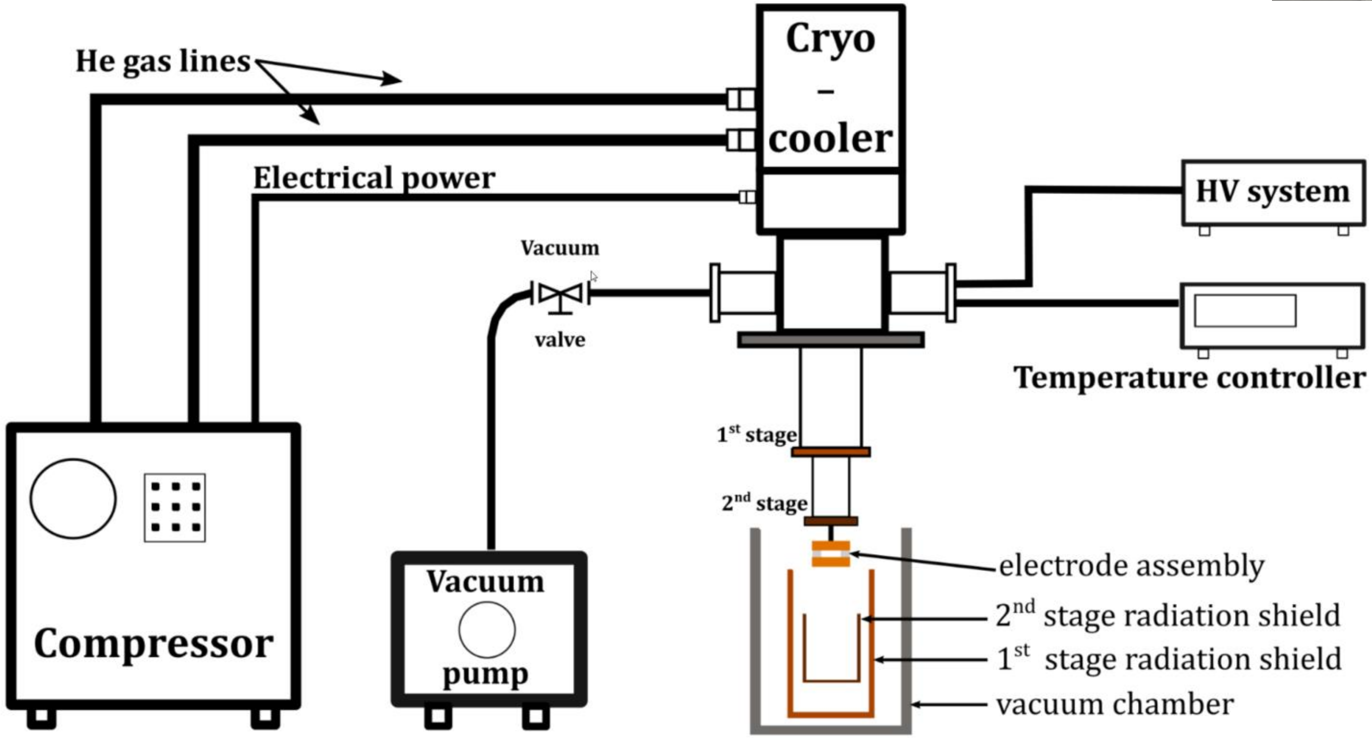
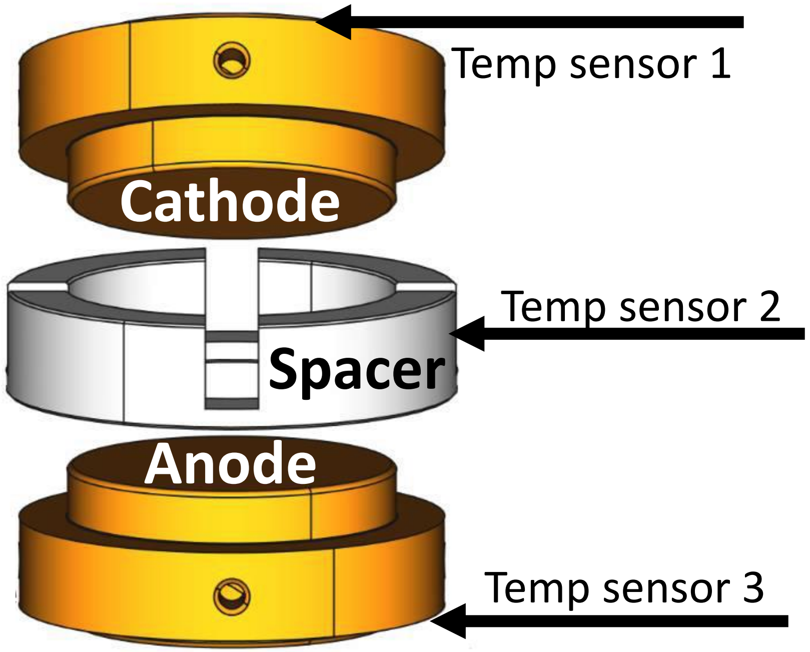
Field emission current evolution during conditioning at cryogenic temperatures

Mircea Coman, Marek Jacewicz, Iaroslava Profilatova

Experimental Set-Up

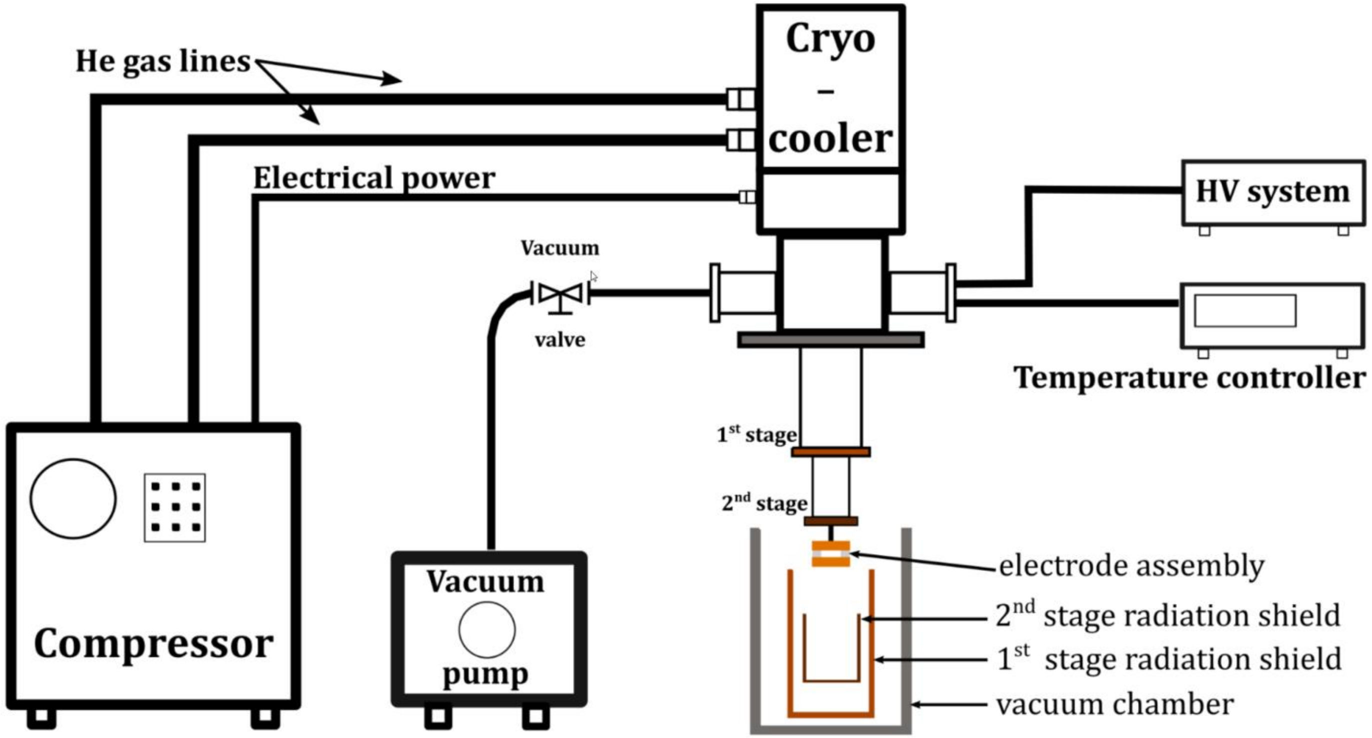
- Condition using a high voltage pulsed DC Marx generator
- Repetition rate 500-1000 Hz
- Maximum output voltage = 10 kV
- Circular electrodes with a diameter of 40/62 mm
- Conditioning at cryogenic temperatures (from 4K) and room temperatures
- 3 temperature sensors





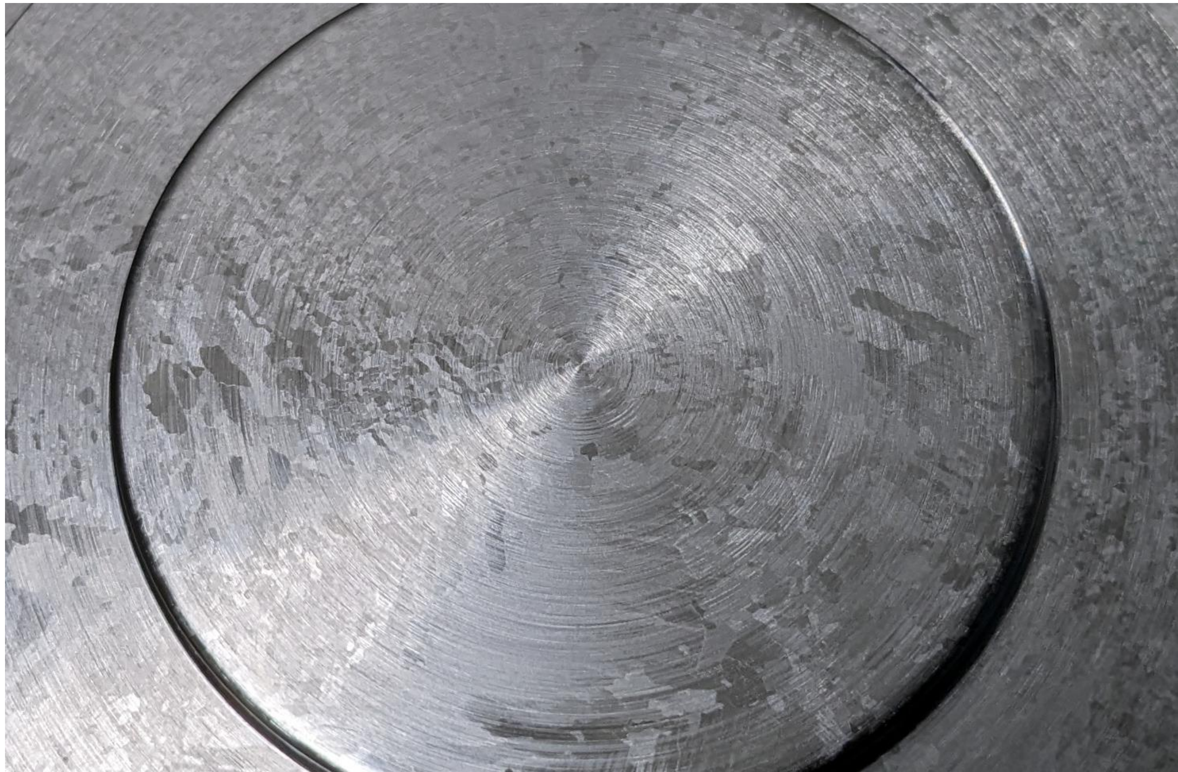
Experimental Set-Up

- Field emission measurements using DC power supply (up to 20kV and 5mA)
- Added a residual gas analyzer to check for desorbed gases during field emission

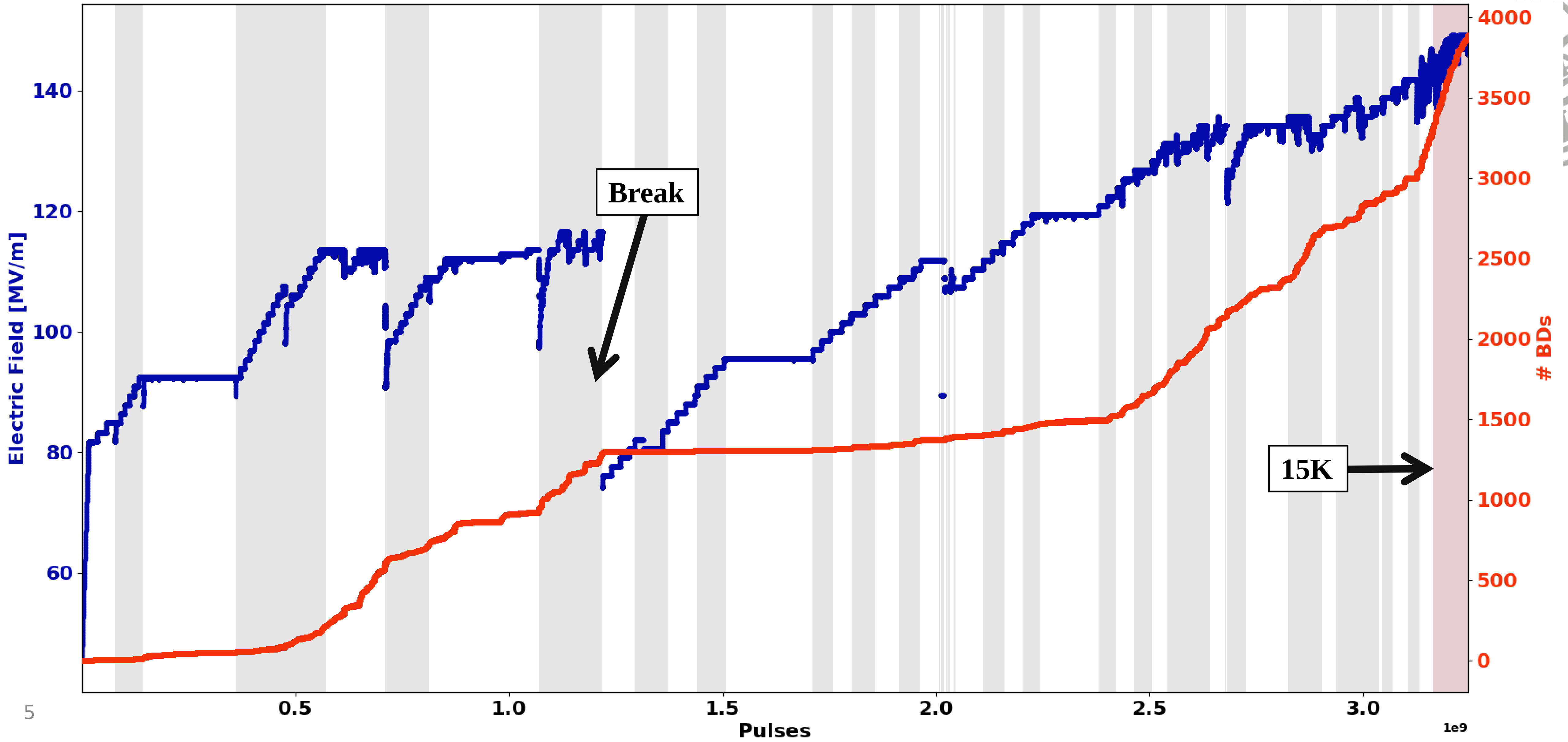


Nb electrode

- Electrodes originally conditioned at CERN at RT, re-machined and sent to Uppsala
- We condition them mostly at 4K
- 66 um gap



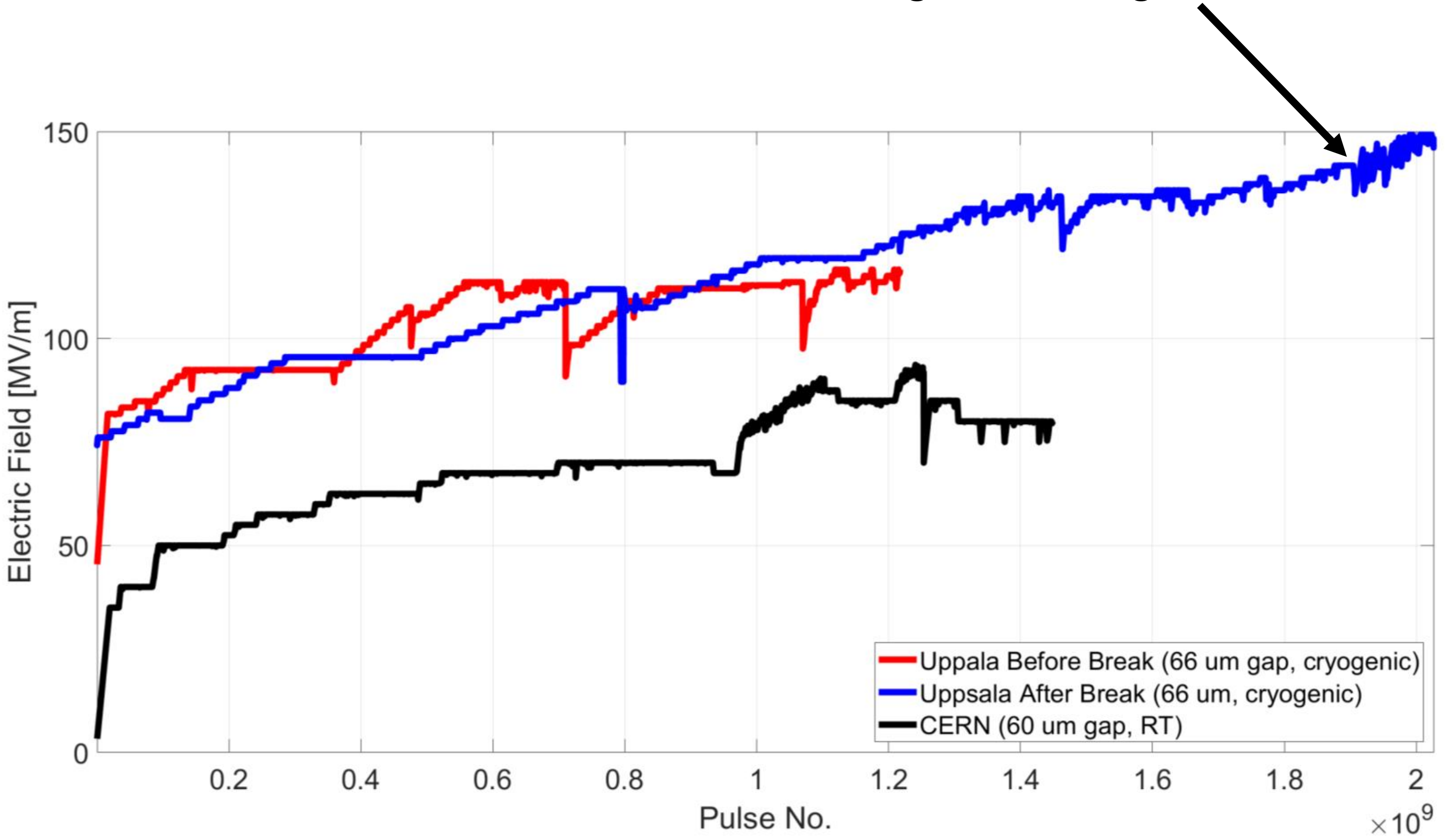
Nb electrodes – Conditioning Curve



Nb Conditioning Results and Comparison to CERN

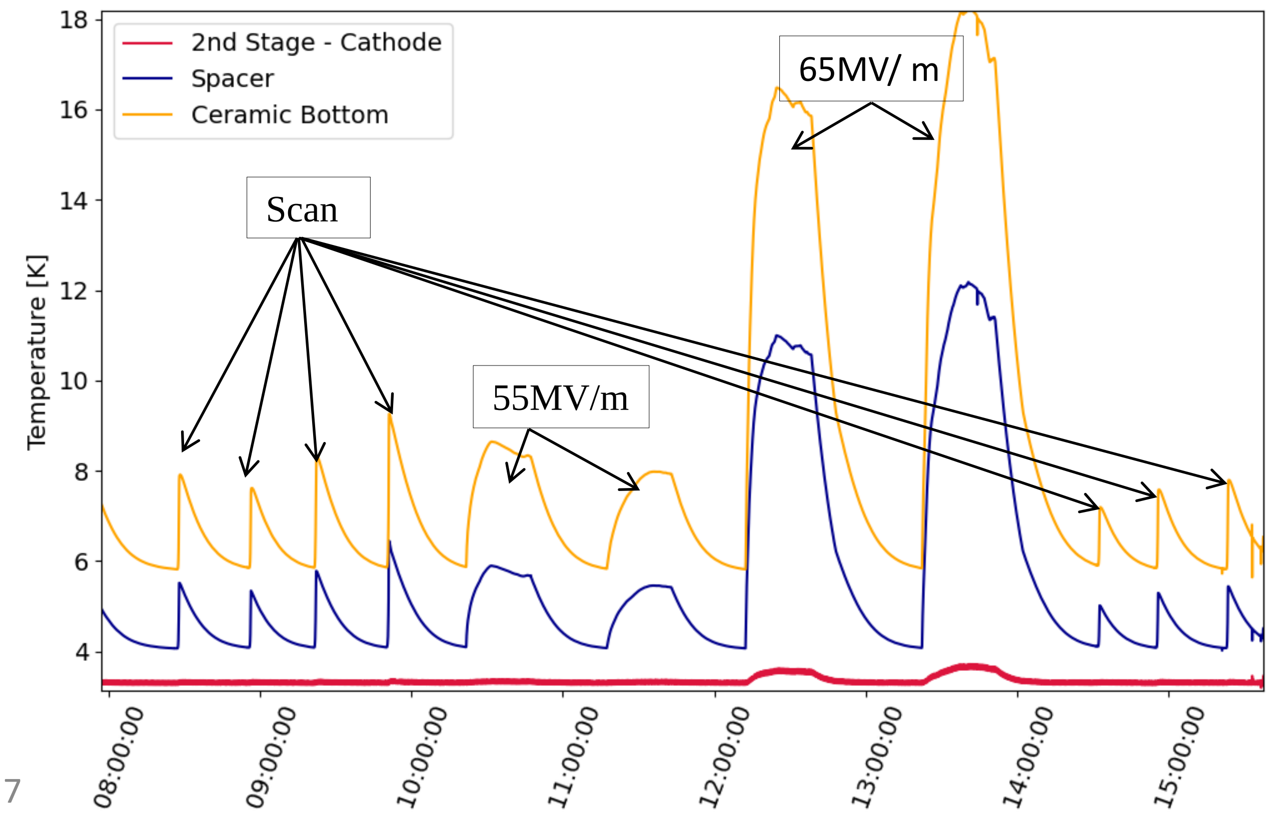
- More gentle algorthm: we do not aim to reach the maximum possible voltage, but the maximum voltage at which the **system is stable**
- **Before break:**
  - Saturation Field: 116 MV/m
  - 1294 BDs to reach the saturation field
- **After Break:**
  - Maximum Field: ~148 MV/m
  - 2596 BDs to reach the saturation field
- **At CERN:**
  - Saturation field: 84.5 MV/m
  - 1740 BDs to reach the saturation field

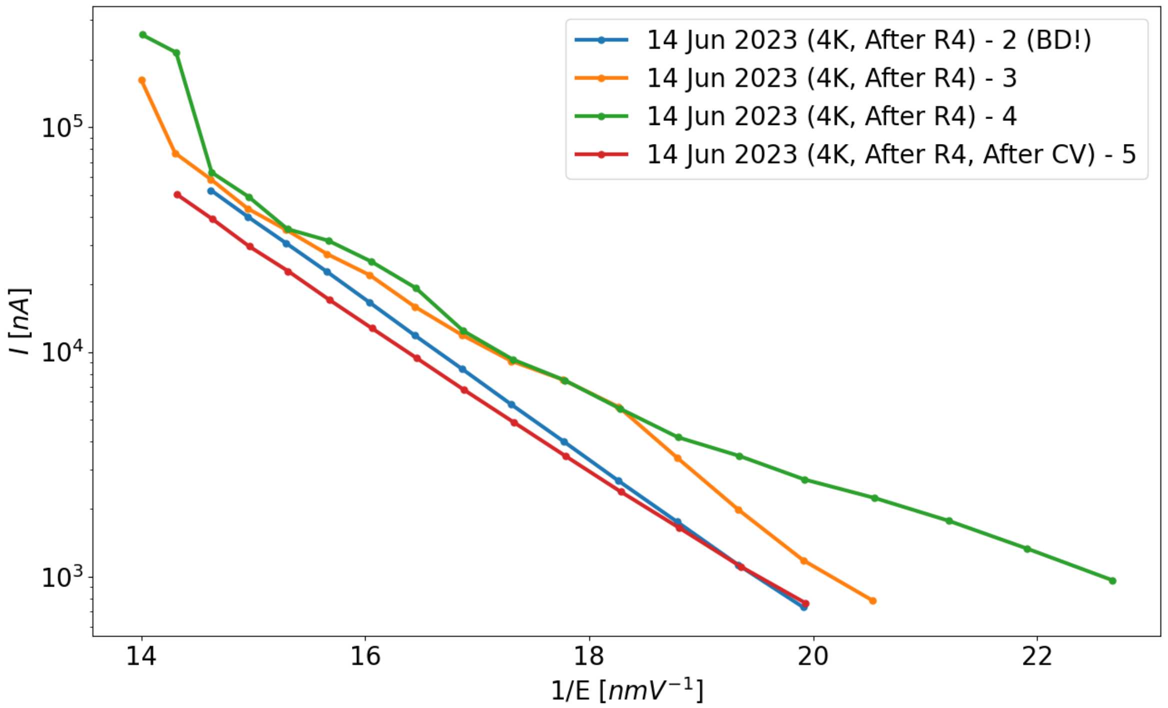
Changed to old algorithm

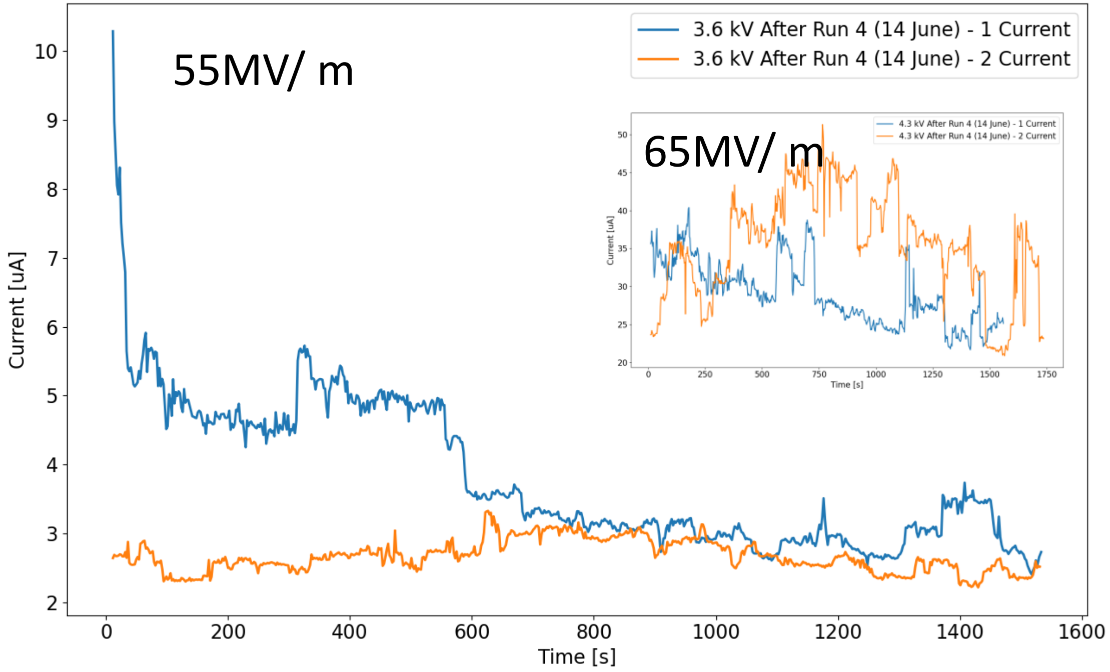


Examples of FE Data – BD during FE

- Two types of measurement:
  - Constant voltage (CV) measurements
  - FE Scan – Fit and obtain the field enhancement factor and the area covered by emitters
- The following measurements are made after conditioning at 108 MV/m

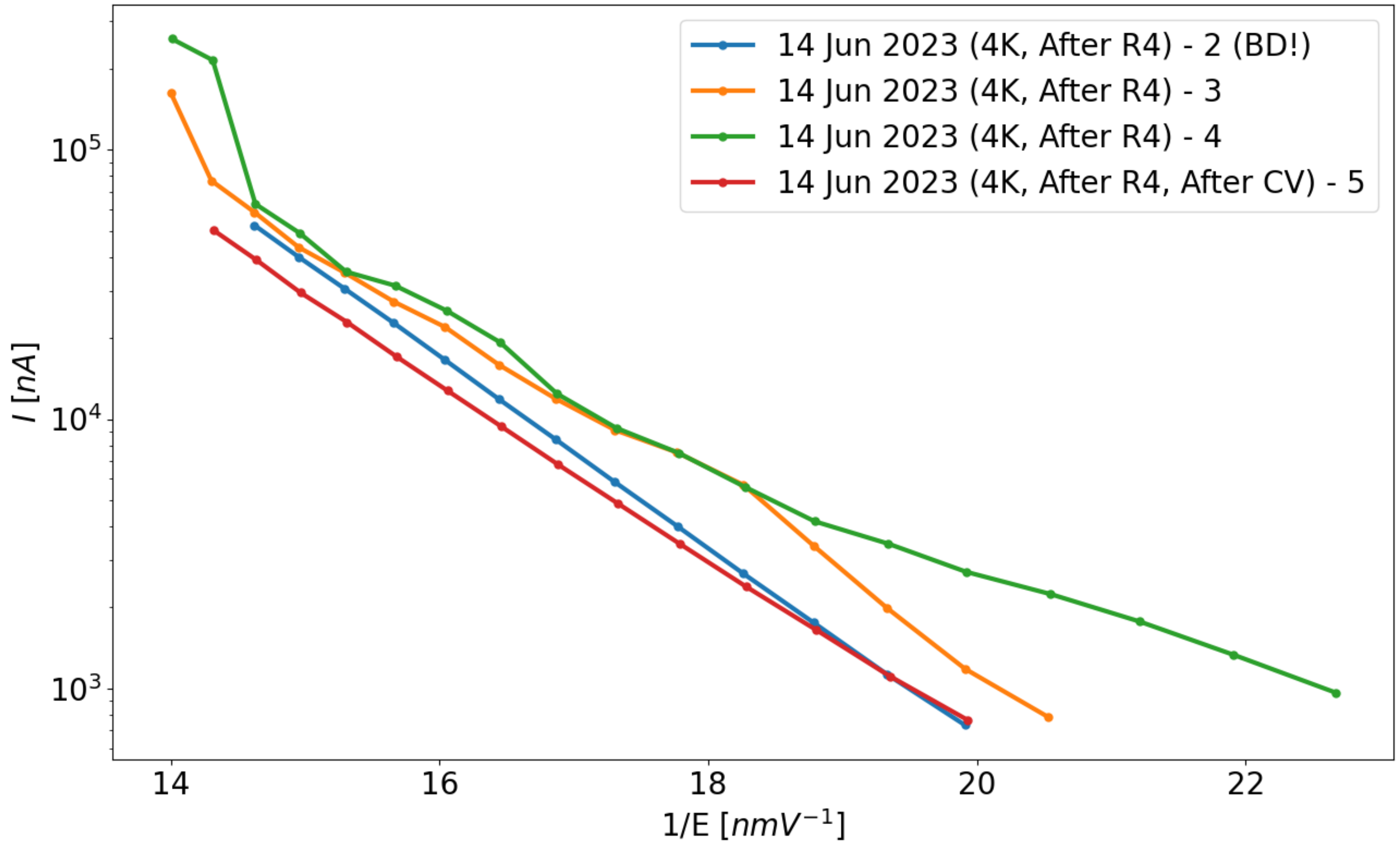






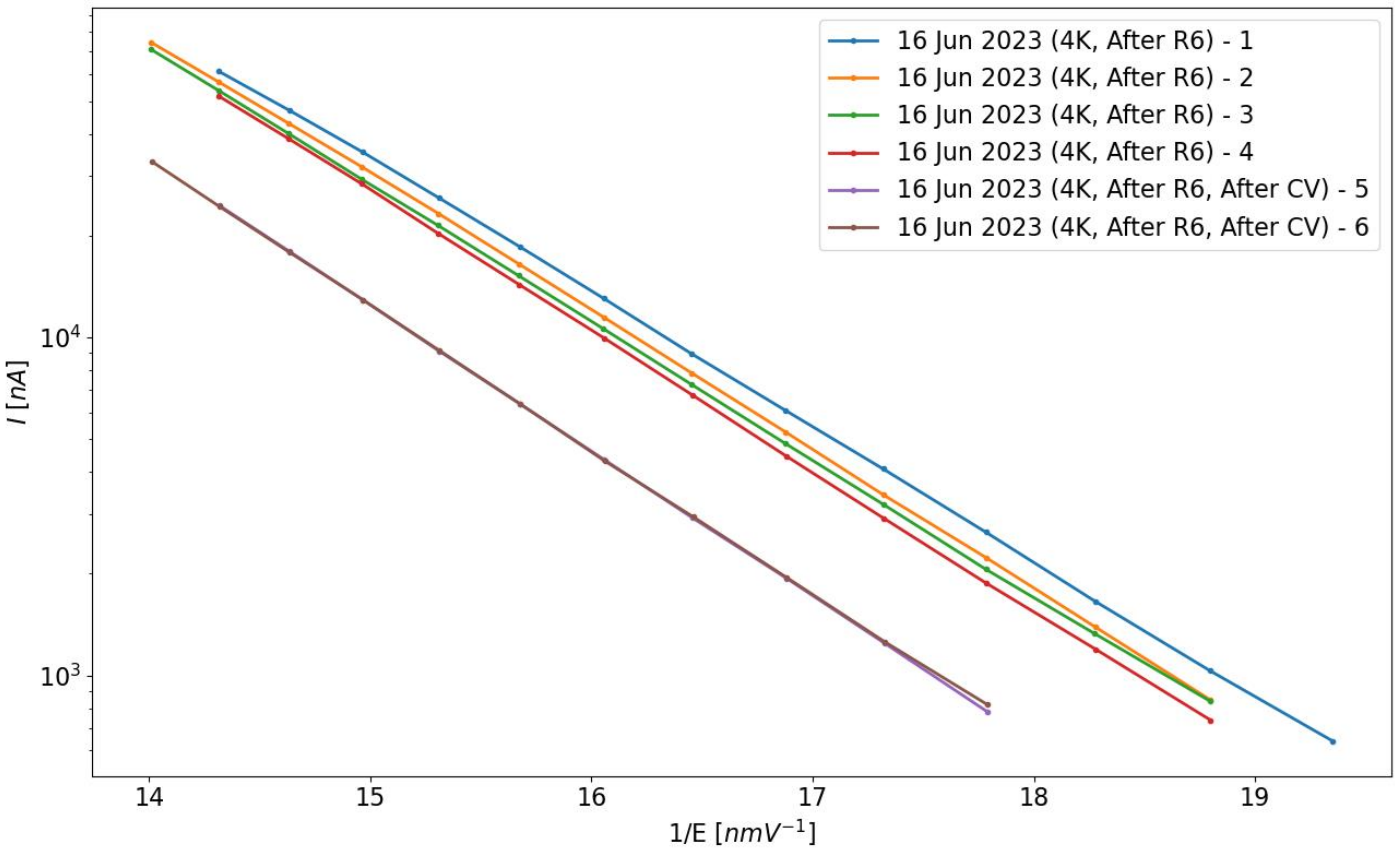
Examples of FE Data – BD during FE

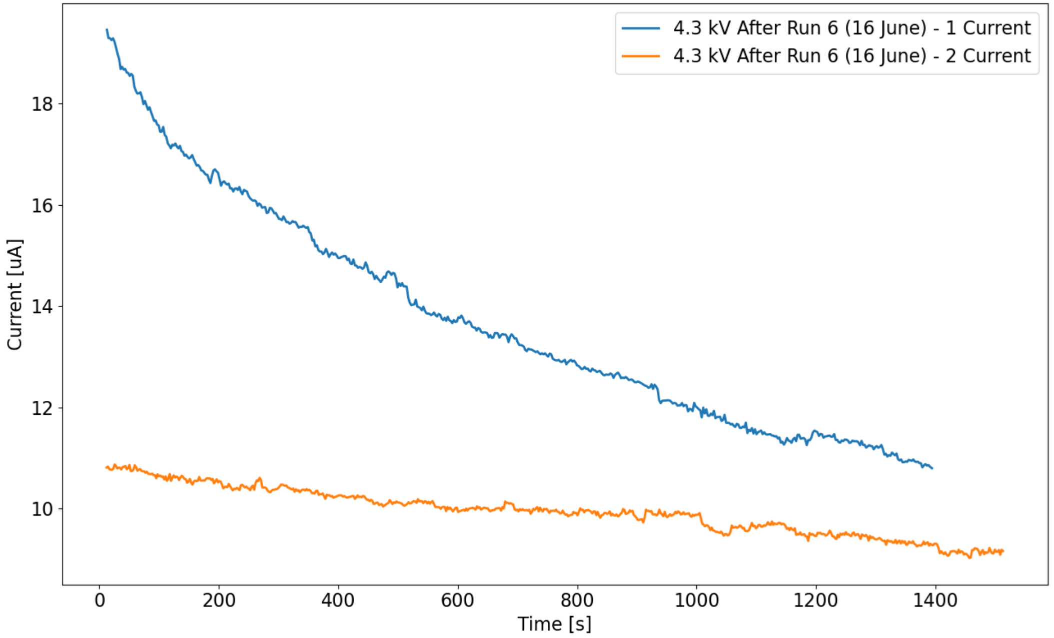
- **BD** after the second measurement, at 69.7 MV/m
- The curve made in the next scan are very distorted!
- After constant voltage measurement at 3.6kV (55 MV/m) and at 4.3kV (65 MV/m) → lower current and straighter curve
  - At 3.6kV, the current decreases fast by 74%!
  - 4.3kV – mostly constant
- Fitting the data:
  - Immediately after conditioning: $\beta = 80$, $A = 1695\ nm^2$
  - After BD: $\beta = 99$, $A = 566\ nm^2$
  - After constant voltage measurements: $\beta = 89$, $A = 369 \pm 18\ nm^2$

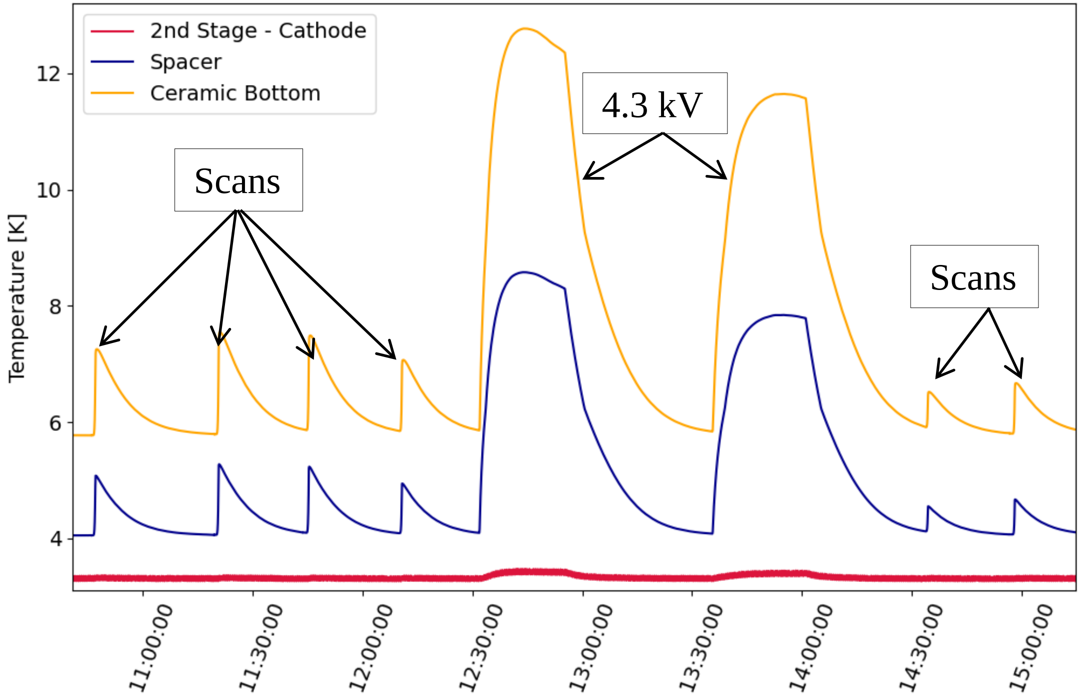


Examples of FE Data – Change in FE current without BDs

- The following measurements are made after conditioning at 112 MV/m

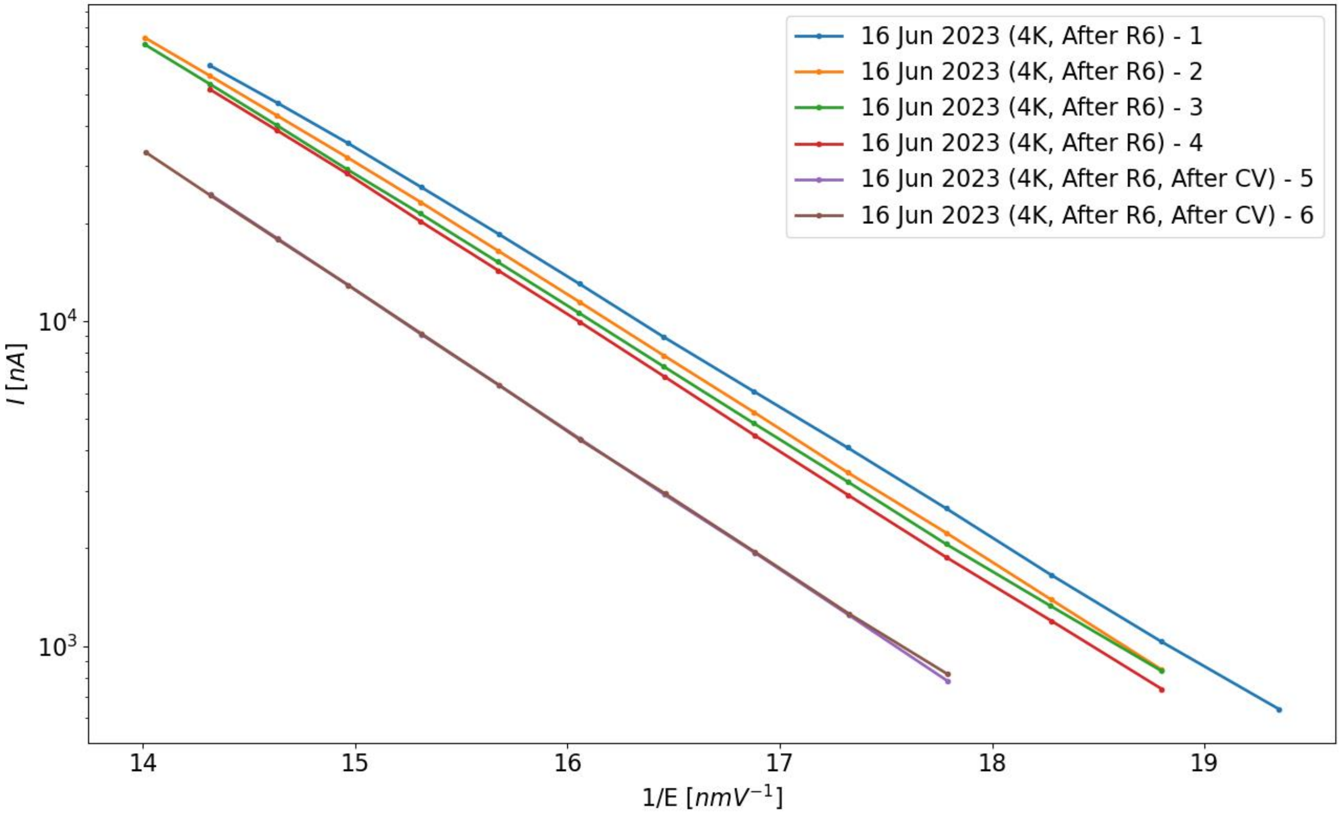






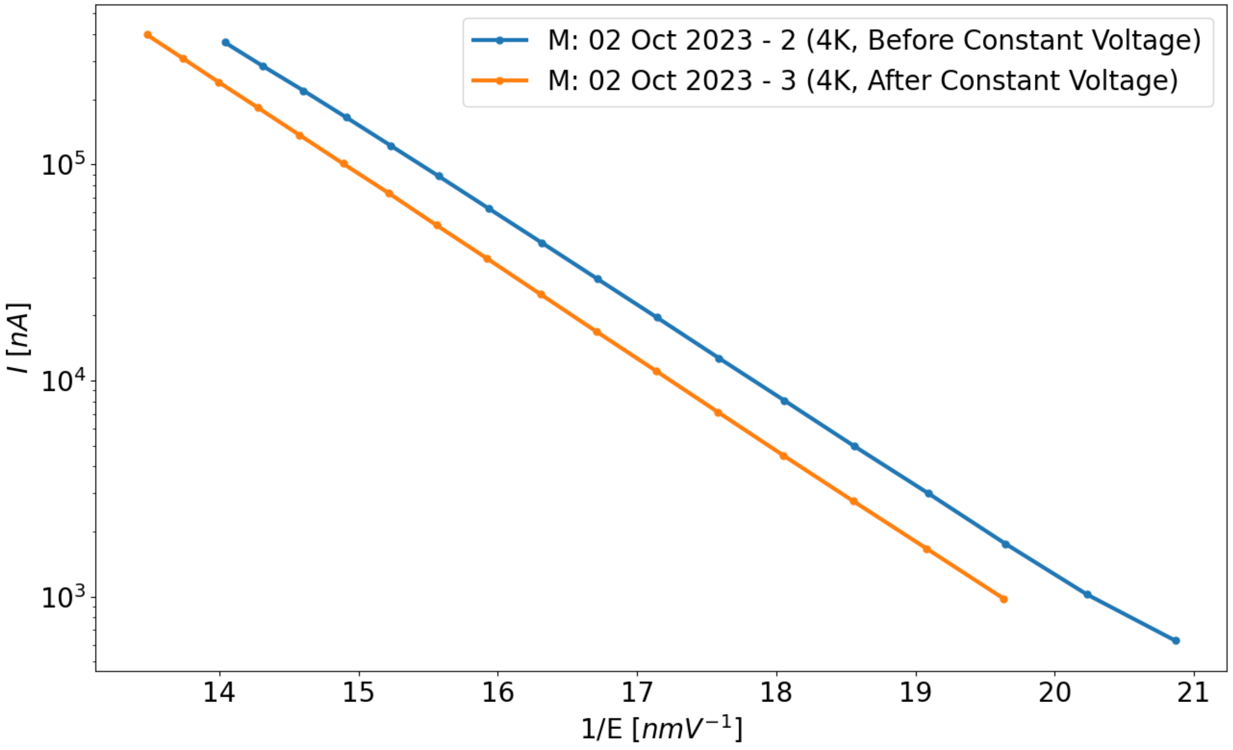
Examples of FE Data – Change in FE current without BDs

- The current gets lower each consecutive measurement
- The surface is conditioned in each FE scan measurement
- During the CV run, the current decreases by 53%
- There is a clear difference between the curves done before and after the CV
- Fitting the data:
  - β = 72, A = 6170 nm²
  - β = 70, A = 7960 nm²
  - β = 70, A = 7930 nm²
  - β = 66, A = 7590 nm²
  - β = 67, A = 6460 nm²

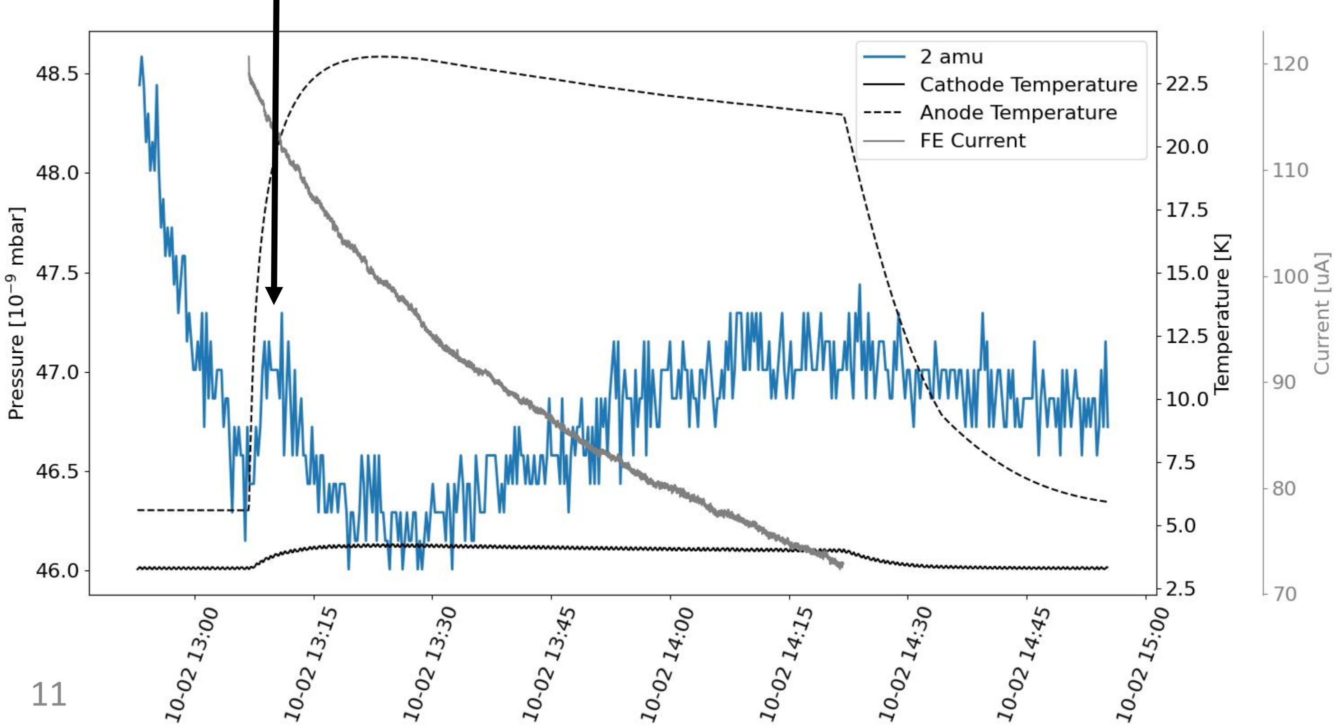


Possible explanations

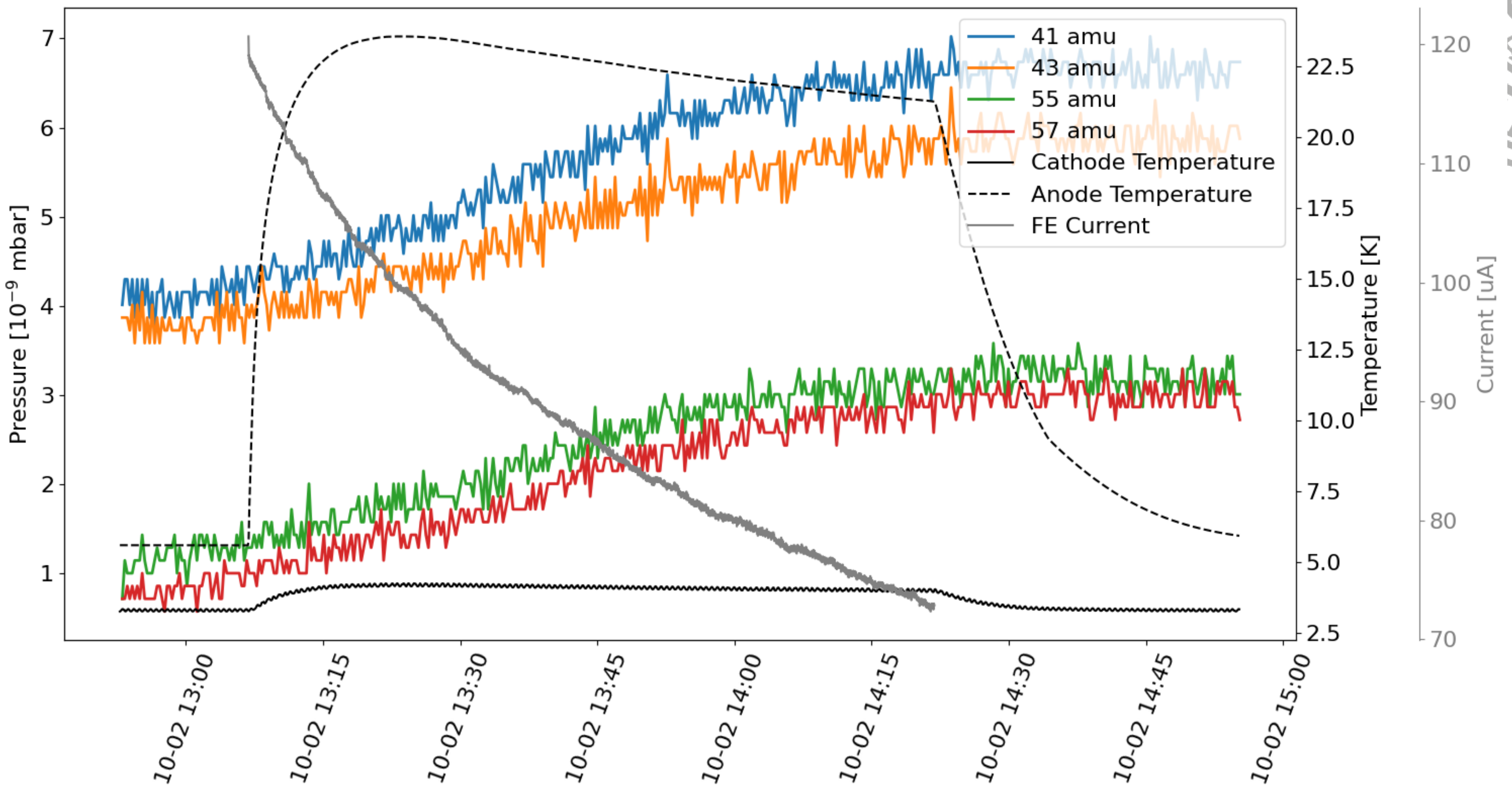
- Gas is being desorbed from the surface by the increasing temperature?
- Hydrocarbons?
- Connect a RGA and check
- Constant voltage FE (67 MV/m)



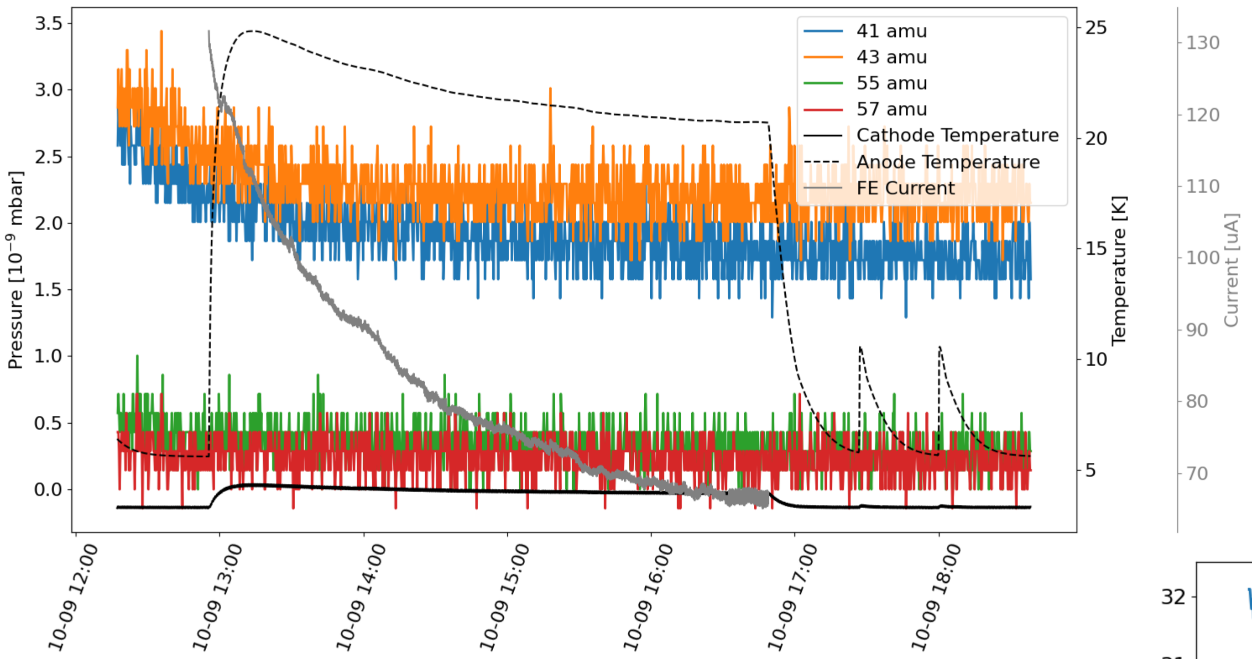
Small H peak?



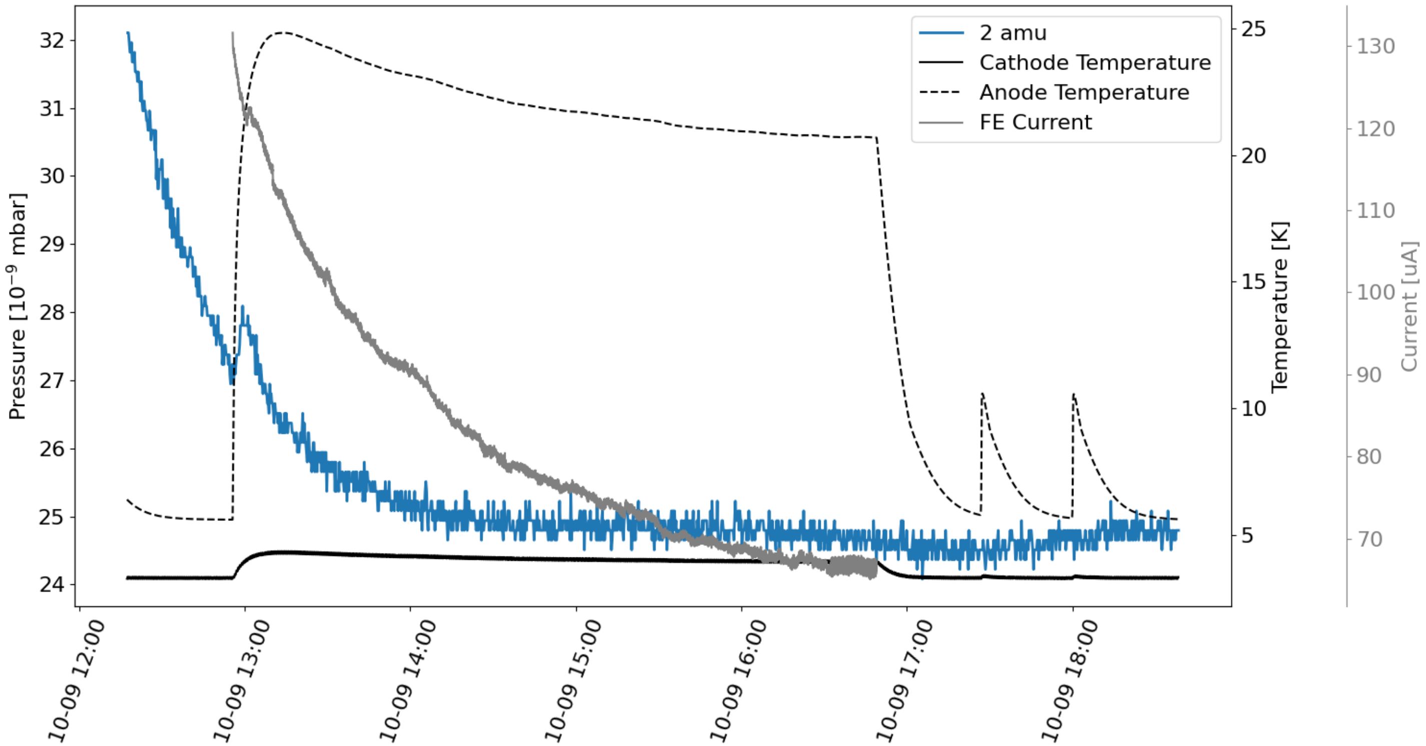
- In this case, we see increases in the partial pressures of hydrocarbon fragments at: 26, 41, 42, 43, 55, 56, 57, 67, 69, 70, 71, 81 amu



- Not always!

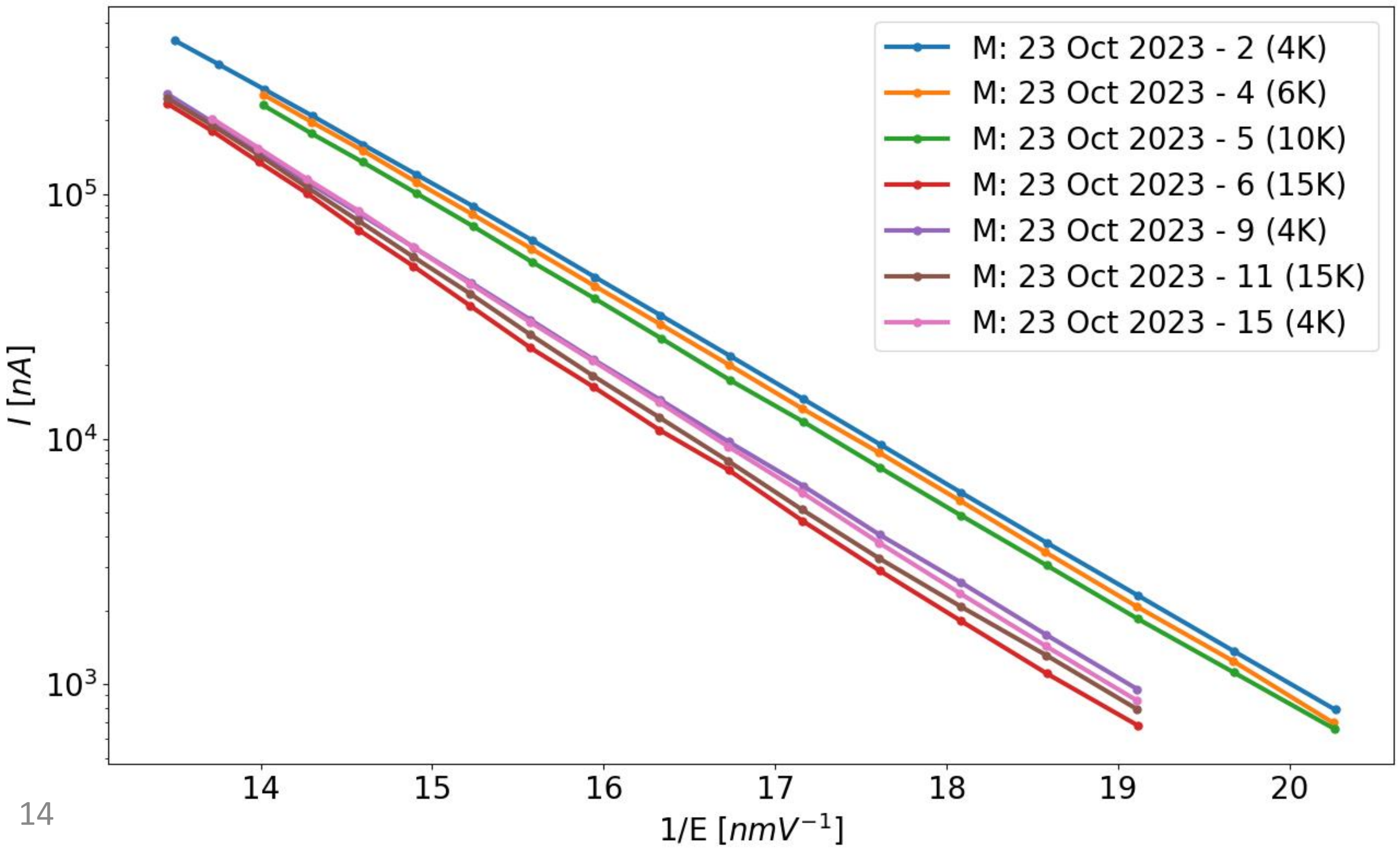


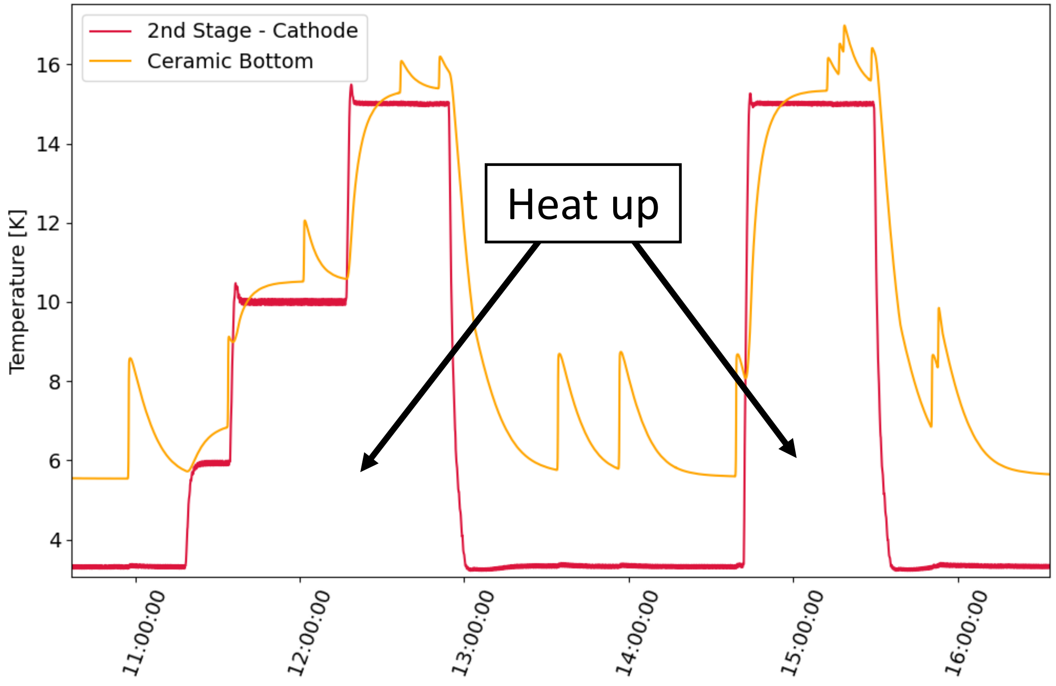
- Almost always we see the H_2 peak at the beginning



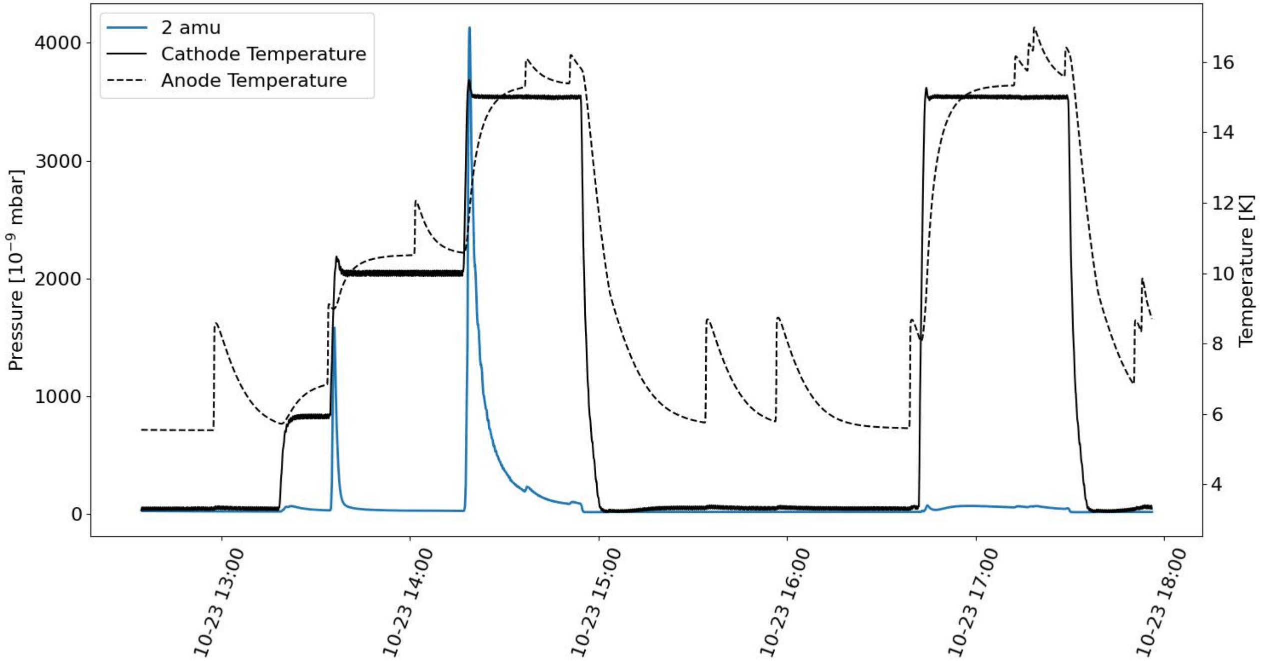
Examples of FE Data – But what if we heat up?

- Is this conditioning without breakdowns or is it some effect due to increased temperature?
- Let's increase the temperature then cool down and see what happens!
- We see the same effect! It must be the temperature increase that makes the current decrease during FE
- Repeatable, 15K is enough to lower the current

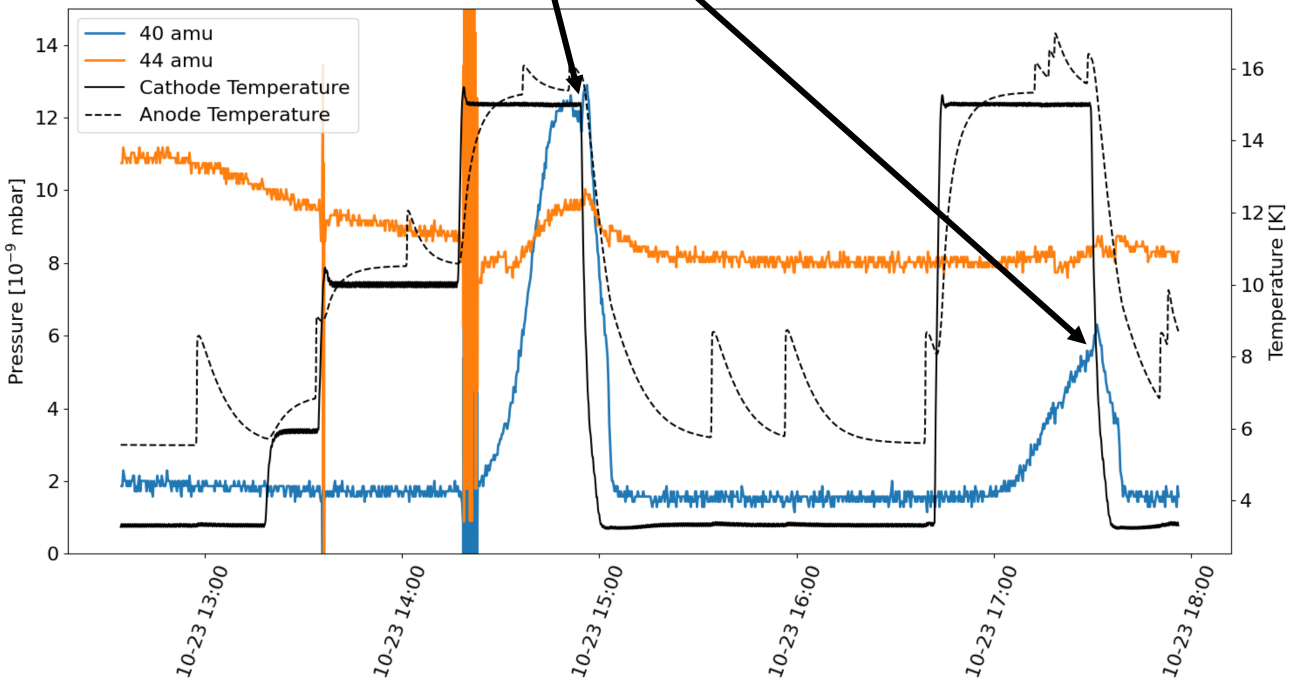




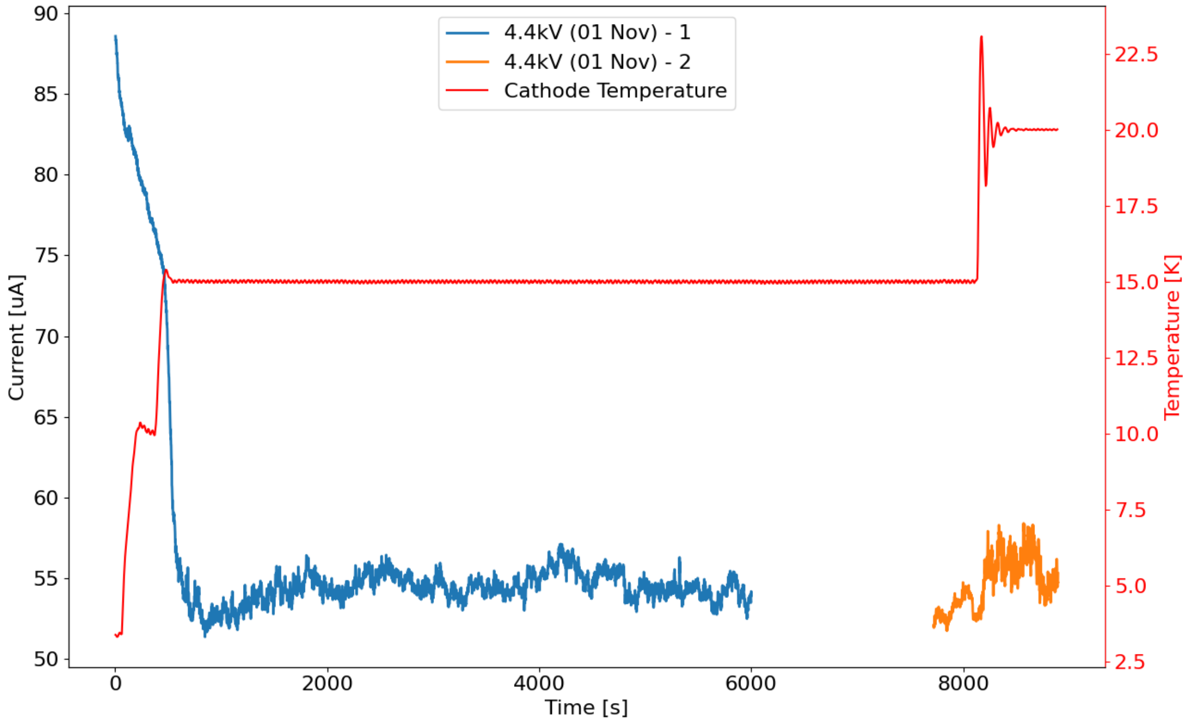
Examples of FE Data – But what if we heat up? - RGA

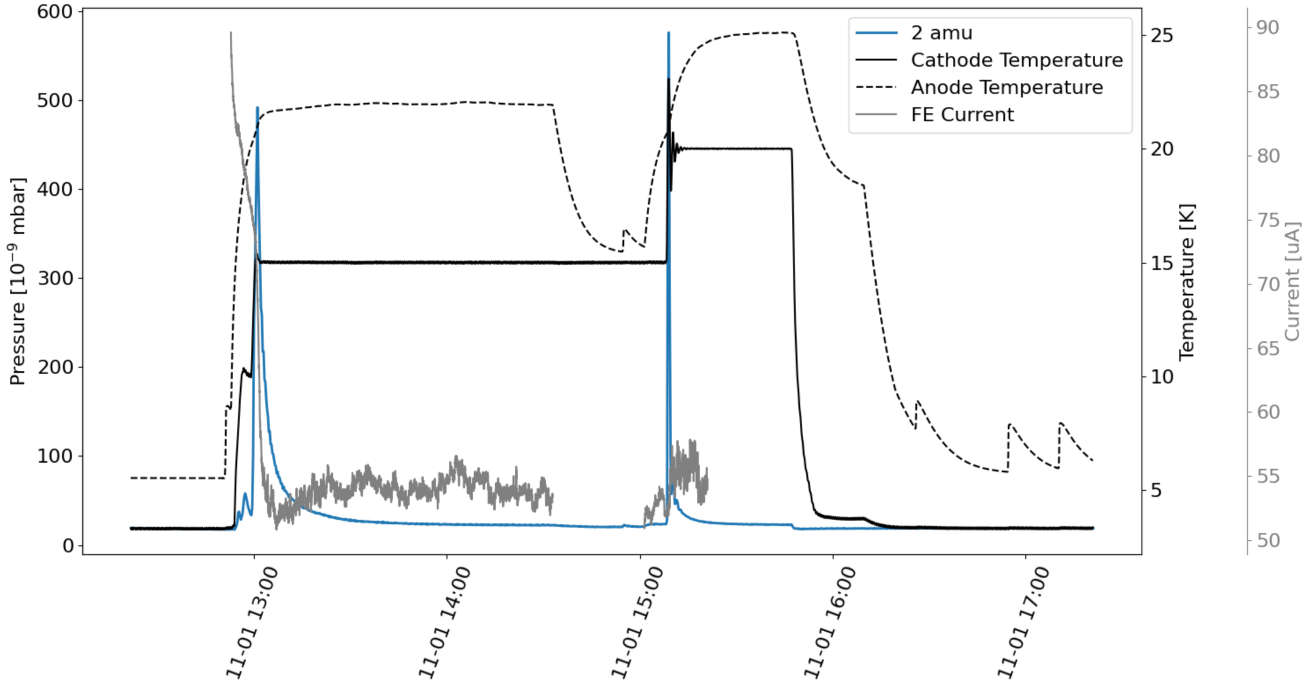


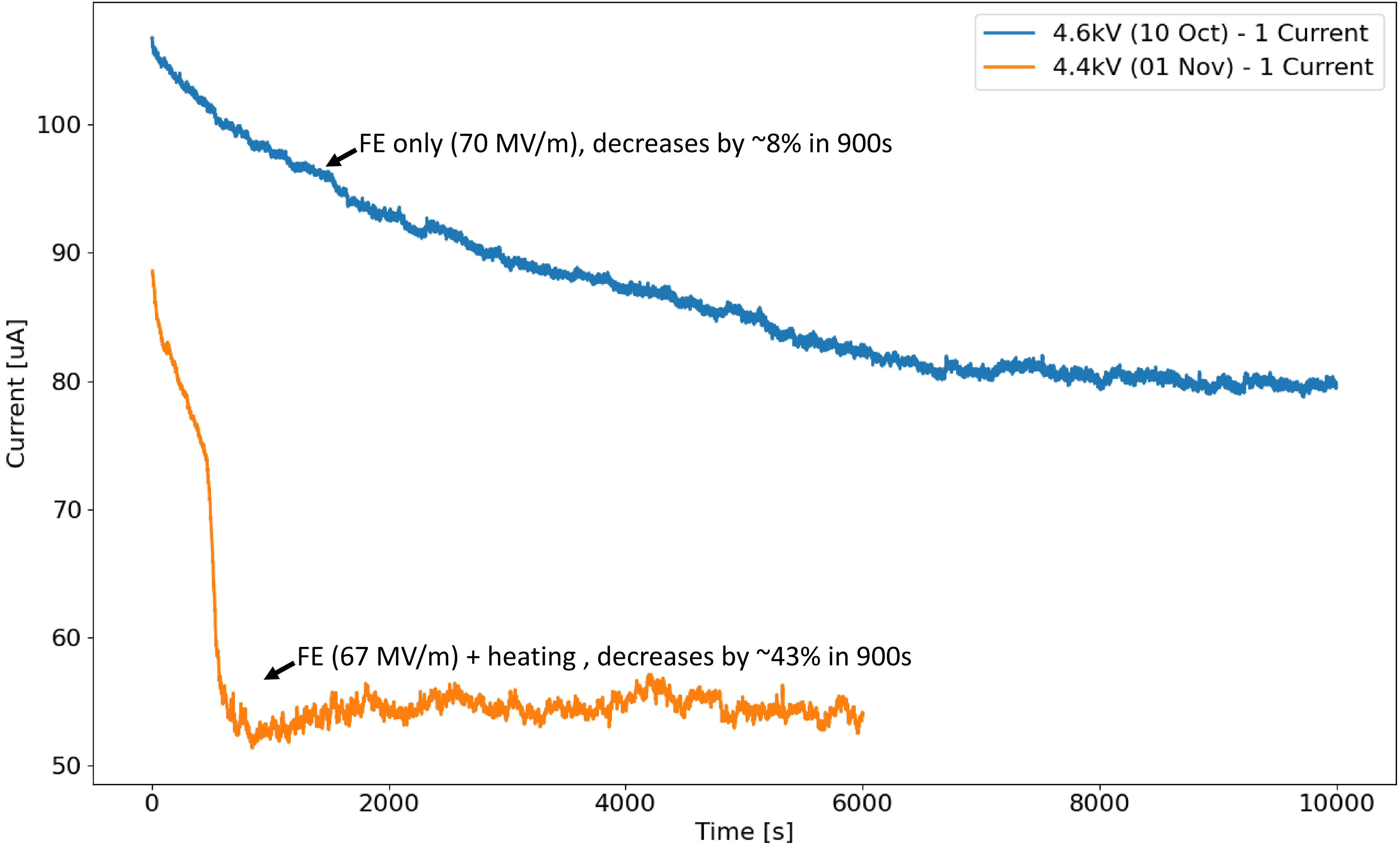
We also see this peak for
14, 16, 20, 28, 29, 30, 32, 33 amu



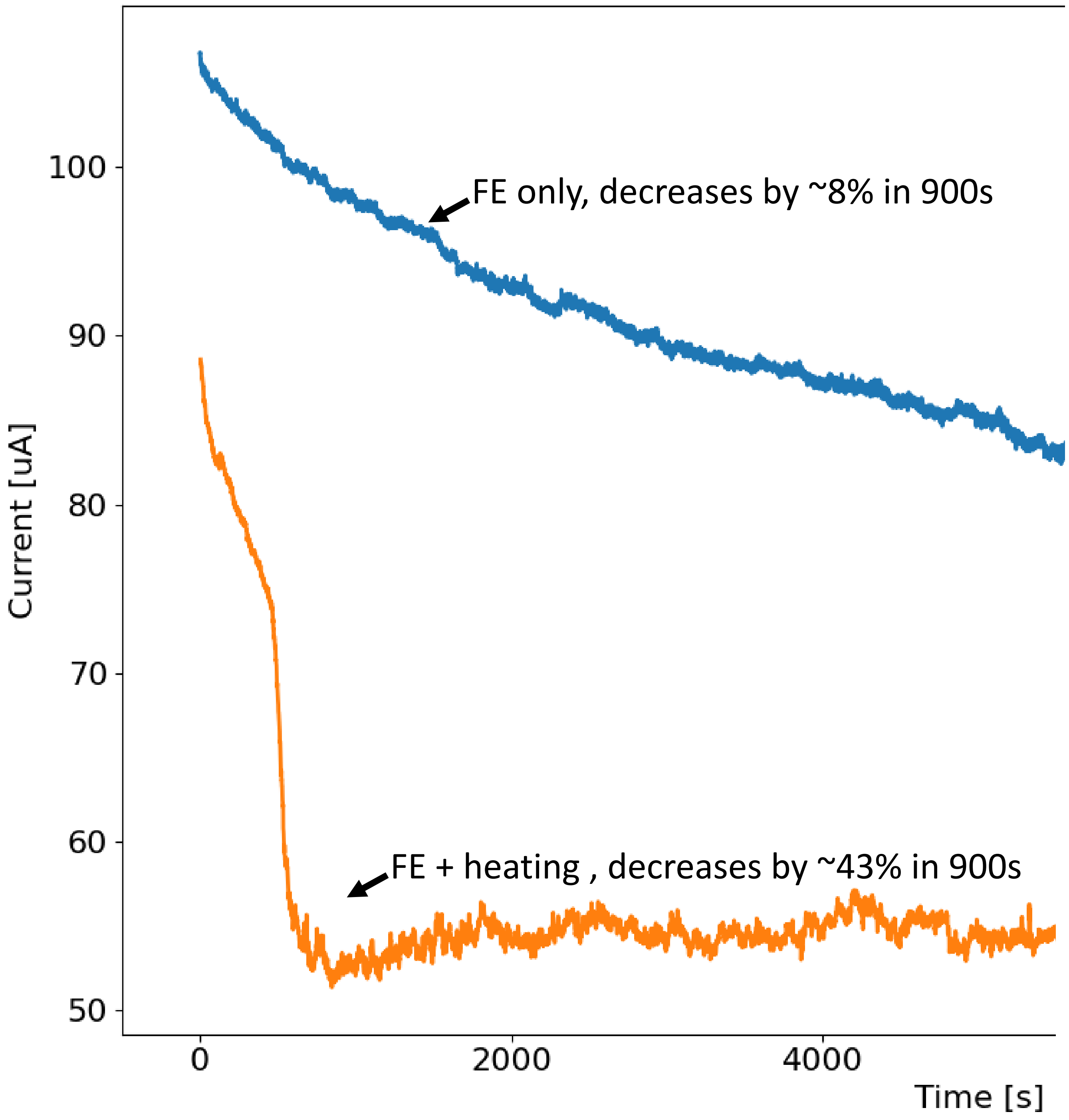
Examples of FE Data – Let's heat up WHILE measuring FE (67 MV/m)



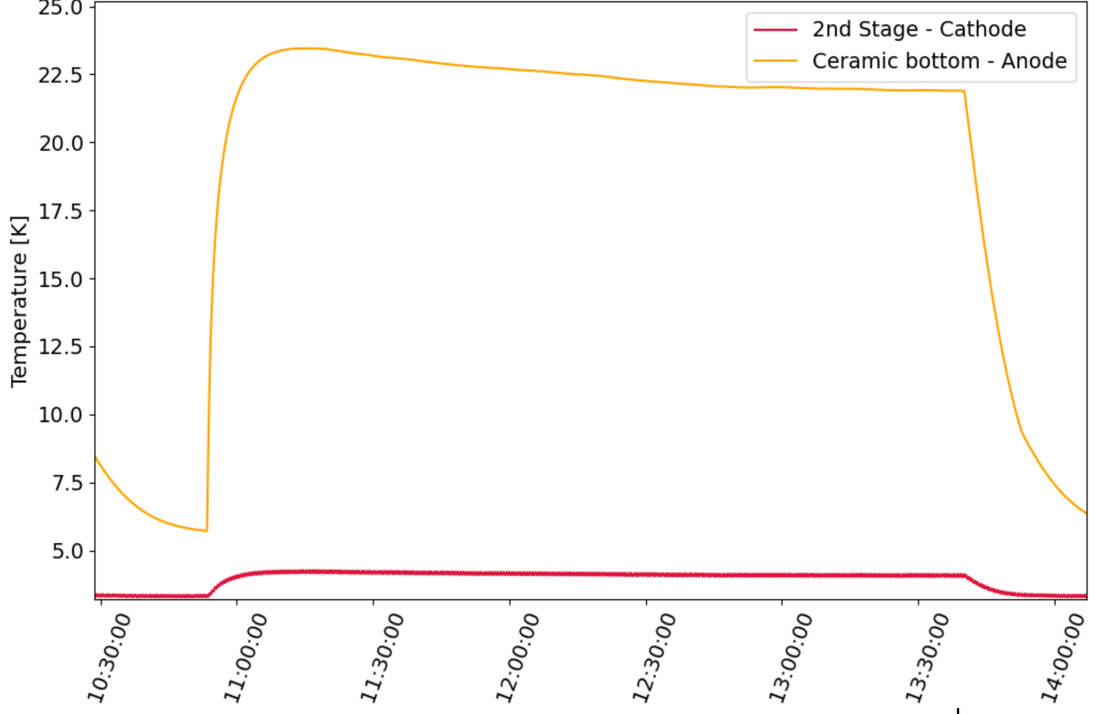




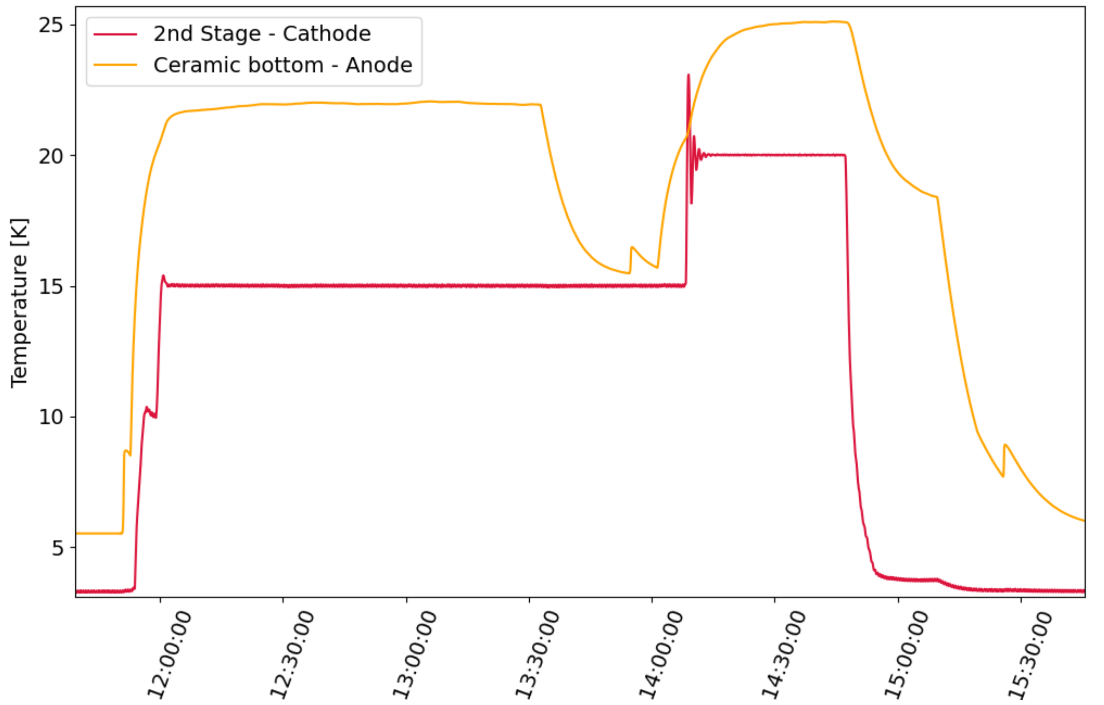
4.6kV (10 Oct) - 1 Current
4.4kV (01 Nov) - 1 Current
FE only (70 MV/m), decreases by ~8% in 900s
FE (67 MV/m) + heating , decreases by ~43% in 900s
Current [uA]
100
90
80
70
60
50
0
2000
4000
6000
8000
10000
Time [s]



FE only, decreases by ~8% in 900s
FE + heating , decreases by ~43% in 900s
Current [uA]
Time [s]



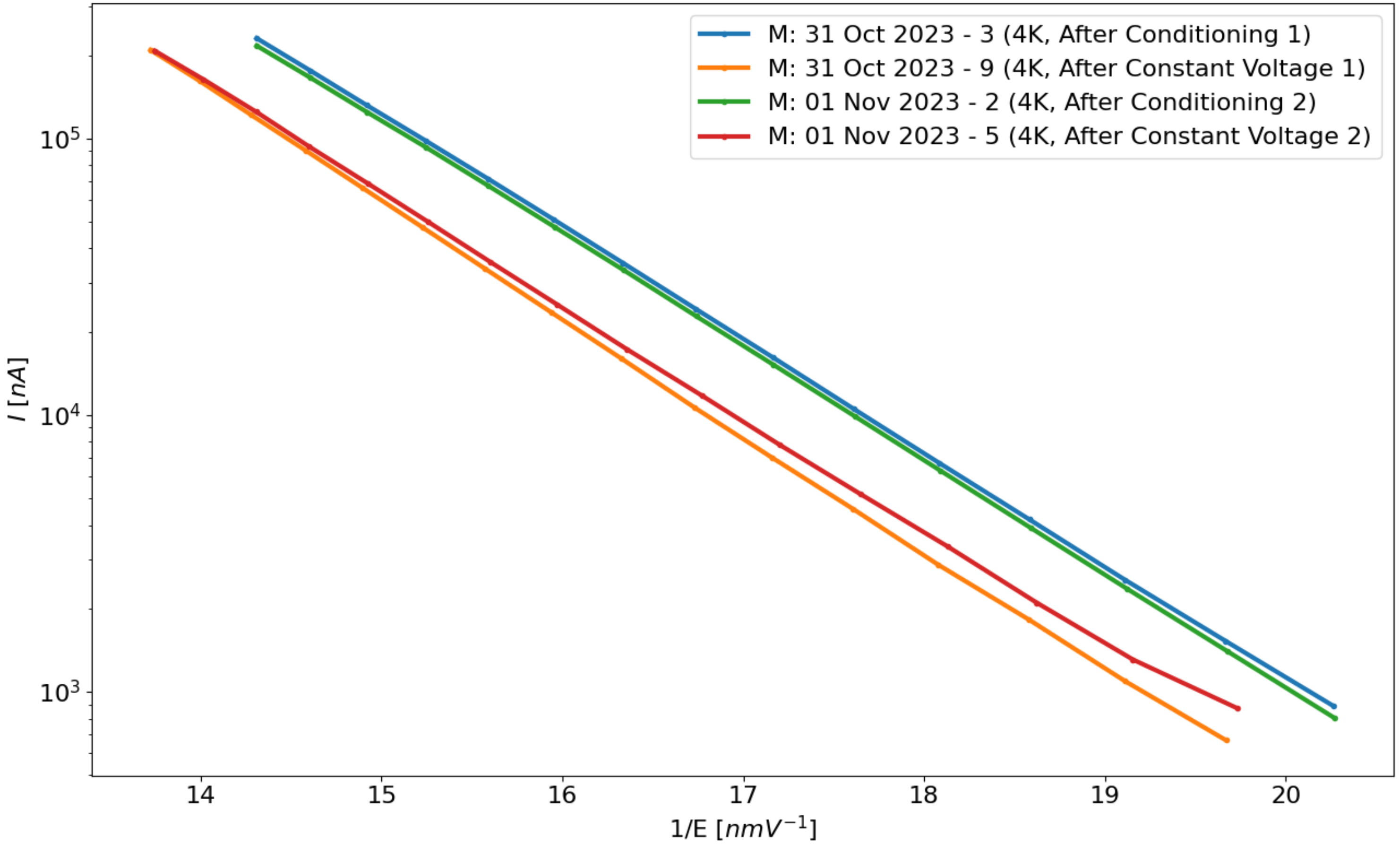
2nd Stage - Cathode
Ceramic bottom - Anode
Temperature [K]



2nd Stage - Cathode
Ceramic bottom - Anode
Temperature [K]

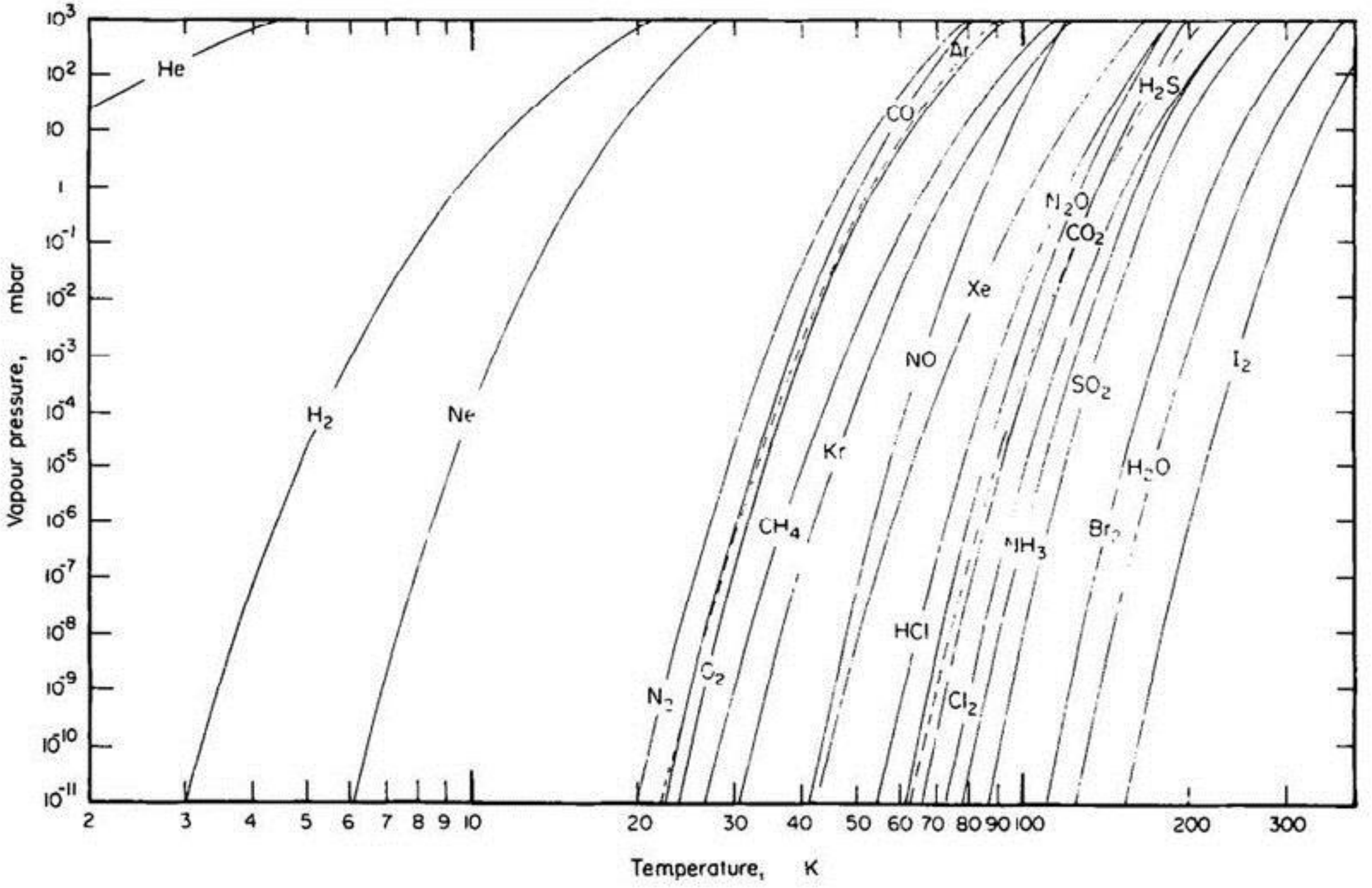
Examples of FE Data – What makes the curve go back up?

- **Is it the BDs or is it the pulses?**
- Condition, then constant voltage run + heating → current decreases
- Condition at 109 MV/m for 3.9 mill pulses (90 minutes!), **no BD!**
- During conditioning, the anode temperature is 14 – 15K
- Curve goes back up!
- Constant voltage run + heating → current decreases back down
- **It seems to be the pulses**
- Repeatable



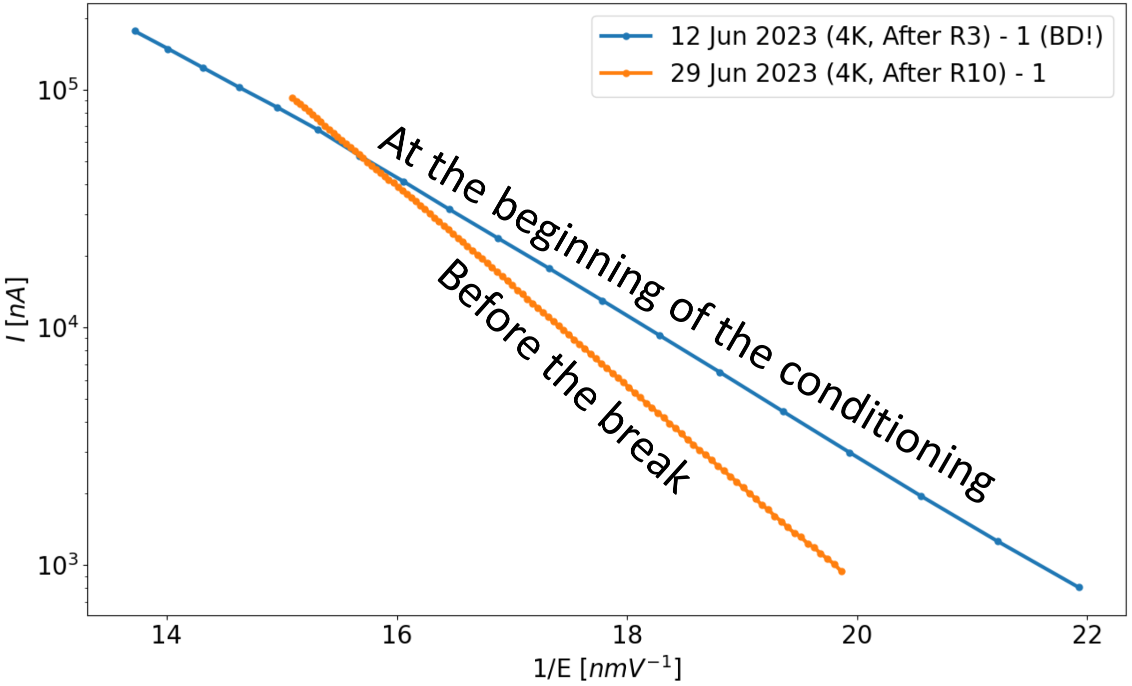
So why does the current decrease?

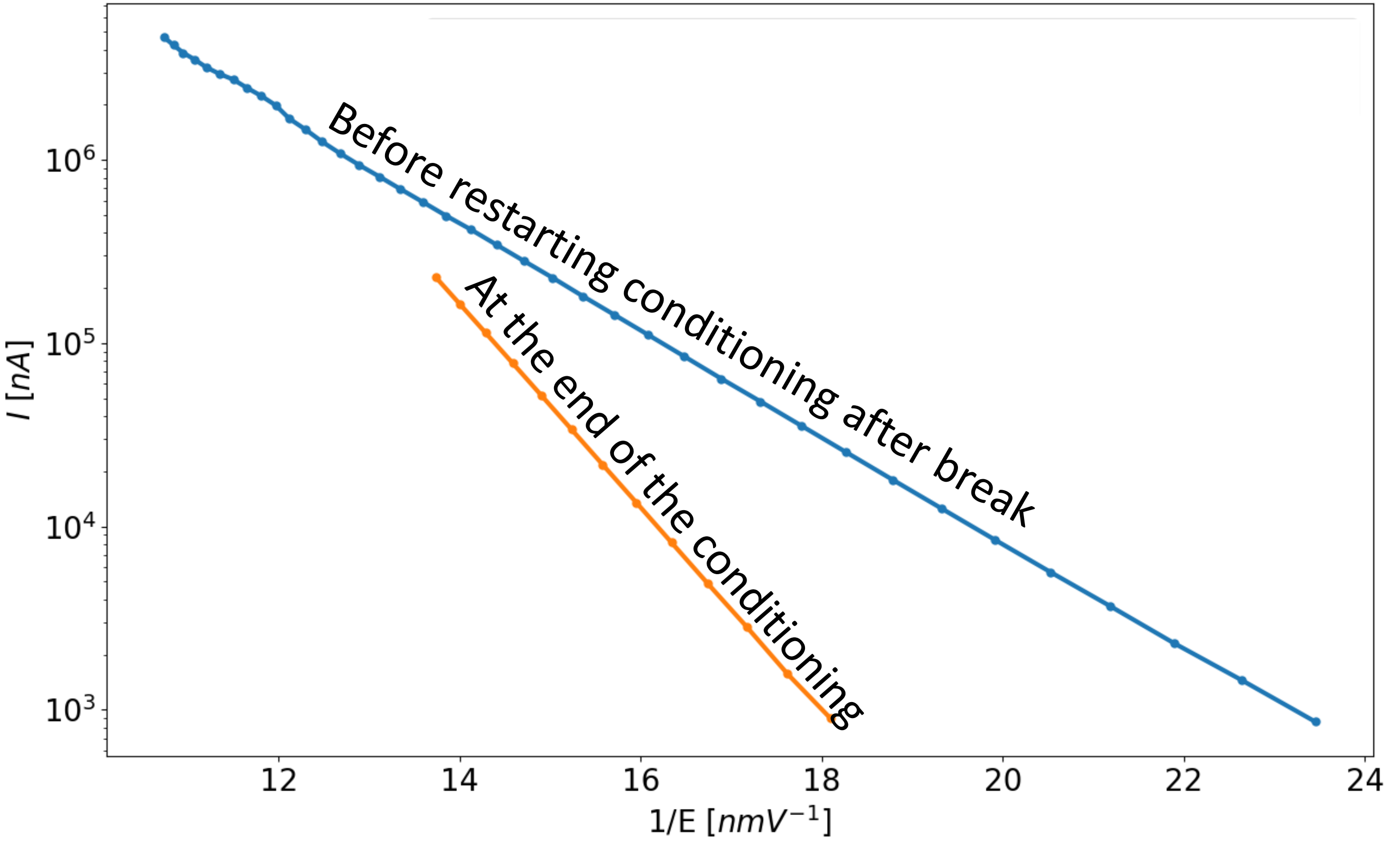
- **Is it the hydrocarbons?**
  - Probably not, they are not always detected
- **Is it the hydrogen?**
  - It could be
  - But why spikes?
  - It does not always correlate with decreases in current
  - The molecules detected by the RGA can be from other parts of the cryostat
  - Why would pulsing make the hydrogen adsorb?
- **New hypothesis: Conditioning at high voltage creates new emitters due to movement of dislocation. Heating up blunts these emitters**
  - Even if the current is smaller, the surface is more unstable. When restarting conditioning, many times we get a BD from the first pulses
  - Conditioning creates dislocations, hardening, increased temperature relaxes the material (?)



How do the FE parameters evolve during conditioning? – Nb, Before Break

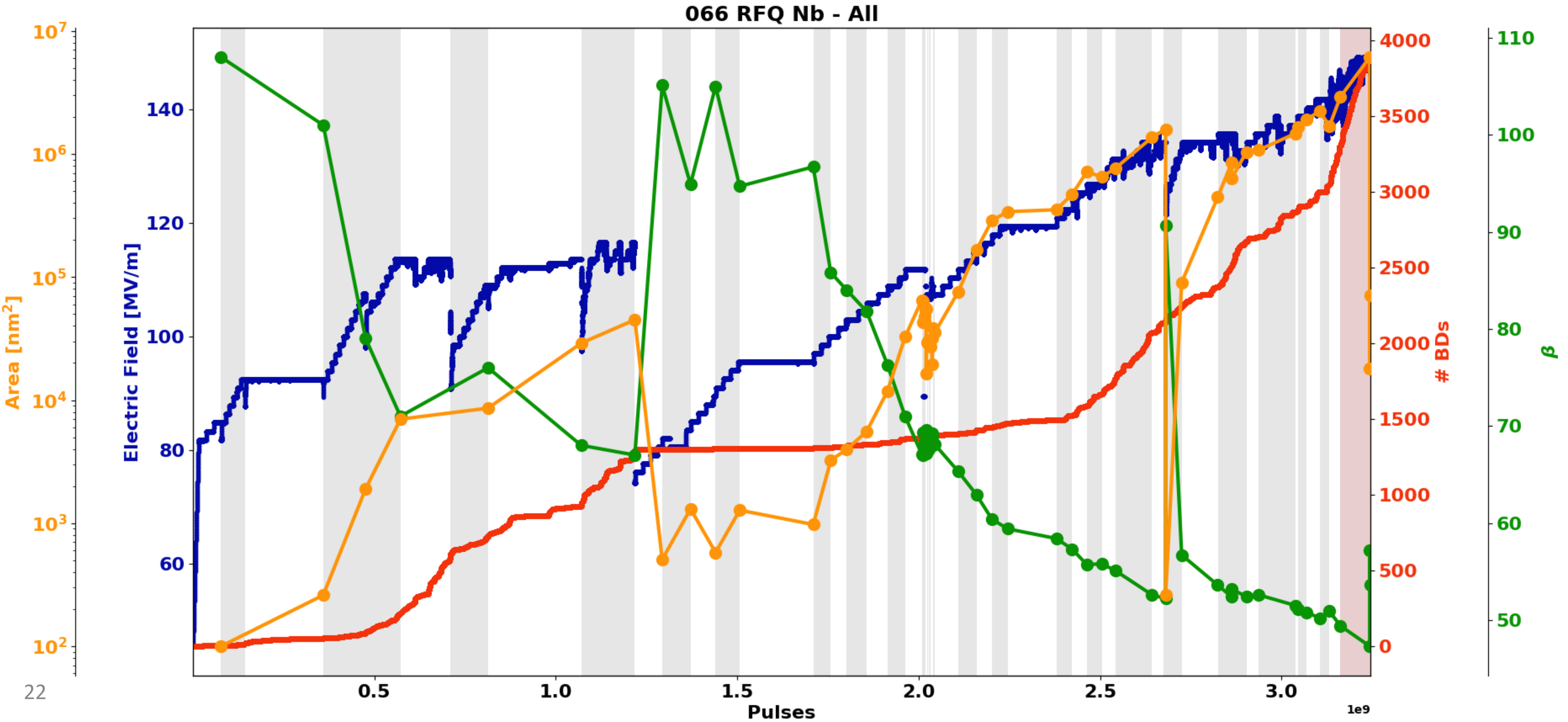
- Get first FE scan made after conditioning and fit → area and field enhancement factor





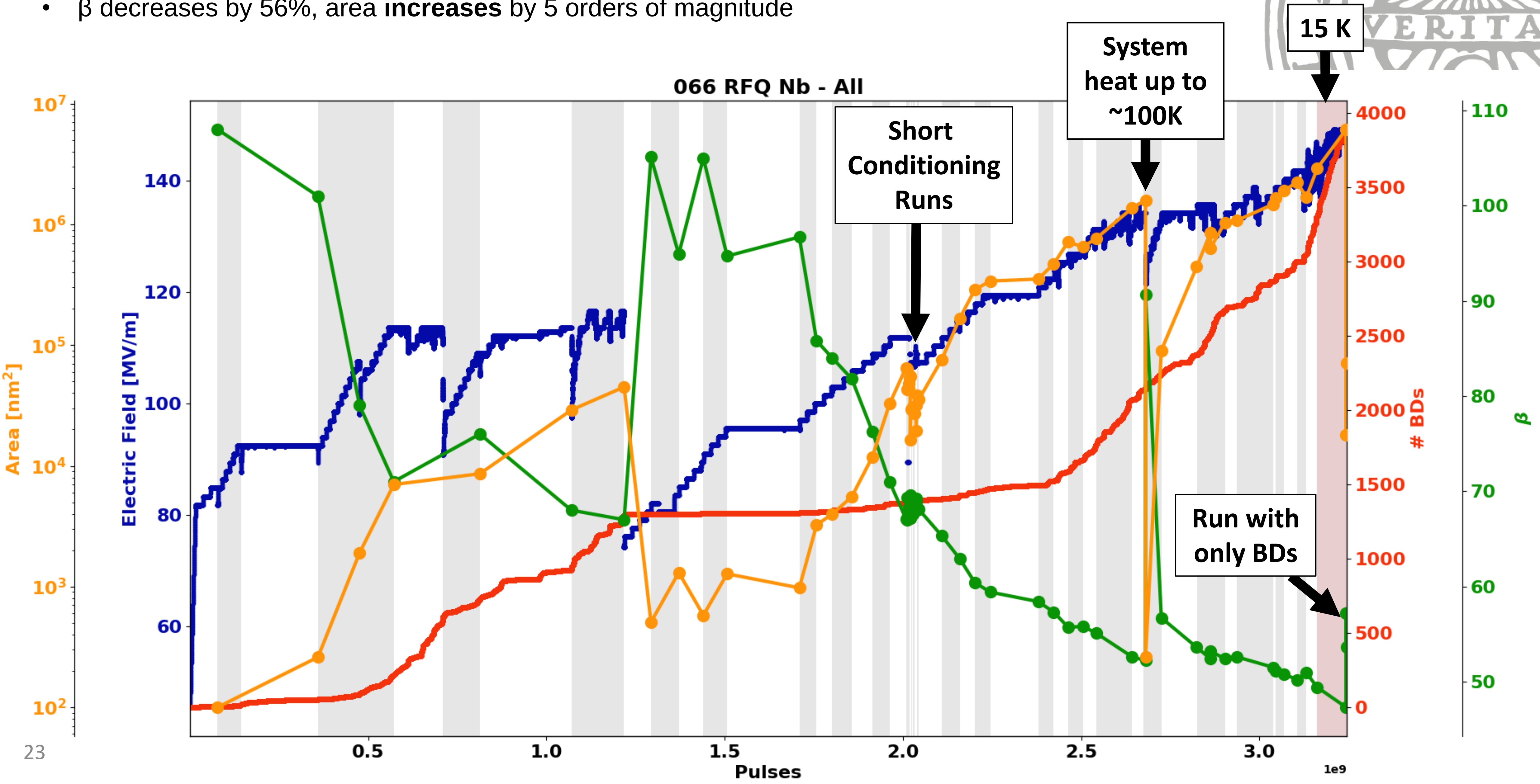
How do the FE parameters evolve during conditioning? – Nb, After break

- β decreases by 56%, area **increases** by 5 orders of magnitude



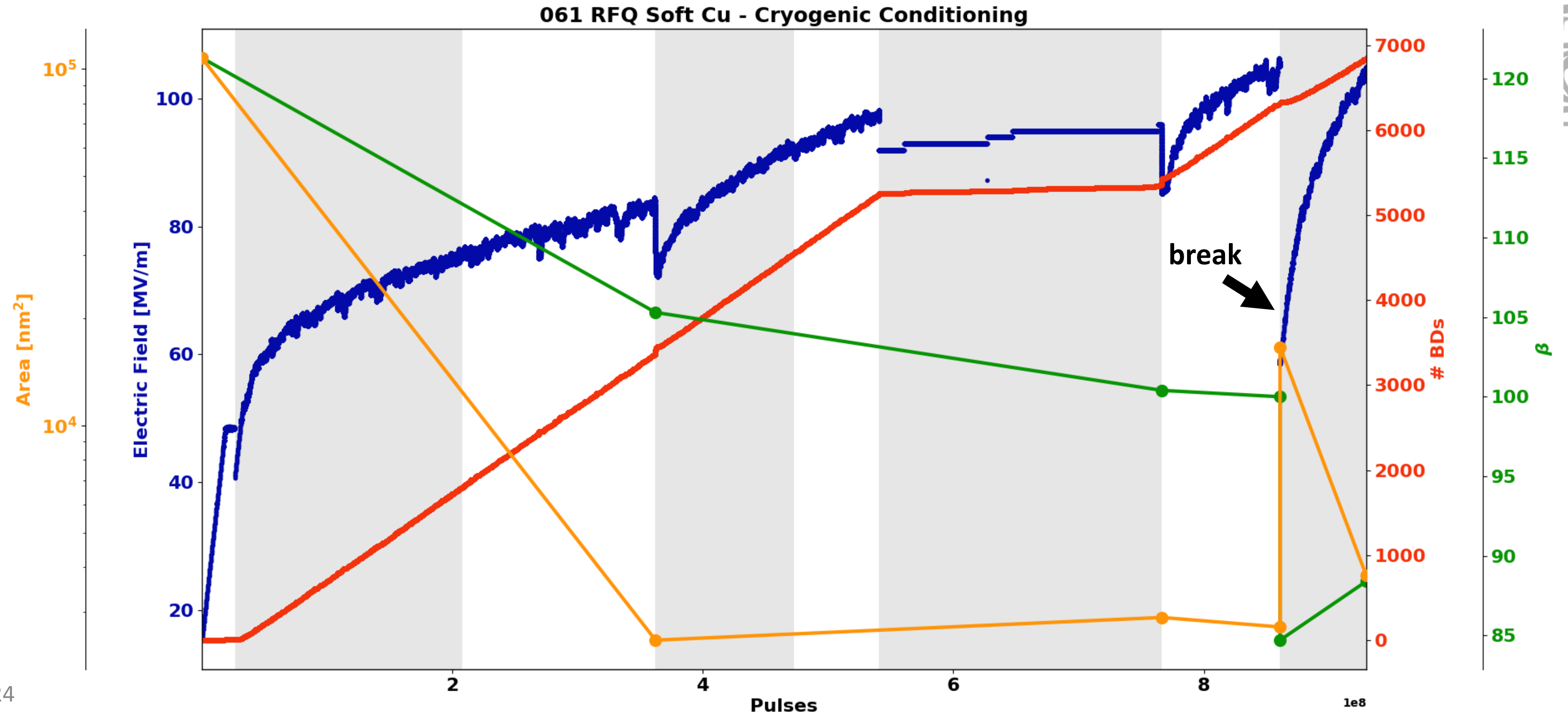
How do the FE parameters evolve during conditioning? – Nb, After break

- β decreases by 56%, area **increases** by 5 orders of magnitude



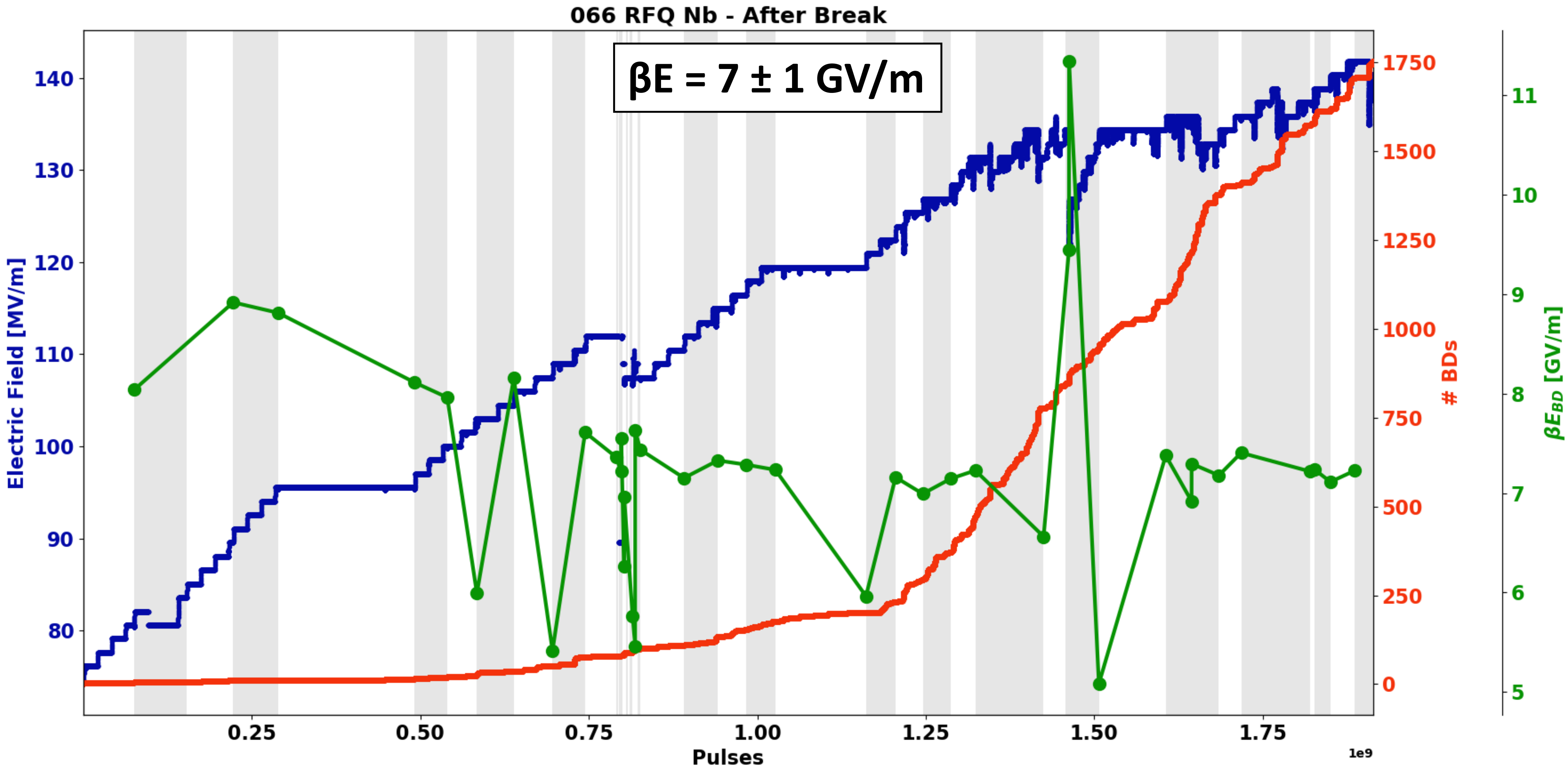
Let’s look at some previous data – irradiated Cu electrodes

- Less data points
- Both area and the field enhancement factor **decrease.** Does the area increase for some metals, while for others it decreases? We need more data



Back to the Nb electrodes – Local field evolution

- How does the local field (βE) evolves during conditioning?
- (β of the last FE curve before restarting conditioning) * (the field of the first BD)



Conclusions

- We have conditioned Nb electrodes at cryogenic temperatures (mainly at 4K)
- FE in between conditioning → information about the state of the surface
- During the FE measurements, we have observed changes in current that are correlated with increases in temperature
    - Current decreases, field enhancement factor decreases
    - When cooling back down, the current does not increase back to the initial value
    - The state of the surface can be reset by HV pulsing → current increases to the initial value
- We have looked at the data from the RGA and correlated it with the behavior of the current. Two hypotheses:
    - **Hydrocarbons** – they are not always detected
    - **Hydrogen** – does not always correlate with current changes
- New hypothesis(?): The emitters are blunted when heating up, but during HV pulsing new emission sites are created due to movement of dislocations. But conditioning hardens the surface, while heating softens it
- We have extracted the field emission parameters during the conditioning process
- **During conditioning, the field enhancement factor decreases by 56%, but the area covered by the emitters increases by 5 orders of magnitude**
- Looking at some older data with irradiated Cu electrodes, the area **decreases**
- For some metals the area decreases, while for others it increases? More data is needed.
- Future plans: Ti and Cu electrode conditioning, resistivity measurement during conditioning, new HV generator