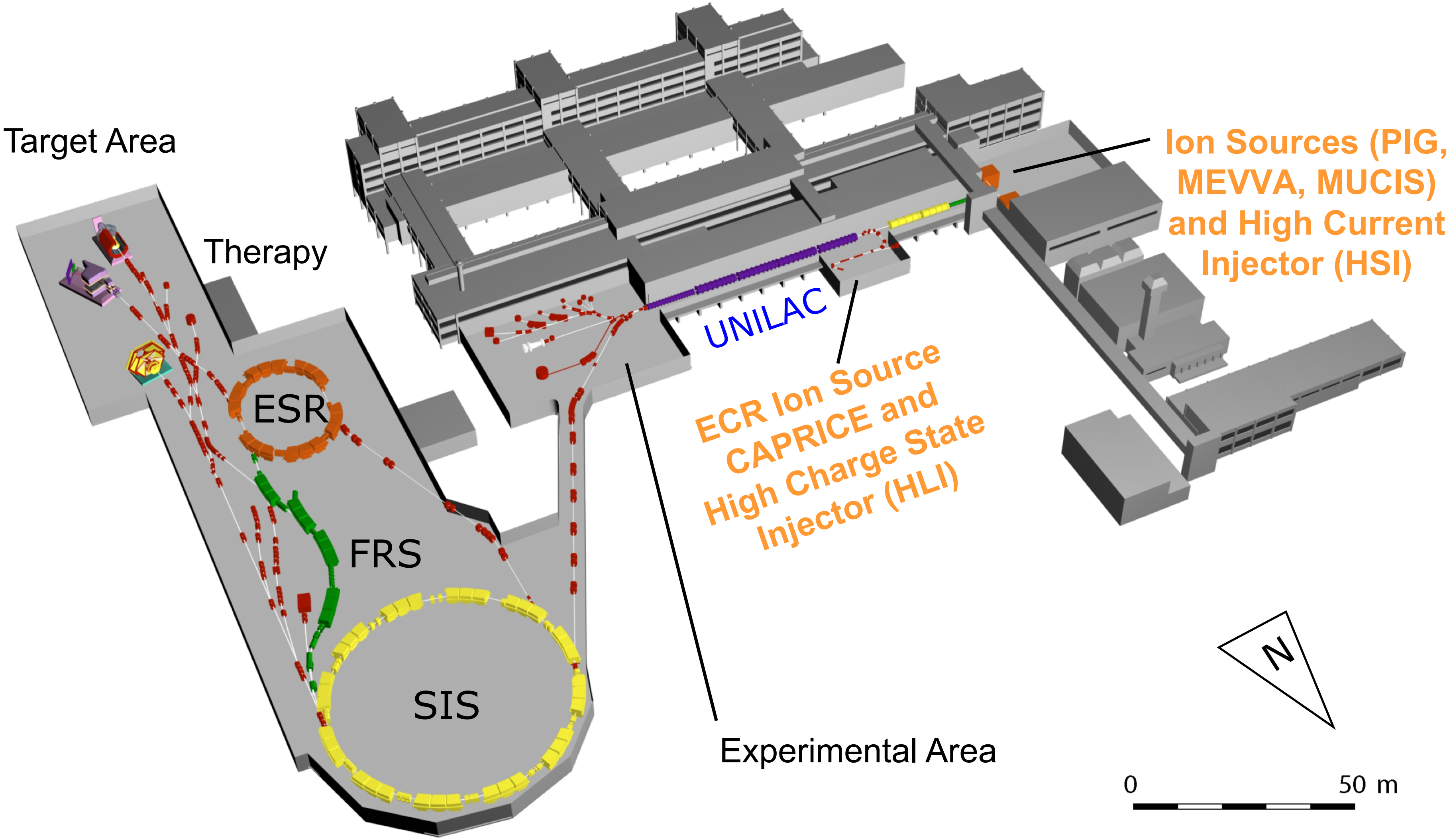
GSI CONTRIBUTION TO OVEN DEVELOPMENT

FABIO MAIMONE

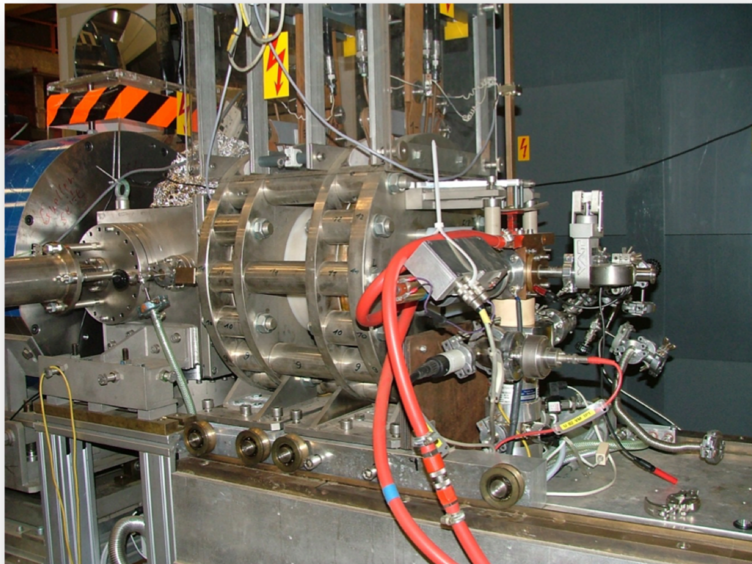
Outline

- Introduction
- Metal ion beam production with Resistive Oven at GSI
- Recent R&D activities with the Standard Temperature Oven (STO)
- ECRIS Upgrade at GSI
- Adapted STO for testing with AISHA ECRIS at INFN-LNS

GSI Accelerator Facility

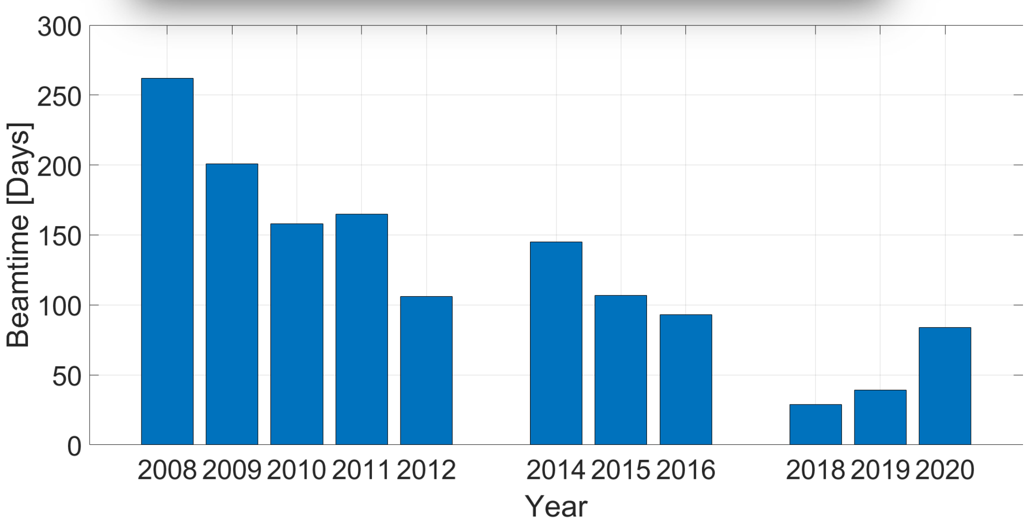


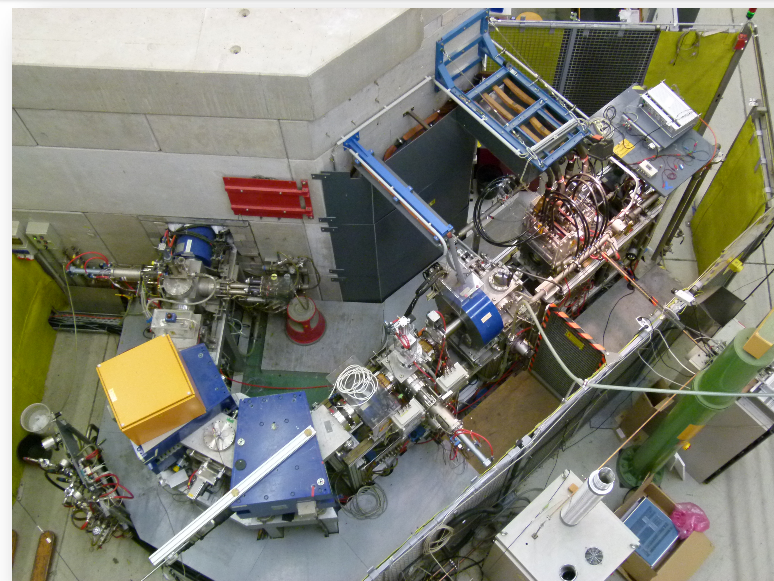
High Charge State Injector (HLI)



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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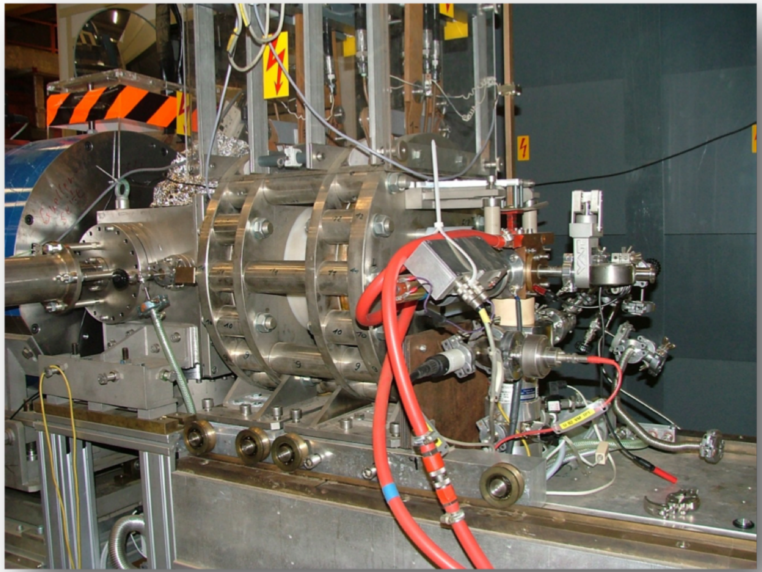

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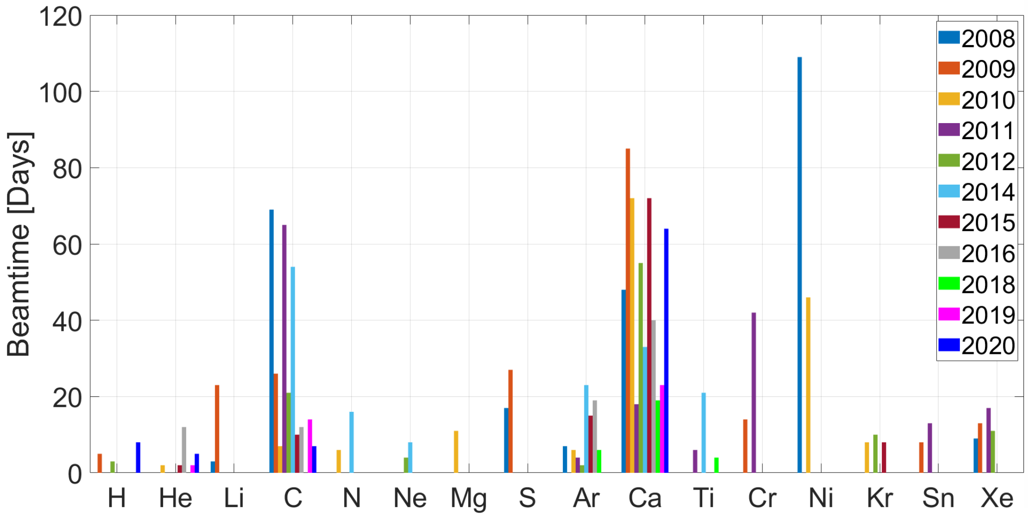
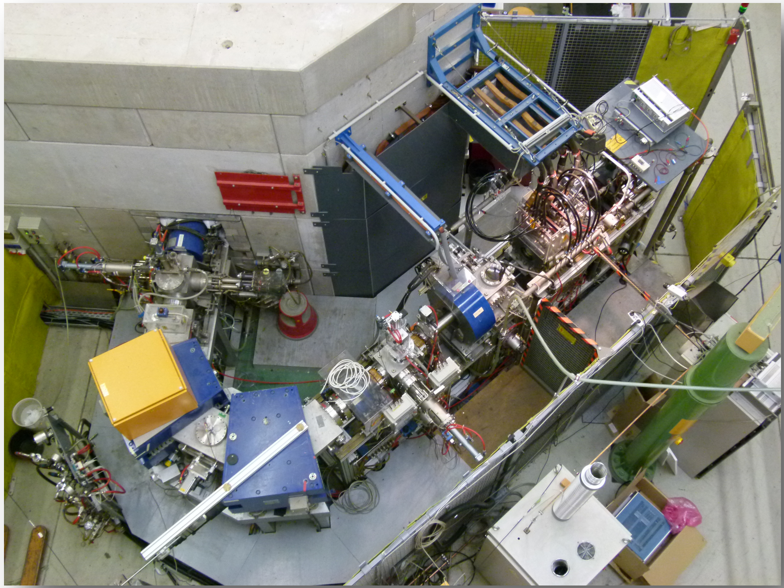
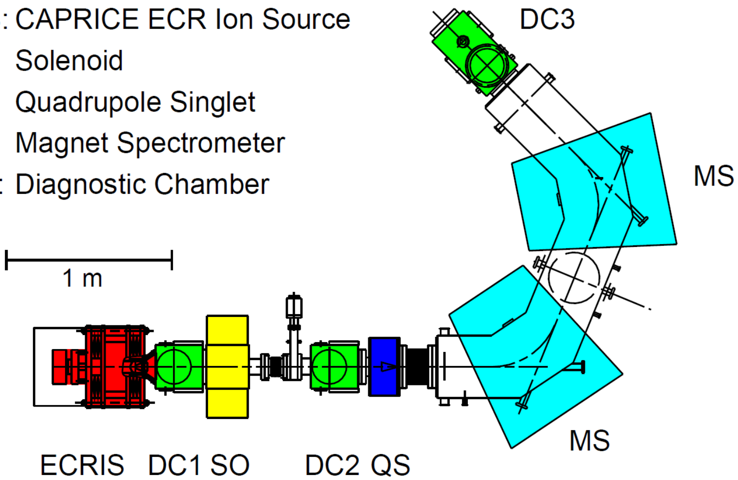
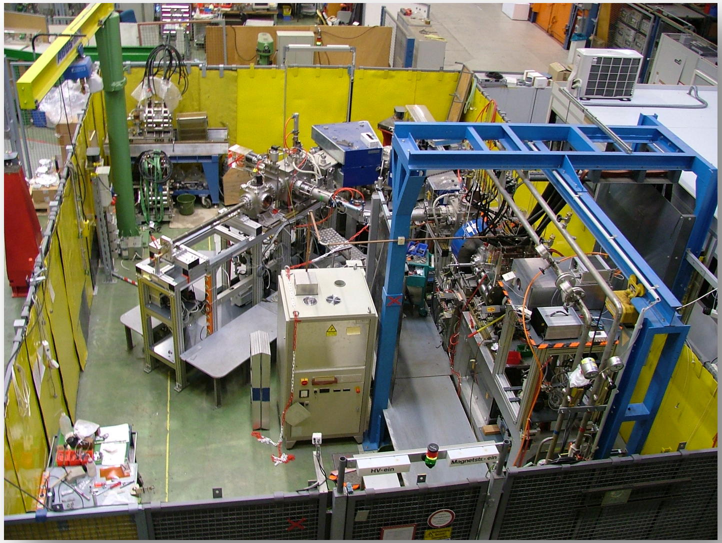


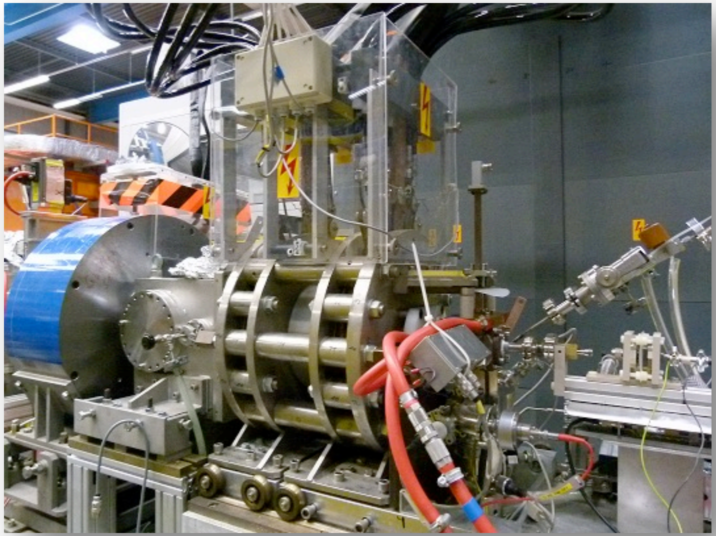


ECR Test-bench (EIS)

ECRIS: CAPRICE ECR Ion Source
SO: Solenoid
QS: Quadrupole Singlet
MS: Magnet Spectrometer
DC1-3: Diagnostic Chamber







R&D ACTIVITIES

- **Metal ion production**
- Ion extraction and transport
- Microwave-based techniques

Evaporation technique for metal ion beam production at HLI

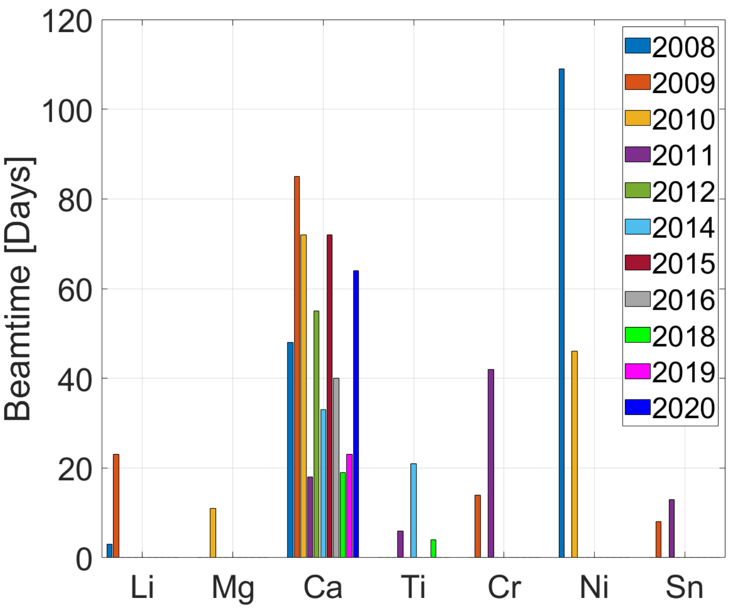
Standard Temperature Oven (STO)

LAYOUT

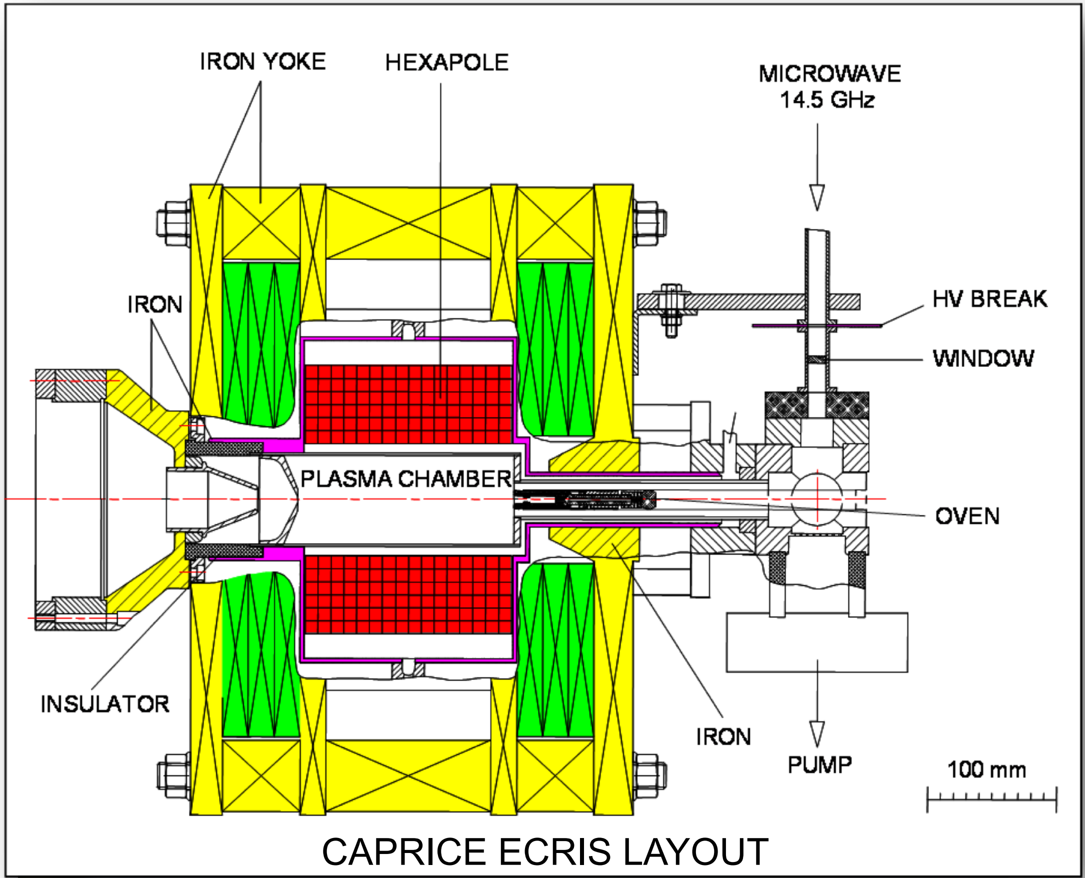
- Central current entry
- Heating helix on ceramic body
- Water cooled support tube
- Crucible or aperture ring

OPERATING PARAMETERS

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



Evaporation technique for metal ion beam production at HLI



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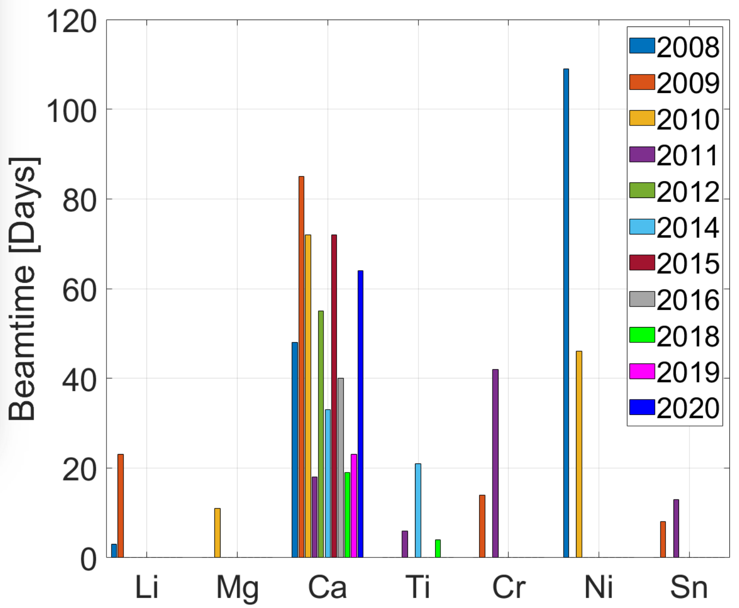
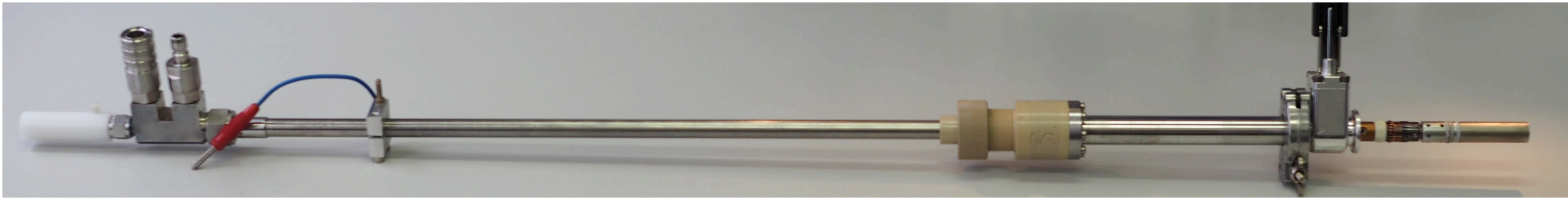
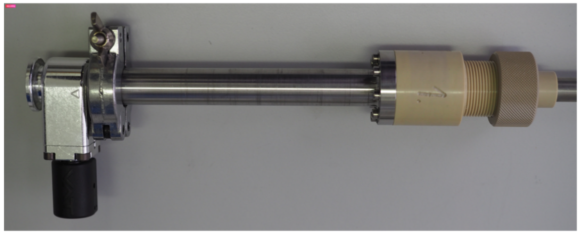
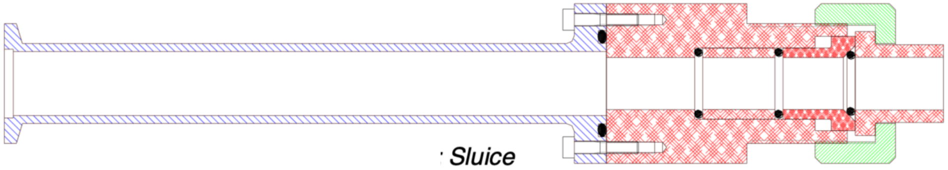


GSI Resistive Oven Concept

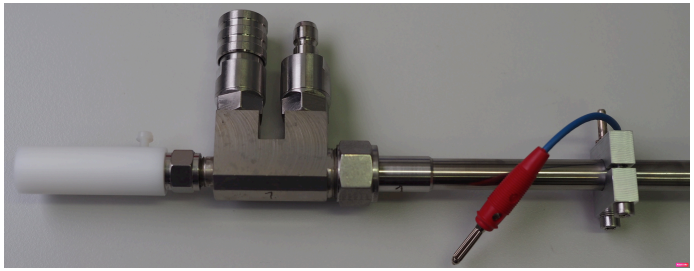


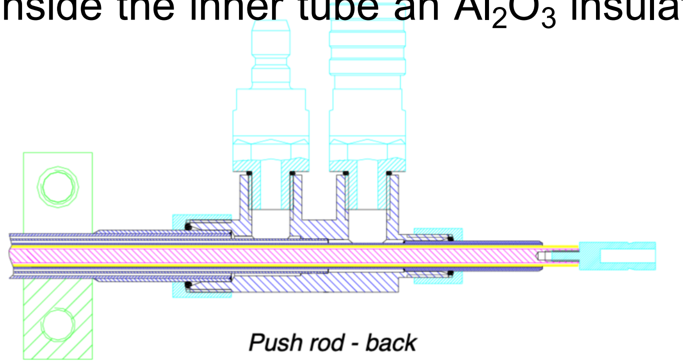
- **The oven head:** Two types for different temperature ranges (STO and HTO)
- **The sluice (exactly the same for both oven types):** Stainless steel part flanged with DN 16 ISO KF for oven exchange without breaking the vacuum (a gate valve is mated)





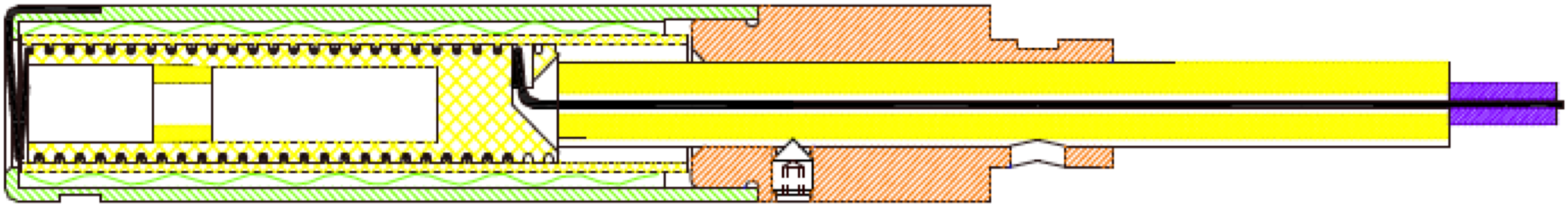
- **The push rod (nearly the same for both oven types):** System of three concentric stainless steel tubes for cooling water flow. Inside the inner tube an Al_2O_3 insulated rod inserted for the current connection.





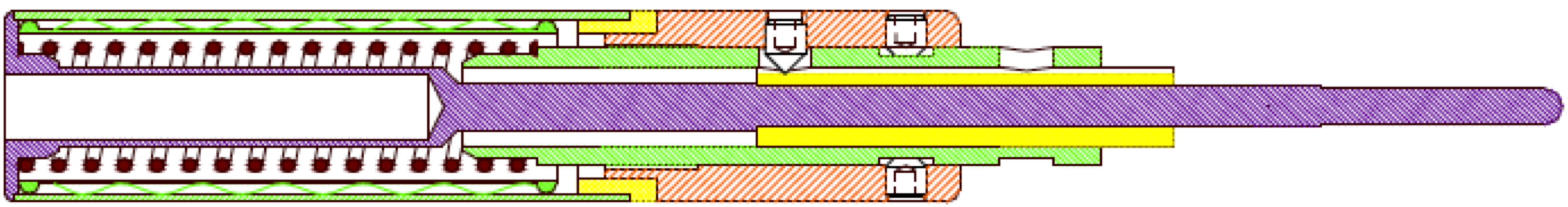
Resistive evaporation oven heads

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)

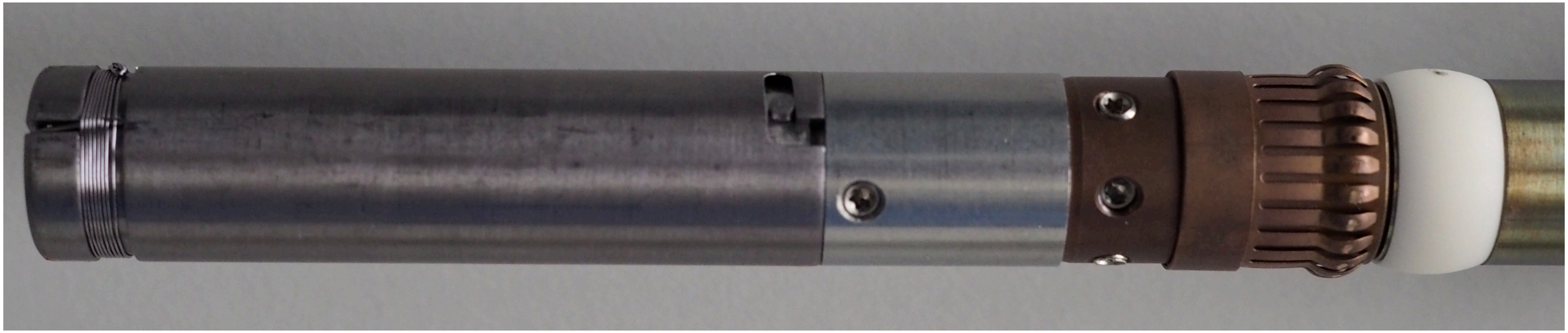


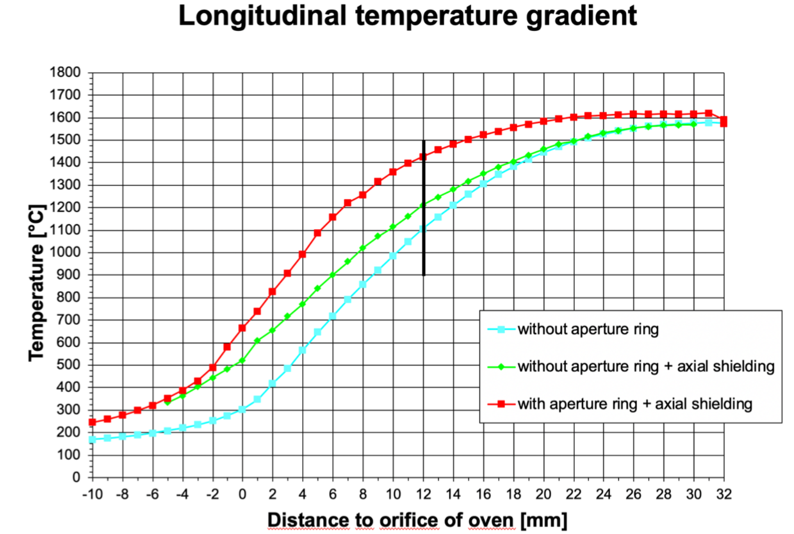
HIGH TEMPERATURE OVEN (HTO)

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



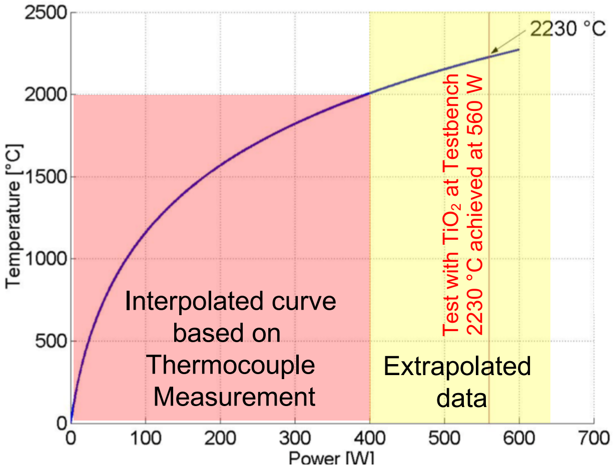


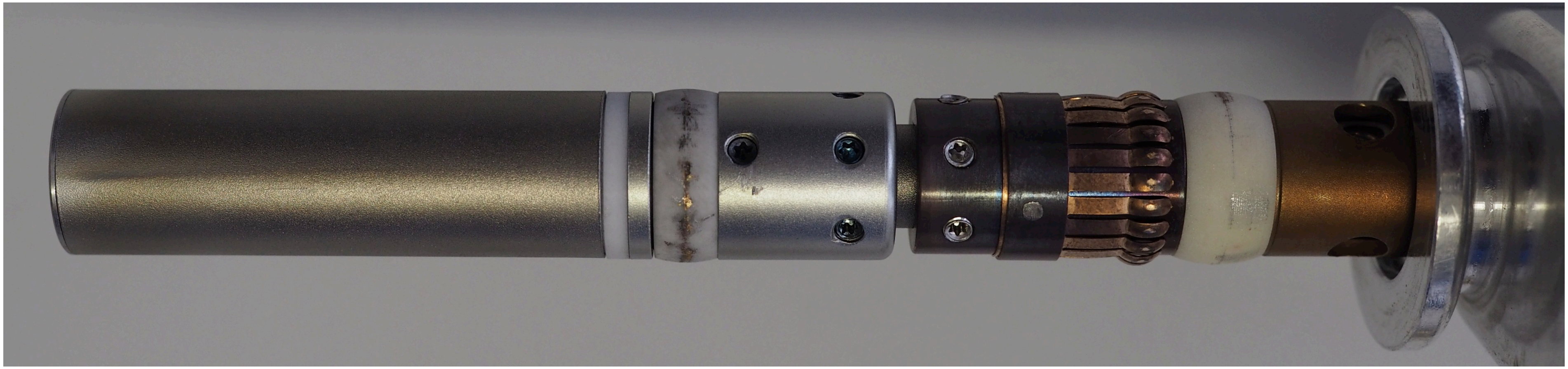
- Tungsten wire wound around a ceramic body (heater)
- Aperture ring necessary if the material is liquid at the required vapour pressure (i.e. Fe, Ni)
- Ta or W crucible used inside the ceramic to avoid chemical reactions (i.e. Mg, Ca, Li)
- Ta and Mo parts dismounted, cleaned and re-used

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)

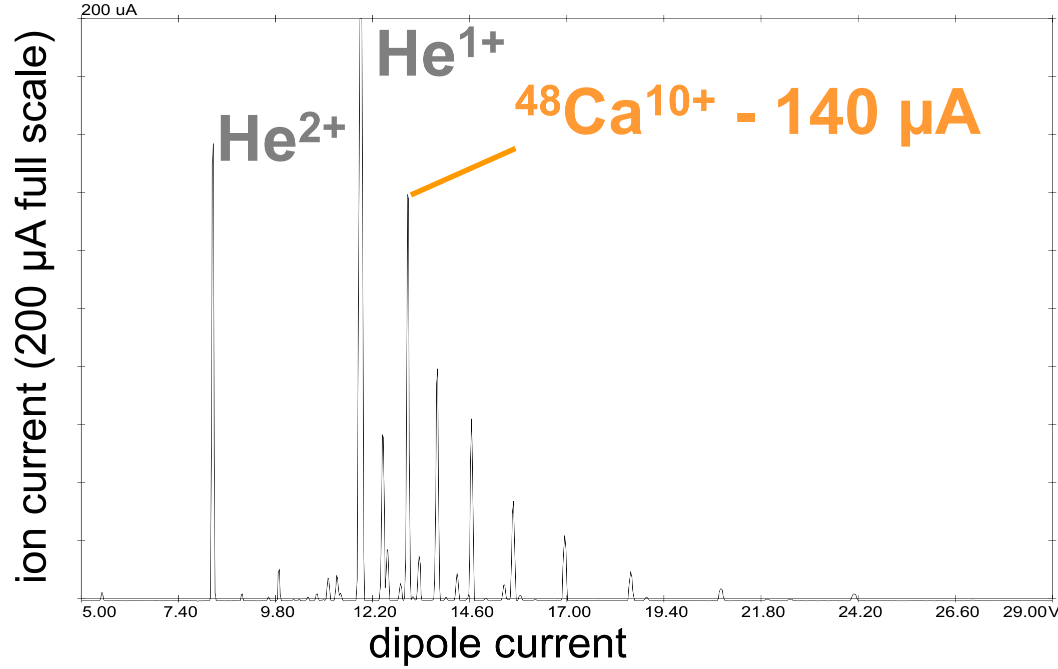


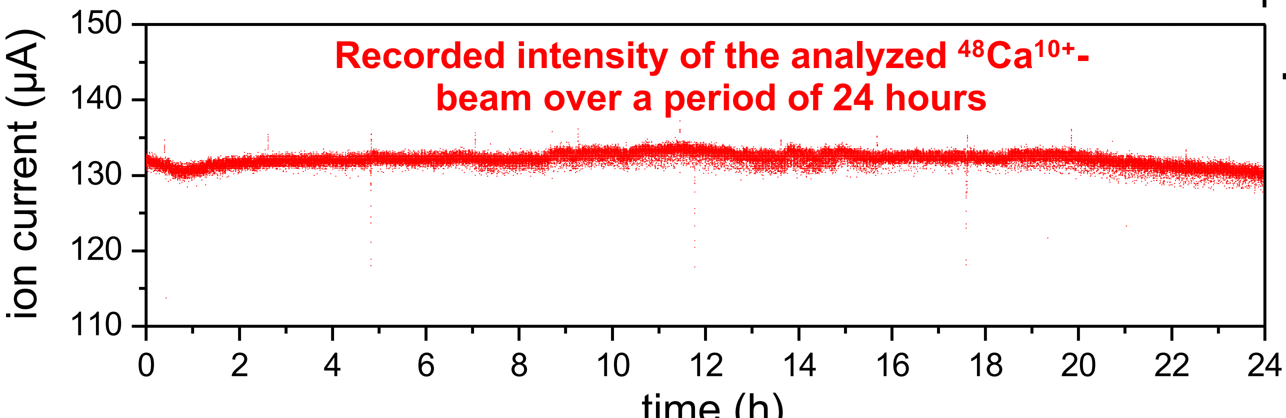


$^{48}Ca^{10+}$ Beam Optimisation

- Ion charge state: $^{48}Ca^{10+}$
- Average intensity: 100 ... 140 eμA
- Total run time: 1500 hours
- 3 refillings of standard oven STO
- Material consumption without recycling:0.5 mg/h
- Material consumption with recycling: 0.2 mg/h
- Efficiency material to ion beam: > 50 % (due to hot liner)

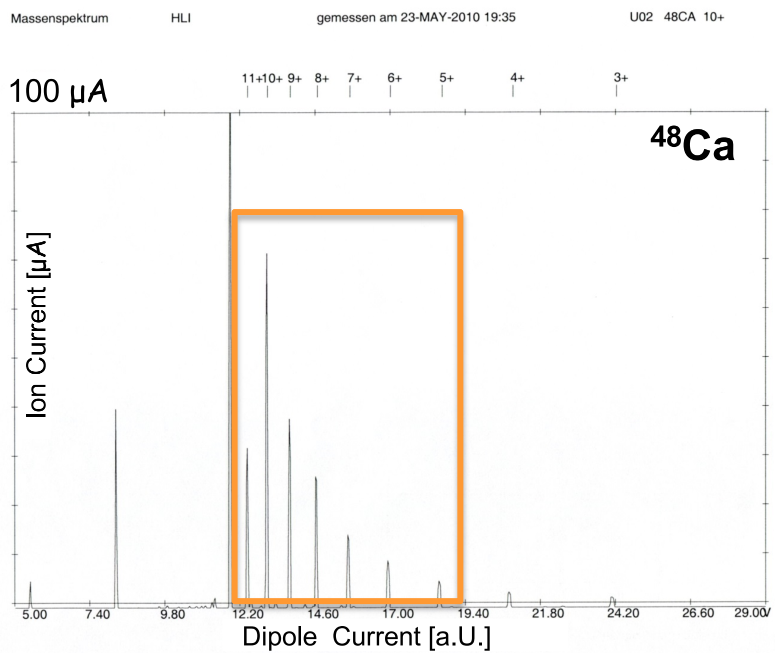
Spectrum of ^{48}Ca + He optimized on $^{48}Ca^{10+}$





79658 pulses in 24 hours (read out from beam transformer)

^{48}Ca charge states distributions and plasma images



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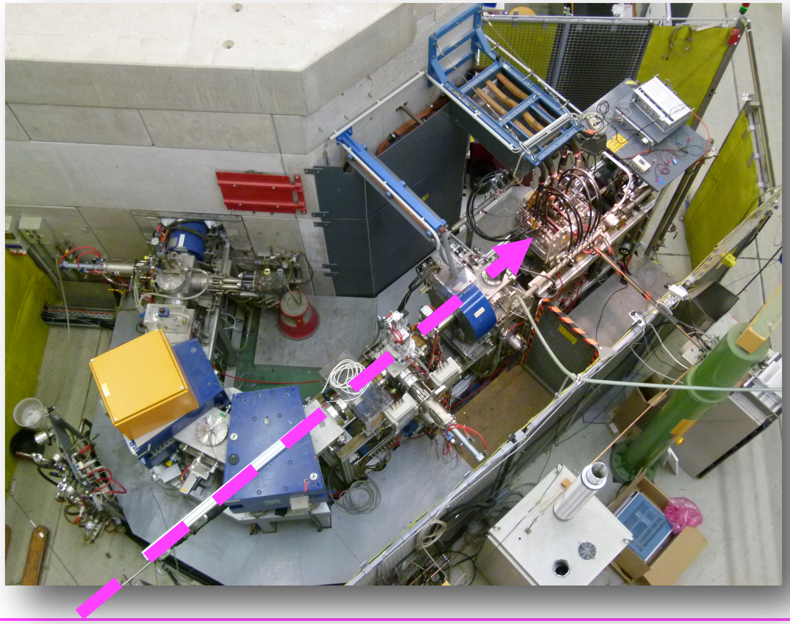
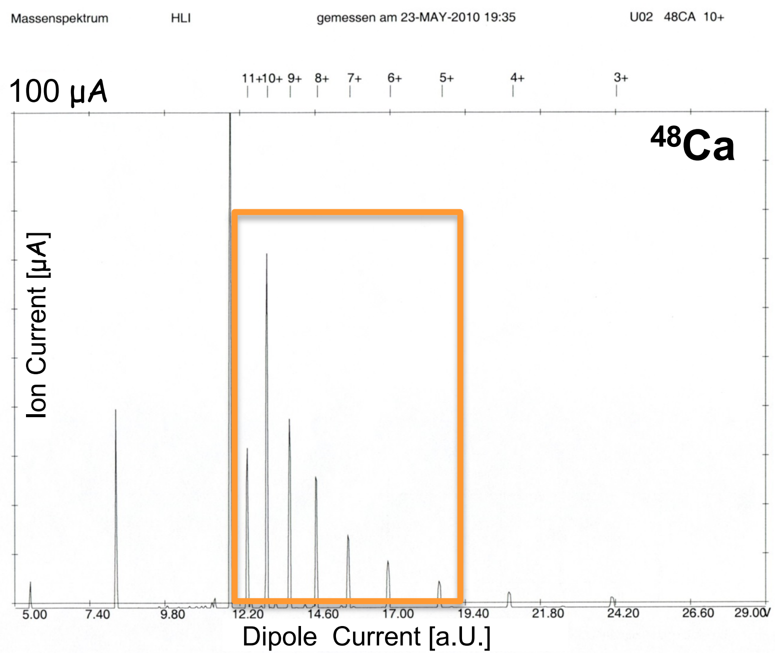


A CCD camera looks through the straight beam line and the extraction aperture into the plasma chamber.

^{48}Ca charge states distributions and plasma images



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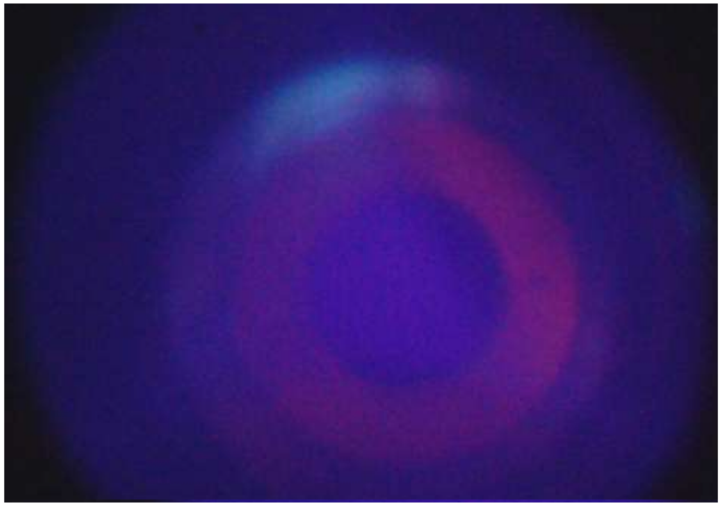

Plasma image recorded with the CCD camera

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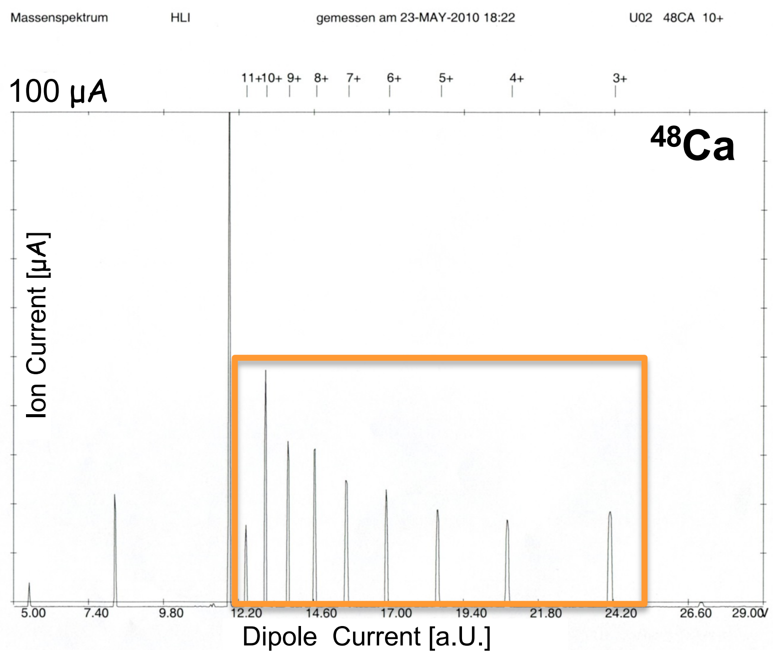
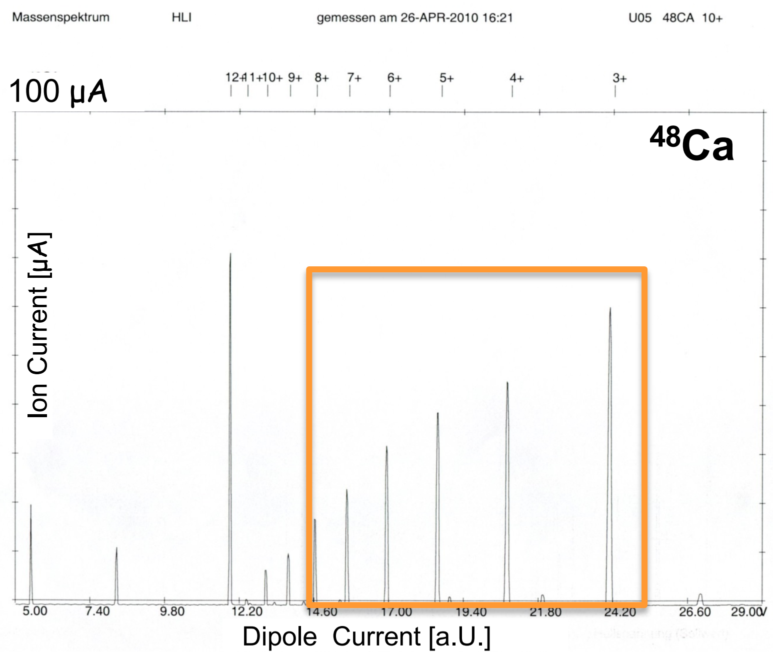


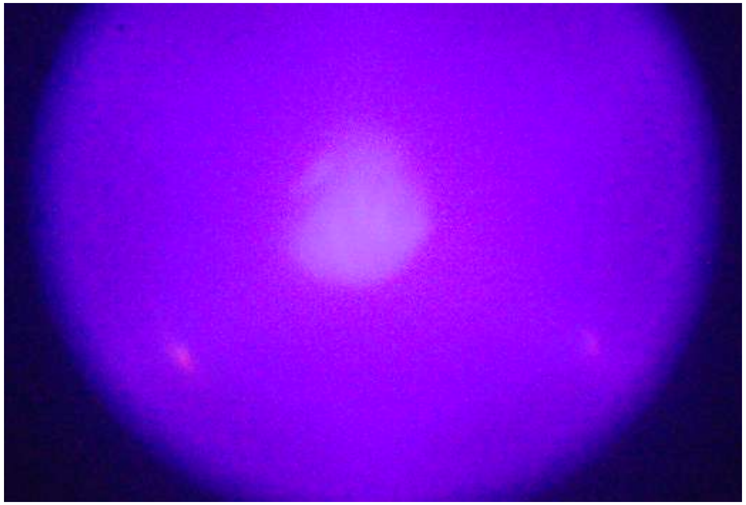
Spectrum of ^{48}Ca + He optimized on $^{48}Ca^{10+}$ after an oven power increase

Plasma image recorded with the CCD camera

^{48}Ca charge states distributions and plasma images

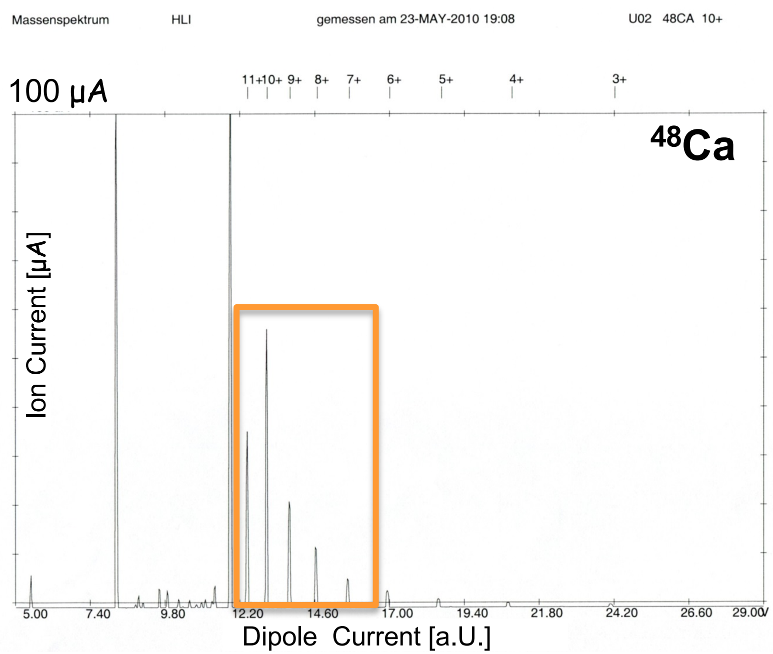


Spectrum of ^{48}Ca + He optimized on $^{48}Ca^{10+}$ during an over heating of the oven

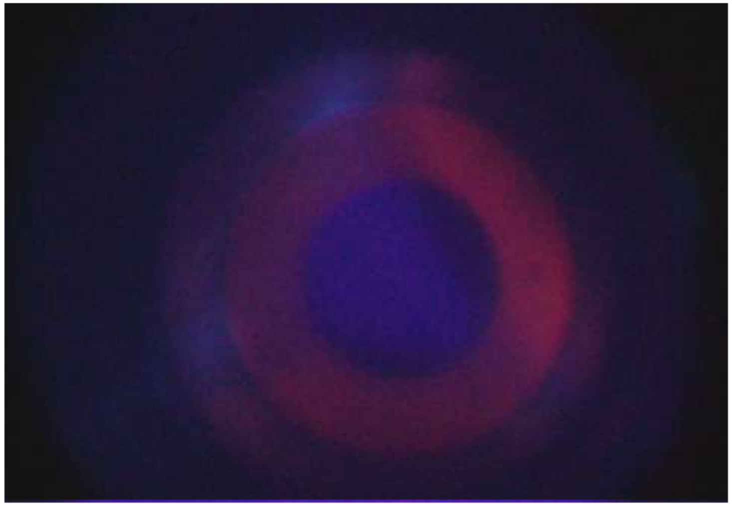


Plasma image recorded with the CCD camera

^{48}Ca charge states distributions and plasma images

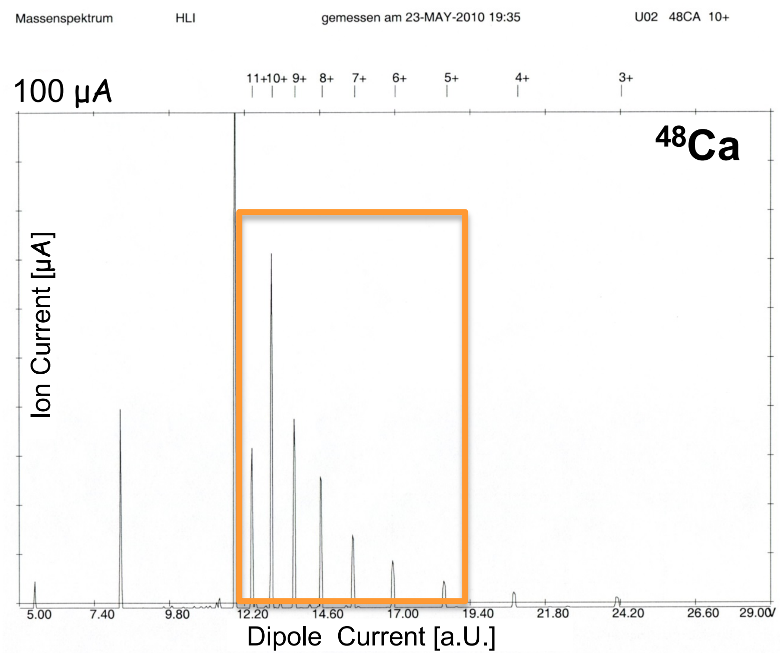


Spectrum of ^{48}Ca + He optimized on $^{48}Ca^{10+}$ after a power reduction of the oven

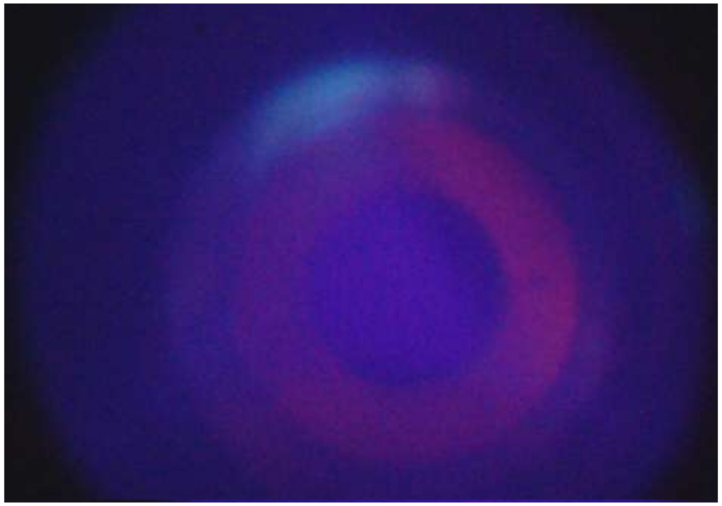


Plasma image recorded with the CCD camera

^{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

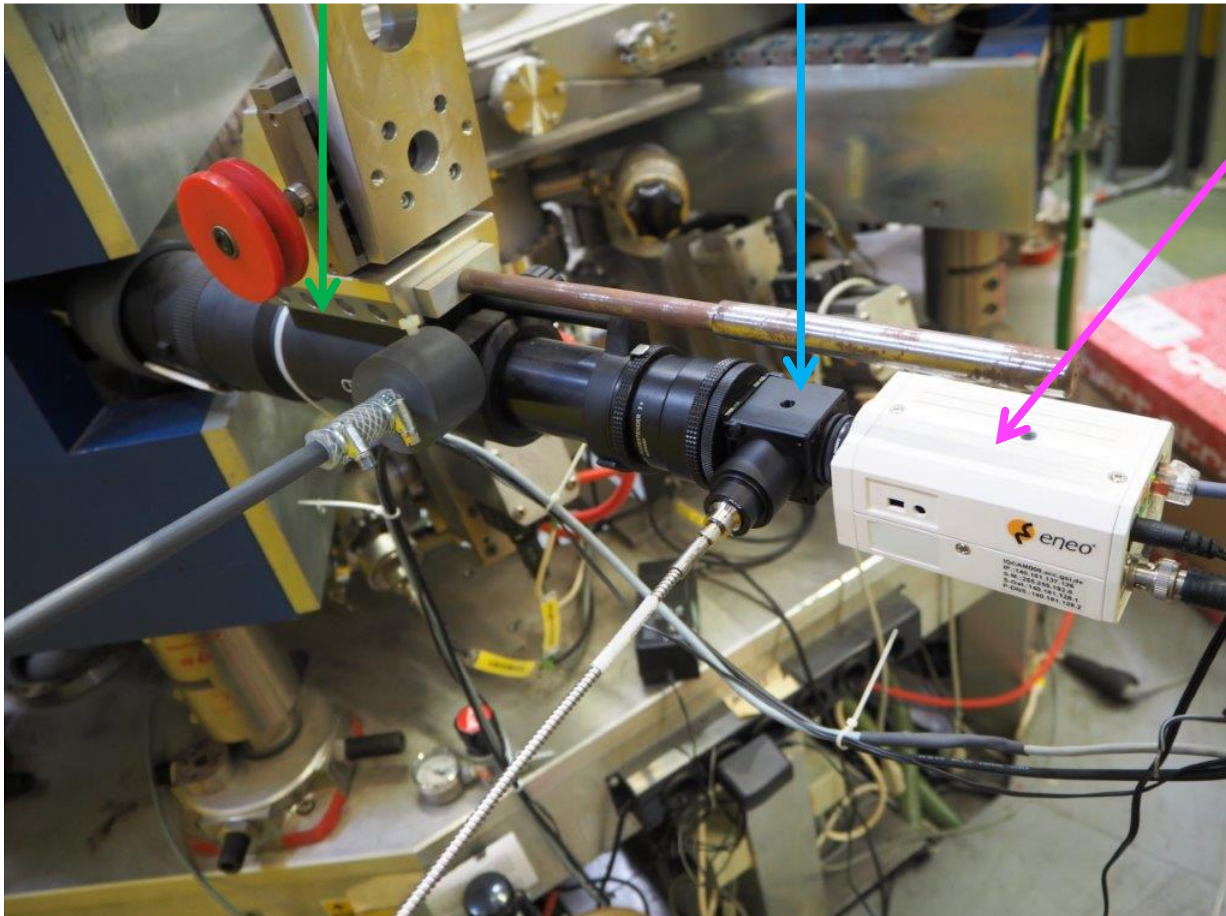
- Hours of beam time wasted, consumption increase of expensive material and experimentalists disappointment.

Optical emission diagnostic devices at HLI

Telephoto Lens

Optical Beam Splitter and Glass Fiber

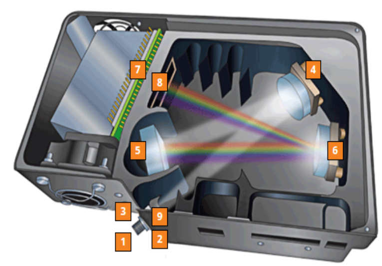
CCD Camera



..to the Optical Emission Spectrometer

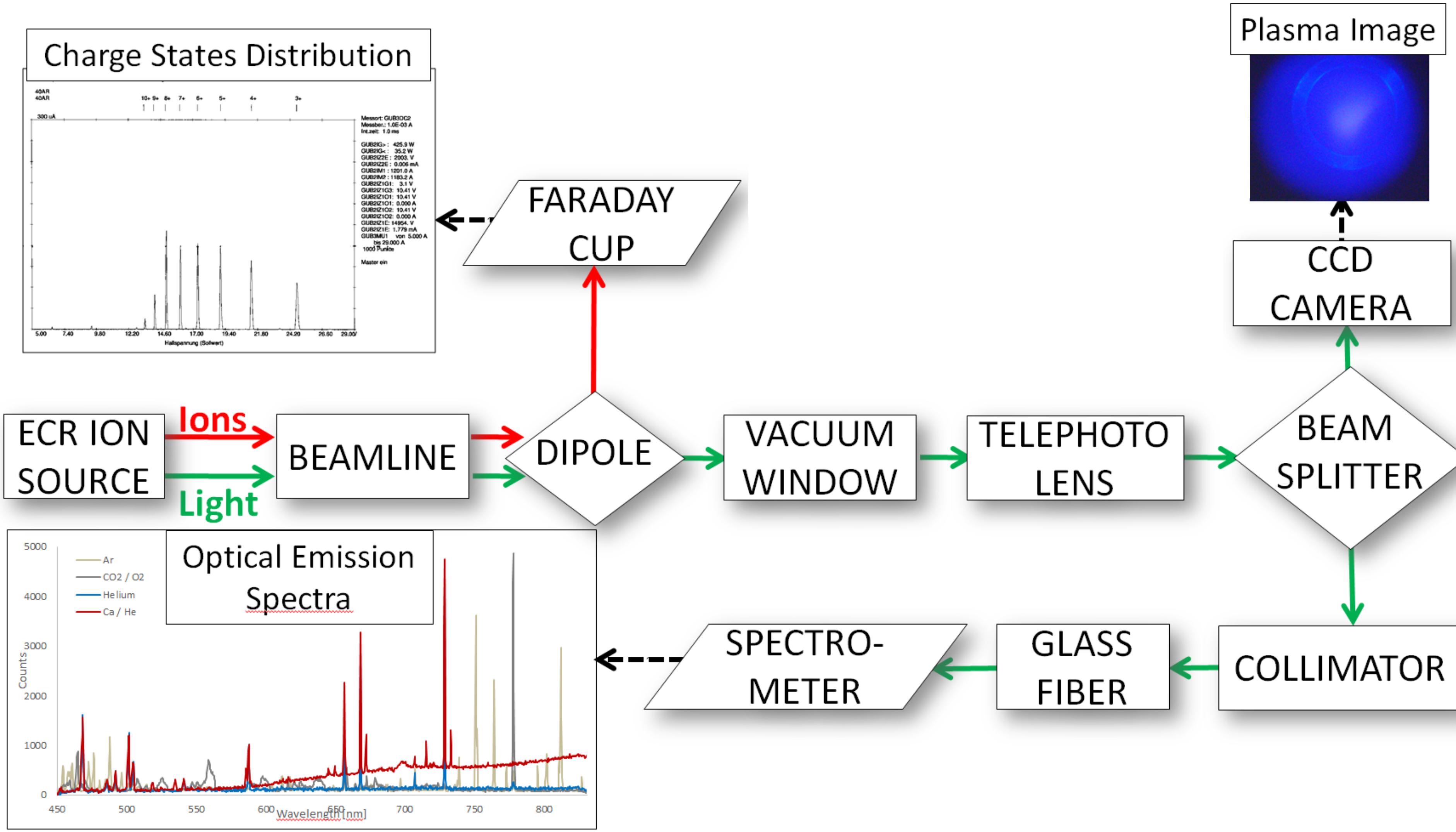
OCEAN OPTICS QE Pro

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



https://www.oceaninsight.com

HLI diagnostic devices set-up



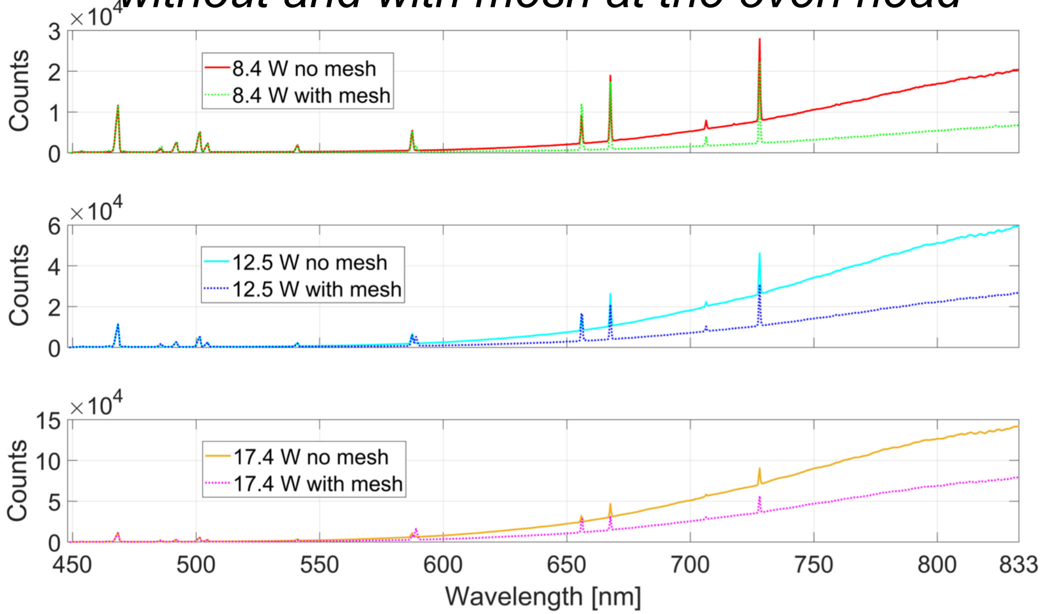
Microwave shielding of the oven orifice

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.

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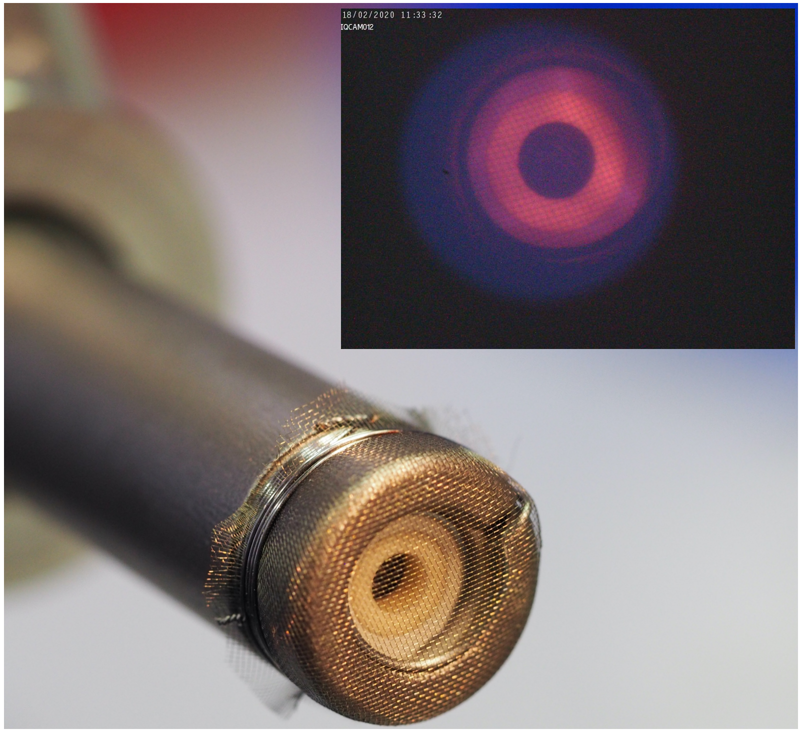

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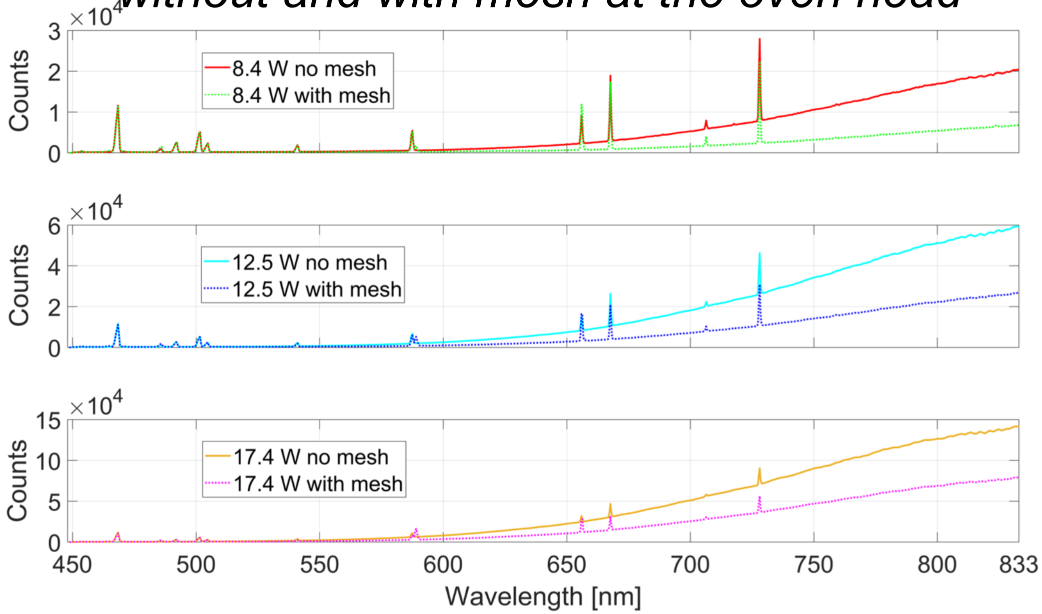

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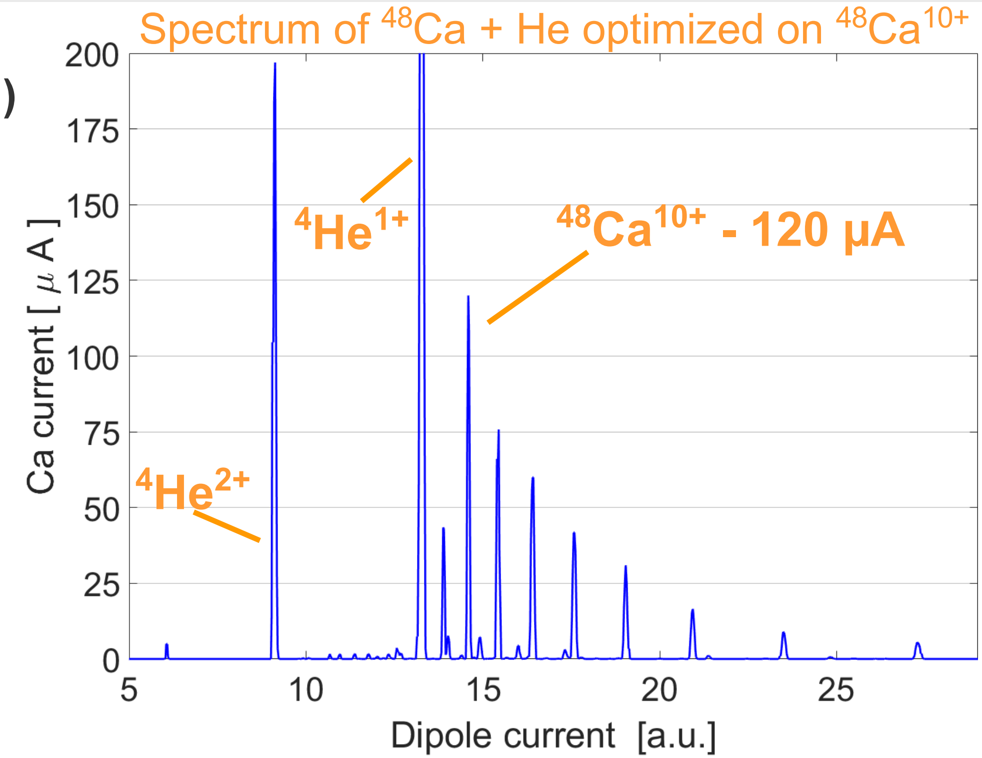
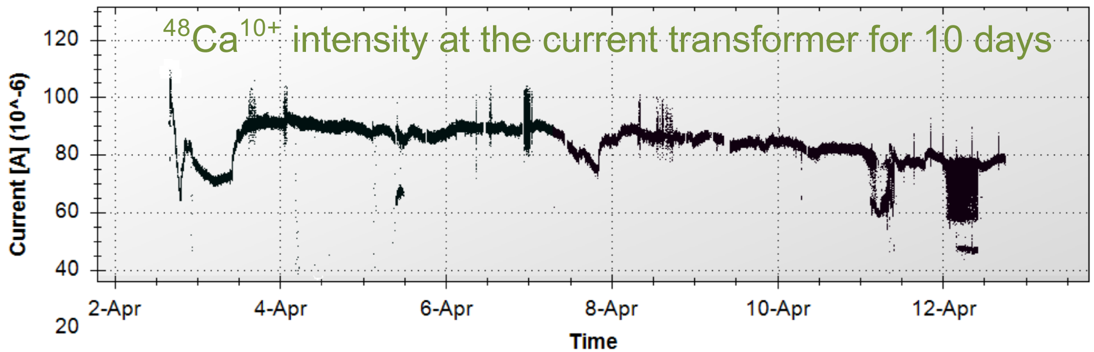
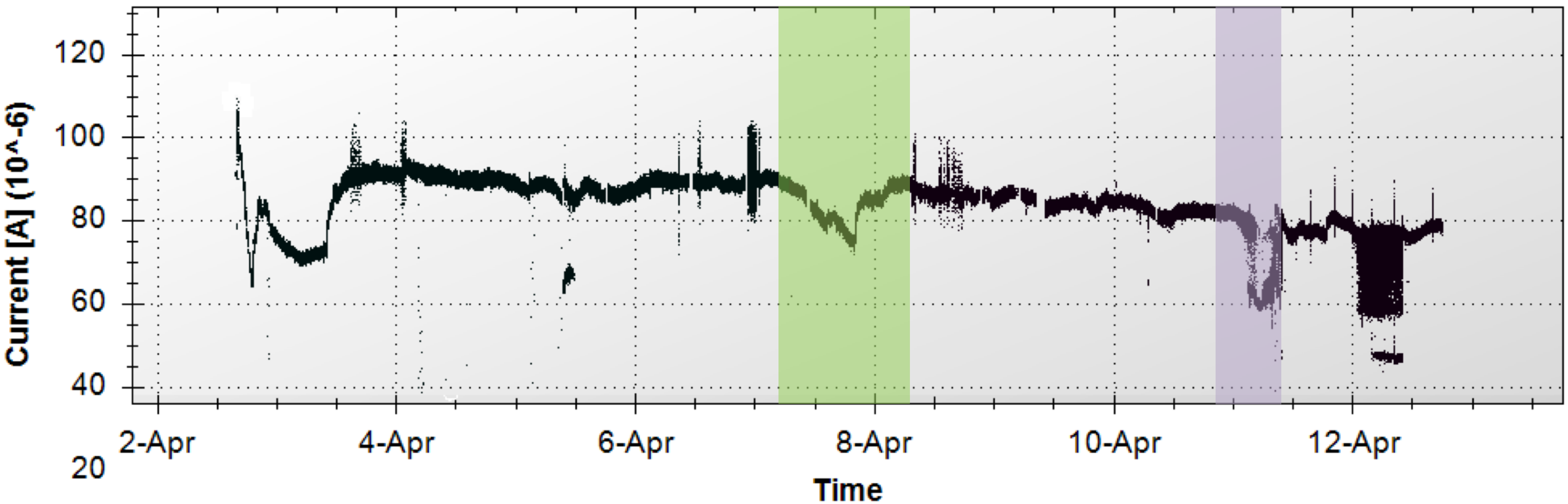
^{48}Ca Beam Times in 2020 (With microwave shielded oven)

- **$^{48}Ca^{10+}$ beam (19 February – 04 March)**
  - Beam intensity: 90-120 µA
  - Stable beam for the entire beam time and no on–call or intervention necessary
- **$^{48}Ca^{10+}$ beam (17-31 March)**
  - Beam intensity: 70-90 µA
  - Two on–call intervention necessary
- **$^{48}Ca^{10+}$ beam (02-15 April)**
  - Beam intensity 90-100 µA
  - Two on–call intervention necessary
  - Beam unstable after source recovery due to software reset (12.04.20)
- **$^{48}Ca^{10+}$ beam (19 April -15 May)**
  - Beam intensity 100-110 µA
  - Non on-call intervention necessary



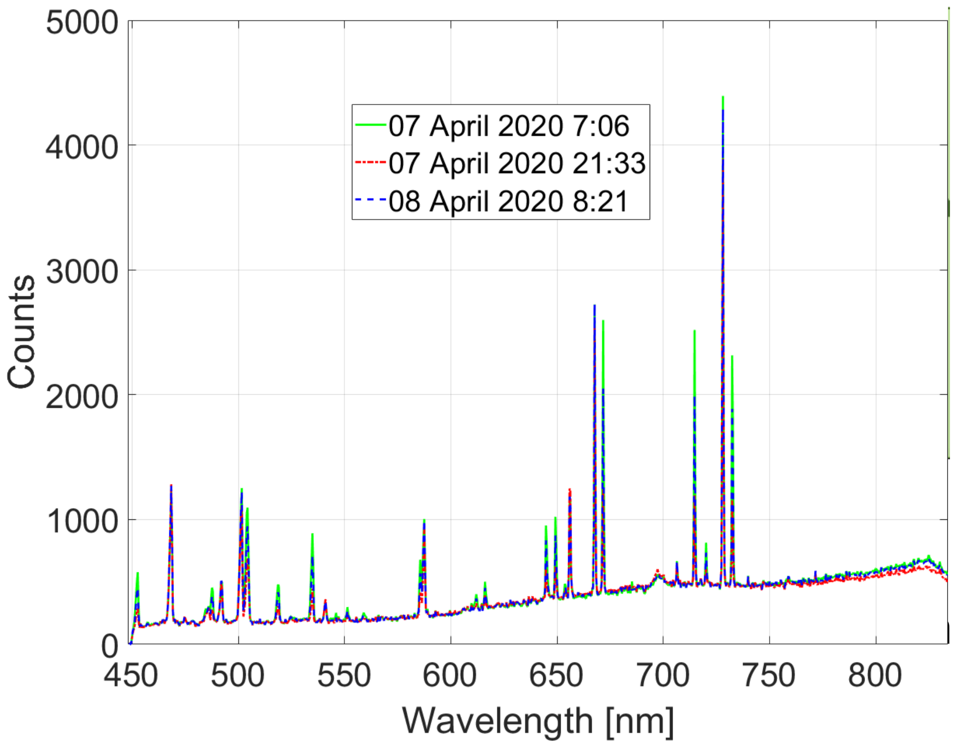


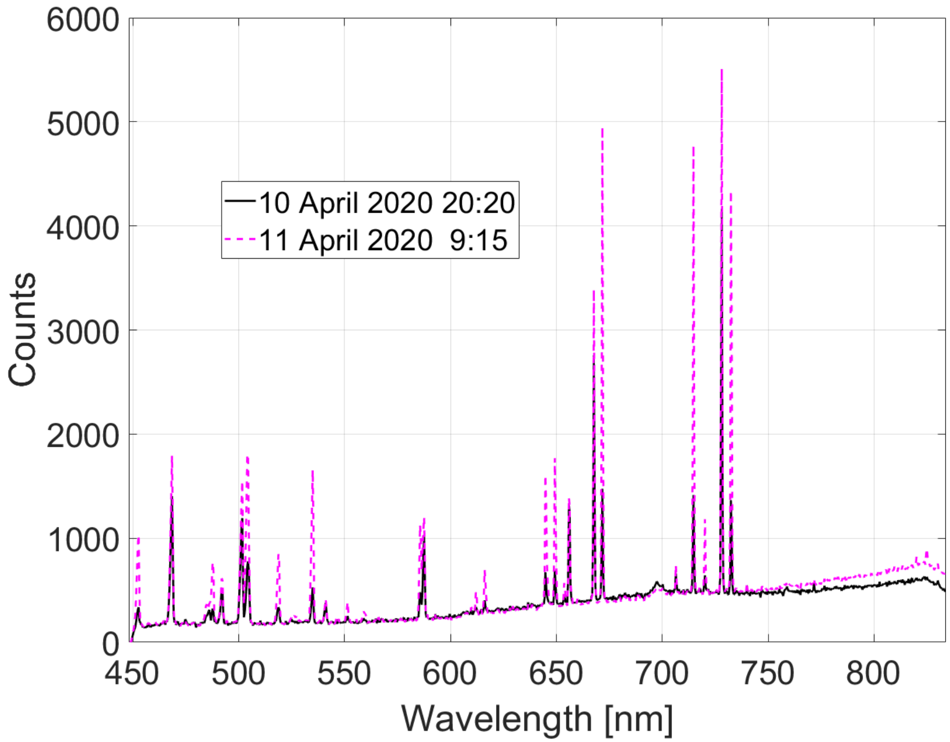
OES diagnostic during the ^{48}Ca beam-run 02-15 April 2020



$^{48}Ca^{10+}$ intensity at the current transformer for 10 days

OES diagnostic during the ^{48}Ca beam-run 02-15 April 2020





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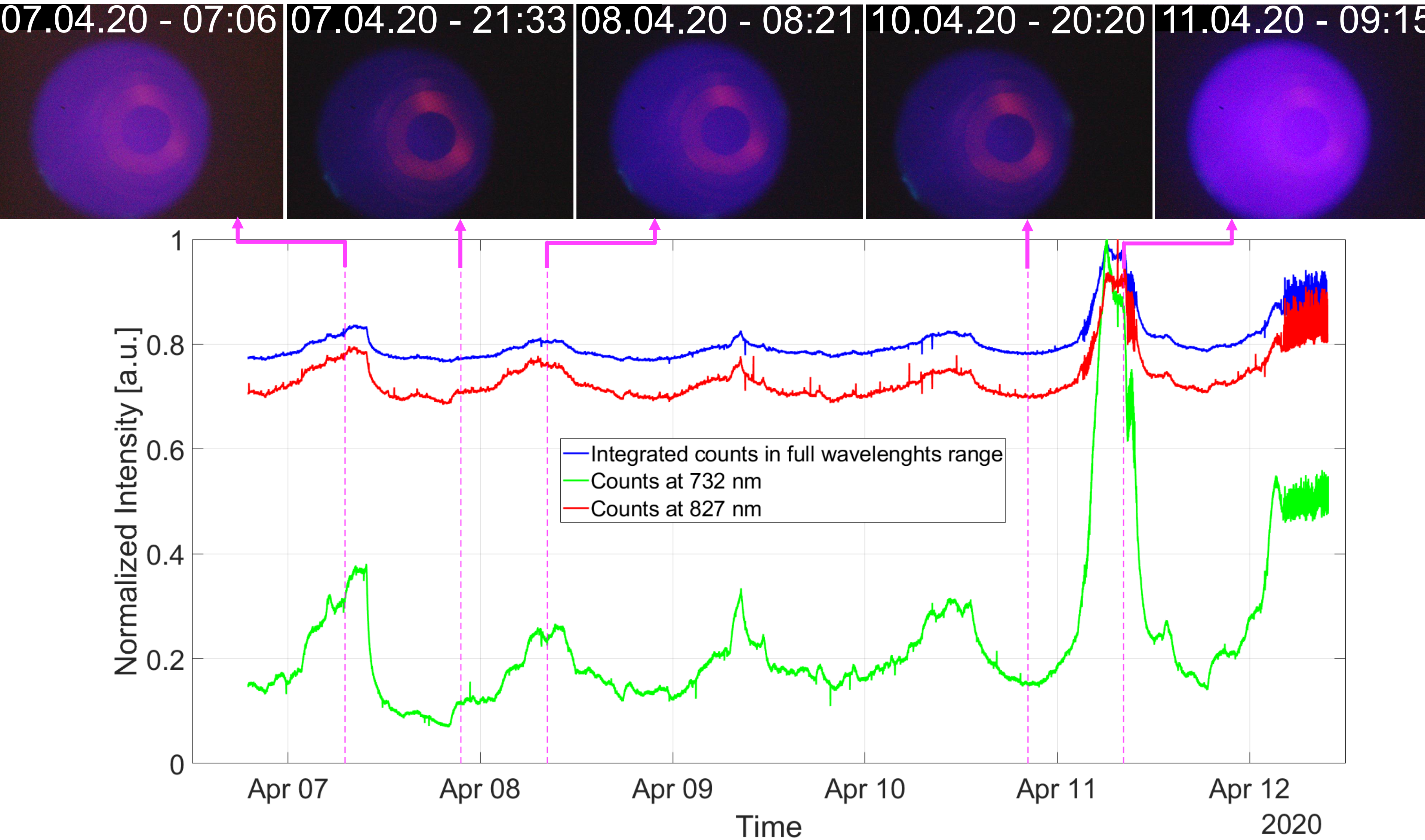


Selection of provided ion species

Gaseous Elements and Compounds				
Element	Isotope	Charge States	Main Gas	Aux Gas
H	$^{1}H_2$	1	H_2	-
C	^{12}C	2	CO_2	O_2
O	^{16}O	3	O_2	He
	^{18}O	3	O_2, *	He
Ne	^{20}Ne	4	Ne	He
	^{22}Ne	4	Ne, *	He
S	^{32}S	5	SO_2	O_2
	^{34}S	6	SO_2, *	O_2
	^{36}S	5	SO_2, *	O_2
Ar	^{36}Ar	5, 6, 7	Ar, *	O_2
	^{40}Ar	6, 7, 8	Ar	O_2
Kr	^{84}Kr	12	Kr	He
	^{86}Kr	12	Kr, *	He
Xe	^{124}Xe	15, 16	Xe, *	O_2
	^{129}Xe	18	Xe, *	O_2
	^{136}Xe	18, 19	Xe, *	O_2

Solid Elements and Compounds				
Element	Isotope	Charge States	Sample Material	Aux Gas
Li	^{6}Li	1	LiF, *	He
	^{7}Li	1	LiF	He
Mg	^{24}Mg	5	Mg	He
	^{25}Mg	4	Mg, *	He
	^{26}Mg	4, 5	Mg, *	He
Si	^{28}Si	5	SiO	He
	^{30}Si	6	SiO, *	He
Ca	^{40}Ca	6, 7	Ca	He
	^{48}Ca	7, 10	Ca, *	He
Ti	^{48}Ti	7	Ti	He
	^{50}Ti	7, 8	Ti, *	He
V	^{51}V	8	V	He
Cr	^{50}Cr	8	Cr, *	He
	^{52}Cr	7	Cr	He
	^{54}Cr	8	Cr, *	He

Solid Elements and Compounds				
Element	Isotope	Charge States	Sample Material	Aux Gas
Fe	^{58}Fe	8, 9	Fe	He
Ni	^{58}Ni	8, 9	Ni	He
	^{62}Ni	9	Ni, *	He
	^{64}Ni	9	Ni, *	He
Zn	^{64}Zn	10, 11	ZnO	O_2
	^{68}Zn	10	ZnO, *	O_2
	^{70}Zn	10	ZnO, *	O_2
Ag	^{107}Ag	15	Ag	O_2
Sn	^{112}Sn	15, 17	Sn, *	O_2
	^{114}Sn	16, 17	Sn, *	O_2
	^{118}Sn	16	Sn, *	O_2
	^{122}Sn	17	Sn, *	O_2
	^{124}Sn	16	Sn, *	O_2
Au	^{197}Au	24	Au	O_2
Pb	^{208}Pb	27	Pb, *	O_2

*** enriched elements**
*** enriched compounds**

➔ Evaporable solids (metals) – vapor pressure of $\approx 10^{-2}$ mbar at T < 1600°C for Standard-Oven (STO), and at T < 2000°C for High-Temperature-Oven (HTO)

Selection of provided ion species

Gaseous Elements and Compounds				
Element	**Isotope**	**Charge States**	**Main Gas**	**Aux Gas**
H	$^{1}H_2$	1	H_2	-
C	^{12}C	2	CO_2	O_2
Xe	^{124}Xe	15, 16	Xe, *	O_2
	^{129}Xe	18	Xe, *	O_2
	^{136}Xe	18, 19	Xe, *	O_2

Solid Elements and Compounds				
Element	**Isotope**	**Charge States**	**Sample Material**	**Aux Gas**
Li	^{6}Li	1	LiF, *	He
	^{7}Li	1	LiF	He
Cr	^{52}Cr	7	Cr	He
	^{54}Cr	8	Cr, *	He

Solid Elements and Compounds				
Element	**Isotope**	**Charge States**	**Sample Material**	**Aux Gas**
Fe	^{58}Fe	8, 9	Fe	He
	^{58}Ni	8, 9	Ni	He
Au	^{197}Au	24	Au	O_2
Pb	^{208}Pb	27	Pb, *	O_2

- **Despite repeated upgrades the ion source and its ancillary equipment show age related deterioration.**
- **Failure probability increased disproportionately in the last years.**

➔ This outdated technical standard implies the replacement by adequate modern technologies.

*** enriched elements**
*** enriched compounds**

➔ Evaporable solids (metals) – vapor pressure of $\approx 10^{-2}$ mbar at T < 1600°C for Standard-Oven (STO), and at T < 2000°C for High-Temperature-Oven (HTO)

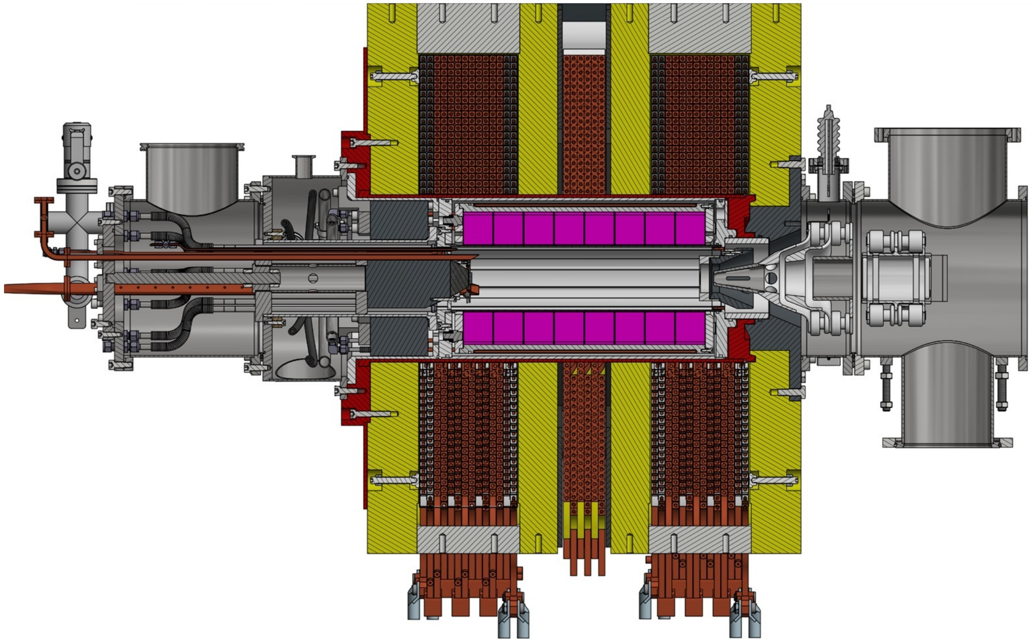
HIISI (Heavy Ion Ion Source Injector)

COURTESY OF HANNU KOIVISTO, JYFL, FINLAND

Motivation: JYFL 14 GHz ECRIS not able to meet future requirements set by nuclear physics community and by radiation effect testing of space electronics. In particular is requested:

- Xe production for space electronics irradiation
- >5 times higher intensities of medium charge states

HIISI specifications	
Frequency	18 GHz + 14.5 GHz
Klystron power	2 kW + 2 kW
TWTA 8-18 GHz	P_{max}: 250 W 2 oscillators available
B_{rad} (24-segm)	1.32 T
B_{rad} (36-segm)	1.42 T
B_{inj}	2.7 T
B_{ext}	1.3 T
L (plasma)	120-150 mm
L plasma chamber	400 mm
D plasma chamber	100 mm
T hexapole	-20 --> +15˚C



The project has received **funding** from:

- Academy of Finland under the Finnish Centre of Excellence Programme 2012-2017 (Nuclear and Accelerator Based Physics Research at JYFL) and under FIRI grant agreement No 273526.
- European Space Research and Technology Centre, European Space Agency, under ESA/GSTP ESTEC/Contract No. 4000112736/14/NL/PA
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Argon charge states	Ion current [μA]	
	18 GHz HIISI at JYFL*	14.5 GHz CAPRICE at GSI
9+	450	70
11+	680	30
12+	570	8
13+	330	2

*FIRST ION BEAMS EXTRACTED FROM A NEW JYFL 18 GHz ECRIS:HIISI
H. Koivisto et al, Proc of ECRIS2018, Catania, Italy

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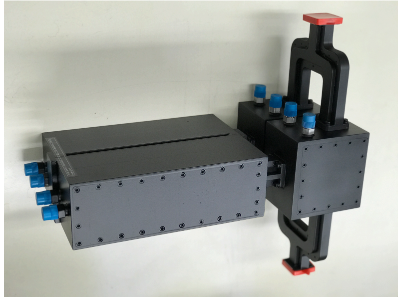
HIISI-Based 18 GHz ECRIS at GSI

- Co-operation agreement between GSI and JYFL signed in Nov 2019
- Budget allocated for the next years
- Technical drawings transferred from JYFL and GSI
- Establishment of first fabrication drawings (required for tendering process)
- Computer simulations on physical and technical properties of the subsystems

Magnet system design for the new 18GHz ECR ion source at GSI: A Andreev, F Maimone, J. Mäder, R Lang, P T Patchakui, K. Tinschert and R Hollinger, Proc of ICIS2021, FRIB-MSU

- 18 GHz Microwave components purchased, delivered and tested.

  - Klystron amplifier 17.3-18.1 GHz Bandwidth, 2400 W CW power.
  - High power waveguide isolator
  - 12.75-18.1 GHz band, 2500 W CW
  - Signal generators Rohde&Schwarz
  - High power waveguide components



- **Investigation on metal ion beam production.**

STO adapted to AISHA ECRIS

…TO BE TESTED

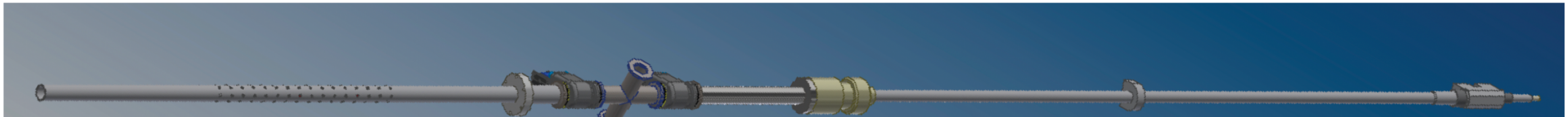
- Higher magnetic field environment
- Larger Plasma chamber
- Higher microwave power
- Performances to be investigated

…TECHNICAL CONSTRAINS

- Longer push rod needed (650 mm longer than GSI standard)
- STO diameter smaller than AISHA oven feedthrough
- CF flange (AISHA) vs KF flange (Oven)

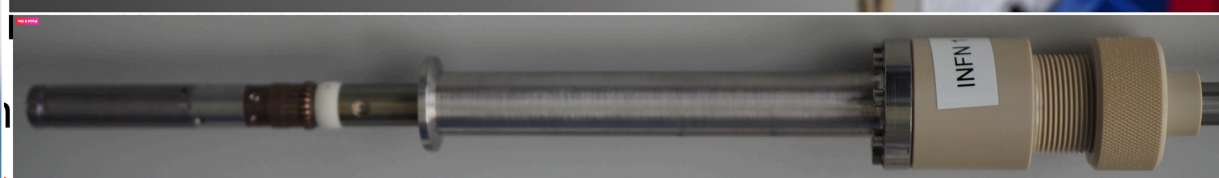
STO Development and testing with AISHA ECRIS at INFN-LNS

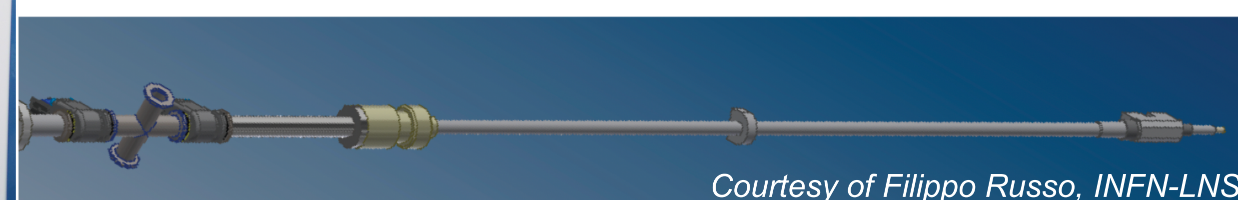
- Technological Transfer: Drawings, data sheets (power supply and vacuum parts) (GSI to INFN-LNS, 2020-2021)
- Matching rod for AISHA injection flange mating designed and machined (INFN-LNS, 2021)
- Longer stainless steel tubes brazed and assembled (Ext. Company, 10.2021)
- Mechanical check, ceramic rod insertion and water and electrical connections mounted (GSI, 11.2021)
- Electrical, water cooling and vacuum test successful (GSI, 11/2021)
- Ready for shipment to INFN-LNS (01-02/2022)
- Schedule of test campaing at INFN-LNS with AISHA ECRIS (**ONGOING**)
  - Commissionig tests with ZnO (after 06/2022), then with Fe



Courtesy of Filippo Russo, INFN-LNS

STO Development and testing with AISHA ECRIS at INFN-LNS





Courtesy of Filippo Russo, INFN-LNS

THANK YOU FOR YOUR ATTENTION
THE ECRIS TEAM
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