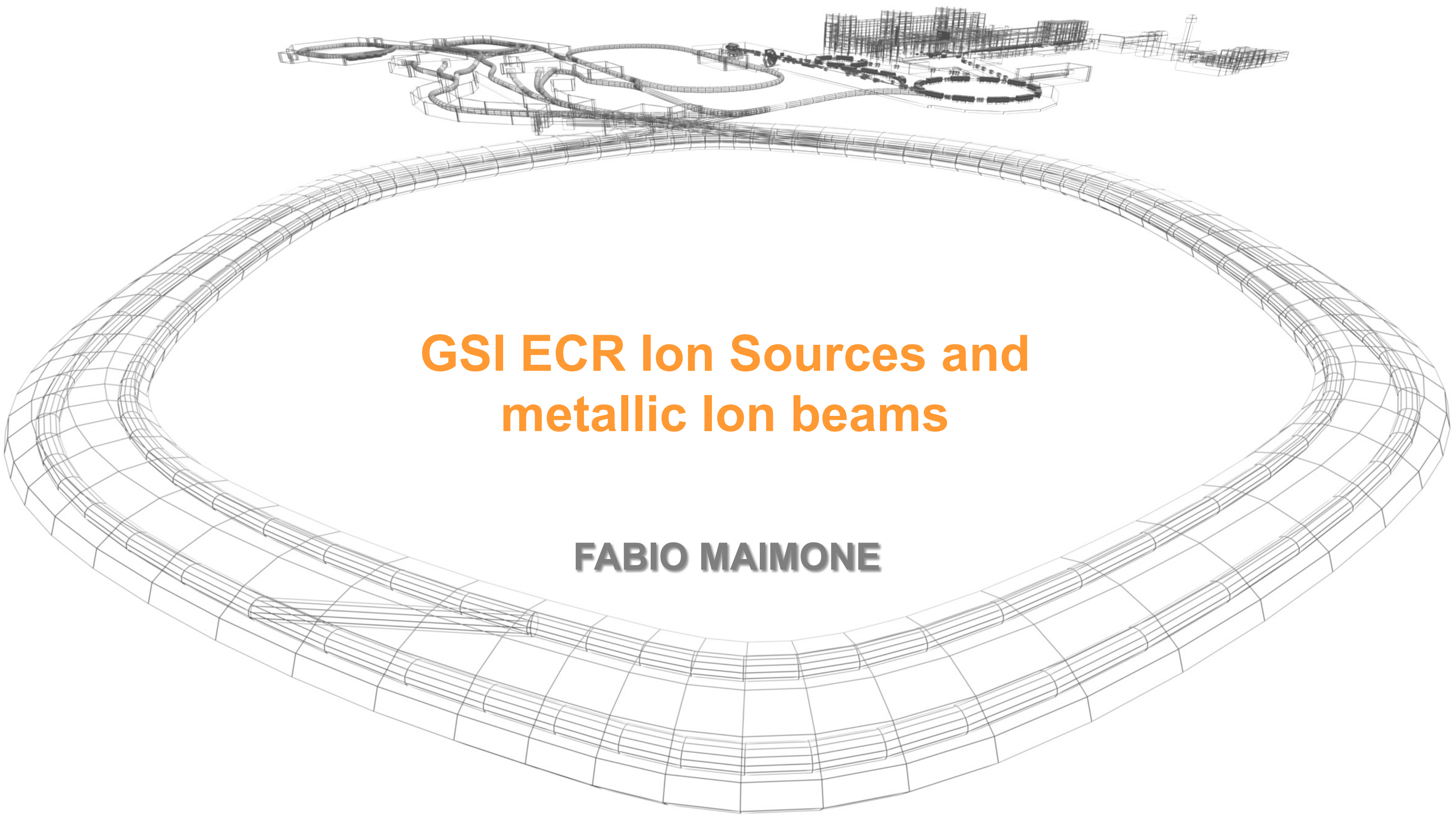


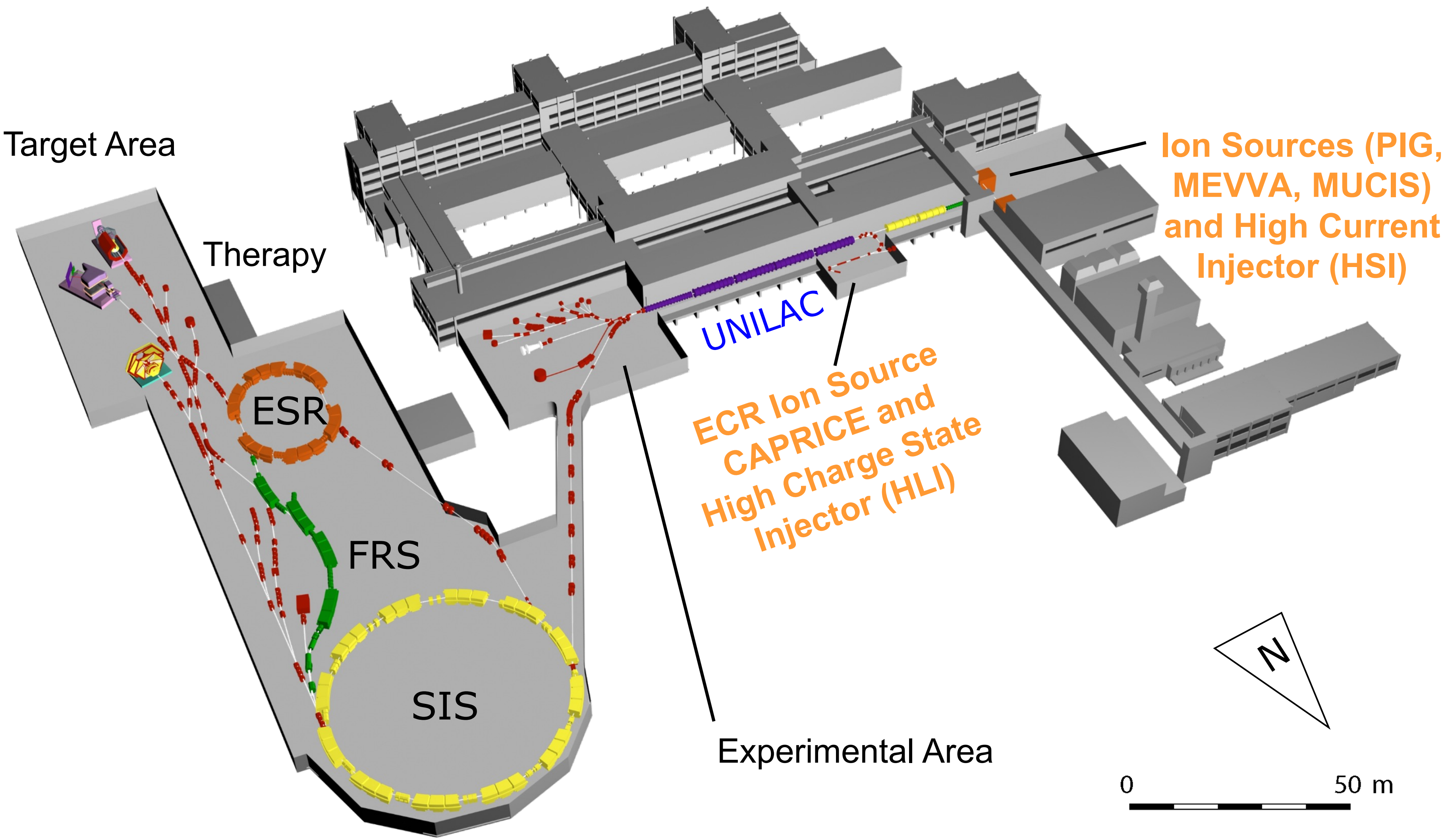
GSI ECR Ion Sources and metallic Ion beams

FABIO MAIMONE

Outline

- Ion sources for metal Ion beam production at GSI
- ECRIS Developments
  - Metal ion beam production with Resistive Oven at GSI
  - Optical emission spectroscopy
  - ^{48}Ca ion beam
  - ^{54}Cr ion beam

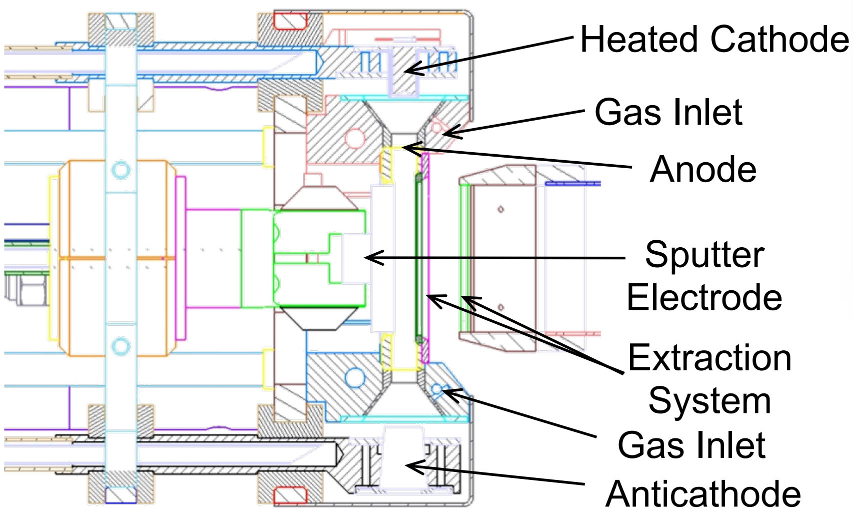
GSI Accelerator Facility

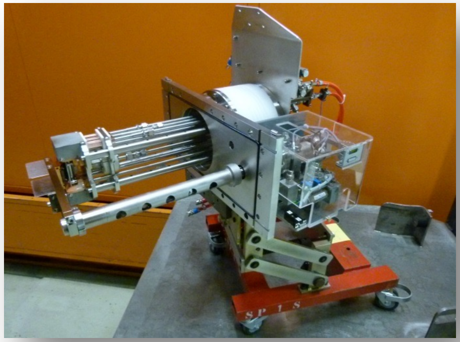


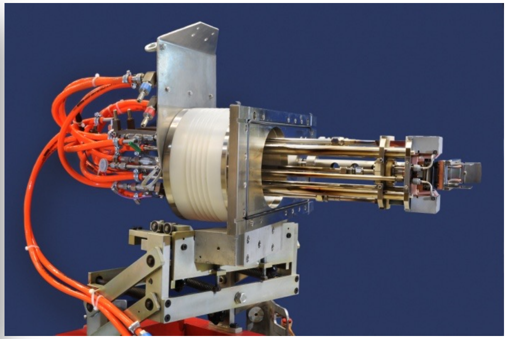
TERMINAL SOUTH
High Current Ion Sources

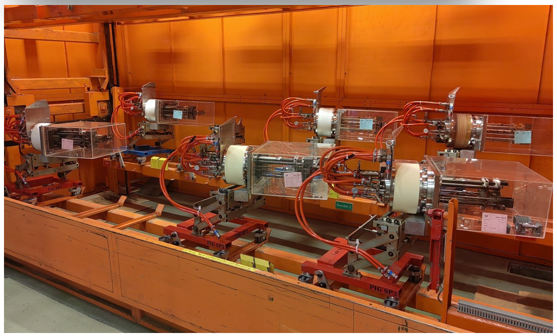
TERMINAL SOUTH
High Current Ion Sources

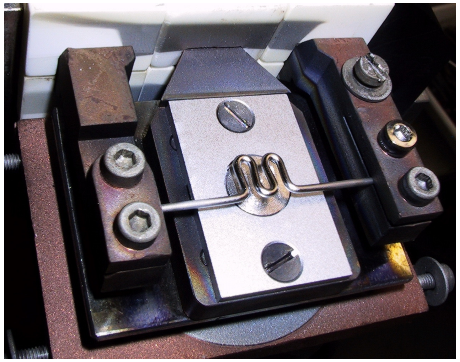
PIG (Penning Ionization Gauge) Ion Source

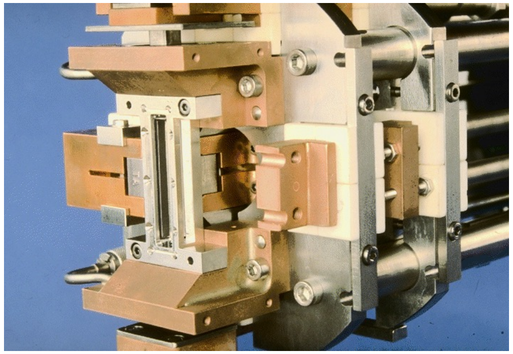










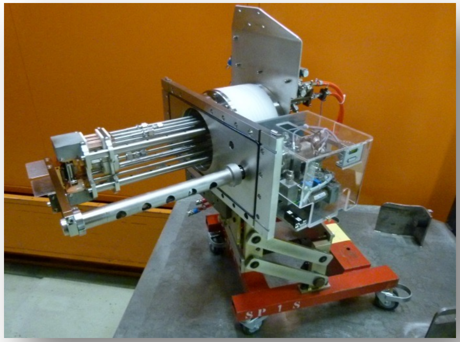
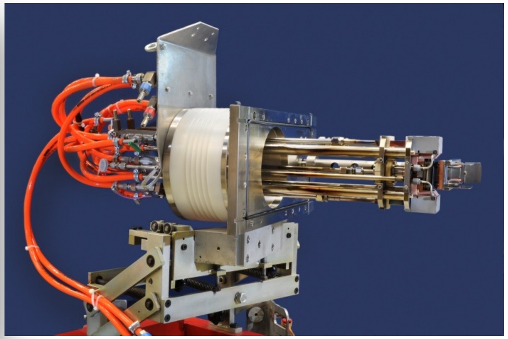
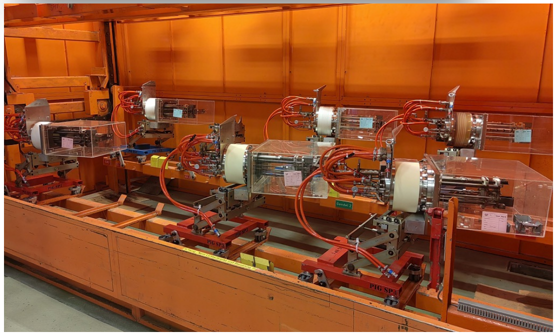


- In operation since 1970´s
- 5 Gaseous and 6 sputter ion sources
- Slit Extraction System
- Working Material: Gases and Metals
- Duty Cycle: up to 50Hz / 5ms
- Emission Current Density: up to 100 mA/cm²
- Charge State: 1+...10+
- Lifetime: 50 Hz-1 day; 10 Hz-3 days

TERMINAL SOUTH
High Current Ion Sources

PIG (Penning Ionization Gauge) Ion Source

Ion species	Intensity (RFQ, emA)
$^{197}Au^{8+}$	0.05
$^{50}Ti^{2+}$	0.05
$^{209}Bi^{4+}$	0.15
$^{6}Li^{1+}$	0.1
$^{56}Fe^{2+}$	0.1
$^{136}Xe^{6+}$	0.17
$^{58}Ni^{1+}$	0.27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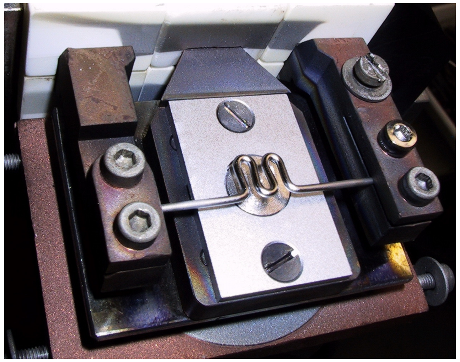
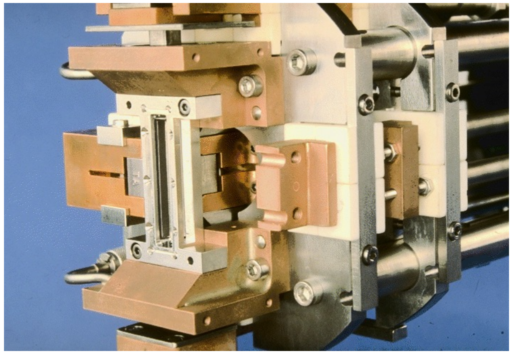
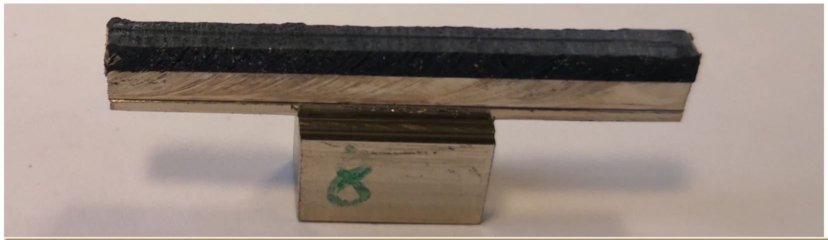
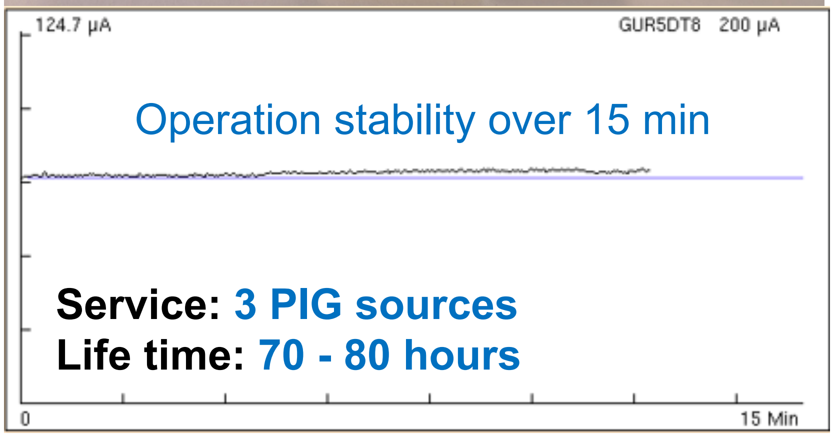



PIG Ion Source Performance

$^{6}Li^{1+}$ Performance



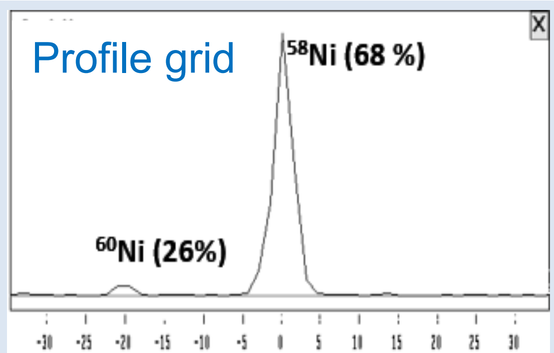


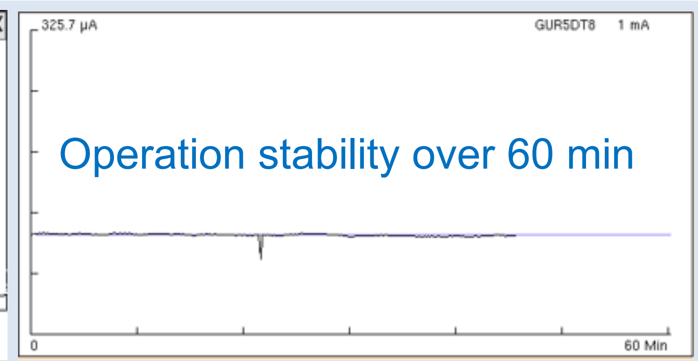
Service: **3 PIG sources**
Life time: **70 - 80 hours**

TERMINAL SOUTH Beamtime 2022			
Ion species	**Duty cycle**	**Intensity RFQ [emA]**	**Duration [days]**
$^{6}Li^{1+}$	5 Hz / 1 ms	0.1	10
$^{40}Ar^{2+}$	5 Hz / 1 ms	0.3	6
$^{56}Fe^{2+}$	5-10 Hz / 1 ms	0.1	8
$^{58}Ni^{1+}$	5 Hz / 1 ms	0.27	12
$^{136}Xe^{6+}$	25 Hz / 3 ms	0.17	6
$^{197}Au^{6+}$	5 Hz / 1 ms	0.3	12
$^{197}Au^{8+}$	25 Hz / 3 ms	0.04	11
$^{209}Bi^{4+}$	5 Hz / 1 ms	0.15	10

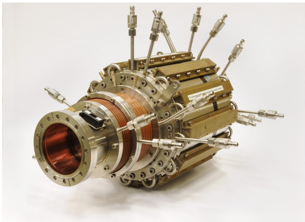
$^{58}Ni^{1+}$ Performance

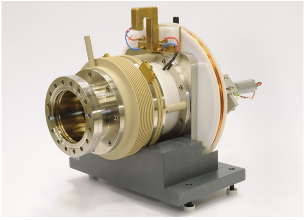
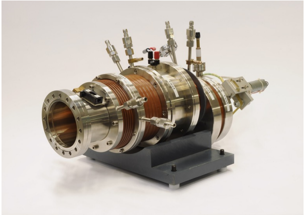
Service: **4 PIG sources**
Life time: **70 - 80 hours**





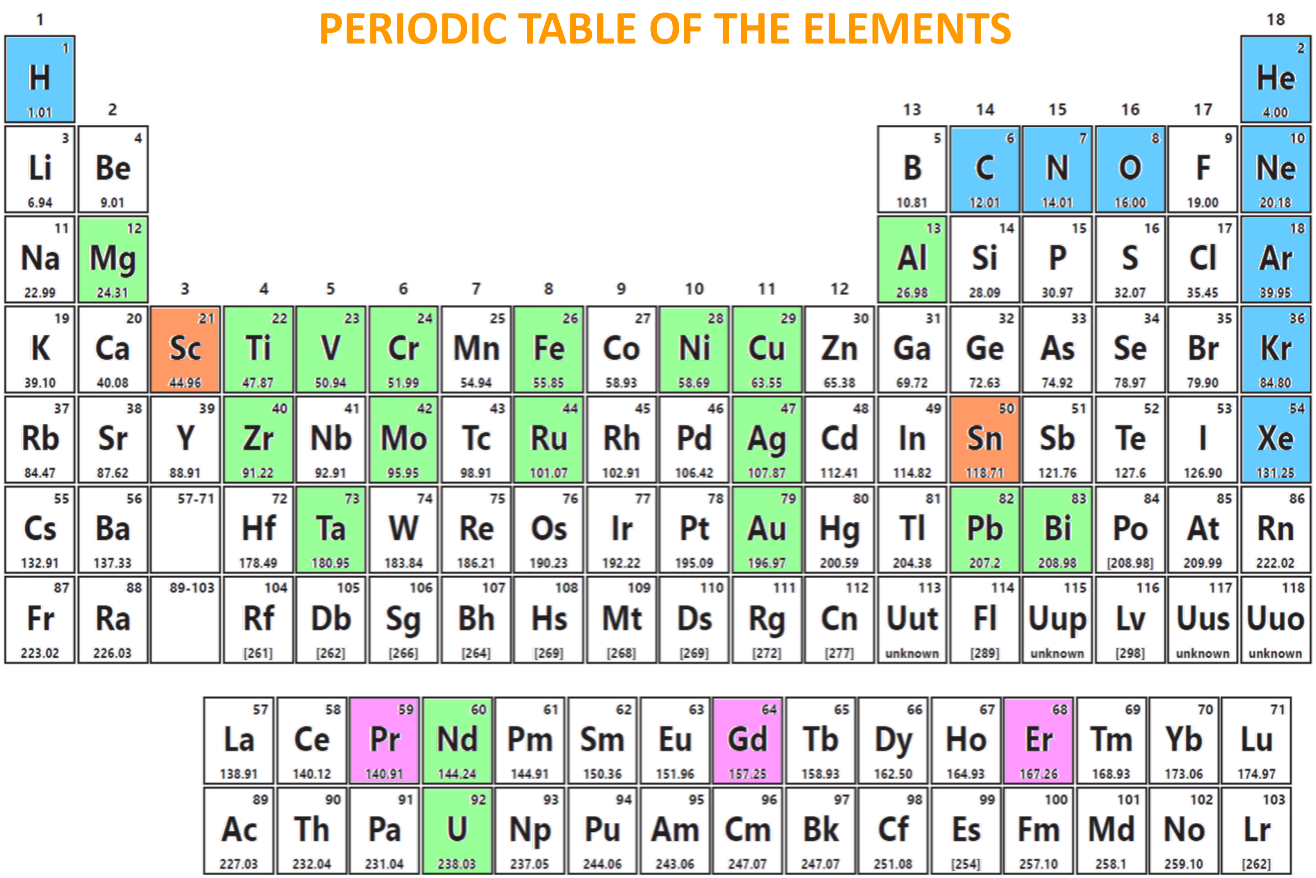
TERMINAL NORTH
High Current Ion Sources



	MUCIS NEW (MUlti Cusp Ion Source) 2010	MUCIS (MUlti Cusp Ion Source)	CHORDIS (Cold or HOt Reflex Discharge Ion Source)	VARIS (Vacuum ARc Ion Source)	MEVVA (MEtal Vapor Vacuum Arc Ion Source)
	FILAMENT DRIVEN ION SOURCE			VACCUM ARC ION SOURCE	
Plasma chamber	ø 250 x 255 mm	ø 205 x 215 mm	ø 90 x 80 mm	ø 65 x 80 mm	ø 40 x 110 mm
Filaments	2 x Tungsten	2 x 3 Tantalum	6 x Tungsten		
Extraction system	Triode, Multi aperture: 13 x ø 3 mm, Aspect ratio: 0.5, Extraction voltage: up to 33 kV Post-acceleration: up to 150 kV				
Arc current	up to 400 A	up to 200 A	up to 400 A	up to 2000 A	up to 2000 A
Emission current dens.	up to 180 mA/cm^2			up to 300 mA/cm^2	up to 170 mA/cm^2
Duty cycle (typ.)	5 Hz, 1 ms (0.5%)			1 Hz, 0.5 ms (0.05%)	1 Hz, 1 ms (0.1%)
Working gas/metal	H_2, D_2, He, CH_4, Ne, N_2, Ar, Kr, Xe		H_2, D_2, CH_4, N_2, O_2, Ne, Ar, Kr, Xe	O_2, Mg, Ca, Ti, Ni, Mo, Ag, Nd, Ta, Au, Pb, Bi, U	O_2, Mg, Ca, Ti, Ni, Mo, Ag, Nd, Ta
In operation	since 2009	since 1987	since 1984	since 2004	since 1999
Developer	GSI, R. Hollinger F. Heymach	GSI, H. Wituschek	GSI, R. Keller	GSI, R. Hollinger	LBNL (USA), I.G. Brown

TERMINAL NORTH
Ion species provided



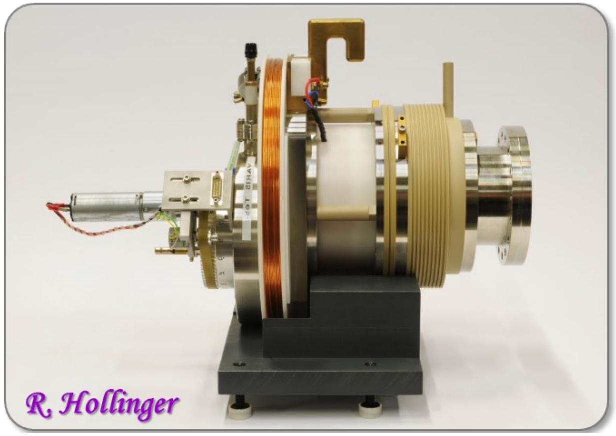
Gaseous ion sources: 9 elements

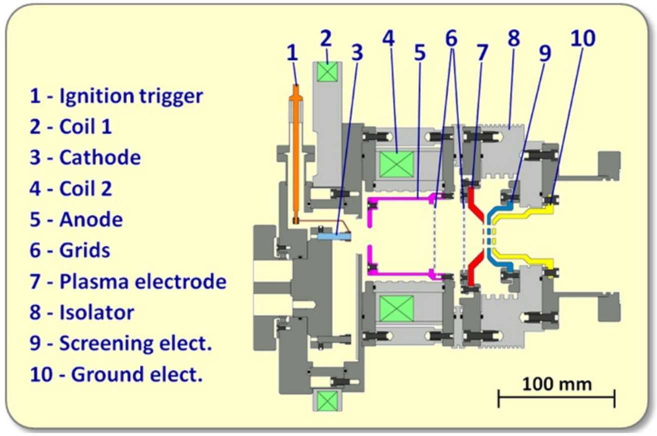
Metal ion sources: 21 elements

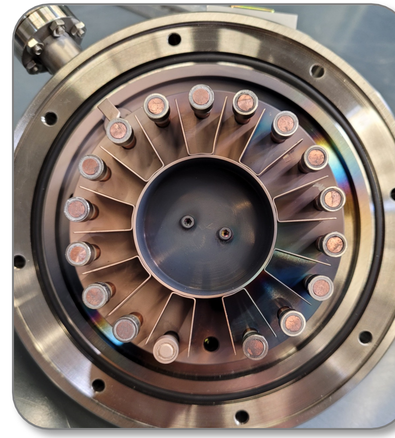
{ recently developed: 3 elements
currently in development: 2 elements

High Current Metal Ion Sources

VARIS (Vacuum Arc Ion Source)







FEATURES

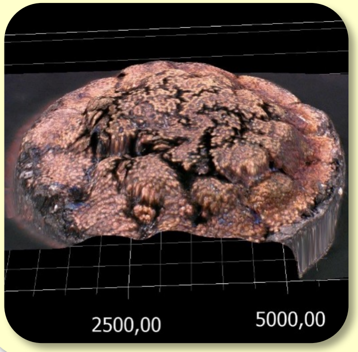
- In operation: **since 2004**
- Typical duty cycle: **1 Hz / 0.5 ms**
- Ion charge states: **up to 4+**
- Extraction system: **triode, multi-aperture 13 x ø3 mm**
- Extraction voltage: **up to 32 kV**
- Ion beam currents: **up to 15 emA** (@ RFQ)

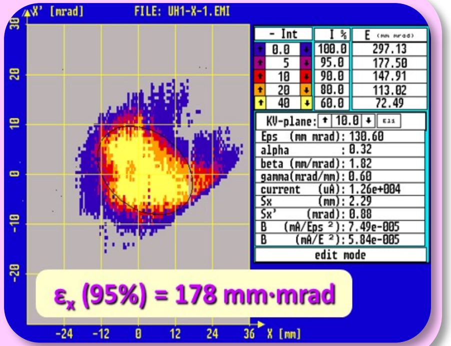
KEY ELEMENTS

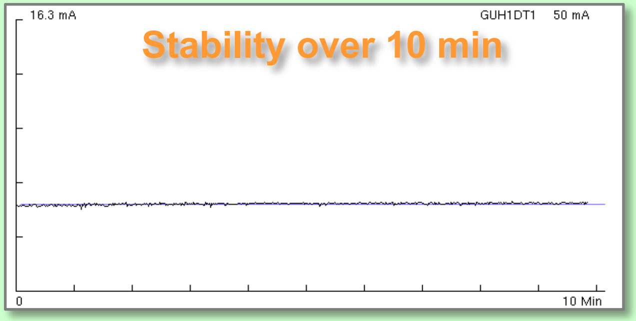
Ion species	Intensity at RFQ
$^{107}Ag^{2+}$	6 emA
$^{197}Au^{4+}$	5 emA
$^{208}Pb^{4+}$	7 emA
$^{209}Bi^{4+}$	10 emA
$^{238}U^{4+}$	15 emA

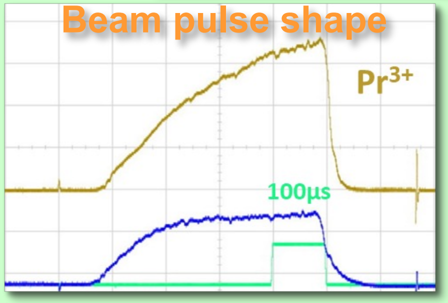
High Current Metal Ion Sources
Recent development

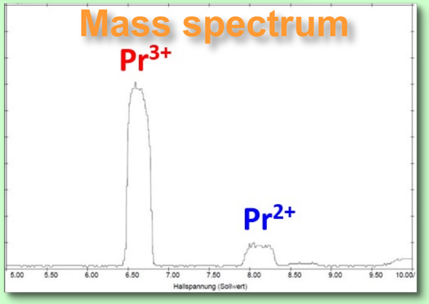
- Cathodes out of composite materials for production of high current ion beams for Au, Pb and Bi
- Increasing of beam brilliance and repetition rate for intense U^{4+} ion beam
- Development of new projectiles in middle-heavy region: Sc, Sn, Pr, Gd, Er

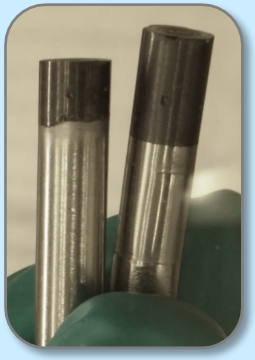




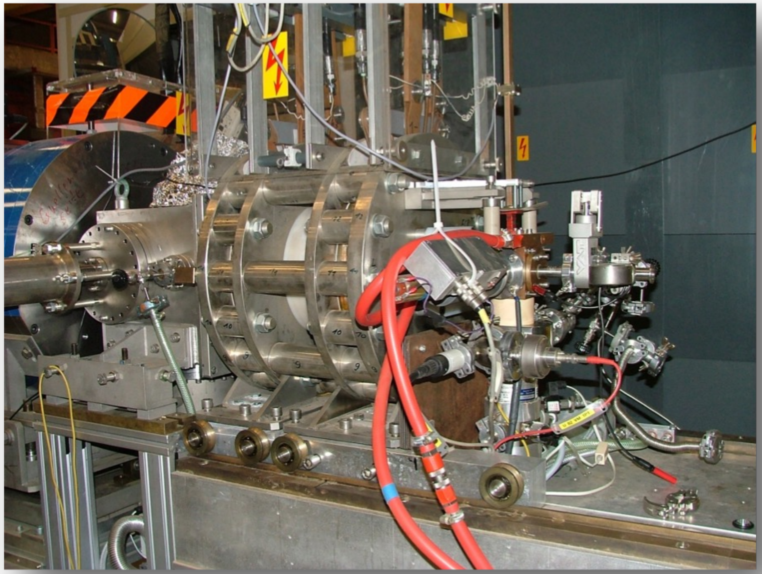






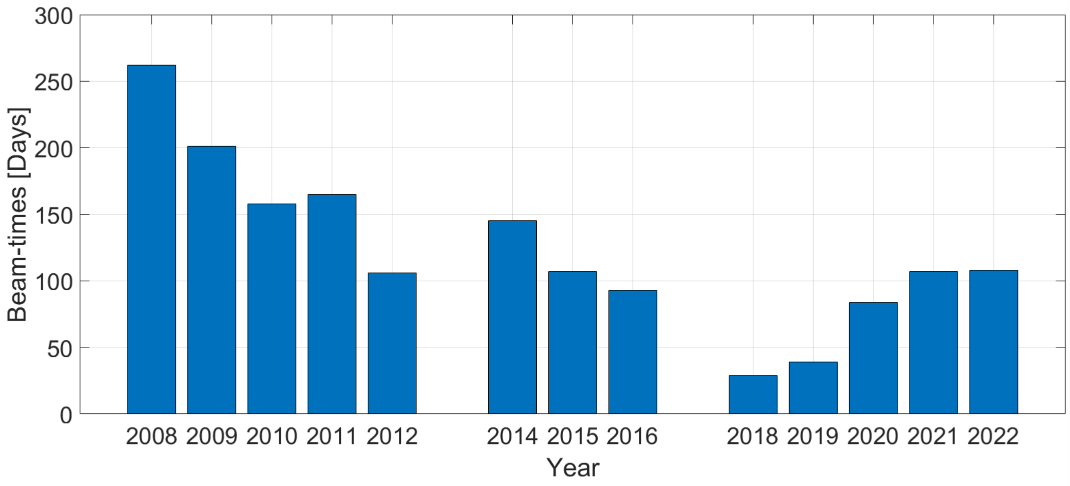


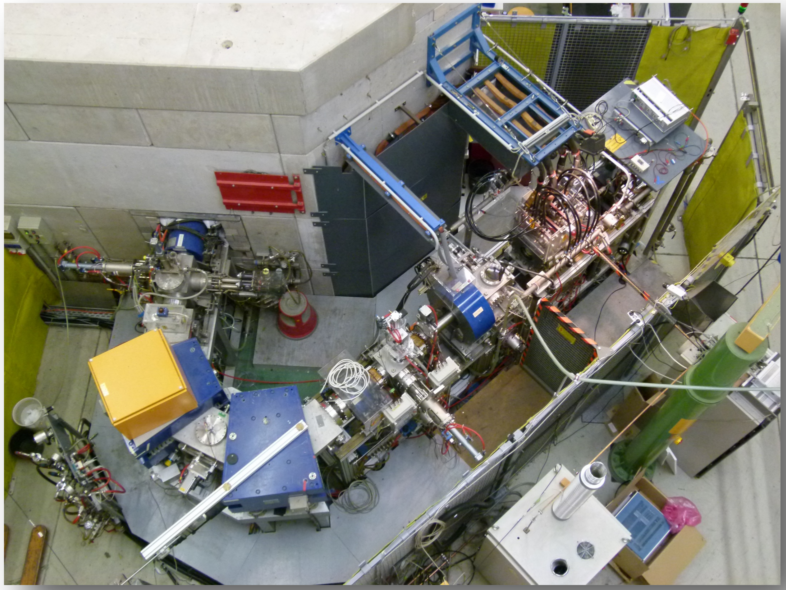
High Charge States Injector (HLI)



CAPRICE ECRIS MAIN PARAMETERS

Hexapole field	1...1,2 T
Solenoid field	0,8...1,5 T
µW-power	10...800 W (CW mode)
µW-frequency	14.5 (12,4...16) GHz
Extraction Voltage [kV]	≤ 22
Ion Species	Gas + Metal
Mode	CW or Pulsed





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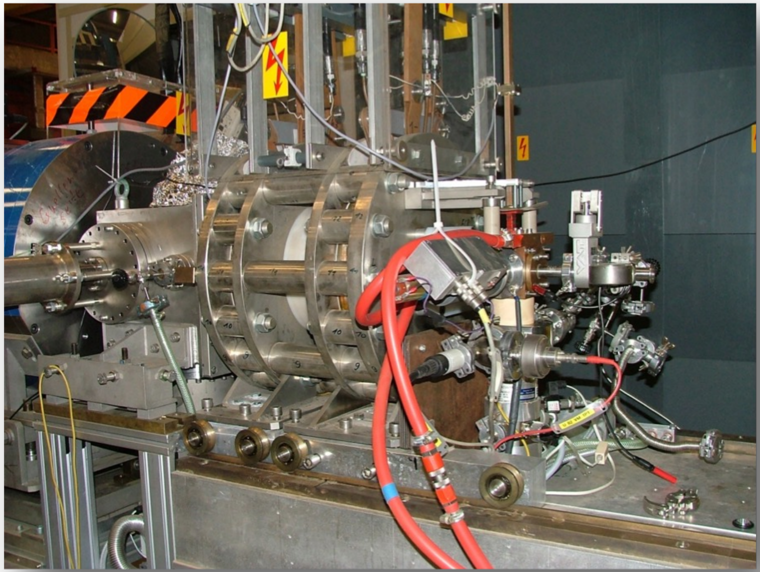

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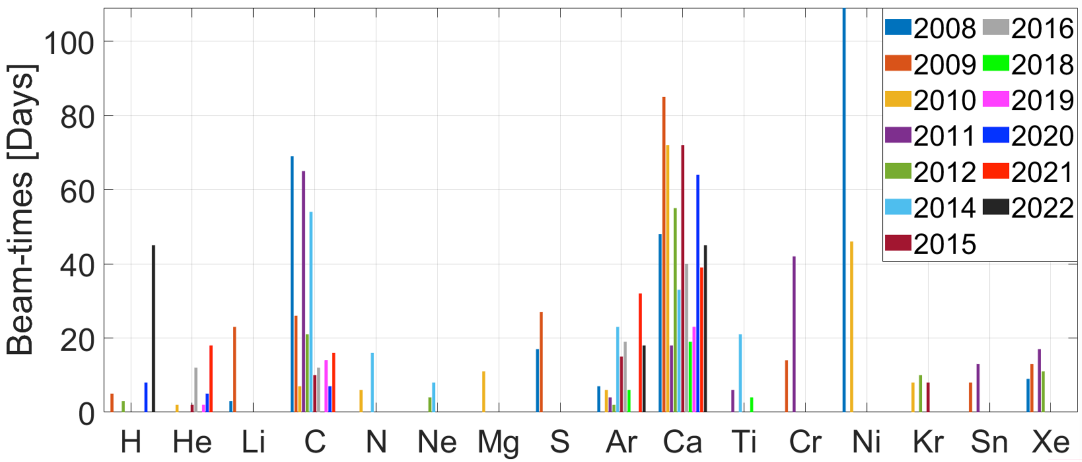
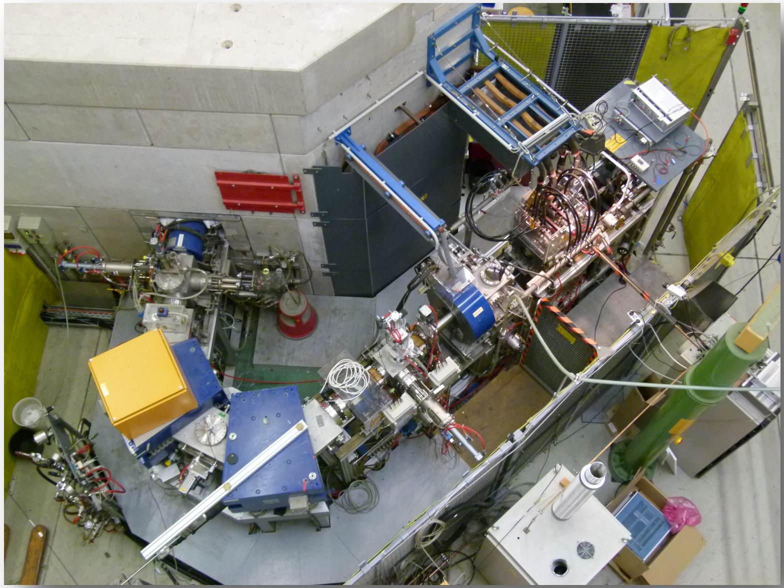
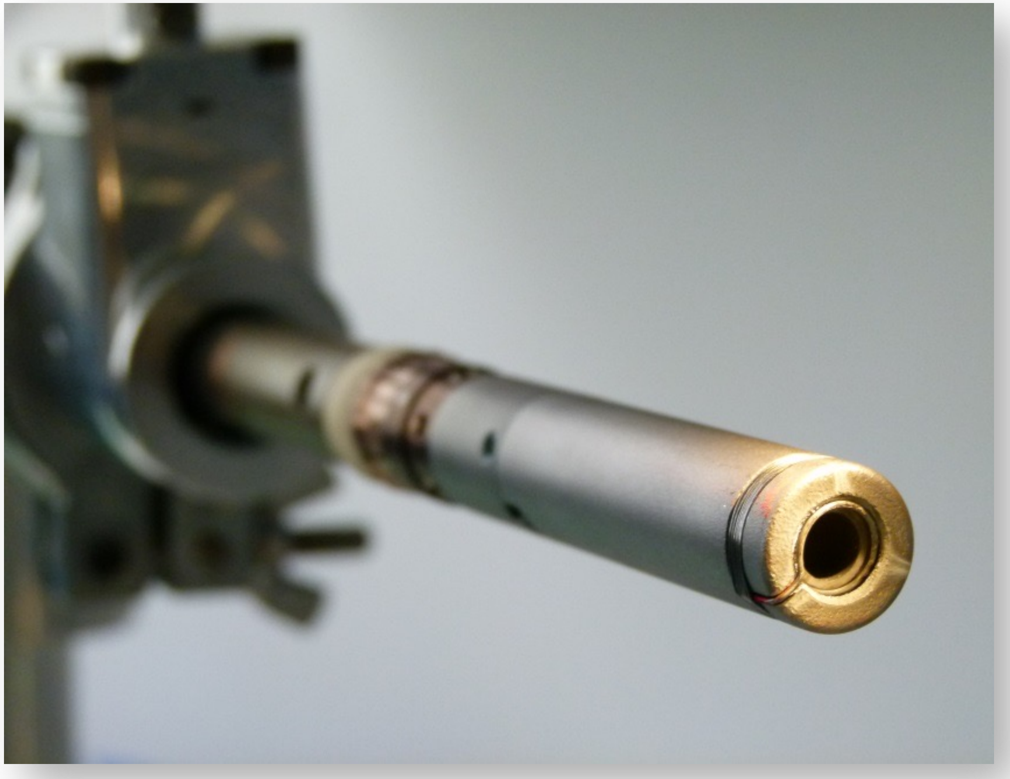




Evaporation technique for metal ion beam production at HLI

Standard Temperature Oven (STO)

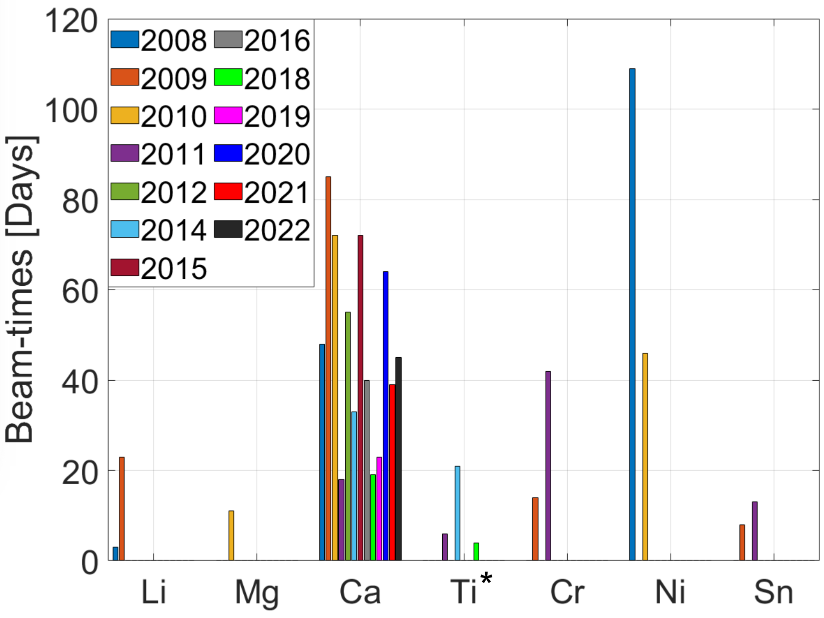


LAYOUT

- Central current entry
- Heating helix on ceramic body
- Water cooled support tube
- Crucible or aperture ring

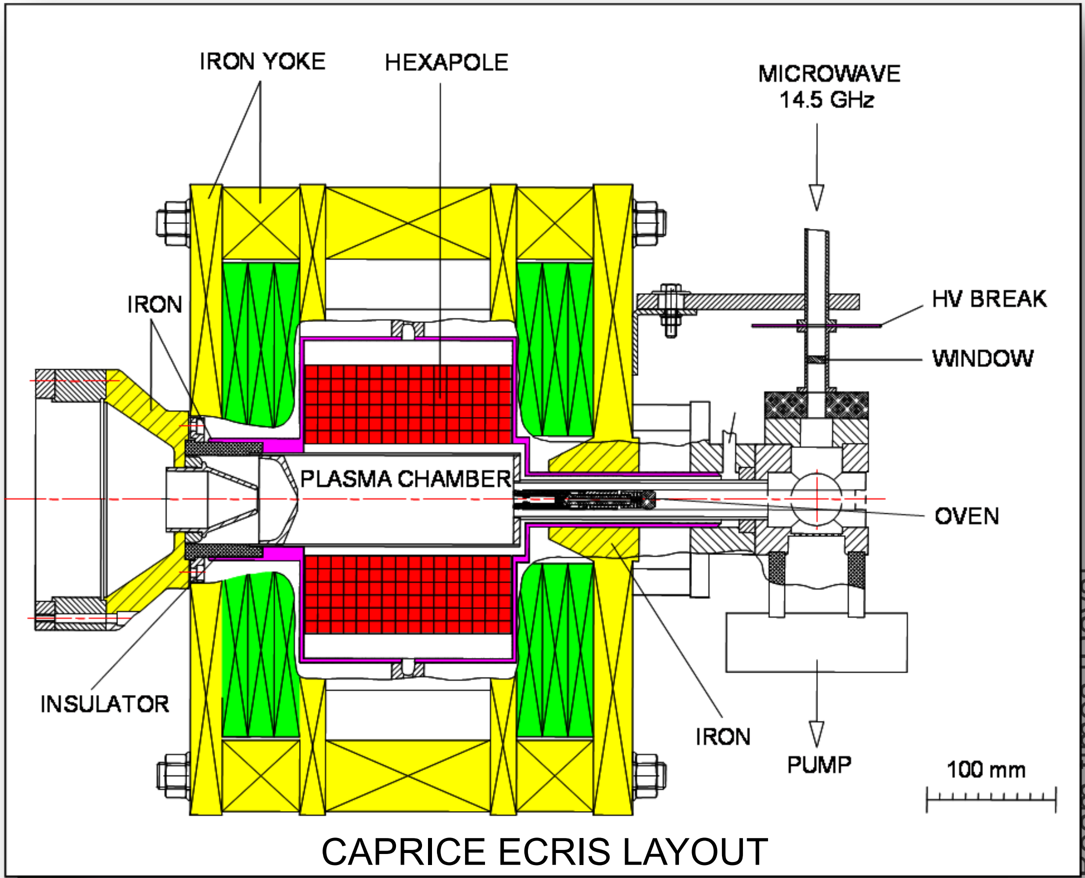
OPERATING PARAMETERS

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



* Ti with High Temperature Oven (HTO)

Evaporation technique for metal ion beam production at HLI



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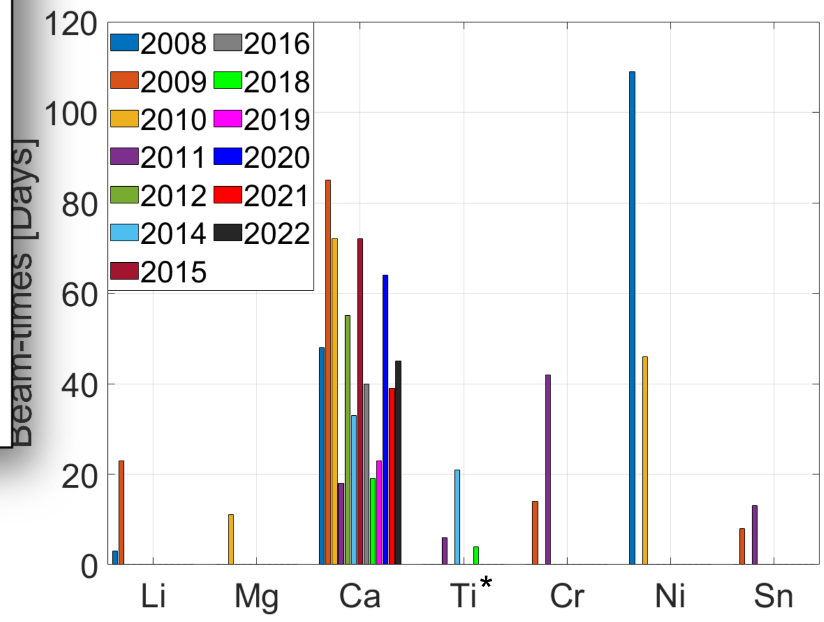
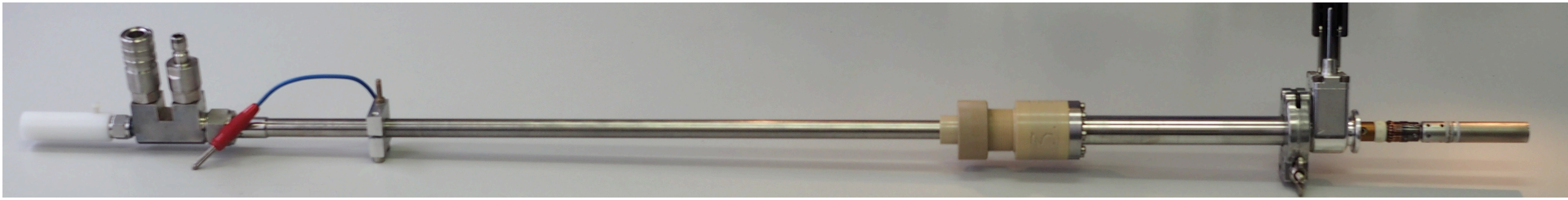
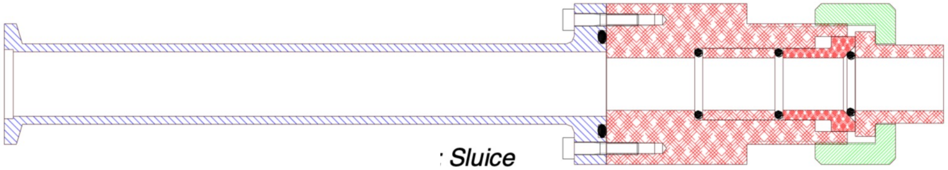


* Ti with High Temperature Oven (HTO)

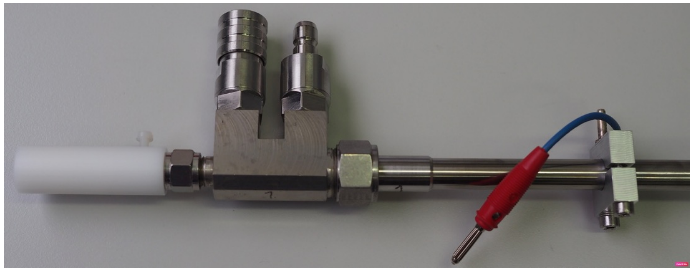
GSI Resistive Oven Concept

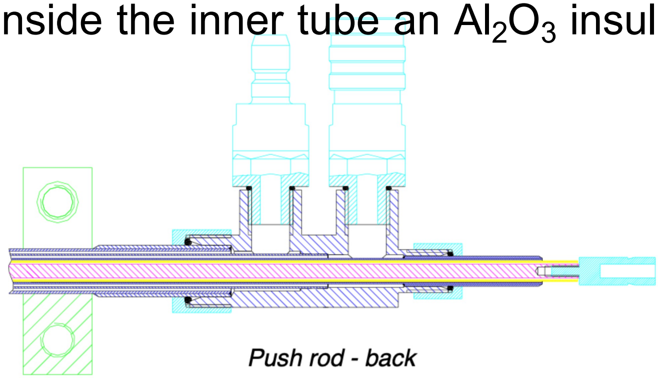


- **The oven head:** Two types for different temperature ranges (STO and HTO)
- **The sluice (exactly the same for both oven types):** Stainless steel part flanged with DN 16 ISO KF for oven exchange without breaking the vacuum (a gate valve is mated)



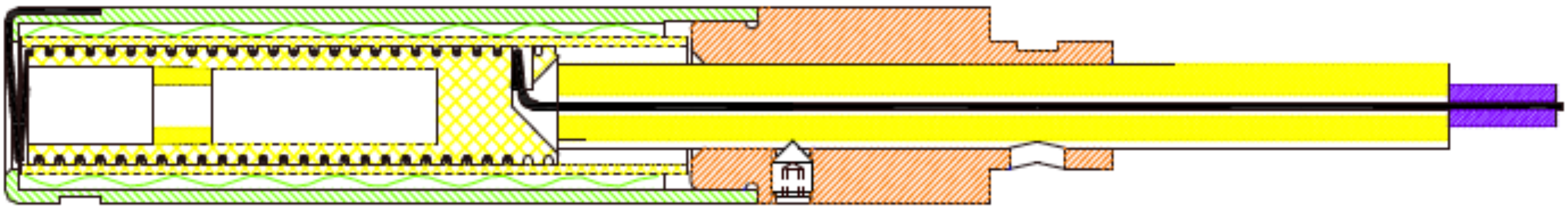
- **The push rod (nearly the same for both oven types):** System of three concentric stainless steel tubes for cooling water flow. Inside the inner tube an Al_2O_3 insulated rod inserted for the current connection.





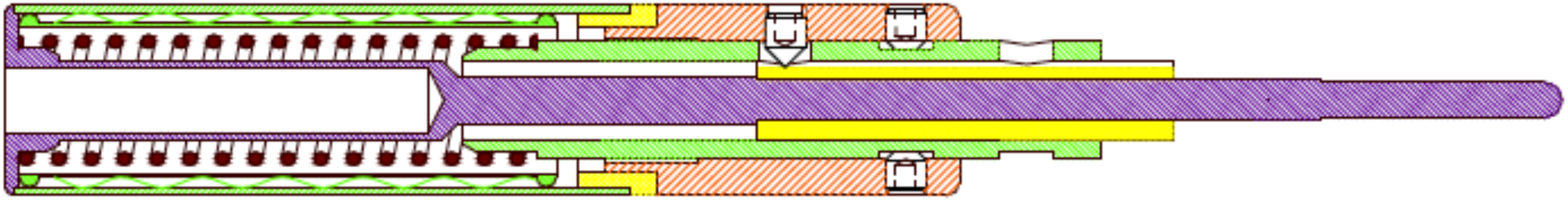
Resistive evaporation oven heads

Outer dimensions: length 70 mm, diameter 14.5 mm



STANDARD TEMPERATURE OVEN (STO)

yellow = Al_2O_3; green = Ta; orange = Mo; violet = $CuBe_2$; black = WRe(26%Re)

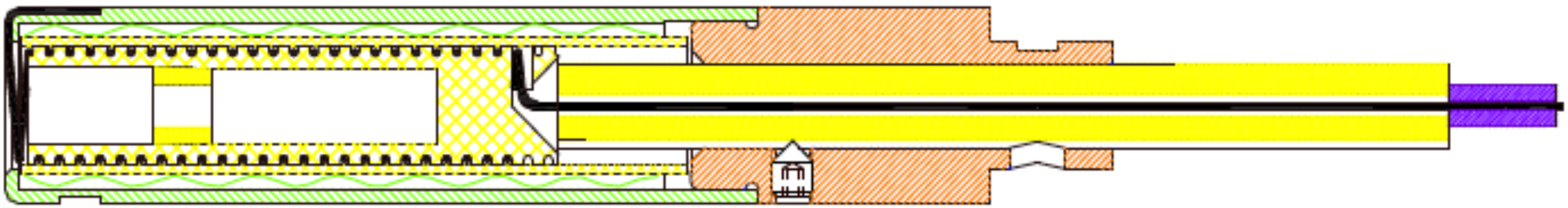


HIGH TEMPERATURE OVEN (HTO)

yellow = Al_2O_3; green = Ta; orange = Mo; violet = WL20 dark red = WVM

Resistive evaporation oven heads

Outer dimensions: length 70 mm, diameter 14.5 mm

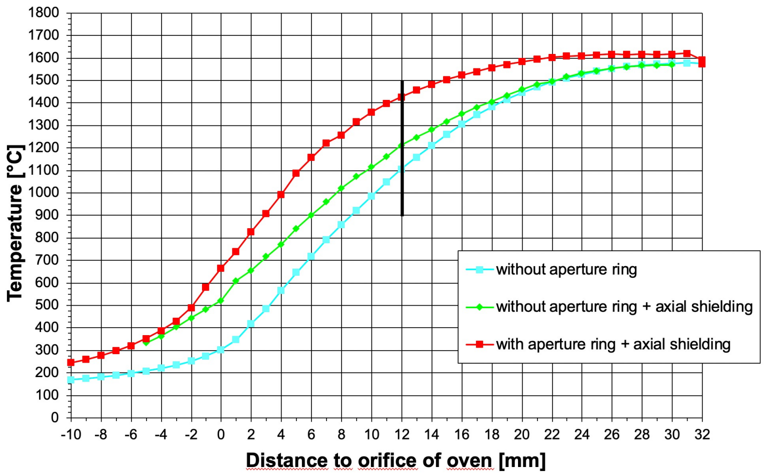


STANDARD TEMPERATURE OVEN (STO)

yellow = Al_2O_3; green = Ta; orange = Mo; violet = $CuBe_2$; black = WRe(26%Re)

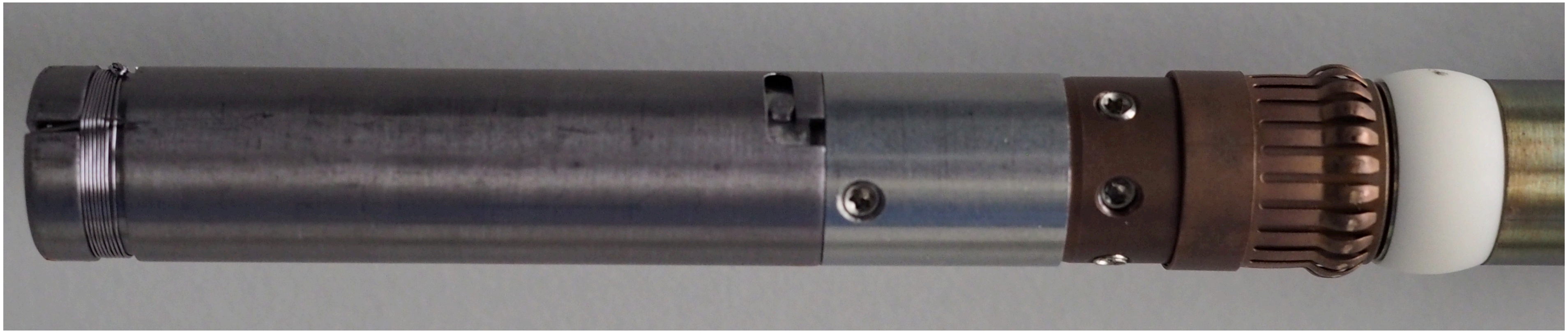
- Tungsten wire wound around a ceramic body (heater)
- Aperture ring necessary if the material is liquid at the required vapour pressure (i.e. Fe, Ni)
- Ta or W crucible used inside the ceramic to avoid chemical reactions (i.e. Mg, Ca, Li)
- Ta and Mo parts dismounted, cleaned and re-used

Longitudinal temperature gradient



Resistive evaporation oven heads

Outer dimensions: length 70 mm, diameter 14.5 mm



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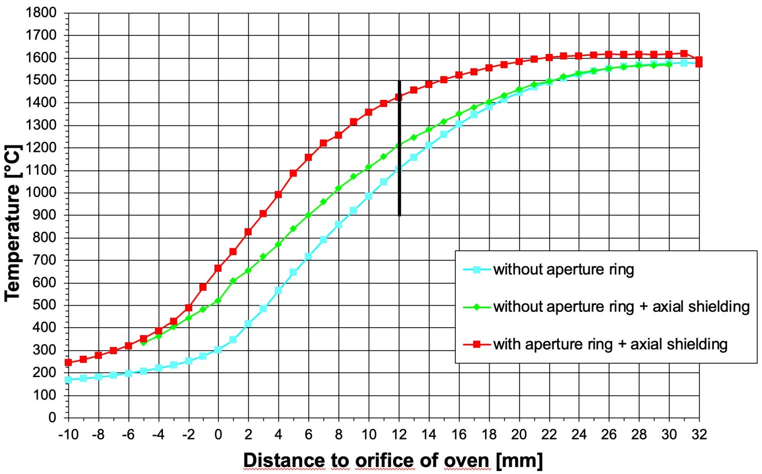
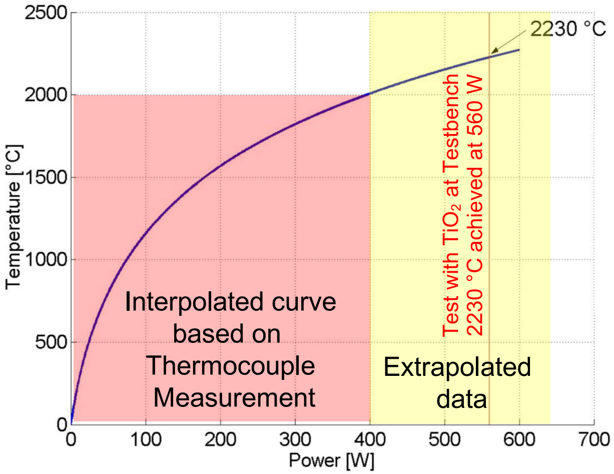
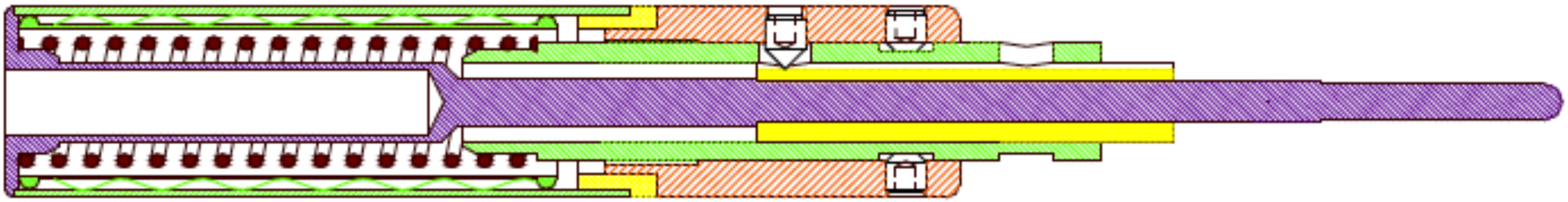


Resistive evaporation oven heads

Outer dimensions: length 70 mm, diameter 14.5 mm

- Removed ceramic body (heater) and ceramic parts where high temperature is expected
- Free standing heating wire made of an Aluminum Potassium Silicate doped Tungsten (WVM) (Plasnee GmbH company)
- Crucible retainer made of a Tungsten alloy with 2% La_2O_3 (WL20 provided by Witstar company)





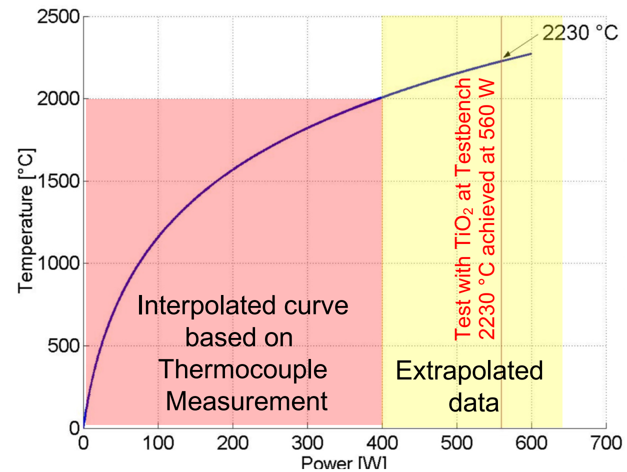
HIGH TEMPERATURE OVEN (HTO)

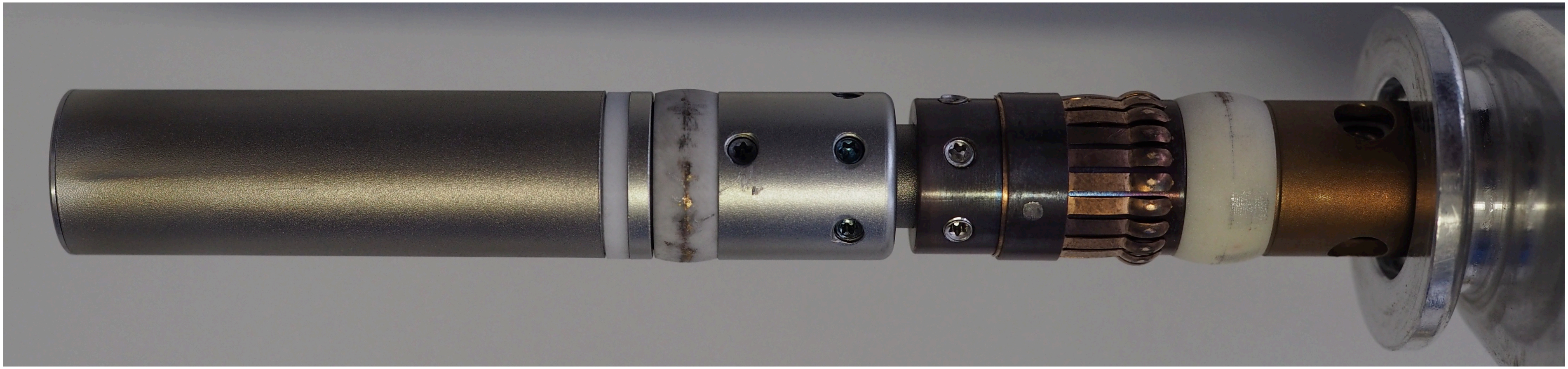
yellow = Al_2O_3; green = Ta; orange = Mo; violet = WL20 dark red: WVM

Resistive evaporation oven heads

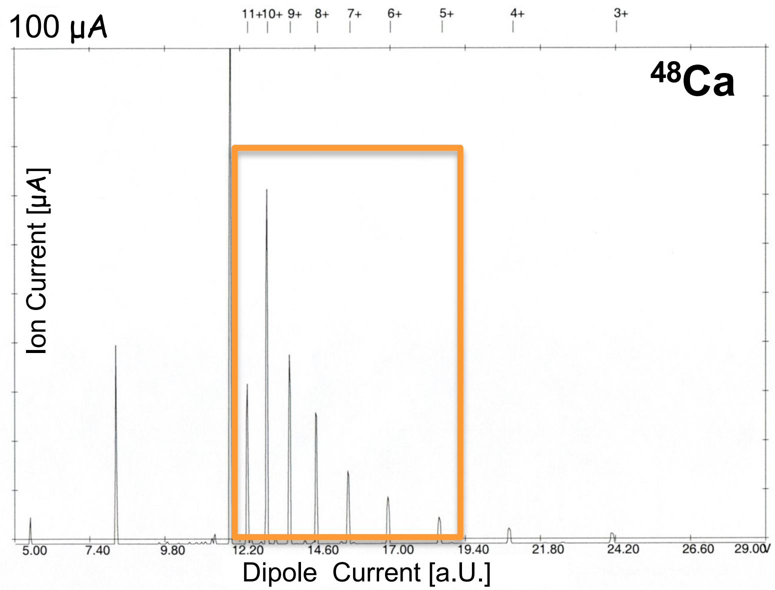
Outer dimensions: length 70 mm, diameter 14.5 mm

- Removed ceramic body (heater) and ceramic parts where high temperature is expected
- Free standing heating wire made of an Aluminum Potassium Silicate doped Tungsten (WVM) (Plasnee GmbH company)
- Crucible retainer made of a Tungsten alloy with 2% La_2O_3 (WL20 provided by Witstar company)

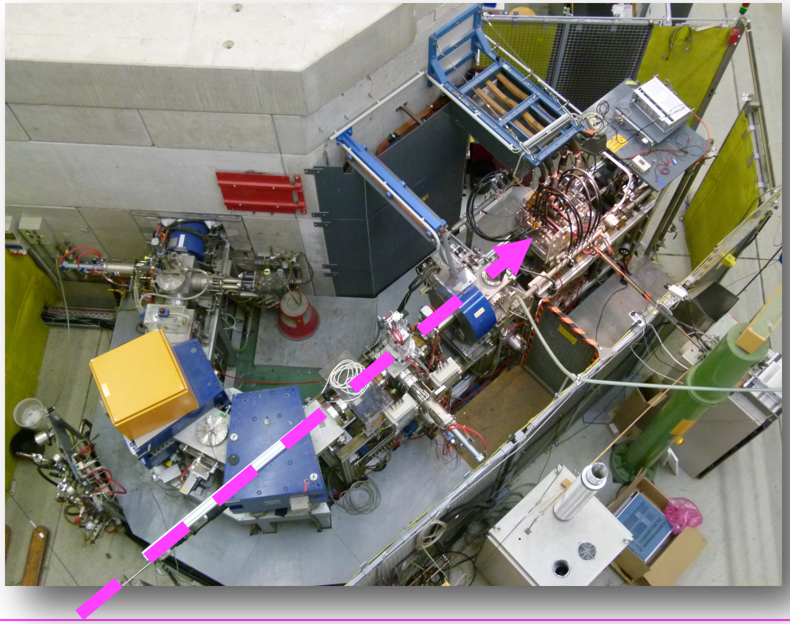




^{48}Ca charge states distributions and plasma images

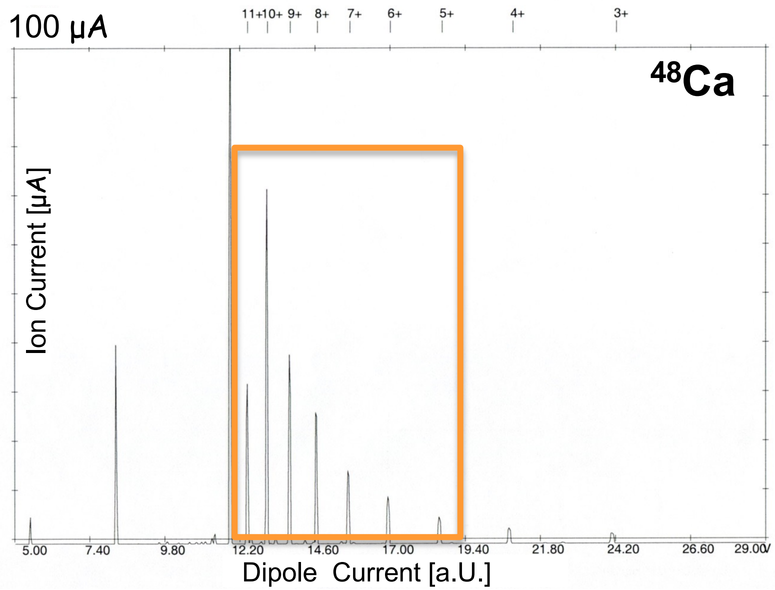


Spectrum of ^{48}Ca + He optimized on $^{48}Ca^{10+}$

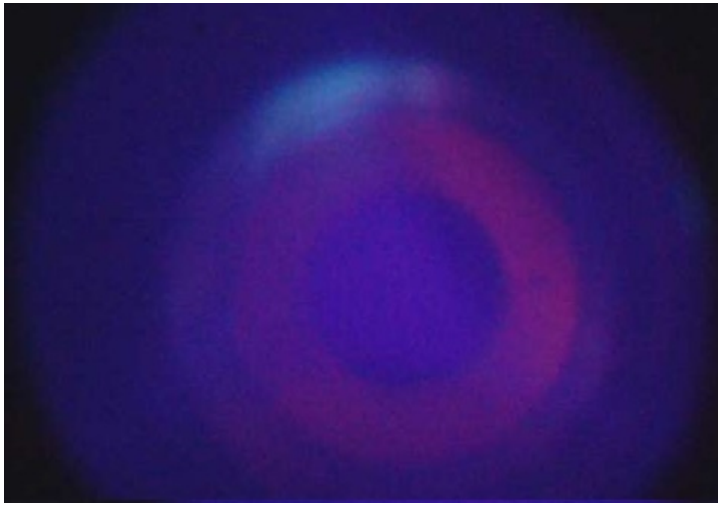


A CCD camera looks through the straight beam line and the extraction aperture into the plasma chamber.

^{48}Ca charge states distributions and plasma images

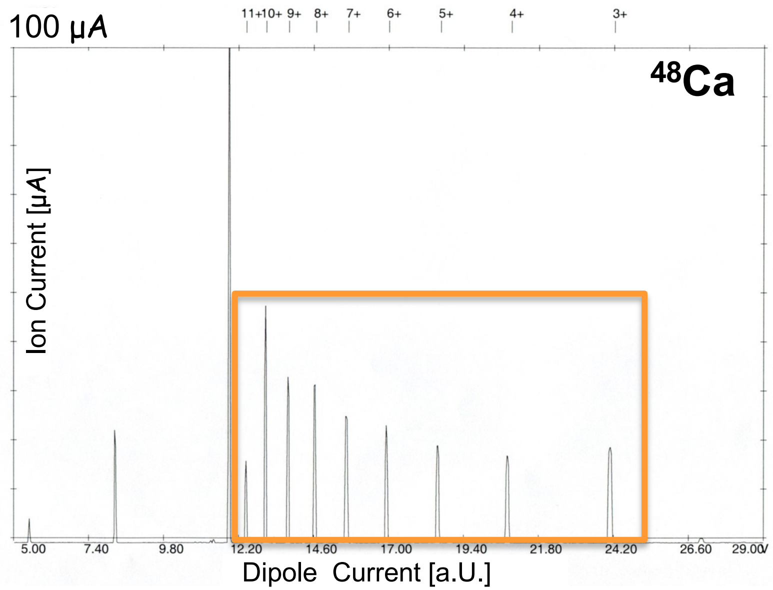


Spectrum of ^{48}Ca + He optimized on $^{48}Ca^{10+}$

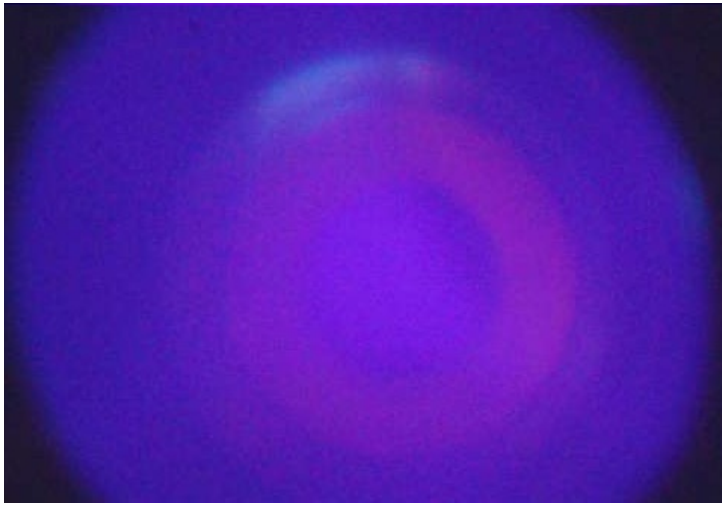


Plasma image recorded with the CCD camera

^{48}Ca charge states distributions and plasma images

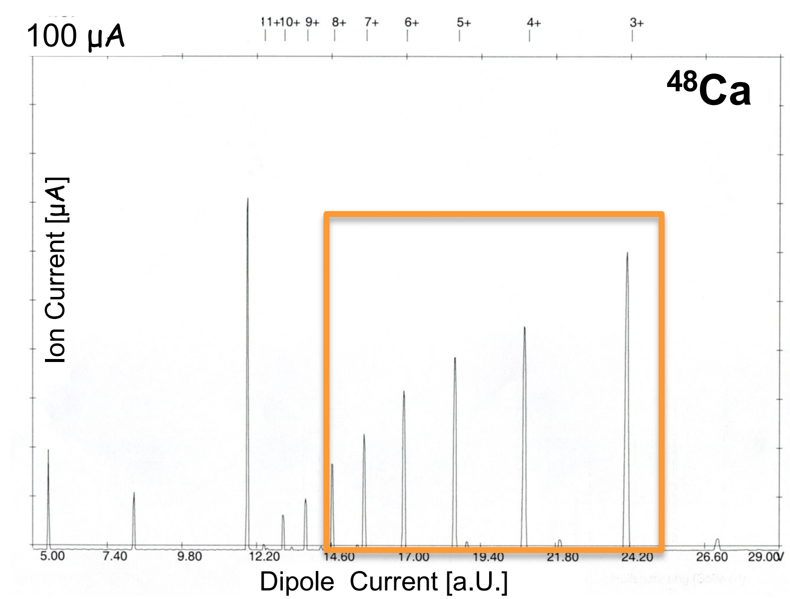


Spectrum of ^{48}Ca + He optimized on $^{48}Ca^{10+}$ after an excessive oven power increase

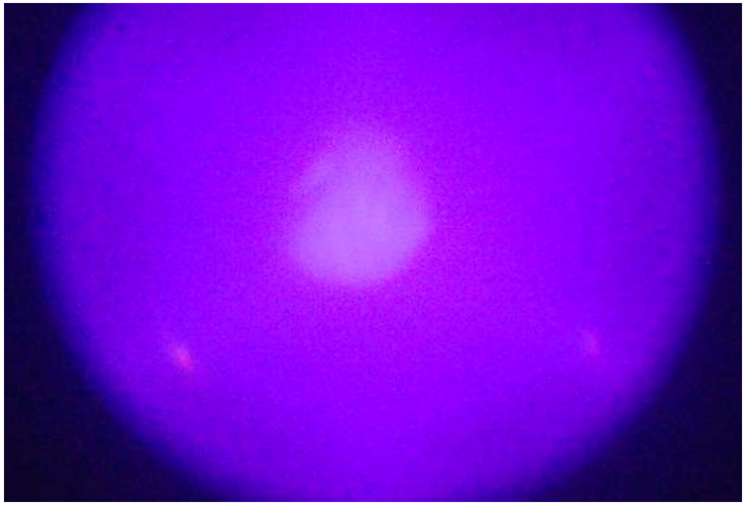


Plasma image recorded with the CCD camera

^{48}Ca charge states distributions and plasma images

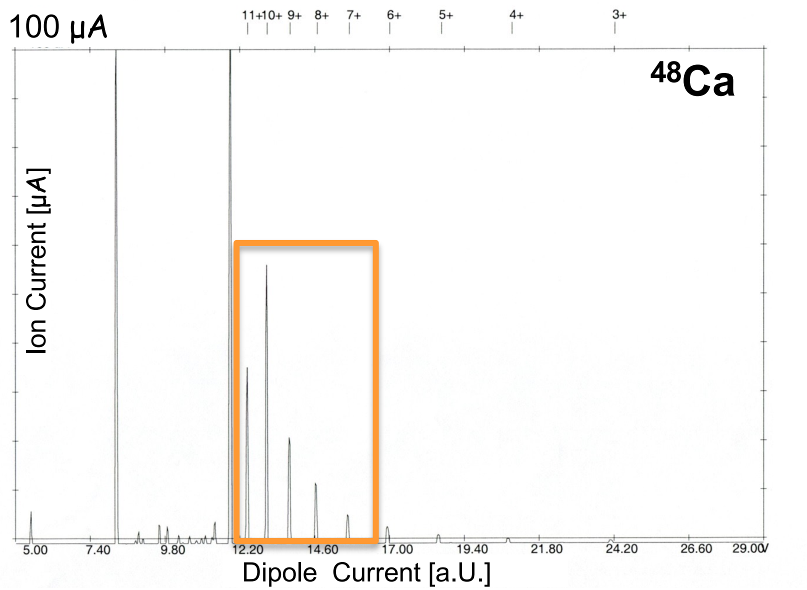


Spectrum of ^{48}Ca + He optimized on $^{48}Ca^{10+}$ during an over heating of the oven

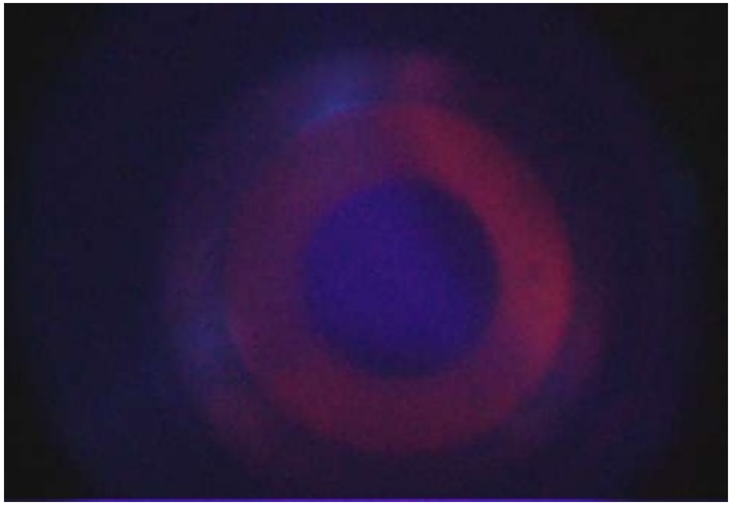


Plasma image recorded with the CCD camera

^{48}Ca charge states distributions and plasma images

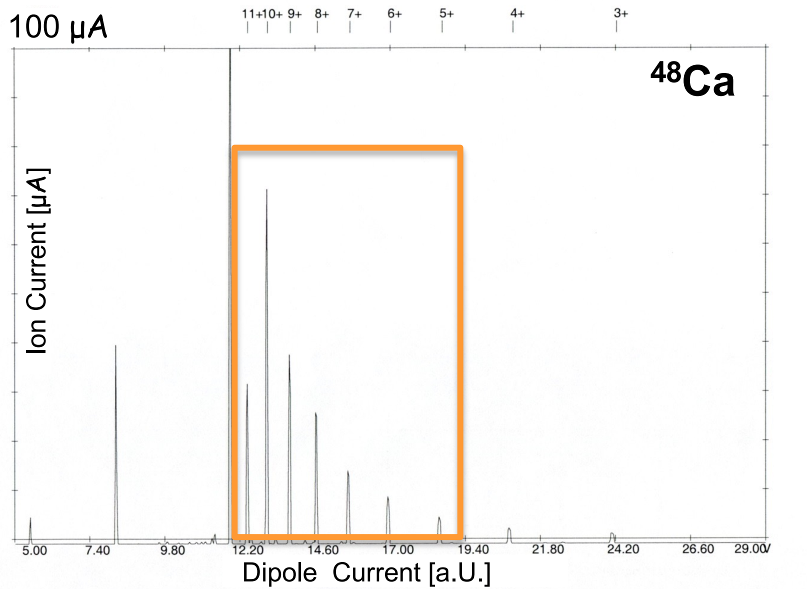


Spectrum of ^{48}Ca + He optimized on $^{48}Ca^{10+}$ after a power reduction of the oven

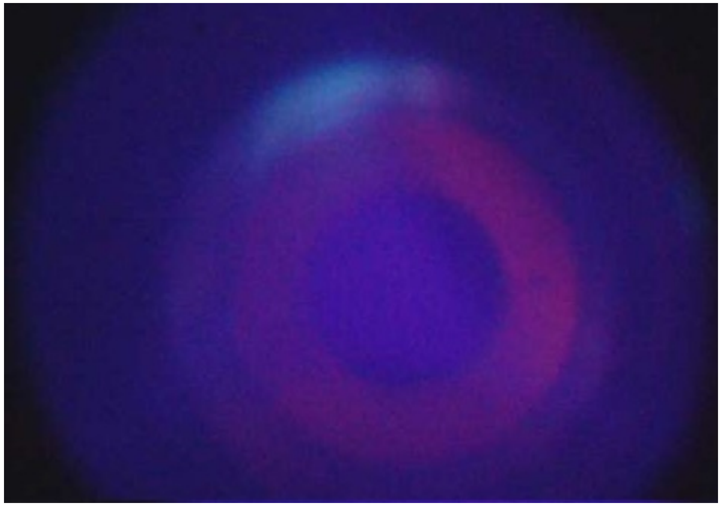


Plasma image recorded with the CCD camera

^{48}Ca charge states distributions and plasma images



Spectrum of ^{48}Ca + He re-optimized on $^{48}Ca^{10+}$



Plasma image recorded with the CCD camera

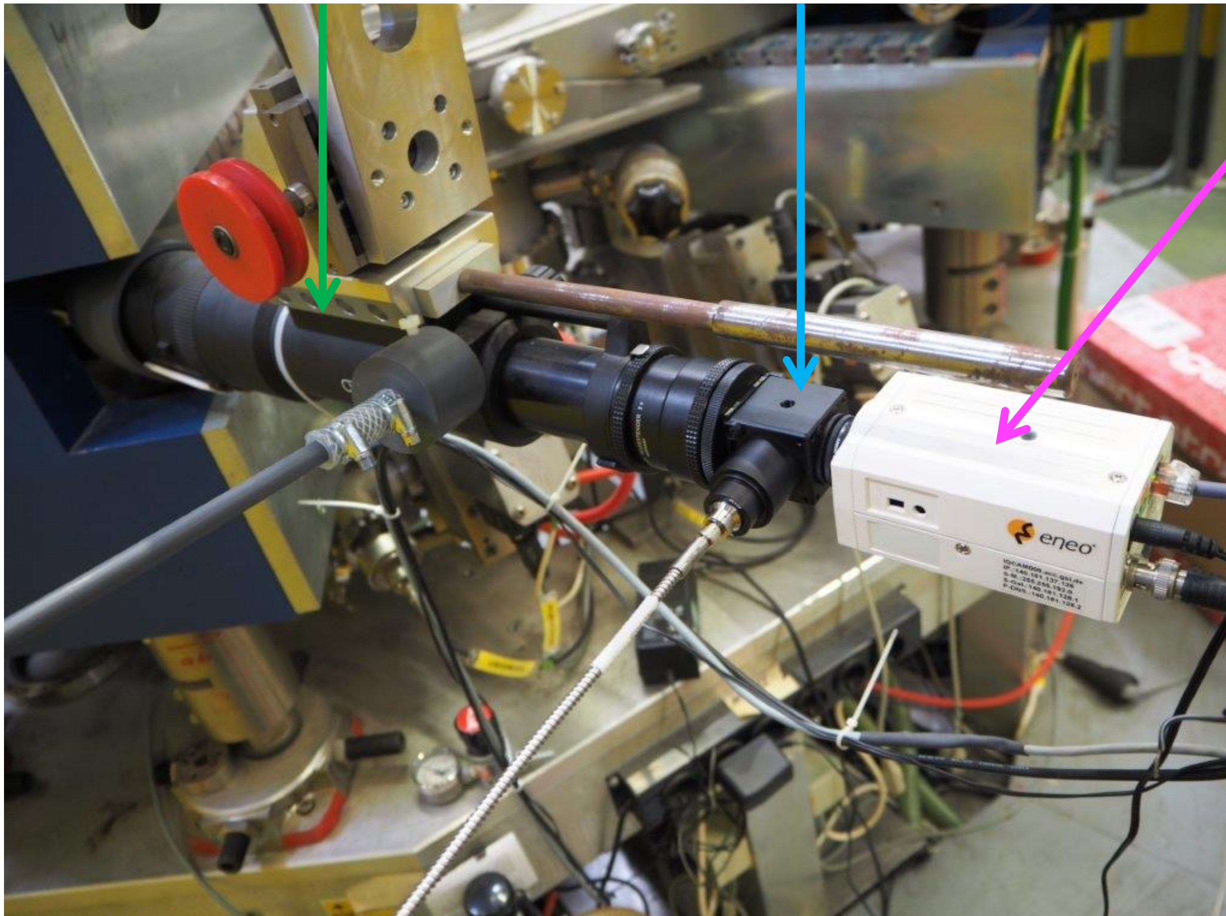
Hours of beam time wasted, consumption increase of expensive material and experimentalists disappointment.

Optical diagnostic devices at HLI

Telephoto Lens

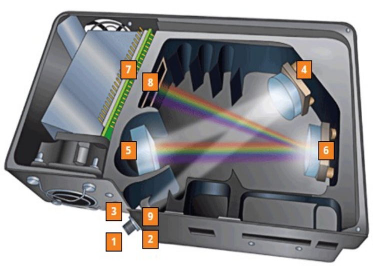
Optical Beam Splitter and Glass Fiber

CCD Camera



OCEAN OPTICS QE Pro

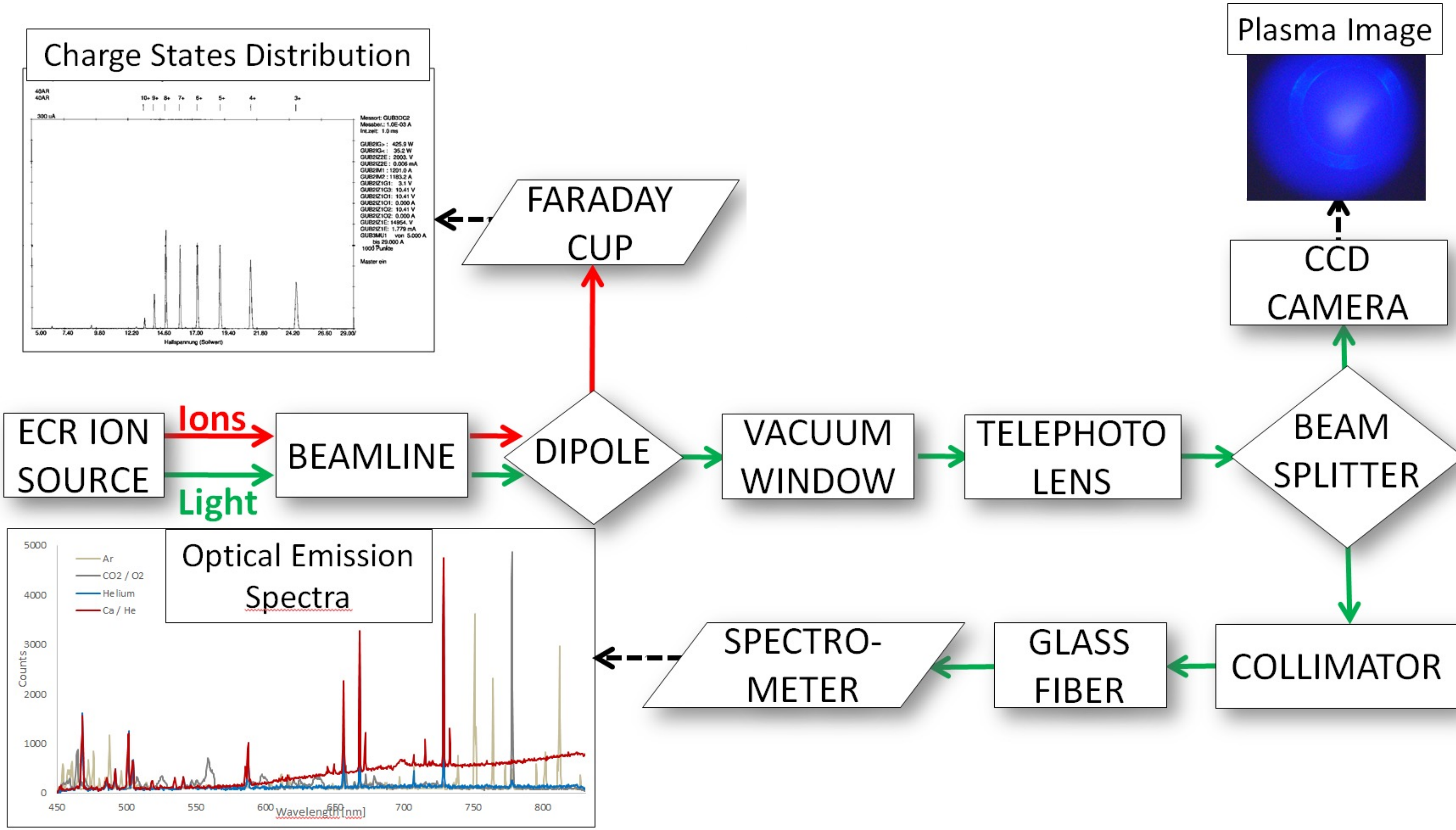
Entrance slits: 25 µm
Wavelenght Range 449-833 nm
Resolution 0.95 nm



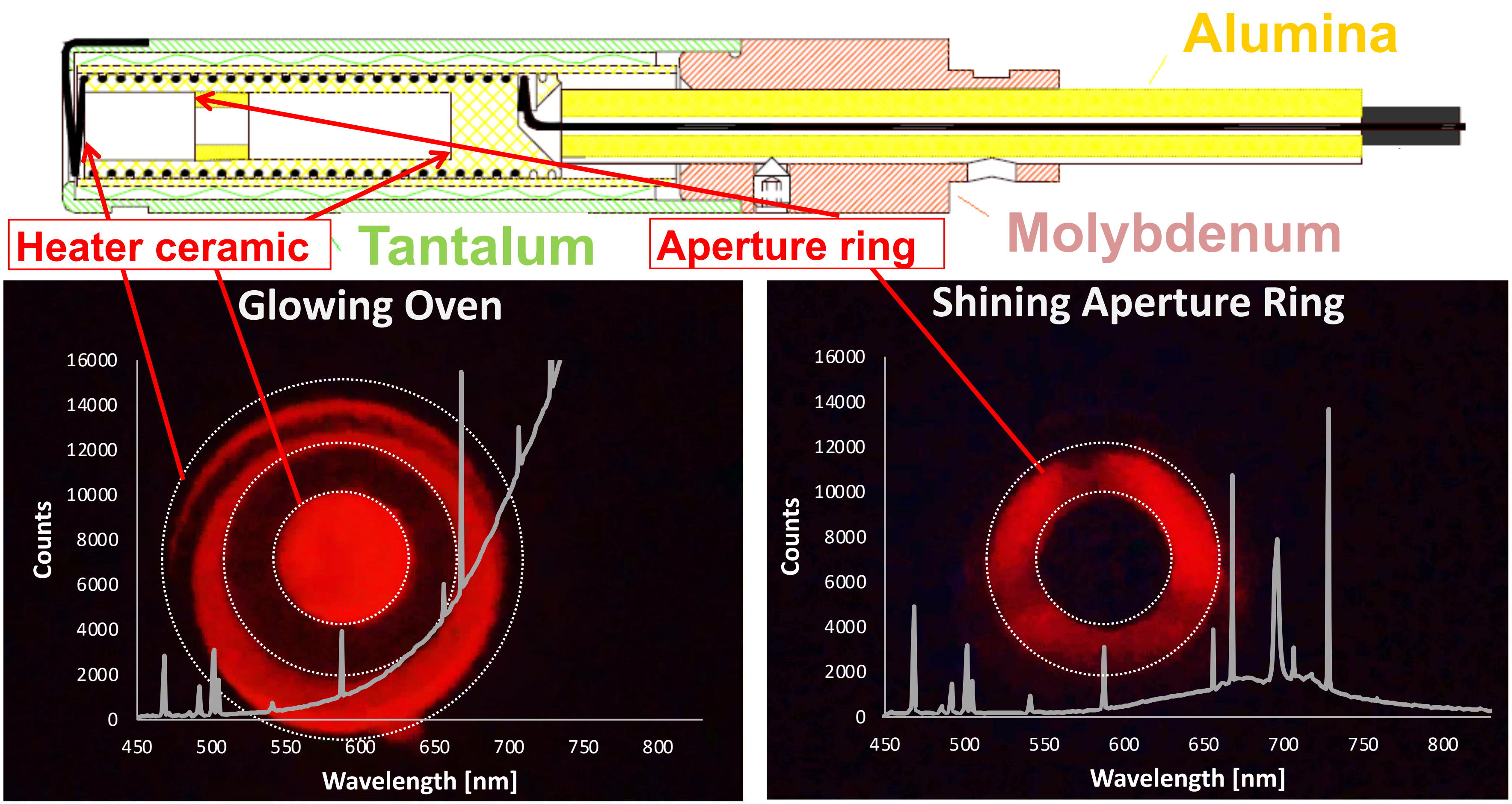
https://www.oceaninsight.com

..to the Optical Emission Spectrometer

HLI diagnostic devices set-up



Optical Emission Spectroscopy on a Standard Temperature Oven



Oven heating: CCD Camera images and Optical Emitted Spectrum

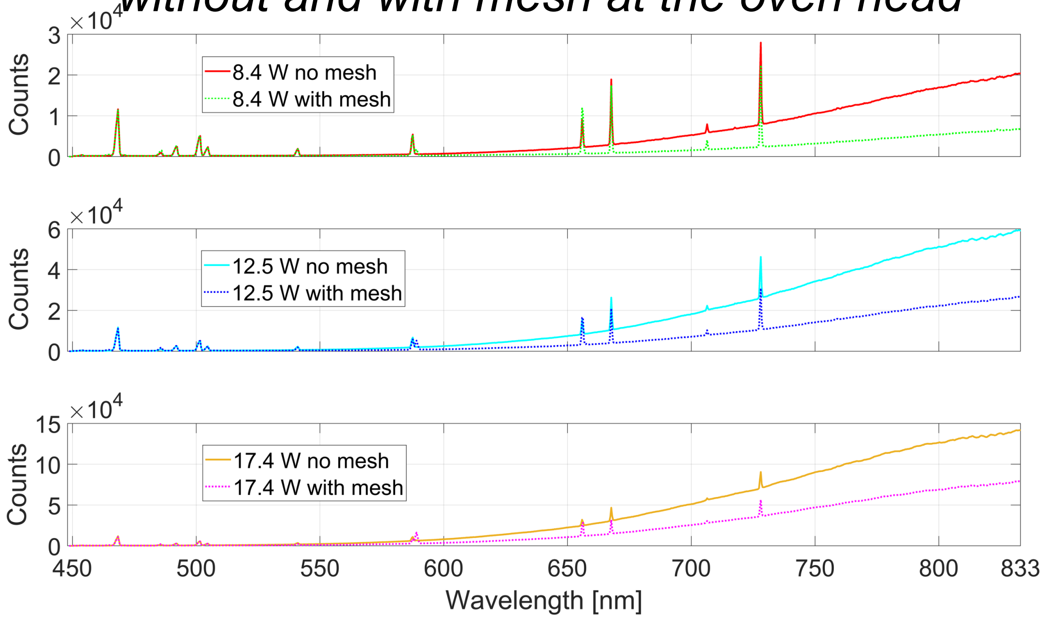
Microwave shielding of the oven orifice

MICROWAVE SHIELDING

- Material: Tungsten
- Mesh 100 (149 µm) – 25.4 µm wire

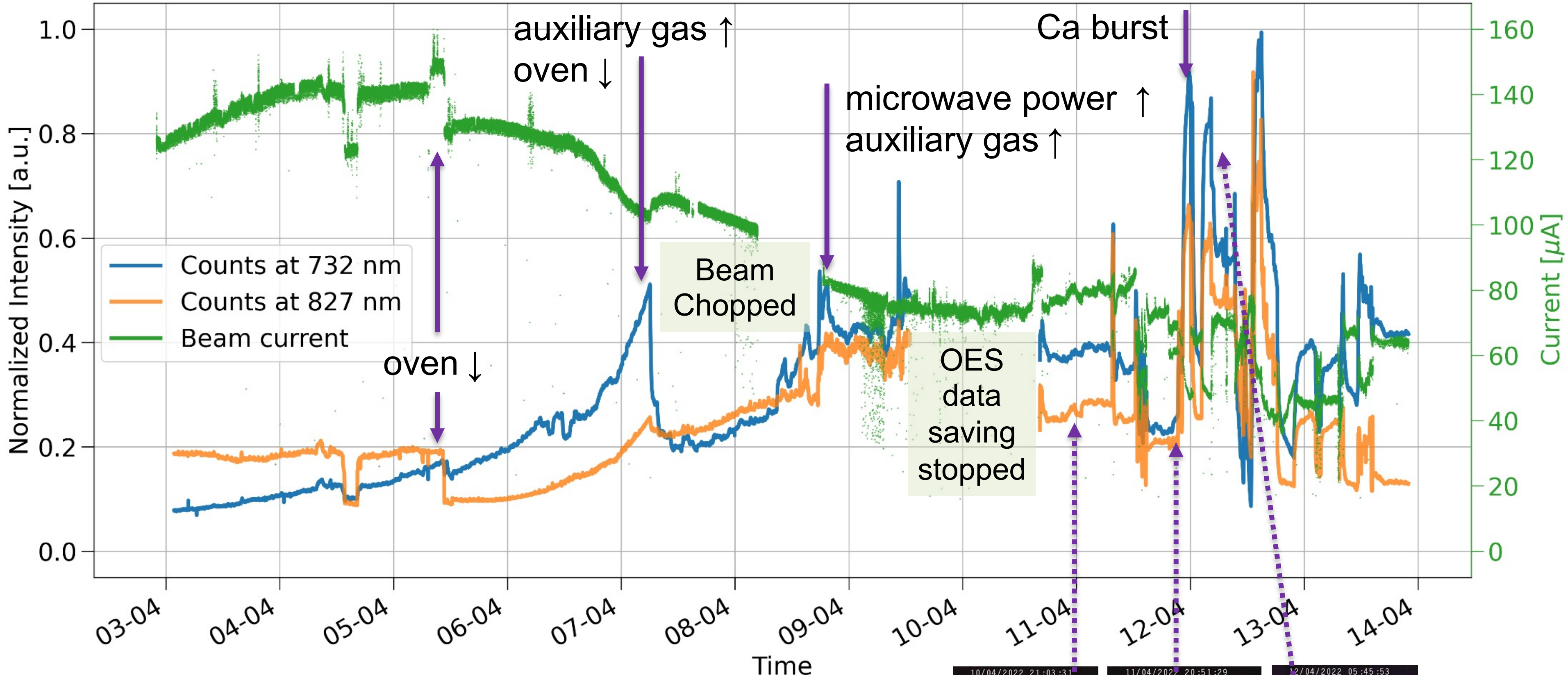
Optical spectroscopy as a diagnostic tool for metal ion beam production with an ECRIS
F.*Maimone, J.Mäder, R.Lang, P.T.Patchakui, K.Tinschert R.Hollinger* , Rev. Sci. Instrum. 90, 123108, 2019

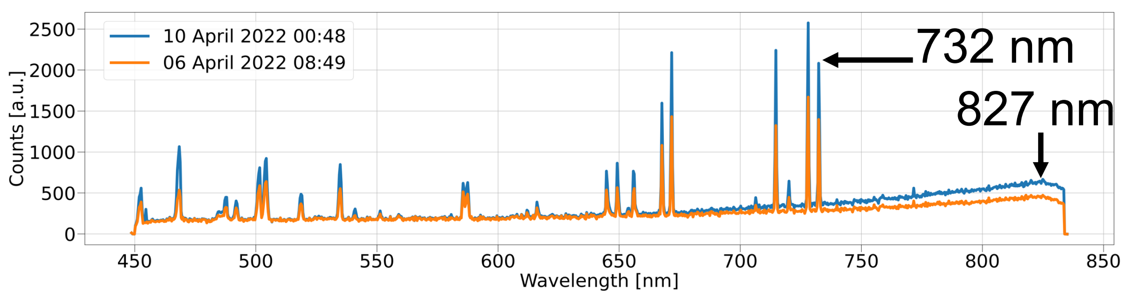
OES measurements for different oven powers without and with mesh at the oven head

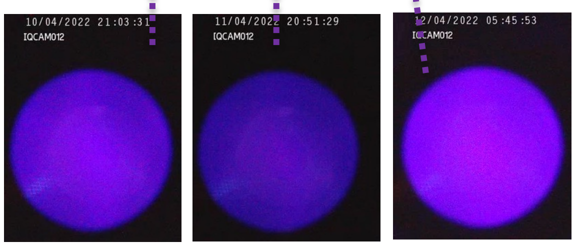


- Measurements carried out with the shielded empty oven inserted inside the ECRIS.
- Helium plasma generated by coupling up to 650 W microwave power.
- Oven power settings: 8.4, 12.5, 17.4 W.
- Up to 69% shielding due to the mesh.
- **Succesfull test at EIS testbench with ^{40}Ca**

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

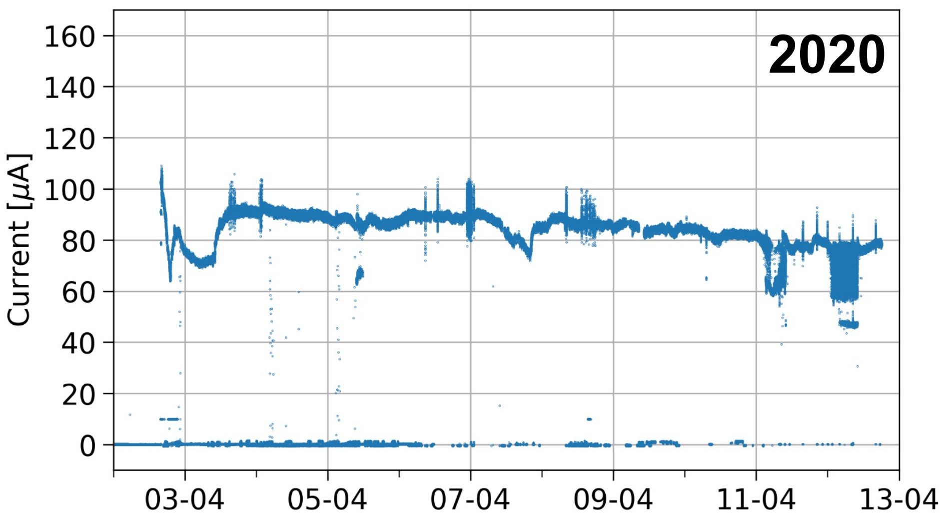


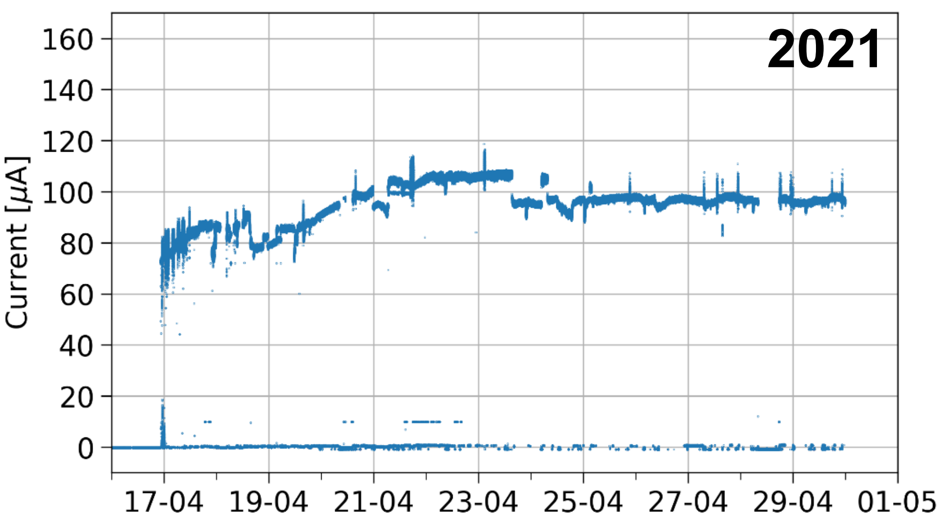


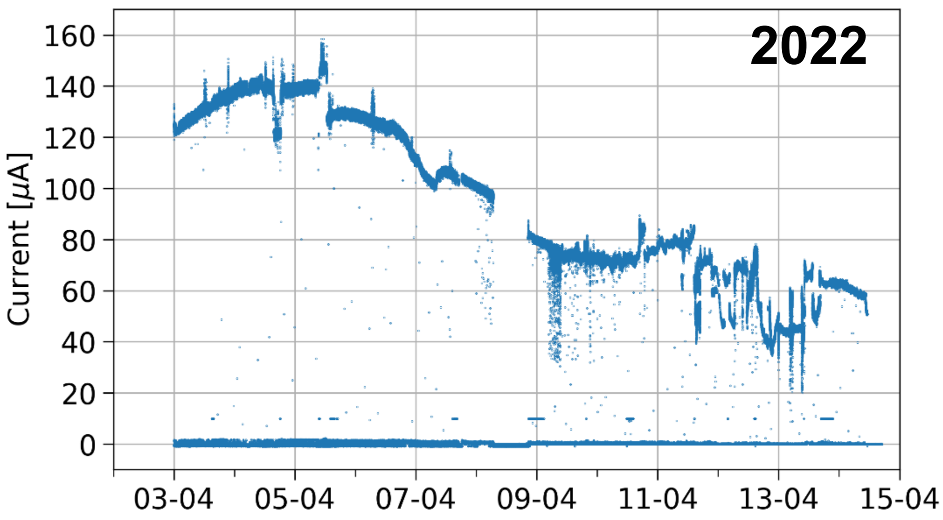


HLI $^{48}Ca^{10+}$ last beam-runs

- Higher intensity and stability achieved
- Highest current:140 eµA
- Less optimizations and parameters tuning required
- Less on call interventions



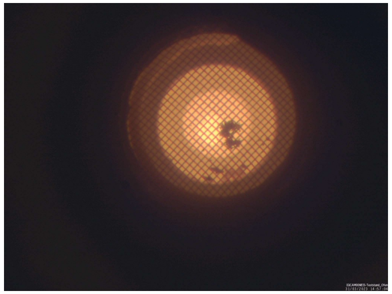


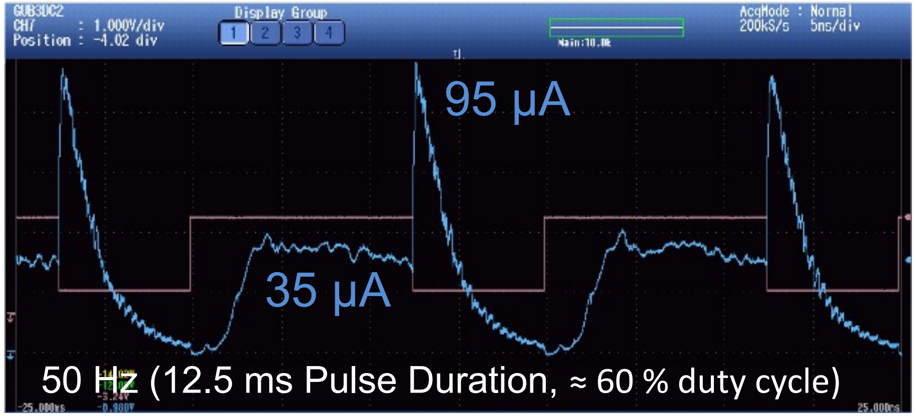


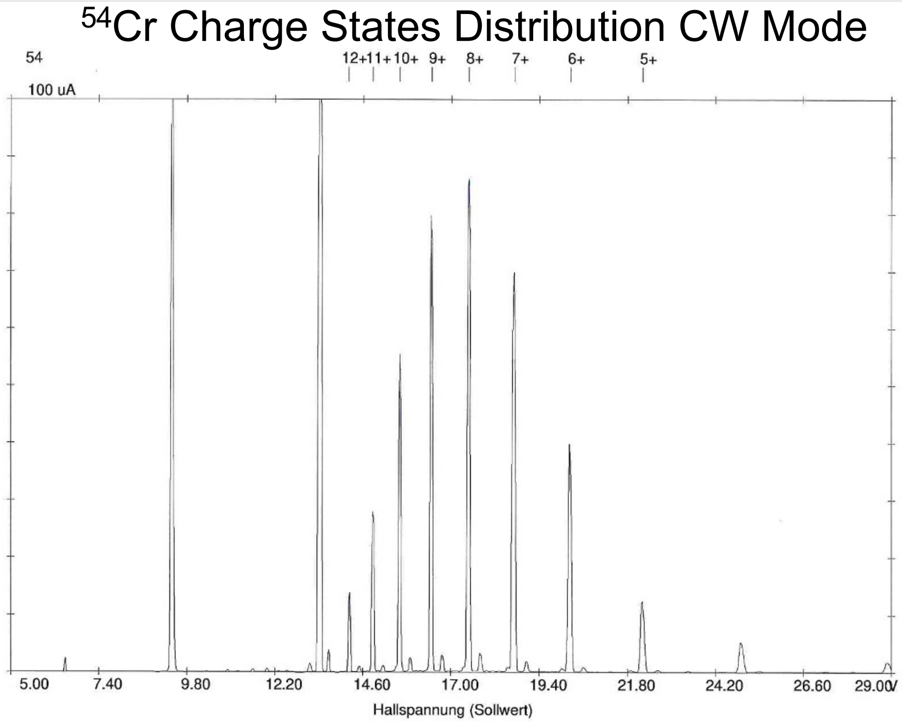
^{54}Cr Performance improvement

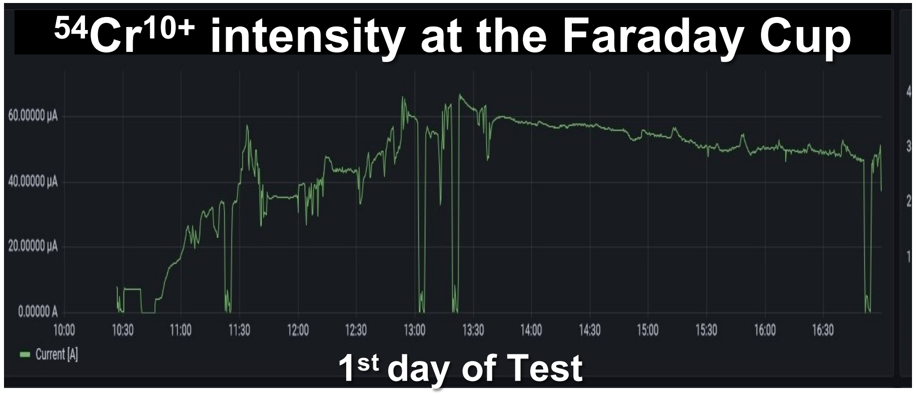
Oven head microwave shielding

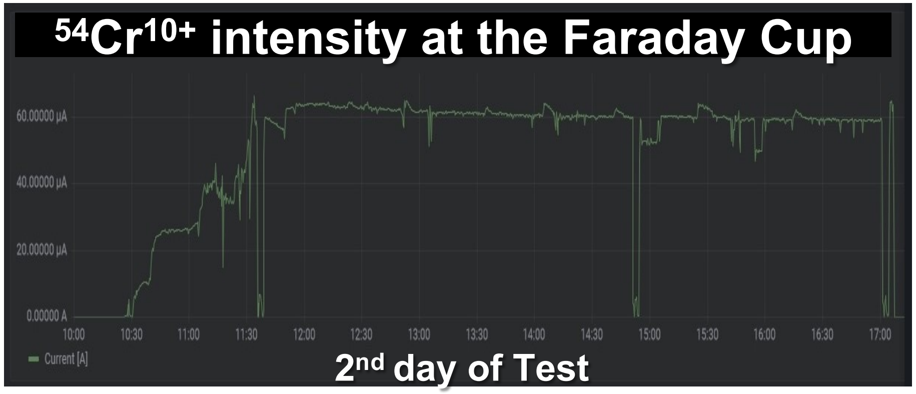
Condensated material after hours of operation











Summary

- GSI offers a wide selection of **metallic ion beams from three separate injectors**.
  Choice of injector/ion source based on the ion beam requirements
  - Duty cycle
  - Beam Intensity/Stability
  - Material consumption
  - Technical constrains
- The **resistive heated oven** is the established technique for metallic element evaporation with the ECRIS at GSI
- **Optical emission spectroscopy** together with **plasma images** are powerfull diagnostic and monitoring tools for metal ion beam production from ECRISs
- The **microwave schielding** can prevent parasitic heating of the oven (possible condensation of evaporated material)


THANK YOU FOR YOUR ATTENTION
ION SOURCES Dpt.
Ralph Hollinger (dpt. Leader), Ralf
Lang, Jan Mäder, Patrick Tedit
Patchakui, Aleksandr Andreev,
Michael Galonska, Aleksey
Adonin, Rustam Berezov, Me