Copper Surfaces: Comparative Studies in Cryogenic High Fields

Elias Waagaard

Supervisor: Marek Jacewicz

In collaboration with: S. Calatroni, R. Peacock, I. Profatilova, W. Wuensch, CERN

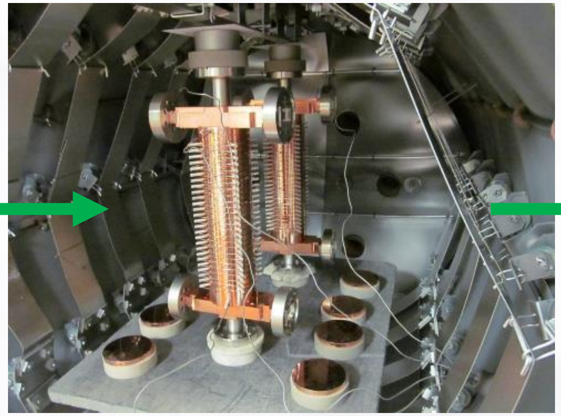
MeVArc, March 8th 2021

UPPSALA UNIVERSITET

Outline

- Background and motivation
- Experimental set-up
- Results Hard and Soft Cu
  - Conditioning
  - Field emission
- Summary and outlook

Background and Motivation



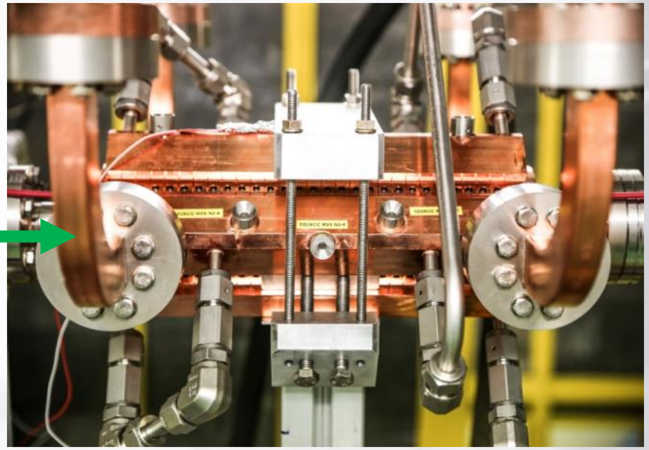


Image courtesy: Walter Wuensch

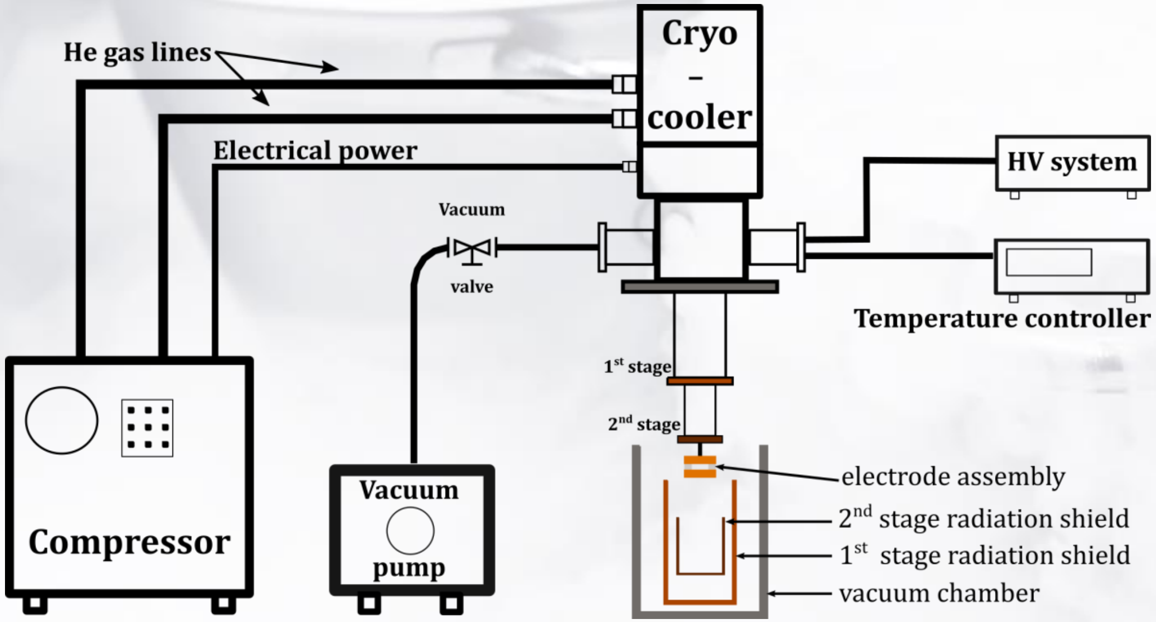
- Cryo experiments: provide new information for vacuum arc theories
- Purpose of this study: behaviour of hard/soft copper at cryogenic temperatures
- Development of low-loss cryo-accelerating structure with high-purity copper
- Recent studies at SLAC: cryogenic setting reduces BDR
  - Gradient: 250 MV/m @ 45 K with 2e-4 BD/pulse/m
- Possible approaches to ultra-compact linac

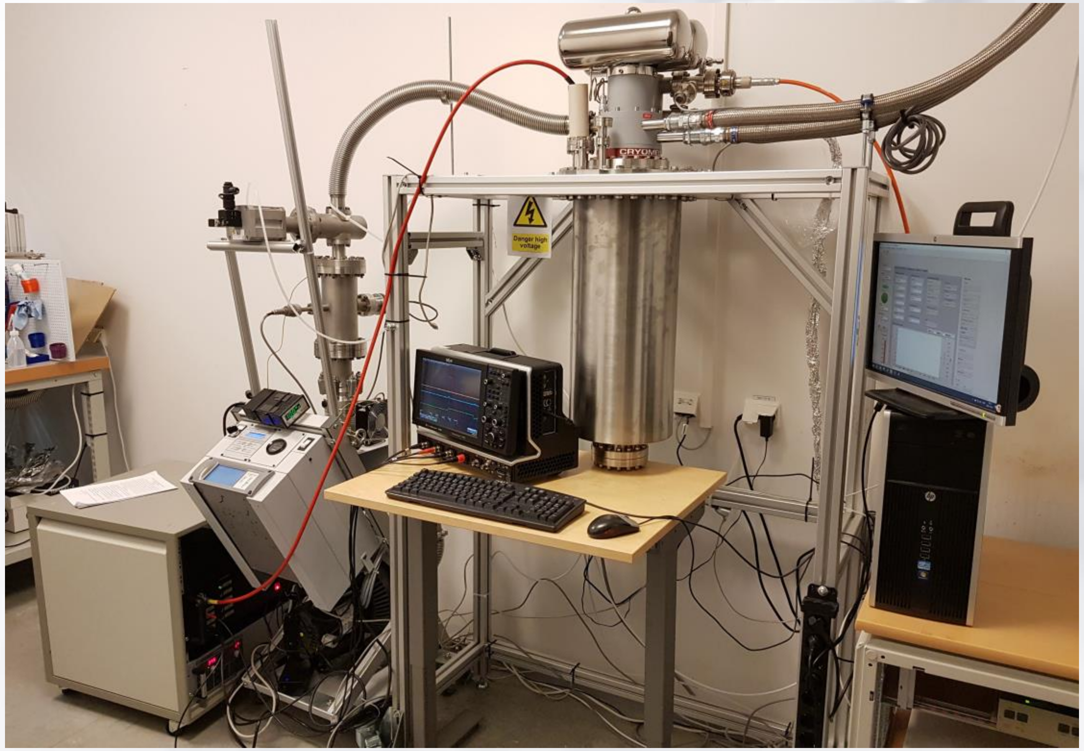
A. Iino et al NIM A 866, 40–47 (2017)

DOI: 10.1103/PhysRevAccelBeams.21.102002

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

Experimental Set-up

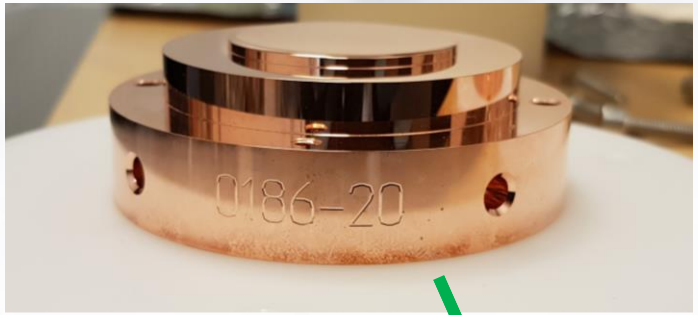




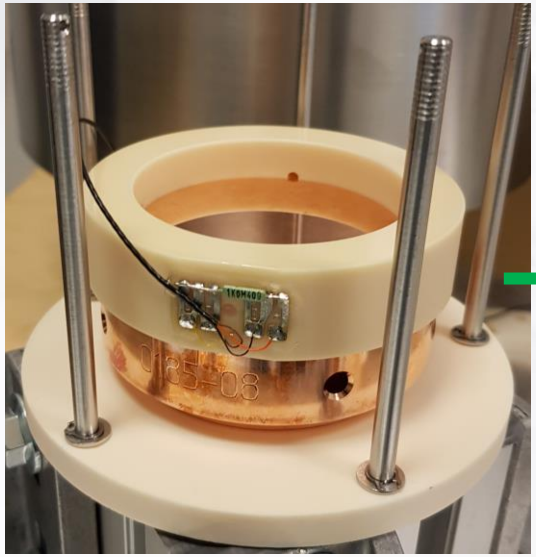
Typical pressure values:
@ room temperature: < 1e-7 mbar
@ cryo temperatures: < 5e-9 mbar

Set-up: Electrodes

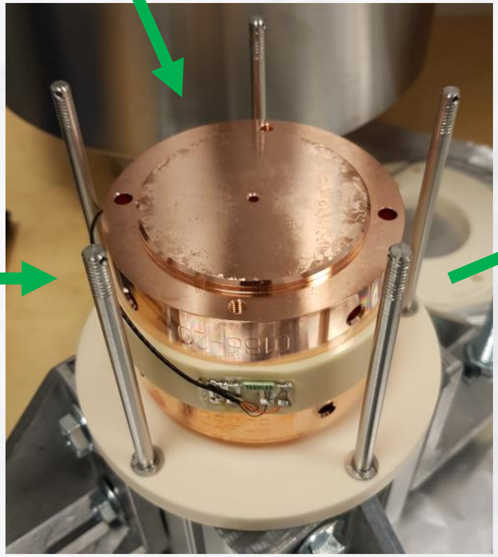
Hard Cu cathode from previous experiments

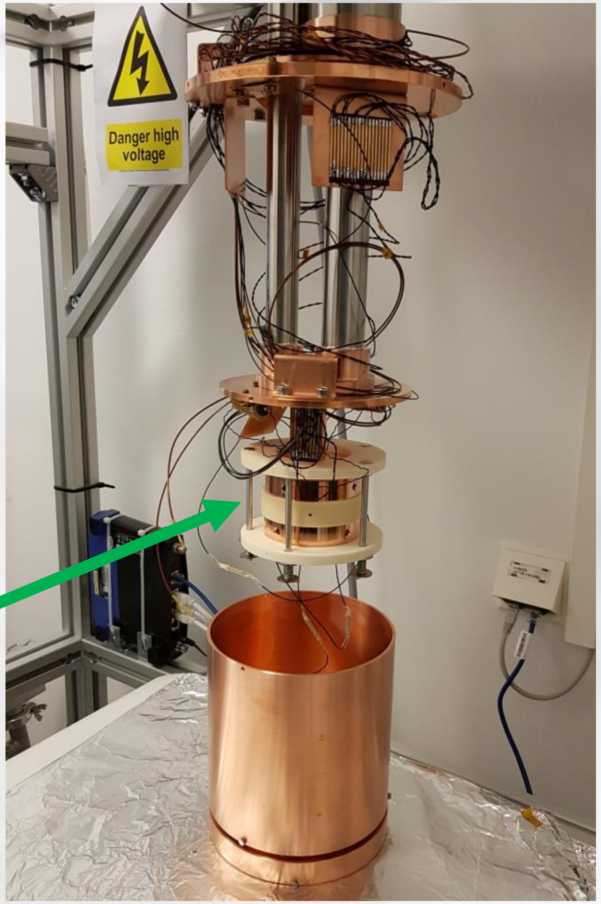


Soft Cu Anode



Soft Cu Cathode





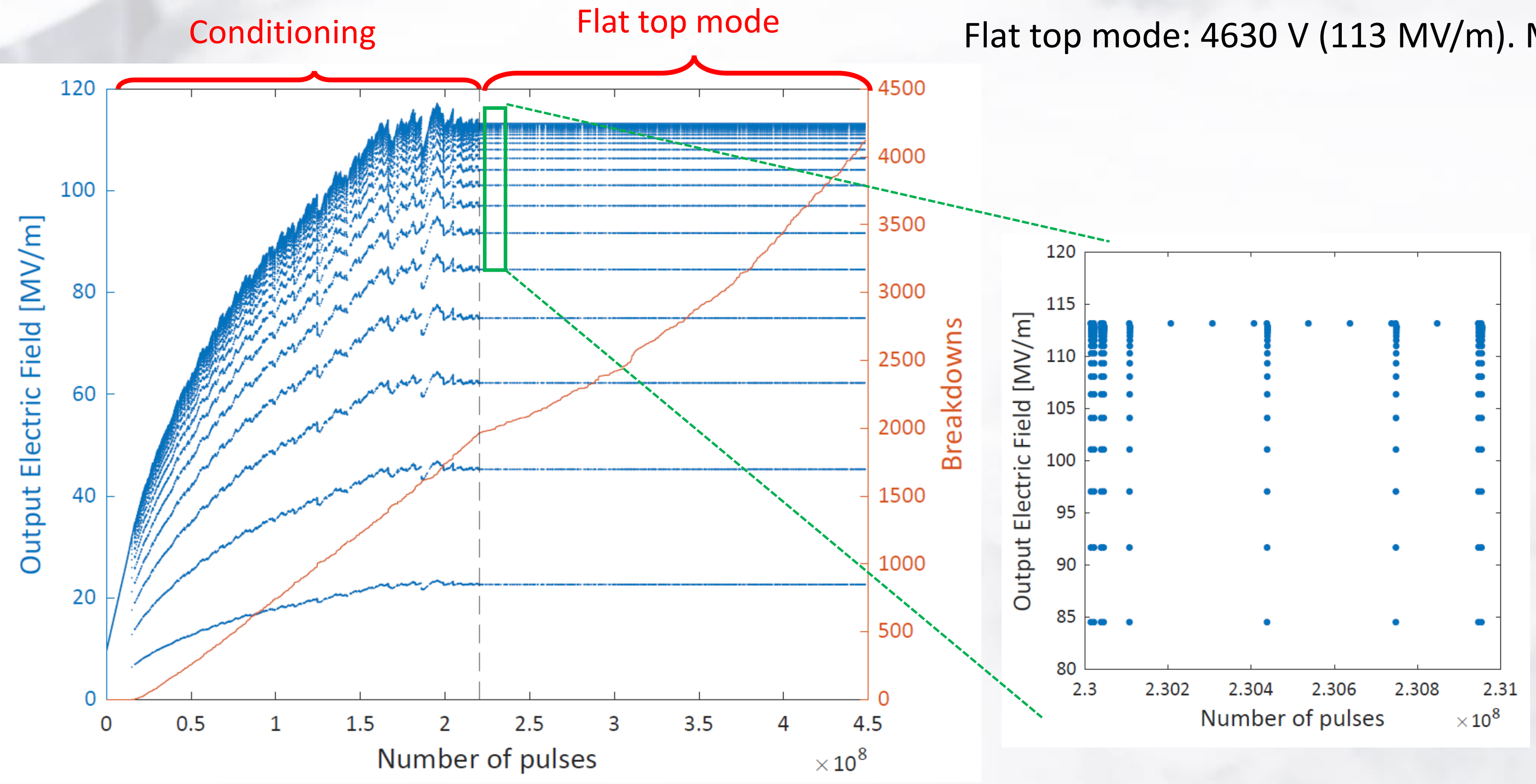
Electrodes and first stage radiation shield

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

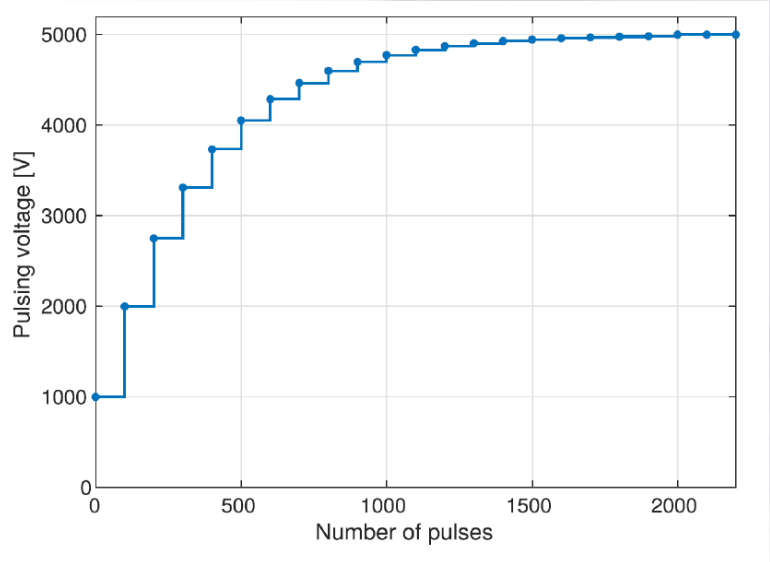
Results: Conditioning @ 300K (d = 41µm)

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



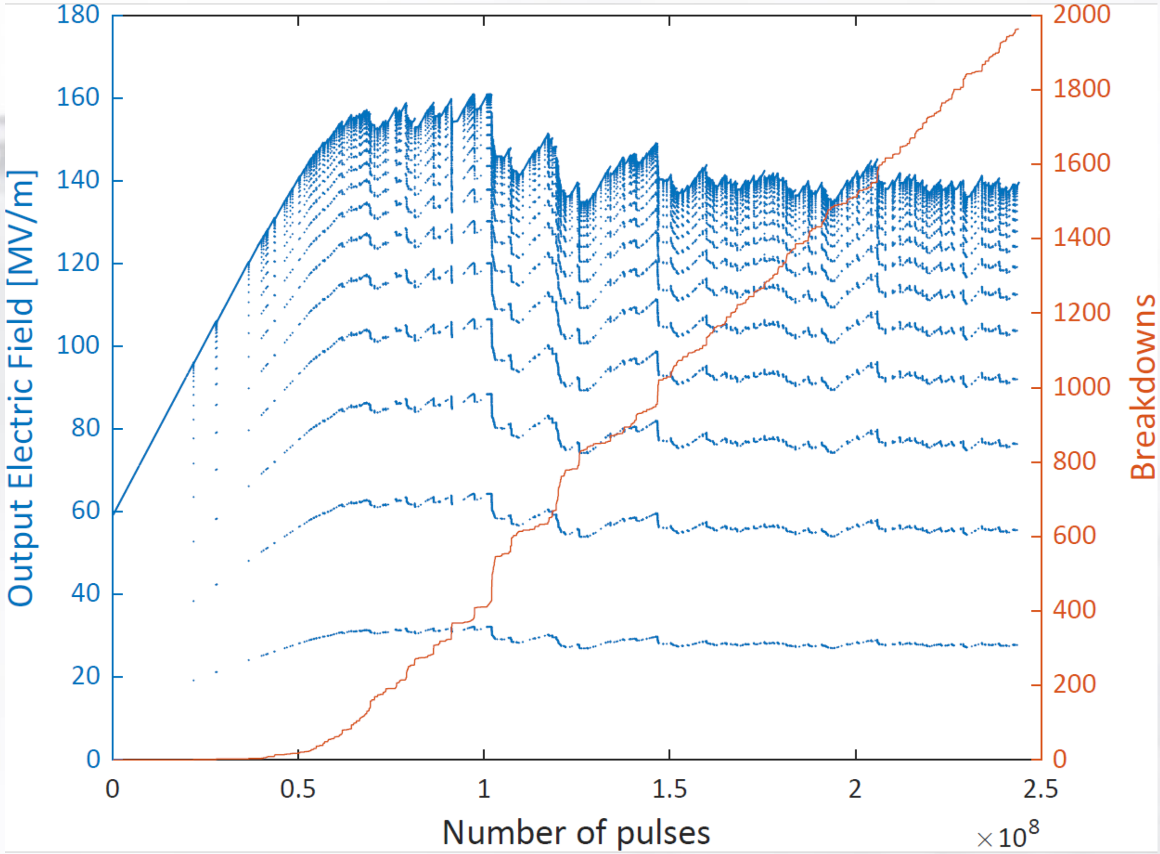
Conditioning: Soft Cu @300K

Ramping



Saturation voltage: 4759.4 V, saturation field: 116.1 MV/m

Results: Conditioning @ 30K (d = 59μm)



Conditioning: Soft Cu @30K

Saturation voltage: 9068.1 V, saturation field: 153.7 MV/m

Normalization

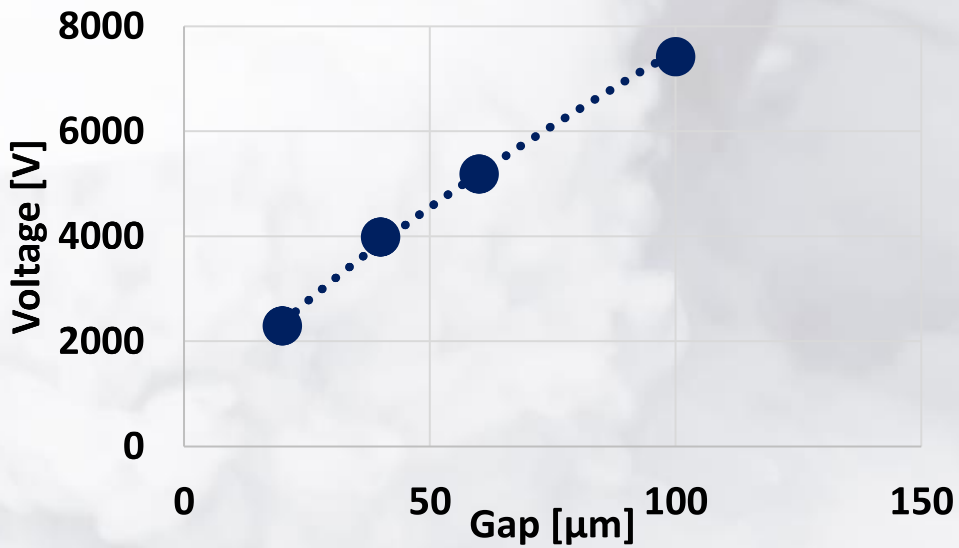
- Saturation fields decreases with increasing gap size

$$V_{\text{sat}} = k \times d^{0.7}$$

$$E_{\text{sat}} = V_{\text{sat}}/d = k \times d^{-0.3}$$

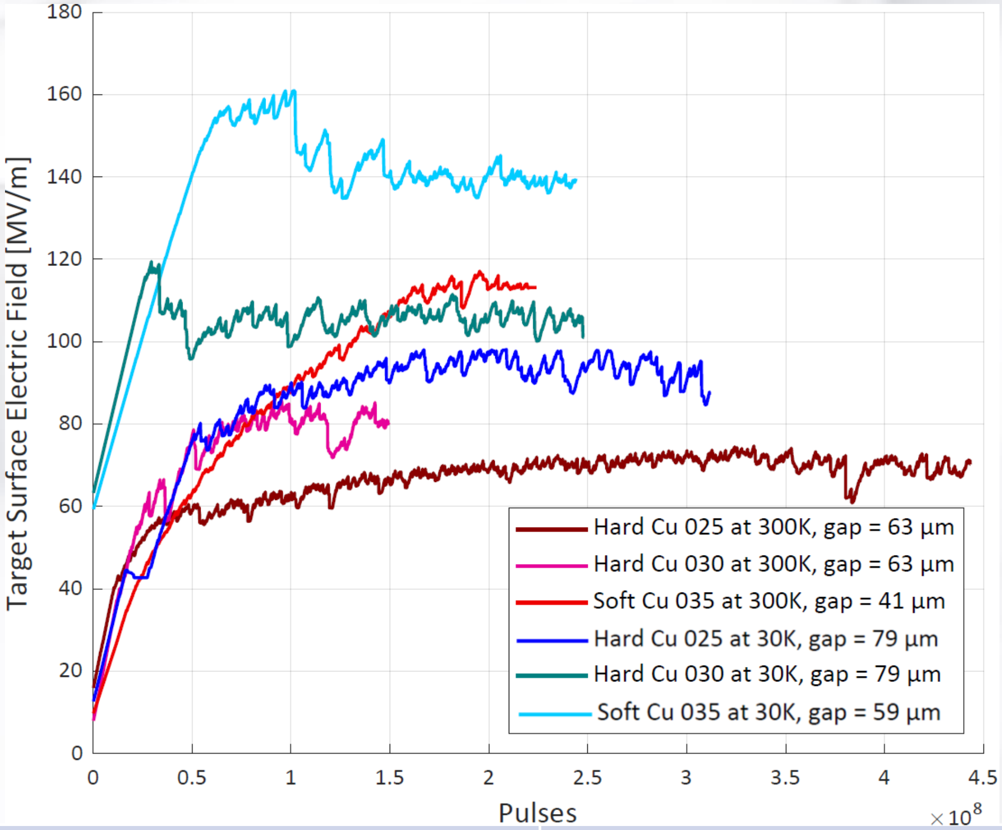
(where k depends on surface properties and conditioning procedure)

- Calculate $E_{\text{sat}}^{\text{est}}$ at cryogenic temperatures with k from room temperature data to compensate for gap size effect



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

Results: Comparison of conditioning curves



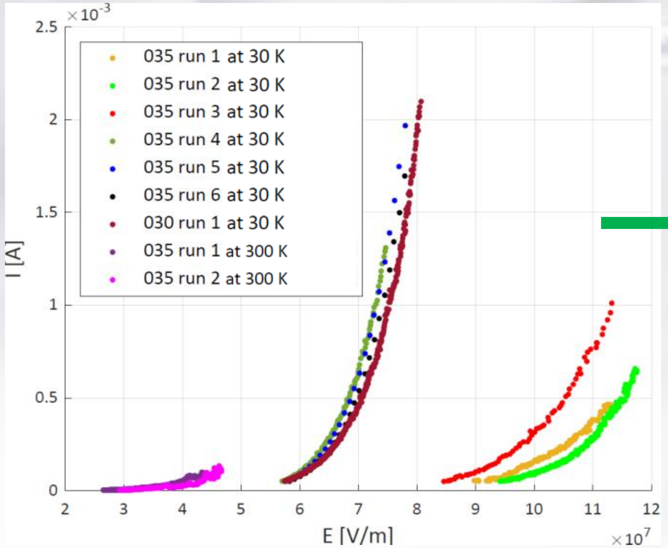
- Recall normalization

$$E_{\text{sat}}^{\text{est}} = V_{\text{sat}}^{\text{est}}/d = k \times d^{-0.3}$$

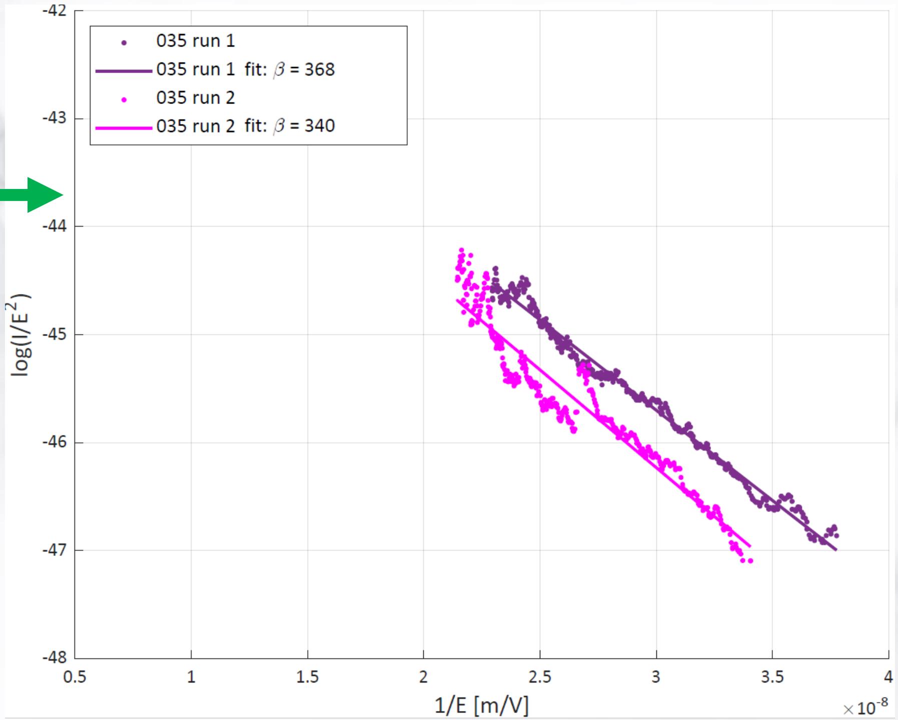
	Hard Cu 025			Hard Cu 030			Soft Cu 035		
T [K]	$E_{\text{sat}}^{\text{est}}$ [MV/m]	E_{sat} [MV/m]	$\Delta E/E$ (%)	$E_{\text{sat}}^{\text{est}}$ [MV/m]	E_{sat} [MV/m]	$\Delta E/E$ (%)	$E_{\text{sat}}^{\text{est}}$ [MV/m]	E_{sat} [MV/m]	$\Delta E/E$ (%)
30	67.4	96.7	43	78.3	117.1	50	104.1	153.7	48
300	72.2	72.2	0	83.9	83.9	0	116.1	116.1	0

Results: Field emission and Fowler-Nordheim plots

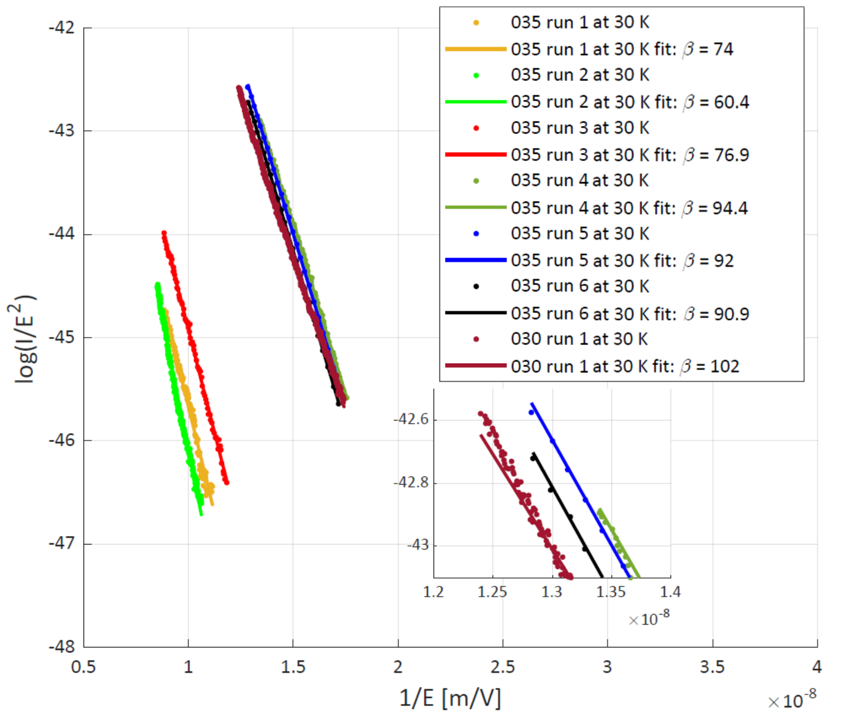
$$\frac{d(\log I_F/E^2)}{d(1/E)} = -\frac{6.53\times 10^9 \phi^{1.5}}{\beta}$$



Field emission current

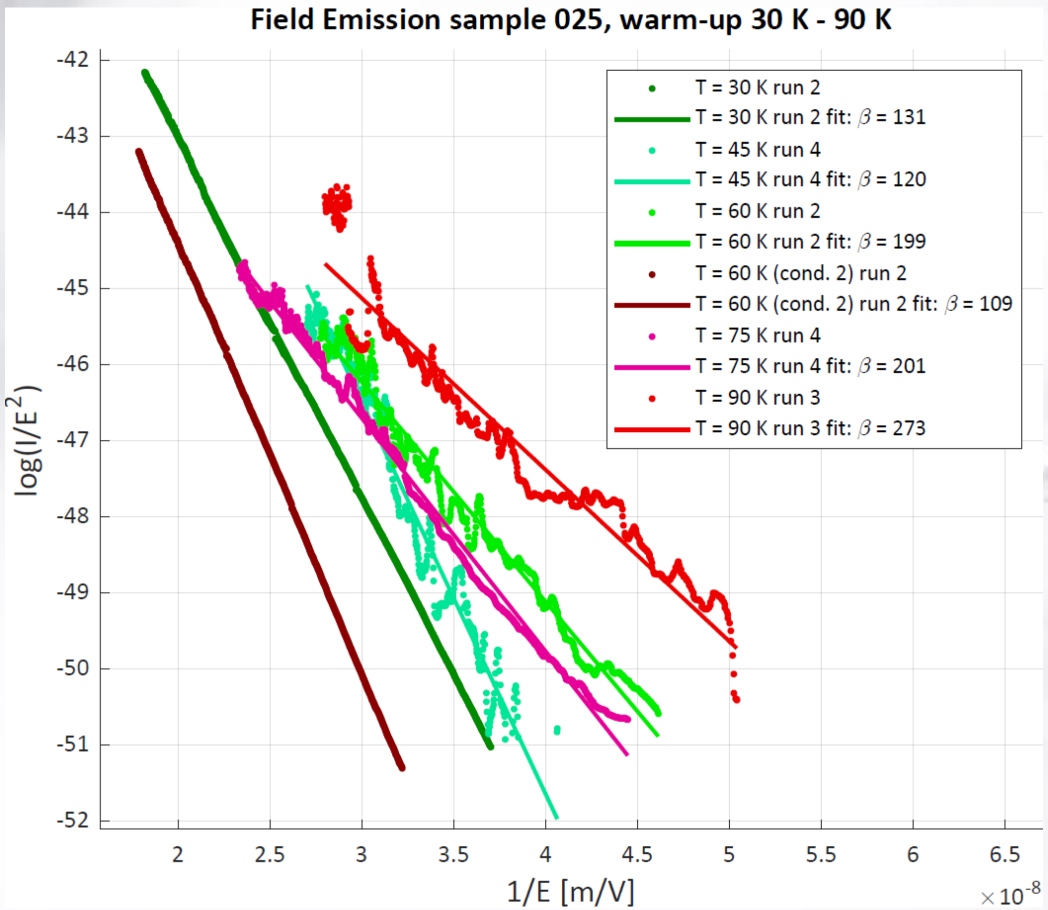


Field emission: Soft Cu @ 300 K

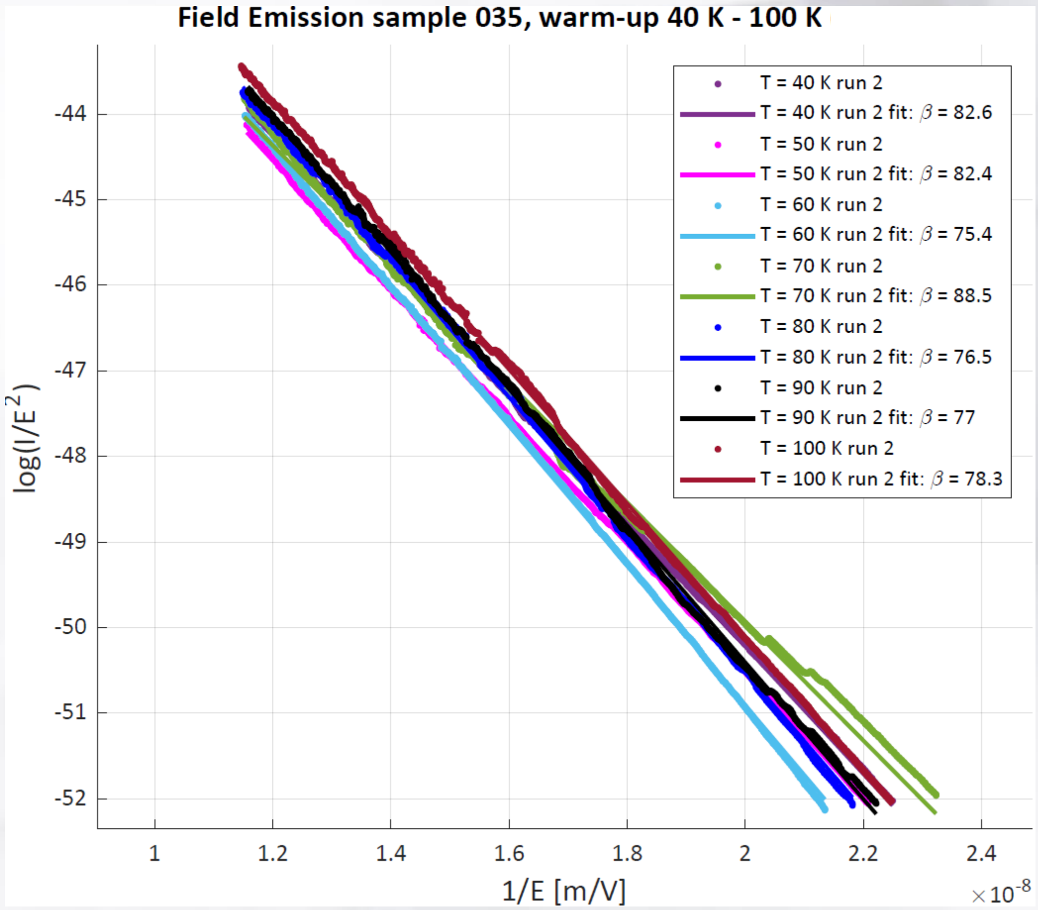


Field emission: Soft Cu @ 30 K

Results: Field emission Hard and Soft Cu

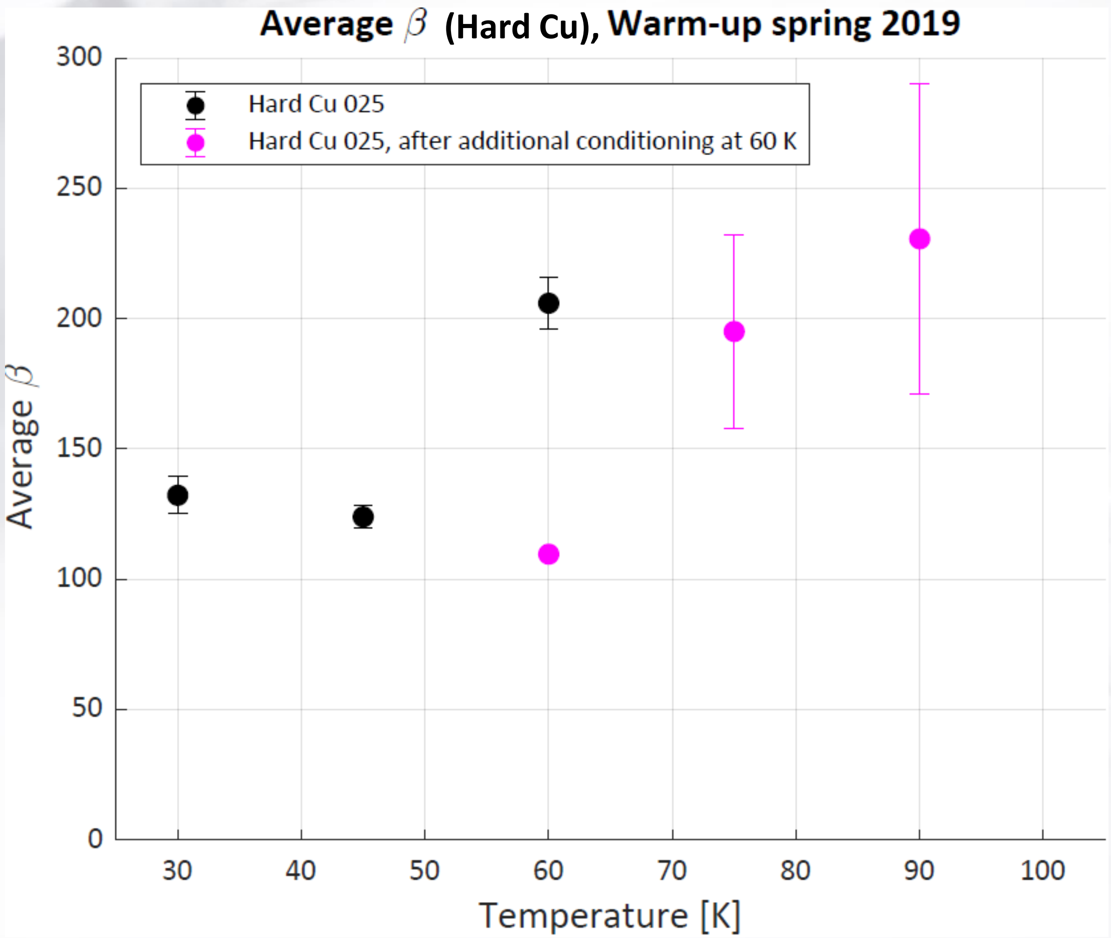


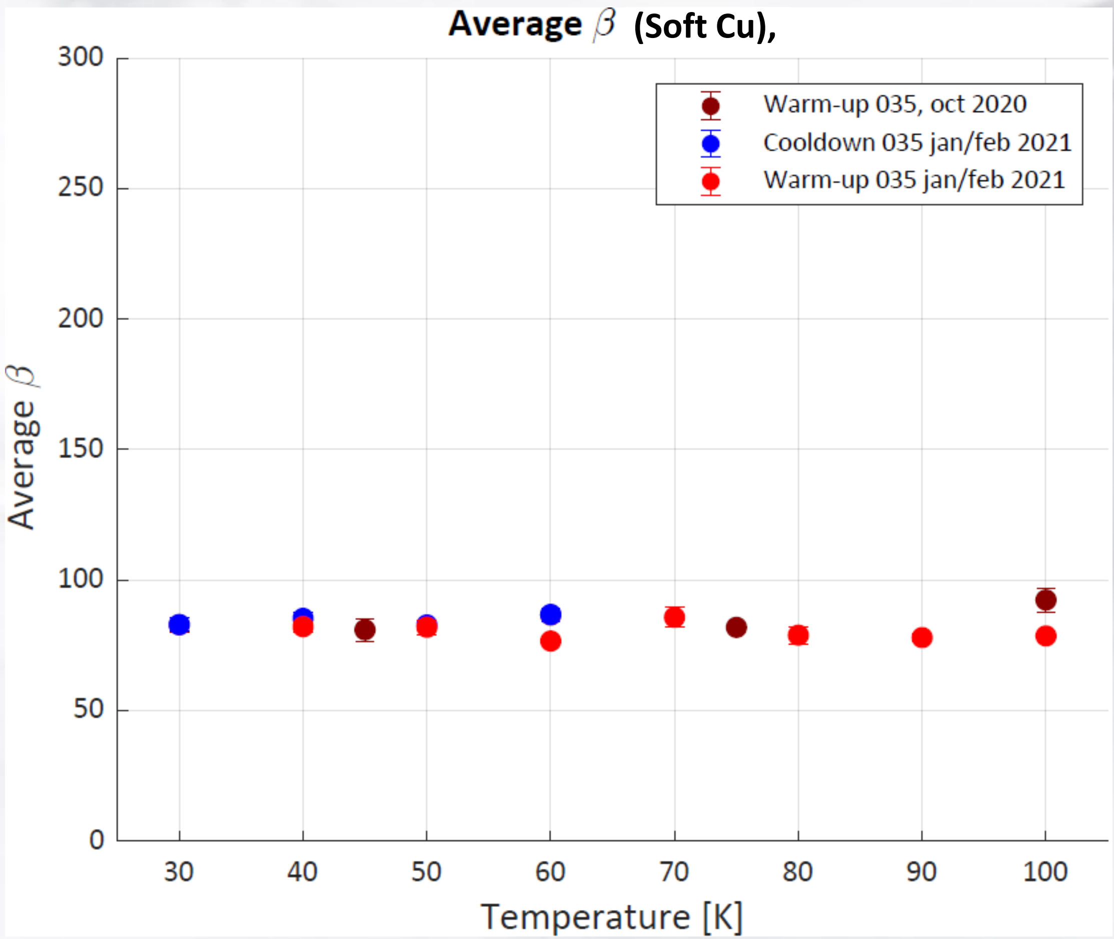
Field emission: Hard Cu 025 @30-90K



Field emission: Soft Cu 035 @40-100K

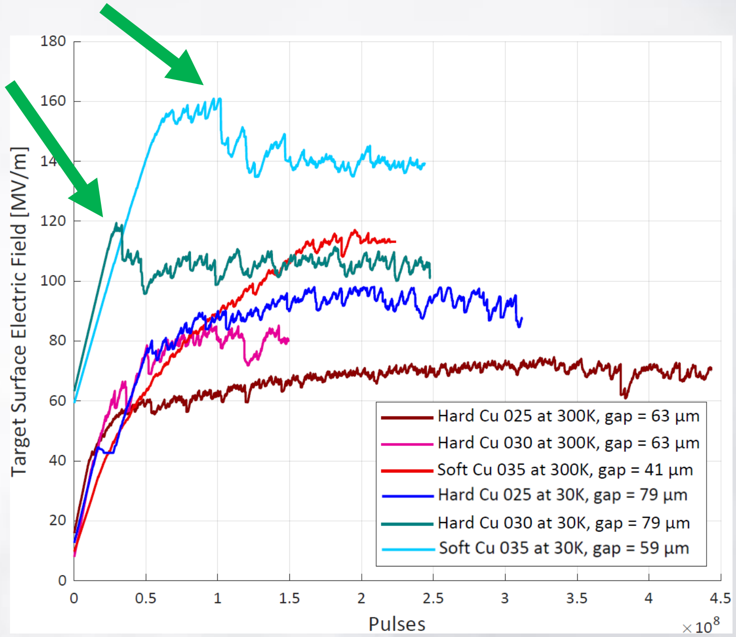
Field emission for Hard and Soft Cu



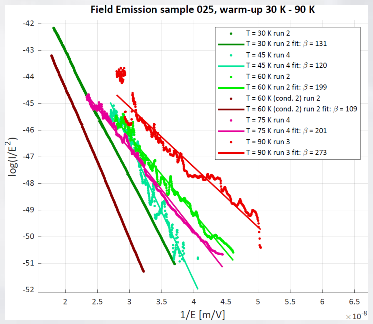


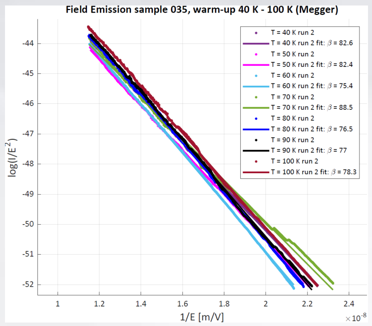
Summary and outlook

- Conditioning @300K and @30K
  - Successful conditioning; Soft Cu BDR = 6.96e-6 BD/pulse at flat top @300K
  - Higher accelerating gradient in cryogenic setting: @30K saturated field 48% higher than @300K
  - Higher saturation field for Soft Cu than Hard Cu, but same temperature effect
  - “Ricochet” effect?



- Field emission
  - Warm-up and cooldown of Soft Cu at different T gradient (fast/slow)
  - Little β dependence on temperature compared to Hard Cu
  - Much smaller fluctuations than Hard Cu in Fowler-Nordheim plots





- Cryogenic experiments important for high-gradient accelerating technology!