

Na-K-Sb photocathode operation in an SRF photoinjector

Results, lessons learned & outlook

Photocathode for Accelerator Science in Europe 2026

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Thank you for your support!

Thanks to the support of the photocathode community we got the possibility for a final SEALab run in Q2 2026



Na-K-Sb photocathodes for SEALab

- Na-K-Sb photocathodes promising candidate for high-brightness applications
- High QE, low intrinsic emittance, improved thermal stability and lifetime compared to Cs-K-Sb
- Improved SRF compatibility expected due to lack of Cs
- Triple evaporation growth for more homogeneous and reproducible photocathodes [1]

[1] Wang, C., et al. "Triple evaporation growth of sodium–potassium–antimonide thin films as photoemission source for electron accelerators." *Journal of Physics D: Applied Physics* 59.7 (2026): 075102.

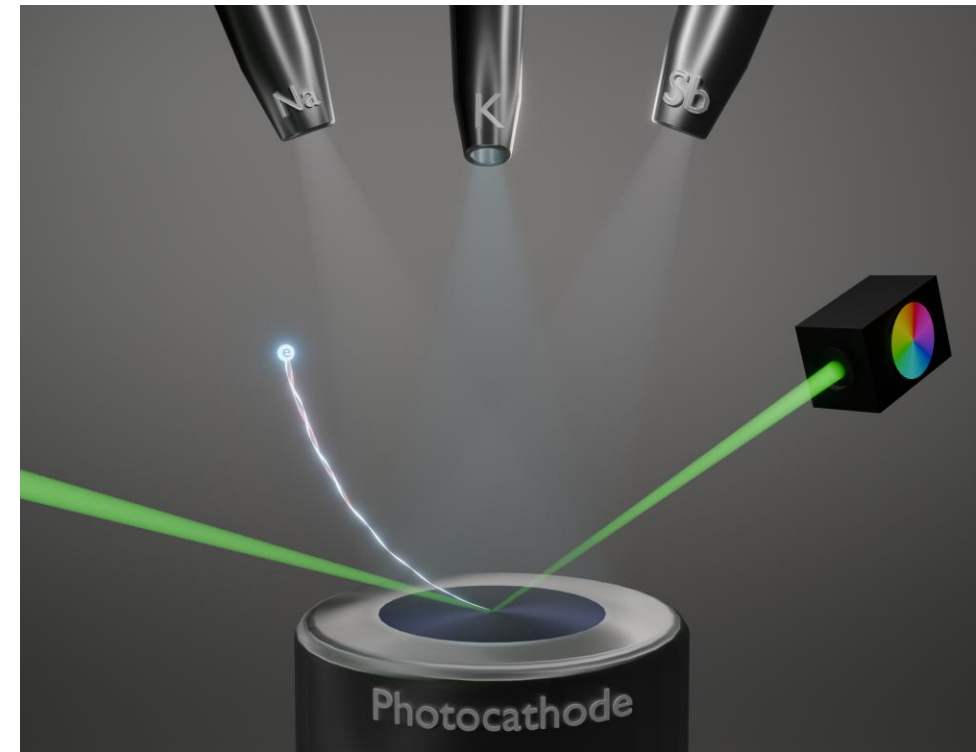
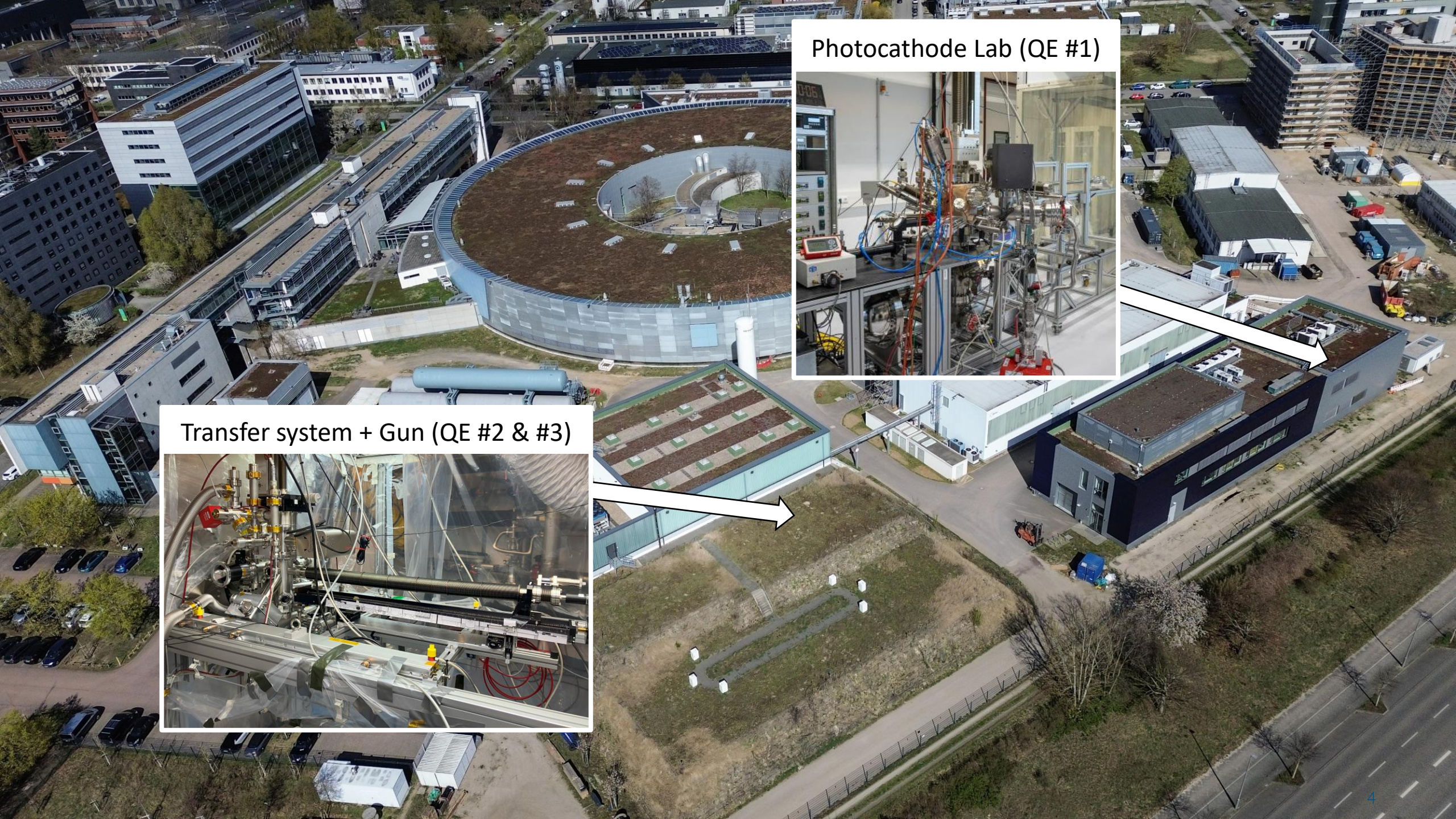
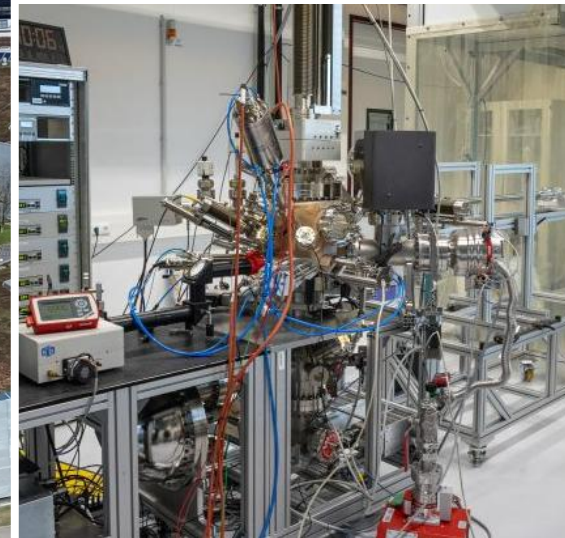


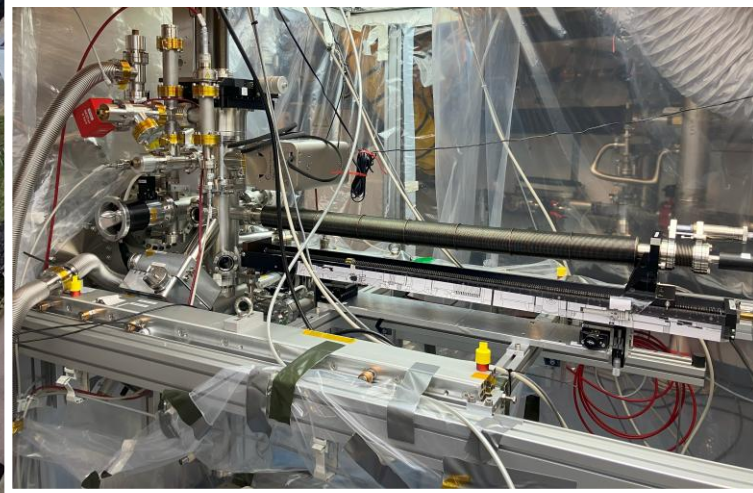
Fig 1: Triple evaporation growth procedure



Photocathode Lab (QE #1)



Transfer system + Gun (QE #2 & #3)



Na-K-Sb photocathodes for SEALab

- > 5 % regularly achieved, highest QE close to 10 % (at 520 nm)
- Strong degradation between preparation and operation
- Improved by one order of magnitude due to recipe optimization and vacuum improvement

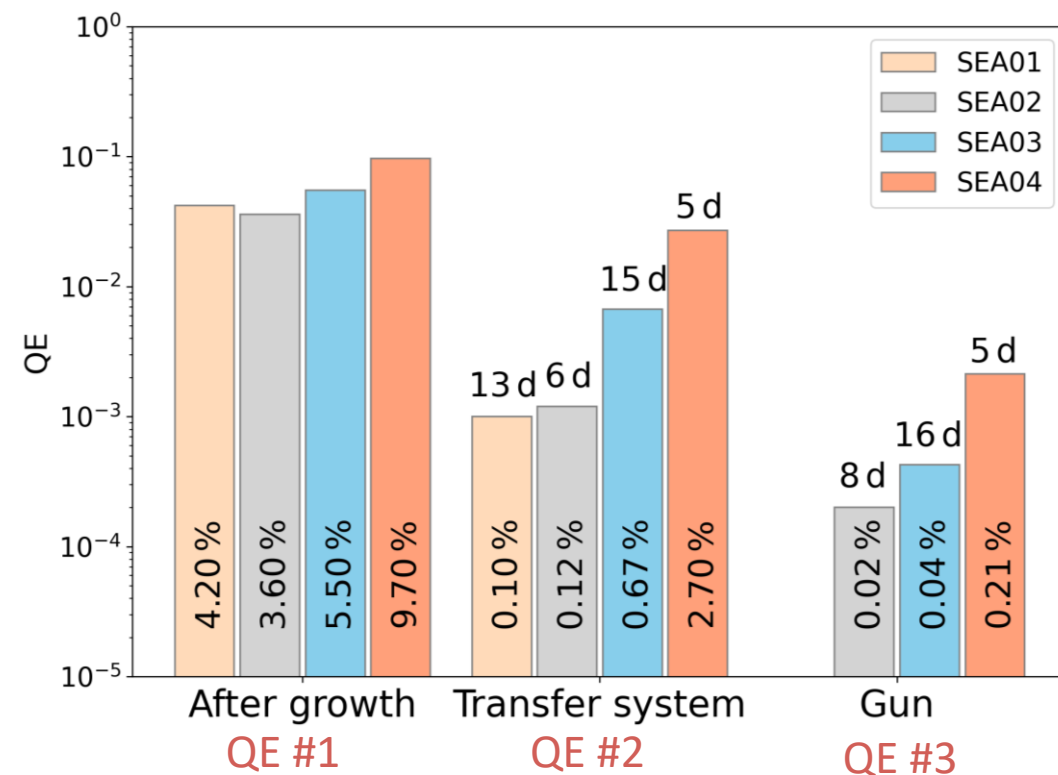
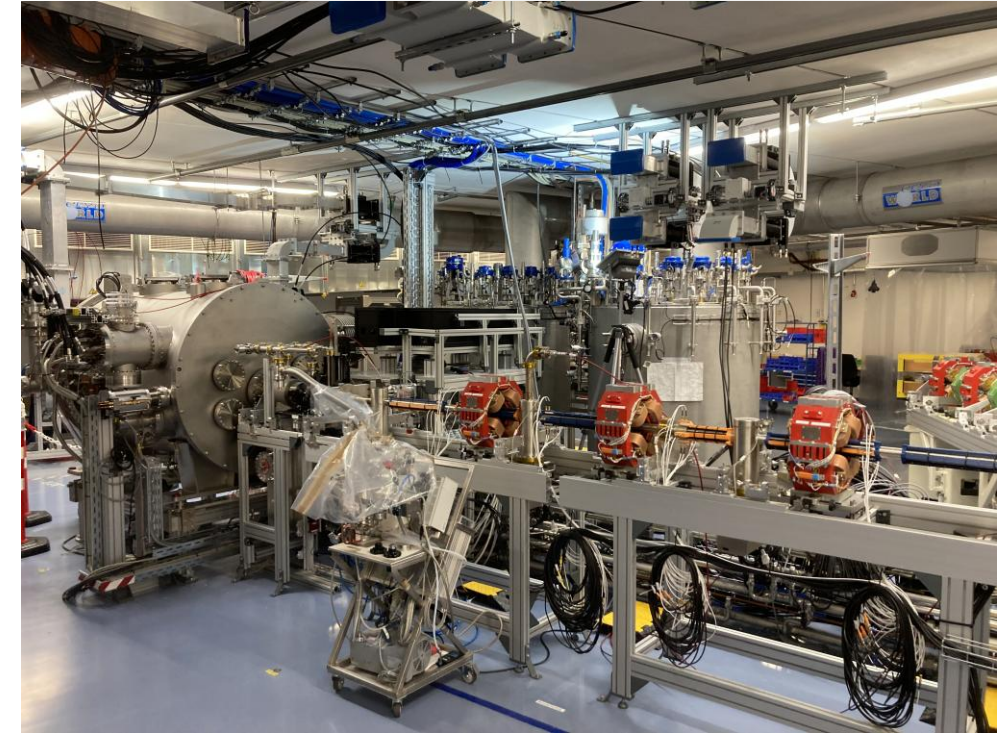


Fig 2: Overview of the 4 photocathodes prepared for SEALab

Na-K-Sb photocathodes for SEALab

- First operation of Na-K-Sb photocathodes in an SRF photoinjector in 2025
- Low field emission
- No multipacting (at 3 kV DC bias at cathode insert)

Fig 3: The SEALab photoinjector



PHYSICAL REVIEW MATERIALS **10**, 074601 (2026)

- Results of the first two runs published [2]



Quantitative framework for photoemissive materials: From bialkali-antimonide synthesis to performance in superconducting RF electron injectors

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The final SEALab run (May – July 2026)

- About 240 h of RF and beam operation
- ~0.42 C total extracted charge
- Photocathode QE can recover → already observed during first run, this time detailed investigations
- Investigation of photocathode parameters (QE, MTE, threshold energy)

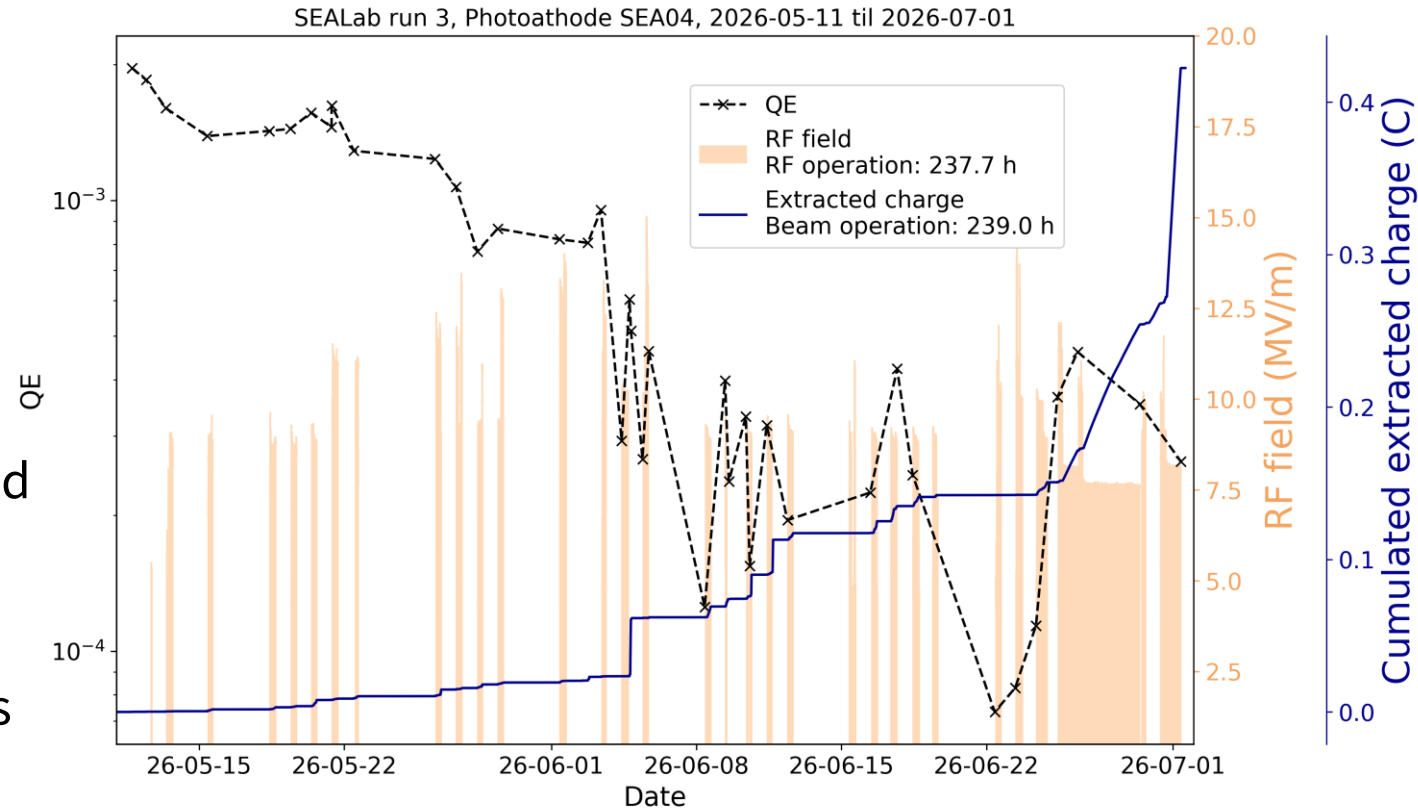


Fig 4: Overview of the final SEALab run with the photocathode SEA04. The QE, RF operation and extracted charge is shown.

Threshold energy - Schottky scans

- Threshold energy E_T is a key parameter for photocathode performance
- $E_T = E_{vac} - E_{VBM}$
- It describes QE, MTE and degradation
- Measure the QE as a function of the phase shift between RF and laser pulse

- $$QE \propto \left(\hbar\omega - E_T + \sqrt{\frac{e^3}{4\pi\epsilon_0} E \sin \Theta} \right)^2$$

Known
↑

Fit
↑

Vary
↑

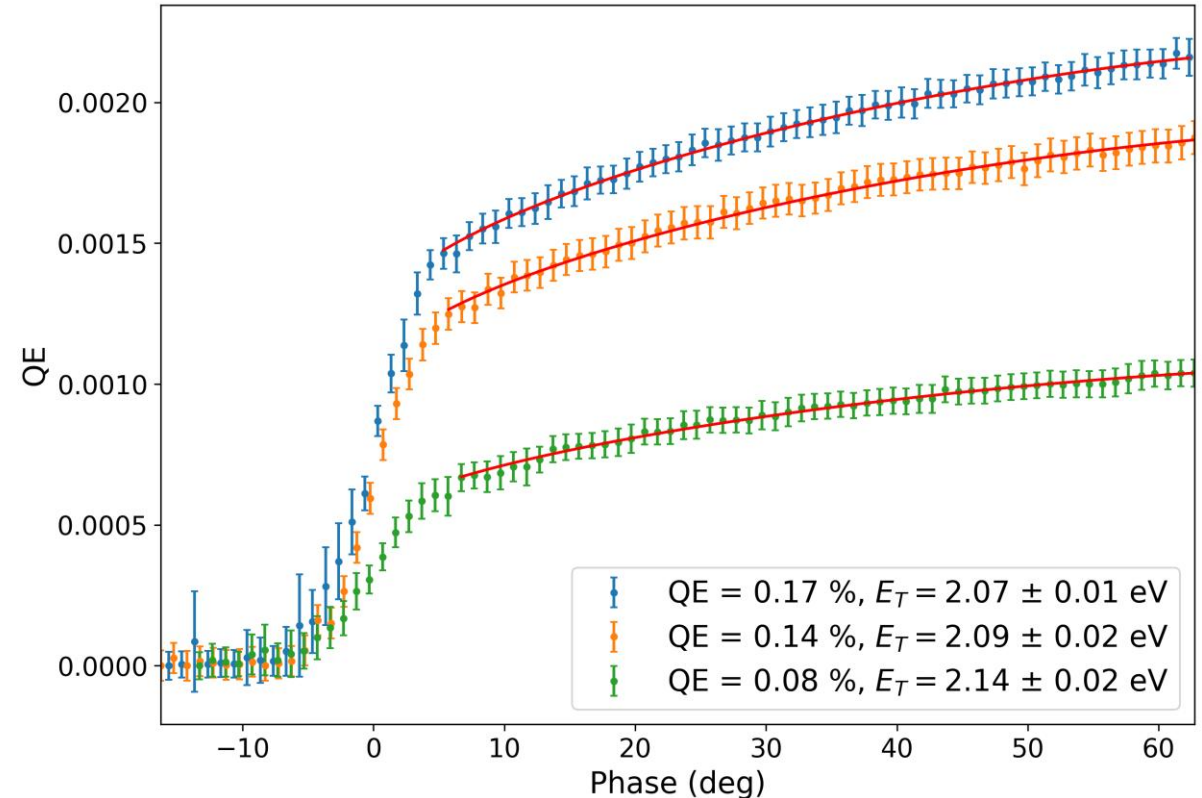


Fig 5: Schottky scans (RF-laser phase scans) are used to determine the threshold energy in the photoinjector. A clear correlation between threshold energy and QE can be seen.

Intrinsic emittance

- Normalized emittance measured by solenoid scans for different laser spot sizes
- Very good linearity with MTE = 368.8 meV (horizontal) and 248.6 meV (vertical)
- Emittance growth by a factor of 2-3 compared to expected value from threshold energy,
→ Contributions from aberrations from RF, and solenoid

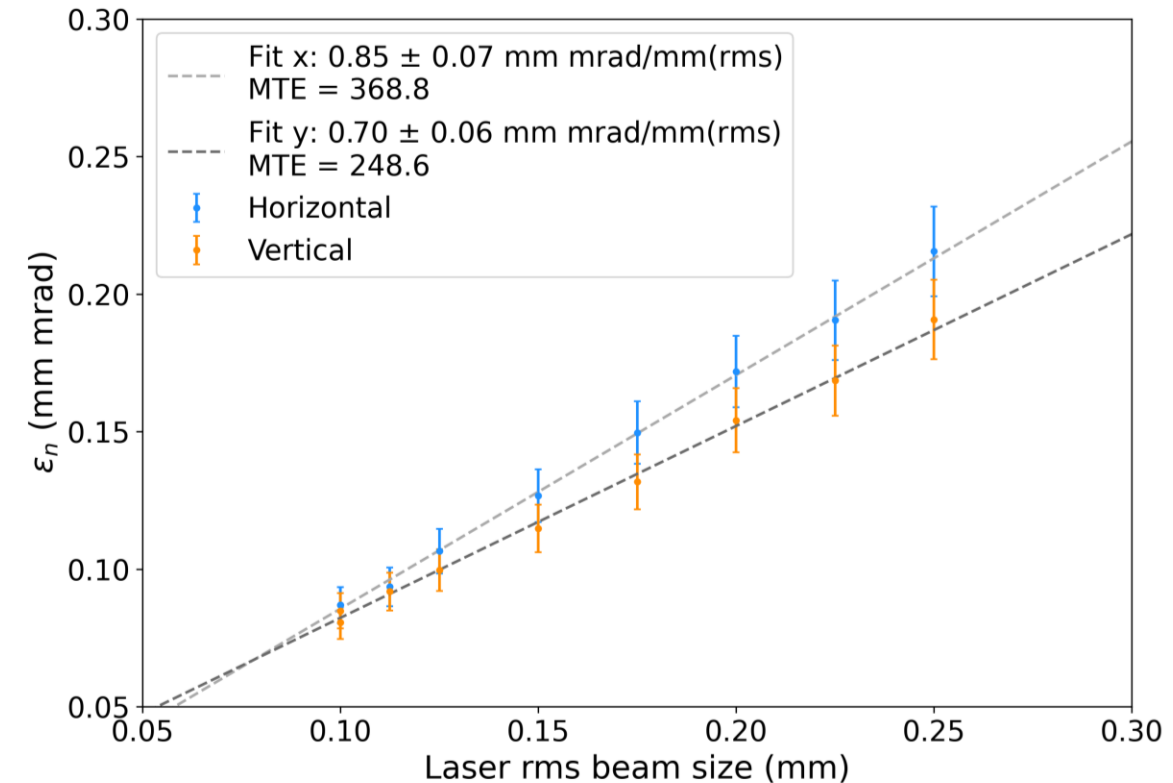


Fig 6: The thermal emittance/MTE of the photocathode SEA04 was measured by solenoid scans in the photoinjector of SEALab

Photocathode Recovery

- First observed during first SEALab run [3]
- QE increases over time during beam operation
- It was not increasing with the laser shutter closed

→ Detailed investigations during the last run

2025-04-02, RF set amplitude=10MV/m, RF phase=40deg,
Laser pulse length=4ps, 1MHz, Bias voltage=3003V

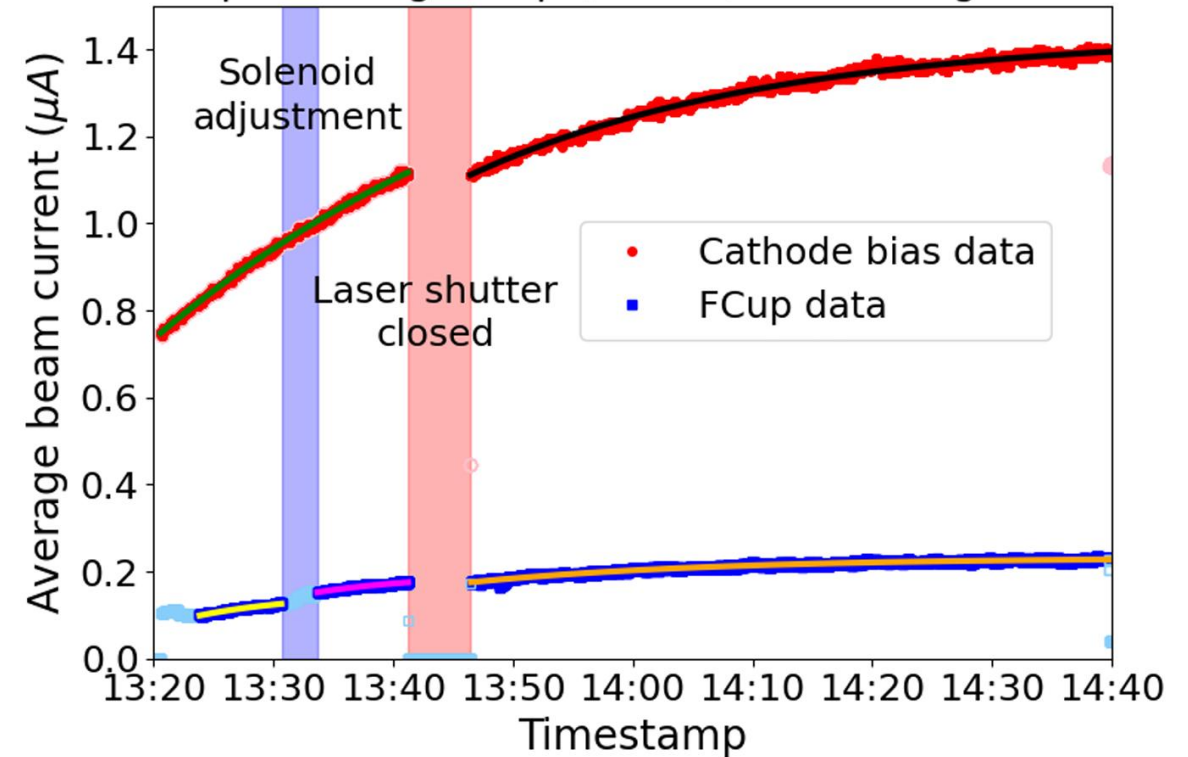


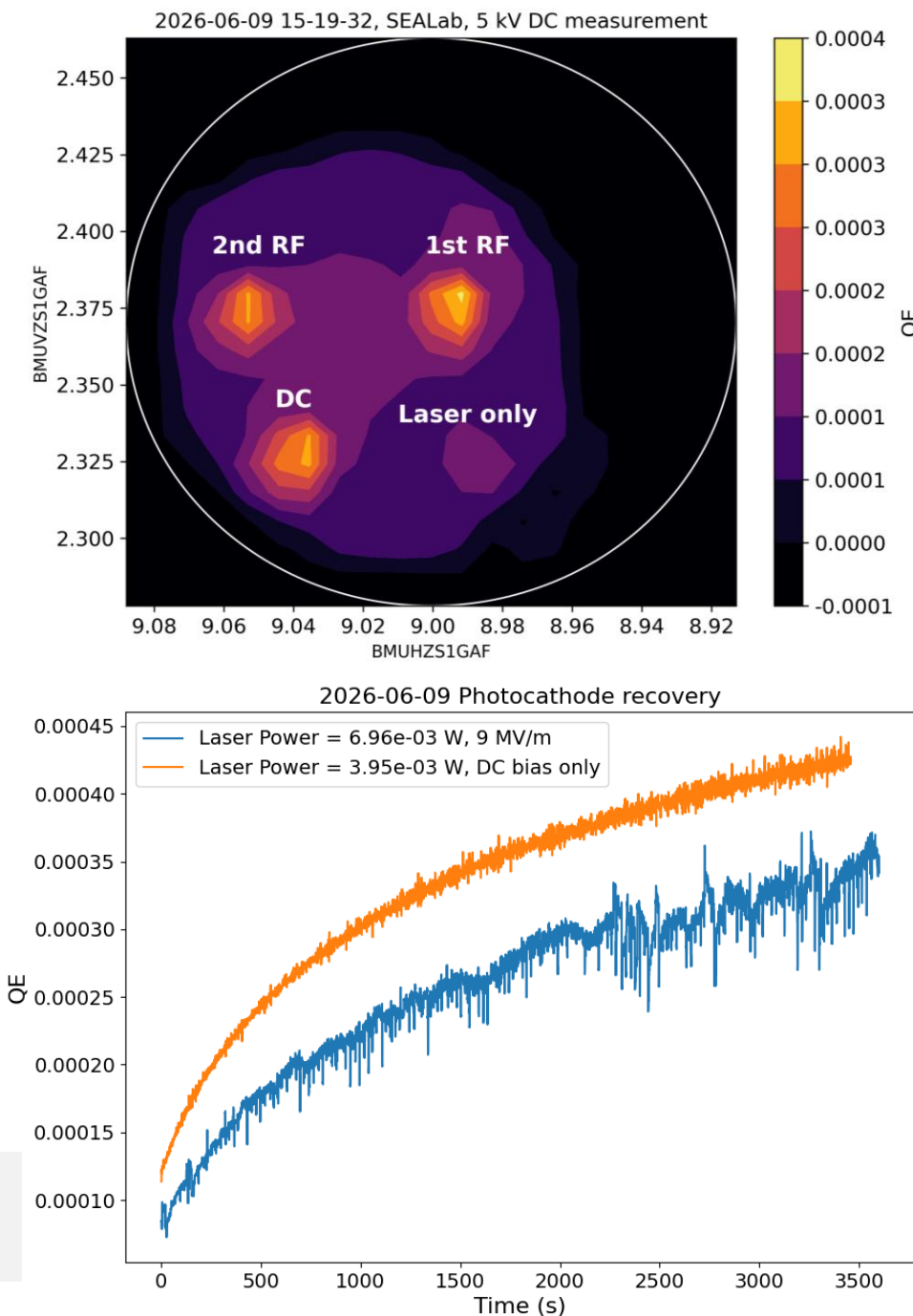
Fig 7: First evidence of QE recovery of the photocathode SEA02 during the first run of SEALab. The effect only occurs with laser shutter open.

[3] Kamps et al. "First beam commissioning of the HZB SRF photoelectron gun." *Proc. IPAC'25*. 2025.

Photocathode Recovery

1. With RF + laser → beam operation: **Strong recovery**
 2. With DC + laser → electron extraction: **Strong recovery**
 3. With laser only → no electron extraction: **No recovery**
(Very little recovery in map probably just from the measurement itself)
- Photocathode QE increasing during operation
 - The effect is very local at the emission point
 - No recovery with laser only
 - → We can exclude thermal effects

Fig 8: (top) QE map after recovery studies; (bottom) QE recovery curves for DC and RF operation



Photocathode Recovery

- Variation of the laser power showed that recovery is a function of charge, not of time
- Based on the observations a theoretical model was developed

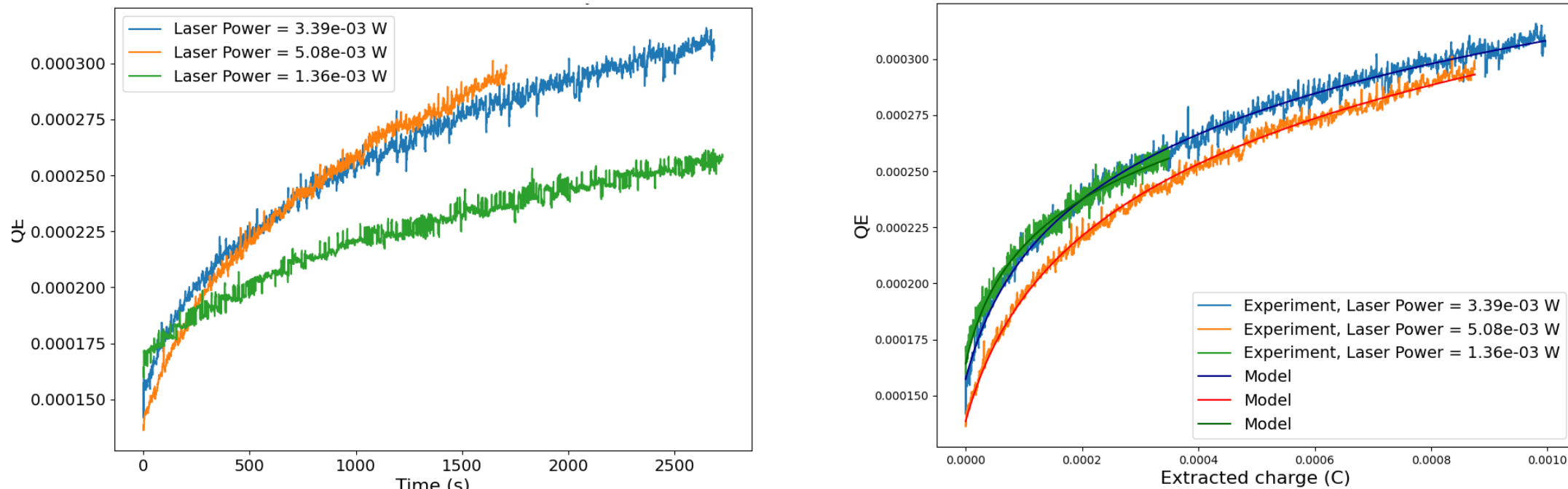


Fig 9: (left) QE recovery curves with different laser powers plotted against time; (right) same data plotted against cumulated extracted charge. A model was developed and is in good agreement with the experimental data

Photocathode Recovery

1. A stable oxide layer is formed at the surface acting as protective layer by chemisorption
 2. Physisorbed oxygen further reducing QE but only has a low binding energy (reversible)
 3. Electron emission stimulates the desorption of physisorbed oxygen
- Desorption induced by electronic transitions (DIET); Here: no incident electrons but emitted electrons

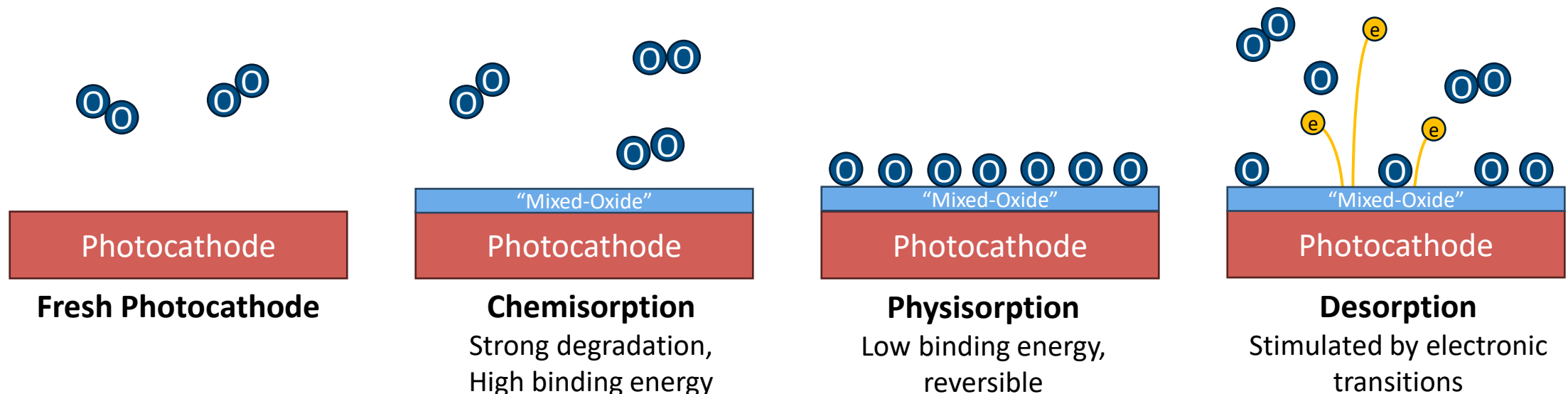
$$\frac{dN}{dQ} = -kN$$

Exp. decay

$$k = A \exp\left(-\frac{E_a}{RT}\right)$$

Arrhenius eq.

with $E_a = E_0 - \beta N$



Photocathode Recovery

- The effect was reproduced under clean lab conditions with an O₂ poisoned photocathode
- Clean degradation mechanism, photocathode did not experienced other effects like transfer, EBB, high fields, cool down, ...

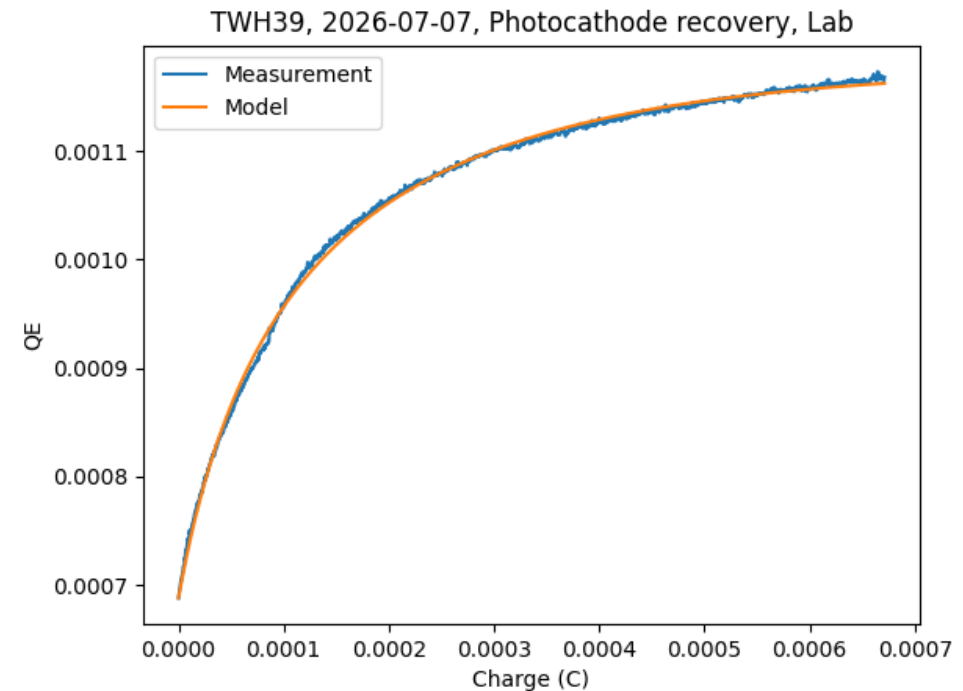
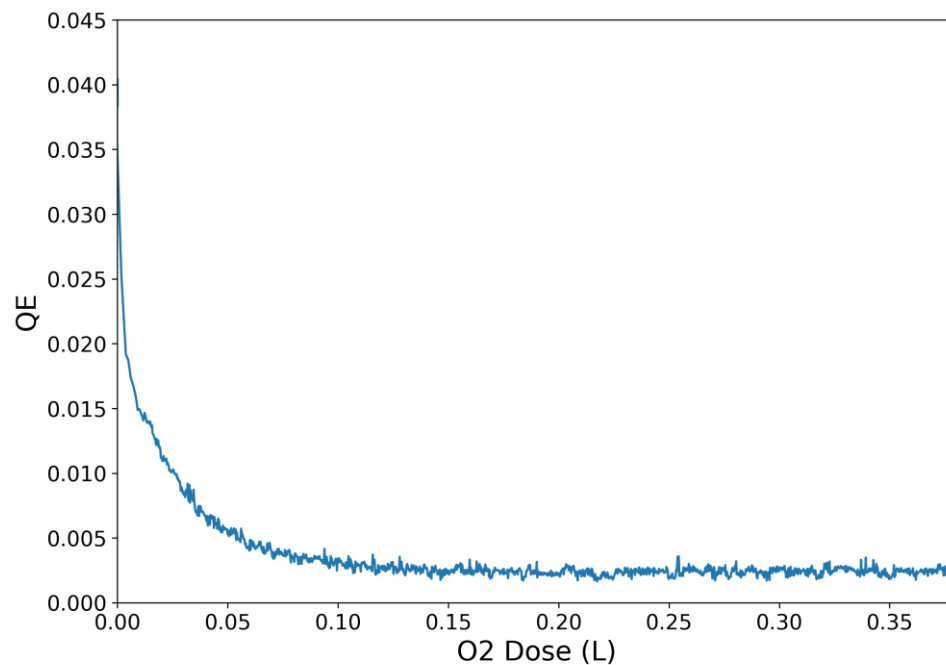


Fig 10: (left) A photocathode was degraded by pure O₂ poisoning; (right) the QE was recovered by electron extraction. The curve again follows the theoretical model.

Photocathodes for DALI

- SEALab project ended July 2026
- Now collaboration with Rong Xiang et al. (HZDR) to develop Na-K-Sb photocathodes for DALI



HZB Helmholtz
Zentrum Berlin



HZDR HELMHOLTZ ZENTRUM
DRESDEN ROSSENDORF



Conclusions & Outlook

- **Na-K-Sb shows good compatibility with SRF environment, low field emission, no multipacting**
- **Na-K-Sb photocathodes can recover by stimulated desorption of contaminants**

Further Research:

- **Growth optimization & automation for increased reproducibility**
- **Poisoning studies to understand the degradation mechanisms**
- **Electronic structure and in-depth analysis of chemical composition at beamline**
 - → Talk by Alice Galdi in the session “semiconductor photocathodes“
 - → Poster from Lucia Santen

Acknowledgments

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SRF Team at HZB:

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Thank you for your attention!



Visual Tour of SEALab on YouTube

<https://www.youtube.com/watch?v=N0cUq7n-nkM>

