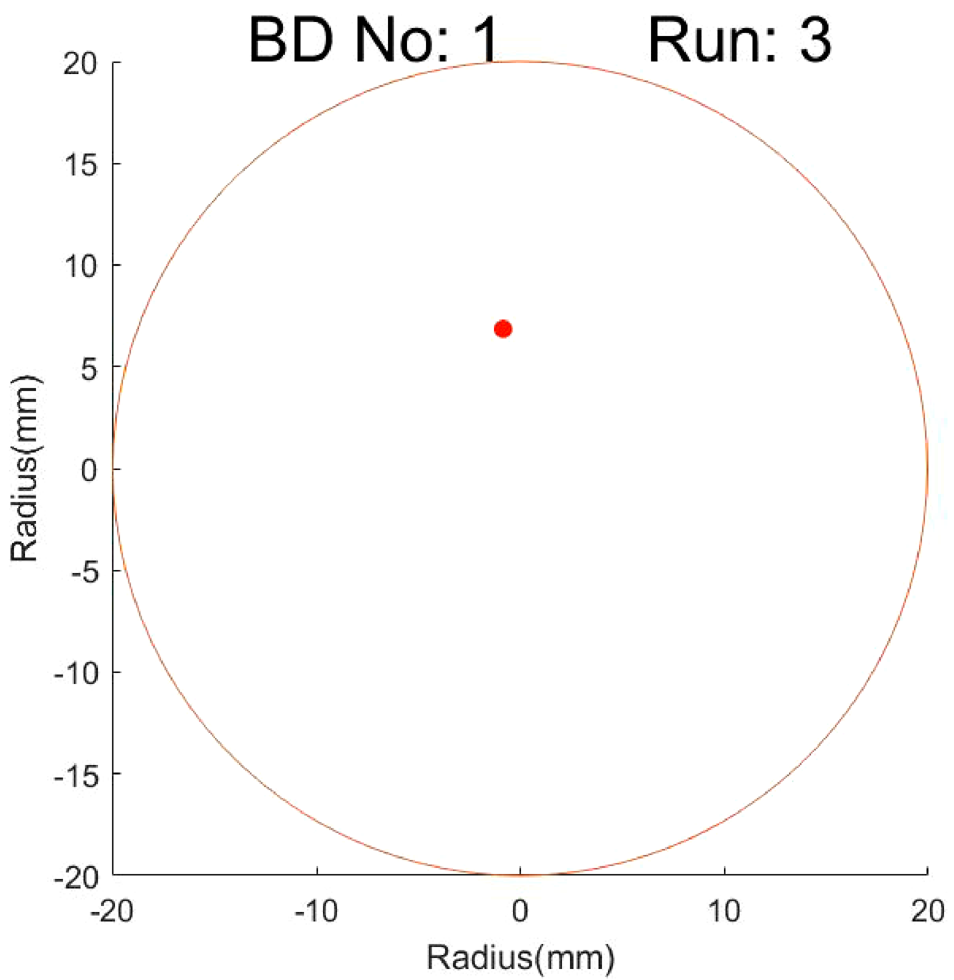
(2019). Breakdown localisation in a pulsed DC electrode system. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 953. 10.1016/j.nima.2019.163079.



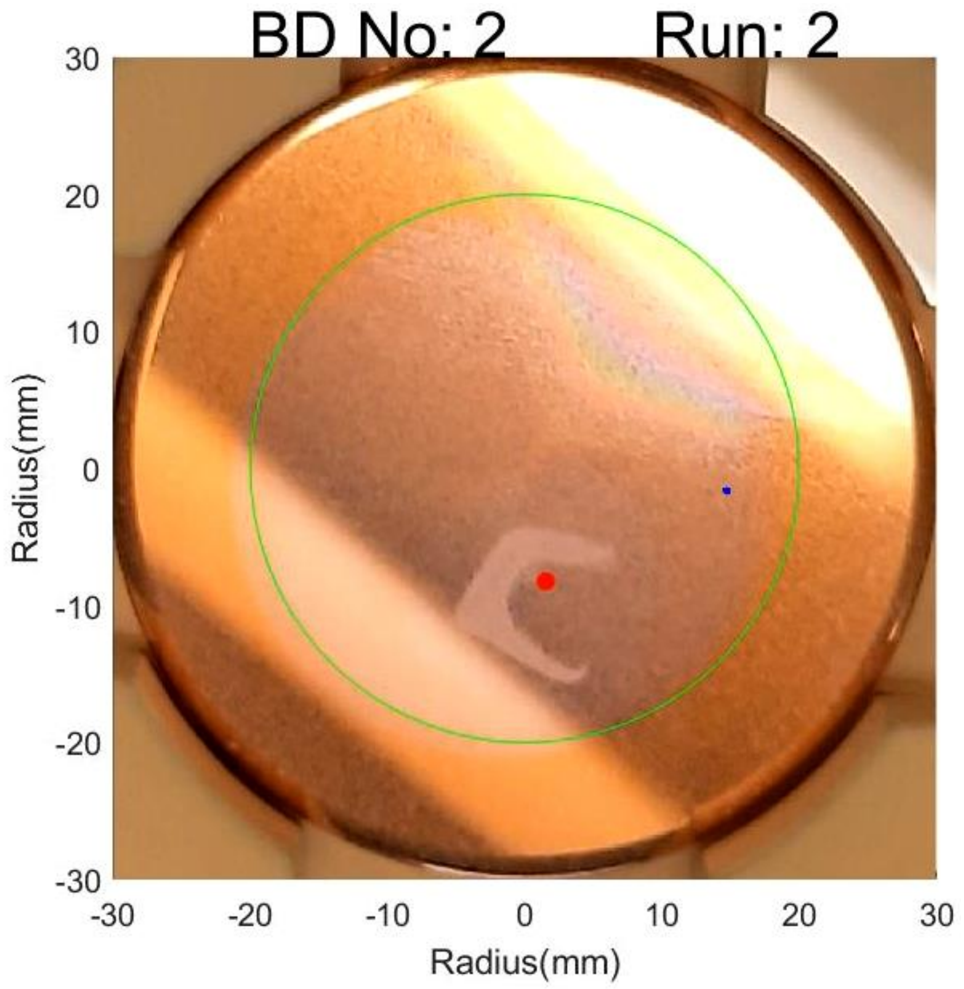


Breakdown Locations

Non-Irradiated Electrode

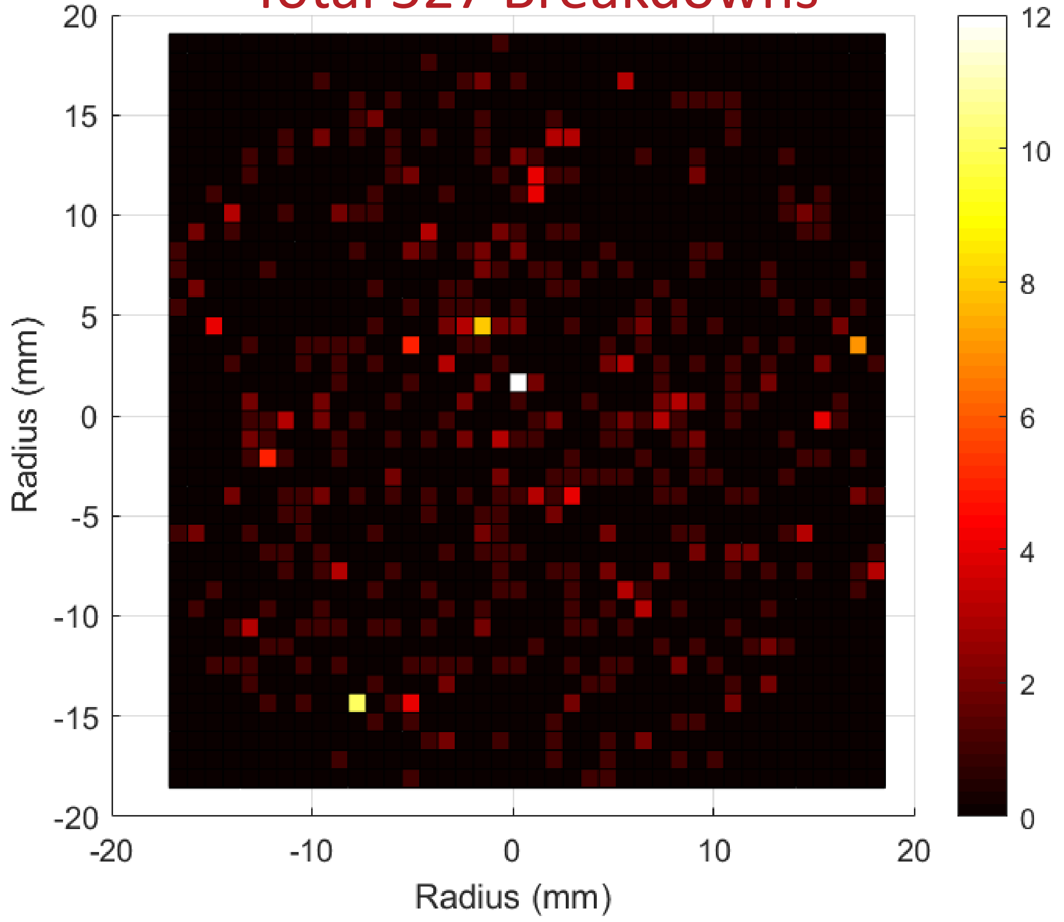


Irradiated Electrode

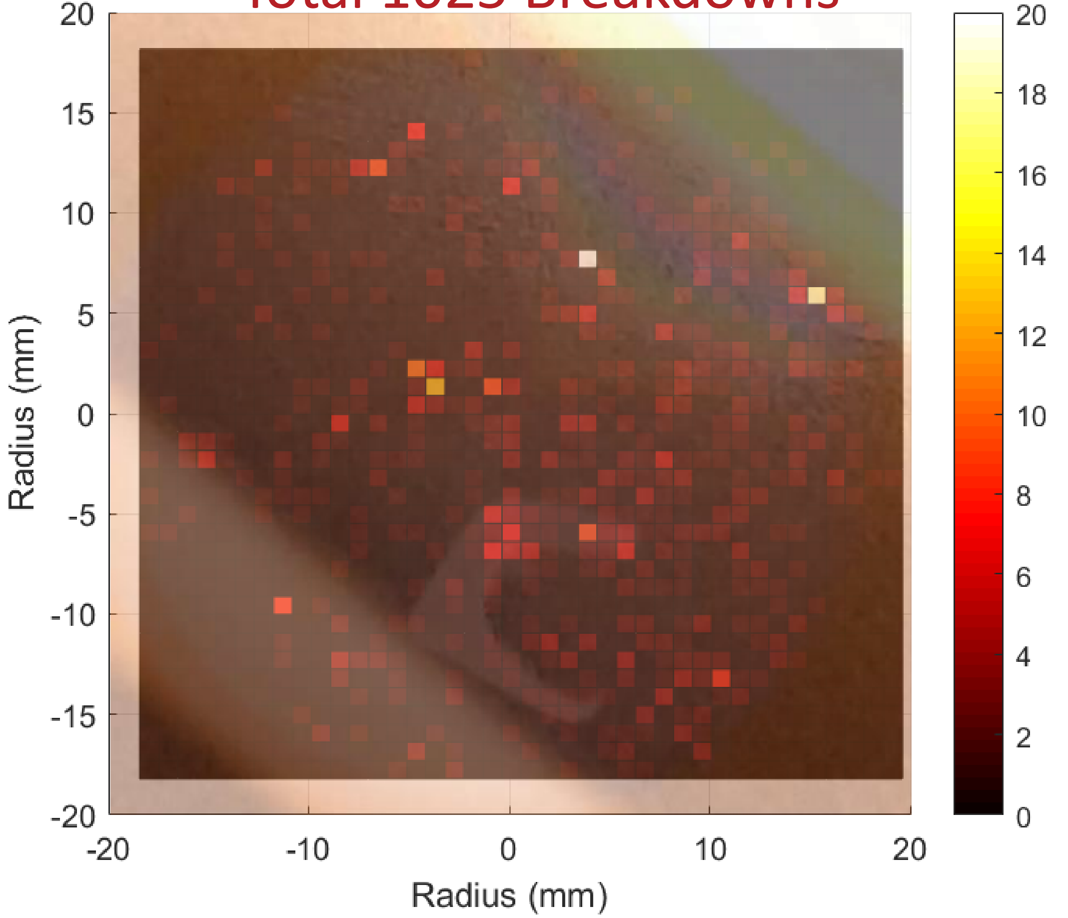


2D Histogram of Breakdown Locations

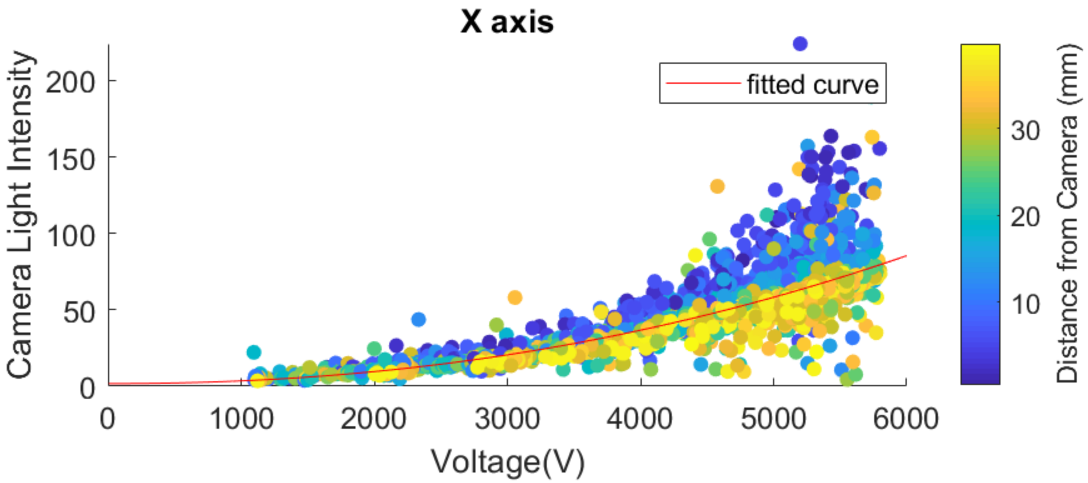
Non-Irradiated Electrode
-Total 527 Breakdowns

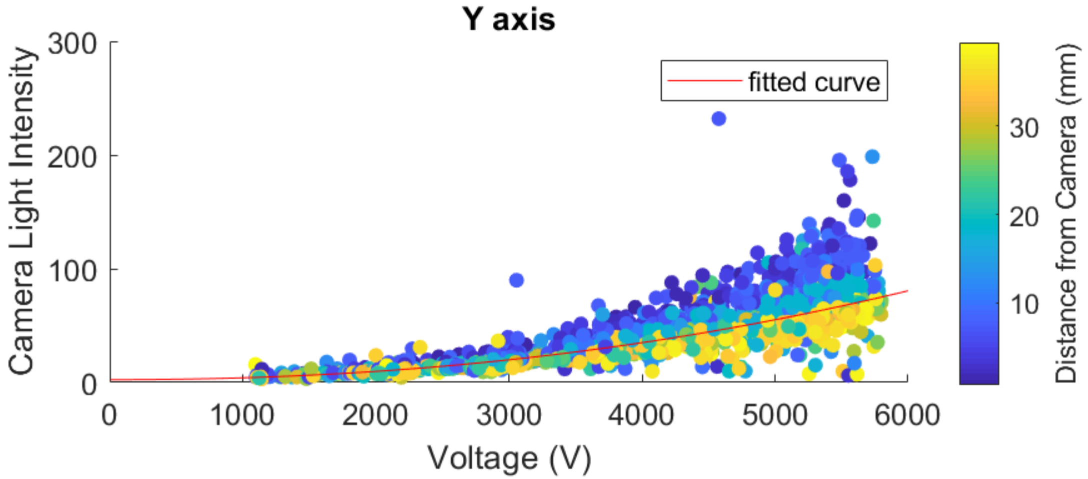


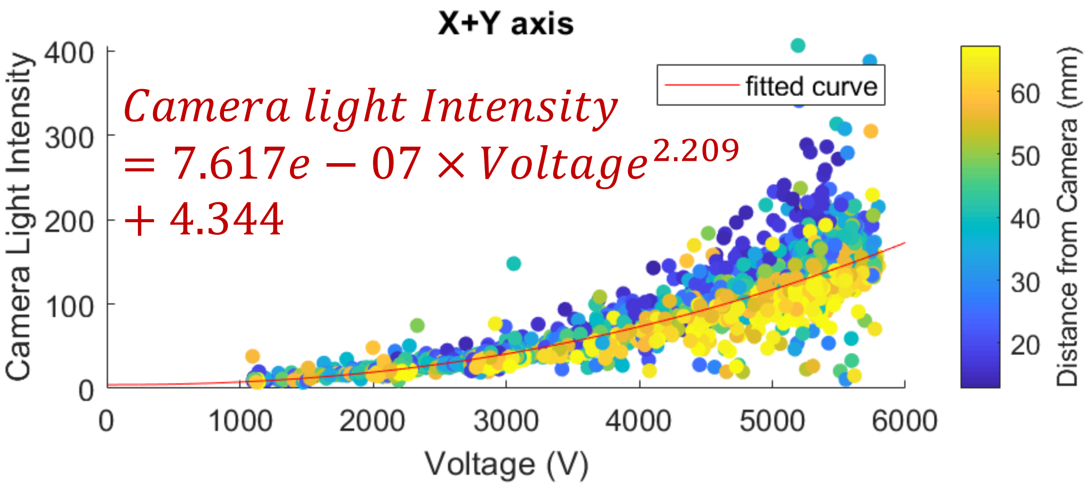
Irradiated Electrode
-Total 1025 Breakdowns

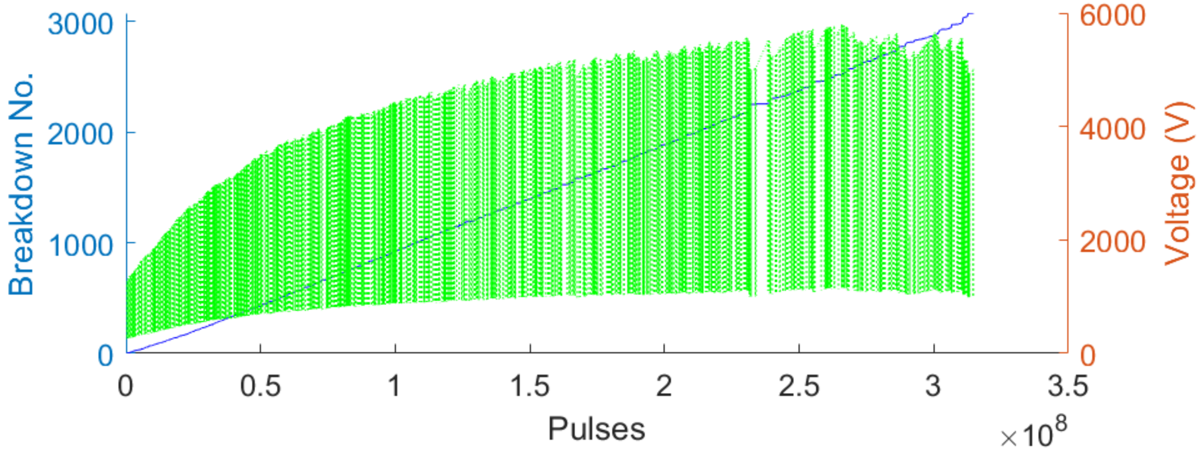


Voltage effect on breakdown light intensity

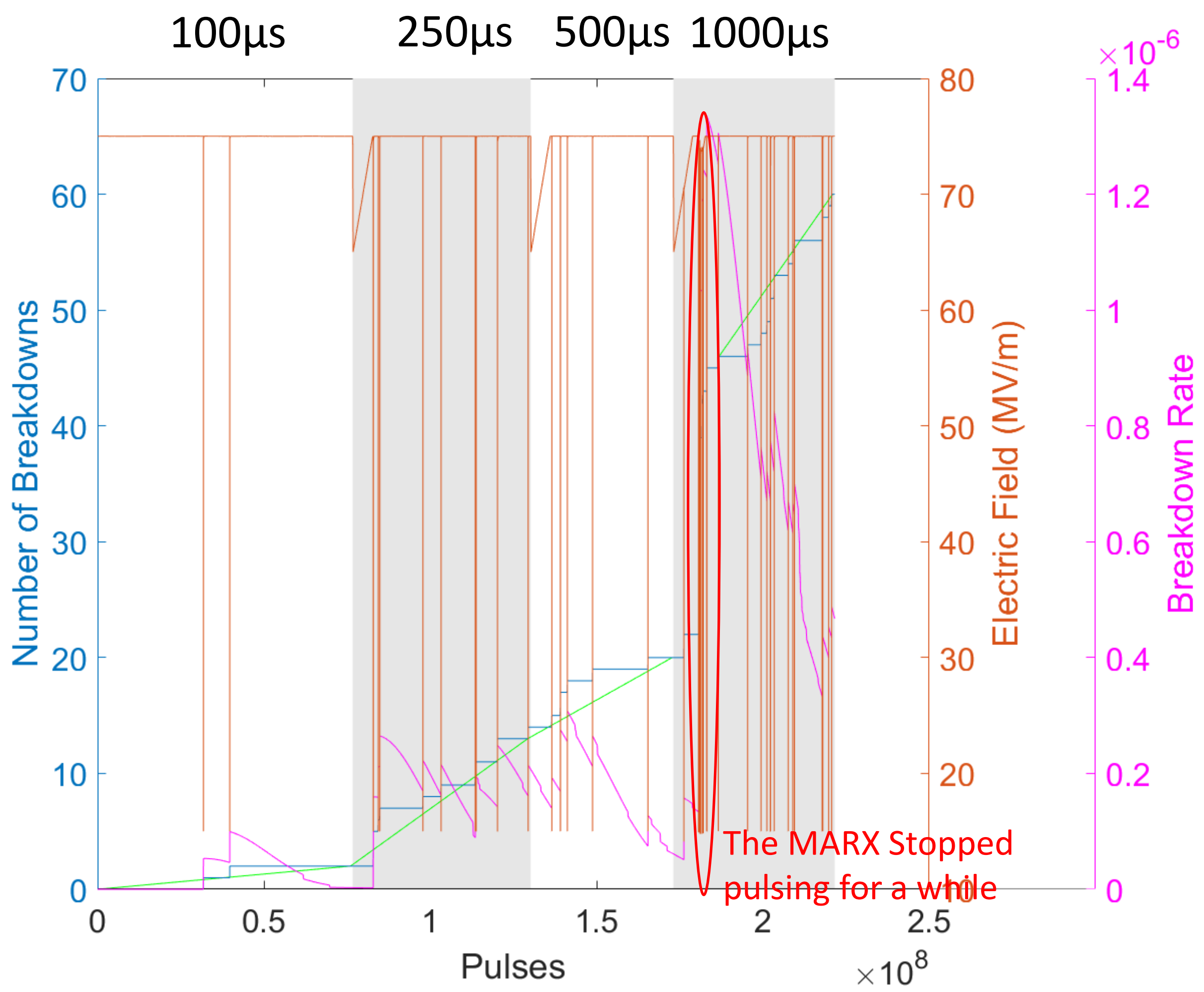


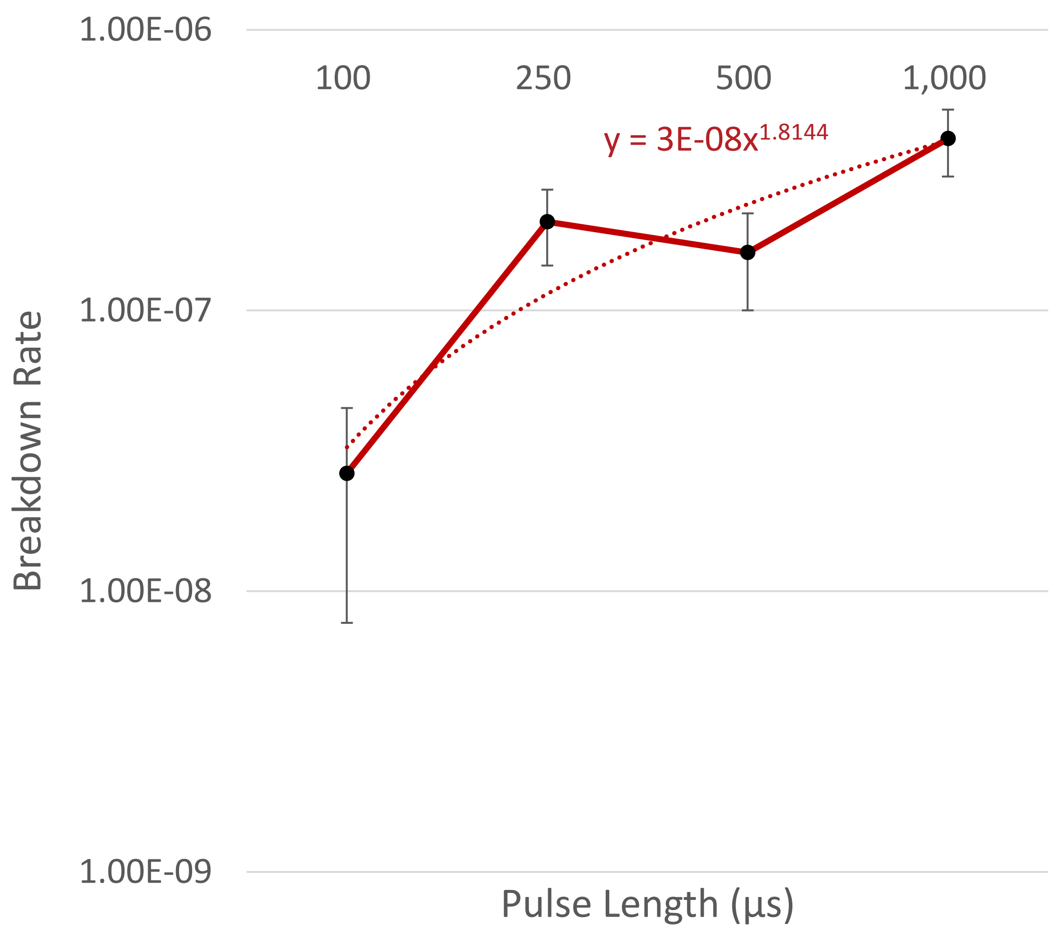






Pulse Length Dependence





Grudiev, Alexej & Wuensch, Walter & Calatroni, Sergio. (2009). New local field quantity describing the high gradient limit of accelerating structures. Physical Review Special Topics - Accelerators and Beams. 12. 10.1103/PhysRevSTAB.12.102001.

Summary

- There were more breakdowns with irradiated electrodes during initial conditioning
- Possibly fixing defects making it able to reach similar/higher voltages - this differs from the RFQ with constant irradiation during operation
- Holding at intermediate voltages reduces probability of clusters
- Areas around the beam spot with higher carbon and H-neutrals also cause breakdown clusters
- Pulse length has a relatively insignificant effect to the BDR
- An additional test of Copper OFE with parameter matching the irradiated pair is required

Thank you!!

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Irradiated Niobium