The Cryogenic DC Spark System

Elias Waagaard

Supervisor: Marek Jacewicz

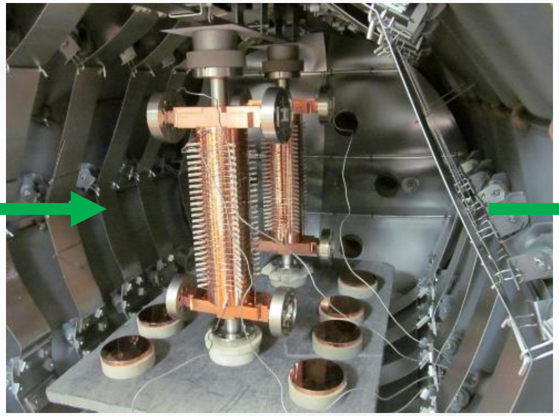
December 10th 2020

UPPSALA UNIVERSITET

Outline

- Background and Motivation
- Experimental set-up
- Preliminary results
  - Conditioning
  - Field emission
- Summary
- Outlook

Background and Motivation



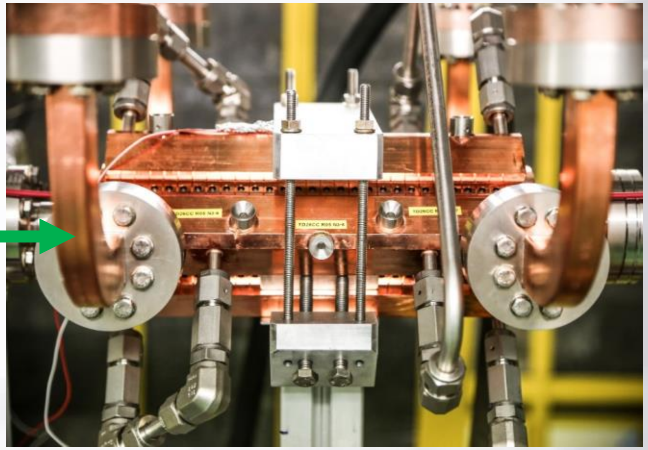


Image courtesy: Walter Wuensch

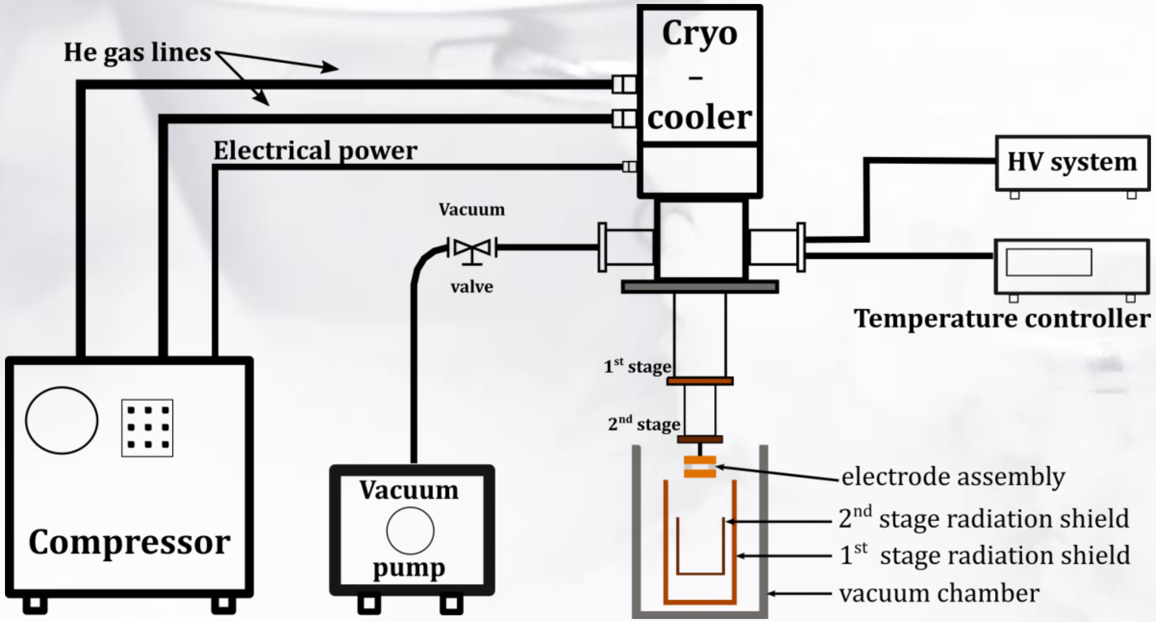
- Hard and soft copper
- Cryo experiments: provide new information for vacuum arc theories
- Purpose of this study: behaviour of soft copper at cryogenic temperatures
- Recent studies at SLAC: cryogenic setting reduces BDR
    - Gradient: 250 MV/m @ 45 K with 2e-4 BD/pulse/m

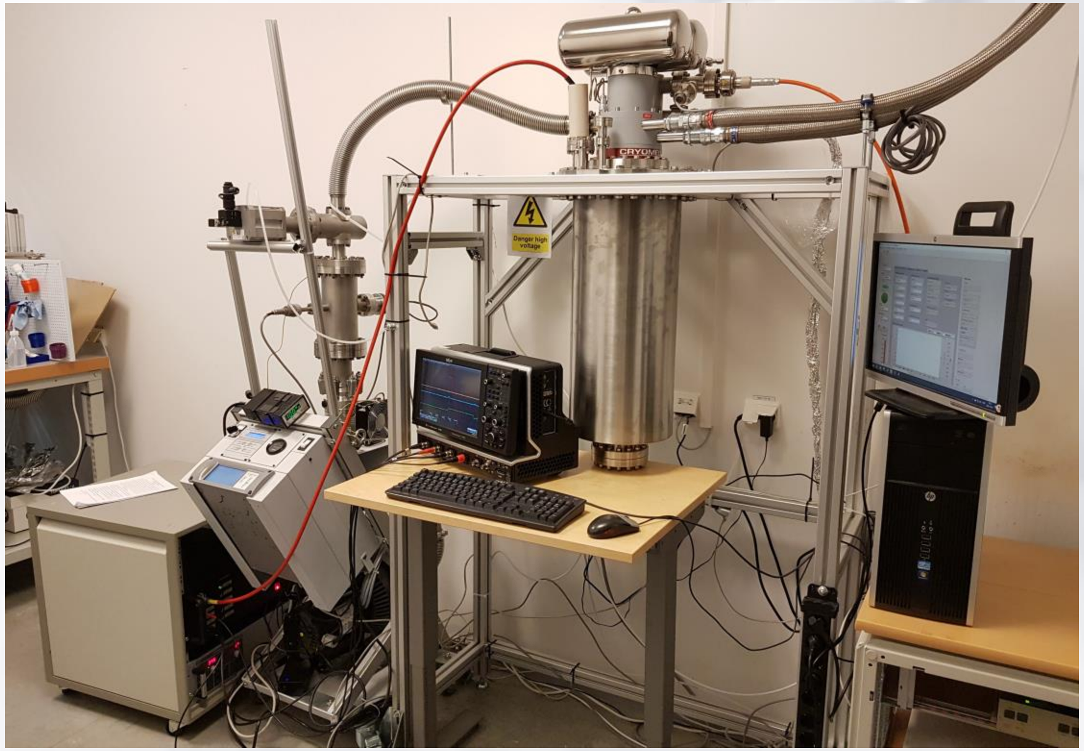
DOI: 10.1103/PhysRevAccelBeams.21.102002

- Possible approaches to ultra-compact linac

J B Rosenzweig *et al* 2020 *New J. Phys.* **22** 093067

Experimental Set-up

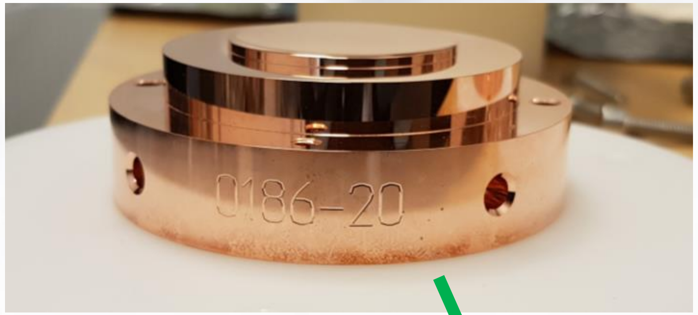




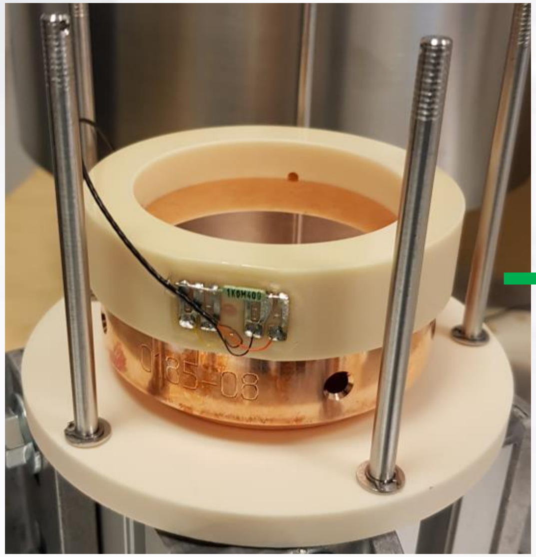
Typical pressure values:
@ room temperature: < 1e-7 mbar
@ cryo temperatures: < 5e-9 mbar

Set-up: Electrodes

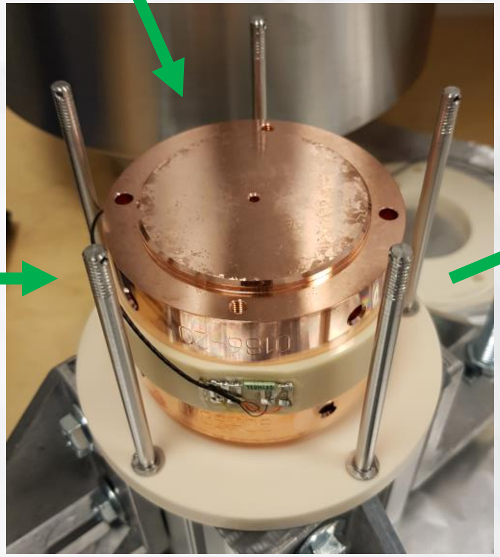
Hard Cu cathode from previous experiments

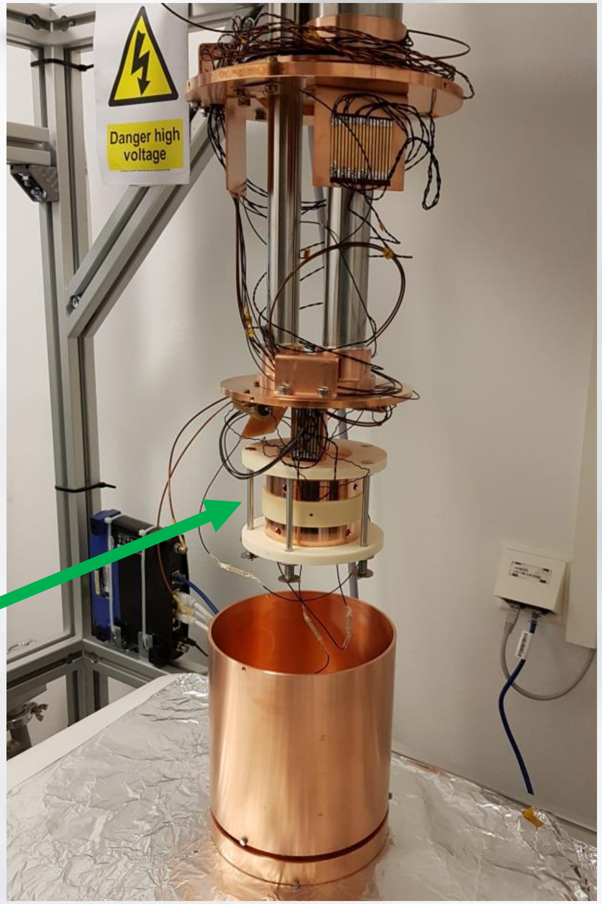


Soft Cu Anode



Soft Cu Cathode





Electrodes and first stage radiation shield

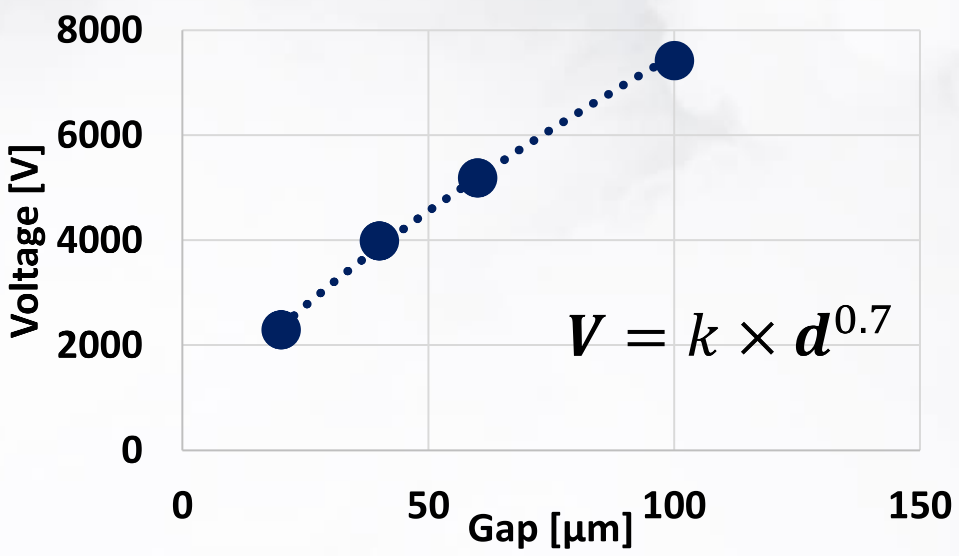
Main goals of study

- Breakdown behaviour during conditioning phase
- Maximum electric field and BDR
- Field emission current and enhancement factor β
- Comparison with previous Hard Cu data

Normalization

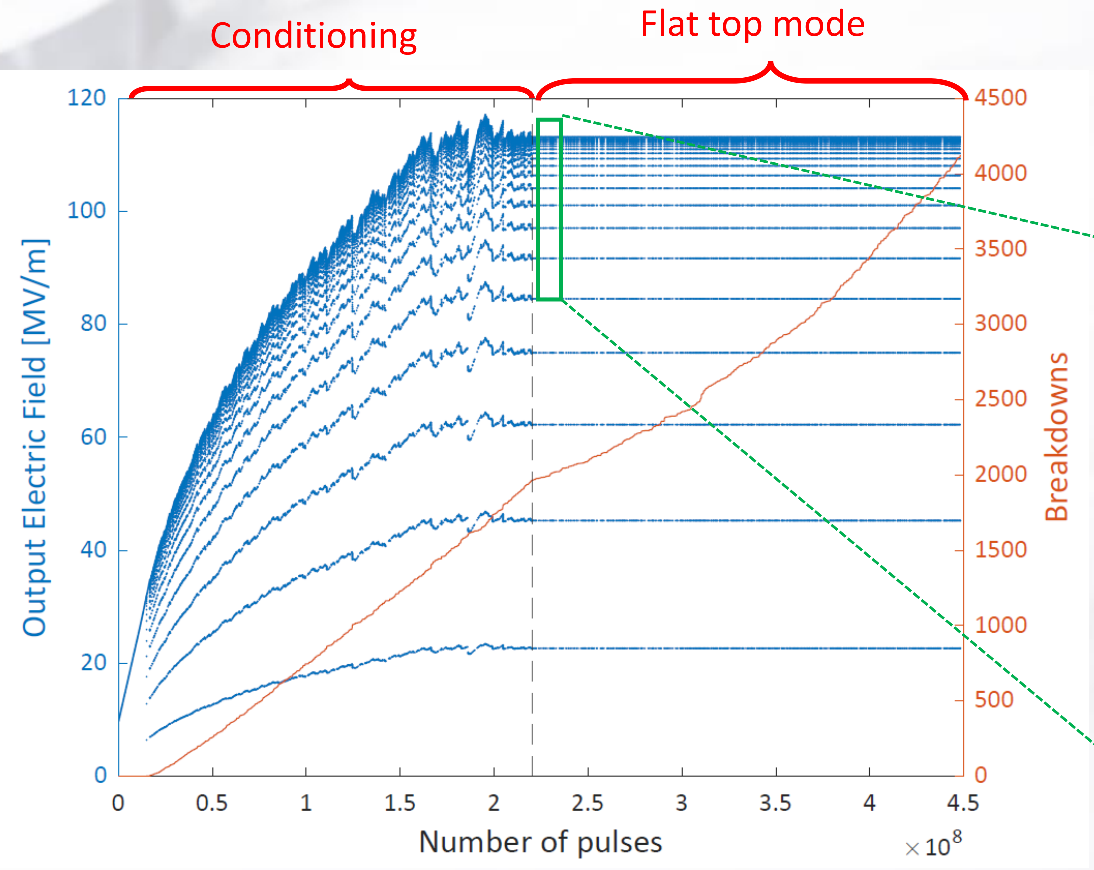
- Cryogenics changes gap size → need normalized field

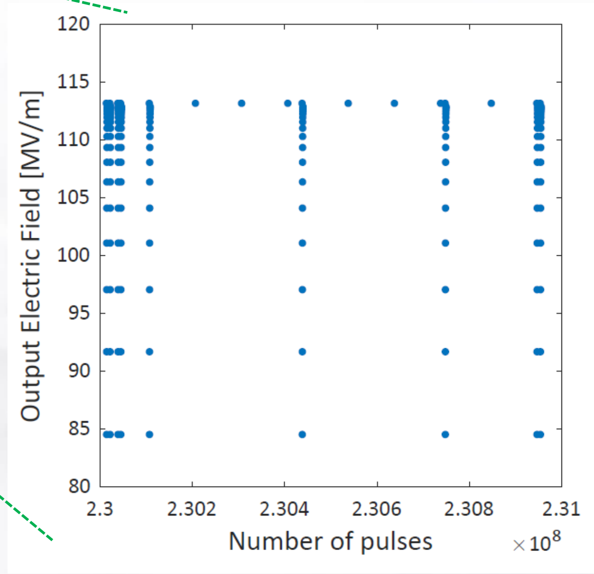
$$E_{norm} = \left(\frac{V}{V_{max}}\right)\left(\frac{d_{max}}{d}\right)^{0.7}$$



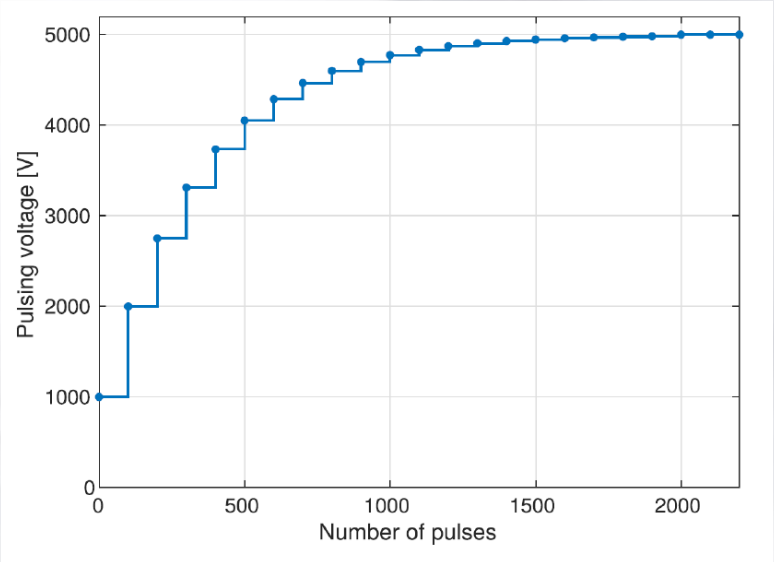
From I. Profatilova et al. (2019)
In agreement with
A. Maitland, J. Appl. Phys., vol. 32, pp. 2399-2407, 1961.

Results: Conditioning @ 300K





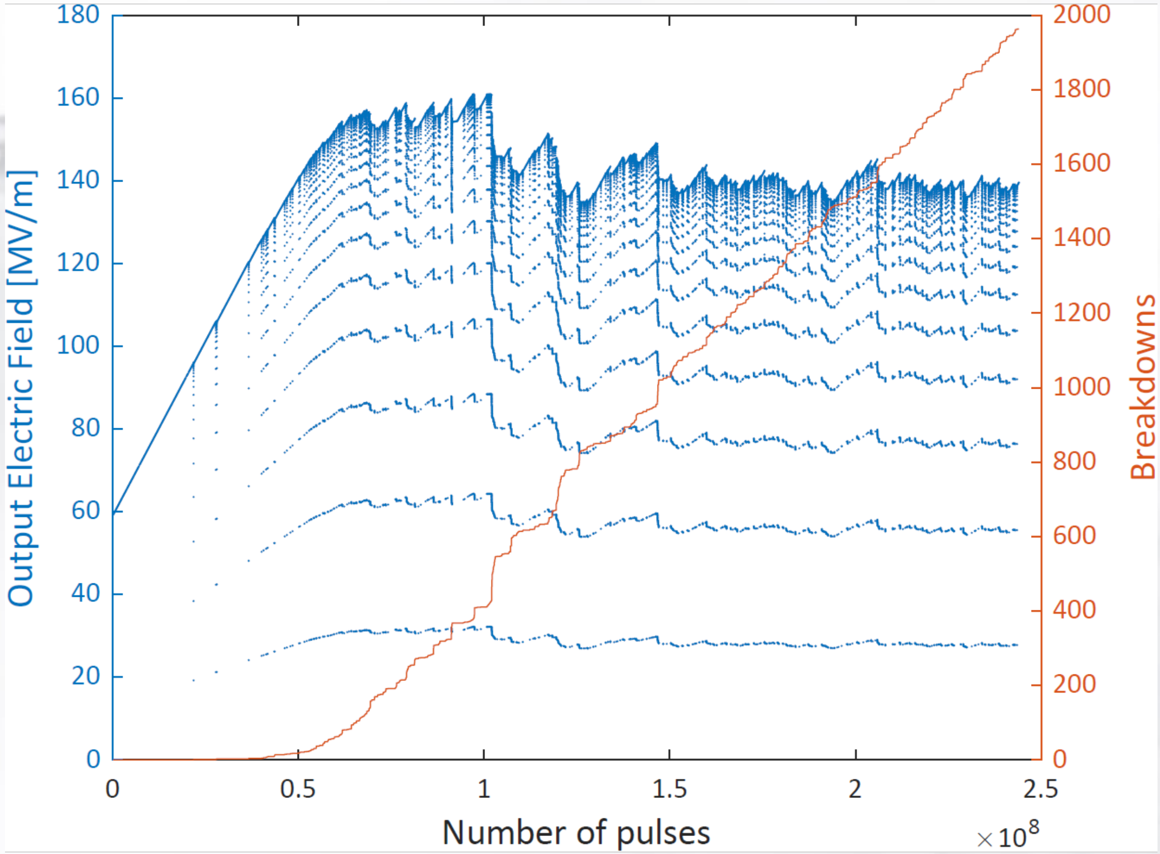
Ramping



Conditioning: Soft Cu @300K

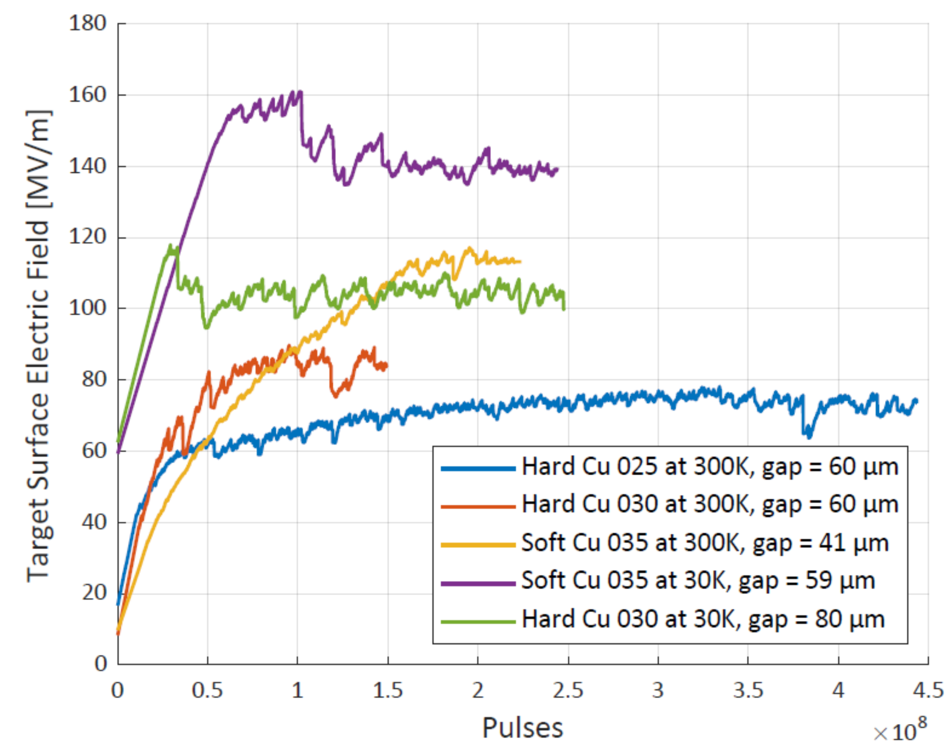
Flat top mode: 4630 V (113 MV/m). Measured BDR: 6.96e-6 BD/pulse

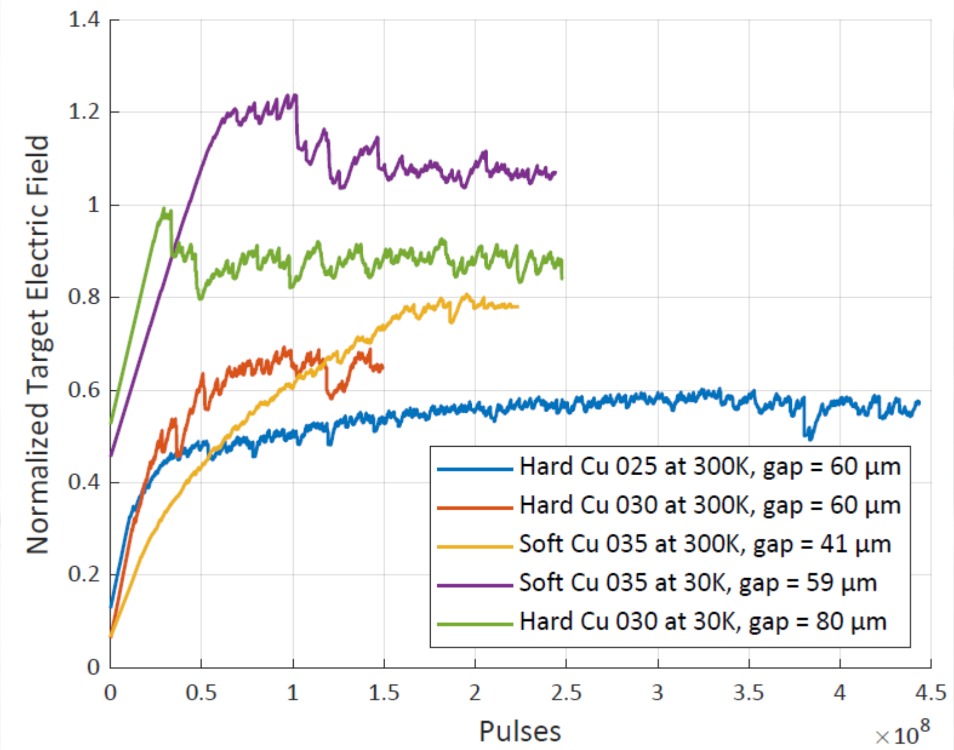
Results: Conditioning @ 30K



Conditioning: Soft Cu @30K

Results: Comparison of conditioning curves

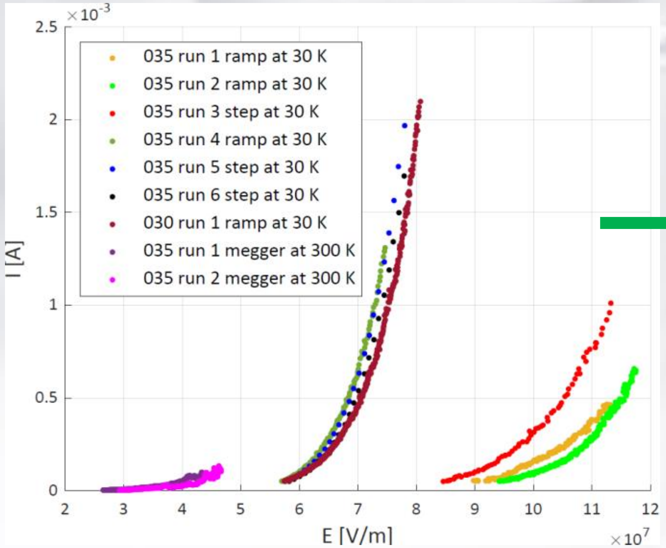




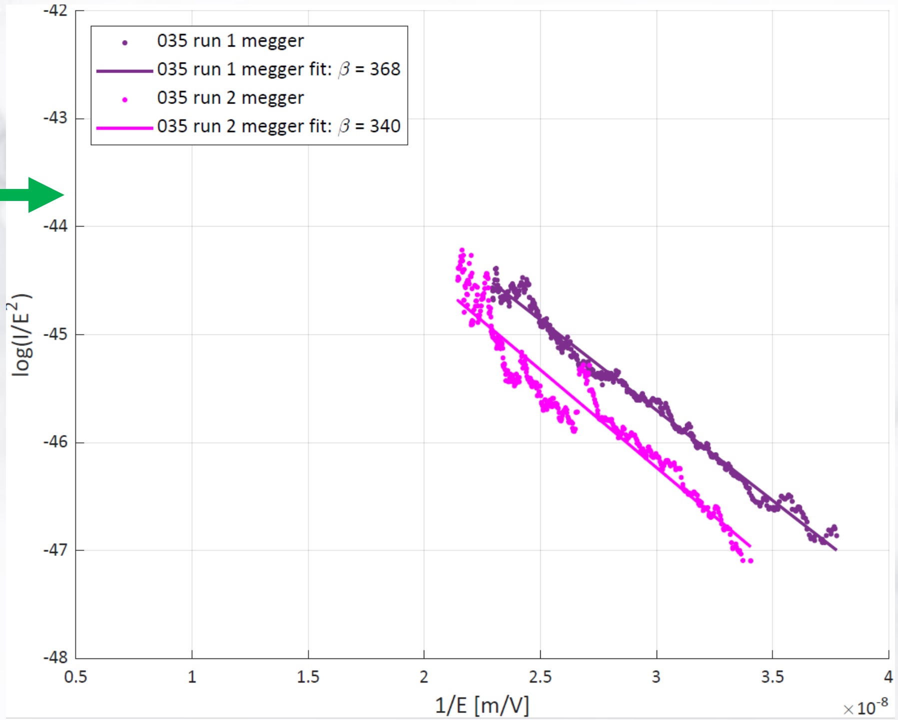
	T = 300 K			T = 30 K	
	Hard Cu 025	Hard Cu 030	Soft Cu 035	Hard Cu 030	Soft Cu 035
E_{max} [MV/m]	78.17	89.75	117.1	117.9	160.9
$E_{norm,max}$	0.604	0.693	0.808	0.994	1.24

Results: Field emission and Fowler-Nordheim plots

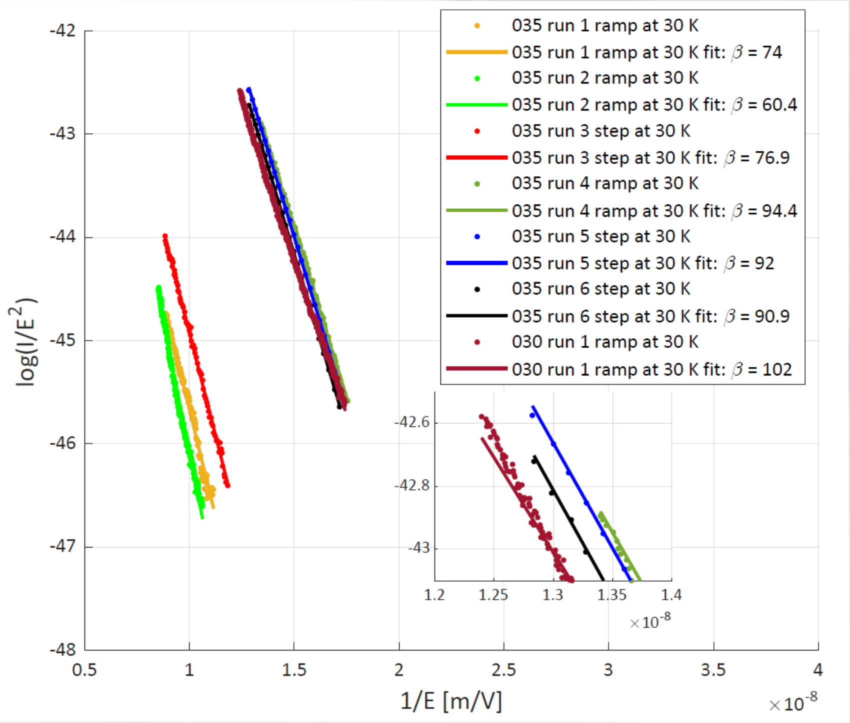
$$\frac{d(\log I_F/E^2)}{d(1/E)} = -\frac{6.53\times10^9\phi^{1.5}}{\beta}$$



Field emission current

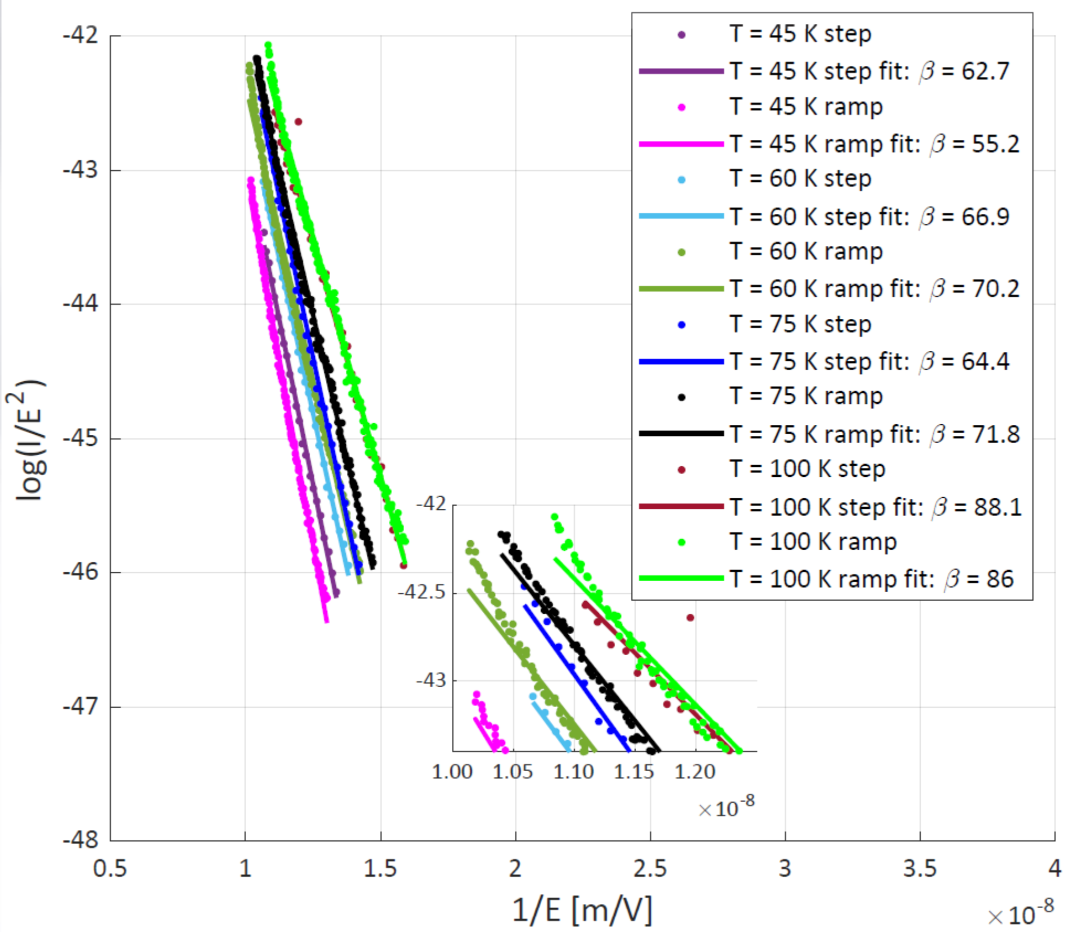


Field emission: Soft Cu @ 300 K

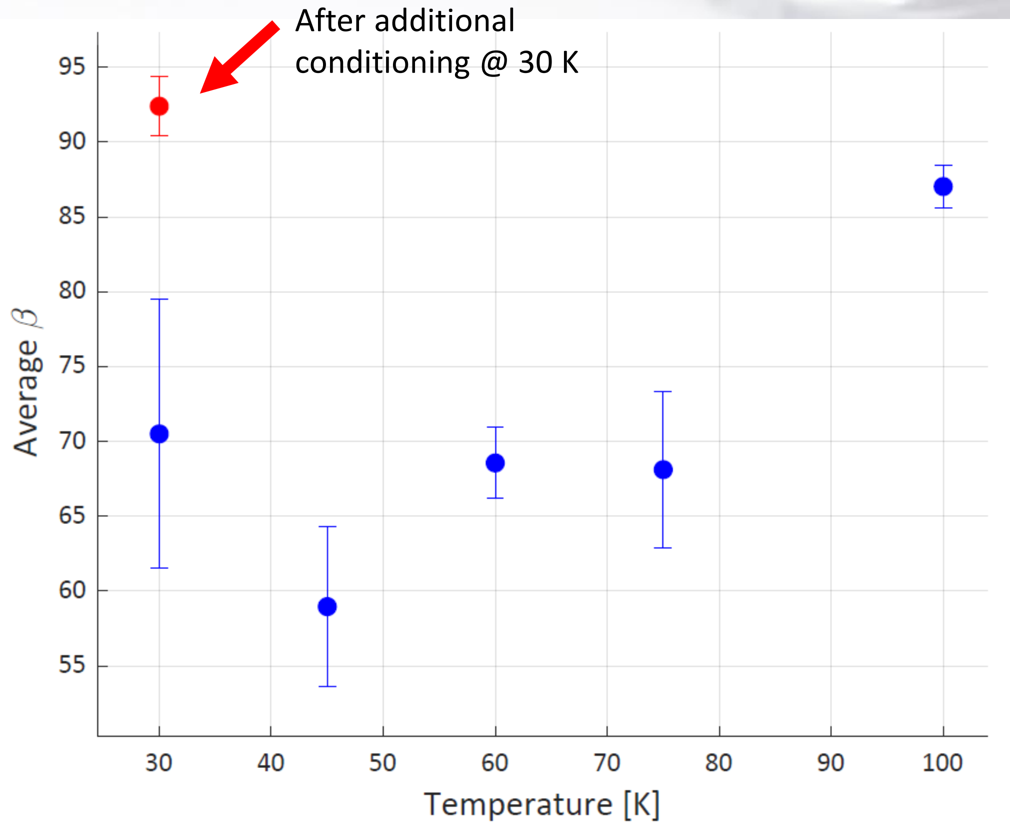


Field emission: Soft Cu @ 30 K

Results: Field emission at warm-up



Field emission: Soft Cu @45-100K



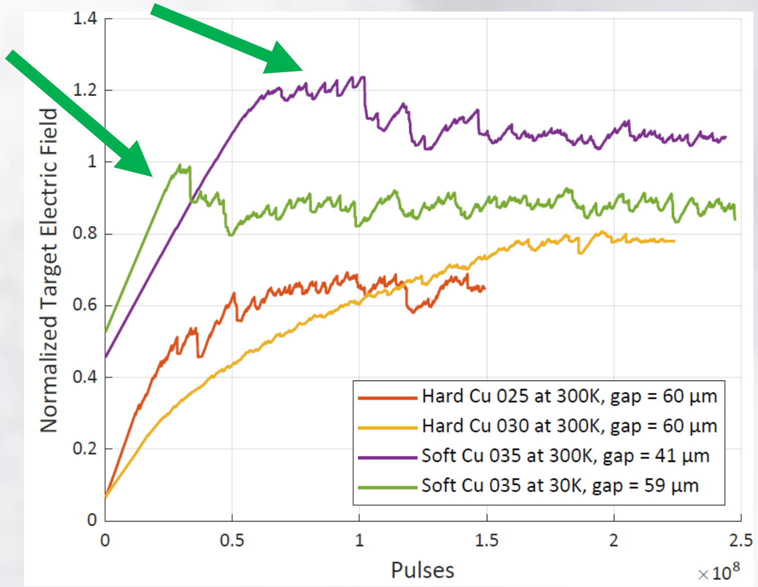
Average enhancement factor β during warm-up

At @ 300 K:
β = 354 +/- 20

Summary

- Conditioning @300K and @30K
  - Successful conditioning, BDR = 6.96e-6 BD/pulse at flat top @300K
  - Higher accelerating gradient in cryogenic setting: @30K normalized field 53% higher than @300K
  - Higher saturation field for Soft Cu than Hard Cu, but slower conditioning
  - “Ricochet” effect?

- Field emission
  - Enhancement factor β increasing with temperature
  - “Cleaner” linear trend in cryogenic setting



Outlook

- Conditioning: ricochet effect
- Field emission: cooldown instead of warm-up?
- Possible improvements for superconducting materials
  - Improved cleanliness (important for e.g. niobium)
  - Additional LN2 pre-cooling
- Cryogenic experiments important for high-gradient accelerating technology!

Thank you for your attention!

Extra slide: Set-up, HV Power Supply

Conditioning with MARX generator
1 μs pulses, 200Hz to 2kHz, up to 10 kV

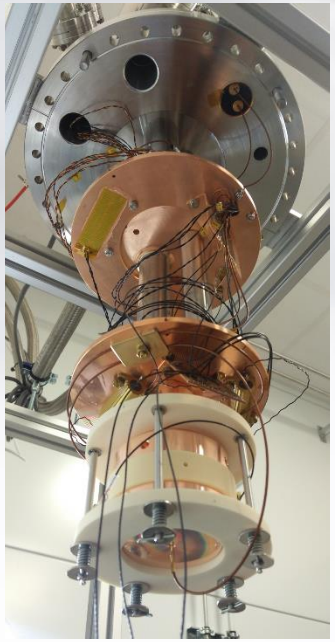
Field emission

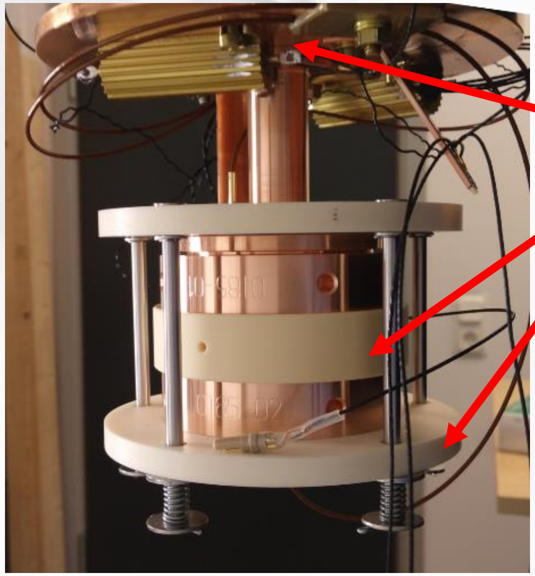
Megger MIT525
Ramp mode up to 5 kV
Current range: 0.01 nA to 3 mA
Current accuracy: ±2%

Heinzinger HNC 20.000
Programmable
Voltage up to 20 kV
Current range: 0.001 to 5 mA
Current accuracy: ±0.1%

UPPSALA
UNIVERSITET

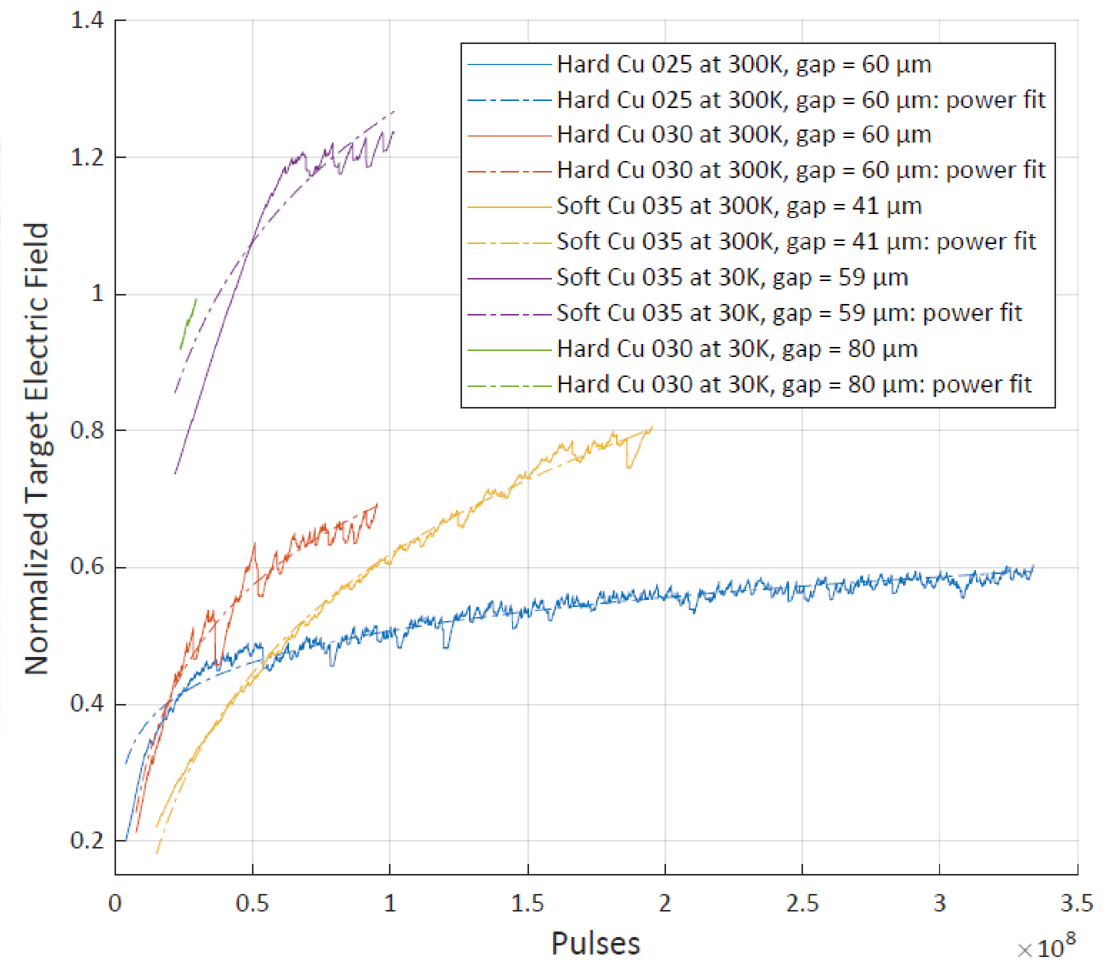
Extra slide: Set-up, Temperature Control





6 temperature sensors:
3 temperature sensors close to electrodes
+
1 on each radiation shield
1 at the first stage of cryocooler
+
2 heaters for temperature control

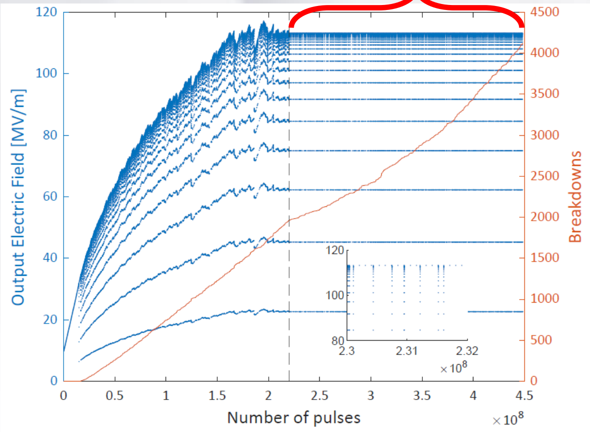
Extra results: Conditioning curve fit

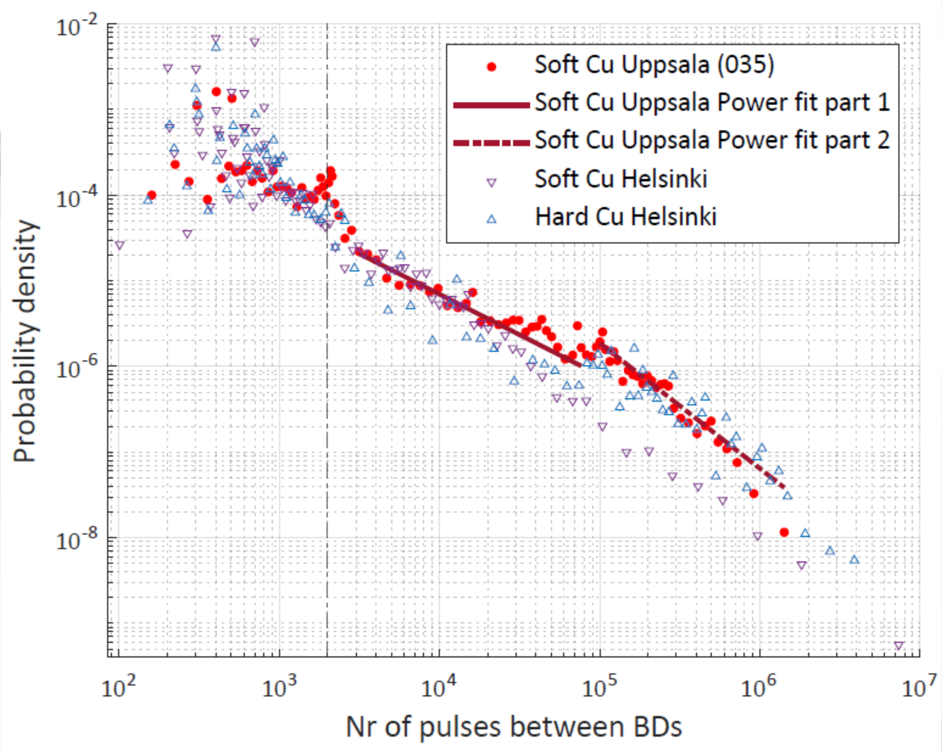


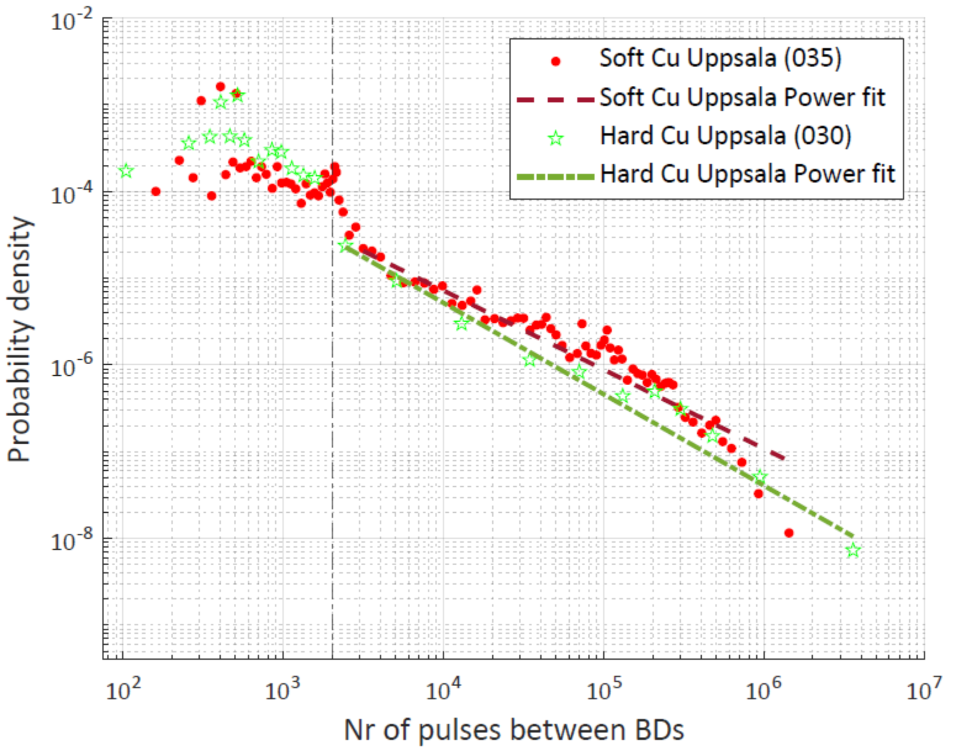
Normalized electric field with power fits

Extra results: Pulses between breakdowns

During flat top mode:



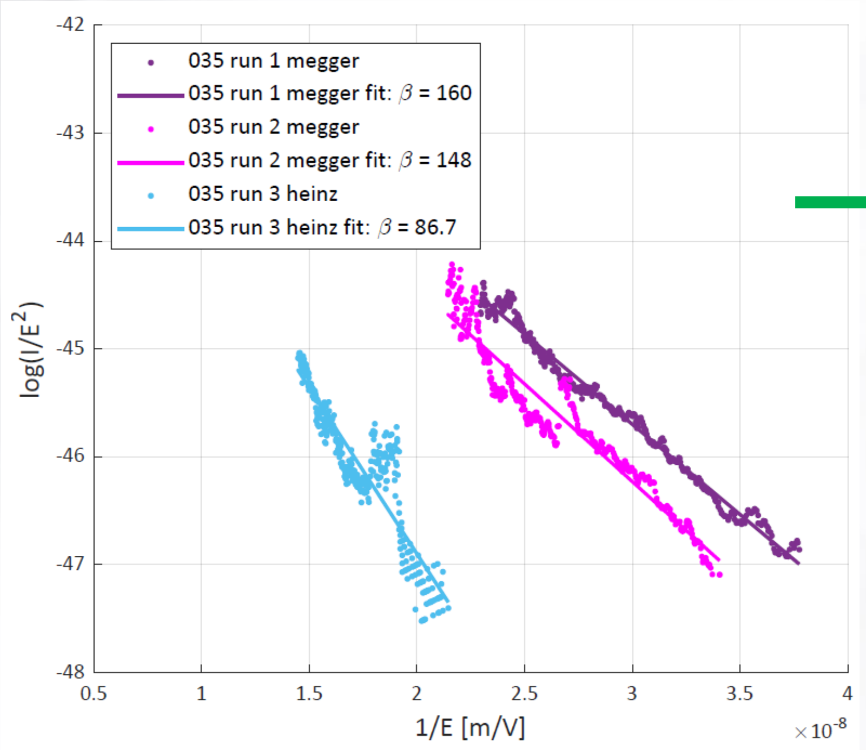




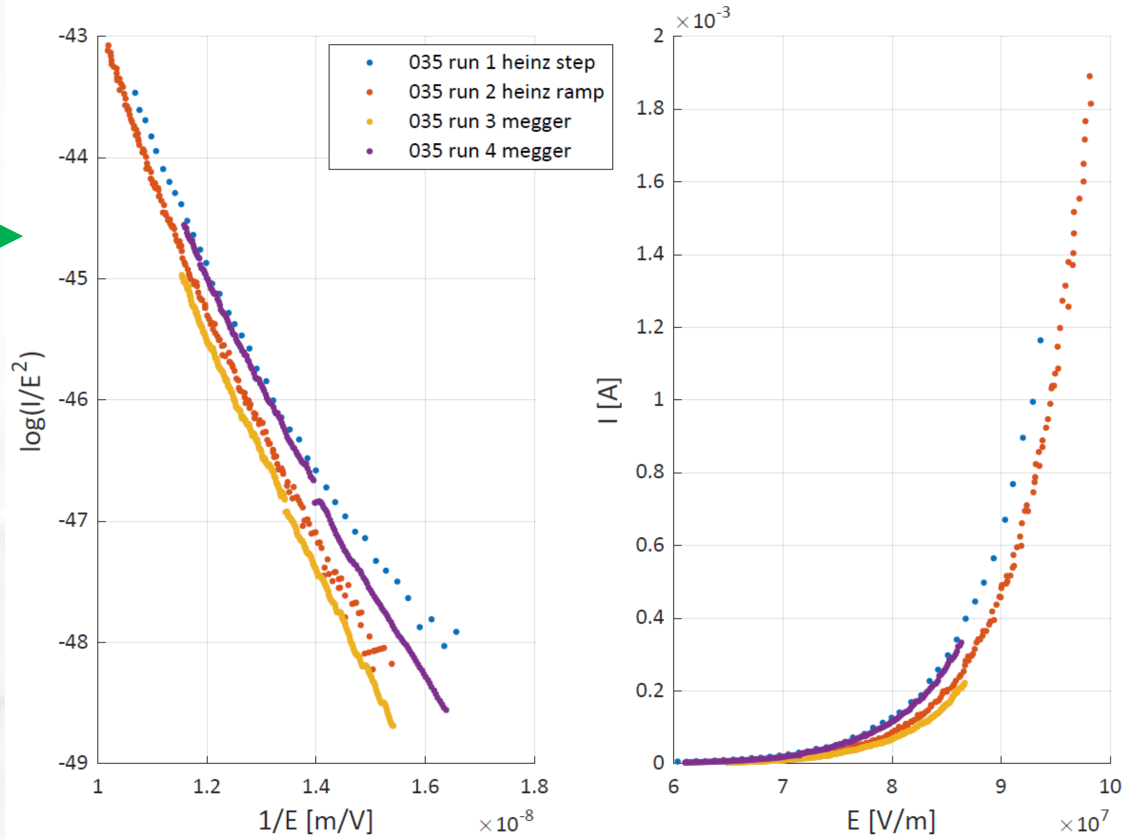
Fitting coefficients for model $P(S) = kS^{-\alpha}$

Power fit	Soft Cu Uppsala (2020)	Soft Cu Helsinki	Hard Cu Helsinki	Hard Cu Uppsala (2019)
Single	$\alpha = 0.91 \pm 0.08$	$\alpha = 1.30 \pm 0.05$	N/A	$\alpha = 1.05 \pm 0.1$
Double	$\alpha_1 = 0.95 \pm 0.1$ $\alpha_2 = 1.47 \pm 0.3$	N/A	$\alpha_1 = 1.30 \pm 0.05$ $\alpha_2 = 1.37 \pm 0.05$	N/A

Extra results: Field emission instrument check



Field emission at 300 K



Field emission currents at 45 K for soft copper

- No systematic difference in instruments Megger/Heinzinger