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Canada's National Laboratory for Particle and Nuclear Physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

Operation of an ECRIS Charge State Breeder at TRIUMF

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TRIUMF

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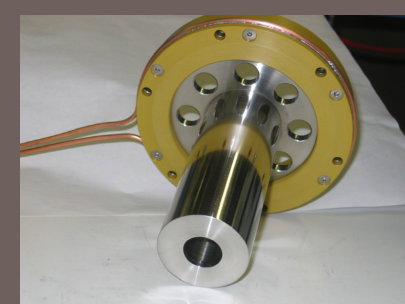

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   - efficiency
   - purity
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   - efficiency
   - purity

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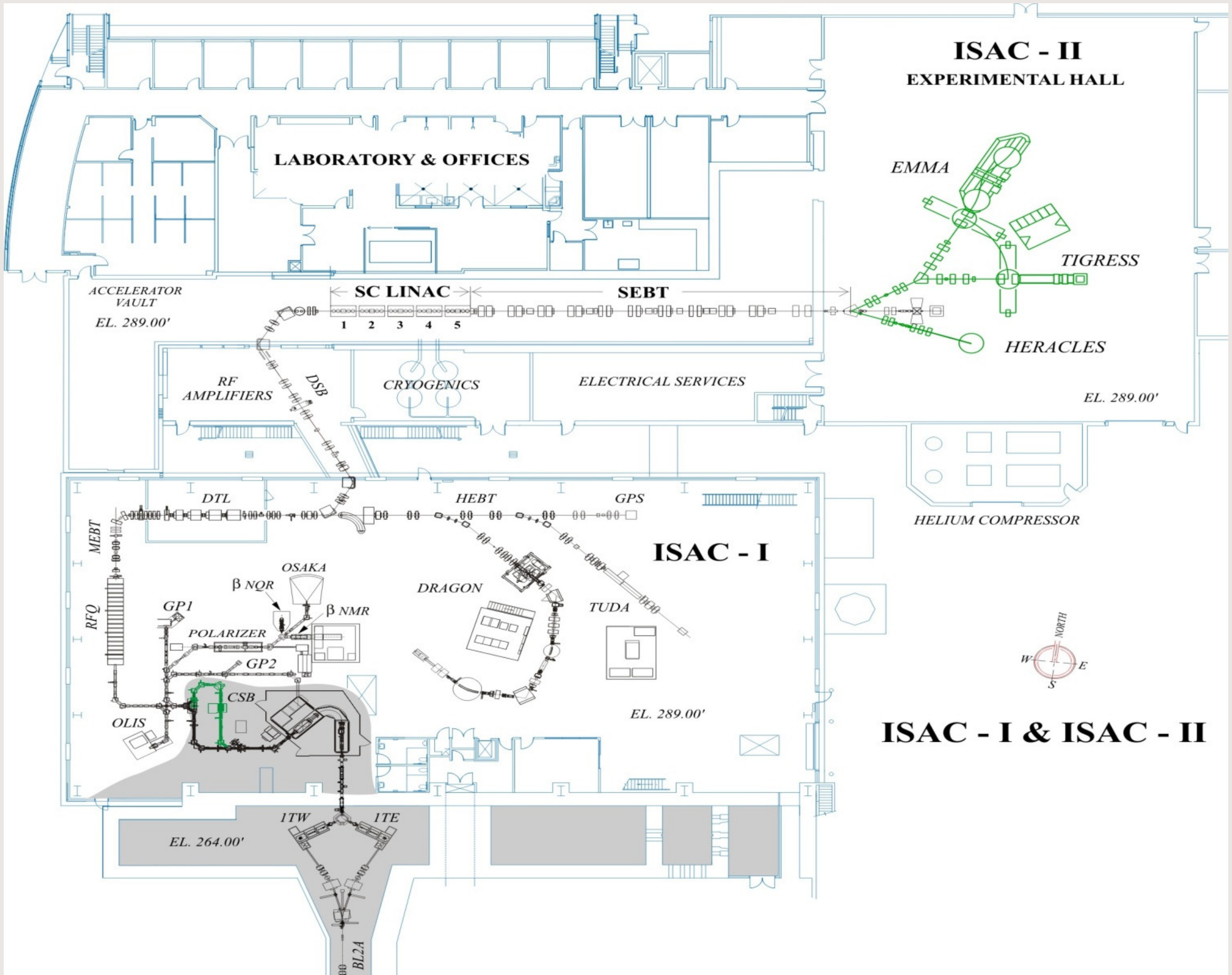
layout of the ISAC facility



Charge State breeding at ISAC

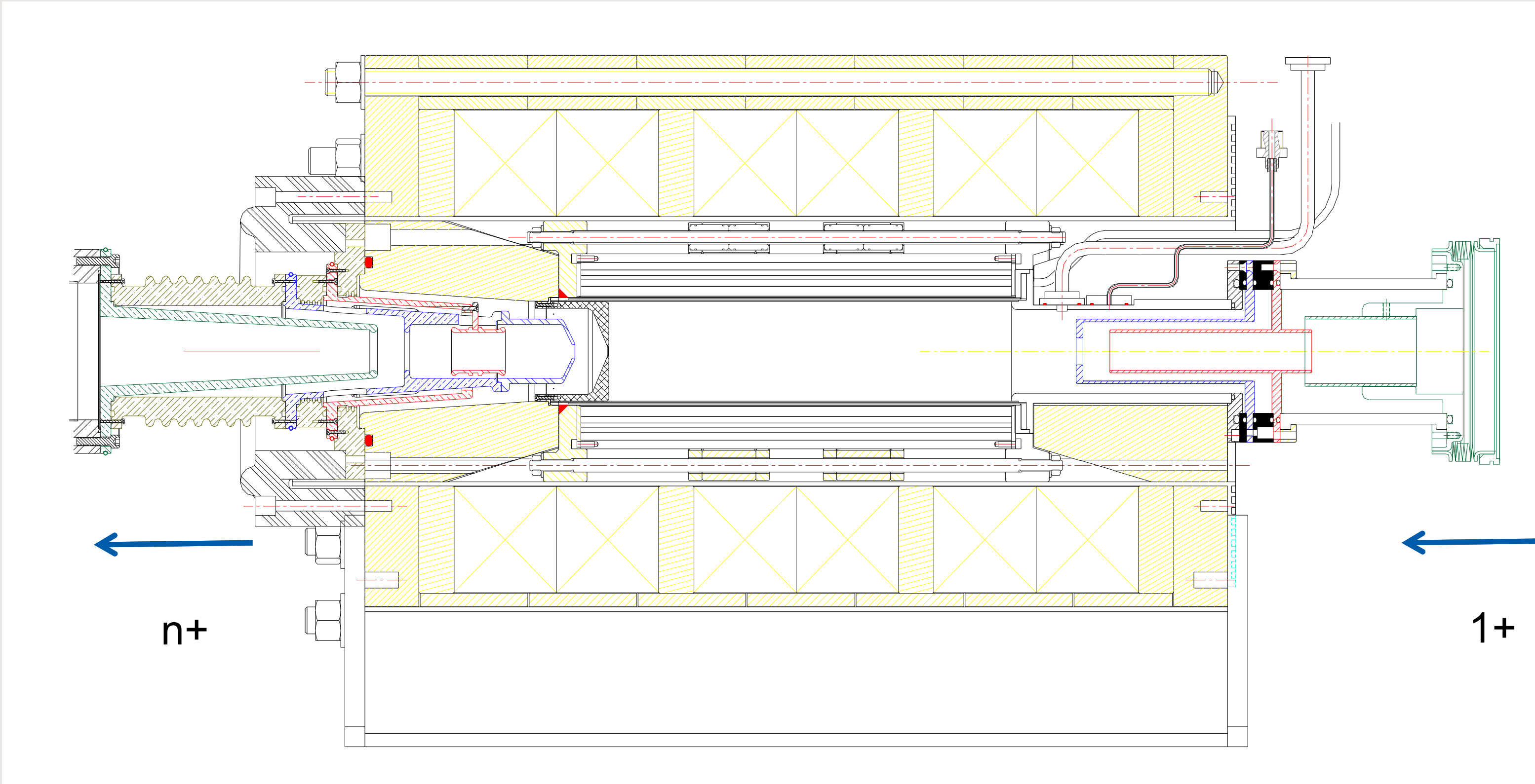
Requirements:

- $M/Q < 30$ with additional stripping after first acceleration stage (150 keV/u)
- $M/Q < 7$ without additional stripping
- ion velocity: 2 keV/u
- transversal emittance for highly charged ions: $\leq 30\ \pi$ mm mrad

Incoming beam:

- singly charged ions continuous beam
- typical emittance $< 20\ \pi$ mm mrad @ 30 keV
- beam intensity: 1 … $> 10^8$ ions/sec

Charge State Breeder

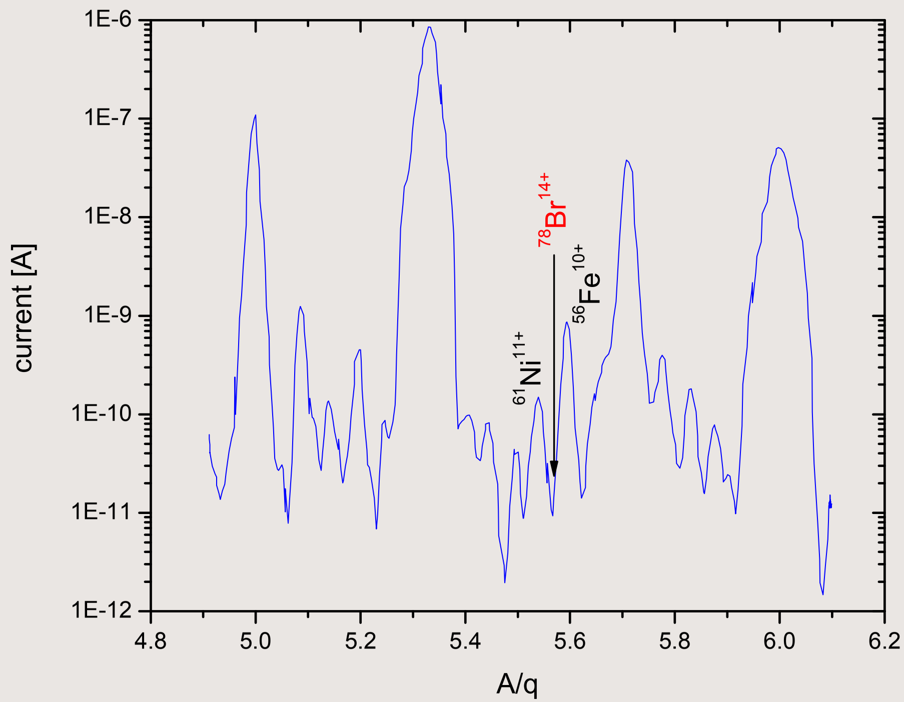


modified 14.5 GHz PHOENIX ECR ion source from Pantechnik
2 step deceleration for the injection of singly charged ions
2 step acceleration scheme for the extraction of the highly charged ions
Aluminum plasma chamber

radioactive isotopes, stainless steel plasma chamber

isotope	q	A/q	efficiency [%]	I (in) [1/s]	background [pA]
46K	9	5.11	0.5	4.0E4	340
64Ga	13	4.92	0.7	8.4E4	150
64Ga	14	4.57	0.75	8.4E4	210
74Br	14	5.28	3.1	3.2E7	10000
74Br	15	4.93	2.1	3.2E7	25
78Br	14	5.57	4.5	2.8E7 AlBr	20
74Kr	15	4.93	6.2	2.1E6	25
76Rb	15	5.07	1.68	3.8E6	15
80Rb	13	6.15	1.17	5.7E7	35
80Rb	14	5.71	1.1	5.7E7	70000
122Cs	19	6.42	1.1	3.1E5	6
124Cs	20	6.2	1.37	2.75E7	50

background

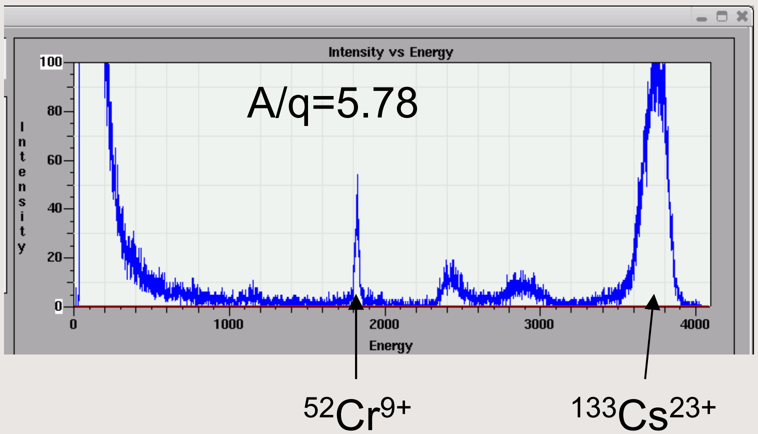


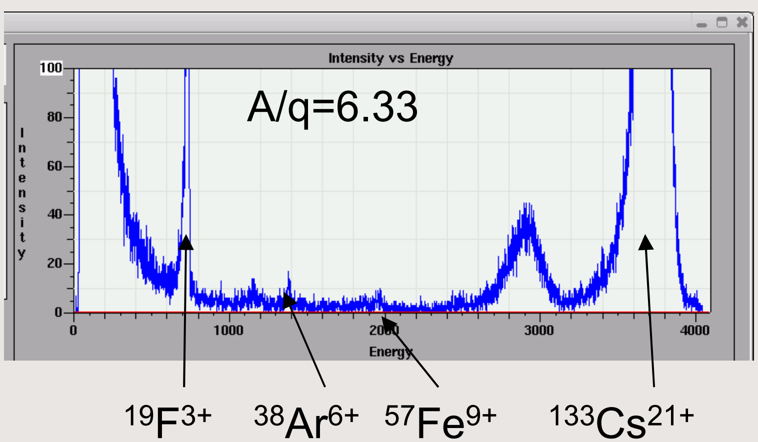
A/q	Isotopes (+/- 0.005amu/e)
5	$^{40}Ar^{8+}$, $^{20}Ne^{4+}$,…
5.11	$^{133}Cs^{26+}$
5.14	$^{36}Ar^{7+}$
5.2	$^{52}Cr^{10+}$, $^{78}Kr^{15+}$, $^{130}Xe^{25+}$
5.24	$^{84}Kr^{16+}$, $^{131}Xe^{25+}$
5.33	$^{16}O^{3+}$
5.41	$^{54}Cr^{10+}$, $^{54}Fe^{10+}$, $^{130}Xe^{24+}$
5.44	$^{136}Xe^{25+}$
5.5	$^{22}Ne^{4+}$, $^{132}Xe^{24+}$
5.54	$^{61}Ni^{11+}$, $^{133}Cs^{24+}$
5.6	$^{28}Si^{5+}$, $^{56}Fe^{10+}$
5.66	$^{17}O^{3+}$, $^{136}Xe^{24+}$
5.71	$^{40}Ar^{7+}$
5.78	$^{52}Cr^{9+}$, $^{133}Cs^{23+}$
5.83	$^{134}Xe^{23+}$
5.88	$^{129}Xe^{22+}$
5.90	$^{53}Cr^{9+}$, $^{124}Xe^{21+}$
6	$^{12}C^{2+}$, $^{18}O^{3+}$, $^{54}Cr^{9+}$, $^{54}Fe^{9+}$, $^{60}Ni^{10+}$,…

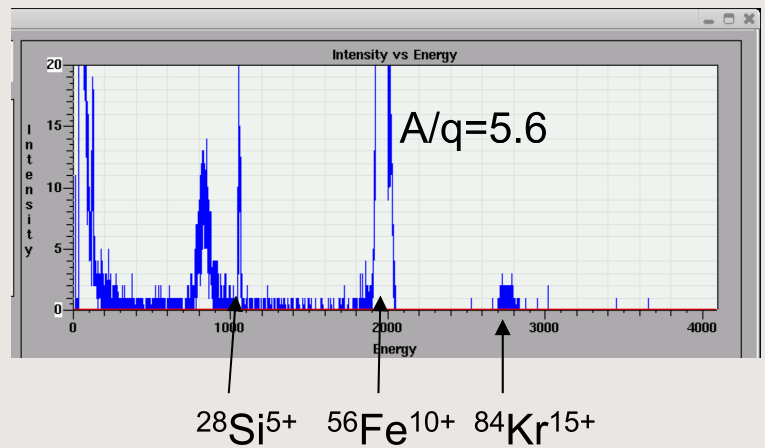
$^{78}Br^{14+}$ (1E6 ion/s) A/q = 5.57 amu/e
injected as AlBr from ZrC target
accelerated to 5MeV/u
measured at TIGRESS detector
background ≈ 20 pA

beam purity

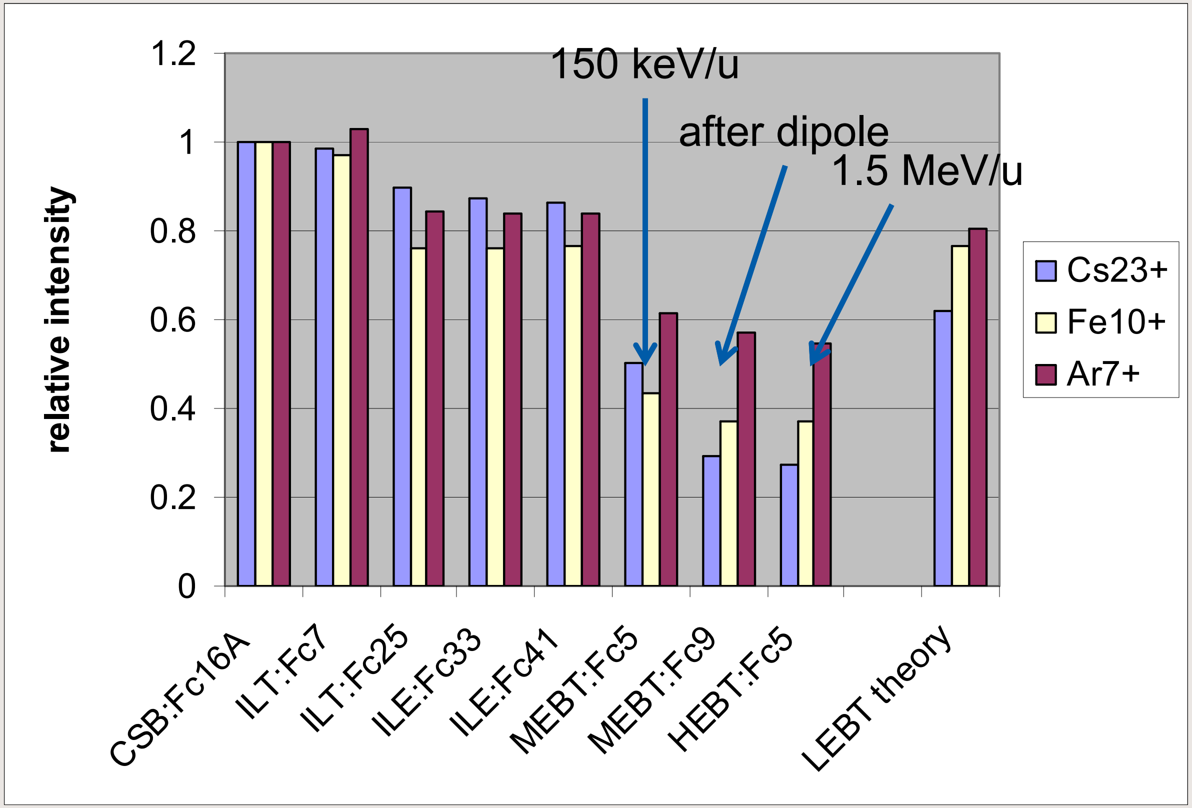
energy spectrum after scattering from a gold foil (77μg/cm^2) at 1.5 MeV/u







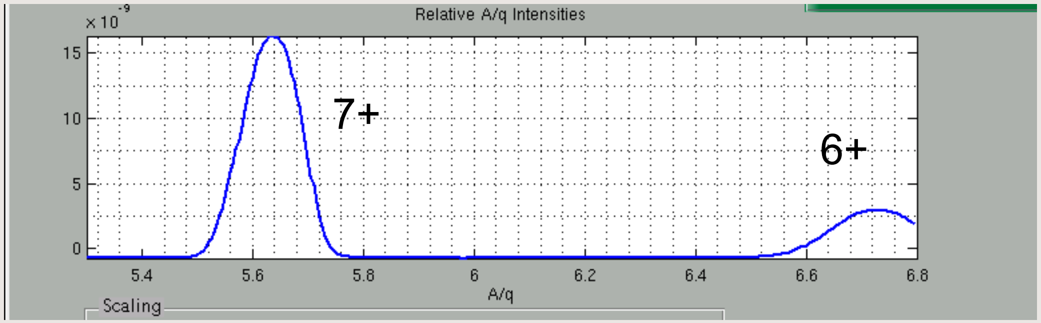
beam transport



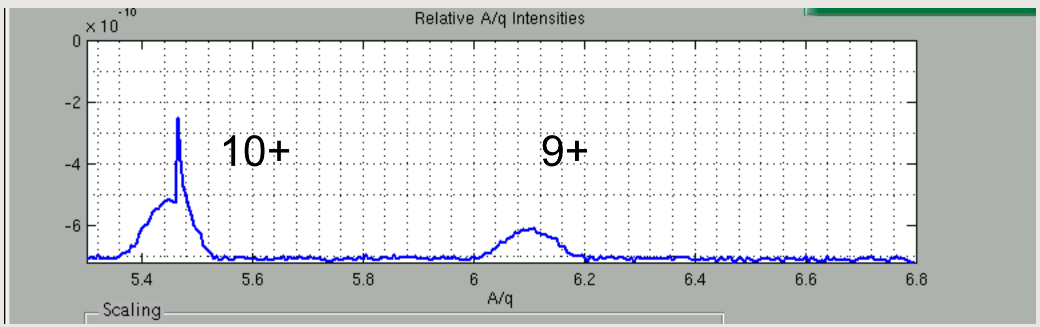
Measured beam current relative to the current after the CSB on several Faraday cups.
The theoretical value for the LEBT assumes charge exchange
at a pressure of 2 10^{-7} T over 25 m.
Cross sections from F. Ames et al., High Energy Phys Nucl Phys. 31 (2007) 211, ECRIS'06 proc.

charge exchange

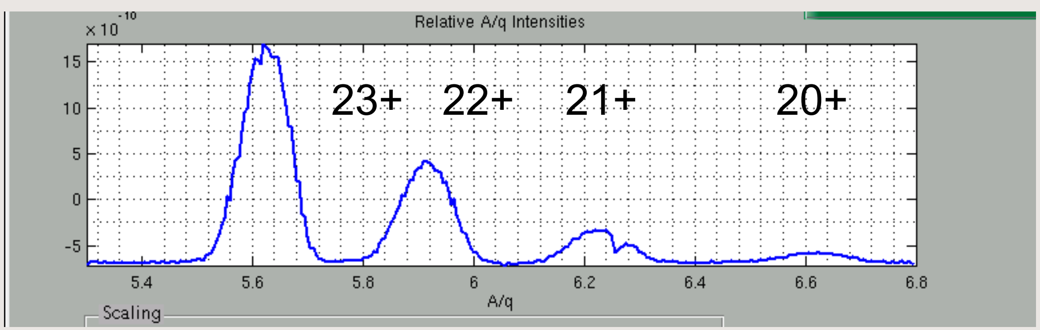
scan of MEBT dipole



$^{40}Ar^{7+}$

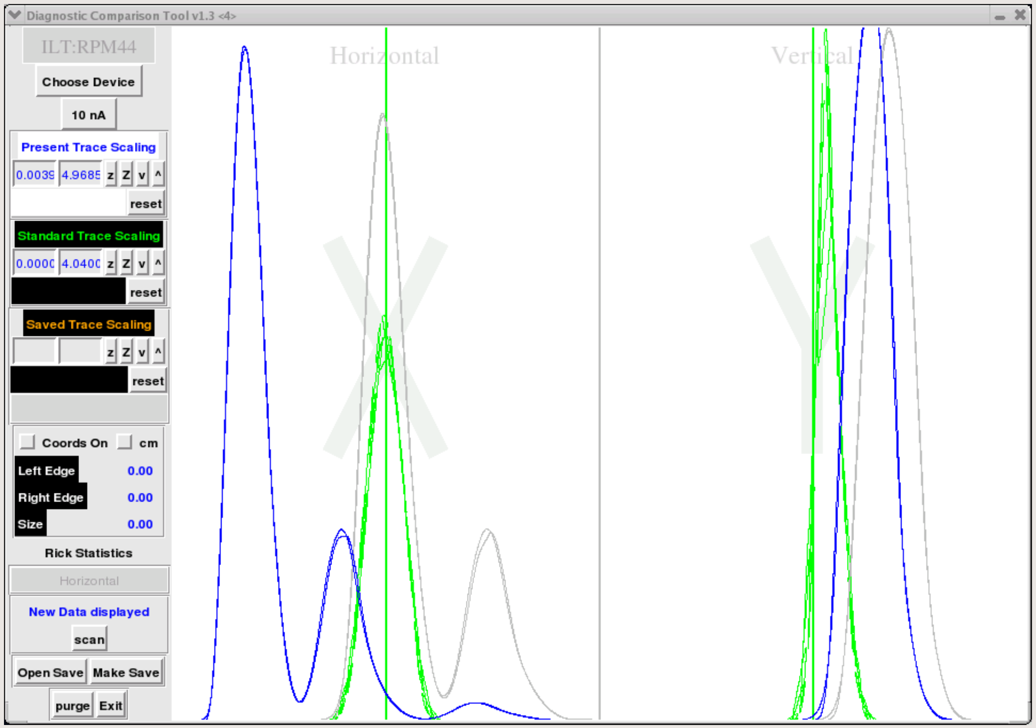


$^{56}Fe^{10+}$



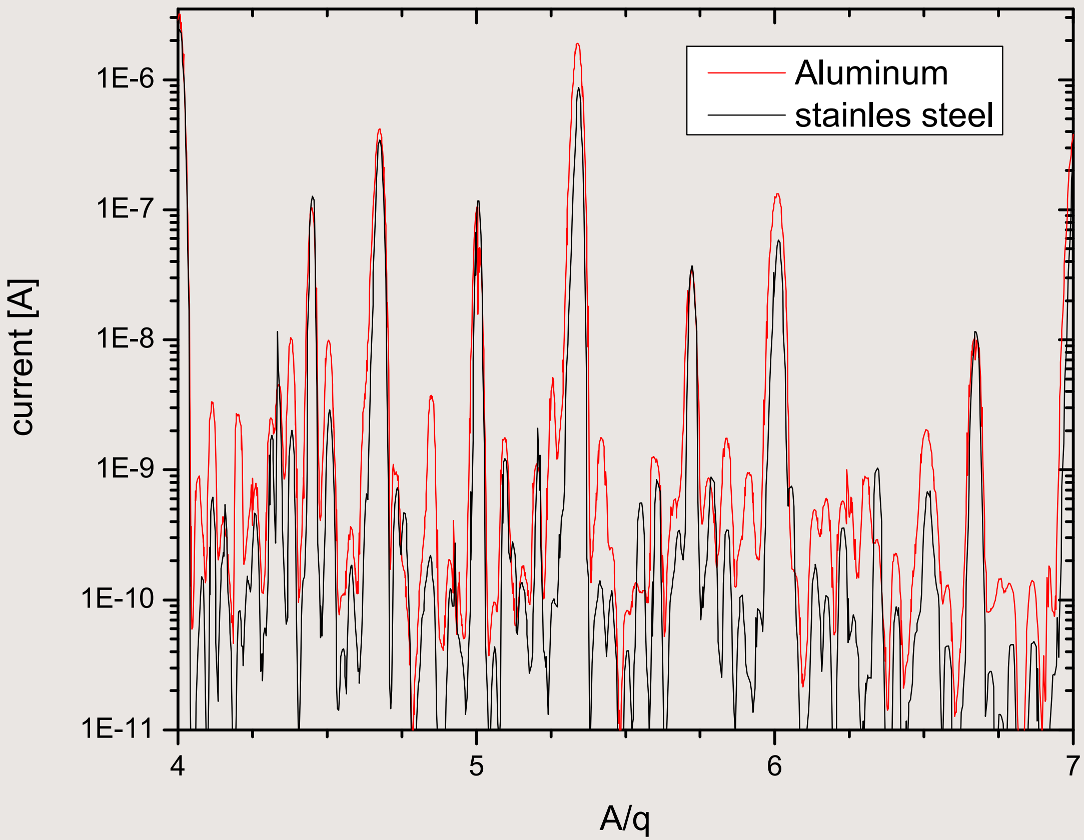
$^{133}Cs^{23+}$

charge exchange



Cs^{23+} beam profile (blue) at ILT:RPM44 (focal plane of first bender in front of RFQ)
The center of the beam has been moved in horizontal (x) direction
to show more beam components.

Aluminum plasma chamber first try



mass spectrum with stainless steel and aluminum plasma chamber

Additional peaks from Al chamber Cl^{n+}, most other peaks remain

higher total beam current

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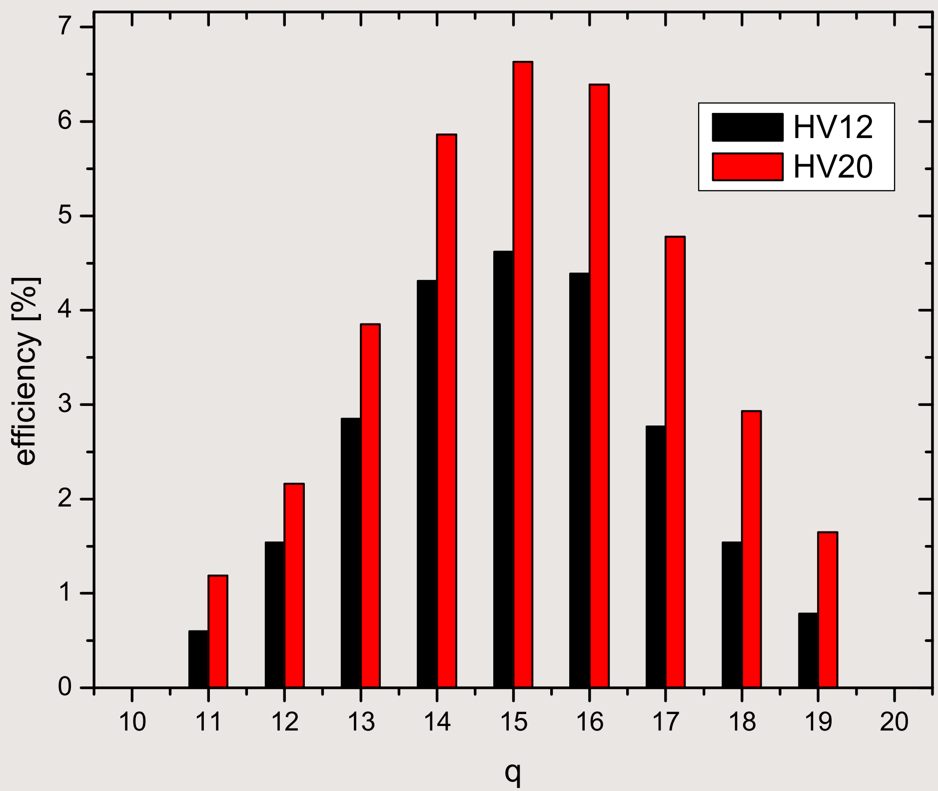
aluminum plasma chamber efficiency



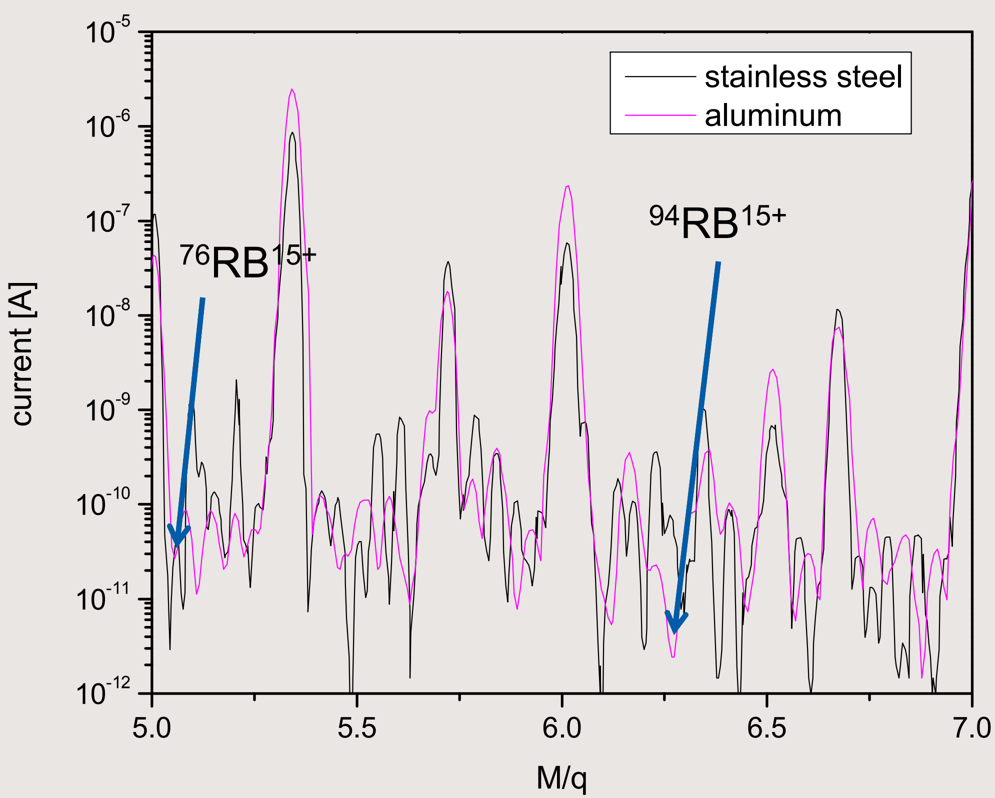
^{80}Rb charge state distribution from Al plasma chamber with different injection/ extraction voltage

charge breeding efficiency
of radioactive ions from stainless steel
and aluminum plasma chamber

increase of efficiency

	steel	Al
$^{48}K^{9+}$		0.67%
$^{46}K^{9+}$	0.5 %	
$^{80}Rb^{15+}$		4.5% (6.5%
$^{76}Rb^{15+}$	1.68%	
$^{124}Cs^{20+}$	1.37%	2.0%

aluminum plasma chamber second try



mass spectrum after exchange of all electrodes to aluminum and coating plasma chamber and iron with pure aluminum

peaks from ^{56}Fe, $^{52,53}Cr$… missing or reduced

$\Rightarrow$new test with $^{76,94}Rb$

background identified

$^{76}Rb^{15+}$ A/q=5.06

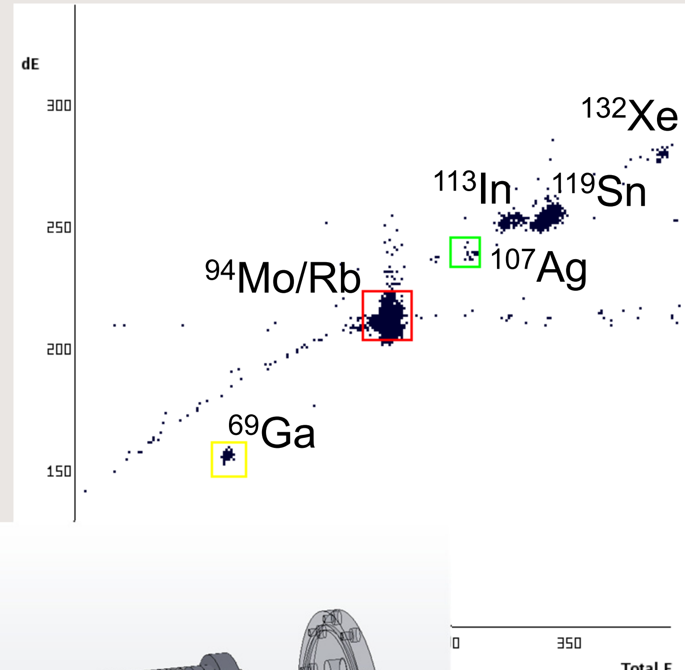
$^{61}Ni^{12+}$, $^{76}Se^{15+}$, $^{76}Ge^{15+}$

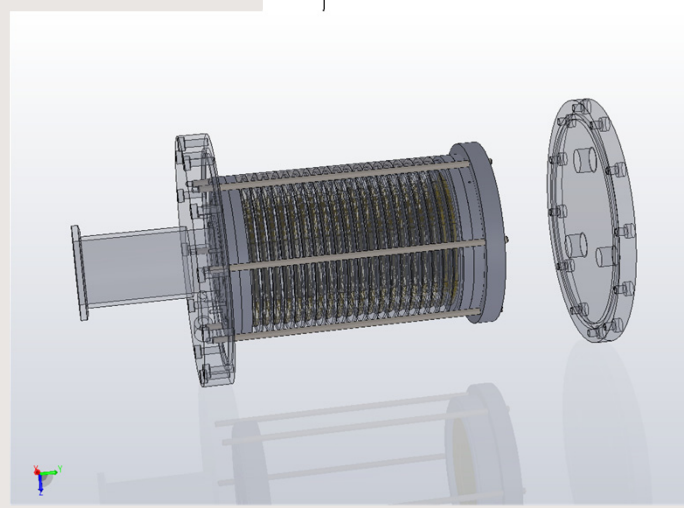
$^{94}Rb^{15+}$ A/q=6.26

$^{69}Ga^{12+}$, $^{94}Mo^{15+}$, $^{107}Ag^{17+}$, $^{113}In^{18+}$, $^{119}Sn^{19+}$, $^{132}Xe^{21+}$,

New diagnostics for particle identification

- Stopping gas counter in ISAC-II experimental hall
- **Particle ID from ΔE-E after acceleration**
- Tolerant of high count rates
- Thickness can be adjusted by varying gas pressure





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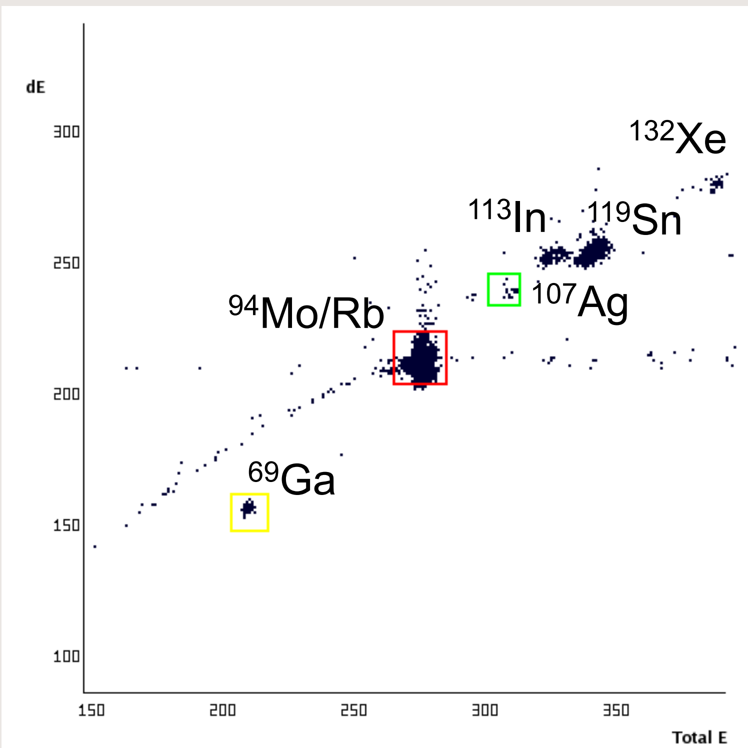
In flight purification

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

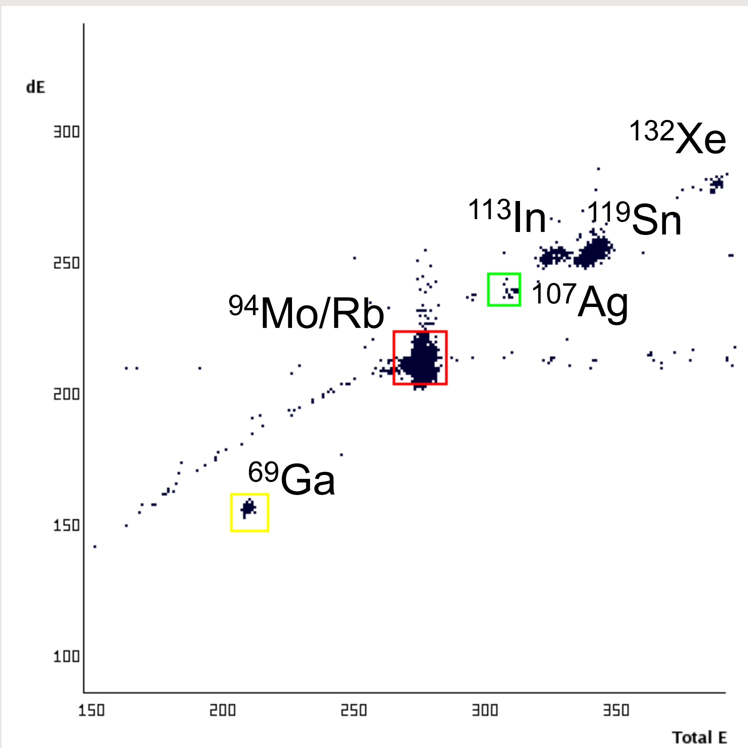
Before final filtration

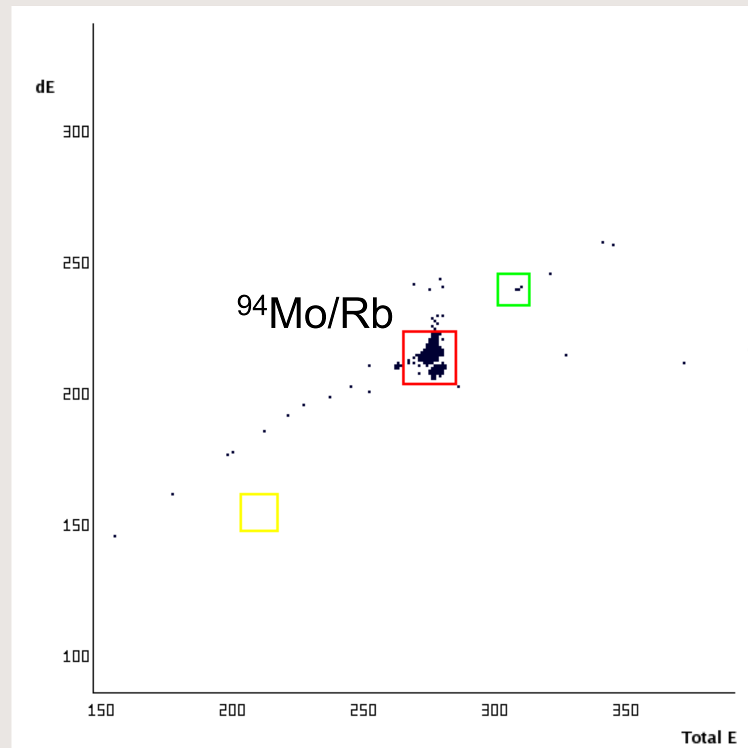


In flight purification

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

Before final filtration





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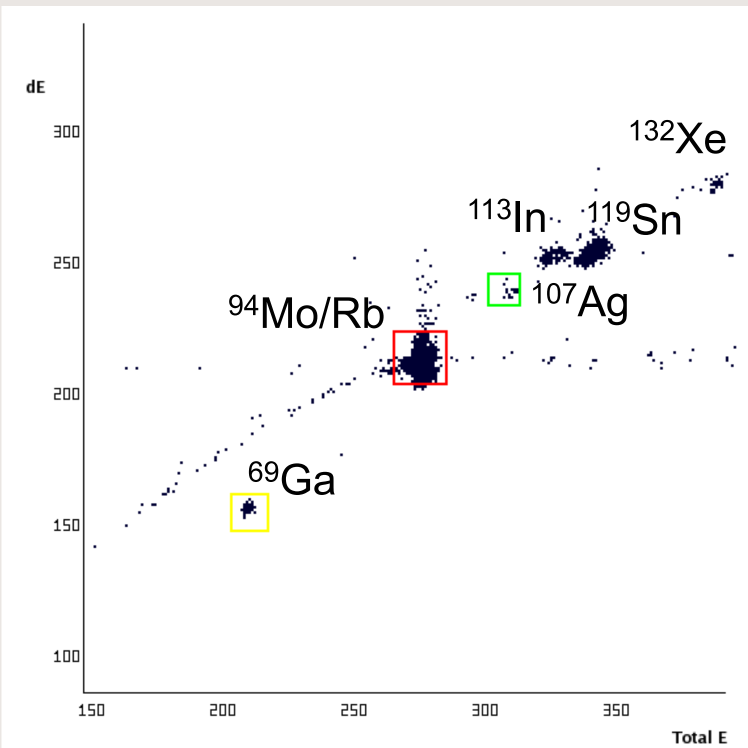
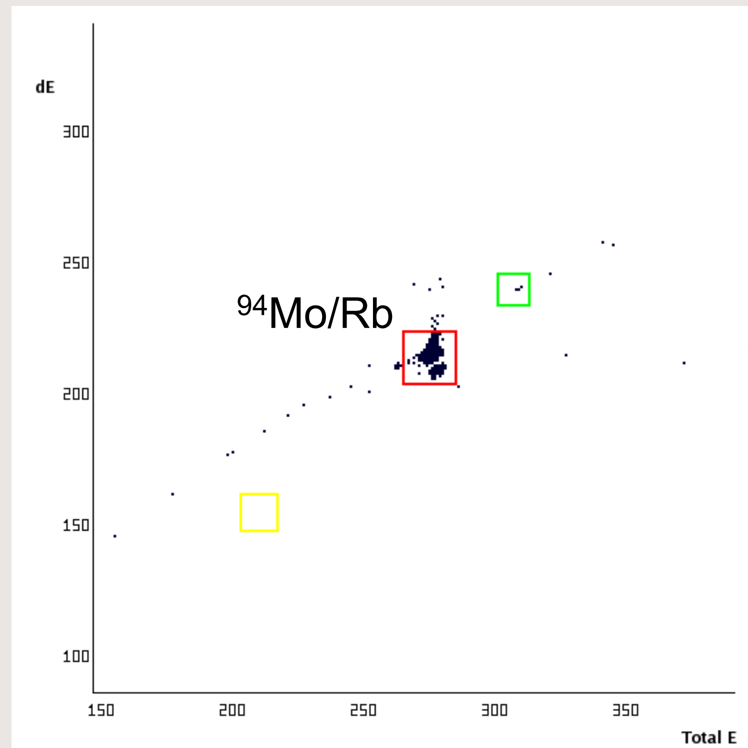


After final filtration



new tools: CSB calculator

CSB Assistant - Mozilla Firefox

File Edit View History Bookmarks Tools Help

Welcome to Ibis Darling Harbour Internet... | CSB Assistant

trshare.triumf.ca/~garns/CSB/

Charge-State Booster Page

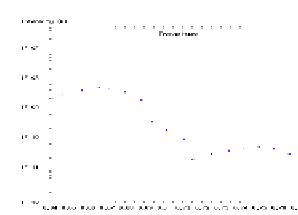
The Charge-State Booster (CSB) is intended to produce radioactive ion beams in charge states greater than 1+. Stable isotopes are also ionized and produced by this device so must be considered when selecting which beam to extract. This page may help identify which charge-state might be the cleanest.

Select Mass and Element: 94 Rb [Show A/Q values]

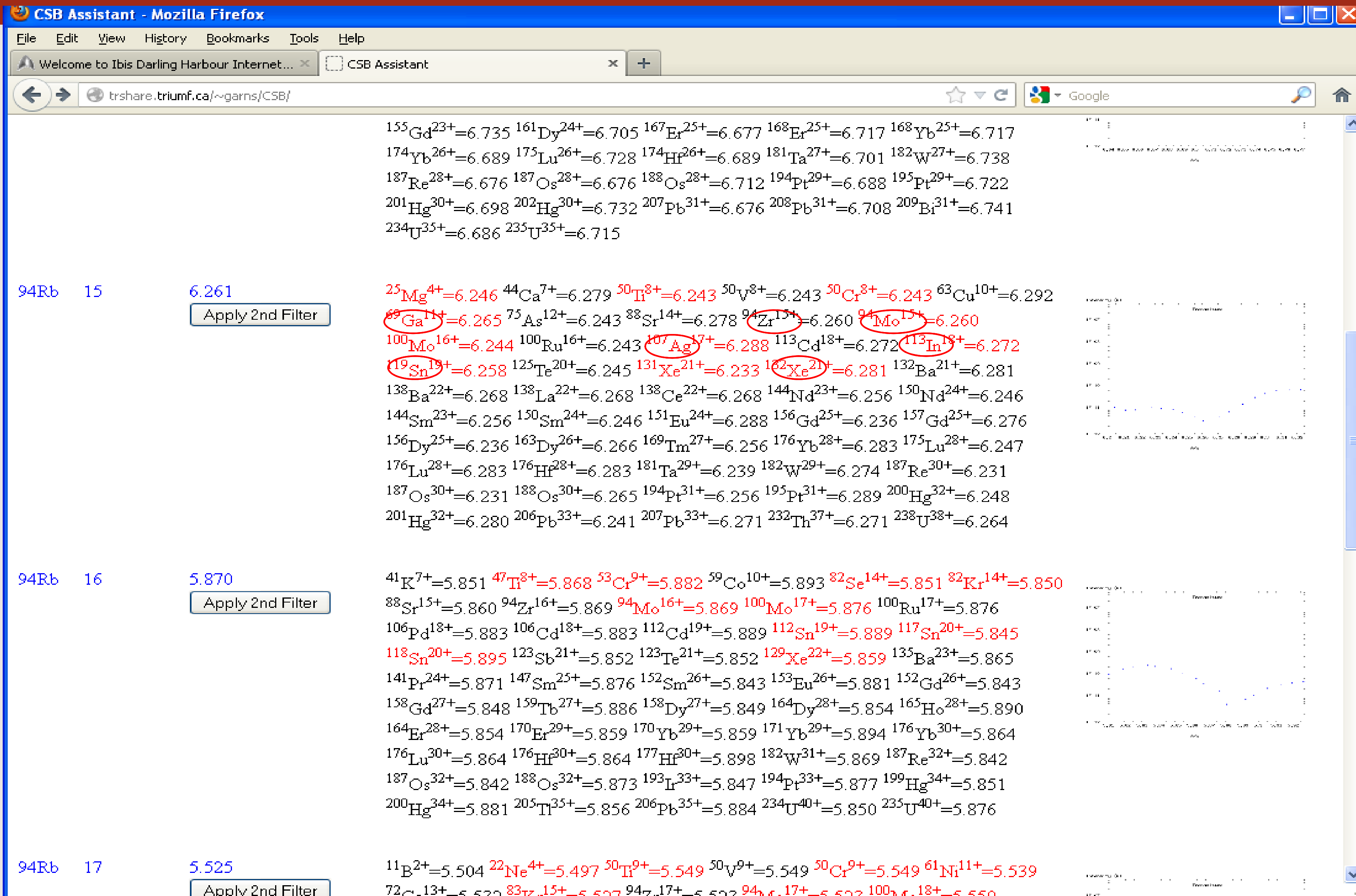
Rb has an atomic number: 37
94Rb has an atomic mass of: 93.926405 amu.
The CSB ECR source has an Aluminium liner.
The resolving power of the magnet immediately following the CSB is 1/100

Blue font indicates species which can currently be delivered to ISAC II (i.e. have an A/Q value between 5 and 6.4 only).
"Possible Companions" includes any stable species with an A/Q value within +/- 0.5% (1/100 resolving power of magnet) of the species of interest. Obviously not all of these stable species will be present and the amount of each species will depend on the operating conditions of the CSB (temperature/pressure etc.) as well as the recent CSB history (i.e. isotopes recently injected into the device).
Red font indicates elements which are known to come from the CSB. (Residual gases and the material of the CSB itself).
The masses used here to calculate A/q values are taken from the AME2003 atomic mass evaluation available at http://www.nndc.bnl.gov/masses.
The plot on the right is of the Charge-State Booster Background Intensity as measured on August 13th 2012.

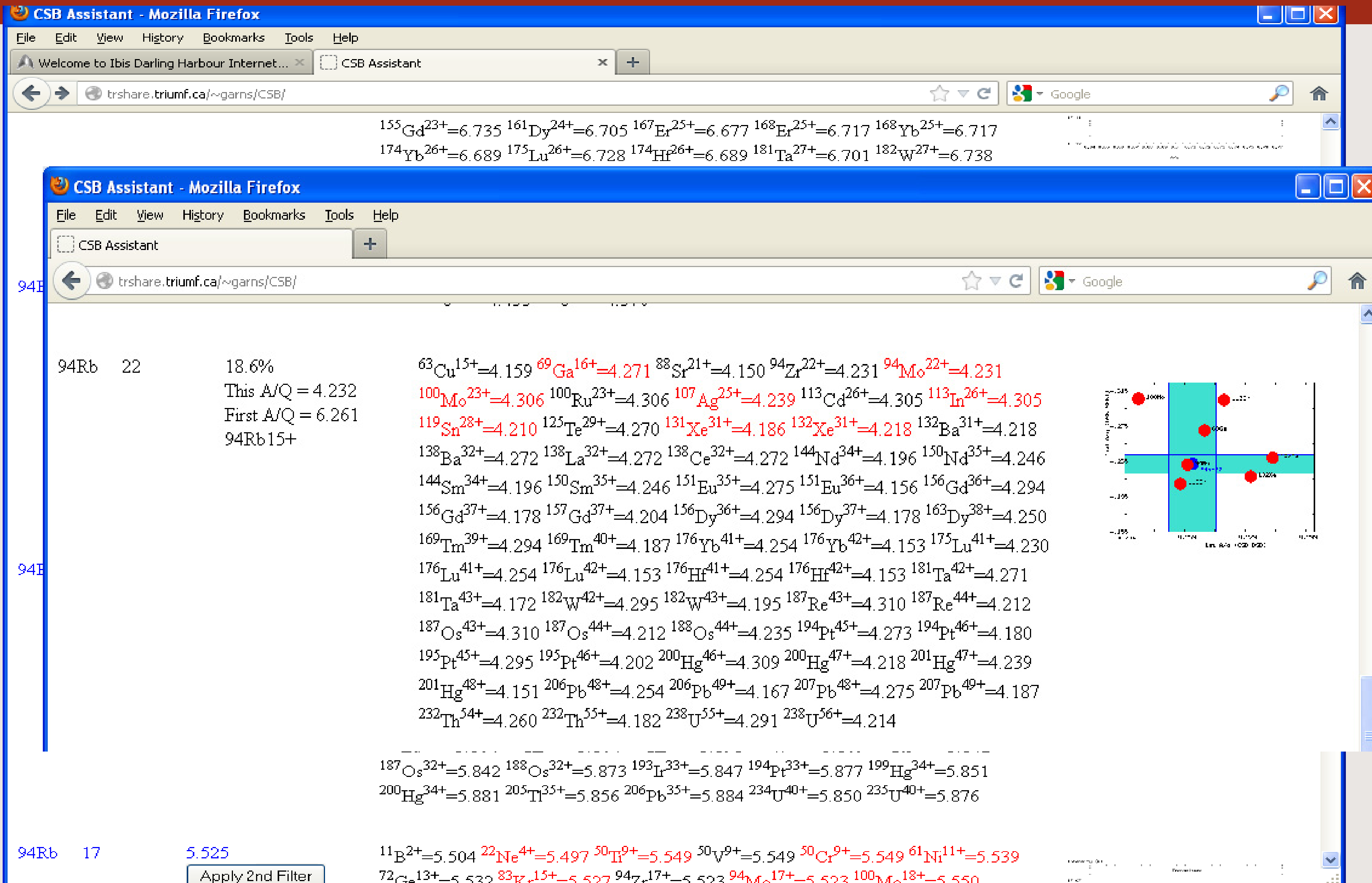
Species	Charge State	A/Q Value	Possible Companions
94Rb	14	6.708 [Apply 2nd Filter]	$^{47}Ti^{7+}$=6.707 $^{54}Cr^{8+}$=6.742 $^{54}Fe^{8+}$=6.742 $^{67}Zn^{10+}$=6.692 $^{74}Ge^{11+}$=6.720 $^{74}Se^{11+}$=6.720 $^{87}Rb^{13+}$=6.685 $^{87}Sr^{13+}$=6.685 $^{94}Zr^{14+}$=6.707 $^{94}Mo^{14+}$=6.707 $^{101}Ru^{15+}$=6.726 $^{107}Ag^{16+}$=6.681 $^{114}Cd^{17+}$=6.700 $^{114}Sn^{17+}$=6.700 $^{121}Sb^{18+}$=6.716 $^{128}Te^{19+}$=6.731 $^{127}I^{19+}$=6.679 $^{128}Xe^{19+}$=6.731 $^{134}Xe^{20+}$=6.695 $^{134}Ba^{20+}$=6.695 $^{141}Pr^{21+}$=6.709 $^{148}Nd^{22+}$=6.723 $^{147}Sm^{22+}$=6.677 $^{148}Sm^{22+}$=6.723 $^{154}Sm^{23+}$=6.692 $^{154}Gd^{23+}$=6.692 $^{155}Gd^{23+}$=6.735 $^{161}Dy^{24+}$=6.705 $^{167}Er^{25+}$=6.677 $^{168}Er^{25+}$=6.717 $^{168}Yb^{25+}$=6.717 $^{174}Yb^{26+}$=6.689 $^{175}Lu^{26+}$=6.728 $^{174}Hf^{26+}$=6.689 $^{181}Ta^{27+}$=6.701 $^{182}W^{27+}$=6.738 $^{187}Re^{28+}$=6.676 $^{187}Os^{28+}$=6.676 $^{188}Os^{28+}$=6.712 $^{194}Pt^{29+}$=6.688 $^{195}Pt^{29+}$=6.722 $^{201}Hg^{30+}$=6.698 $^{202}Hg^{30+}$=6.732 $^{207}Pb^{31+}$=6.676 $^{208}Pb^{31+}$=6.708 $^{209}Bi^{31+}$=6.741 $^{234}U^{35+}$=6.686 $^{235}U^{35+}$=6.715



new tools: CSB calculator



new tools: CSB calculator



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Summary

- charge breeding of radioactive ions
- 2.0% efficiency for $^{124}Cs^{20+}$ (A/q = 6.2), 4.5% efficiency for $^{80}Rb^{15+}$ A/q=5.33
  6.2% for 74Kr15+
- higher efficiency at higher injection energy
- injection of molecular ions $\Rightarrow$ beam purification from isobars
- acceleration of $^{76,80,94}Rb^{14,15+}$ and $^{78}Br^{14+}$

- background reduction methods
- Aluminum coated plasma chamber
- "In flight" purification in LINAC chain
- new diagnostics
- new software tools (CSB calculator, automatic accelerator scaling routines)

- plans for the future
- continue optimizing the system with radioactive ions, short half lives
- further optimization of breeding and accelerator efficiency
- background reduction ??

next generation charge state breeder

Possible strategies for improved ECR charge breeder

- efficiency
- higher voltage at charge breeder
  - floating RFQ and / or charge breeder
  - new RFQ with higher velocity acceptance
- new ECR source design
  - symmetric magnetic field at injection
  - higher and/or dual frequency plasma heating

- beam transport
- relocate charge breeder closer to accelerator
- improve vacuum in beam line for low energy highly charged ions

- purity
- ultra high vacuum source and ultra pure support gas
  - will reduce only some gaseous impurities
- high resolution mass separator after charge breeding ($\Delta M/M$ >1000)
  - limited by source emittance

Thank you!
Merci!