Field Testing at CERN's DC Lab

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Walter Wuensch

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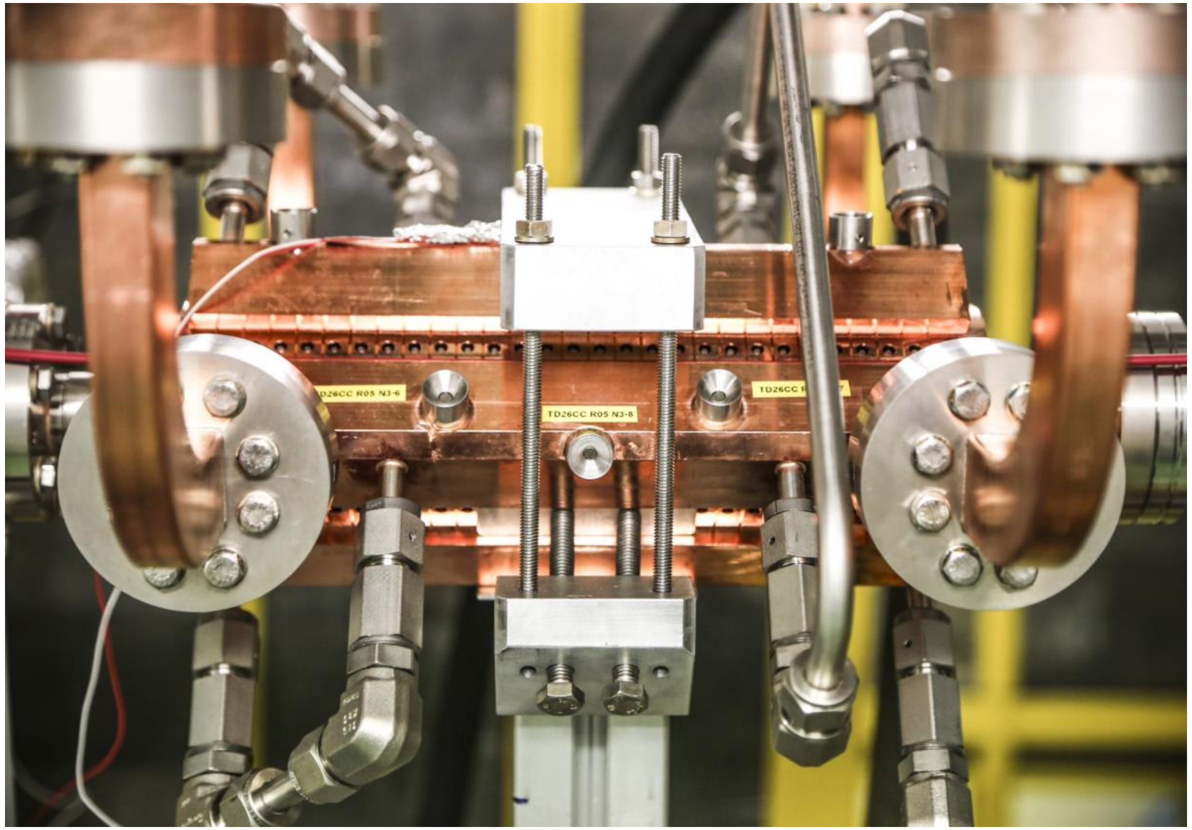
Introduction: Application of the LES system.

- 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.

Introduction: Application of the LES system.

- LES = Large Electrode System
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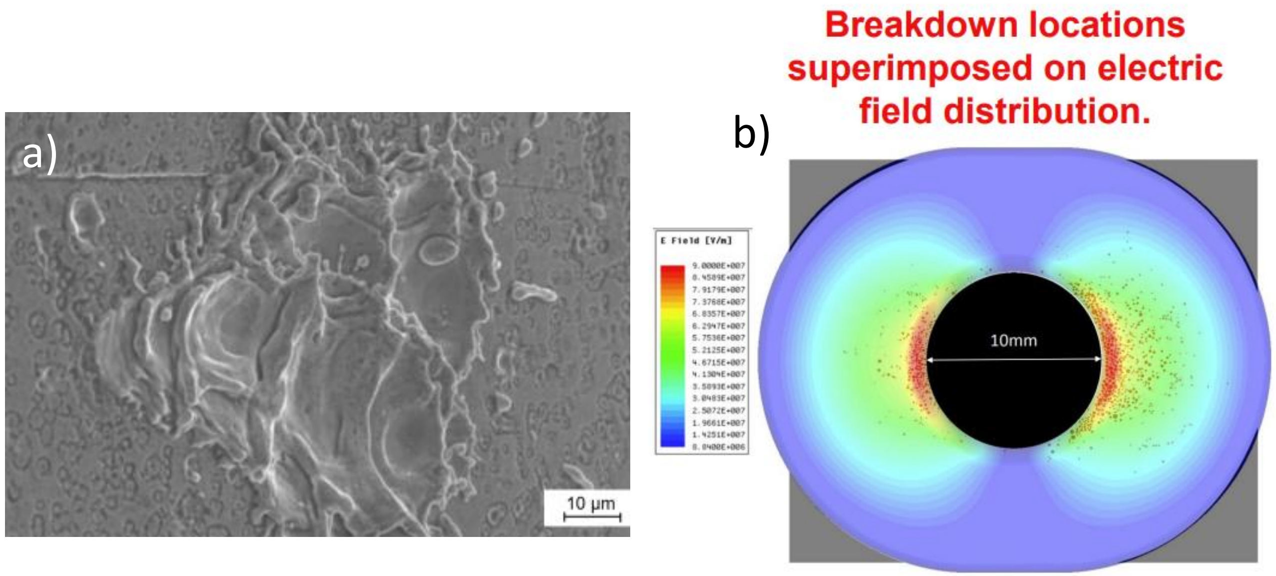
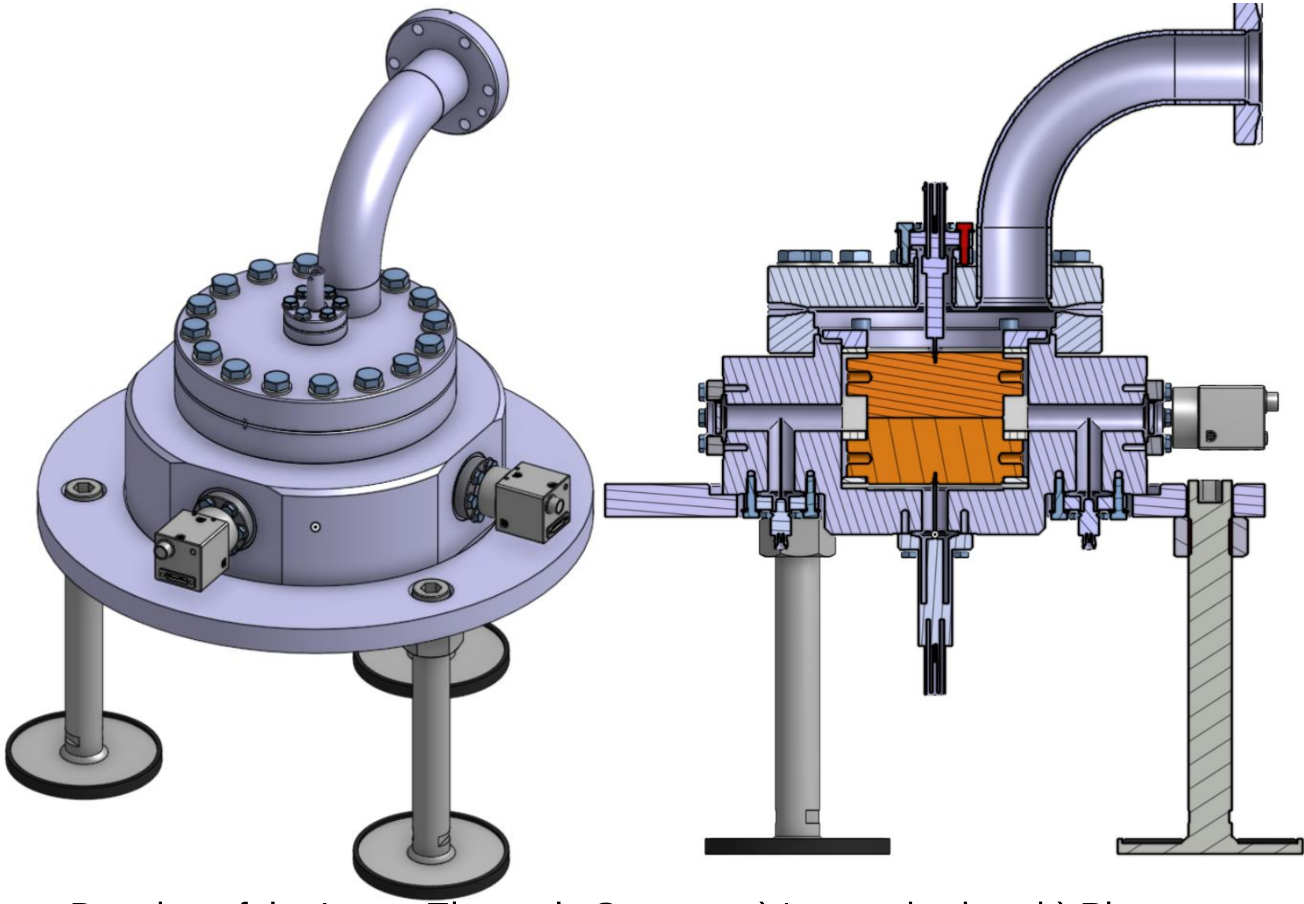


a)Damage caused by a breakdown inside an RF structure [2]. b) Uneven electric field distribution inside RF Cavity. Several breakdowns are marked on the side of the strucutre [3]

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.

Introduction: Application of the LES system.

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

- Better material understanding!

Image of Uppsalas Cryogenic LES [6].

Introduction: Previous work

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

10:30 AM - 11:00 AM

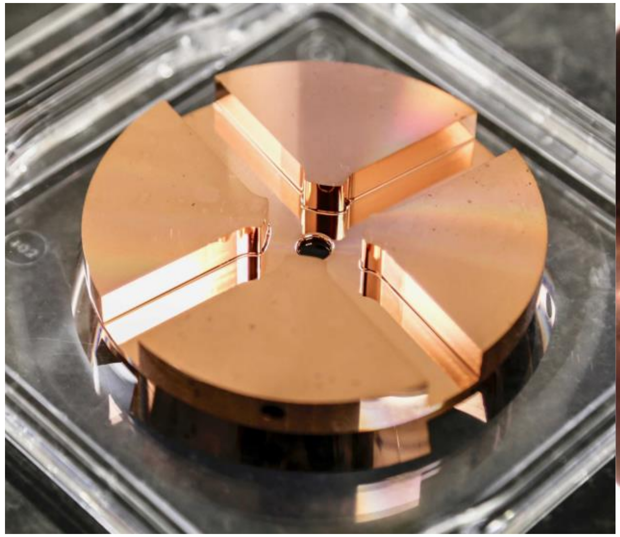
Presenter Catarina Serafim

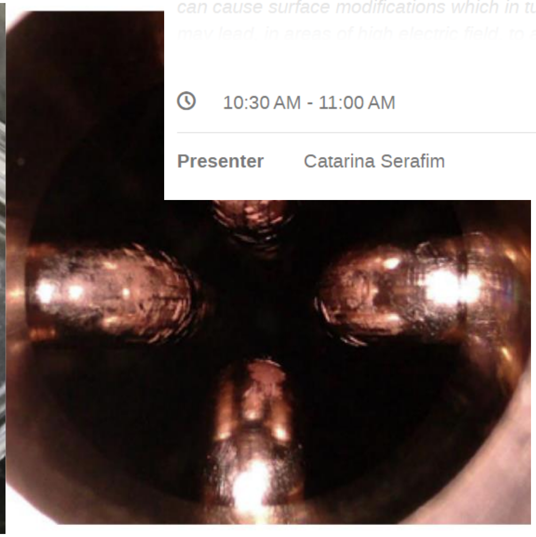
The LES has been involved in several large scale project trough the years, such as:

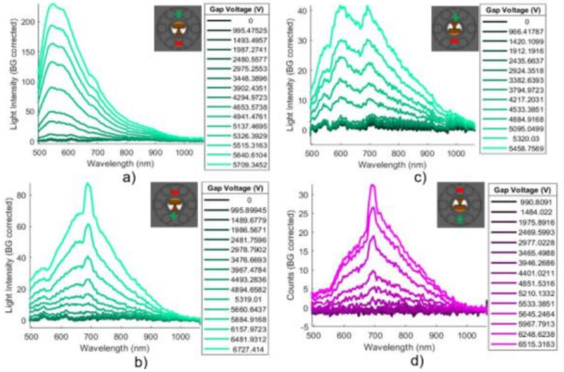
- High field exposure for CLIC material investigation
- Hydrogen blistering effect on conditioning related to RFQ structures.

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.

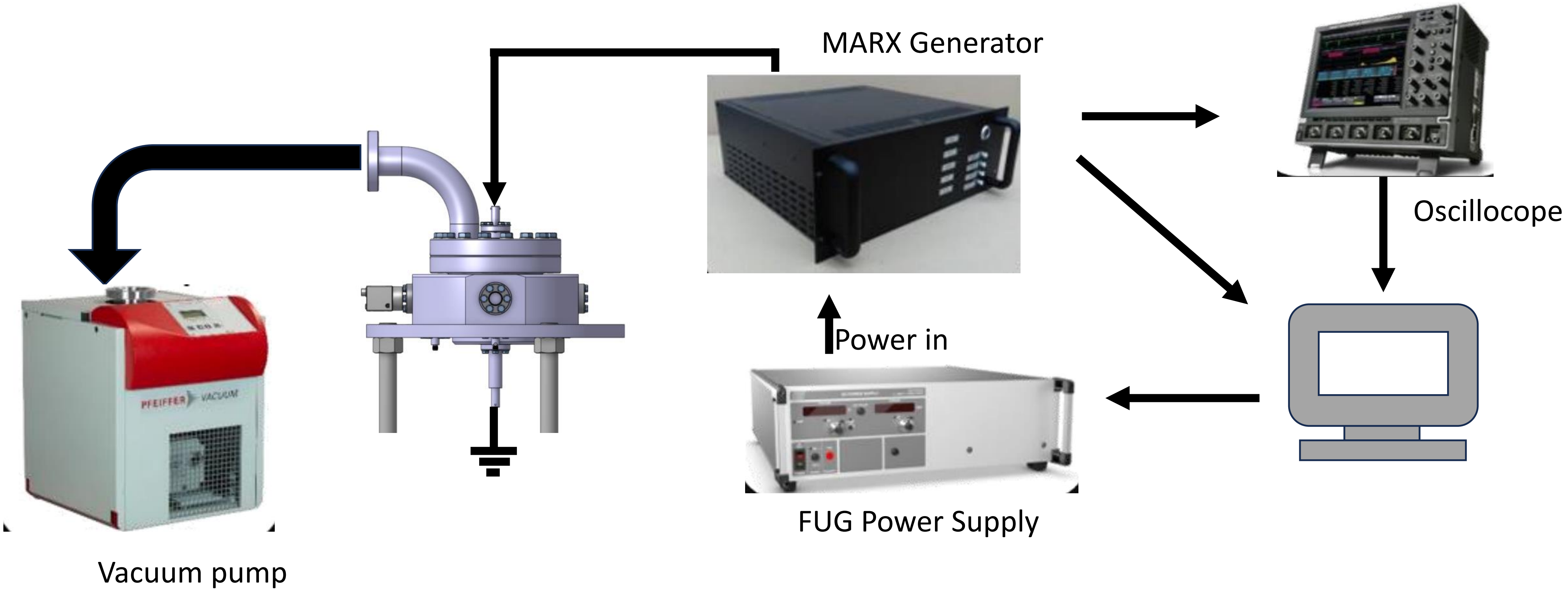




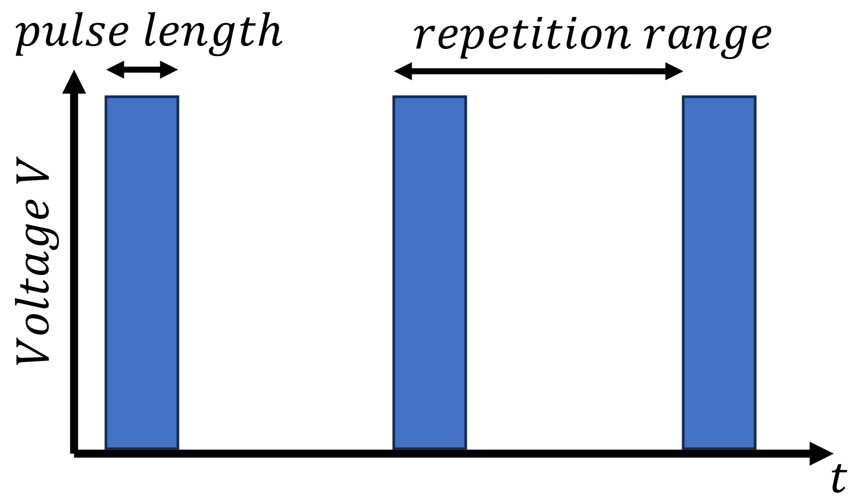


a) Image of CLIC accerlator cavity structure [5]. b) Inside an RFQ structure [6]. c) Light emission spectra from ridged electrodes [7].

Large Electrode System: Chamber and Setup



Large Electrode System: Conditioning

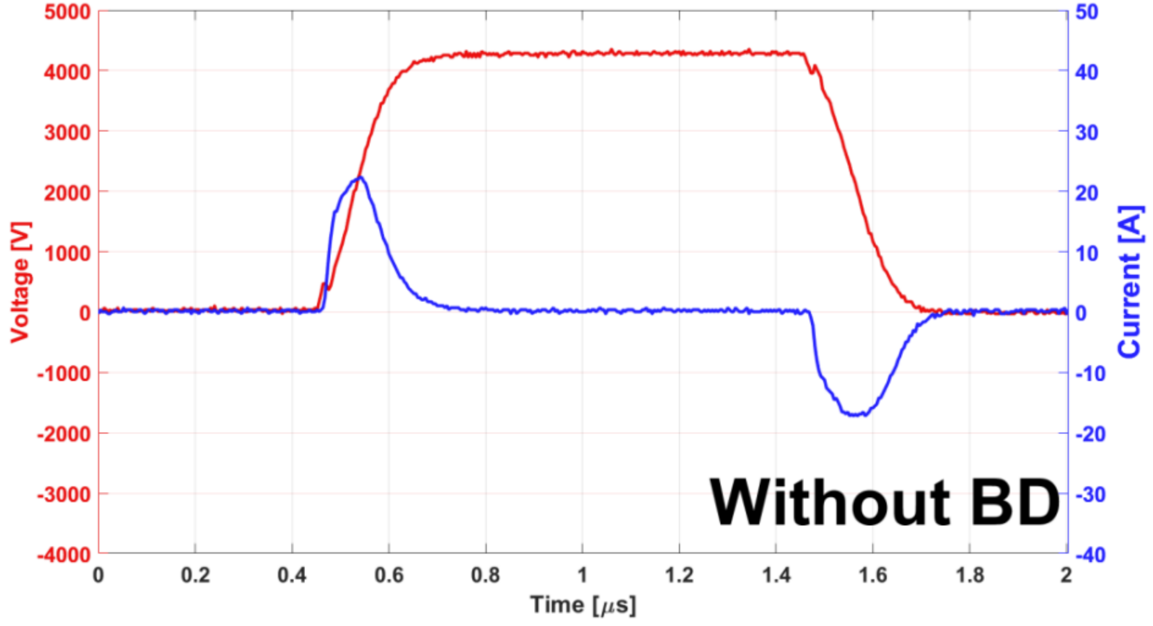


To condition:

Apply 1μs-1ms DC pulses to the electrodes

Can see breakdown in form of:

- High current
- Pressure Increase
- Light.



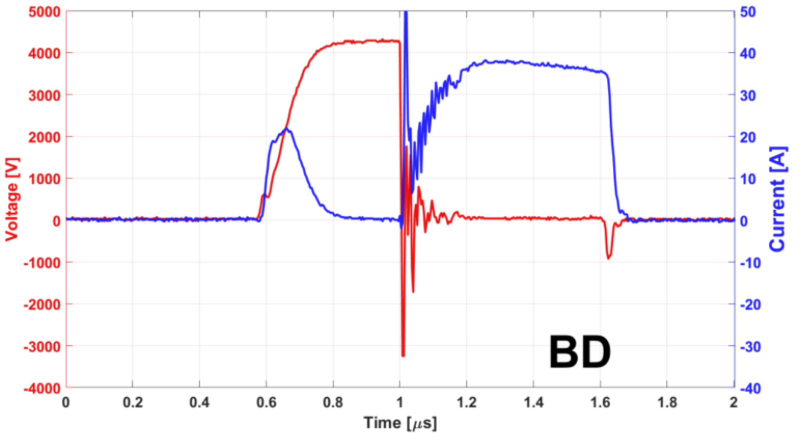
Large Electrode System: Breakdown Detection

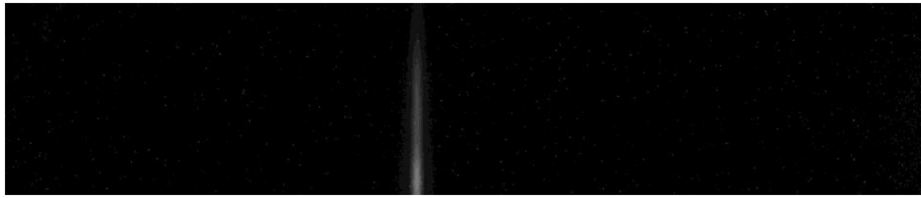
To condition:

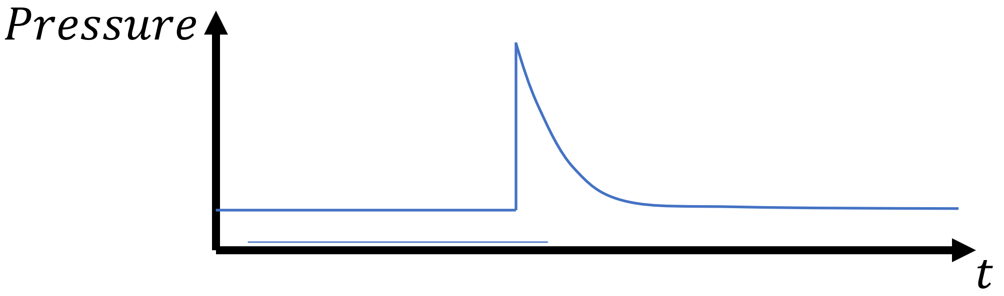
Apply 1μs-1ms DC pulses to electrodes

Can see breakdown in form of:

- High current
- Pressure Increase
- Light





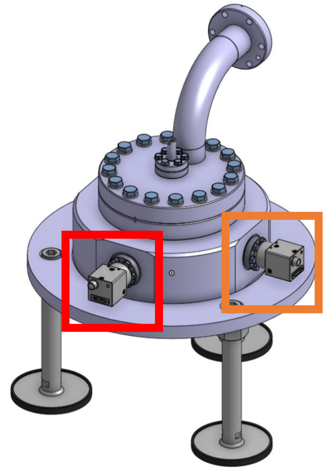


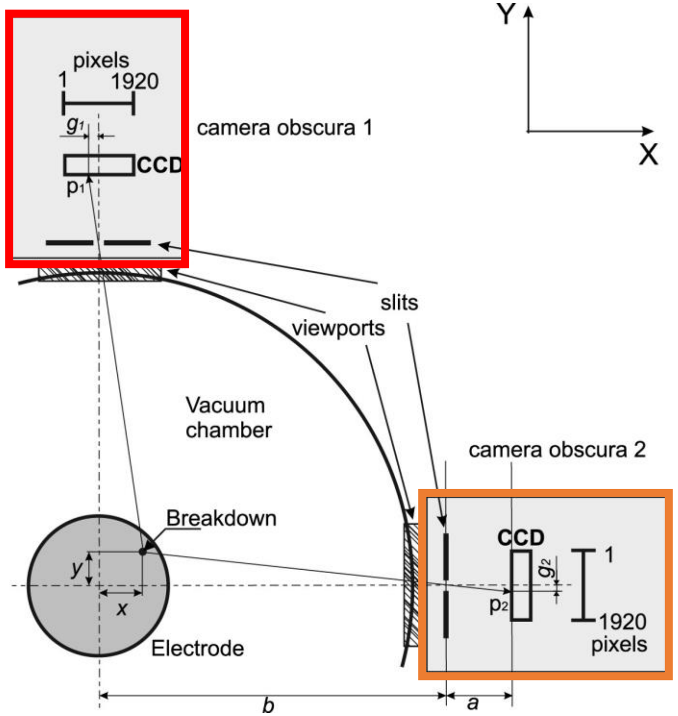
Large Electrode System: Breakdown Localization

- Uniquely identifiable breakdowns.
  - Position
  - Time
  - Applied Field

- Position on CCD

  → position on surface

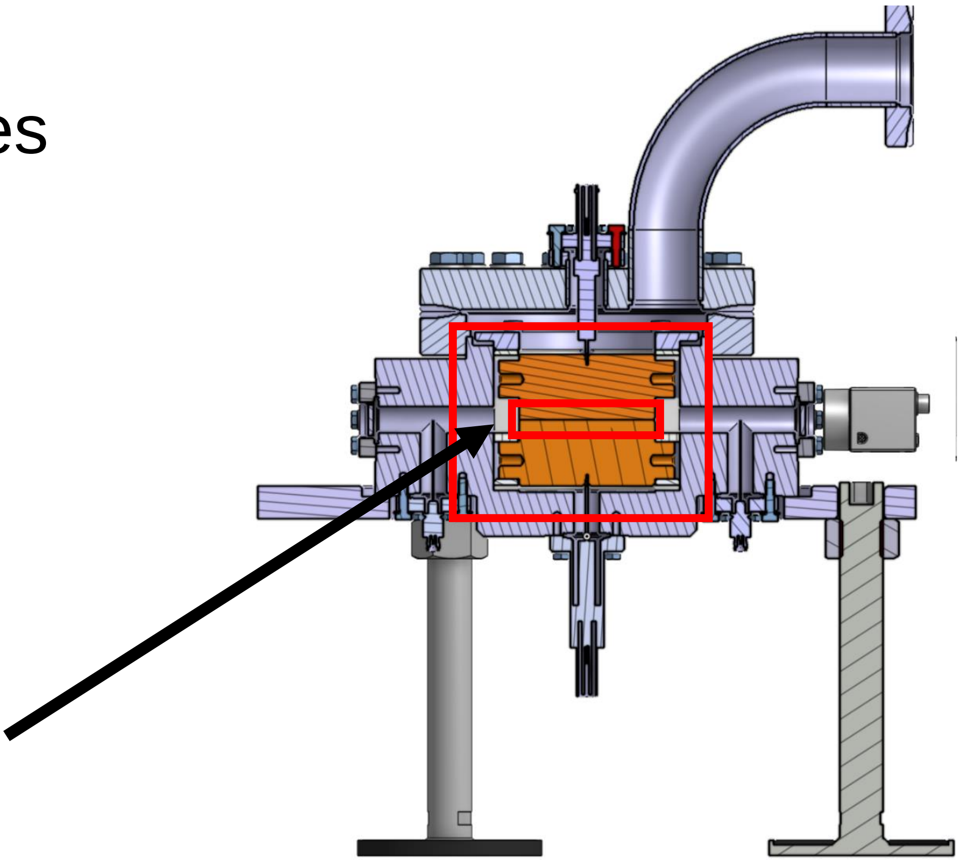


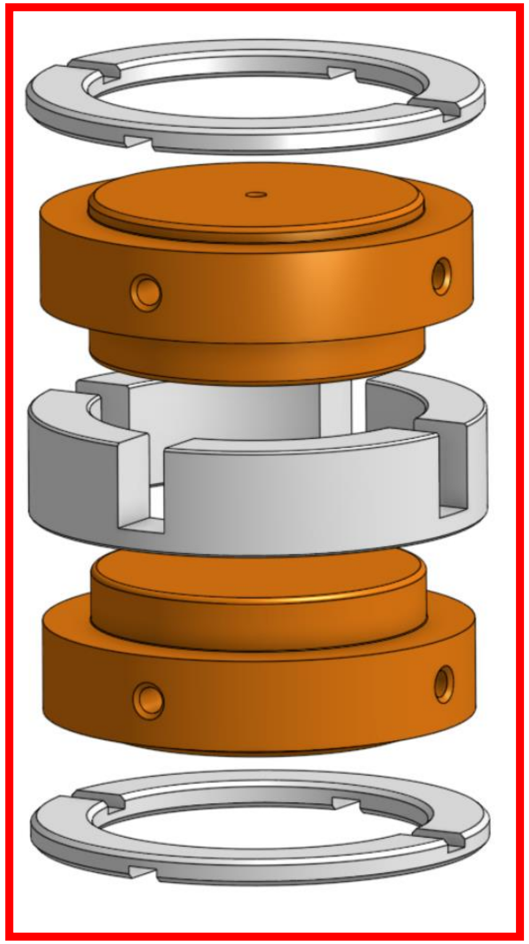


Breakdown identification setup. Two CCDs look inside the chamber and captures breakdown light [7].

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

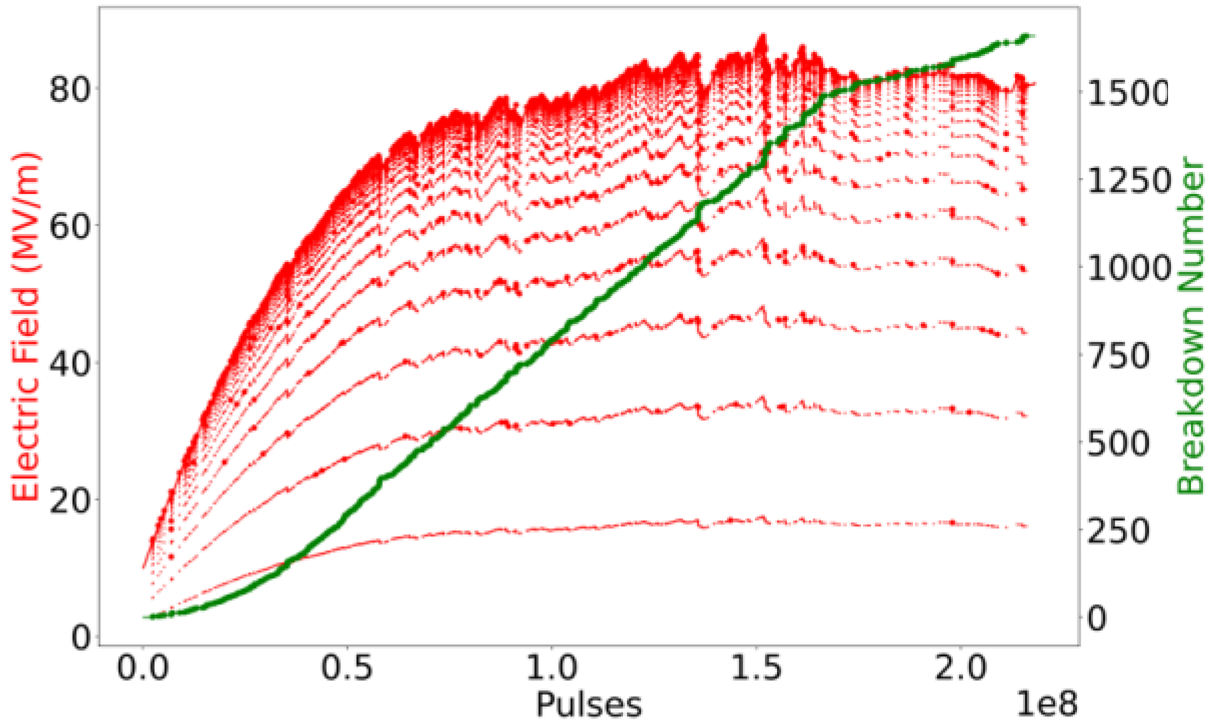




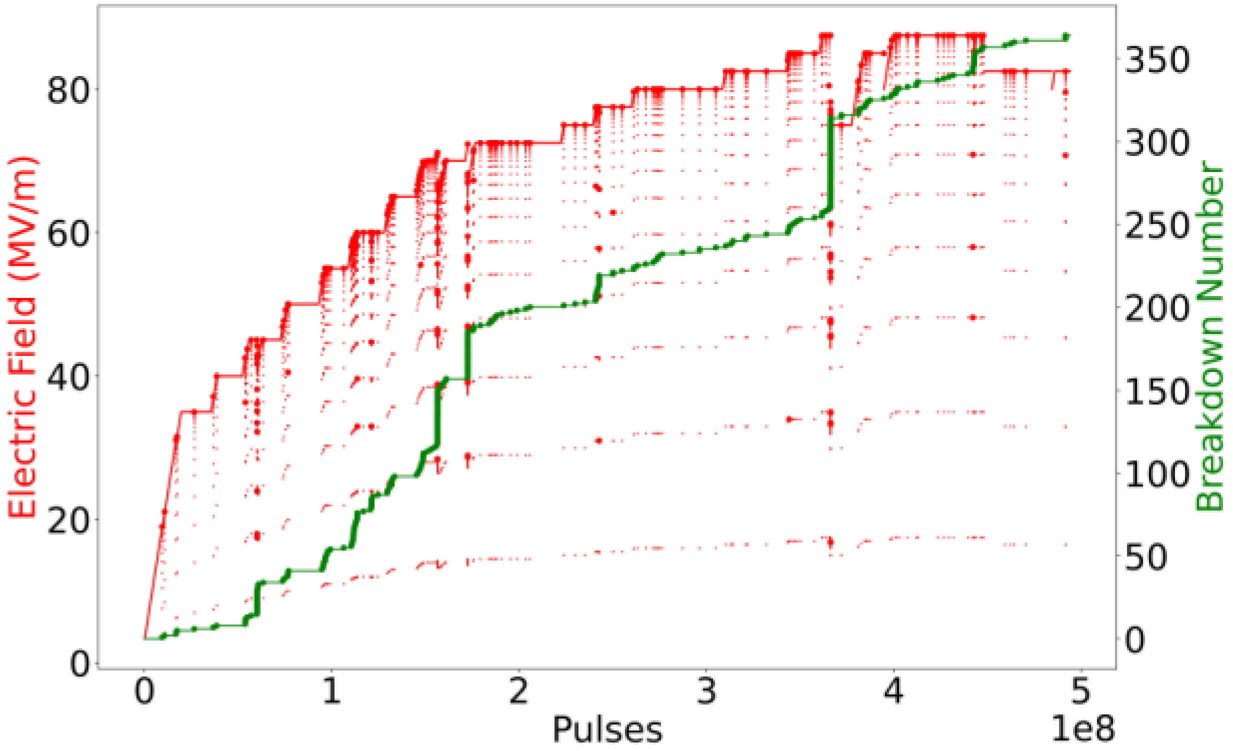
Conditioning Testing and Automatic Algorithm

Maximum Fields of Materials

- Conditioning controlled by breakdown rate



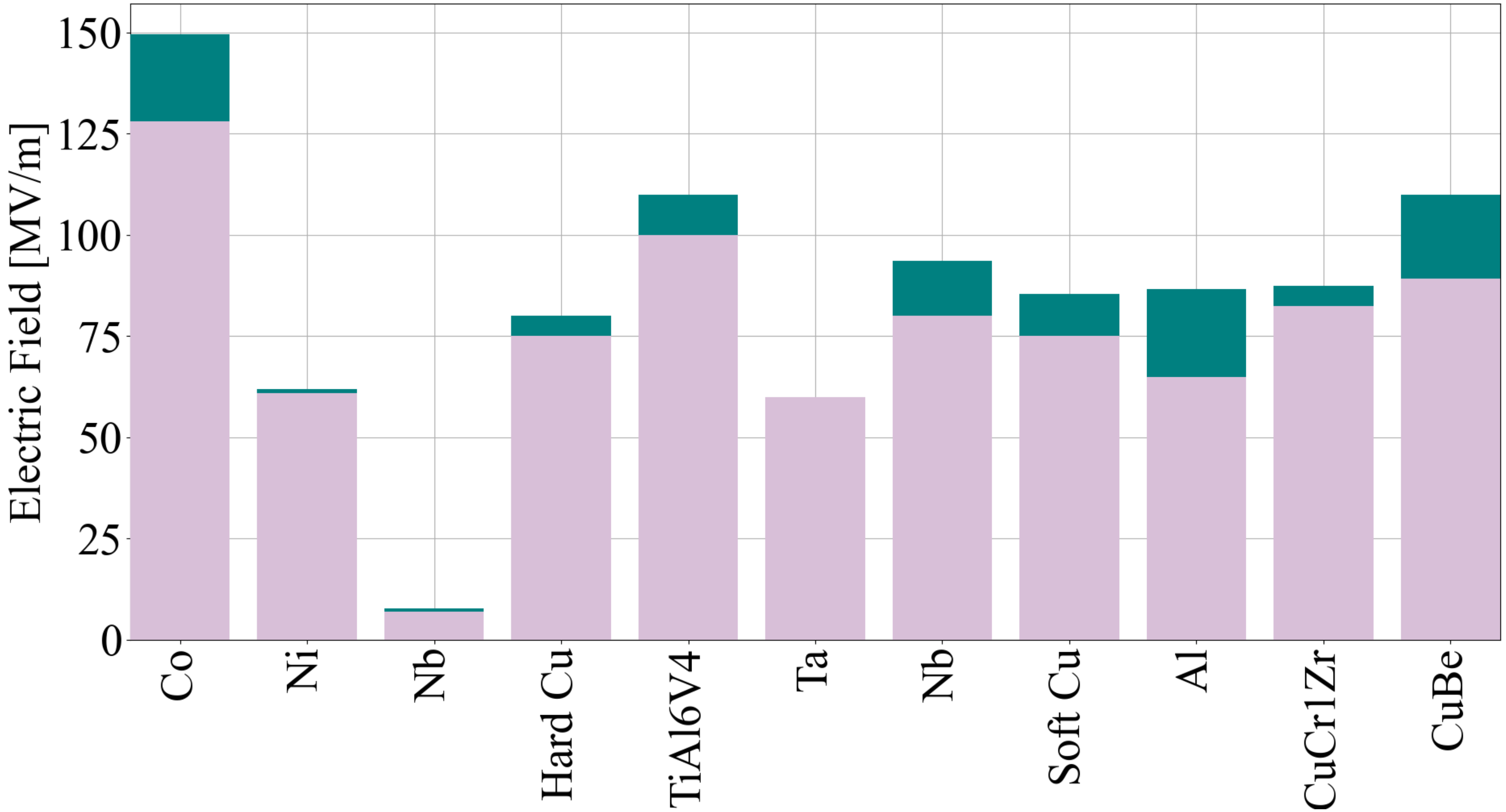
- Conditioning controlled by user
- Stays on the same field for several thousands of pulses



Maximum Fields of Materials

- Many materials have been tested and characterized at CERN

- Pink = Stable Field
- Green =Maximum field



Maximum Fields of Materials

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

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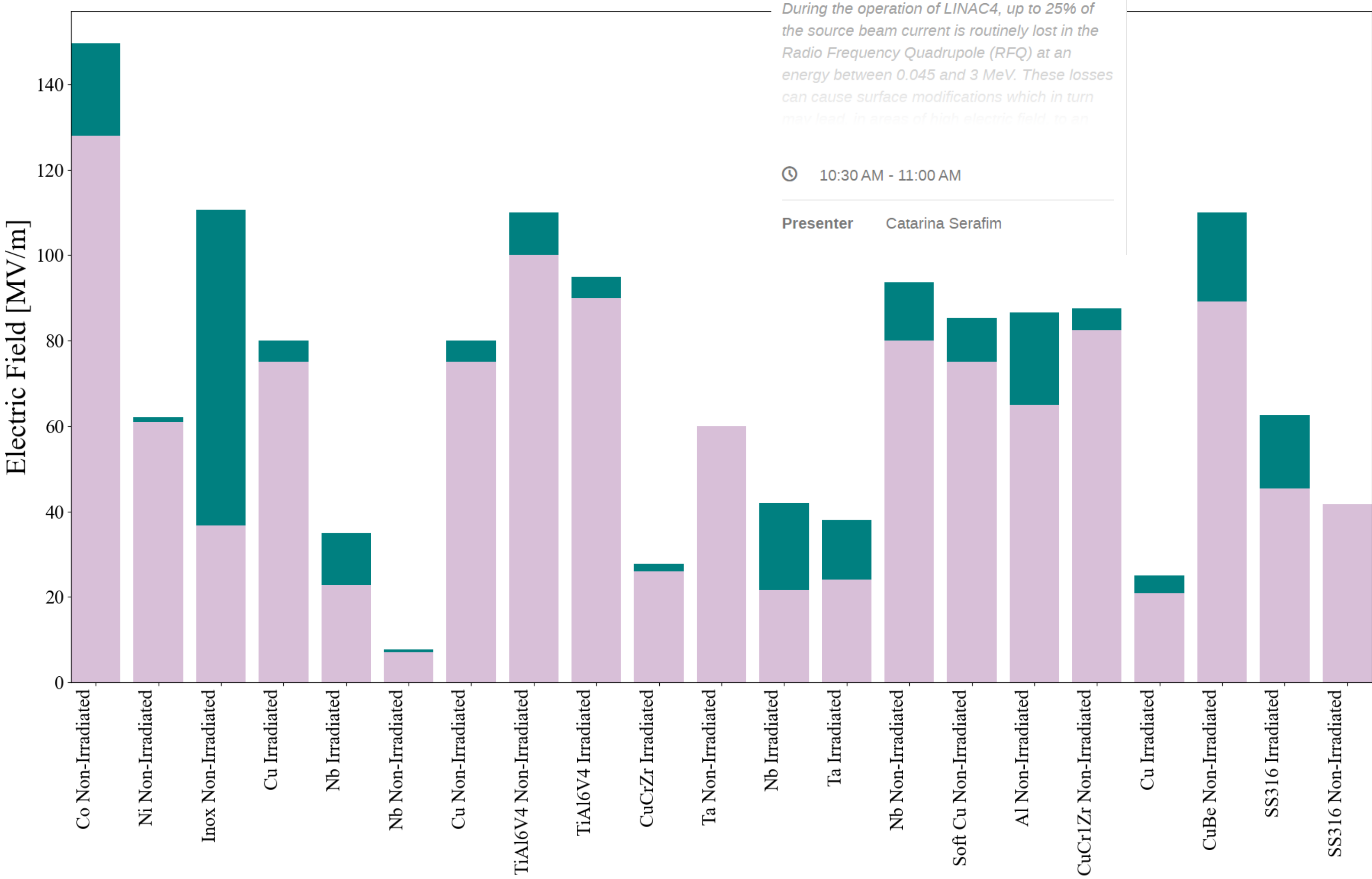
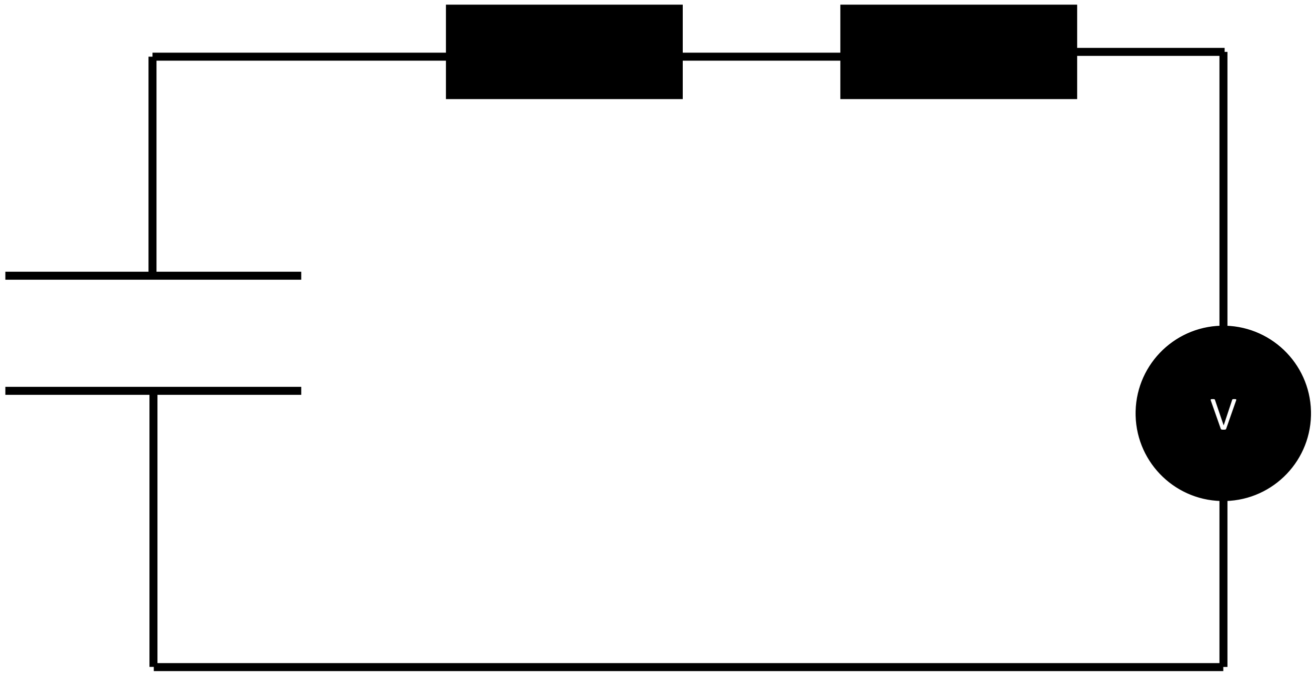
- Many materials have been tested and characterized at CERN
- Pink = Stable Field
- Green =Maximum field
- Irradiated materials have also been tested



Field Emission

Field Emission Test Stand

- Imagine a simple circuit with
  - Capacitor
  - Load resistor
  - Variable measuring resistor
  - Power source.

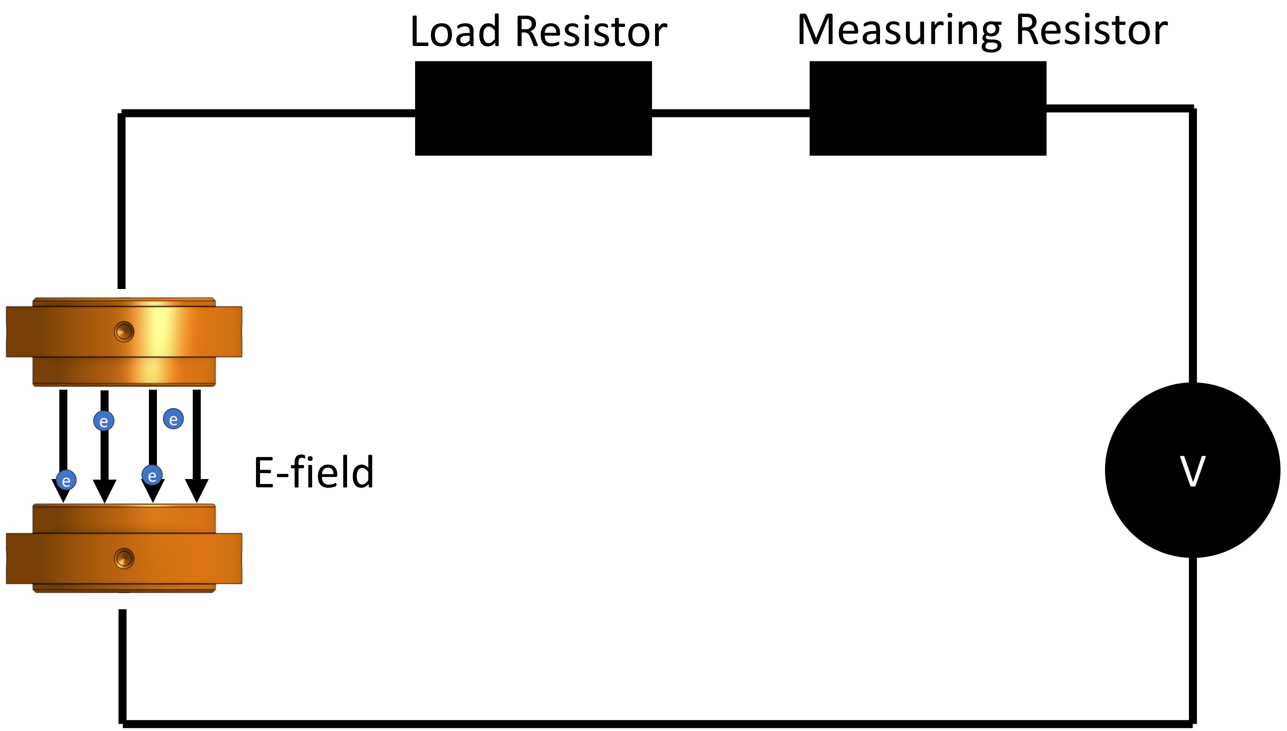


Field Emission Test Stand

- Imagine a simple circuit with
  - Capacitor
  - Load resistor
  - Variable measuring resistor
  - Power source.

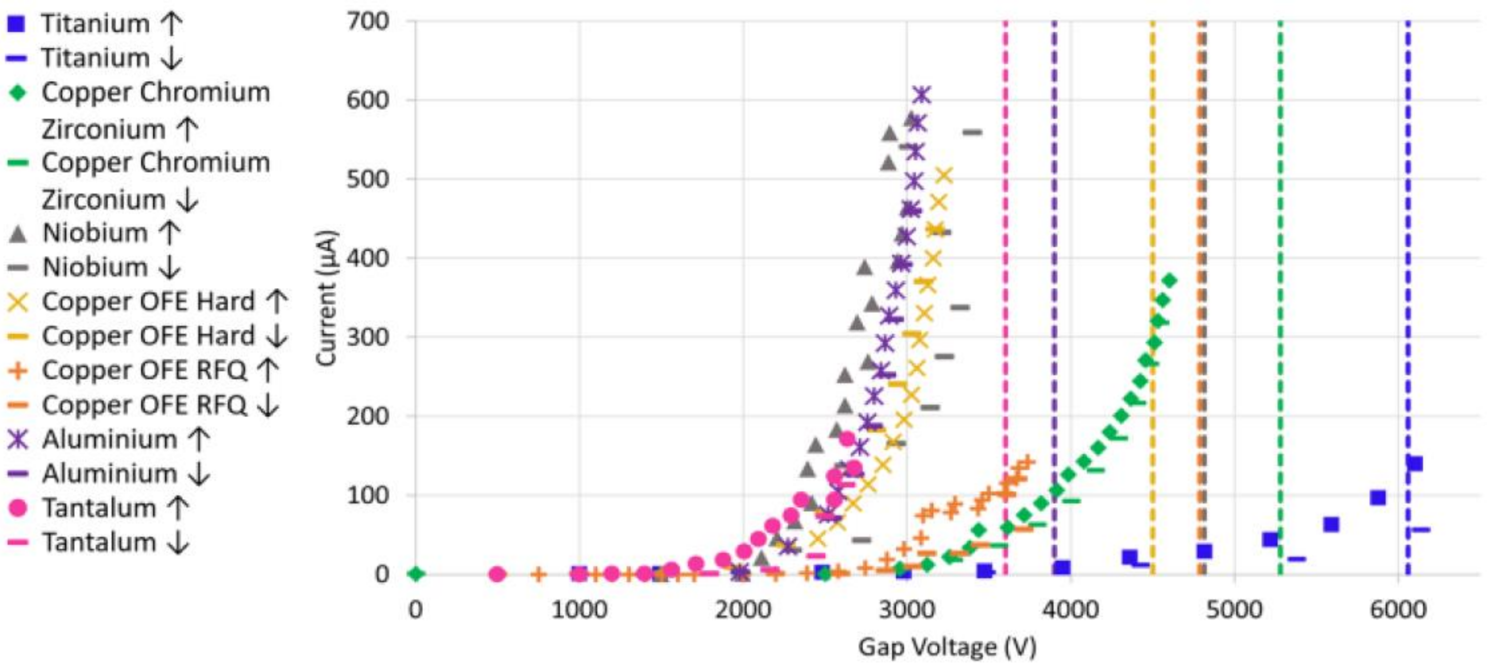
- Measure the current and fit it against the Fowler-Nordheim Equation

$$J = A\frac{\beta^2 E^2}{\phi}\exp(-\frac{\beta\phi^{\frac{3}{2}}}{\beta E})$$



Field Emission of Materials

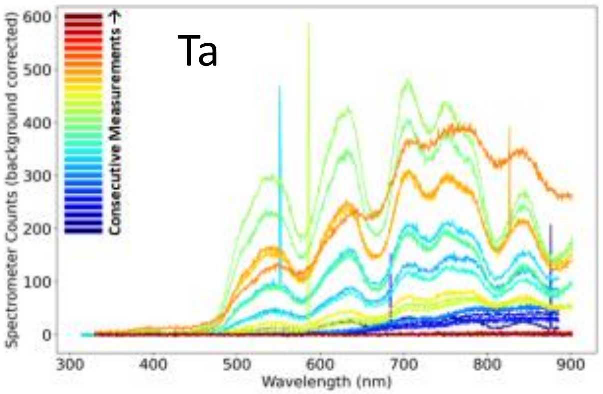
- Field emission current will have an exponential correlation with applied voltage.
- Dashes lines = maximum field reached during conditioning
- Higher field reached
  ⟶ Lower current emitted

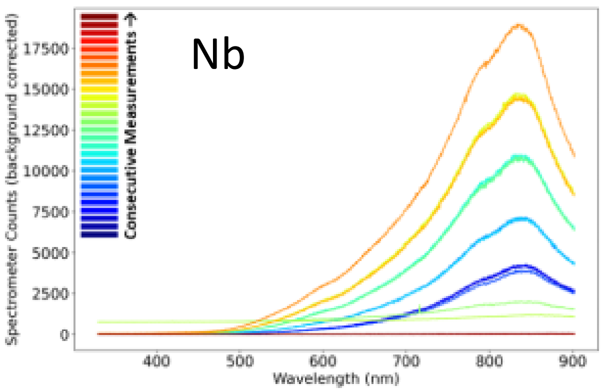


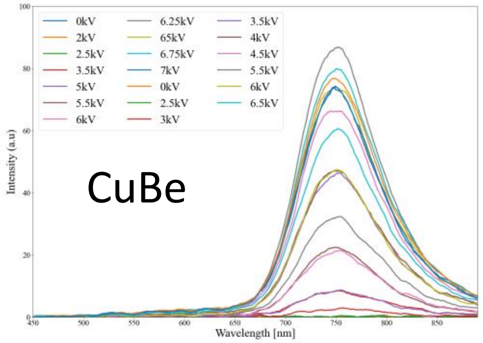
Light Spectroscopy

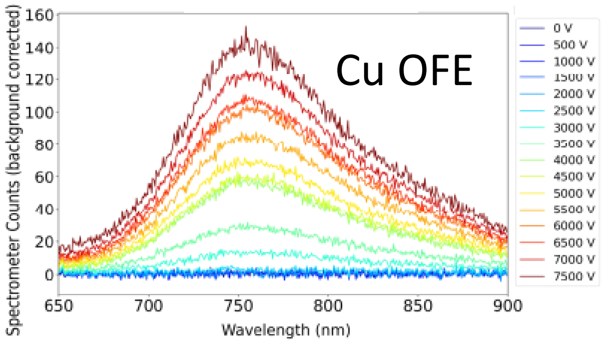
Light emission during field emission

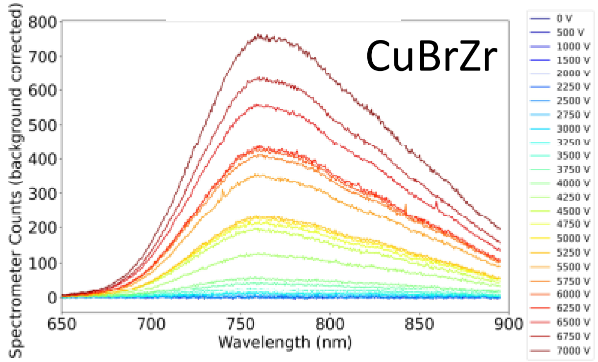
- Light emission is oberved during field emission.
- Spectra depends on the material
- In the optical-IR spectra
- Origin of emission:
    - Optical transition radiation?
    - Cathodeluminescence?
    - Plasmonic radiation?











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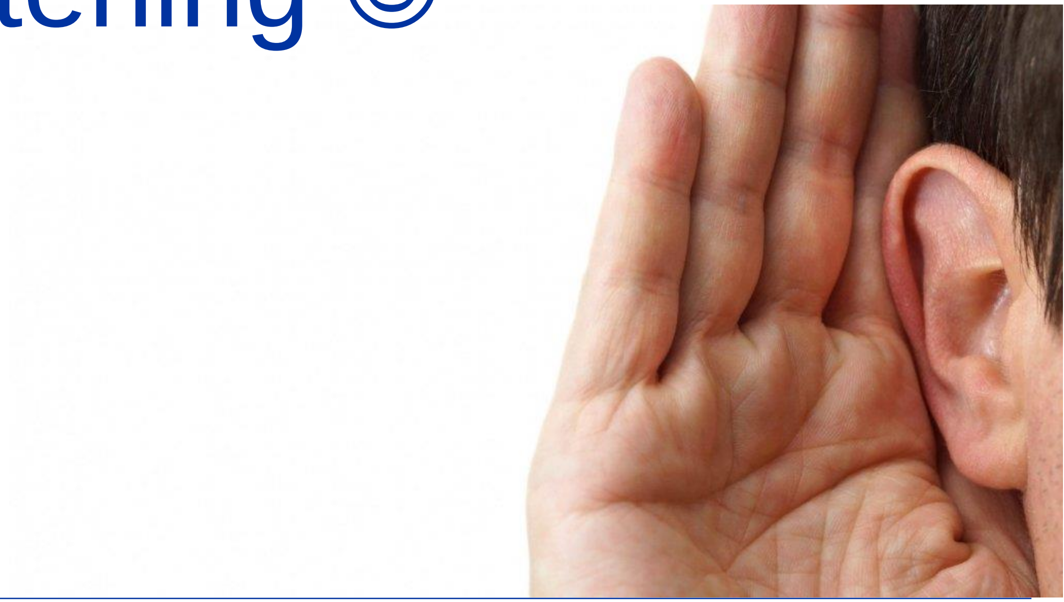


Additively Manufactured Electrodes

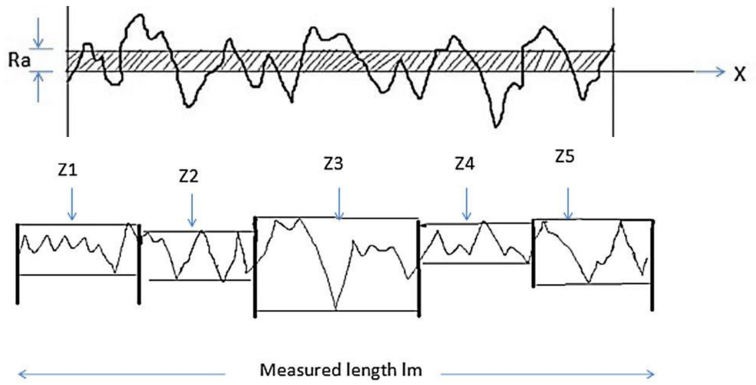
Additively manufacturing verus Milling

- Milling
  - Cutting out material from a chunk
  - Typical in manufacturing
  - Limits complexity

- Additively Manufacturing
  - Melt metal spheres using lasers
  - Causes very rough structures

Additively Manufactured Cathode

- Additively manufactured cathode was tested at CERN.
- Unlike the usual diamond machined surface.



$$R_z = \frac{z_1 + z_2 + z_3 + z_4 + z_5}{5}$$

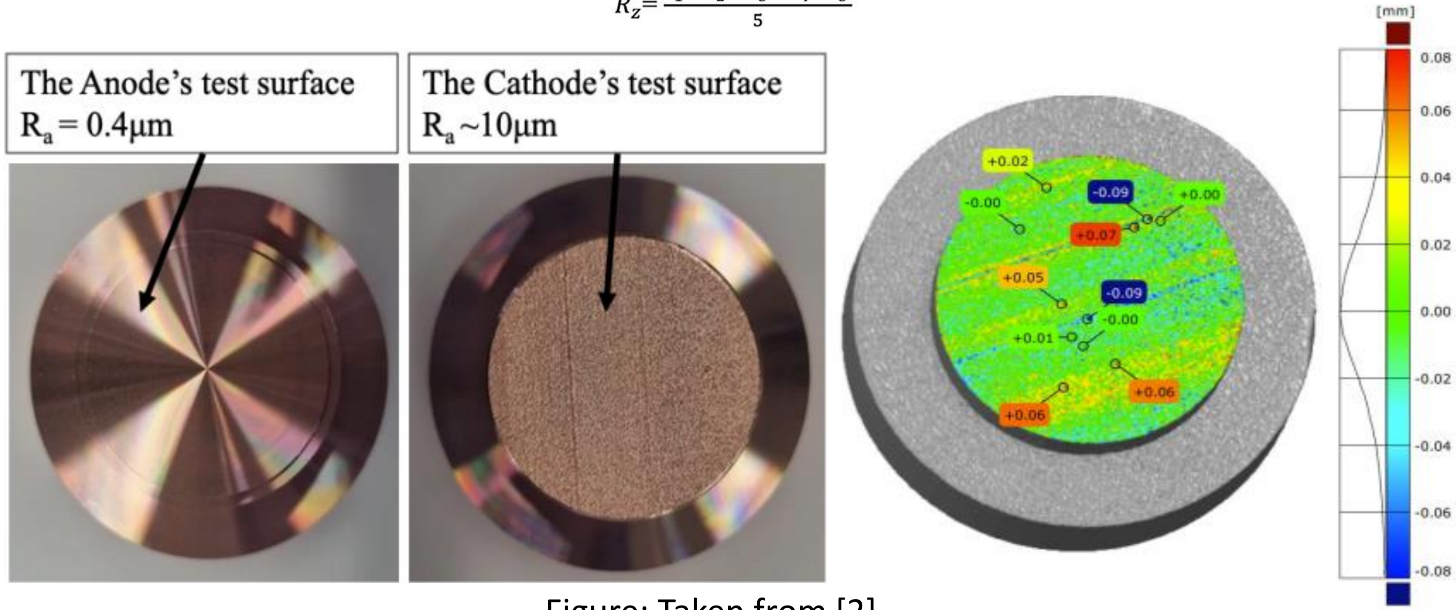


Figure: Taken from [2]

Additively Manufactured Cathode

- Reaches high electric fields

- DISLCAIMER:
  More thorough gap estimations to come.

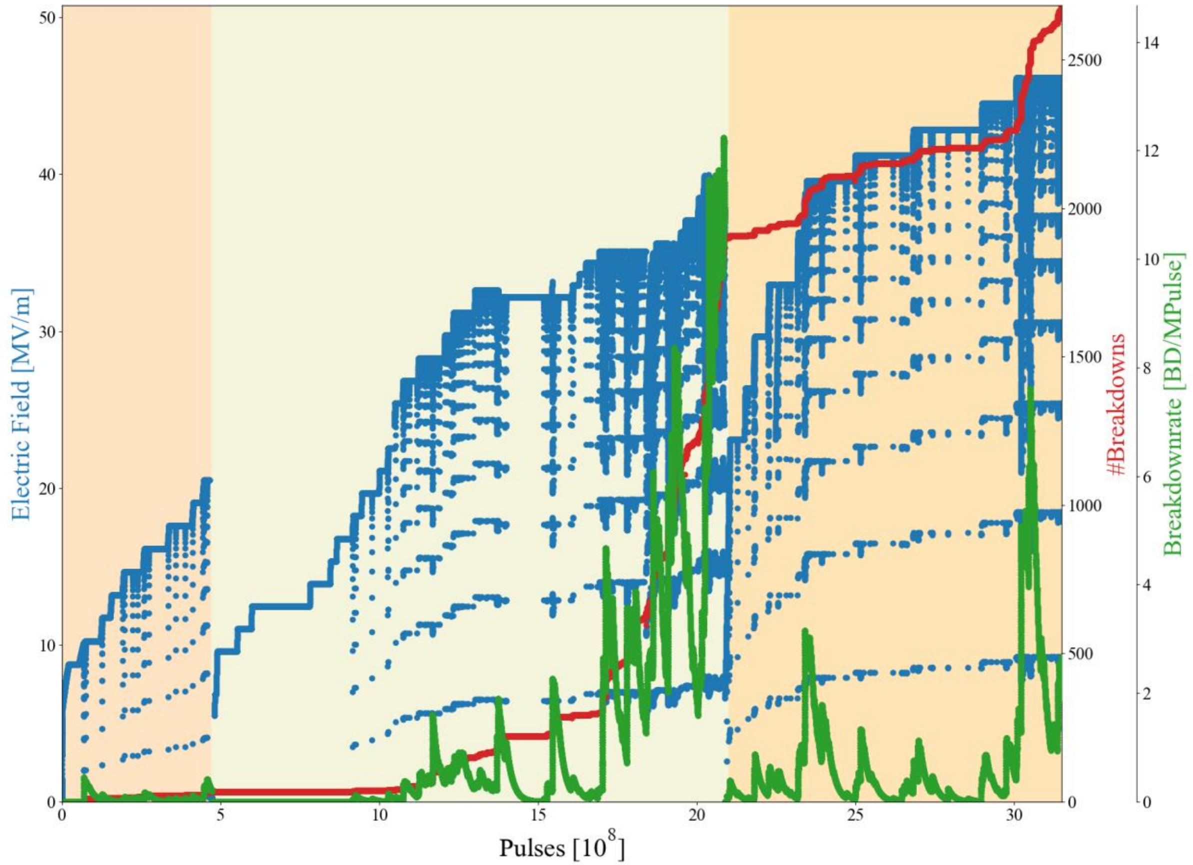


Figure: Taken from [2]

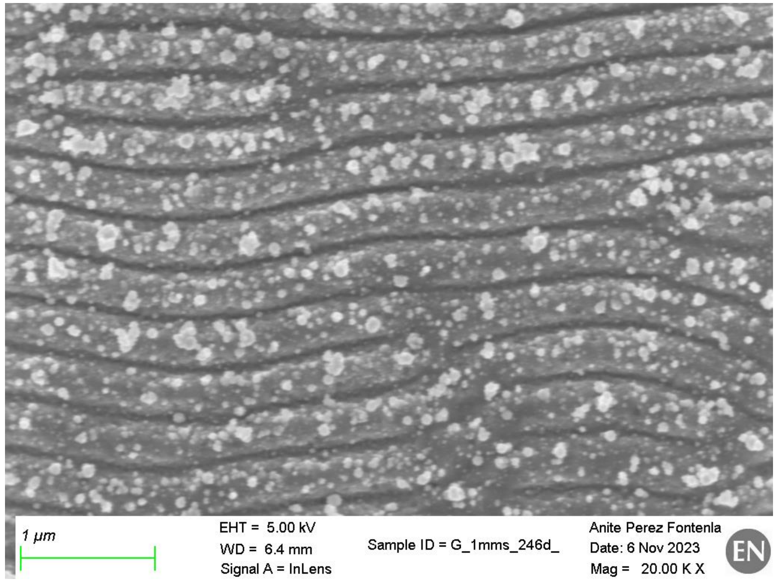
Future Plans

Nichrome Electrode Testing

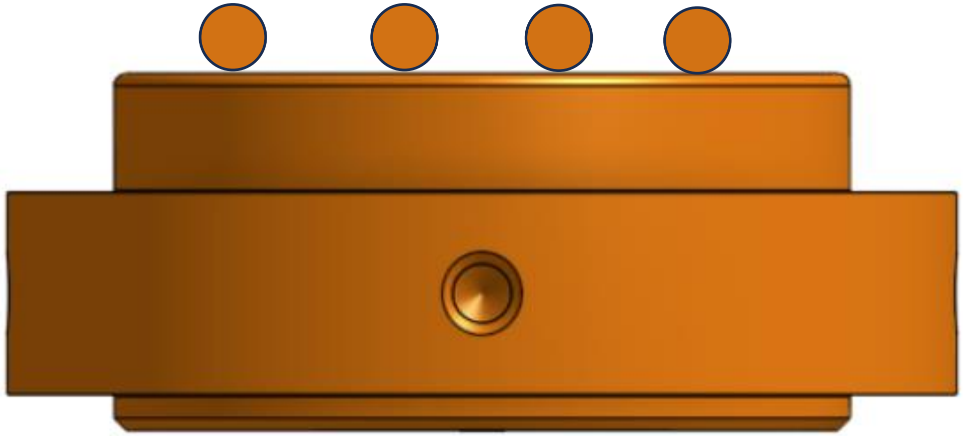
- The fabrication of a Nichrome covered Cu Electrode have been completed.

- Will reveal the field holding capabilities of this HOM absorption material for the CCC

Laser Ablation Nanopattern



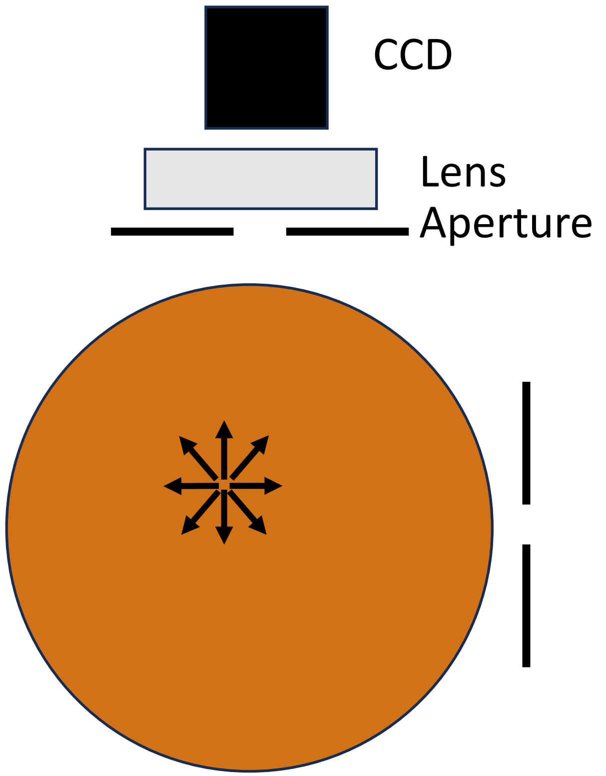
- Laser applied to surface causes surface plasmons
  - -> Causes periodic patterns
  - ->Causes nanospheres as a bi-product

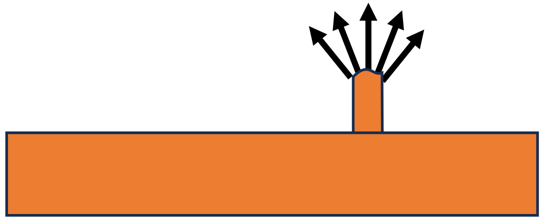


- Investigation of plasmonic structures in high field application and its reaction to conditioning

Field Emitter Localization

- By upgrading the already establish breakdown localization system, we hope to localize poential field emitters ocurring during conditioning/field emission





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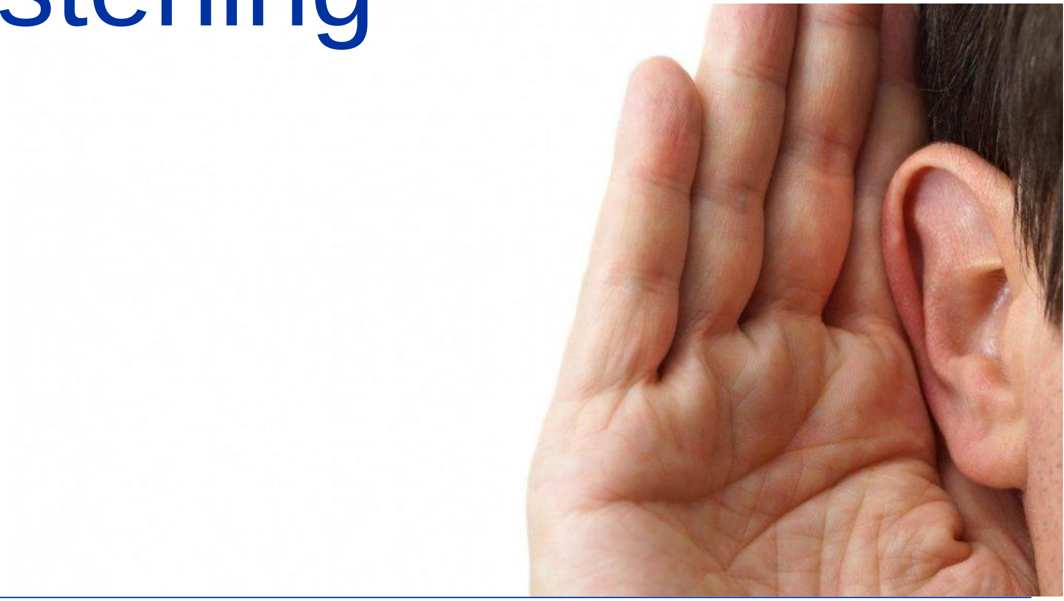
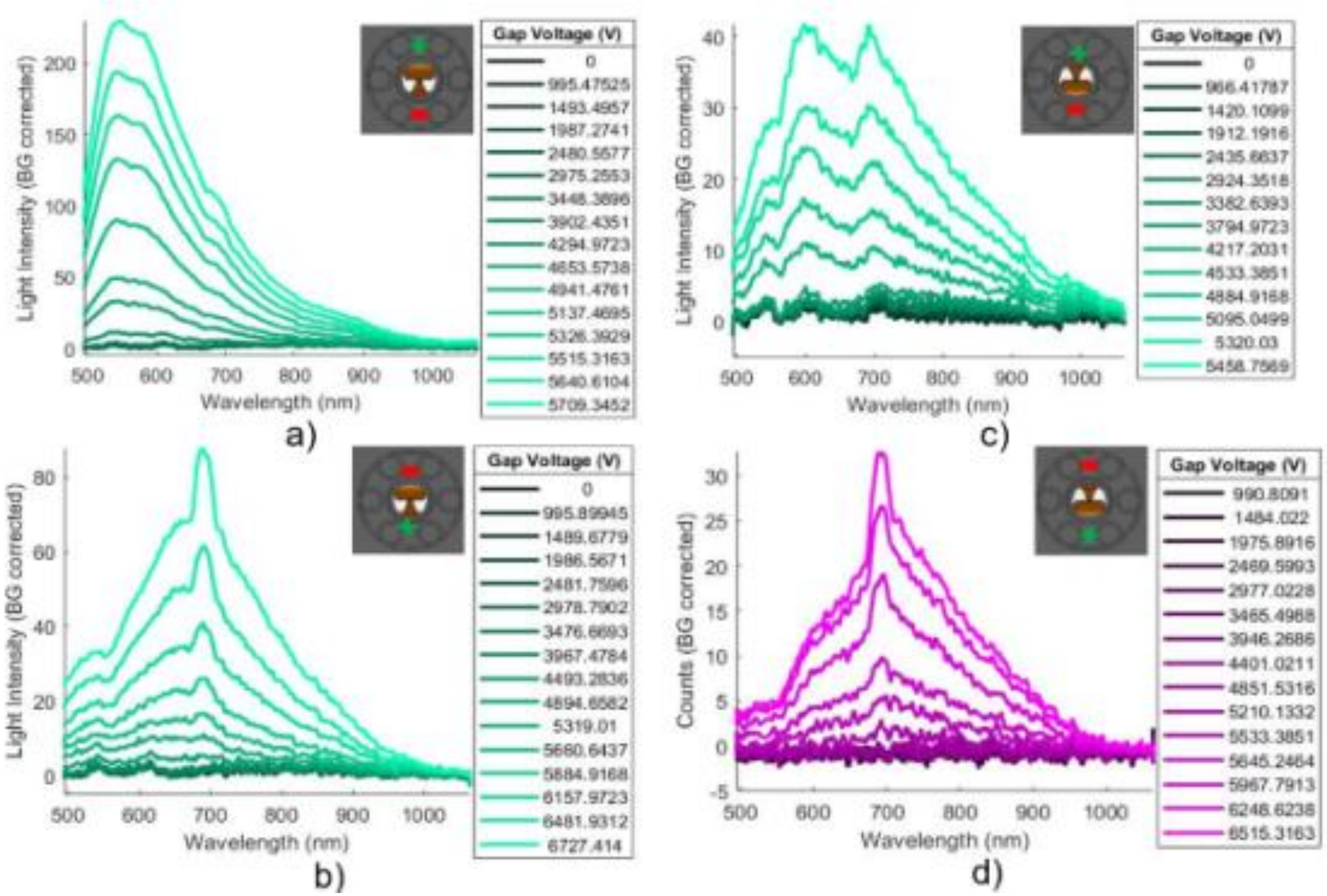


Light emission during field emission

- Spectra can change due to electrode geometry.



Nichrome Electrode Testing [hoder slide in case we start testing this week]

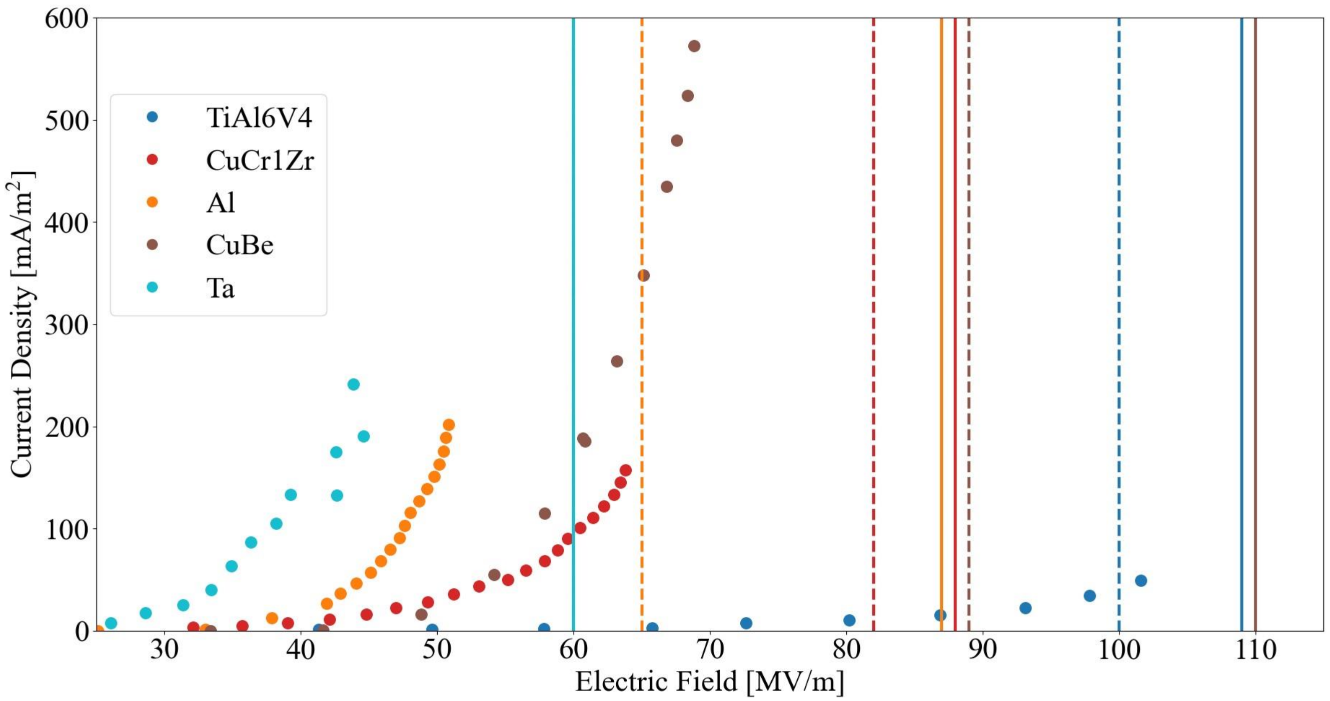
- The fabrication of a Nichrome covered Cu Electrode have been completed.

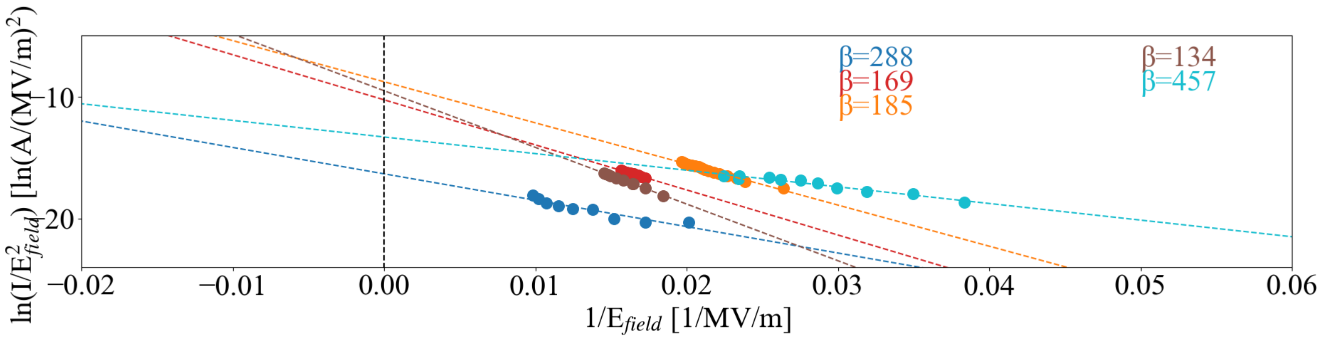
- Will reveal the field holding capabilities of this HOM absorption material for the CCC

Field Emission of Materials (normalized surface area, does it

- Many materials have been tested and characterized at CERN

- Pink = Stable Field
- Green =Maximum field





Plasma ignition during breakdown

- Breakdown spectra during breakdown
- Identifyable ions from materials
- Cu I, Cu II, Cu III

- Measure time intensity at specific wavelengths