Vacuum breakdown and field emission using CERN’s pulsed DC systems.

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Outline

CLIC Project

What is a breakdown?

RF and DC breakdown investigation systems.

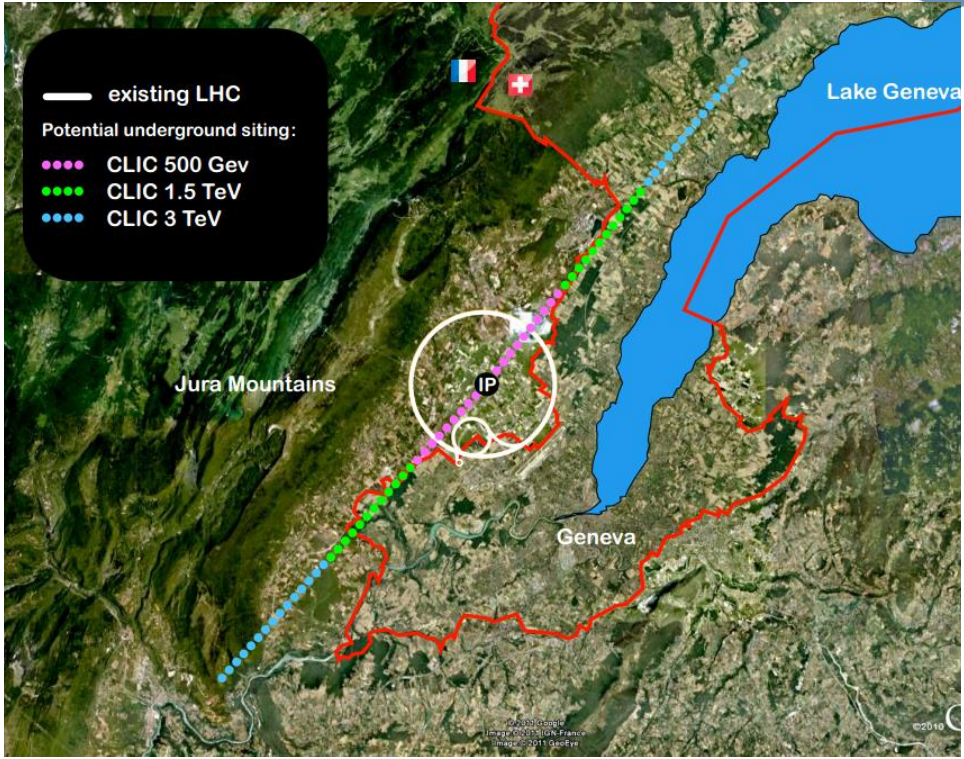
Observations of Breakdowns

Conditioning and material testing

Field Emission Measurements and Development

THE CLIC PROJECT

- **C**ompact **L**inear **C**ollider
- Electron positron collider
- 3 phase build
- 3TeV collision energy

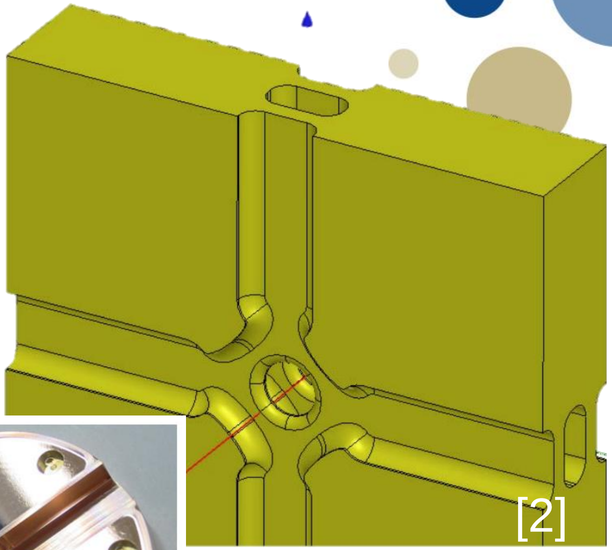


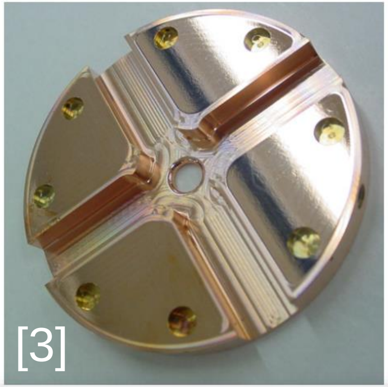
CLIC STRUCTURES

- Why can’t we have unlimited acceleration?
- Due to breakdowns!

CLIC STRUCTURES

- 100MV/m acceleraton
- 250MV/m surface electric field.
- BDR ~1e-7
- Limited by breakdowns!





[2] CLIC ACCELERATING STRUCTURE DEVELOPMENT –W. WUENSCH
[3] DESIGN OF THE CLIC MAIN LINAC ACCELERATING STRUCTURE FOR CLIC CONCEPTUAL DESIGN REPORT- A. GRUDIEV, W. WUENSCH

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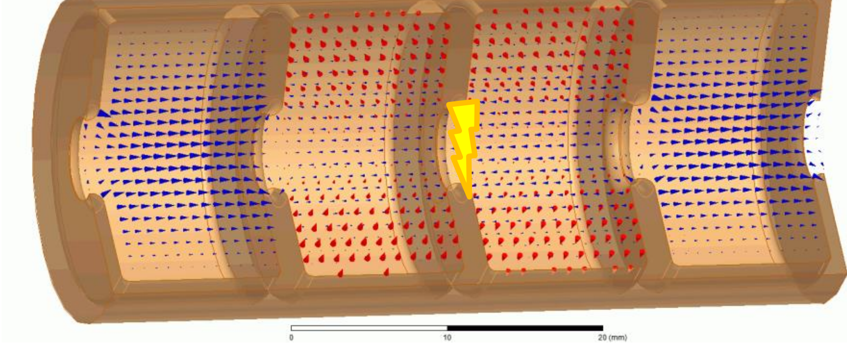
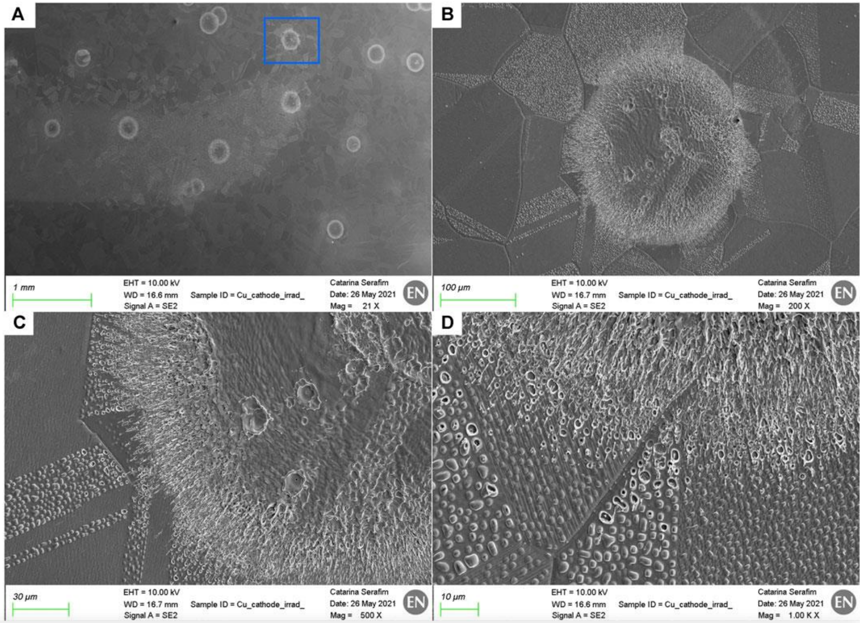
What is a breakdown?

- When applying high surface electric field, a discharge will occur.
- Atoms and electrons flow out from an emitting area.
- Ionization leads to a plasma avalanche!
- Disturbs/kick the beam
- Breakdowns leaves physical damage on the surface

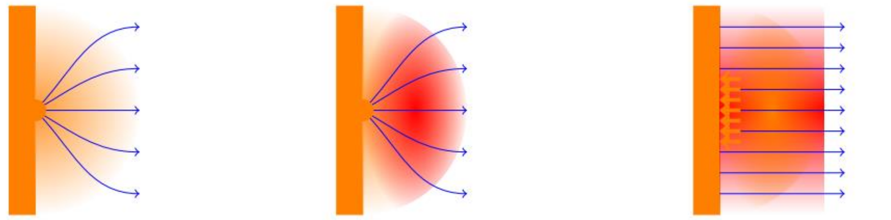




[5] INVESTIGATION ON DIFFERENT MATERIALS AFTER PULSED HIGH FIELD CONDUCTING AND LOW-ENERGY H-IRRADIATION – C. SERAFIM
[6] MULTIPACTING BREAKDOWNS – W. WUENSCH

How do breakdowns evolve?

- Atoms and electrons starts emitting from a spot on the cathode surface.
- Unknown why it occurs.
- Electrons ionize neutrals, are accelerated back at the cathode surface.
- Plasma sheath results in a huge increase in emitted current.
- The electron current collapses the field.

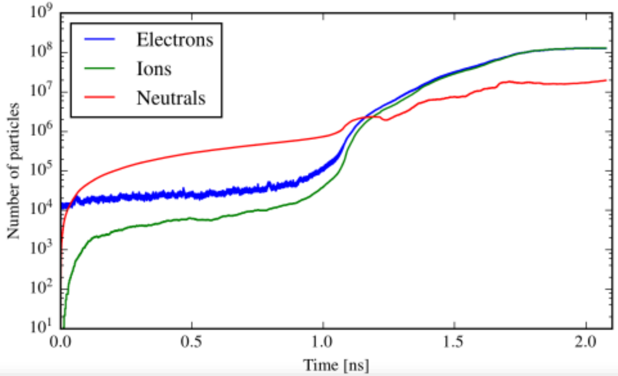


(a) Field electron emission and gas buildup.

(b) Ionization of the built-up gas.

(c) Volume-defined phase and surface bombardment.

Figure 4.1.: Important stages in the ignition of a vacuum arc.



[7] AVOIDING VACUUM ARCS IN HIGH GRADIENT NORMAL CONDUCTING RF STRUCTURES – K. NÆSS

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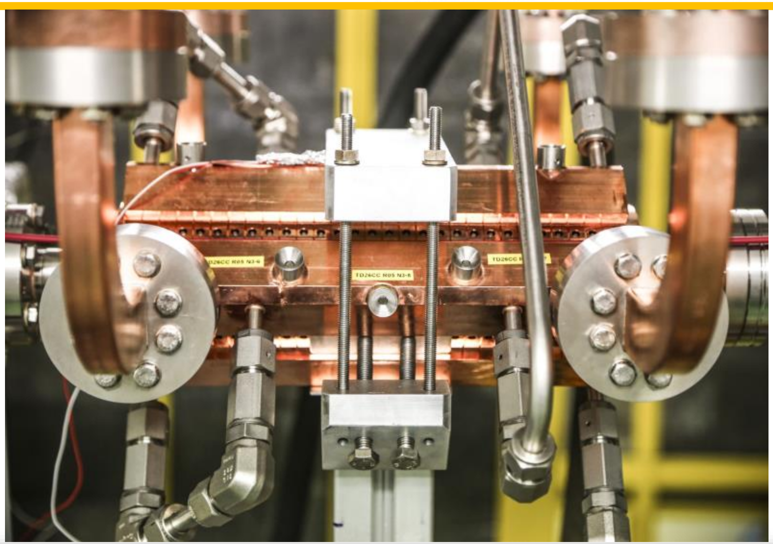
RF Structure Testing

- CLIC has several klystron based X-band test stands

- Testing prototype accelerating structures+ other RF components.

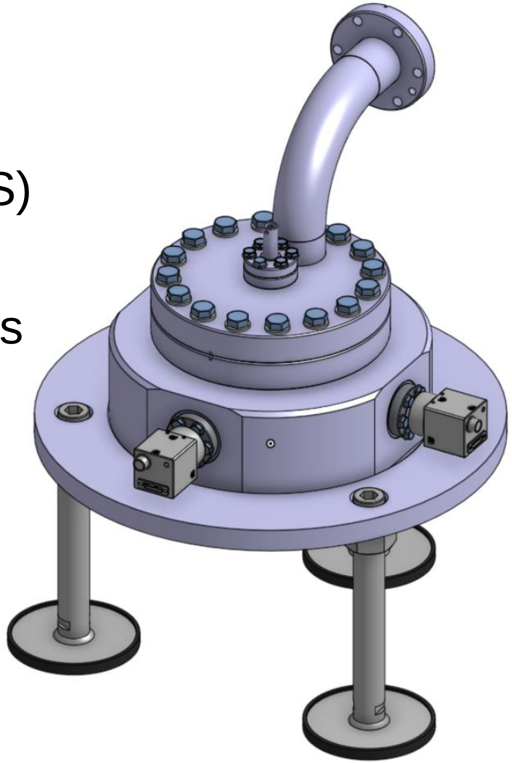
- We can complement the system!

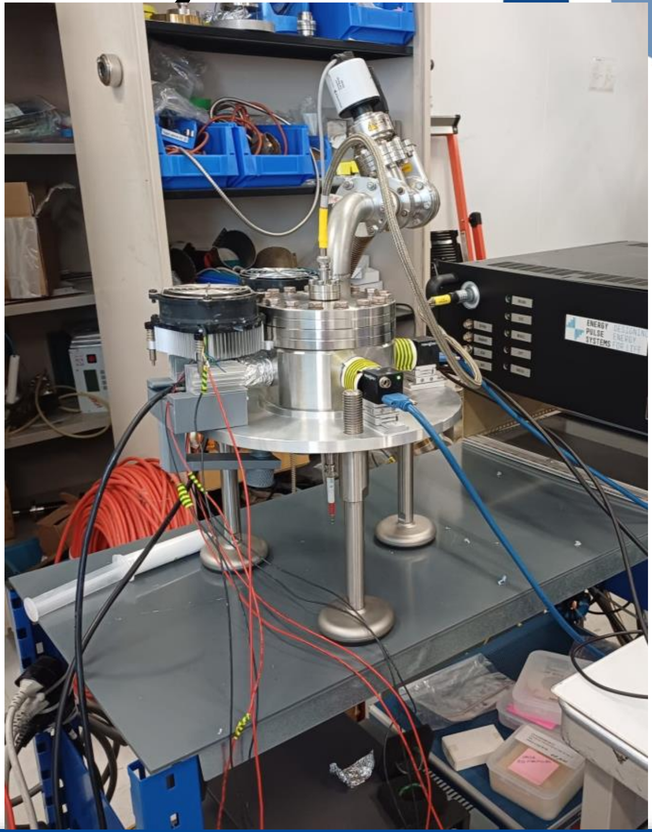


Xbox 2 test stand. Image provided by Lee Milar.

CERN’s Large Electrode System

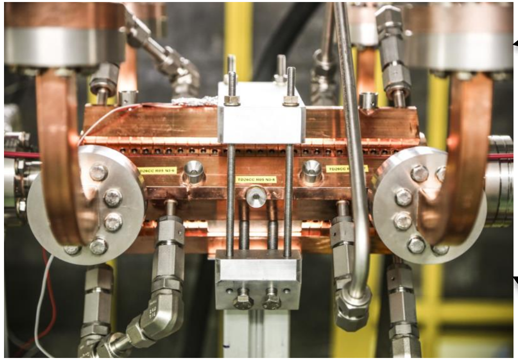
- Large Electrode System (LES)
- Small vacuum chamber
- Replacable, simple electrodes
- HV pulses via a Marx generator.
- Adaptabel diagnostics.

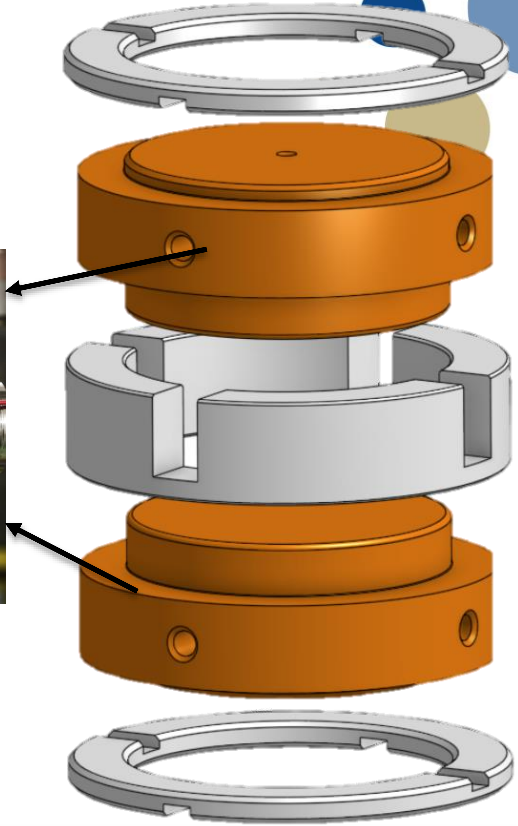




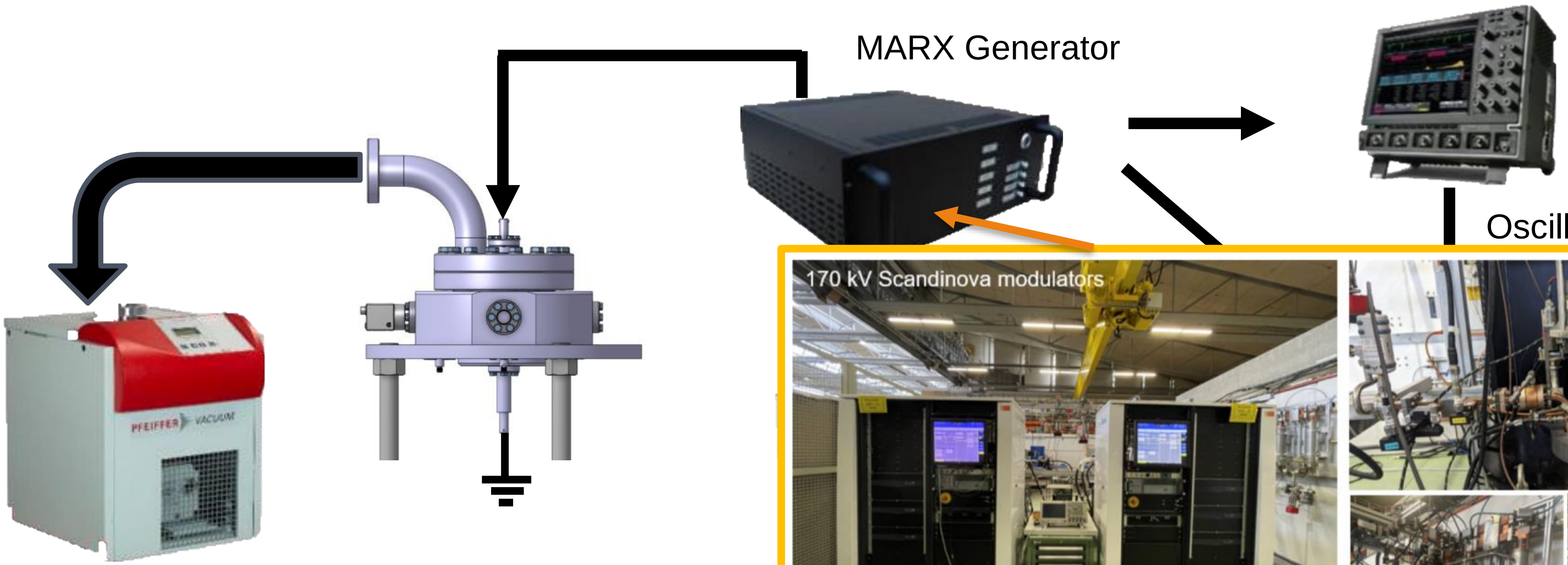
CERN’s LES

- Anode and cathode are sandwhiched together
- Achieve 20-100 um spacing.
- Equivalent to RF testing components.





LES Circuit



RF imitation
MARX Generator
Oscillocope
Vacuum pump

170 kV Scandinova modulators
Xband 6MW klystron
Canon E37113
Pulse compressor
LLRF and
Vacuum controllers

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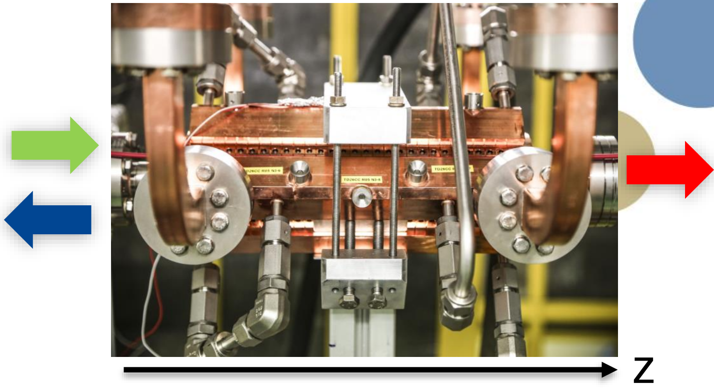
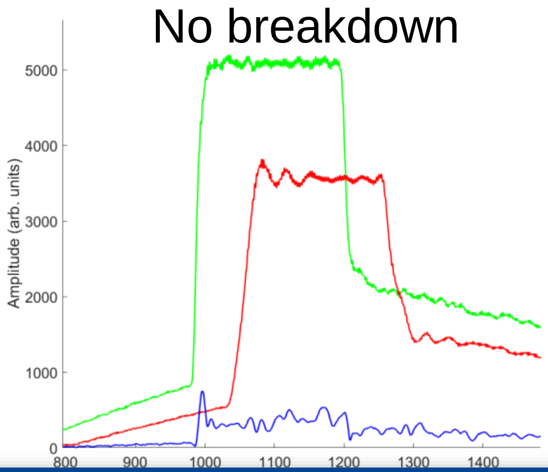
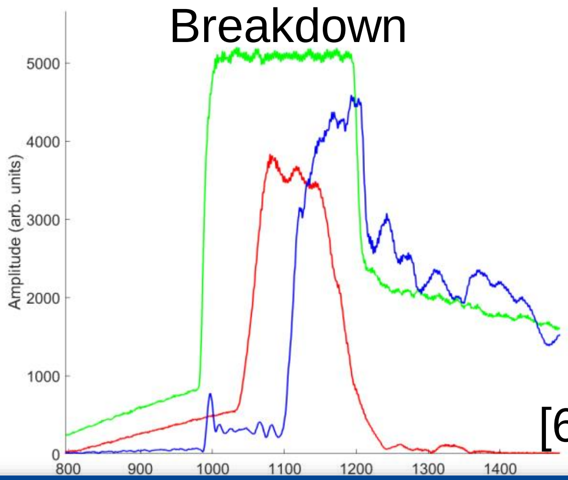
Experimental Signature of Breakdowns

- Incoming wave
- Transmitted wave
- Reflected wave



- Breakdowns increase the reflected wave.
- Can find position along the z plane.



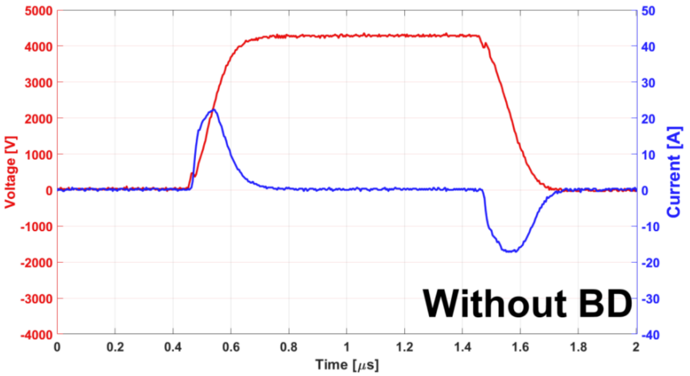


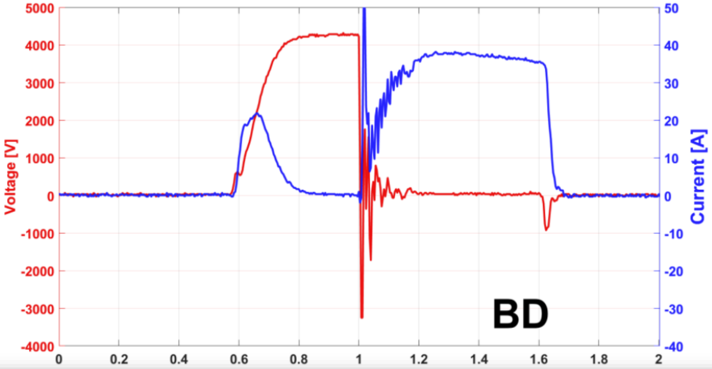
[6]

Experimental Signature of Breakdowns

- LES ≈ 360pF Capacitor
- Breakdown signature:
  - Fall in voltage
  - Increase in current

- In the LES system, you can also observe it with pressure and light!

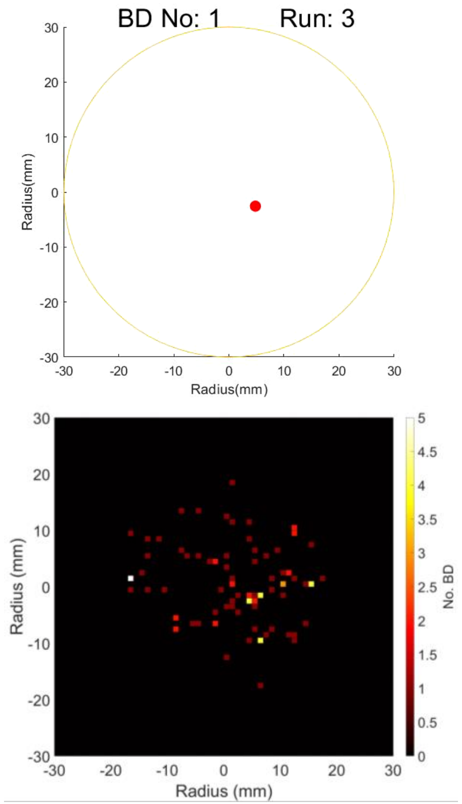


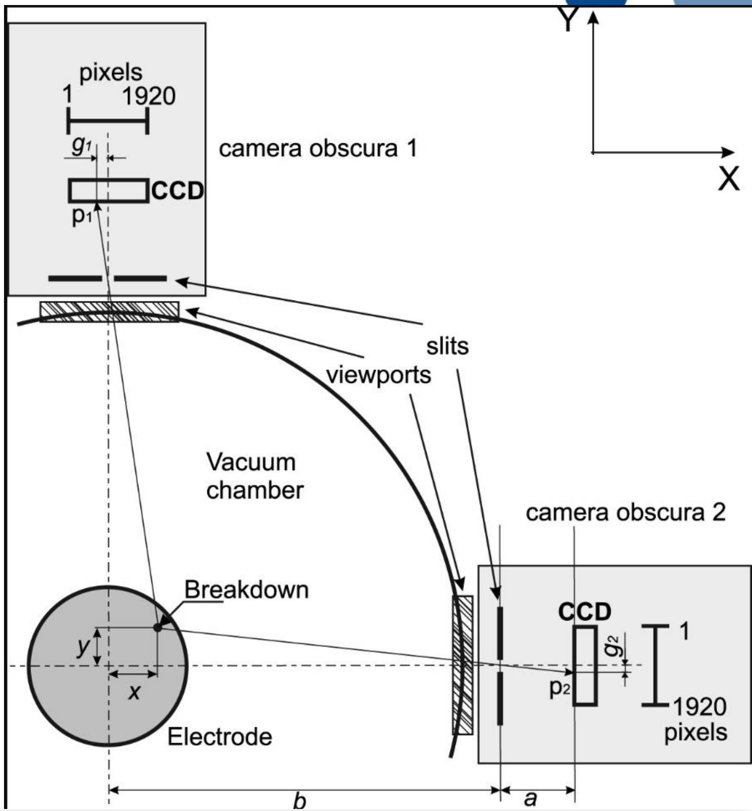


[9] EXPERIMENTAL INVESTIGATION OF VACUUM BREAKDOWN TRIGGERING MECHANISMS IN A DC ELECTRODE SYSTEM- R. PEACOCK

Experimental Signature of Breakdowns

2 CCD (charged couple device) cameras are used to localize breakdowns in realtime pulse pulse.





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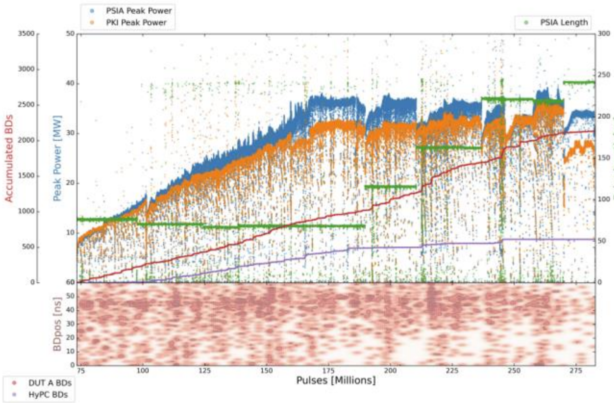
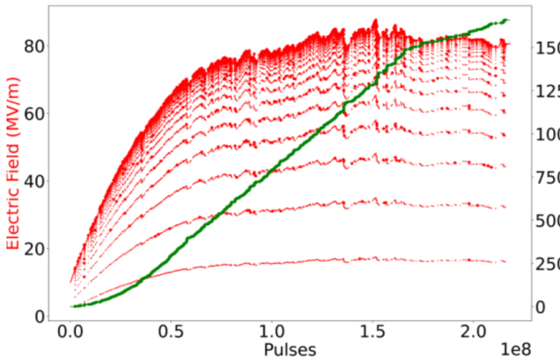
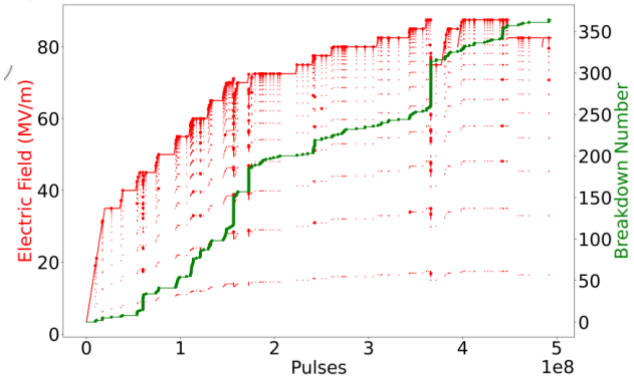
Conditioning

Conditioning examples for td31s, conditioning of Cu in the LES and flat running conditioning in the LES system.

RF Conditioning curve → Mimicing → DC BDR controlled Conditioning → Improving → DC flat run conditioning

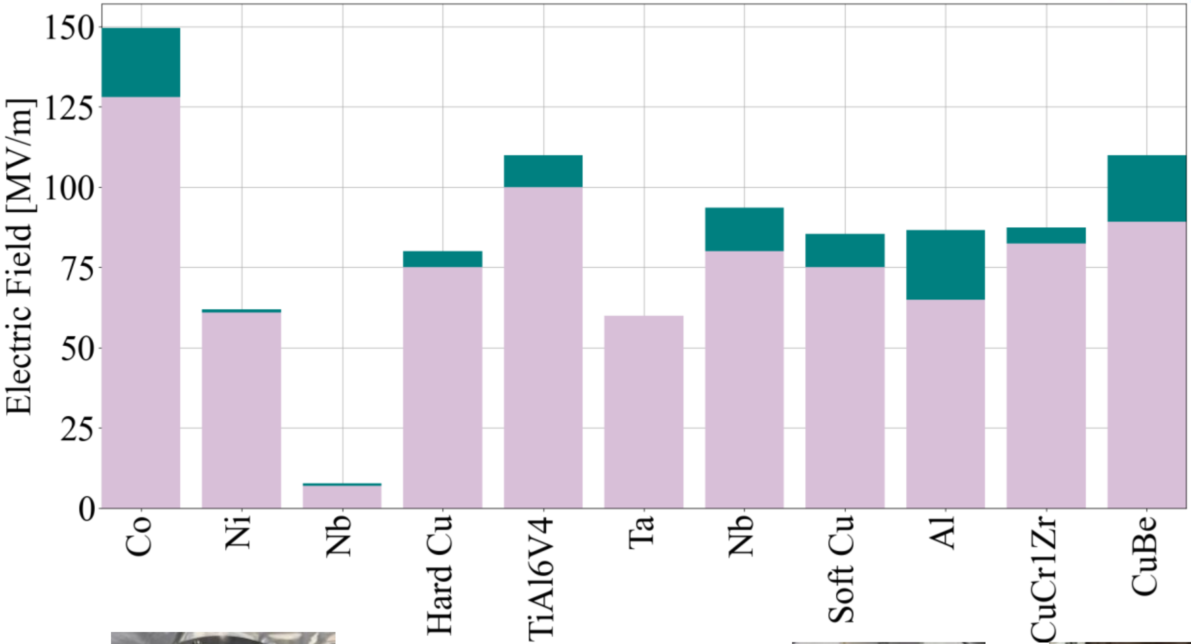


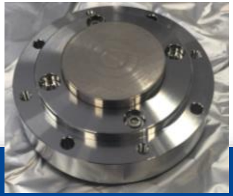


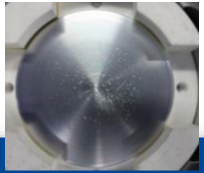


Voltage holding for materials

Helps us characterize and compare different materials to find the most appropiate for field holding.

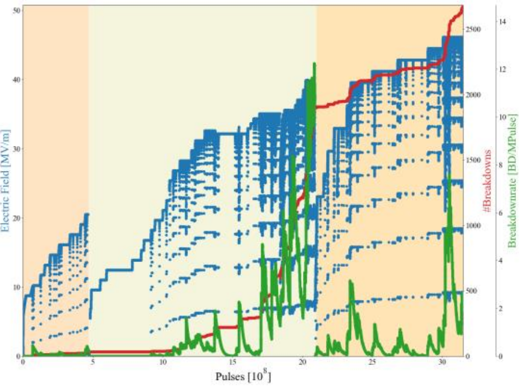


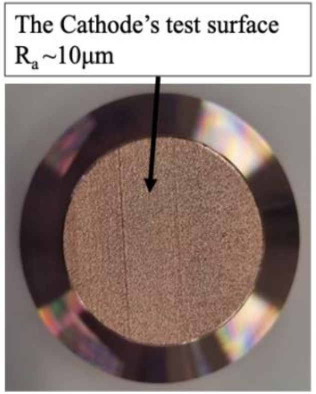




Testing of exotic materials

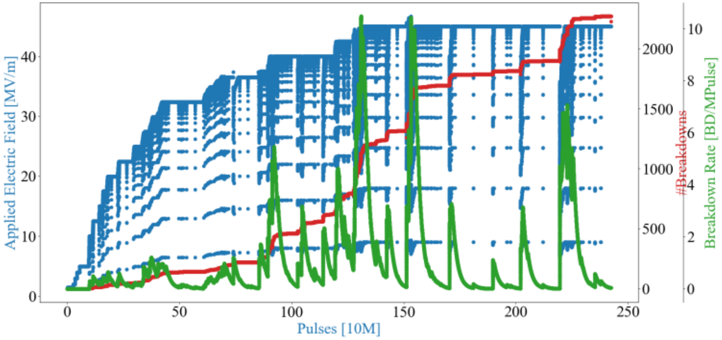
AM Electrodes

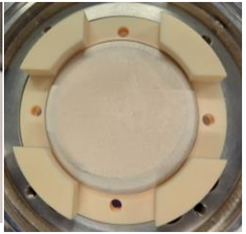




[14]

Nichrome coating

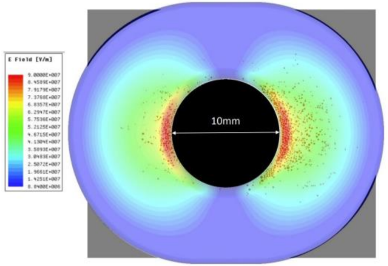


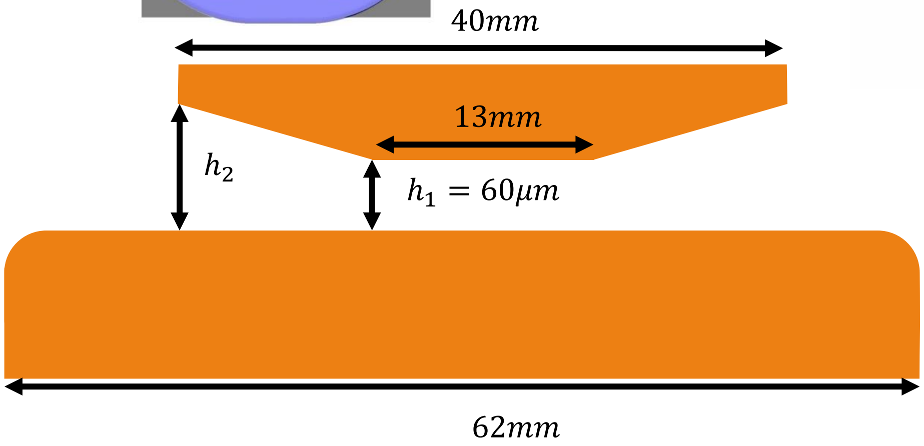


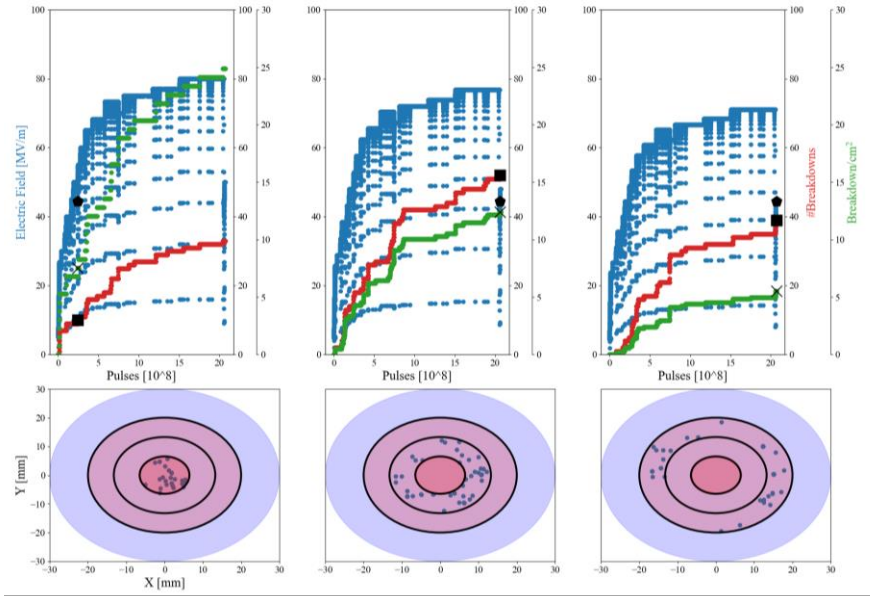
[12] INITIAL HIGH ELECTRIC FIELD- VACUUM ARC BREAKDOWN TST RESULTS FOR ADDITIVELY MANUFACTURED PURE COPPER ELECTRODES- A. RATKUS
[13] THE COOL COPPER COLLIDER CONCEPT FOR A HIGGS FACTORY

Example of breakdown localization

Breakdown locations superimposed on electric field distribution.







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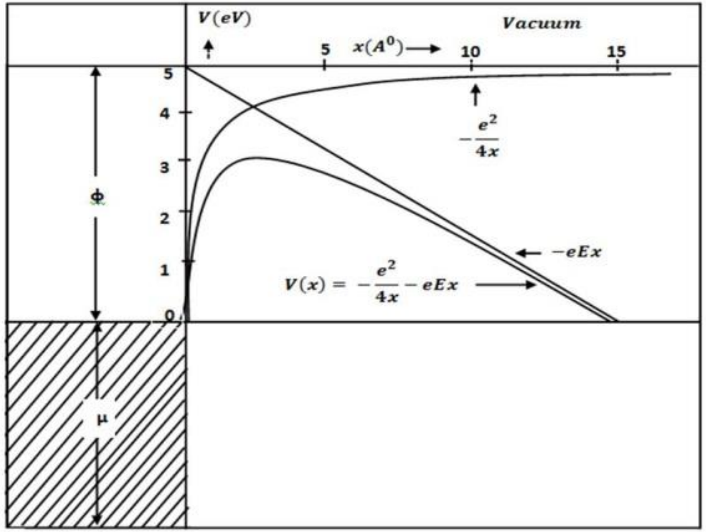
Field Emission

When high electric fields are applied to a surface, it lowers the potential barrier, enablign electrons to escape.

Predictable using Fowler-Norhdeim equation

Works without correction factor

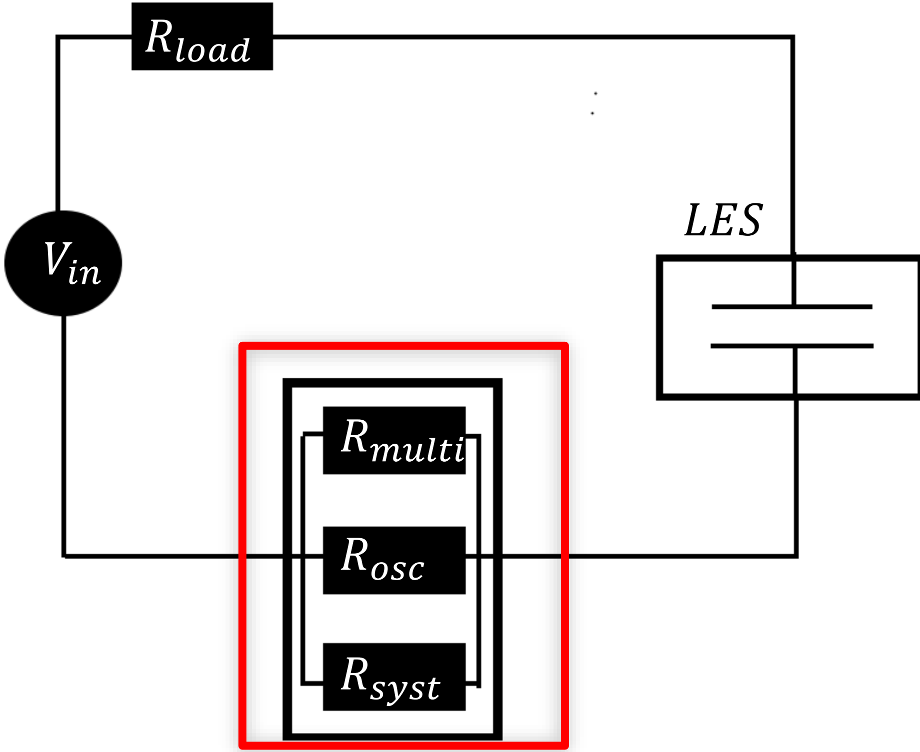
on nanoscopic scales



Field Emission Measurement

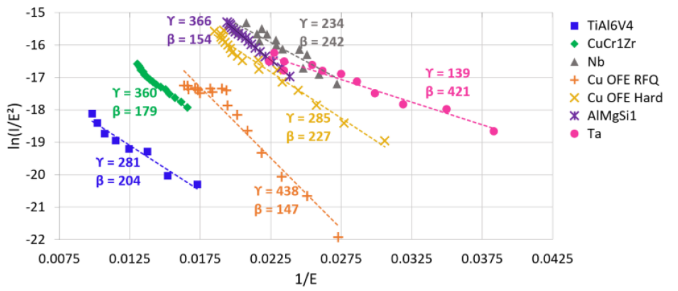
- We connect our system to an extra circuit to measure the field emission.

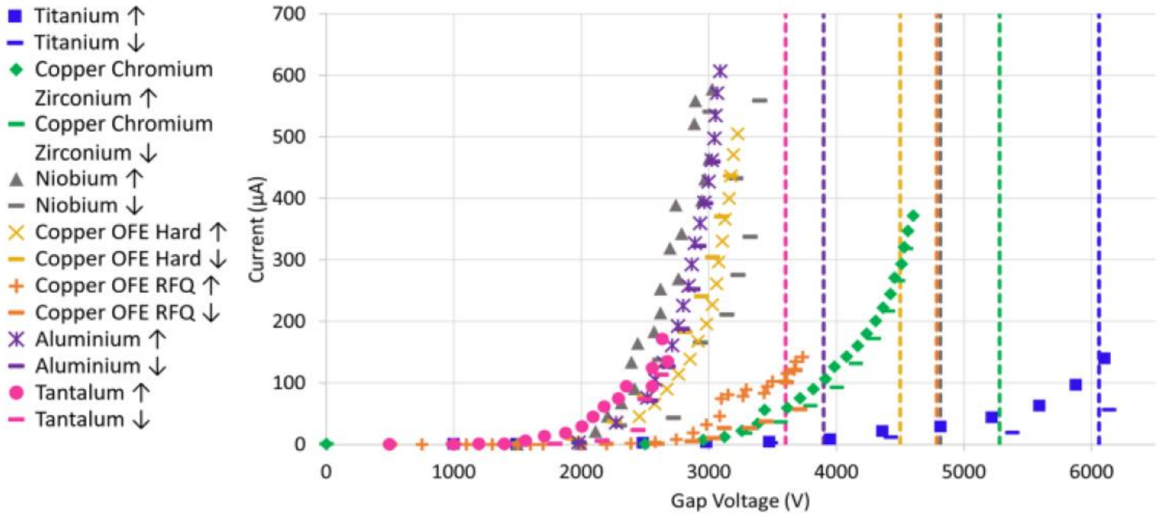
- We record it using an oscilloscope, controle it using a multimeter and can adjust the current using our system resistance.



Field Emission Measurement

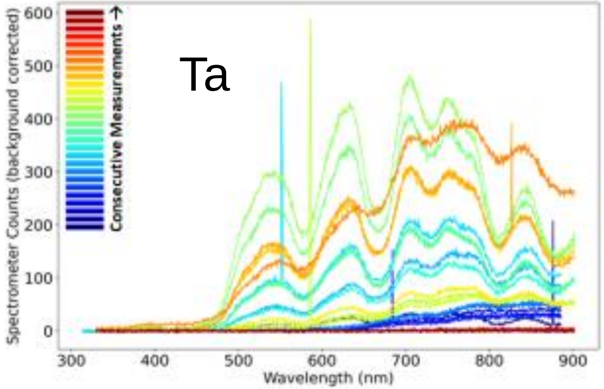
- IV curves of materials
- Needs a field enhancement factor β to work.

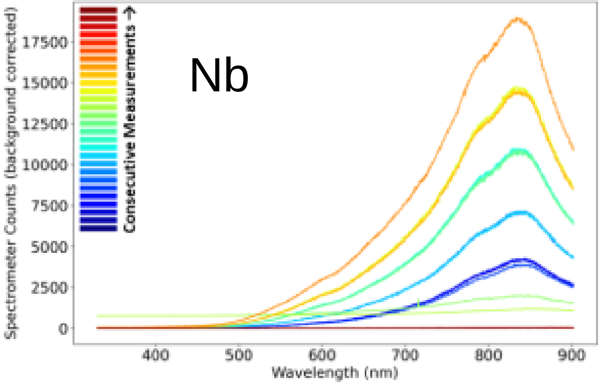


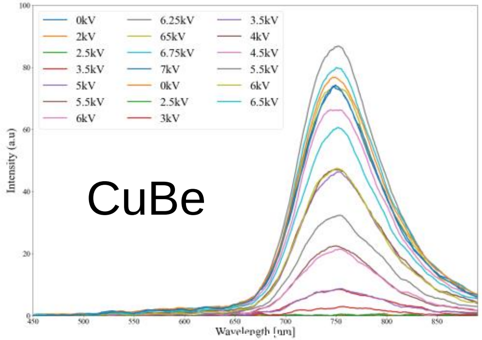


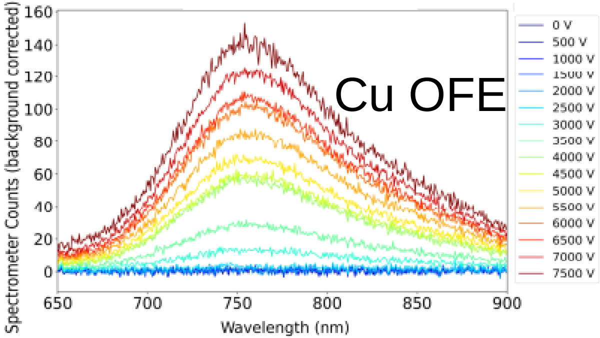
Light during Field Emission

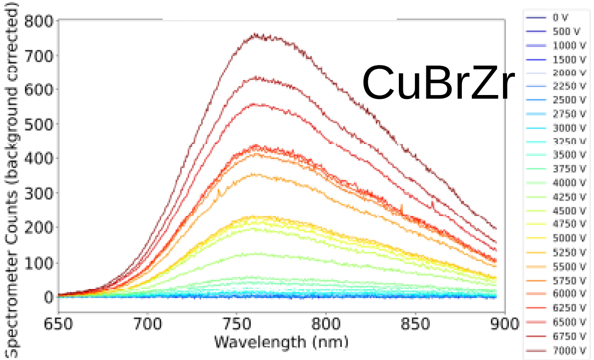
Light seen during field emission





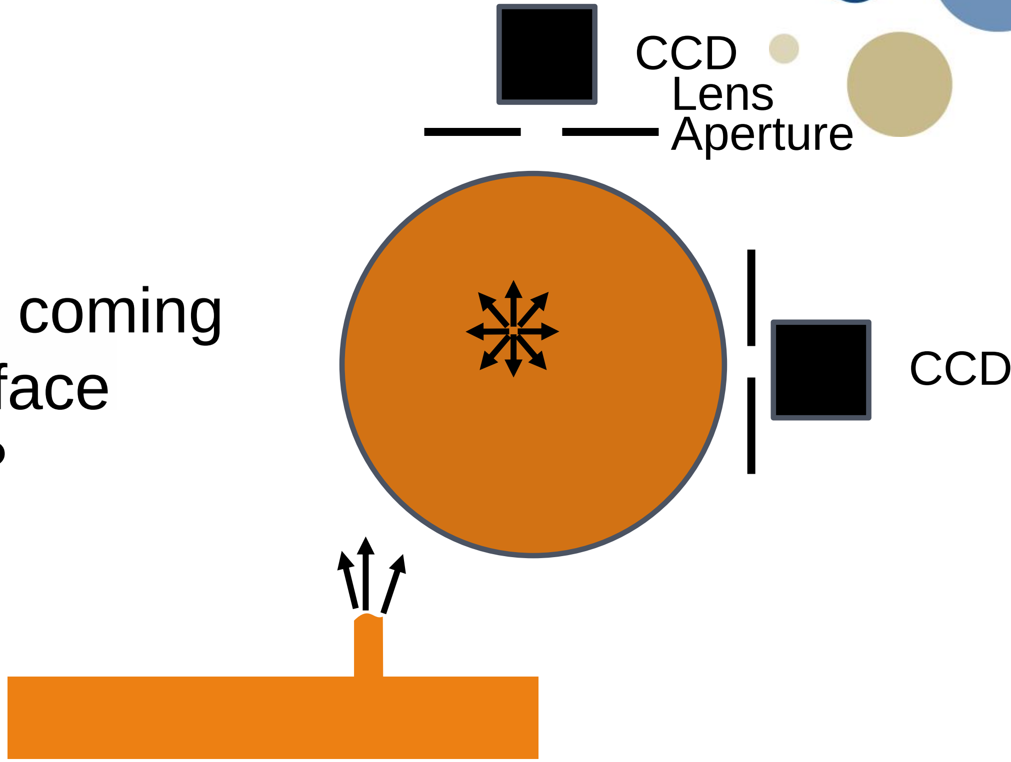






Light Emitter Localization

Is the field enhancment factor coming from certain points on the surface or uniformly over the surface?



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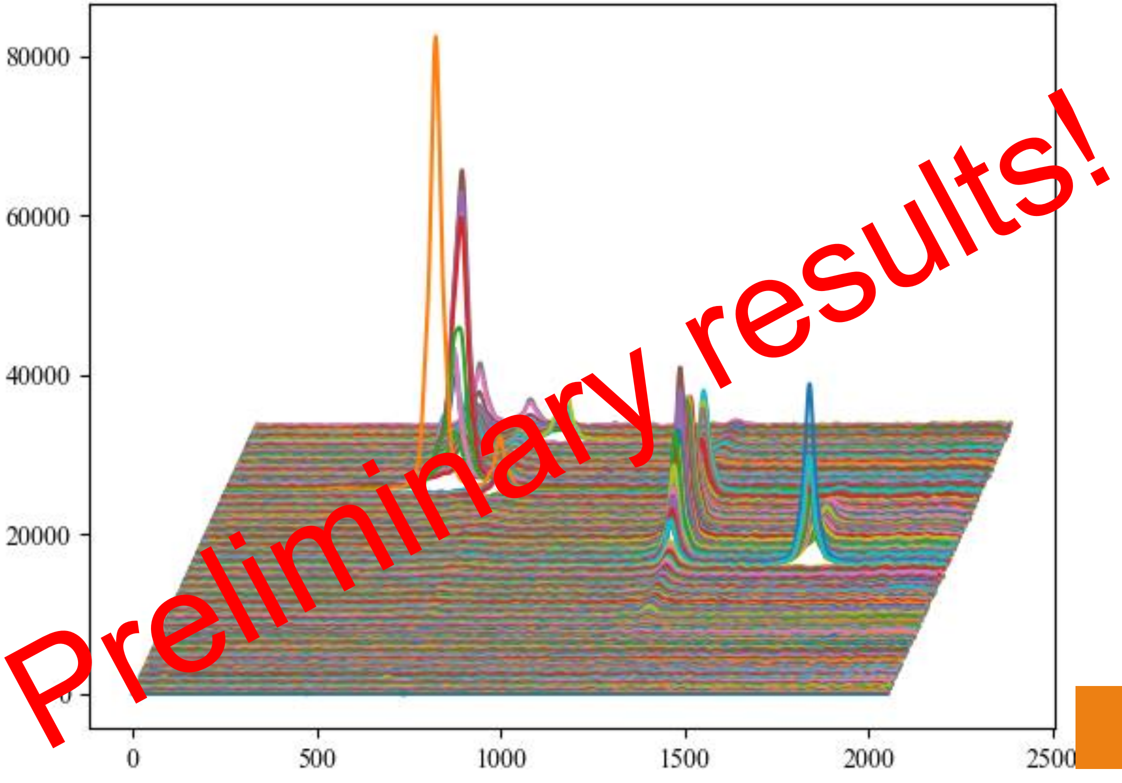

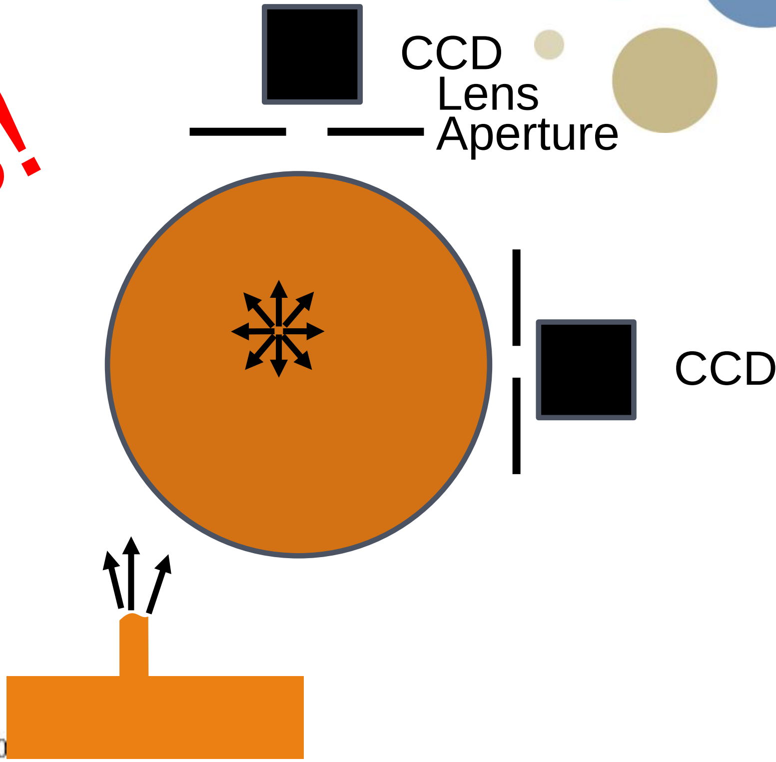

Questions?

References

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[5] https://www.frontiersin.org/journals/physics/articles/10.3389/fphy.2024.1308455/full
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