UPPSALA UNIVERSITET

Measuring Field Emission Currents in-situ SEM

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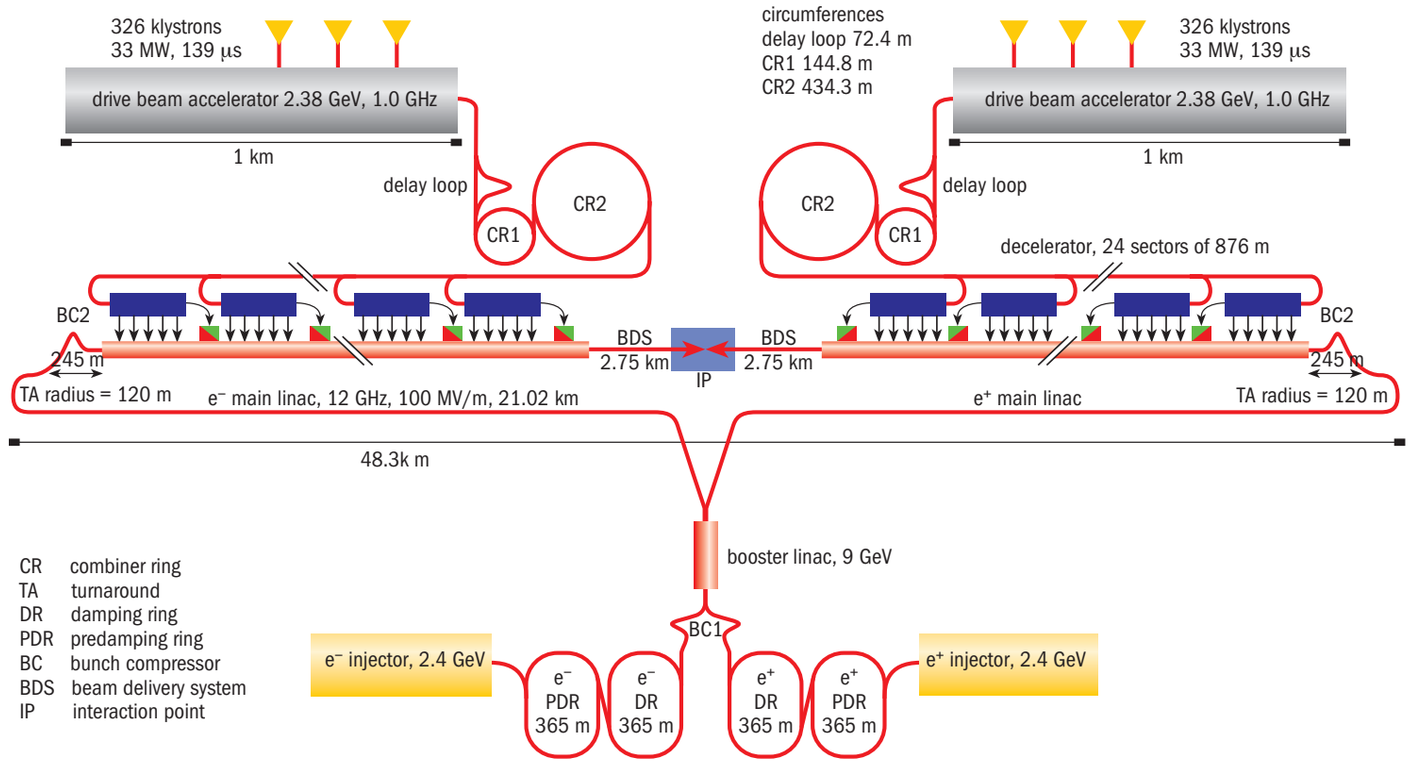
CLIC and RF Breakdowns

- Compact Linear Collider
  - High-gradient, high power
  - ~140,000 accelerating structures
  - Breakdowns limit performance
- Vacuum discharges
  - Complex phenomenon
  - DC-experiments
  - Field emission studies



Source: CLIC CDR

Field Emission

- Electrons tunnel through barrier under presence of external field.
- Fowler-Nordheim eq:

$$I = A_e \frac{1.54 \times 10^6 \beta^2 F^2}{\phi} \mathrm{e}^{10.41\phi^{-1/2}} \times \mathrm{e}^{-6.53\times10^3 \phi^{3/2}/\beta F}$$

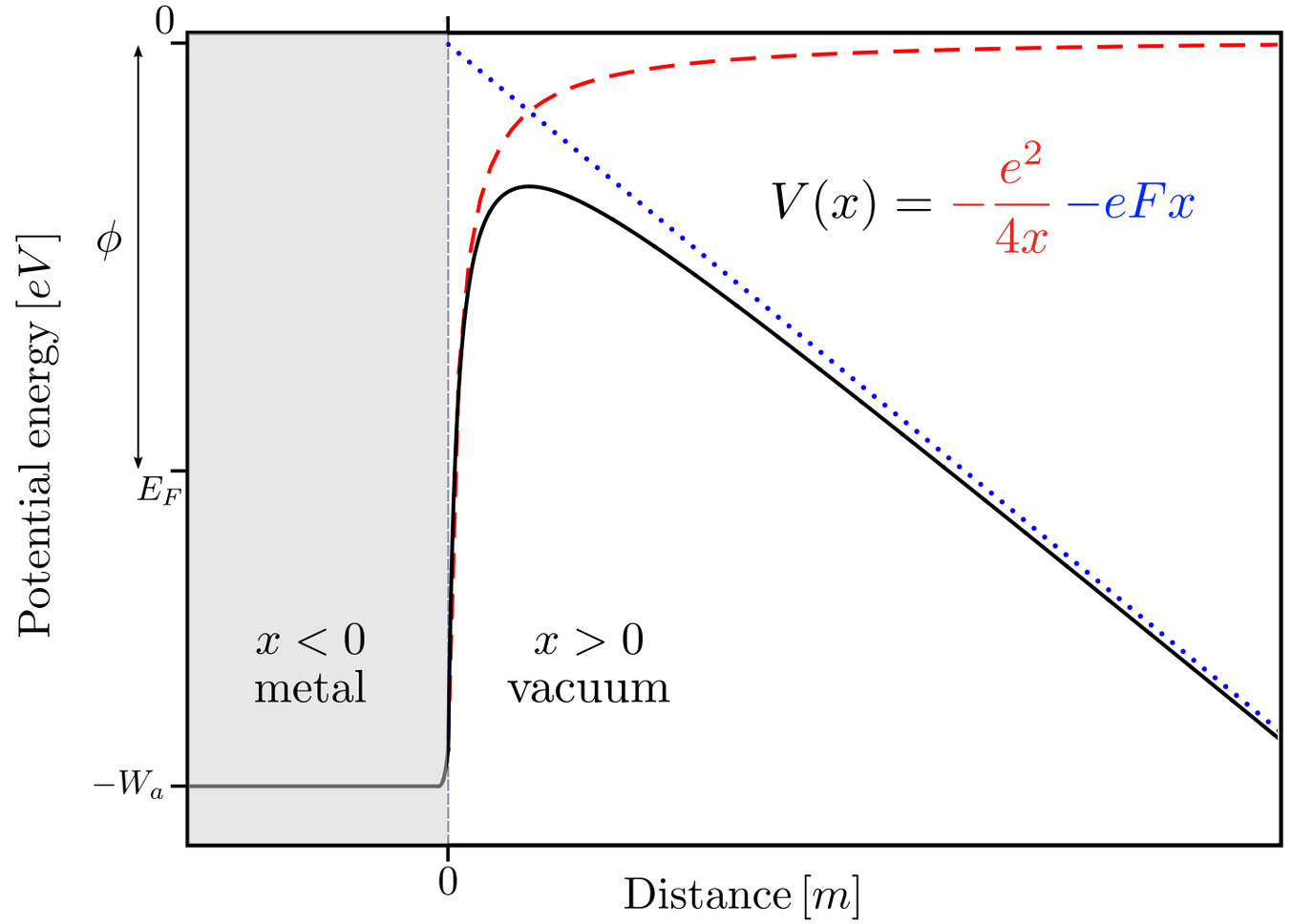
$$= aF^2 \mathrm{e}^{-b/F}$$

$$\ln\left(\frac{I}{F^2}\right) = \ln(a) - \frac{b}{F}$$

Field enhancement β can be determined from the slope b:

$$\beta = \frac{6.53 \times 10^3 \phi^{3/2}}{b}$$

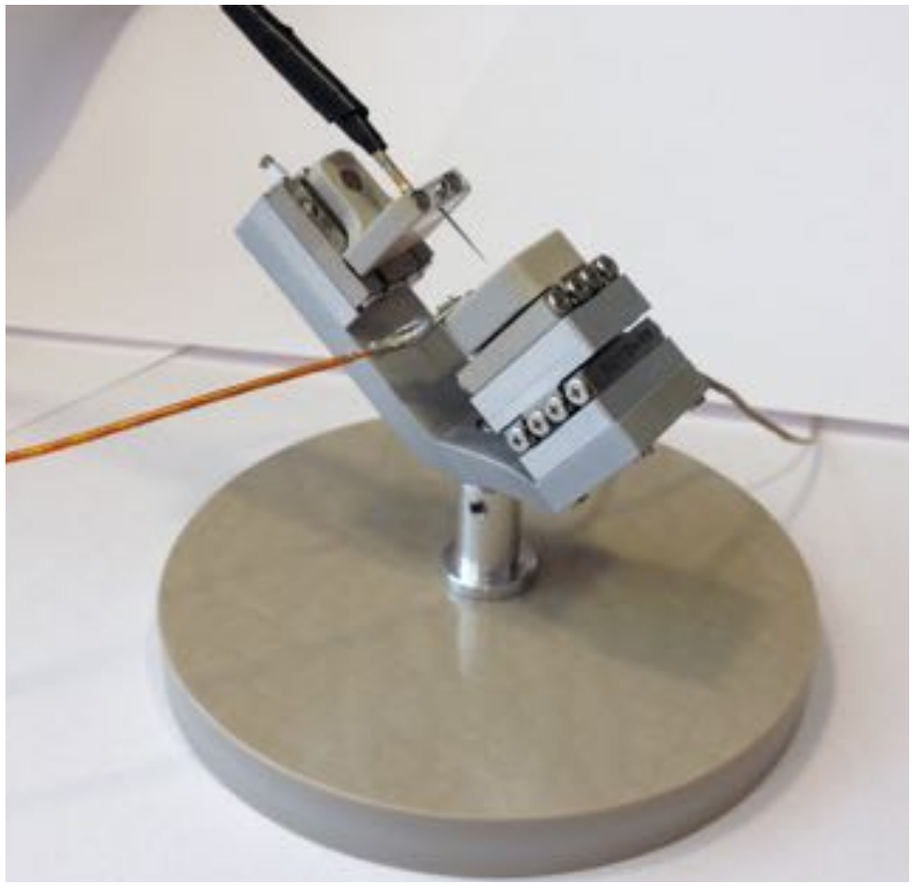
$$F_{loc} = \beta F$$



- Microscopic protrusions and surface features are believed to enhance the local field.

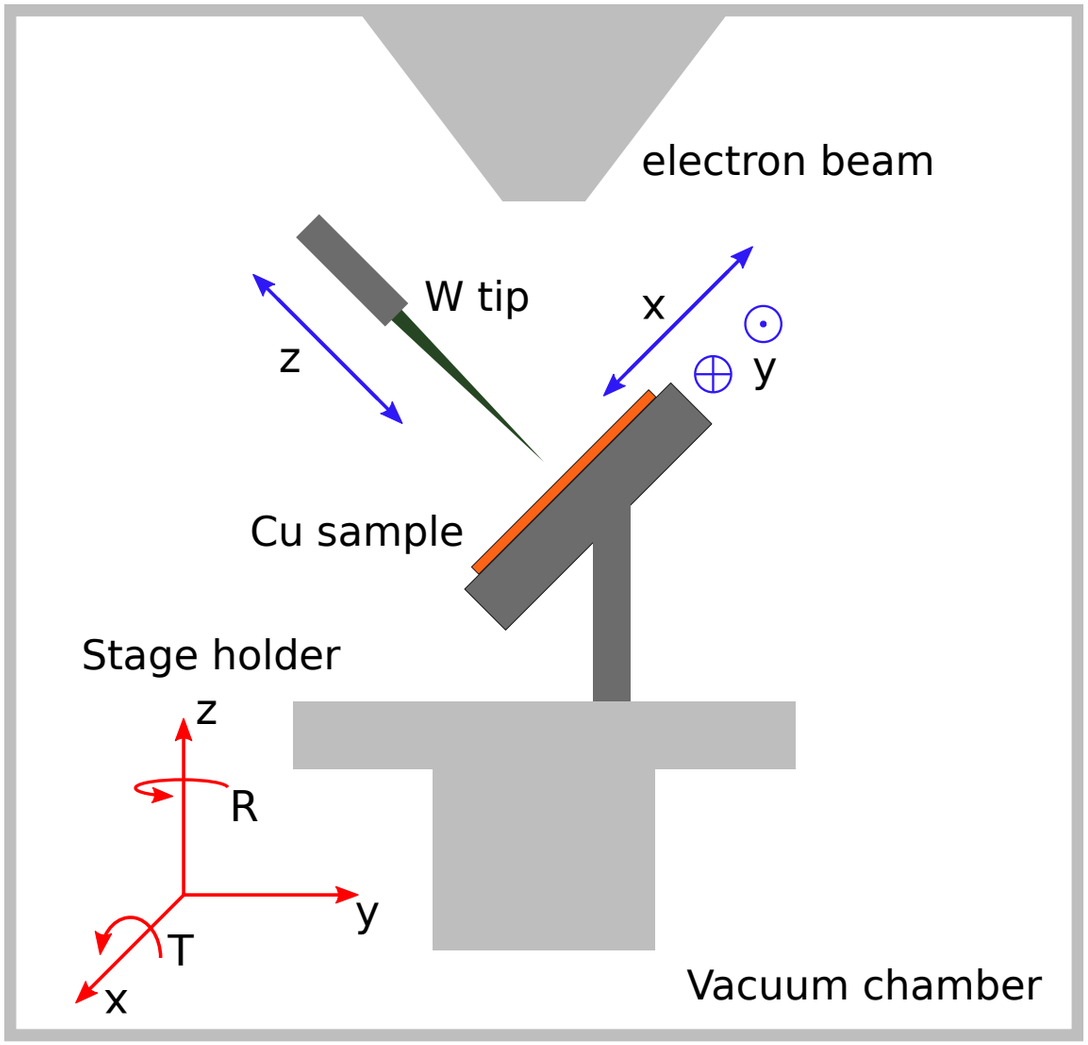
In-situ SEM setup

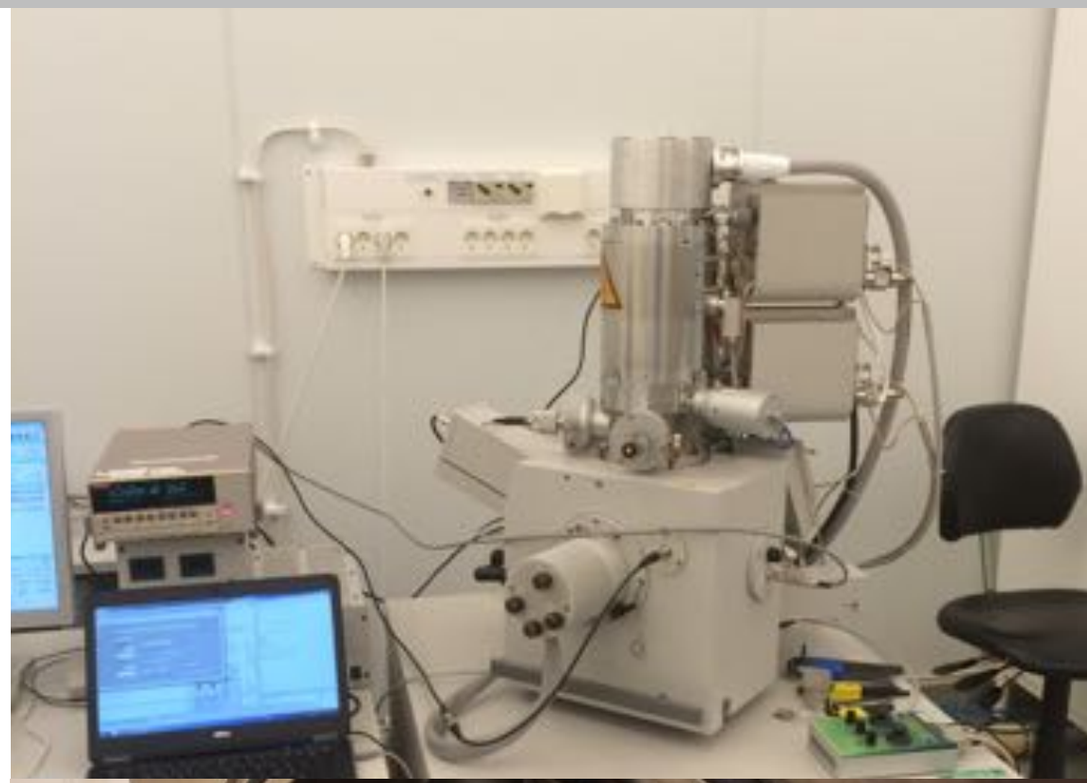
- Continuation of T. Muranaka's work
- Cu sample
- W tip, radius of curvature 5 µm.
- Piezo-motors for 3D control with position sensors with nm precision
- Keithley 6517a Electrometer for measuring FE currents
  - Sourcing up to 1 kV
  - Range from sub-pA to mA
  - 50 Hz sample rate
- SEM
  - Environmental SEM
  - Field emitting gun, 10-30 kV
  - Vacuum ~7×10^{-5} mBar

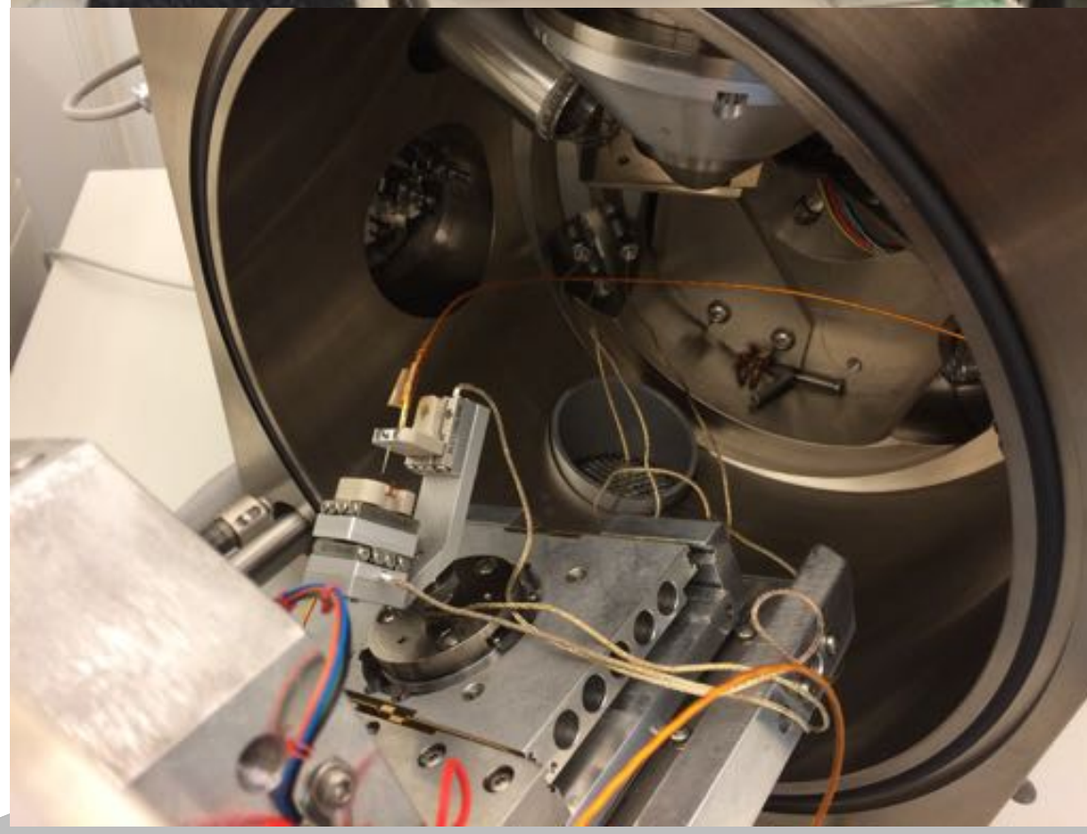


Scanning electron microscope

Right: SEM
Down right: vacuum chamber
Below: 3 DOF tip and sample surface,
5 DOF on SEM stage holder.



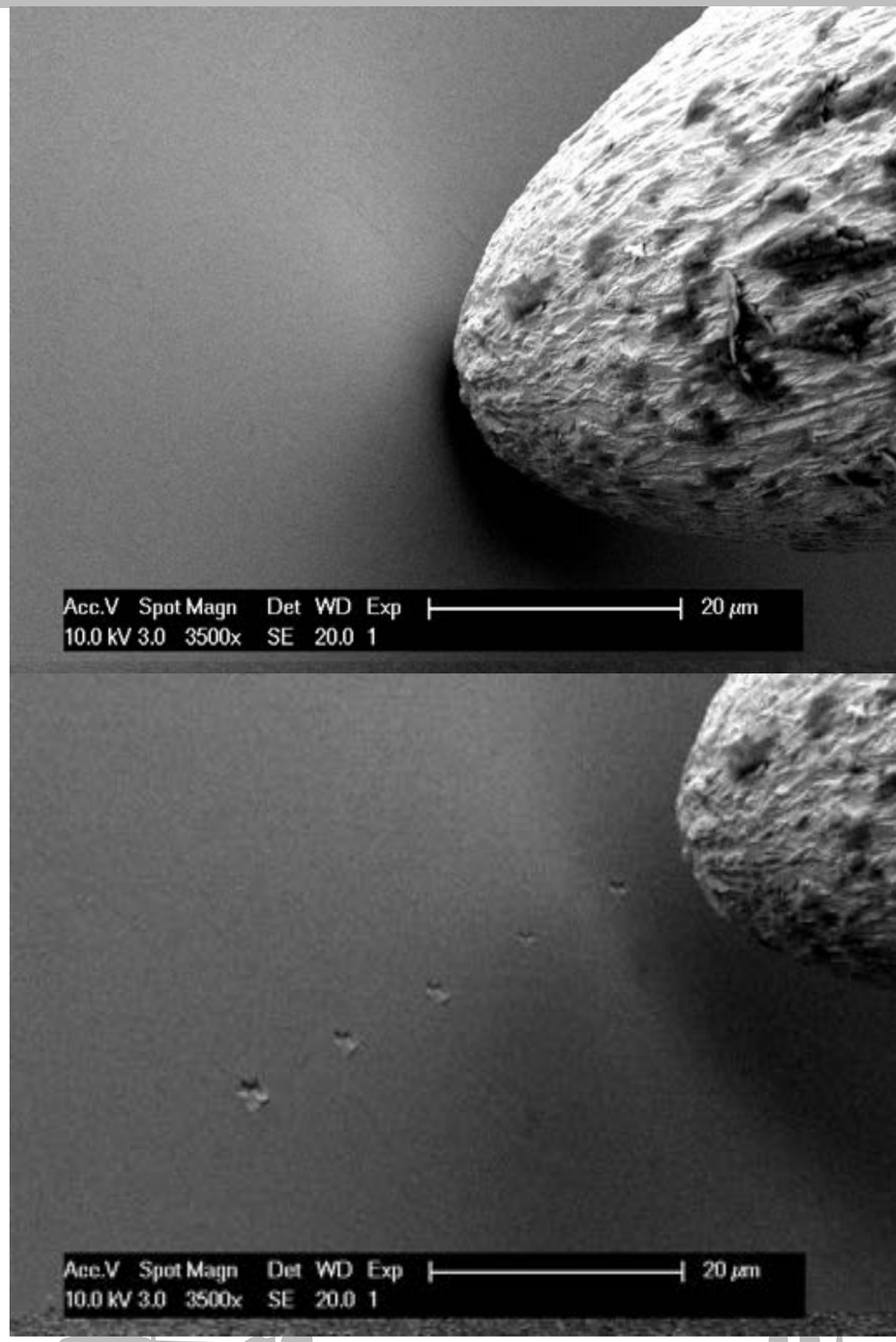




Knowing the gap distance

- Find surface method:
  - Set low voltage 1 V
    - Approach tip in steps of 2 nm
    - Measure current
    - Repeat until current exceeds threshold
- High reproducibility
  - 10 repeated times: σ ≈ 20 nm
- Small marks on surface
  - Use surrounding positions

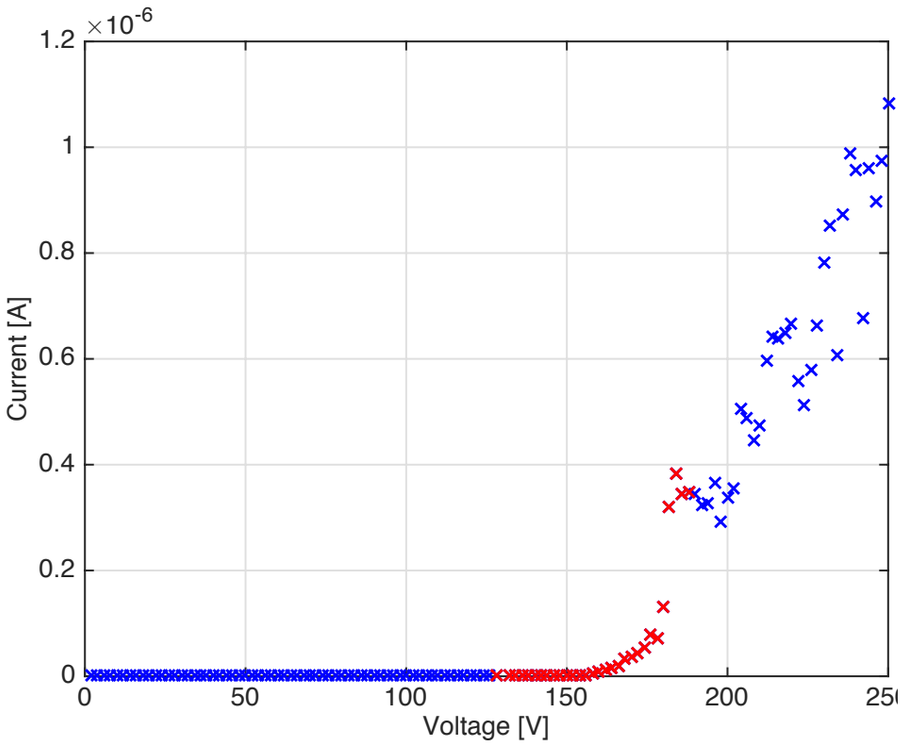
Tip at surface

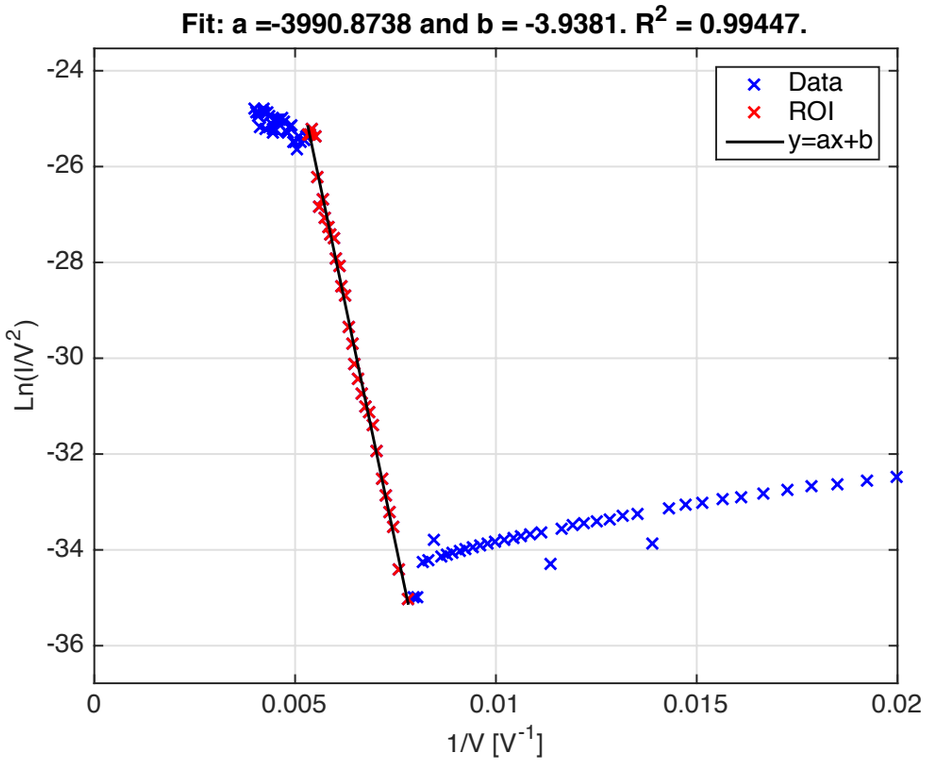


Preliminary results

- Voltage scans and Fowler-Nordheim plots
- Evolution of beta
- Crater formations
- Activation behaviour
- Detection of emitted electrons

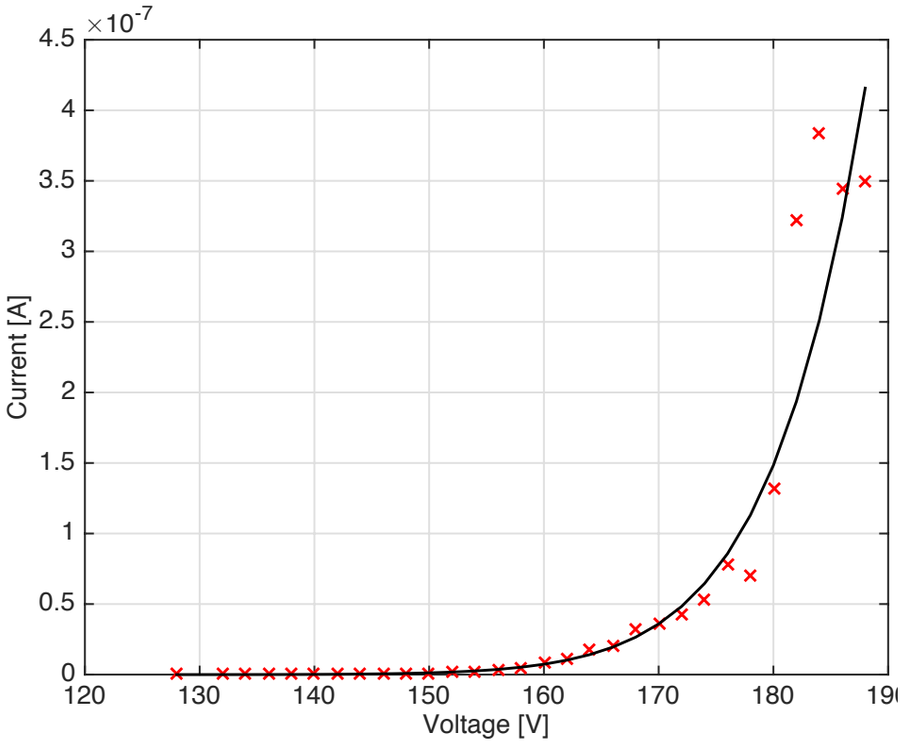
Voltage scans

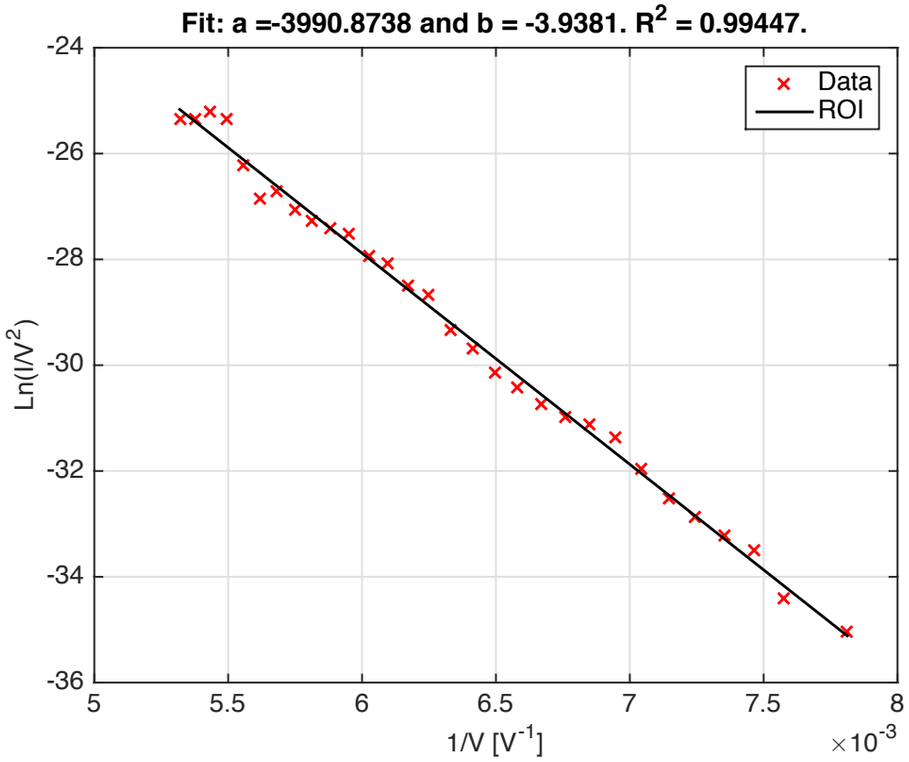




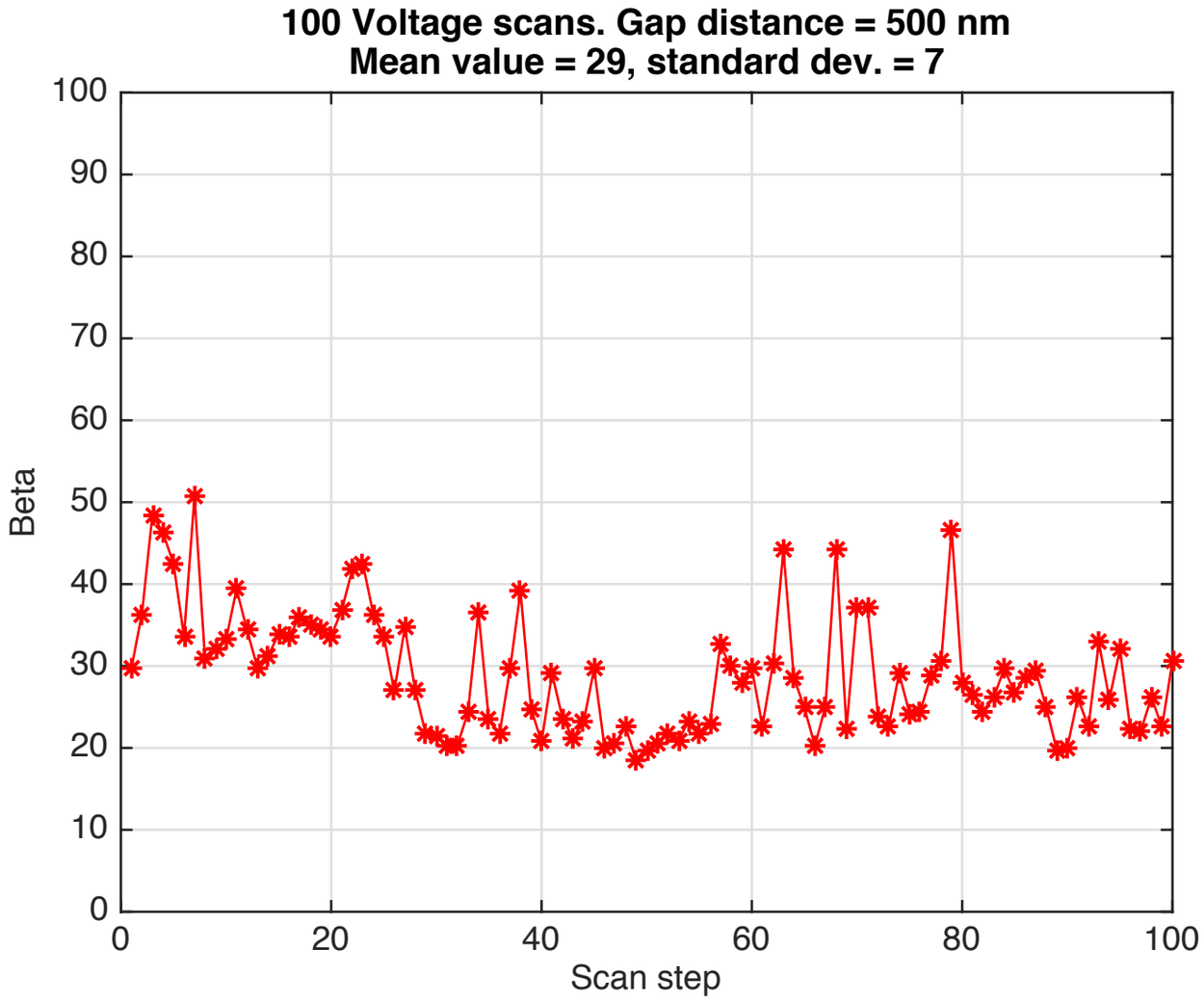
Gap distance
500 nm

β = 31





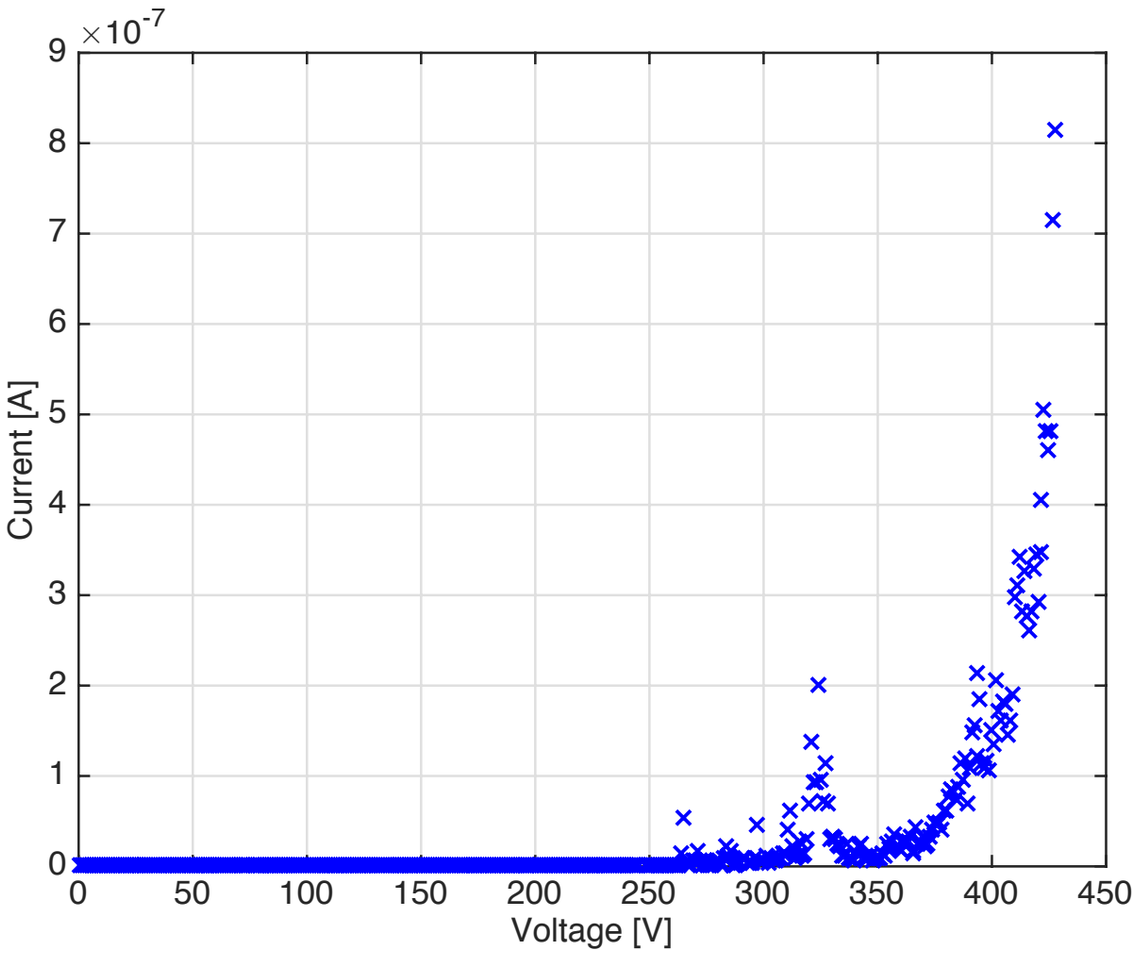
Evolution of beta

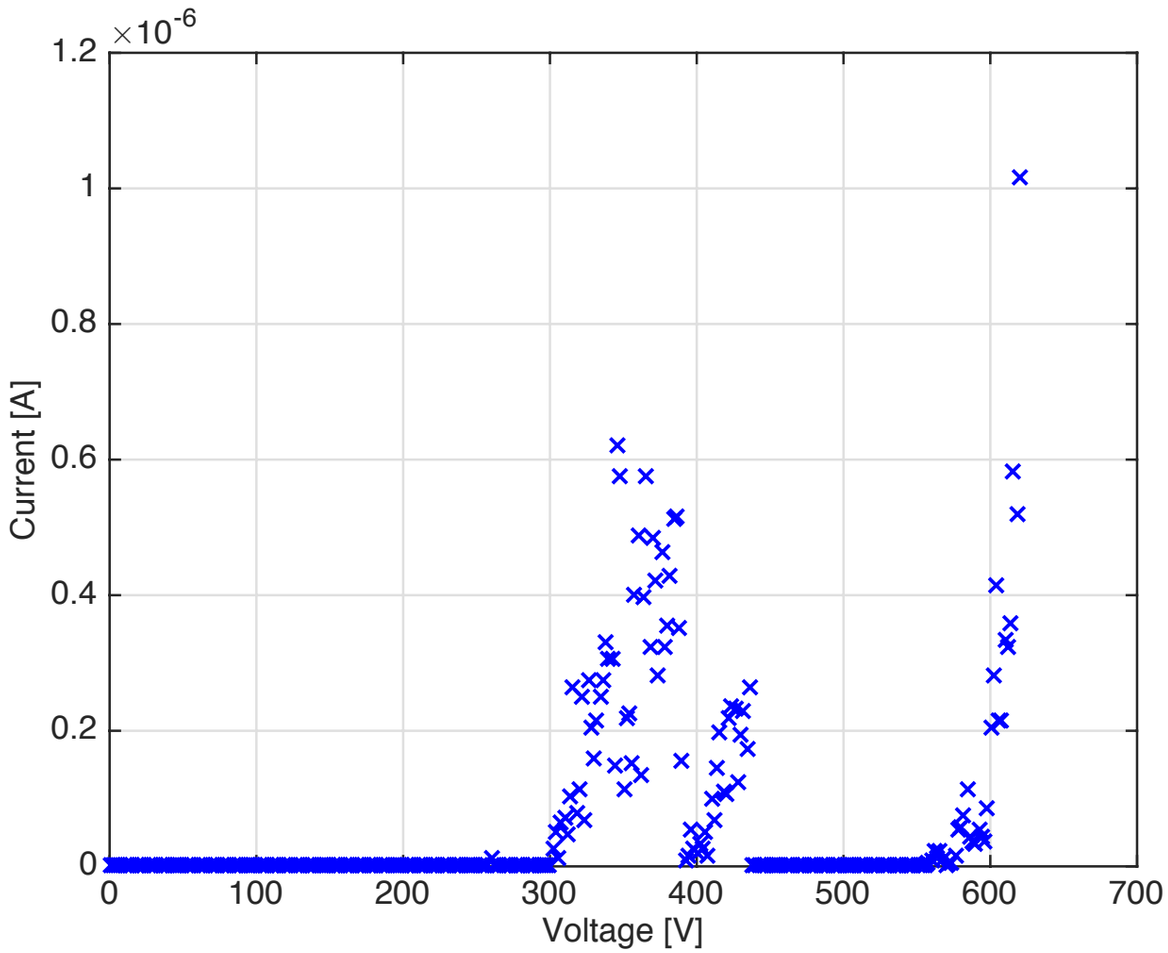


- 100 consecutive voltage scans
- Estimation of emission area:
  - Range from 1×1 nm to 50×50 μm
  - Majority around 1×1 nm
  - Sensitive parameter

Multiple F-N curves

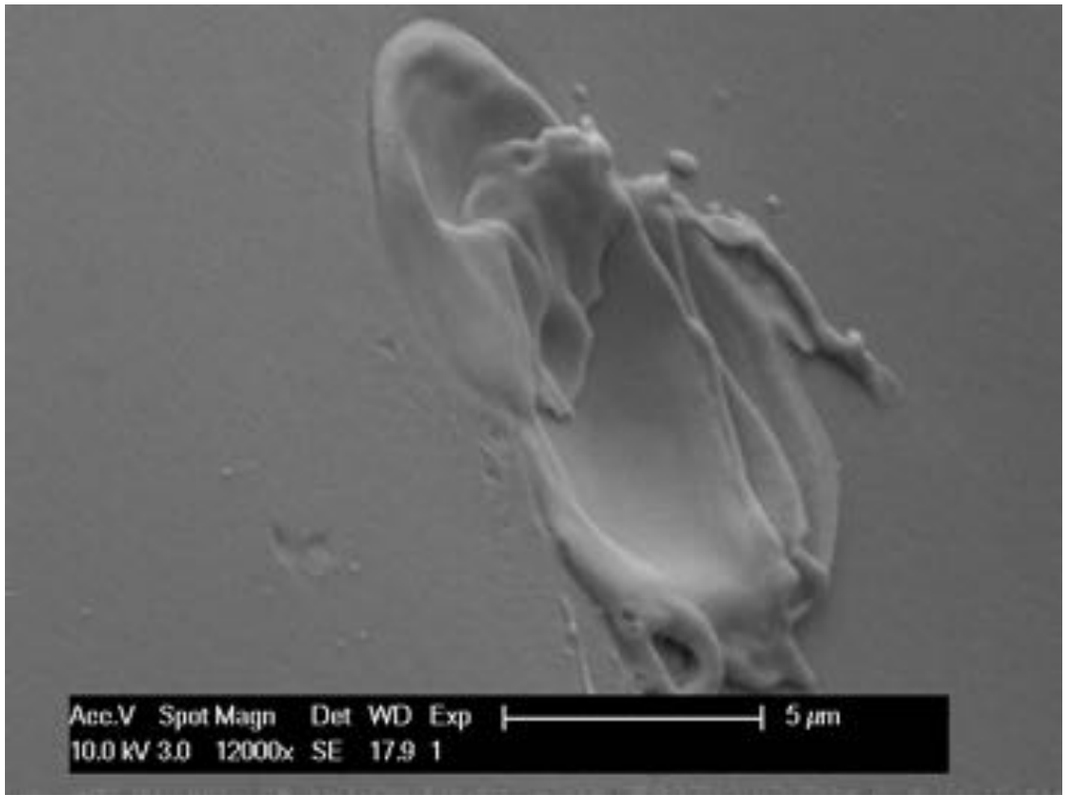
- In some cases we observed multiple F-N characteristics.
- Many measurements also yielded no F-N characteristics at all

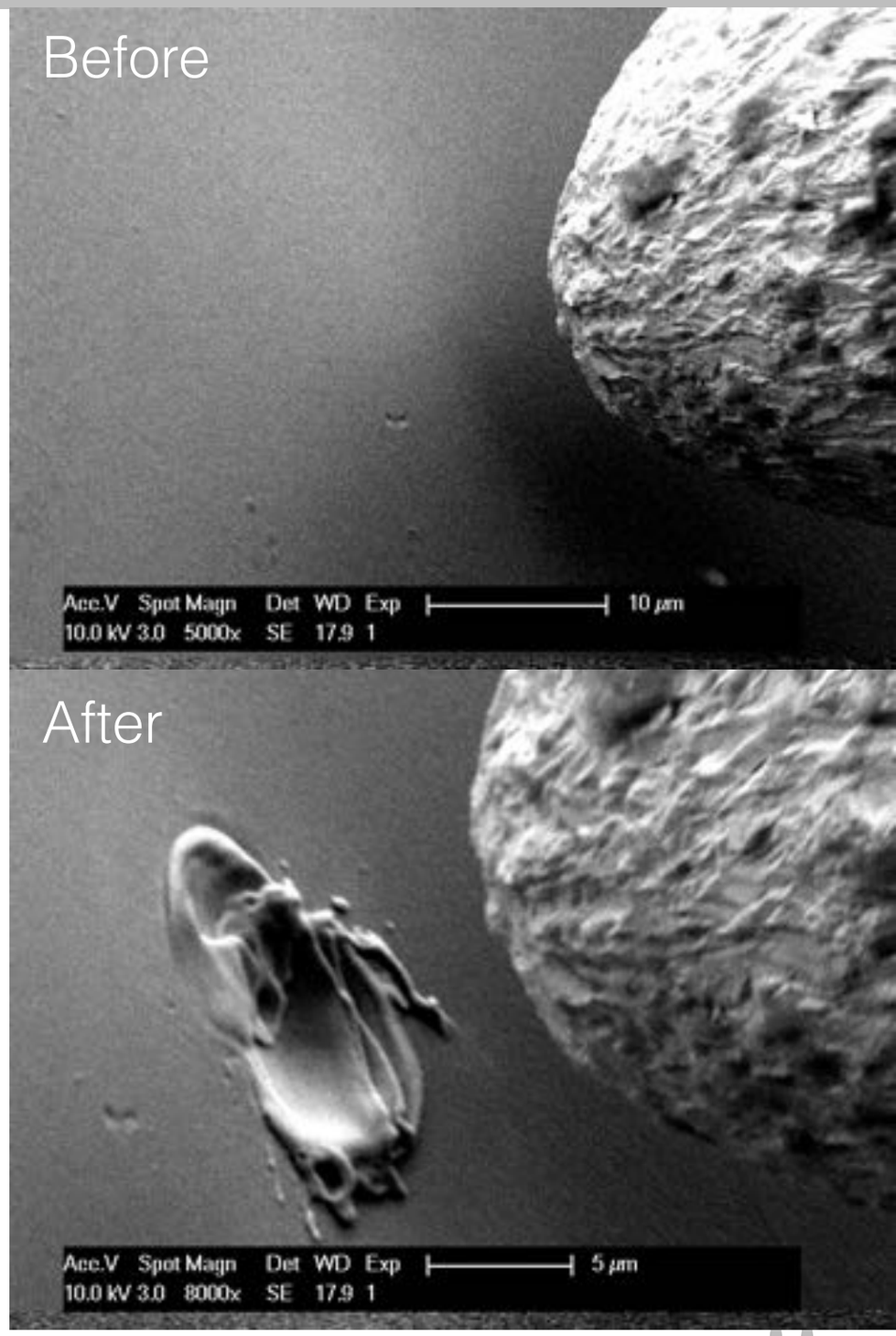




Crater due to breakdown

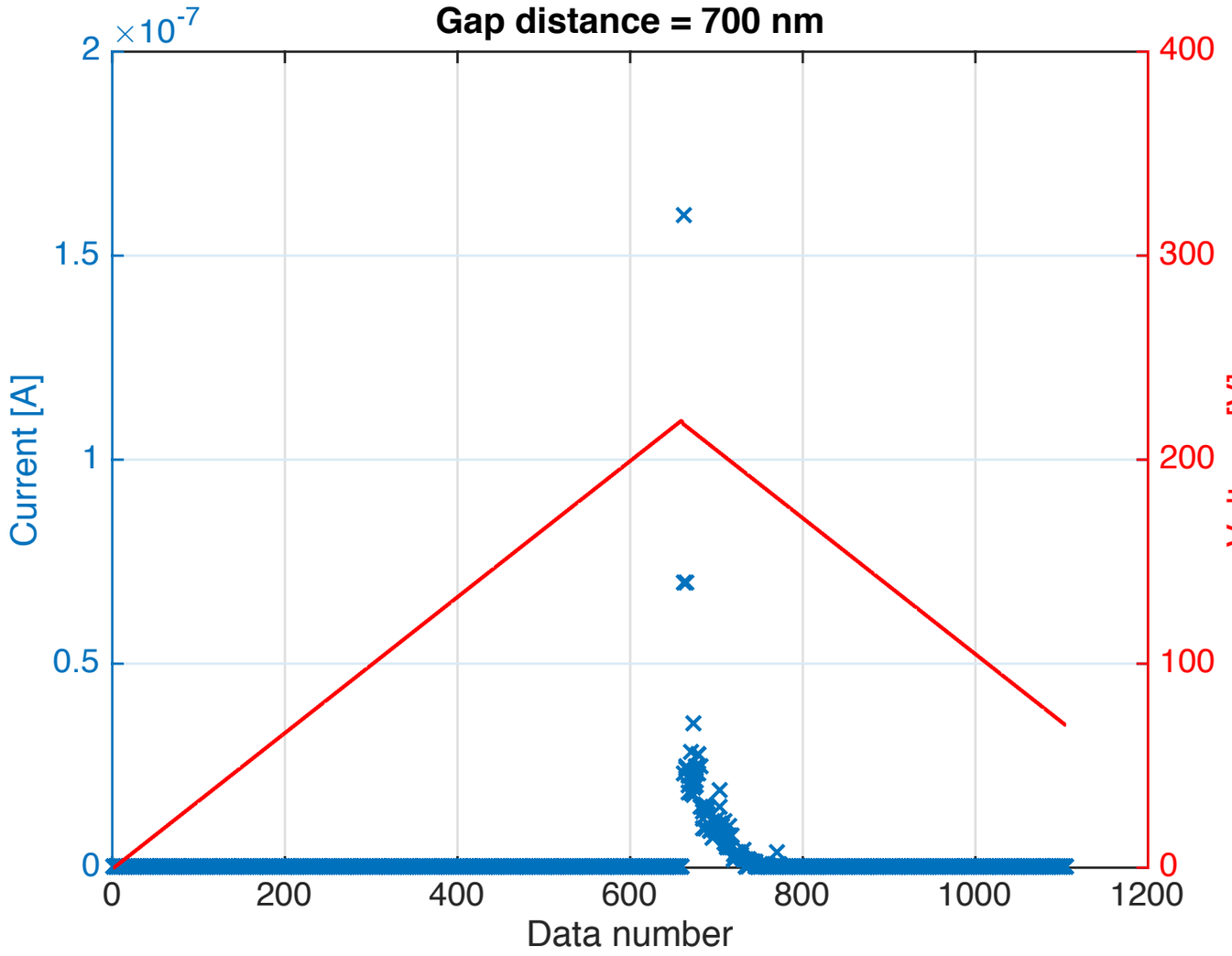
- In some voltage scans we have seen crater formation
- Assign given set of I-V measurements to an observed surface change
- Crater size similar to tungsten tip ~5 µm.





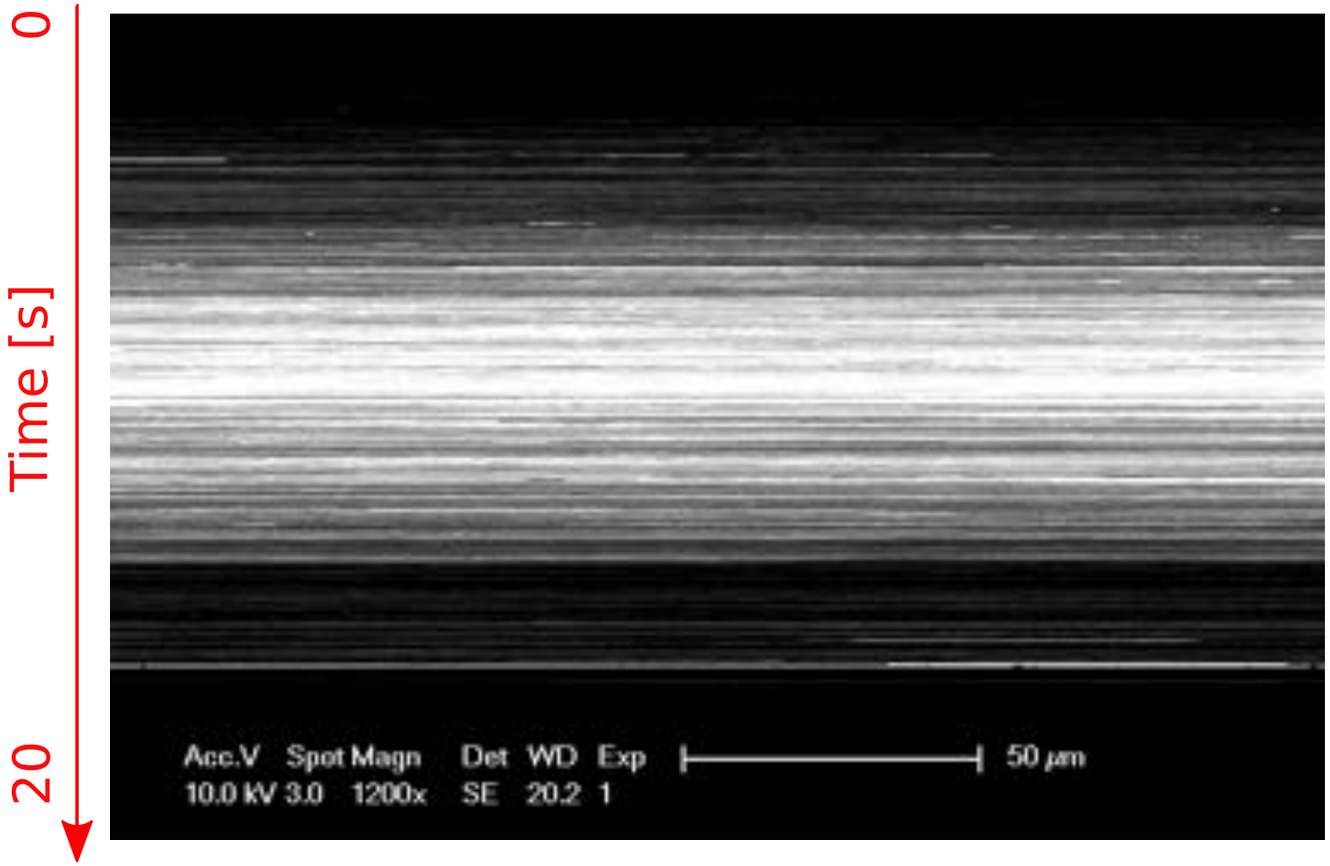
Activation effect

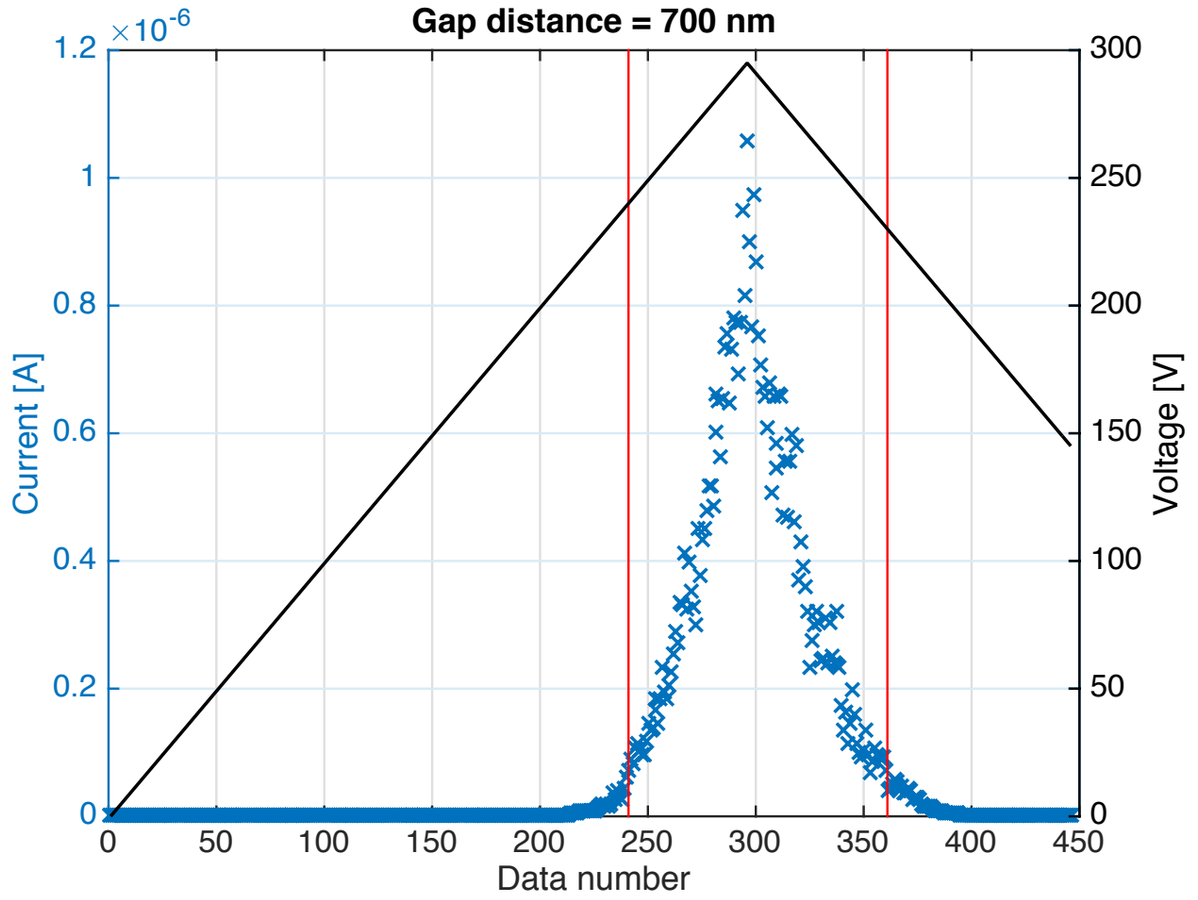
- Ramp voltage to a certain current threshold and then reverse voltage
- Mostly symmetric behaviour but in some cases asymmetric.
  - Activation effect
  - Removal of oxidation layer?
  - Other changes on surface?



Emitted electrons detected by SEM

- The Everhart-Thornley detector was (accidentally) left on during a voltage scan and could detect a signal.
- Slow scan (about 20 s) was run simultaneously to current peak
- Implies that the detector was detecting emitted electrons from field emission and/or breakdown?





Outlook

Summary

- A piezo motor-driven setup for field emission measurements in-situ SEM has been commissioned and is operational with precise position control.

Open questions

- So far, many different I-V characteristics observed
- What kind of reproducibility in F-N plots is reasonable to expect?
- Over a large number of voltage scan we saw few breakdowns, why?
- Why any BDs? Is there enough energy to create crater with a small gap distance and low potential difference?

Outlook

- New samples from CERN
- Continuation of commissioning of system and optimising settings
- Line and surface scans
- Correlate surface features to FE-maps
- Maybe you have suggestions?