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ECRIS operation and developments at TRIUMF

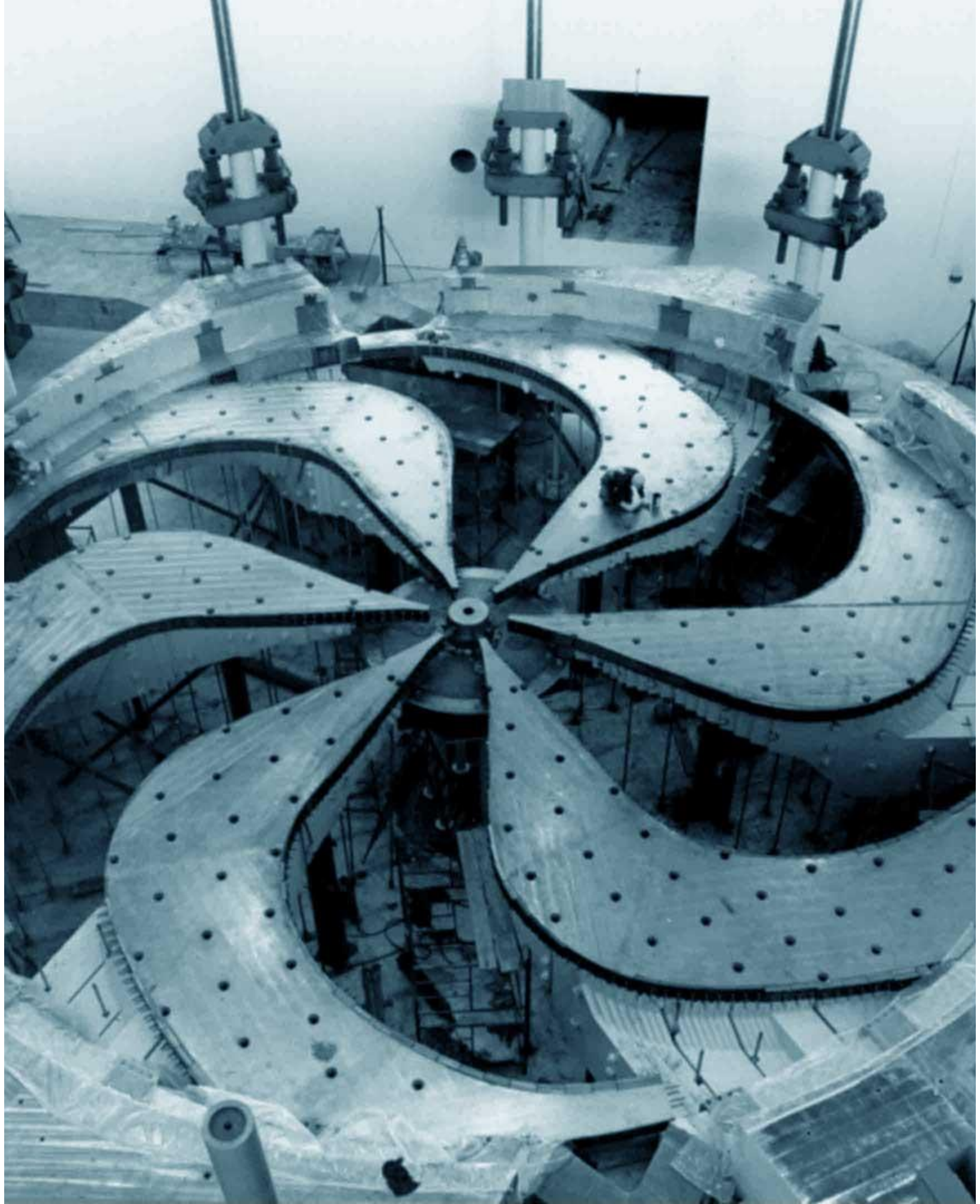
Friedhelm Ames, Joseph Adegun, Christopher Charles, Keerthi Jayamanna, Brad Schultz, Oliver Kester

ECRIS’24 workshop

Darmstadt

September 15-19, 2024

2024-09-15



Discovery, accelerated

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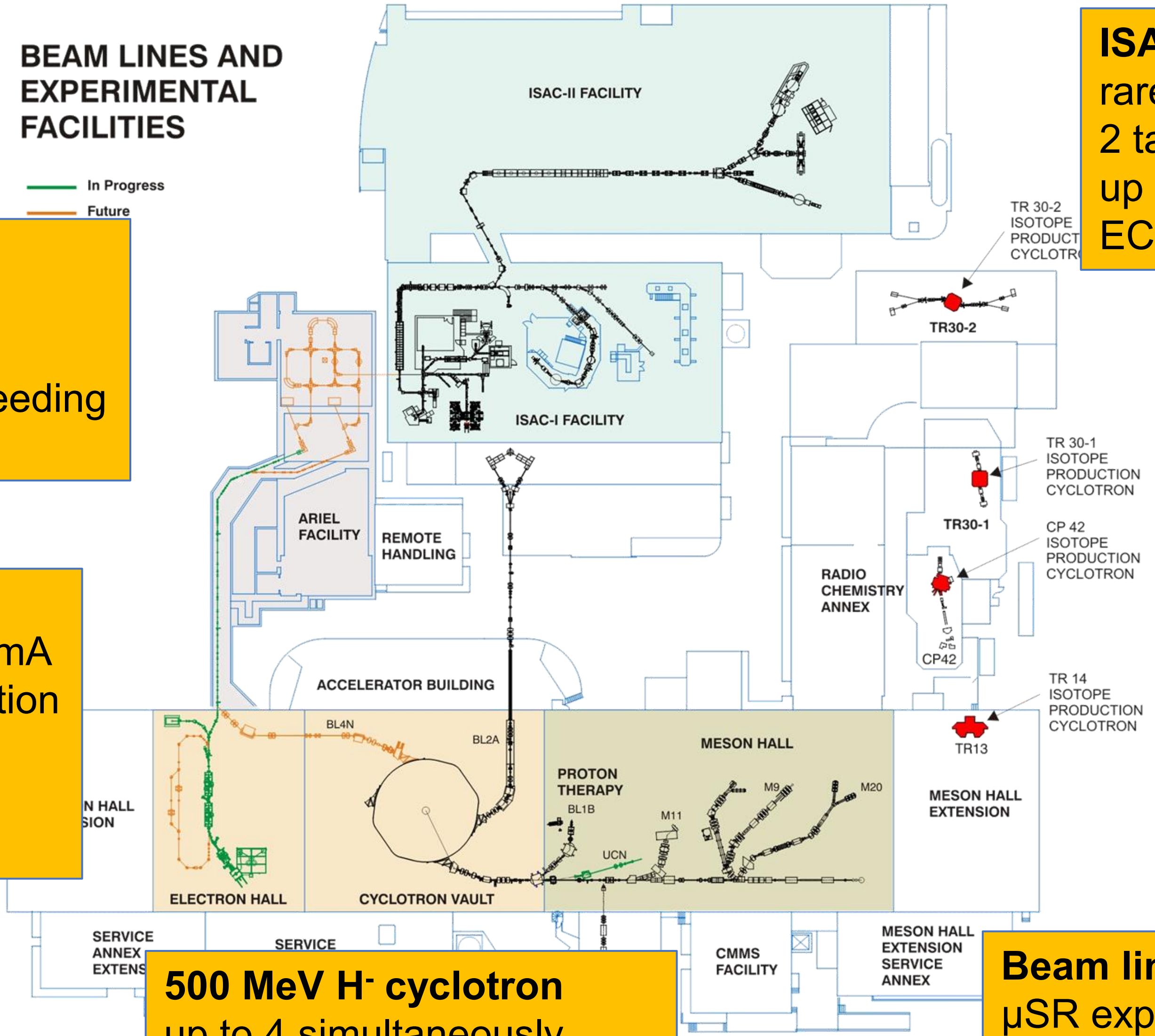
BEAM LINES AND EXPERIMENTAL FACILITIES



ISAC I and II
rare isotope beams up to 15 MeV/u
2 target stations for
up to 100 μA p beam @ 480 MeV
ECRIS charge state breeding

CANREB
high resolution
mass separation
EBIS charge state breeding

4 cyclotrons 13-30 MeV
for medical isotope production
(BWTX)

ARIEL
e-linac 30 MeV 10 mA
e^- and p^+ target station
for rare isotope
beam production

500 MeV H^- cyclotron
up to 4 simultaneously
extracted p^+ beams
individually variable energy
up to 120 μ A per beam line

Beam line 1
μSR experiments
isotope production
ultra cold neutron source
p and n irradiation
(p therapy)

Discovery, accelerated

post acceleration

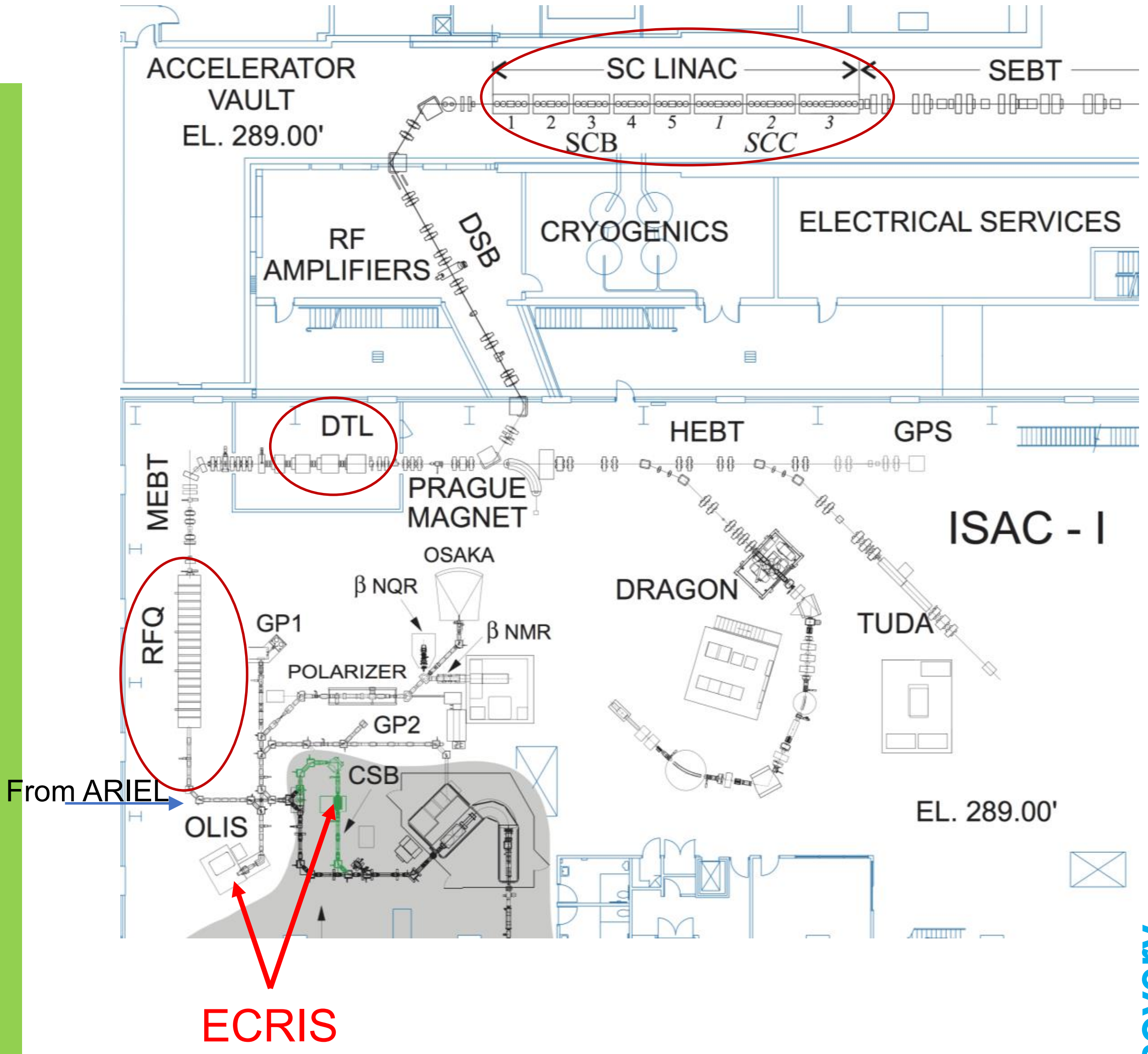
ISAC accelerator chain

• **RFQ: (radiofrequency quadrupole accelerator)**
acceptance : A/q < 30 @ 2.04 keV/u
final energy: 150 keV/u

• **DTL: (drift tube linear accelerator)**
acceptance A/q <7
final energy 1.5 MeV/u

• **superconducting LINAC:**
acceptance A/q <7
final energy 15 MeV/u for A/q=3

A/q < 30 injection of 1+ ions, stripping after RFQ
A/q > 30 charge state breeding to A/q <7
stripping after DTL for higher energy or purification
Off-line ion source (OLIS) for setup and experiments



Discovery, accelerated

RIB operation

Up to 2017 (9 month /year)

Scheduled operation of ISAC	5000 hours/ year
Overhead and downtime	2000 hours/ year
Beam to experiments and development	3000 hours/ year

Typical duration of an experiment 2 days to 3 weeks (average ~1 week)
Ratio accelerated to non accelerated beams ~30%

Since 2018
~8 months per year reduced schedule for ARIEL installations
2020-22 further reduction due to COVID

ECRIS charge state breeding

Requirements for post acceleration:

Mass	<238
Charge:	A/Q <7
Energy:	2.04 keV/u
Intensity:	1 – 10^9 ions/s
High purity	

Charge breeding systems for post acceleration at TRIUMF

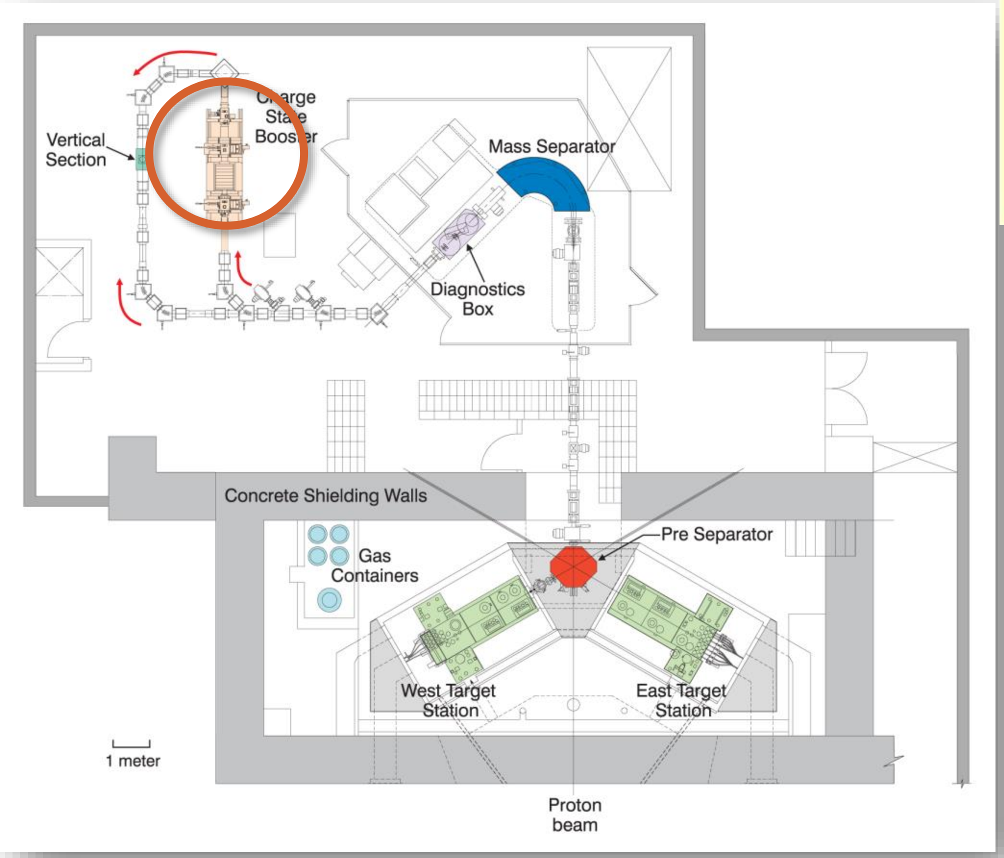
ECRIS operational
EBIS in preparation

ECRIS charge state breeding

charge state breeding with an ECR ion source
At ISAC

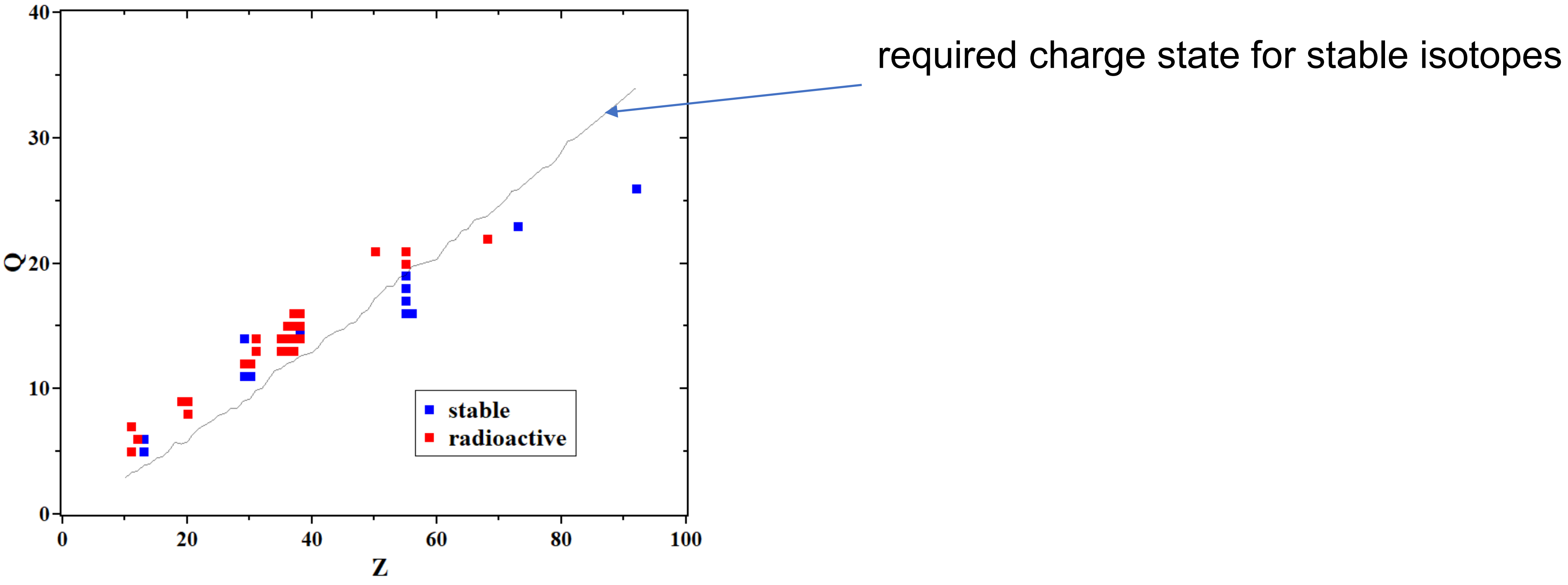
14.5 GHz PHOENIX from PANTECHNIK

- 2004 off-line tests
- 2008 modified injection and extraction optics and start of on-line operation
- 2012 Aluminum plasma chamber with pure aluminium coating
- 2014 klystron rf amplifier replaced by TWT
- 2021 two frequency operation



charge state breeding results

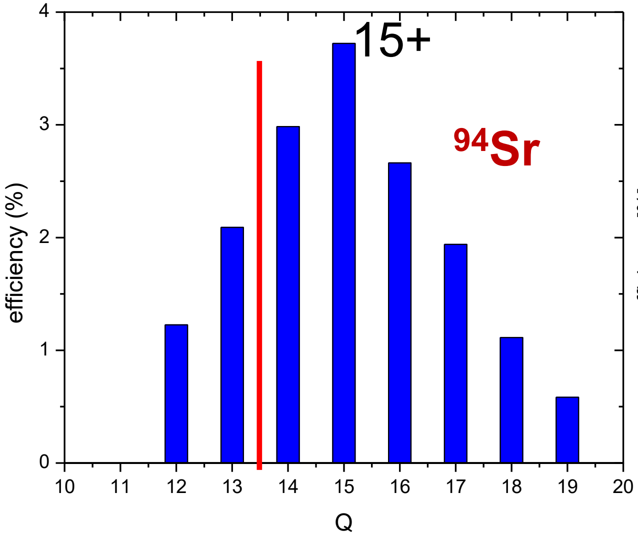
maximum of charge state distribution
or charge state used for experiment for Na to U

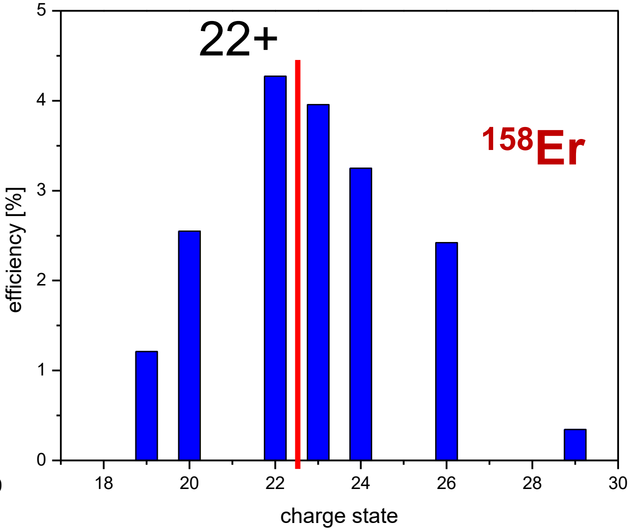


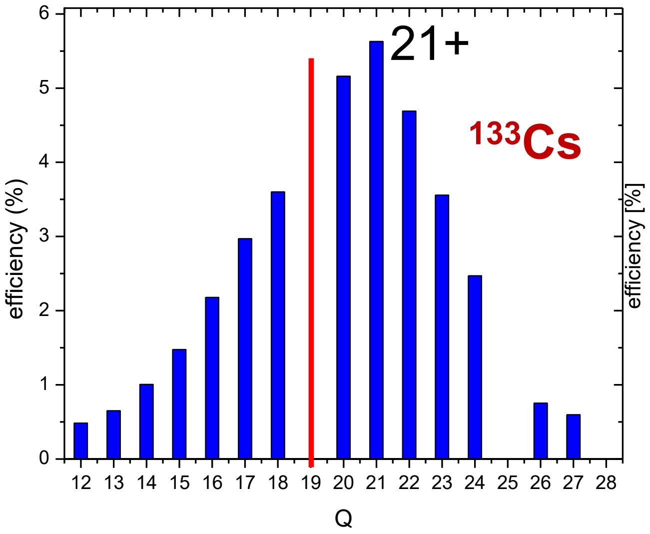
A/Q requirements can be fulfilled for elements with Z~< 60-70

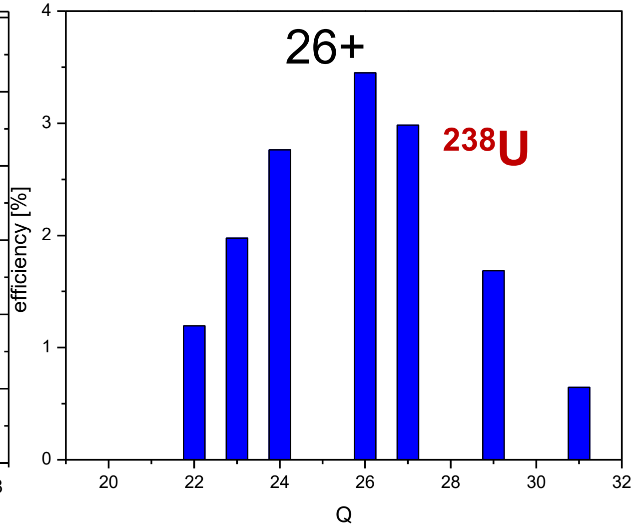
charge state breeding results

efficiency and charge state distribution









radioactive ions from on-line ion source
total efficiency >17%

stable ions from off-line and on-line ion source
total efficiency 35%

Red line indicates A/Q = 7
^{238}U would require Q = 34+

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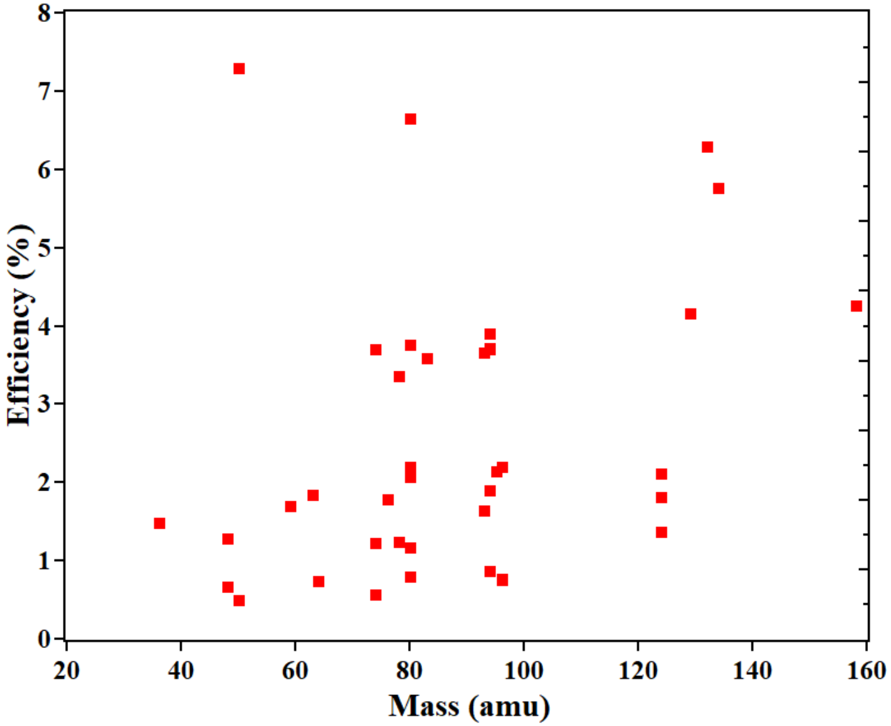
ECRIS efficiency

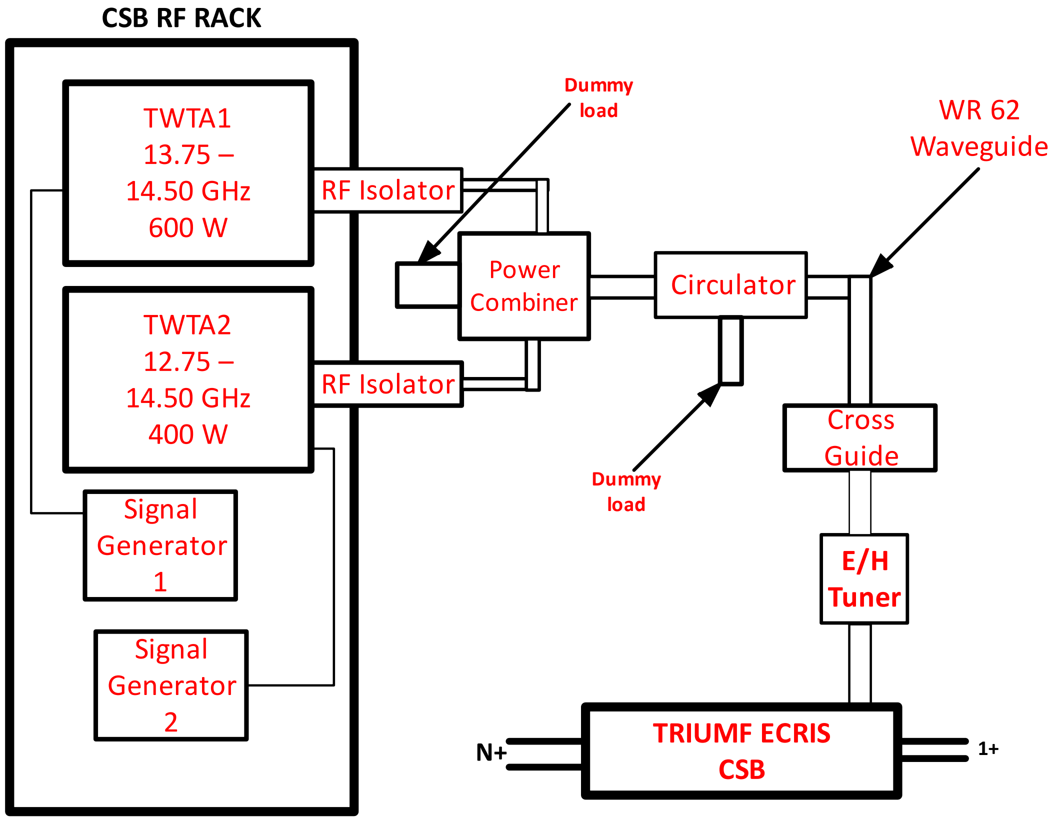
Radioactive isotopes
(used for experiment)



Efficiency range ~1-7%

- Not always possible to use the maximum in the distribution due to background
- Losses due to decay
- Different values for the same isotope due to changes over time

Recent upgrades



- Two frequency injection via one waveguide

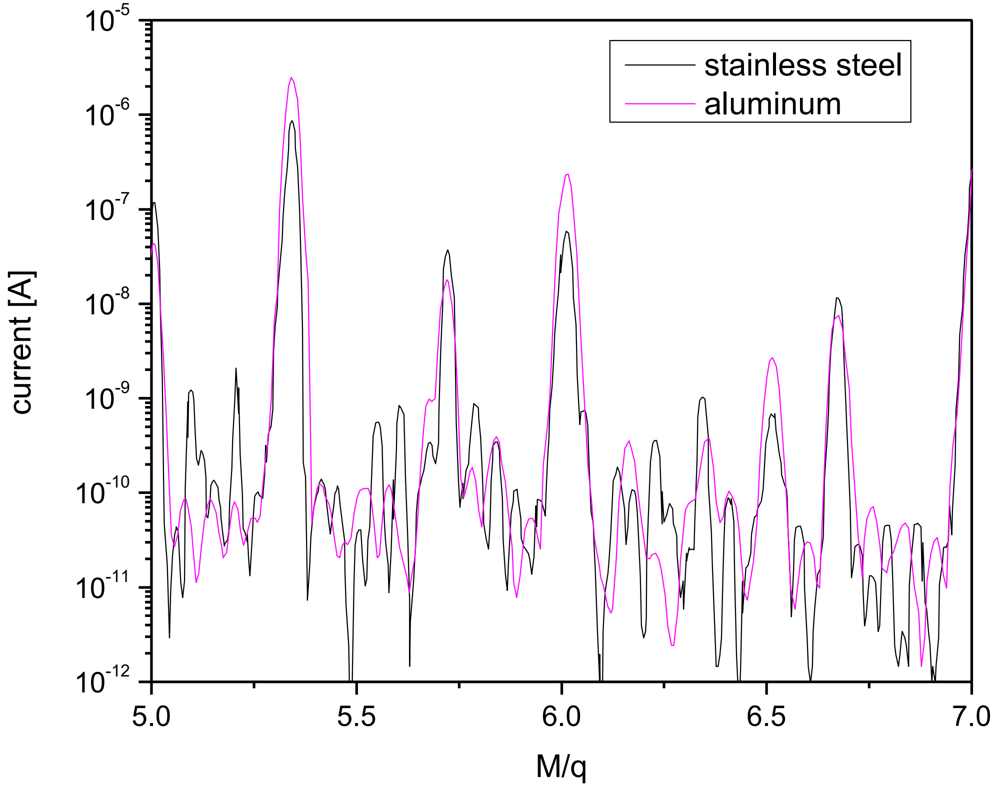
➢ Increase in efficiency up to factor 2
➢ Higher charge states possible
➢ More stable operation

- Improvement of injection

➢ Correction of asymmetry in magnetic field
➢ To be installed within the next few months

→ Joseph Adegun presentation TUA1

ECRIS background



background from residual gas and plasma chamber materials

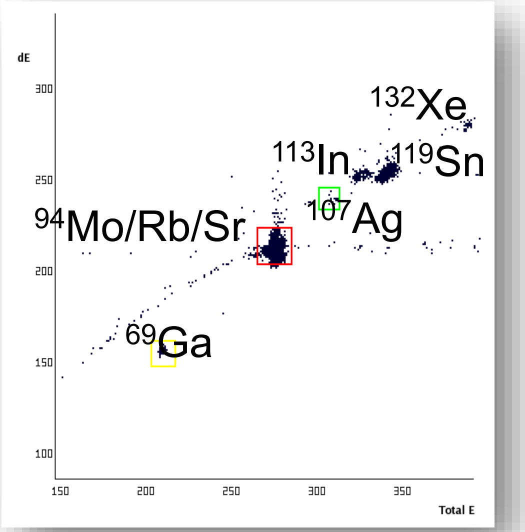
Material has been changed from stainless steel to aluminum

Use additional stripping at 1.5 MeV/u for purification from non isobaric background

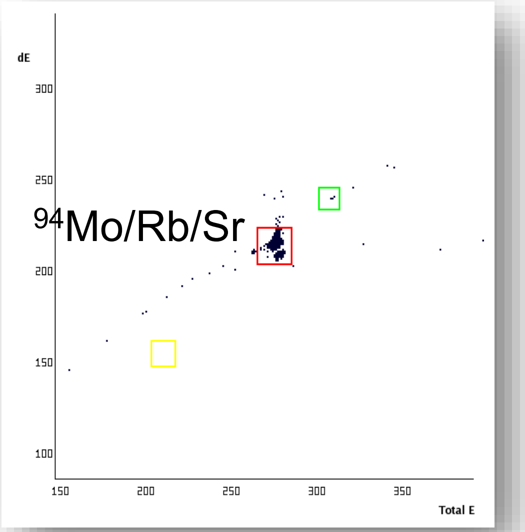
background reduction

using LINAC chain as mass filter (M/ΔM≈1000)
additional stripping at 1.5 MeV/u to $^{94}Rb^{22+}$

Before final filtration



After final filtration



laser ionized ^{94}Sr:
Sr:Rb = 3:1
charge bred to $^{94}Sr^{15+}$
$1 \cdot 10^7$ ions/s (~1.5%)

accelerated and delivered
to TIGRESS experiment

- **Particle ID from ΔE-E after acceleration**

(M. Marchetto et al. proceedings LINAC2012, JACoW.org)

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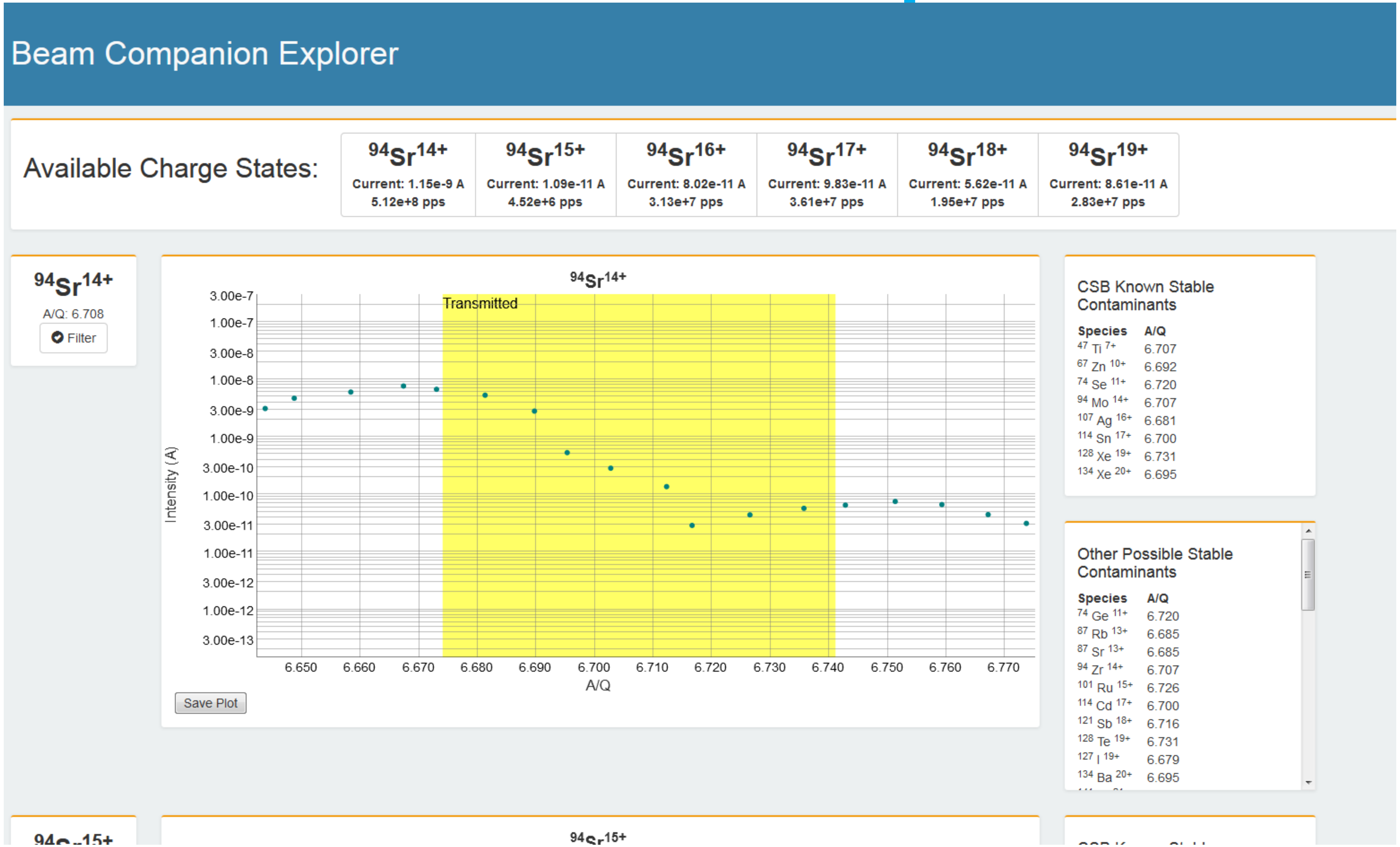
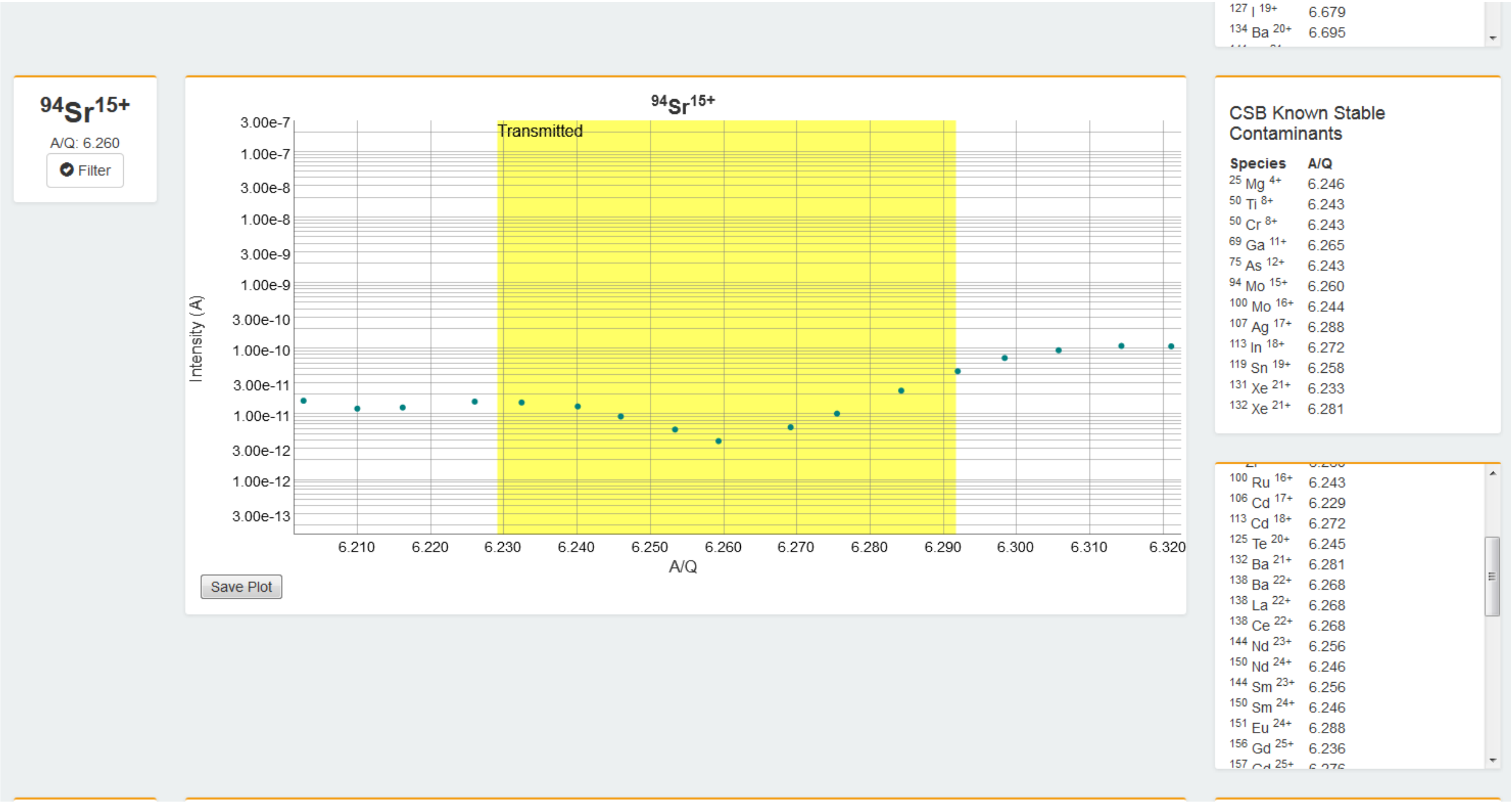
software tools for set-up

example ^{94}Sr

After A/Q selector



software tools for set-up



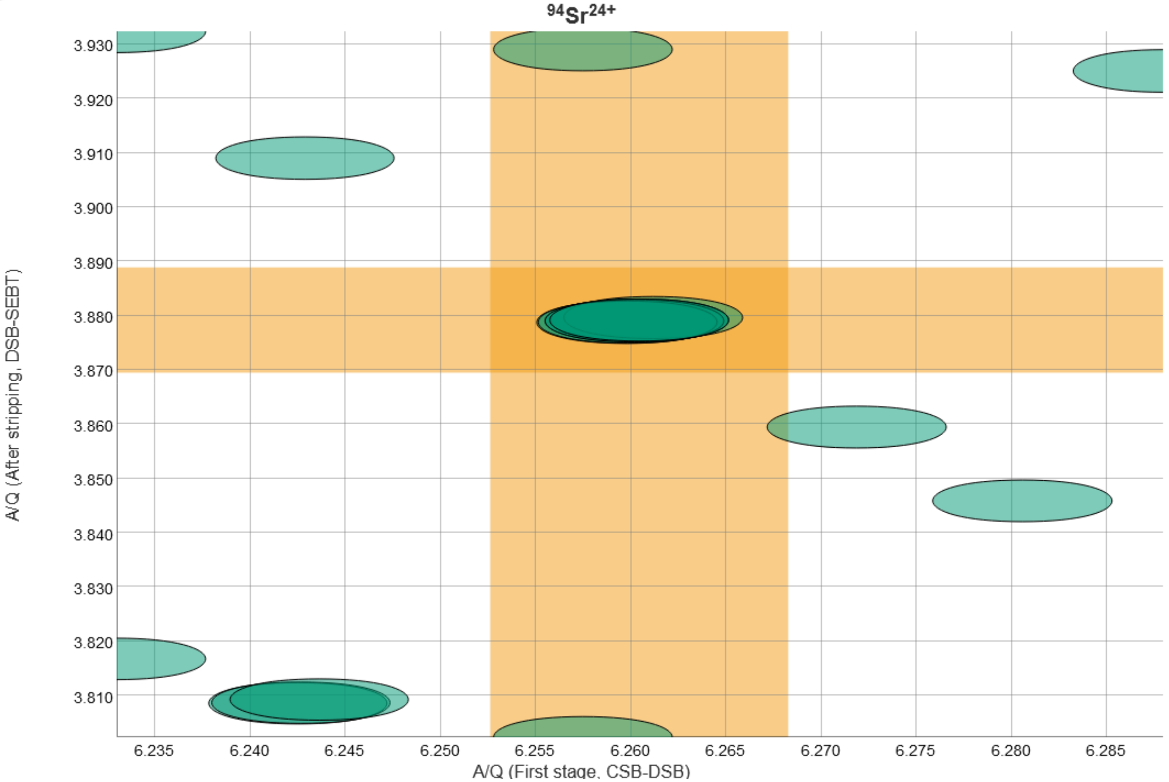
software tools for set-up

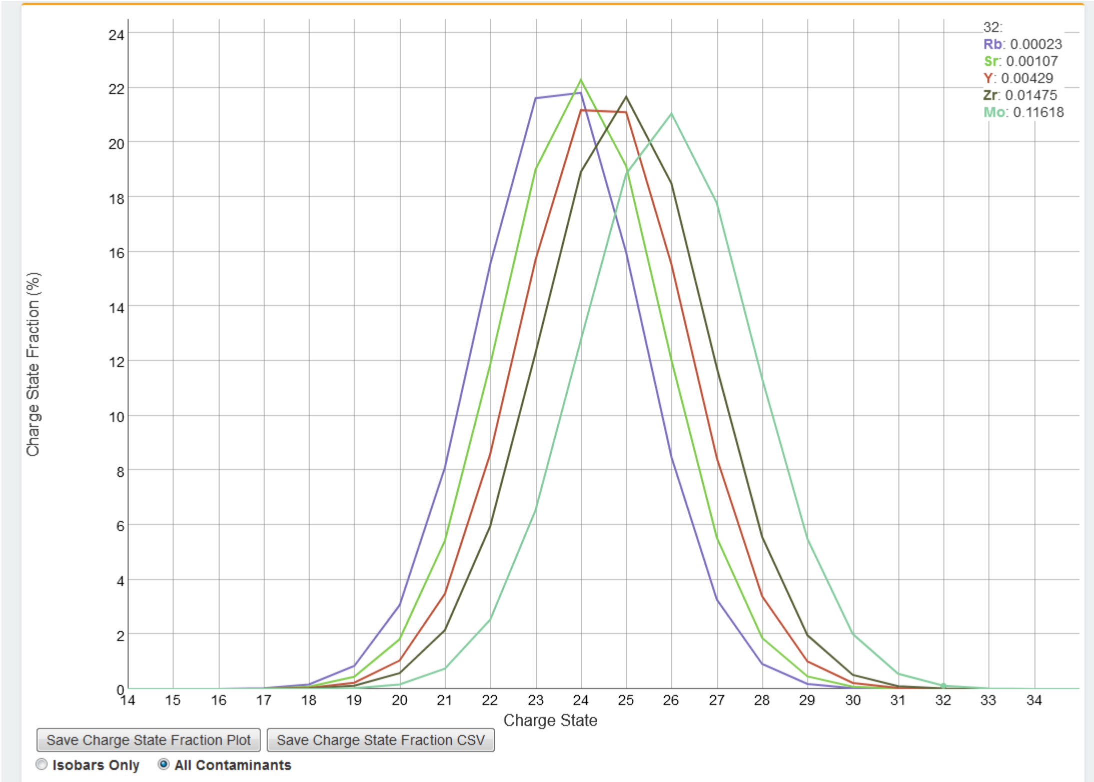
After stripping to 24+ at 1.5 MeV/u, only isobars left

Available Charge States:

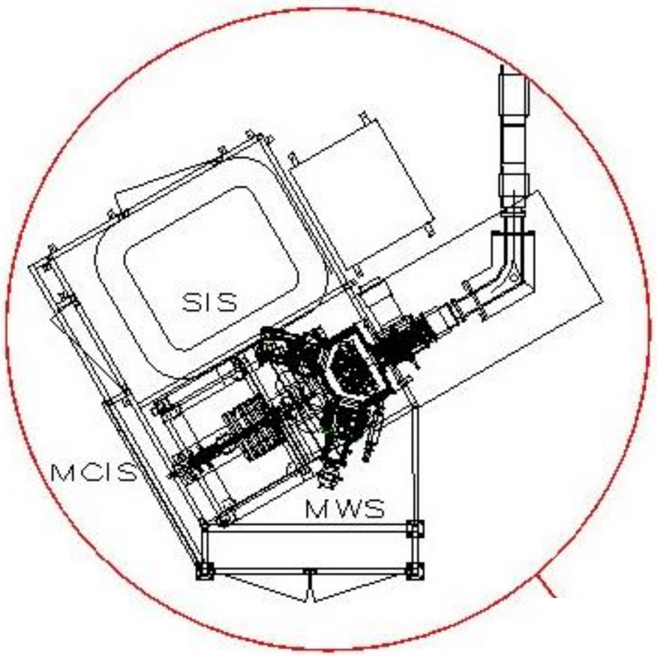
Click to generate plots & companion lists.

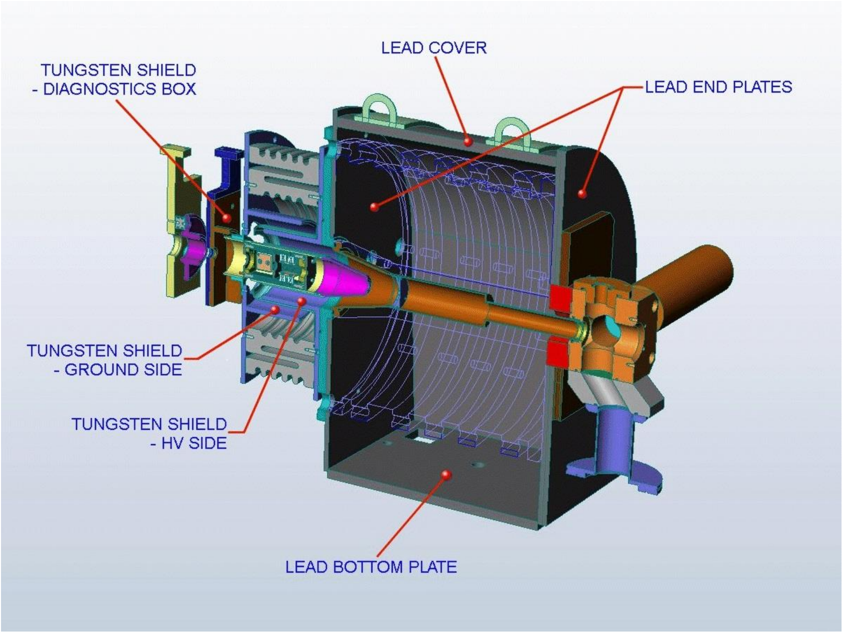
$^{94}Sr^{15+}$	$^{94}Sr^{20+}$	$^{94}Sr^{21+}$	$^{94}Sr^{22+}$	$^{94}Sr^{23+}$	$^{94}Sr^{24+}$	$^{94}Sr^{25+}$	$^{94}Sr^{26+}$	$^{94}Sr^{27+}$	$^{94}Sr^{28+}$
CF: 0.0%	CF: 1.8%	CF: 5.4%	CF: 11.9%	CF: 19.0%	CF: 22.3%	CF: 19.1%	CF: 12.0%	CF: 5.5%	CF: 1.9%





Off-line ion source (OLIS)



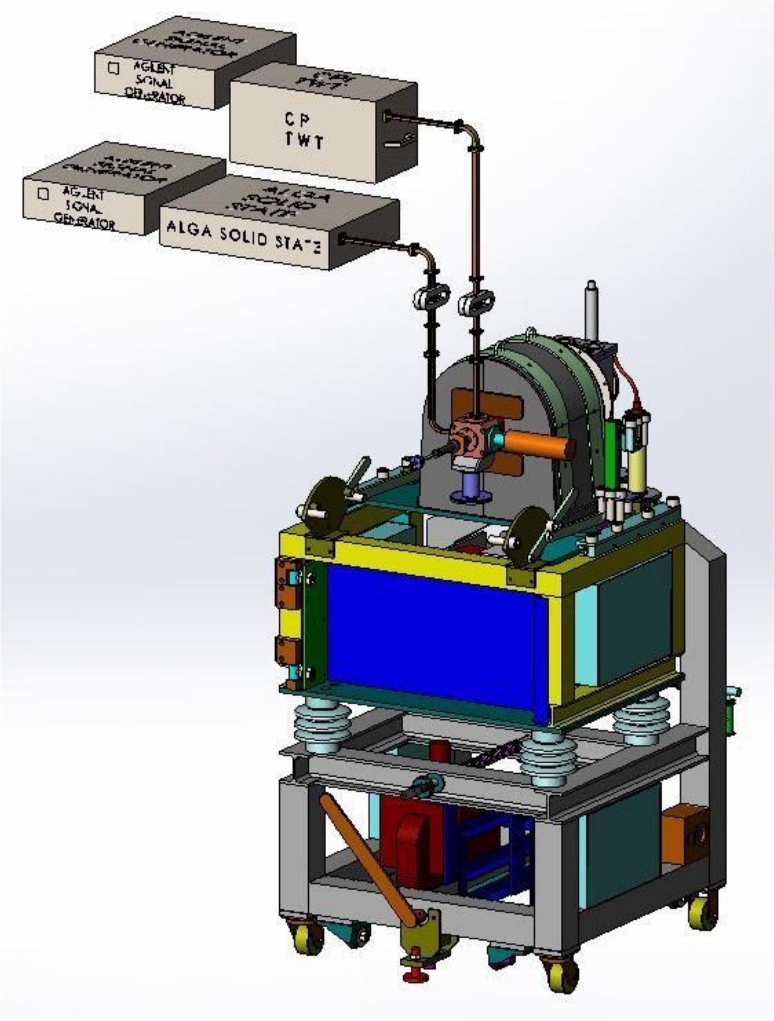


OLIS terminal
- 2.5 GHz plasma ion source
- Surface ion source
- 14.5 GHz SUPERNANOGAN

- Pilot beams for accelerator set-up
- Stable ion beams for experiments

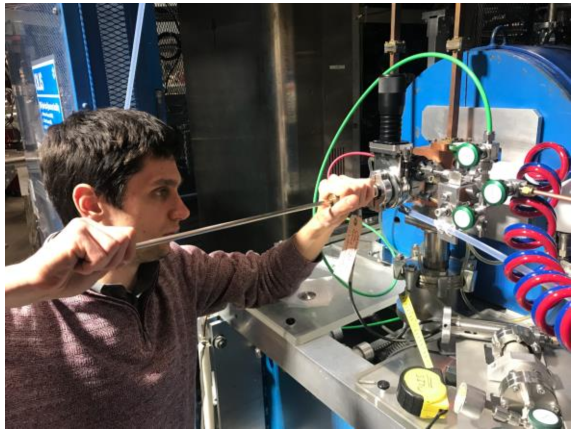
- Current: ~nA to μA
- All elements He to Pb

Multicharge ion source (MCIS) SUPERNANOGAN

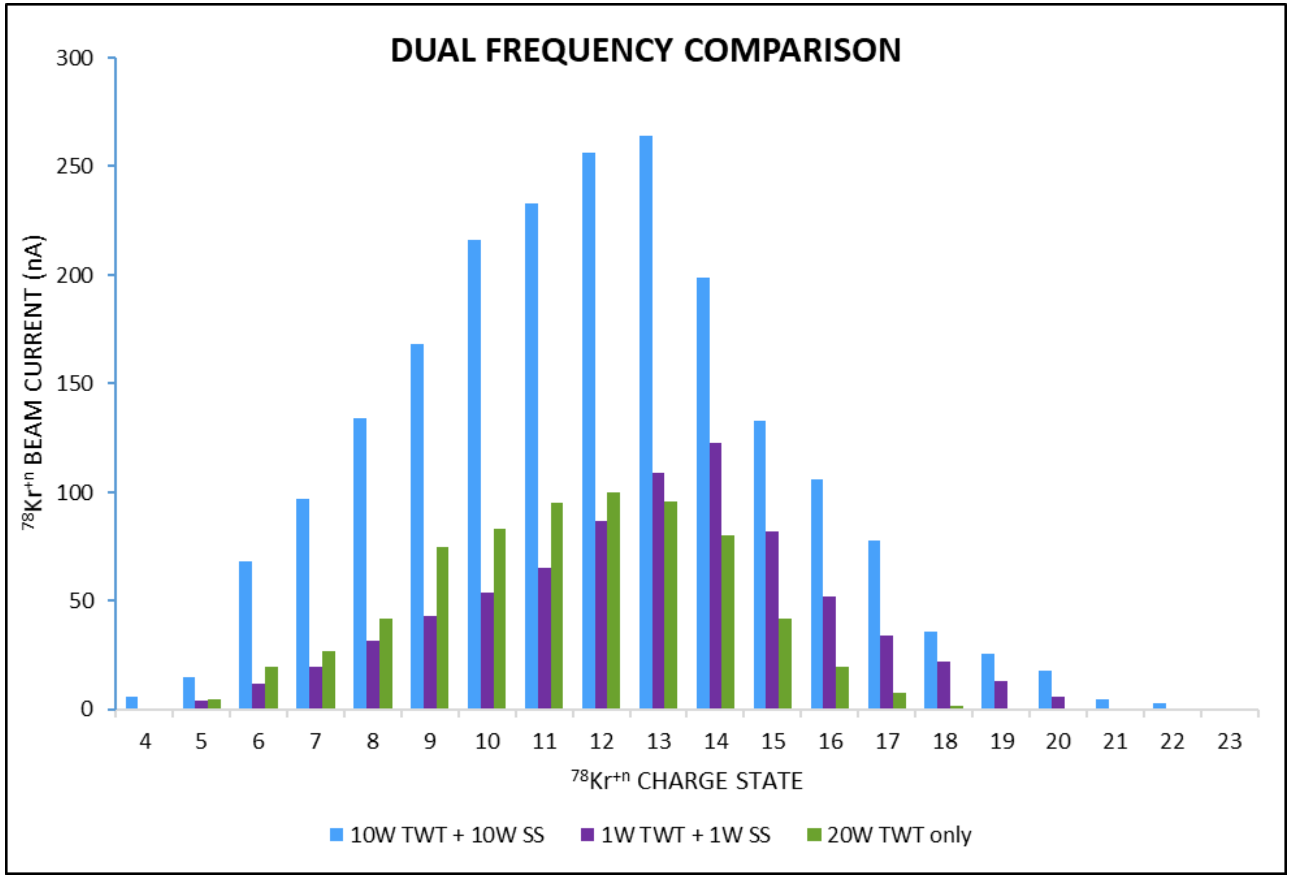


- Dual frequency heating 12.75GHz to 14.5 GHz
  - TWT up to 400 W solid state up to 50 W

- Mobile design
  - Allows preparing and conditioning while other sources are operating
- Material injection
  - Gas
  - Oven
  - Sputter target



DUAL frequency heating result



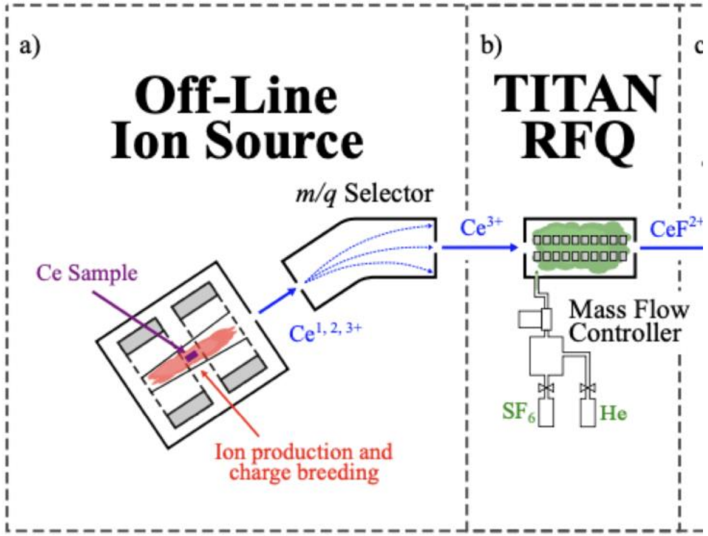
^{78}Kr

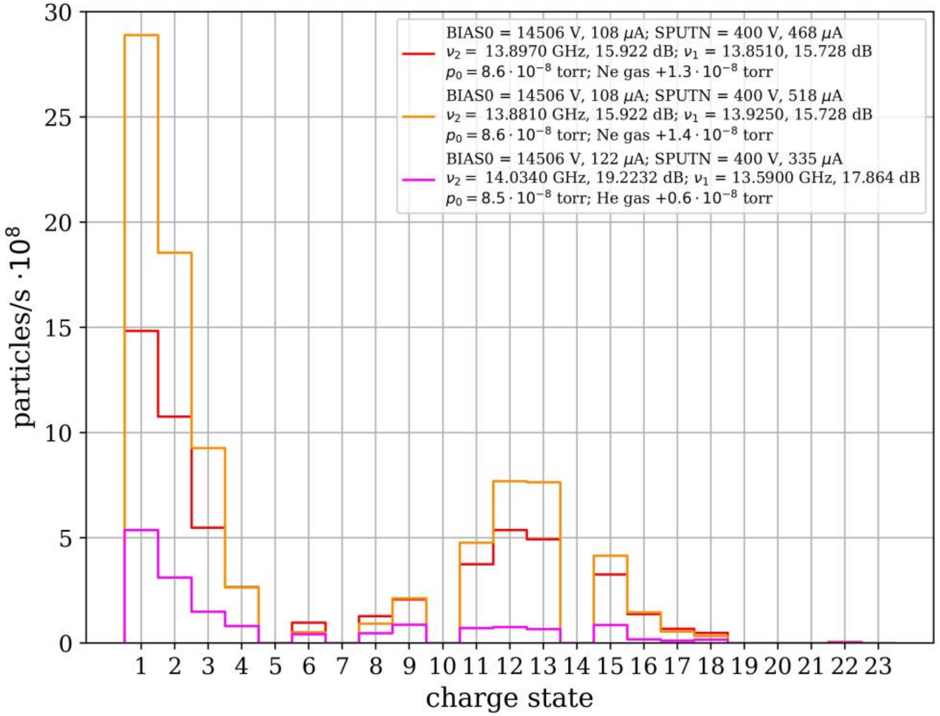
Blue: Single frequency 12.98GHz at 20W
Green: Dual frequency 12.98GHz and 13.78GHz at 1 W each.
Purple: Dual frequency 12.98GHz and 13.76GHz at 20 W each.

K. Jayamanna et al. J. Phys. Conf. Ser. 2743, 12053 (2024)

Lanthanide beam development (^{140}Ce)

- ^{140}Ce as ^{232}Th analog for radioactive molecular beams
  - Sputtered Ce-metal strip in Ne, Ar, CO_2 support gases.
  - Operated MCIS at higher gas-pressures to favour $^{140}Ce^{+1+2+3}$





Charge state distributions at different Ne pressure
P. Justus et al. J. Phys Conf Ser. 2743, 012055 (2024)

Summary:

- ECR charge state breeder for radioactive ions at ISAC operational since 2008
  - isotopes from more than 15 elements have been charge bred so far
  - range of ions charge bred for acceleration: ^{21}Na – ^{160}Er
  - efficiency 1-7%

  - problems:
  - high background

  - Ongoing developments:
  - implementing 2 frequency heating and improving injection/ extraction optics
    → higher efficiency, higher charge states, more stable operation
  - investigating "off-line" operation for long lived isotopes

- ECR off-line ion source
  - Versatile to produce ions of many elements and charge states

  - Ongoing developments:
  - Extraction optics change to 2 step acceleration
    → higher flexibility in beam energy, reduced losses in beam transport

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Thank you
Merci

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