PAUL SCHERRER INSTITUT

PSI

R. Ganter

Photocathodes for SwissFEL

16.06.2021

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Outline

- Photocathode substrate and coating
- QE Performance

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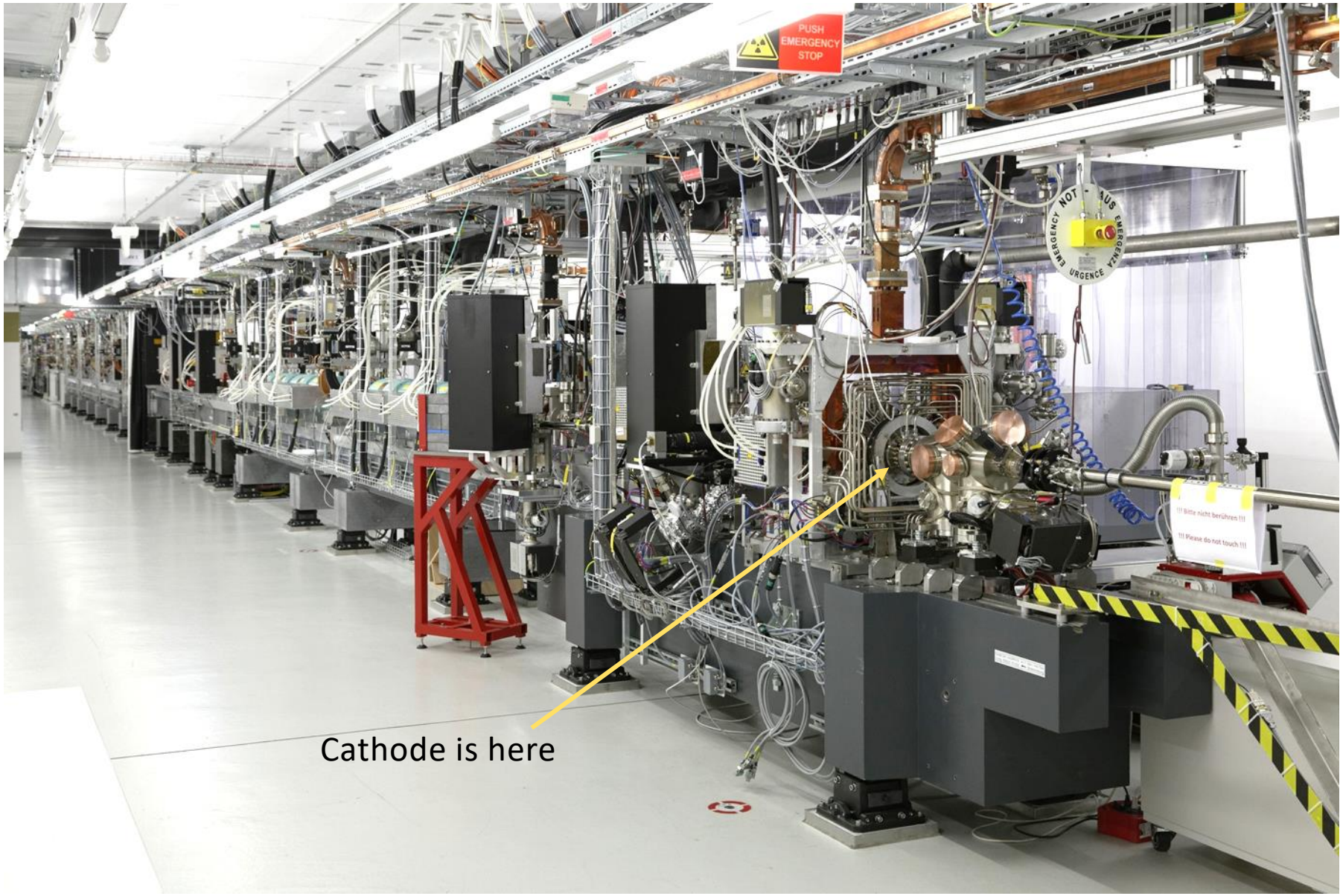
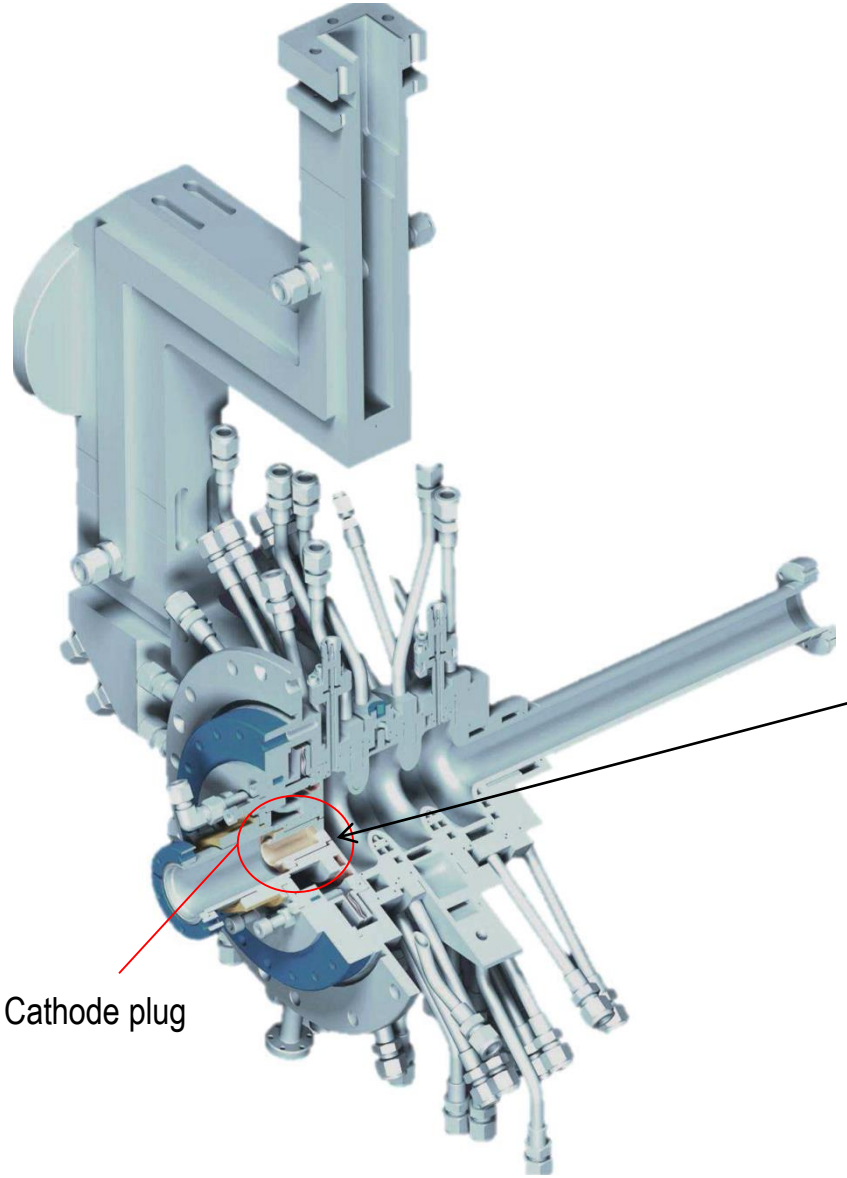
- QE Performance

SwissFEL Electron Gun and Loadlock



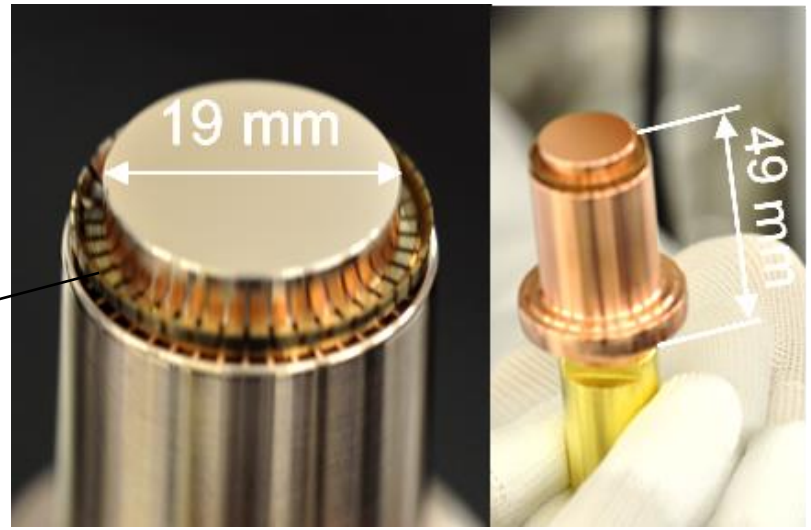
SwissFEL RF Photoinjector



SwissFEL RF Photoinjector:

S band, 2.5 Cell; 7 MeV;

100 MV/m; 100 Hz; 2*200 pC



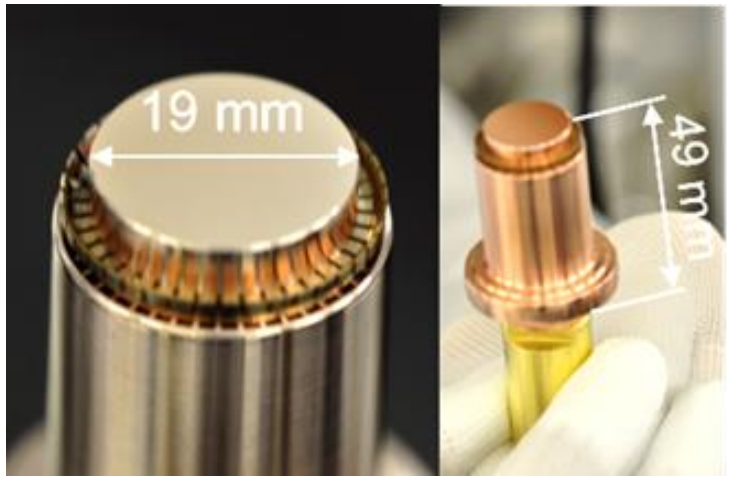
Exchangeable cathode plug(*)

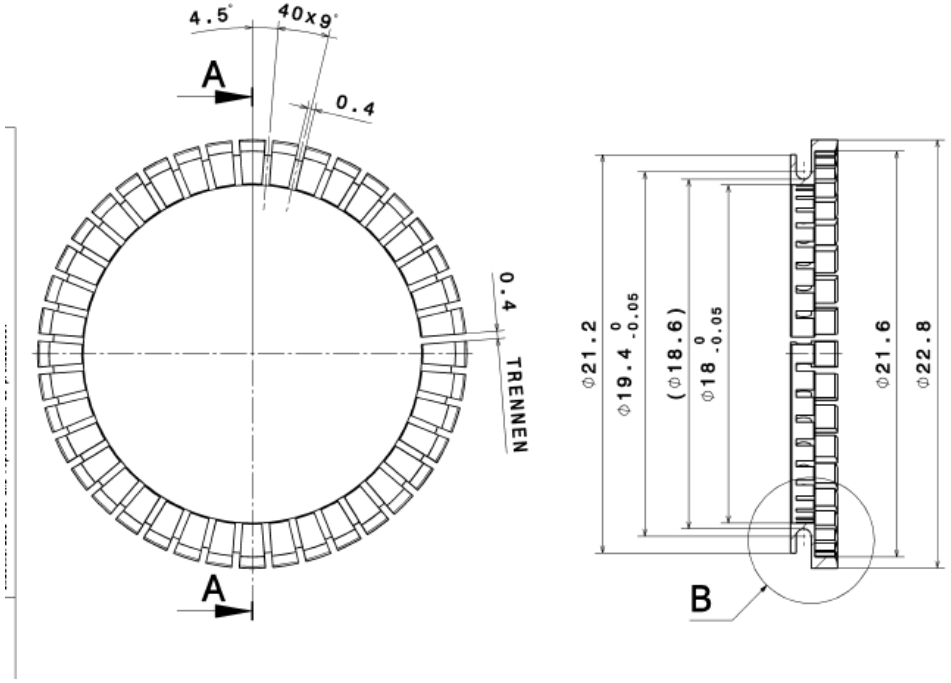
(*) CERN design: CLIC Note 303 (1996)

Photocathode Plug Material

SwissFEL Photocathode Material:

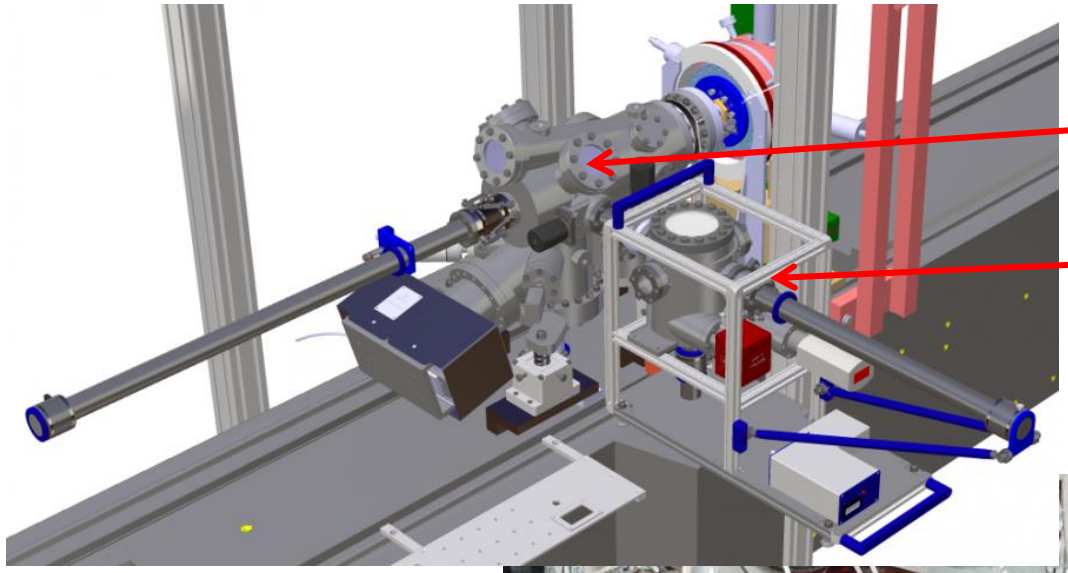
- **Copper OFE**:
  - 99.99 % purity (< 5 ppm O2);
  - 3D Forged (grain size < 90um)
- RF spring **$CuBe_2$** (tempered at 315° C for 3 hours)

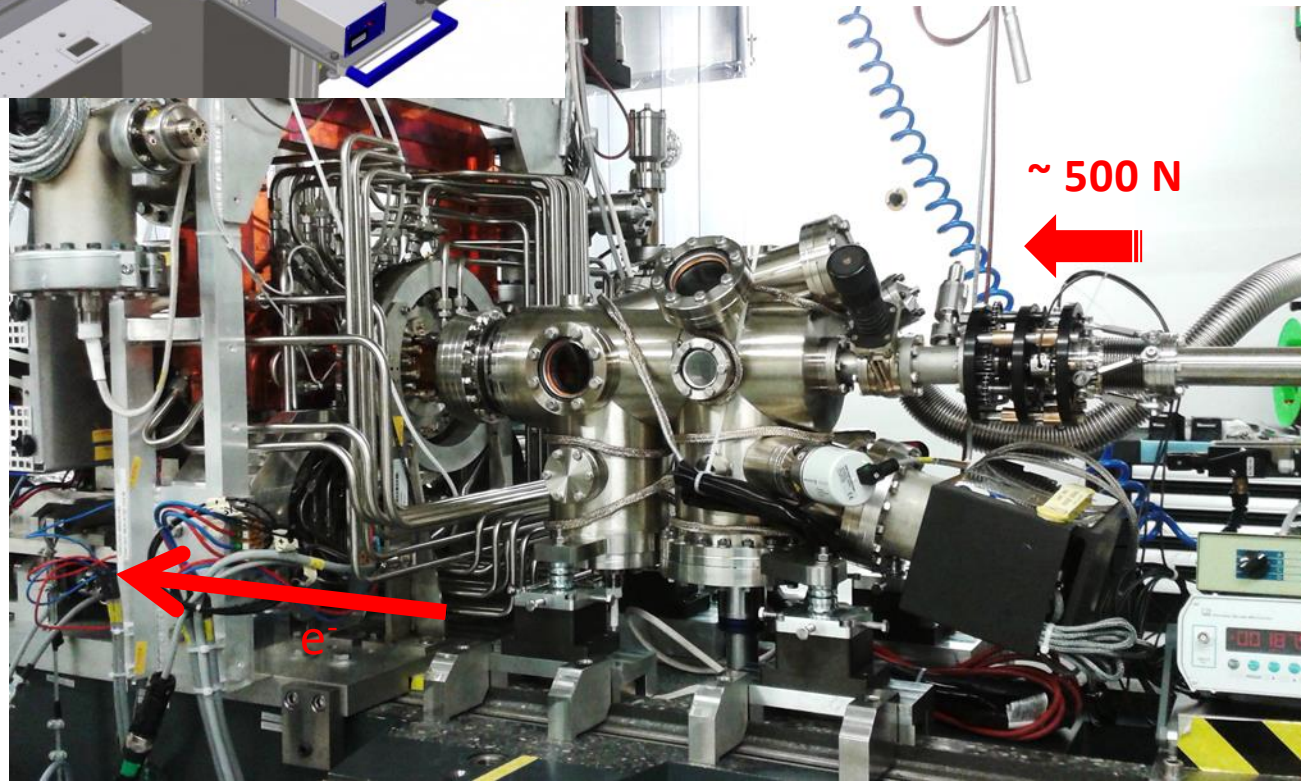




Gun Dark Current ~ 11 pC (100 MV/m)
(measurement courtesy of P. Craievich)

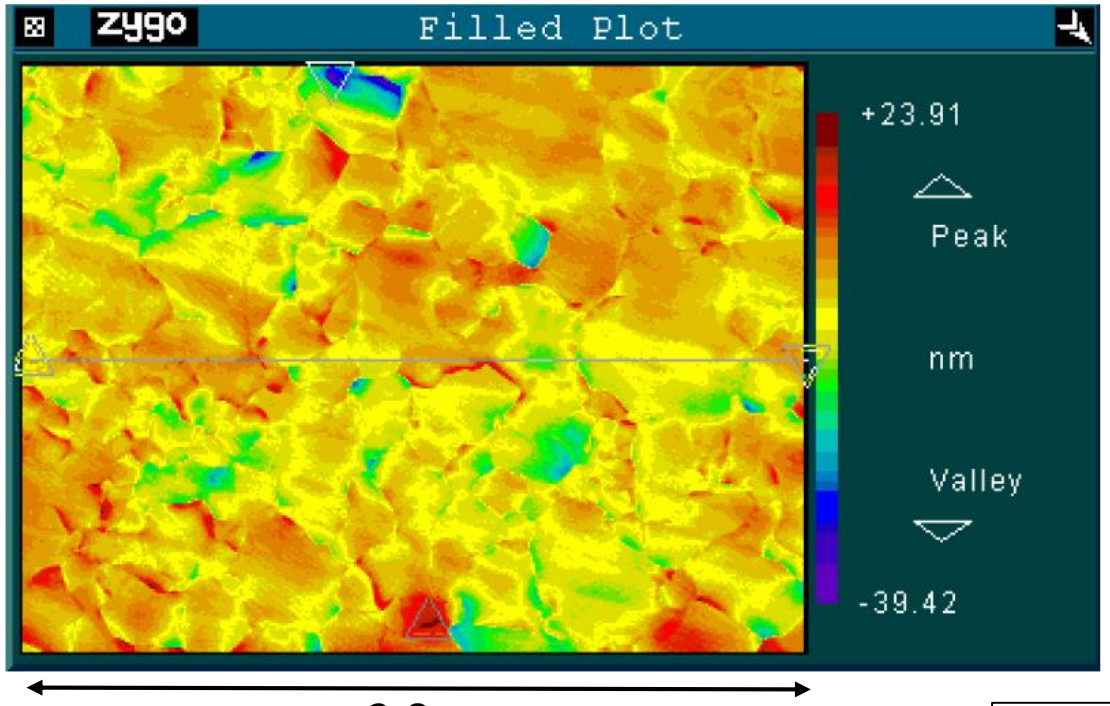
Loadlock chamber behind RF gun





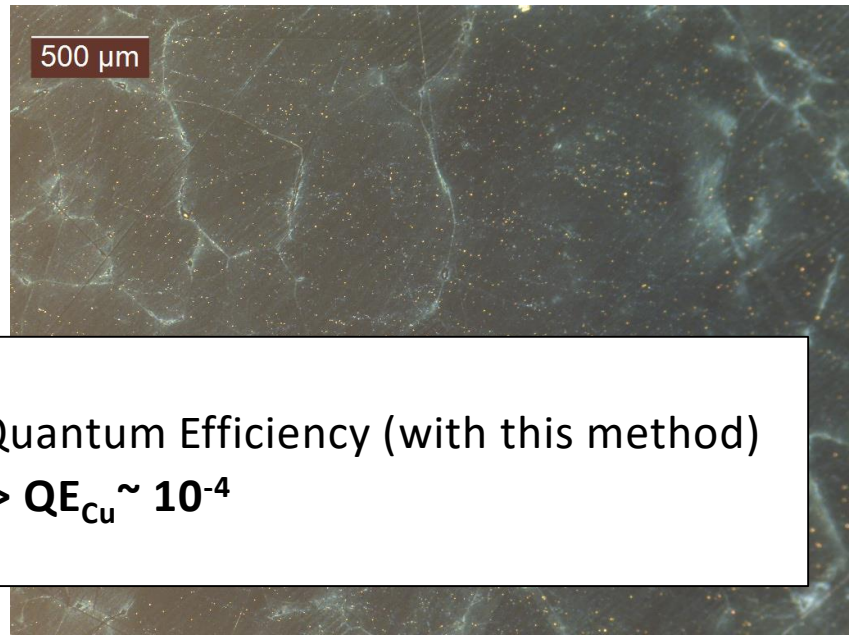
Photocathode surface preparation

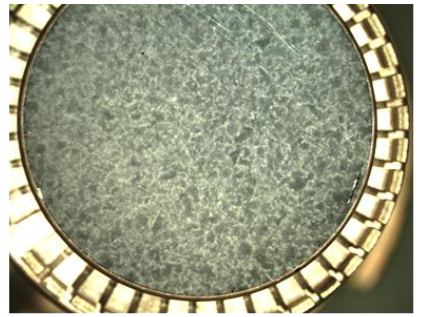
1. Surface Finish by Diamond turning (LT Ultra):
   R_a= 5 nm rms
2. Ultrasound cleaning to remove contaminants
   & Chemical etching to remove oxyde layer.
3. **Vacuum Anealing at 250° C** for 10 h to desorb water before coating.



2.8 mm

Grain Size: 300 um
Ra ~ 5 nm
Height Peak to Valley ~ 30 nm





Copper Quantum Efficiency (with this method)
=> QE_{Cu}~ 10^{-4}

Semiconductor Photocathode: Cs_2Te at SwissFEL

Copper substrate

Forged OFE copper (less inclusions, 10 ppm impurities)
Ultra precision diamond turning (Ra ~ 3 nm)

↓

Ultrasonic Cleaning

Soap > Water > Acetone > Alcohol

↓

Annealing

10 hours at 250 C
At 1e-9 mbar

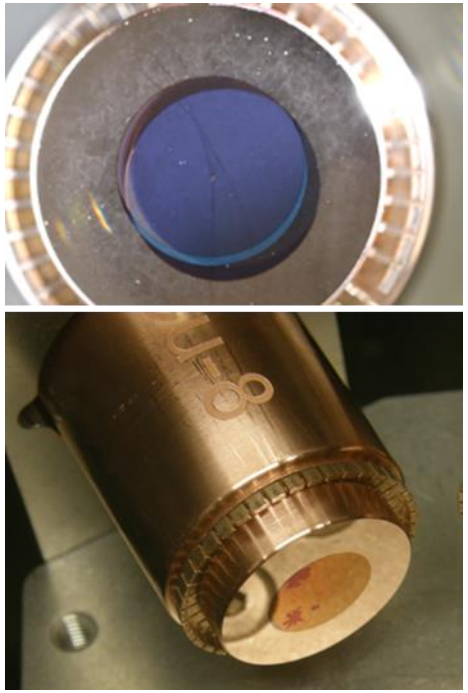
→ Cu Photocathode

$QE_{initial}$ ~ 10^{-4}

↓

Cs_2Te Deposition (*):

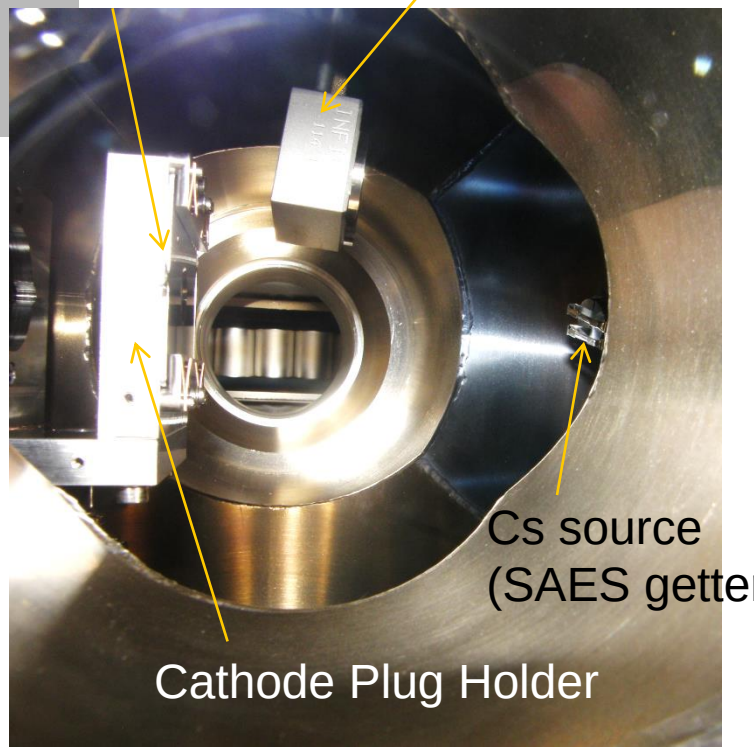
- Cathode plug heated to 110 deg C
- **Evaporation of 15 nm Te**
- **Evaporation of 25 nm Cs**
- pressure stays below 1e-8 mbar during evaporation
  - $QE_{initial}$ ~ 1 %

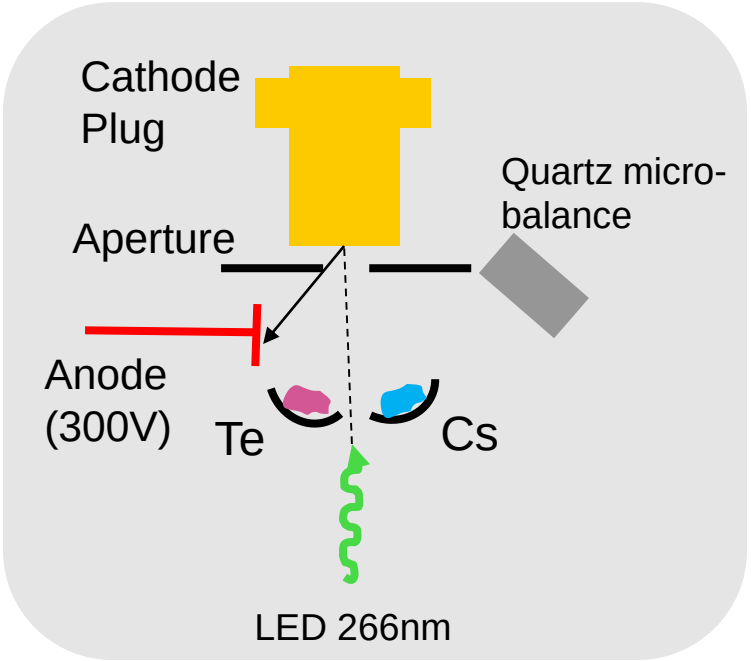


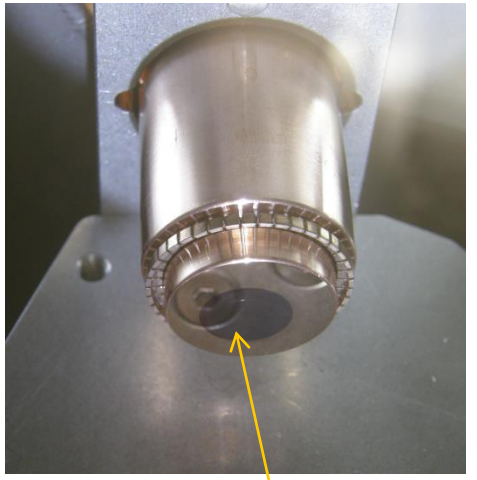
SwissFEL Photocathodes

(*) recipe from CERN: CERN - CLIC Note 299 – E. Chevallay

Cs_2Te Deposition





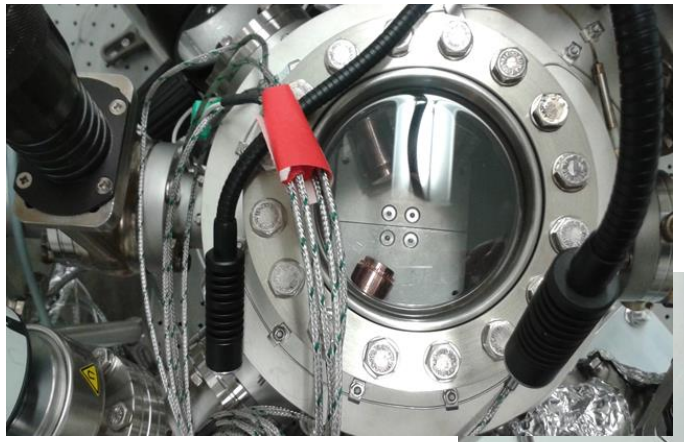


Cs_2Te layer (ø=1cm; 40 nm)

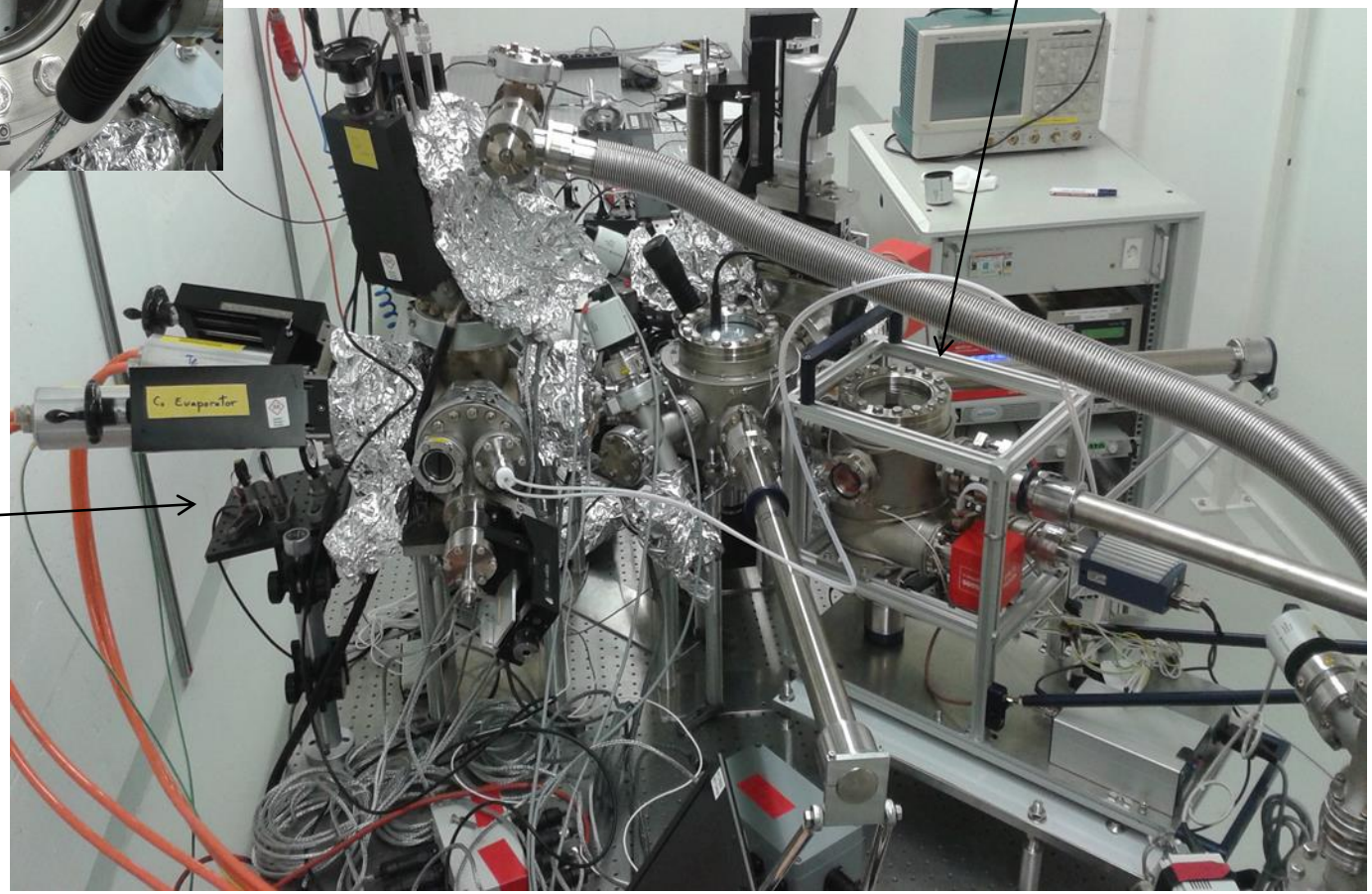
SAES alkali metal dispensers

- **successive deposition of Te and then Cs**
  (recipe from CERN: CERN - CLIC Note 299 – E. Chevallay)
- **Coevaporation of Cs and Te**

SwissFEL Cathode Preparation system

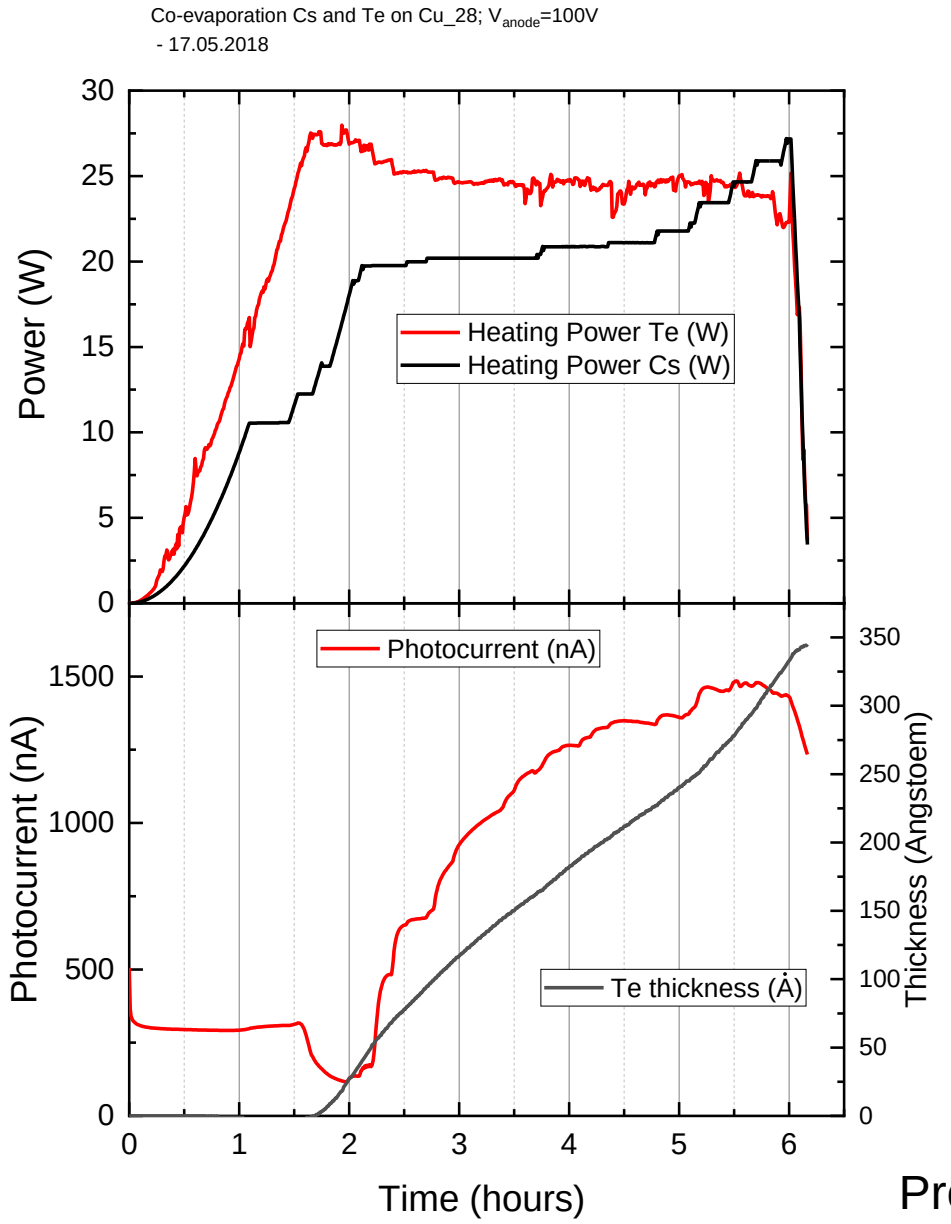


Vacuum Suitcase



266nm LED
for QE monitoring

Cs_2Te co-evaporation on Cu Plug

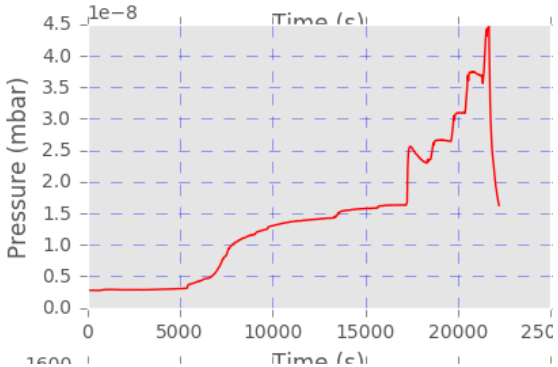


Recipe:

- Cu plug annealed 10 h at 250 deg C
- Co-evaporation while monitoring photocurrent

Difficulty:

- Control of stoichiometry
  (**Cs source heats Te source** !)
- No independent Cs thickness monitoring

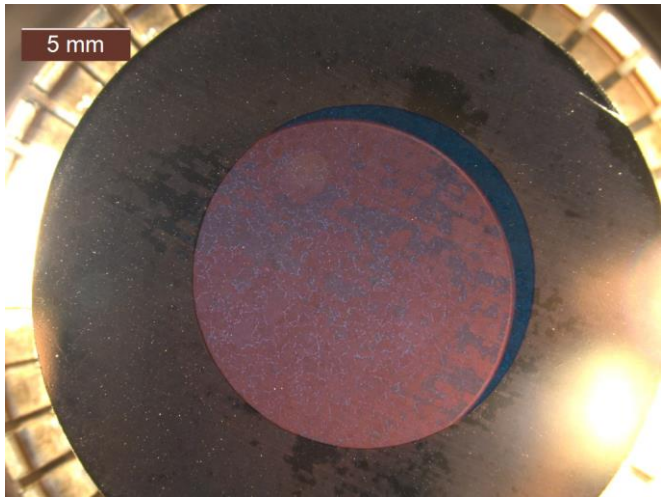


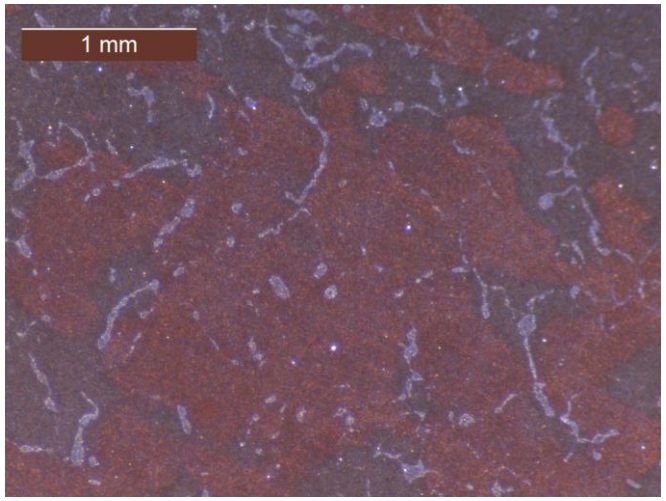
Pressure rises from 10^{-10} to 10^{-8} mbar

Outline

- Photocathode substrate and coating
- QE Performance

Example of Photocathode Cu_25 currently in SwissFEL





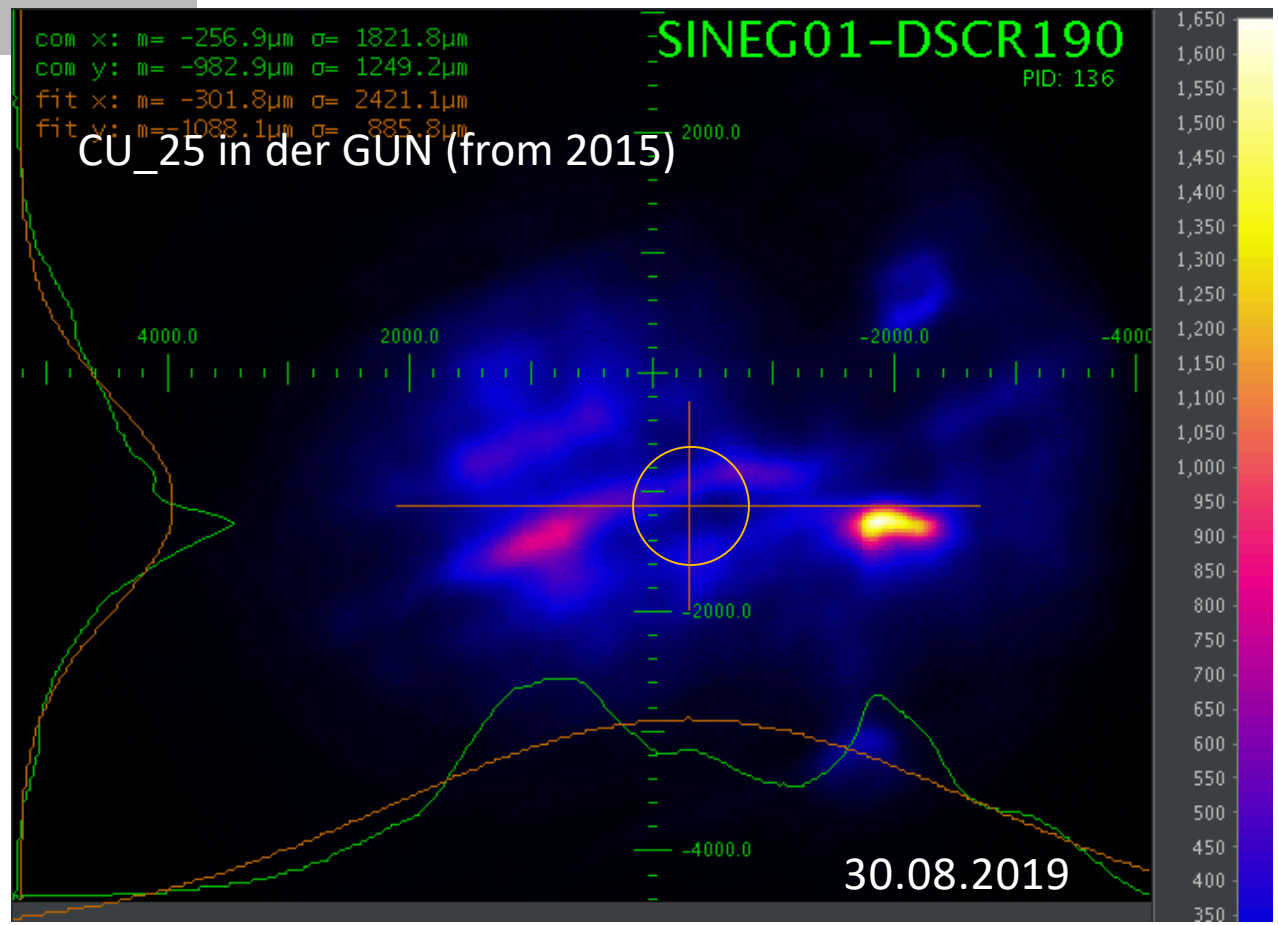
Copper surface **after** annealing (250 deg C – 10 H) and after coating (2015)

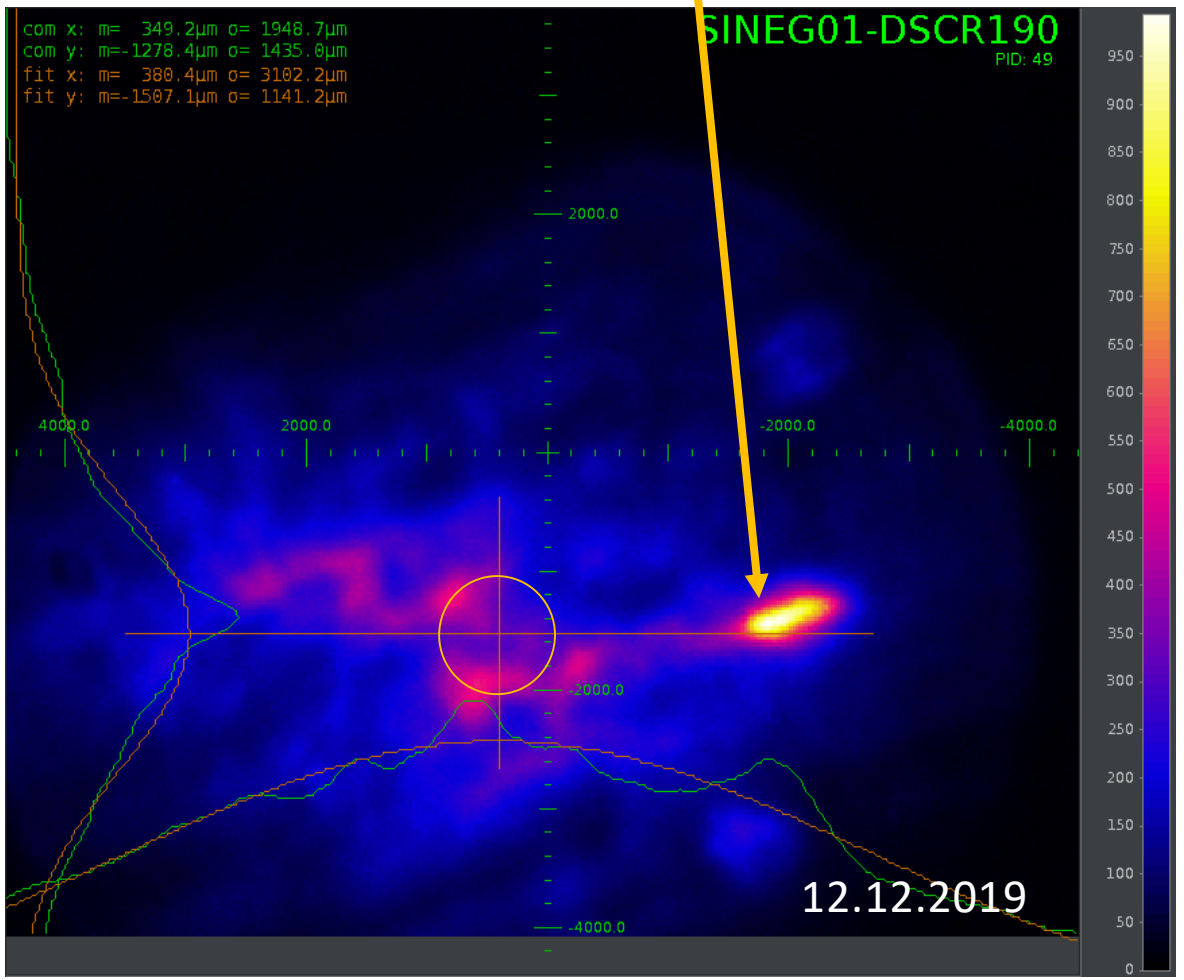
- Successive deposition (**September 2015**) :
  15 nm Te + 24.3 nm Cs
- QE in the laboratory: 3%

- Installation in the Gun: **August 2019**
- Initial QE in the Gun: 1%

Cathode imaging with the solenoid onto a YAG

Some structures and hot spot from cathode



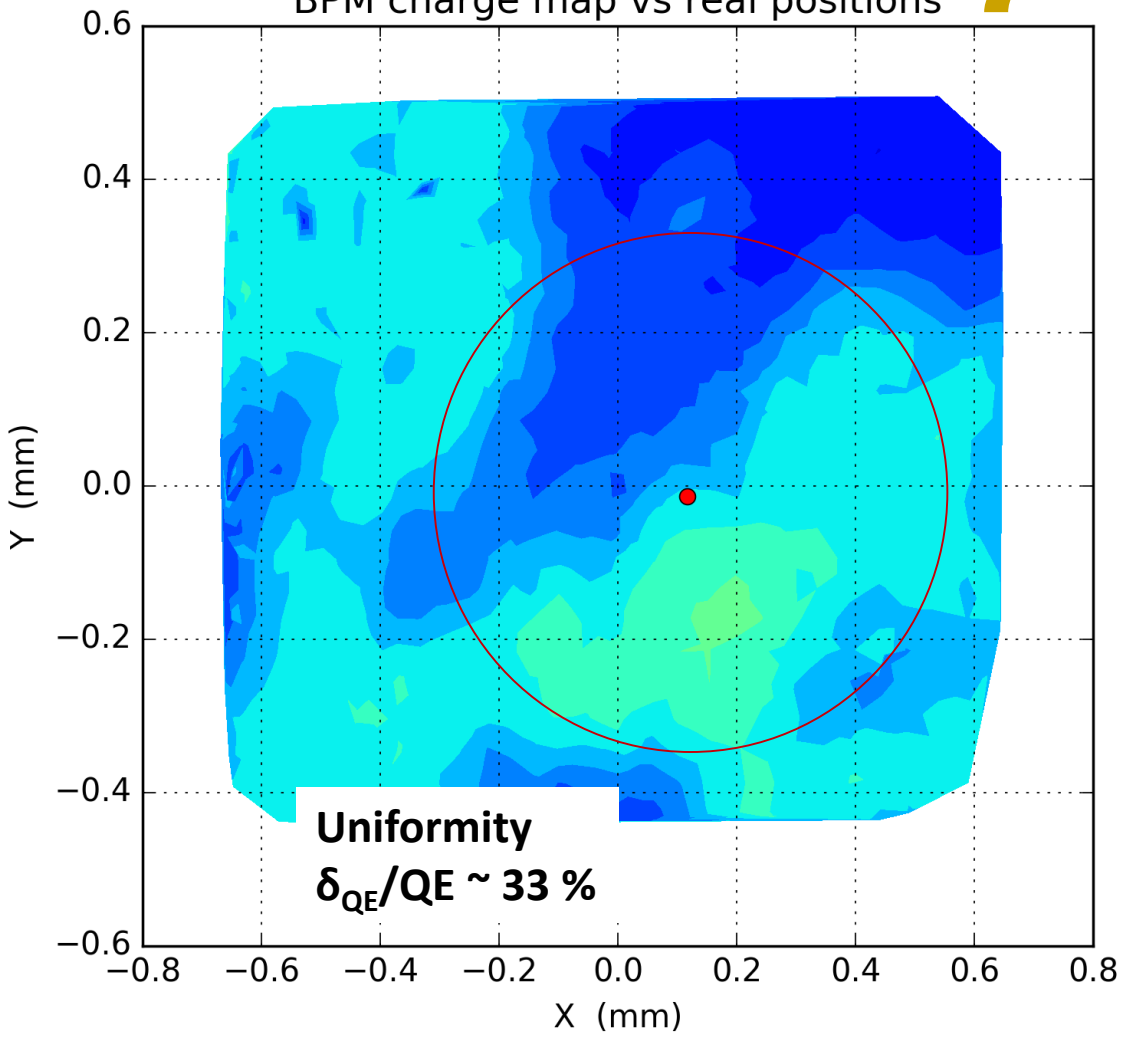


Convolution of laser non uniformities with QE non uniformities

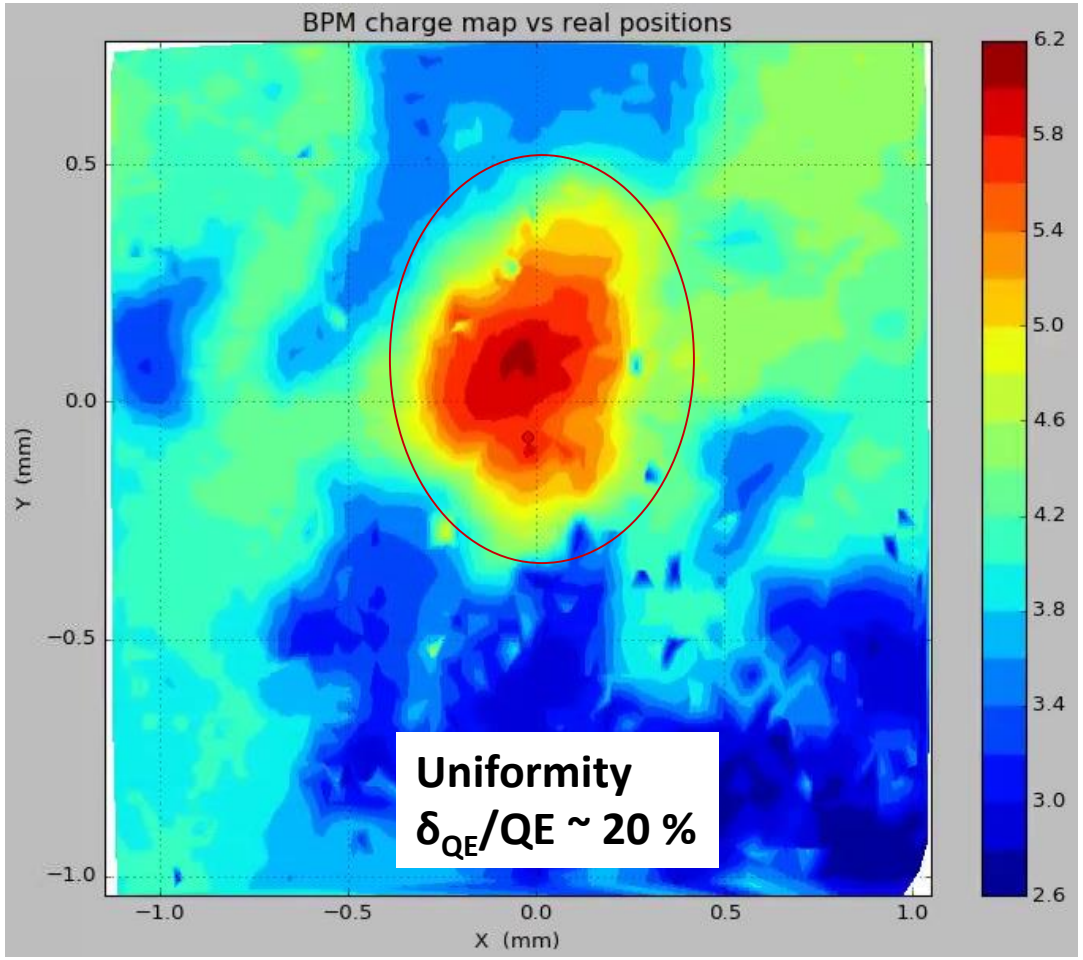
QE map Cu_25

QE map (10 um spot size)

After 15 months

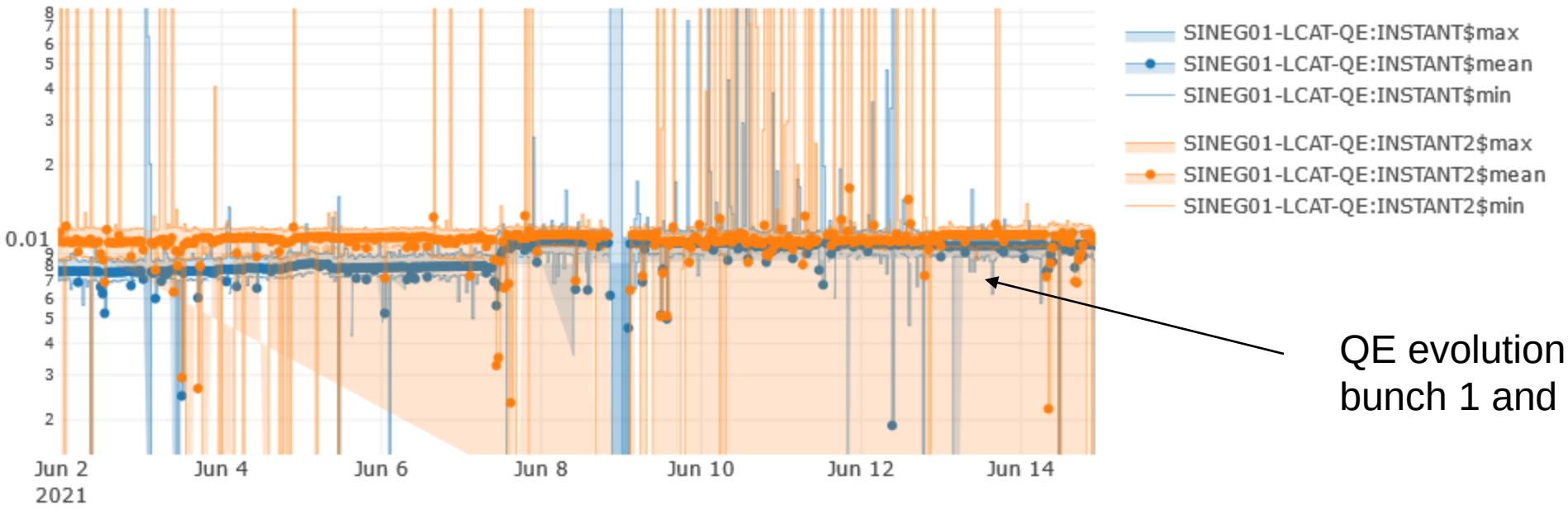


23.12.2019



21.02.2021

Cathode Cu_25: QE lifetime

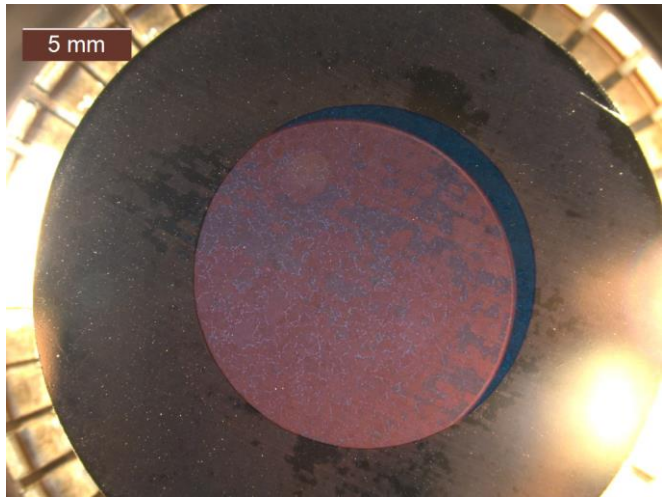


QE evolution last two weeks for bunch 1 and bunch 2 => **QE ~ 1%**

September 2019 to today :

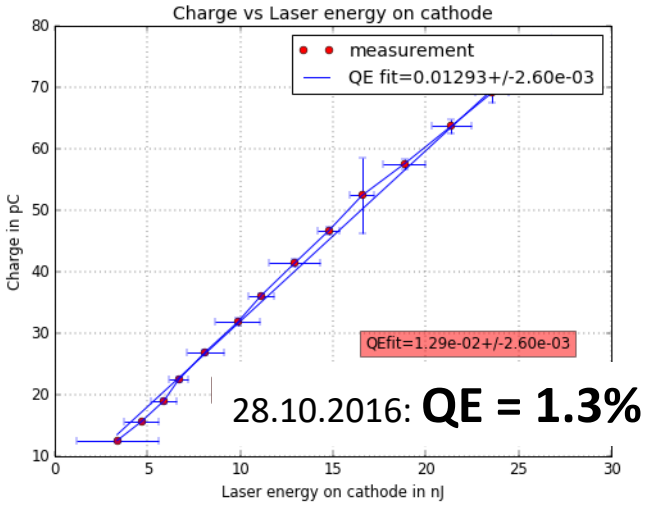
- QE varied between **0.7% and 1%**
- Laser pulse energy **~ 80 nJ /bunch**
- Laser spot size: 170 um rms
- P_{gun} =6.e-11 mbar

100 MV/m; 200 pC/bunch; 100 Hz

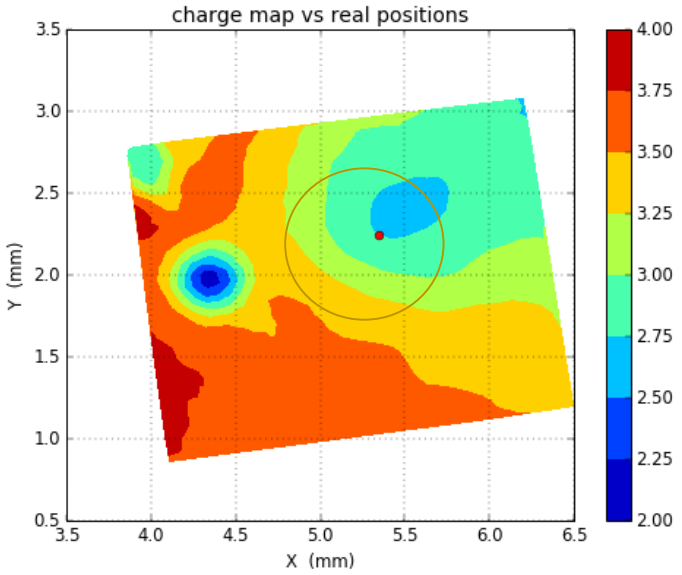


Example of a “not so good cathode” : Cu_32

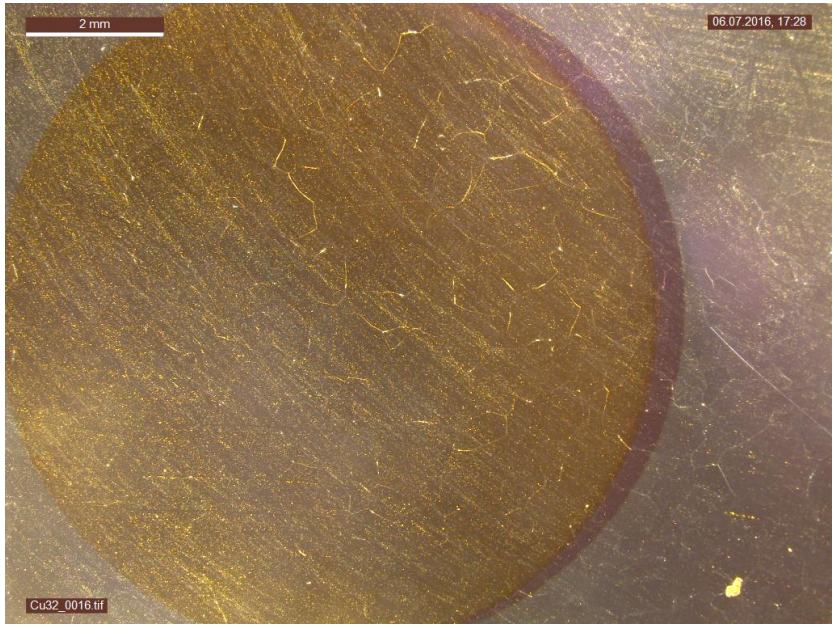
From October 2016 to July 2017: Cathode #32



28.10.2016: **QE = 1.3%**



04.07.2017:
QE ~ 1.3%
δ_{QE}/QE ~15 %

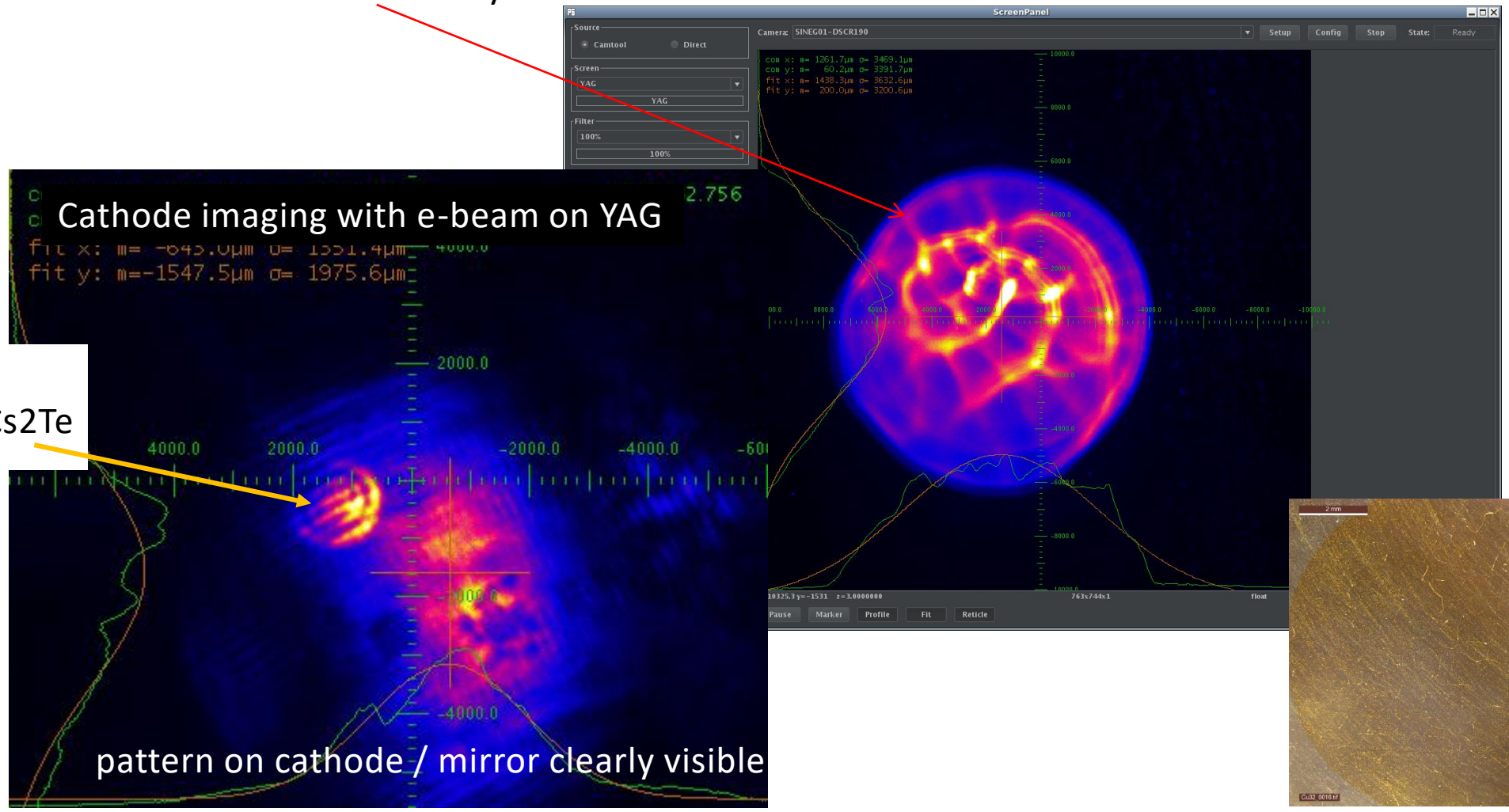


Cathode#32: Cs_2Te by co-evaporation ;
very thin layer < 20nm

No QE decay in 10 Months

Example of cathode Cu_32: Oct. 2016 – Jul. 2017

Electron Beam uniformity issues



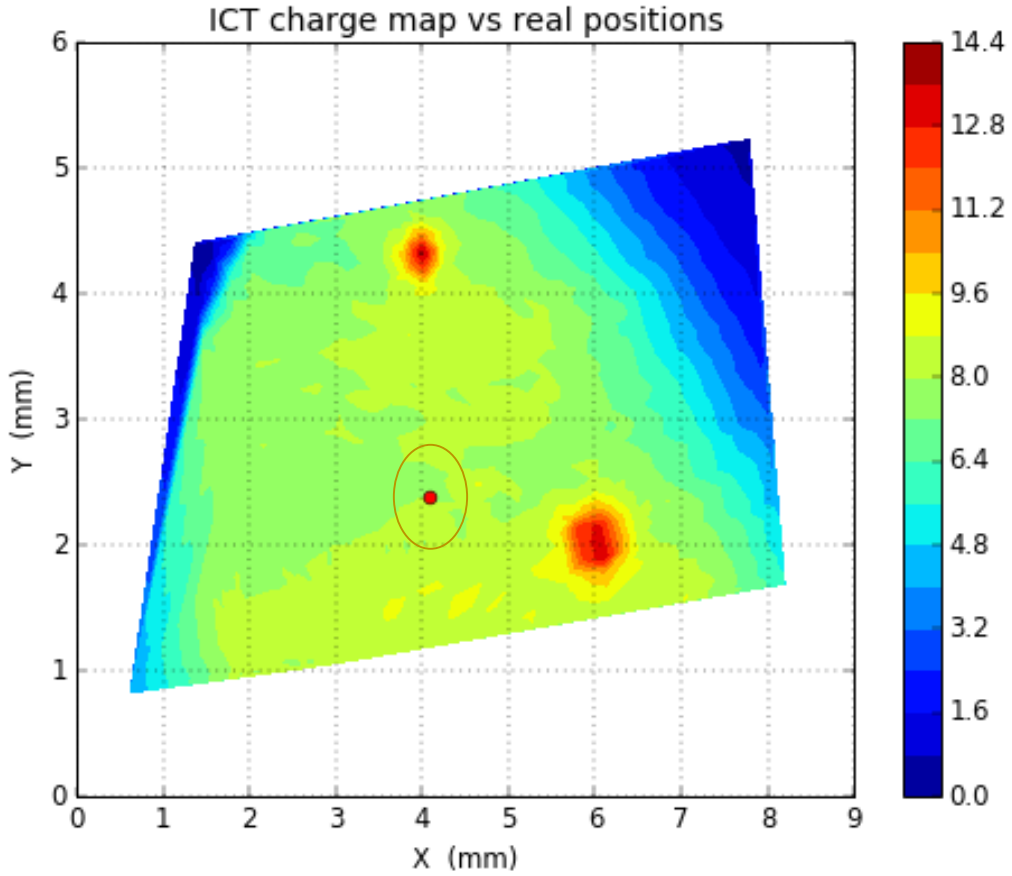
Laser pattern imprinted in Cs2Te

⇒ Exchanged cathode on July 21st 2017 (**after 10 months**)

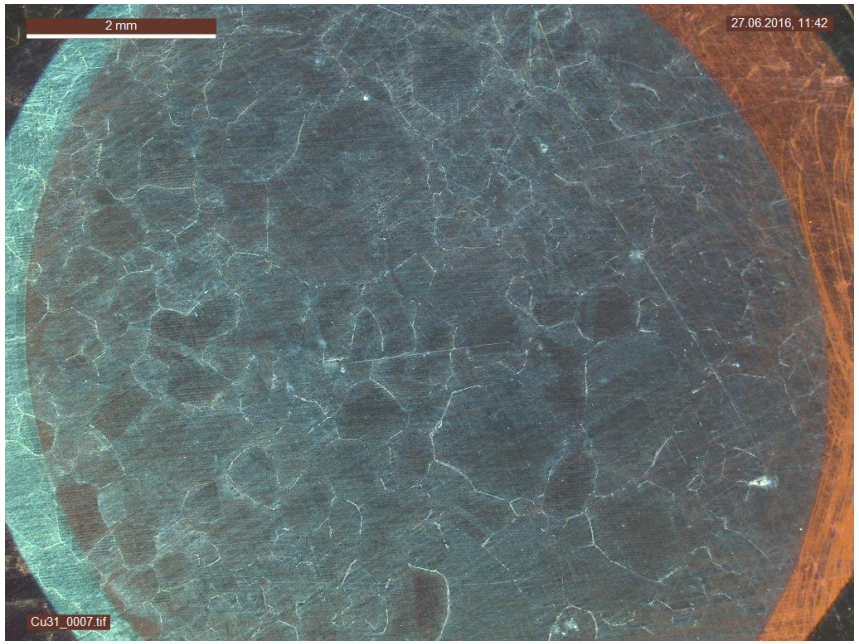
⇒ Cs_2Te detached at some area (dark spot visible by eye on cathode)

SwissFEL Cathode History 2016-2018

From July 2017 to August 2019: Cathode #31



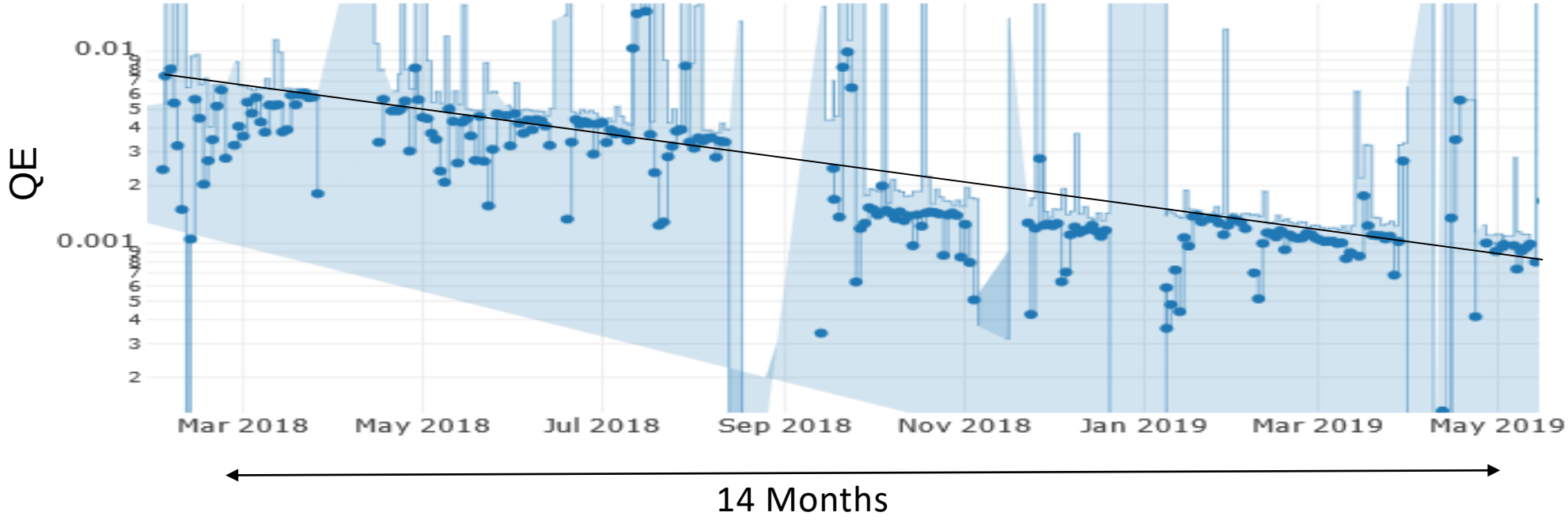
24.07.2017:



Cathode#31: Cs_2Te by successive evaporation ; **~ 40nm**

Averaged QE after installation: QE ~ 0.6 %

QE lifetime in SwissFEL Gun Cu_31



- Averaged QE dropped by factor 10 after 14 Months (~ 35 mC charge)
- Lifetime until QE~0.1% > 2 years

Cathode #31 (Cs_2Te): July 17 – August 19

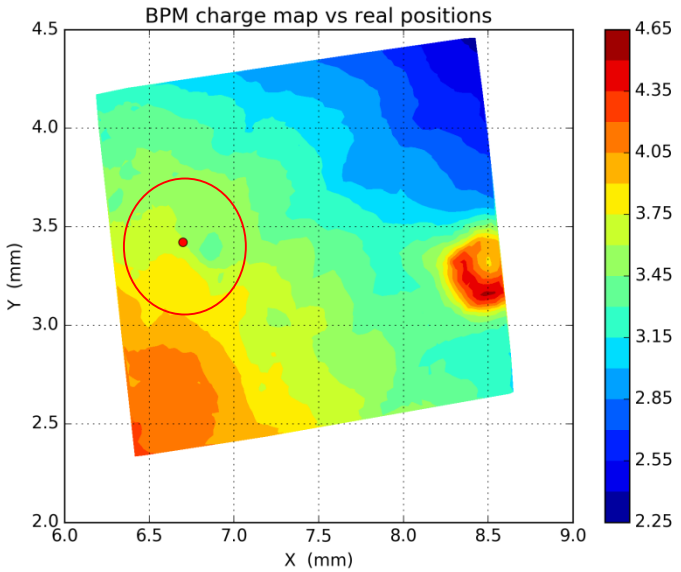
10 Hz; 200 pC

100 MV/m

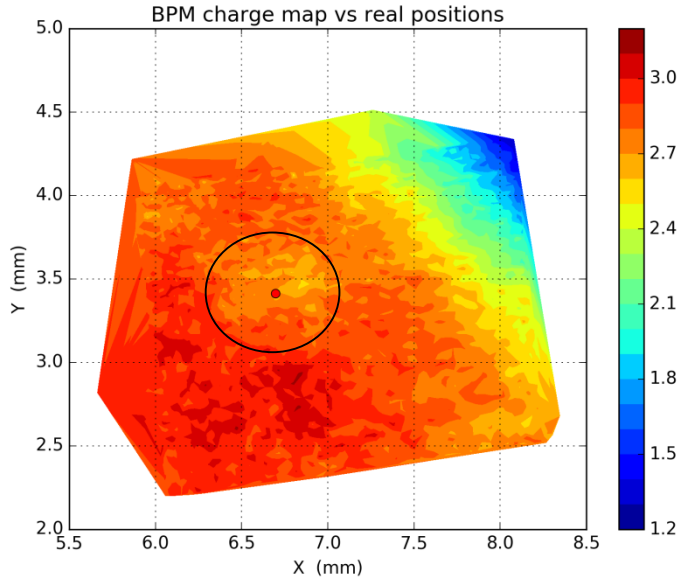
$P_{cathode} < 1.10^{-9}$ mbar

(1.1e-11 mbar at the pump)

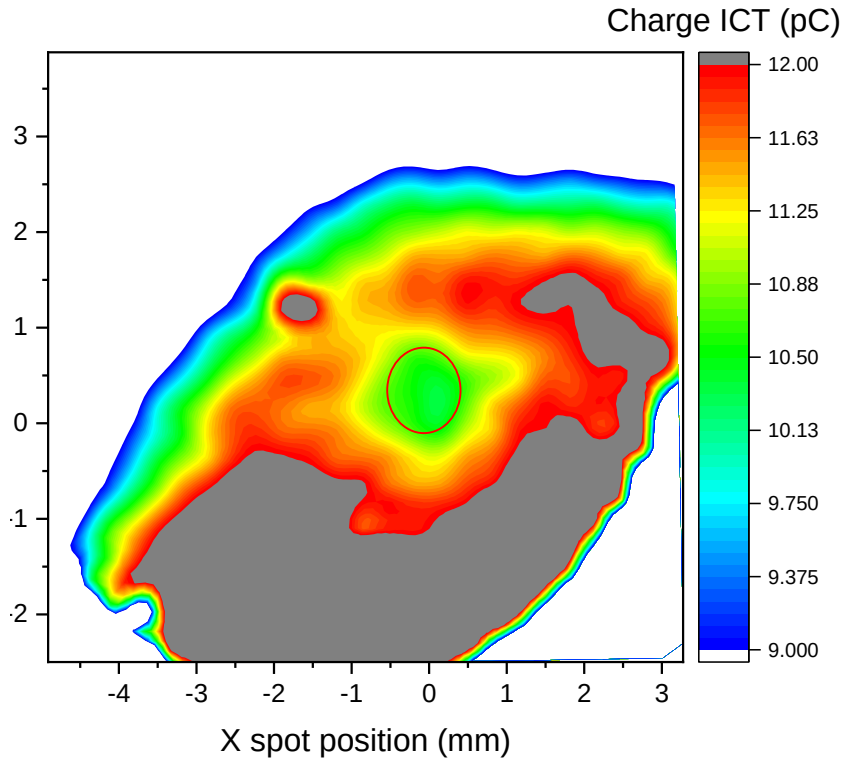
Cathode Cu_31: July 2017 – August 2019



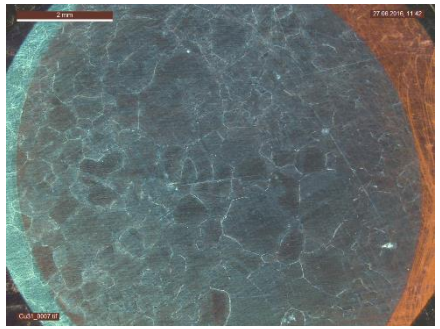
02 Sept. 2017:
Uniformity δ_{QE}/QE ~15 %



22 Dec. 2017
Uniformity δ_{QE}/QE ~13 %



31 Jul. 2018
Uniformity δ_{QE}/QE ~10 %



Cathode #31

Cathode#31:
Cs_2Te by successive evaporation ; **~ 40nm**

Cathode develops a **QE hole** after 10 months !
=> Gain in uniformity !

Conclusion

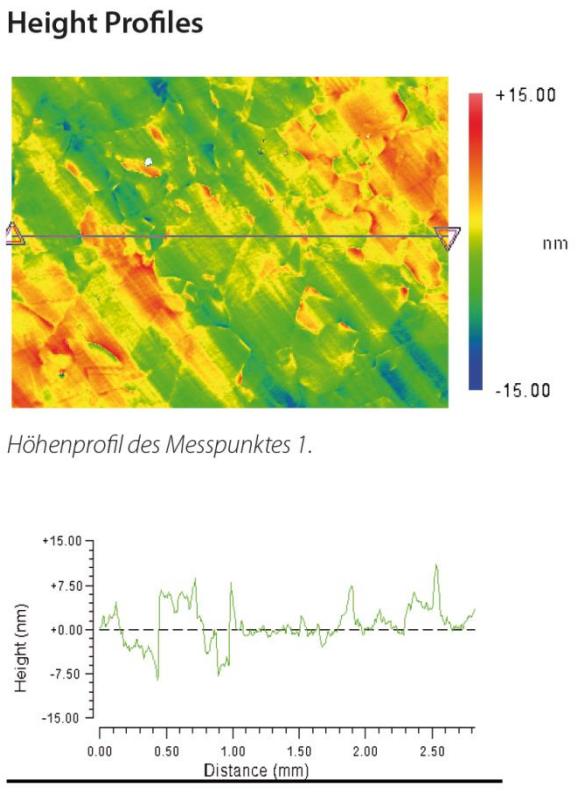
- Cathode production very basic: Pressure and cleaning should be improved !
- Since SwissFEL Operation started in 2016: 3 cathodes
- Lifetime seems to get better: 10 months -> 25 months -> ???
- Initial QE ~ 1% (to be compared to the 10-20% of expert laboratory like INFN, BNL, Cornell, …)

Are Intrinsic emittance and QE related in SC ?

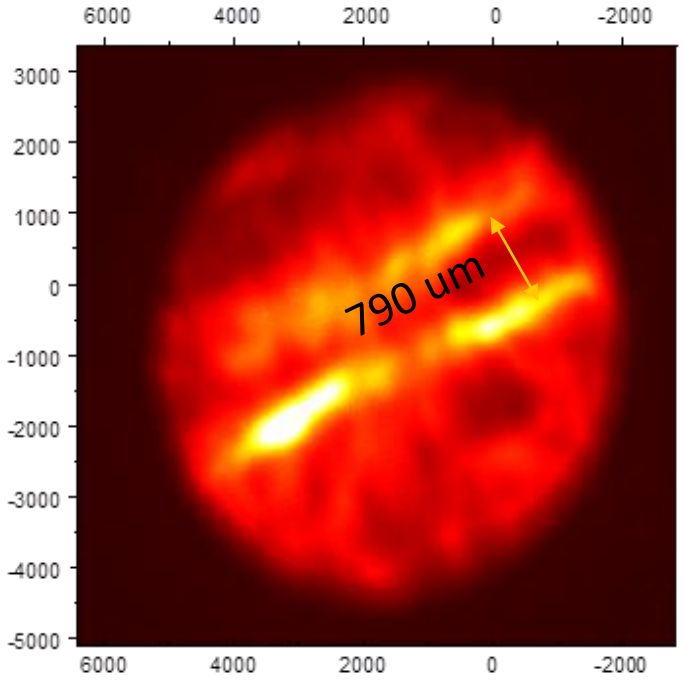
In metal, small QE => smaller momentum spread of emitted electrons
=> less electrons with large transverse momentum
=> smaller emittance

Phys. Rev. ST Accel. Beams **12,** 074201 (2009)

Many Thanks

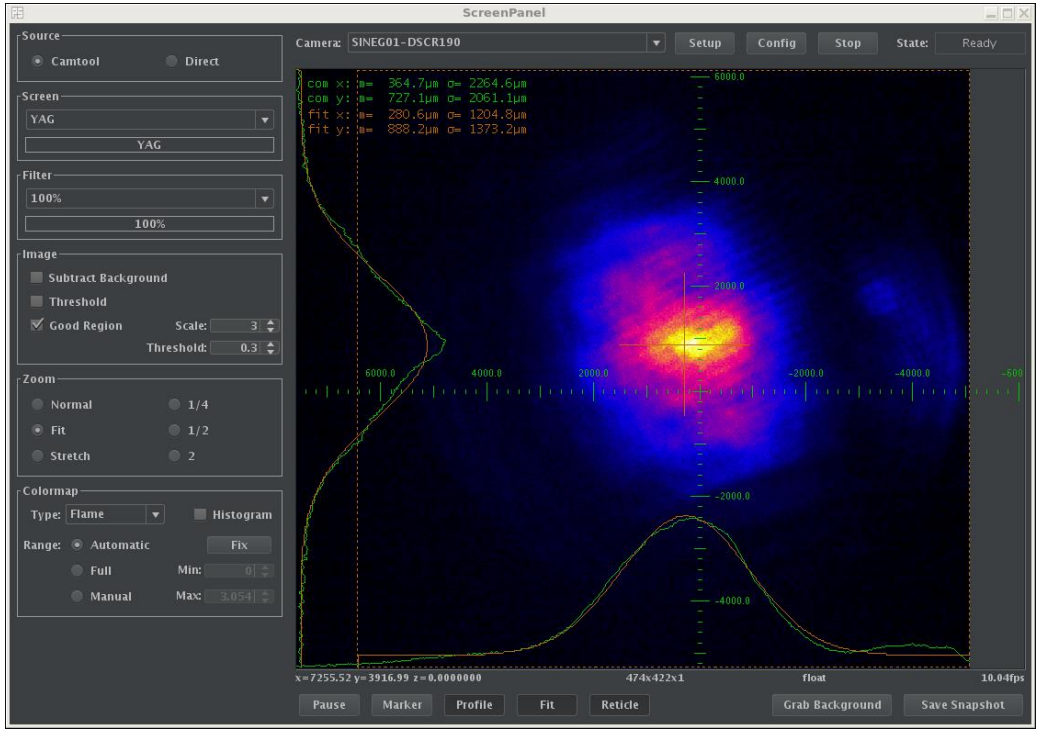


Profilometry measured on Cu_1



Electrons imaging of cathode Cs2Te_31 on Dec. 4th

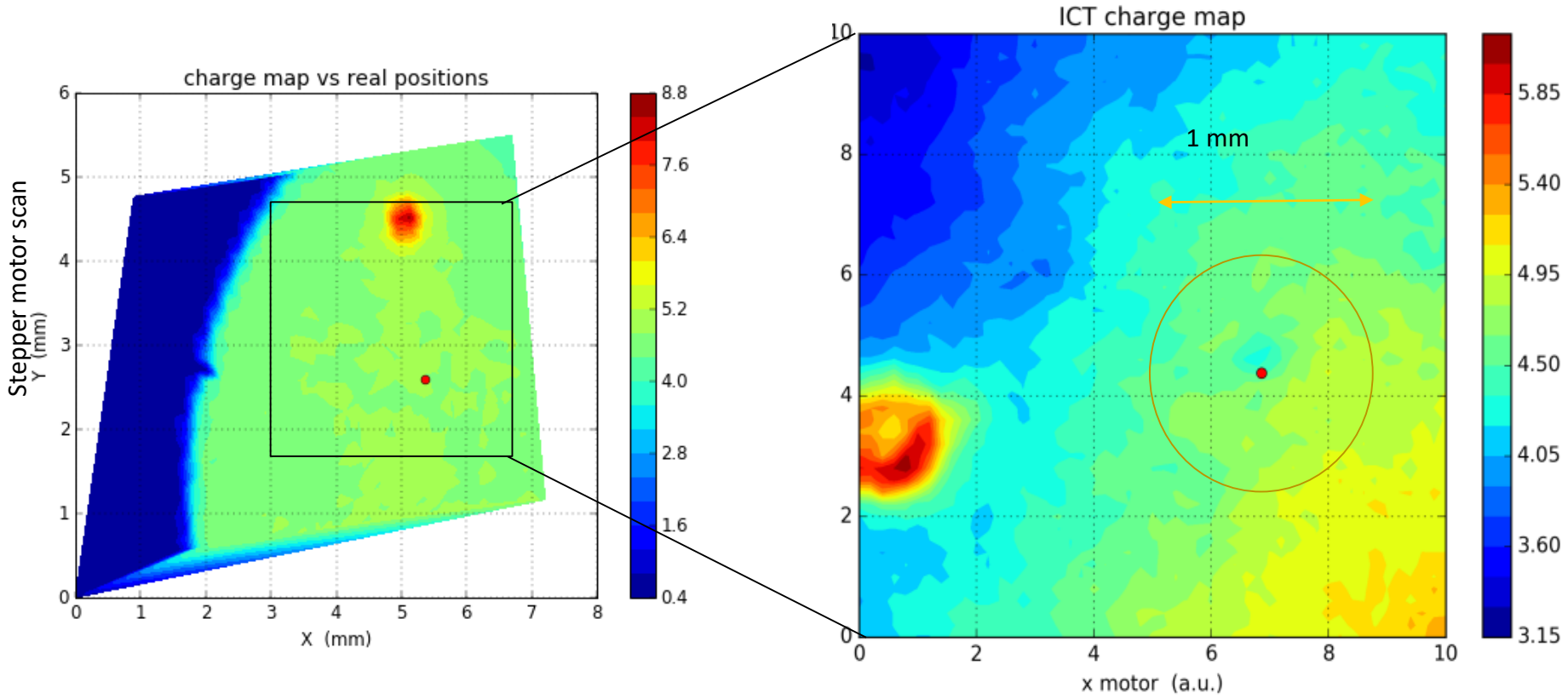
Cathode imaging with e-beam on YAG



No defects clearly visible

Courtesy of N. Hiller

Uniformity of Cathode#31



14.07.2017

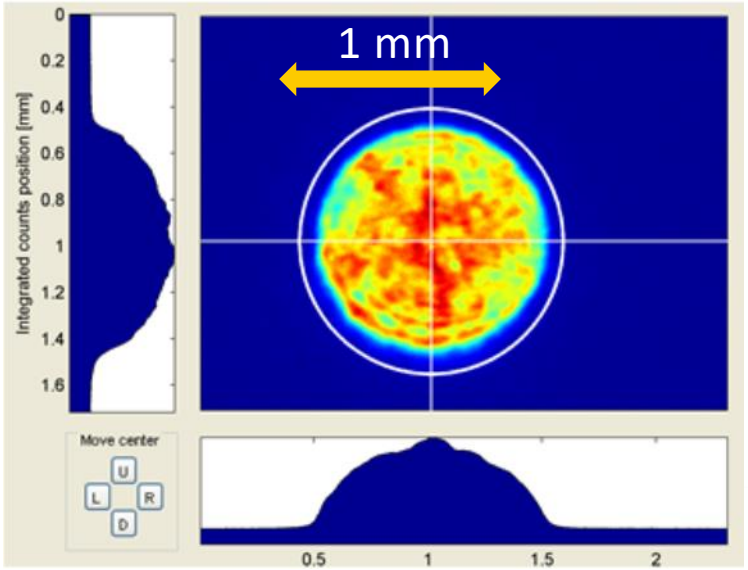
18.08.2017

Uniformity δ_{QE}/QE ~ 15 %

QE scans: 5 pC; $\sigma_{r,laser}$~100 um

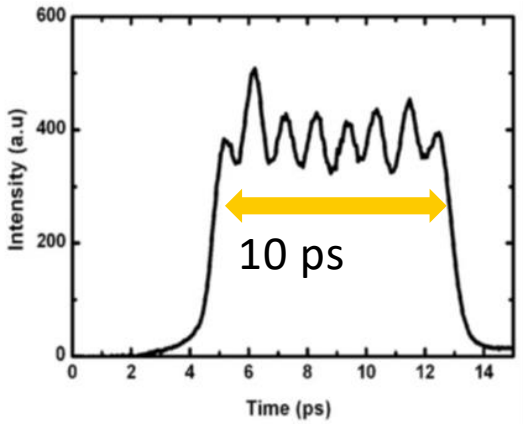
Laser illumination

Laser Transverse Profile (263 nm)



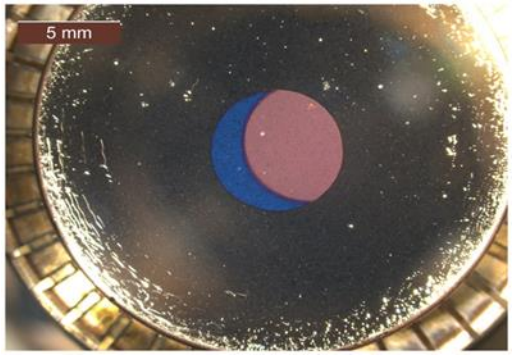
Ref. C.P. Hauri – FEL2011

Laser Longitudinal Profile

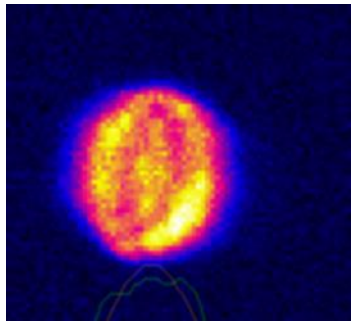


Truncated Gaussian
or pulse stacking

+



Photocathode
Uniformity



Electron Beam Profile

ε_{slice}= 155 nm.rad
Charge 200 pC; 300 MeV
SwissFEL - PSI