Radioactive Ion Beams at TRIUMF:
Status and Perspectives

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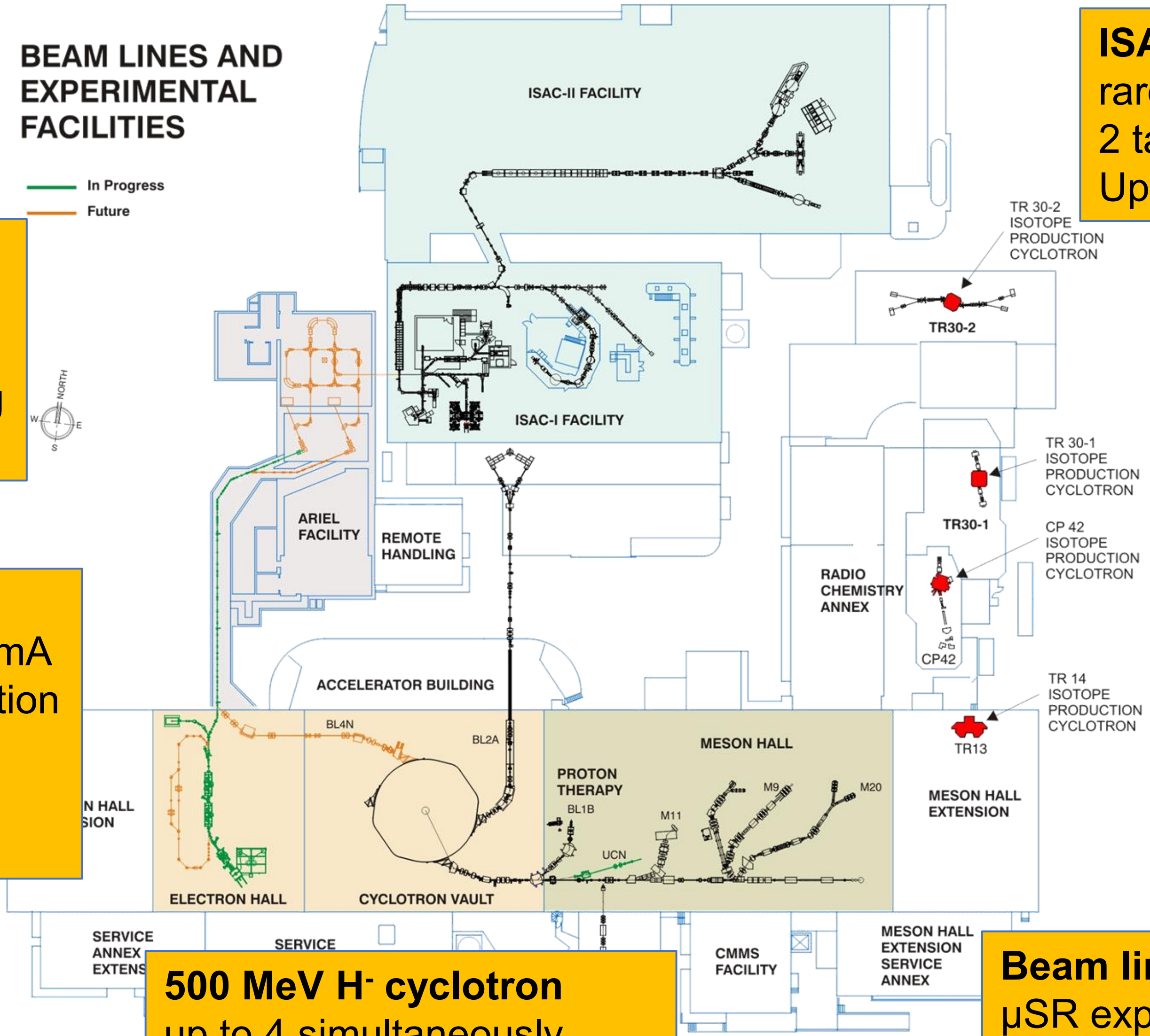
HIAT2022, June 27, 2022

Discovery, accelerated

outline

- Introduction
- rare isotopes production at ISAC
- rare isotope accelerated beams
- new opportunities with ARIEL and CANREB



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

CANREB
high resolution
mass separation
charge state breeding

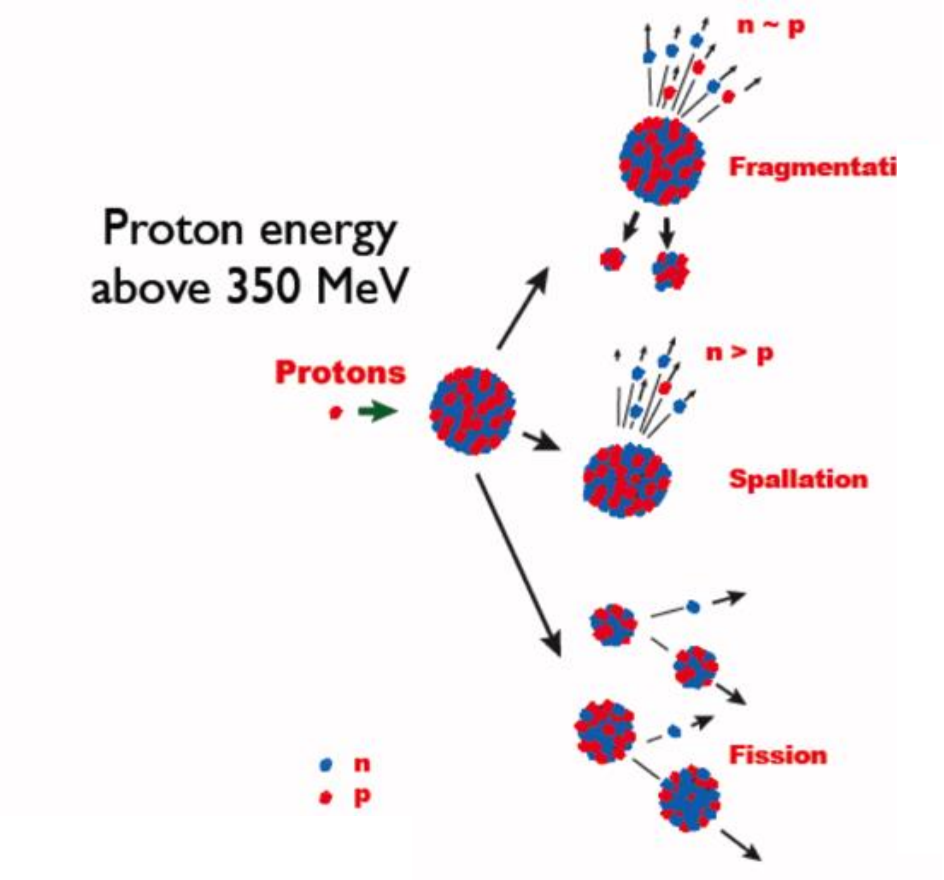
4 cyclotrons 13-30 MeV
for medical isotope production
(BWTX)

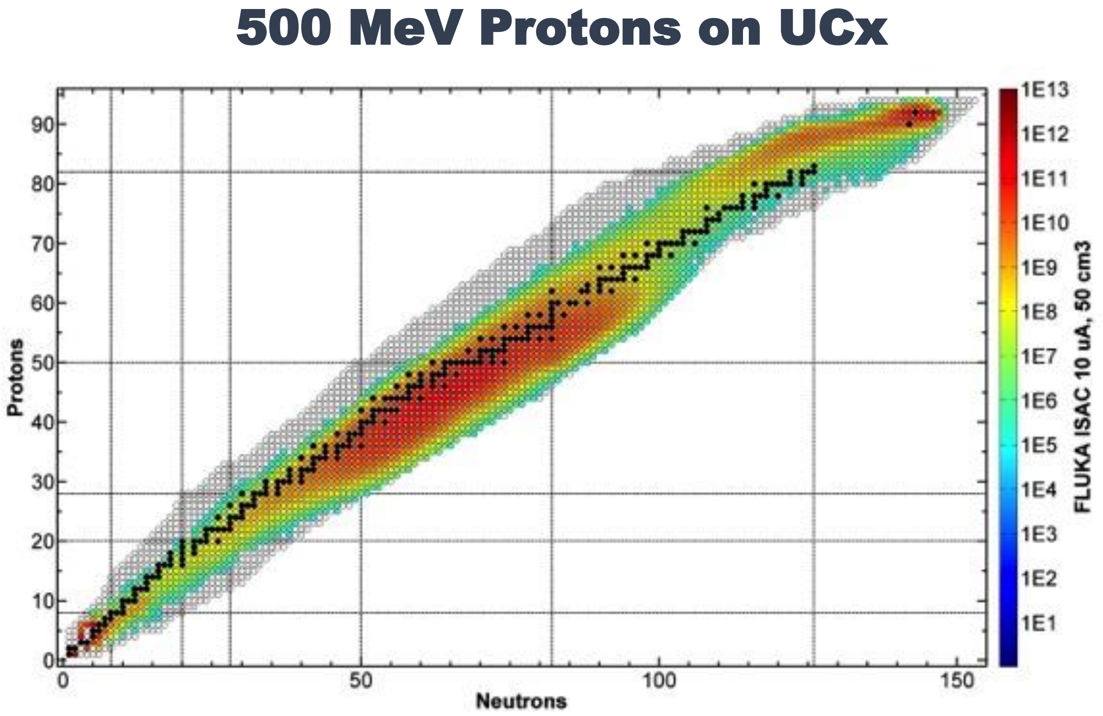
ARIEL
e-linac 30 MeV 10 mA
e^- and p^+ target station
for rare isotope
beam production

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)

Rare Isotope production with proton beam driver





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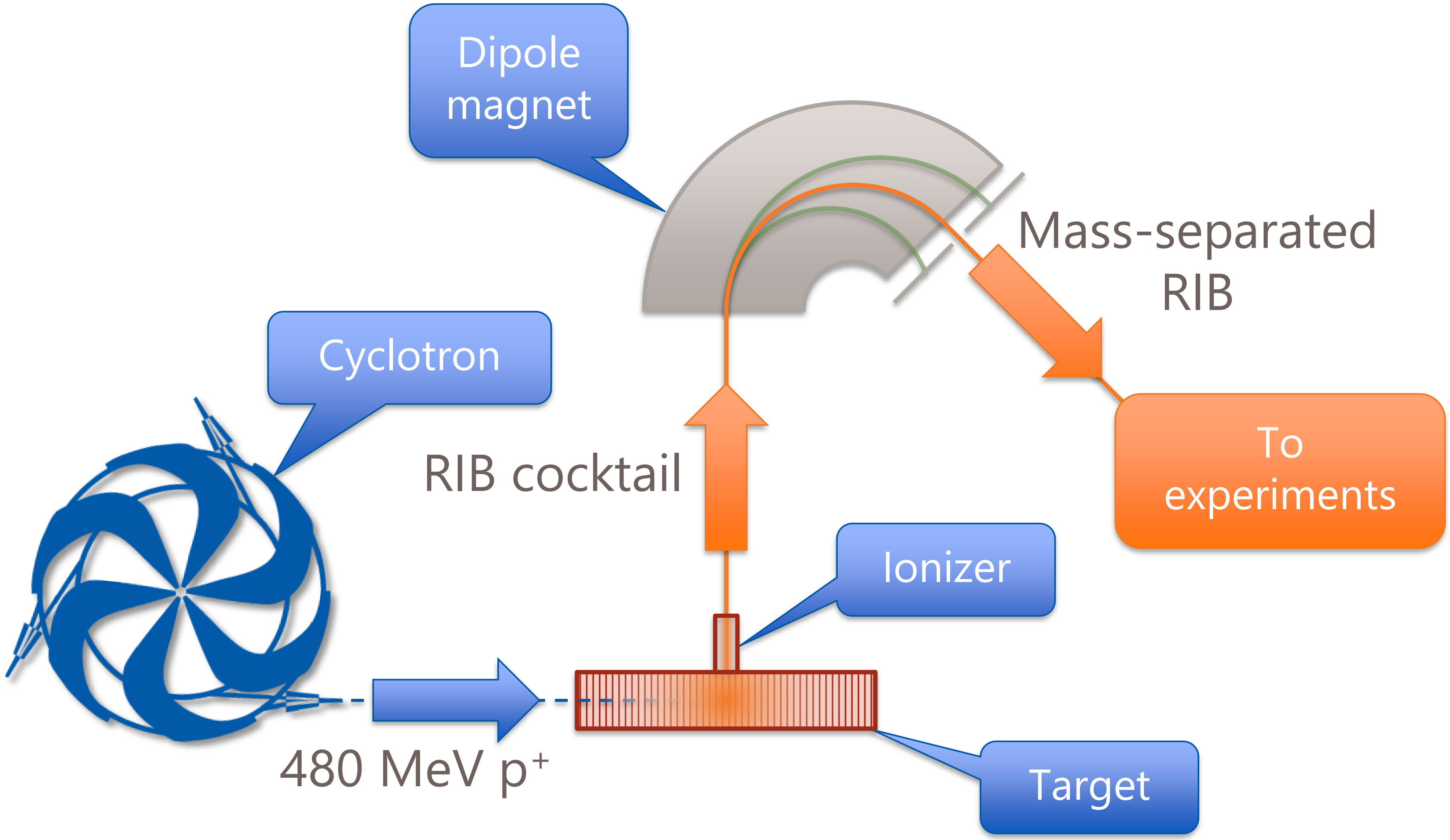
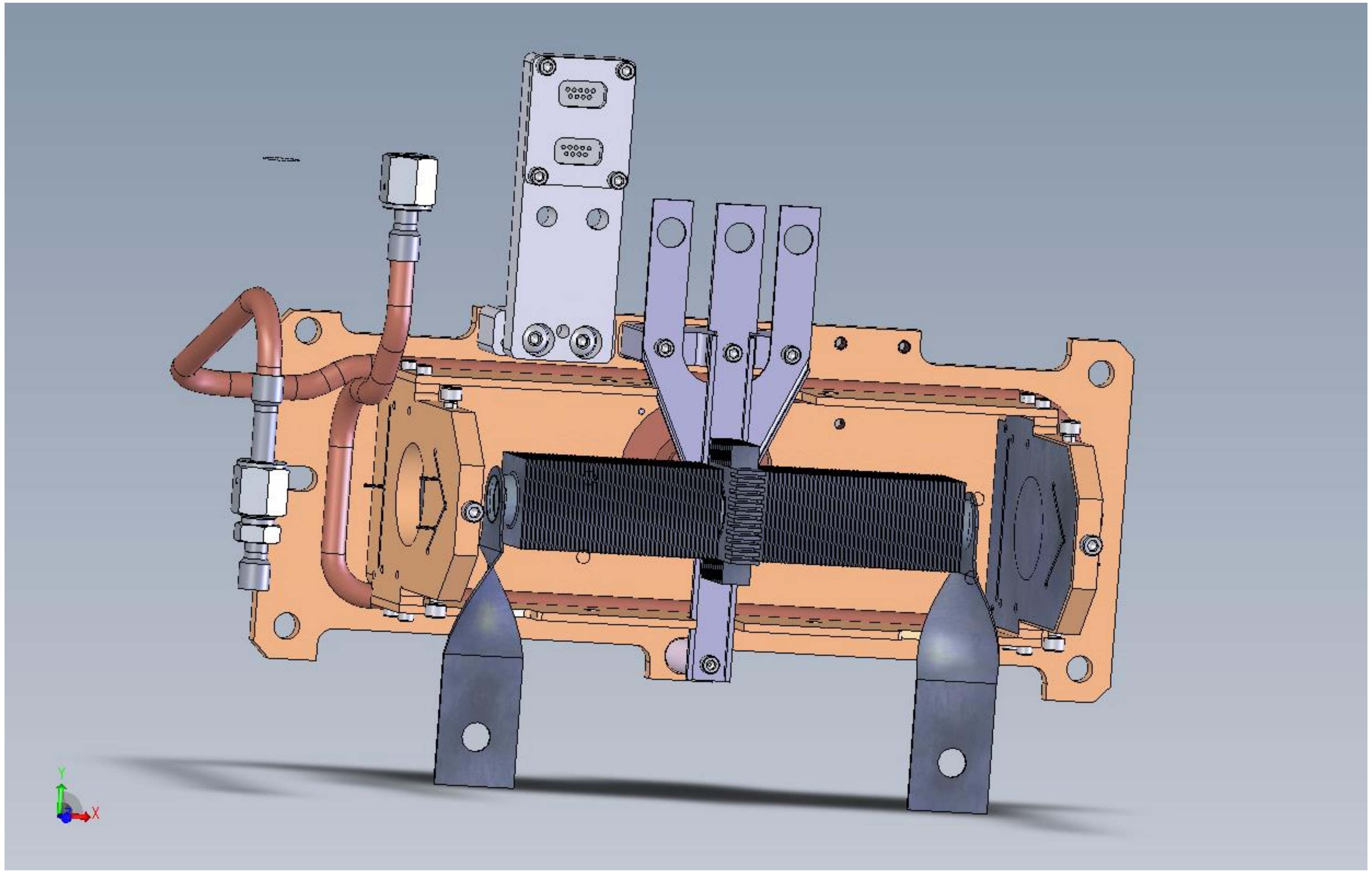
Isotope Separation On-Line (ISOL)



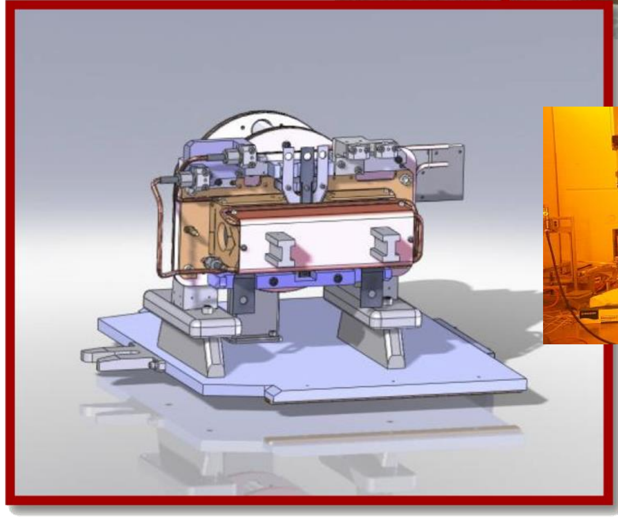
ISAC target assembly

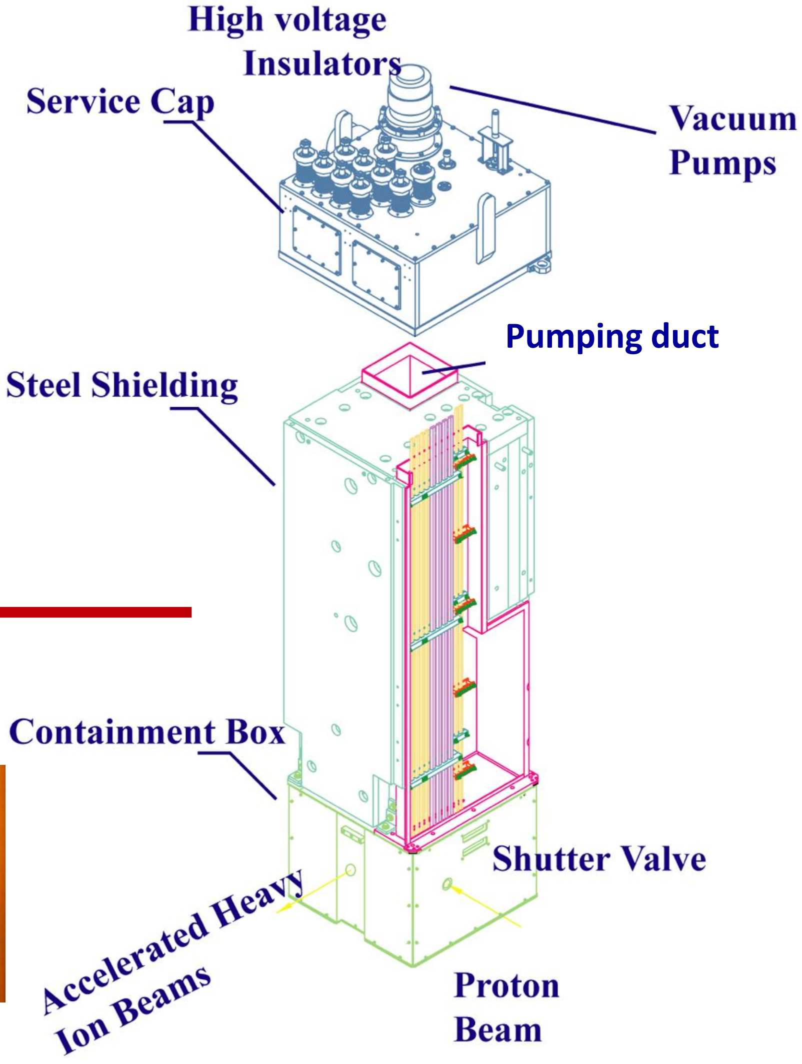


high power

up to 100 μ A

ISAC target station





- target at bottom of shield plug
- no rad. sensitive components near to target
- remote manipulations with crane and in hot-cell

- 2 target stations

  one operating while target exchange on other one

- maximum proton current

  100 μA @ 500 MeV

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Target materials

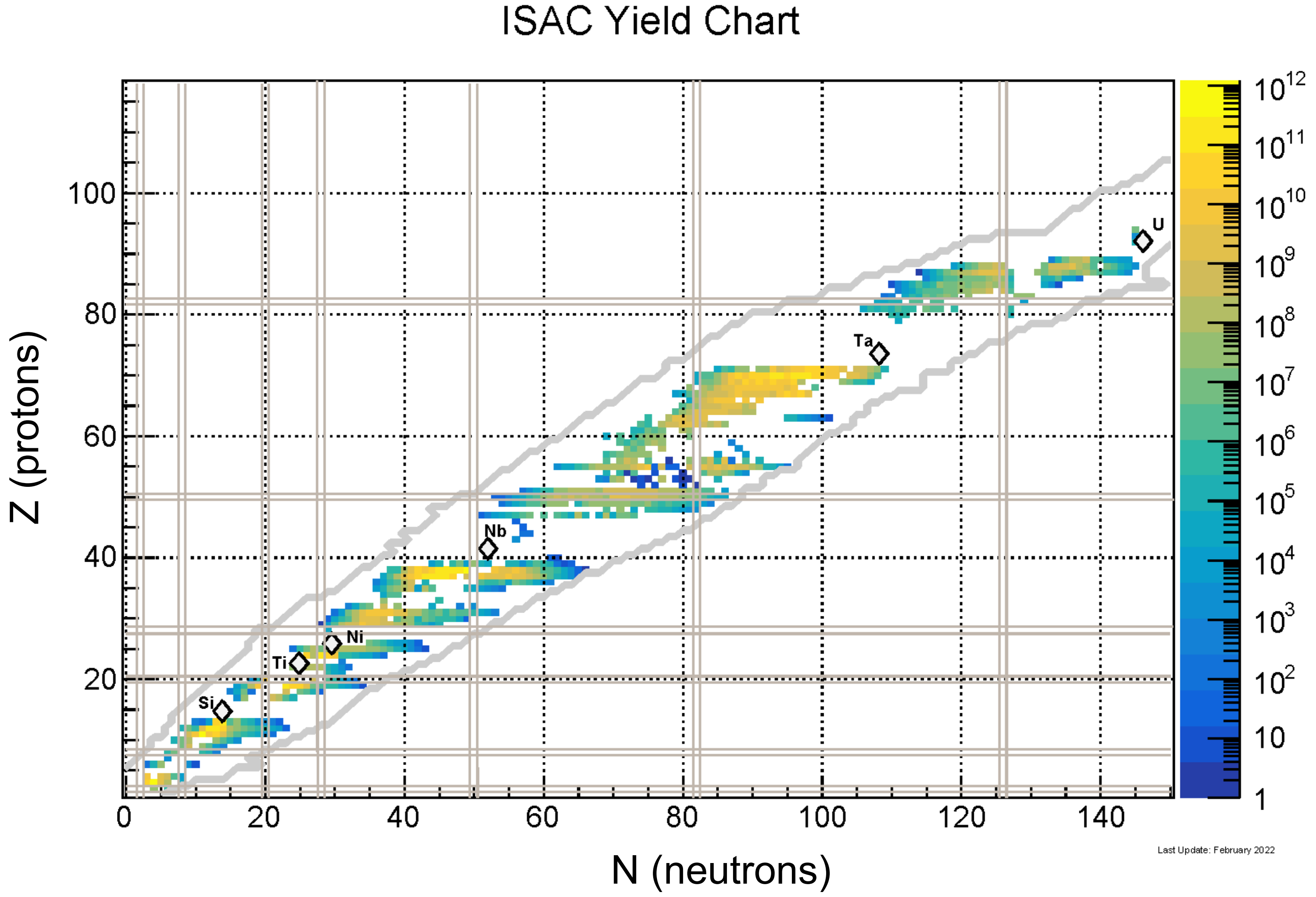
Material	LP SIS	LP FEBIAD	HP SIS	HP FEBIAD	ECRIS	LP IGLIS	total
Al_2O_3				1			1
SiC	14		10	11	1	2	38
CaO	2						2
CaZrO	1				1		2
TiC	3			1			4
NiO				2			2
Nb	5		4				9
Nb_5SiC_3	1						1
ZrC	5		1	2			8
Ta	35		27		1		63
TaC	1						1
UO	1	2					3
UCx	26			1		6	33
Ucx(p2n)			2				2
C			3				3

ISAC targets
1998-2021

Total 173

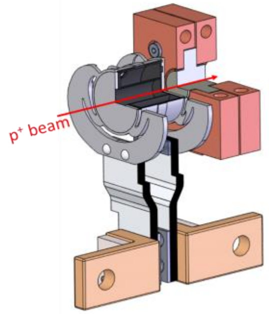
~10 targets/year

isotopes produced at ISAC

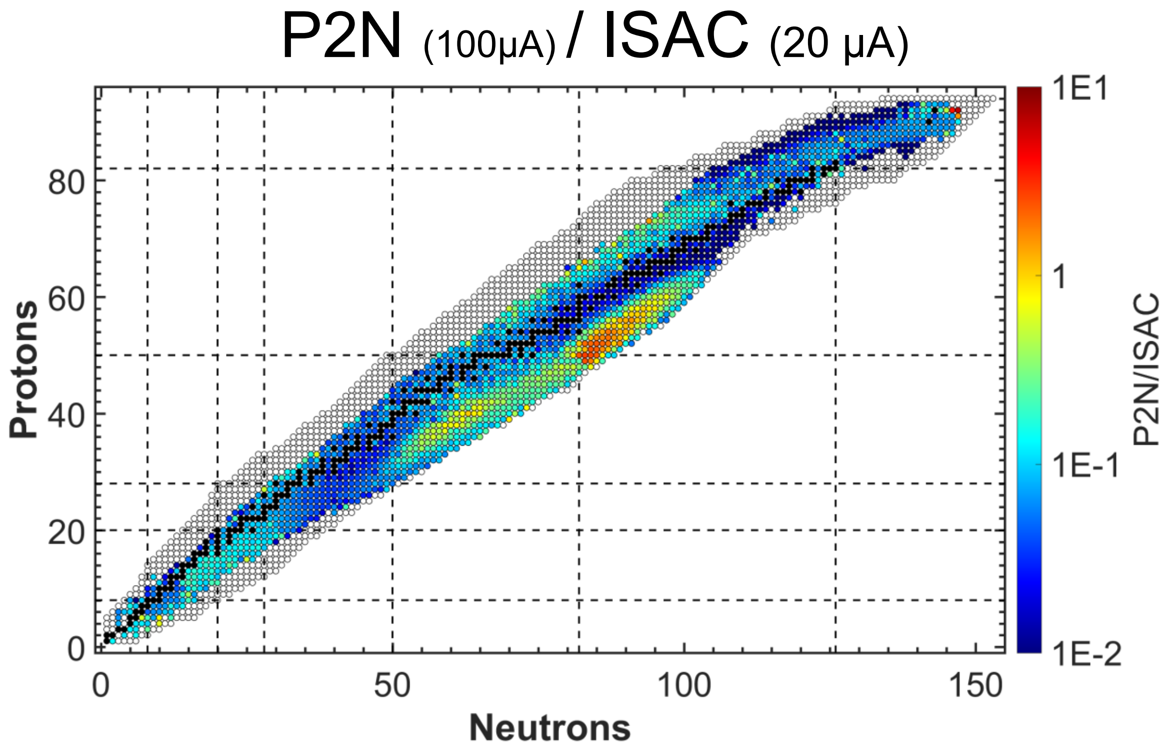


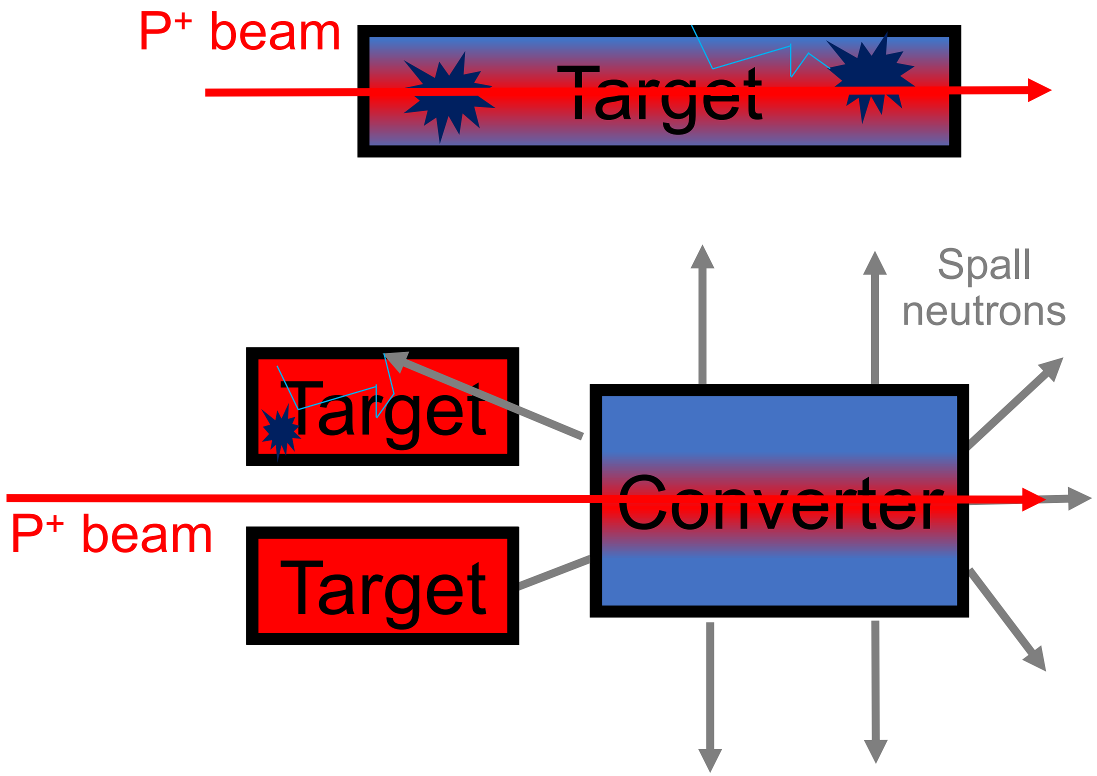
for more details, please check https://yield.targets.triumf.ca/search/yield/data P. Kunz

Proton to neutron (p2n) converter target



- produce comparable n-rich isotopes to standard UC_x ISAC targets
- suppress the n-deficient isobaric contamination by x10 or more
- exploit the full proton beam intensity from the TRIUMF cyclotron

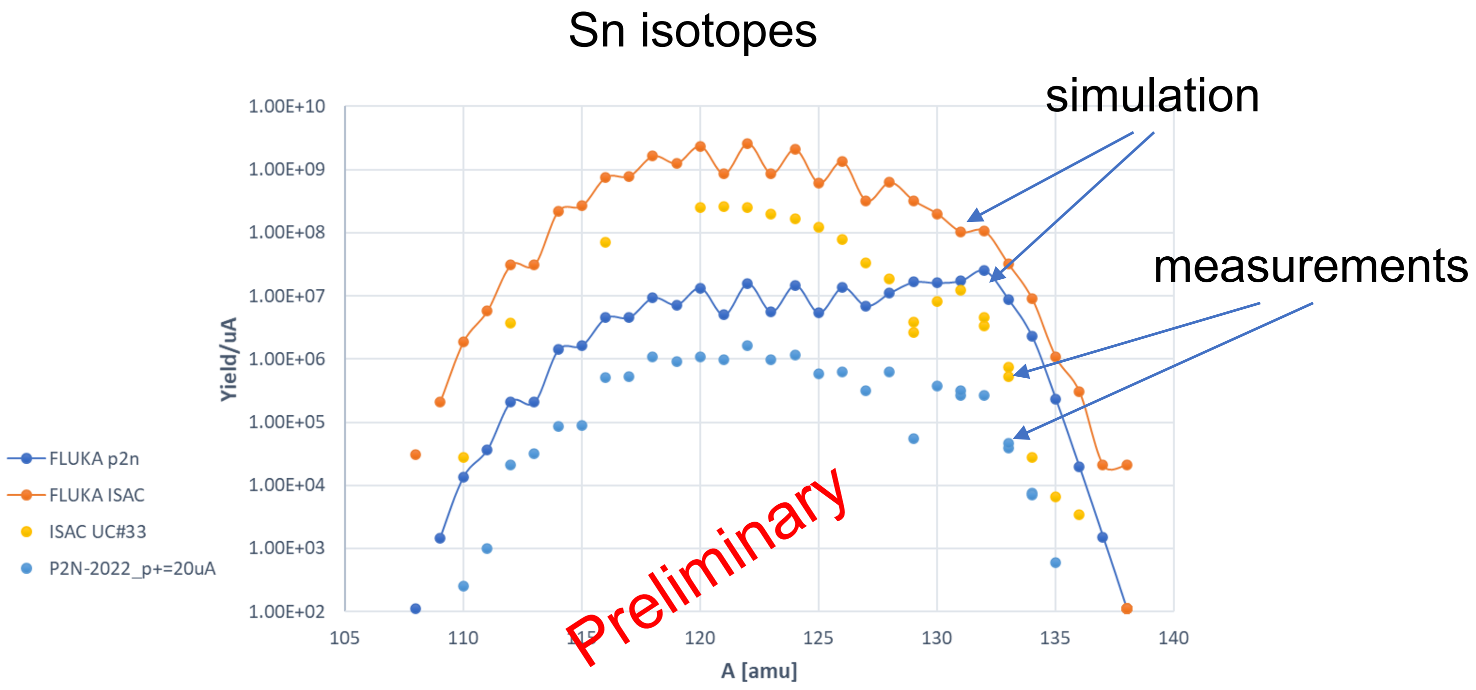




L. Egoriti

Results from two p2n targets

- ✓ Elements extracted: Rb, Cs, Sn, Zn, Ga, Na, Fr, Ra
- ✓ Max proton intensity on P2N: 80 μA → yields shown normalized *per μA of protons*
- ✓ Yields linearly proportional to proton beam intensity
- ✓ Higher purity: p-rich from the same chain reduced by **5x – 50x** with respect to previous ISAC-UCx targets



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post acceleration

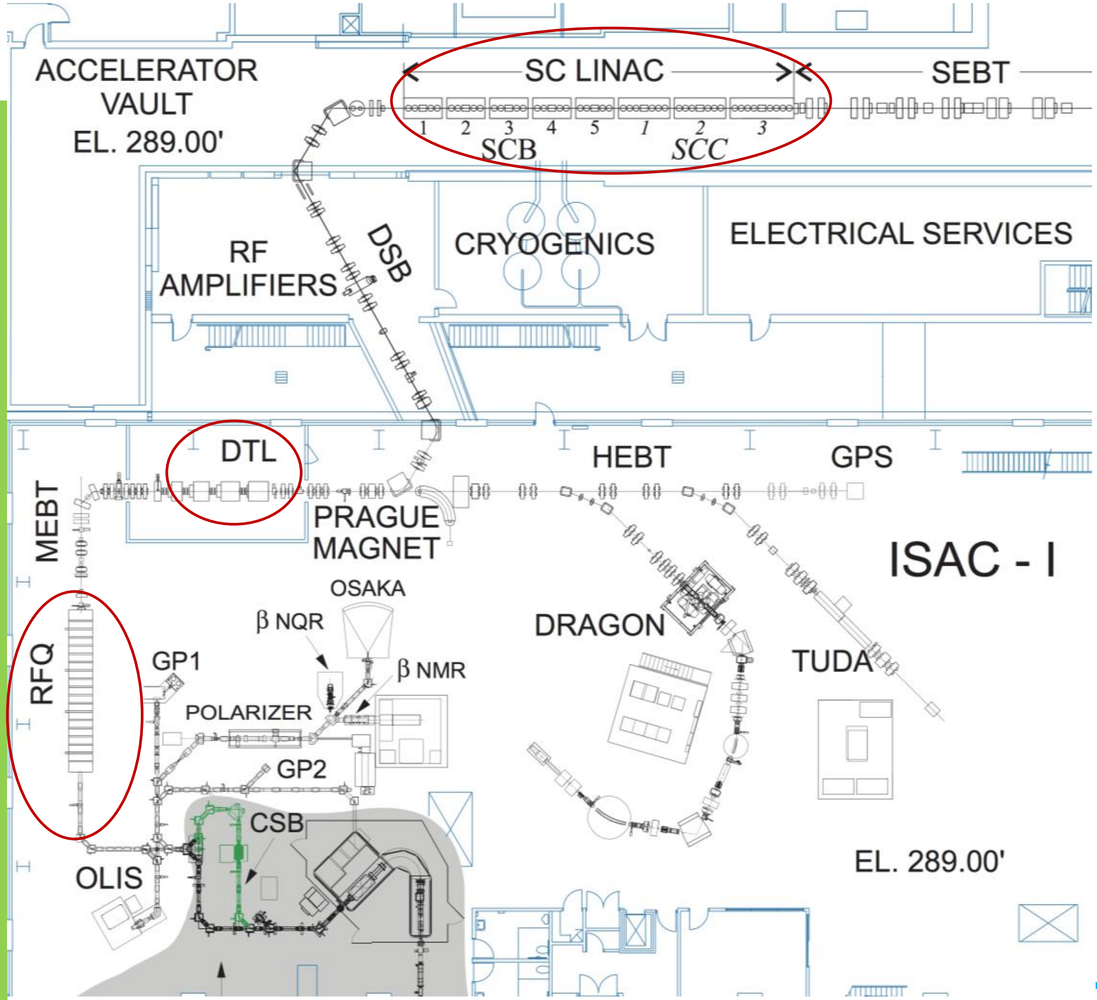
ISAC accelerator chain

• **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

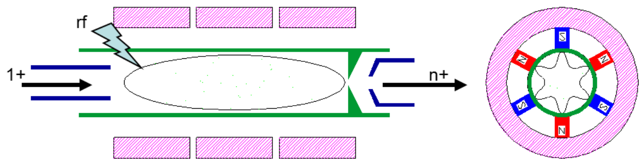
A/q < 30 injection of 1+ ions, stripping after RFQ
A/q > 30 charge state breeding to A/q <7
stripping after DTL for higher energy or purification



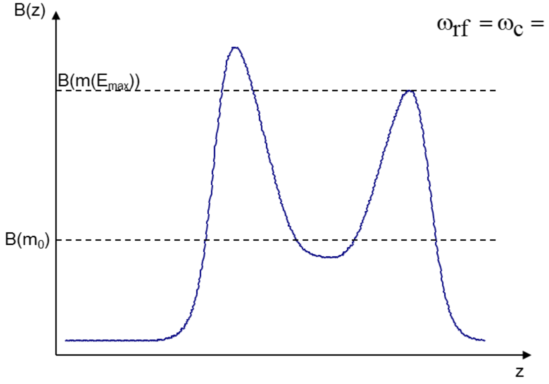
charge state breeding

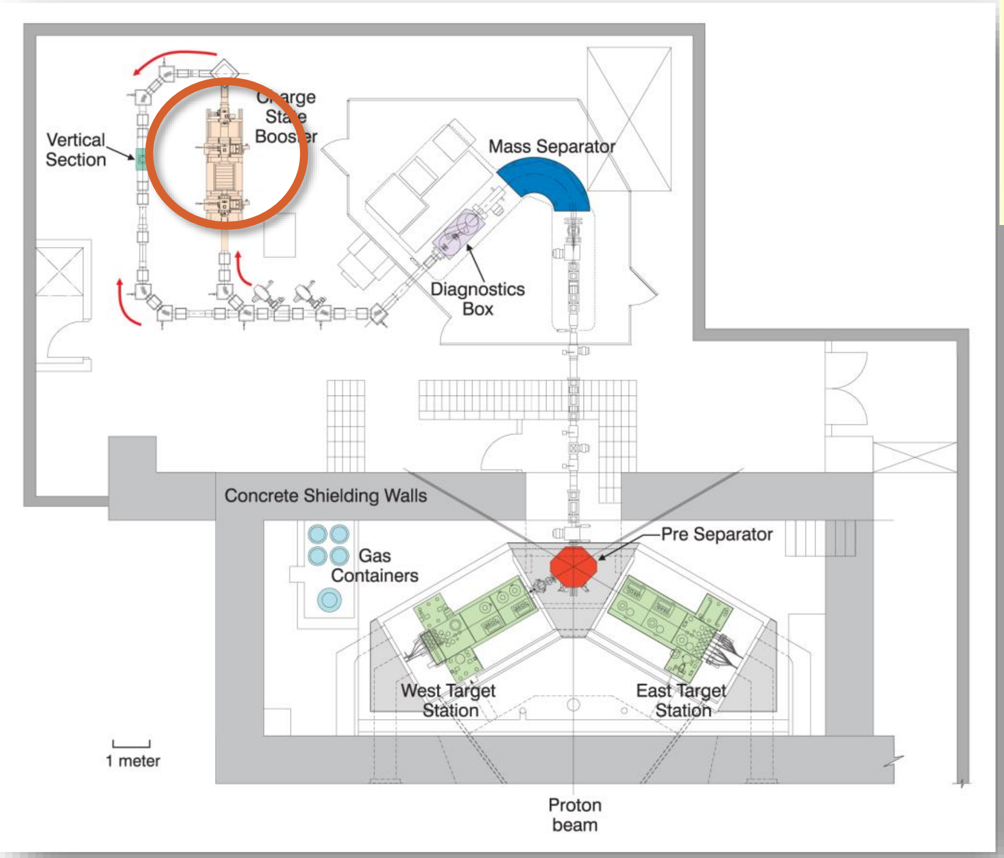
charge state breeding with an ECR ion source
14.5 GHz PHOENIX from Pantechnik

• continuous beam



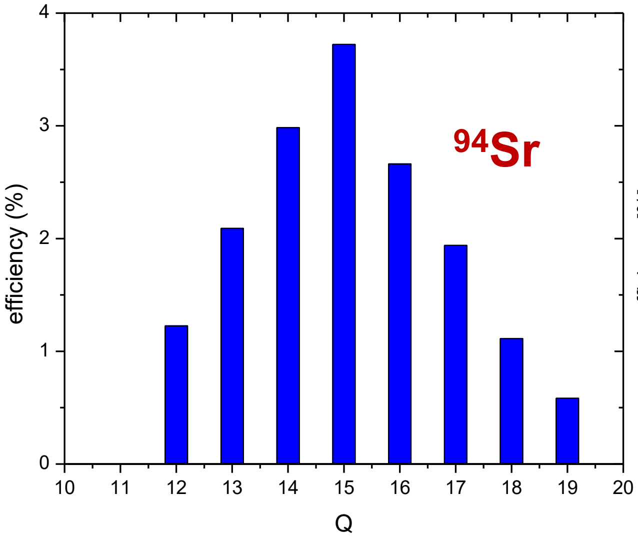
$$\omega_{rf} = \omega_c = \frac{q}{m(E)} B$$

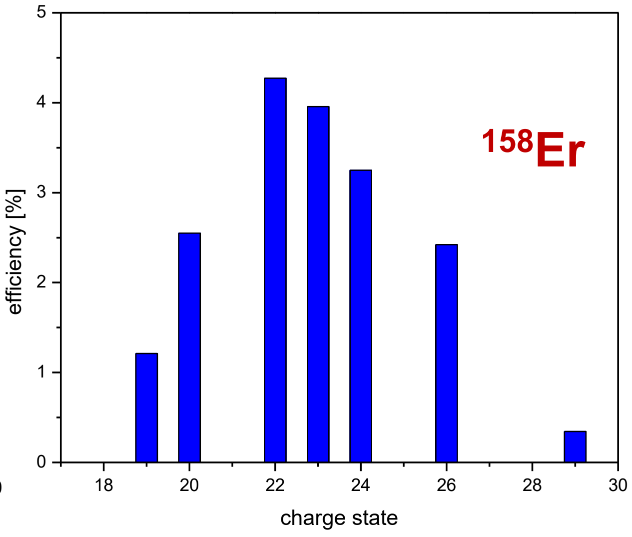


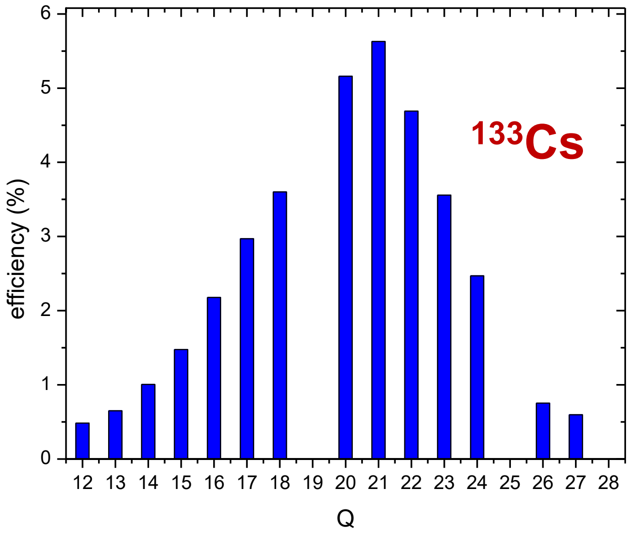


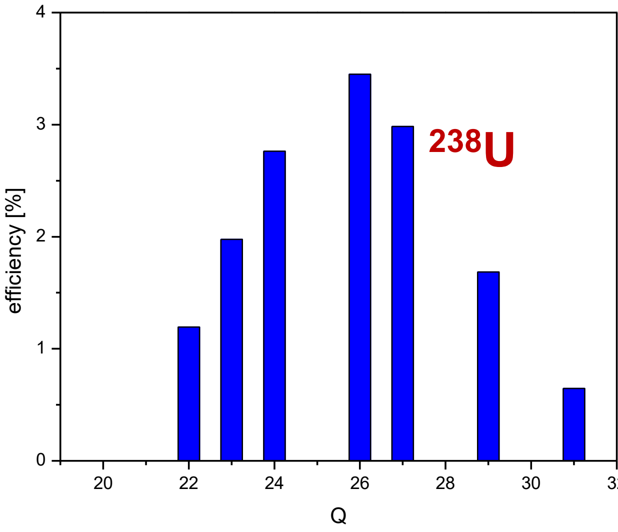
charge state breeding results

efficiency and charge state distribution







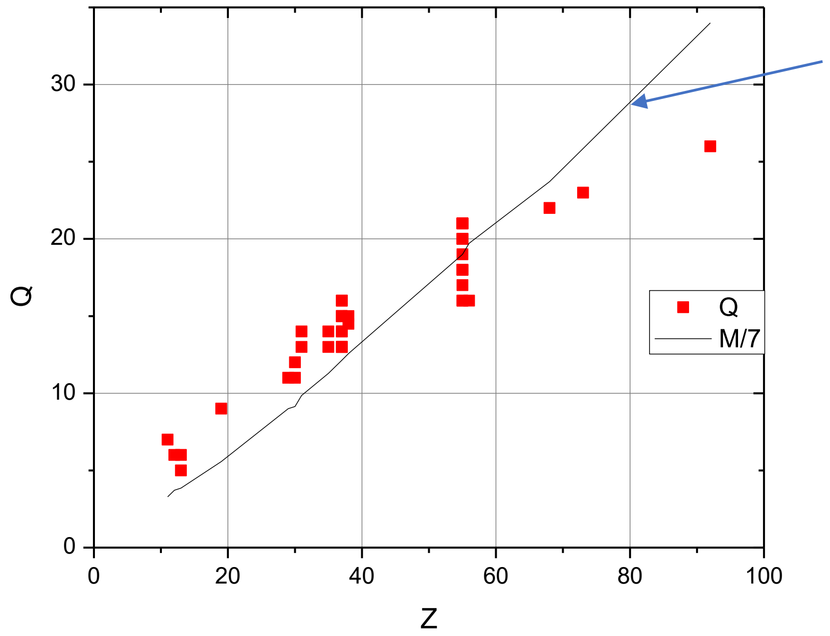


radioactive ions from on-line ion source
total efficiency >17%

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

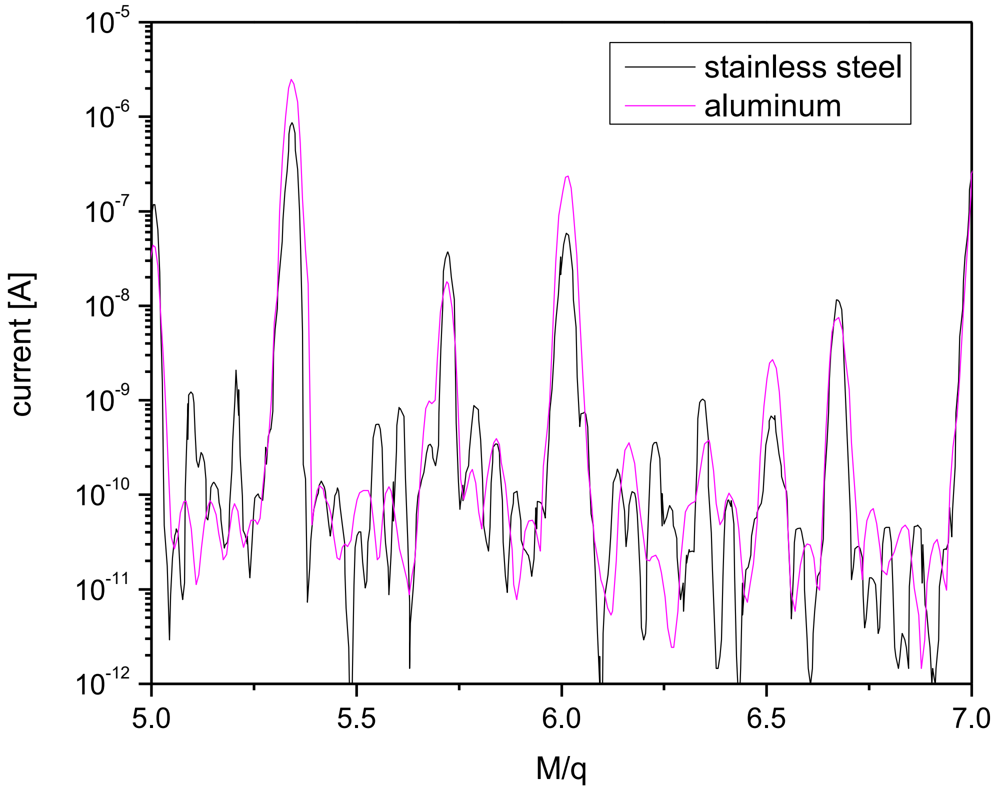
charge state breeding results

maximum of charge state distribution for Na to U



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

ECRIS background



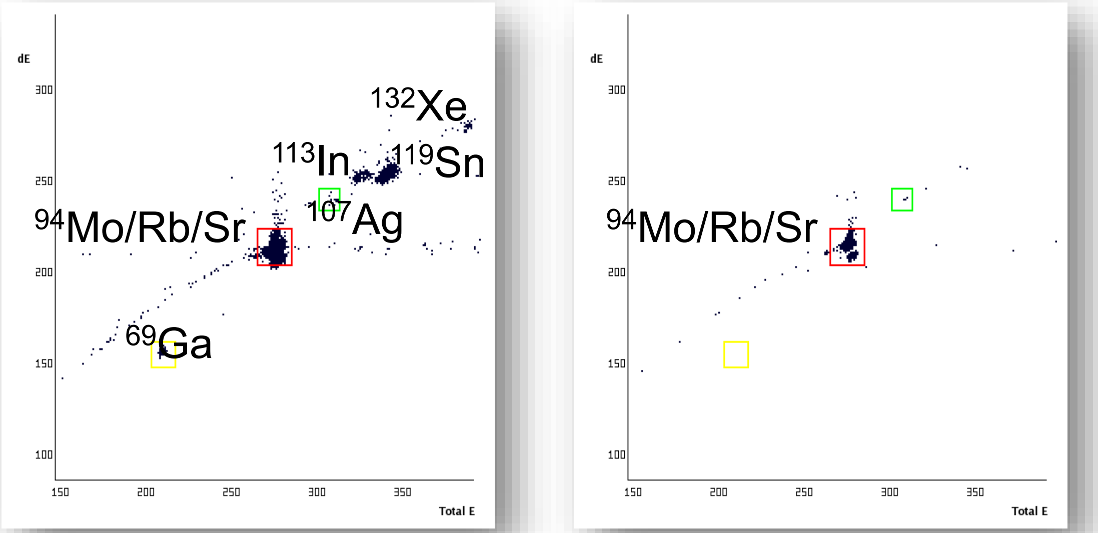
background from residual gas and plasma chamber materials

Material has been changed from stainless steel to aluminum

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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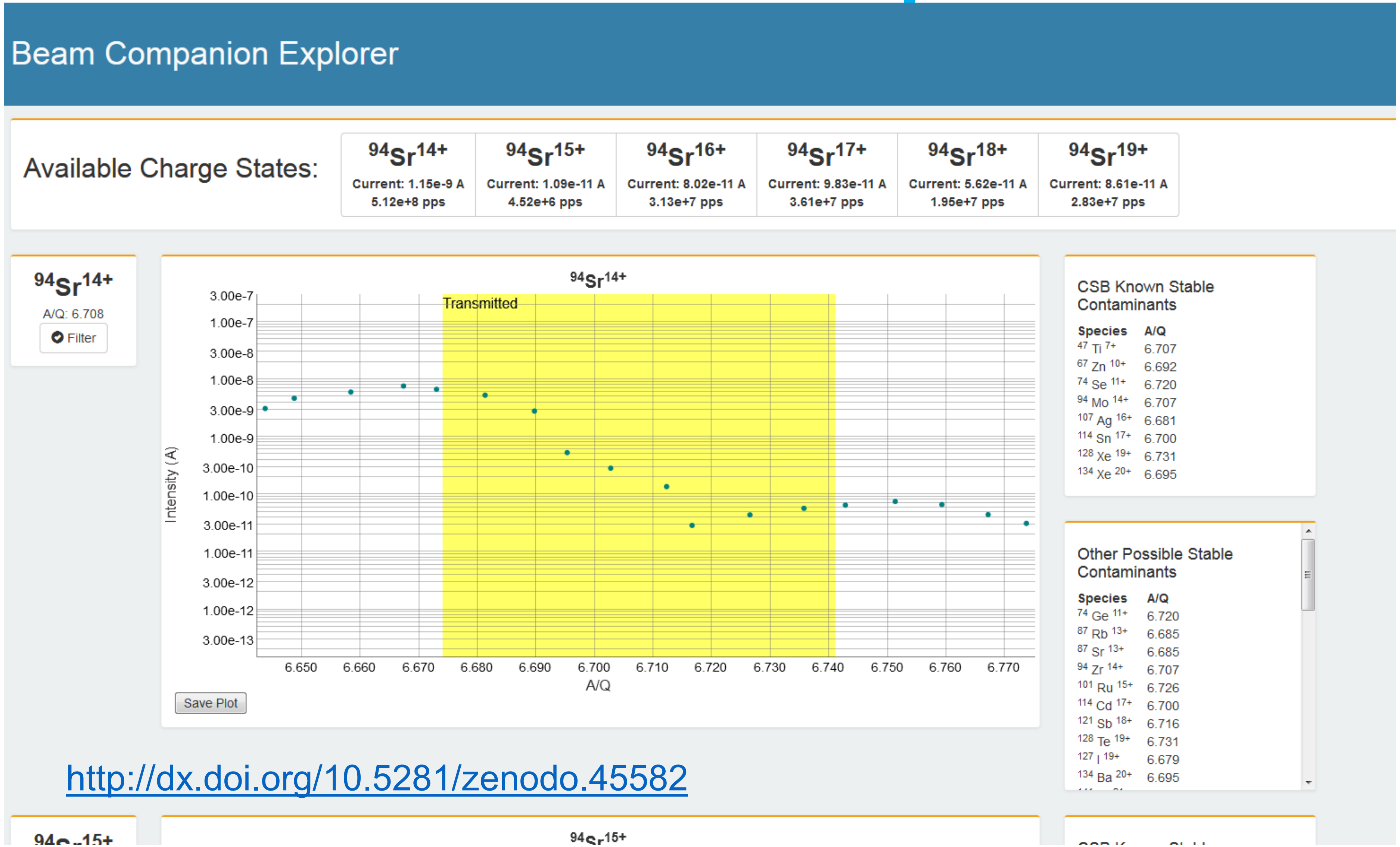
software tools for set-up

example ^{94}Sr



http://dx.doi.org/10.5281/zenodo.45582

Discovery, accelerated

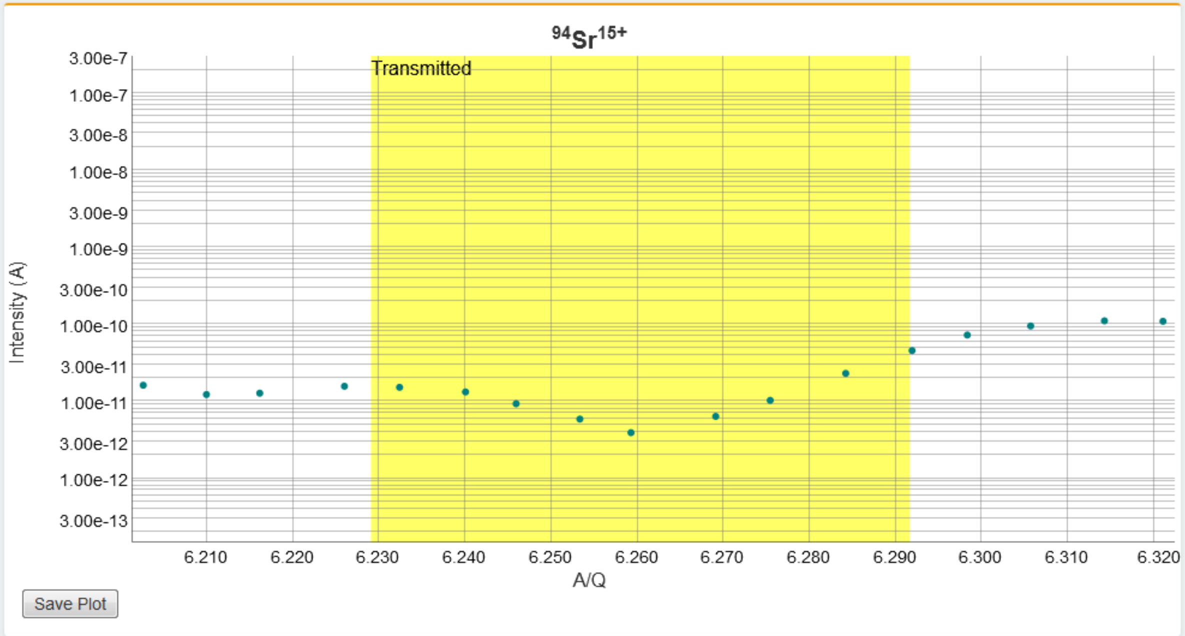
software tools for set-up

$^{127}I^{19+}$	6.679
$^{134}Ba^{20+}$	6.695

$^{94}Sr^{15+}$

A/Q: 6.260

Filter



CSB Known Stable Contaminants

Species	A/Q
$^{25}Mg^{4+}$	6.246
$^{50}Ti^{8+}$	6.243
$^{50}Cr^{8+}$	6.243
$^{69}Ga^{11+}$	6.265
$^{75}As^{12+}$	6.243
$^{94}Mo^{15+}$	6.260
$^{100}Mo^{16+}$	6.244
$^{107}Ag^{17+}$	6.288
$^{113}In^{18+}$	6.272
$^{119}Sn^{19+}$	6.258
$^{131}Xe^{21+}$	6.233
$^{132}Xe^{21+}$	6.281

$^{100}Ru^{16+}$	6.243
$^{106}Cd^{17+}$	6.229
$^{113}Cd^{18+}$	6.272
$^{125}Te^{20+}$	6.245
$^{132}Ba^{21+}$	6.281
$^{138}Ba^{22+}$	6.268
$^{138}La^{22+}$	6.268
$^{138}Ce^{22+}$	6.268
$^{144}Nd^{23+}$	6.256
$^{150}Nd^{24+}$	6.246
$^{144}Sm^{23+}$	6.256
$^{150}Sm^{24+}$	6.246
$^{151}Eu^{24+}$	6.288
$^{156}Gd^{25+}$	6.236

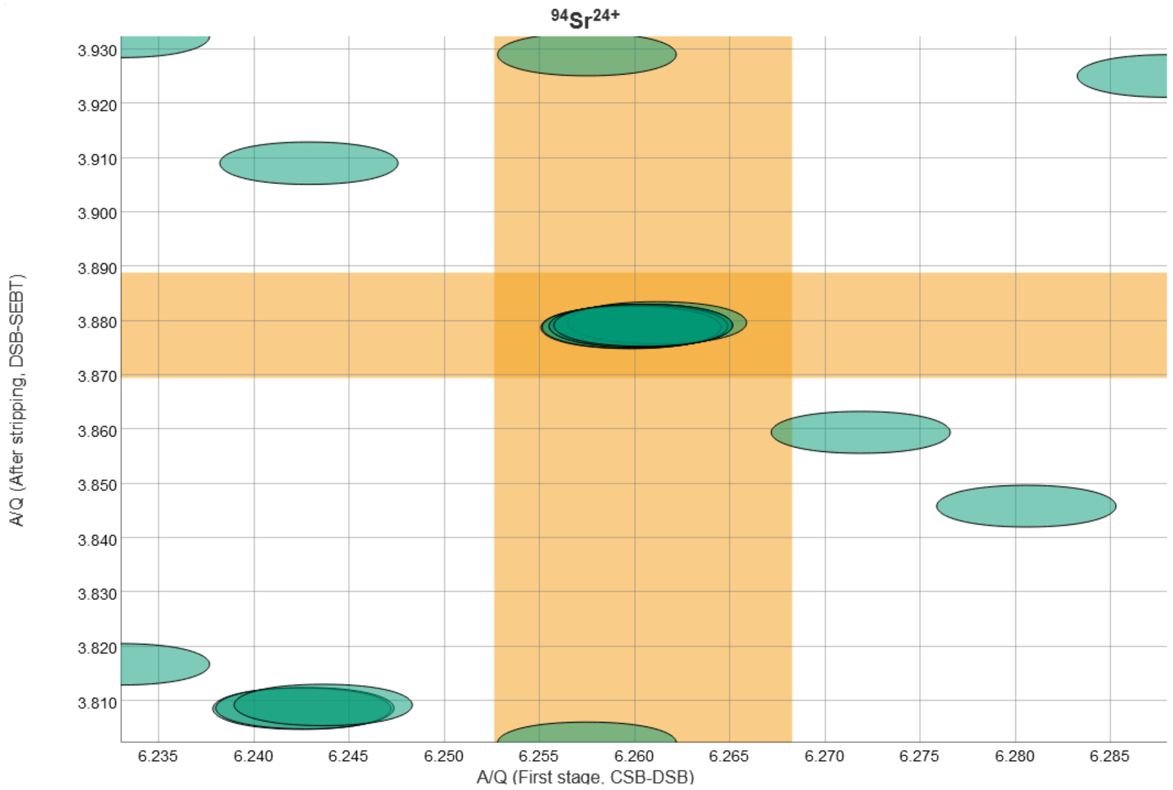
Discovery, accelerated

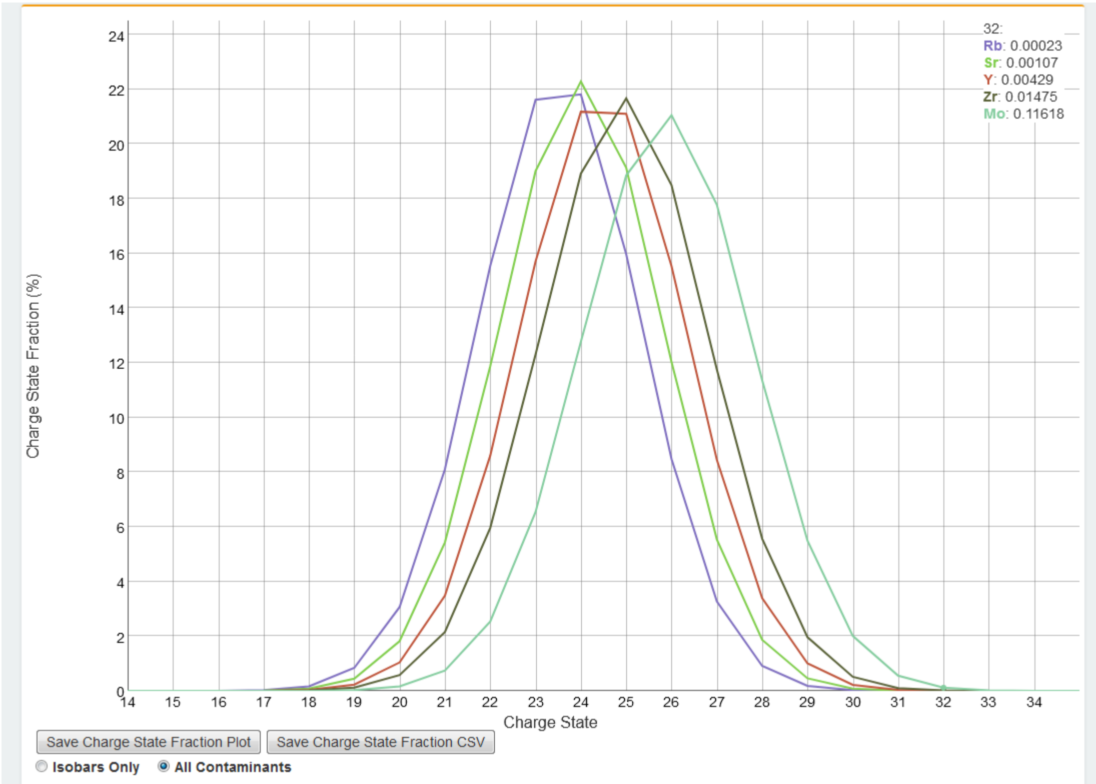
software tools for set-up

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%





Summary ISAC :

- More than 20 years radioactive beam delivery
- More than 800 isotopes
- Post-acceleration up to 15 MeV/u

- ECR charge state breeder 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 1-5%

  - problems:
  - high background
  - long breeding time (~20 ms*q)

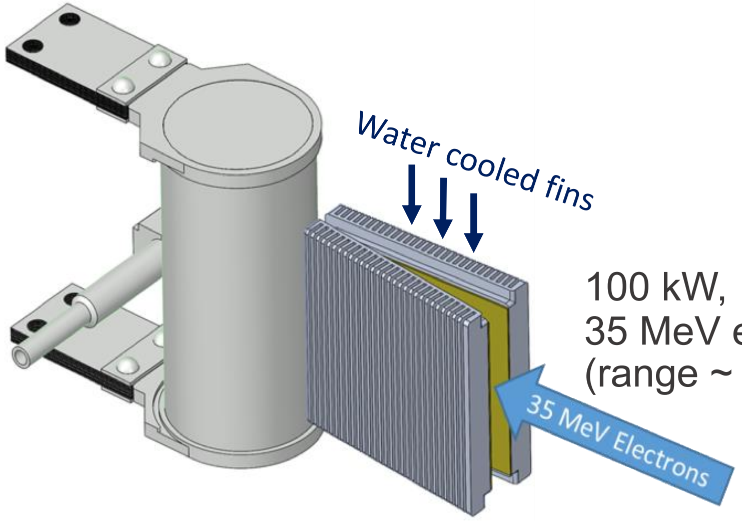
  - Ongoing improvements to ECR charge breeder:
  - implementing 2 frequency heating and improving injection/ extraction optics
  - → higher efficiency, higher charge states, more stable operation

New opportunities with ARIEL and CANREB

Advanced RarE Isotope Laboratory
CANadian Rare isotope facility with Electron Beam ion source

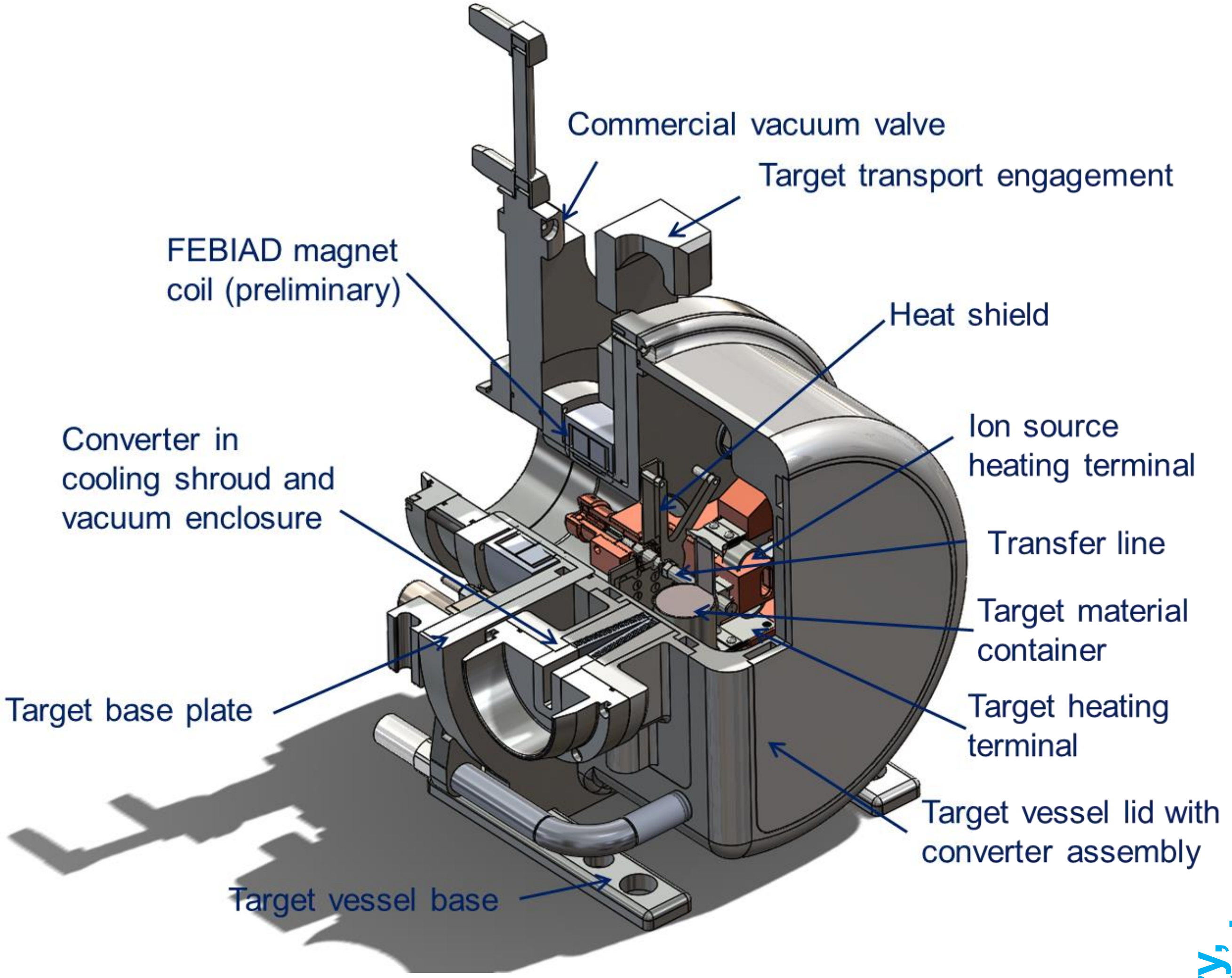
- One additional target 30 MeV using (100 kW) and photo fission
- One additional target using 500 MeV protons similar like ISAC
- High resolution mass separation M/ΔM =20 000
- Charge state breeding with an EBIS

ARIEL electron target design

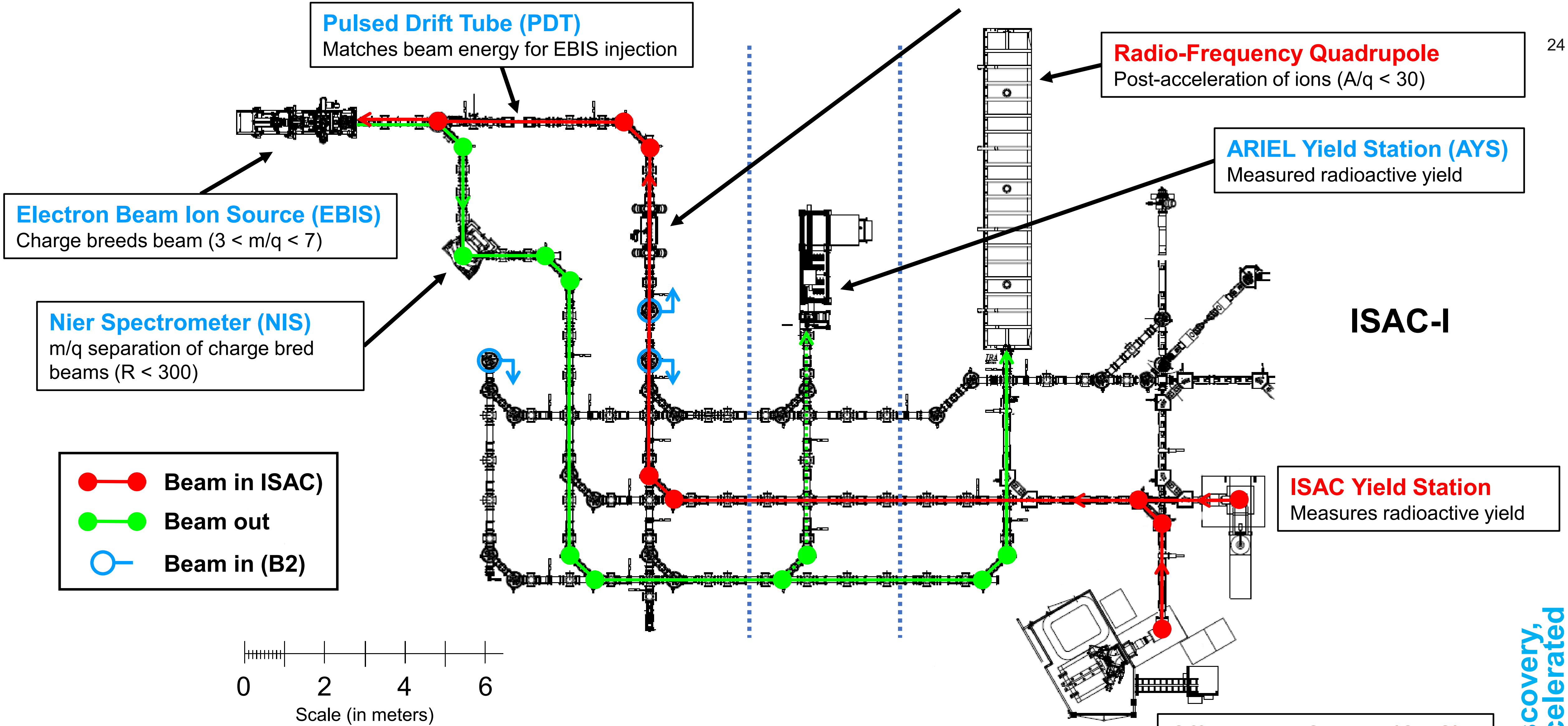


target

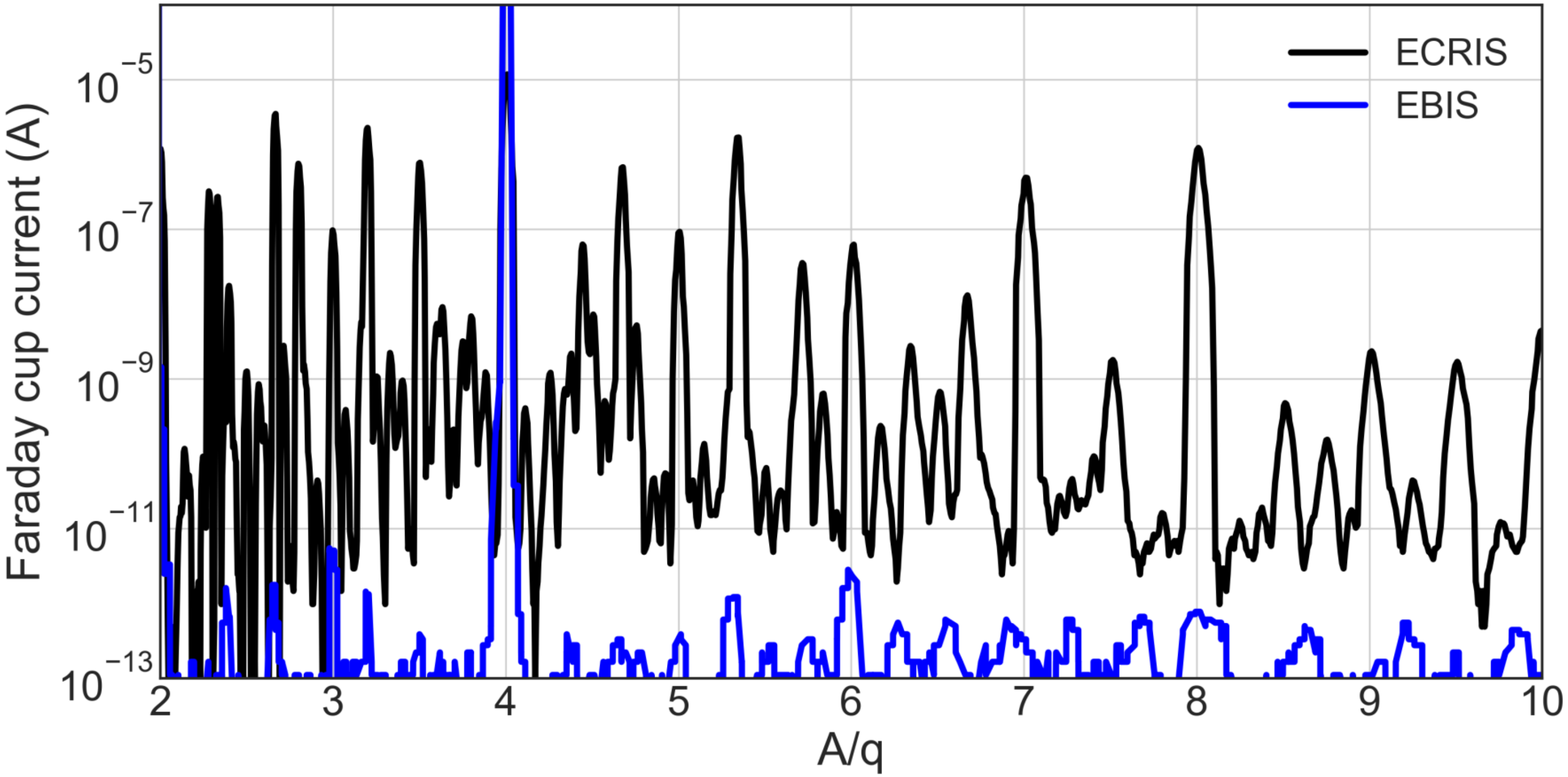
converter
Ta explosion welded on Al



CANREB overview

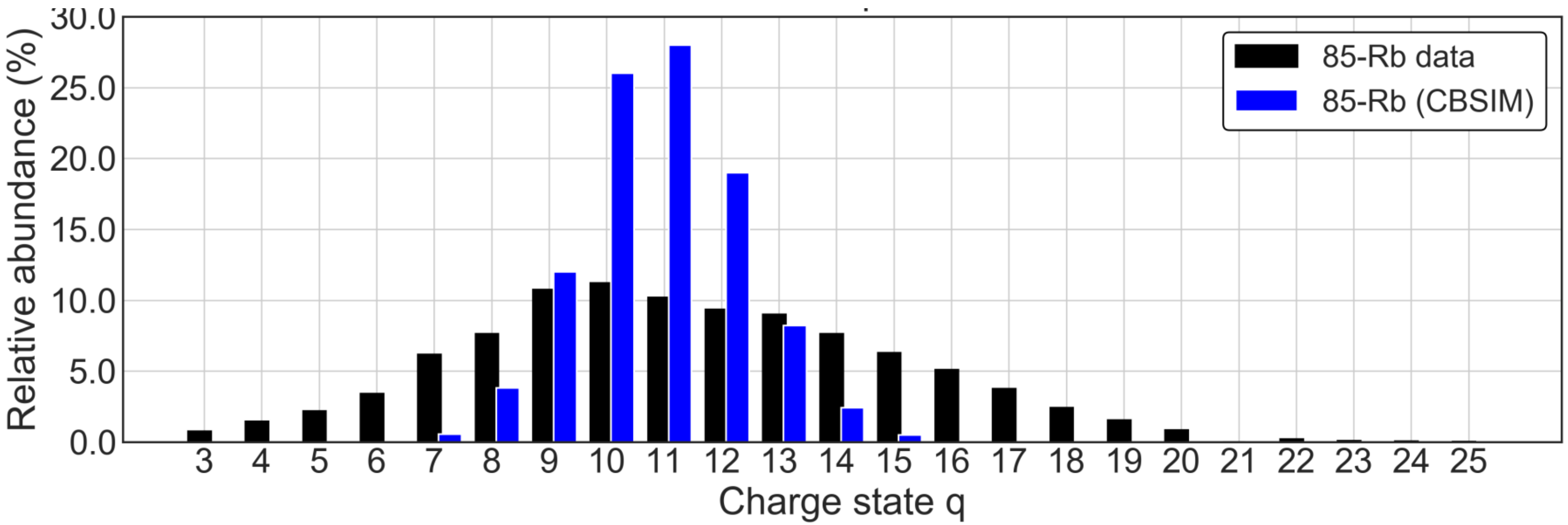


ECRIS background



- Generally orders of magnitude less than typical background from ECRIS
- Exception: A/q = 4 (He^{+}) → Increased by gas diffusion from RFQ

B. Schultz



- Charge state distribution for Rb ions

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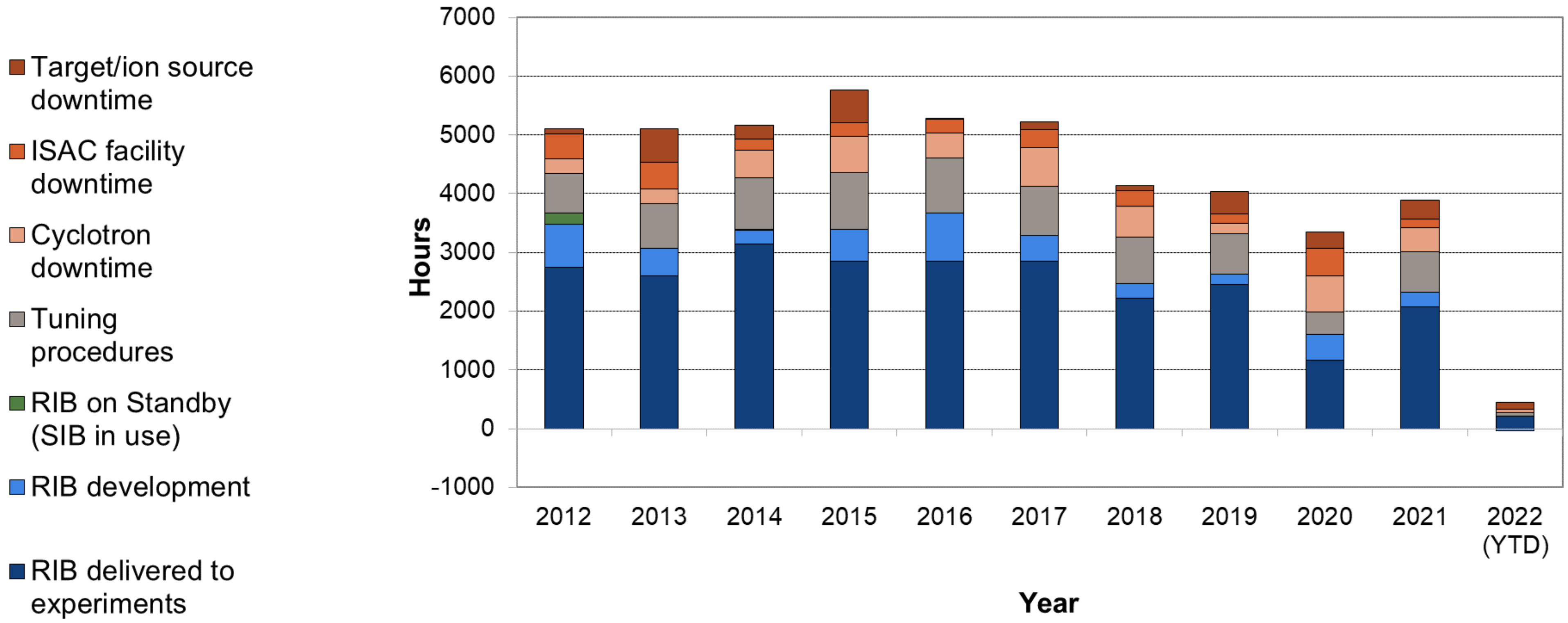
operation

ISAC beam delivery



Typical duration of one experiment 2 days to 3 weeks
~8 months per year since 2018 reduced schedule for ARIEL installations and COVID

Future operation

ISAC + ARIEL beam delivery

- Total hours to users: 9000 per year
- 3 simultaneous beams
  - 2 to low energy experiments
  - 1 accelerated beam
- Fixed duration for one target (3 weeks)
- Reduce overhead for beam tuning by implementing high level applications using ion optics model-based tuning, scaling and accelerator phasing
  → Spencer Kiy, presentation Tuesday, 11:50
  poster Tuesday, 16:00

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Thank you
Merci

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