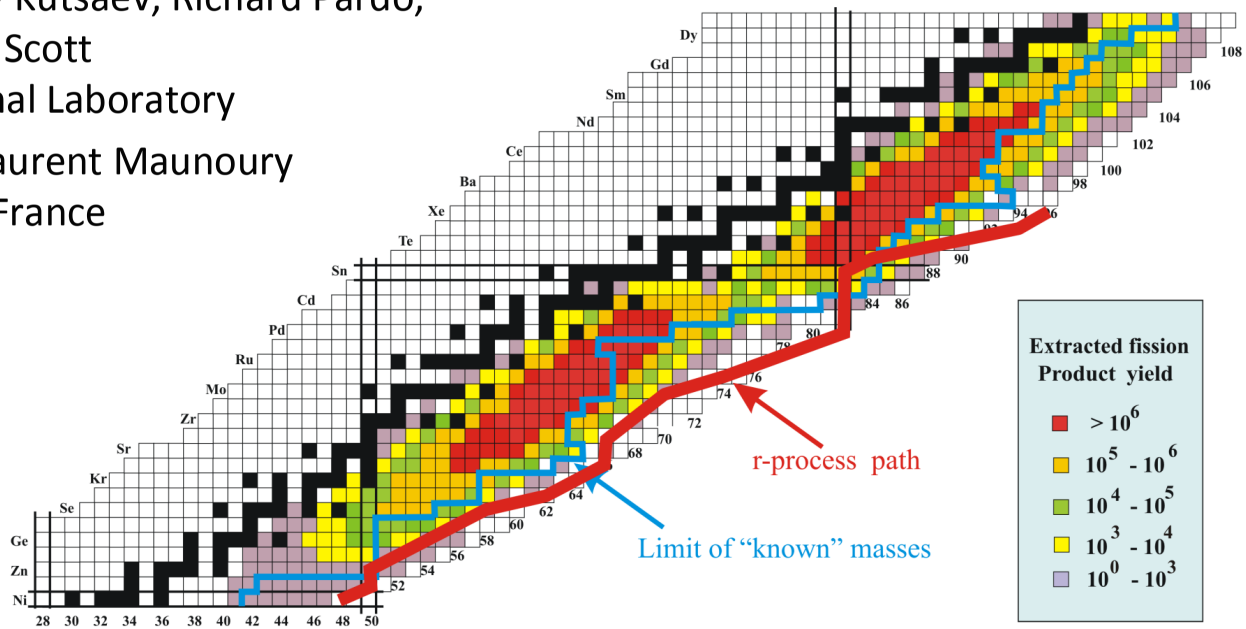
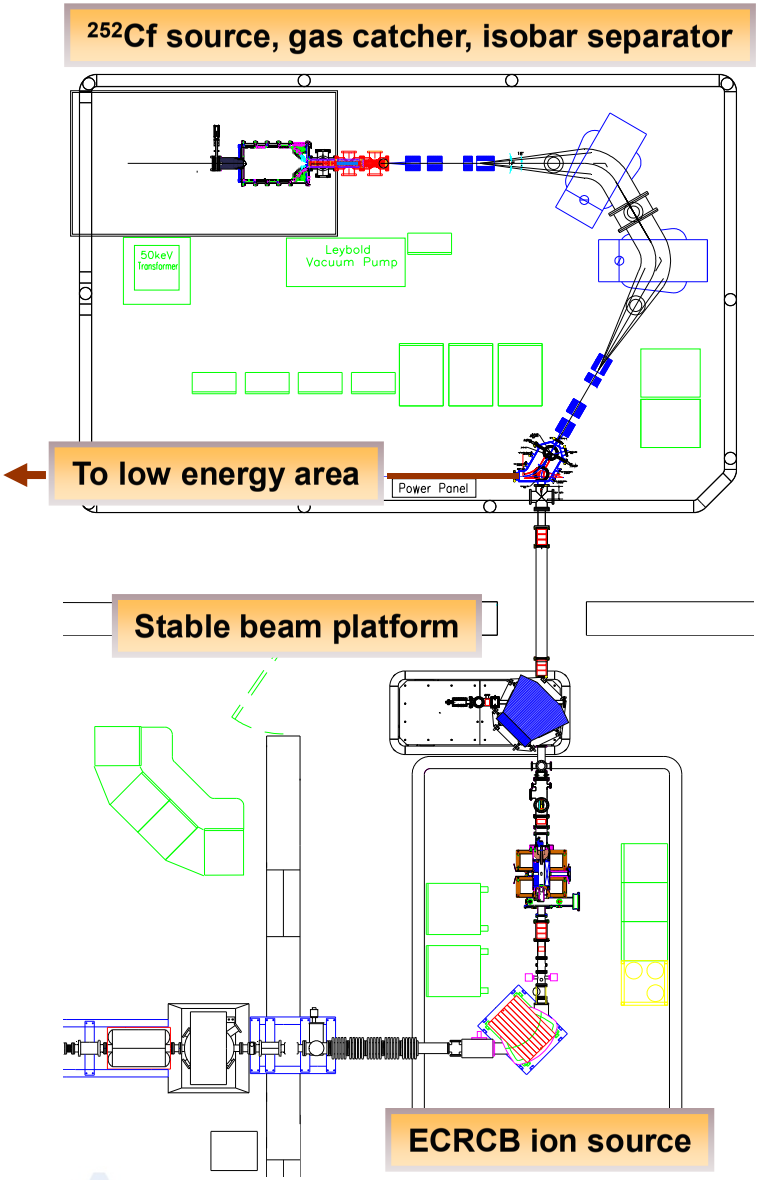
Performance of the ANL ECR Charge Breeder with Low Mass Beams

Richard Vondrasek, Sergey Kutsaev, Richard Pardo,
Robert Scott
Argonne National Laboratory
Pierre Delahaye, Laurent Maunoury
GANIL, France

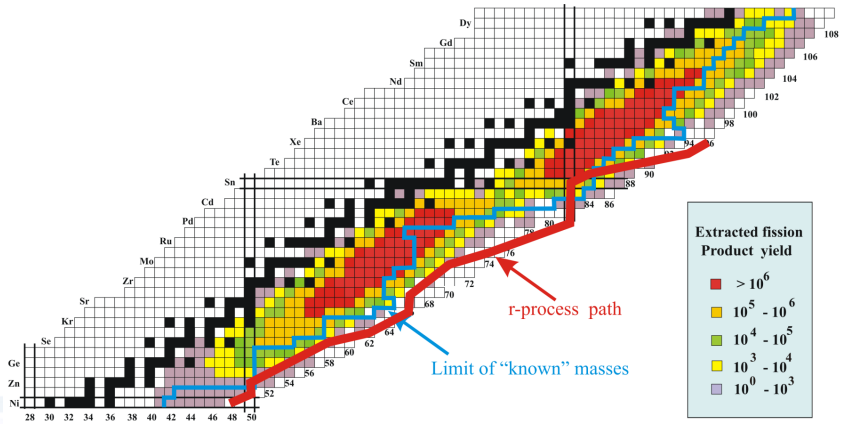


- Review of charge breeder design
- Investigations with low mass species
- Injection simulations

CARIBU - Californium Rare Ion Breeder Upgrade

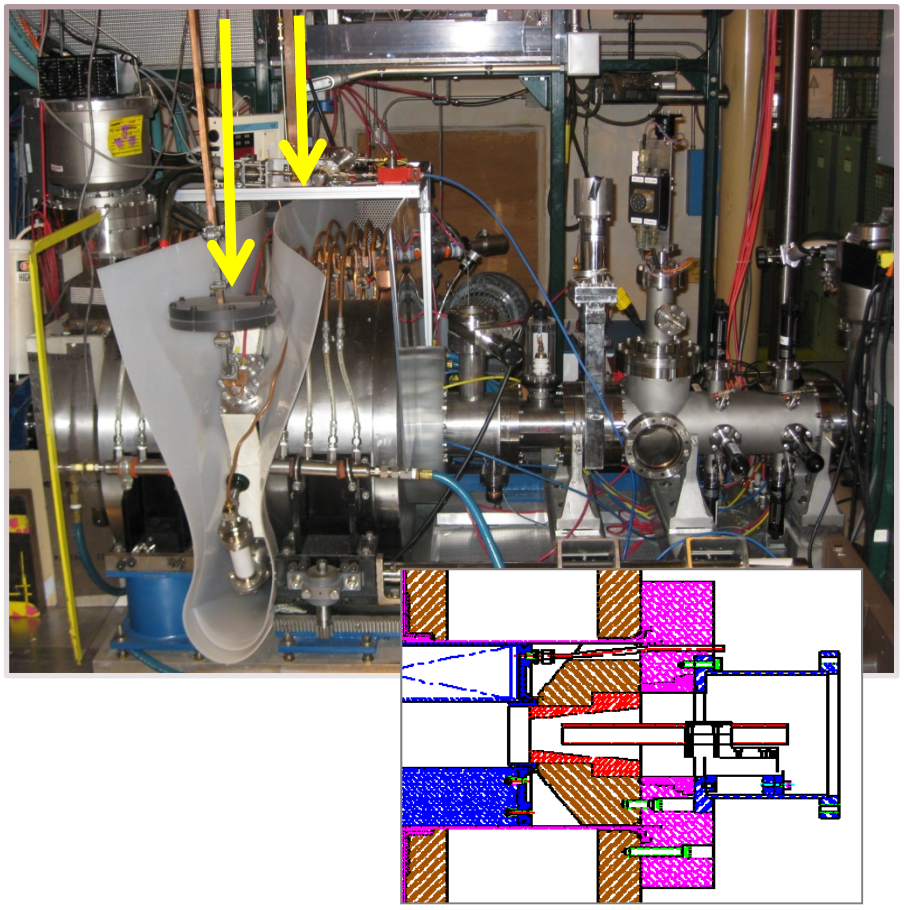


- ^{252}Cf fission source provides radioactive species
  - $T_{1/2}$=2.6 a 3.1% fission branch
  - 500 mCi source installed September 5, 2012
- High quality beam out of gas catcher
  - Energy spread of 1 eV
  - Emittance of 3 π mm mrad
- Stopped beams and reaccelerated beams up to 15 MeV/u
- Highest yields are in the mid-mass species
  - Above Germanium, below Dysprosium



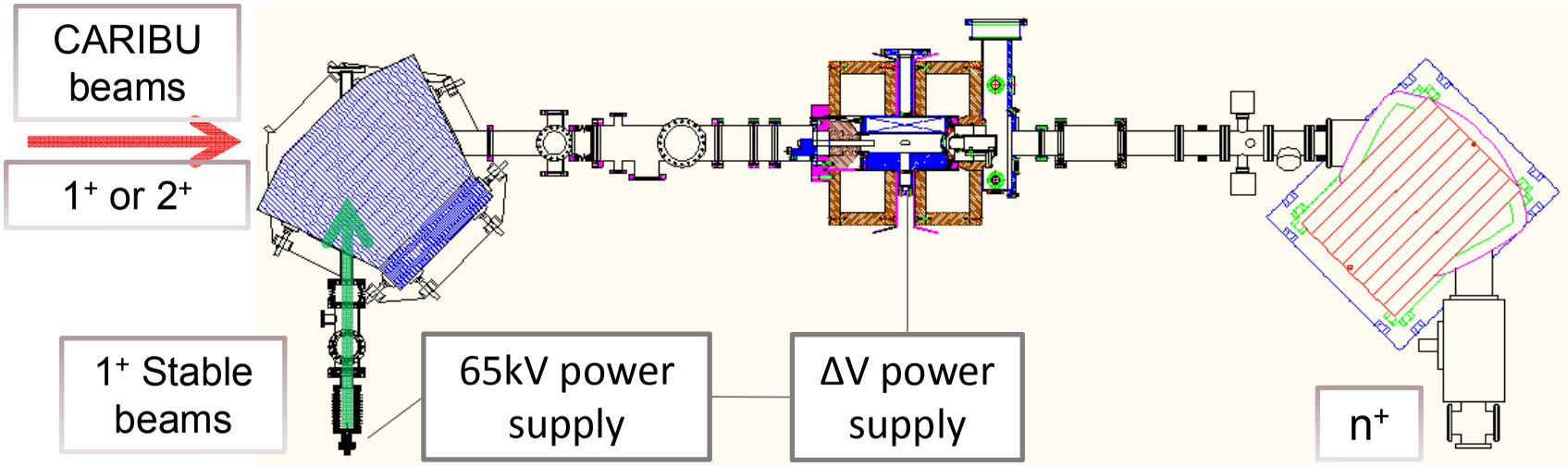
ECR charge breeder

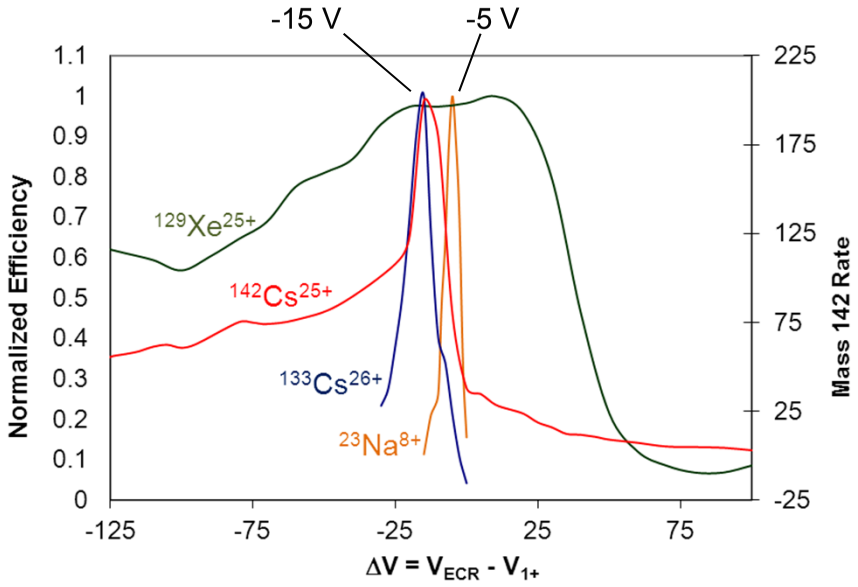
- Multiple frequency operation
  - Klystron: 10.44 GHz, 2 kW
  - TWTA: 11→13 GHz, 0.5 kW
- Open hexapole structure
  - RF is injected radially
  - Uniform iron in the injection region for symmetrical fields
  - Improved pumping to the plasma chamber region
    - Base pressure: 2×10^{-8} mbar
    - Operation: 7×10^{-8} mbar
    - Extraction pressure: 4×10^{-8} mbar
- Movable grounded tube
  - 2.5 cm of travel
- 50 kV high voltage isolation



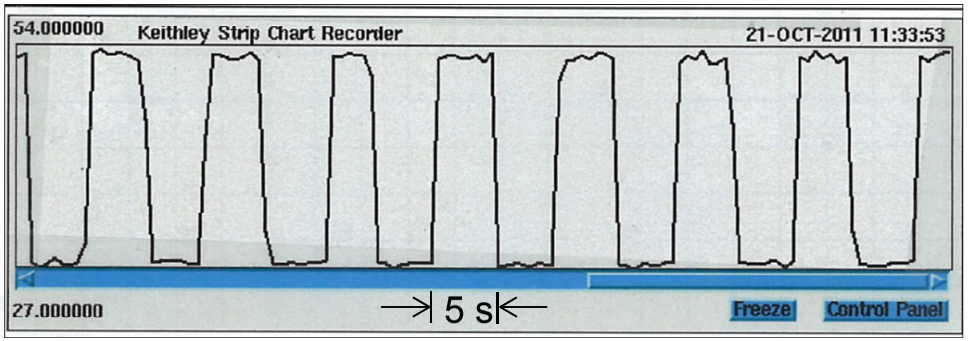
	Design value	Running condition
B_{inj}	1.31 T	1.16 T
B_{min}	0.31	0.27
B_{ext}	0.85	0.83
$B_{(radial)}$		0.86 T
Last closed surface		0.61 T

Charge breeder and stable beam source



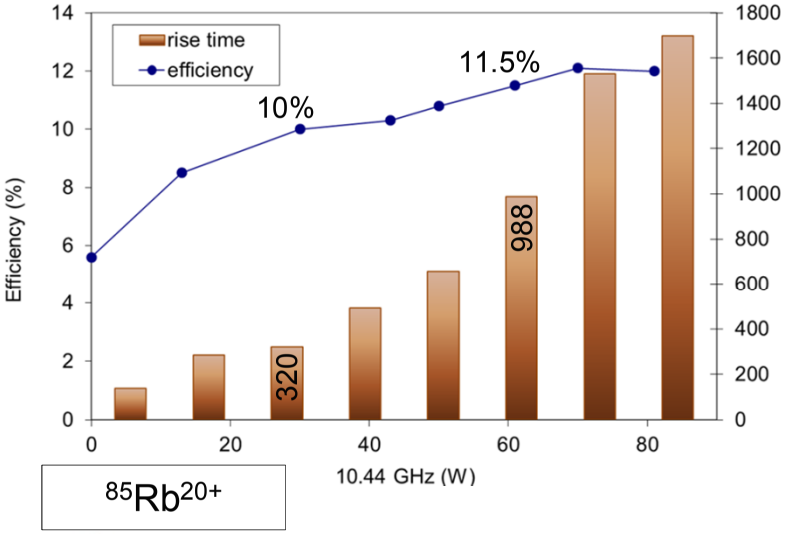


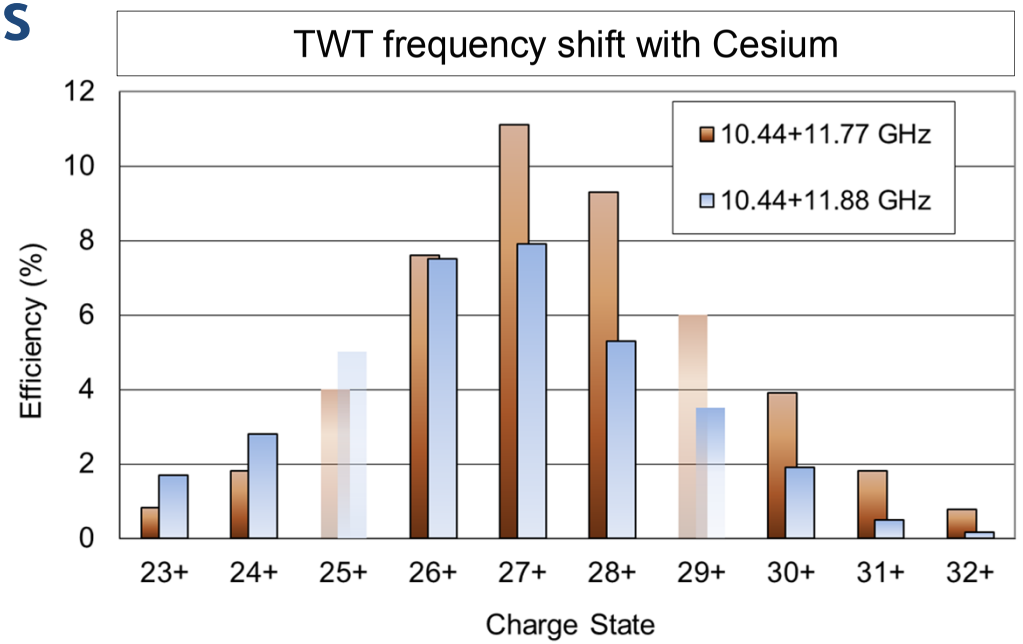
- Narrow tuning range for condensable elements, wide range for gases
- Stable and radioactive Cs peak at the same position
- For radioactive beams, have two separate 65 kV supplies

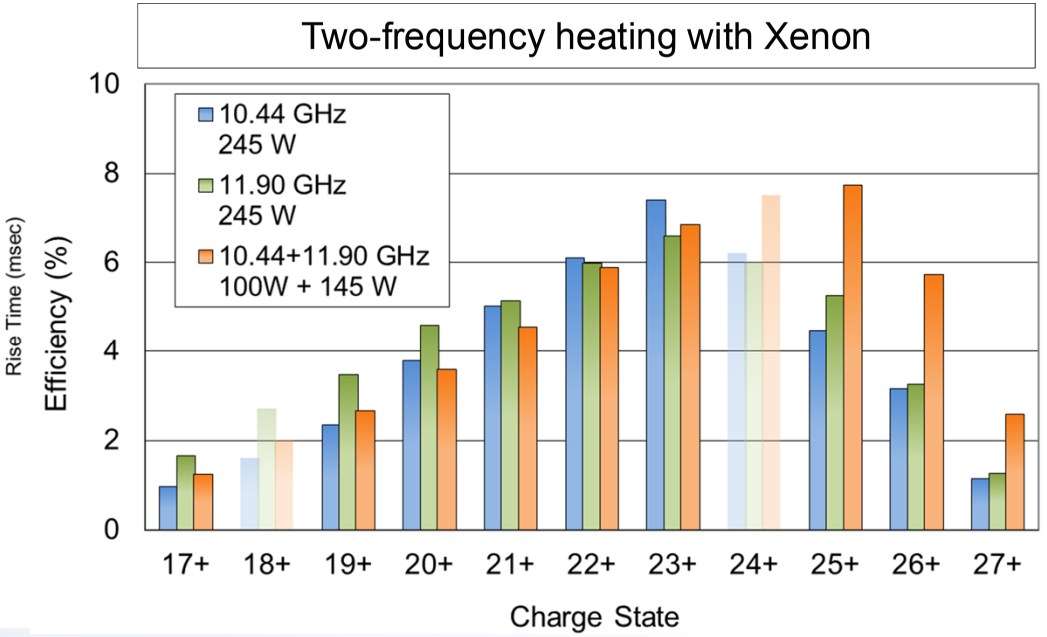


Charge breeding results

Ion	Charge State	Efficiency (%)	A/Q
^{23}Na	8+	3.6	2.87
^{84}Kr	17+	15.6	4.94
^{85}Rb	19+	13.7	4.47
^{129}Xe	25+	13.4	5.16
^{133}Cs	27+	13.0	4.93
^{143}Cs (1+) ($t_{1/2}$ = 1.79 s)	27+	11.7	5.30
^{143}Ba (2+) ($t_{1/2}$ = 14.33 s)	27+	14.7	5.30

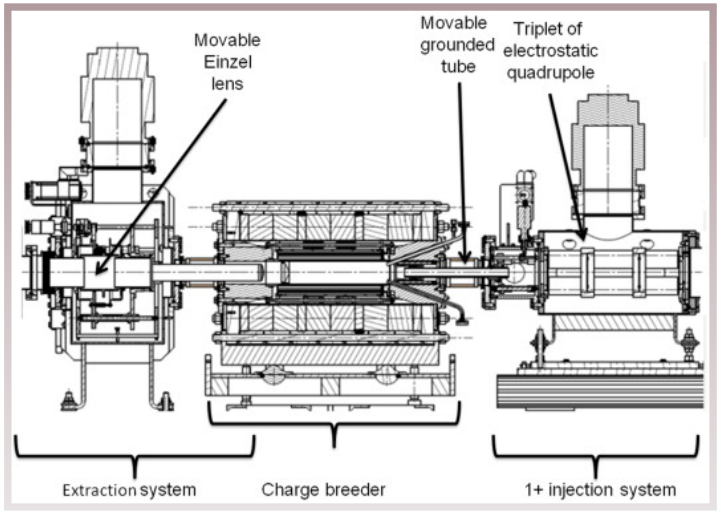


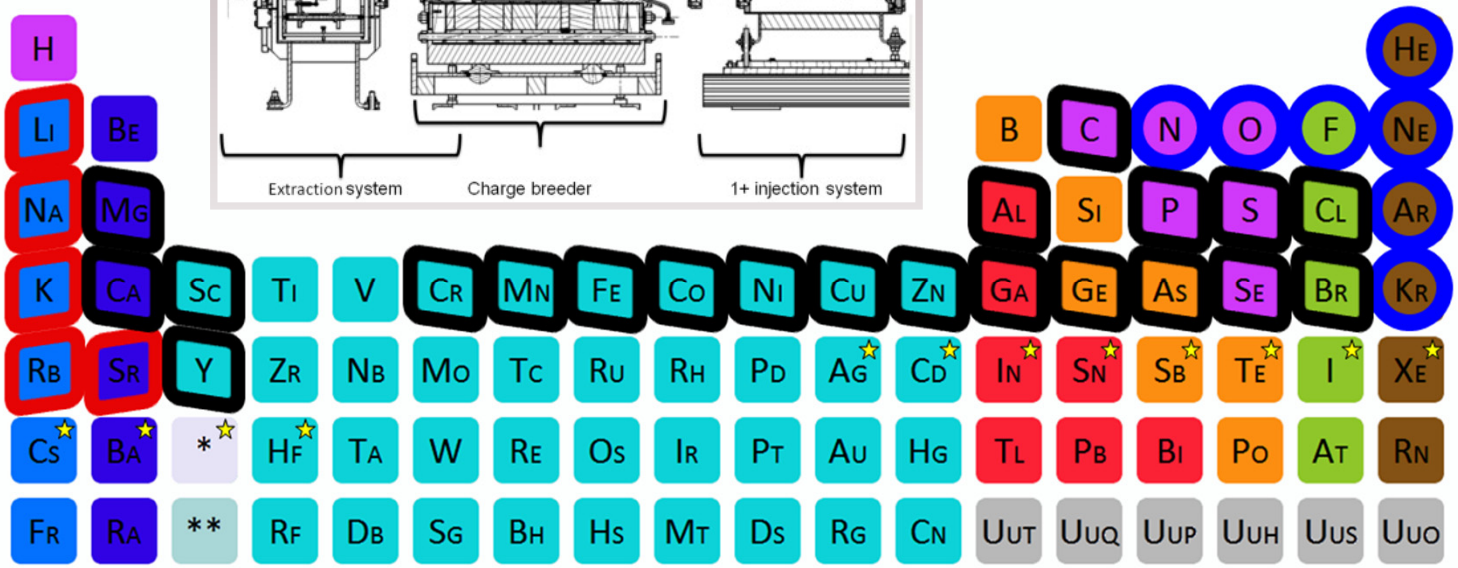




Interest in low mass species

- GANIL is upgrading the SPIRAL facility and they are interested in light ions (A<90)
- The upgrade will extend the range of elements available for post-acceleration to condensable elements
- Charge breeder will be a modified Phoenix ECR ion source formerly at ISOLDE





FEBIAD

Surface

New targets

NANOGAN

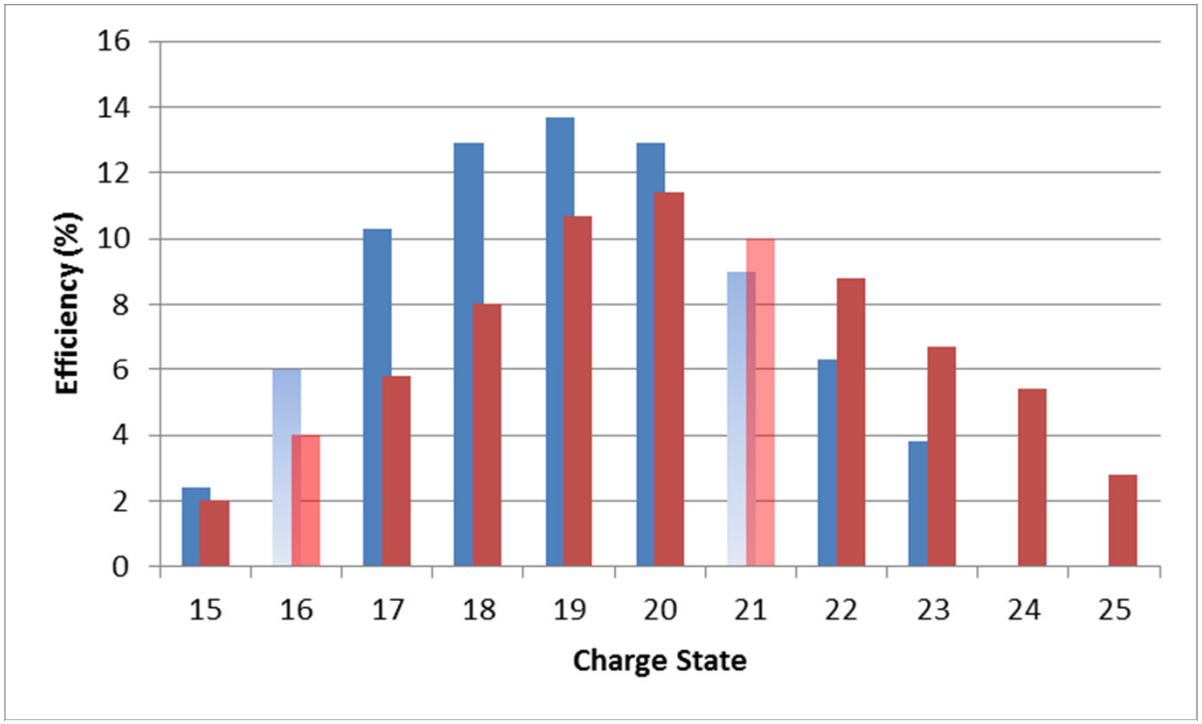
Charge breeding results with low mass species

- Goals were to….
  - Verify previous results
  - Determine critical parameters for good breeding efficiency
  - Determine if the observed efficiencies for the mid-mass species could be extended to the low mass species
- Series of tests performed over one week with sodium, potassium, and rubidium

Ion	Charge State	Efficiency (%)	A/Q
^{23}Na	6+	6.6	3.83
	7+	10.1	3.29
	8+	8.6	2.87
	9+	3.4	2.56
^{39}K	7+	3.0	5.57
	8+	4.9	4.87
	9+	15.6	4.33
	10+	17.9	3.90

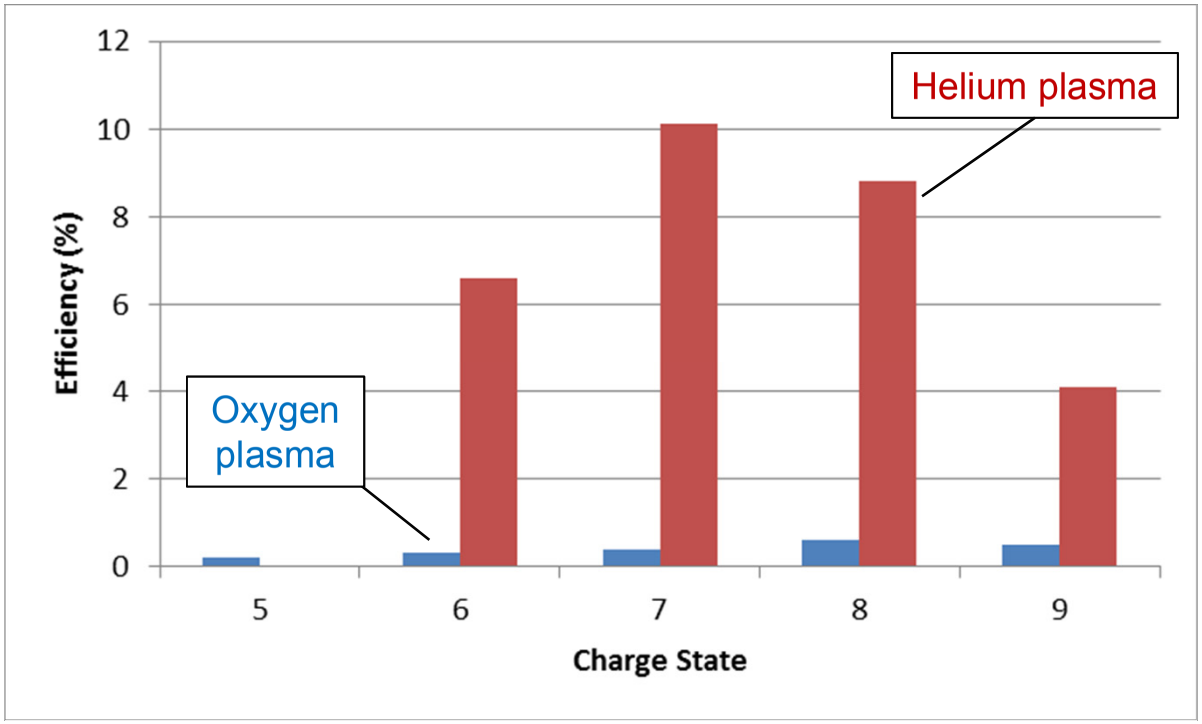
Rubidium performance

- Established baseline performance with rubidium beam
  - Not at the highest achieved efficiency but CSD was shifted higher
  - Oxygen plasma – operating pressure 6.1 x 10^{-8} mbar
  - Two-frequency heating
    - 85 W (10.44 GHz) + 323 W (11.77 GHz)
  - 30 kV extraction voltage



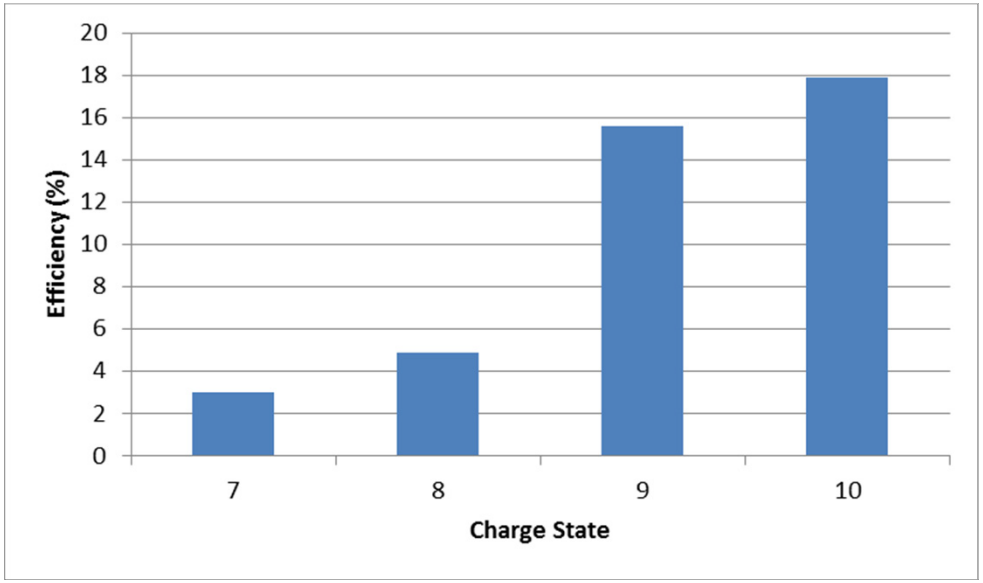
Sodium performance

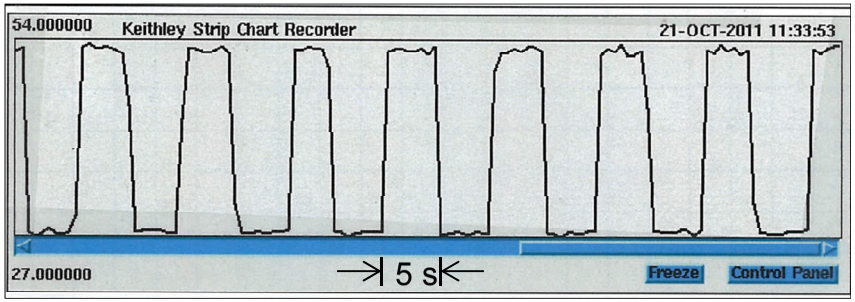
- Sodium produced from surface ionization source
- Base pressure: 3.7 x 10^{-8} mbar
- Helium plasma: 8.8 x 10^{-8} mbar
  - First tried oxygen plasma before switching to helium plasma
  - Adding oxygen to helium plasma reduced $^{23}Na^{8+}$ efficiency from 6% to 5%
  - Changing support gas to He-3 versus He-4 made no difference



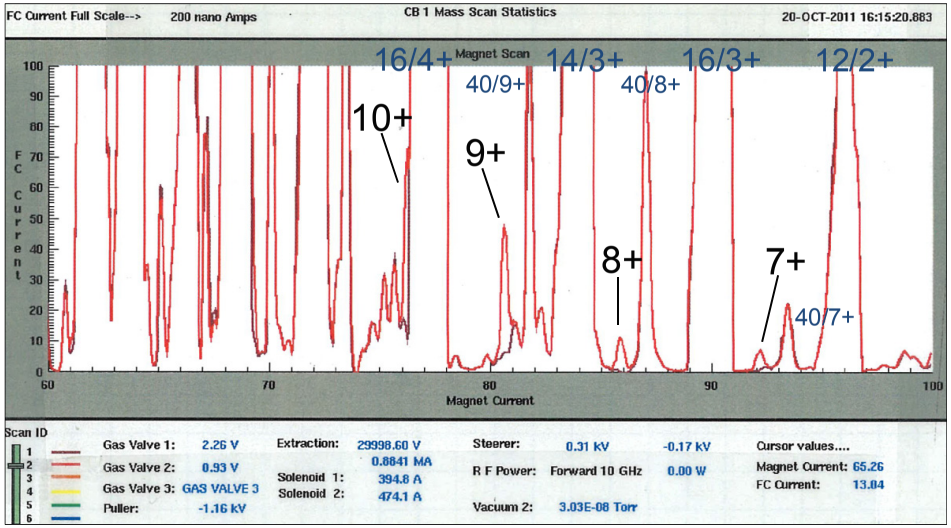
Potassium performance

- Potassium produced from surface ionization source
- Base pressure: 3.7 x 10^{-8} mbar
- Helium plasma: 9.5 x 10^{-8} mbar
  - Adding oxygen reduced breeding efficiency
  - Higher charge states were obscured by intense beams





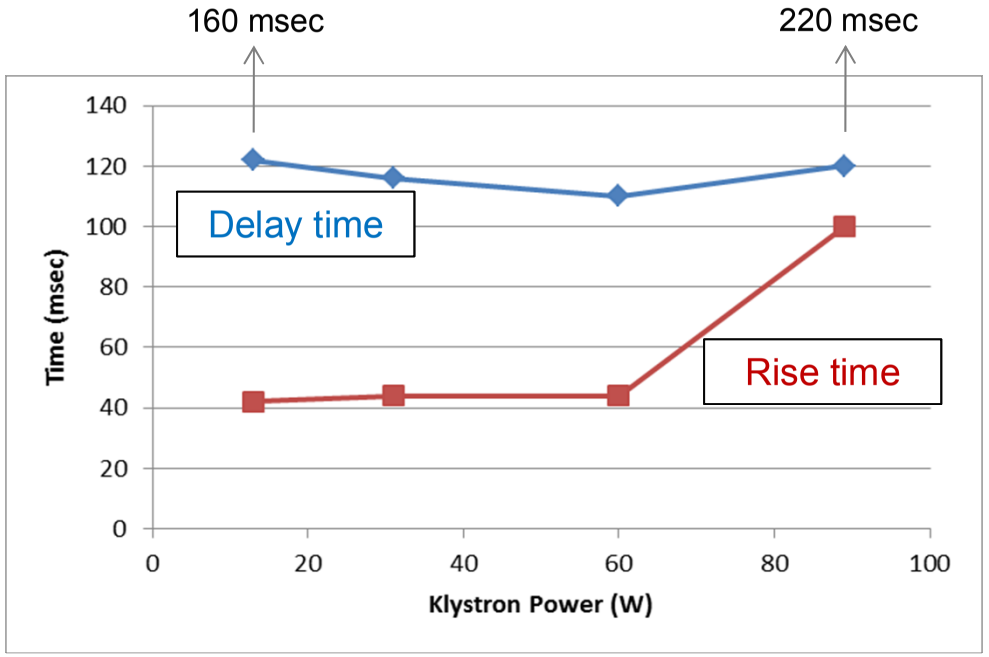
Response of $^{39}K^{10+}$ beam current to pulsing an incoming K^{+} beam with an intensity of 17 enA. Beam is pulsed with electrostatic steerer immediately after the surface ionization source.

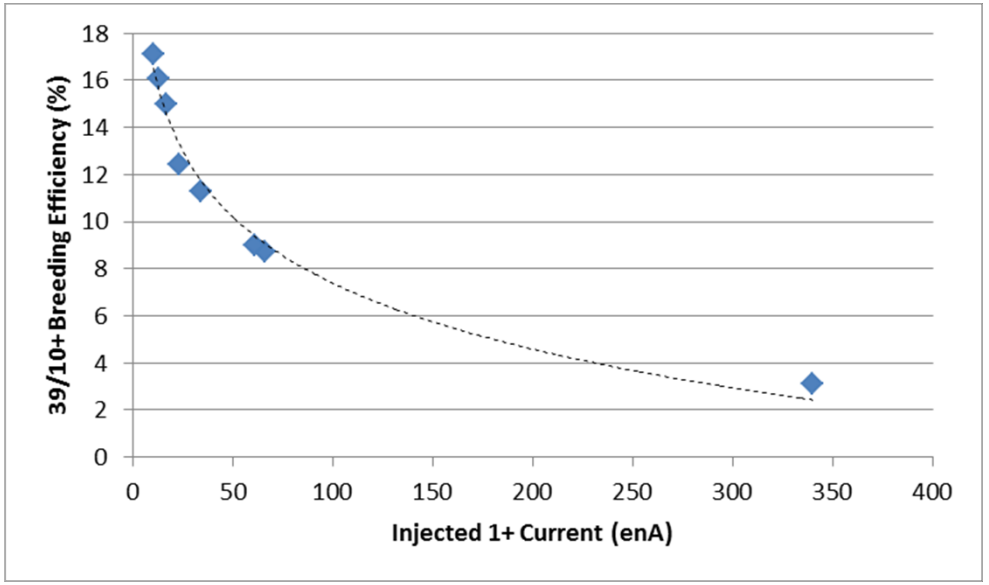


Mass scan of background plasma constituents and charge bred ^{39}K beam showing peaks for 7+, 8+, 9+, and 10+.

Potassium performance

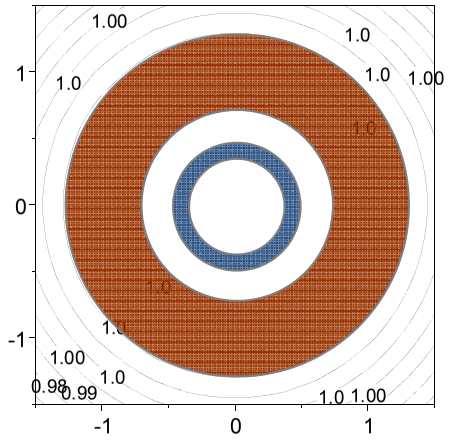
- The measured breeding time for $^{39}K^{9+}$ was 150 msec, and 160 msec for $^{39}K^{10+}$
  - Delay time of 116 msec between injection of $^{39}K^{+}$ and when $^{39}K^{10+}$ beam appears
  - Further 44 msec rise time to get to full value
- Reduced intensity of $^{39}K^{+}$ using 4-jaw slits
  - Affects the breeding efficiency presumably by reducing the beam emittance

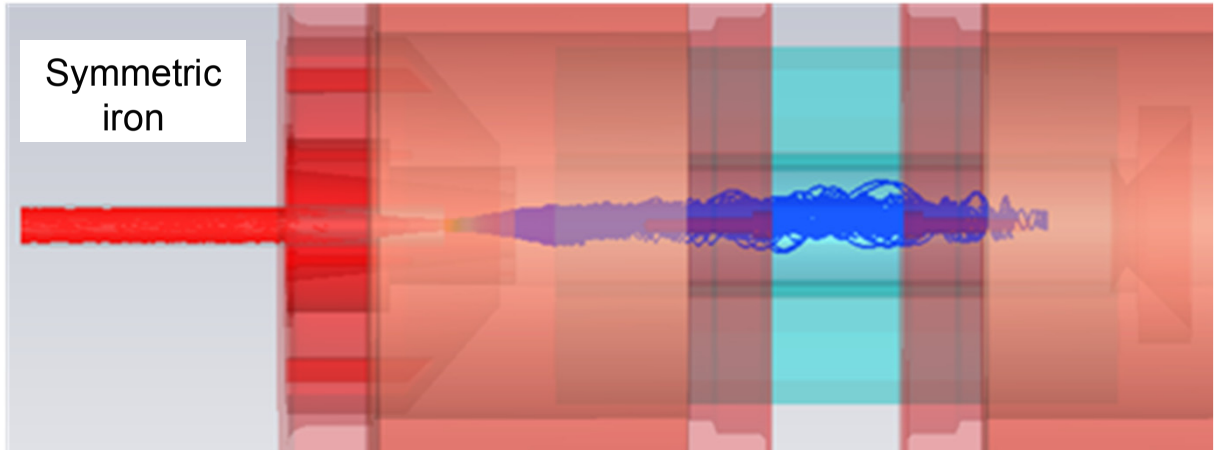


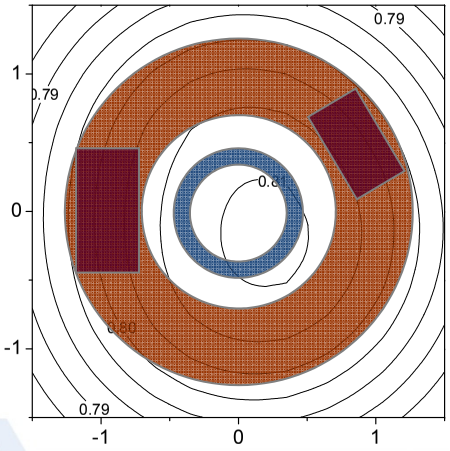


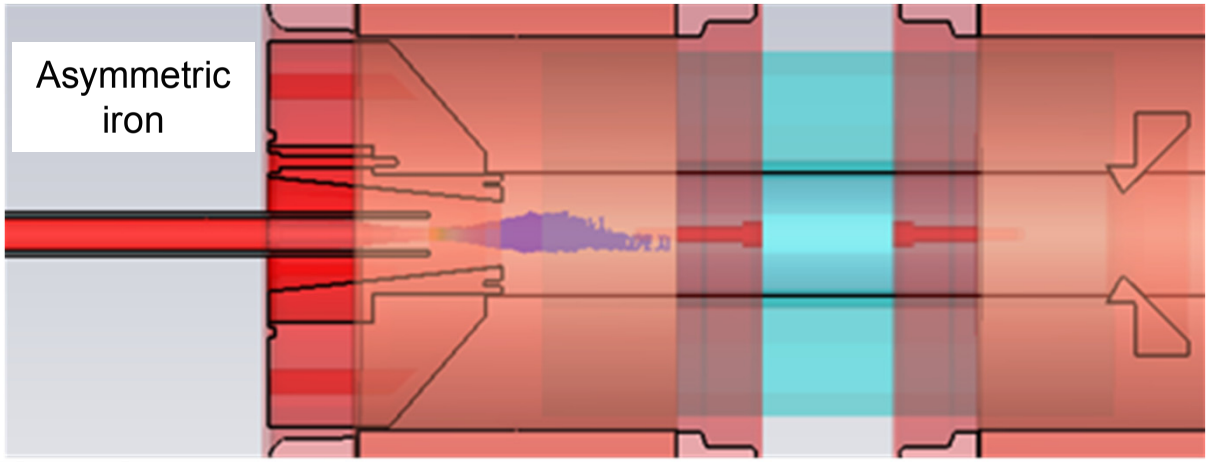
Injected ion penetration

- $^{133}Cs^{+}$ ions, V_{1+}: 30 kV, ΔV: -10 V
- Simulations utilized running conditions for coils, hexapole, and potentials
- No plasma or collision effects included in simulation



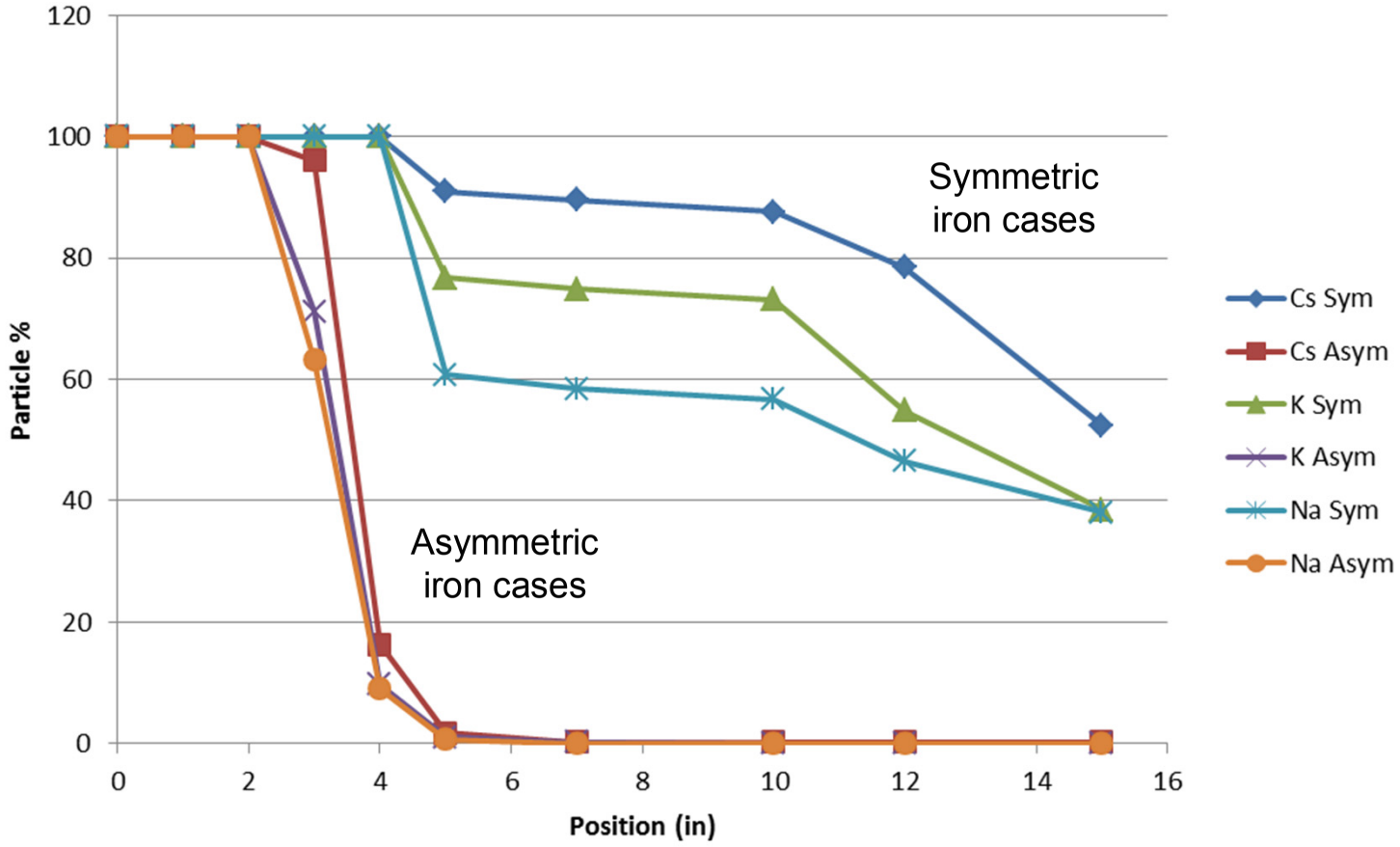






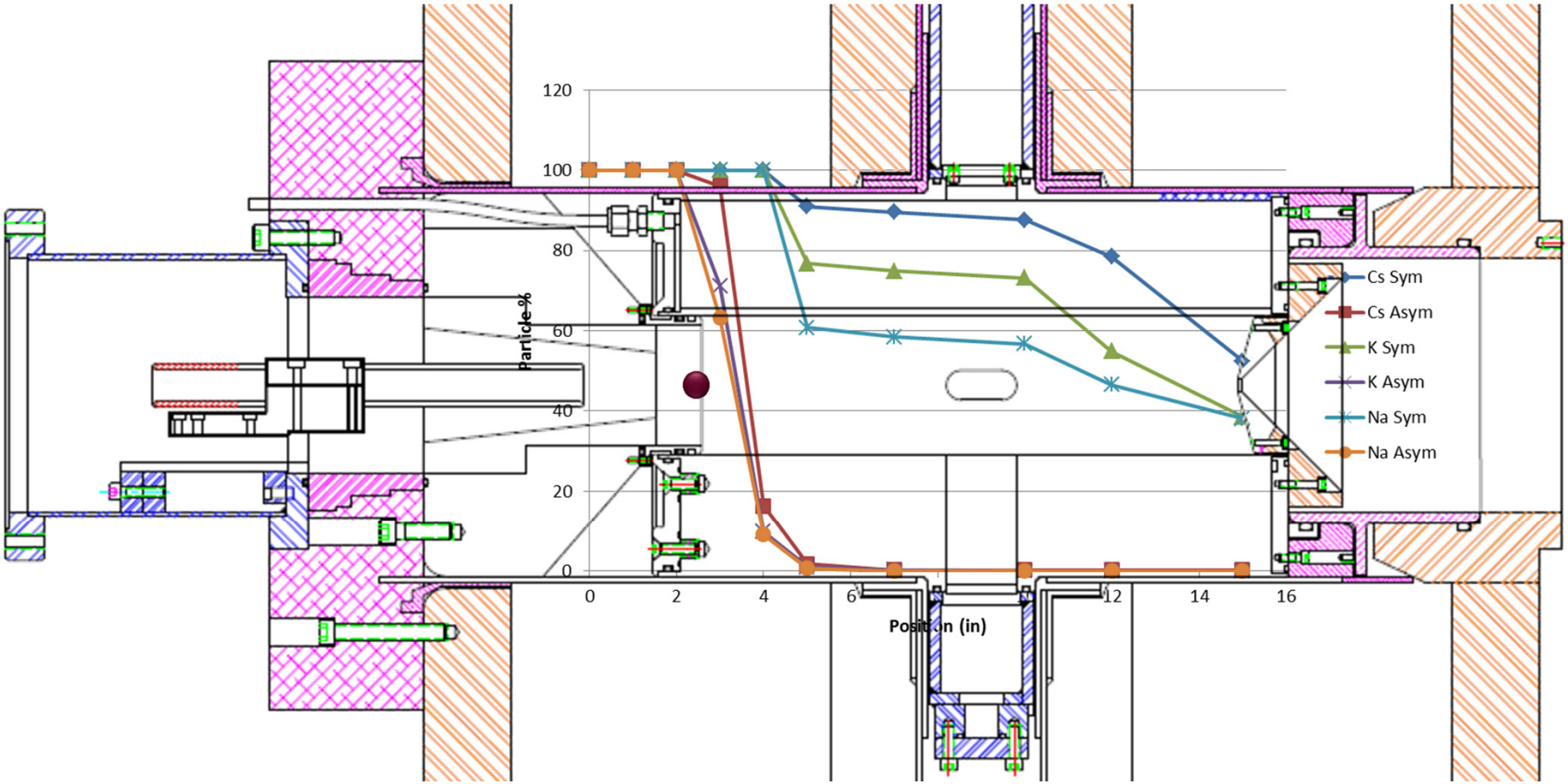
Injected ion penetration

- $^{133}Cs^{+}$, $^{39}K^{+}$, $^{23}Na^{+}$ ions
- V_{1+}: 30 kV, ΔV: -10 V



Injected ion penetration

- $^{133}Cs^{+}$, $^{39}K^{+}$, $^{23}Na^{+}$ ions
- V_{1+}: 30 kV, ΔV: -10 V



Conclusion

- Have demonstrated high efficiencies for low mass species
  - Symmetric magnetic fields and source pressure
- Simulations need to be repeated with addition of plasma and collision effects
- CARIBU is on line with 500 mCi source
  - Recent commissioning experiment with $^{141,142}Cs^{27+}$