AWAKE Collaboration Meeting
Photocathode Performance
and Production Reliability

Ralf Erik ROSSEL

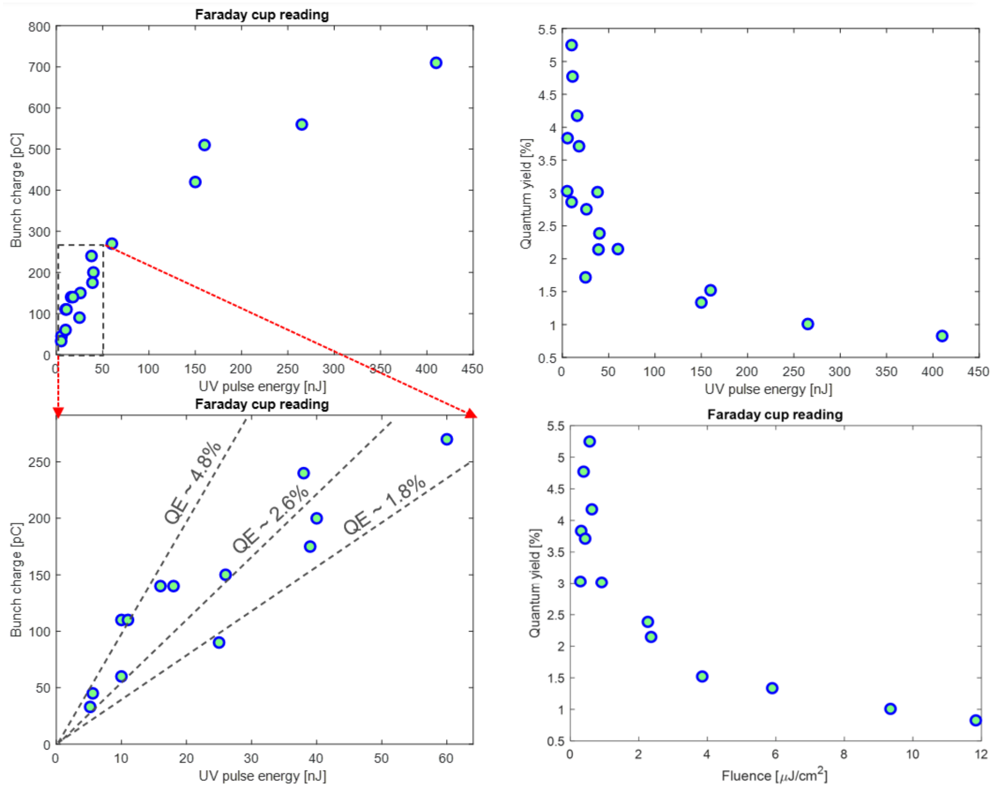
Wednesday, 13.03.2024

Content Outline

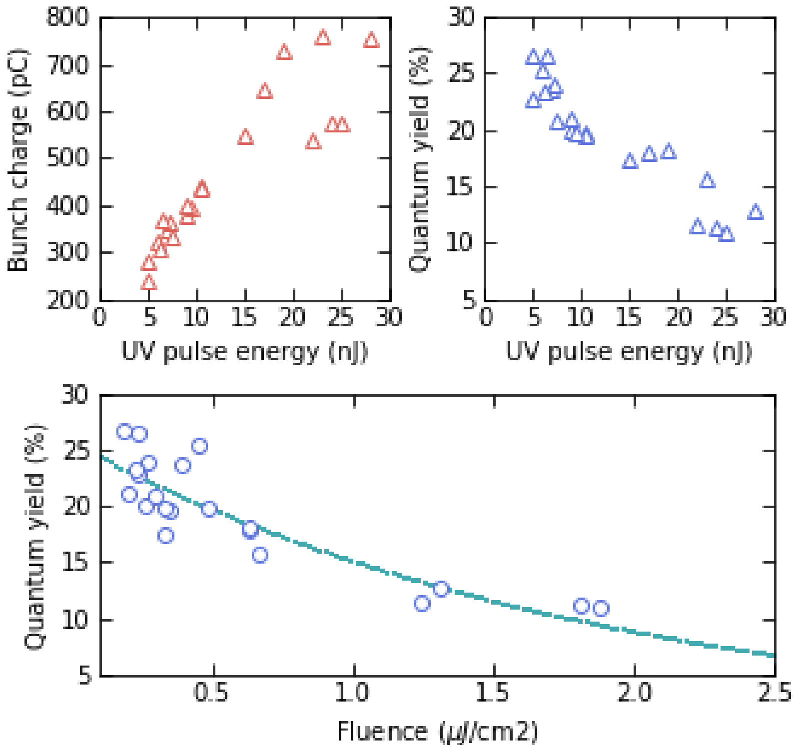
- **AWAKE Photocathode Performance 2021 to 2024**
- **CERN Photoemission Laboratory Setup**
- **Photocathode Production Process and Analysis**
- **R&D, Future Work, and Outlook**

AWAKE Photocathode Performance 2021 and 2022

2021: Photocathode reached end of life, replaced with new high-QE photocathode

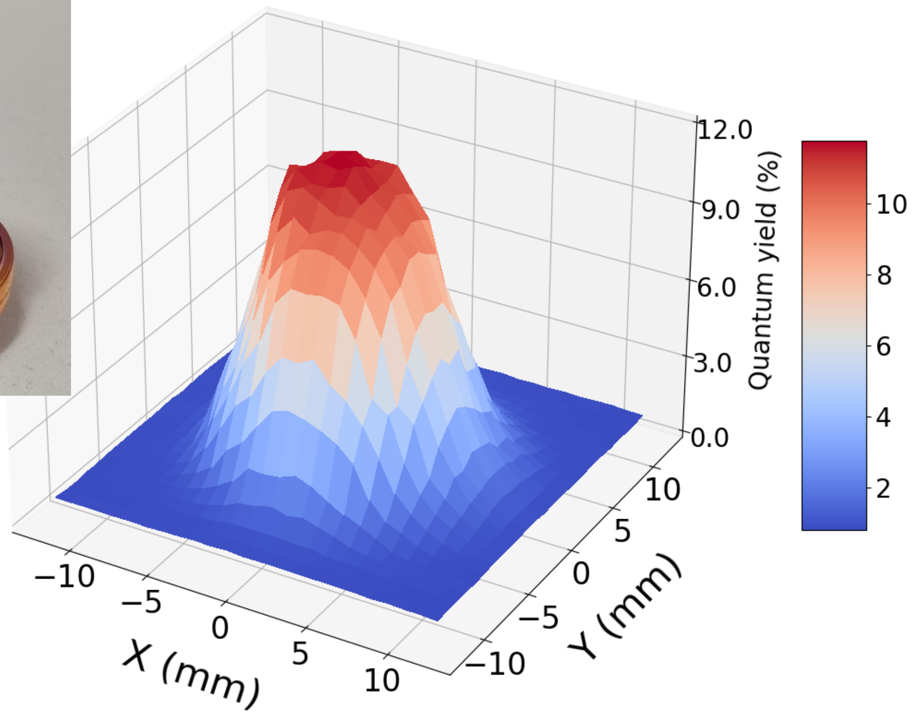


2022: High-QE photocathode replaced after vacuum incident in winter 22 / 23

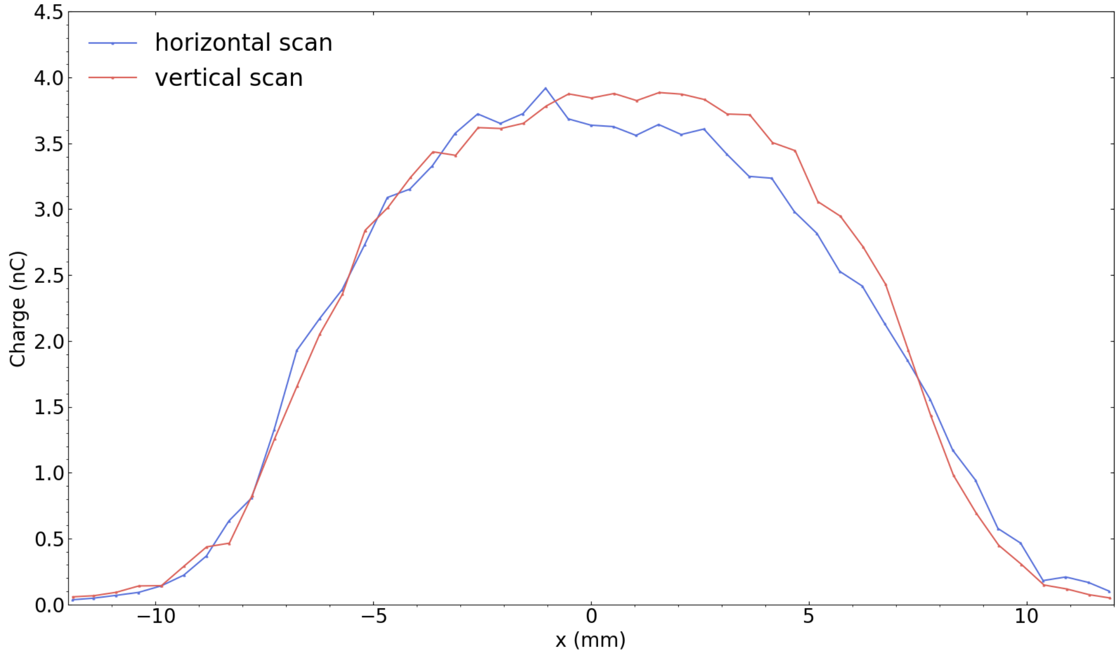


Photocathode #229 Installed at AWAKE in May 2023
Fabrication Results in CERN Photoemission Laboratory

Measured around 12% quantum yield in the Photoemission Lab in 2022



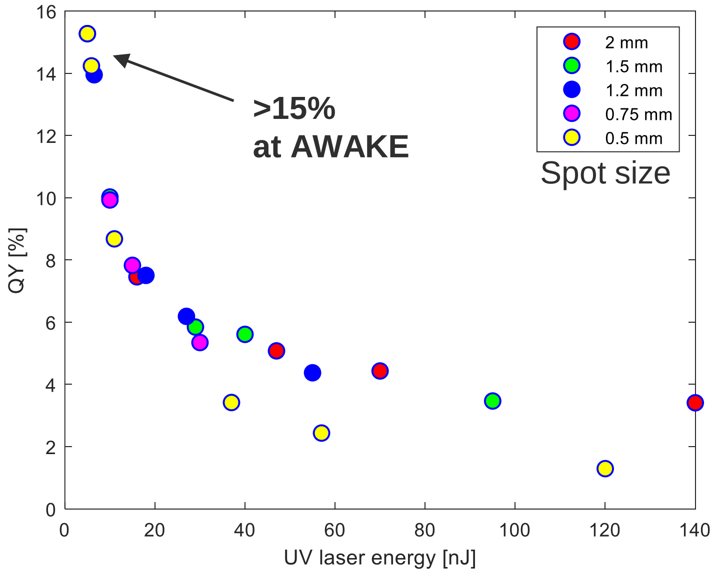
Stored since production in static UHV transport vessel docked to RF gun



AWAKE Photocathode Performance 2023

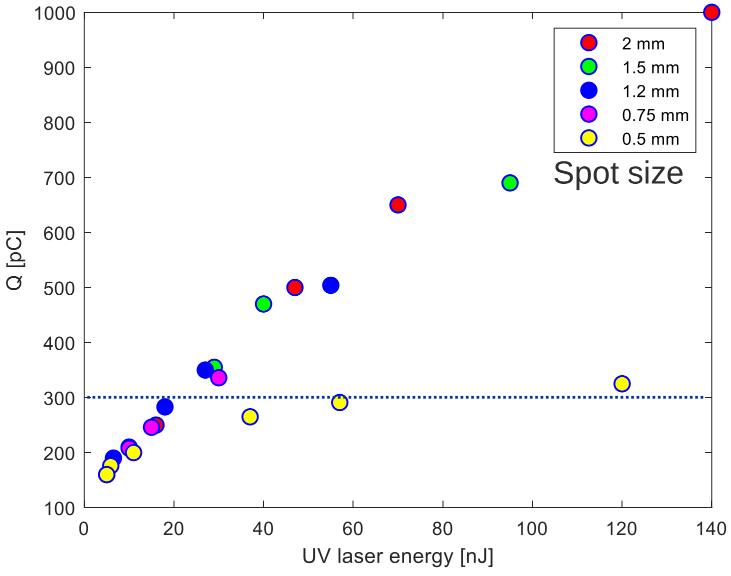
Quantum Yield

Photoemission Lab estimate was 12%



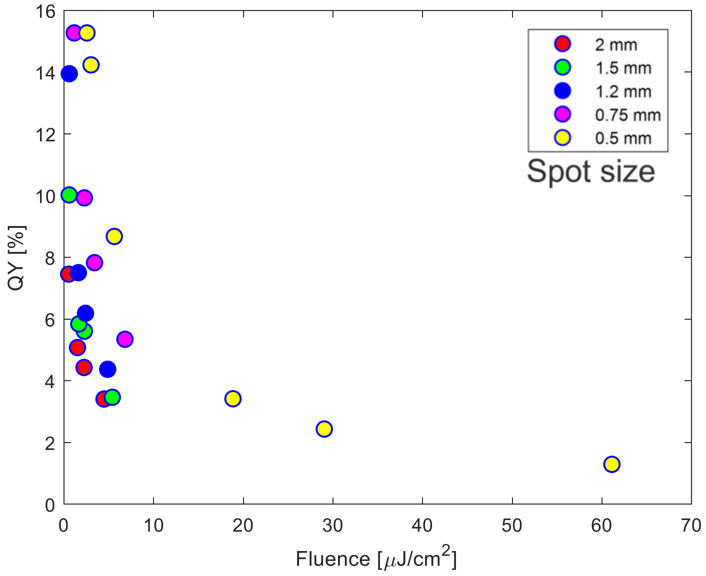
Charge Production

Up to 300 pC with smallest laser spot size



Saturation

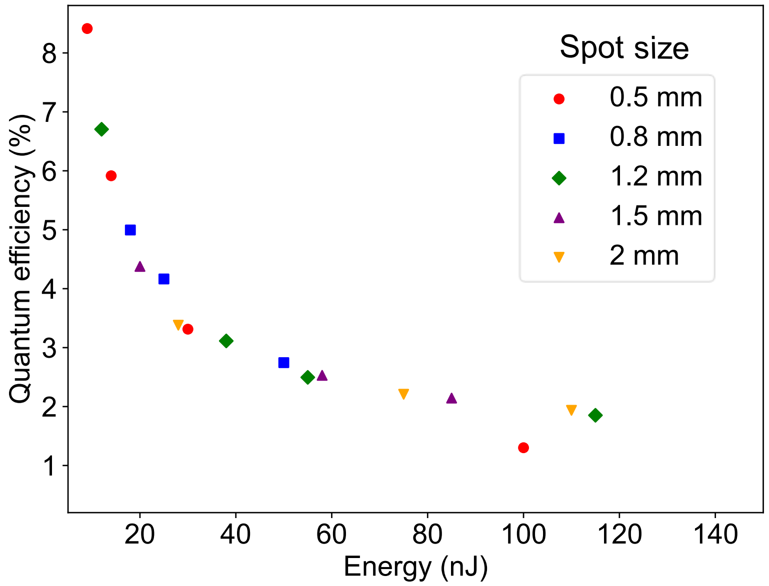
Saturation fluence occurs around 5 μJ/cm²



AWAKE Photocathode Performance 2024

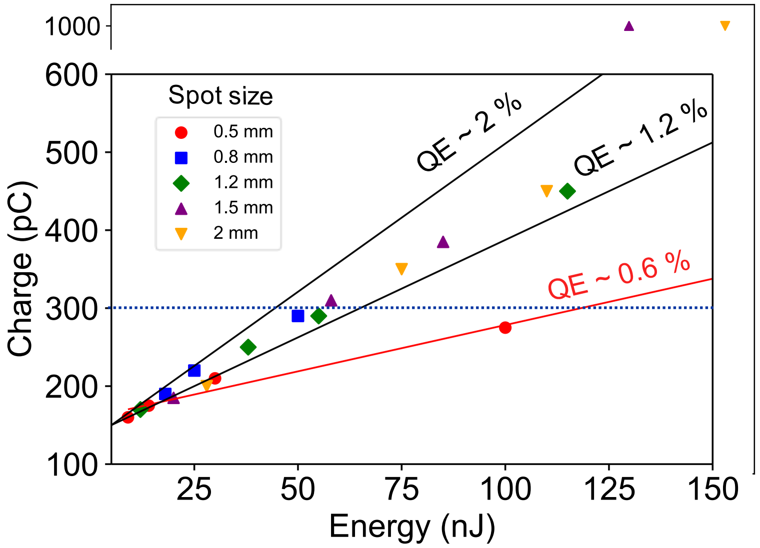
Quantum Yield

Measured to around 8% after a year of operation



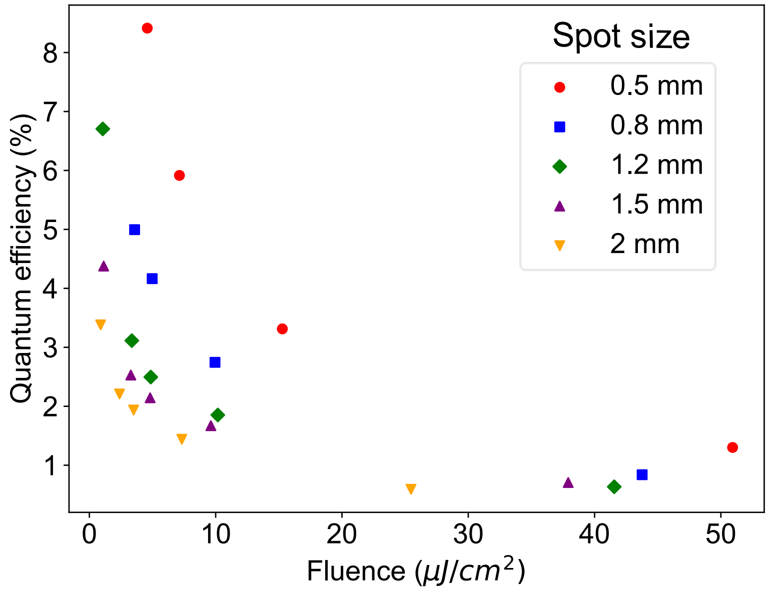
Charge Production

Above 250 pC with smallest laser spot size

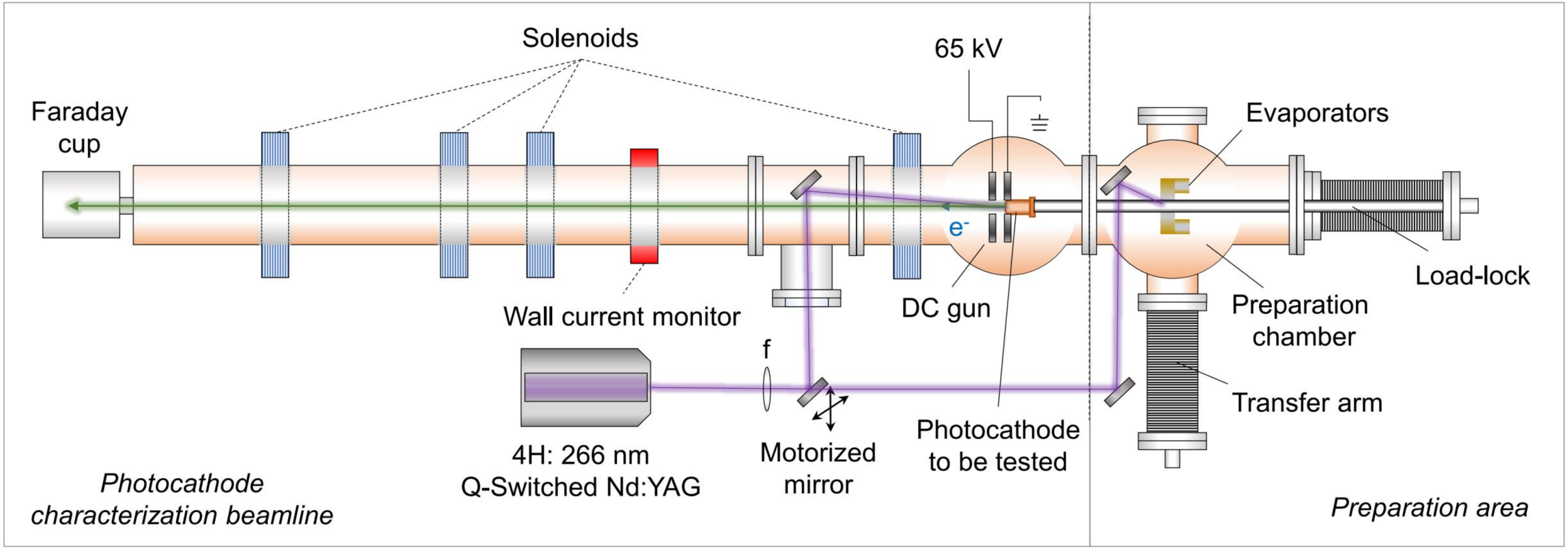


Saturation

Saturation fluence occurs around 4 μJ/cm²



CERN Photoemission Laboratory Setup

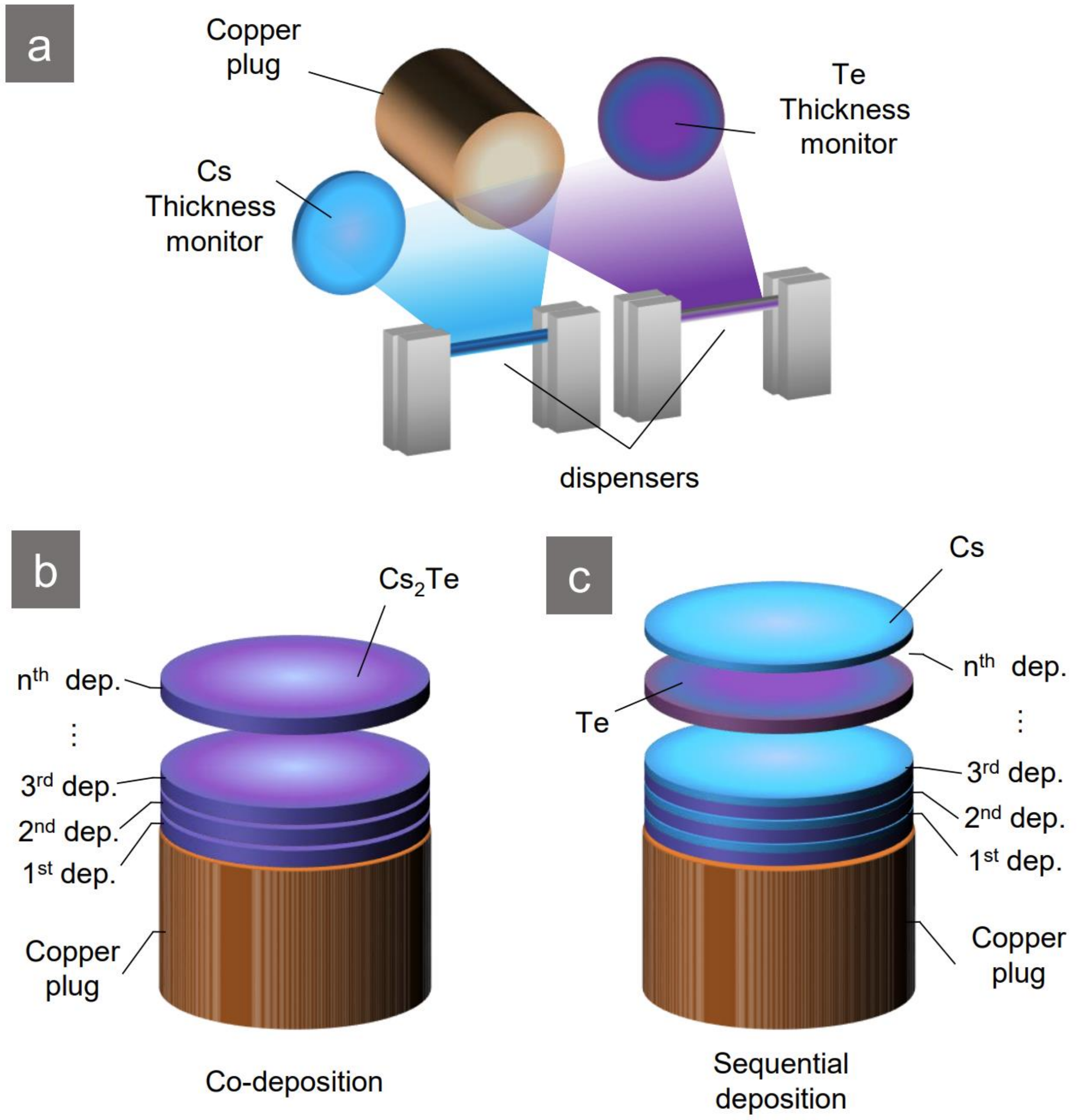


Photocathode Production Process

a Cesium and tellurium layer applied to copper substrate ‘plug’ via physical vapor deposition (PVD) process

b Monitored co-deposition of Cs and Te is performed in the Photoemission Lab for AWAKE photocathodes

c Sequential deposition of Cs and Te is performed in situ at the CLEAR facility



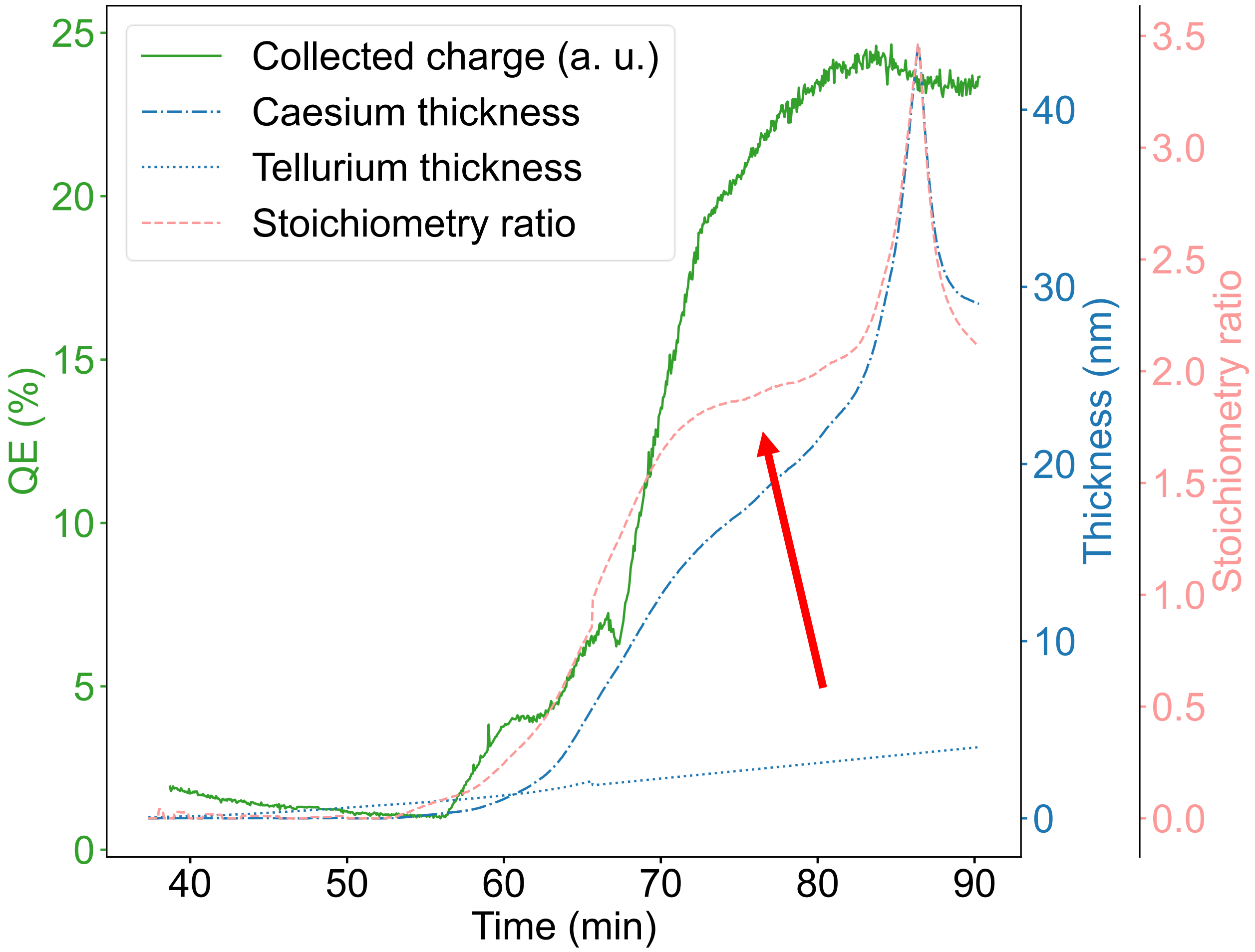
Related publication (2024-02-08) by M. Martinez Calderon et al.: https://link.aps.org/doi/10.1103/PhysRevAccelBeams.27.023401

Photocathode Production Analysis

Data analysis of high-QE Cs_2Te photocathode #217 produced at the Photoemission Lab and installed at AWAKE in 2021 / 2022

- **PVD process time spent at stoichiometric ratio around 2.0 is significant**
- **Need to compare and relate to historical production parameters of other photocathodes**

Production parameters yielding highest QE

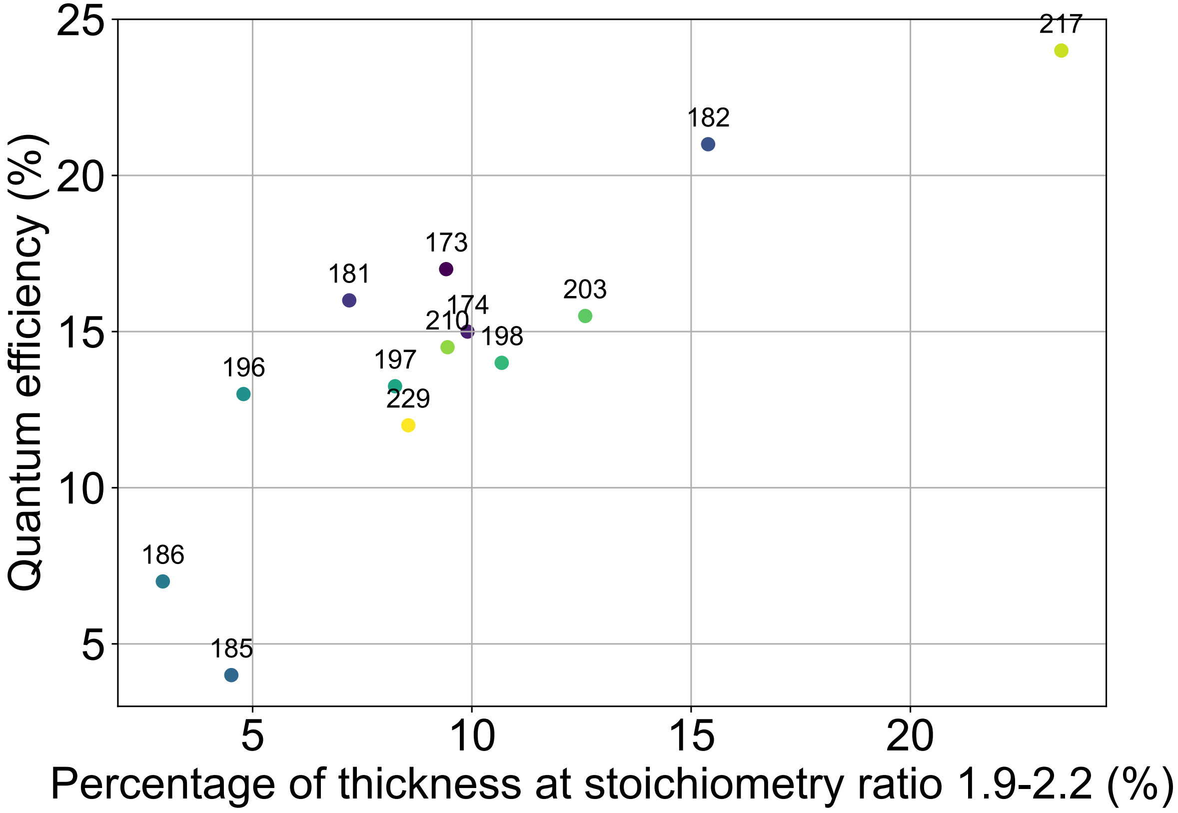


Photocathode Production Analysis

Production parameter and QE relation for other photocathodes

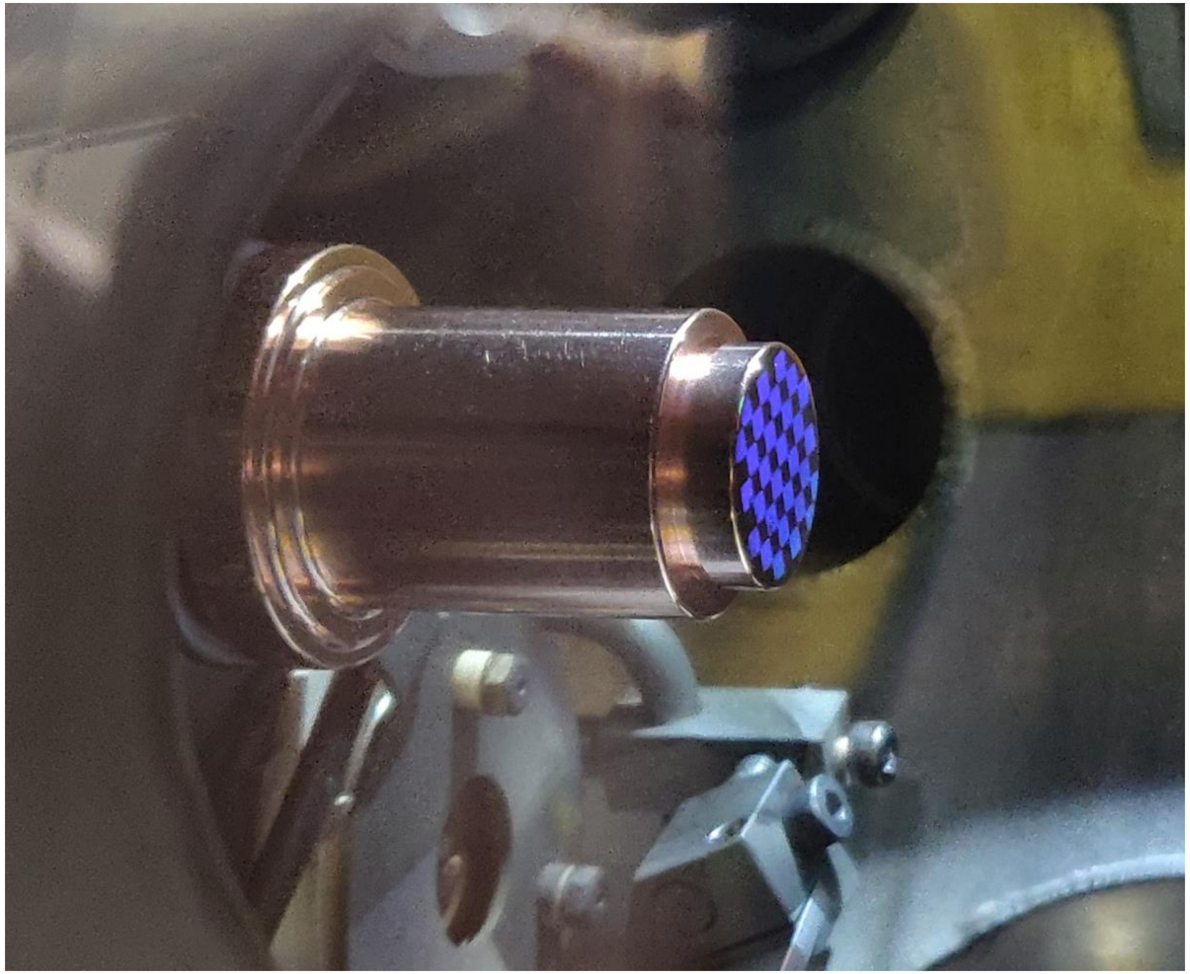
Data analysis of 13 Cs_2Te photocathodes produced during 12 years at the Photoemission Lab

- **Successive narrowing of the stoichiometric ratio 'window' to gain insights to optimal Cs_2Te layer thickness**
- **Analysis points to options for process reliability improvements and process recipe automation**



R&D, Future Work and Outlook
Nanoplasmonic Photocathodes

- **Manufacture nanostructured photocathode surface**
- **Reduce vacuum requirements for photocathodes and investigate expected lifetime**
- **Compromise on achievable quantum efficiency**
- **Require reliable emittance measurements**

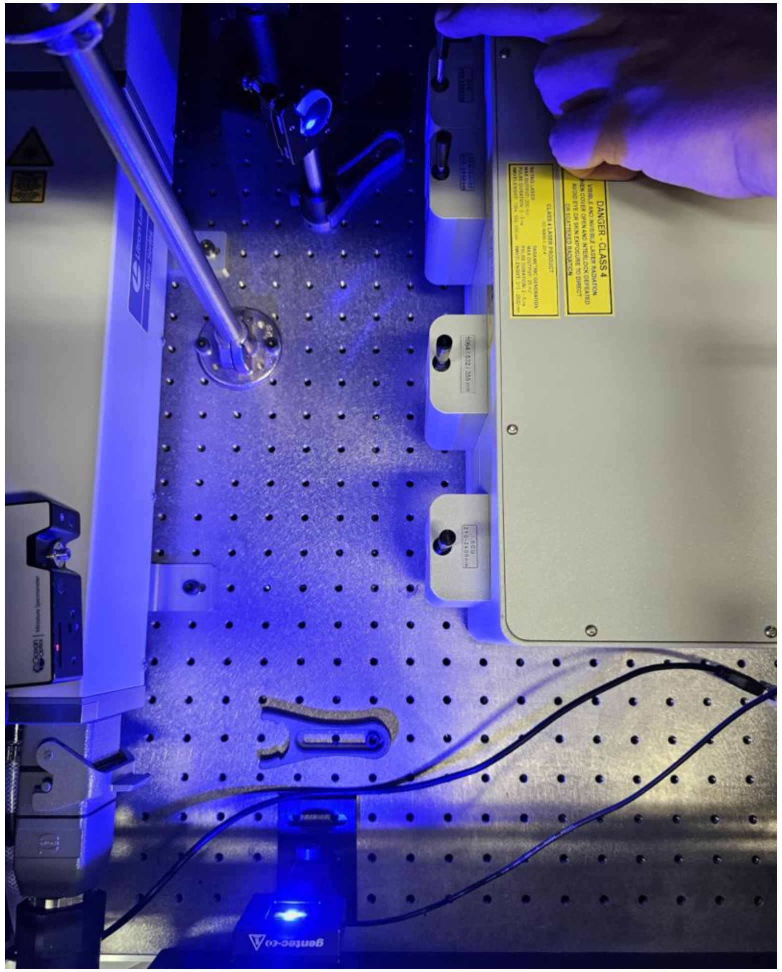


Related publication (2023-10-17) by M. Martinez Calderon et al.:
https://doi.org/10.1515/nanoph-2023-0552

R&D, Future Work and Outlook
Photometric Deposition Layer Measurements

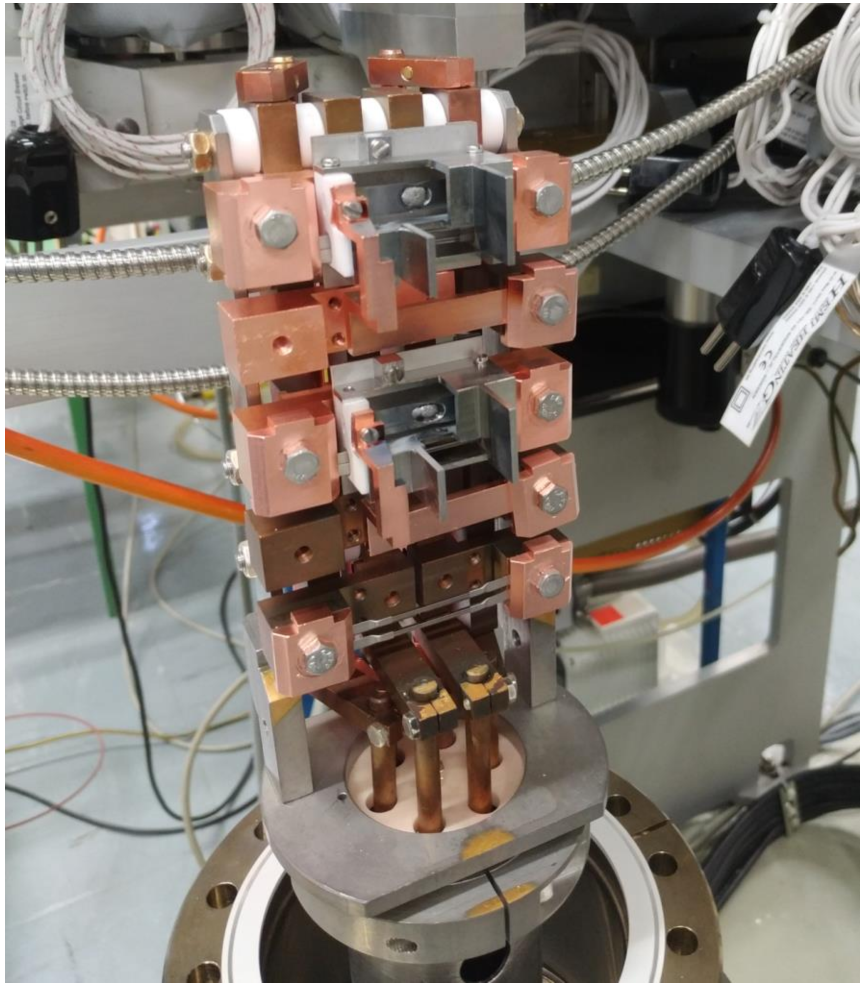
- **Frequency tunable optical parametric oscillator (OPO) laser installed in Photoemission Lab**

- **Perform work function measurements for different photocathode production strategies and deposition layers e.g. for ‚rejuvenated' photocathodes**



R&D, Future Work and Outlook
Photocathode Production Reliability Upgrades

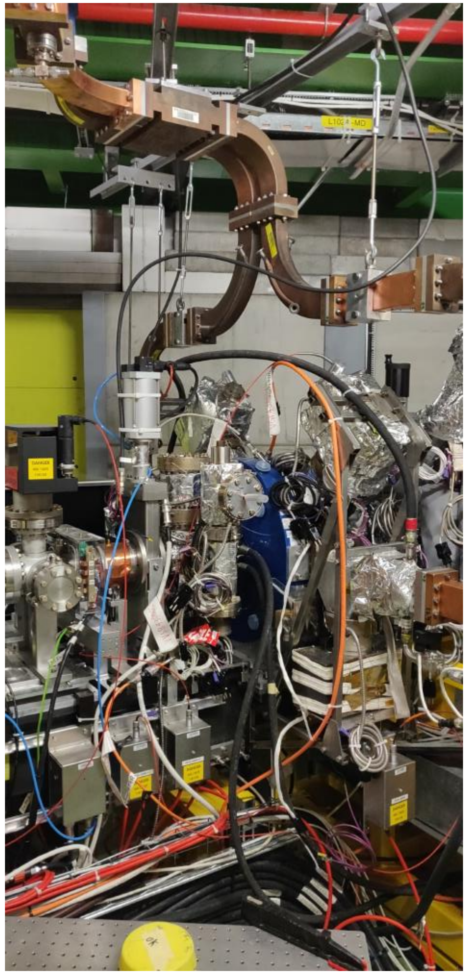
- **Production setup maintenance and dispenser renewal**
- **Automation of production process in accordance with recent data analysis results**
- **Potential installation of Transverse Energy Spread Spectrometer (TESS), collaborating with Daresbury Laboratory**



R&D, Future Work and Outlook
CTF2 Commissioning (AWAKE Run 2c Preparation)

- **Installation of AWAKE photocathode exchange load-lock system at CTF2 during the CNGS clean-up project**

- **Use of CTF2 as test platform for photocathodes produced with improved production methods**



Thank you for your attention.

Special thanks to
Eric CHEVALLAY, Eduardo GRANADOS, Miguel MARTINEZ CALDERON, Vittorio BENCINI, Palma KATONA, and Cyril BERNERD for additional material and data, as well as to SY-STI, SY-RF, TE-VSC, and other groups for their continued support.

home.cern

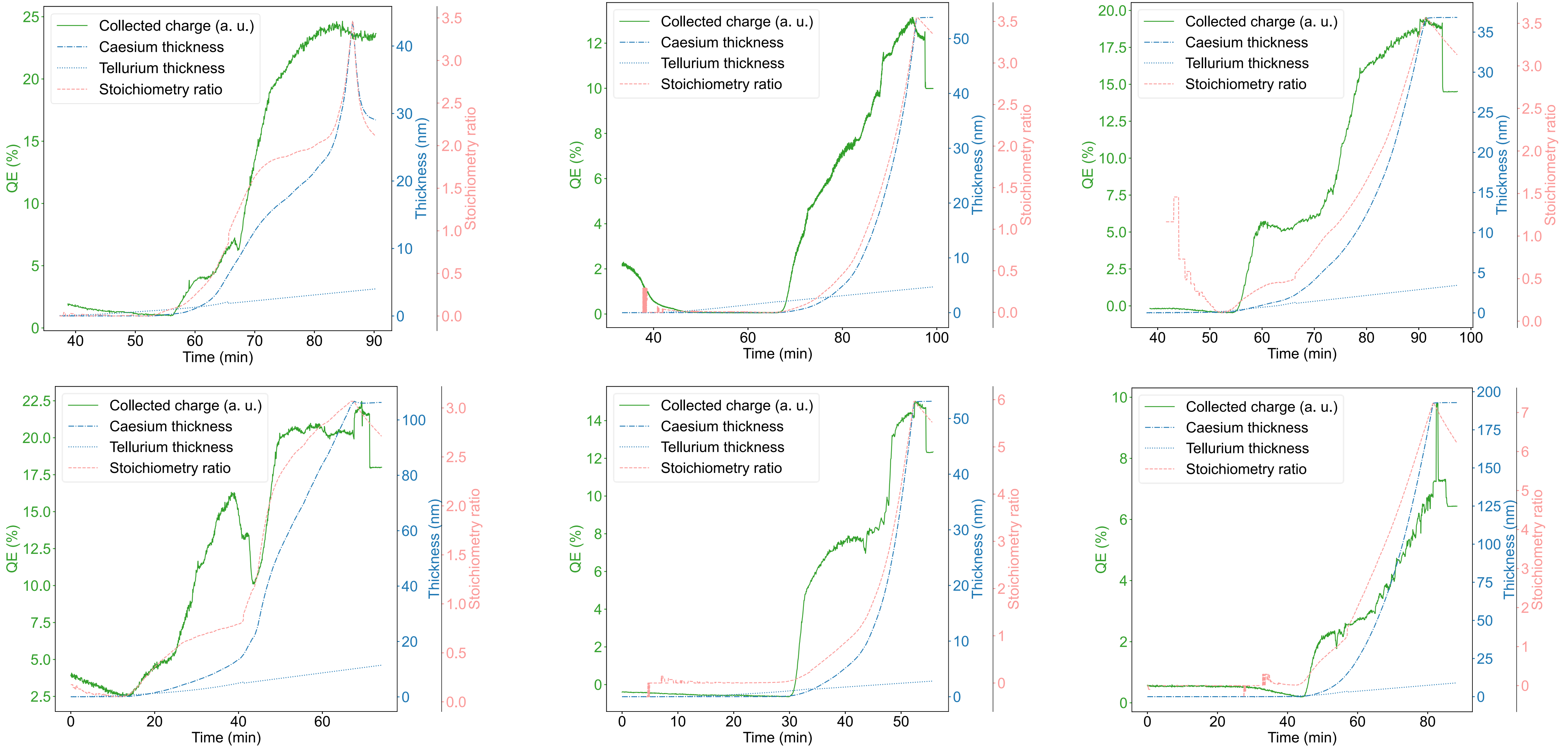
Additional Detail Slides

Photocathode Performance Comparison and Conclusion

Parameter	2021	2022	2023	2024
QE	5.5% (used)	25%	15%	8%
Saturated QE	1.8%	5%	4%	2.5%
Saturation fluence	4 µJ/cm^2	2.5 µJ/cm^2	5 µJ/cm^2	4 µJ/cm^2

- Spare photocathode (#229) was installed in the RF gun after restoring UHV (baking was needed)
- Replicated applied pressure, seems reliable (RF gun was still in tune)
- Photocathode survived exposure to 10^-9 mbar during a week
- QE measurement in agreement with photocathode production measurements at Photoemission Lab
- Maximum charge for smallest emittance is about 300 pC.

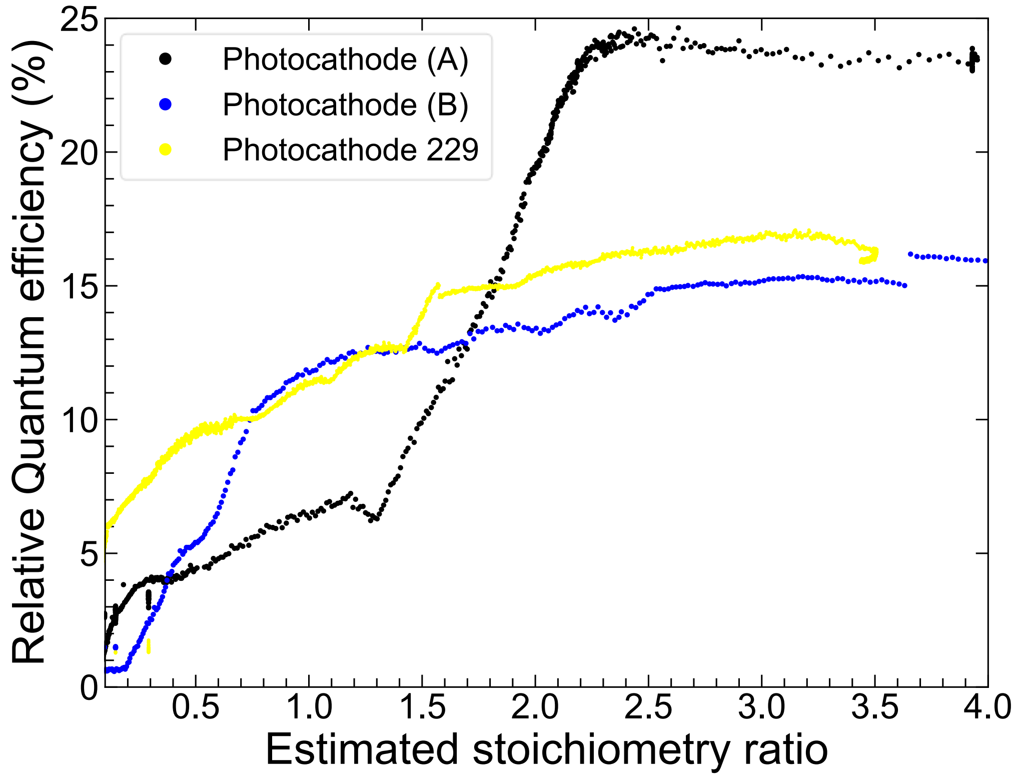
Cs_2Te Photocathode Production Data Analysis

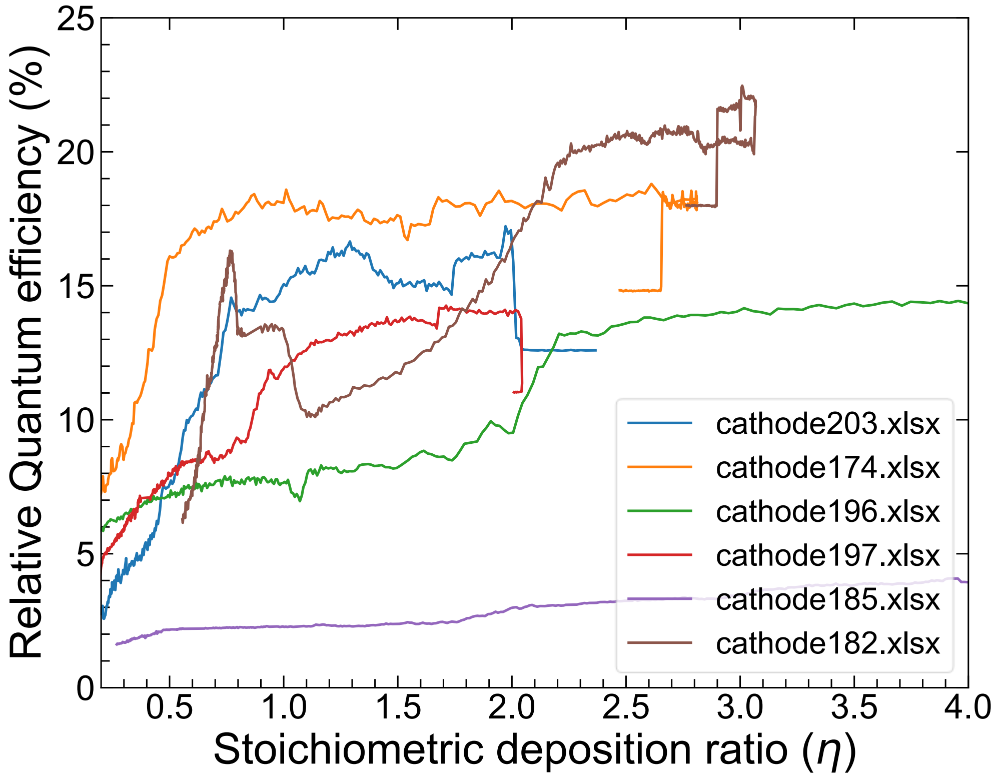


Courtesy of M. Martinez Calderon

CsTe photocathodes analysis

From the previous study that we just published it seems to be an optimum window for stoichiometry ratio





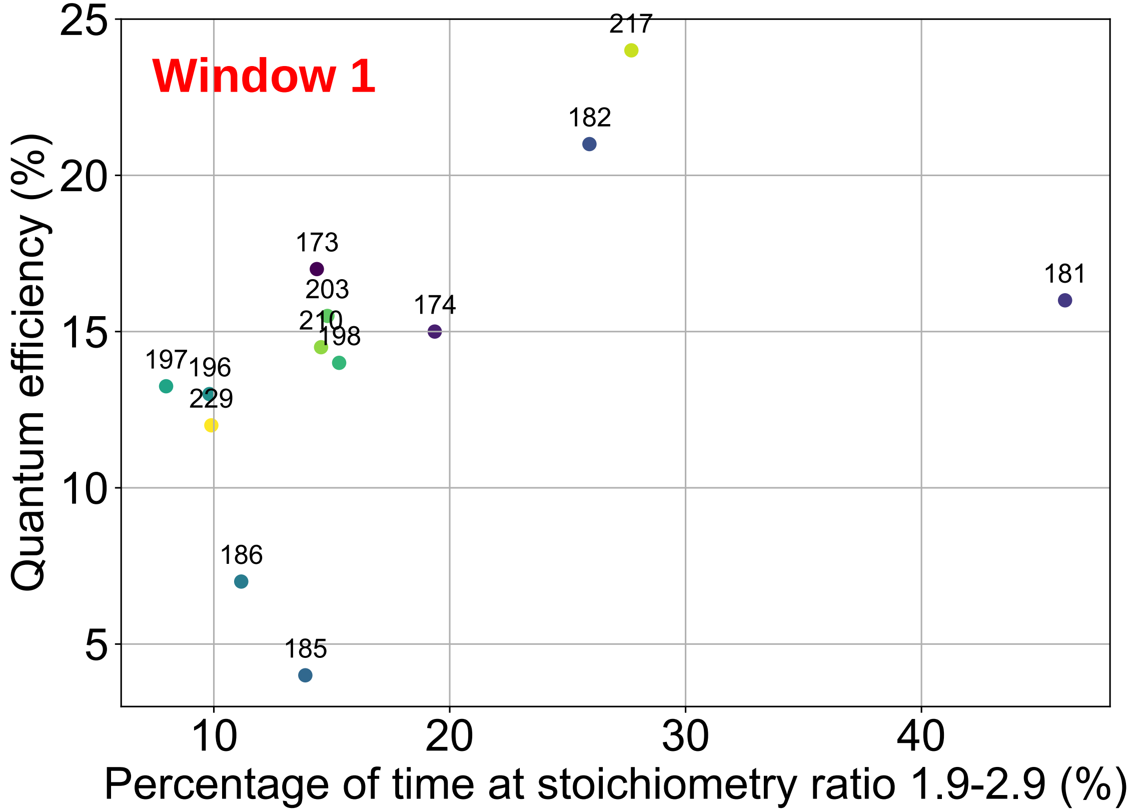
Courtesy of M. Martinez Calderon

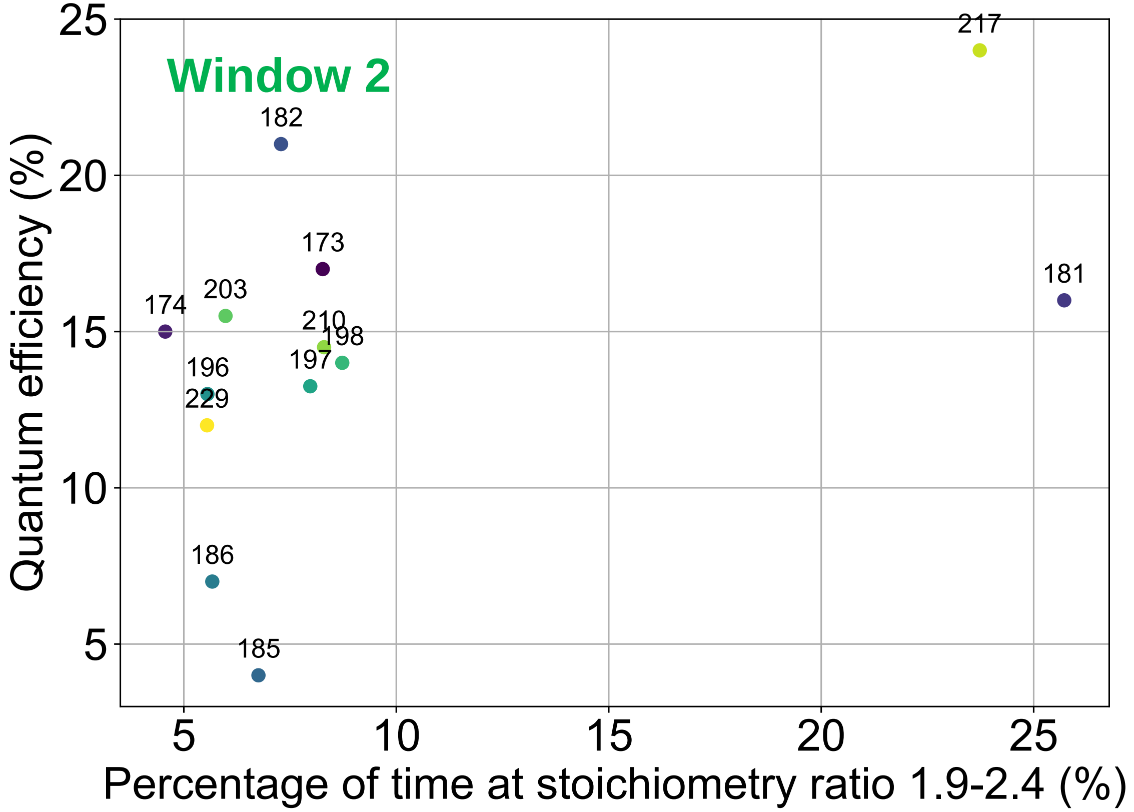
CsTe photocathodes analysis

So, we wanted to further characterize the window which seems to be crucial for achieving high QE

First, the time spent at different "windows" of optimum stoichiometry ratio

Window 1: st_ratio = 1.9 – 2.9; Window 2: st_ratio = 1.9 - 2.4



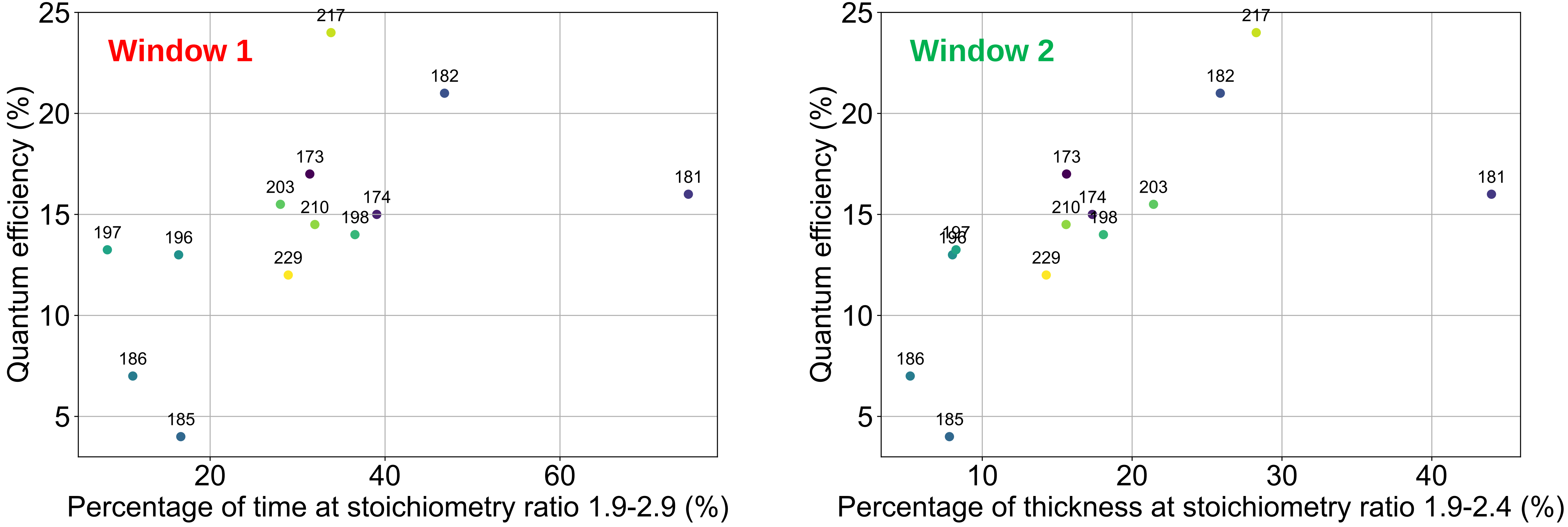


Courtesy of M. Martinez Calderon

CsTe photocathodes analysis

Second, the % of thickness at different "windows" of optimum stoichiometry ratio

Window 1: st_ratio = 1.9 – 2.9; Window 2: st_ratio = 1.9 - 2.4

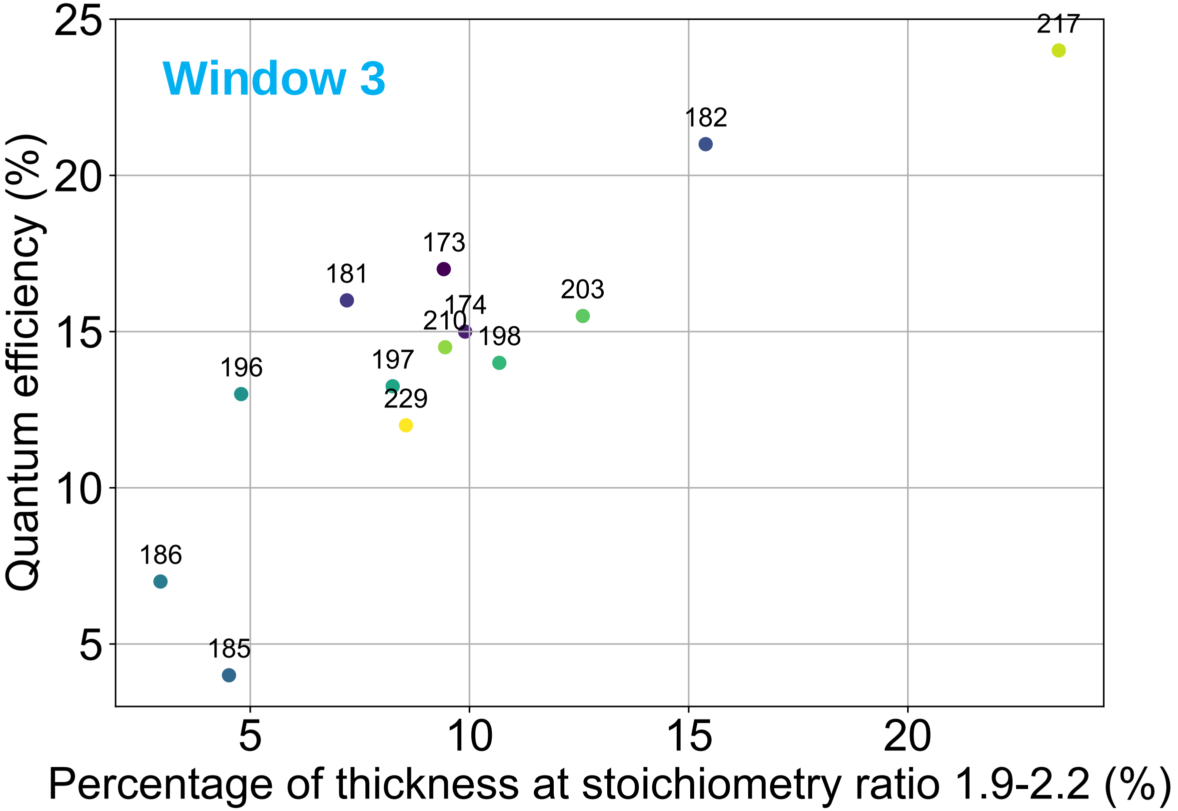


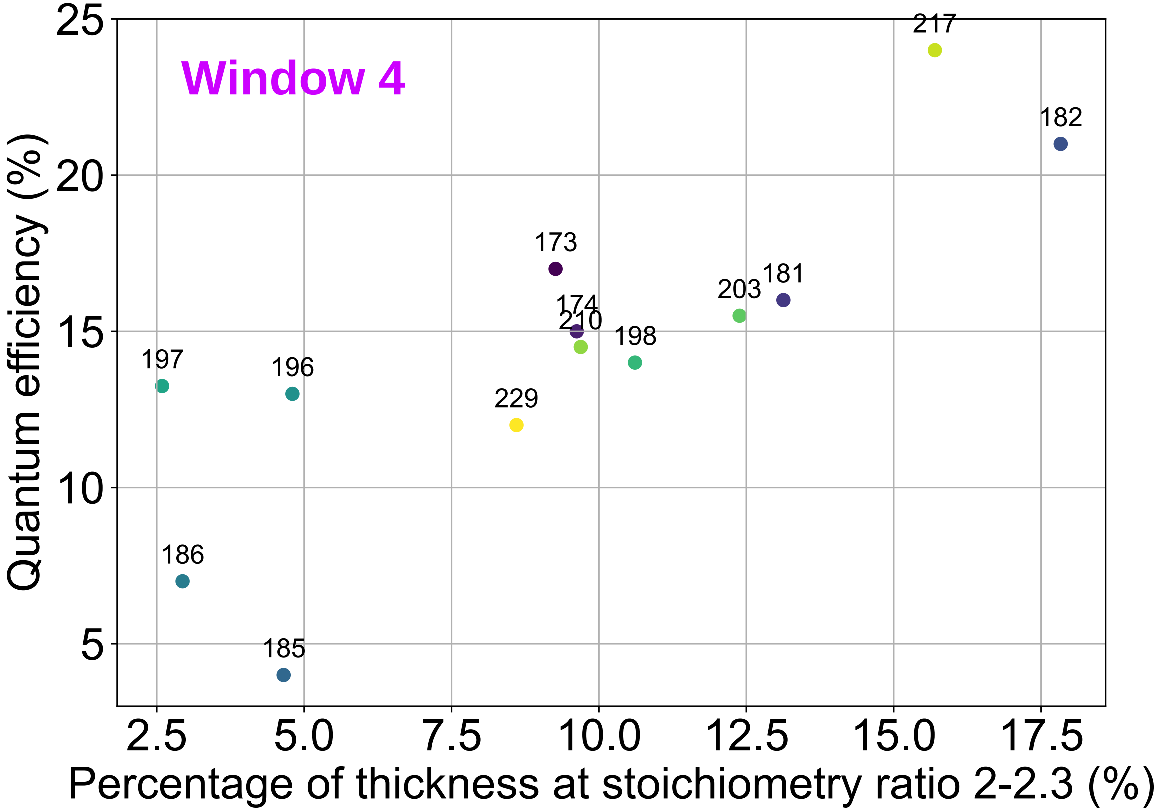
Courtesy of M. Martinez Calderon

CsTe photocathodes analysis

Second, the % of thickness at different “windows” of optimum stoichiometry ratio

Window 3: st_ratio = 1.9 – 2.2; Window 4: st_ratio = 2 - 2.3





Courtesy of M. Martinez Calderon