



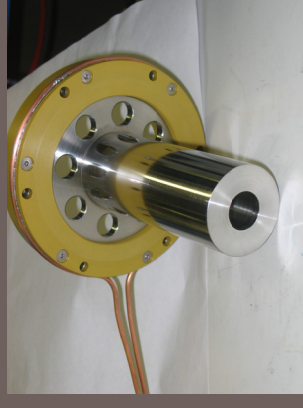
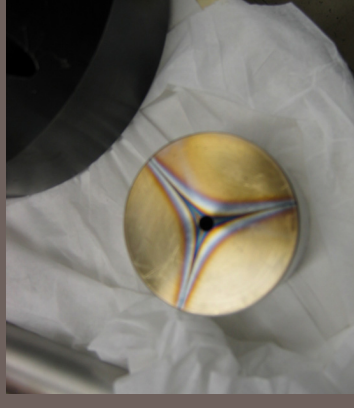
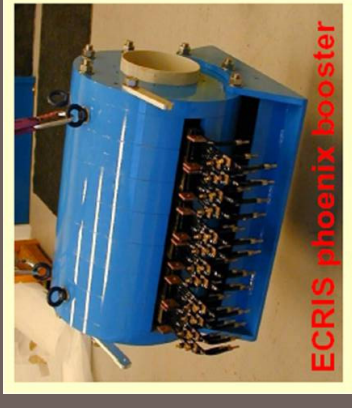
TRIUMF

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

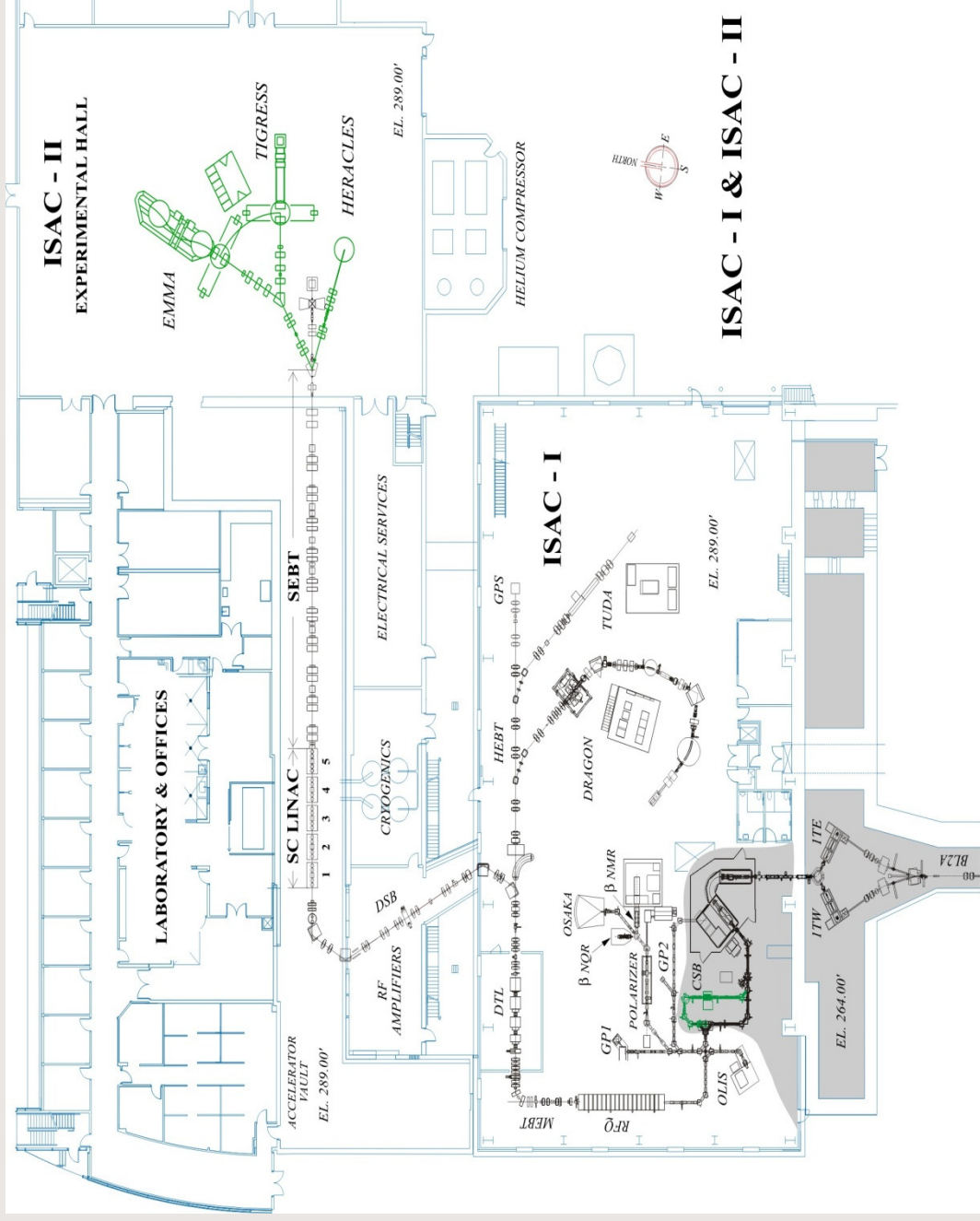
F.Ames , R. Baartman, P. Bricault, K. Jayamanna, A. Mjøs
TRIUMF

ECRIS 2012 workshop, September 25- 28, Sydney, Australia



1. Introduction
2. set-up
3. charge breeding results with stainless steel plasma chamber
 - efficiency
 - purity
 - beam transport
4. first results with aluminum plasma chamber
 - efficiency
 - purity
5. beam purification tools
6. summary

layout of the ISAC facility



Charge State breeding at ISAC

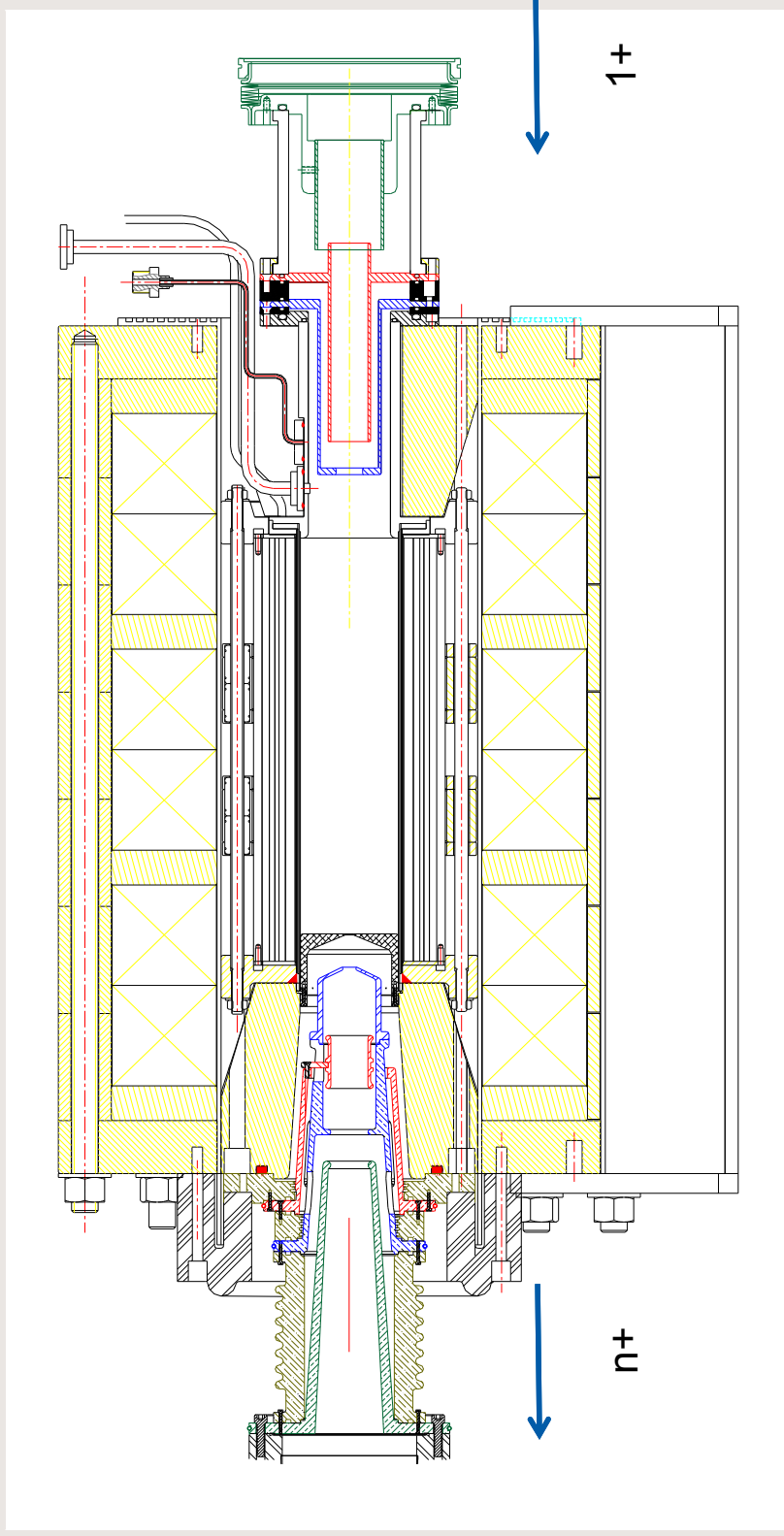
Requirements:

- $M/Q < 30$ 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

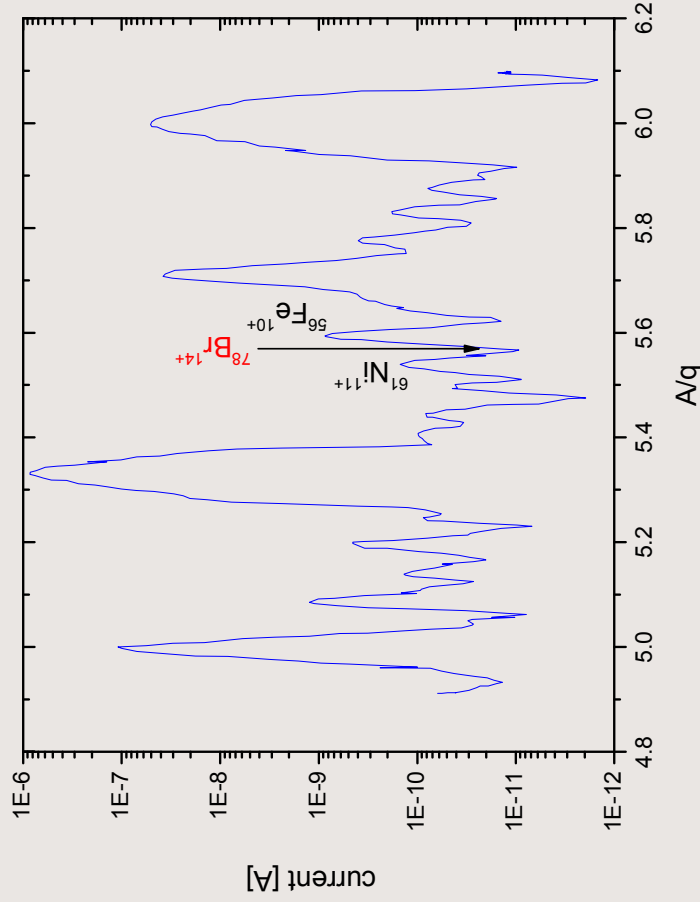


modified 14.5 GHz PHOENIX ECR ion source from Pantechnik
 2 step deceleration for the injection of singly charged ions
 2 step acceleration scheme for the extraction of the highly charged ions
 Aluminum plasma chamber

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 AIBr	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

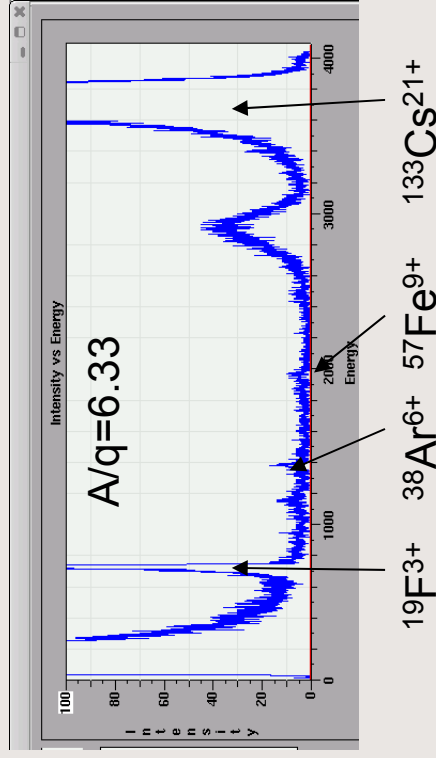
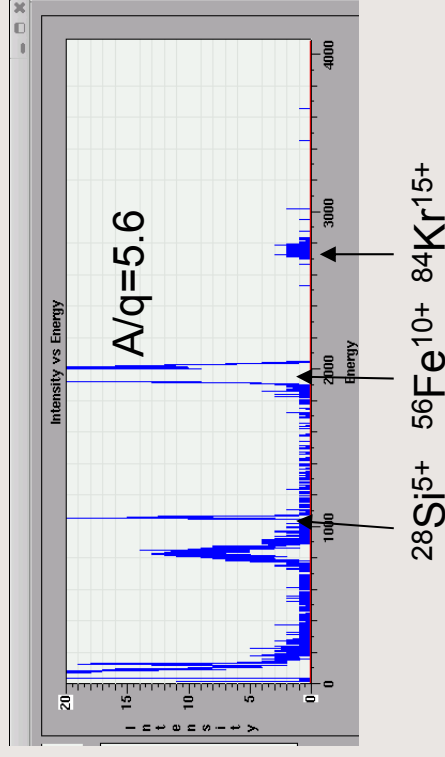
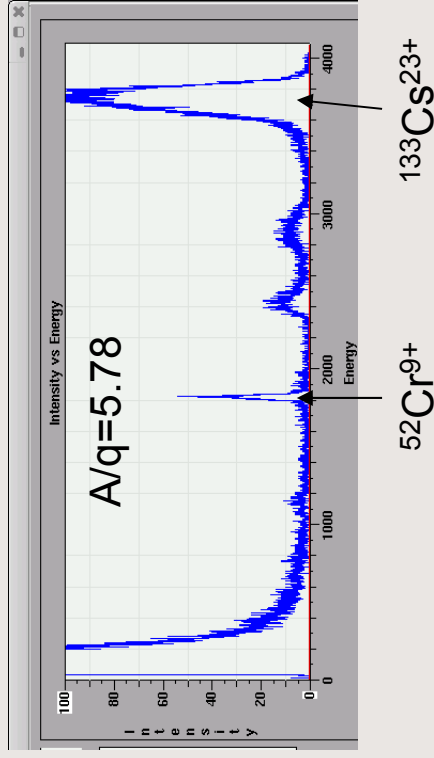


**$^{78}\text{Br}^{14+}$ (1E6 ion/s) $A/q = 5.57$ amu/e
injected as AlBr from ZrC target
accelerated to 5MeV/u
measured at TIGRESS detector
background ≈ 20 pA**

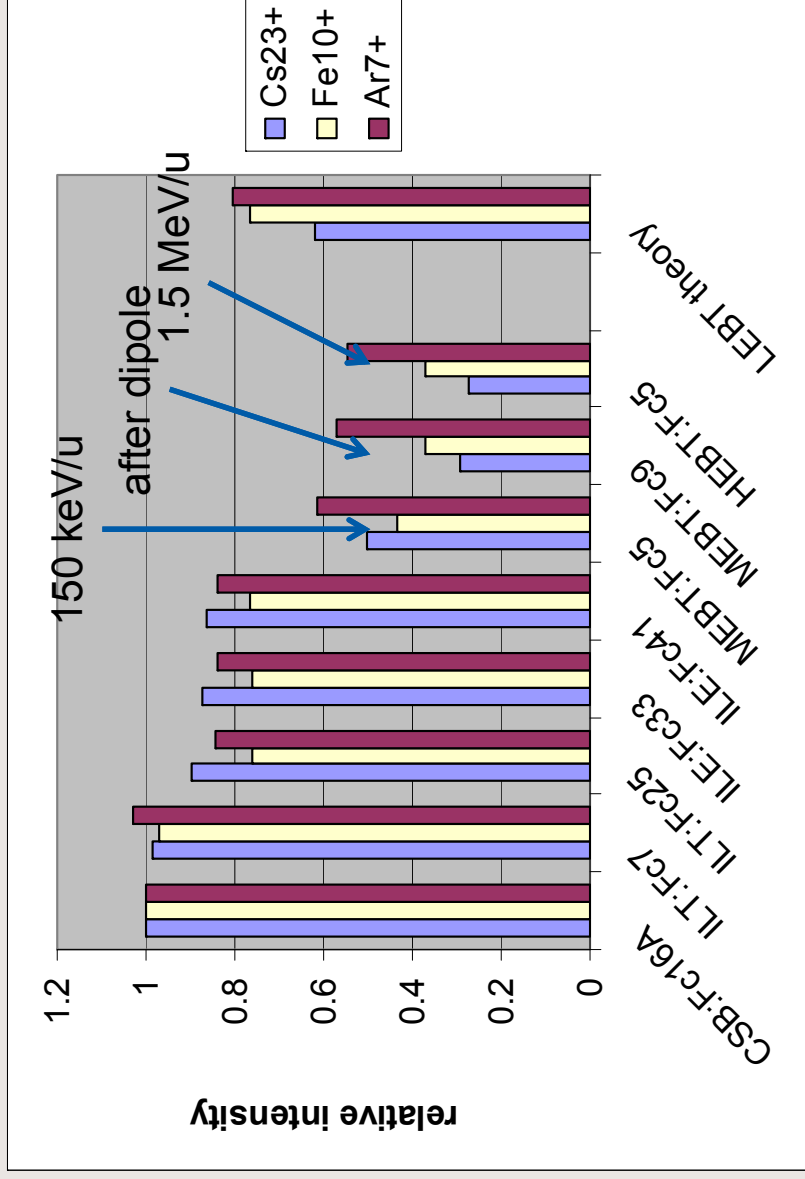
A/q	Isotopes (± 0.005 amu/e)
5	$^{40}\text{Ar}^{8+}$, $^{20}\text{Ne}^{4+}$, ...
5.11	$^{133}\text{Cs}^{26+}$
5.14	$^{36}\text{Ar}^{7+}$
5.2	$^{52}\text{Cr}^{10+}$, $^{78}\text{Kr}^{15+}$, $^{130}\text{Xe}^{25+}$
5.24	$^{84}\text{Kr}^{16+}$, $^{131}\text{Xe}^{25+}$
5.33	$^{16}\text{O}^{3+}$
5.41	$^{54}\text{Cr}^{10+}$,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

beam purity

energy spectrum after scattering from a gold foil ($77\mu\text{g}/\text{cm}^2$) at 1.5 MeV/u



beam transport

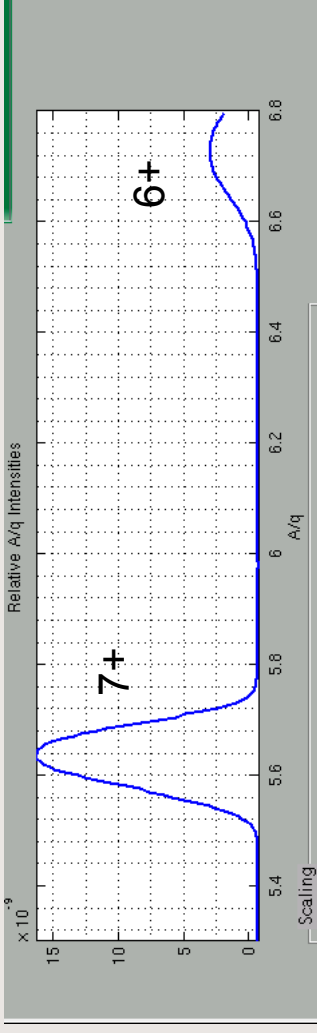


Measured beam current relative to the current after the CSB on several Faraday cups.
 The theoretical value for the LEBT assumes charge exchange
 at a pressure of $2 \cdot 10^{-7}$ T over 25 m.

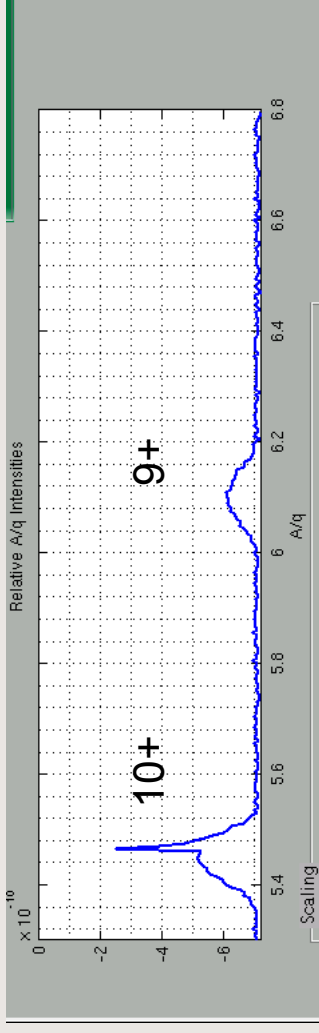
Cross sections from F. Ames et al., High Energy Phys Nucl Phys. 31 (2007) 211, ECRIS'06 proc.

charge exchange

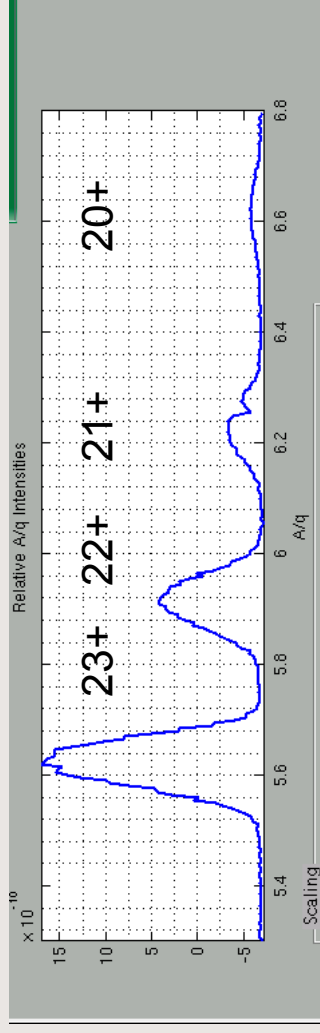
scan of MEBT dipole



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

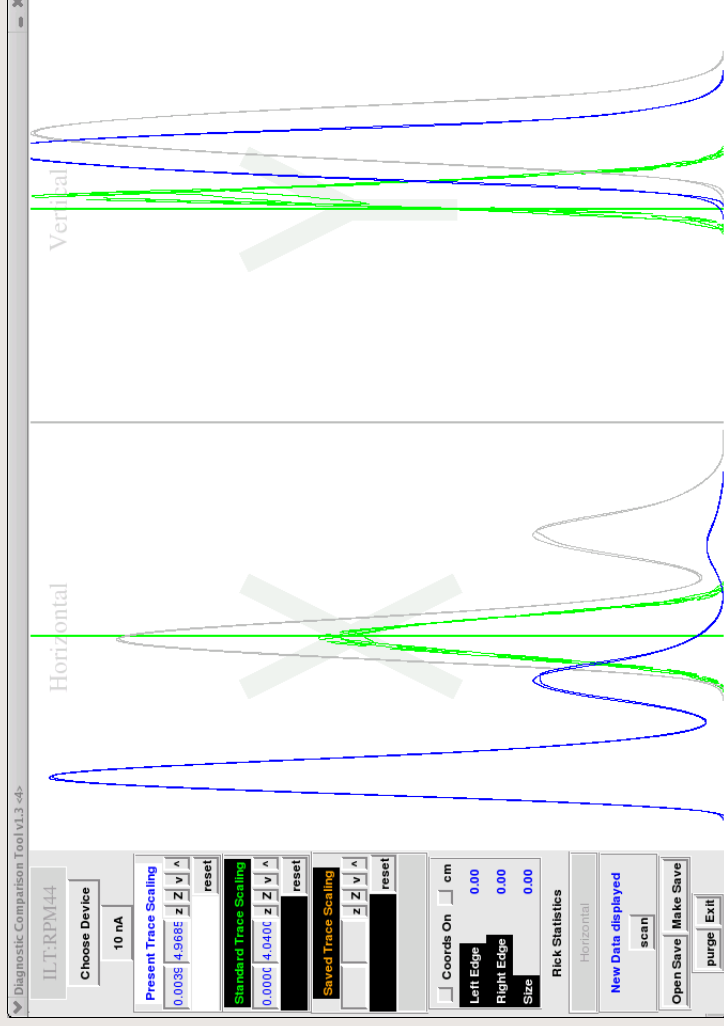


$^{56}\text{Fe}^{10+}$



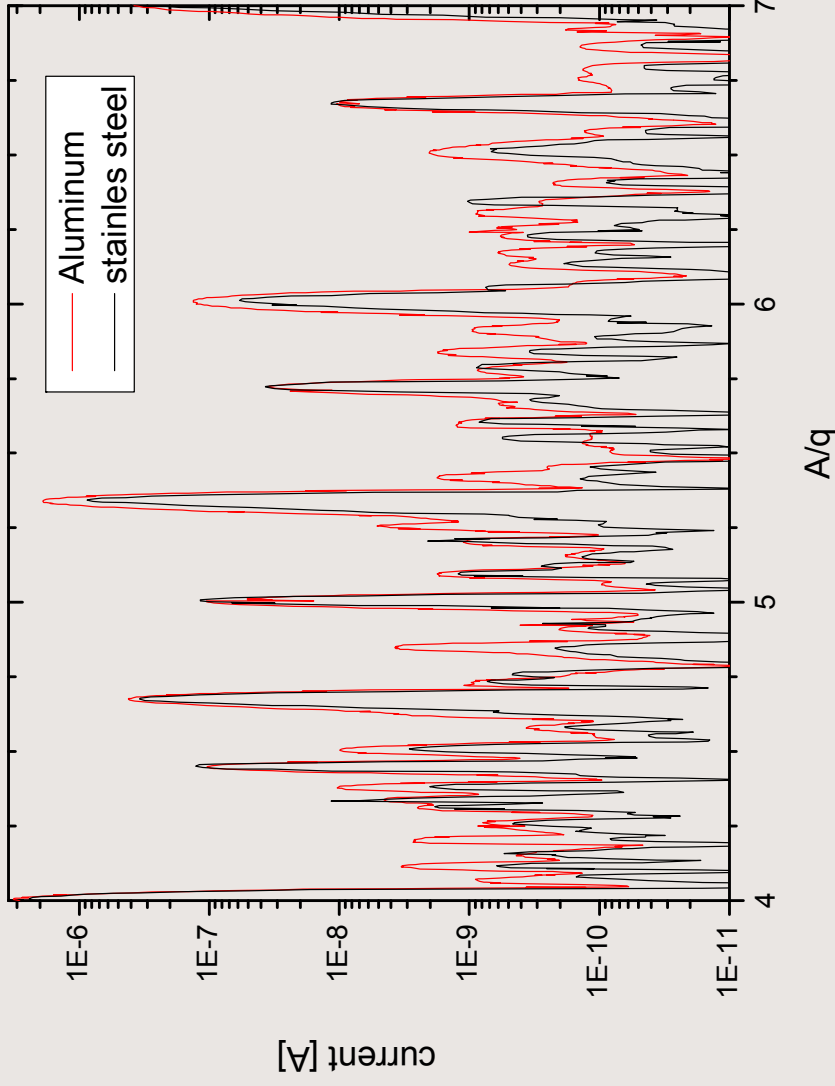
$^{133}\text{Cs}^{23+}$

charge exchange



Cs²³⁺ 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

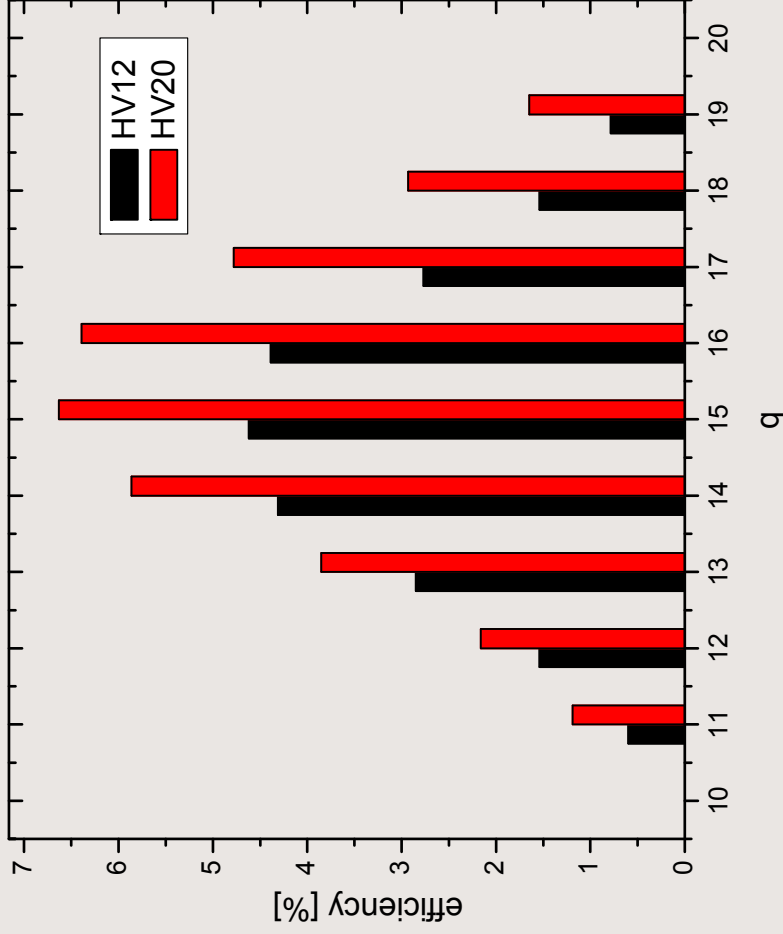


mass spectrum with stainless steel
and aluminum plasma chamber

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

higher total beam current

aluminum plasma chamber efficiency



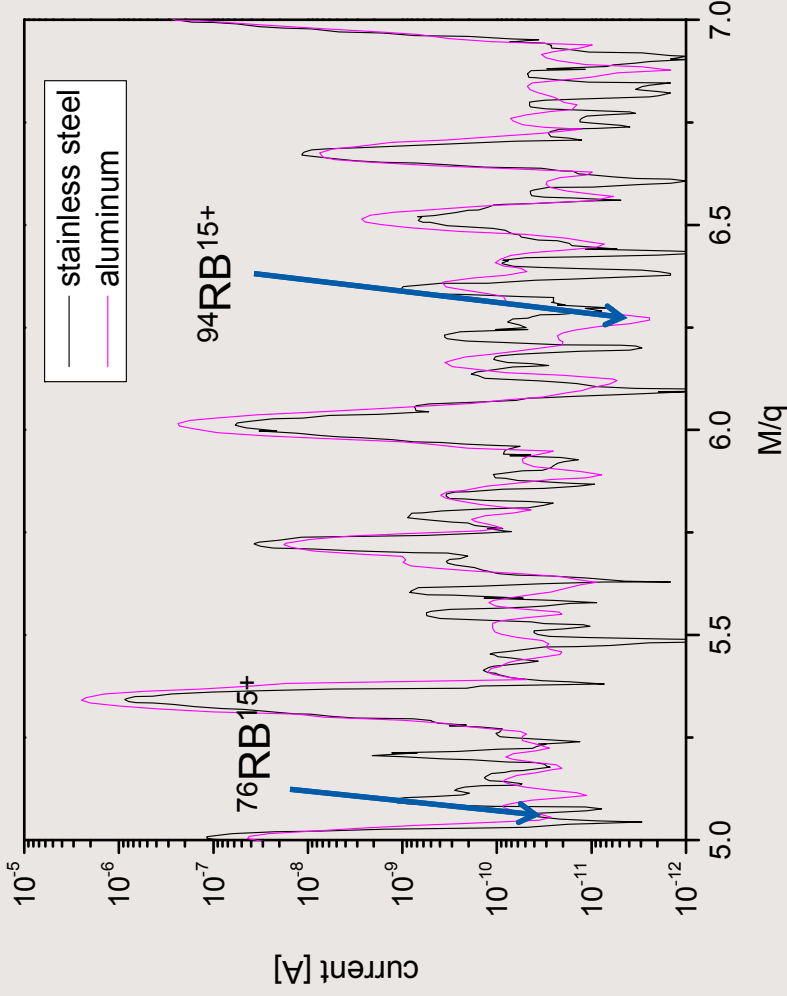
^{80}Rb charge state distribution from Al plasma chamber with different injection/ extraction voltage

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

increase of efficiency

	steel	Al
$^{48}\text{K}^{9+}$		0.67%
$^{46}\text{K}^{9+}$	0.5 %	
$^{80}\text{Rb}^{15+}$		4.5% (6.5%)
$^{76}\text{Rb}^{15+}$	1.68%	
$^{124}\text{Cs}^{20+}$	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 , $^{52,53}\text{Cr}$... missing or reduced

⇒ new test with $^{76,94}\text{Rb}$

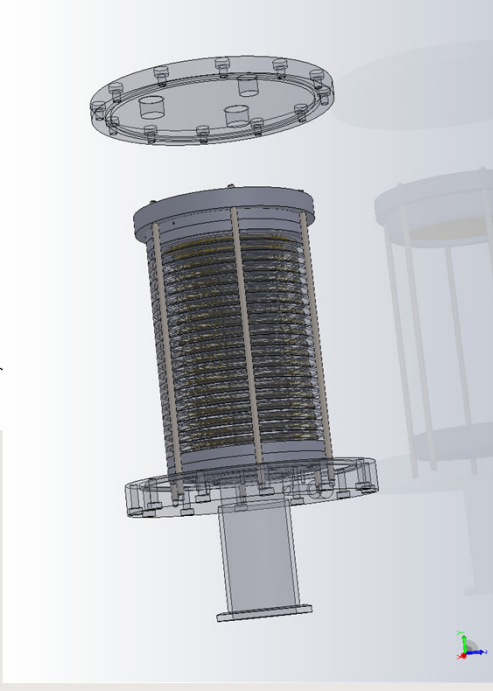
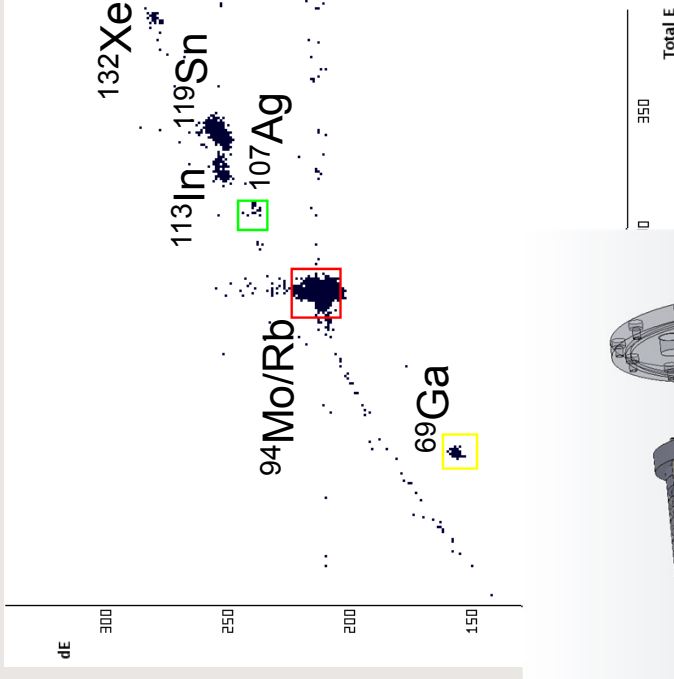
background identified
 $^{76}\text{Rb}^{15+}$ $A/q=5.06$

$^{61}\text{Ni}^{12+}$, $^{76}\text{Se}^{15+}$, $^{76}\text{Ge}^{15+}$
 $^{94}\text{Rb}^{15+}$ $A/q=6.26$

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

New diagnostics for particle identification

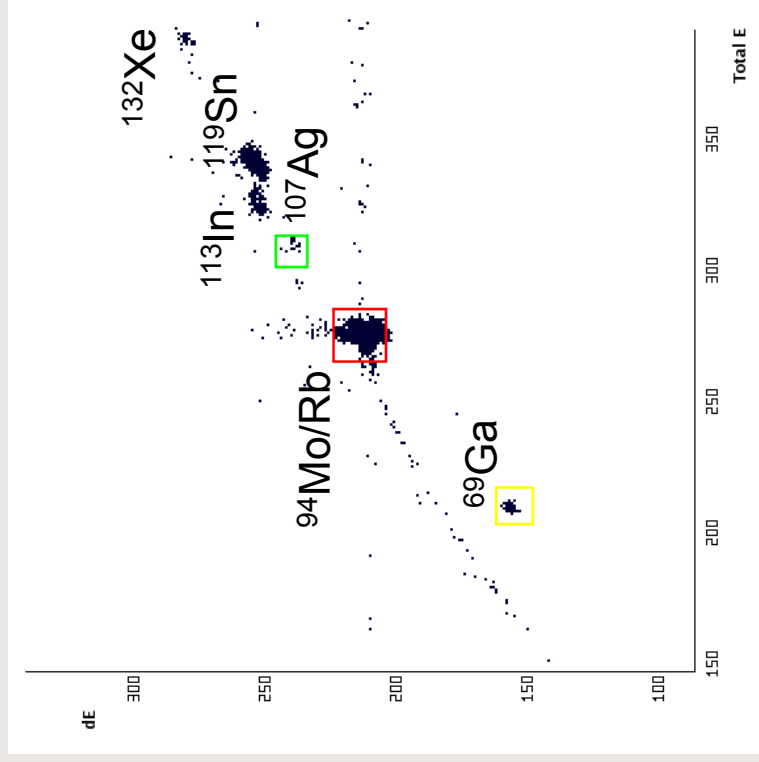
- Stopping gas counter in ISAC-II experimental hall
- **Particle ID from ΔE -E after acceleration**
- Tolerant of high count rates
- Thickness can be adjusted by varying gas pressure



In flight purification

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

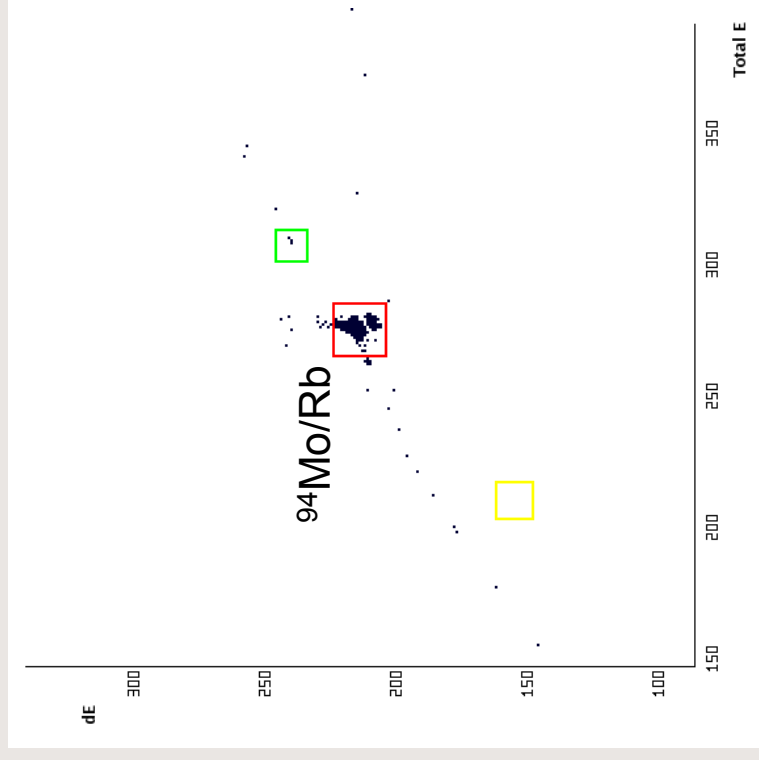
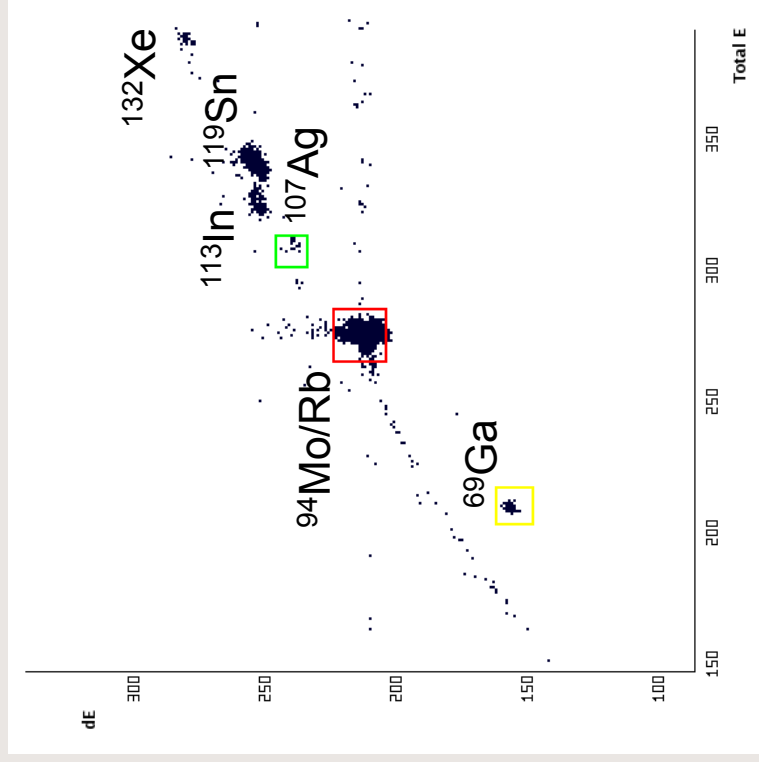
Before final filtration



In flight purification

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

Before final filtration

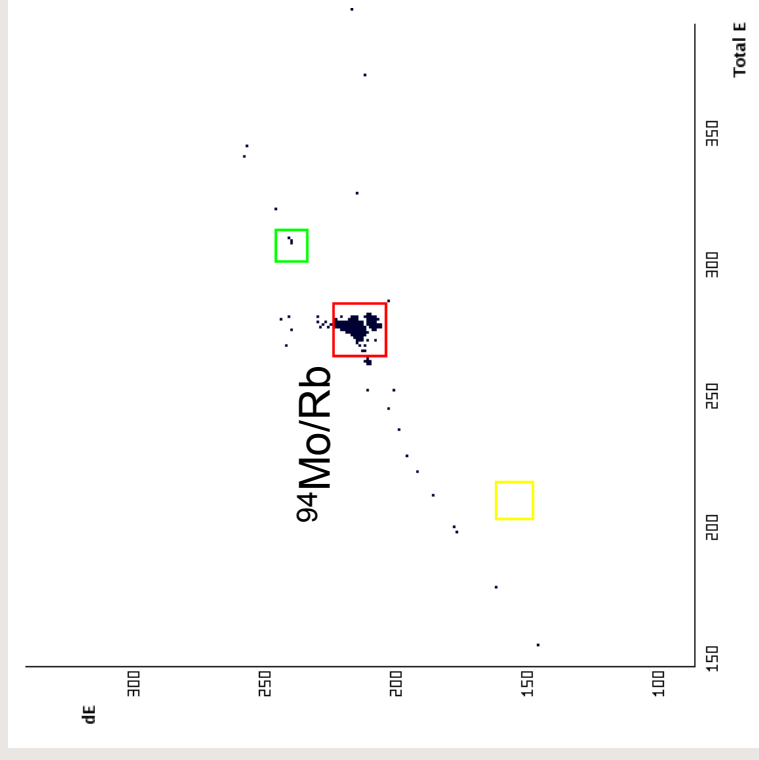
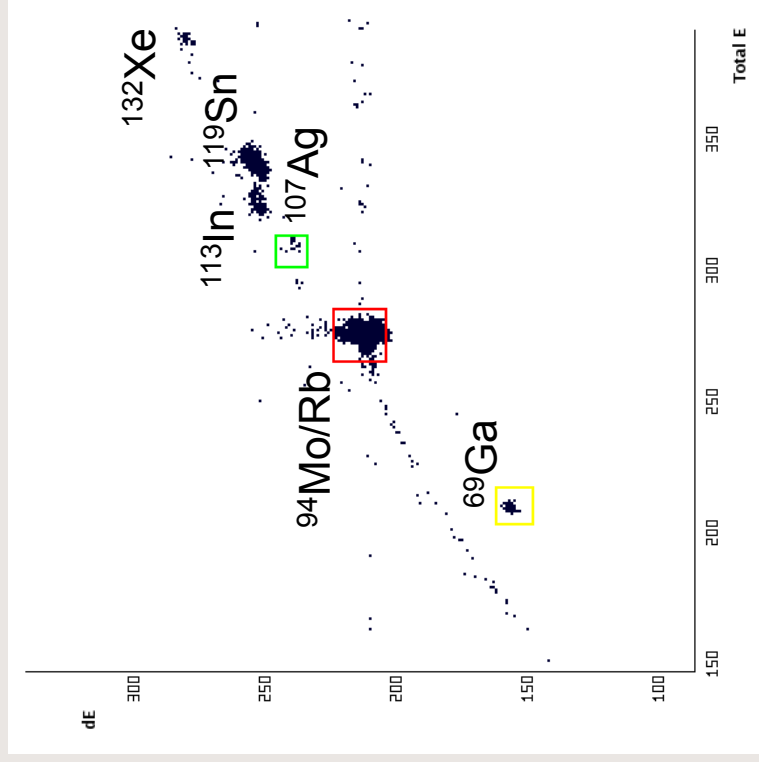


In flight purification

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

Before final filtration

After final filtration



new tools: CSB calculator



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:

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).

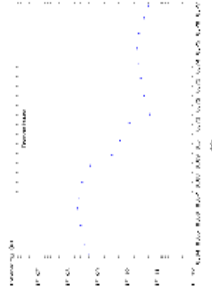
"Possible Companions" includes any stable species with an A/Q value within +/- 0.5% (1/100 resolving power of magnet) of the species of interest. Obviously not all of these stable species will be present and the amount of each species will depend on the operating conditions of the CSB (temperature/pressure 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
⁹⁴ Rb 14	6.708 <input type="button" value="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 Pd 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

CSB Assistant - Mozilla Firefox

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Google

94Rb 15

6.261

Apply 2nd Filter

$^{155}\text{Gd}^{23+}=6.735$ $^{161}\text{Dy}^{24+}=6.705$ $^{167}\text{Er}^{25+}=6.677$ $^{168}\text{Er}^{25+}=6.717$ $^{168}\text{Yb}^{25+}=6.717$
 $^{174}\text{Yb}^{26+}=6.689$ $^{175}\text{Lu}^{26+}=6.728$ $^{174}\text{Hf}^{26+}=6.689$ $^{181}\text{Ta}^{27+}=6.701$ $^{182}\text{W}^{27+}=6.738$
 $^{187}\text{Re}^{28+}=6.676$ $^{187}\text{Os}^{28+}=6.676$ $^{188}\text{Os}^{28+}=6.712$ $^{194}\text{Pt}^{29+}=6.688$ $^{195}\text{Pt}^{29+}=6.722$
 $^{201}\text{Hg}^{30+}=6.698$ $^{202}\text{Hg}^{30+}=6.732$ $^{207}\text{Pb}^{31+}=6.676$ $^{208}\text{Pb}^{31+}=6.708$ $^{209}\text{Bi}^{31+}=6.741$
 $^{234}\text{U}^{35+}=6.686$ $^{235}\text{U}^{35+}=6.715$

$^{25}\text{Mg}^{4+}=6.246$ $^{44}\text{Ca}^{7+}=6.279$ $^{50}\text{Ti}^{8+}=6.243$ $^{50}\text{V}^{8+}=6.243$ $^{50}\text{Cr}^{8+}=6.243$ $^{63}\text{Cu}^{10+}=6.292$
 $^{69}\text{Ga}^{11+}=6.265$ $^{73}\text{As}^{12+}=6.243$ $^{88}\text{Sr}^{14+}=6.278$ $^{94}\text{Zr}^{17+}=6.260$ $^{94}\text{Mo}^{17+}=6.260$
 $^{100}\text{Mo}^{16+}=6.244$ $^{100}\text{Ru}^{16+}=6.243$ $^{107}\text{Ag}^{17+}=6.288$ $^{113}\text{Cd}^{18+}=6.272$ $^{115}\text{In}^{18+}=6.272$
 $^{119}\text{Sn}^{19+}=6.258$ $^{125}\text{Te}^{20+}=6.245$ $^{131}\text{Xe}^{21+}=6.233$ $^{132}\text{Xe}^{21+}=6.281$ $^{132}\text{Ba}^{21+}=6.281$
 $^{138}\text{Ba}^{22+}=6.268$ $^{138}\text{La}^{22+}=6.268$ $^{138}\text{Ce}^{22+}=6.268$ $^{144}\text{Nd}^{23+}=6.256$ $^{150}\text{Nd}^{24+}=6.246$
 $^{144}\text{Sm}^{23+}=6.256$ $^{150}\text{Sm}^{24+}=6.246$ $^{151}\text{Eu}^{24+}=6.288$ $^{156}\text{Gd}^{25+}=6.236$ $^{157}\text{Gd}^{25+}=6.276$
 $^{156}\text{Dy}^{25+}=6.236$ $^{163}\text{Dy}^{26+}=6.266$ $^{169}\text{Tm}^{27+}=6.256$ $^{176}\text{Yb}^{28+}=6.283$ $^{175}\text{Lu}^{28+}=6.247$
 $^{176}\text{Lu}^{28+}=6.283$ $^{176}\text{Hf}^{28+}=6.283$ $^{181}\text{Ta}^{29+}=6.239$ $^{182}\text{W}^{29+}=6.274$ $^{187}\text{Re}^{30+}=6.231$
 $^{187}\text{Os}^{30+}=6.231$ $^{188}\text{Os}^{30+}=6.265$ $^{194}\text{Pt}^{31+}=6.256$ $^{195}\text{Pt}^{31+}=6.289$ $^{200}\text{Hg}^{32+}=6.248$
 $^{201}\text{Hg}^{32+}=6.280$ $^{206}\text{Pb}^{33+}=6.241$ $^{207}\text{Pb}^{33+}=6.271$ $^{232}\text{Th}^{37+}=6.271$ $^{238}\text{U}^{38+}=6.264$

94Rb 16

5.870

Apply 2nd Filter

$^{41}\text{K}^{7+}=5.851$ $^{47}\text{Ti}^{8+}=5.868$ $^{53}\text{Cr}^{9+}=5.882$ $^{59}\text{Co}^{10+}=5.893$ $^{82}\text{Se}^{14+}=5.851$ $^{82}\text{Kr}^{14+}=5.850$
 $^{88}\text{Sr}^{15+}=5.860$ $^{94}\text{Zr}^{16+}=5.869$ $^{94}\text{Mo}^{16+}=5.869$ $^{100}\text{Mo}^{17+}=5.876$ $^{100}\text{Ru}^{17+}=5.876$
 $^{106}\text{Pd}^{18+}=5.883$ $^{106}\text{Cd}^{18+}=5.883$ $^{112}\text{Cd}^{19+}=5.889$ $^{112}\text{Sn}^{19+}=5.889$ $^{117}\text{Sn}^{20+}=5.845$
 $^{118}\text{Sn}^{20+}=5.895$ $^{123}\text{Sb}^{21+}=5.852$ $^{123}\text{Te}^{21+}=5.852$ $^{129}\text{Xe}^{22+}=5.859$ $^{135}\text{Ba}^{23+}=5.865$
 $^{141}\text{Pr}^{24+}=5.871$ $^{147}\text{Sm}^{25+}=5.876$ $^{152}\text{Sm}^{26+}=5.843$ $^{152}\text{Eu}^{26+}=5.881$ $^{152}\text{Gd}^{26+}=5.843$
 $^{158}\text{Gd}^{27+}=5.848$ $^{159}\text{Tb}^{27+}=5.886$ $^{158}\text{Dy}^{27+}=5.849$ $^{164}\text{Dy}^{28+}=5.854$ $^{165}\text{Ho}^{28+}=5.890$
 $^{164}\text{Er}^{28+}=5.854$ $^{170}\text{Er}^{29+}=5.859$ $^{170}\text{Yb}^{29+}=5.859$ $^{171}\text{Yb}^{29+}=5.894$ $^{176}\text{Yb}^{30+}=5.864$
 $^{176}\text{Lu}^{30+}=5.864$ $^{176}\text{Hf}^{30+}=5.864$ $^{177}\text{Hf}^{30+}=5.898$ $^{182}\text{W}^{31+}=5.869$ $^{187}\text{Re}^{32+}=5.842$
 $^{187}\text{Os}^{32+}=5.842$ $^{188}\text{Os}^{32+}=5.873$ $^{193}\text{Ir}^{33+}=5.847$ $^{194}\text{Pt}^{33+}=5.877$ $^{199}\text{Hg}^{34+}=5.851$
 $^{200}\text{Hg}^{34+}=5.881$ $^{205}\text{Tl}^{35+}=5.856$ $^{206}\text{Pb}^{35+}=5.884$ $^{234}\text{U}^{40+}=5.850$ $^{235}\text{U}^{40+}=5.876$

94Rb 17

5.525

Apply 2nd Filter

$^{11}\text{B}^{2+}=5.504$ $^{22}\text{Ne}^{4+}=5.497$ $^{30}\text{Ti}^{9+}=5.549$ $^{50}\text{V}^{9+}=5.549$ $^{30}\text{Cr}^{9+}=5.549$ $^{61}\text{Ni}^{11+}=5.539$
 $^{72}\text{Ge}^{13+}=5.532$ $^{83}\text{Kr}^{15+}=5.527$ $^{94}\text{Zr}^{17+}=5.523$ $^{94}\text{Mo}^{17+}=5.523$ $^{100}\text{Mo}^{18+}=5.550$

September 27, 2012

Triumf, Operation of an Ion Charge State Detector at TRIUMF

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CSB Assistant

135Gd²³⁺=6.735 161Dy²⁴⁺=6.705 167Er²⁵⁺=6.677 168Er²⁵⁺=6.717 168Yb²⁵⁺=6.717

174Yb²⁶⁺=6.689 175Lu²⁶⁺=6.728 174Hf²⁶⁺=6.689 181Ta²⁷⁺=6.701 182W²⁷⁺=6.738

63Cu¹⁵⁺=4.159 69Ga¹⁶⁺=4.271 88Sr²¹⁺=4.150 94Zr²²⁺=4.231 94Mo²²⁺=4.231

100Mo²³⁺=4.306 100Ru²³⁺=4.306 107Ag²⁵⁺=4.239 113Cd²⁶⁺=4.305 113In²⁶⁺=4.305

119Sn²⁸⁺=4.210 125Te²⁹⁺=4.270 131Xe³¹⁺=4.186 132Xe³¹⁺=4.218 132Ba³¹⁺=4.218

138Ba³²⁺=4.272 138La³²⁺=4.272 138Ce³²⁺=4.272 144Nd³⁴⁺=4.196 150Nd³⁵⁺=4.246

144Sm³⁴⁺=4.196 150Sm³⁵⁺=4.246 151Eu³⁵⁺=4.275 151Eu³⁶⁺=4.156 156Gd³⁶⁺=4.294

156Gd³⁷⁺=4.178 157Gd³⁷⁺=4.204 156Dy³⁶⁺=4.294 156Dy³⁷⁺=4.178 163Dy³⁸⁺=4.250

169Tm³⁹⁺=4.294 169Tm⁴⁰⁺=4.187 176Yb⁴¹⁺=4.254 176Yb⁴²⁺=4.153 175Lu⁴¹⁺=4.230

176Lu⁴¹⁺=4.254 176Lu⁴²⁺=4.153 176Hf⁴¹⁺=4.254 176Hf⁴²⁺=4.153 181Ta⁴²⁺=4.271

181Ta⁴³⁺=4.172 182W⁴²⁺=4.295 182W⁴³⁺=4.195 187Re⁴³⁺=4.310 187Re⁴⁴⁺=4.212

187Os⁴³⁺=4.310 187Os⁴⁴⁺=4.212 188Os⁴⁴⁺=4.235 194Pt⁴⁵⁺=4.273 194Pt⁴⁶⁺=4.180

195Pt⁴⁵⁺=4.295 195Pt⁴⁶⁺=4.202 200Hg⁴⁶⁺=4.309 200Hg⁴⁷⁺=4.218 201Hg⁴⁷⁺=4.239

201Hg⁴⁸⁺=4.151 206Pb⁴⁸⁺=4.254 206Pb⁴⁹⁺=4.167 207Pb⁴⁸⁺=4.275 207Pb⁴⁹⁺=4.187

232Th⁵⁴⁺=4.260 232Th⁵⁵⁺=4.182 238U⁵⁵⁺=4.291 238U⁵⁶⁺=4.214

187Os³²⁺=5.842 188Os³²⁺=5.873 193Ir³³⁺=5.847 194Pt³³⁺=5.877 199Hg³⁴⁺=5.851

200Hg³⁴⁺=5.881 205Tl³⁵⁺=5.856 206Pb³⁵⁺=5.884 234U⁴⁰⁺=5.850 235U⁴⁰⁺=5.876

94Rb 22 18.6%

This A/Q = 4.232

First A/Q = 6.261

94Rb15+

63Cu¹⁵⁺=4.159 69Ga¹⁶⁺=4.271 88Sr²¹⁺=4.150 94Zr²²⁺=4.231 94Mo²²⁺=4.231

100Mo²³⁺=4.306 100Ru²³⁺=4.306 107Ag²⁵⁺=4.239 113Cd²⁶⁺=4.305 113In²⁶⁺=4.305

119Sn²⁸⁺=4.210 125Te²⁹⁺=4.270 131Xe³¹⁺=4.186 132Xe³¹⁺=4.218 132Ba³¹⁺=4.218

138Ba³²⁺=4.272 138La³²⁺=4.272 138Ce³²⁺=4.272 144Nd³⁴⁺=4.196 150Nd³⁵⁺=4.246

144Sm³⁴⁺=4.196 150Sm³⁵⁺=4.246 151Eu³⁵⁺=4.275 151Eu³⁶⁺=4.156 156Gd³⁶⁺=4.294

156Gd³⁷⁺=4.178 157Gd³⁷⁺=4.204 156Dy³⁶⁺=4.294 156Dy³⁷⁺=4.178 163Dy³⁸⁺=4.250

169Tm³⁹⁺=4.294 169Tm⁴⁰⁺=4.187 176Yb⁴¹⁺=4.254 176Yb⁴²⁺=4.153 175Lu⁴¹⁺=4.230

176Lu⁴¹⁺=4.254 176Lu⁴²⁺=4.153 176Hf⁴¹⁺=4.254 176Hf⁴²⁺=4.153 181Ta⁴²⁺=4.271

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Summary

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



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Thank you! Merci!