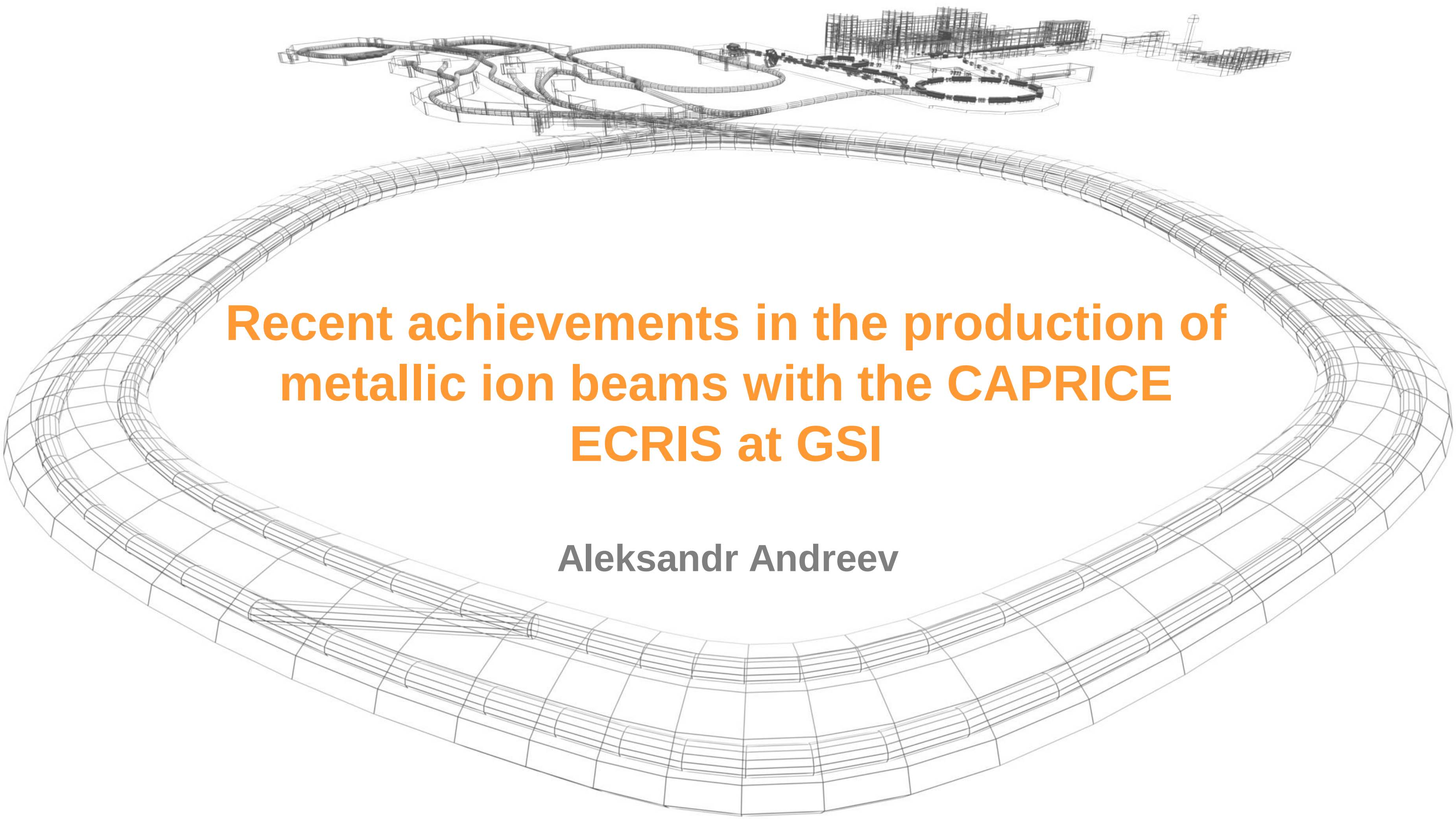


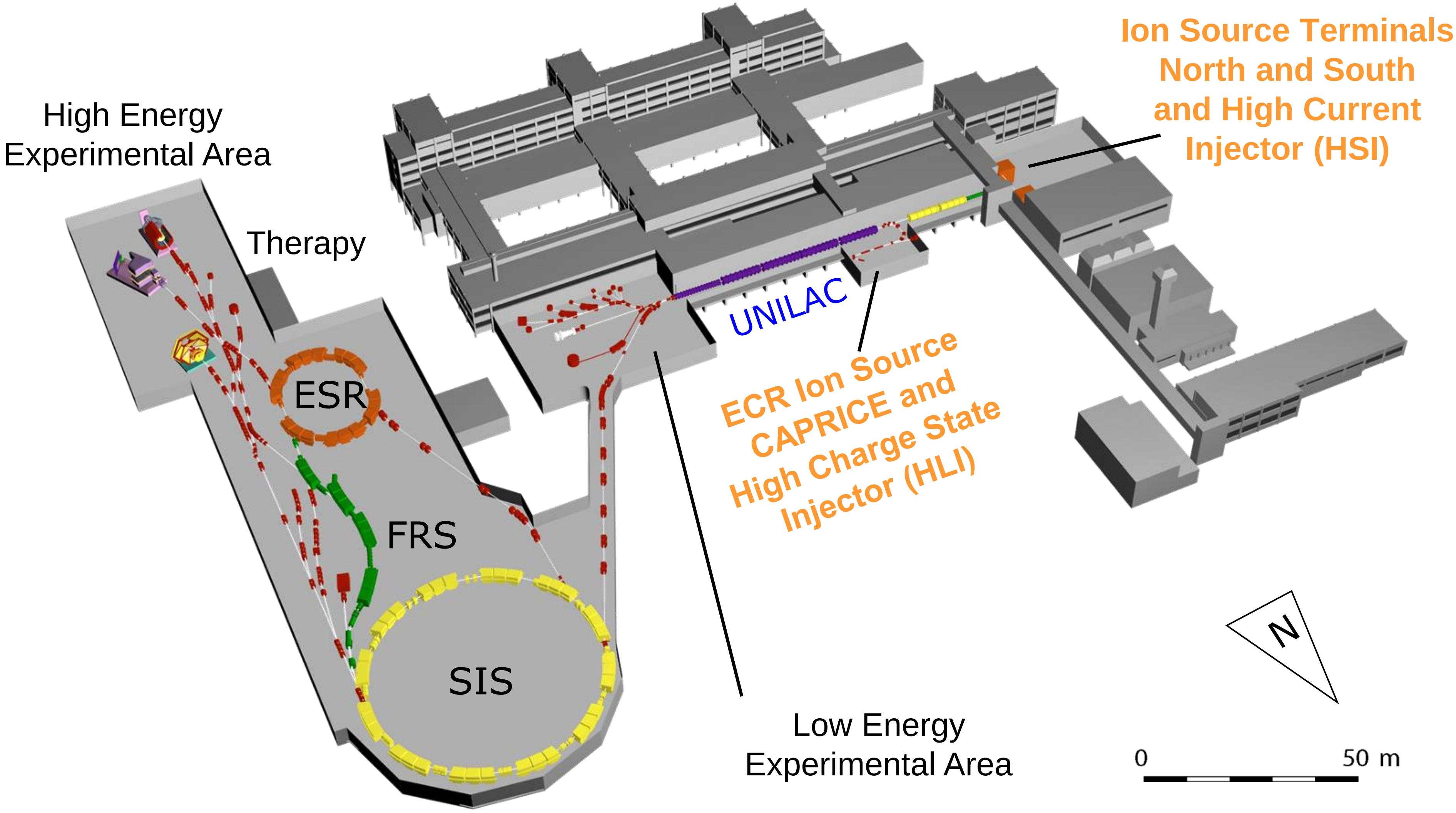
Recent achievements in the production of metallic ion beams with the CAPRICE ECRIS at GSI

Aleksandr Andreev

Outline

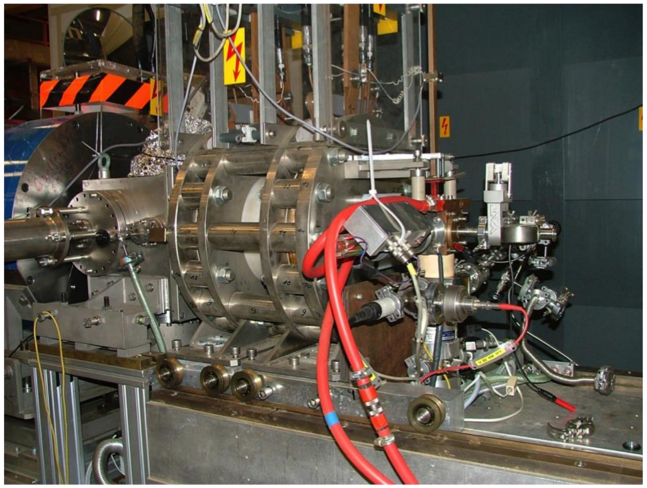
- **Introduction to CAPRICE ECRIS at GSI**
- **Metal Ion Beam Production at GSI**
- **Diagnostic Devices**
- **Results: Chromium & Manganese Beam Tests**

GSI accelerator facility



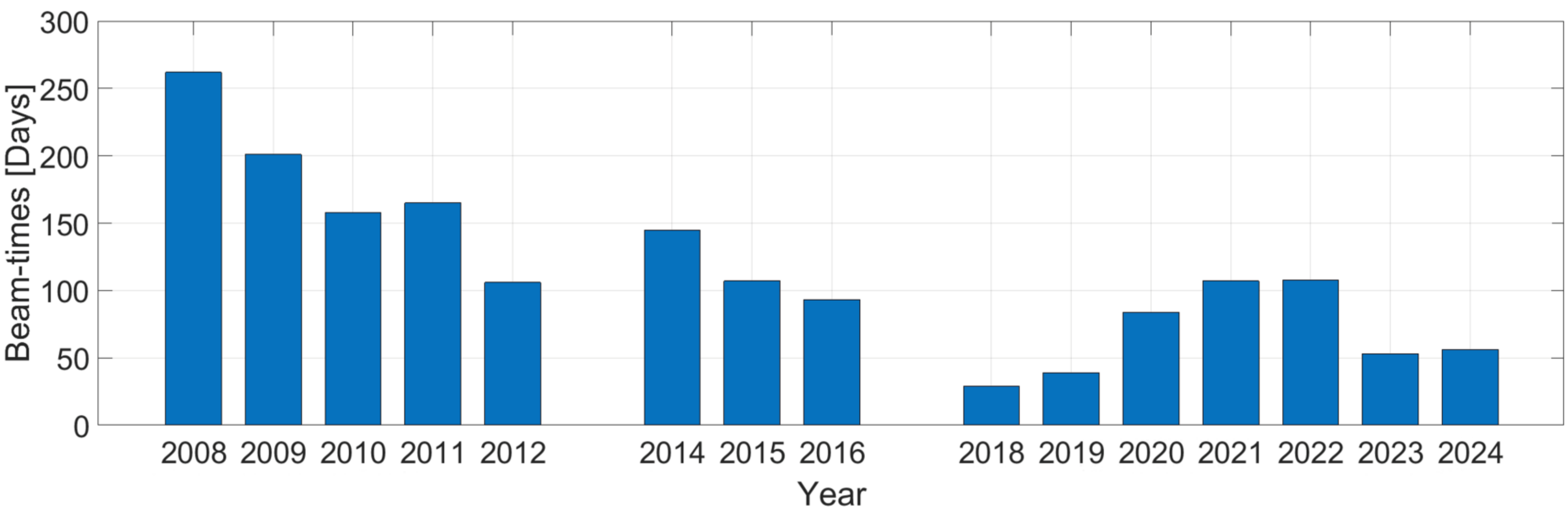
CAPRICE ECRIS @ HLI

CAPRICE ECRIS

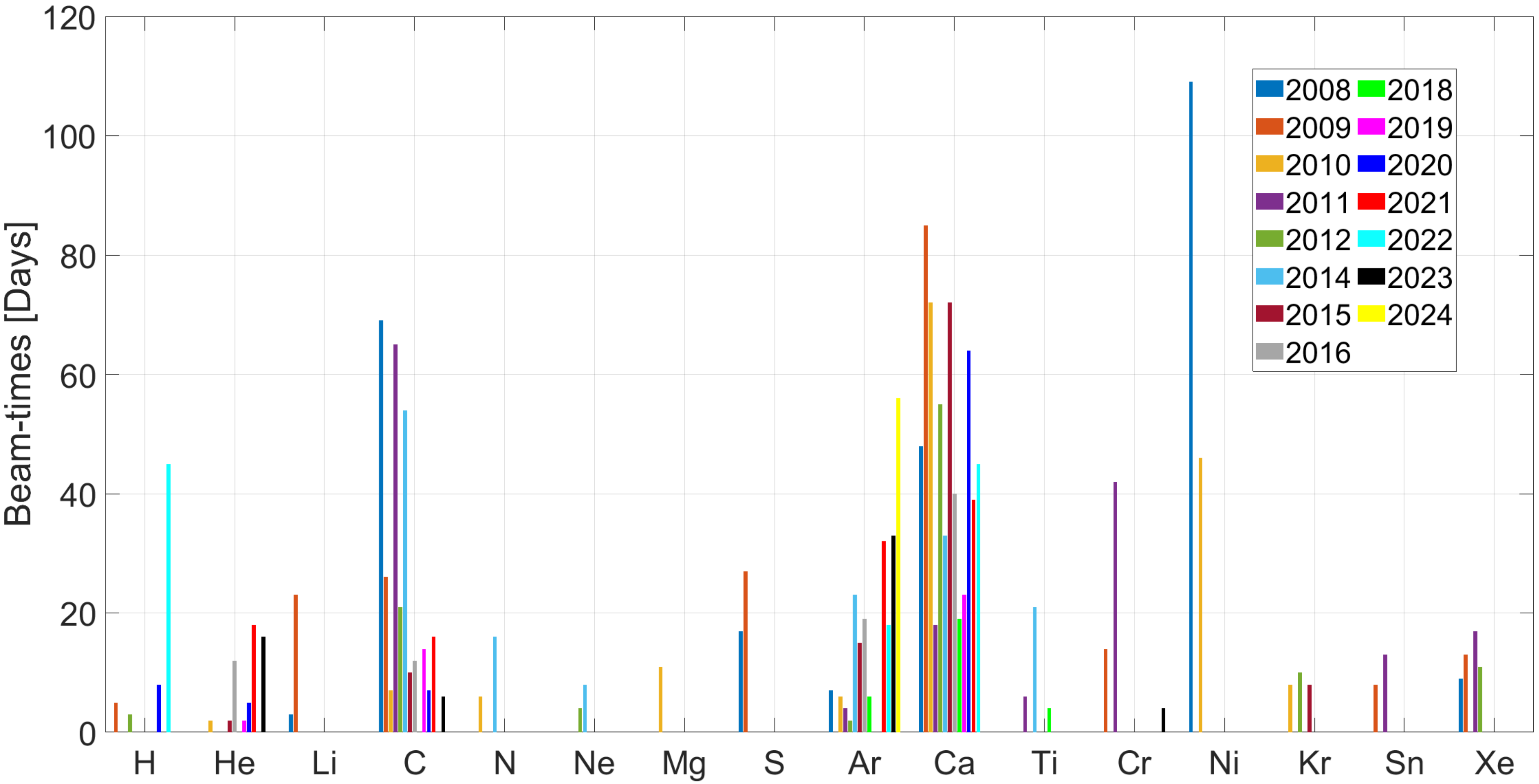


CAPRICE ECRIS main parameters

Hexapole field	1,2 T
Solenoid field	0,8...1,5 T
µW-power	800 W (CW mode)
µW-frequency	14.5 (12,4...16) GHz
Extraction Voltage [kV]	≤ 22
Ion Species	Gas + Solid state (Me)
Mode	CW or Pulsed

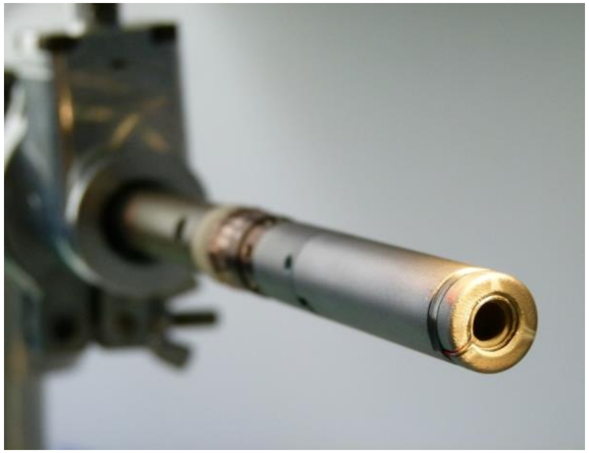


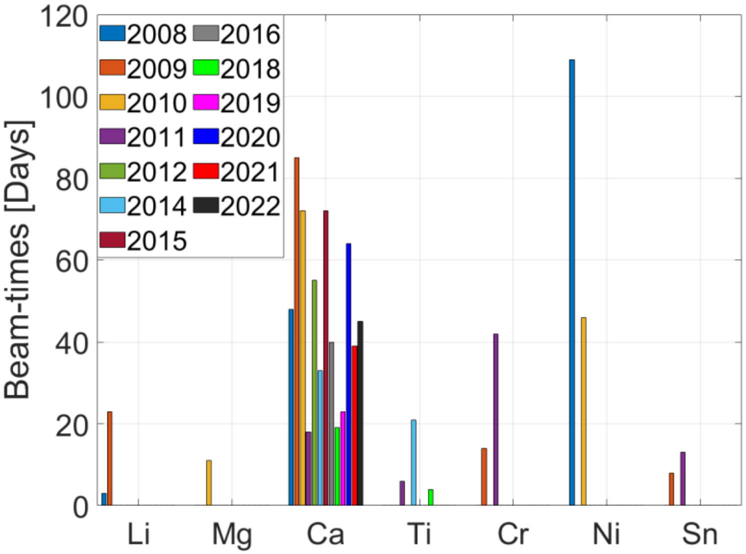
CAPRICE ECRIS @ HLI



Evaporation technique for metal ion beam production @ HLI

Standard Temperature Oven (STO)





Layout

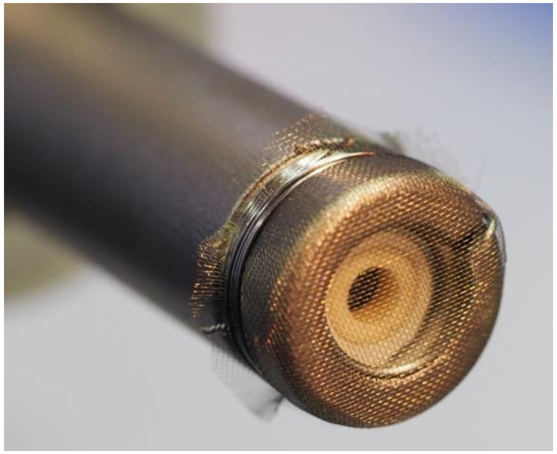
- Resistively heated by current running around the heater body, central current entry
- Aperture ring or crucible
- Water cooled support tube
- Tungsten mesh shielding to prevent parasitic heating (Tungsten, type 100 holes/inch, 25.4 µm wire, 81% transparency)

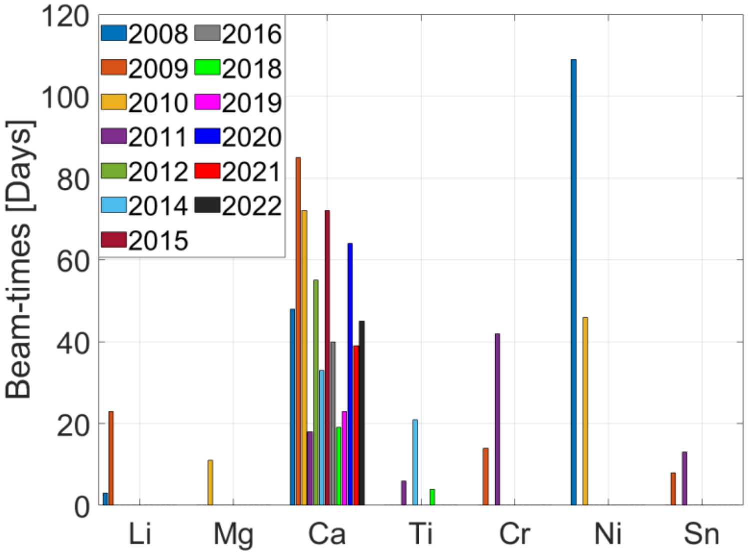
Operating parameters

- Power: 2-120W
- Temperature: 400 -1550°C
- Consumption: 0,2 – 5 mg/h
- Lifetimes days: ^{48}Ca ≤ 30, ^{64}Ni ≤ 6

Evaporation technique for metal ion beam production @ HLI

Microwave shielding





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Oven preparation stand @ HLI

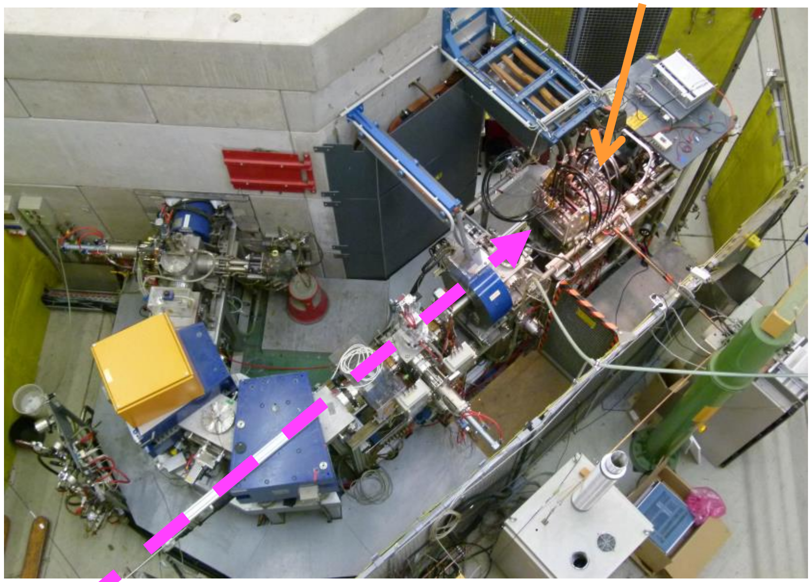
Purpose:

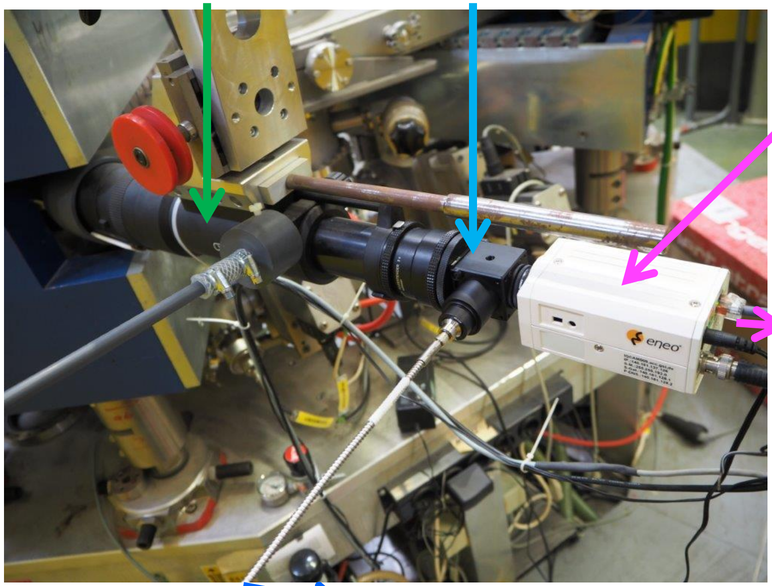
- Essential tool for conditioning ovens before beam operation
- Minimizes downtime during operation
- Improves beam stability and reproducibility

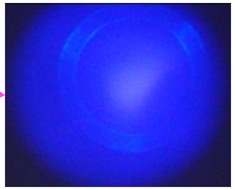
Key features:

- **Controlled environment** for oven outgassing and material preheating (e.g. Ni)
- **Simultaneous oven insertion** with 6 airlocks (previously 4)
- **Water cooling system** for ovens and the stand
- **Online monitoring** (planned: 2-3 cameras) for material conditioning
- **Residual gas analyzer** (planned) for better analysis and process control

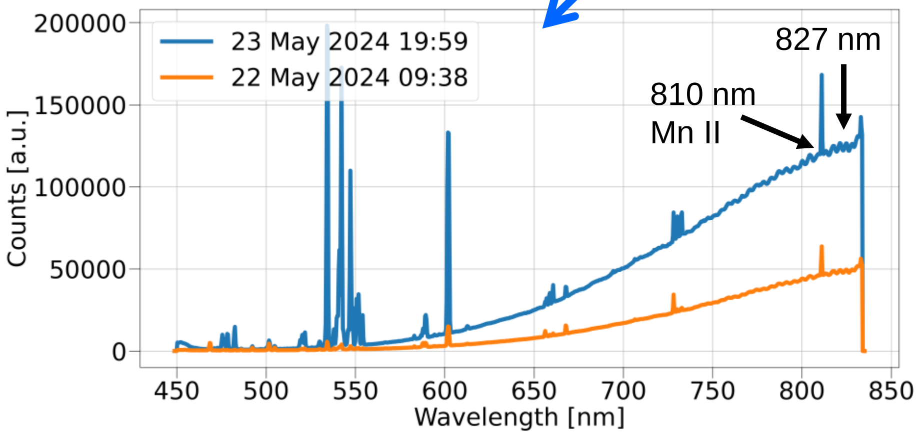
Optical diagnostic devices @ HLI





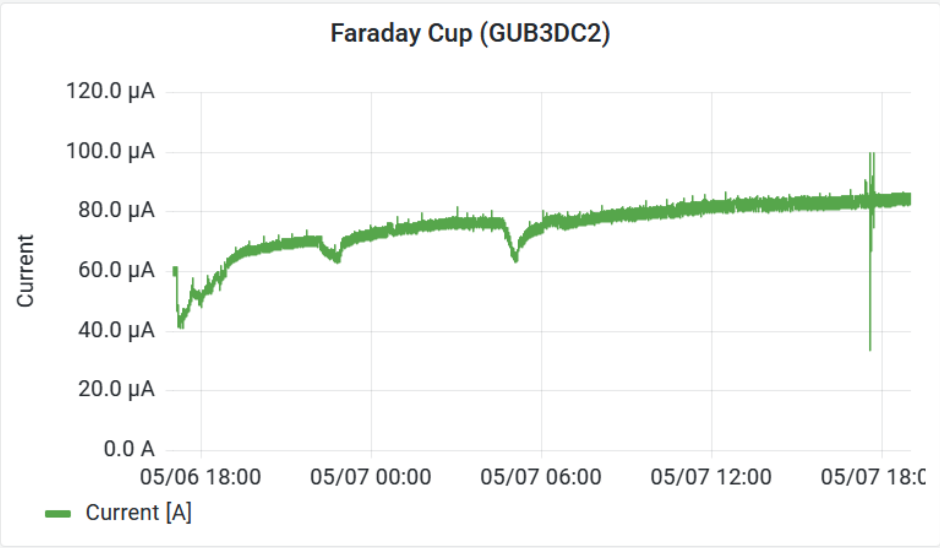


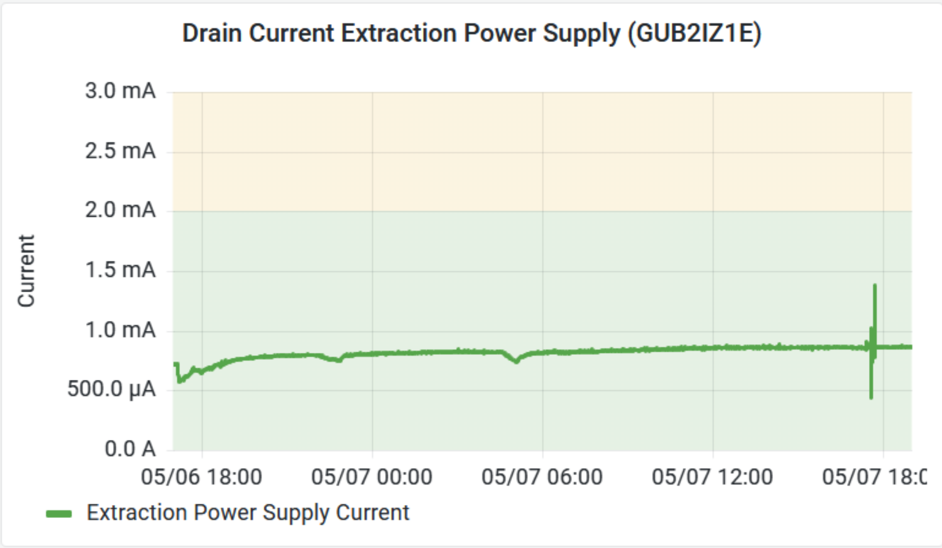
A CCD camera looks through the straight beam line and the extraction aperture into the plasma chamber.

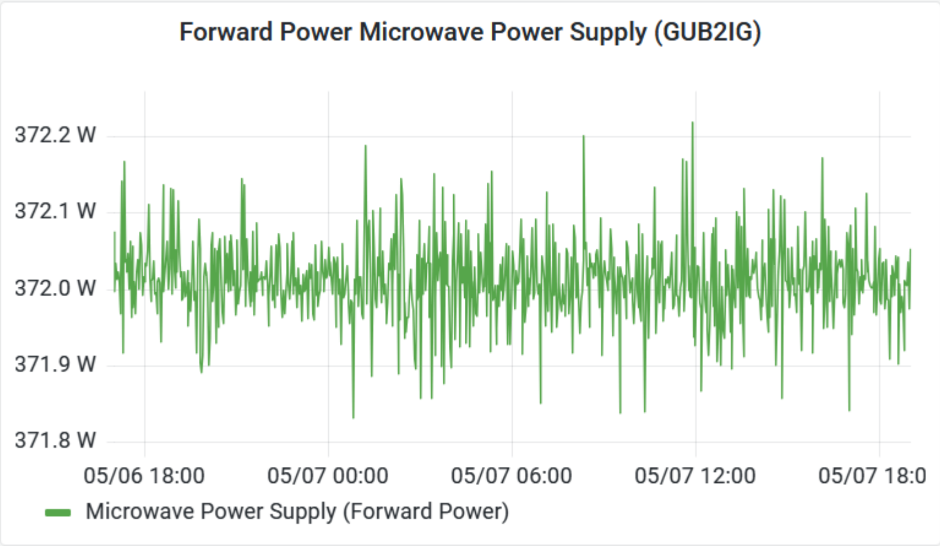


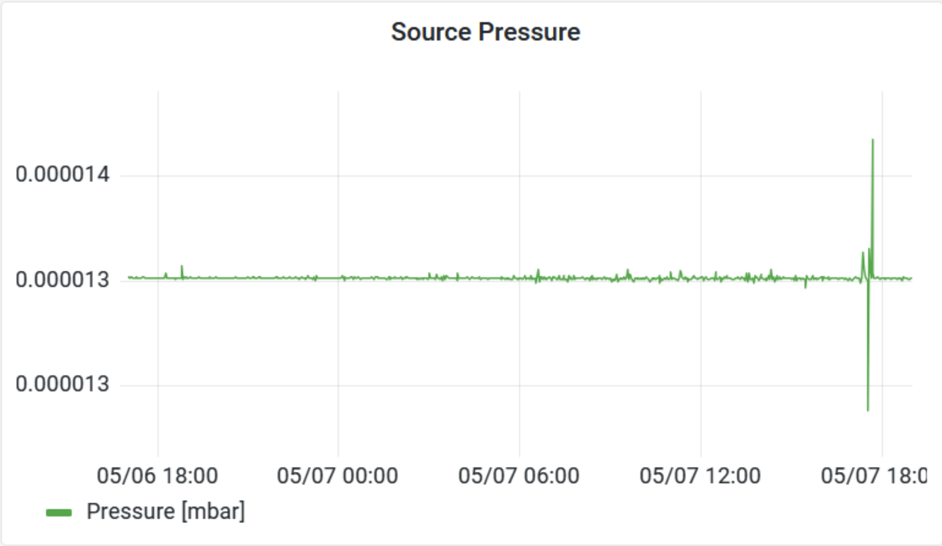
Optical spectroscopy as a diagnostic tool for metal ion beam production with an ECRIS
F.*Maimone, J.Mäder, R.Lang, P.T.Patchakui, K.Tinschert R.Hollinger* , Rev. Sci. Instrum. 90, 123108, 2019

Optical diagnostic devices @ HLI

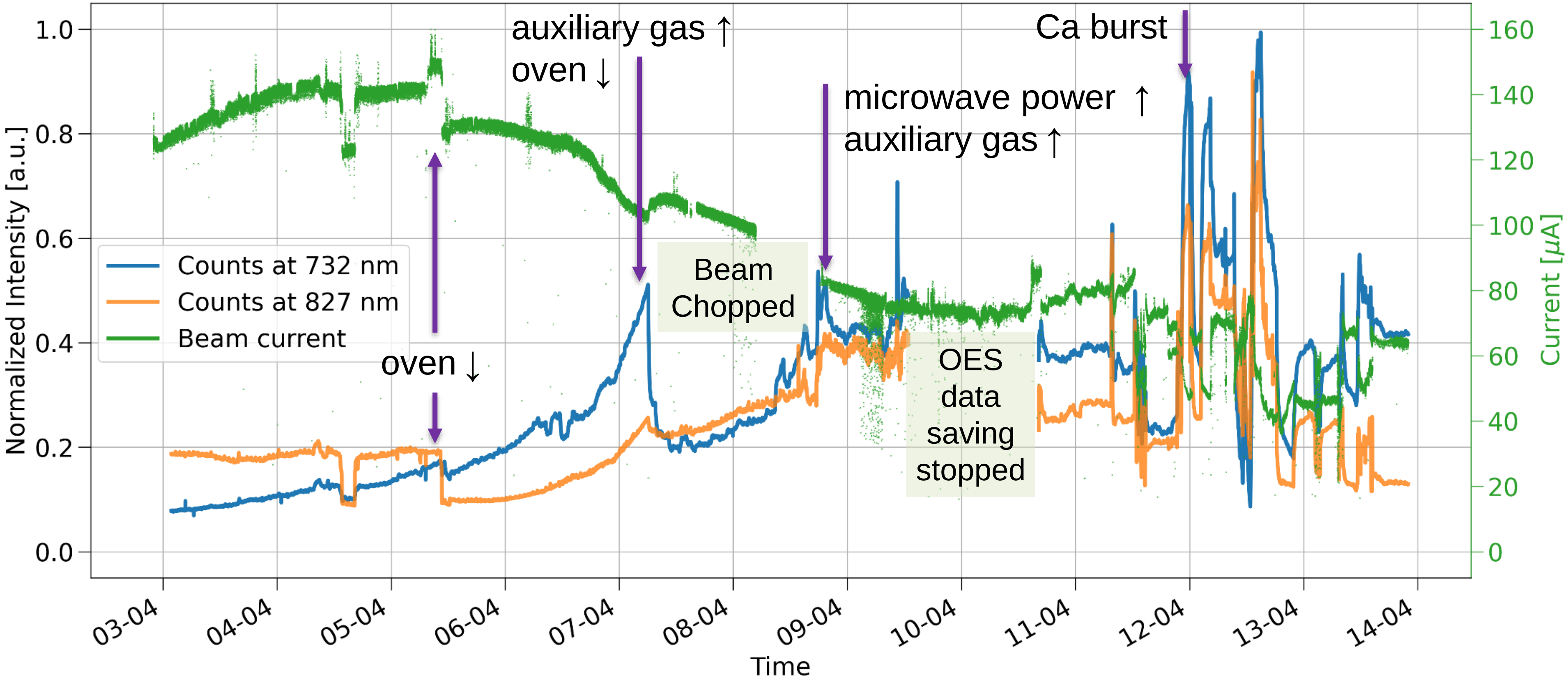


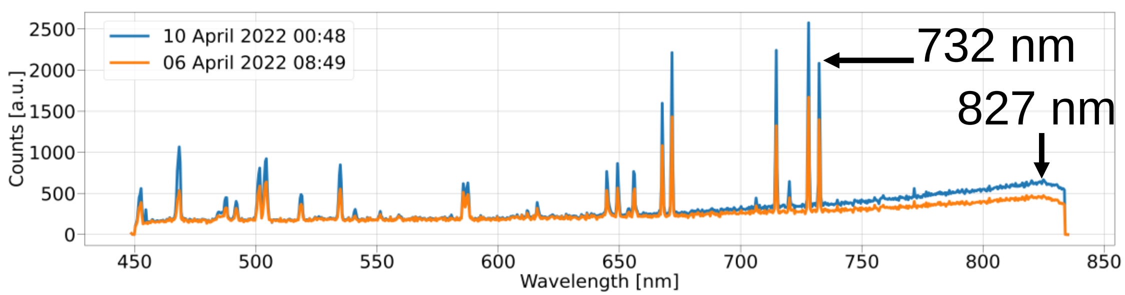






Example: OES diagnostic during first $^{48}Ca^{10+}$ beam run in 2022



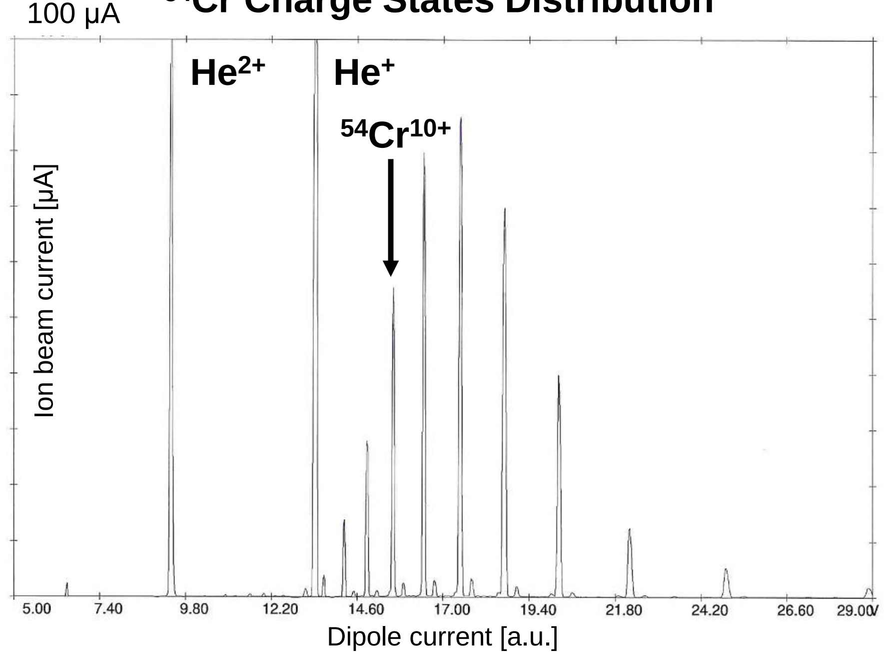


$^{54}Cr^{10+}$ engineering run results

Short-term tests at the test bench (6-8 hours):
- Set target **50 µA $^{54}Cr^{10+}$** for beam intensity, stability, and oven lifetime
- Material consumption w.o. recycling: 8 mg/h

Engineering run (3 days):
- Target intensity reached on Day 1
- Discharges began on Day 2, increasing in frequency over time, affecting beam stability
- Discharges impacted beam stability**,** target intensity could not be maintained

^{54}Cr Charge States Distribution



$^{54}Cr^{10+}$ intensity at the Faraday Cup

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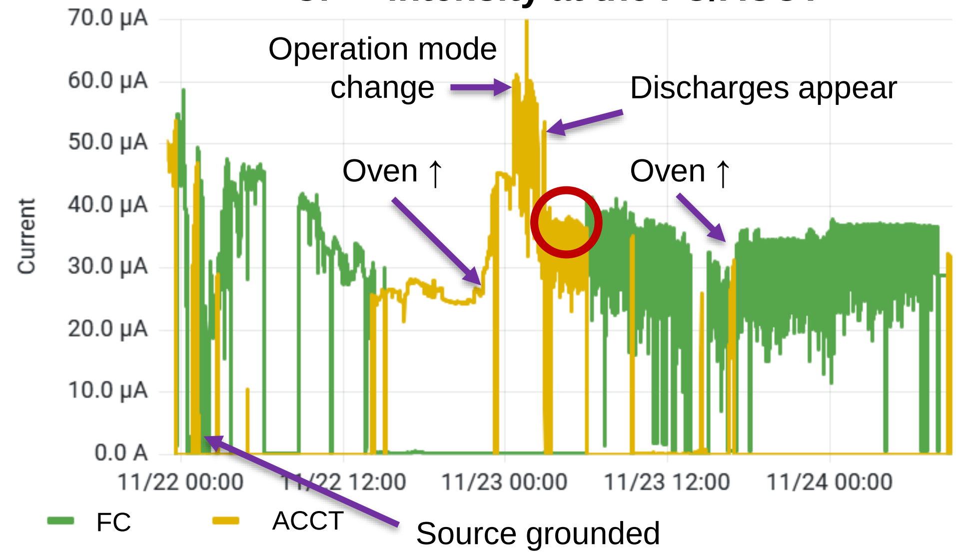
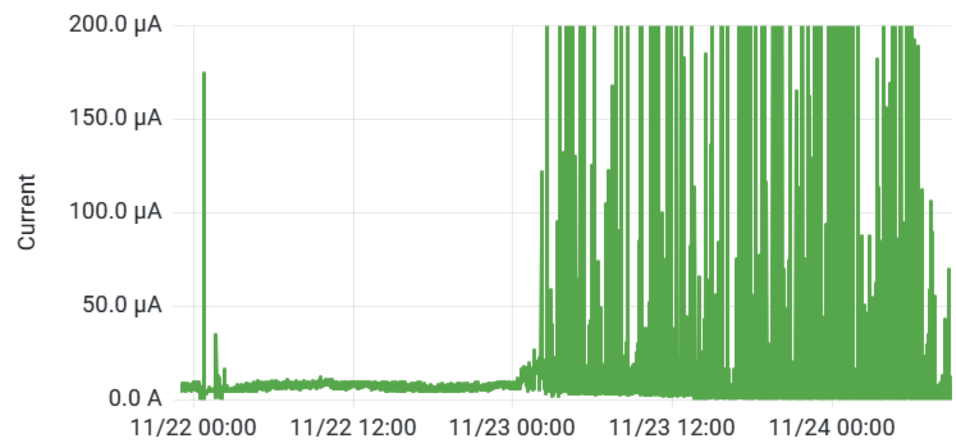
$^{54}Cr^{10+}$ intensity at the FC/ACCT



Current at the screening electrode



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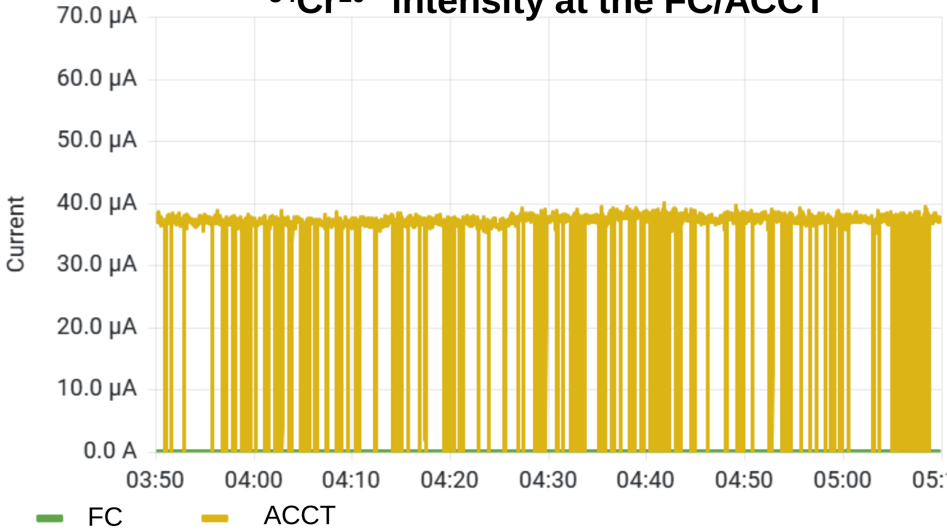

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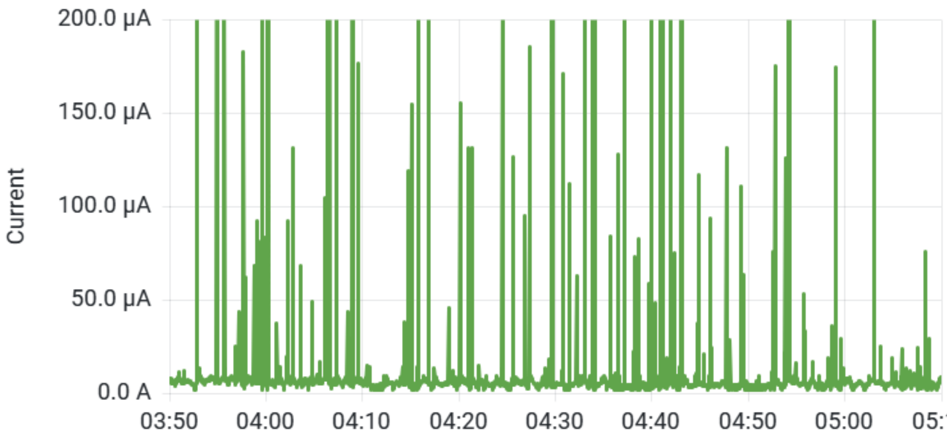
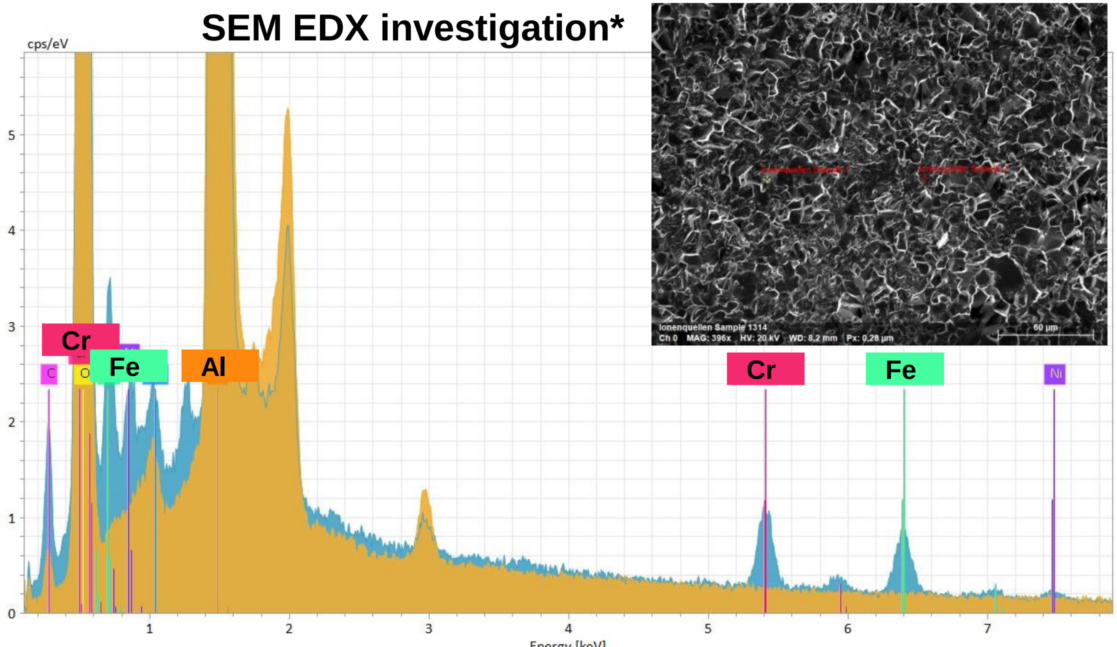
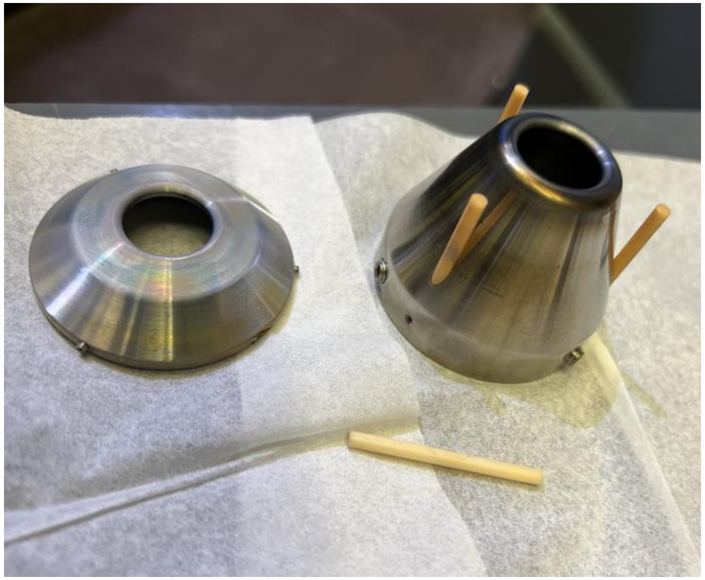


Discharges during ^{54}Cr beam operation

- After disassembling the ECRIS, metallic traces were found on ceramic insulators in the extraction column
- SEM EDX investigation could not determine the traces material
- Possible explanation: discharges between the screening electrode and high-voltage section (17 kV) due to metal buildup on the ceramic

SEM EDX investigation*





*Courtesy of GSI Materials Research Department

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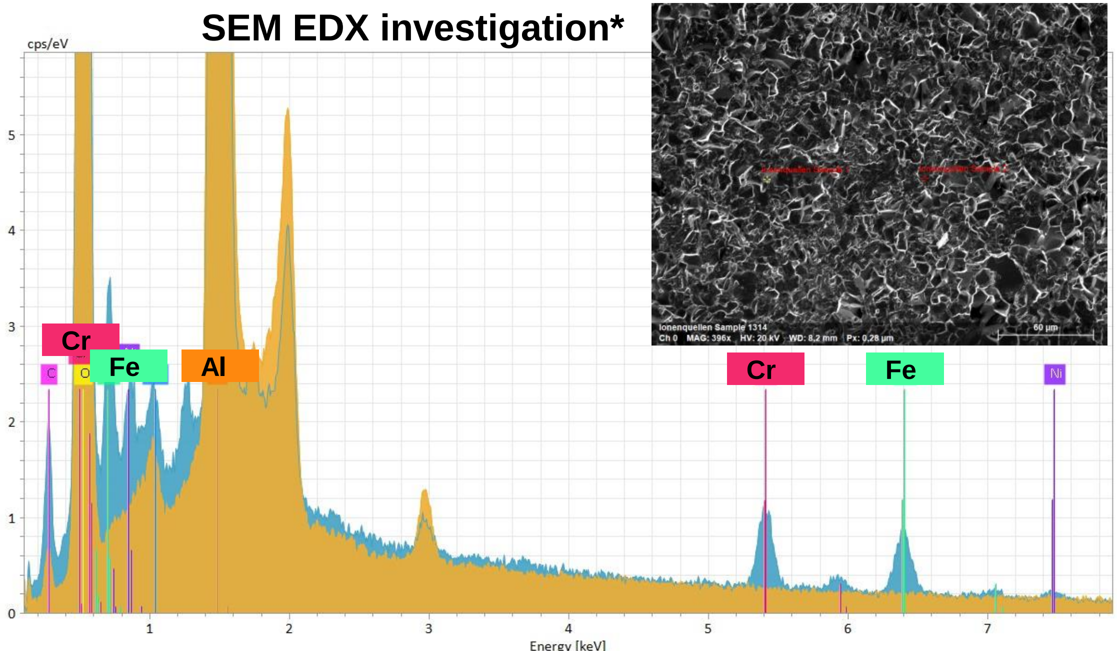
- Planned tests with a hot screen (similar to Mn) to mitigate metal buildup

SEM EDX investigation*

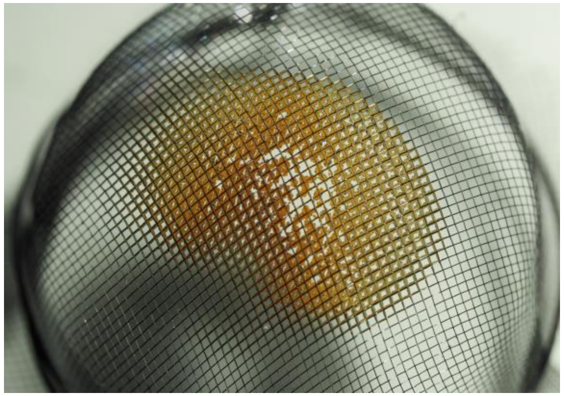


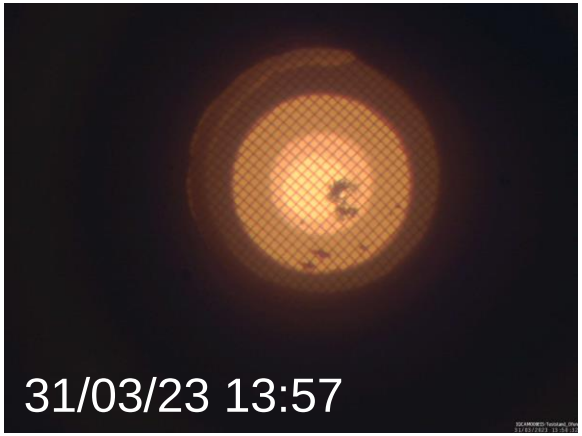
*Courtesy of GSI Materials Research Department

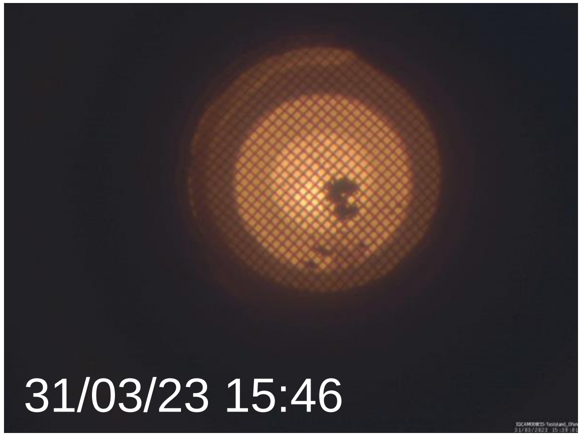
^{54}Cr beam operation with mesh and CCD oven images

- **Tungsten mesh** installed to prevent parasitic microwave heating
- Condensed Cr material started accumulating on the mesh after a few hours
- Beam operation was stable, but the mesh clogged, reducing beam intensity
- **Oven images** show material gradually decreases inside the oven over 5 days
- Material also condenses around the colder oven orifice; could affect stable beam production
- Real-time monitoring with CCD camera provides feedback on evaporation efficiency and material behavior

Mesh clogged after ^{54}Cr operation







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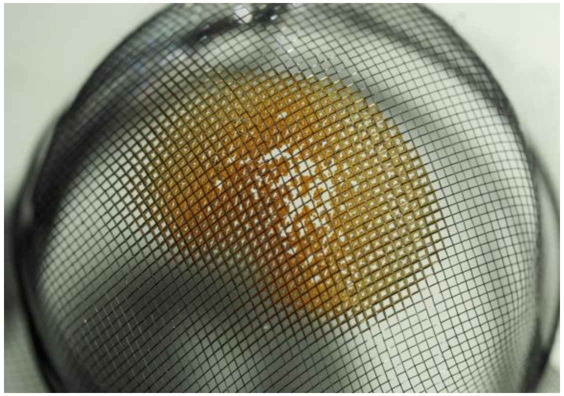
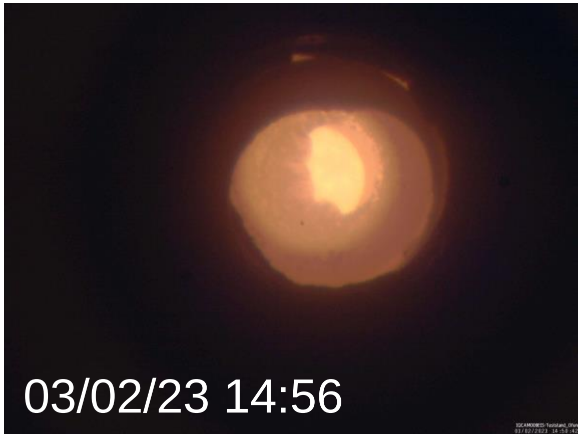
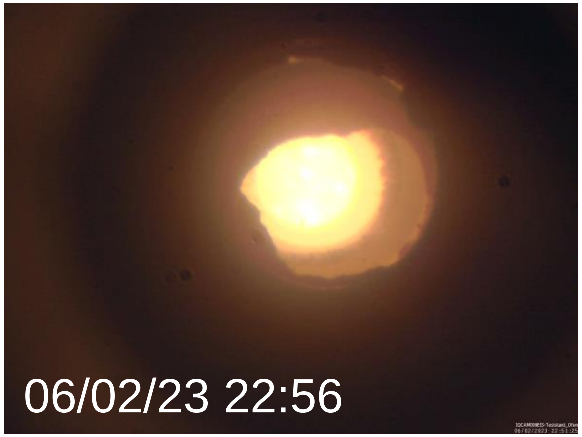


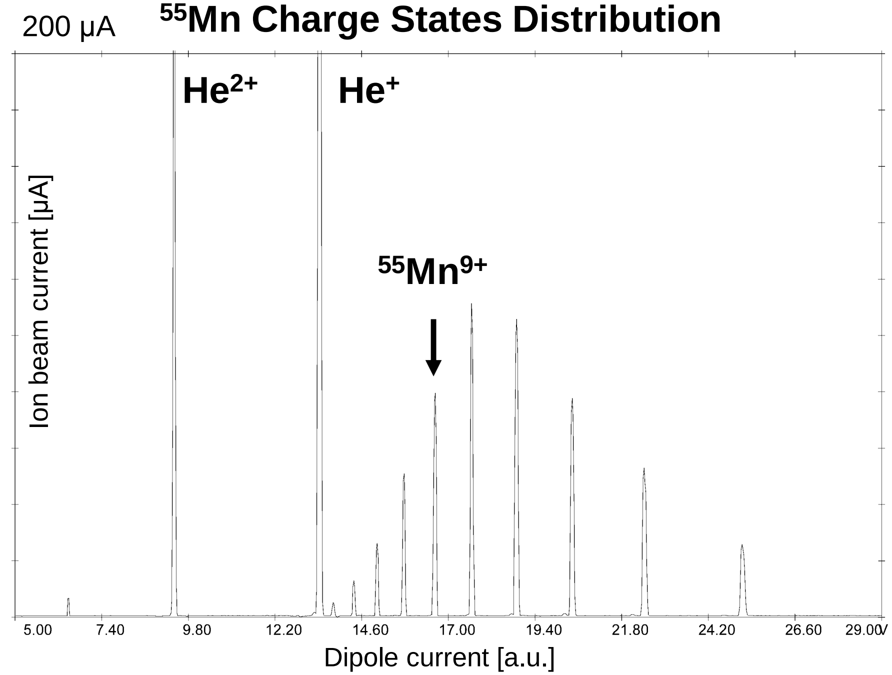




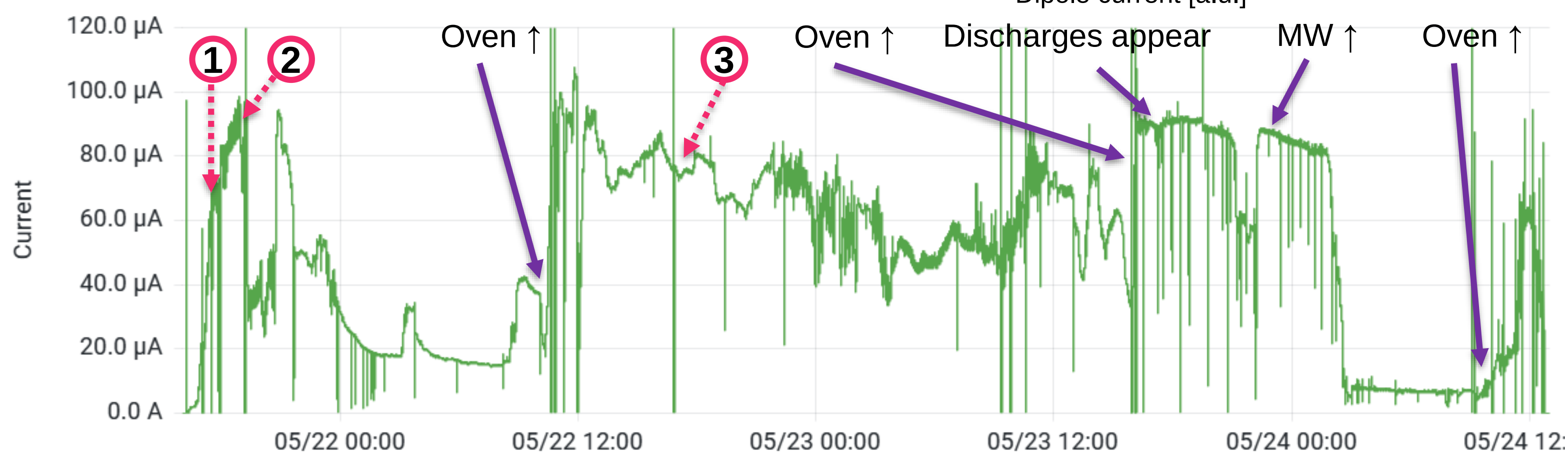
$^{55}Mn^{9+}$ beam establishment test results

- First-time ^{55}Mn beam production at GSI
- 3 days test at test bench (hot screen used)
- **80 µA $^{55}Mn^{9+}$** beam intensity achieved
- Discharges appeared on Day 2
- Discharge frequency was low enough to maintain stable beam production
- Hot screen helped to improve the beam stability
- Less disruptions during operation
- Consumption w.o. recycling: 8.1 mg/h

^{55}Mn Charge States Distribution



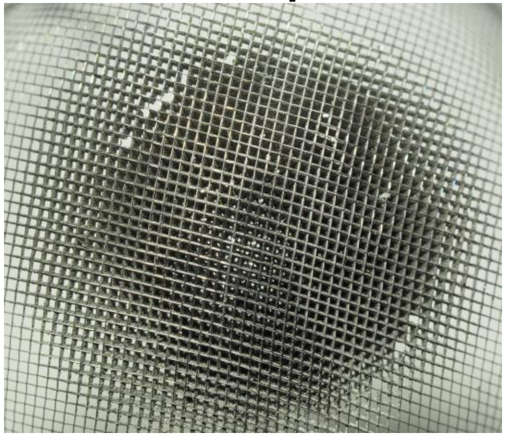
$^{55}Mn^{9+}$ intensity at the Faraday Cup

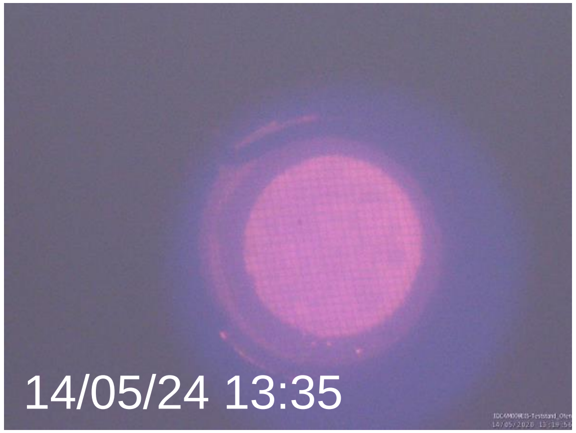


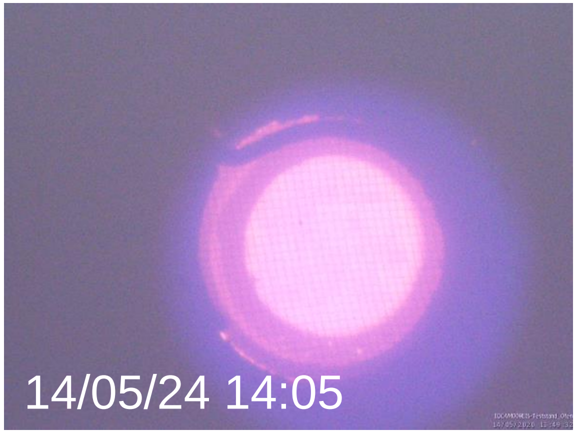
^{55}Mn beam operation with mesh and CCD oven images

- Test run using **Tungsten mesh**, as with the Cr beam
- The mesh clogged heavily with condensed ^{55}Mn after one day of operation
- By the end of the test a stable beam could no longer be produced
- **Oven images** show material reduction inside the oven over 2 days
- Material also condenses around the colder oven orifice
- **Condensed ^{55}Mn** (1.1 g) was recovered, reinserted, and reused in subsequent operations, improving material consumption efficiency

Mesh clogged after ^{55}Mn operation







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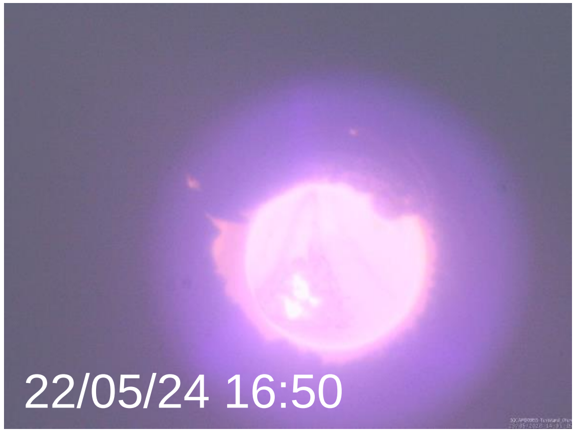
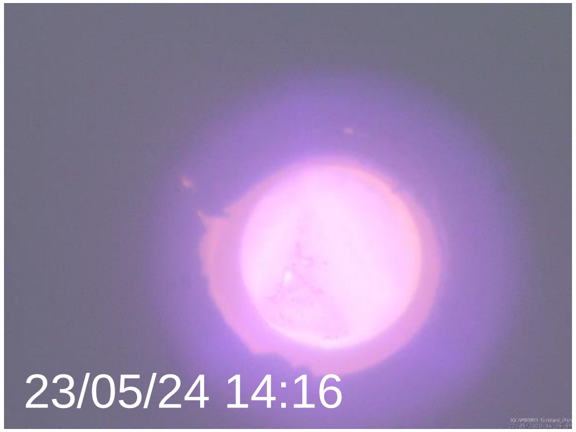
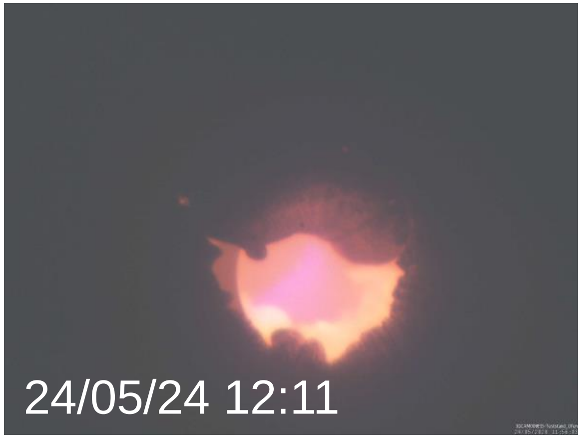
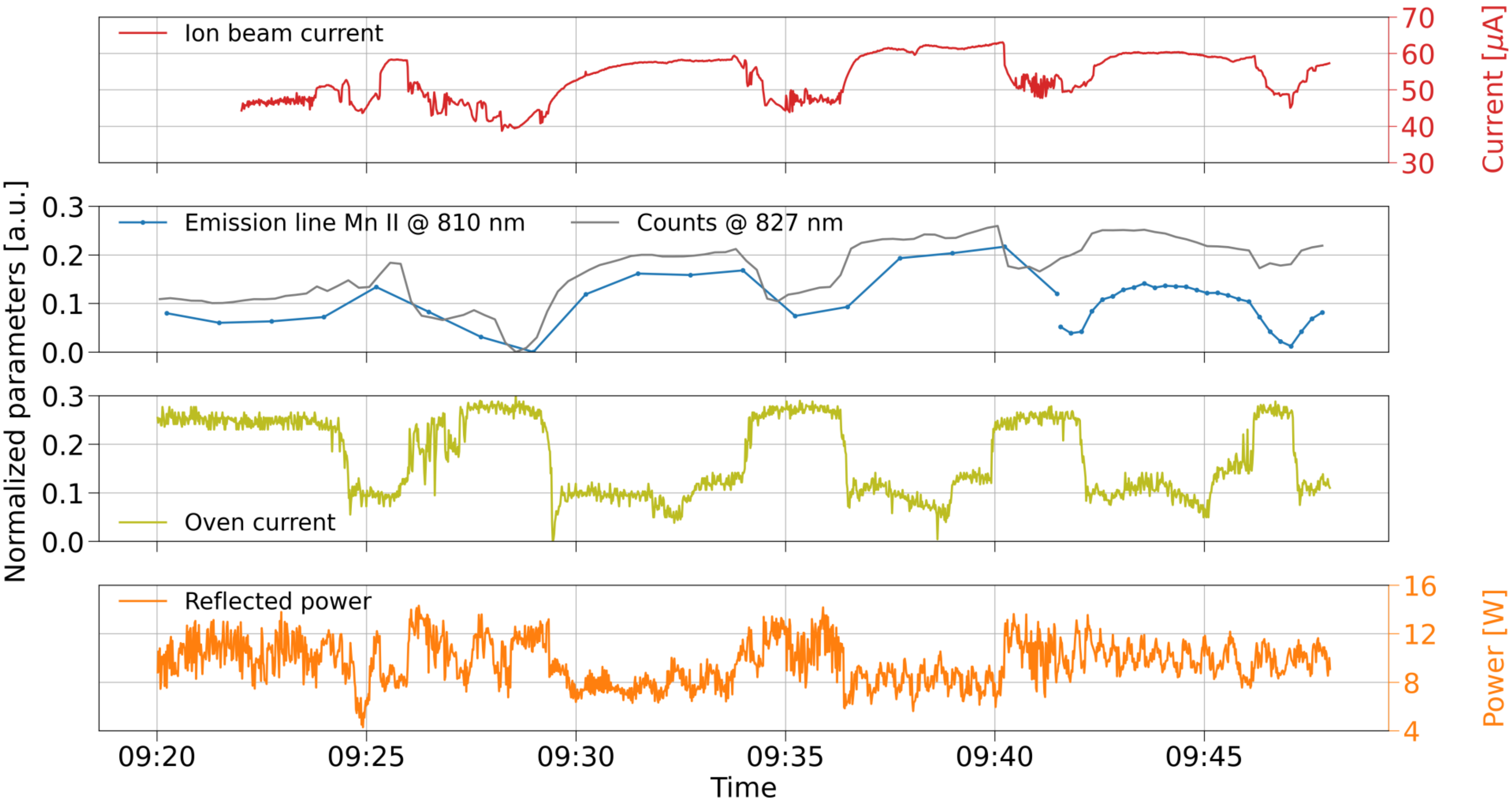
Condensed ^{55}Mn (1.1g) from the oven after operation



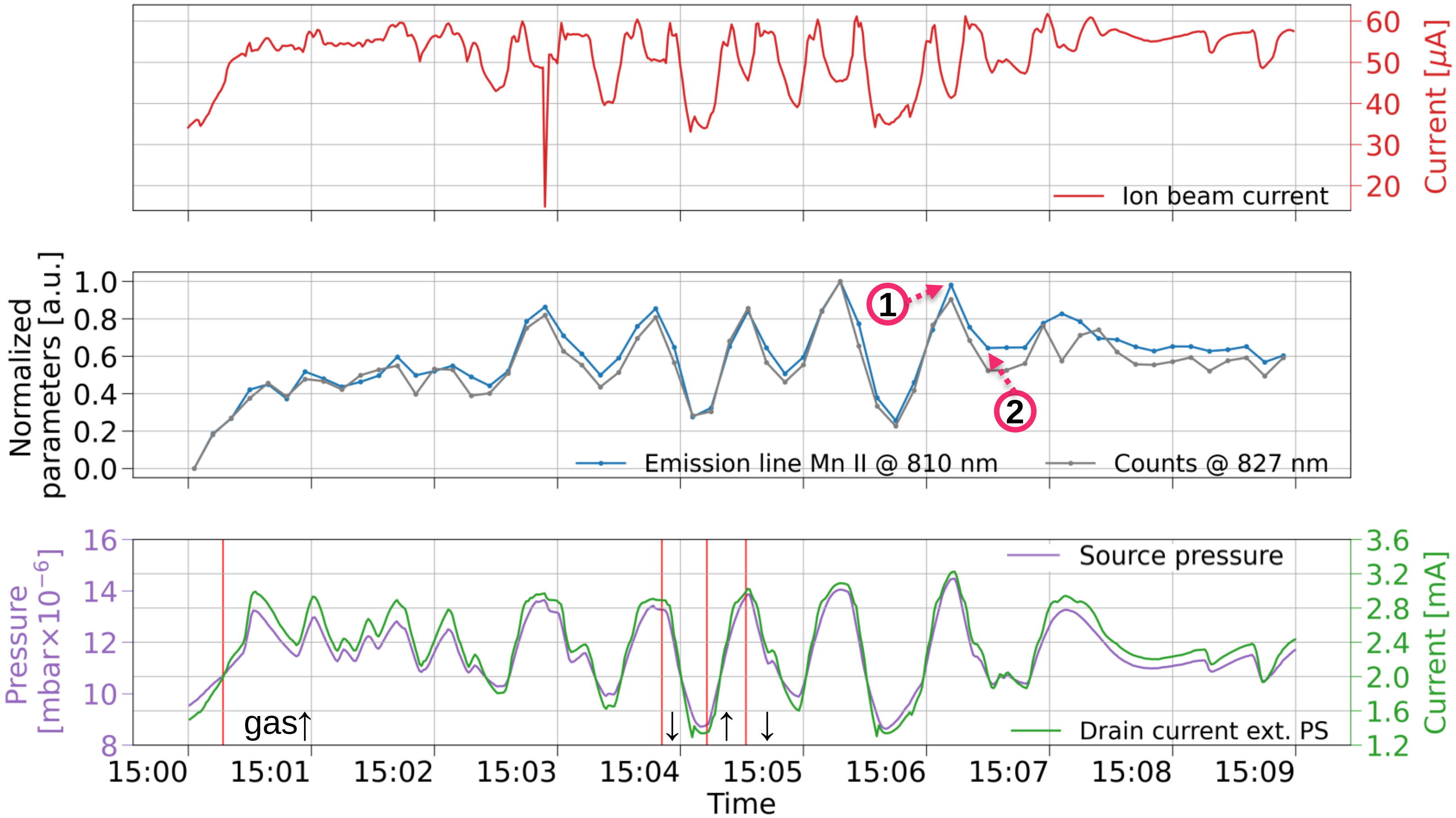


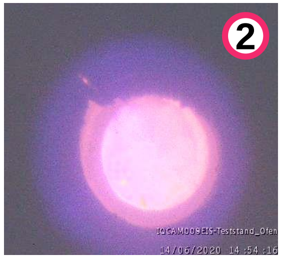


Oven parasitic microwave heating during ^{55}Mn beam operation



Plasma condition monitoring with OES during ^{55}Mn beam operation





Summary

- The resistive heated oven is an established technique for metallic element evaporation with the CAPRICE ECRIS at GSI. The CAPRICE ECRIS successfully produces beams of **$^{54}Cr^{10+}$** and **$^{55}Mn^{9+}$** at high intensities, with good control over the ECRIS parameters.

- Long term operation for ^{54}Cr is limited by the material deposition on the ceramic isolators in the extraction column.

- The use of a **Ta liner** extends the operational time for ^{55}Mn, and tests for ^{54}Cr are planned.

- **Microwave shielding** can prevent parasitic heating of the oven for elements with low sublimation temperature. However, this approach was ineffective for both ^{54}Cr and ^{55}Mn, which became clogged after just a few hours to one day of operation due to material condensation.

- **Optical emission spectroscopy** and **plasma/oven imaging** are powerful diagnostic tools for metal ion beam production with ECRIS. These tools allow us to detect instabilities, observe changes in plasma conditions and identify parasitic microwave heating of the oven, as well as to monitor material consumption and condensation in real time.

Thank you for your attention!

THE ECRIS TEAM

Ralph Hollinger (dpt. Leader)
Fabio Maimone
Michael Galonska
Ralf Lang
Jan Mäder
Michael Händler
Me