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.

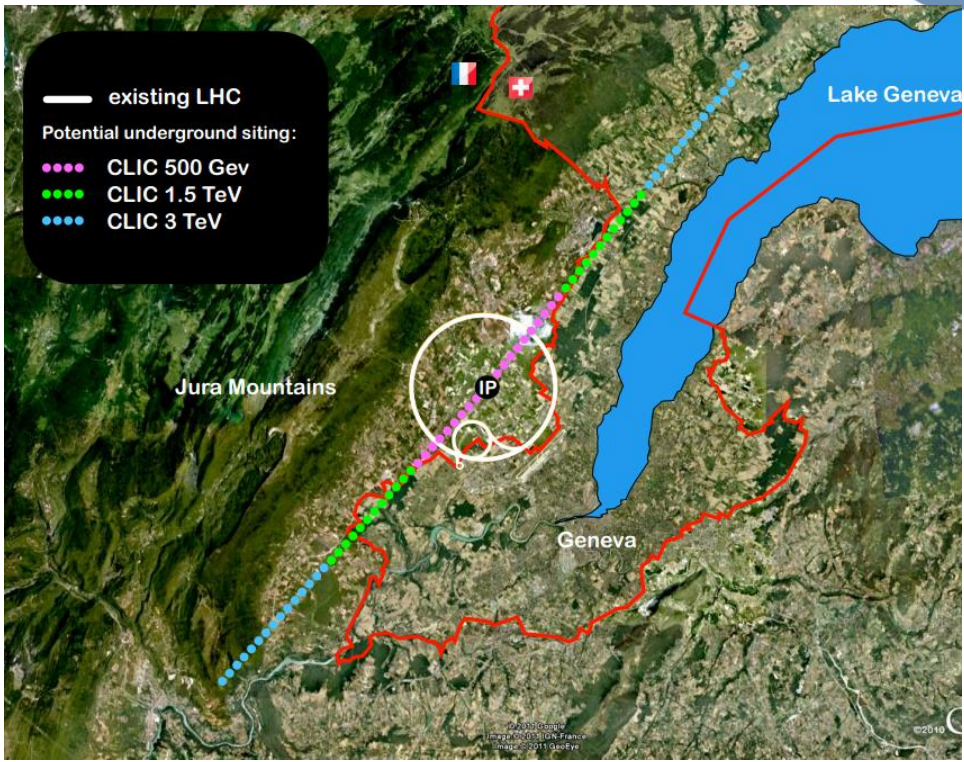
Observations of Breakdowns

Conditioning and material testing

Field Emission Measurements and Development

THE CLIC PROJECT

- **C**ompact **Li**near **C**ollider
- Electron positron collider
- 3 phase build
- 3TeV collision energy

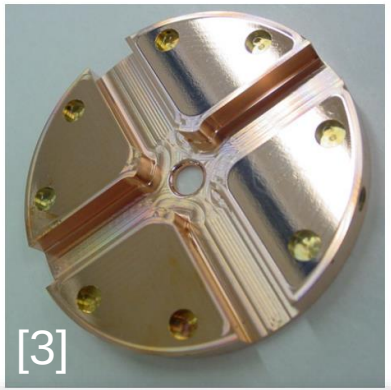


CLIC STRUCTURES

- 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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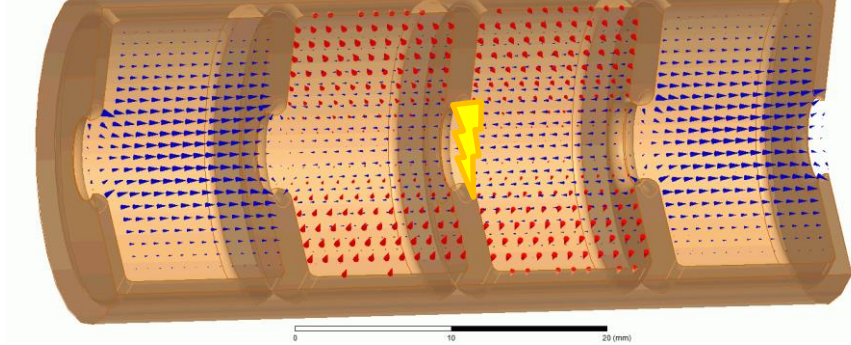
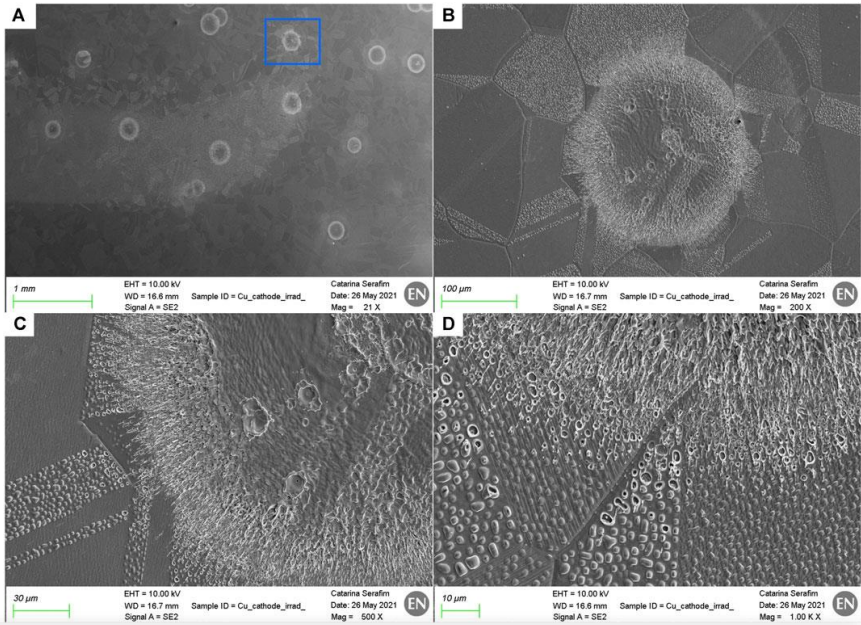
What is a breakdown?

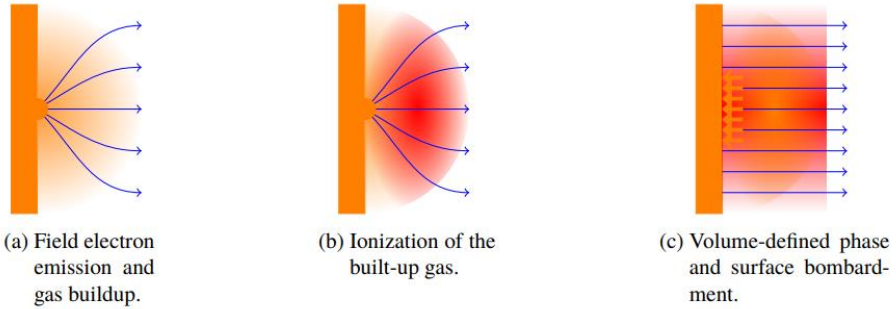
- When applying high surface electric field, a discharge will occur.
- Atoms and electrons flow out from an emitting area.
- Ionization leads to a plasma avalanche!
- Disturbs/kick the beam
- Breakdowns leaves physical damage on the surface





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.

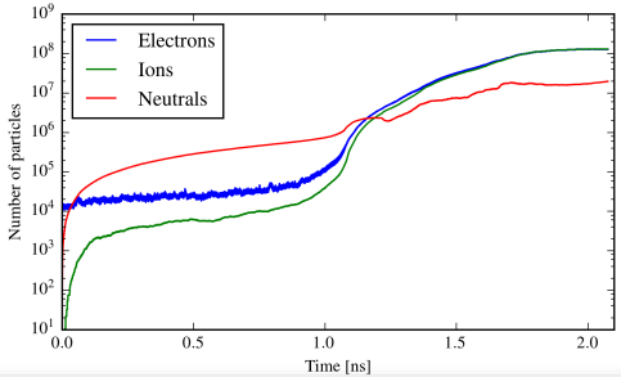


(a) Field electron emission and gas buildup.

(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.



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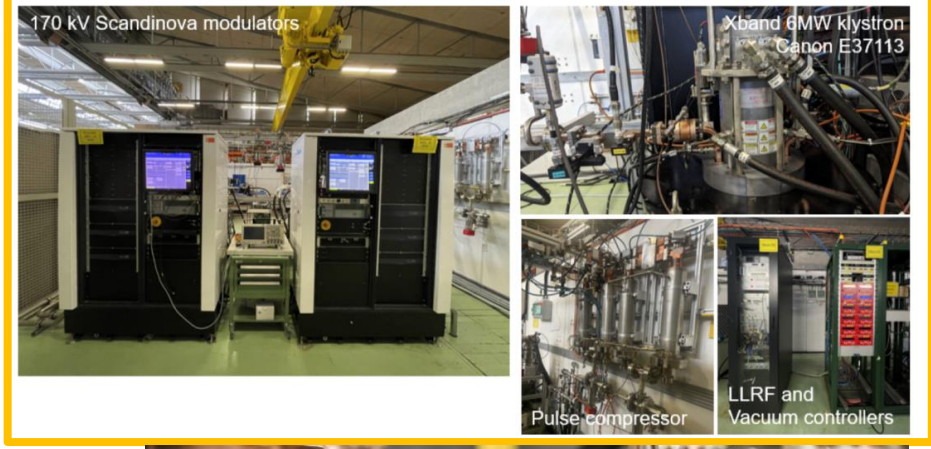
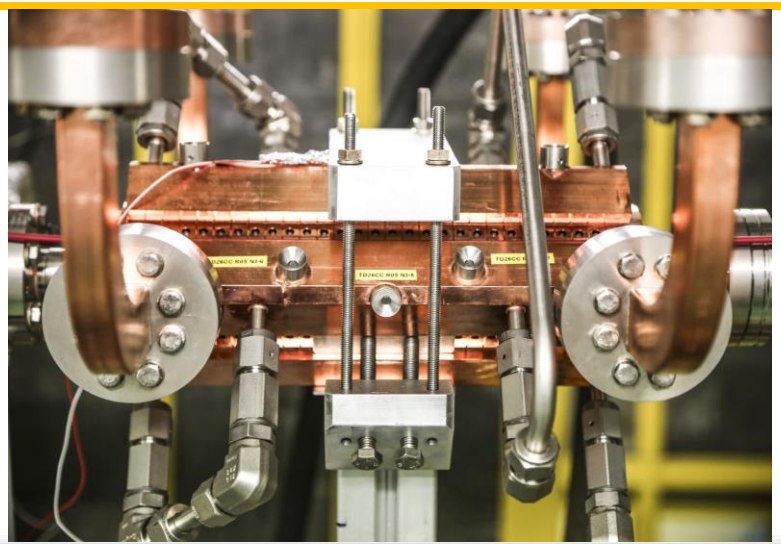
RF Structure Testing

- CLIC has several klystron based X-band test stands
- Testing prototype accelerating structures+ other RF components.
- We can complement the system!

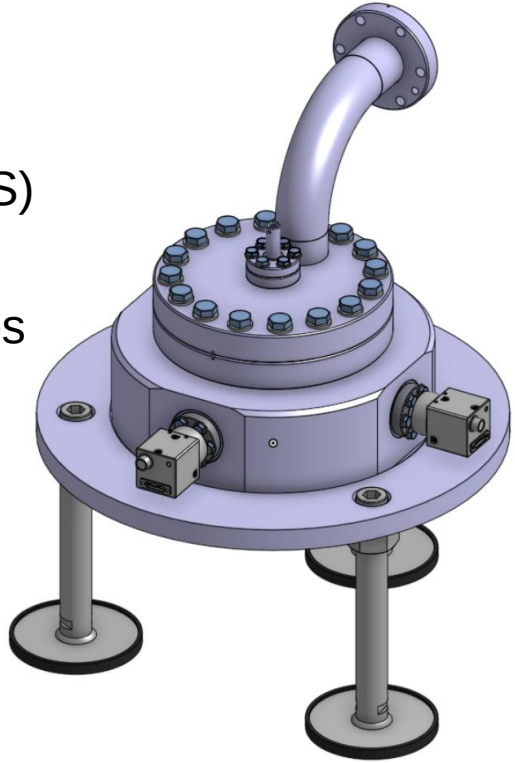


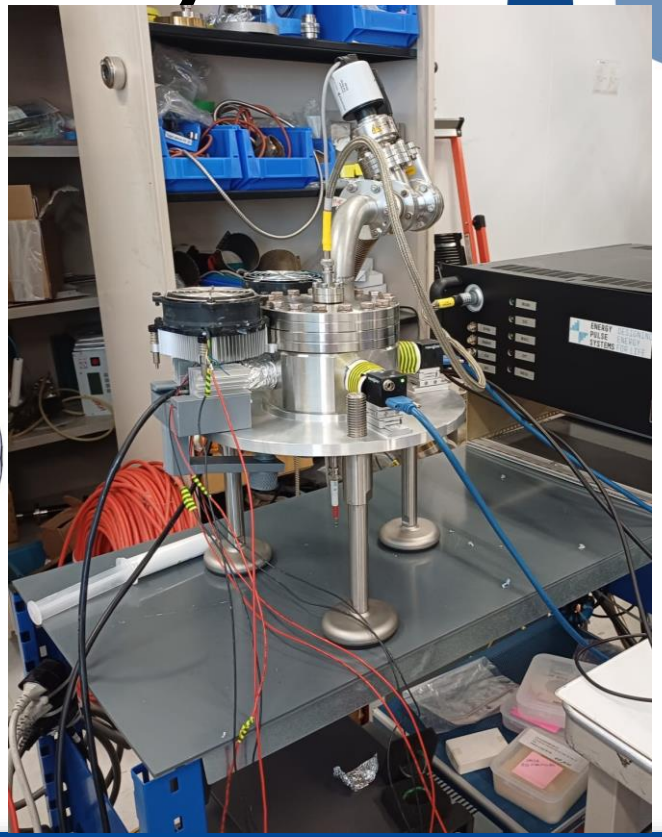


Xbox 2 test stand. Image provided by Lee Milar.

CERN’s Large Electrode System

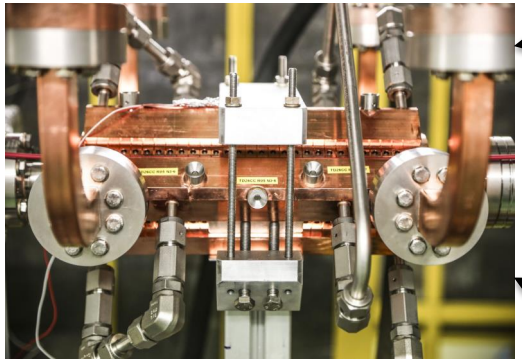
- Large Electrode System (LES)
- Small vacuum chamber
- Replacable, simple electrodes
- HV pulses via a Marx generator.
- Adaptabel diagnostics.

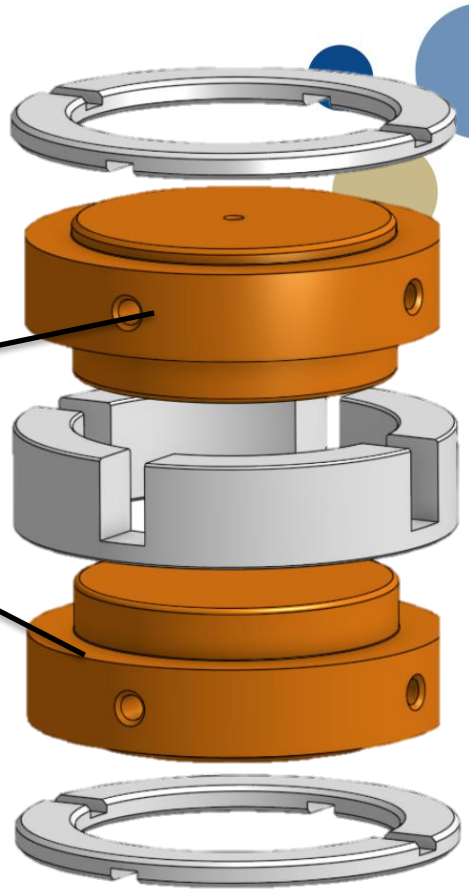




CERN's LES

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



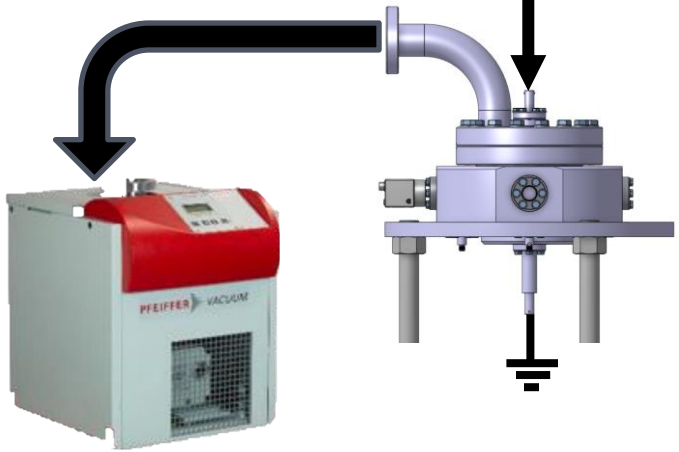


LES Circuit

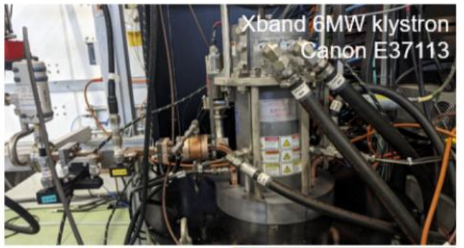
RF imitation

MARX Generator

Oscillocope



Vacuum pump



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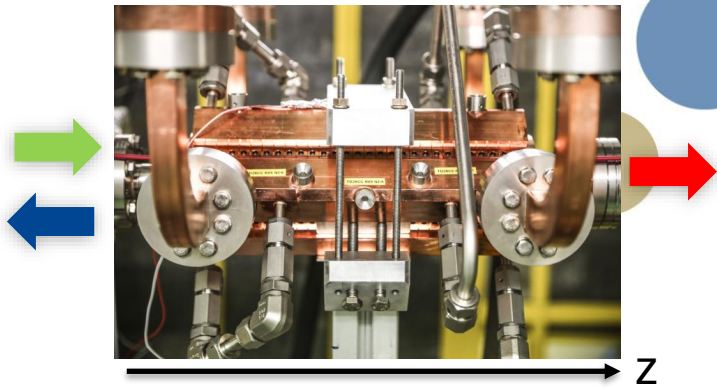
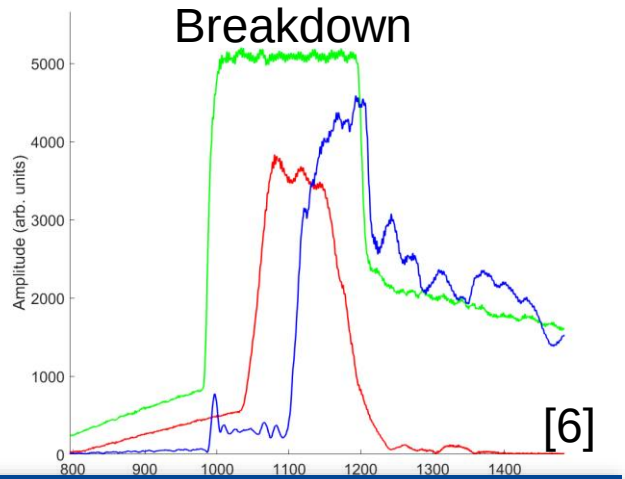
Experimental Signature of Breakdowns

- Incoming wave
- Transmitted wave
- Reflected wave



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

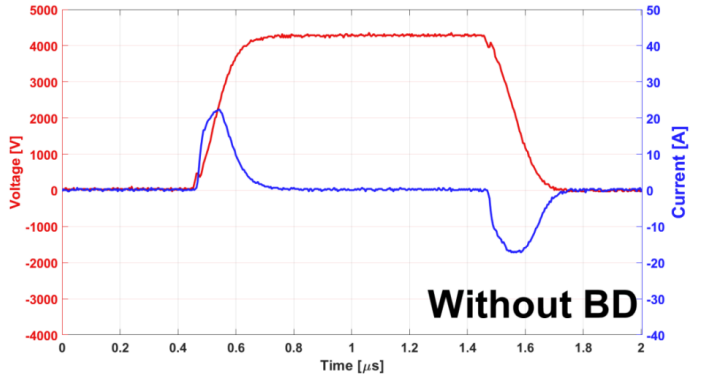


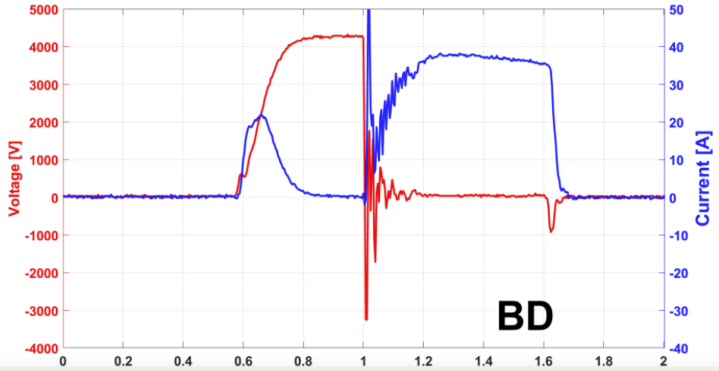
[6]

Experimental Signature of Breakdowns

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

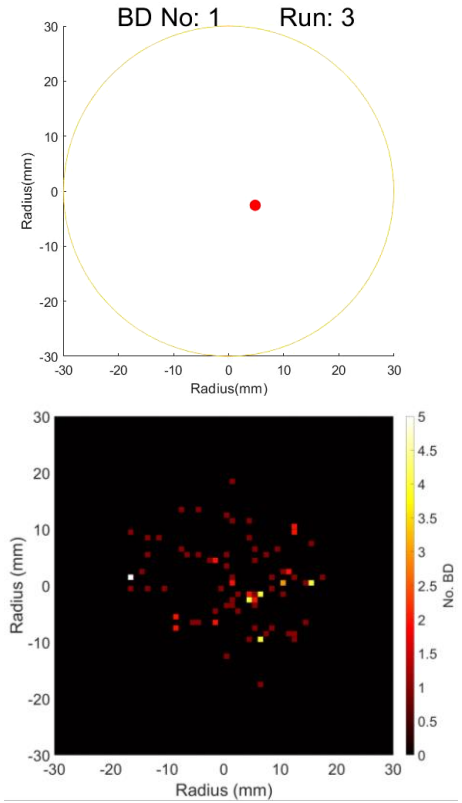
- In the LES system, you can also observe it with pressure and light!

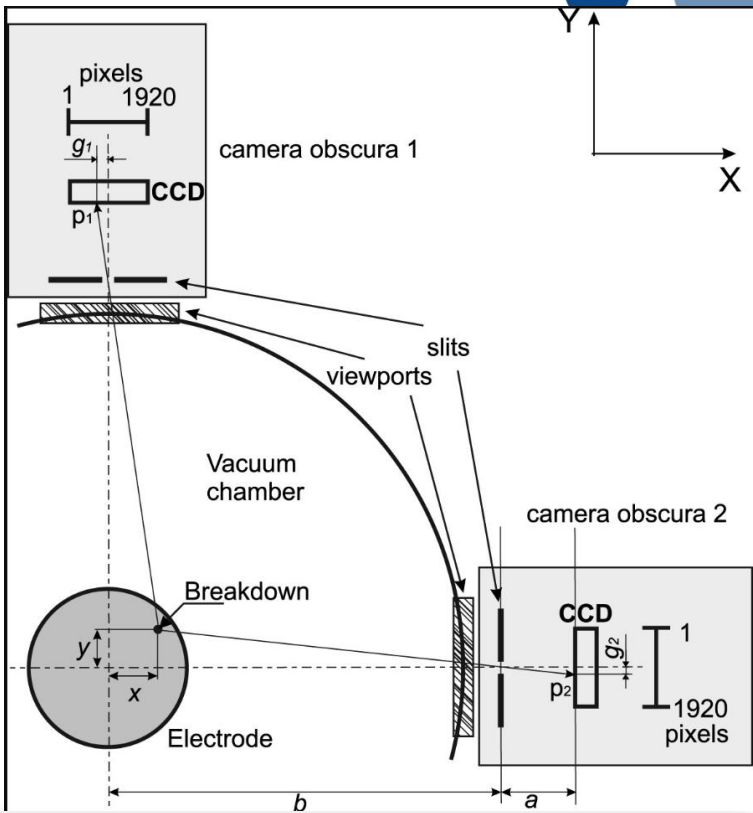




Experimental Signature of Breakdowns

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





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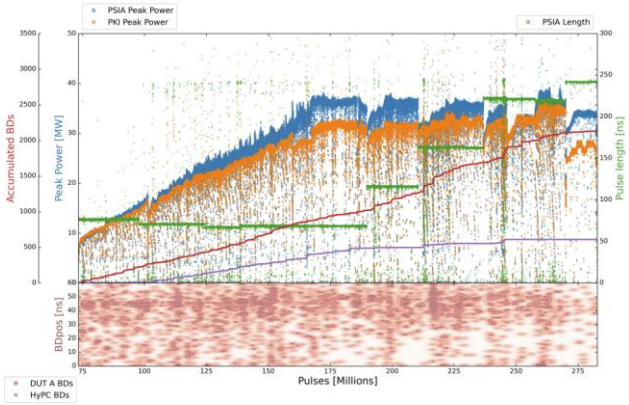
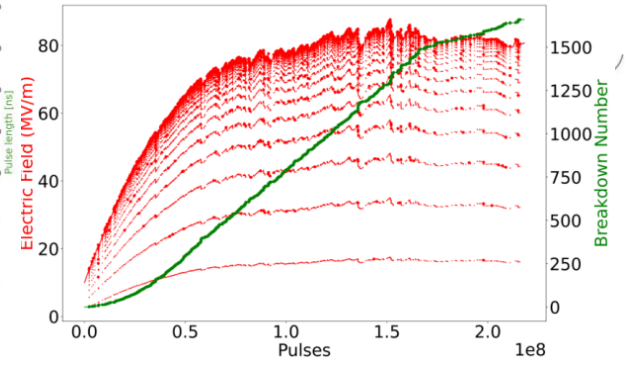
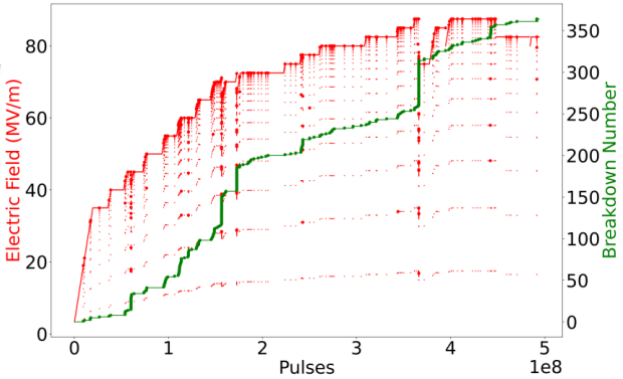
Conditioning

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



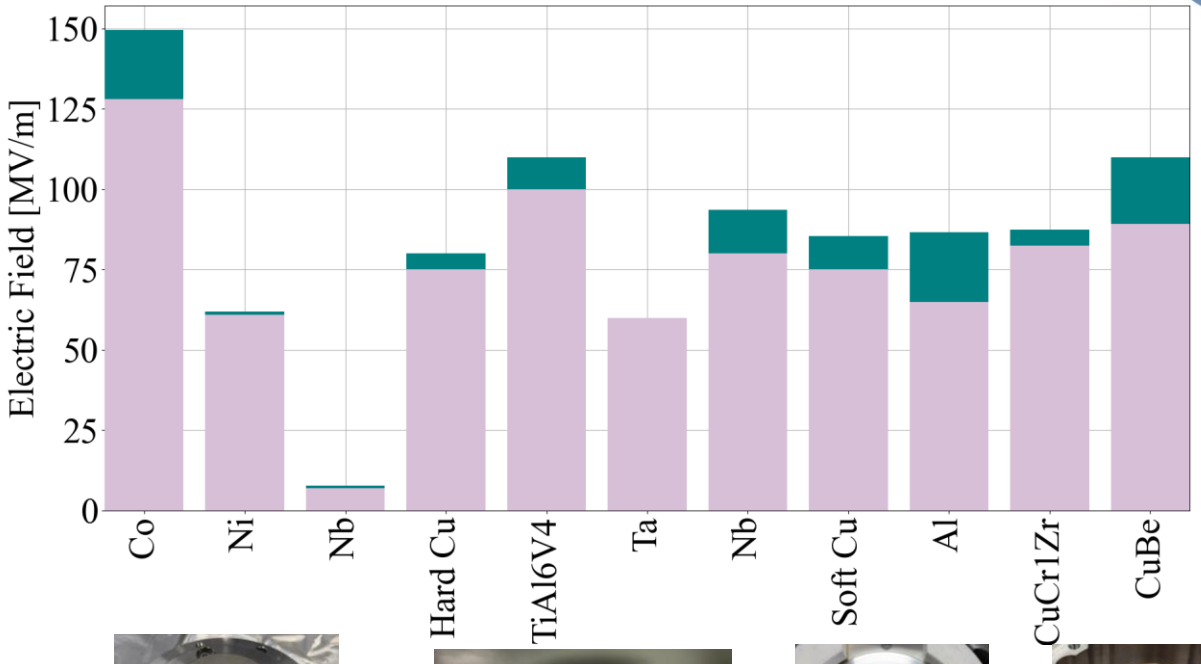


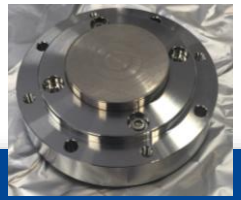


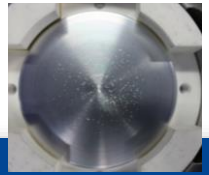
[9] EXPERIMENTAL INVESTIGATION OF VACUUM BREAKDOWN TRIGGERING MECHANISMS IN A DC ELECTRODE SYSTEM- R. PEACOCK
[11] CERN'S HIGH GRADIENT X-BAND TEST STANDS: STATUS AND UPDATE – M. BORONAT

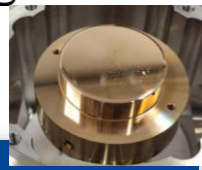
Voltage holding for materials

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



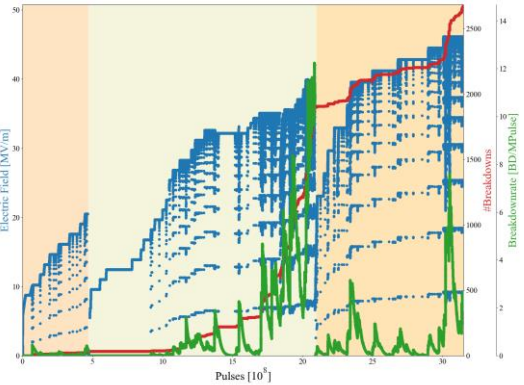


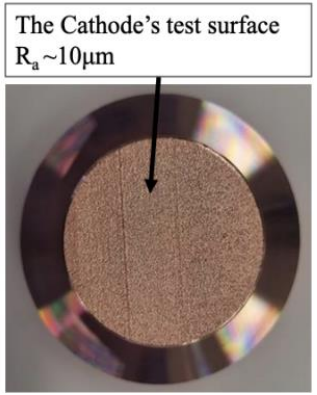




Testing of exotic materials

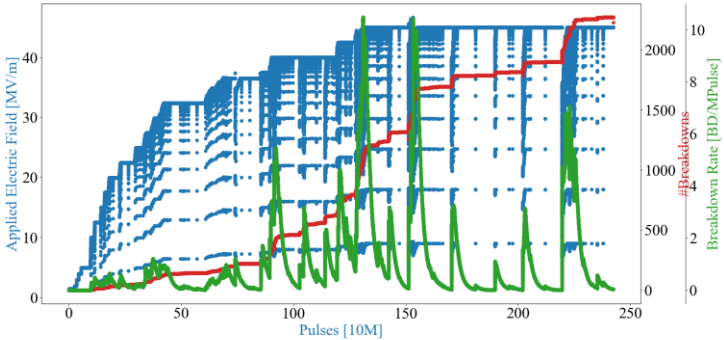
AM Electrodes





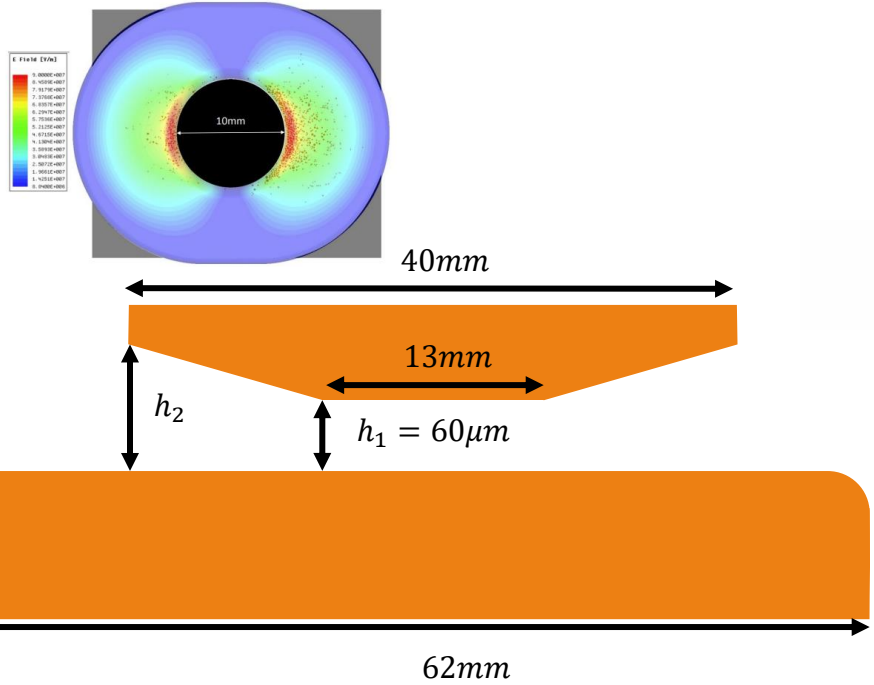
[14]

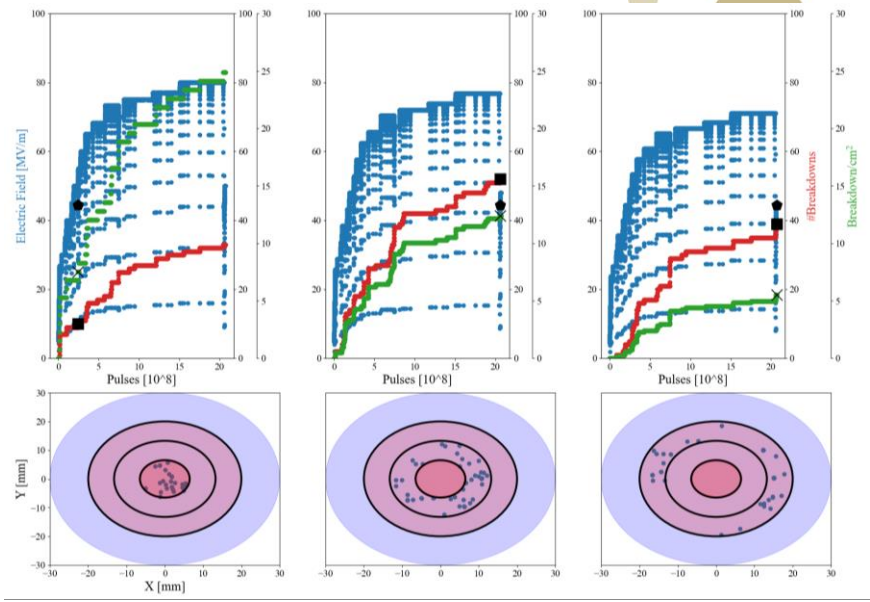
Nichrome coating



Example of breakdown localization

Breakdown locations superimposed on electric field distribution.





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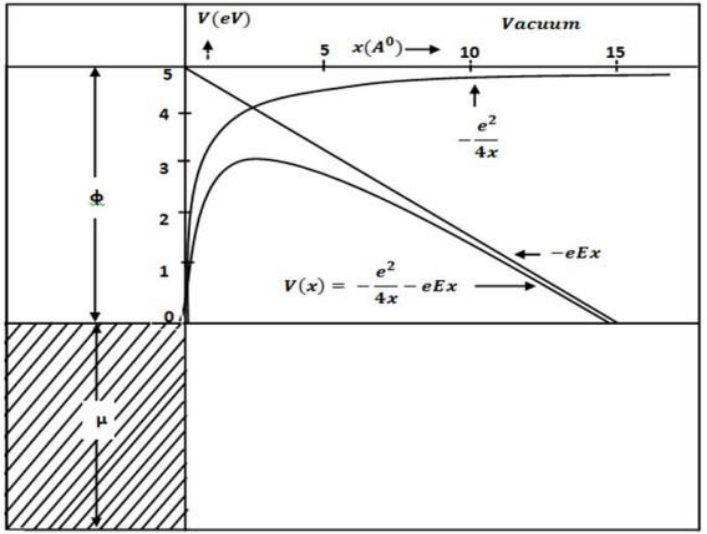
Field Emission

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

Predictable using Fowler-Norhdeim equation

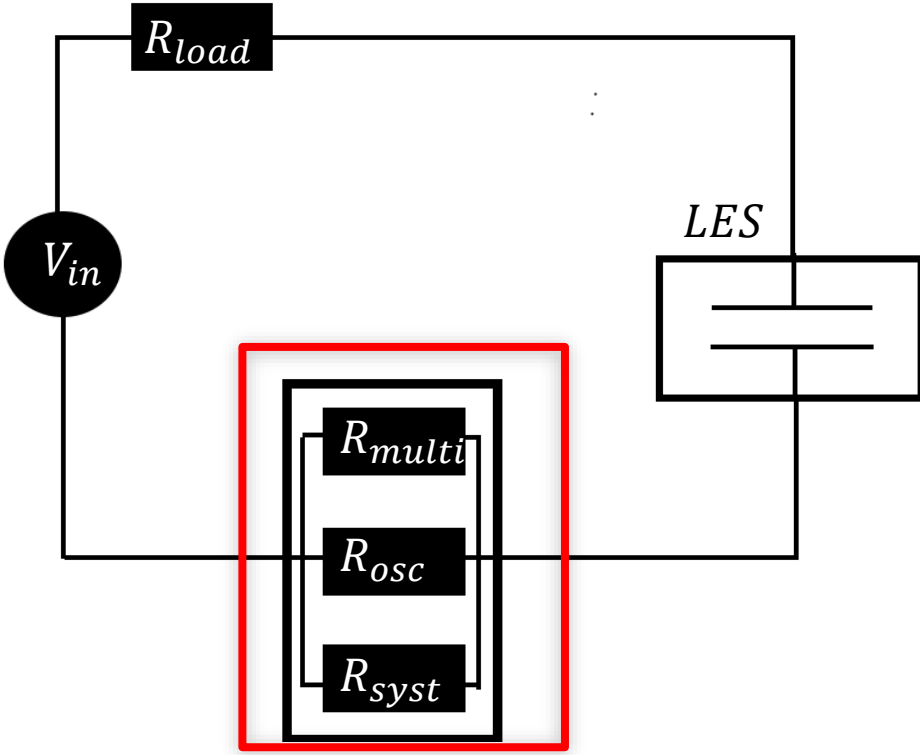
Works without correction factor

on nanoscopic scales



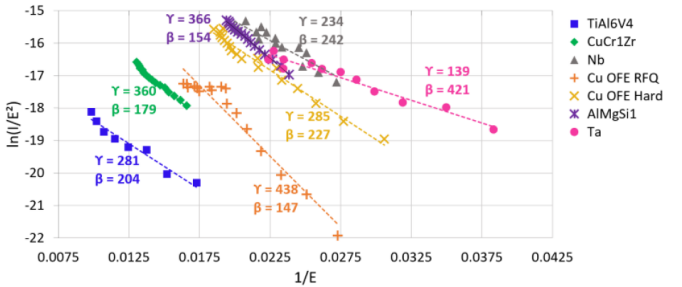
Field Emission Measurement

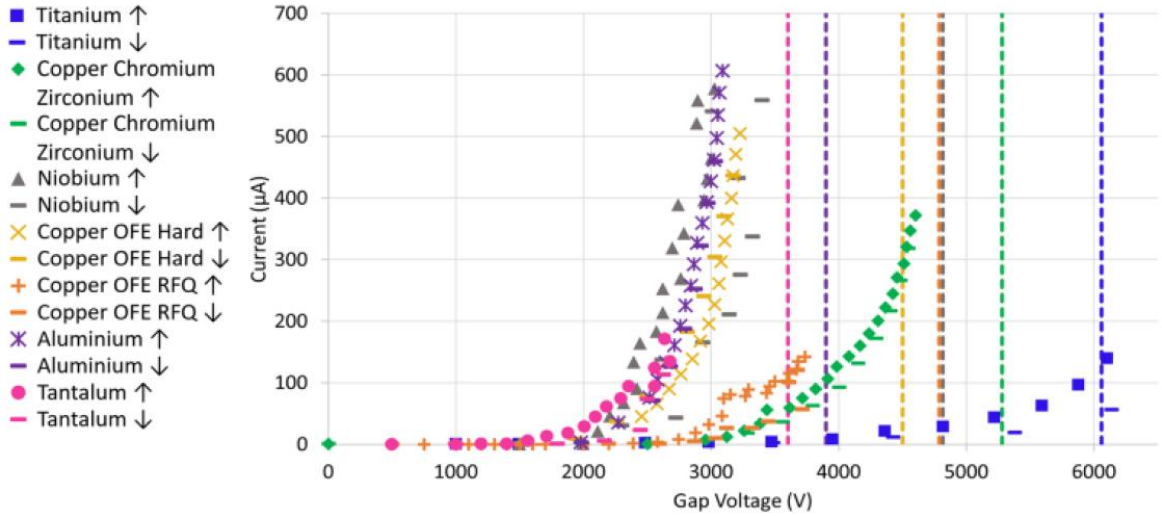
- We connect our system to an extra circuit to measure the field emission.
- We record it using an oscilloscope, controle it using a multimeter and can adjust the current using our system resistance.



Field Emission Measurement

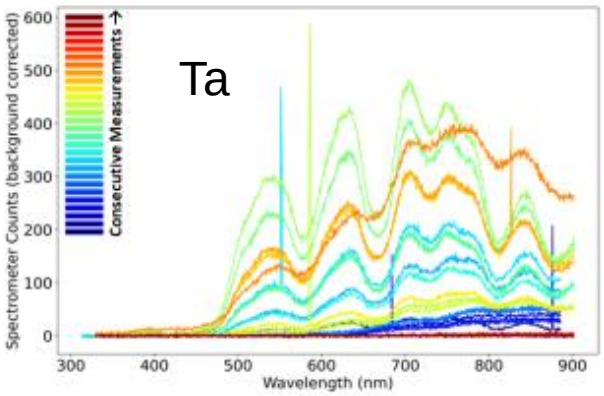
- IV curves of materials
- Needs a field enhancement factor β to work.

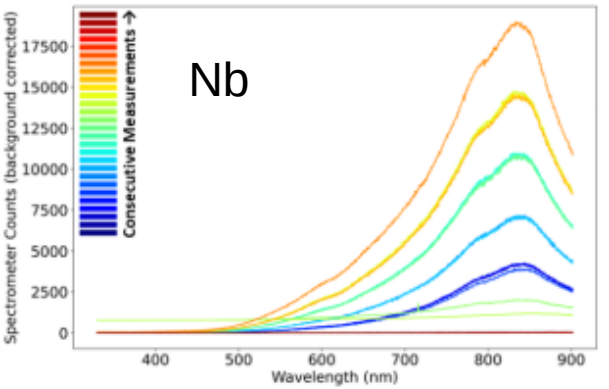


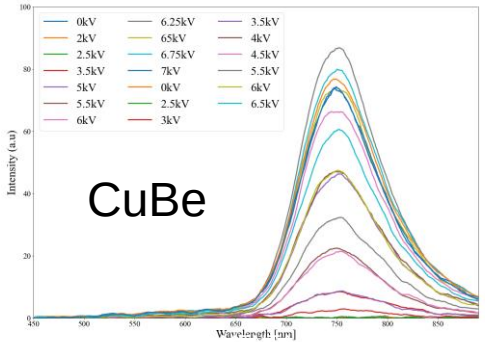


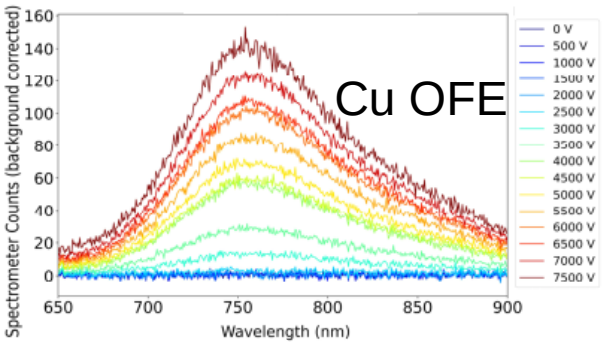
Light during Field Emission

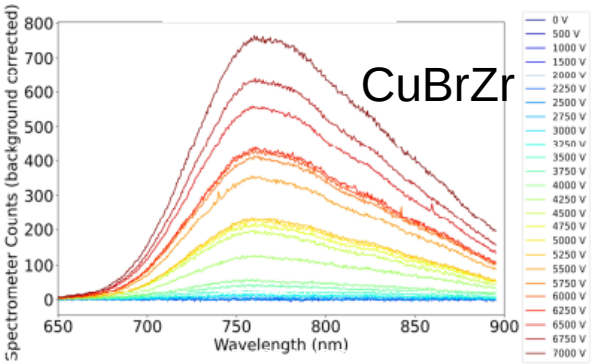
Light seen during field emission





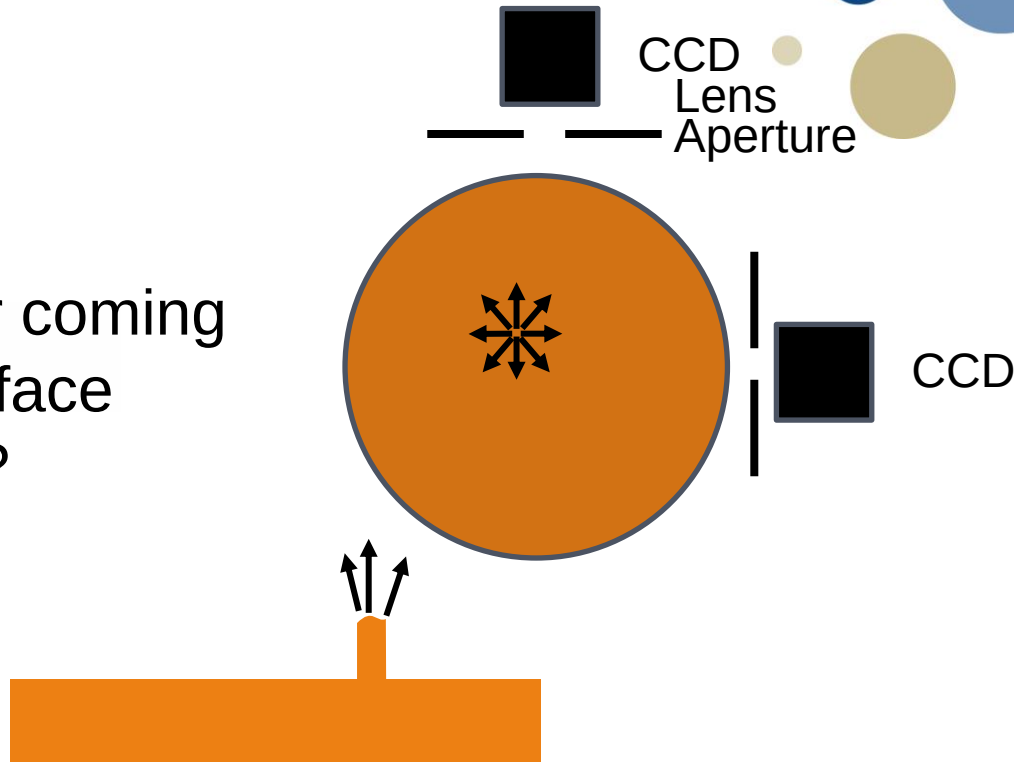




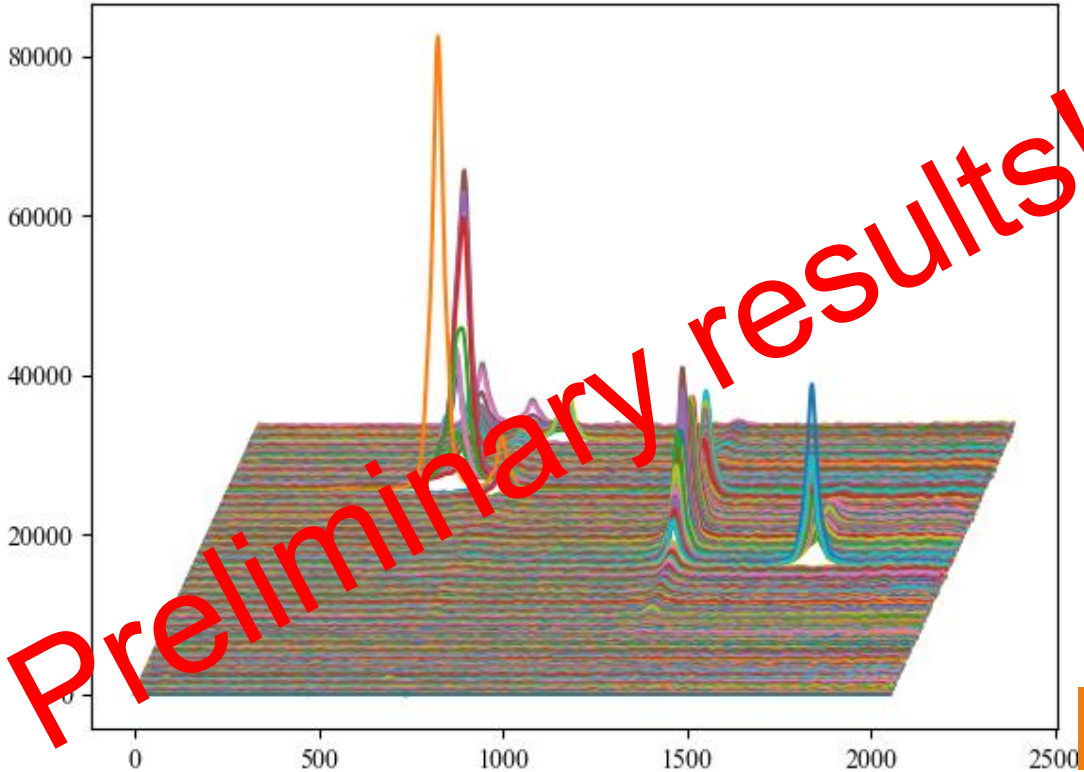


Light Emitter Localization

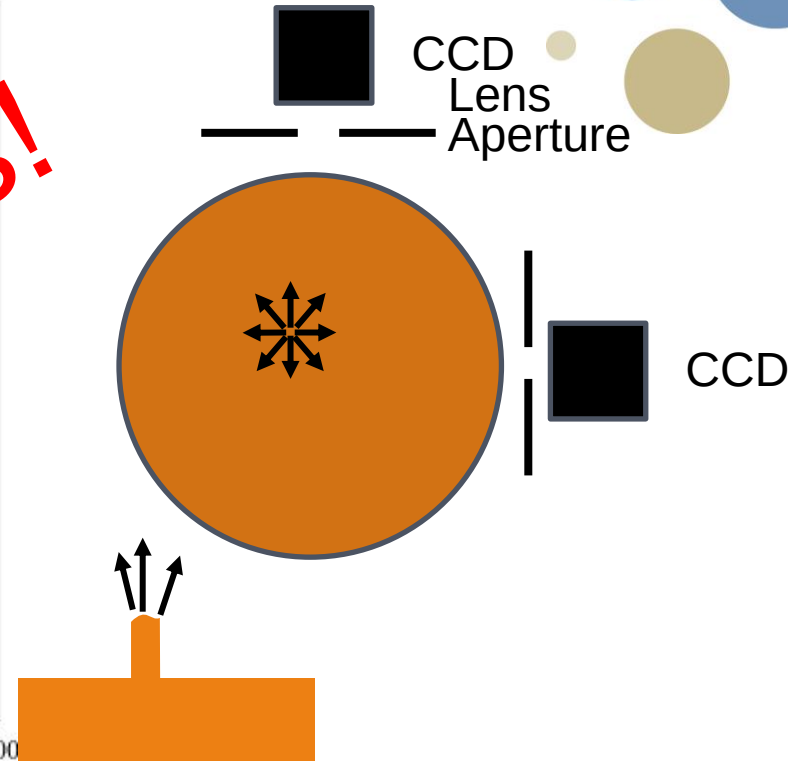
Is the field enhancment factor coming from certain points on the surface or uniformly over the surface?



Light Emitter Localization



Preliminary results!



Questions?

References

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[2] https://accelconf.web.cern.ch/e08/papers/thxm01.pdf
[3] https://cds.cern.ch/record/1346987/files/mop068.pdf
[4] https://home.cern/science/accelerators/compact-linear-collider
[5] https://www.frontiersin.org/journals/physics/articles/10.3389/fphy.2024.1308455/full
[6] https://indico.cern.ch/event/1212689/contributions/5377907/
[7] https://www.duo.uio.no/handle/10852/52944
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