Field Dependence of Conditioning Part 2- Experimental Measurements

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- LES
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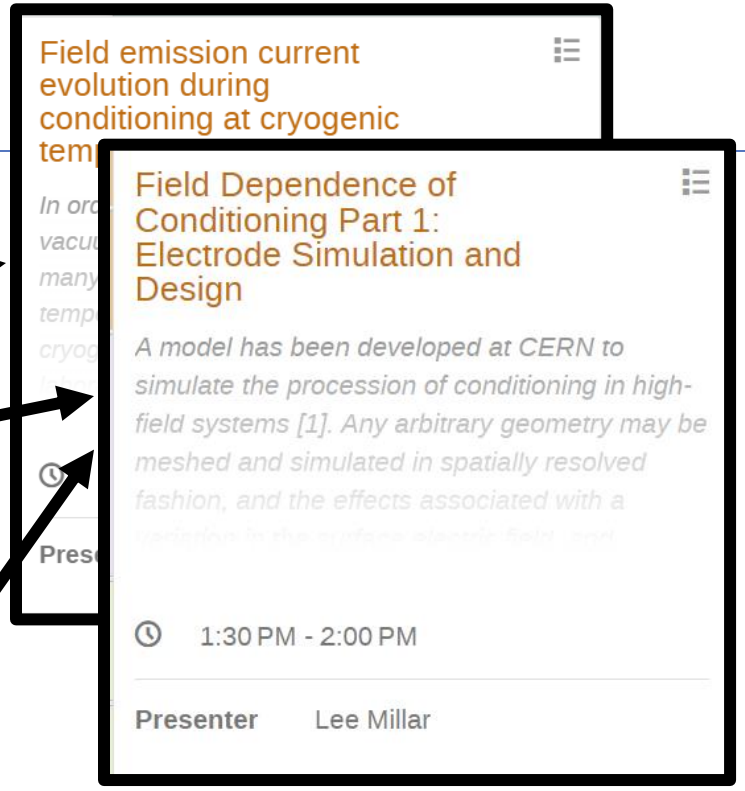
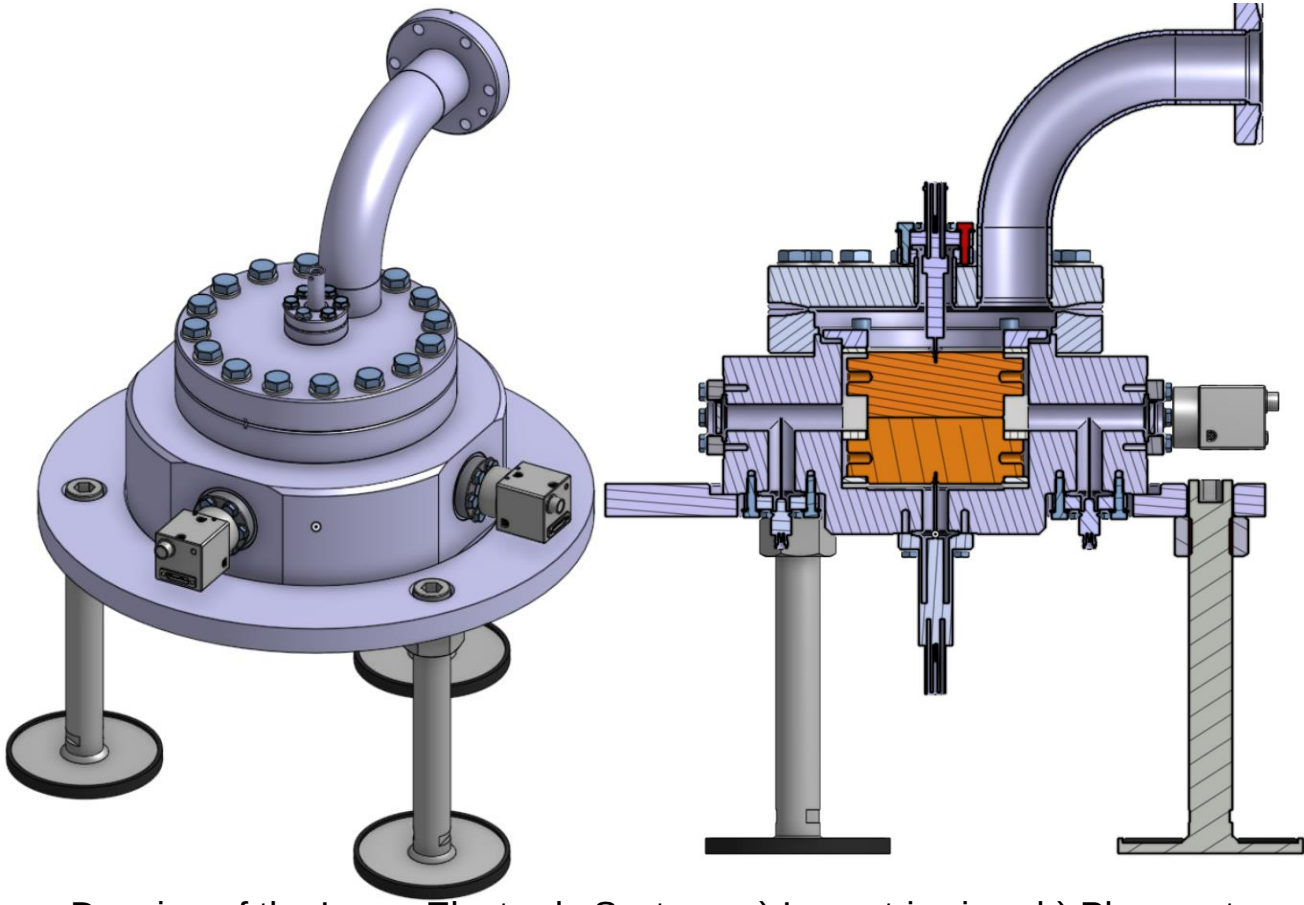


Introduction: Application of the LES system.

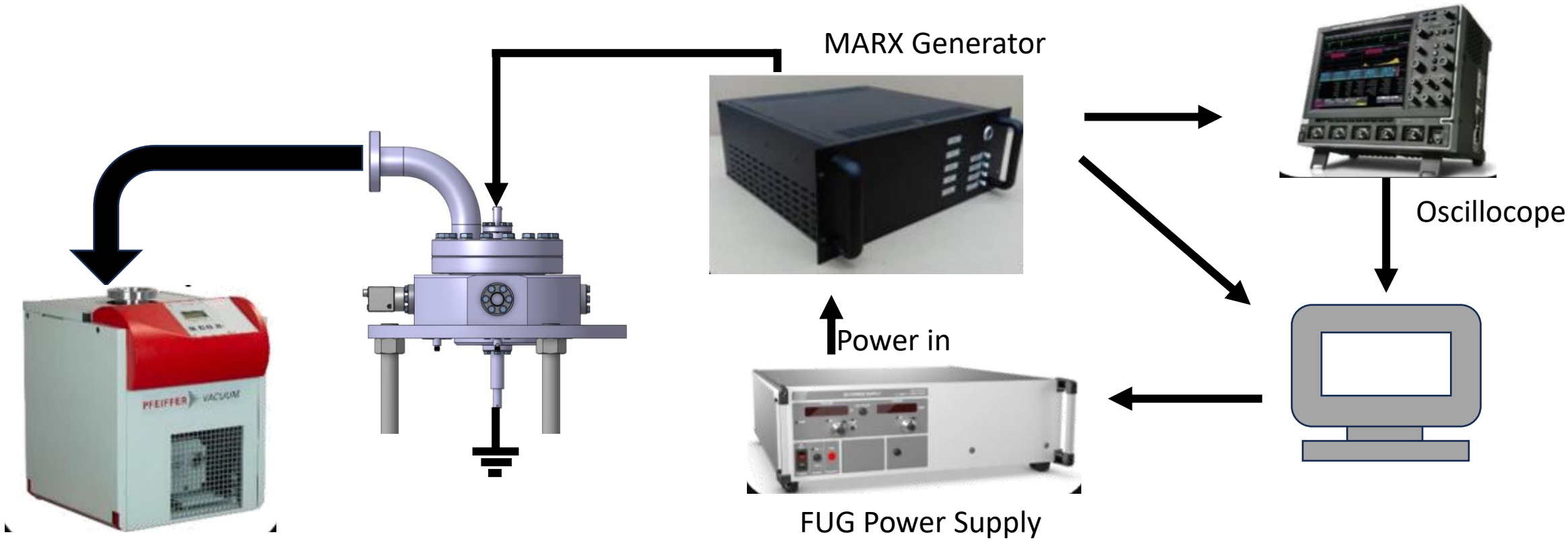
- The LES/DC Spark System is
  - Cheaper
  - Faster
  - Simpler
  - Safer
  - Profilable Field Distribution

- Better material understanding!



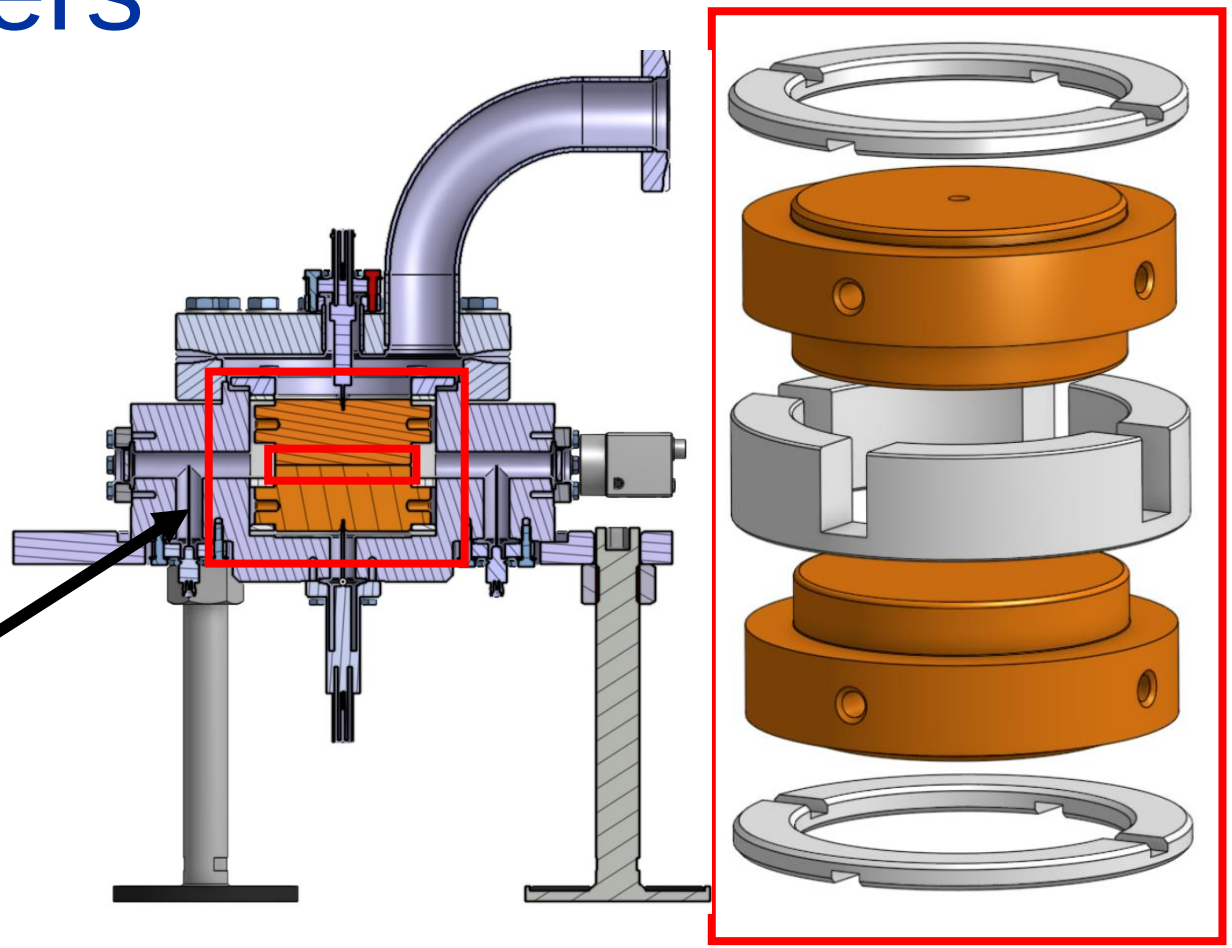
Drawing of the Large Electrode System. a) Isometric view. b) Plane cut view.

Large Electrode System: Chamber and Setup

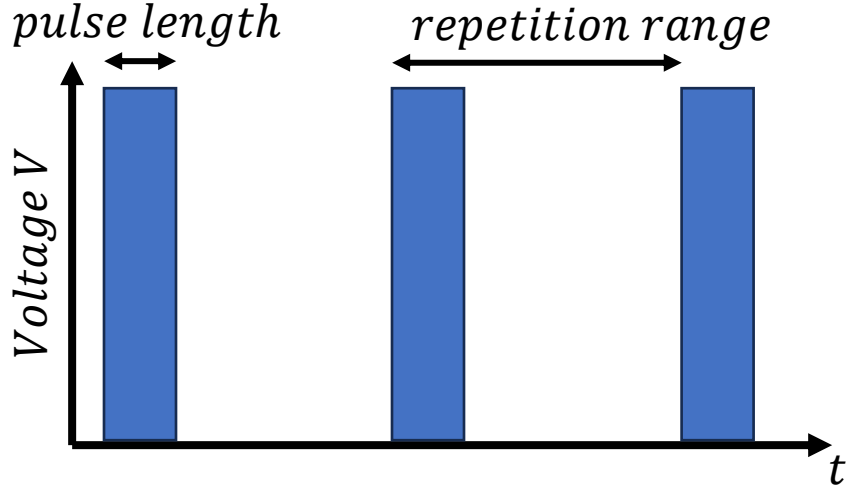


Large Electrode System: Electrodes and Spacers

- Anode and cathode electrodes
- Seperated by well-machined spacers
- Internally insulated from chamber
- Only high E-field at center of the electrodes



Large Electrode System: Breakdown Detection

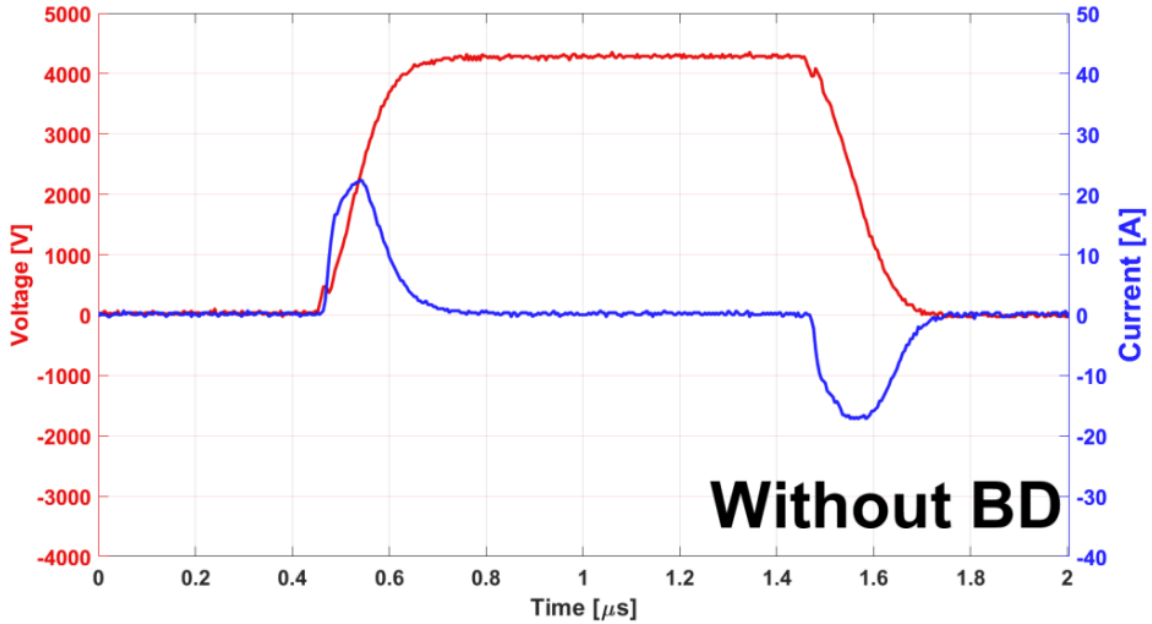


To condition:

Apply 1μs-1ms DC pulses to the electrodes

Can see breakdown in form of:

- High current
- Pressure Increase
- Light.



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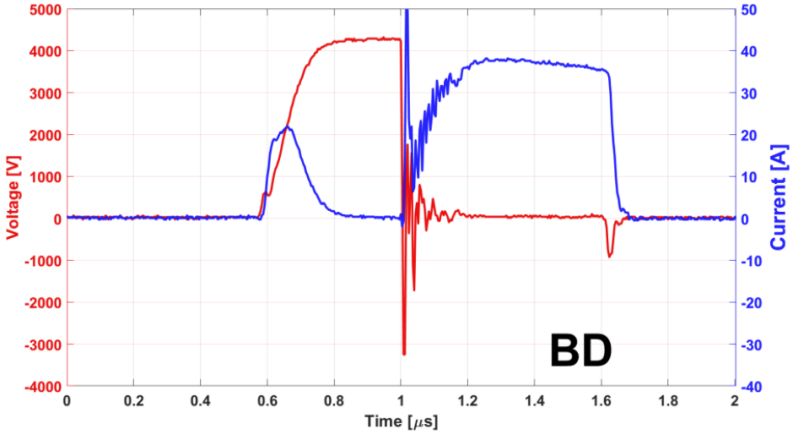
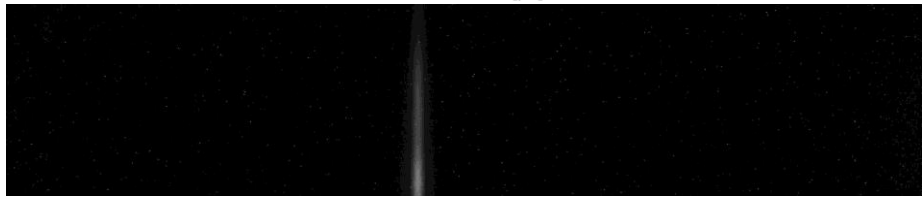
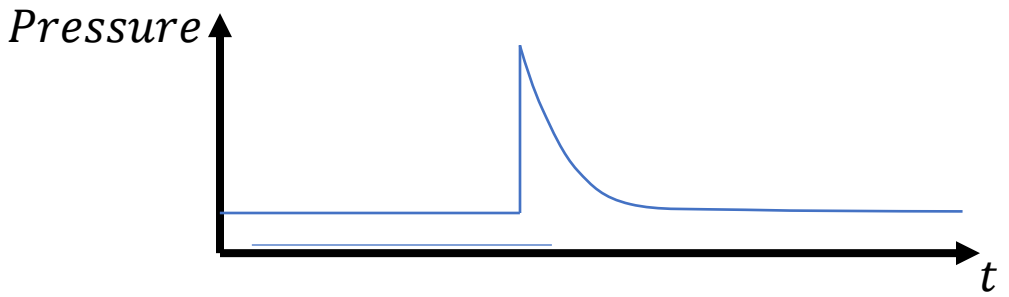




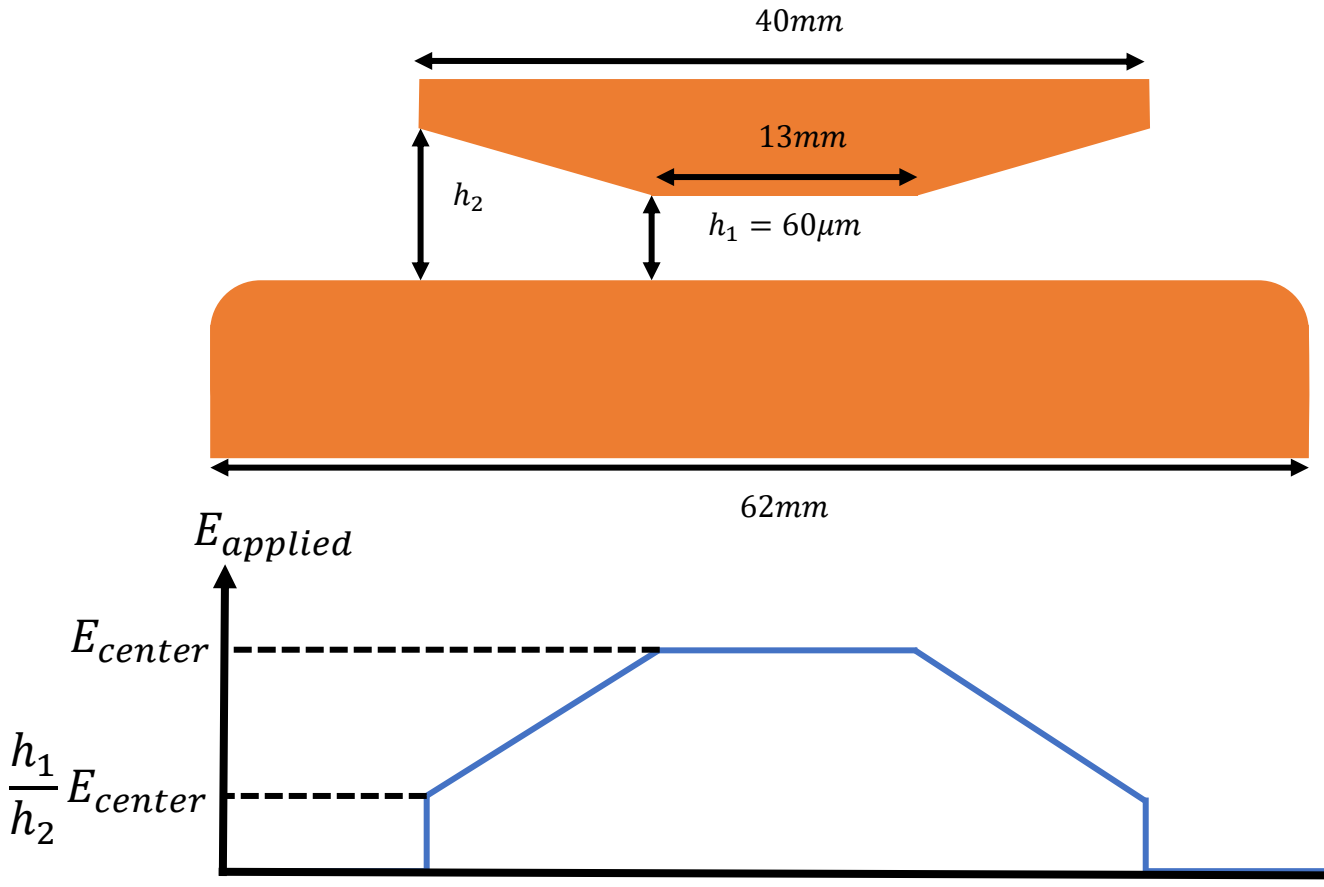


Frustum Electrodes: Decaying Electric Field over the Surface

- Sloped anode surface
- Center height $h_1 = 60\mu m$
- Outer edge height

Electrode 1: $h_2 = 70\mu m$

Electrode 2: $h_2 = 120\mu m$



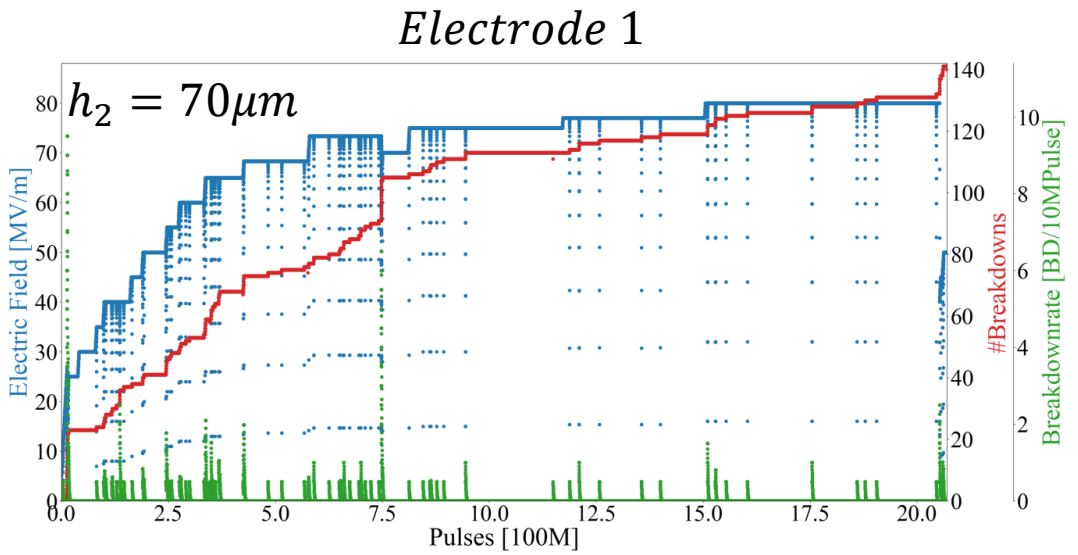
RESULTS

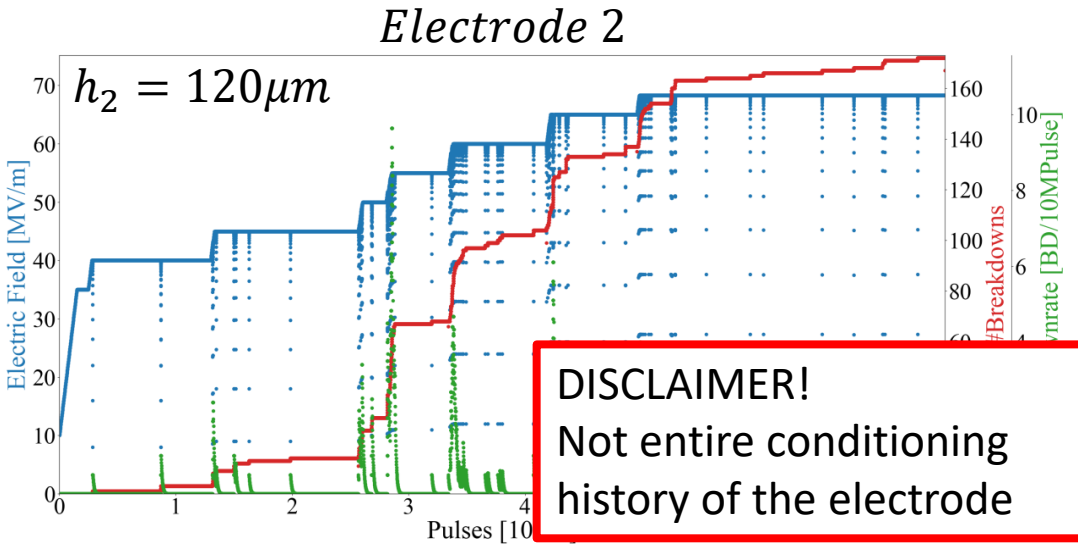
Conditioning

- Conditioning of the two electrodes

- 1us pulse length
- 1kHz repeition rate

- Applied field at center of electrode
- Breakdown rate
- Accumulated number of breakdowns

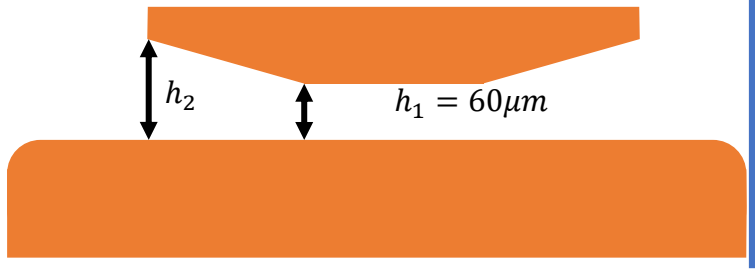


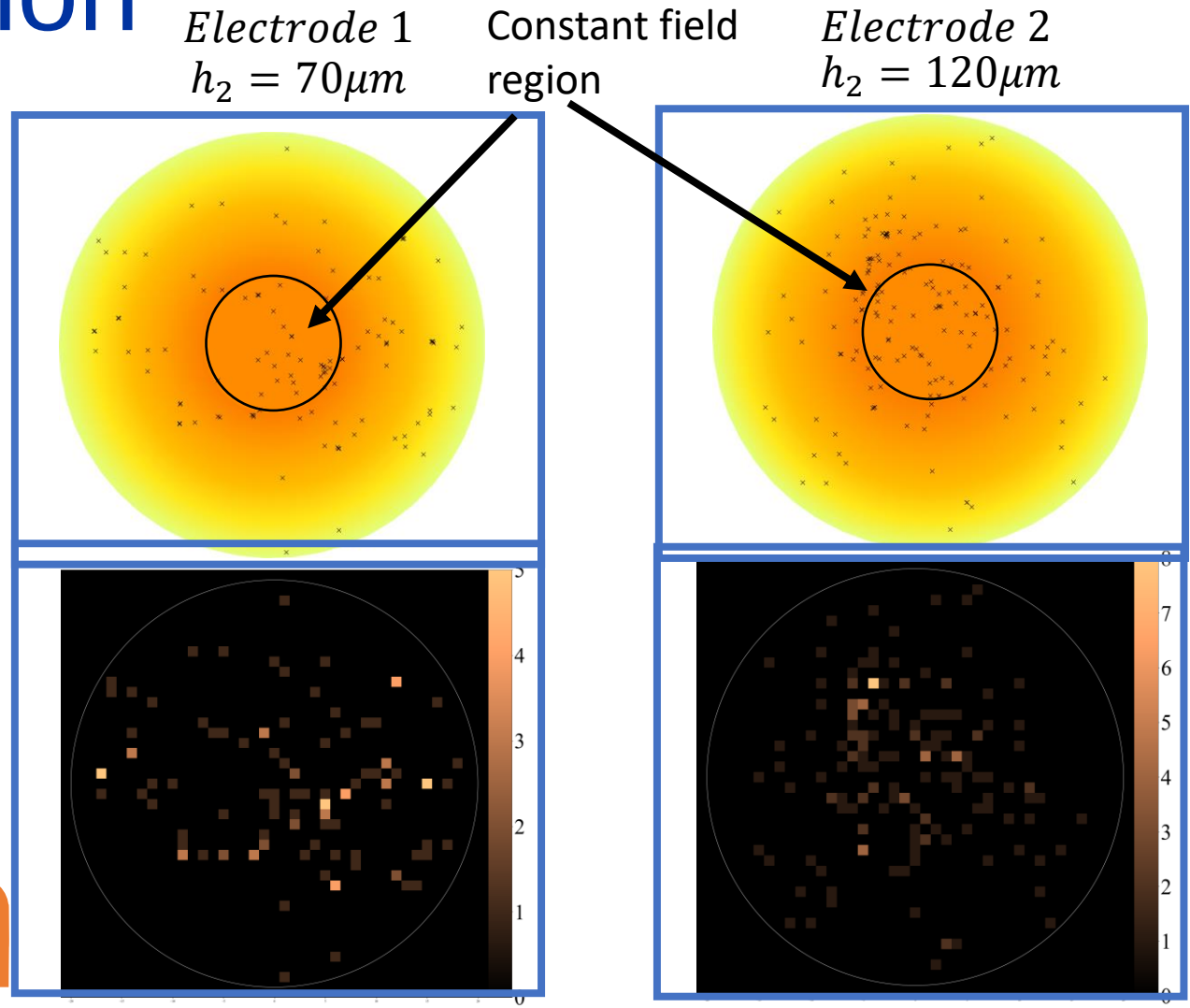


DISCLAIMER!
Not entire conditioning history of the electrode

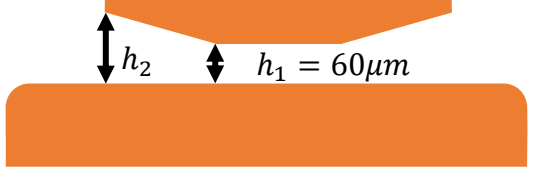
Breakdown Localization

- Surface distribution of breakdowns
- Surface heat map of breakdowns

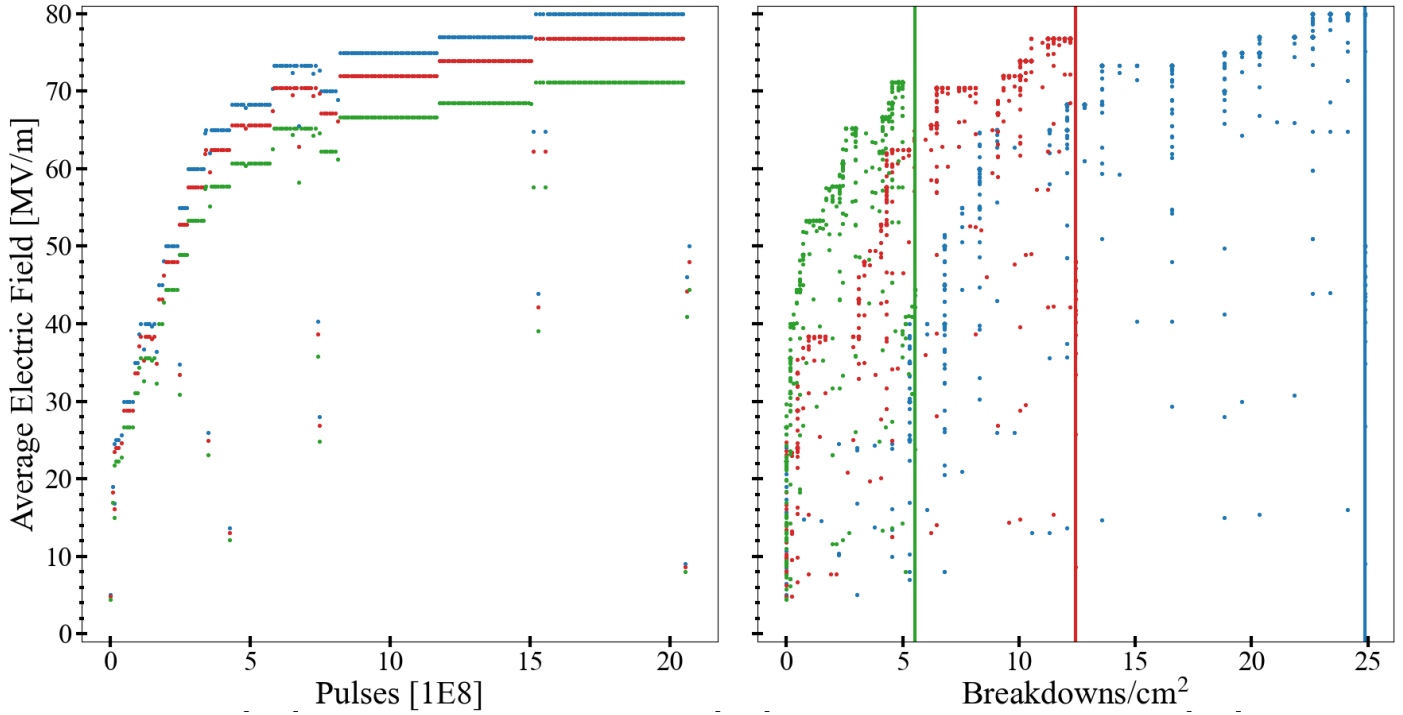


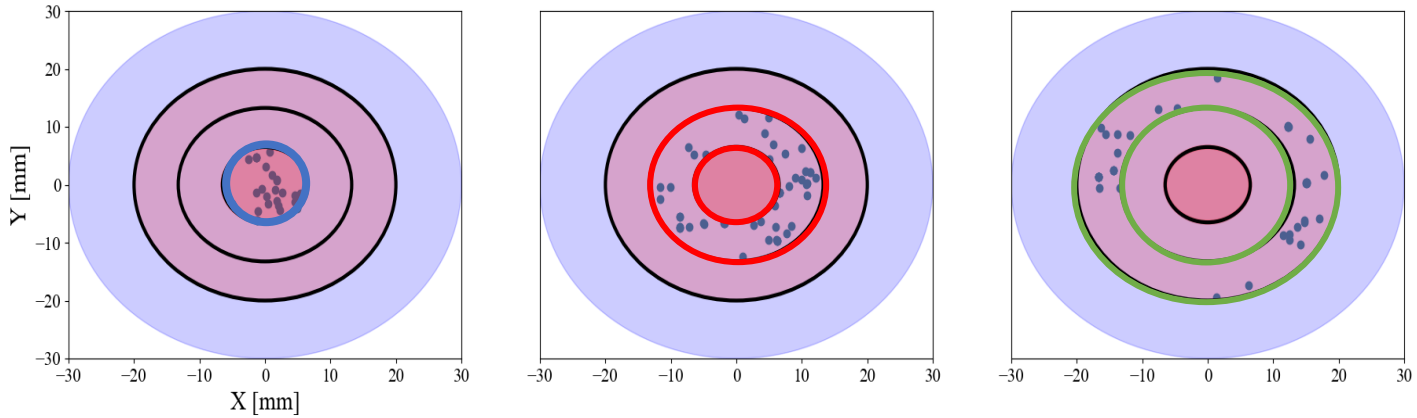


Breakdown Density Over Electrode Surface: Electrode 1

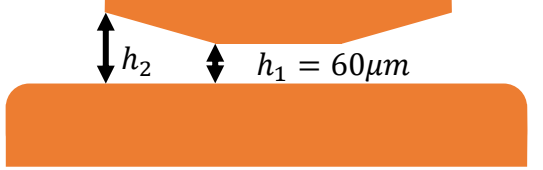


- Section electrode into 3 parts:
  - Inner circle: Blue
  - Intermediate step: Red
  - Outer edge: Green
- Right plot represents the cumulated breakdowns for each region weighted for the surface area.
- Same electric field ≠ same breakdown rate!





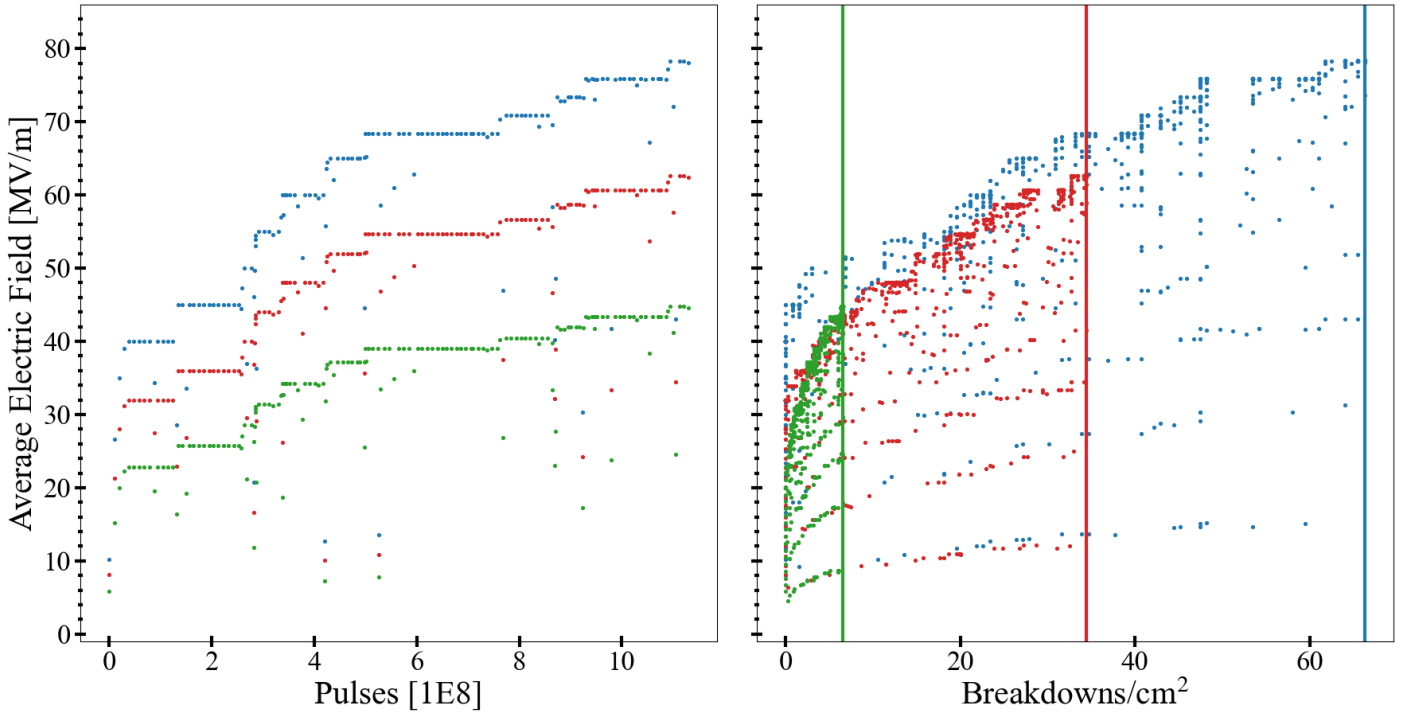
Breakdown Density Over Electrode Surface: Electrode 2

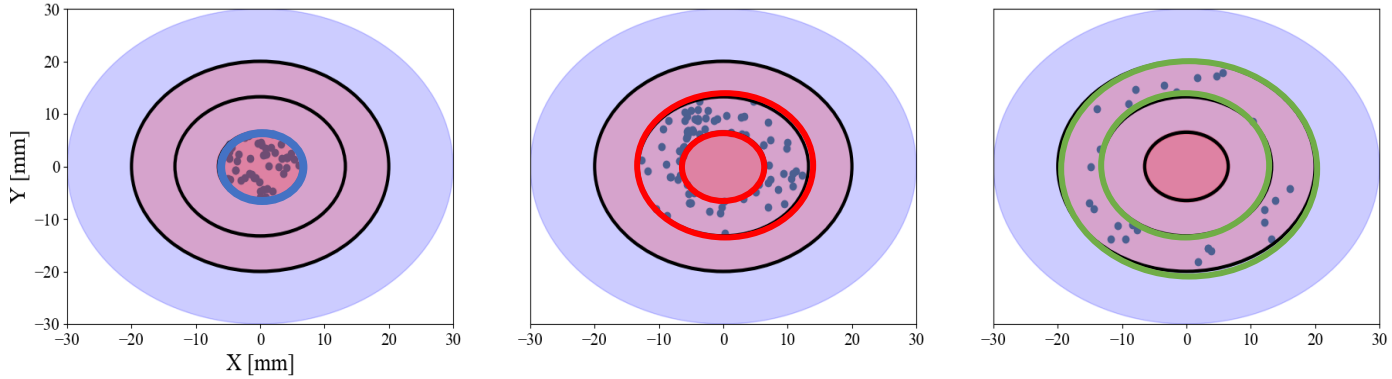


- Section electrode into 3 parts:
  - Inner circle: Blue
  - Intermediate step: Red
  - Outer edge: Green

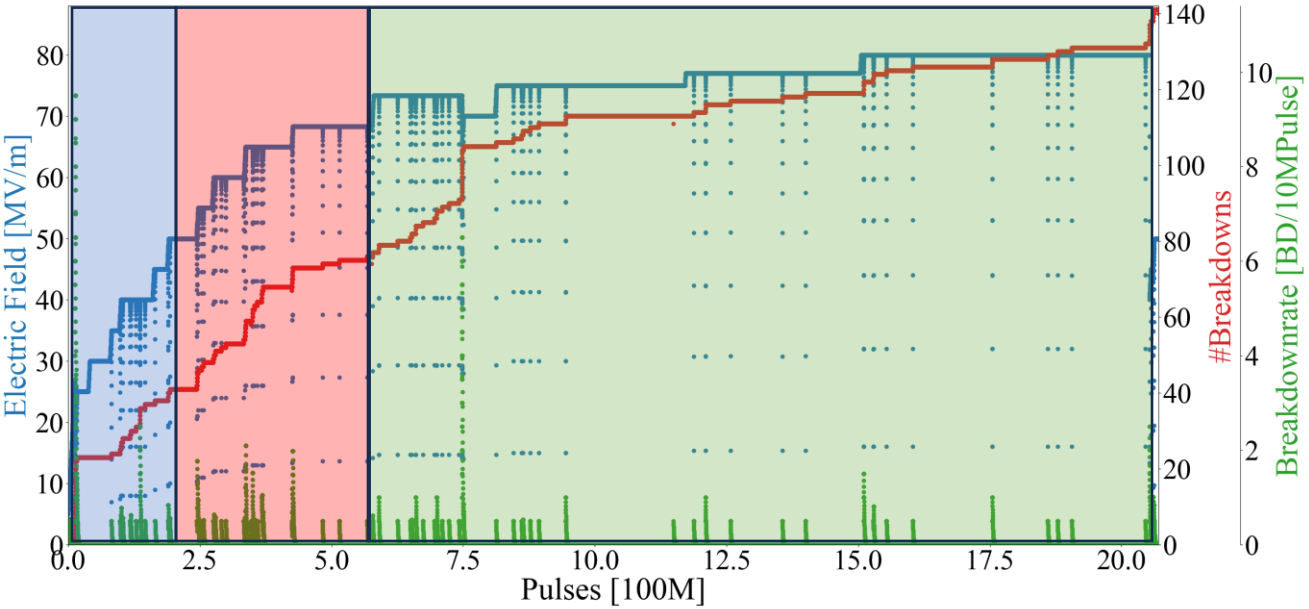
- Same electric field ≠ same breakdown rate!

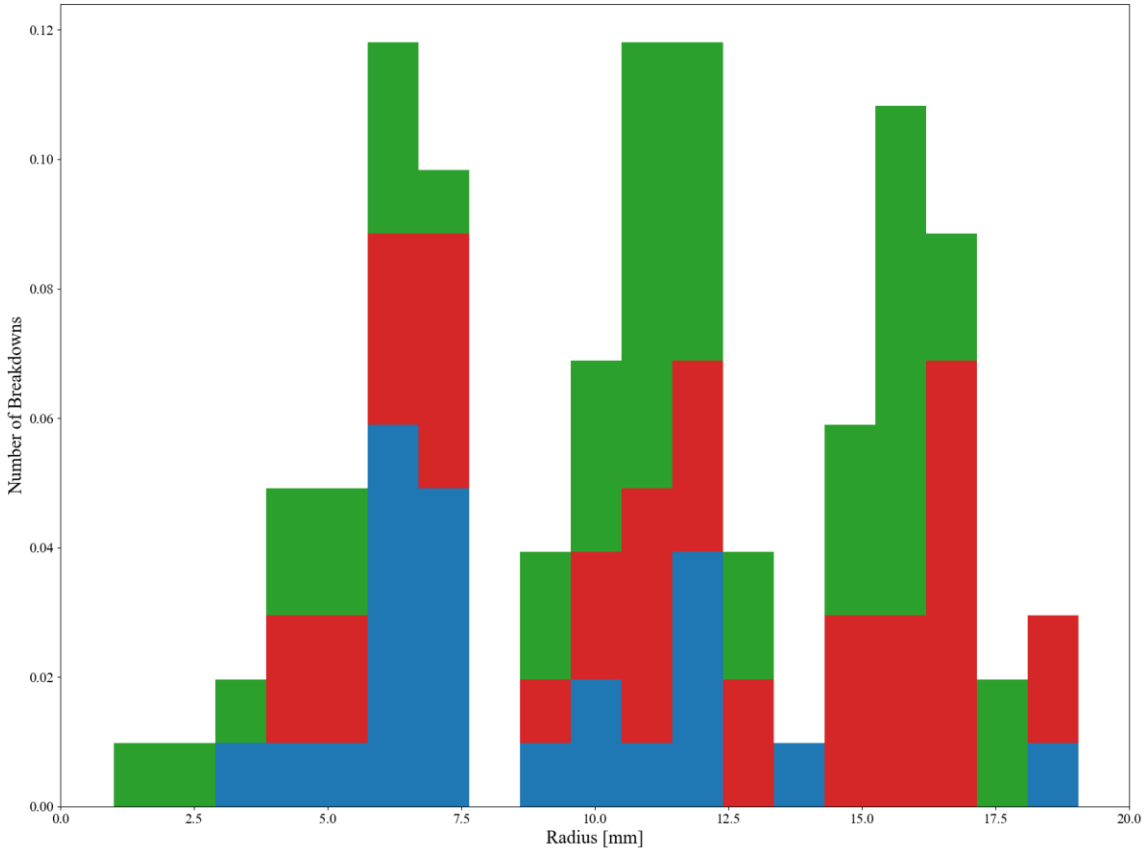
- DISCLAIMER!:
  First breakdowns not recorded. Blue and red data should be shiftet further to the right.





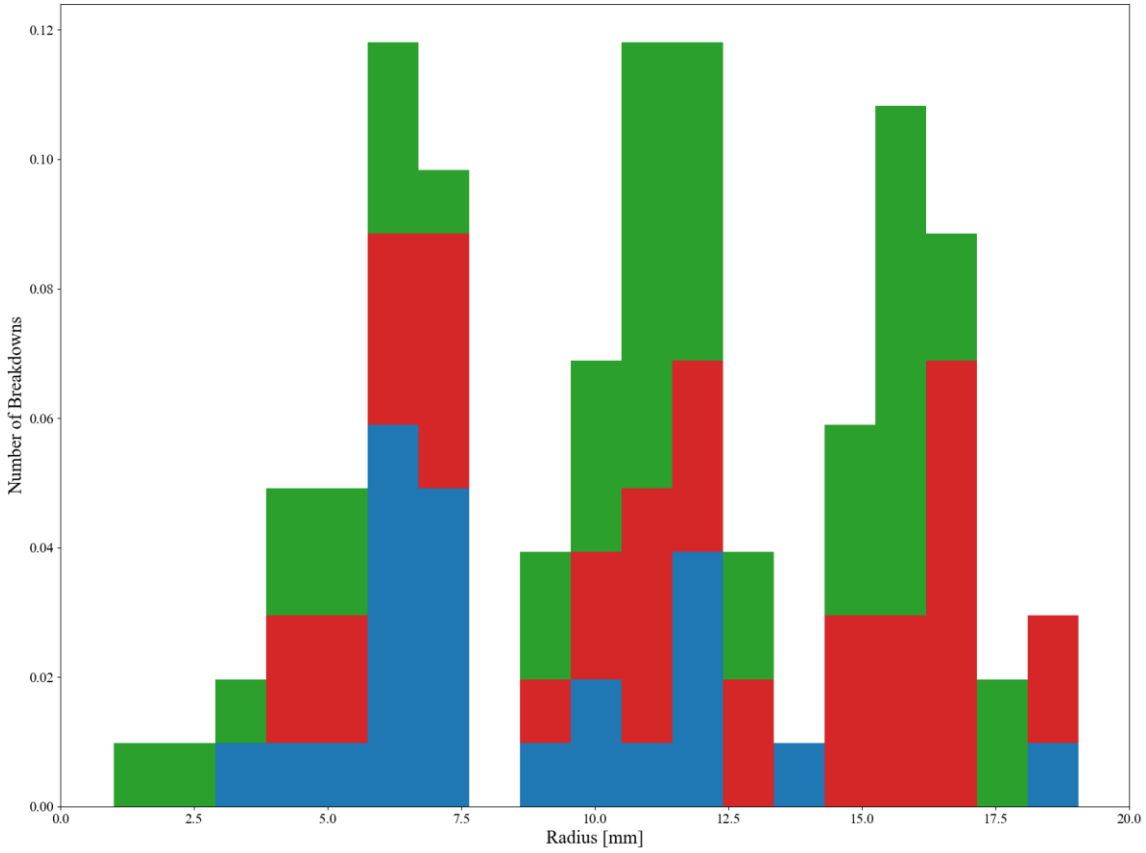
Breakdown Distribution over Radius and Condtioning time: Electrode 1



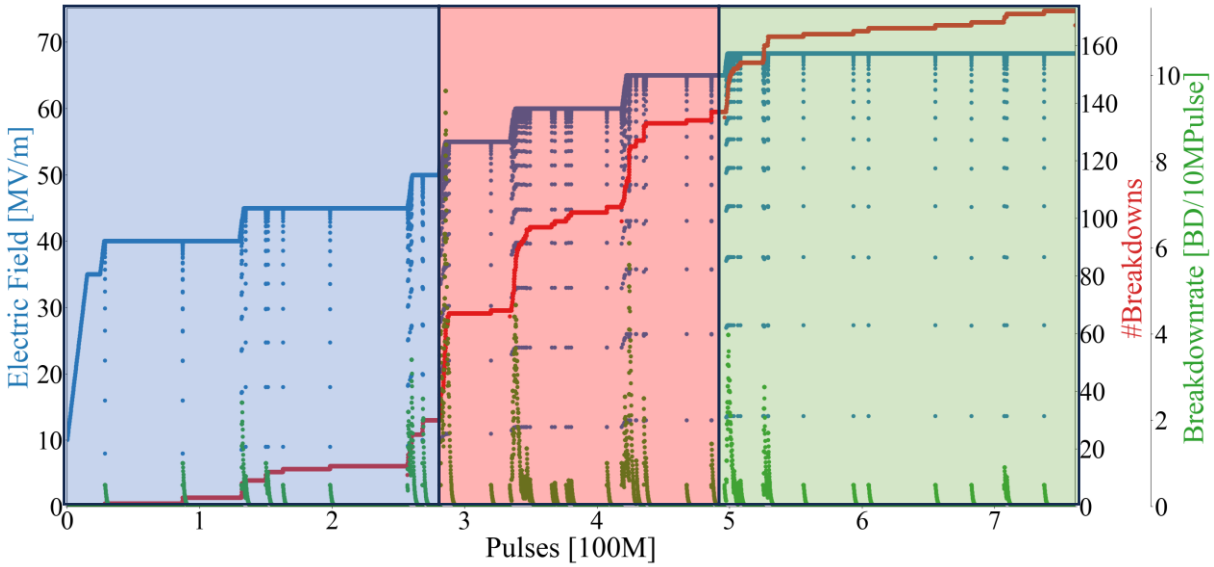


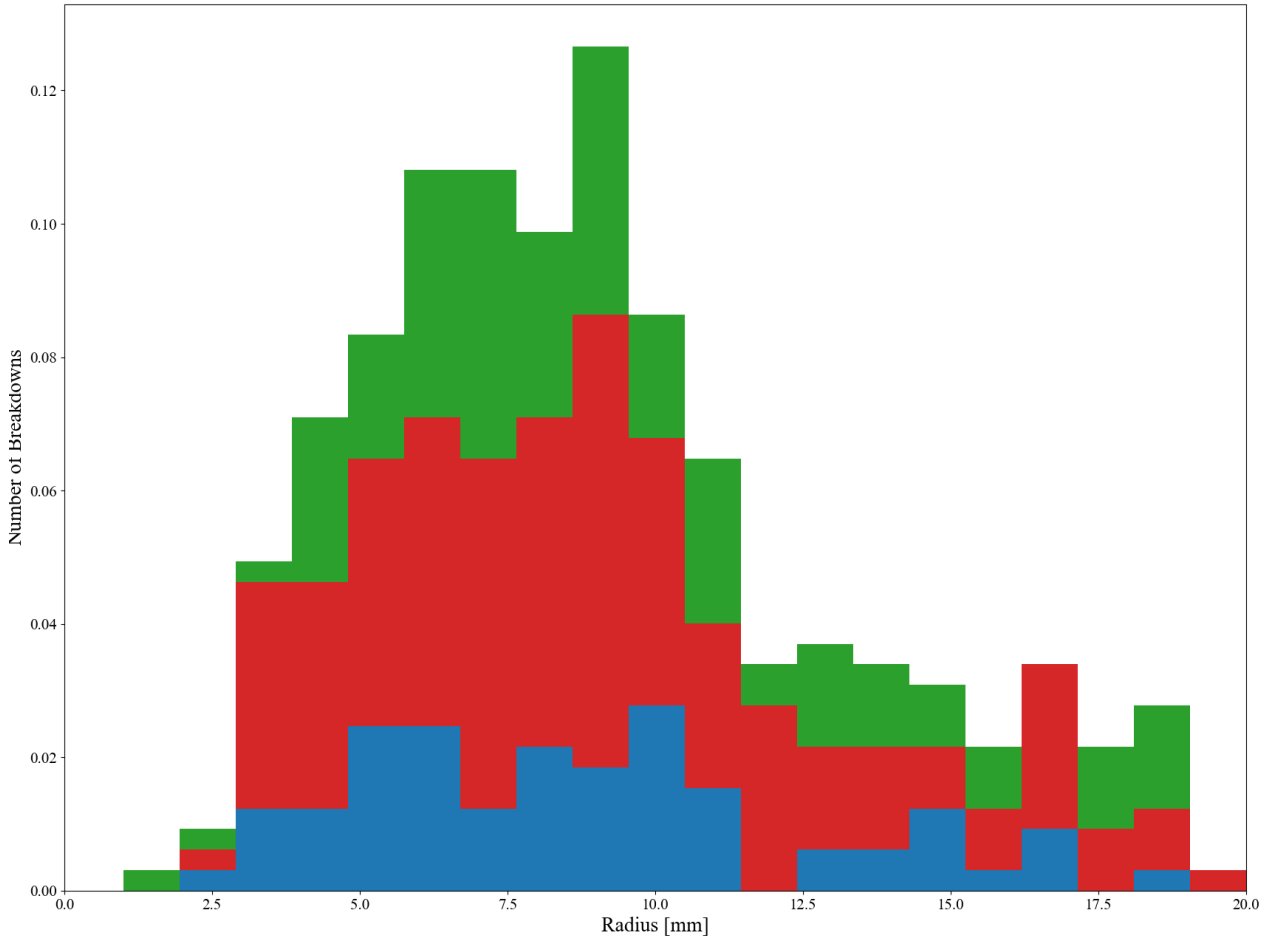
Breakdown Distribution over Radius and Condtioning time: Electrode 1

- Number of breakdowns over radius
- The blue region dominates in BD at r<7.5mm.
- Red region more evenly spread over surface
- Green dominates further into the edge of the electrode



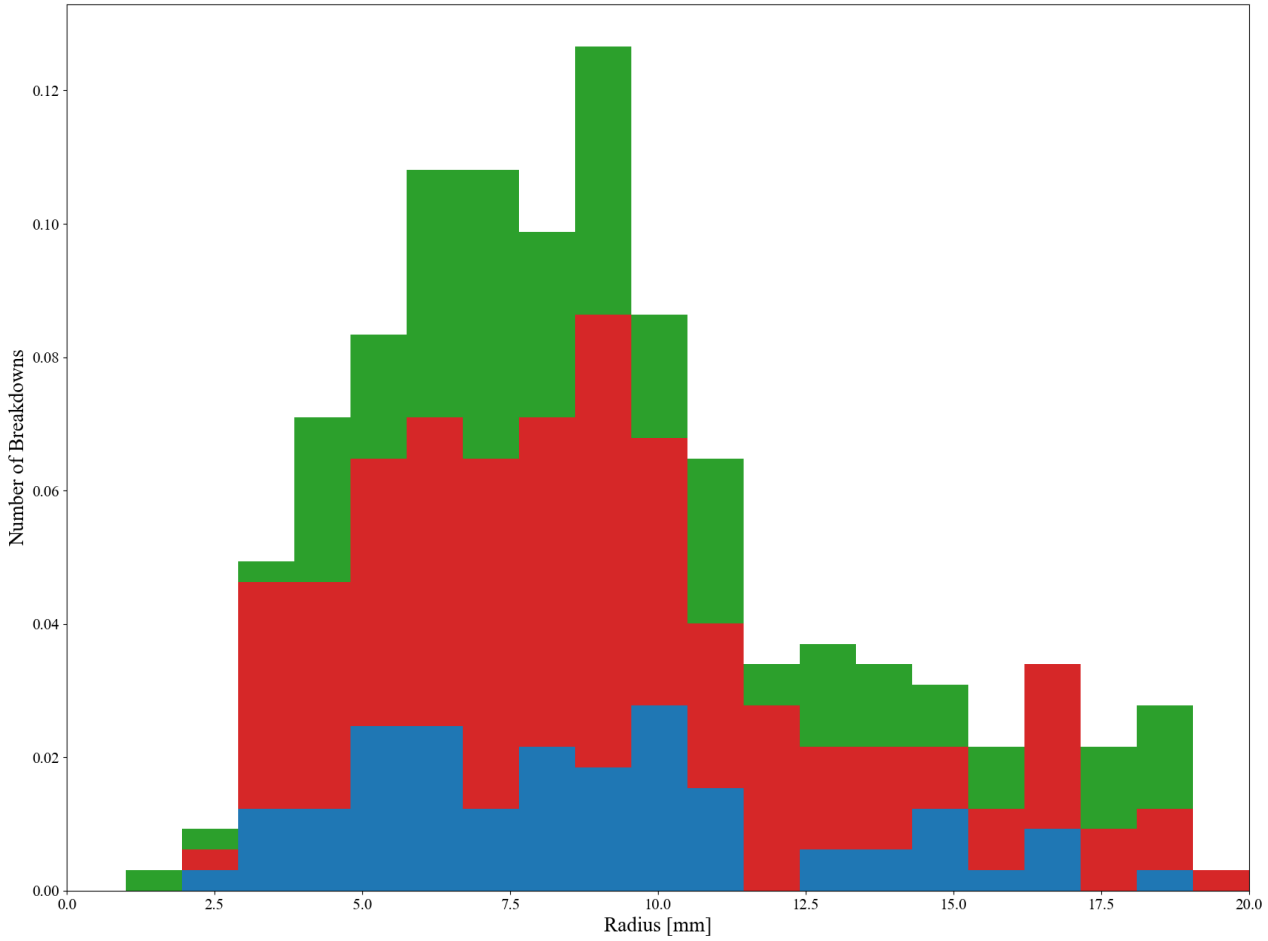
Breakdown Distribution over Radius and Condtioning time: Electrode 2





Breakdown Distribution over Radius and Condtioning time: Electrode 2

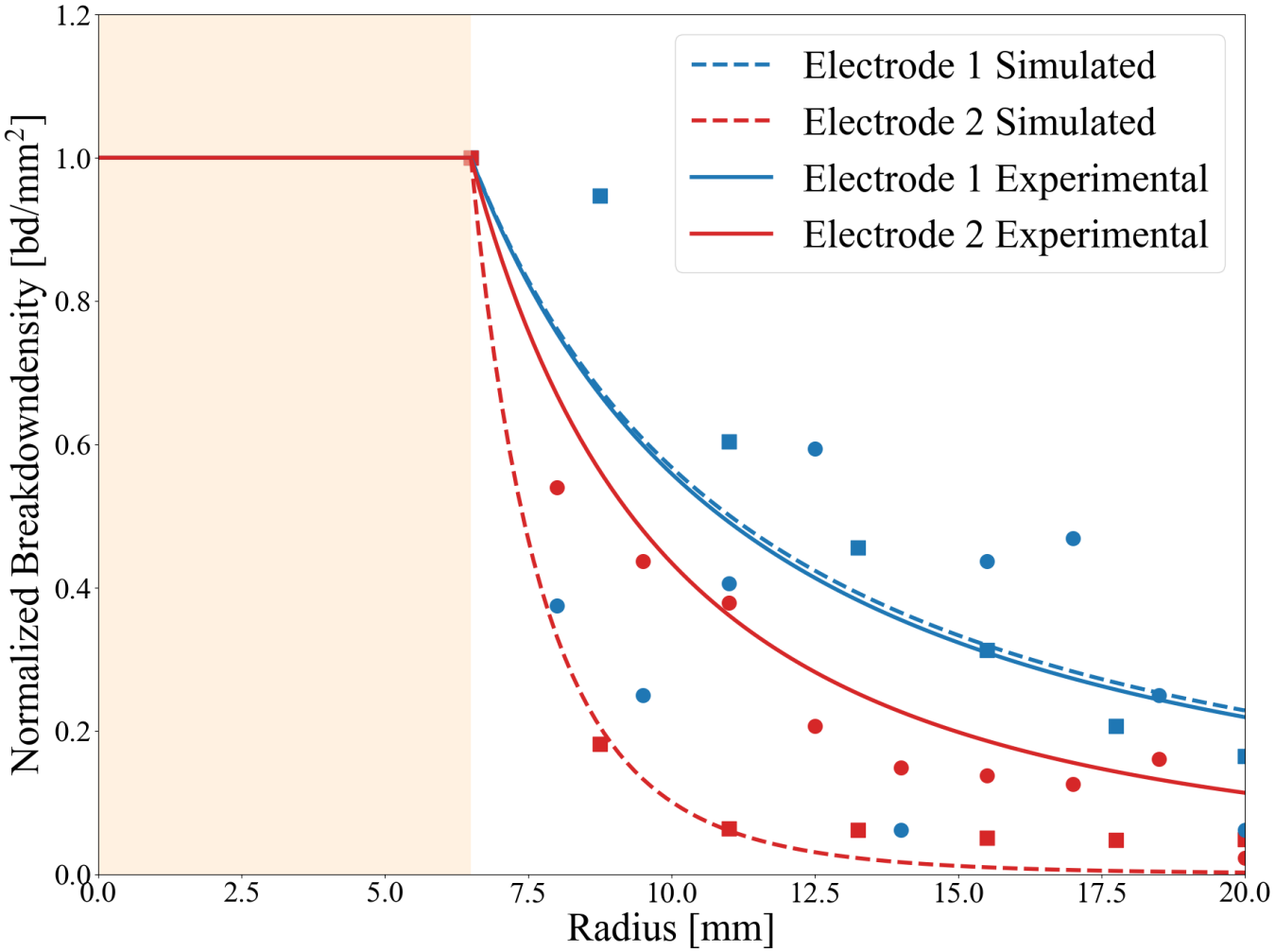
- Number of breakdowns over radius
- Most of breakdowns are dominated in the inner region of the electrode for all conditioning stages.
- If $BDR \propto E^{30}$, we would only see breakdowns at r<6.5mm



COMPARISON TO SIMULATIONS

Simulation Comparison

- Experimental data fitted with
  - $BDR = \alpha * r^{-\beta}$
  - Experimental Electrode 1: $\beta = 1.35$
  - Experimental Electrode 2: $\beta = 1.93$
  - Simulated Electrode 1: $\beta = 1.31$
  - Simulated Electrode 2: $\beta = 5.32$
  - Far away from the $BDR \propto E^{30}$
- Both experience a reduction over radius
- Electrode 1 (10 μm) slope has a slower decay
- Better statistics on simulated data
- Electrode 2 experiences many more breakdowns than Electrode 1



Conclusion

- Demonstrated never tested before varying electric field electrodes
- Shows experimental link with Monte Carlo simulations
- Gives better insight into the effect of the exposer to high fields-opposing effect of breakdown and conditioning.
- Repeating tests are planned for the future

Questions?

References

[7] “Breakdown localisation in a pulsed DC electrode system”- Iaroslava Profilova https://www.sciencedirect.com/science/article/pii/S016890021931423 8

[2]https://www.researchgate.net/publication/358579070_Explainable_Machine_Learning_for_Breakdown_Prediction_in_High_Gradient_RF_Cavities

[1]https://agenda.linearcollider.org/event/8217/contributions/44703/attachments/35017/54152/LCWS2019_Lee_Millar.pdf

[3]https://indico.cern.ch/event/1080222/contributions/4844116/attachments/2446713/4192574/HG_2022_MonteCarlo_Millar.pdf

[6]https://indico.cern.ch/event/918452/contributions/3860214/attachments/2054608/3448854/Linac4-RFQ-Issues.pdf

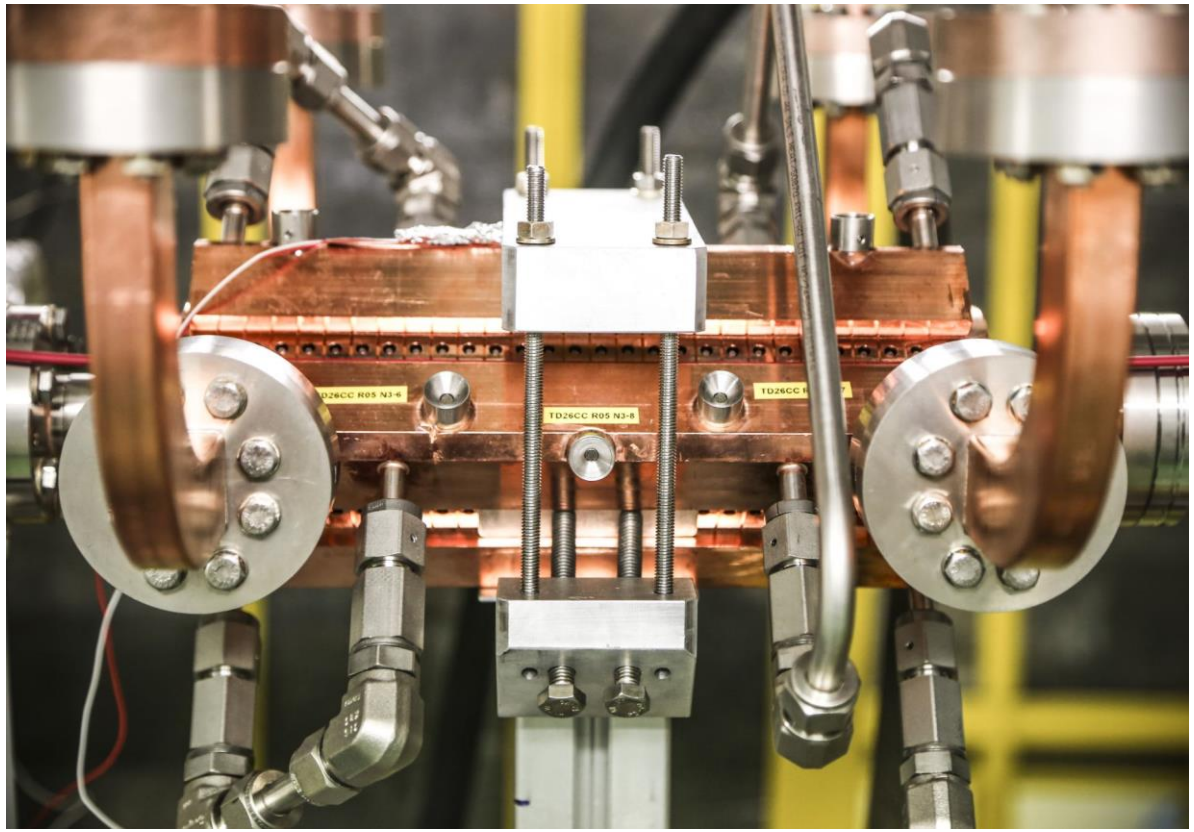
[4]https://indico.cern.ch/event/766929/contributions/3454027/attachments/1861527/3059556/HG2019_jacewicz_final.pdf

[5] https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.20.011007

[7]Ruths thesis

Introduction: Application of the LES system.

- LES = Large Electrode System
- RF Structures experience breakdowns
- Breakdowns cause
  - Loss of beam
  - Surface damage
- Difficult to analyse because
  - Non-uniform field
  - Time varying field
  - Expensive



Xbox 2 test stand. Image provided by Lee Milar.

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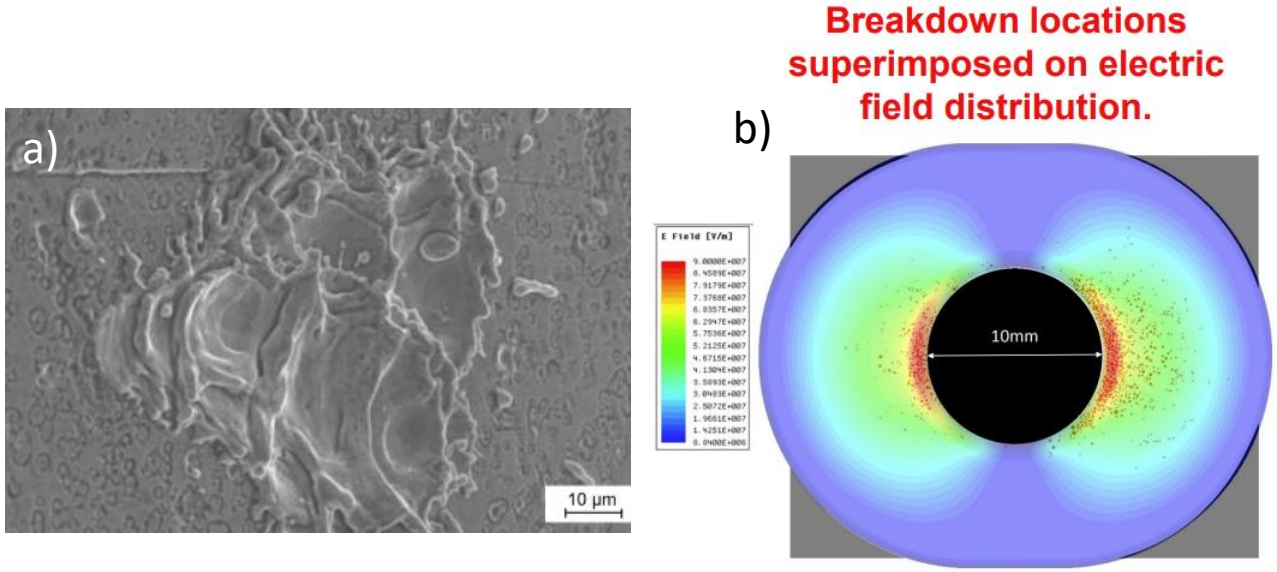

a)Damage caused by a breakdown inside an RF structure [2]. b) Uneven electric field distribution inside RF Cavity. Several breakdowns are marked ont he side of the strucutre [3]

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- Better material understanding!

Image of Uppsalas Cryogenic LES [6].

Introduction: Previous work

The LES has been involved in several large scale project trough the years, such as:

- High field exposure for CLIC material investigation
- Hydrogen blistering effect on conditioning related to RFQ structures.

It has also been involved in smaller scale projects to better understand the origin of breakdowns:

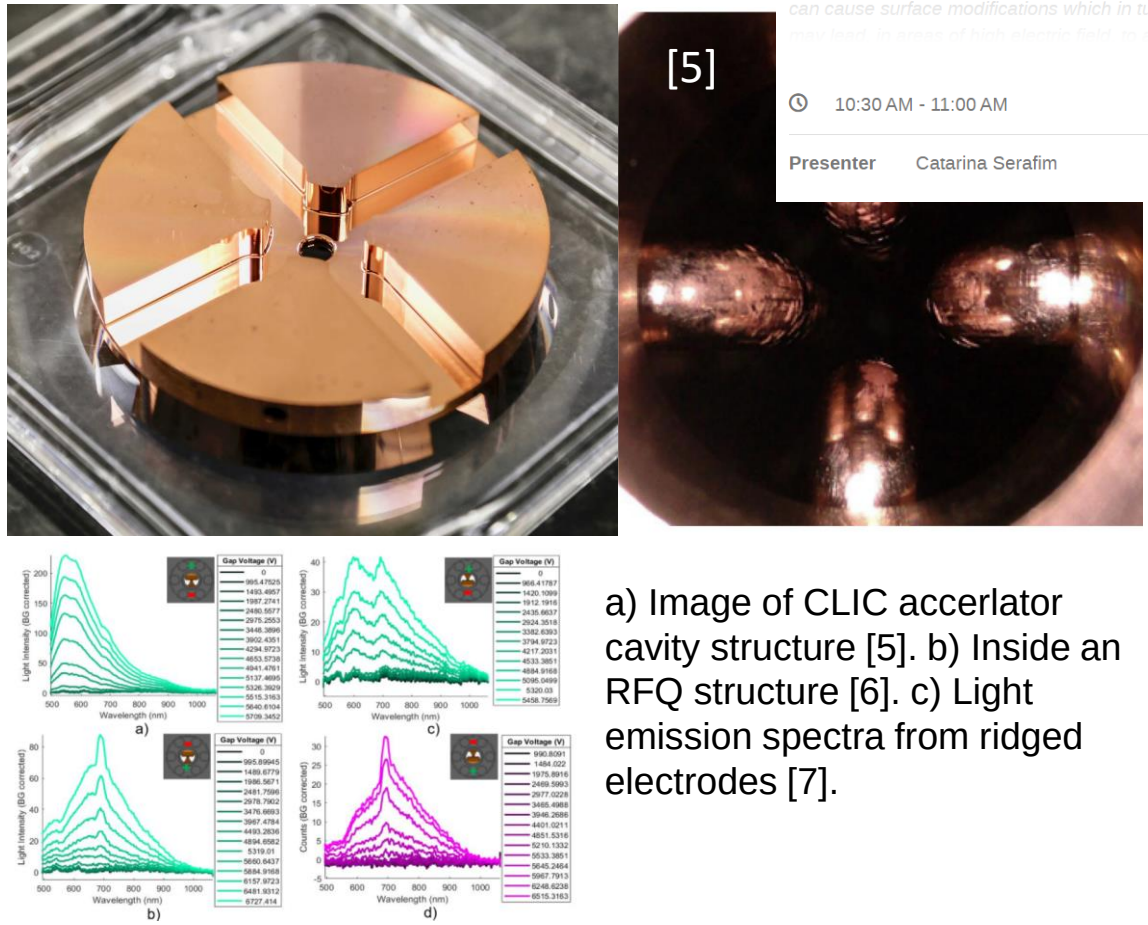
- Breakdown light emission spectras
- Light emission during field emission
- Experimental data for investigating fluctuation theories.

Study of different materials exposed to low energy H- irradiation and its effects on high voltage breakdown resistance

During the operation of LINAC4, up to 25% of the source beam current is routinely lost in the Radio Frequency Quadrupole (RFQ) at an energy between 0.045 and 3 MeV. These losses can cause surface modifications which in turn may lead, in areas of high electric field, to an

10:30 AM - 11:00 AM

Presenter Catarina Serafim



a) Image of CLIC accerlator cavity structure [5]. b) Inside an RFQ structure [6]. c) Light emission spectra from ridged electrodes [7].

HOLDER SLIDE: Yionon/Katie Analysis

Extra Slides

Heat Treatement

Conditioning Algorithm

True Conditioning Curve of Electrode 2

Division of Breakdown over Radius Electrode 1