

# Status of high gradient studies at Uppsala

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**and**

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**Applied Materials Sciences, UU**

*Mini MeVArc 2018, 13-14/11/2018*



- **In-SEM Field Emission Studies**
- **Dark current at Xbox RF test stand**
- **Summary**

### Stage

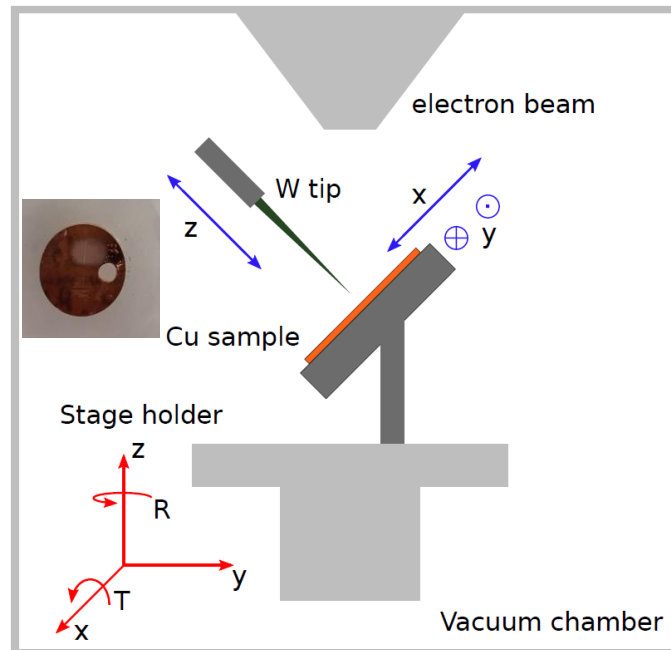
W tip, radius of curvature 5  $\mu\text{m}$   
nm precision piezo-motors

### Environmental SEM

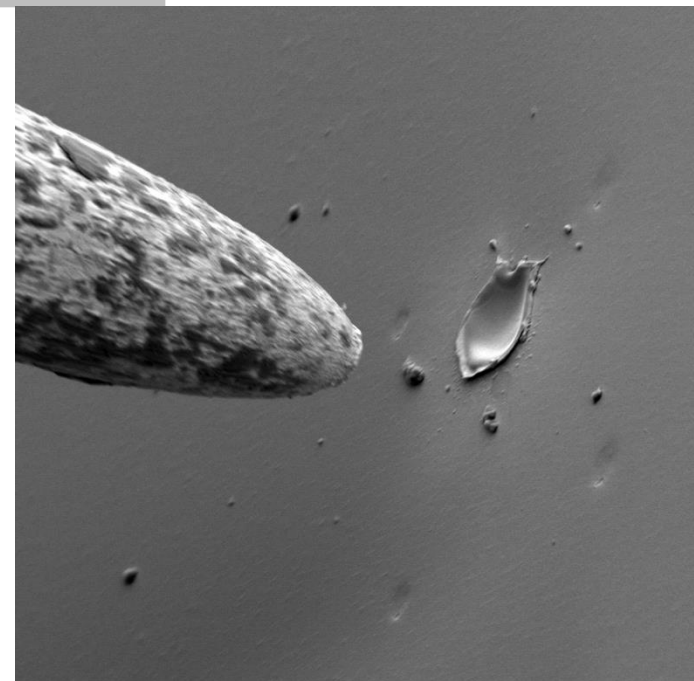
Field emitting gun, 10-30 kV  
Vacuum  $\sim 7 \times 10^{-5}$  mBar

### Keithley 6517a Electrometer

FE currents from sub-pA to mA  
Applied V = up to 1 kV, 50 Hz



## In-SEM Setup



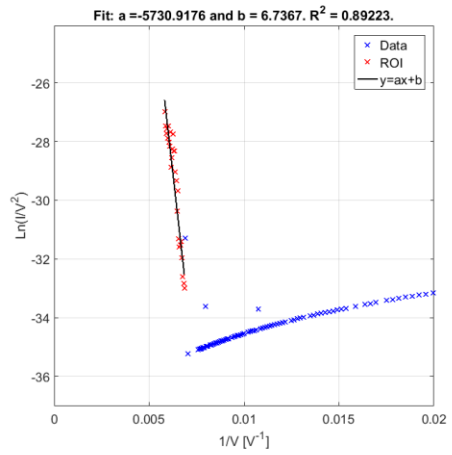
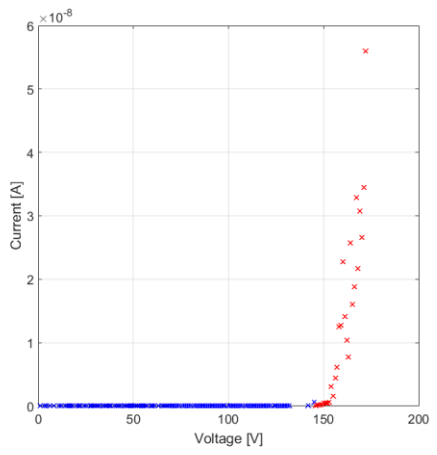
**Typical gap distance  $\rightarrow$  700 nm**

Surface search procedure:

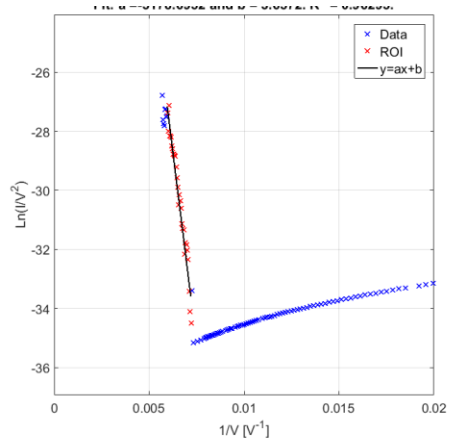
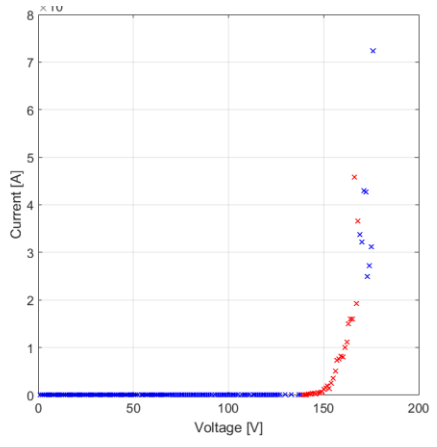
Low voltage, approach surface in steps (2 nm) while measuring current until threshold breach (done 2 times just left and right to the area-of-interest)

# I-V curves

## Fitting of $\beta$ parameter

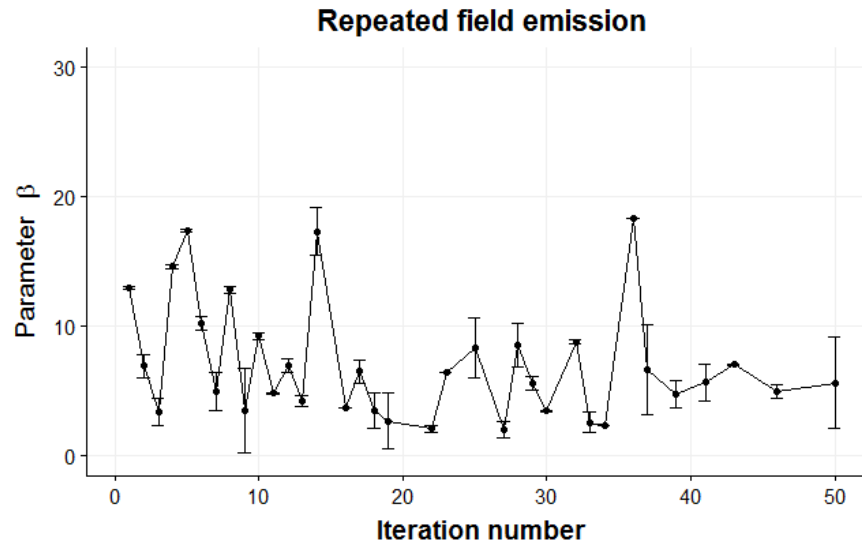


$\beta = 15.5$

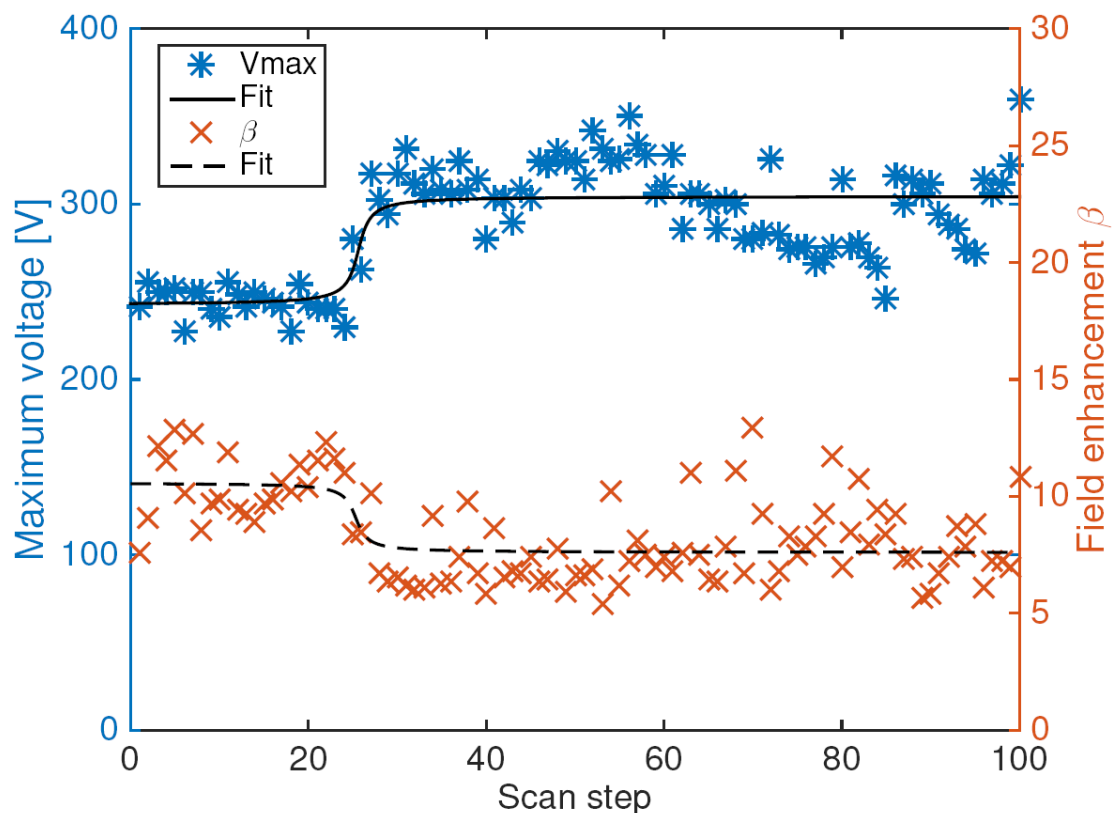


$\beta = 17.6$

# Repeated scan $\beta$ parameter



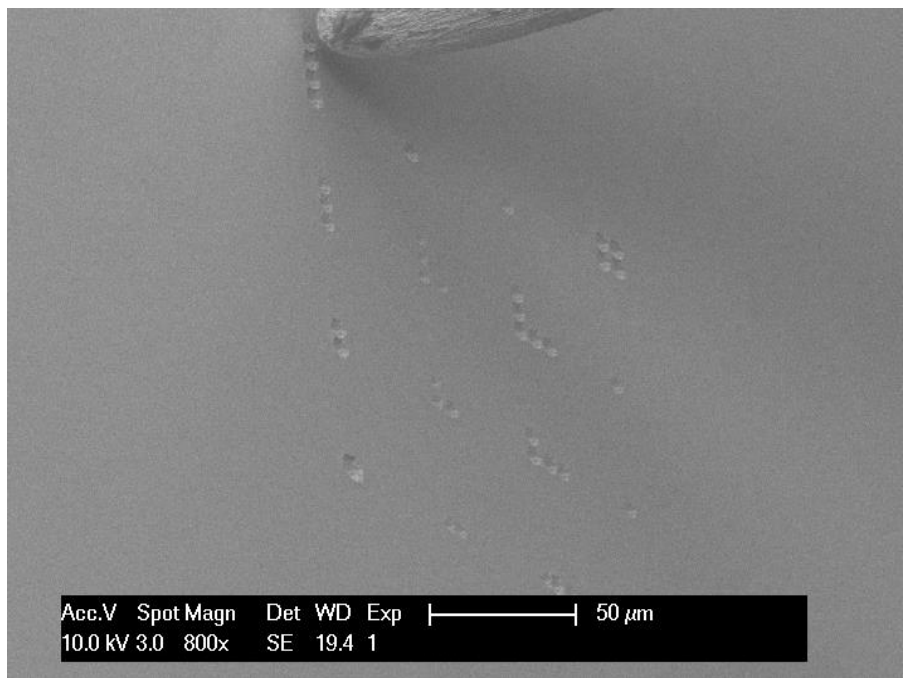
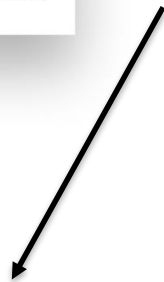
# Repeated scan $\beta$ parameter



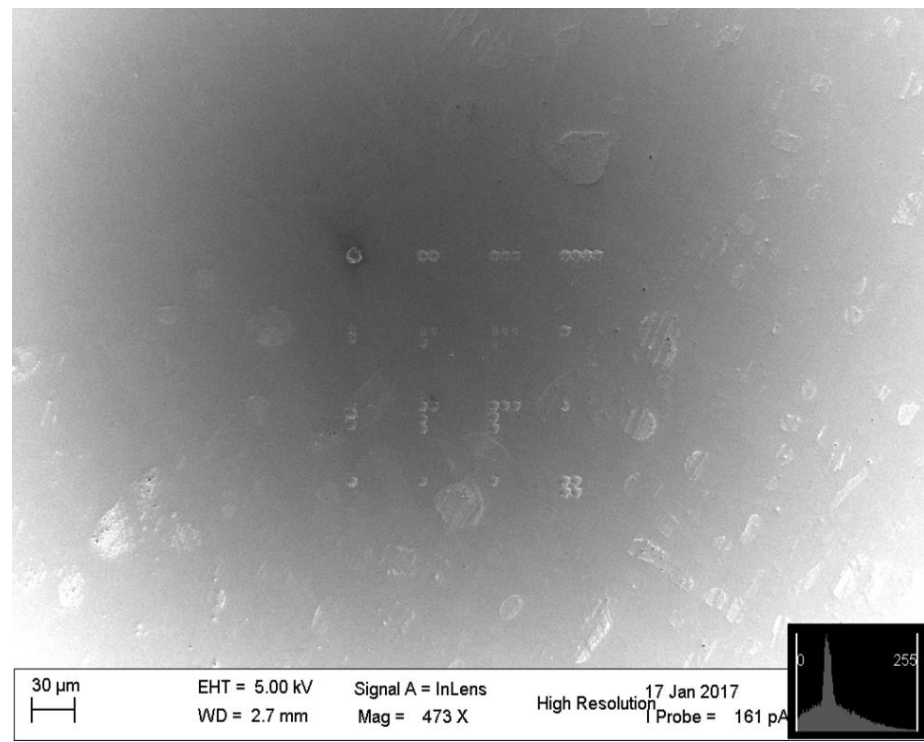
Let's look at field emission currents' dependence on surface morphology -> need higher resolution SEM scans

# Experimental procedure

Marking an area in ESEM (for easy recognition)  
**Move sample to HR-SEM for surface microscopy of the area**



Areas are marked in ESEM before initial surface analysis  
 Here: 150 x 150 μm ; 5μm depth

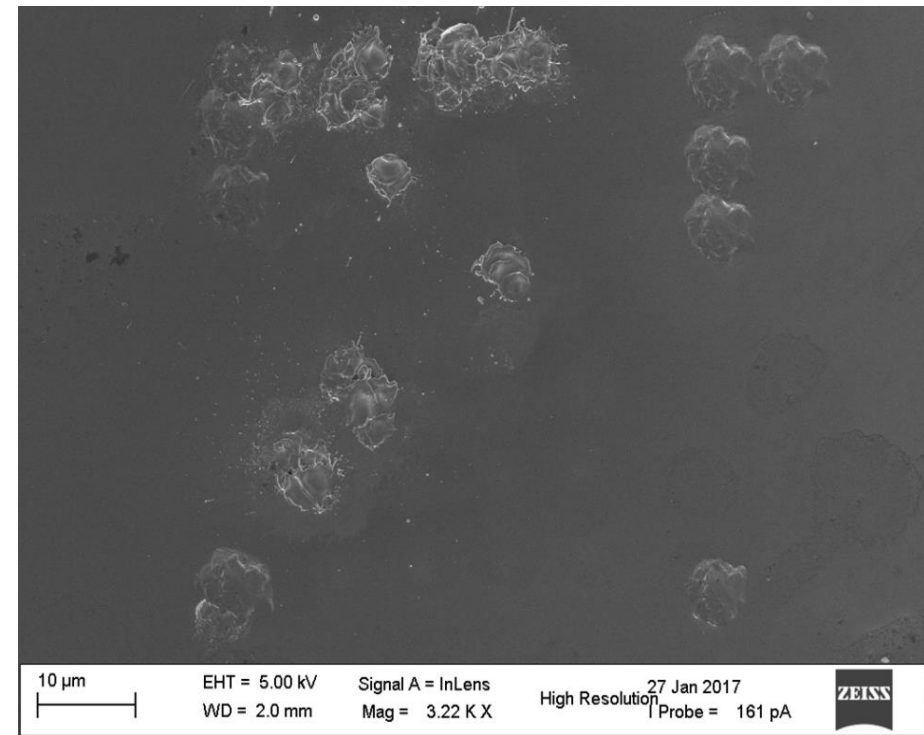
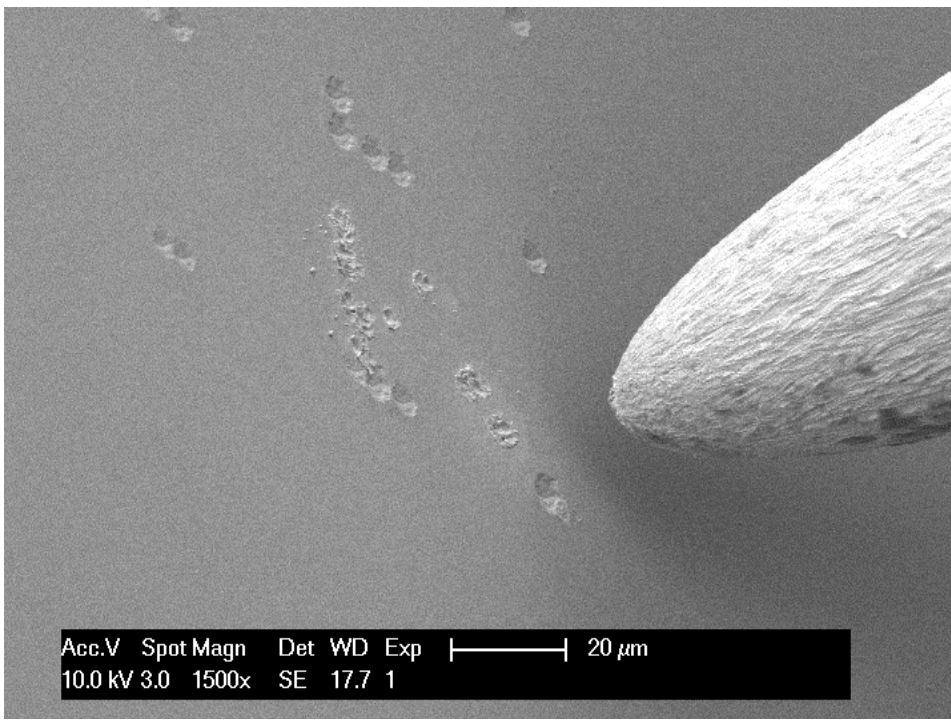
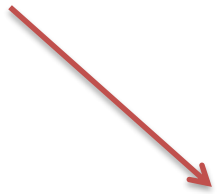


High-resolution SEM  
 Zeiss LEO 1550 FEG

# Experimental procedure

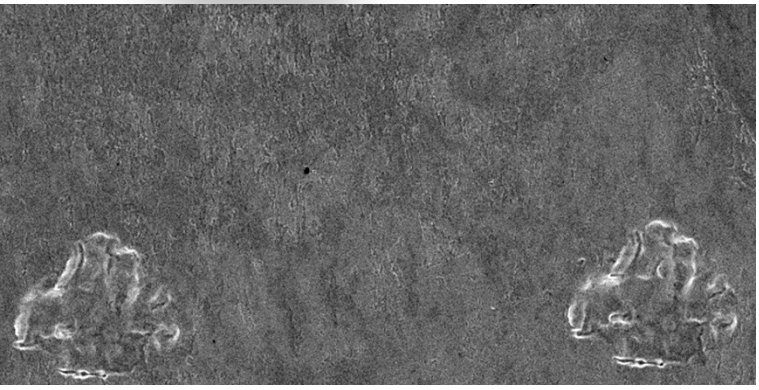
Move back to ESEM for FE experiments

Move sample back to HR-SEM for post-experiment surface microscopy





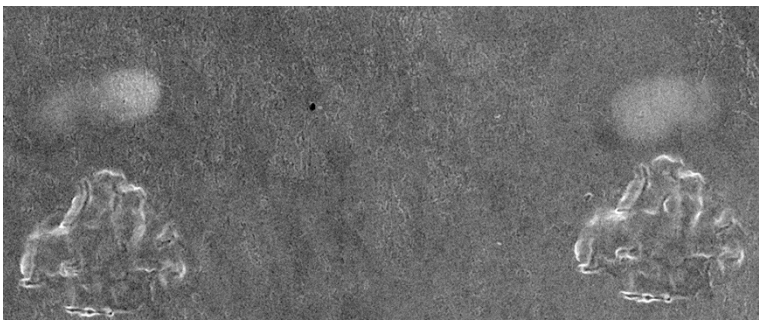
# Results of high res surface scan contrast change



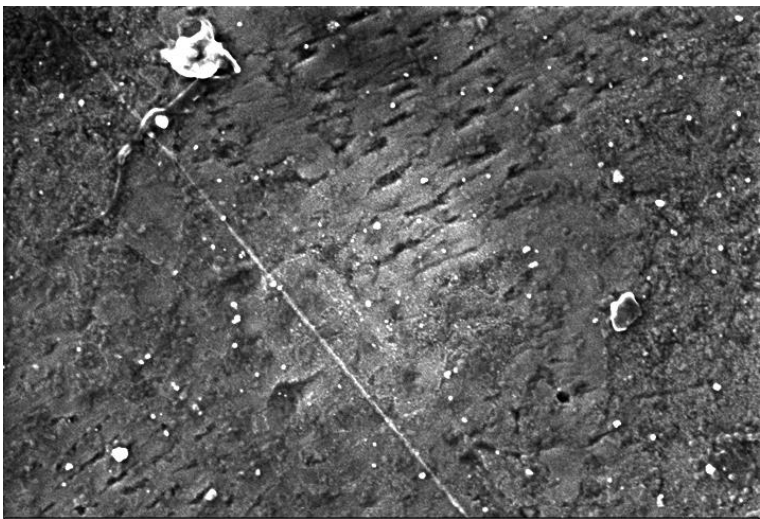
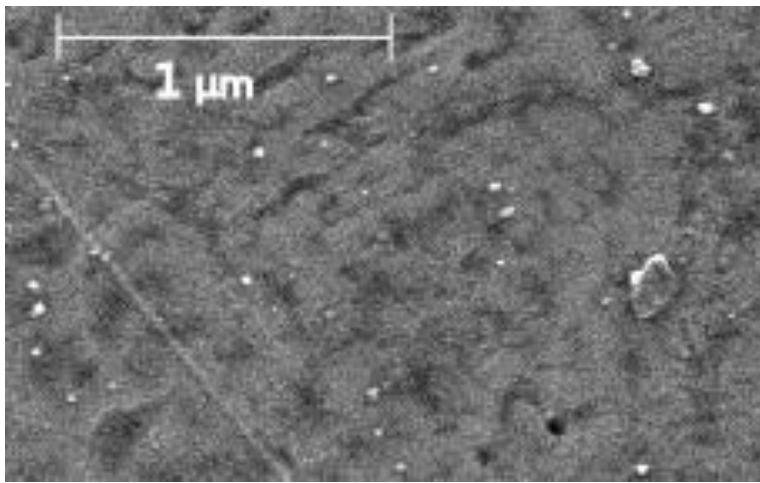
“FE” areas

before

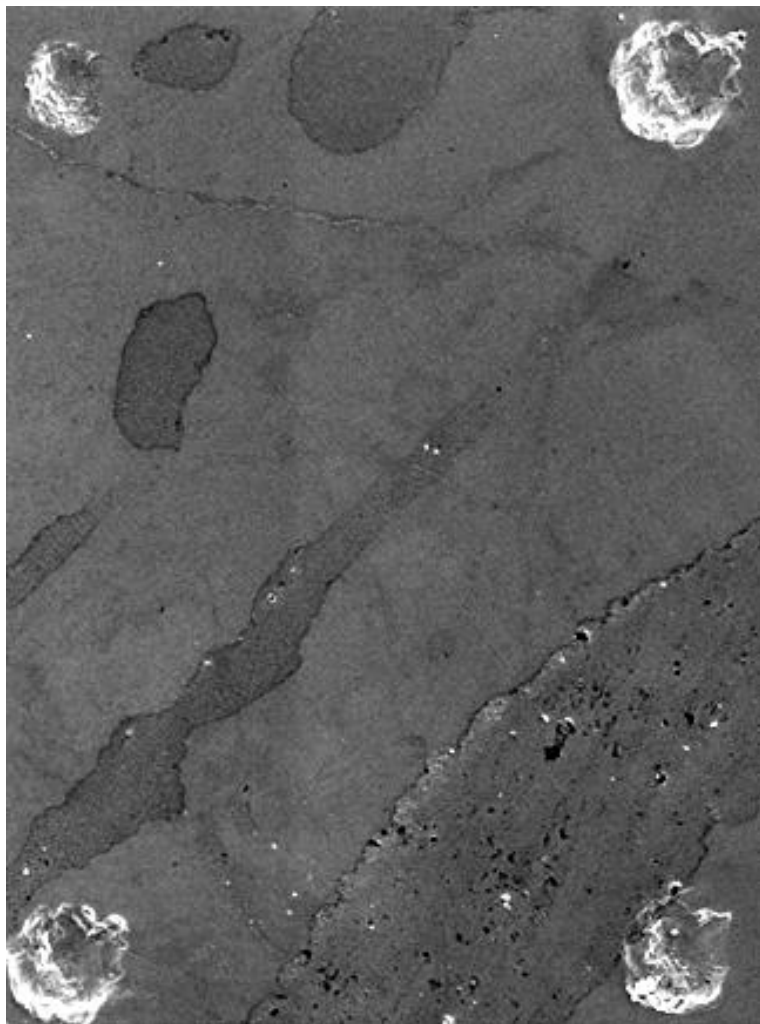
and



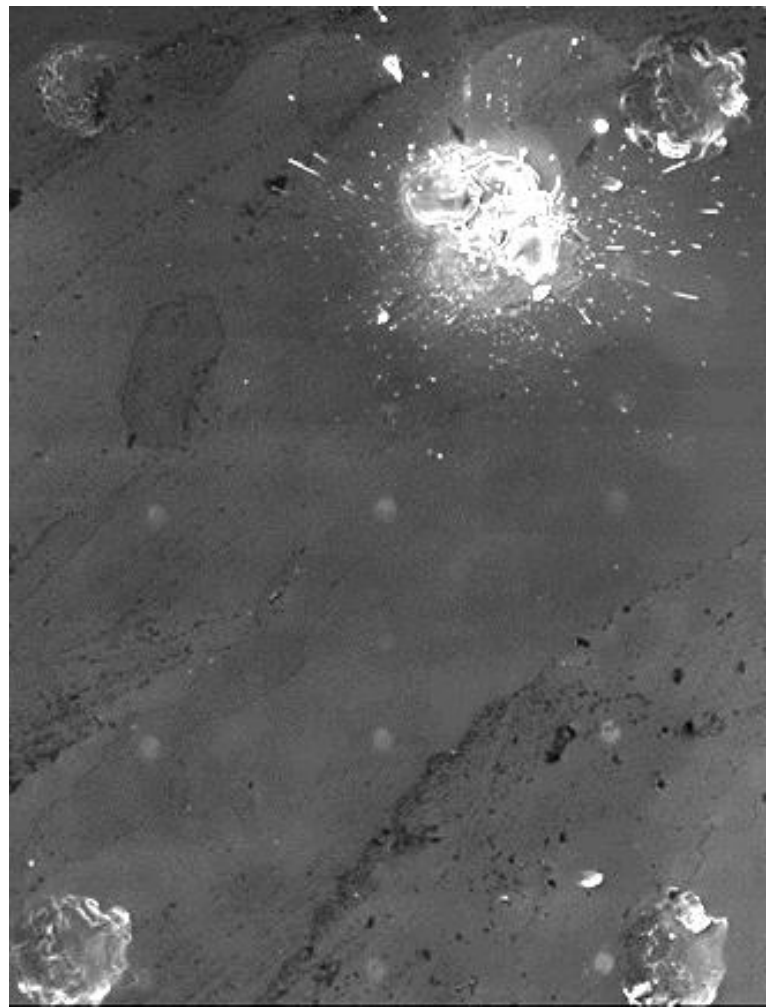
after



Before



After



# Surface composition

## XPS analysis

We found no correlation to surface morphology  
 -> field emission currents do not so much depend on surface morphology, but rather on something else such as surface chemistry.

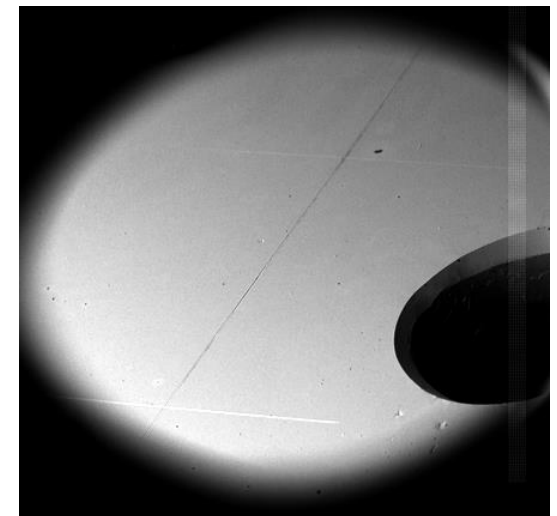
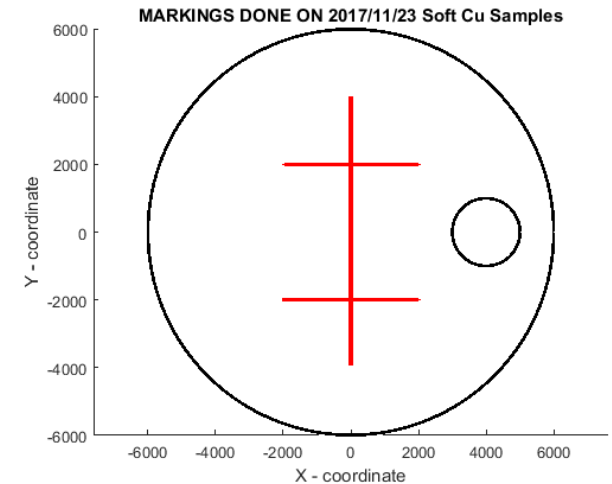
We know that we affect the surface, but what happens?

Adding X-ray photoelectron spectroscopy information

Steps \*):

1. Markings
2. XPS analysis and Ar sputtering
3. HR-SEM observation
4. FE experiments
5. Final HR-SEM observation
6. Final XPS analysis

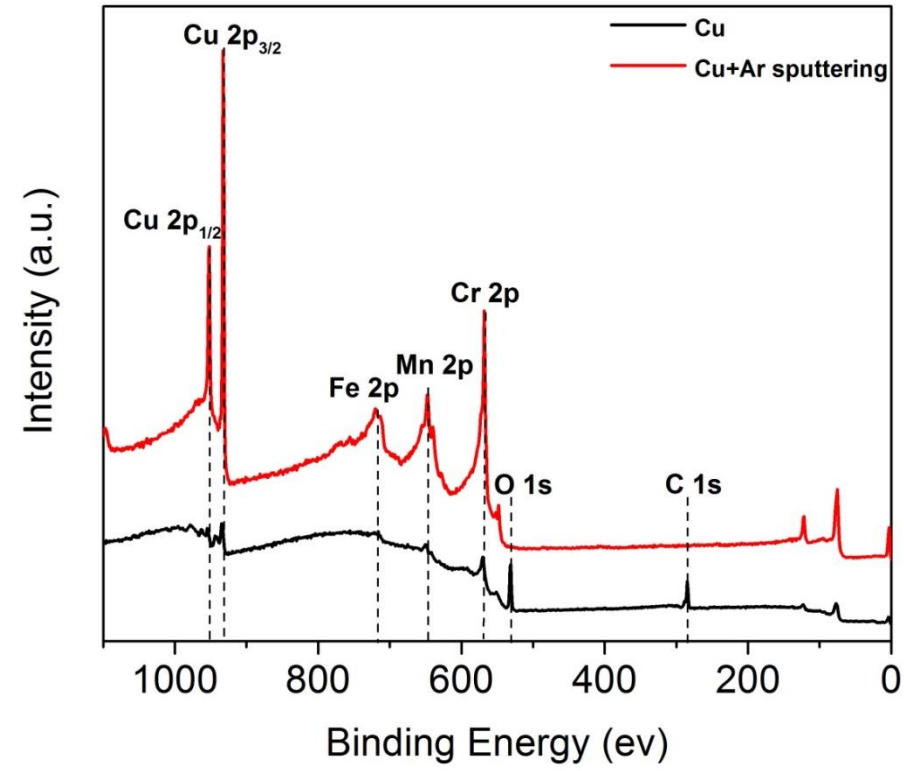
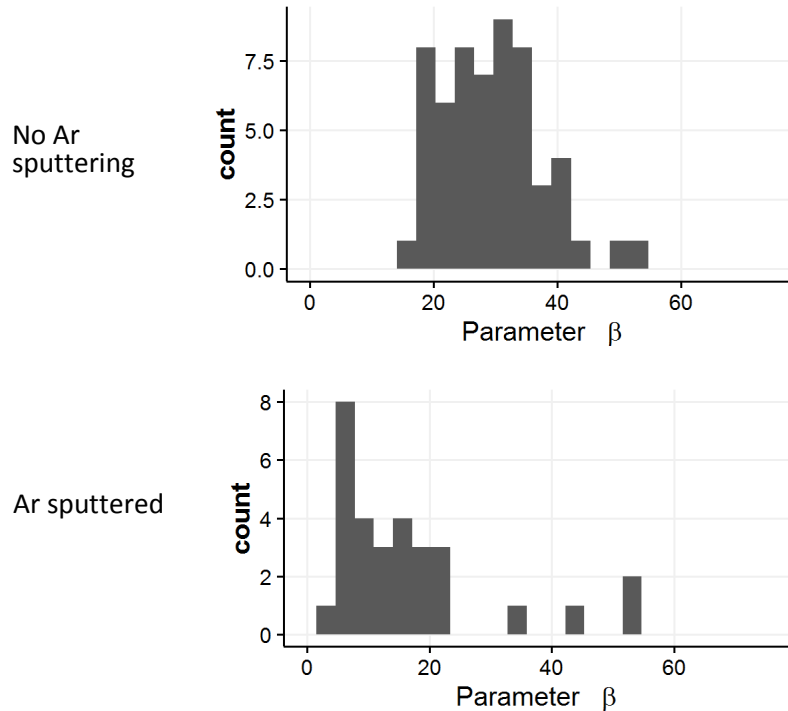
\*) Between steps the sample is placed in a vacuum desiccator



# Surface composition

## Effect of argon sputtering

- After Ar sputtering O and C peaks disappear.
- C contamination on surface equals to a thickness of 3.6 nm on top of Cu (rough estimate)



XPS analysis works only on large areas, > 50  $\mu\text{m}$

*Calculated beta parameter with argon cleaning  
Voltage scans at several location*

# Surface composition

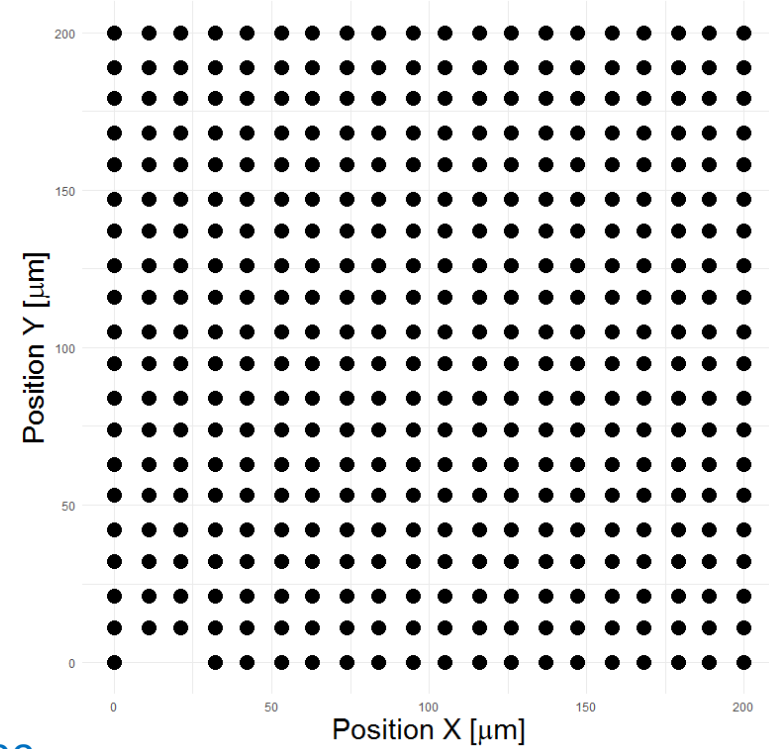
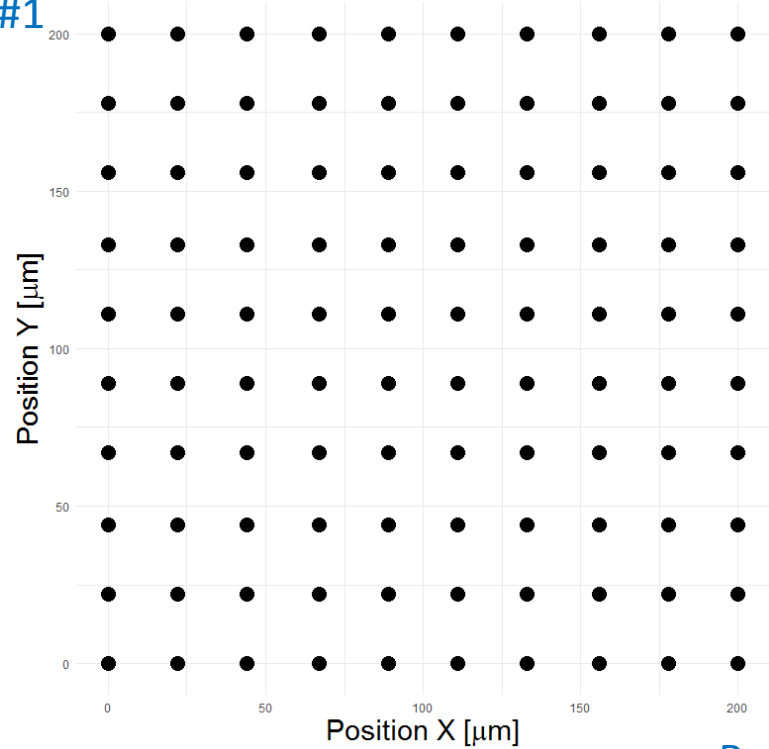
## HR-SEM images after FE experiments

**Experimental area: 200  $\mu\text{m}$  x 200  $\mu\text{m}$  in both cases**

**Area 1: Pattern 10 x 10 FE points**

**Area 2: Pattern 20 x 20 FE points**

Point #1



Point #100

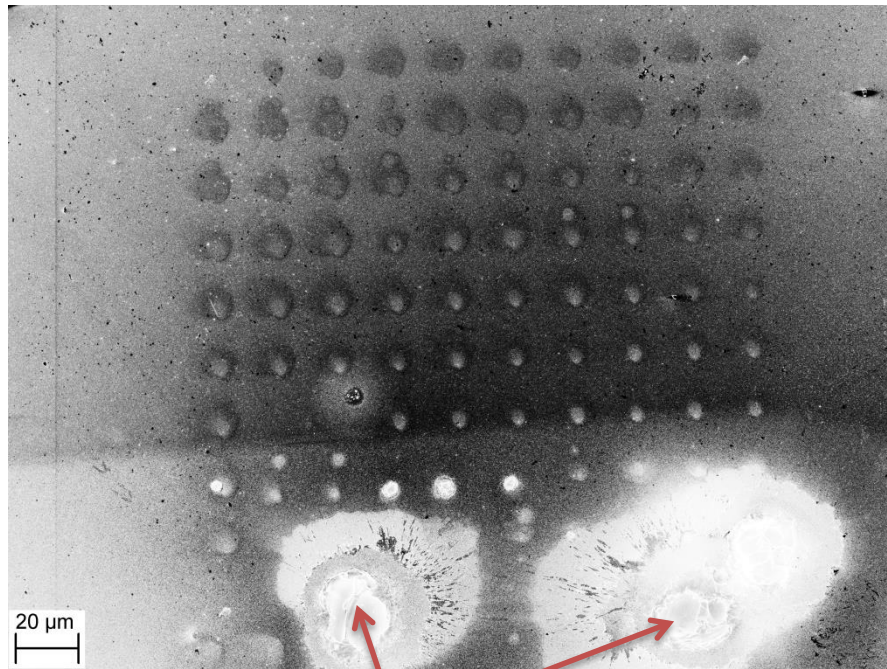
# Surface composition

## HR-SEM images after FE experiments

Experimental area: 200  $\mu\text{m}$  x 200  $\mu\text{m}$  in both cases

Area 1 after experiments

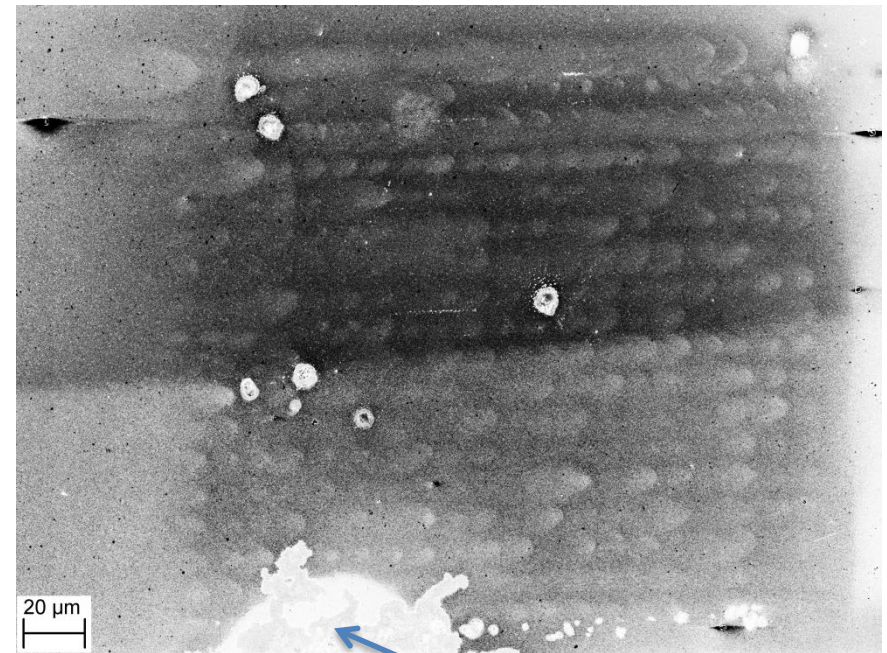
Pattern 10 x 10 FE points



14 Breakdowns at the end of scan

Area 2 after experiments

Pattern 20 x 20 FE points



Breakdown at the end of scan

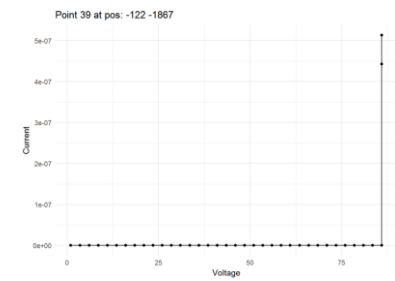
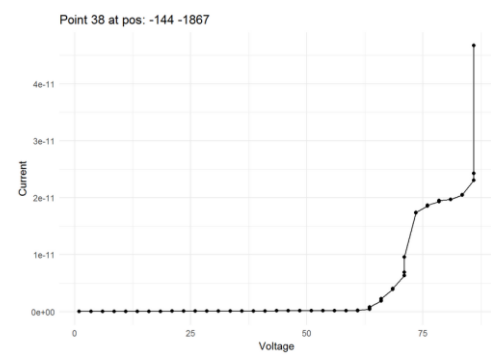
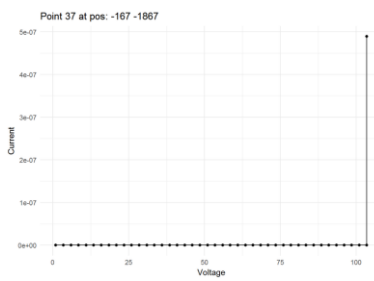
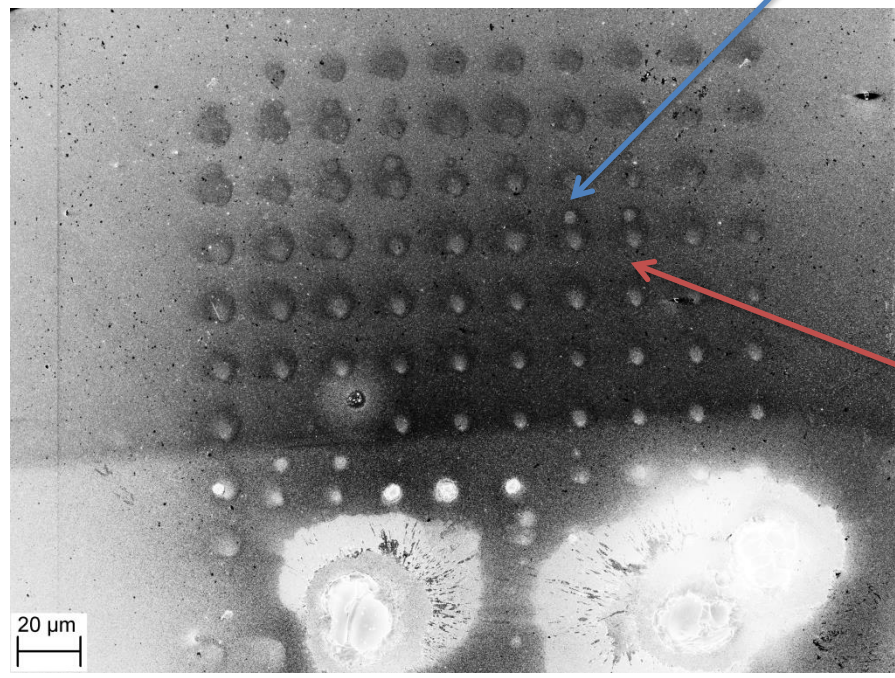
# Surface composition

## HR-SEM images after FE experiments

**Experimental area: 200  $\mu\text{m}$  x 200  $\mu\text{m}$  in both cases**

**Area 1 after experiments**

**Pattern 10 x 10 FE points**



**Double-spots I-V curves  
 have sometimes different  
 shape**

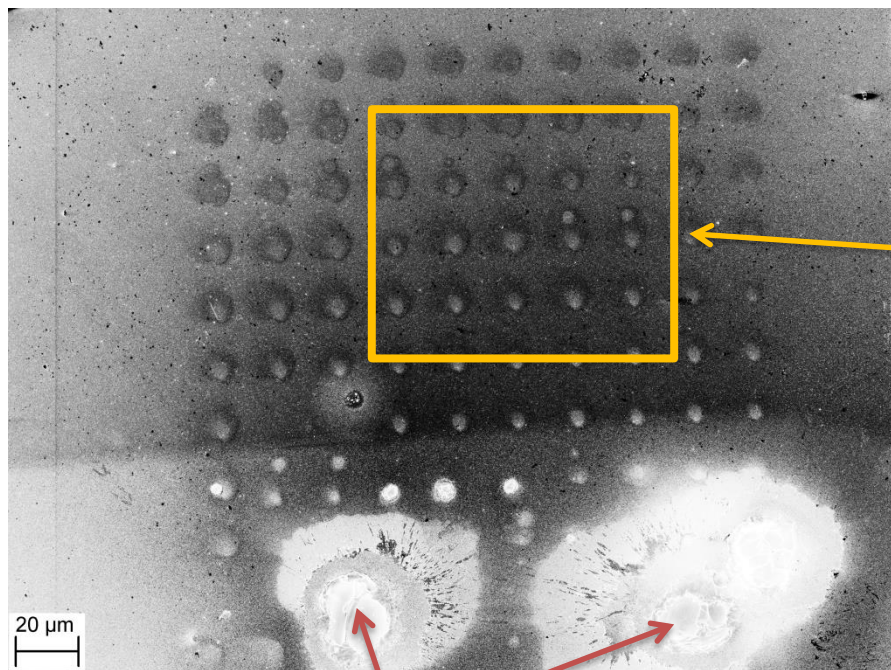
# Surface composition

## HR-SEM images after FE experiments

Experimental area: 200  $\mu\text{m}$  x 200  $\mu\text{m}$  in both cases

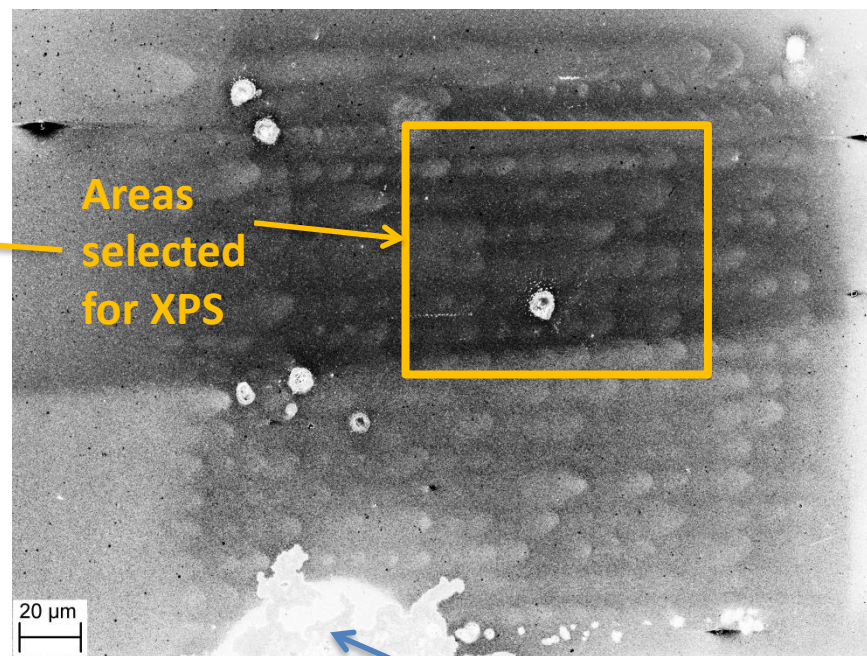
Area 1 after experiments

Pattern 10 x 10 FE points



Area 2 after experiments

Pattern 20 x 20 FE points



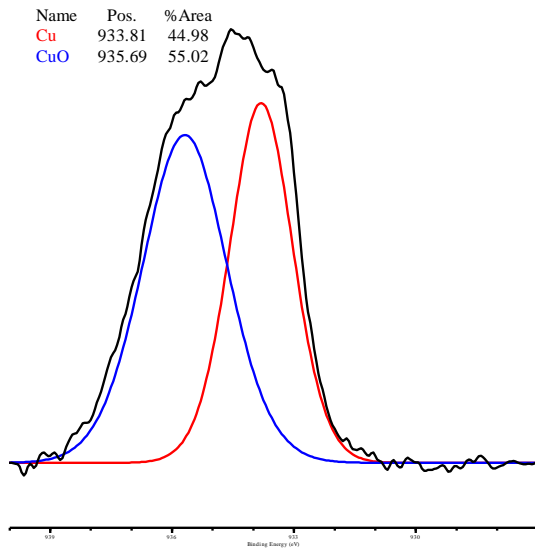
16 Breakdowns at the end of scan

Breakdown at the end of scan

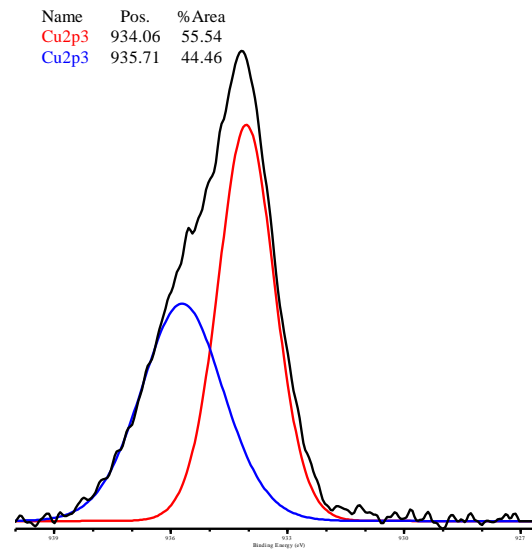


# Surface composition XPS results

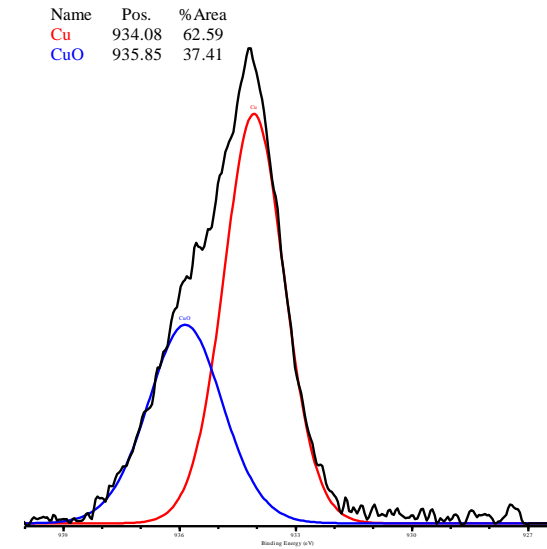
The contrast change is related to a change of oxidation state of the Cu surface atoms



REF



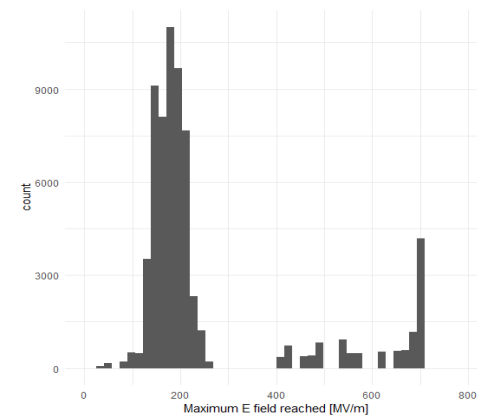
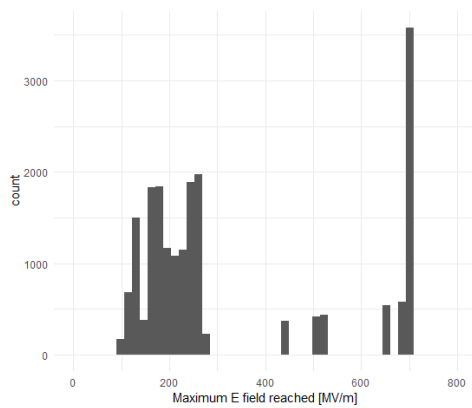
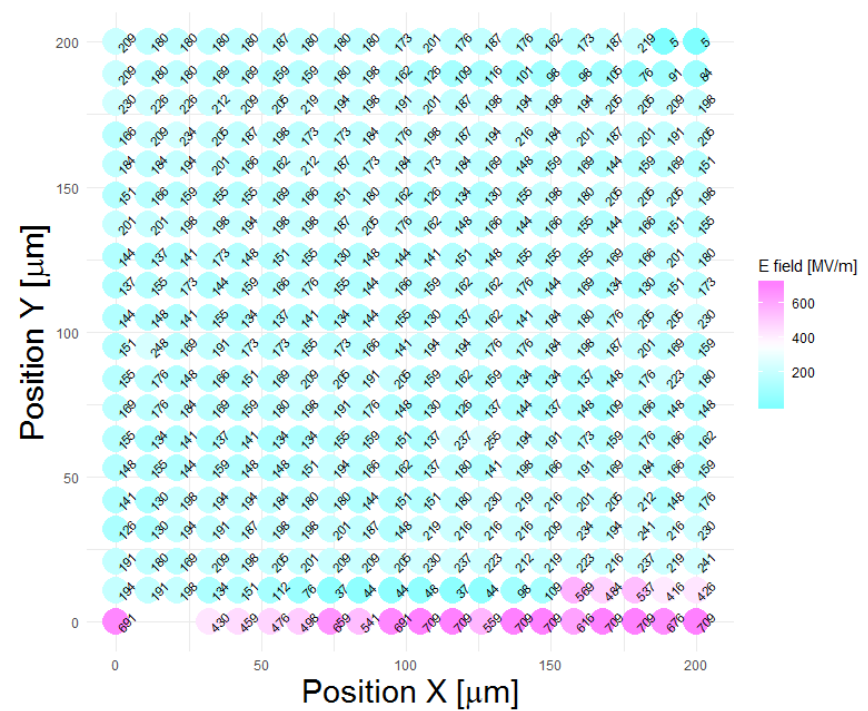
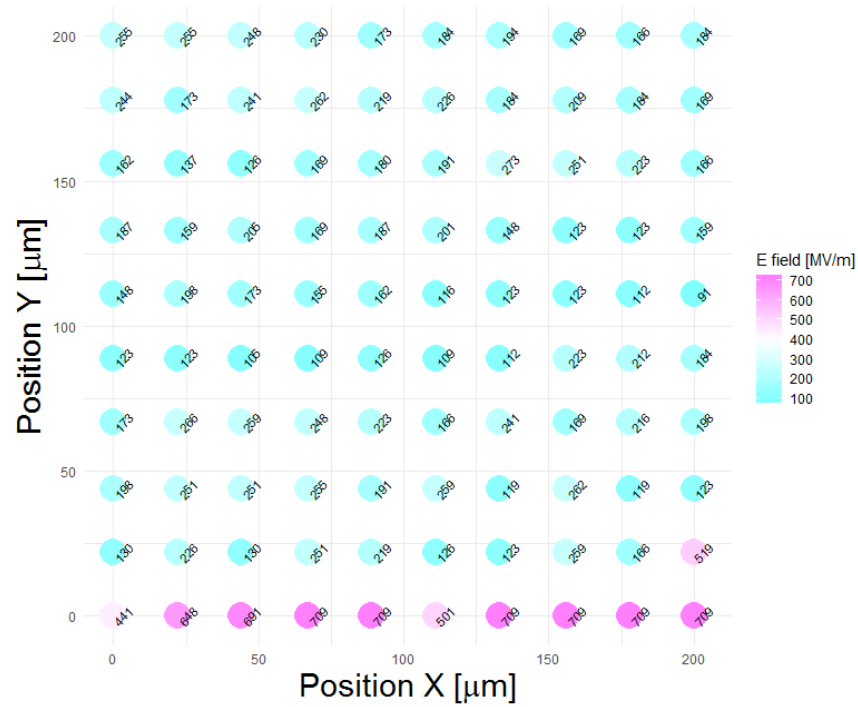
Area 1



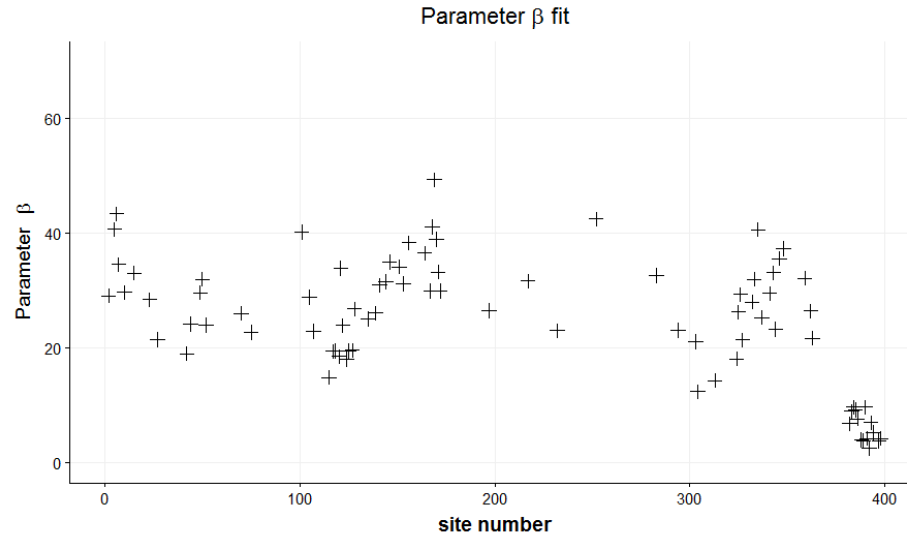
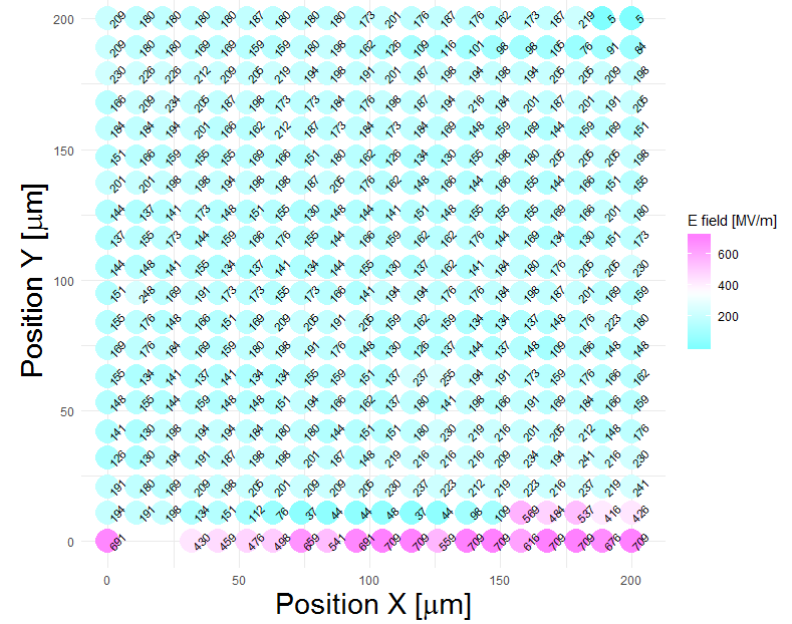
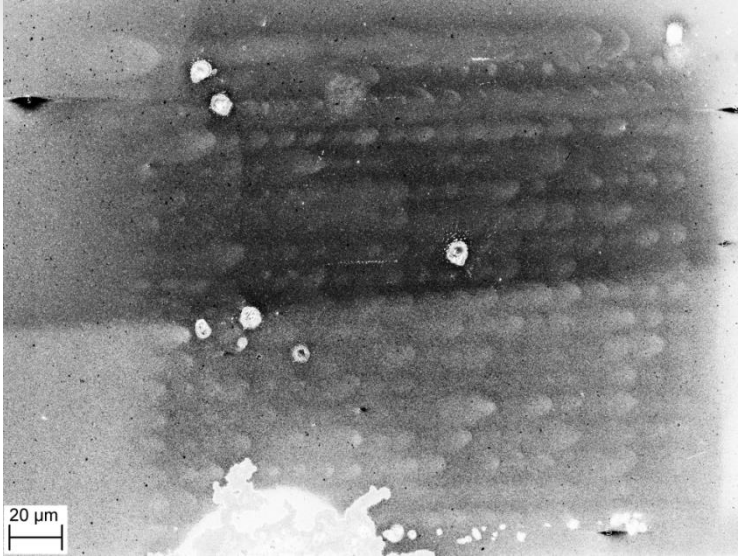
Area 2

Area	Pattern density	Cu [%]	CuO [%]	CuO thickness
Reference	0	44.98	55.01	1.13 nm
Area 1	10 x 10 FE points	55.54	44.46	0.82 nm
Area 2	20 x 20 FE points	62.59	37.41	0.65 nm

# Max field reached during FE scans

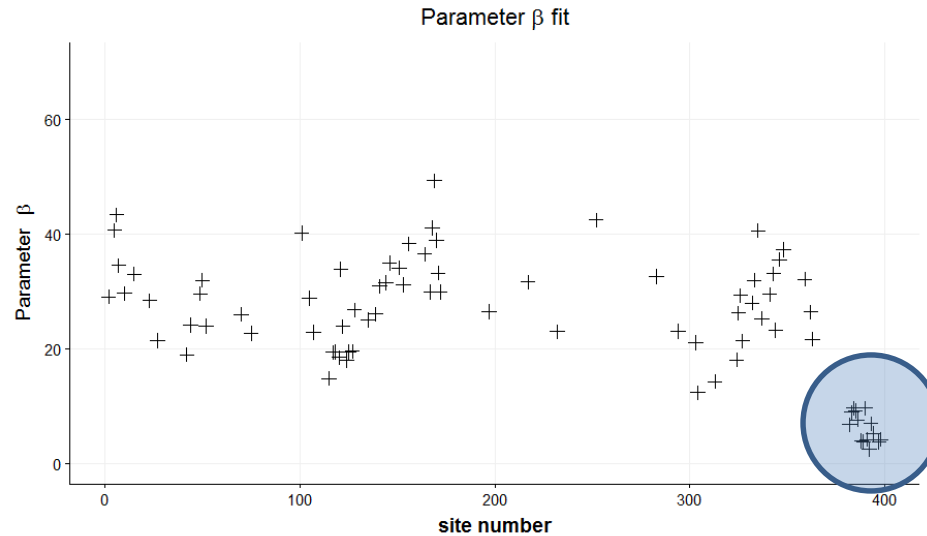
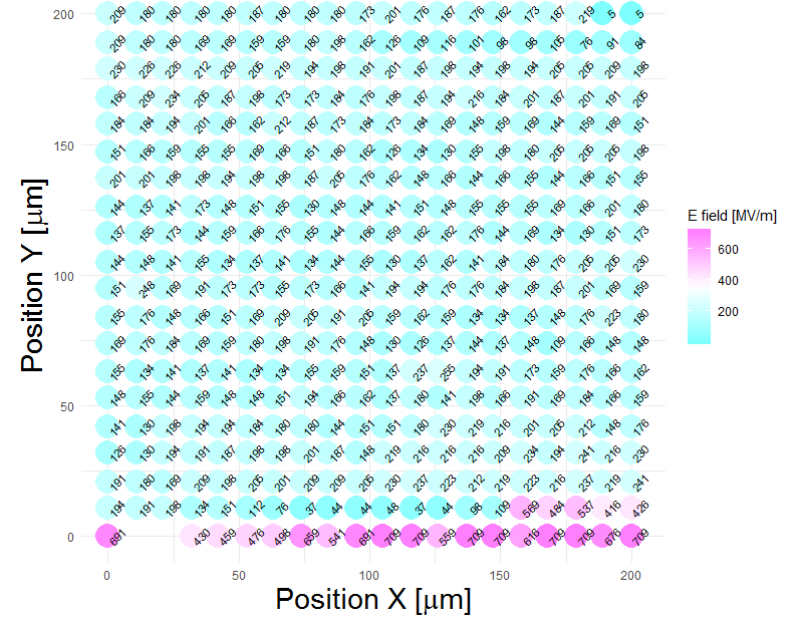
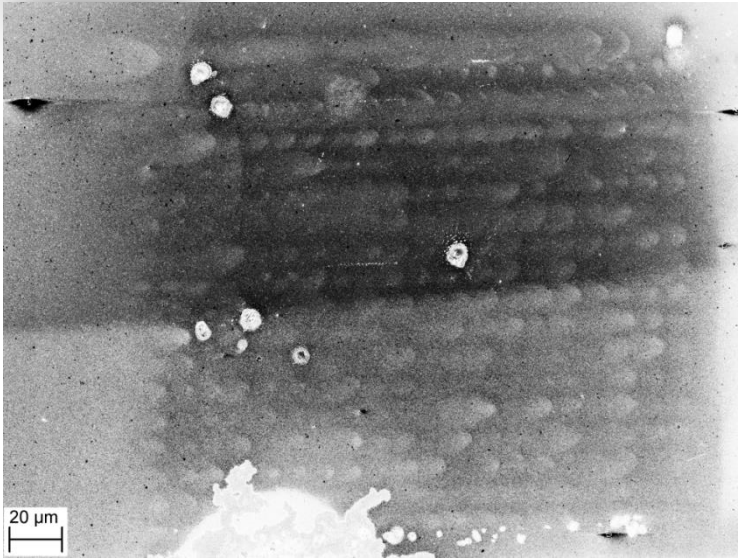


# Beta parameter during FE scans



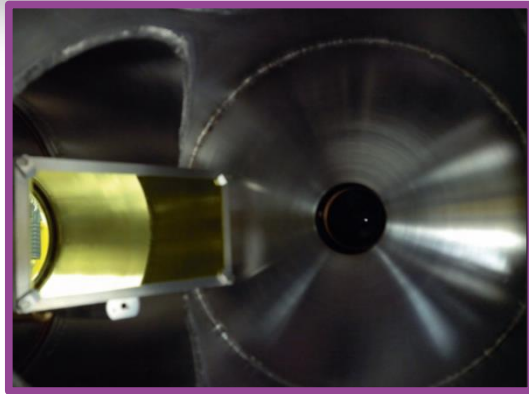


# Beta parameter during FE scans

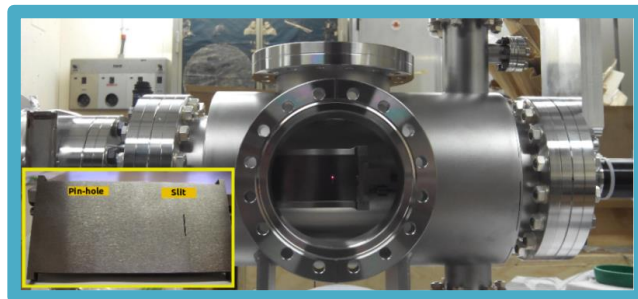
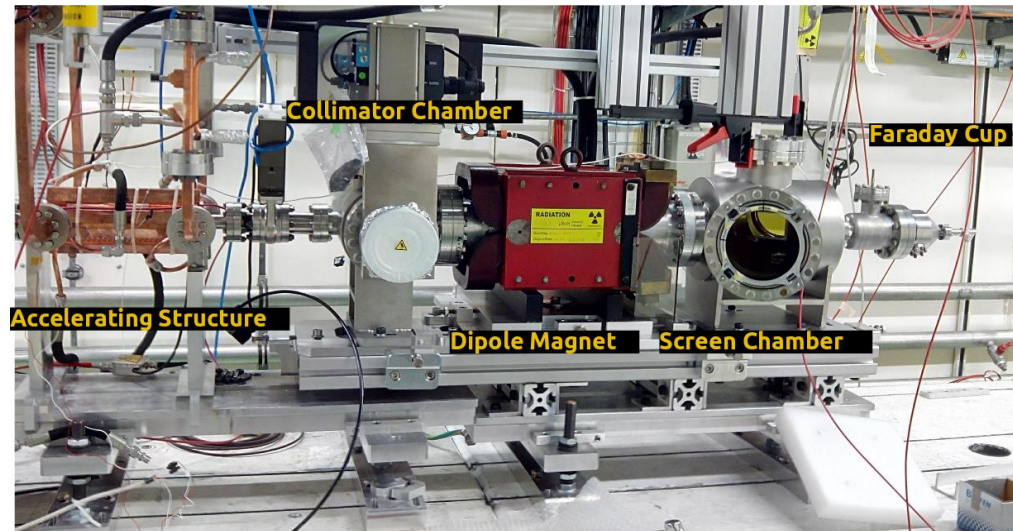
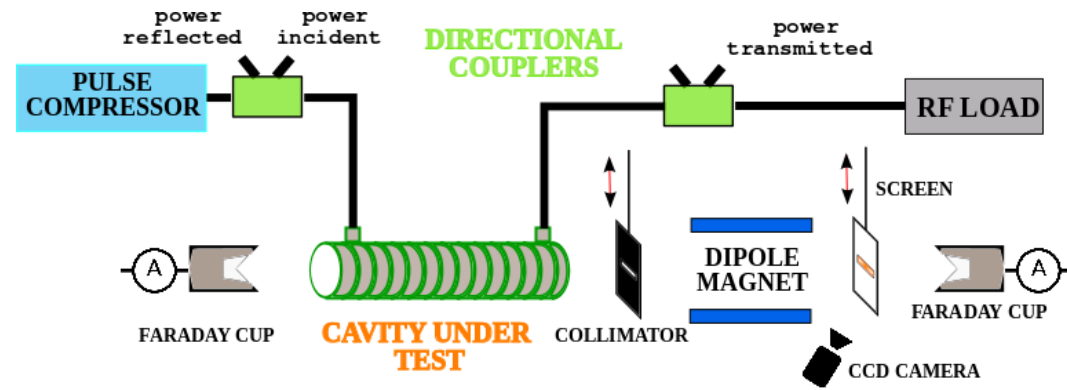


# Uppsala/CLIC X-band Spectrometer (UCXS)

## Currently at "XBox1" 12GHz 50 MW RF test stand @CERN



**Screen** (100x50x0.5 mm YAG:Ce)  
linear actuator (fully retractable)  
30 degrees angle w.r.t. the beam axis  
2M pixel, 50fps camera with focuser

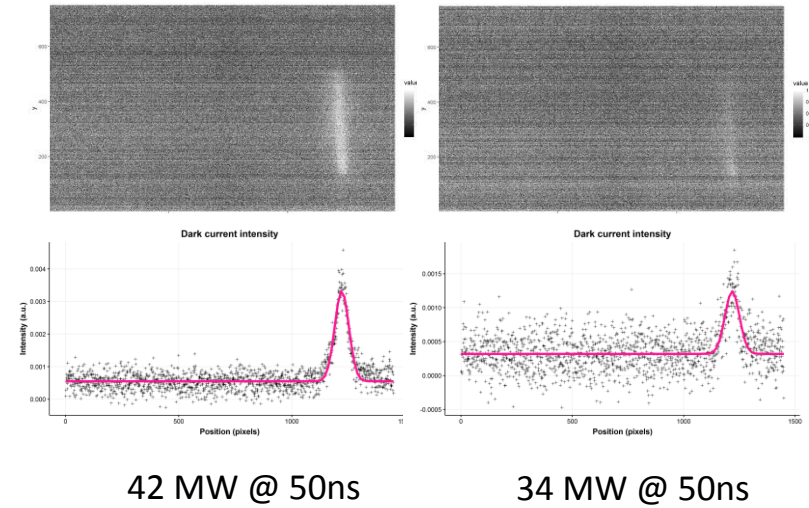


**Collimator** (5 mm tungsten plate)  
linear actuator (retractable), place for two patterns,  
presently: **pin-hole** 0.5mm and **slit** 10x0.5mm

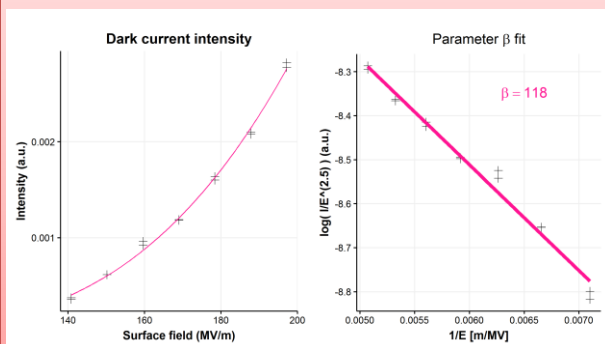
**Energy resolution with dipole magnet**  
Maximum expected electron energy ~20MeV  
Rel. energy spread (single slit) 10% - 25%  
Full energy coverage with magnetic field scan

# Recent dark current measurements after transfer to Xbox1

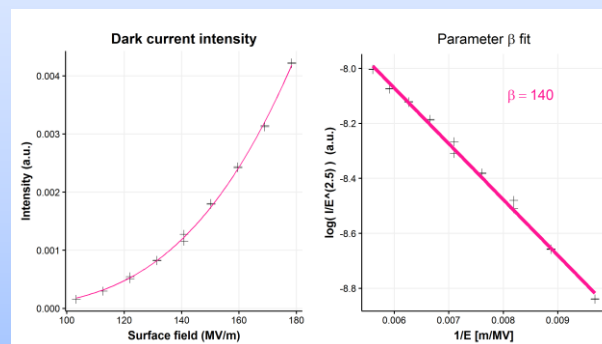
## Power scans at different pulse length



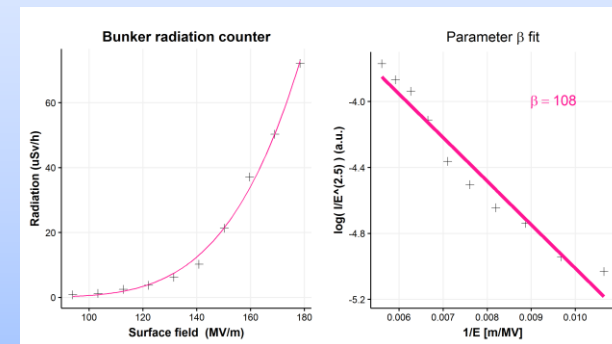
### 50 ns pulses



### 100 ns pulses

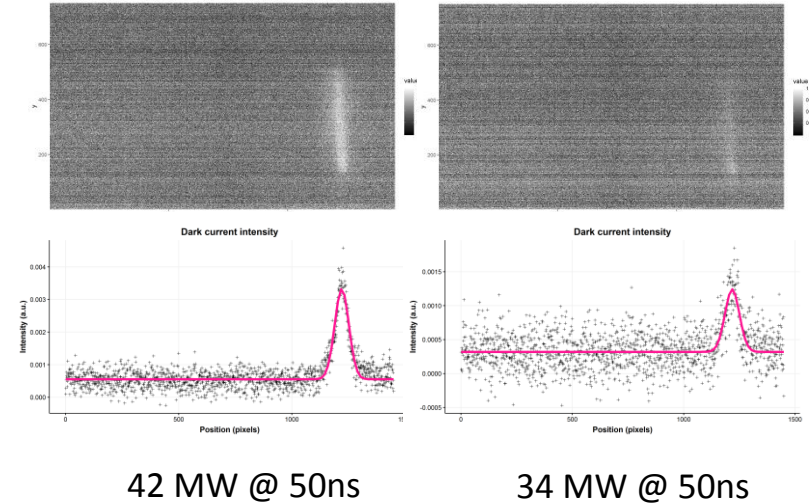
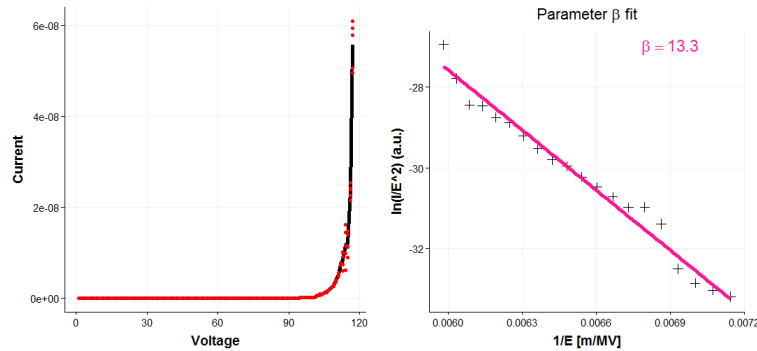


### 100 ns pulses



# Recent dark current measurements after transfer to Xbox1

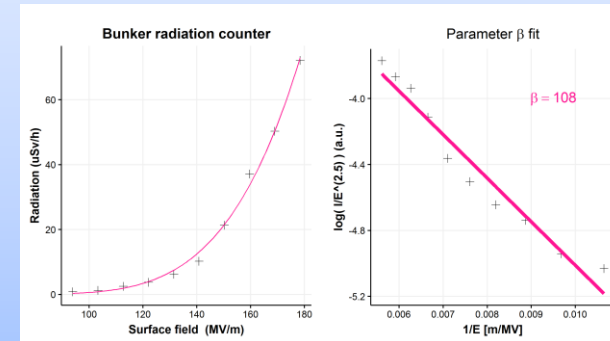
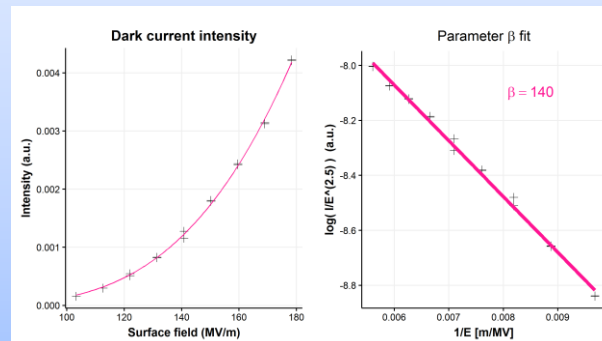
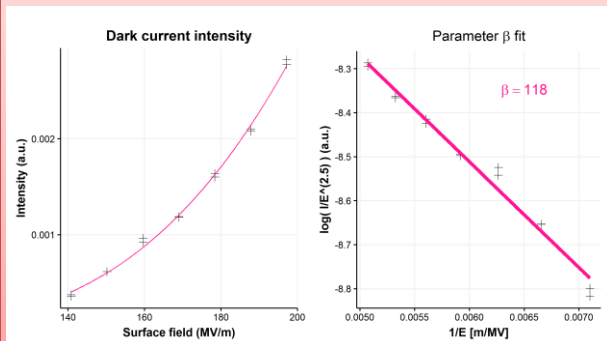
Effective beta parameter rather high comparing to measured during in-SEM experiments



50 ns pulses

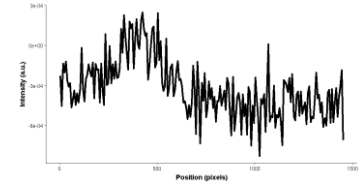
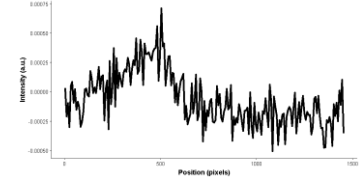
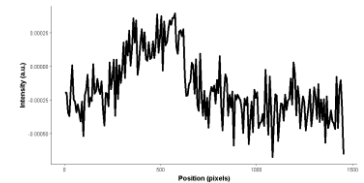
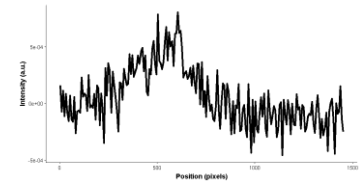
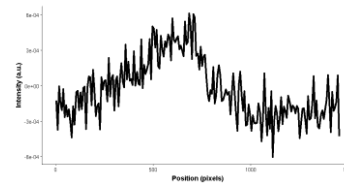
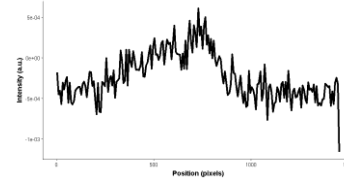
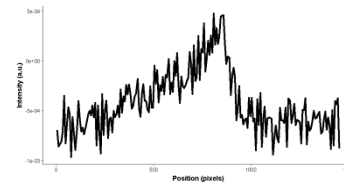
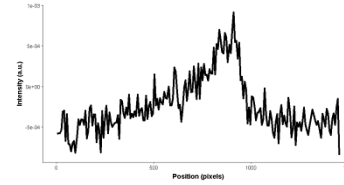
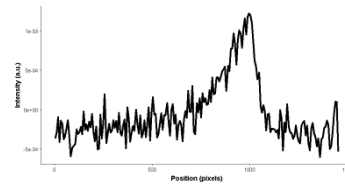
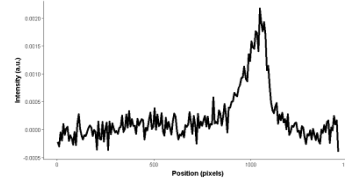
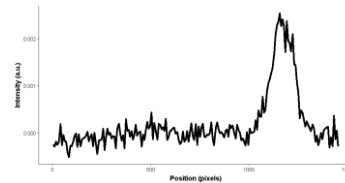
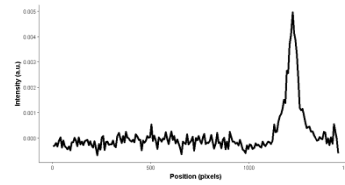
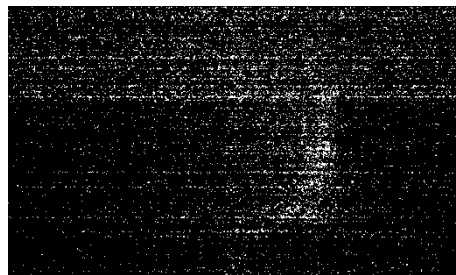
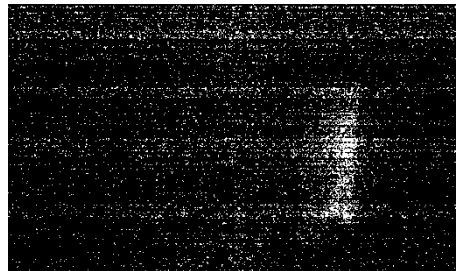
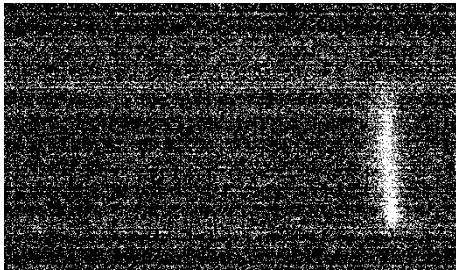
100 ns pulses

100 ns pulses



# Dark current measurements magnet scans

## Magnet scans at constant RF power example for 40 MW @ 50ns





# Dark current studies Simulations

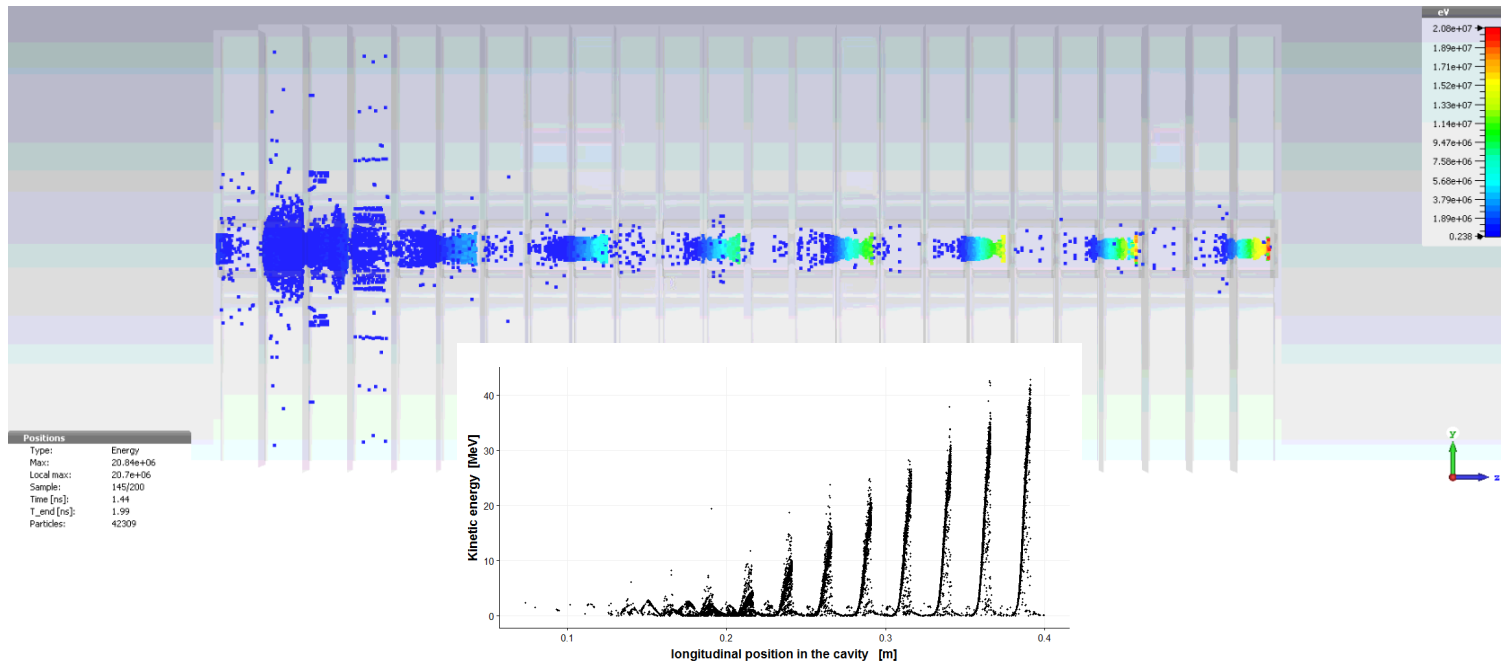
**Dark current simulations by Thomas G. Lucas (CST Studio 3D electromagnetic simulation)**  
**+**  
**Spectrometer simulation by Daniel Persson (GEANT4 Monte Carlo physics simulation suite)**  
**= dark current studies in XBox1 with the spectrometer**

Example questions to address:

Can we detect turn-on signature of single emitter?

Can we detect hot spots and their location?

What sensitivity do we need for this?



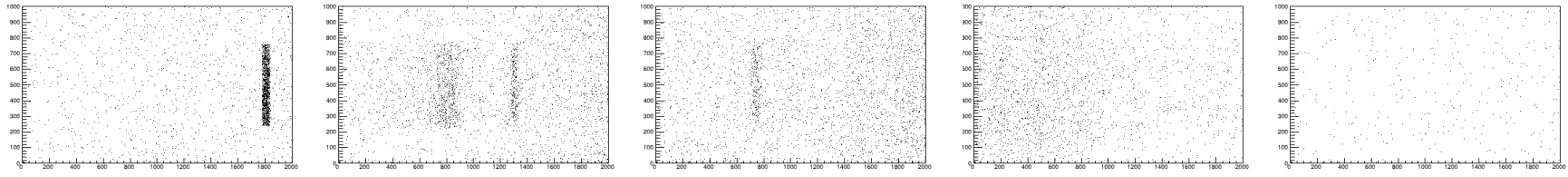
# Dark current studies

## Simulations

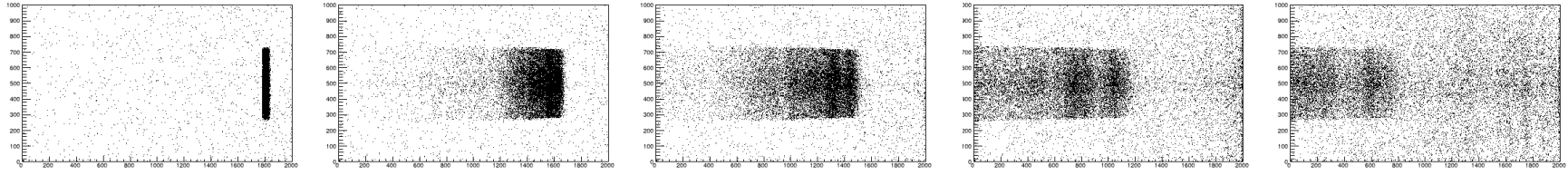
Example: Magnet scans

Initial electron position in the cavity vs distributions on the screen

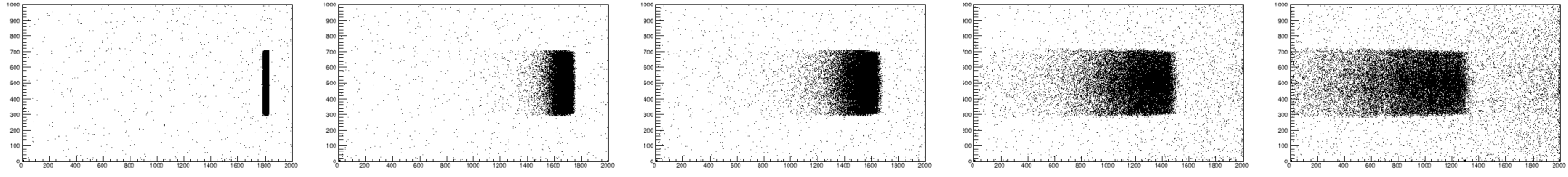
Beginning



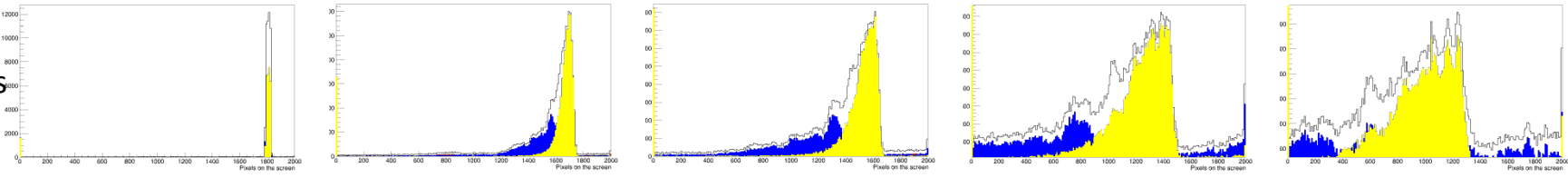
Middle



End



Projections



0T

2.5mT

5mT

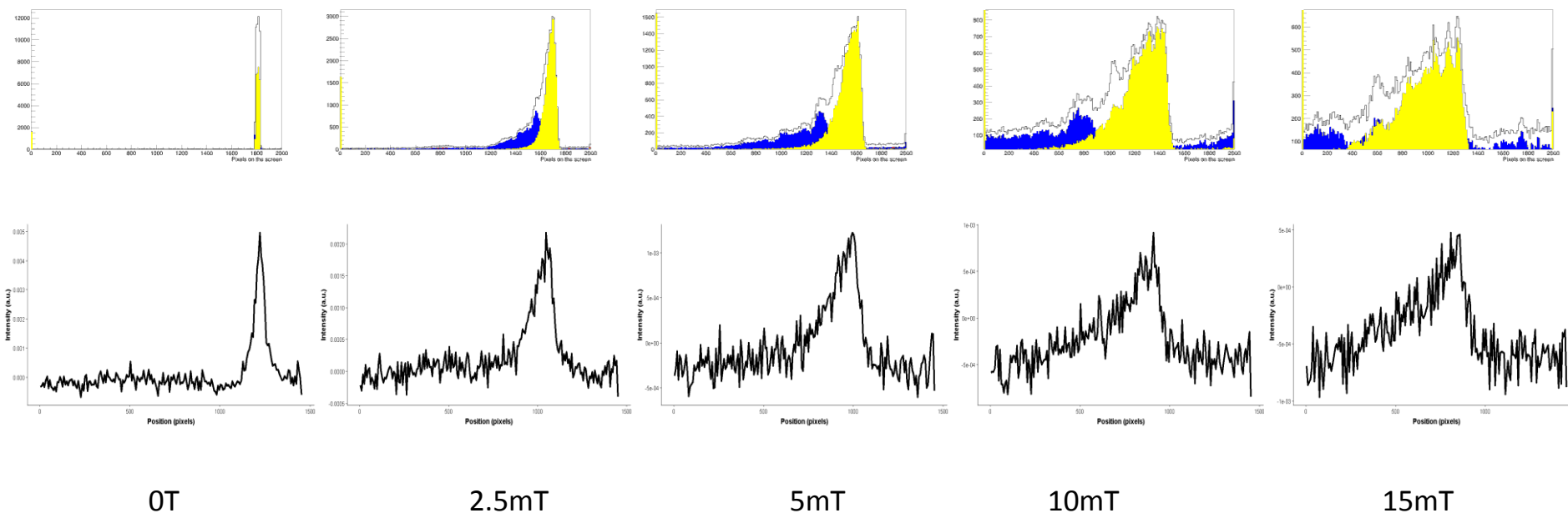
10mT

15mT

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## Simulations

Matching simulation with experimental data



# *Summary and outlook*

## **In-SEM setup**

- Correlate surface features to FE-scans
  - We see effect of the FE scans directly after, however spots disappear after days
  - No indication of other, long lasting, surface changes (like e.g. melting)
- Quantify surface changes with XPS
  - Requires large surface affected by our experiments
  - Relative concentration of CuO had decreased after FE
- Working on mechanism to explain the change in oxidation state of surface Cu

## **Xbox experiments status**

- Experiments with focus on dark current at Xbox1
  - Power scans
  - Magnet scans
  - Study dark current behavior (trends and before/after breakdowns)
- High effective beta parameter measured during power scans
- Xbox setup simulations: spectrometer simulation with RF simulation of CLIC cavity-ongoing
- Dark current changes with temperature
- Need to improve the setup with focus on dark current for further studies

Next :



Thank you for attention