R. Ganter, S. Bettoni, R. Gaiffi, M. Huppert, C. Kittel, E. Prat, T. Schietinger, A. Zandonella

Photocathodes for SwissFEL

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- SwissFEL Introduction
- Photocathode Experience at SwissFEL
- Cs_2Te coating (successive, co-evaporation)
- Cs_3Sb coating attempts
- Conclusion and perspectives

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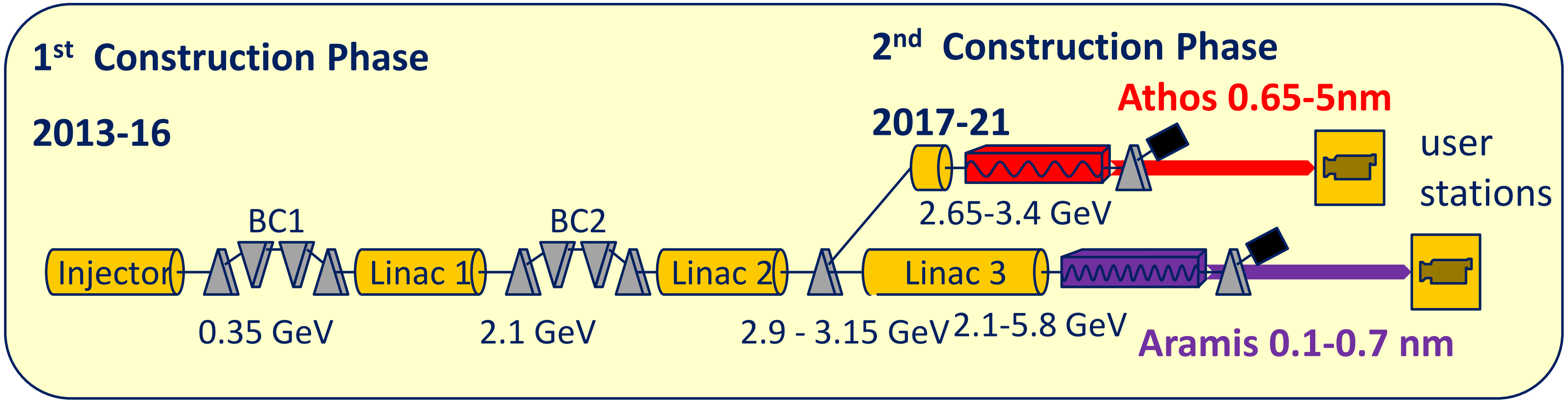
PSI West
PSI East
Hard X-Ray FEL
740 m Long
First Beam End 2016
SwissFEL



Aramis

Linear polarization, variable gap, in-vacuum Undulators

First users 2018

Athos

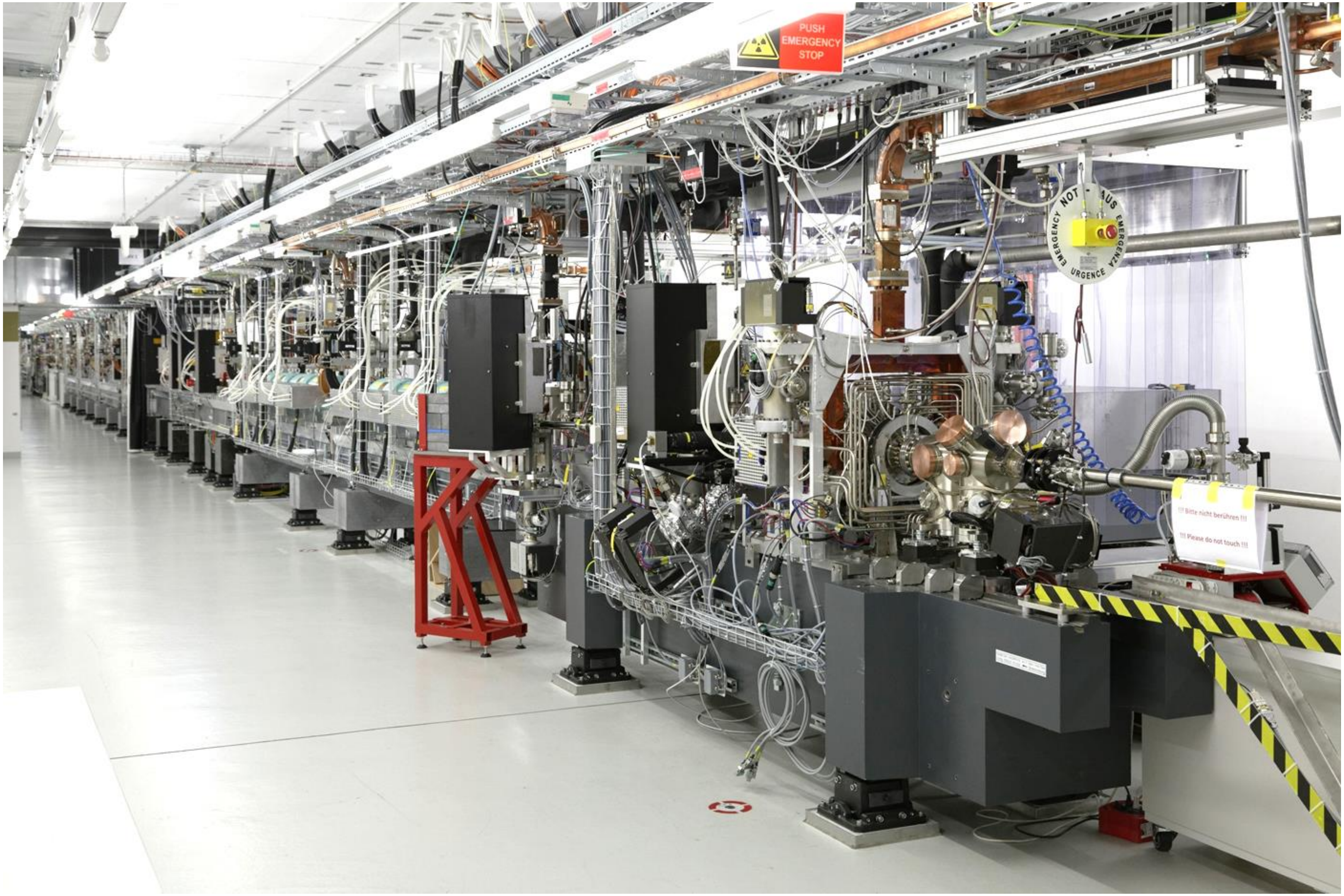
Soft X-ray FEL, variable polarisation

First users 2021

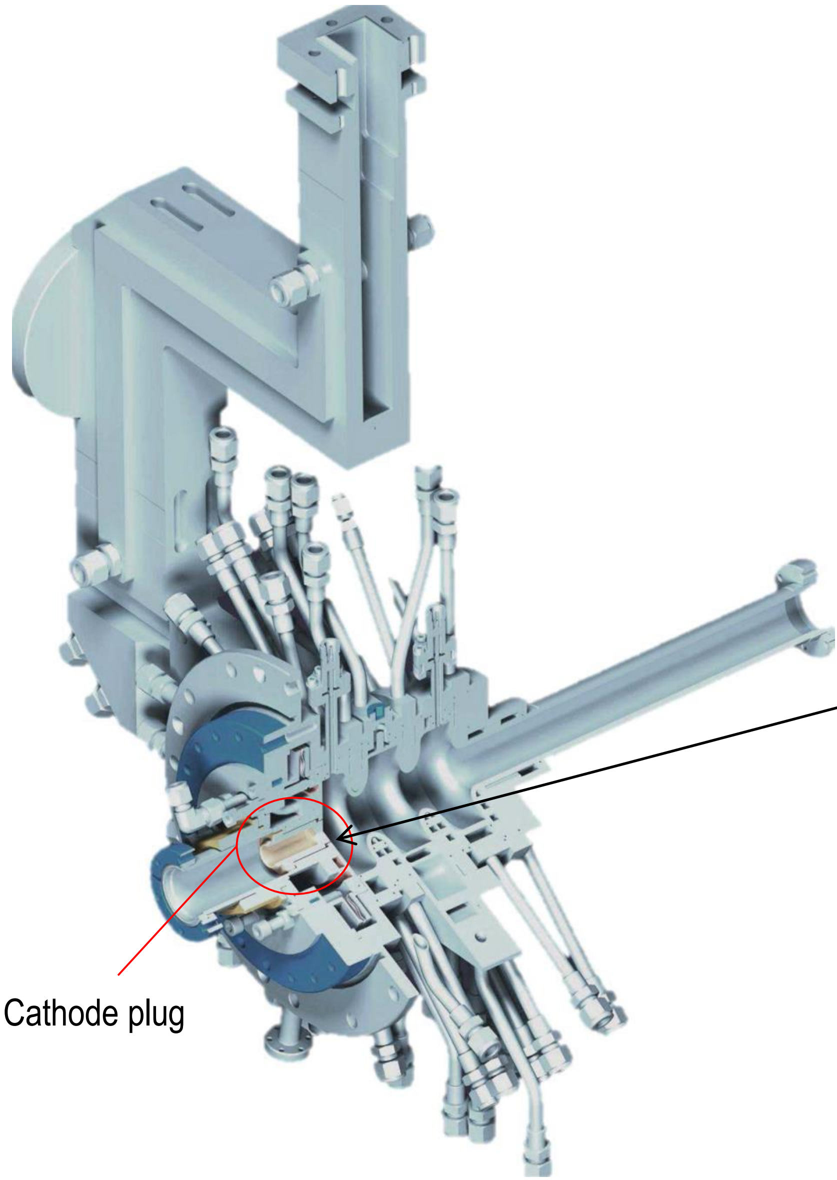
Aramis Main parameters

Photon energy	2 – 12.4 keV
Pulse duration	20 fs
e^- Energy	2.1 - 5.8 GeV
e^- Bunch charge	**10-200 pC**
Repetition rate	**100 Hz**

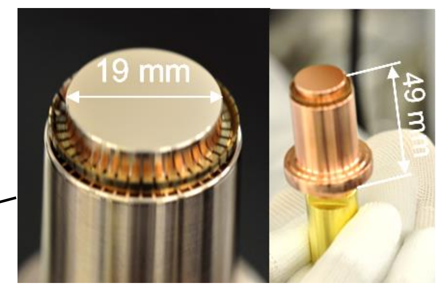
SwissFEL Electron Gun and Loadlock



SwissFEL RF Photoinjector



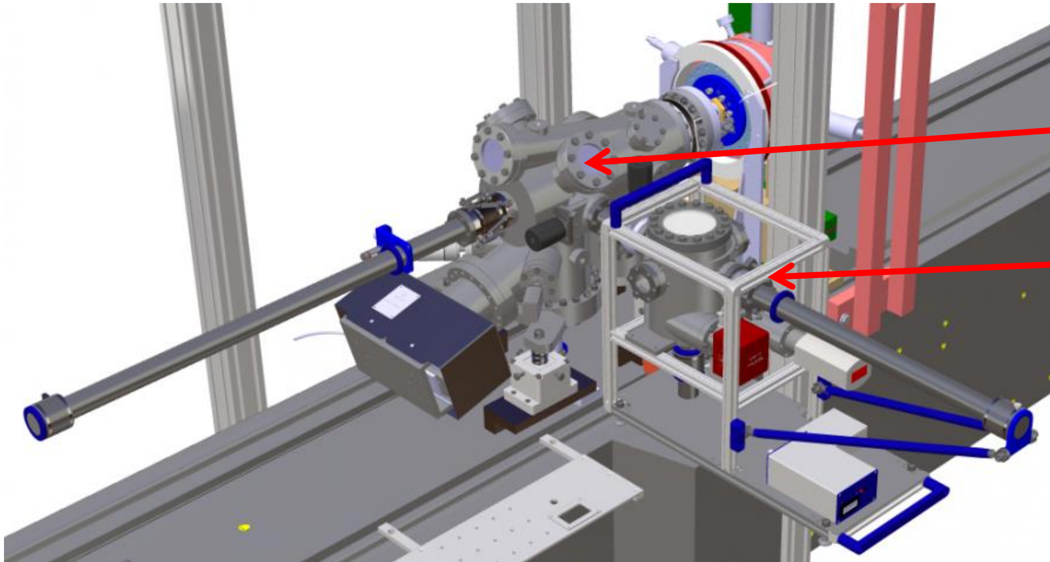
SwissFEL RF Photoinjector:
S band, 2.5 Cell; 7 MeV;
100 MV/m; 100 Hz; 10 - 200 pC

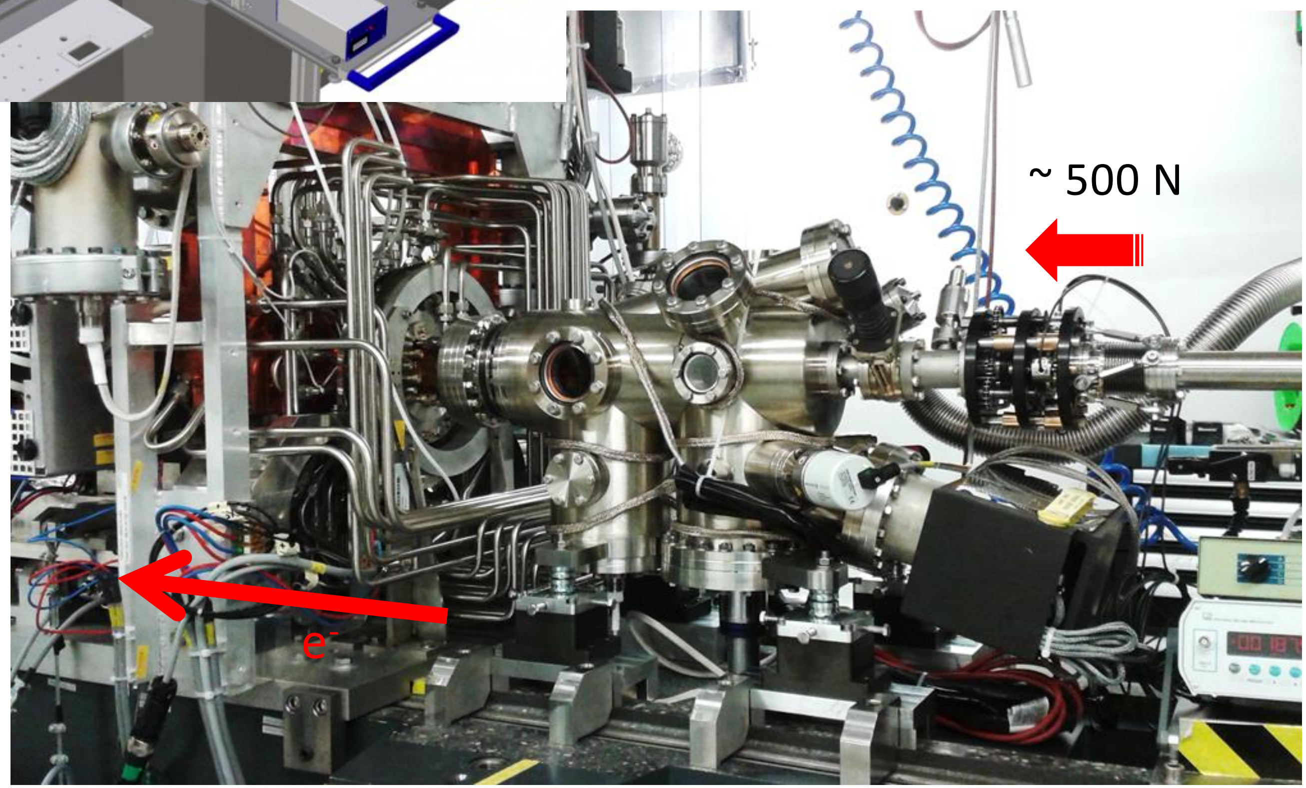


Exchangeable cathode plug(*)

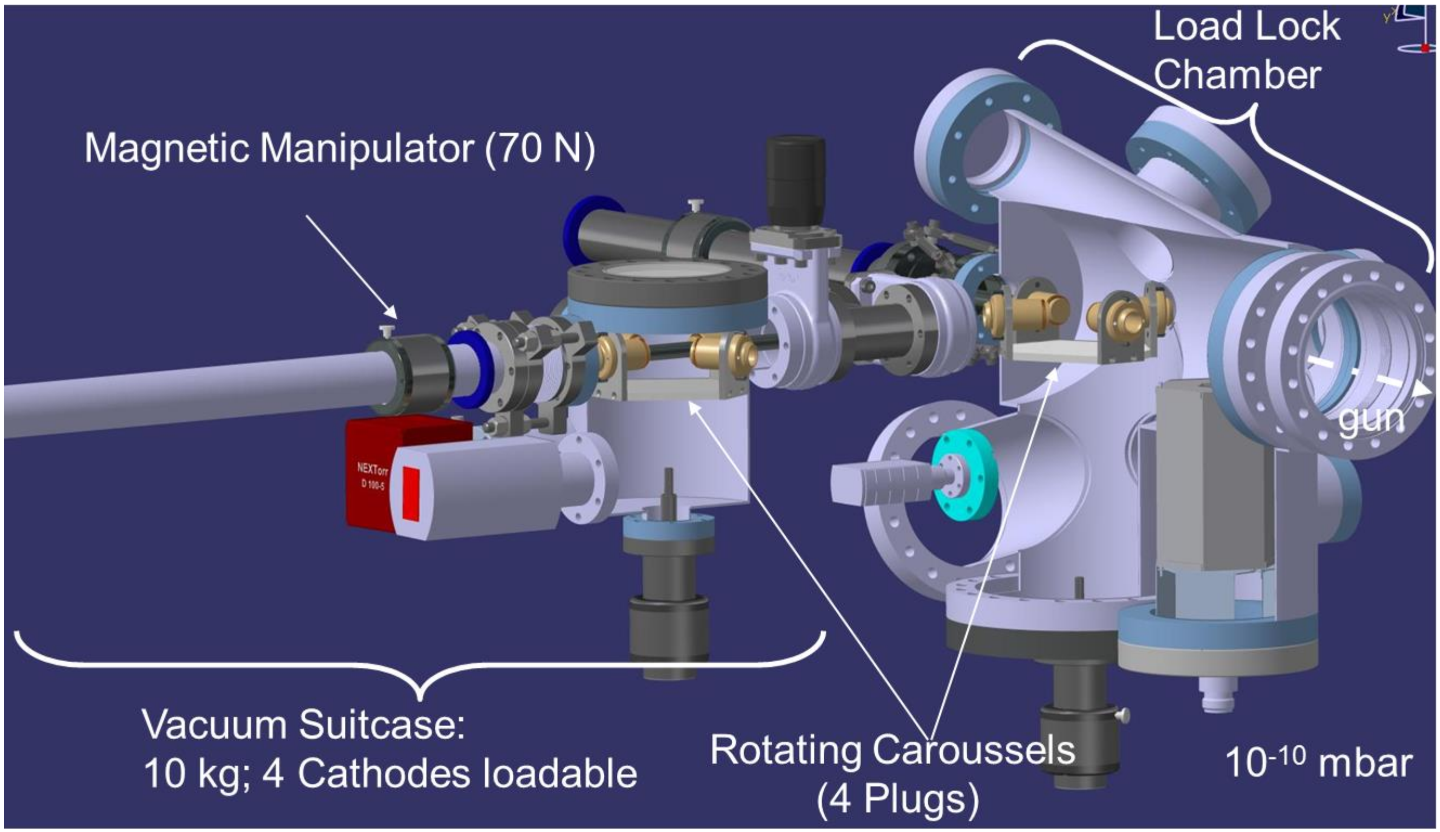
(*) CERN design: CLIC Note 303 (1996)

Loadlock chamber behind RF gun





Loadlock chamber for SwissFEL



Vacuum suitcase connected to the load-lock, showing the cathode transfer principle and the storage carroussels..

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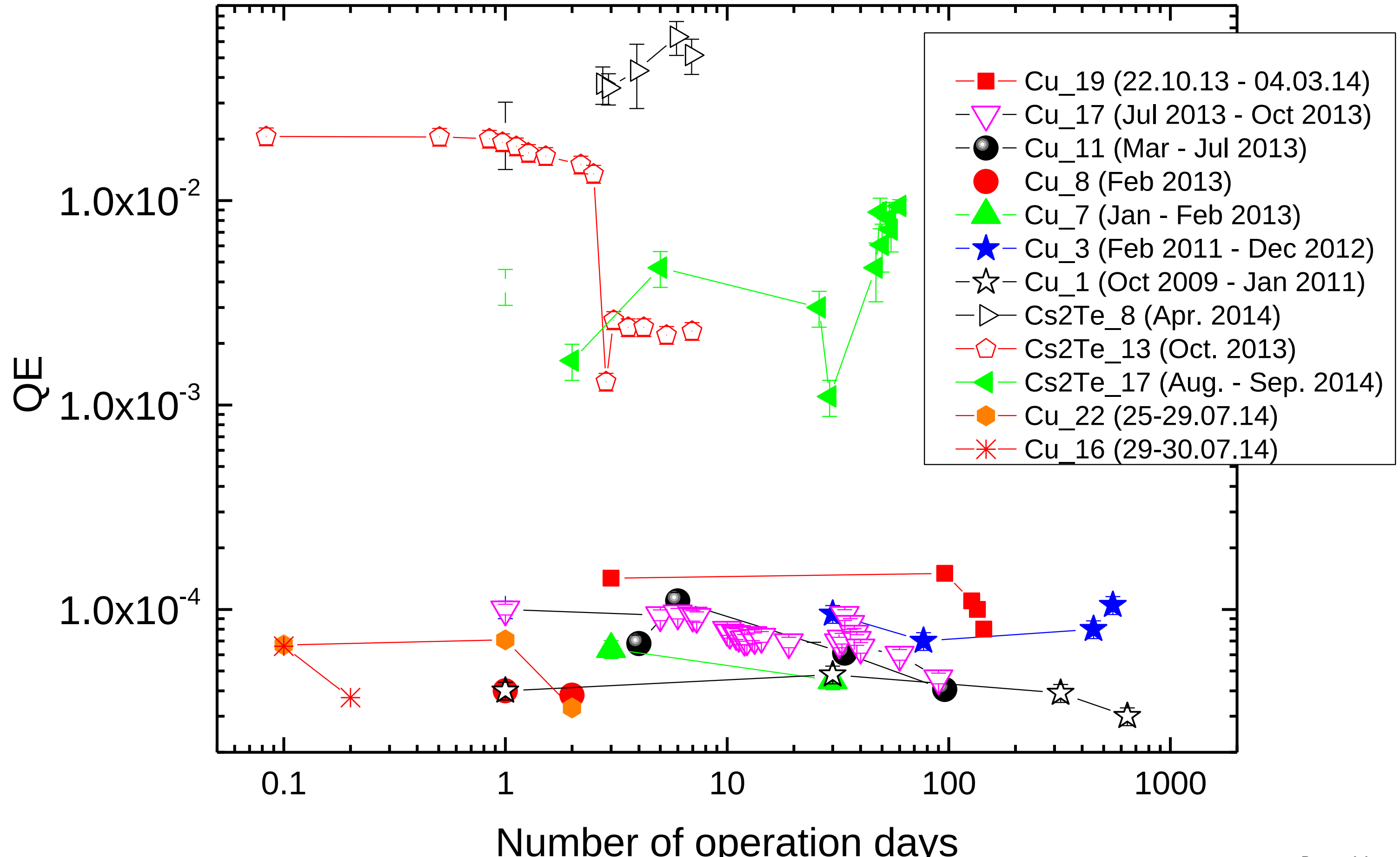
SITF (SwissFEL Test Facility): 2010-2014

Loadlock installed in 2013 at the SITF:

=> Recipe to get reproducible copper QE_{Cu} ~10^{-4}

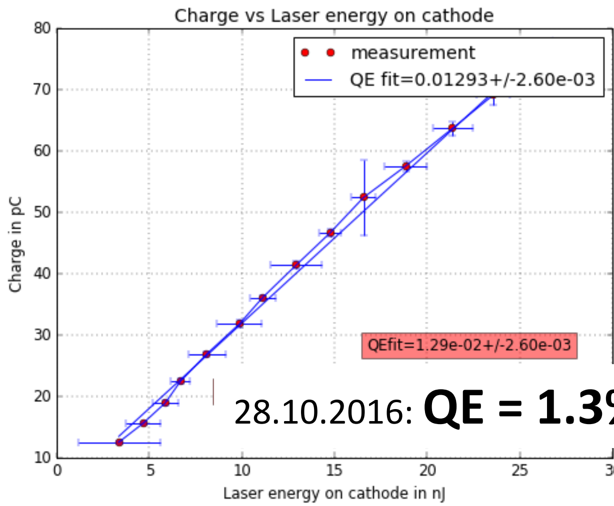
=> First test of Cs_2Te Cathodes: QE ~ 10^{-2}



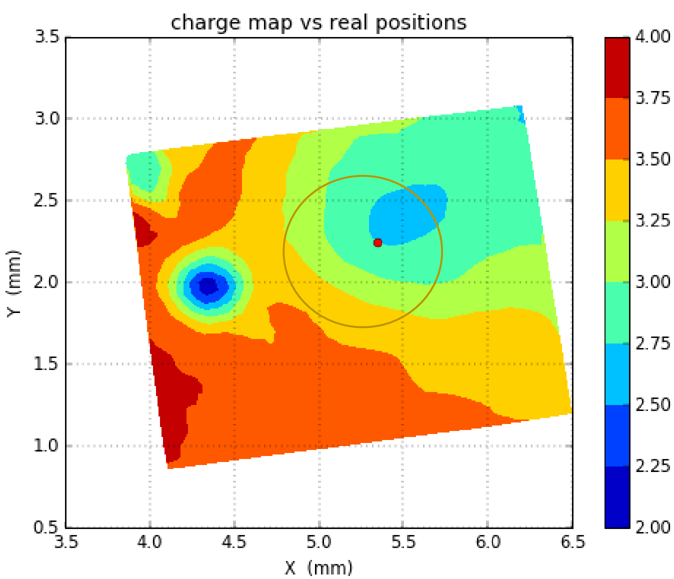
- 2015: Decision to operate SwissFEL only with Cs_2Te
- 2016: Gun + Loadlock moved to SwissFEL

SwissFEL Cathode History 2016- 2018

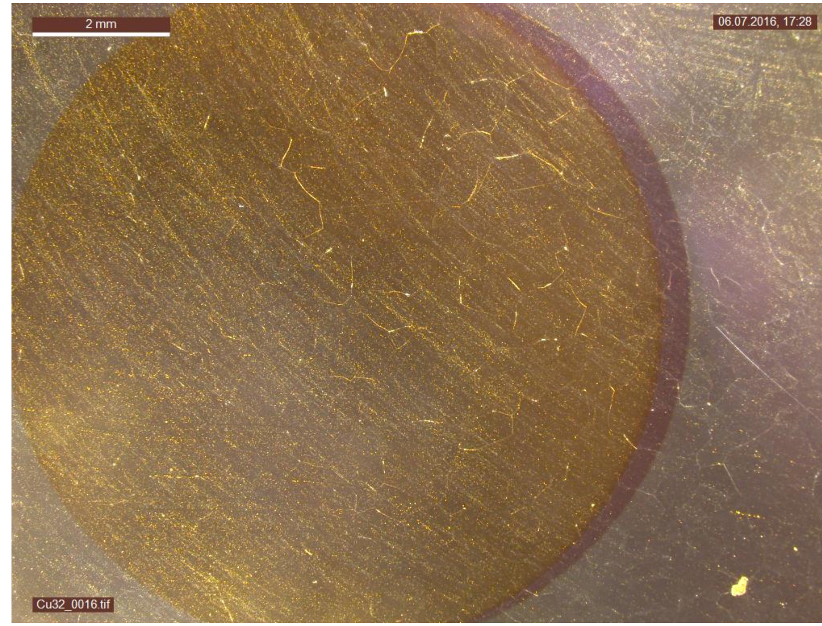
From October 2016 to July 2017: Cathode #32



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

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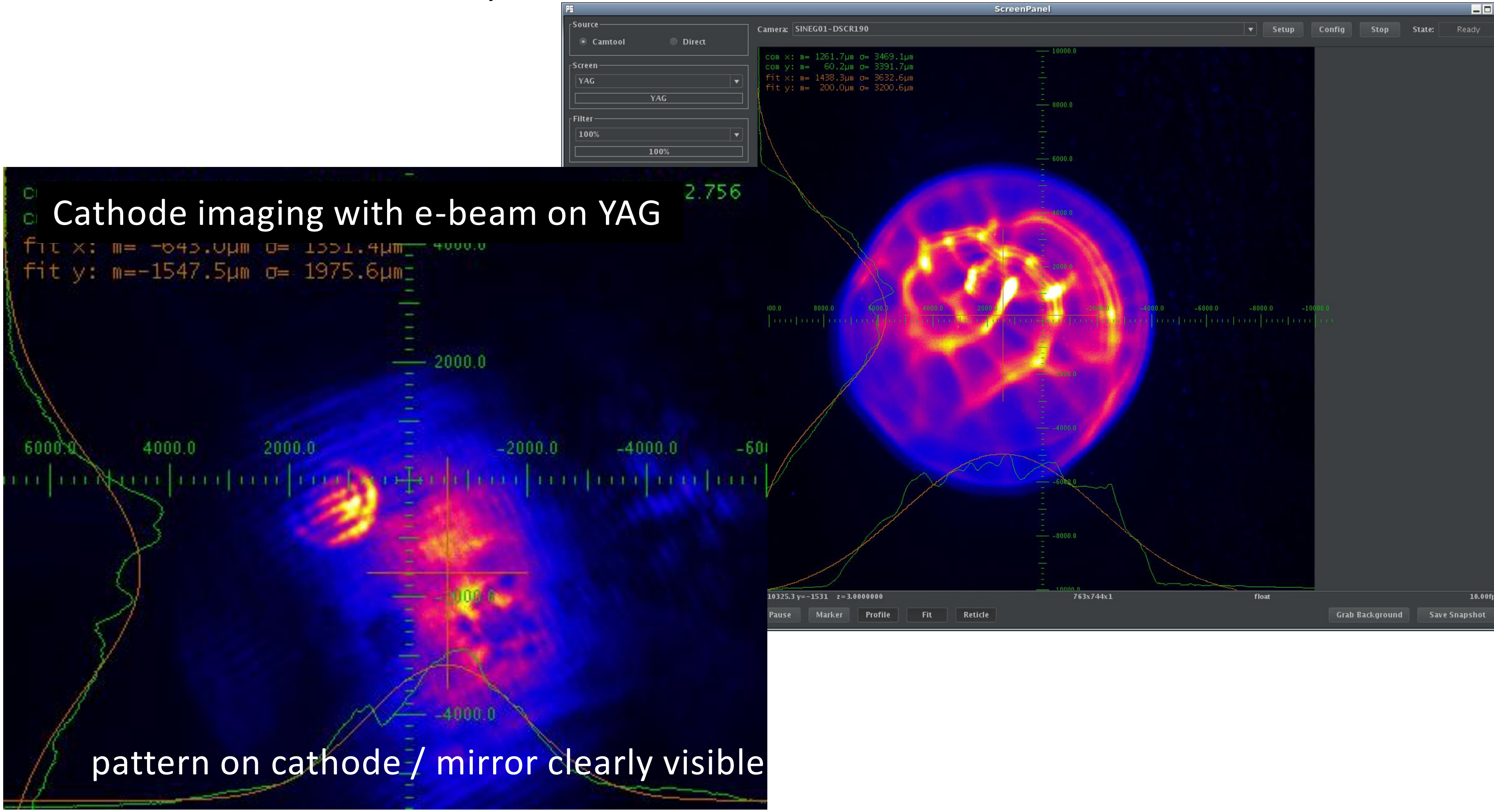
Why was cathode exchanged ?

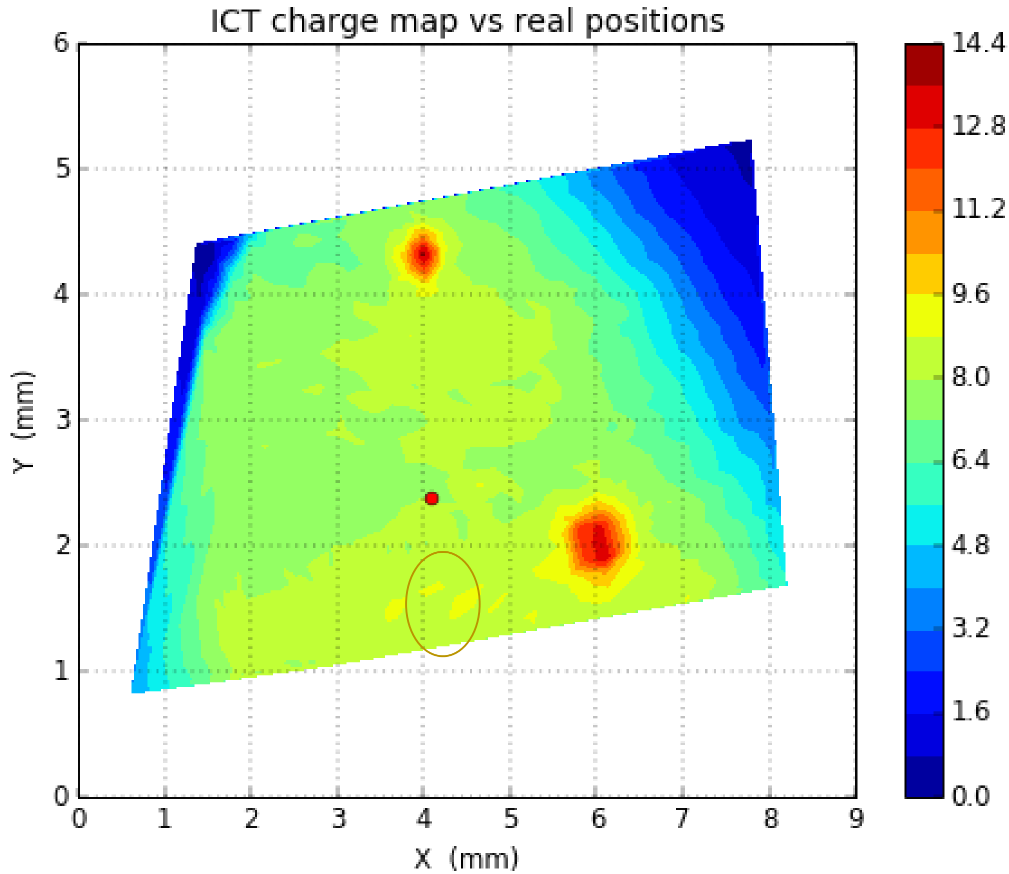
Electron Beam uniformity issues

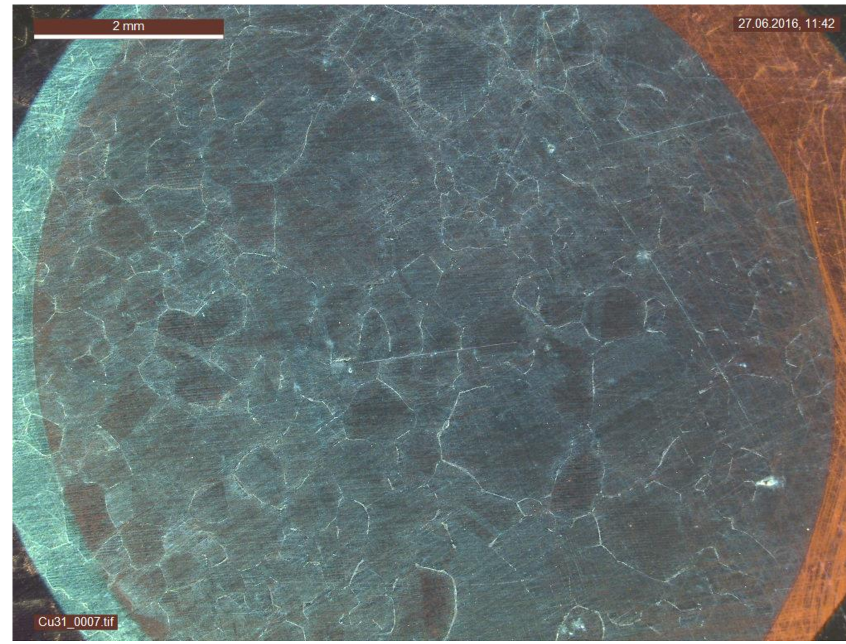


⇒ Exchanged cathode on July 21st 2017

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

From October 2016 to July 2017: Cathode #31





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

24.07.2017:

Averaged QE ~ 0.6 %

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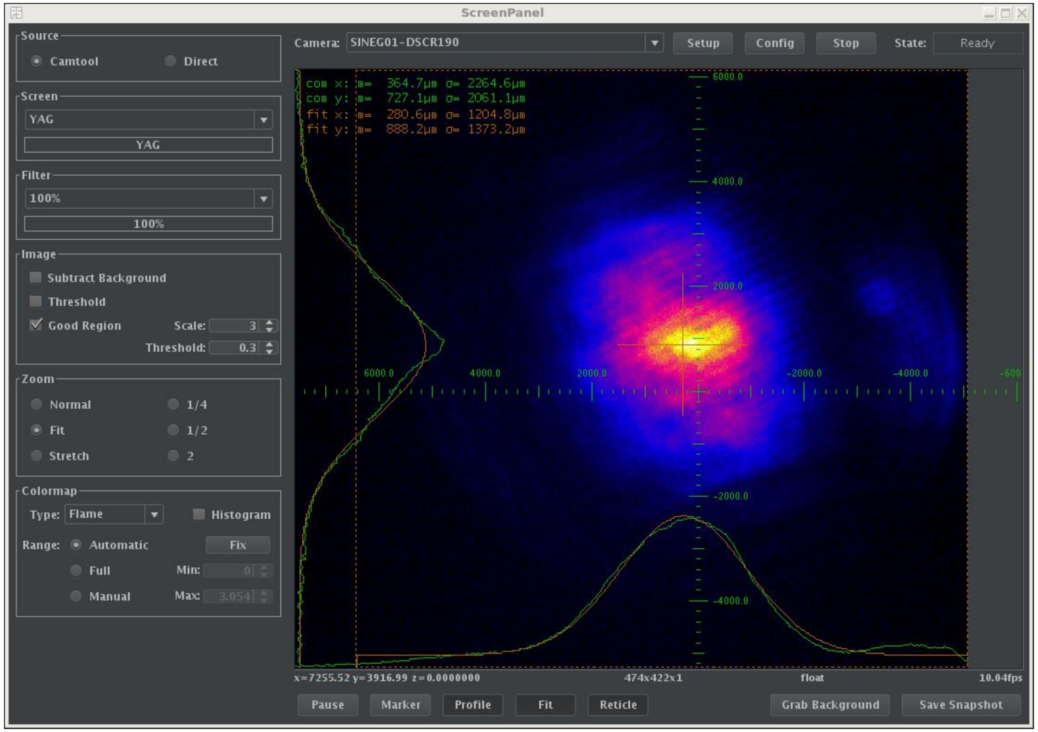
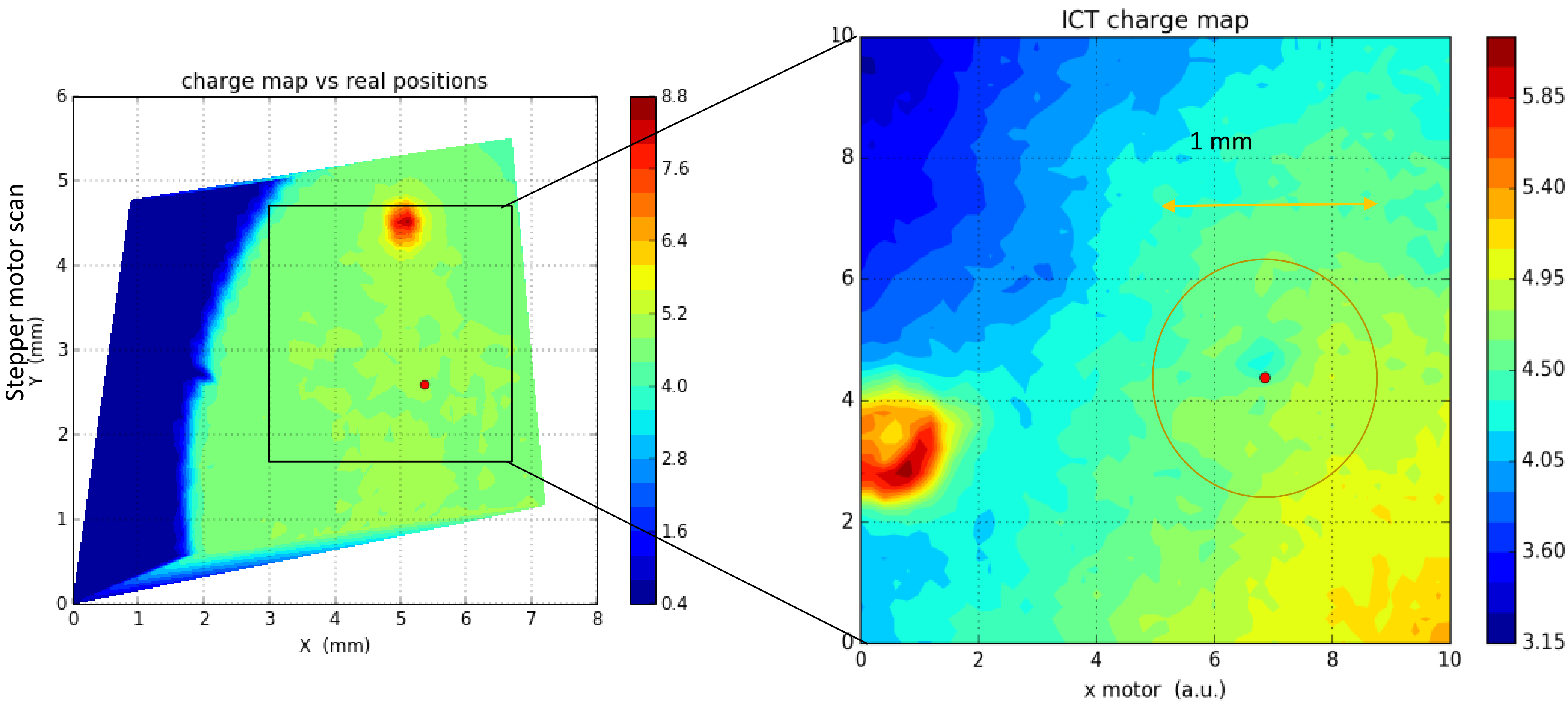
Cathode imaging with e-beam on YAG



No defects clearly visible

Courtesy of N. Hiller

Uniformity of Cathode#31



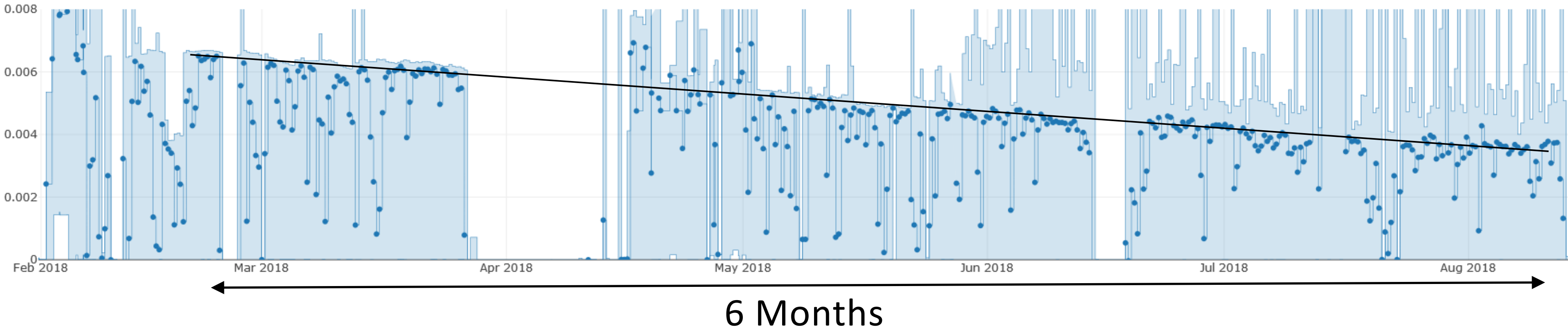
14.07.2017

18.08.2017

Uniformity δ_{QE}/QE ~ 15 %

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

QE evolution in SwissFEL Gun



Averaged QE dropped by 40% after 6 Months

or after ~ 15 mC of charge extraction

$P_{cathode}$ < 1.10^{-9} mbar (1.1e-11 mbar at the pump)

Influence of Cu substrate ?

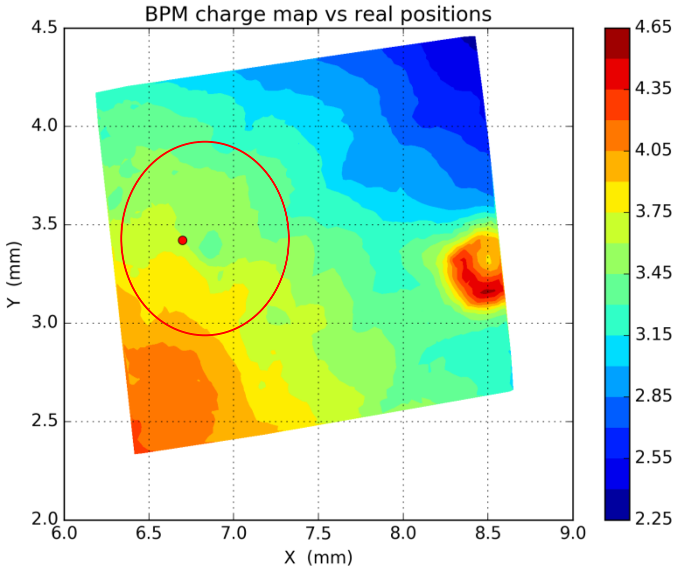
Lifetime until QE~0.1% > 1 year

Cathode #31 (Cs_2Te)

10 Hz; 200 pC

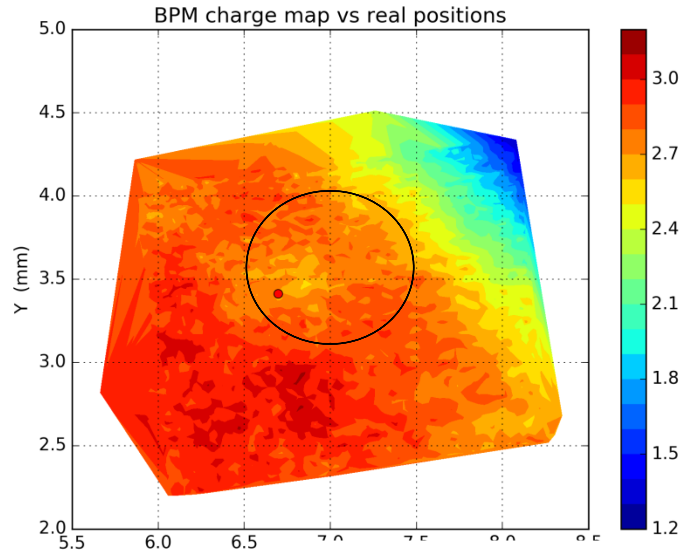
100 MV/m

Cathode emission uniformity



02 Sept. 2017:

Uniformity δ_{QE}/QE ~15 %



22 Dec. 2017

Uniformity

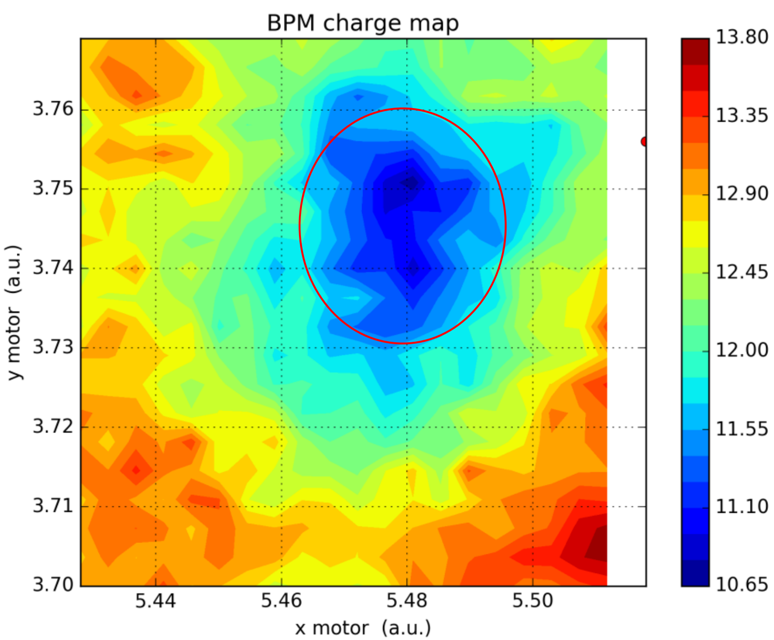
δ_{QE}/QE ~13 %

Cathode started to develop a **QE hole** in recent months !

31 Jul. 2018

Uniformity

δ_{QE}/QE ~10 %



Cathode #31

Slice emittance / Intrinsic emittance

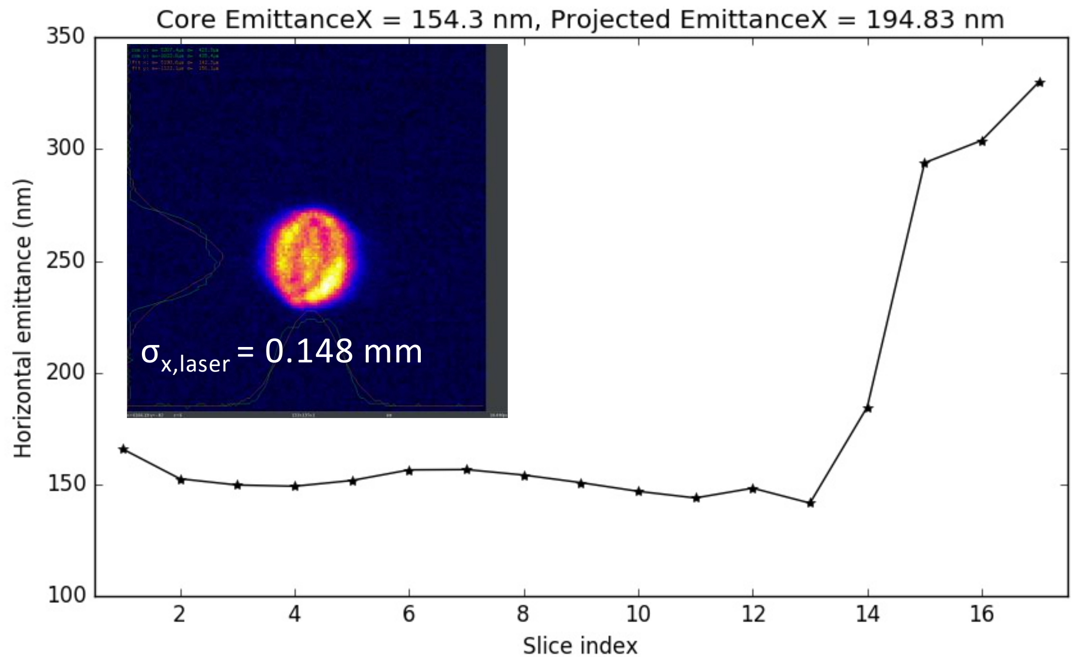
Expected Intrinsic emittance

$$\varepsilon_{Intrinsic,Simple} = \sigma_{x,laser}\sqrt{\frac{h\nu - \Phi_{eff}}{3mc^2}}$$

$\sigma_{x,laser}$ = 0.148 mm
Φ_{Cs2Te} = 3.5 eV
F = 50 MV/m
Φ_{eff} = 3.23 eV
hν = 4.77 eV

$\varepsilon_{intrinsic}$= 145 nm.rad

Measured slice emittance



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

Measured slice emittance close to Intrinsic emittance !

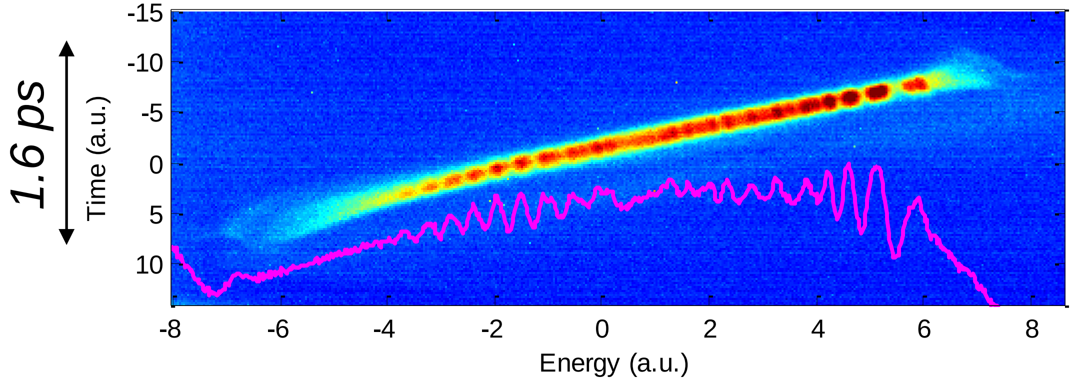
~ Copper emittance (Phys. Rev. ST Accel. Beams 18, 043401 (2015))

Courtesy of E. Prat

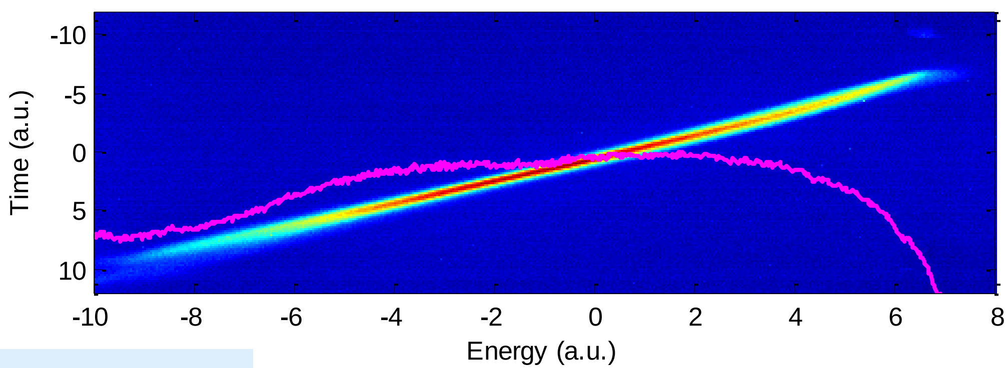
Reducing microbunching gain with Cs_2Te

Beam longitudinal phase space after compression

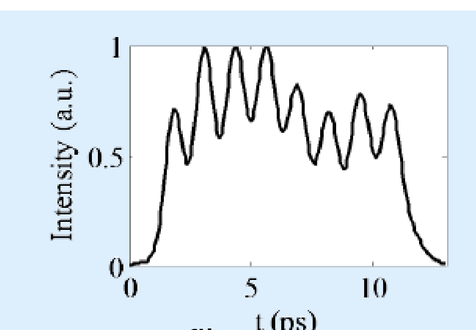
200 MeV; Factor 6 compression



Cu photocathode
100 pC, ~ 60 A



Cs_2Te photocathode
200 pC, ~ 120 A



Laser Profile

Slower extraction smooths out the longitudinal charge modulation induced by the profile of the illuminating laser.

Results from SITF 2014 - Courtesy of S. Bettoni

Small microbunching gain at SwissFEL

- Cs_2Te smooths out the laser profile ripples (more than Cu)
- Microbunching instabilities seems small at SwissFEL

=> Slow cathodes limits microbunching instability gain ?

BUT

- LCLS Simulations showed that Microbunching comes from “shot noise” even if laser profile is ideally flat !
- SACLA observed microbunching instabilities with thermionic gun !

???

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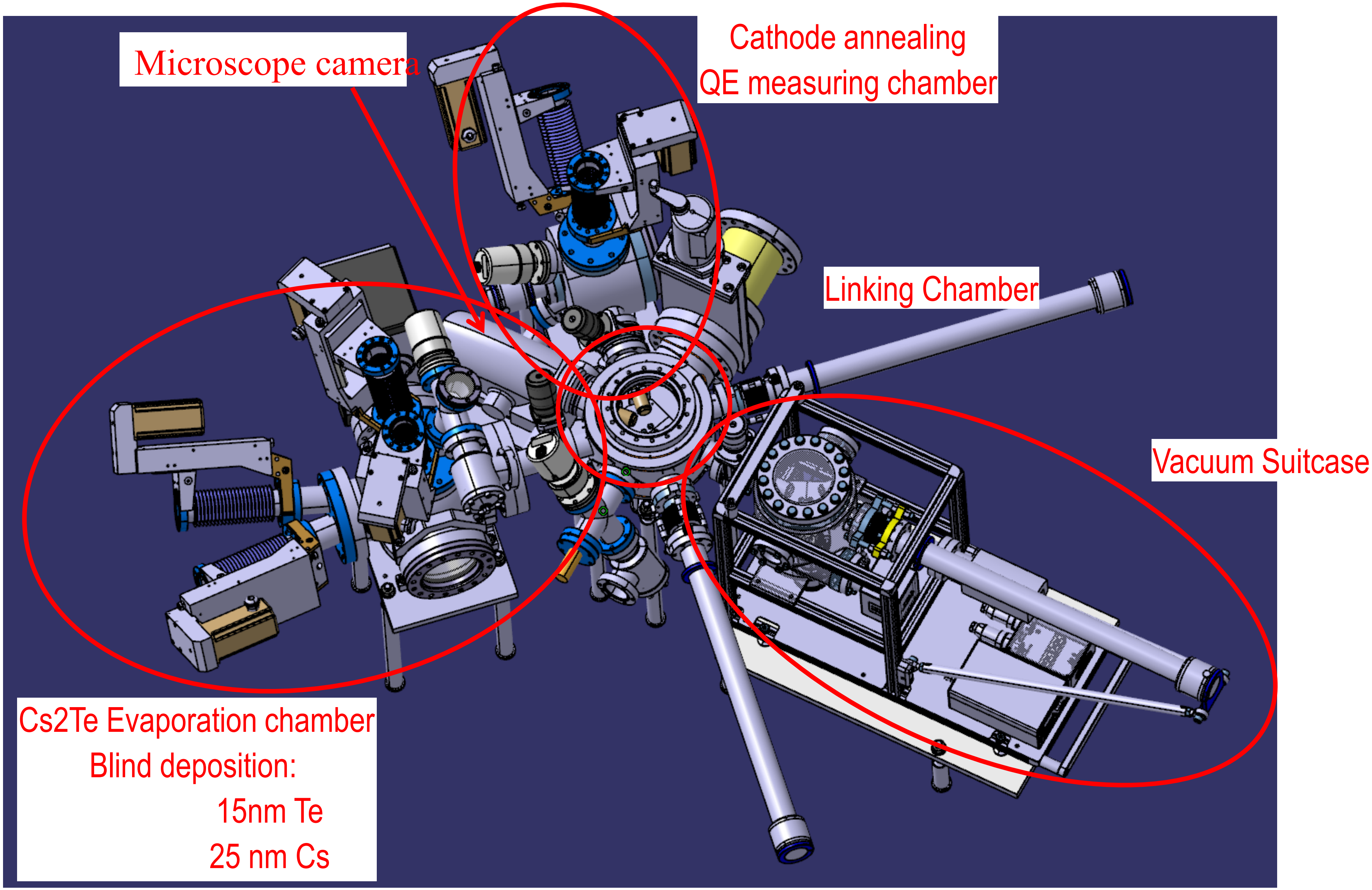
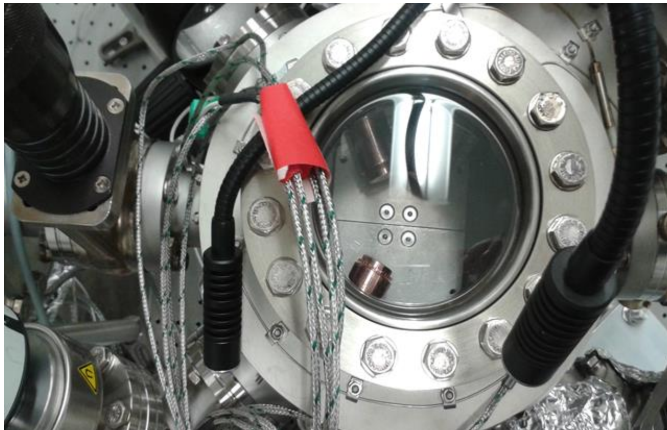
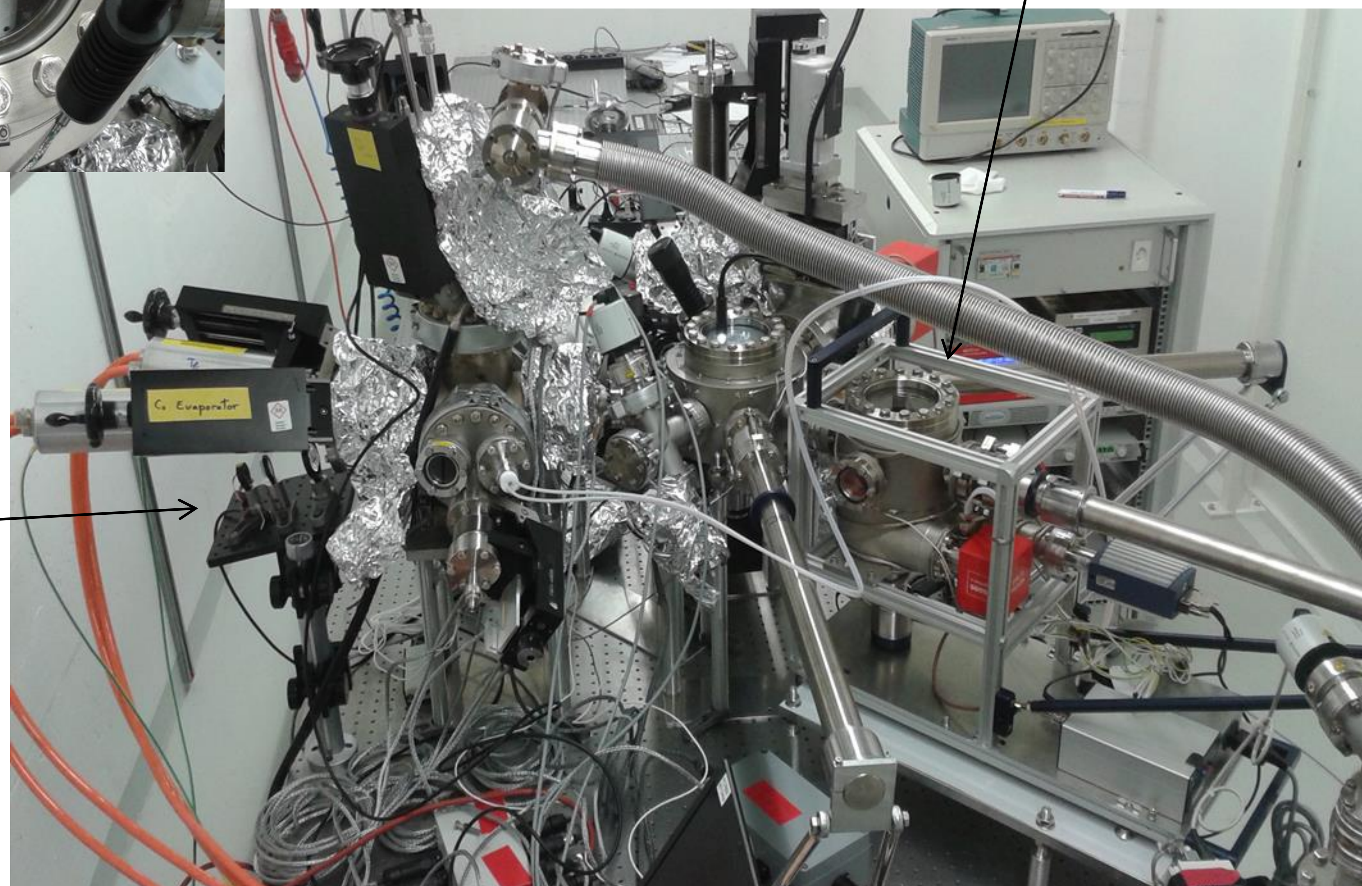
SwissFEL Cathode Preparation system



SwissFEL Cathode Preparation system

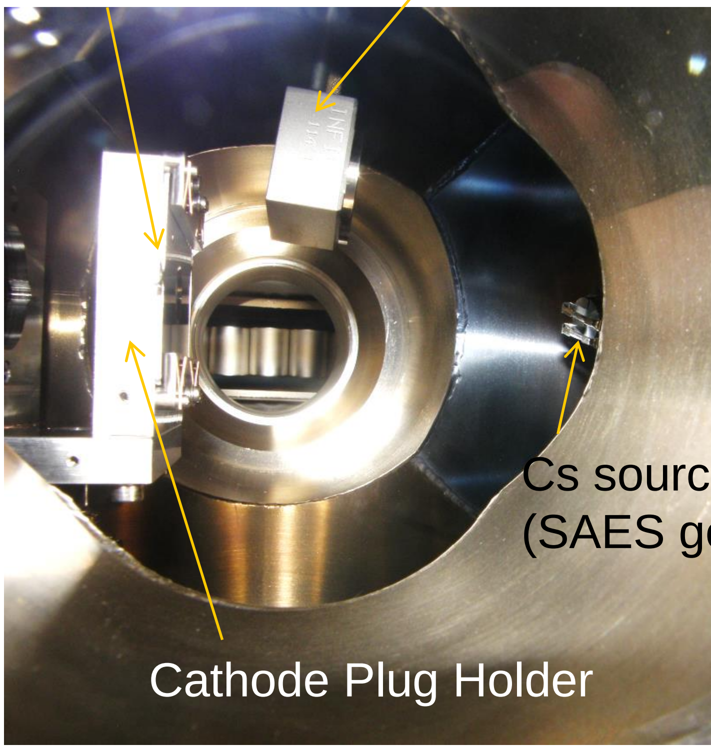


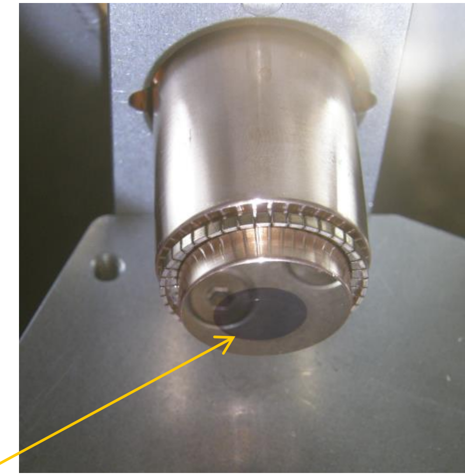


Vacuum Suitecase

266nm LED
for QE monitoring

Cs_2Te Deposition



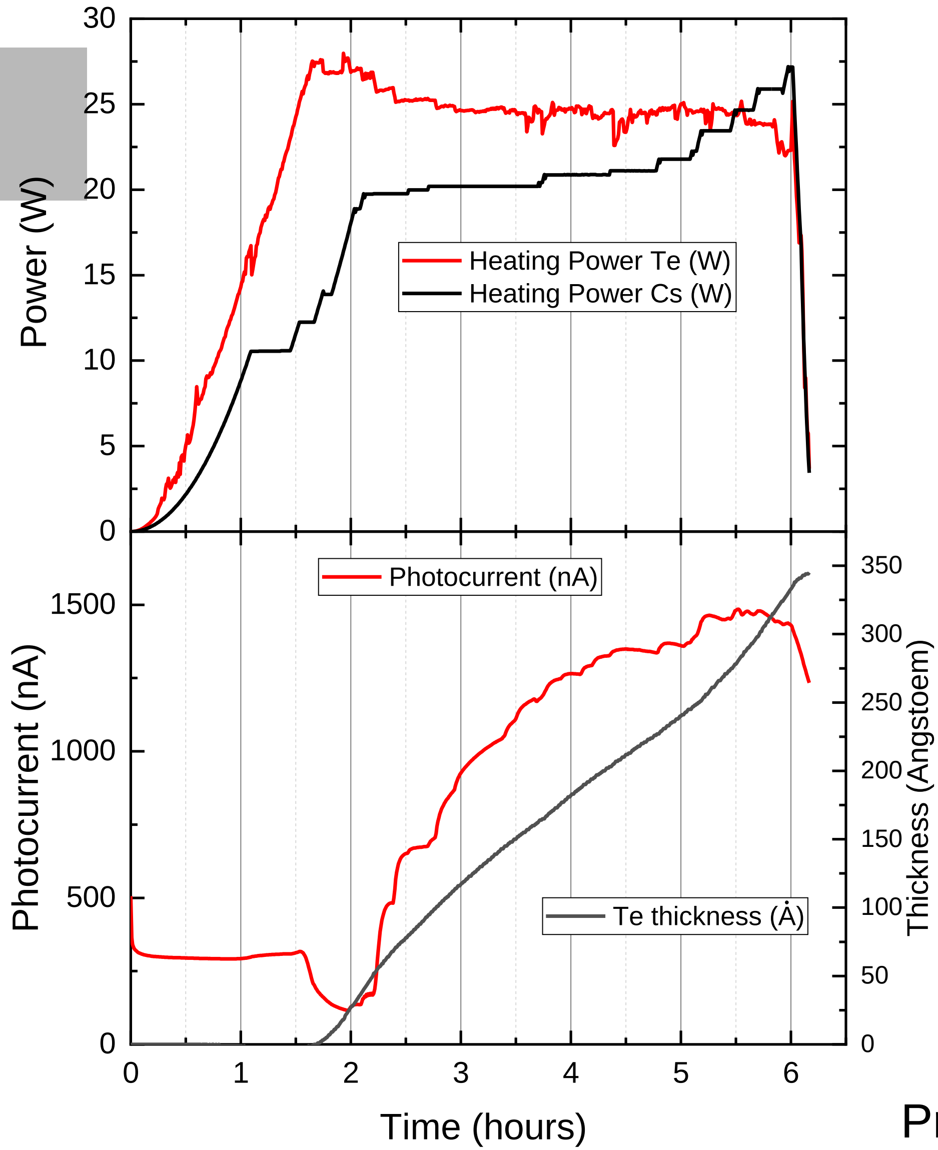


- successive deposition of Te and then Cs
(recipe from CERN: CERN - CLIC Note 299 – E. Chevallay)

- Coevaporation of Cs and Te

Cs_2Te co-evaporation on Cu Plug

Co-evaporation Cs and Te on Cu_28; V_{anode}=100V
- 17.05.2018

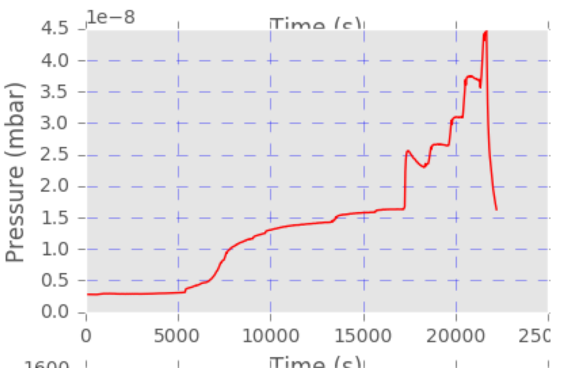


Recipe:

- 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

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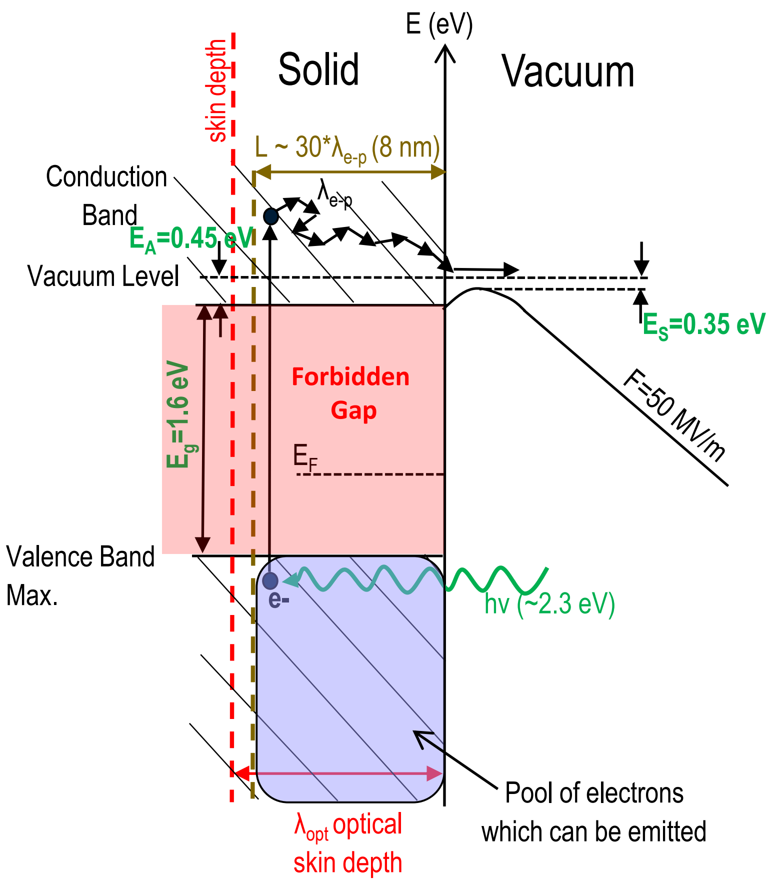
Co-evaporation of Cs and Sb



Motivation for Cs_3Sb :

- illuminate photocathode with 532 nm

=> Better laser shaping possible

=> Less optics degradation

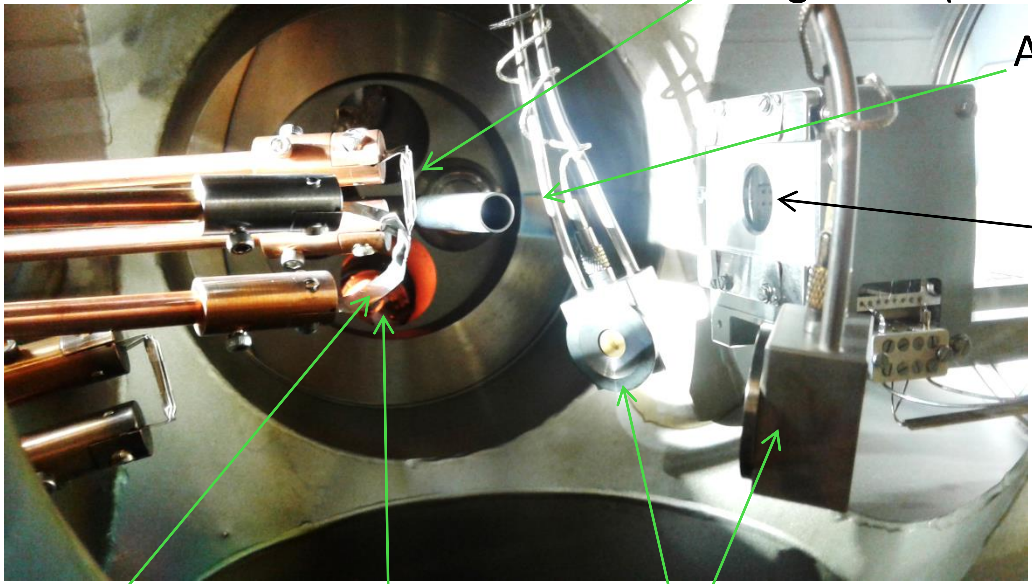
Cs_3Sb compound:

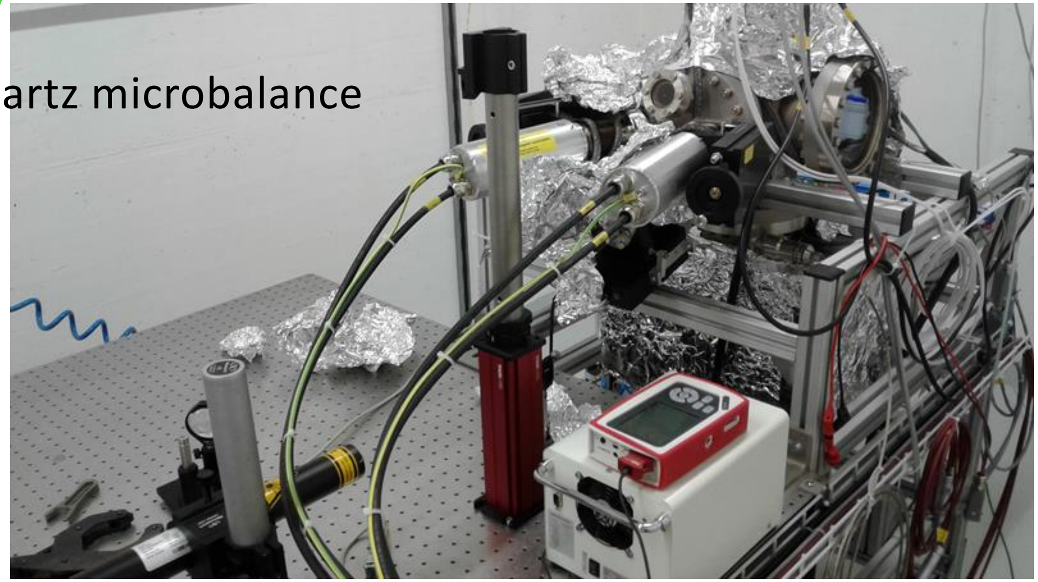
E_{gap}=1.6 eV

$E_{e-\ affinity}$=0.45 eV

$\Phi_{eff}=E_{gap}+E_{e-\ affinity}-E_{schottky}$ =1.7 eV

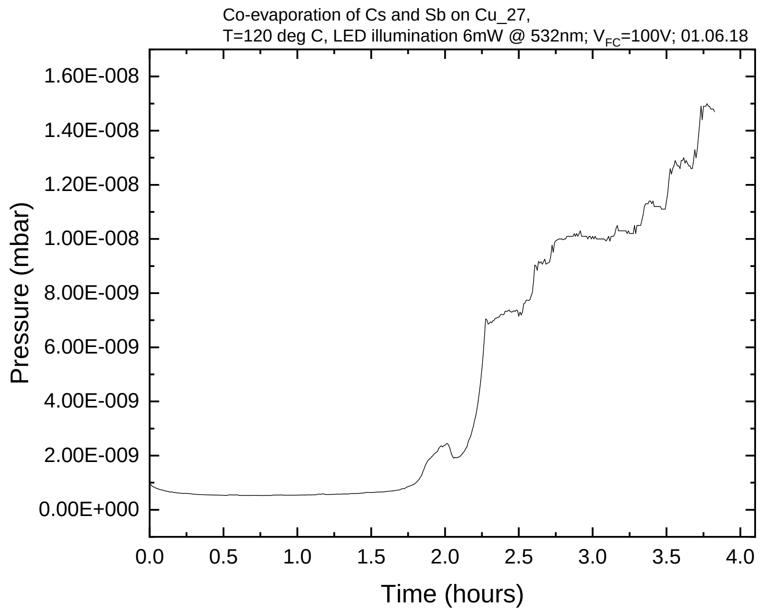
Evaporation chamber for Cs_3Sb

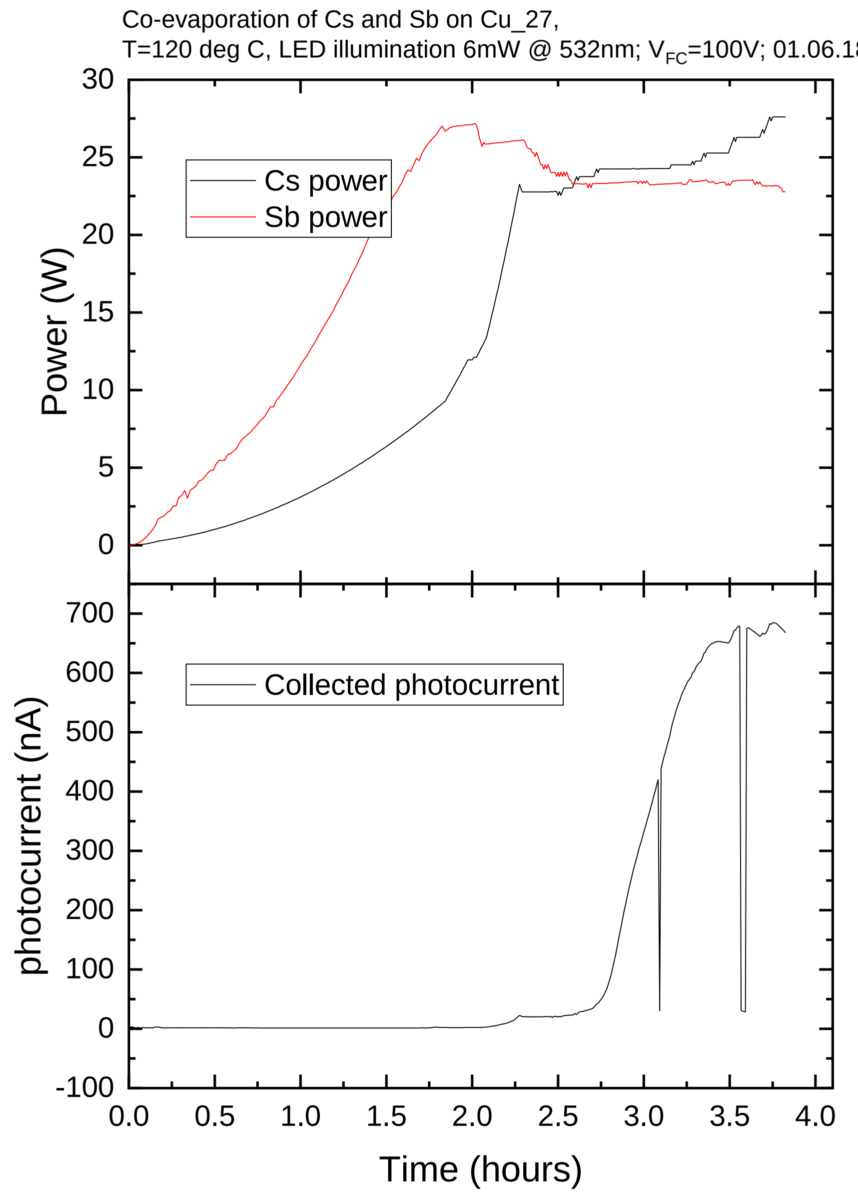




P ~ $1.0*10^{-11}$ mbar

Co-Evaporation Cs & Sb





Recipe:

Sb heating power has to be reduced !

Deposition rate Sb: 0.01 – 0.02 Å/s

Deposition rate Cs: 0.1 Å/s

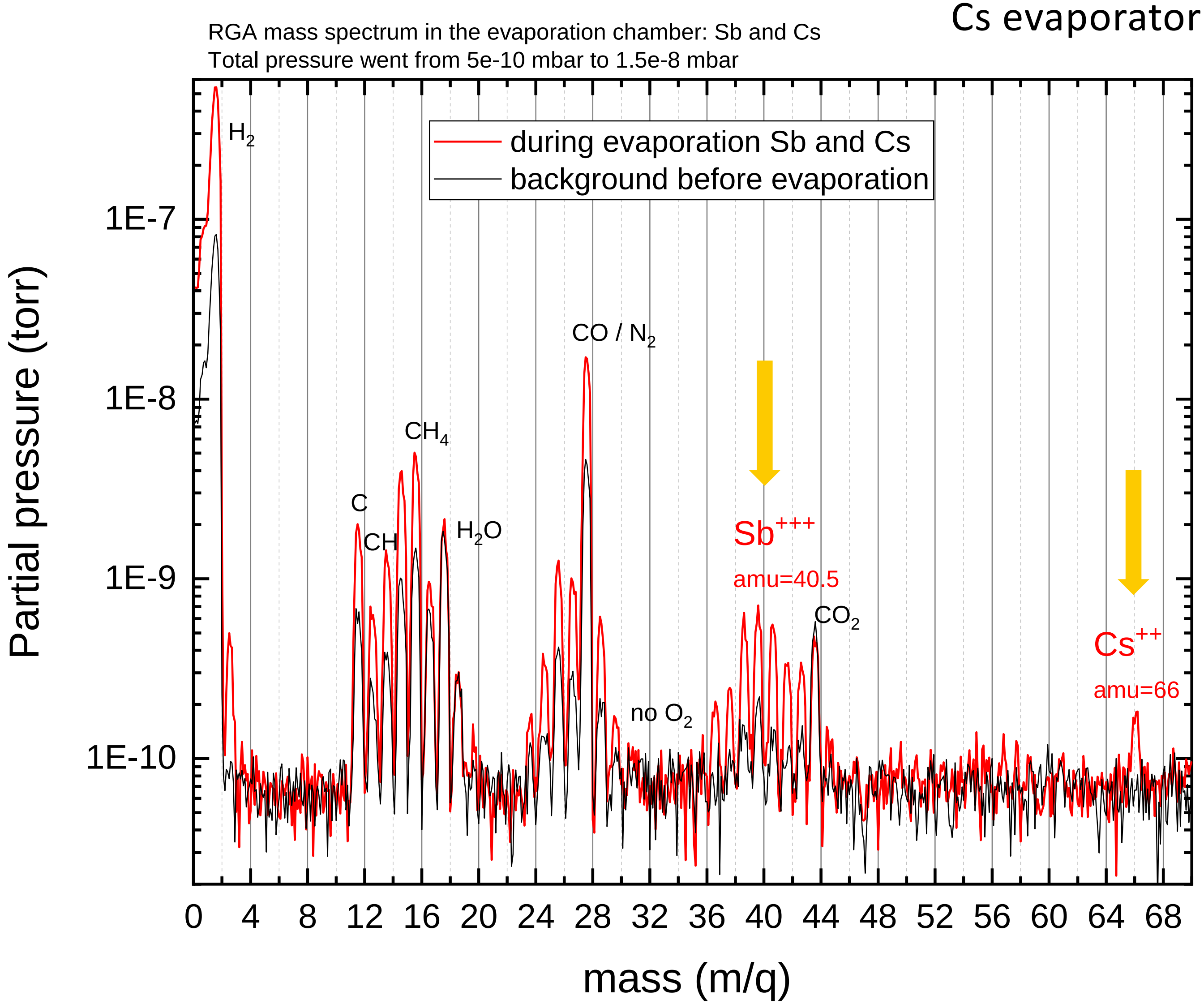
$T_{cathode}$=120°C,

Pressure increases to 1.5e-8 mbar

DC illumination with 532nm LED

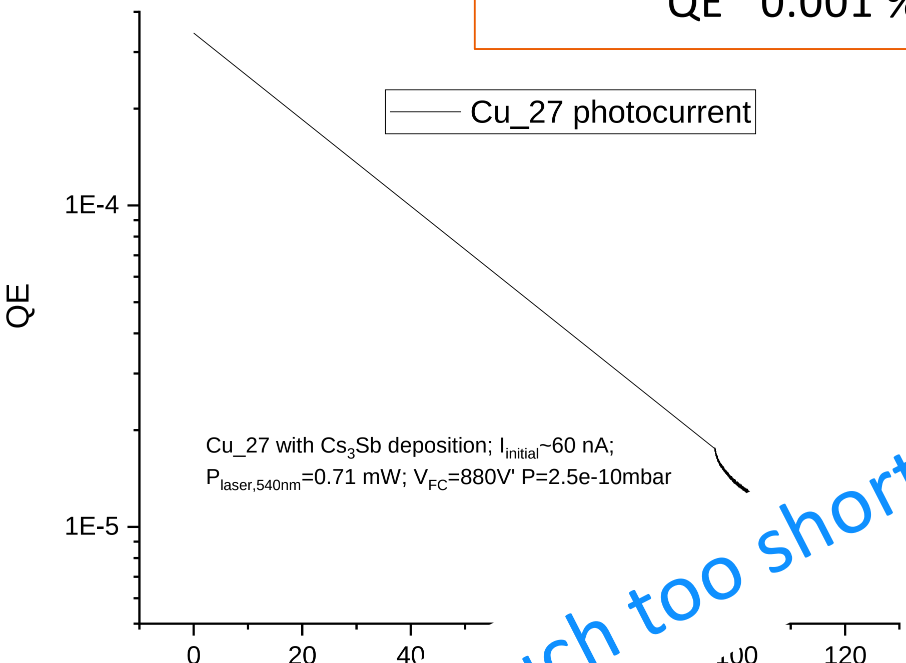
RGA during co-evaporation

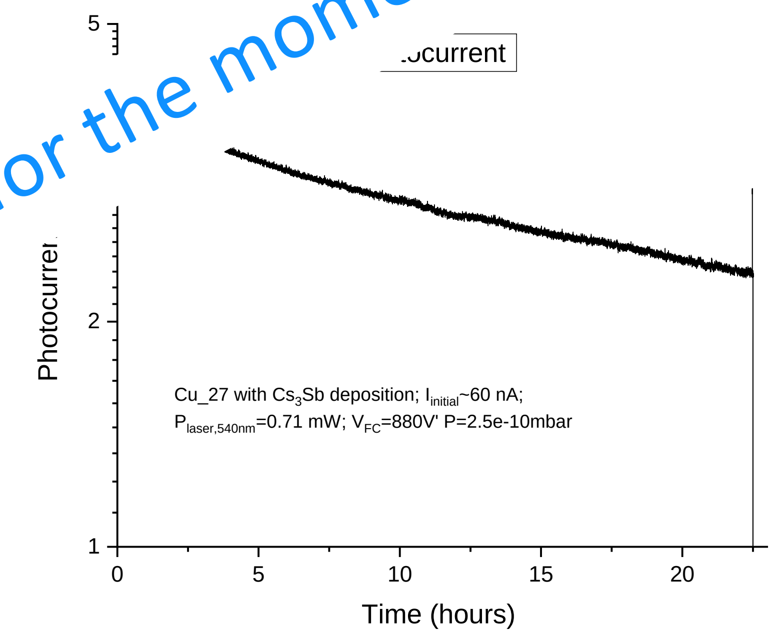
Sb evaporator heats up with Cs evaporator



QE Lifetime of Cs_3Sb cathode #27

Cs_3Sb: QE ~ 0.6% at end of deposition (650 nA)
QE~ 0.1 % after 1 hour
QE~ 0.001 % after 100 hours (w/o illumination)





Lifetime much too short … for the moment !

QE in gun factor 2 larger due to electric field.

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Conclusion

- Cs_2Te experience with SwissFEL user operation rather positive
- Lifetime seems > 1 year with 30 mC/year, 100 MV/m, 5.0×10^{-10} mbar
- Beam quality: slice emittance <300nm; small microbunching instabilities ?
- First Cs_3Sb coating had acceptable QE (>0.1%) but lifetime much too short

Perspectives:

- Photocathodes development with sensitivity to green light
  - Cs_2Te with Ge doping to reduce bandgap (532nm)
  - CdTe with Cs activation to reduce electron affinity

European Photocathode Workshop
11-13 September 2019 – PSI (Switzerland)

https://indico.psi.ch/internalPage.py?pageId=0&confId=6746

EWPAA 2019: European Workshop on Photocathodes for Particle Accelerator Applications

11-13 September 2019 *Paul Scherrer Institut; CH-5232l Villigen PSI; Hörsaal PSI Bildungszentrum: OSGA/EG06*

Europe/Zurich timezone

- **Welcome**
- Programm
- Registration
  - Registration Form
- Venue
- Accommodation
- Contact

Welcome to EWPAA 2019!

Dear Colleagues,

It is our pleasure to announce that the **European Workshop on Photocathodes for Particle Accelerator Applications (EWPAA 2019)**, will be held at the **Paul Scherrer Institut, Switzerland, from September 11 to 13, 2019.**

We invite you to participate to this workshop with focus on the recent progress in research and development of photocathodes for accelerator applications. Contributions are welcome from all related topics, including operational experience, preparation, instrumentations, theoretical modelling, industrial applications and novel materials. The scientific programme of the workshop will consist of invited talks and contributed presentations, either in the form of oral presentations or posters.

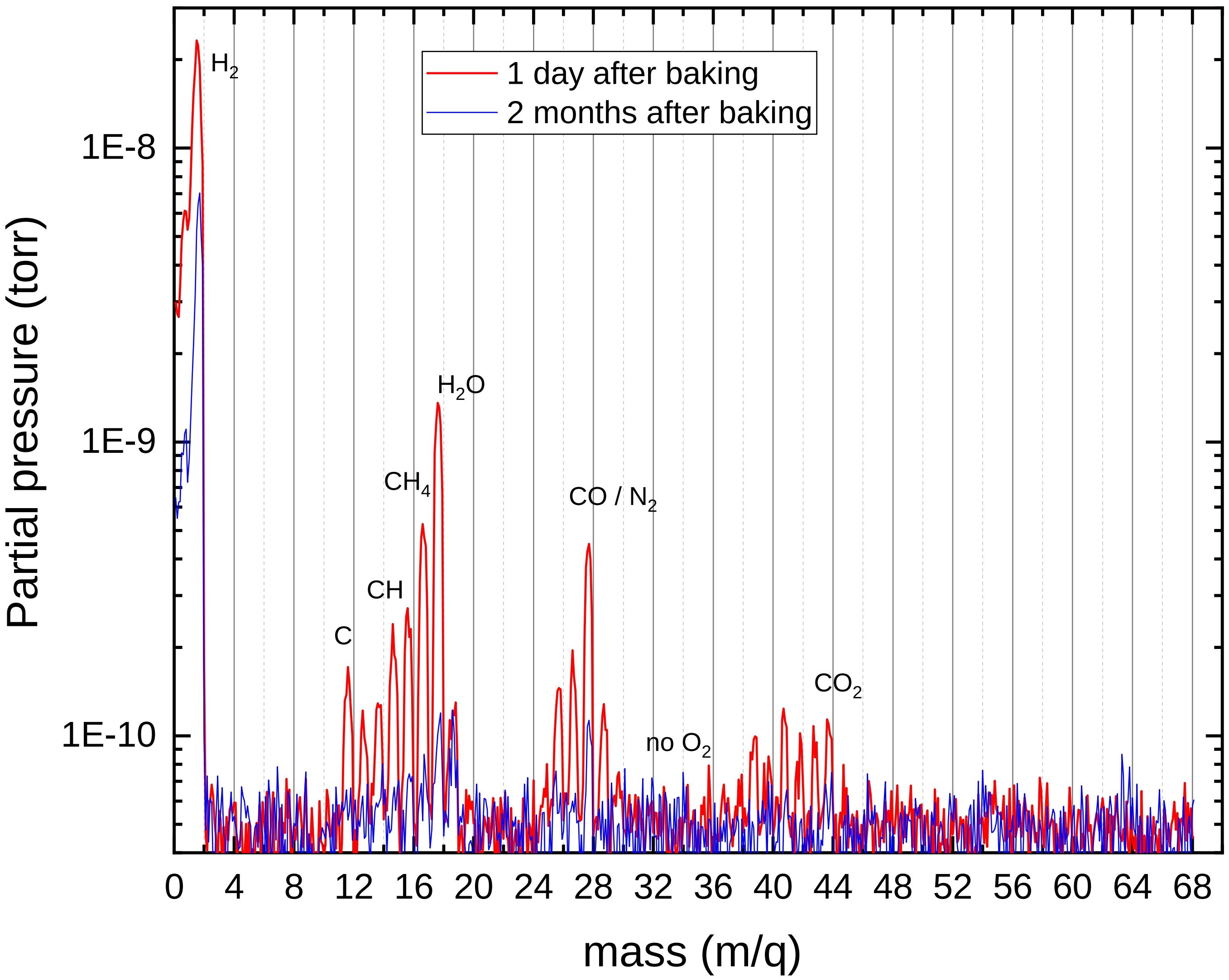
The workshop will be held from **Wednesday noon to Friday noon** with the Wednesday afternoon assigned for the poster session and Thursday afternoon for a visit at the SwissFEL facility and the photocathode laboratory as well as the workshop dinner.

Registration and abstract submission will be opened in March 2019.

Scientific Programme Committee
Julius Kühn (HZB)
Thorsten Kamps (HZB)
Tim Noakes (UKRI STFC)
Lee Jones (UKRI STFC)
Rong Xiang (HZDR)
Antonella Lorusso (INFN Lecce)
Christoph Hessler (CERN)
Romain Ganter (PSI)

Background Vacuum

RGA mass spectrum in the evaporation chamber: Sb and Cs after 100 h baking at 250 deg C
Total pressure 9.e-11 mbar - 17.07.2018



SwissFEL Aramis FEL

Aramis FEL pulses:

$E_{Photons}$: max 12.4 keV

Achieved FEL Pulse Energy:

570 µJ at 3 keV

400 µJ at 6 keV

… still under improvement