

Cesium Telluride Photocathodes for the Eu-XFEL and FLASH

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HELMHOLTZ



Agenda

01 Introduction

- DESY accelerators
- Deposition setup for photocathodes

02 Cs₂Te photocathode

- Plugs
- Deposition parameters
- Coating thickness deviations

03 Overview of past coatings

- Thick coating
- Performance and lifetime in the machines

04 QE measurements

- Degradation and recovery FLASH
- Degradation and recovery XFEL

05 Conclusions

06 Appendix

Introduction

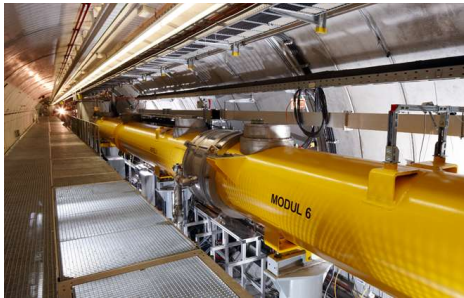
DESY accelerators

Accelerator & Projects at DESY

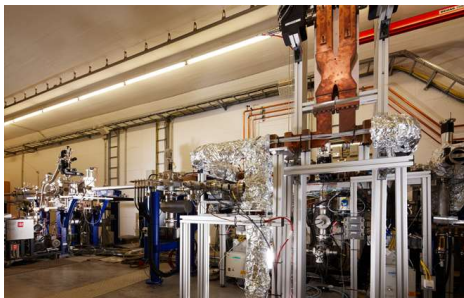
- European XFEL
- PETRA III
- FLASH
- REGAE
- DESY II
- PITZ
- ARES
- PETRA IV (future project)



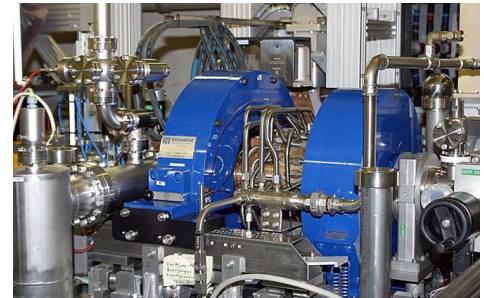
European XFEL



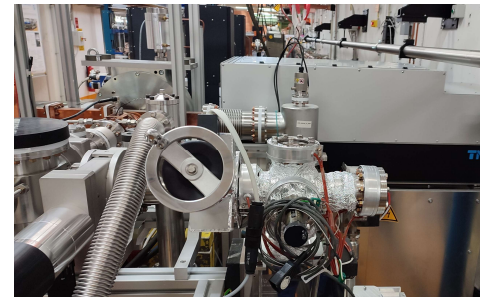
FLASH



REGAE



PITZ



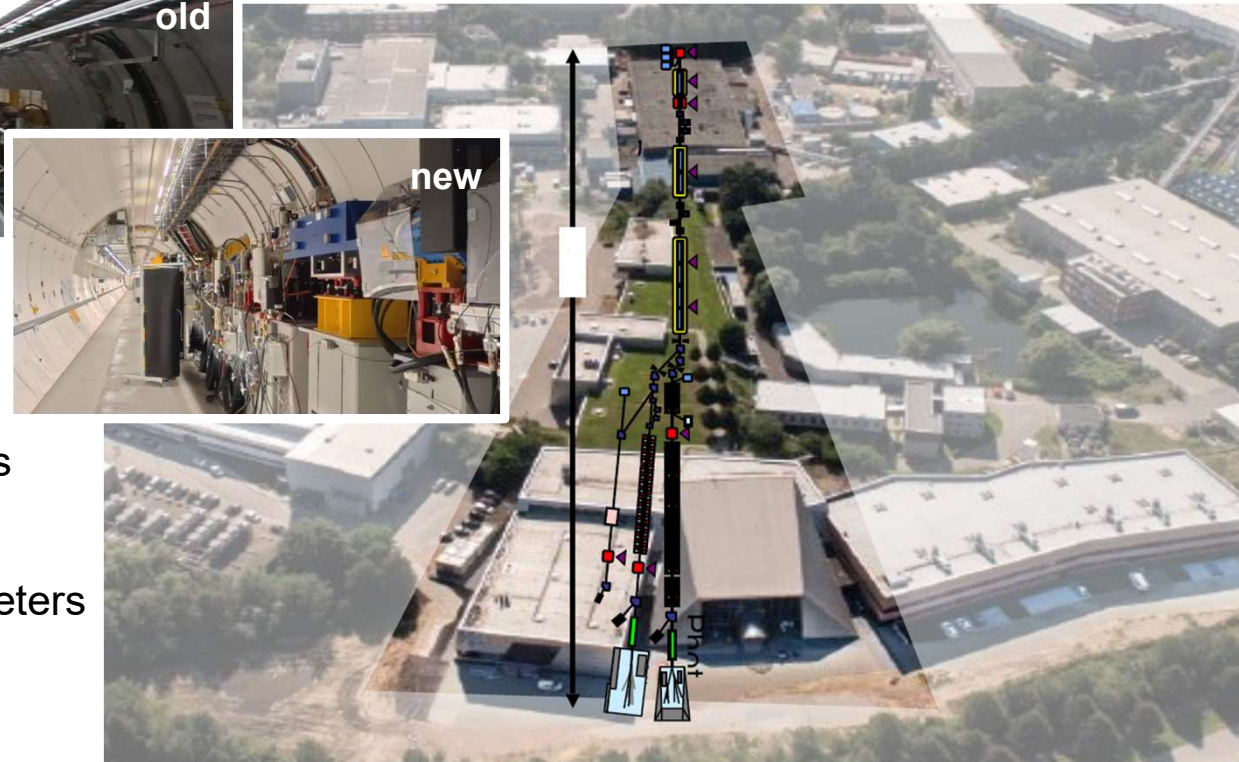
ARES

Introduction

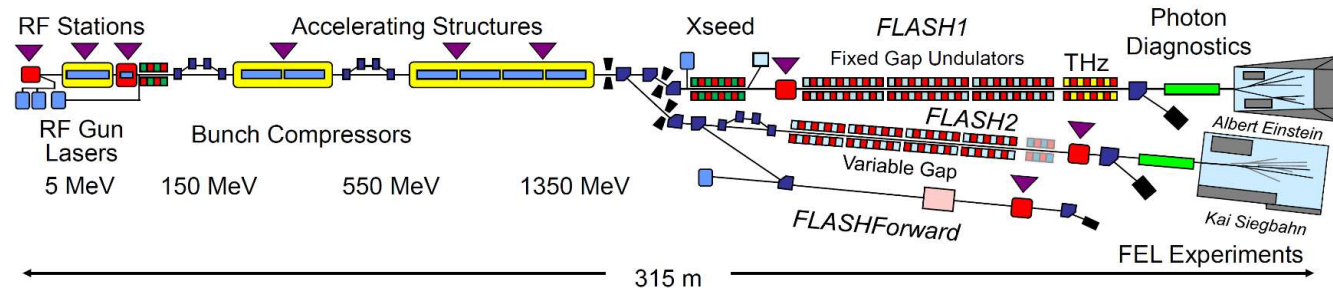
DESY accelerators

FLASH → FLASH2020+

- Extensive refurbishment of FLASH and the accelerator tunnel until August 2025
- First soft X-ray FEL user facility that operates **two undulator beamlines simultaneously**
- Improved photon- and electron beam parameters

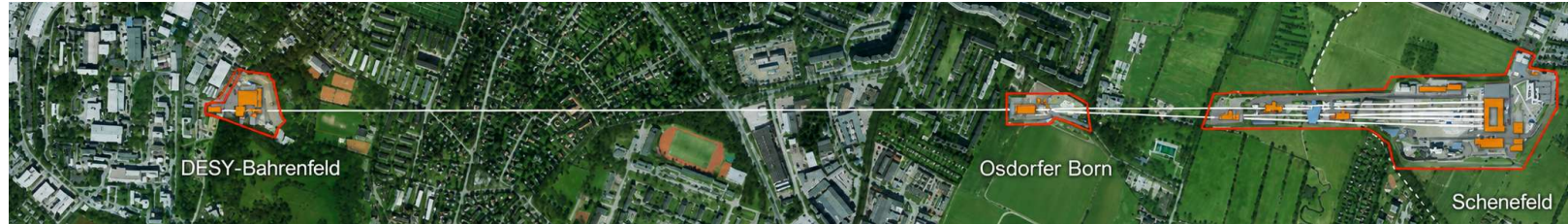


parameter	unit	value
facility length	m	315
energy	GeV	1.35
bunches per second	Hz	5000
emittance	$\mu\text{m rad}$	0.4
bunch charge	nC	0.01... 1.2
photon wavelength	nm	51... 3.4
ph. pulse duration	fs	30... 200



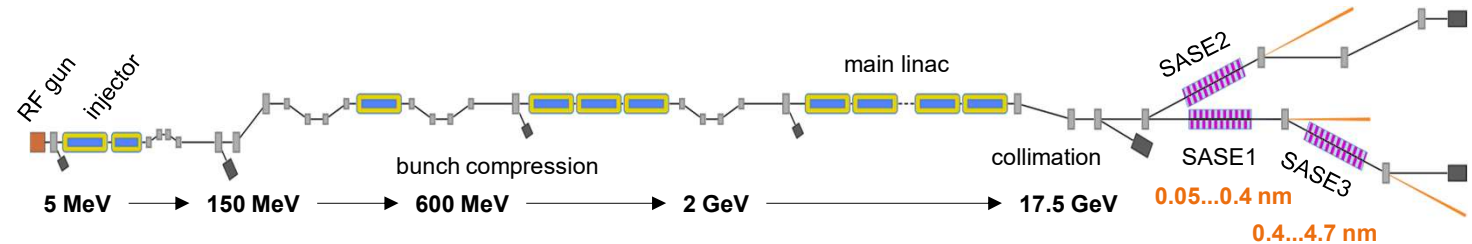
Introduction

DESY accelerators



European XFEL

- Laser driven RF-gun
- 3 bunch compressors
- 96+2 1.3 GHz superconducting accelerator modules
- Up to 600 kW beam power
- Three variable gap undulators
 - SASE1 and SASE2
 - 175 m magnetic length
 - 0.05 – 0.4 nm wavelength (25 keV – 3 keV)
 - SASE3
 - 105 m magnetic length
 - 0.4 – 4.7 nm wavelength (3 keV – 0.26 keV)

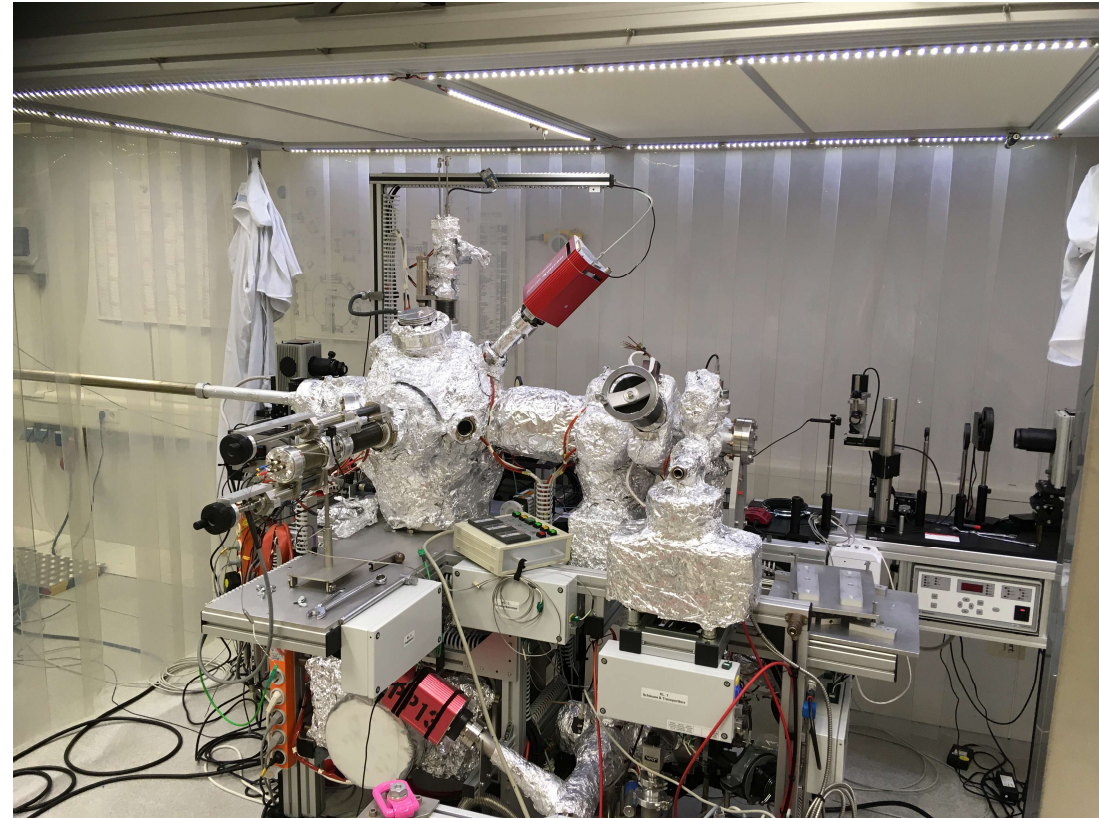


parameter	unit	value
facility length	m	3.4
energy	GeV	17.5
bunches per second	Hz	27000
emittance	$\mu\text{m rad}$	0.8
bunch charge	nC	0.02... 1.0
photon wavelength	nm	4.7... 0.05
ph. pulse duration	fs	<100

Introduction

Deposition setup for photocathodes

- INFN LASA deposition system design
- Assembled by LASA in close collaboration with DESY
- All components are 100 % compatible with the Milano system

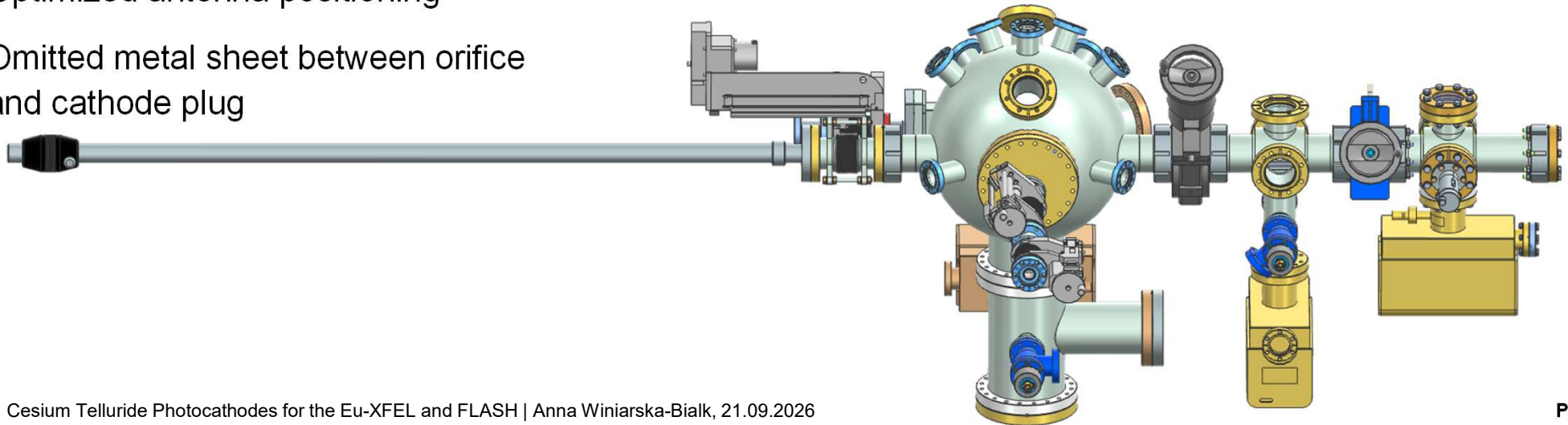
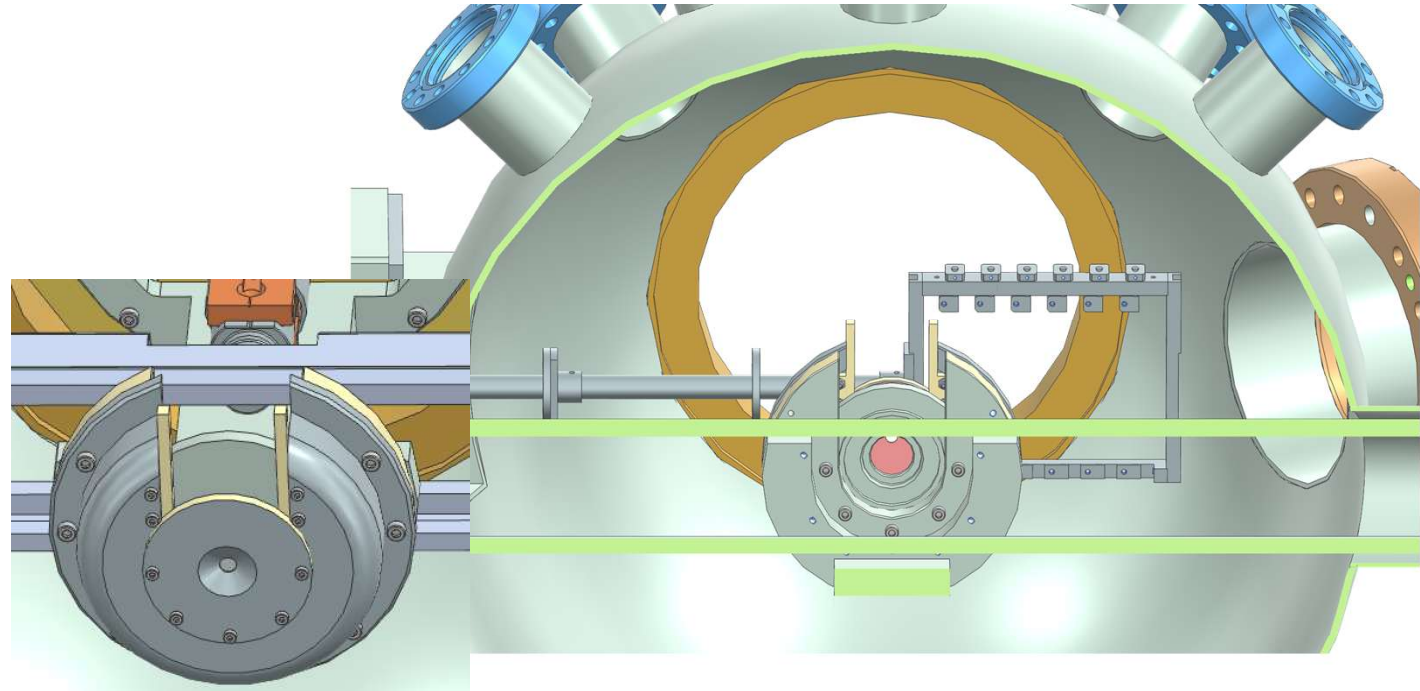


Introduction

Deposition setup for photocathodes

Deposition system improvements

- Reduced system length
- Rectangular flange geometry
- Cutout in the rail for better view
- Improved temperature monitoring
- Optimized antenna positioning
- Omitted metal sheet between orifice and cathode plug

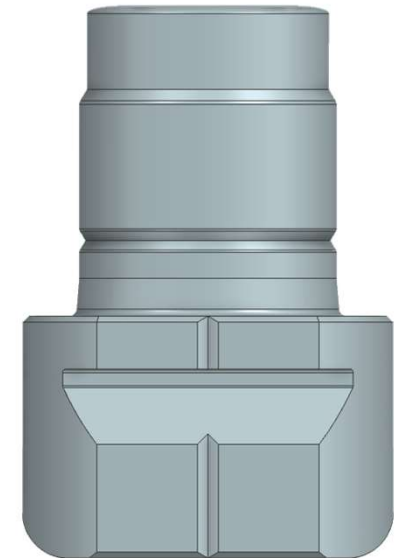
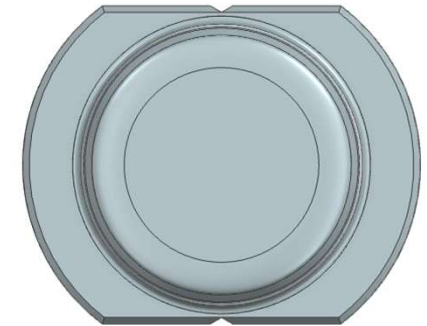
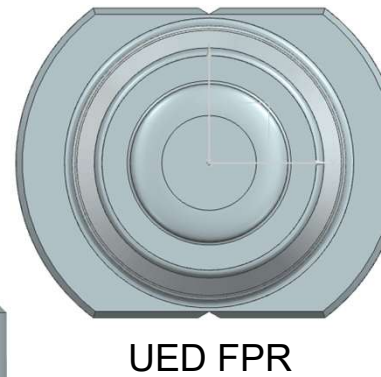
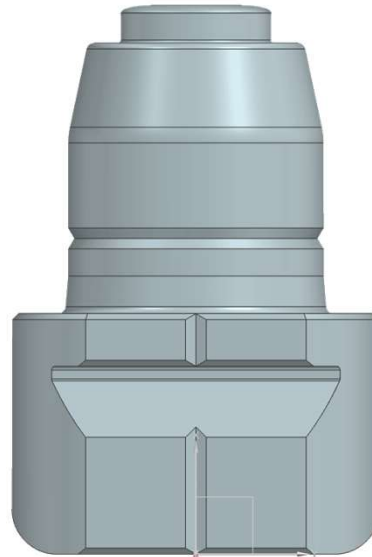
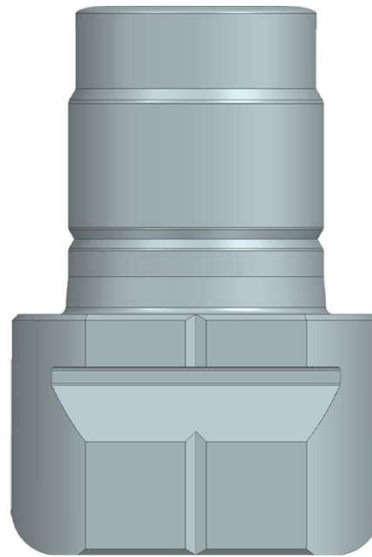


Cs₂Te photocathode

Plugs

Material and design

- Molybdenum plugs
- FEL
 - elliptical (before circular)
- PITZ/XFEL
- UED FPR
 - elliptical (before circular)



PITZ/XFEL

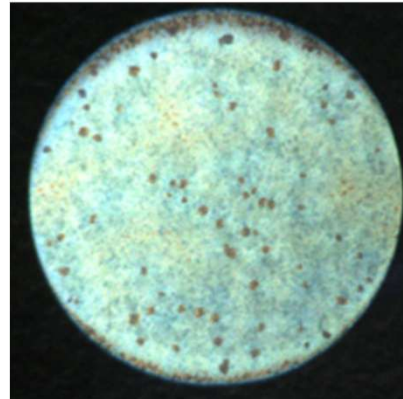
Cs₂Te photocathode

Deposition parameters

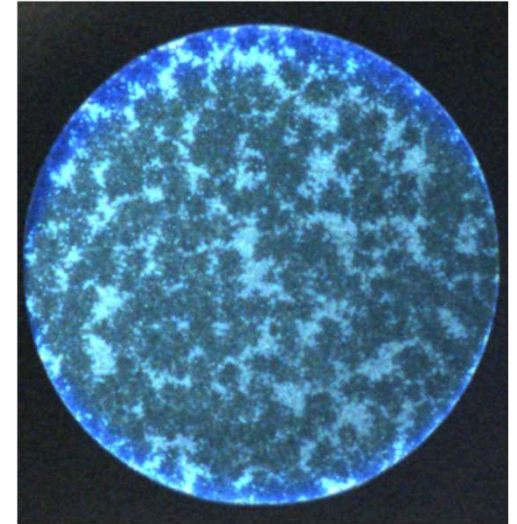
Standard parameters - recipe from INFN Milano

- Plug is heated to 450 °C then kept at 120 °C
- Temperature during deposition: 100-110 °C
- Duration of the whole process: ~2 h
- Spot size ca. 5 mm
- Thickness:
 - Te: 10 nm - 1st layer
 - Cs: ~50 nm - 2nd layer

14.07.2022 0748.1
QE 9,8%
I(Te) 3,24 A 10nm I(Cs) 4,85 A 50nm



13.07.2022 0727.2
QE 12,96%
I(Te) 3,24 A 10nm I(Cs) 4,7 A 50nm



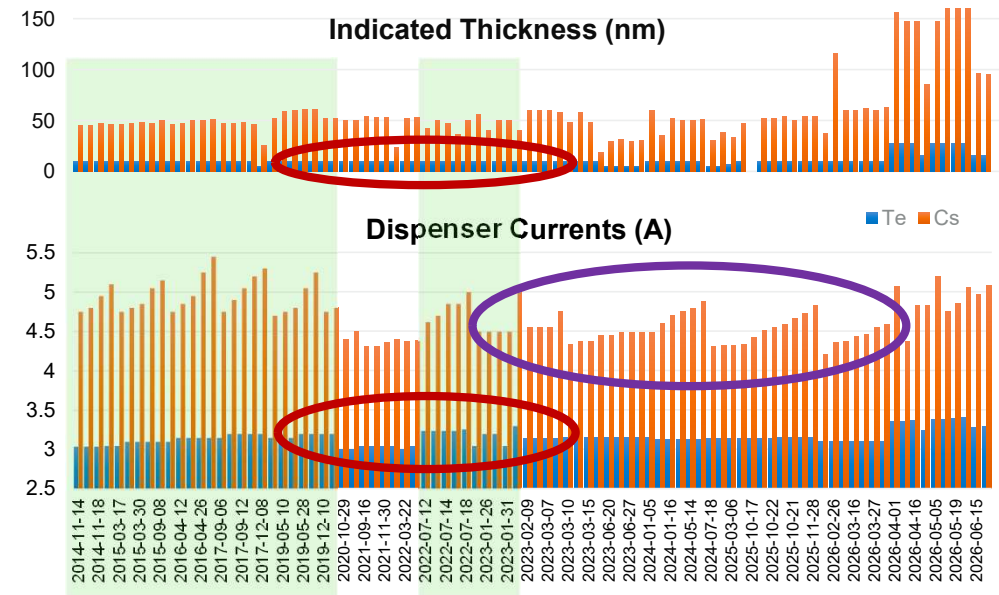
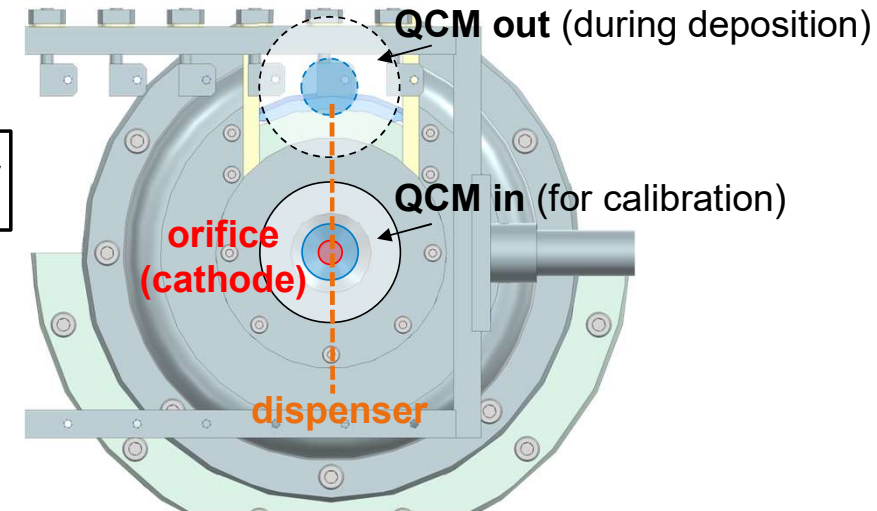
Cs₂Te photocathode

Coating thickness deviations

Problems with thickness monitor...

- **Measurement range** of thickness monitor (Inficon SQM-160) set too high for direct readout
 - **Area factor** of quartz crystal microbalance (QCM) not always or falsely considered in LabVIEW programs
 - The problem was indicated by **changing dispenser currents** (3.0→3.2 A) and **lifetimes** (5→10+ coatings)
 - Same Te dispenser used since beginning!
 - Te dispenser current dropped in 2020 and 2023 while the Cs lifetime increased significantly (usually 4-5 coatings)
- Most **coatings** in the past were **much thicker** than indicated by the programs!
(rate increased by area factor)

$$\text{area factor} = \frac{A_{qcm}}{A_{orifice}} \sim 2.7$$



Overview of past coatings

Thick coating

Improved coating thickness control

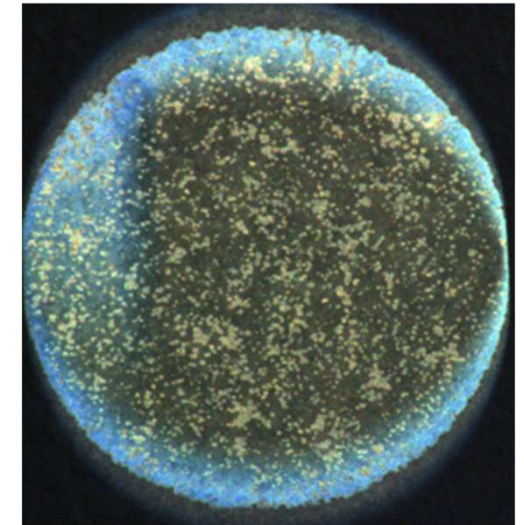
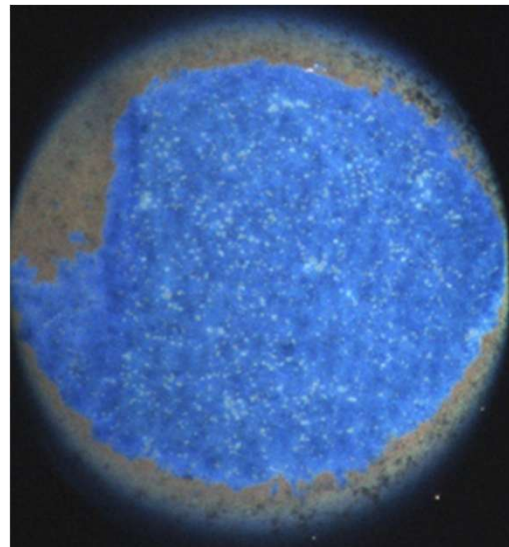
- A new coating thickness determination method was introduced after identifying issues with the area factor
- The new approach provides more accurate and consistent thickness measurements
- It enables better monitoring and comparison of coating variations between photocathodes

05.05.2026
QE 17.1%
I(Te) 3,38 A
I(Cs) 5,20 A
Temp. 103°C

1117.3
QE(map) 18%
27nm
147nm

15.06.2026
QE 13,5%
I(Te) 3,28 A
I(Cs) 4,96 A
Temp. 91,5°C

734.2
QE_(map) 16,8%
15nm
96nm

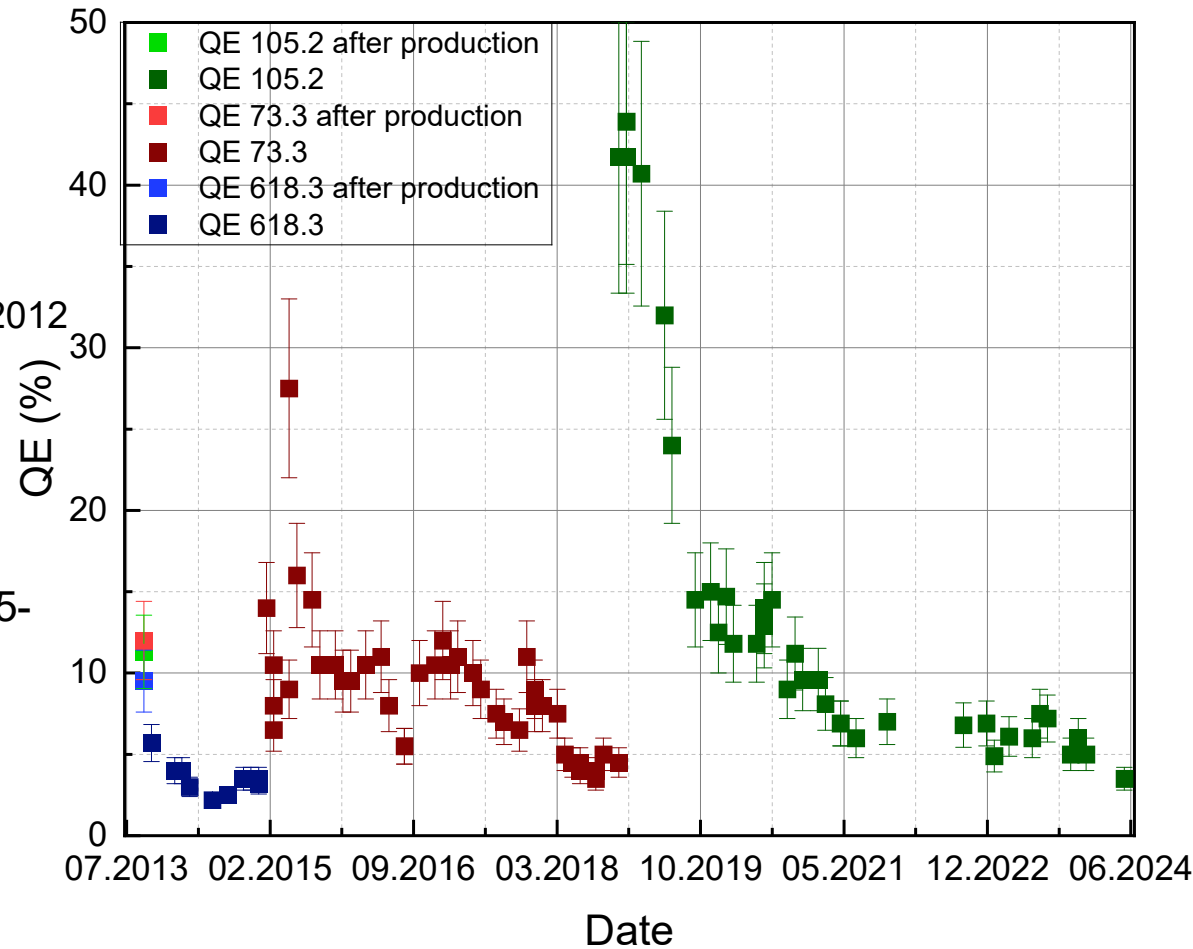


Overview of past coatings

Performance and lifetime in the machines

FLASH:

- #76.3 around 150 days in operation
 - #91.2 around 130 days in operation
 - #77.2 around 175 days in operation
 - #98.2 around 70 days in operation
 - #90.3 around 55 days in operation
 - #114.2 around 100 days in operation
- 2009-2012
- #618.3 since December 2013 until February 2015-439 days in operation
 - #73.3(Milano) since February 2015 until December 2018 - 1413 days in operation
 - #105.2(Milano) since December 2018 until now

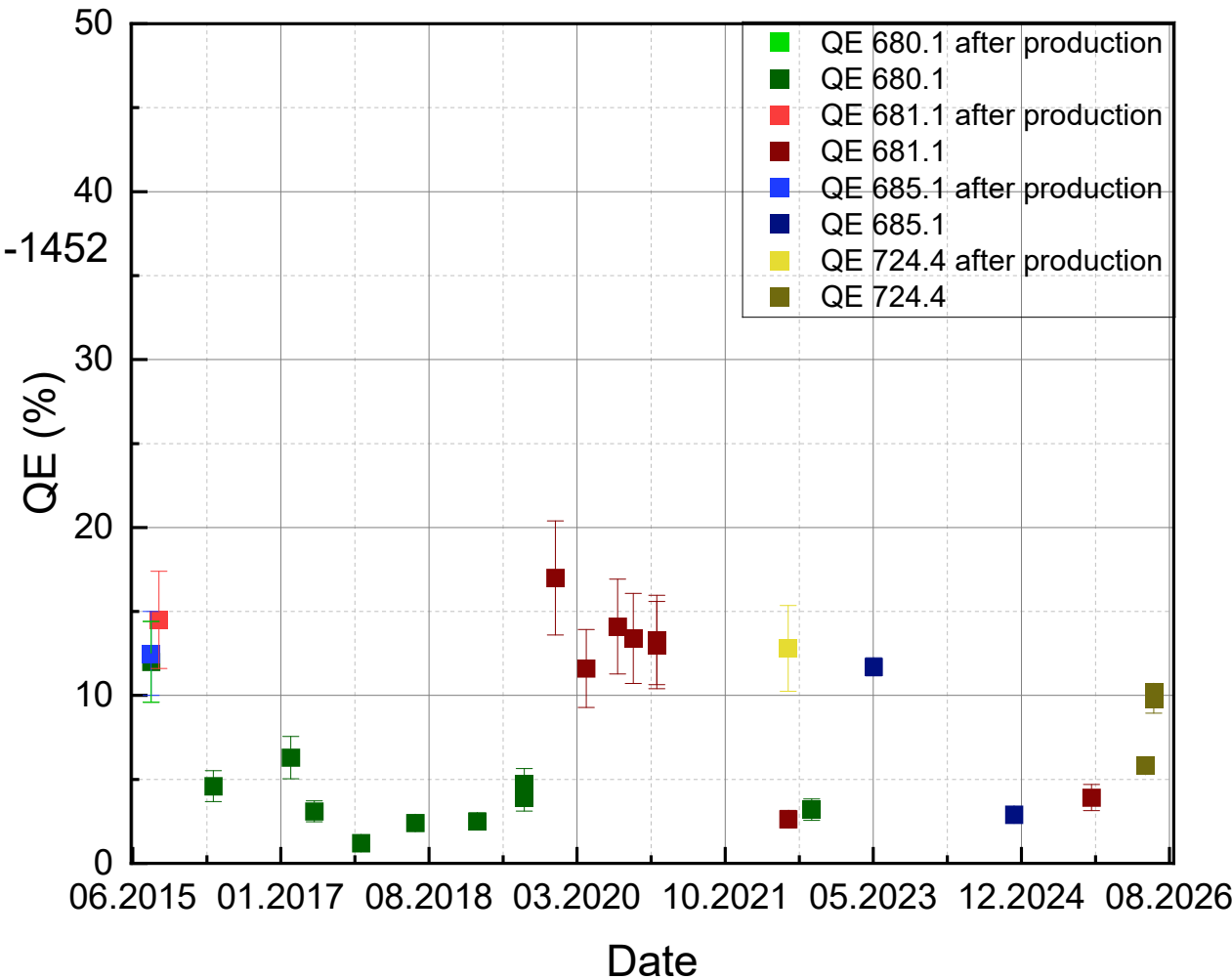


Overview of past coatings

Performance and lifetime in the machines

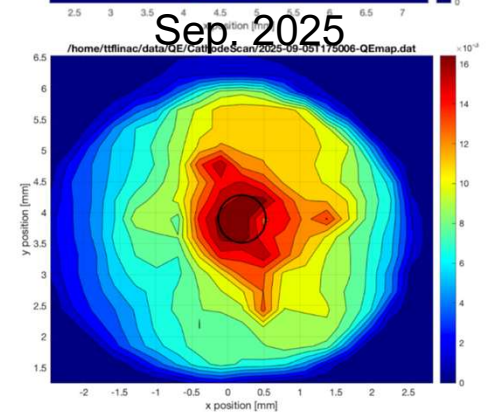
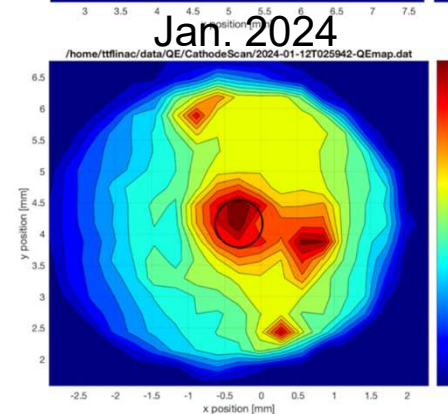
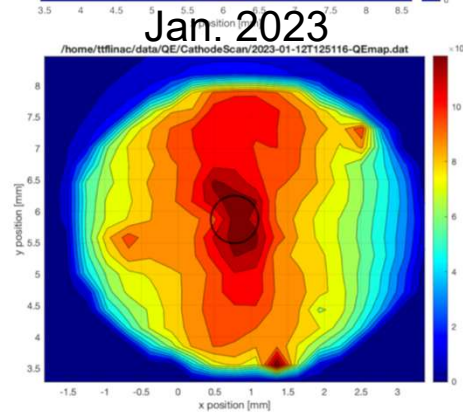
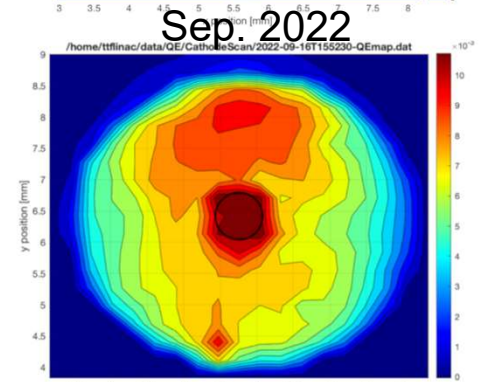
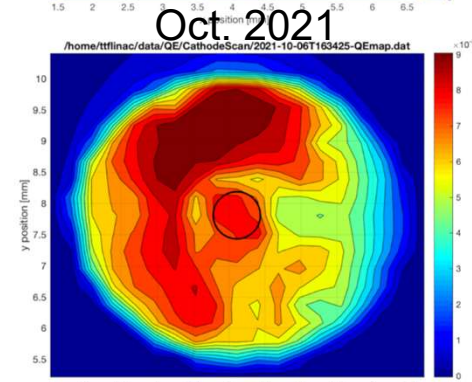
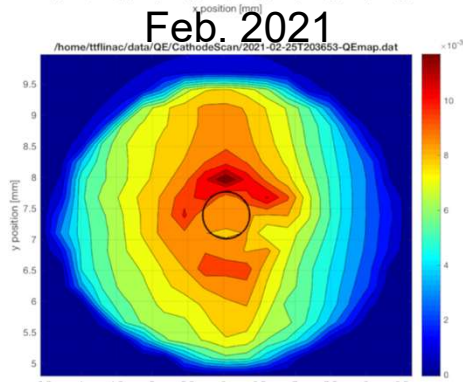
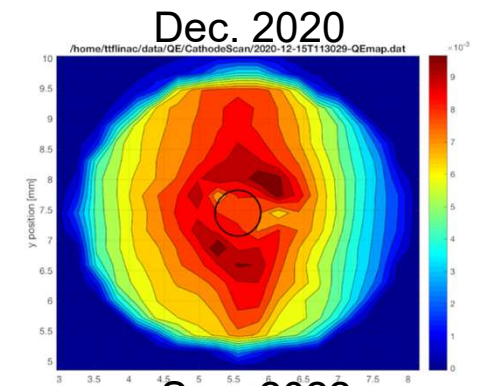
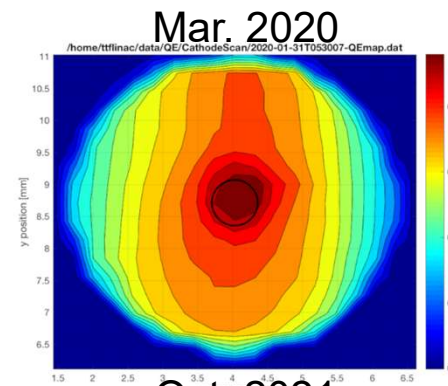
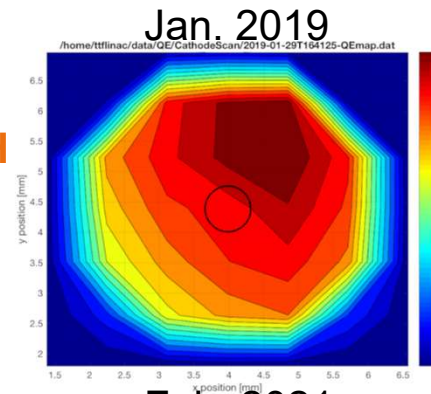
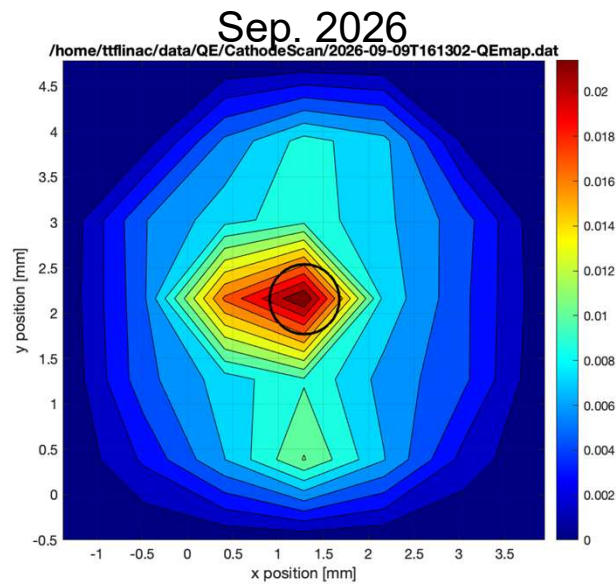
XFEL:

- #680.1 since December 2015 until July 2018 -1452 days in operation
- #681.1 since January 2020 until June 2022
- #681.1 since July 2022 until October 2022 (180 deg rotated in comparison the last time)
- #685.1 since October 2022 until July 2025
- #724.4 since November 2025 until July 2026
- #1117.3 since July 2026 until now



QE measurements

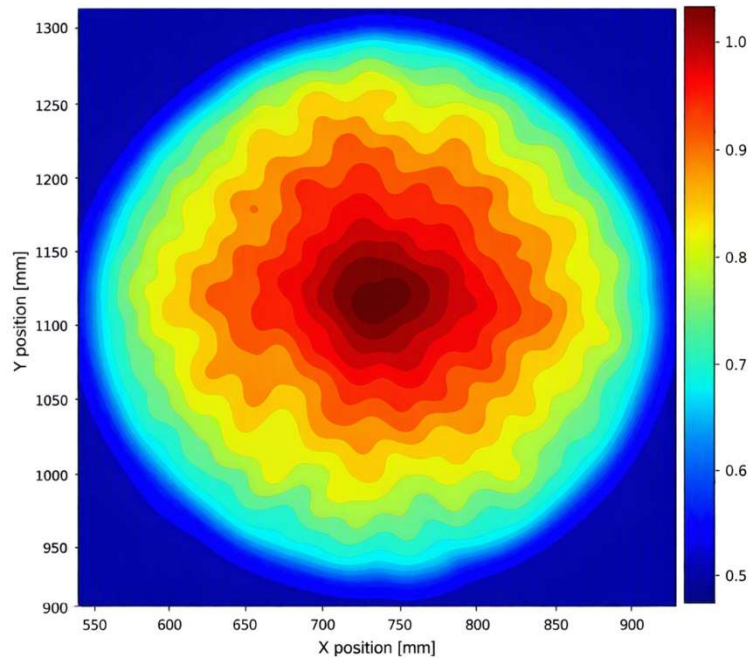
Degradation and recovery FLASH



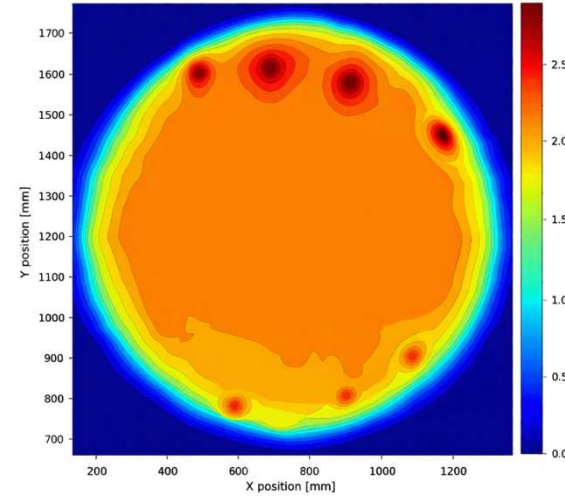
QE measurements

Degradation and recovery XFEL

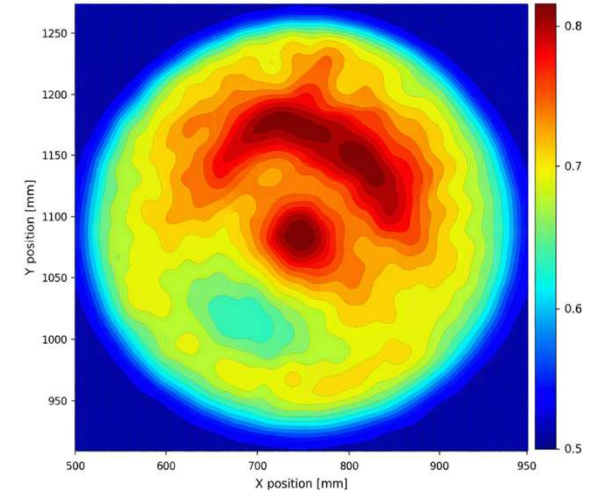
2 Jun. 2026



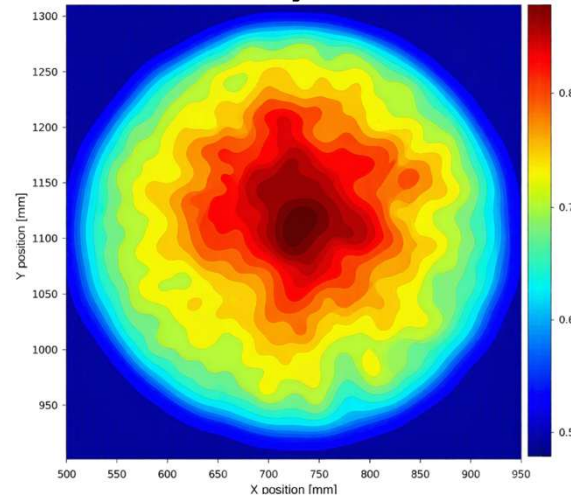
10 Jan. 2026



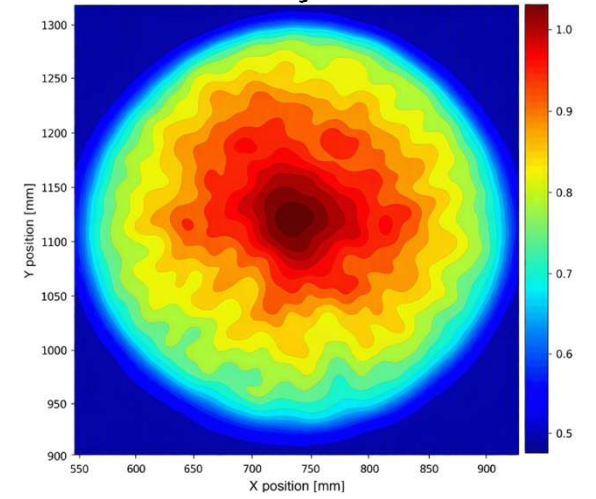
7 May 2026



18 May 2026



26 May 2026



Conclusions

- **Deposition system:** new design with improved functionality and usability
- **Plugs:** continuous development driven by evolving RF gun requirements
- **Coating thickness:** improved monitoring enables systematic investigation of thickness–performance correlations
- **Cs₂Te:** high QE + long lifetime → well suited for FLASH & European XFEL

Thank you

Grateful acknowledgment is made to **Juliane Rönsch-Schulenburg** and **Frank Brinker** for their vital support in performing the measurements and providing the data.

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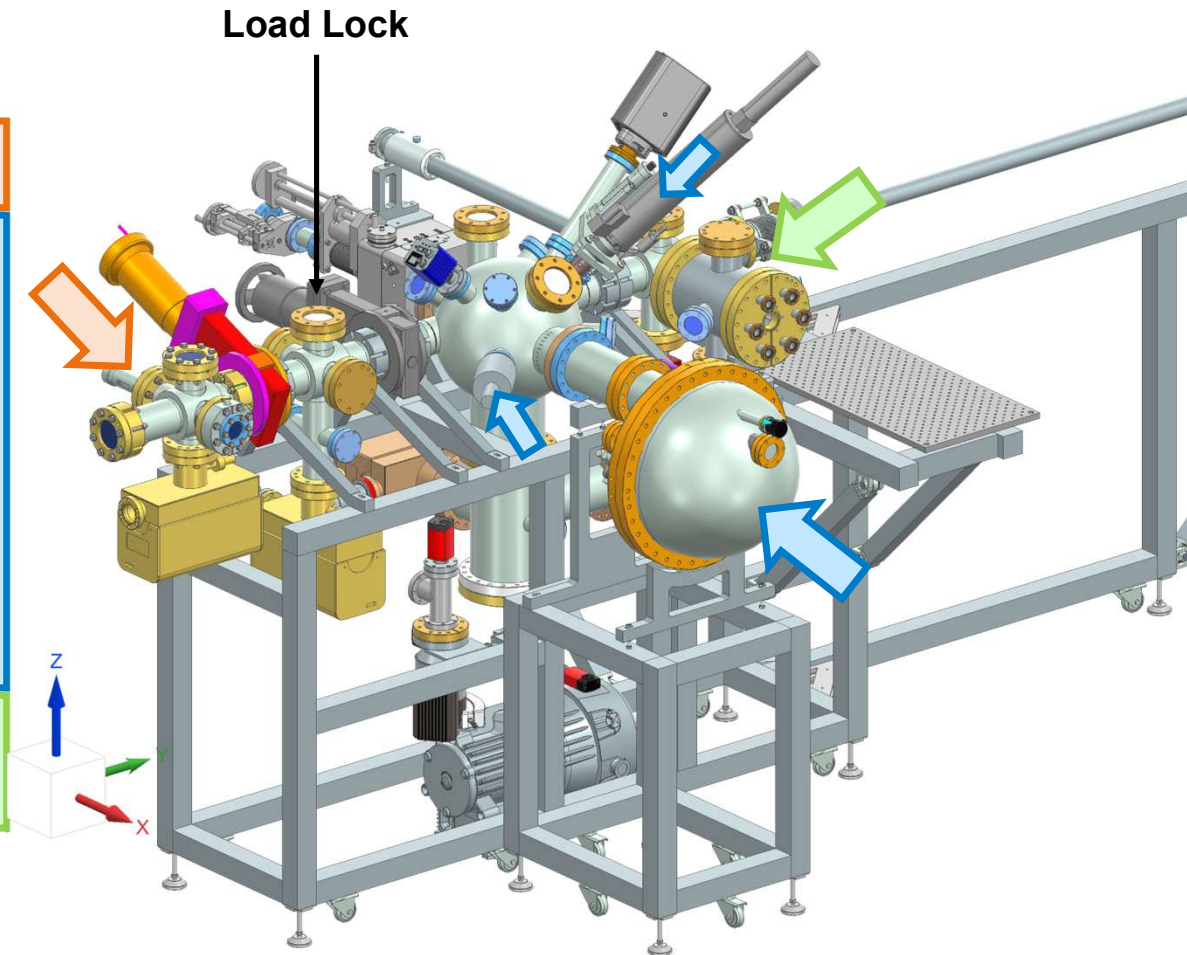
Appendix

Appendix

Complementary XPS and AES measurements

ELAS (ELectron Analysis System)

- Compatible with our cathode transport boxes
- Main chamber equipped with
 - **PHOIBOS 100** (SPECS)
 - **EGG-3101** (Kimball Physics Inc.)
 - **RS 40B1** (PREVAC)
 - **X-ray Photoelectron Spectroscopy (XPS)**
 - **Auger-Electron Spectroscopy (AES)**
- **Mean Transverse Energy (MTE)** measurement via attached **TEMA** setup



Appendix

Complementary XPS and AES measurements

TEMA (Transverse Energy Momentum Analyser)

$$MTE = \frac{eU_A}{2d^2} (\sigma_{\text{det}}^2 - \sigma_0^2)$$

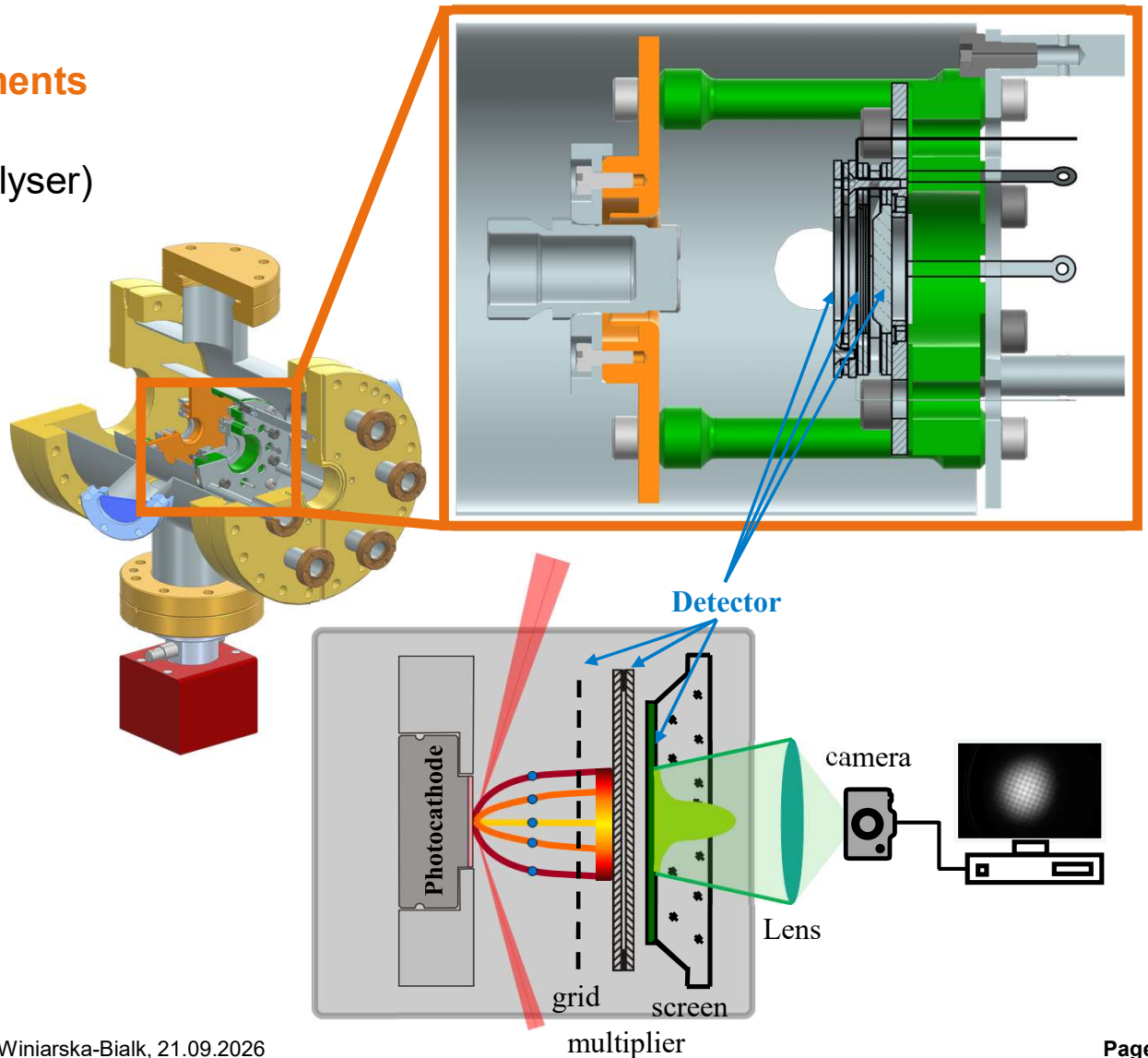
U_A : Acceleration voltage applied across the gap

d : Cathode to detector acceleration gap distance

σ_{det} : RMS radius of electron spot measured on the detector screen

σ_0 : RMS radius of the focused laser spot on the cathode surface

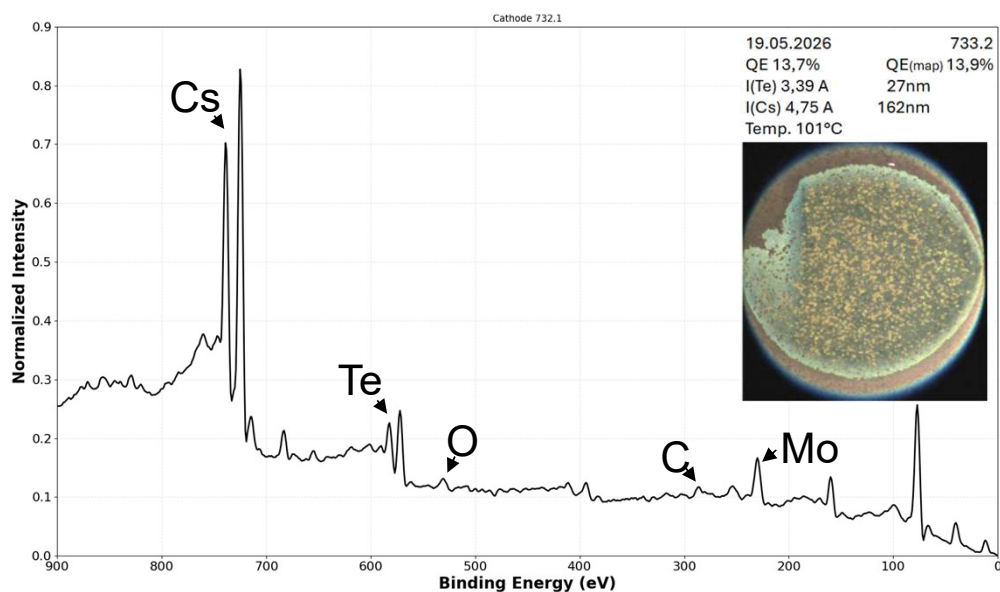
- Adapted to **TESS** design
 - Developed at ASTeC STFC Daresbury
see also: DOI [10.1063/5.0109053](https://doi.org/10.1063/5.0109053)



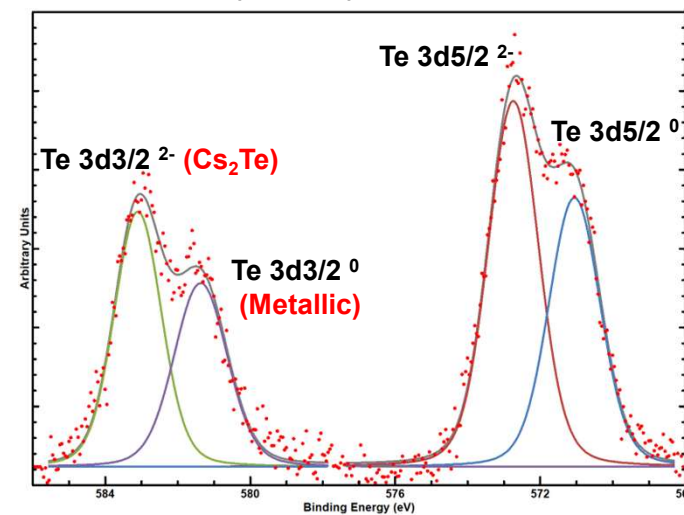
Appendix

Complementary XPS measurements

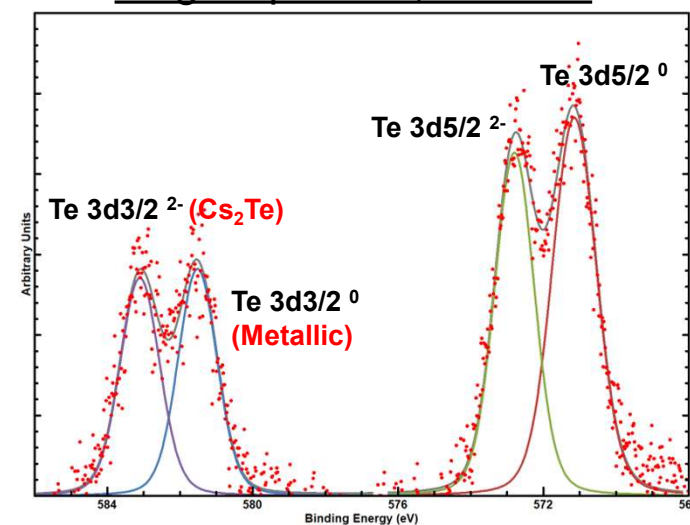
ELAS (XPS Cs_2Te):



High resolution (Te 3d) < 0.5 mm spot size:



Larger spot size, 1-2 mm:

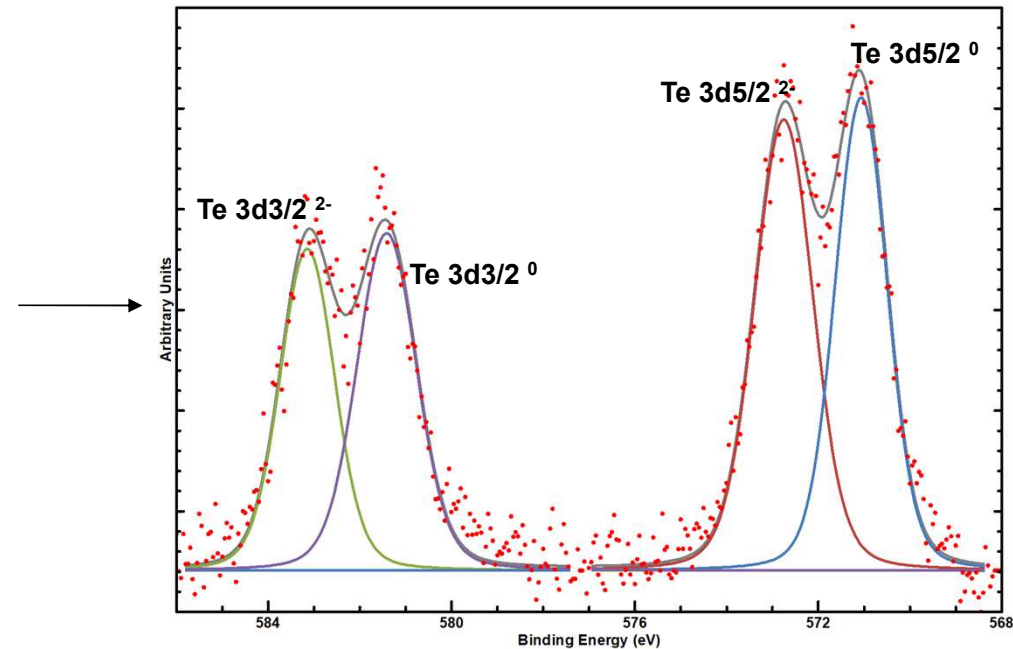
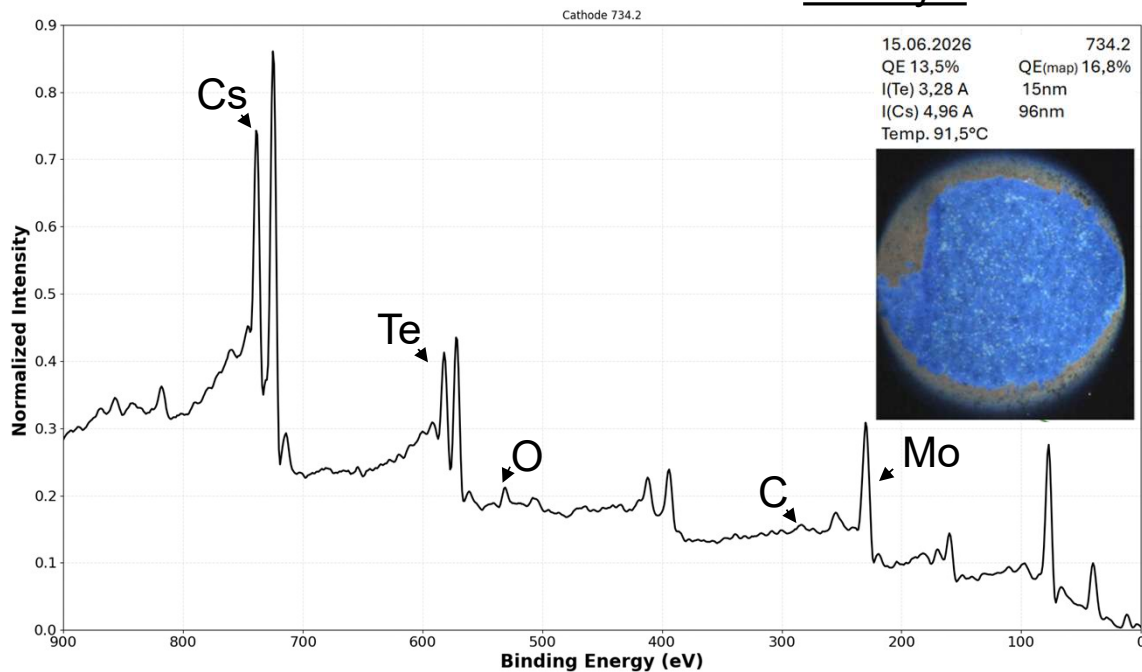


Appendix

Complementary XPS measurements

ELAS (XPS Cs₂Te):

Surveys:



Appendix

Complementary XPS measurements

ELAS (XPS Cs₂Te):

Surveys:

