Initial Results of the ECR Charge Breeder for the ^{252}Cf Fission Source Project at ATLAS

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Argonne NATIONAL LABORATORY

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Overview

- The CARIBU project
- Charge breeder system
  - Stable sources, beamline, ECR source
- Charge breeding results
    - *Faraday cup problems*
    - *Background effect*
  - Current results with Cesium and Rubidium
- Future plans

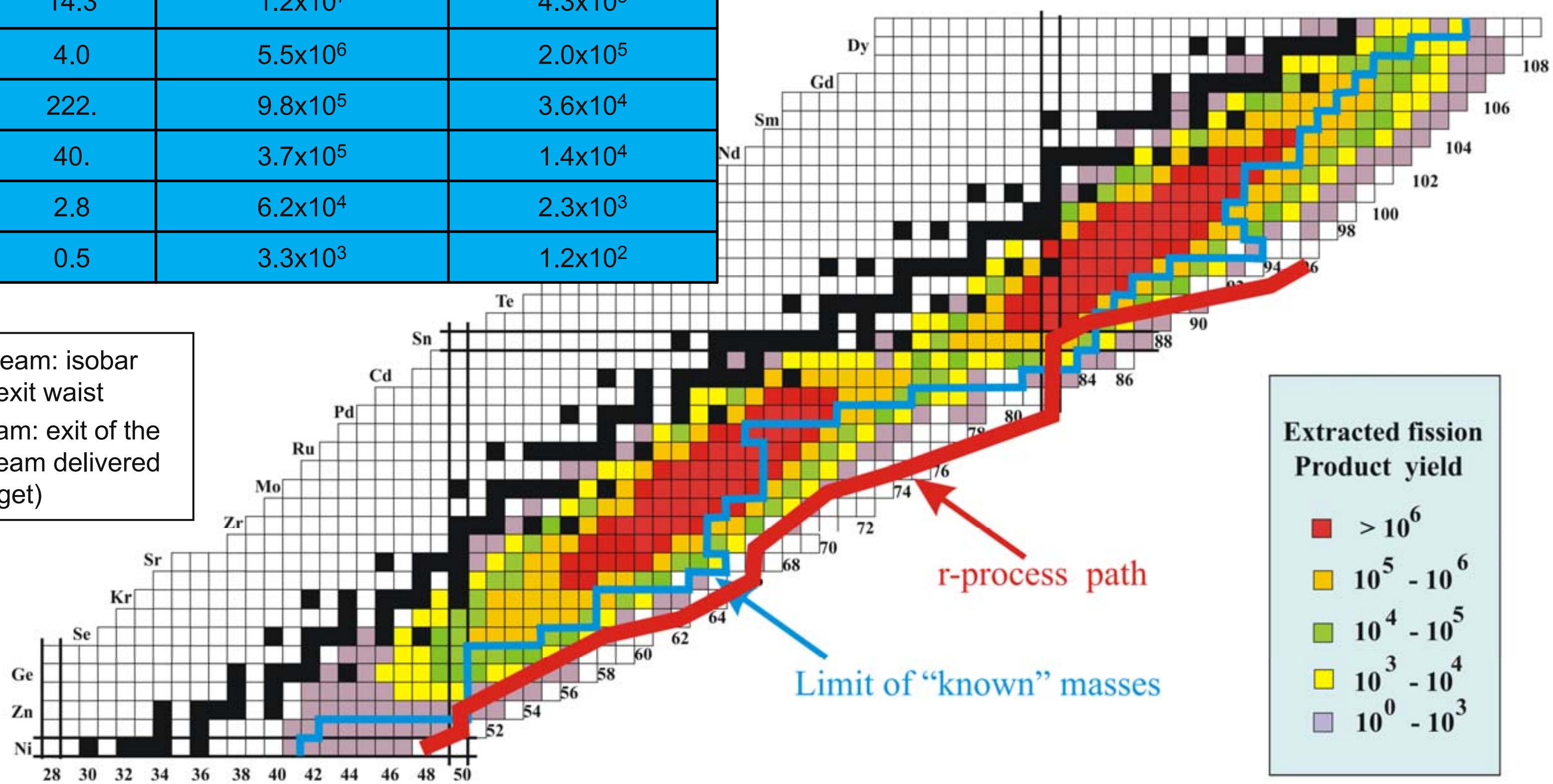
The CARIBU project – CAlifornium Rare Ion Breeder Upgrade

- In its final configuration, a 1.0 Ci ^{252}Cf fission source will provide radioactive species to be delivered to the ECR ion source for charge breeding

Isotope	Half-life (s)	Low-Energy Beam Yield (s^{-1})	Accelerated Beam Yield (s^{-1})
^{104}Zr	1.2	6.0×10^5	2.1×10^4
^{143}Ba	14.3	1.2×10^7	4.3×10^5
^{145}Ba	4.0	5.5×10^6	2.0×10^5
^{130}Sn	222.	9.8×10^5	3.6×10^4
^{132}Sn	40.	3.7×10^5	1.4×10^4
^{110}Mo	2.8	6.2×10^4	2.3×10^3
^{111}Mo	0.5	3.3×10^3	1.2×10^2

Low energy beam: isobar separator exit waist

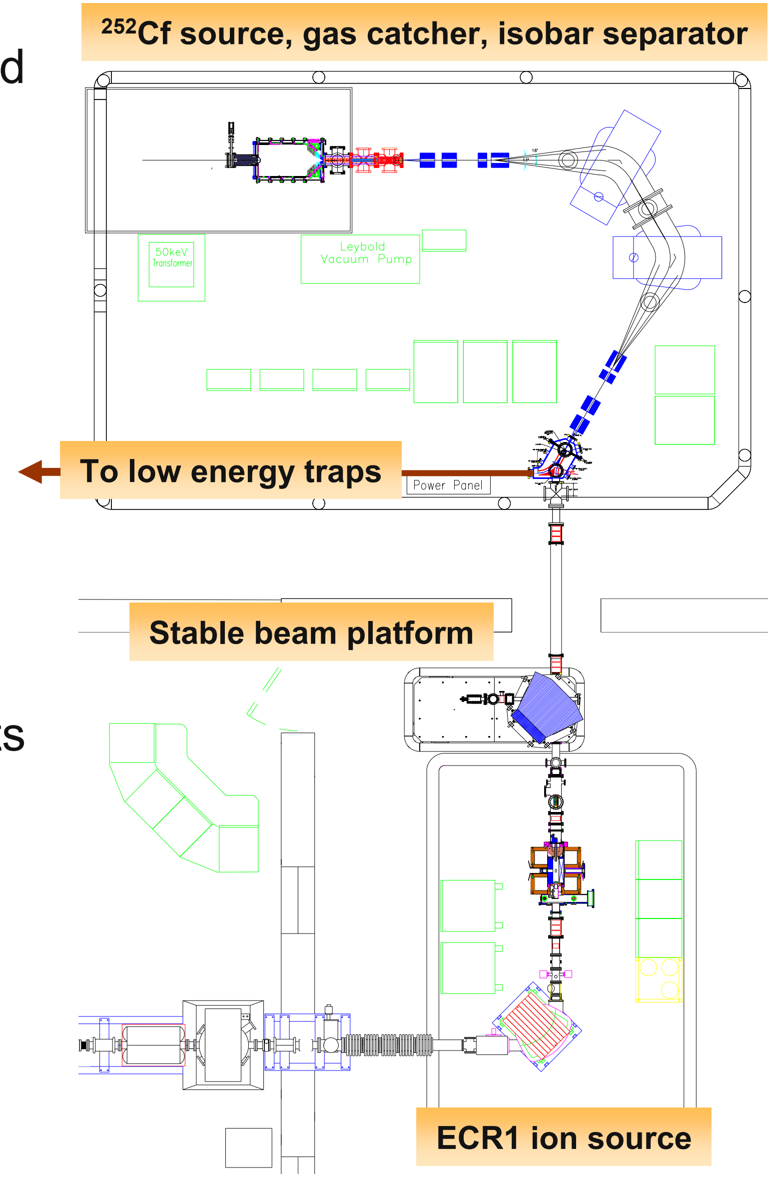
Accelerated beam: exit of the ATLAS linac (beam delivered to target)



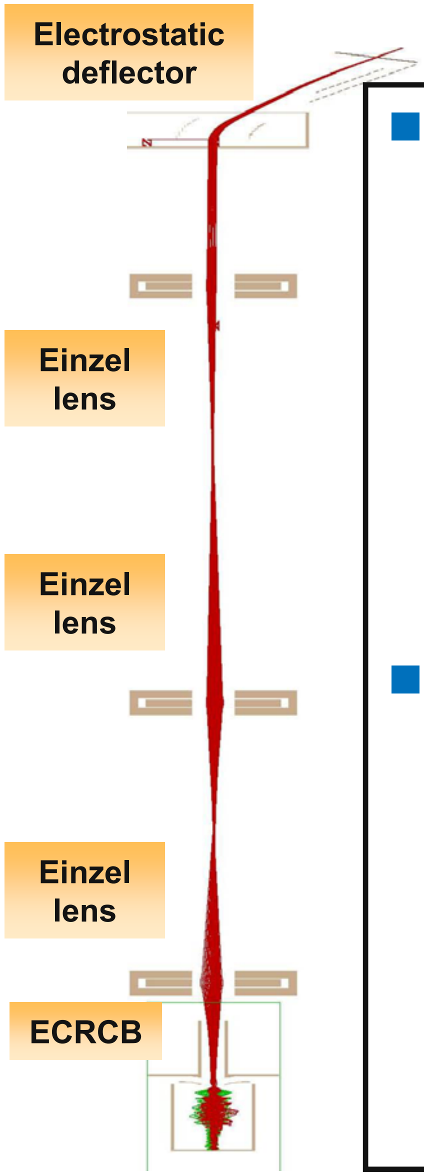
The CARIBU project

- Fission products are collected and thermalized in a helium gas catcher
  - ~20% of all activity extracted as ions
  - Mean delay time <10 msec
  - Extraction is element independent
  - Provides cooled bunched beams for post acceleration
    - *Energy spread <1 eV*
    - *Emittance ~3 π·mm·mrad*

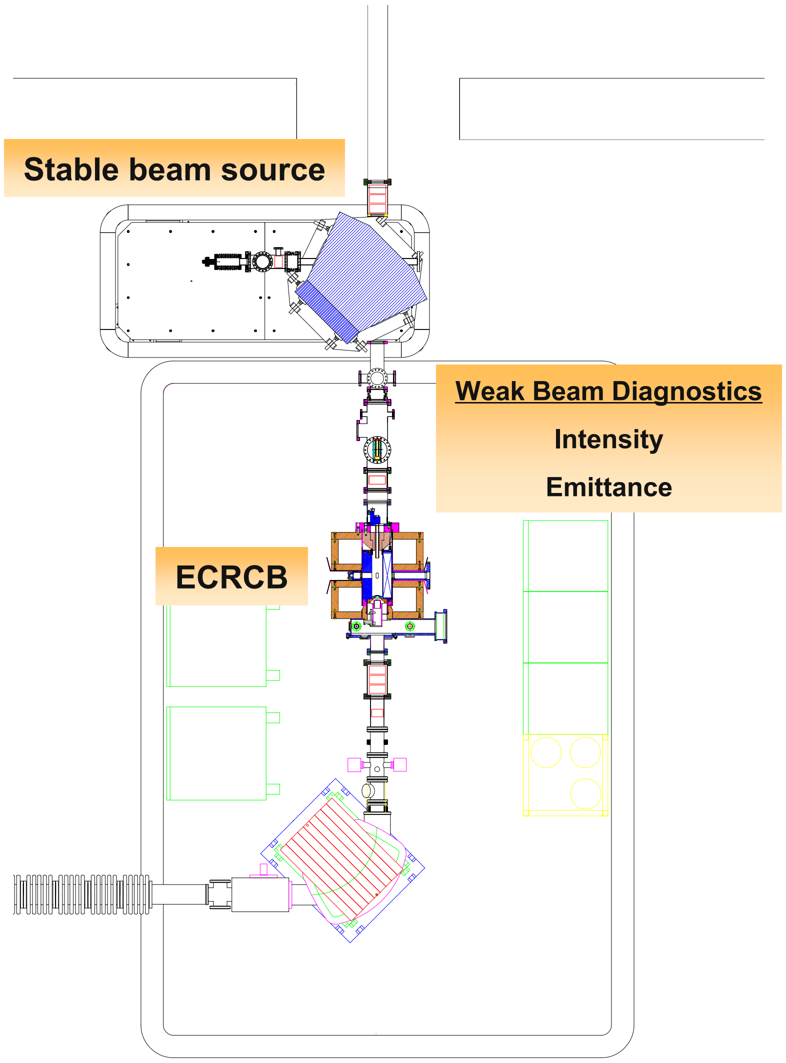
- High resolution mass analysis (1:20,000) limits the number of isobars in the analyzed beam
  - Reduces ECR source contamination
  - To achieve the required resolution, beam extraction must occur at ≥50 kV
  - Must maintain a voltage stability of ±1 V



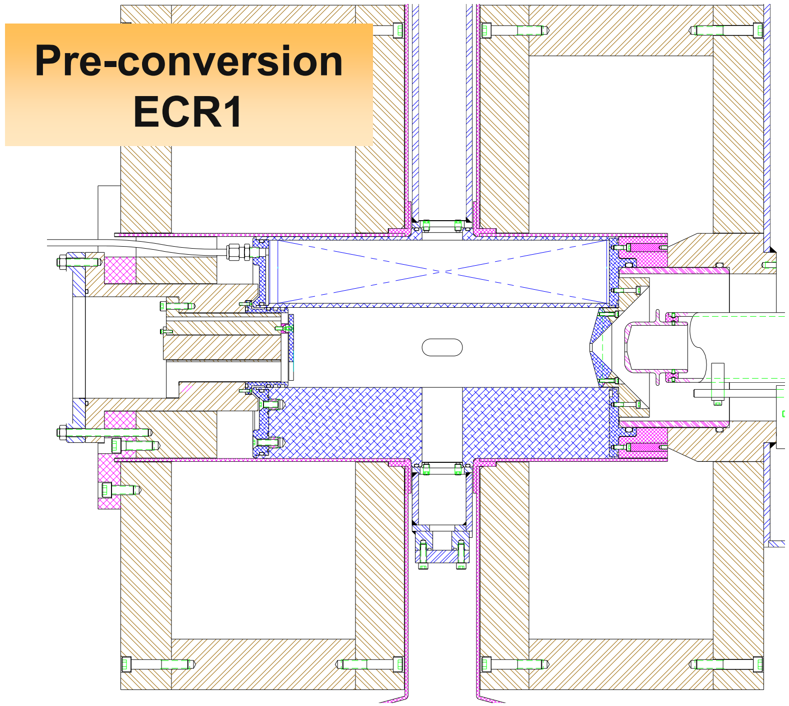
Transfer line and stable beam source

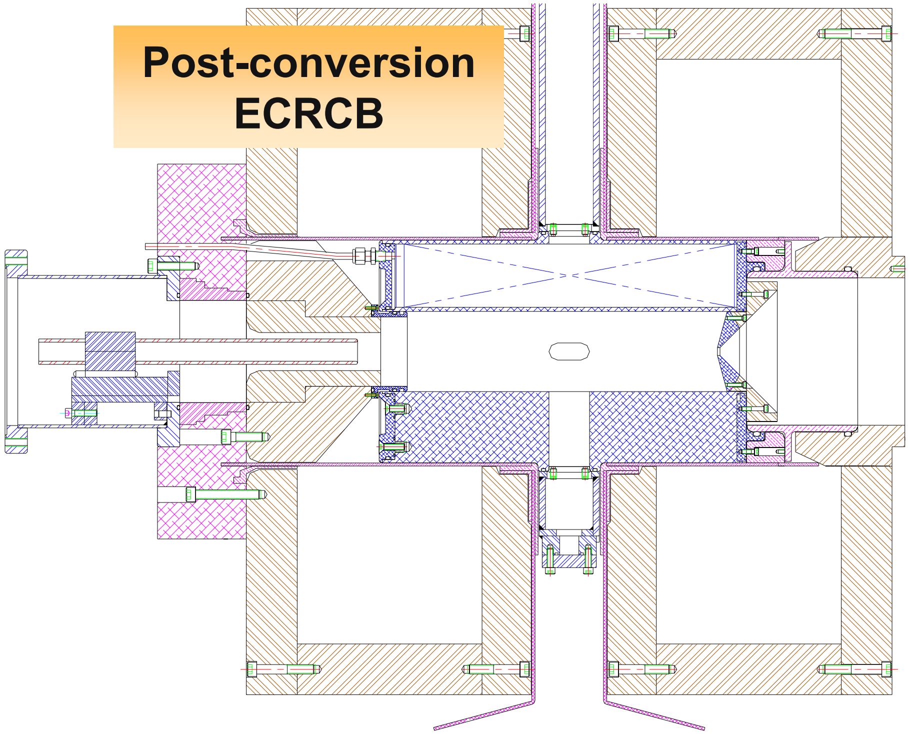


- Transfer line
  - Three einzel lenses with emittance measurement station and weak beam profile and current monitors
  - Image points of transfer line and stable beam source are matched
- Stable beam sources
  - Surface ionization
    - 1.0 eμA beams of Li, Na, Mg, K, Ca, Rb, Cs, Ba, Sr
  - RF discharge source
    - 1-2 eμA beams of Ne, Ar, Kr, and Xe



Source modifications for charge breeder operation

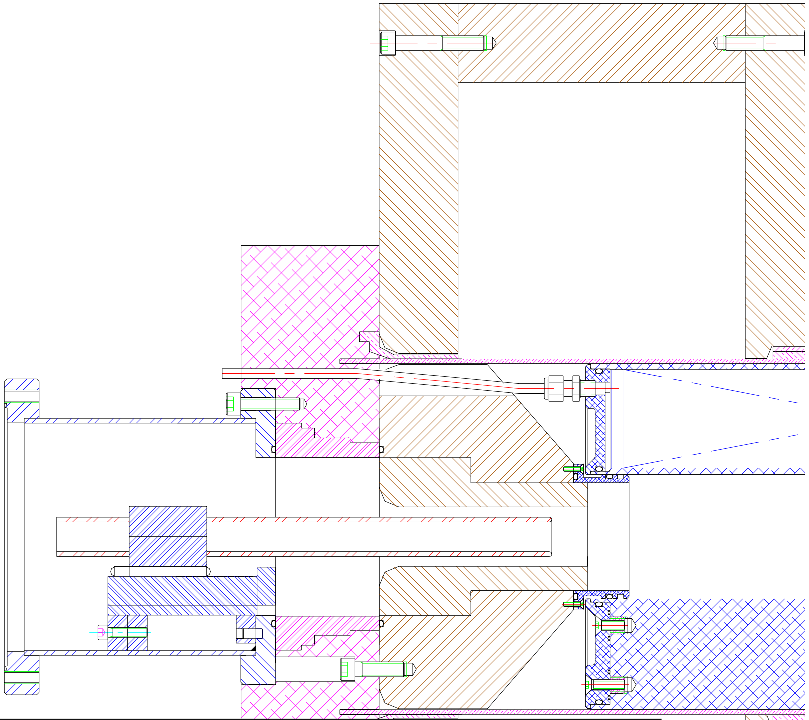


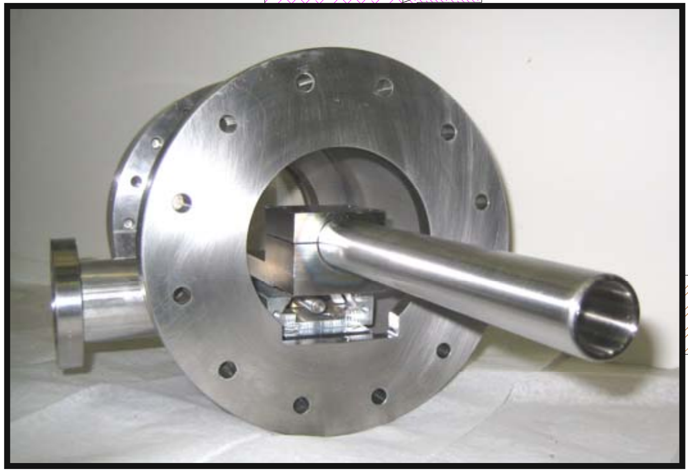


- **Improved the high voltage isolation for 50 kV operation**
- **Modified the injection side of the source to accept low charge state beams**
  - **Removed the central iron plug to allow for transfer tube penetration**
  - **Moved the RF injection from an axial to a radial position**
    - ***Open hexapole allows radial RF injection***
    - ***Provides more iron so that the magnetic field on injection side is symmetric***
  - **Reshaped the remaining iron to improve B_{inj}**

Injection side configuration

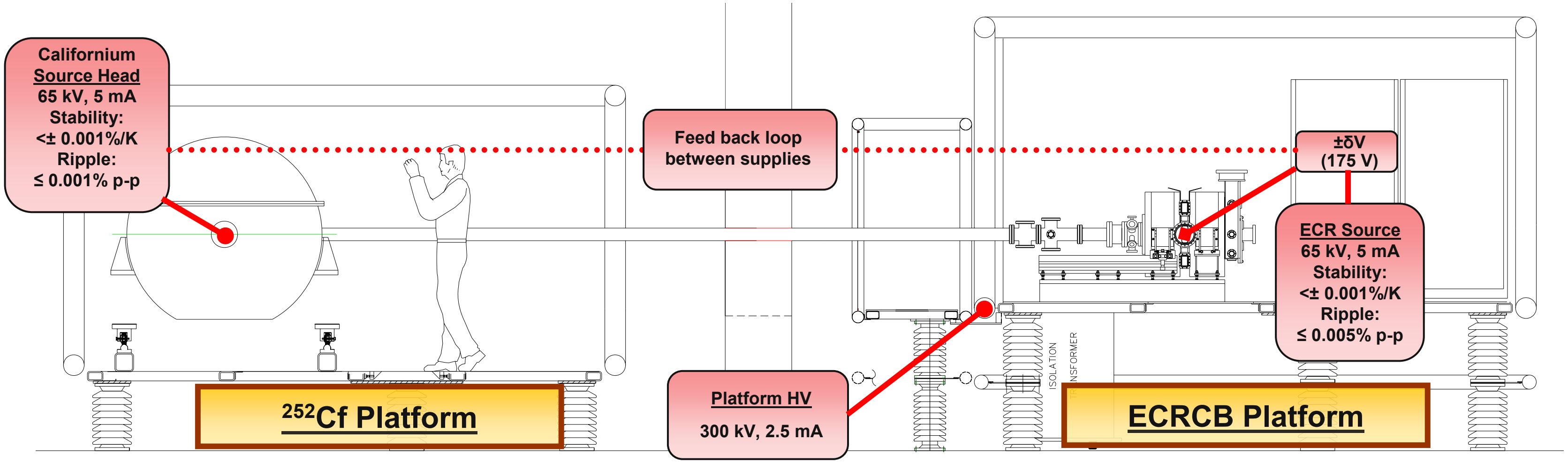
- Lexan insulator provides structure with an alumina liner exposed to vacuum
  - Base pressure in the ECR source and beamline is 2.0×10^{-8} Torr
    - *Source pressure increases to 1.5×10^{-7} with plasma on*
    - *Beamline pressure increases to 2.0×10^{-7} with plasma on*
- Movable transfer tube
  - 3.15 cm of travel
  - Originally placed just outside of the magnetic maximum
    - *Resulted in drain current of 4.0 mA at 50 Watts and unstable source operation*
  - Retracted position by 4.0 cm
    - *Drain current decreased to 0.3 mA and source operation stabilized*





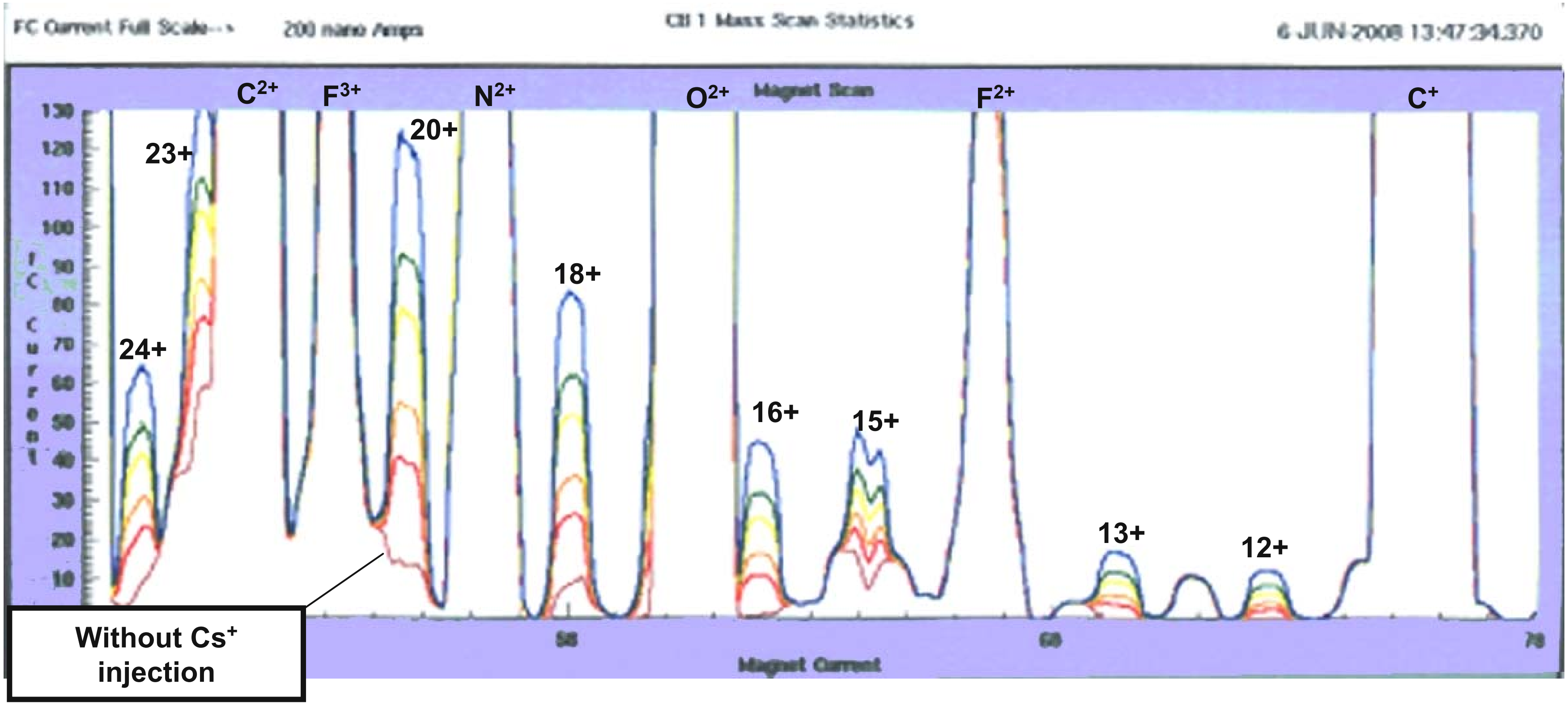
High voltage relationships and stability

- High voltage platforms will be energized by a single power supply (300 kV, 2.5 mA)
  - Beam pipe links the two platforms together ensuring common potential
- Source heads will be energized by separate high voltage power supplies (65 kV, 5 mA)
  - Flexibility to operate in "Stand Alone" mode → low energy traps, source development
  - Decouples any influence of ECR plasma fluctuations on the californium bias voltage
    - *Ensures ±1.0 V voltage stability for isobar separator*
- Additional ±175 V power supply ('tweaker') is in series with the ECRCB
- Feed back controller ensures voltage match between the Cf and ECRCB source heads
  - Adjusts the 'tweaker' supply to match the source potentials (nominally 50 kV)
  - Then an additional voltage is summed in to optimize the 1+ ion capture



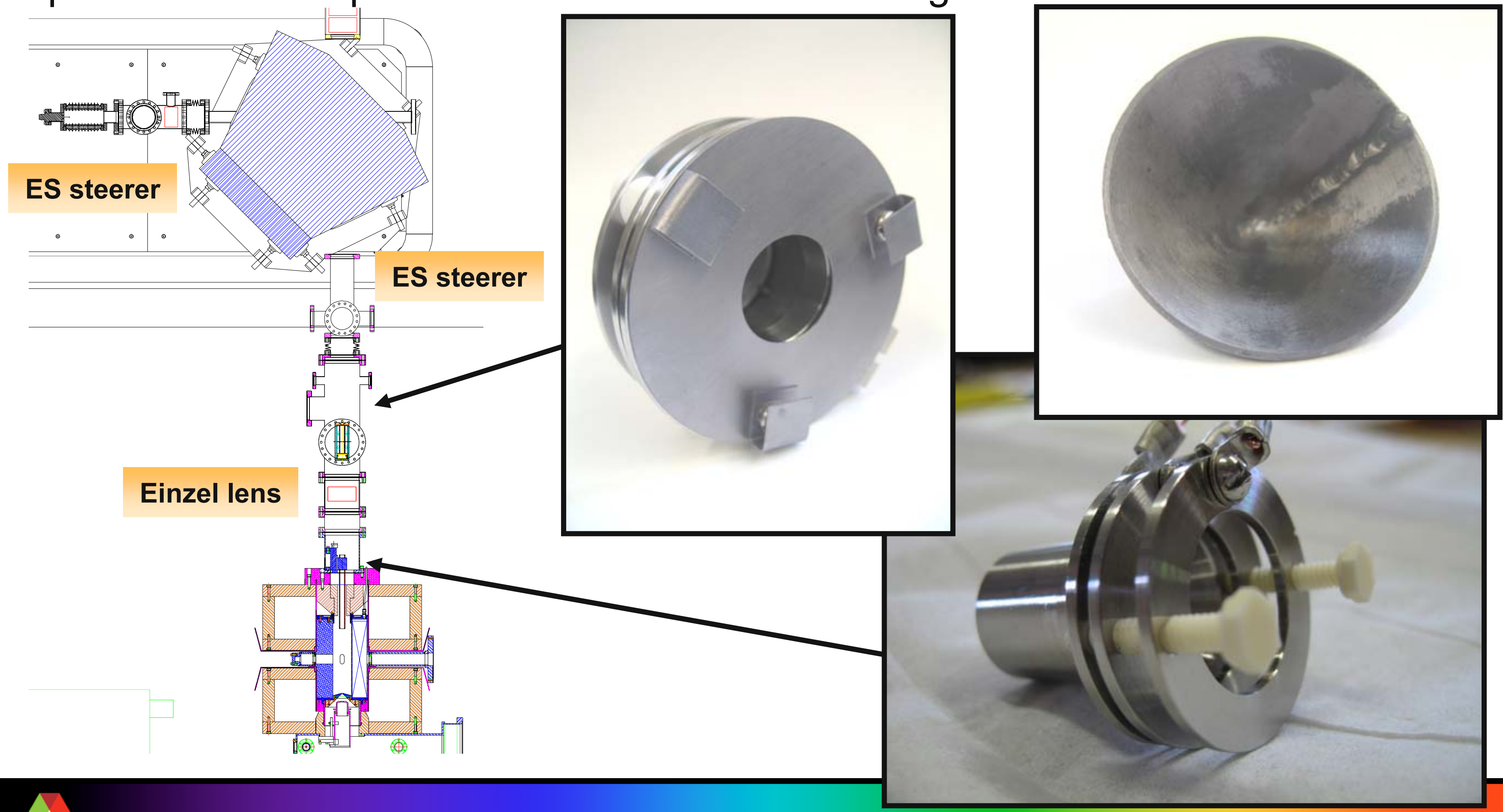
Cesium charge breeding spectrum

- Achieved first charge bred beam in May 2008
- Mass spectrum of the ECRCB output with and without Cs^+ injection
  - Background beam, without Cs^+ injection, is shown in brown
  - Other traces represent varying levels of charge bred cesium as a function of the Cs^+ input intensity



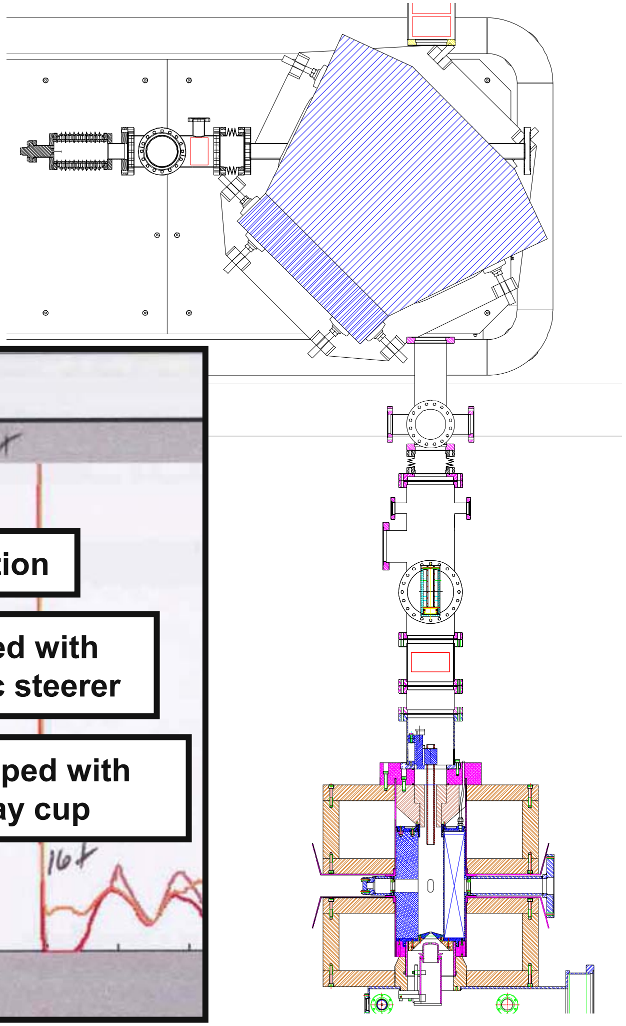
Beam current measurement - 1+

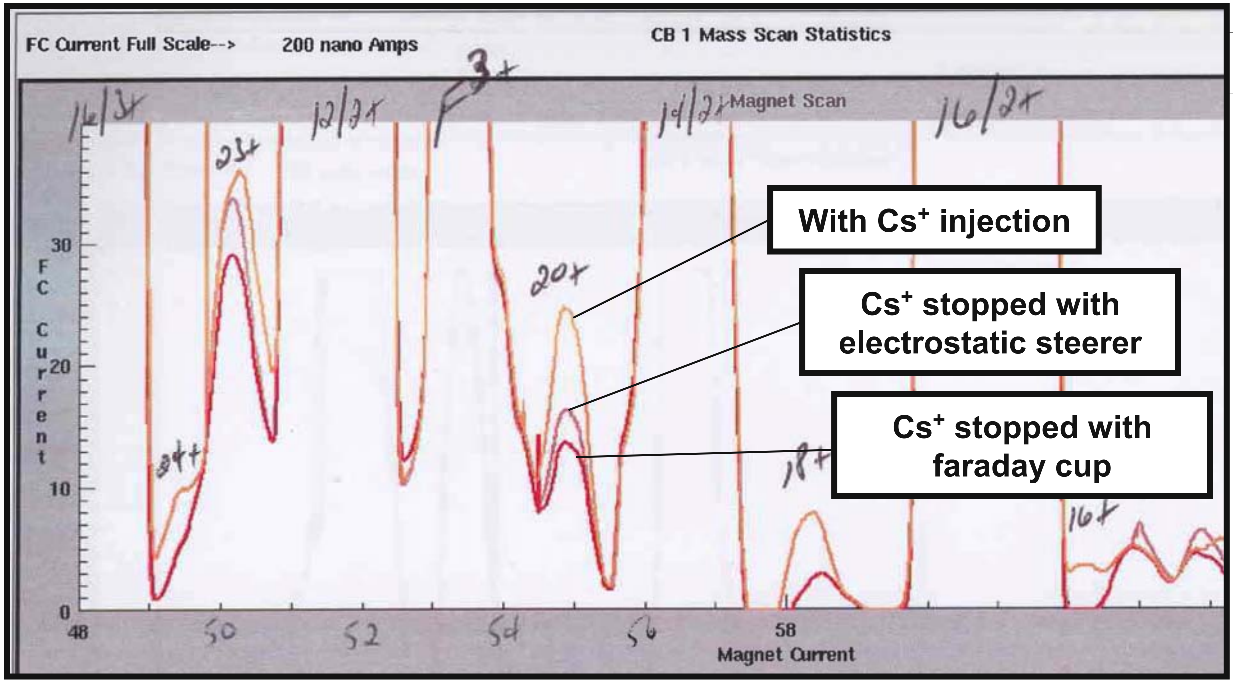
- Obtained unrealistic charge breeding efficiencies – 9→12%
- Constructed a new faraday cup which was placed at front of transfer tube
- Problem traced to an insulating layer on the tantalum charge collector
- Replaced tantalum piece with a stainless steel charge collector



Background measurement

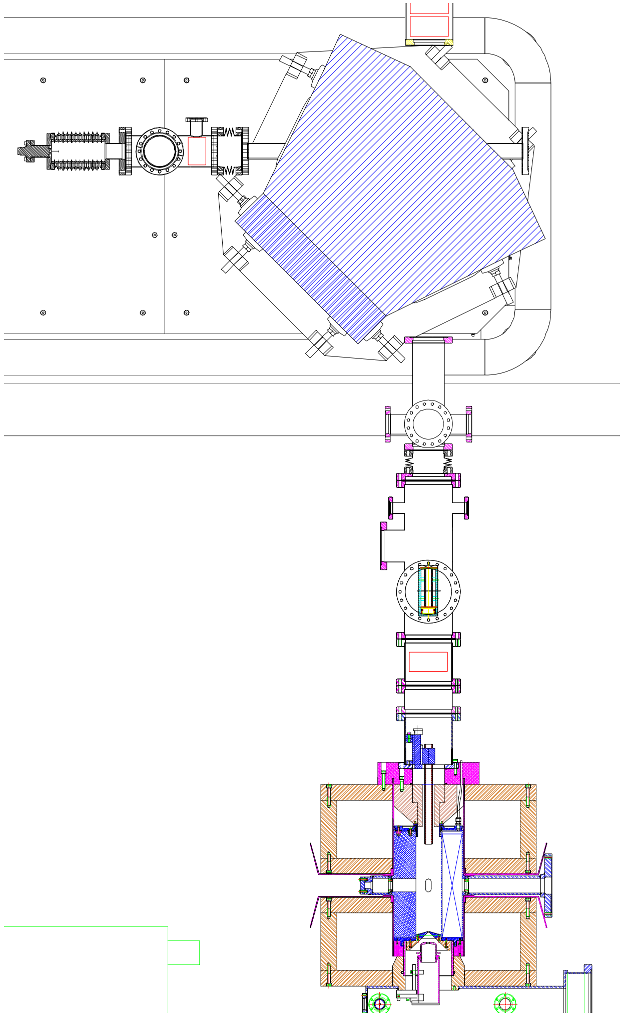
- Observed a difference in background level for some of the Cs peaks which was dependent upon which method was used to stop the 1+ beam from entering the ECR source





Background measurement

- Observed a difference in background level for some of the Cs peaks which was dependent upon which method was used to stop the 1+ beam from entering the ECR source
- Difference in background level is due to outgassing in the 1+ analyzing magnet generated by the n+ beam extracted from the injection side of the ECR source
  - $^{133}Cs^{20+}$ very similar m/q as $^{40}Ar^{6+}$
  - $^{133}Cs^{23+}$ very similar m/q as $^{40}Ar^{7+}$
  - $^{133}Cs^{16+,18+,24+}$ do not exhibit this behavior
- For $^{133}Cs^{20+}$, with the same incoming Cs^{+} intensity, the effect is clear
  - Saturating the steerer
    - *2.6% efficiency*
  - Putting the faraday cup in
    - *6.5% efficiency*



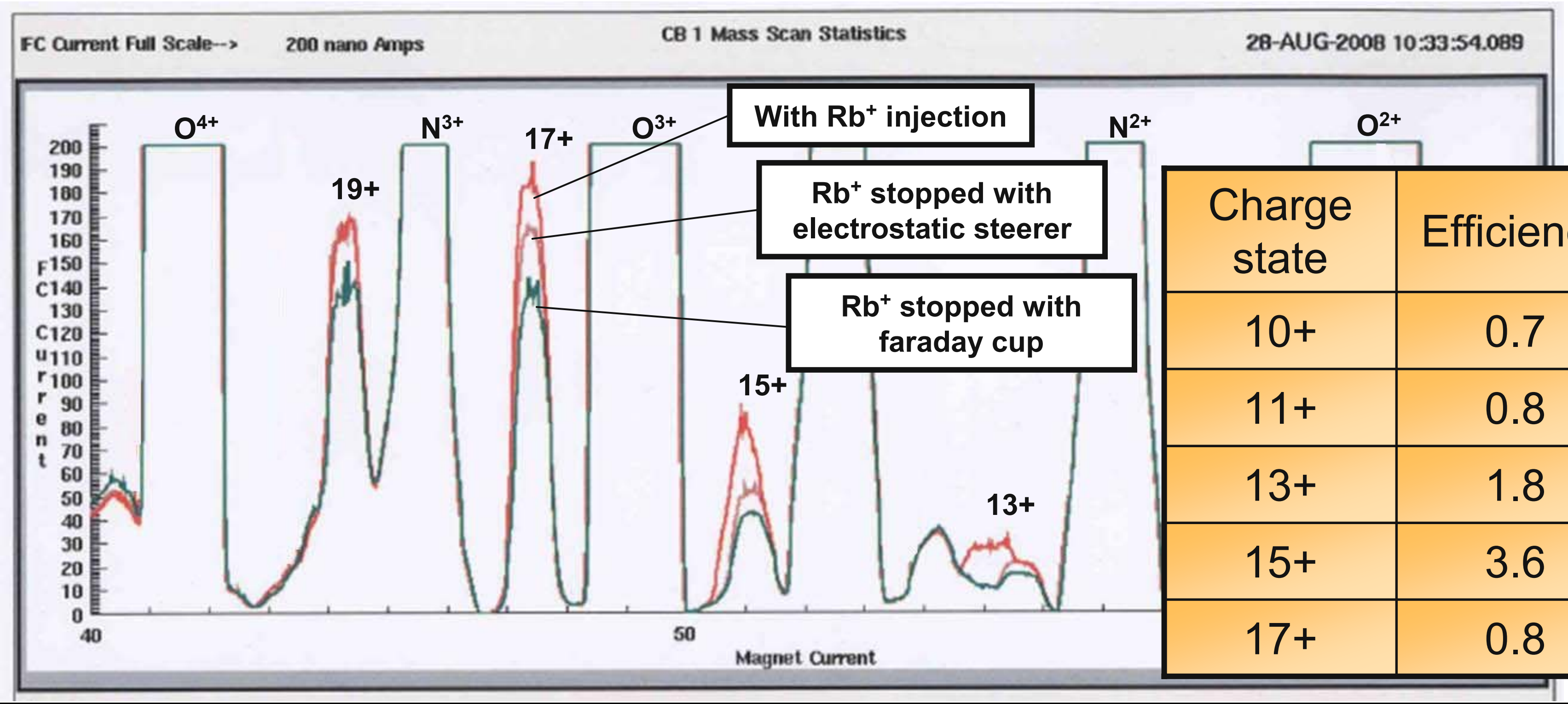
Results of charge bred cesium

- Optimized on $^{133}Cs^{20+}$ using oxygen support gas and 250 W at 10.44 GHz
- Cs^+ beam current was 62 enA
- Also tried two-frequency heating
  - Power levels set so that total power level matched single frequency case
    - *175 W at 10.44 GHz*
    - *75 W at 12.27 GHz*
- Insulators on surface ionization source breaking down
  - Poor optics conditions

Charge state	Single Frequency Efficiency	Two Frequency Efficiency
16+	0.9	1.4
18+	1.0	1.5
20+	2.4	2.9
23+	0.5	1.1

Charge bred rubidium beam (August 2008)

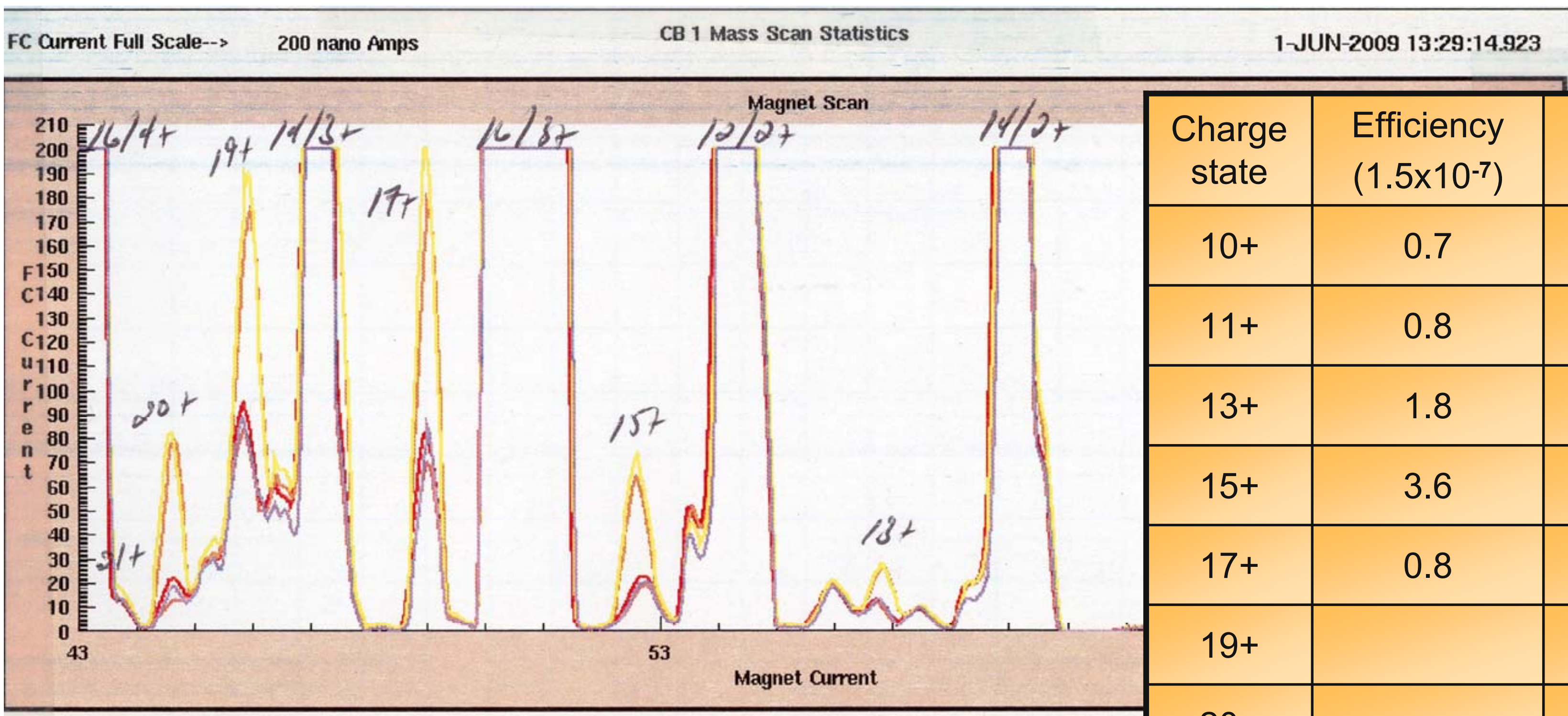
- Mass spectrum of ECR ion source output with and without Rb^+ injection
  - Rebuilt surface ionization source
    - *Cleaned insulators and realigned elements*
  - Optimized on $^{85}Rb^{15+}$ with oxygen support gas and 270 W at 10.44 GHz
  - Source operating pressure 1.5x10^{-7} Torr



Charge state	Efficiency
10+	0.7
11+	0.8
13+	1.8
15+	3.6
17+	0.8

Results of charge bred rubidium (June 2009)

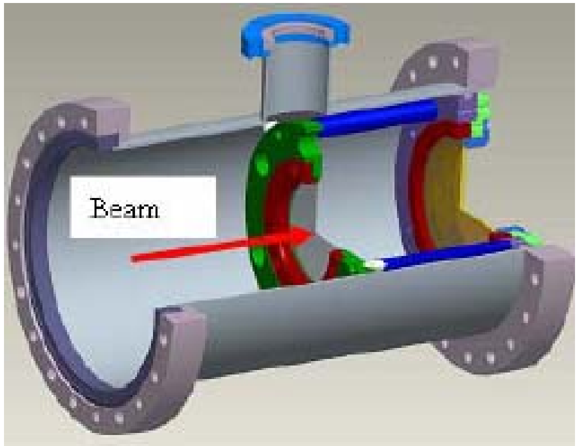
- No work with the ECR charge breeder since September 2008 while other aspects of the CARIBU program were completed
  - Source was under vacuum the entire time and has resulted in the operating pressure improving from $1.5x10^{-7}$ to $7.5x10^{-8}$ Torr
  - Peak of charge state distribution has shifted from 15+ to 17+
  - Breeding efficiency has improved



Charge state	Efficiency ($1.5x10^{-7}$)	Efficiency ($7.5x10^{-8}$)
10+	0.7	
11+	0.8	
13+	1.8	
15+	3.6	3.8
17+	0.8	5.2
19+		3.2
20+		2.9

"Pepper Pot" emittance system on 2Q-LEBT

- Mask has 100, 100 µm pinholes, 3 x 3 mm spacing, working area: 27 x 27 mm
- Behind mask is CsI crystal (80 mm diameter) which is viewed by CCD camera
- Beam energy of 75 keV/q and current density of <1.0 eµA/cm^2 with Bi beam



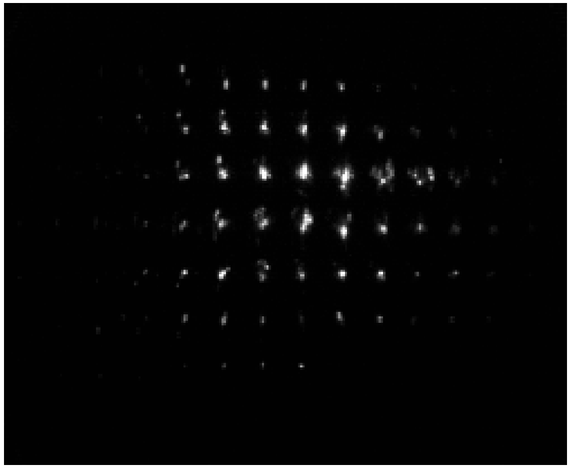


Figure 6: Pepper pot image of $^{129}Xe^{14+}$ ion beam.

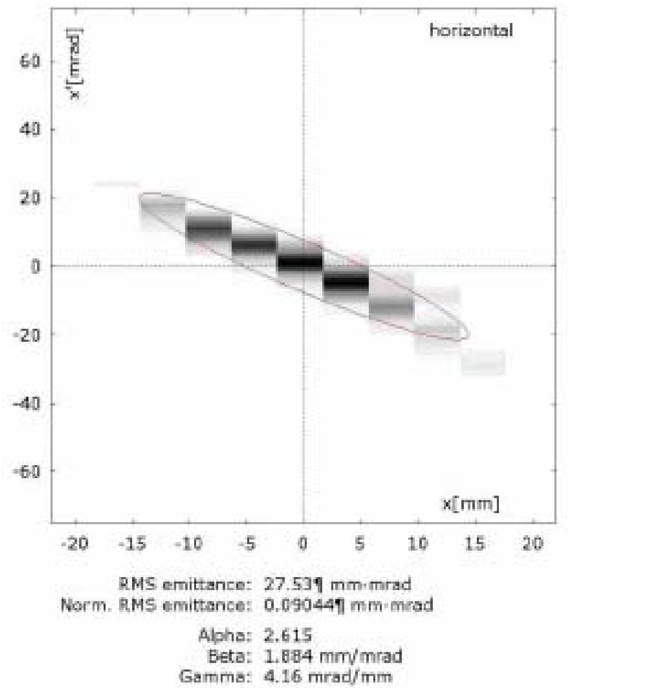


Figure 7: Horizontal phase space plot of the $^{129}Xe^{14+}$ ion beam.

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EXPERIMENTAL RESULTS ON MULTI-CHARGE-STATE LEBT APPROACH*

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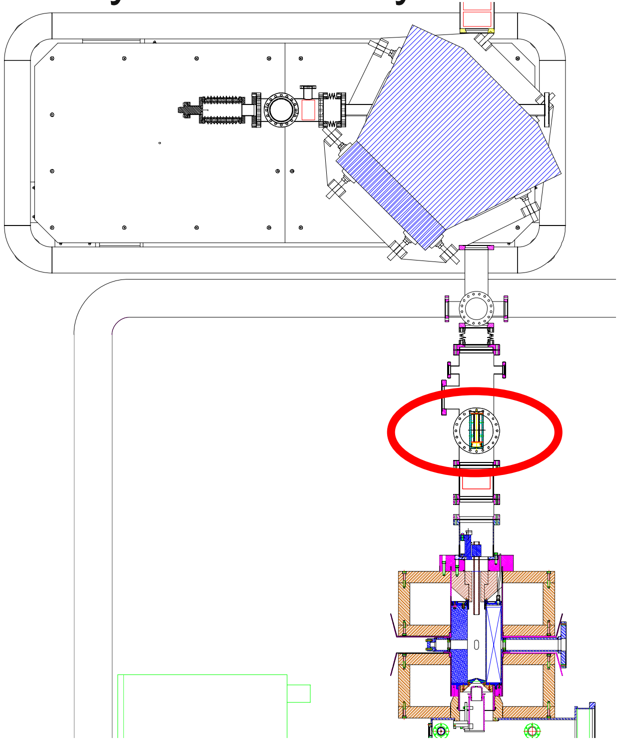
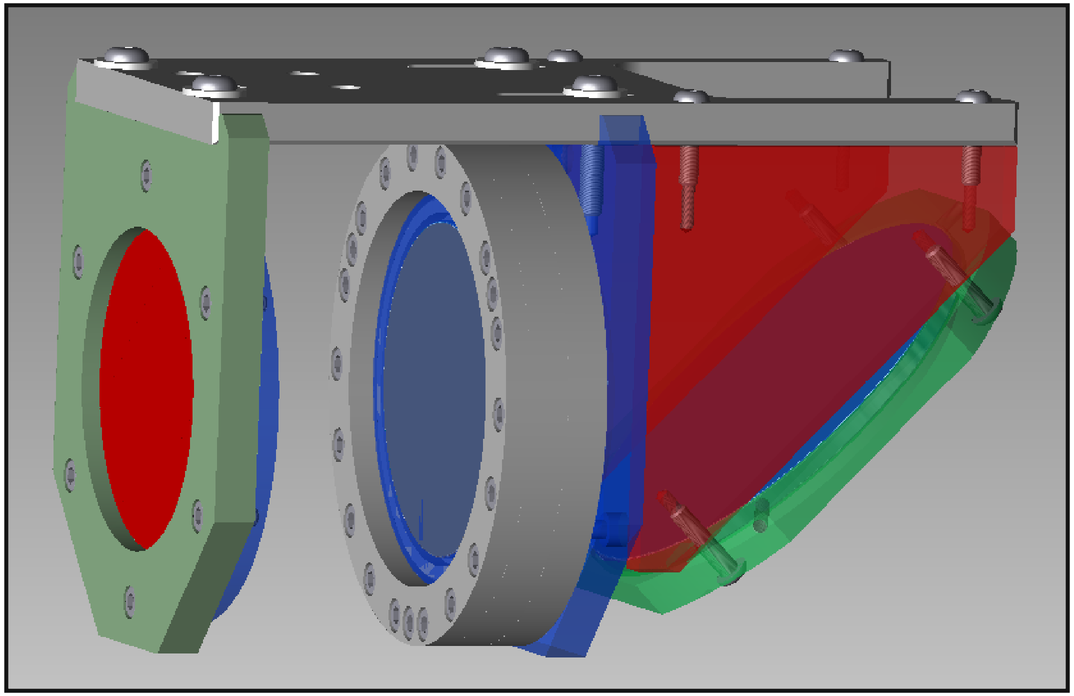
"Pepper Pot" emittance system for ECR charge breeder

- Mask has 20 μm laser drilled holes, 0.5 x 0.5 mm spacing, 40 mm diameter
- Behind the mask is a CsI crystal (40 mm diameter)
  - Scintillator tested with a 300 nA, 10 kV beam
- Distance between the mask and the scintillator is variable
- Improved sensitivity possible with the addition of a micro channel plate/phosphor
- System is ready for installation





Future plans for the charge breeder

- Continue with beam development using rubidium source
  - Multiple frequency heating
- Install RF discharge source to develop source performance with gases
- Replace stainless steel transfer tube with one made of soft iron
  - Improves magnetic field on injection side of ECR source
- Improve pumping at injection region
  - Have seen evidence that a lower pressure will improve the efficiency
  - Modified the injection chamber to accept another turbo pump
- Reduce outgassing
  - Bake out the 1+ transport line
  - Beamline collimators to inhibit backstreaming into ECR source
  - Cooling baffles inside of 1+ analyzing magnet
- Pursue cleaning of plasma chamber using high pressure rinsing
  - Background is not yet a critical issue, but will become more important as CARIBU comes on line
- Hot liner in ECR plasma chamber for wall recycling