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

ECRIS08

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Overview

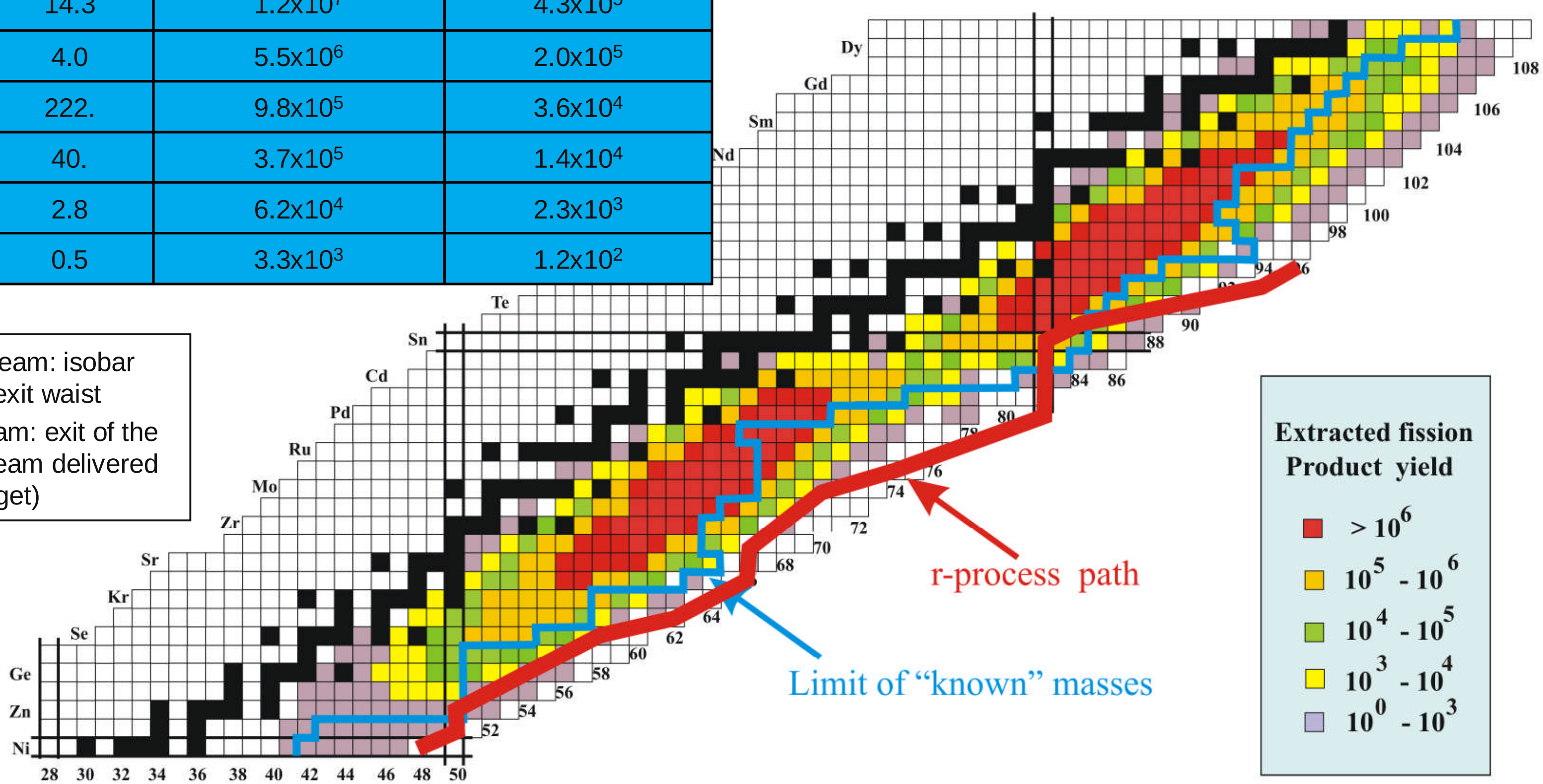
- The CARIBU project overview
- Charge breeder system
  - Stable sources, beamline, ECR source
- Results
  - Initial results with Cesium
    - *Faraday cup problems*
    - *Background effect*
  - Recent results with Cesium and Rubidium
- Future plans

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

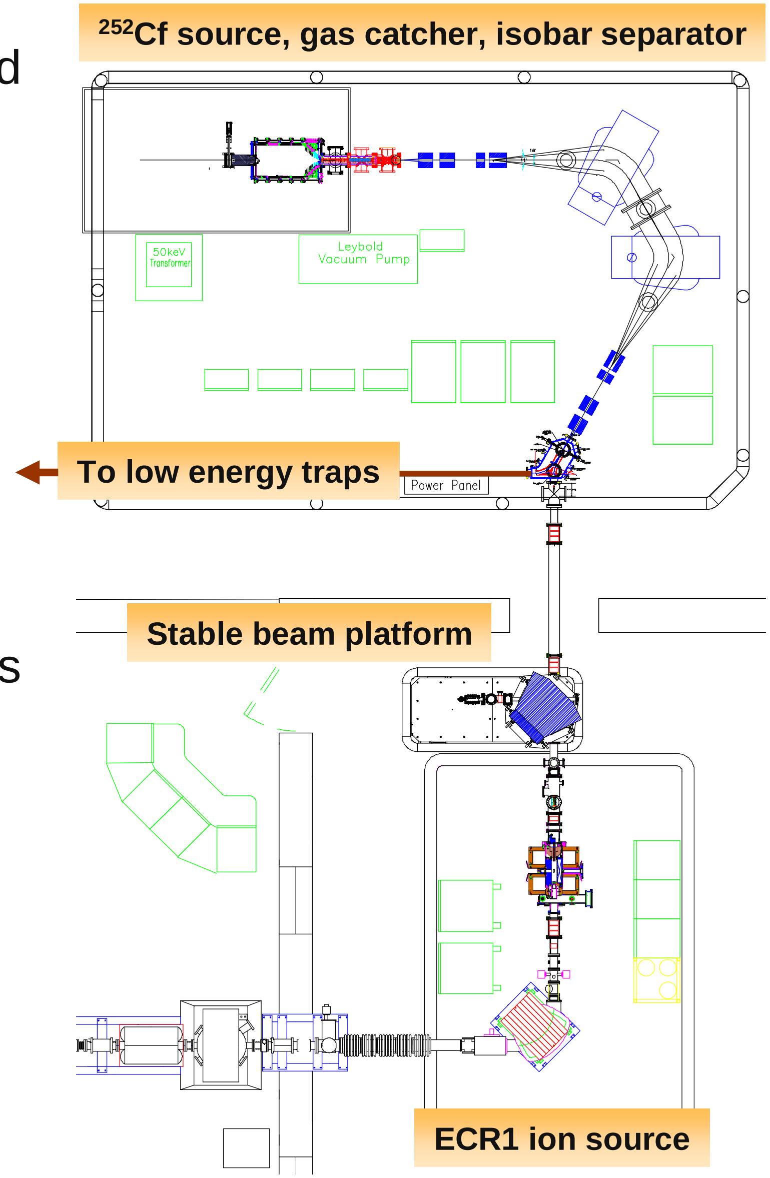
Isotope	Half-life (s)	Low-Energy Beam Yield (s^{-1})	Accelerated Beam Yield (s^{-1})
^{104}Zr	1.2	6.0×10^5	2.1×10^4
^{143}Ba	14.3	1.2×10^7	4.3×10^5
^{145}Ba	4.0	5.5×10^6	2.0×10^5
^{130}Sn	222.	9.8×10^5	3.6×10^4
^{132}Sn	40.	3.7×10^5	1.4×10^4
^{110}Mo	2.8	6.2×10^4	2.3×10^3
^{111}Mo	0.5	3.3×10^3	1.2×10^2

Low energy beam: isobar separator exit waist
Accelerated beam: exit of the ATLAS linac (beam delivered to target)

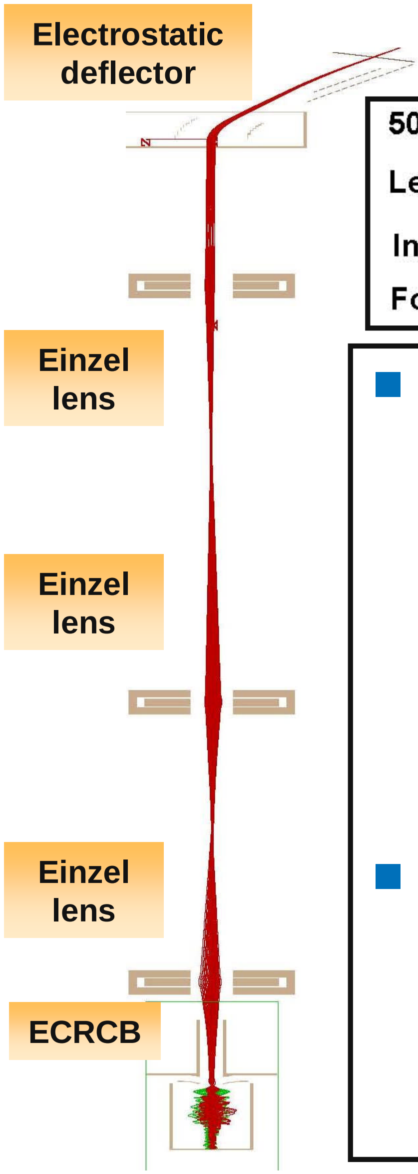


The CARIBU project

- 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
  - 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



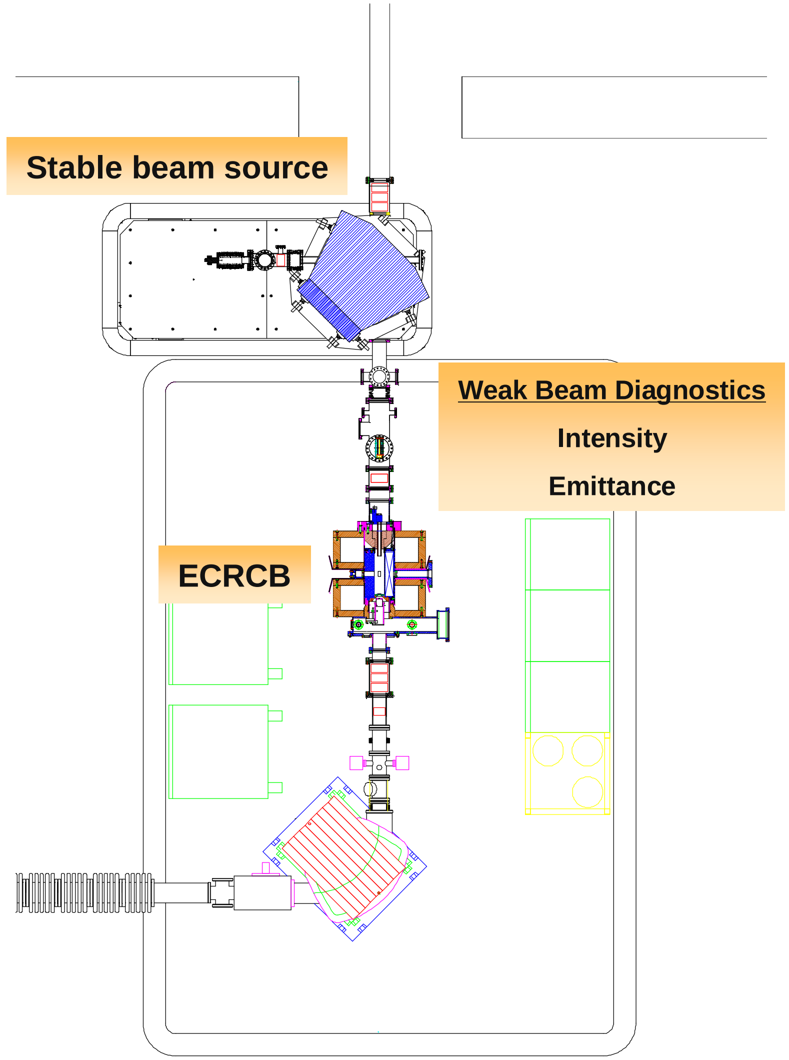
50kV A=100 Single Gap de-celeration

Lens1 17.5; Lens2 21kV; Lens3 23kV

Increase Source voltage to 50.00kV

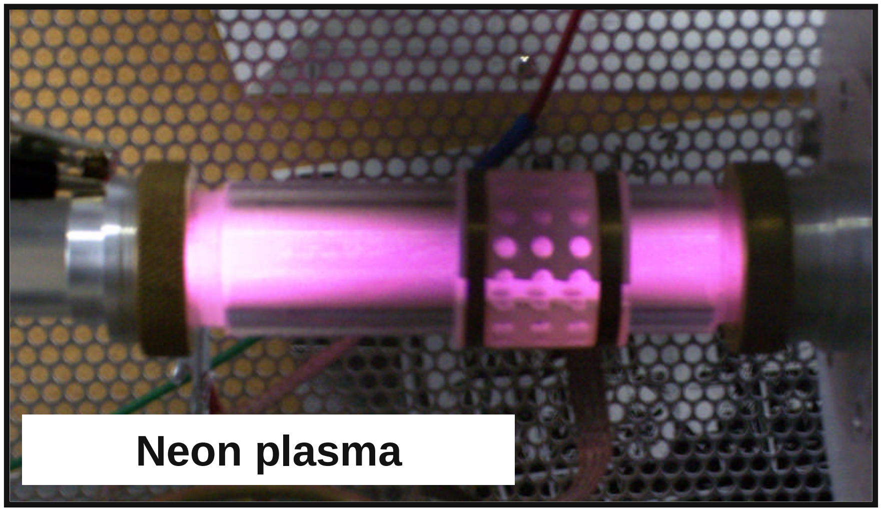
Focusing electrode optics, apt dia=24 mm

- 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
    - *For metals*
  - RF discharge source
    - *For gases*



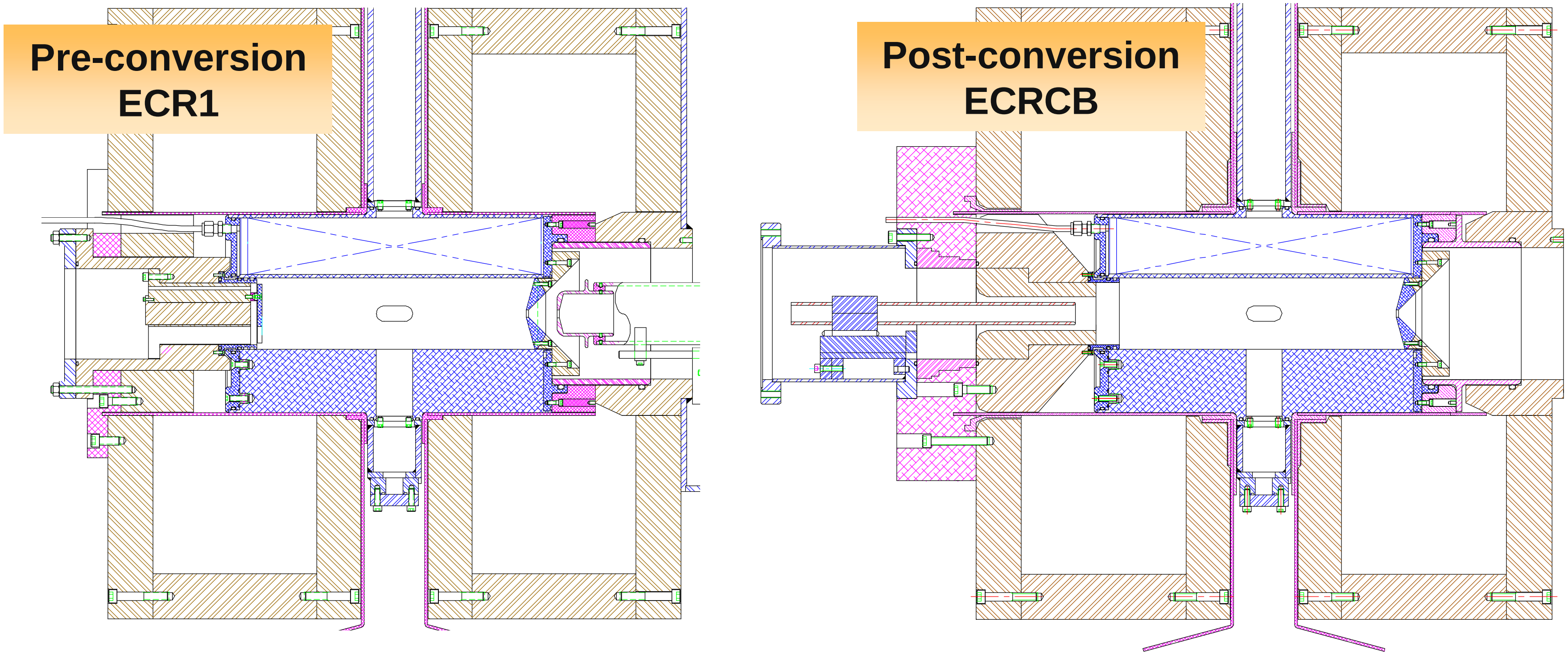
Stable beam sources

- Stable beam sources
  - HeatWave HWIG-250
    - *15 keV beam of over 1.0 μA*
    - *Spot size: <1 mm² at 2.5 cm from aperture*
    - *Pellet materials: Li, Na, Mg, K, Ca, Rb, Cs, Ba, Sr*
  - RF discharge source
    - *Source has been run off line providing 1-2 eμA beams of Ne, Ar, Kr, and Xe*
    - *Expect a larger emittance but can be controlled with slits*



Neon plasma

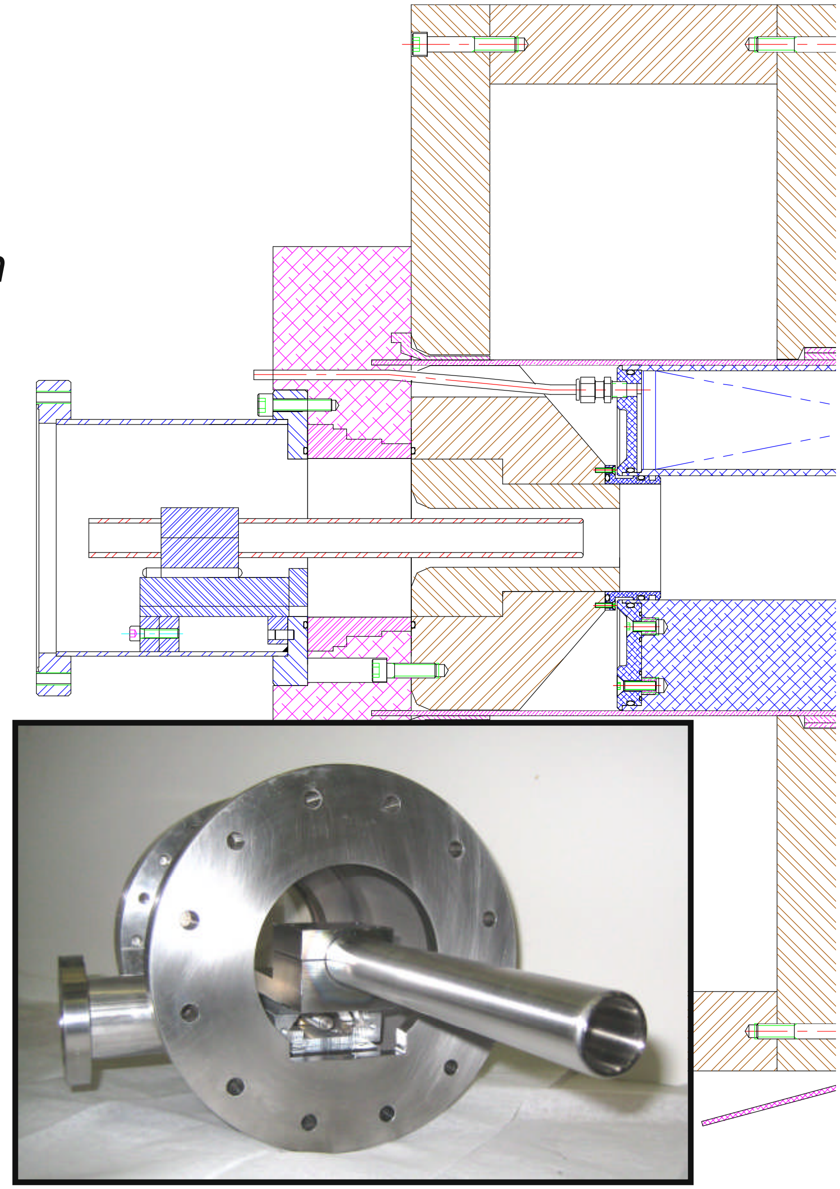
Source modifications for charge breeder operation



- **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}**

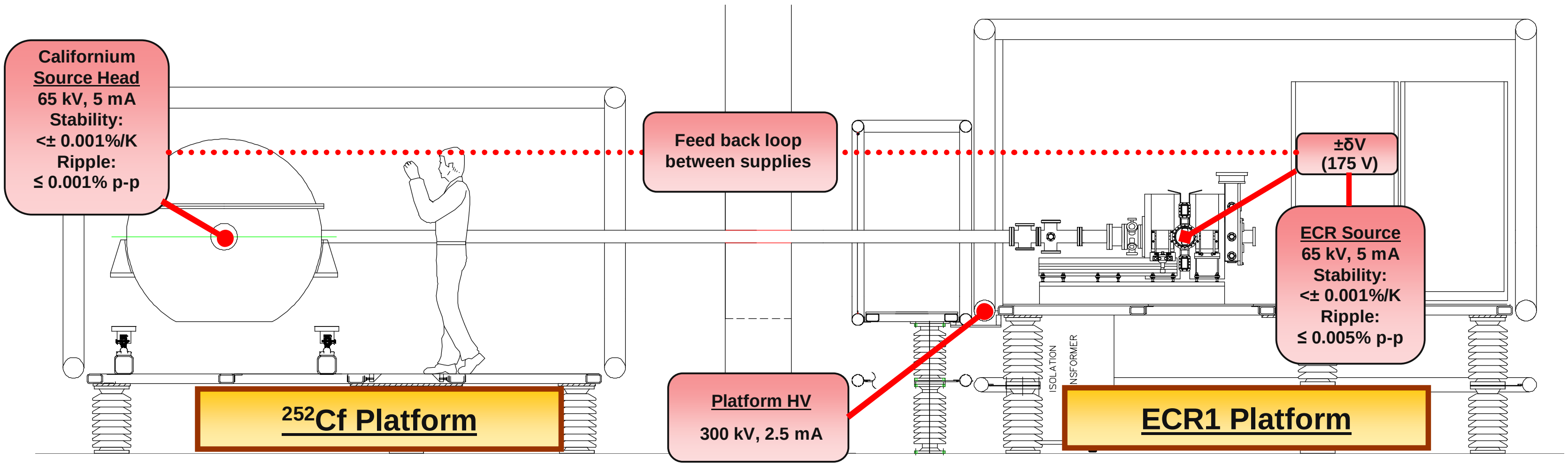
Injection side configuration

- Lexan insulator provides structure with an alumina liner exposed to vacuum
  - Base pressure: 2.0x10^{-8} Torr
    - *Increases to 1.7x10^{-7} with plasma on*
- Movable transfer tube
  - Highly polished stainless steel
  - 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

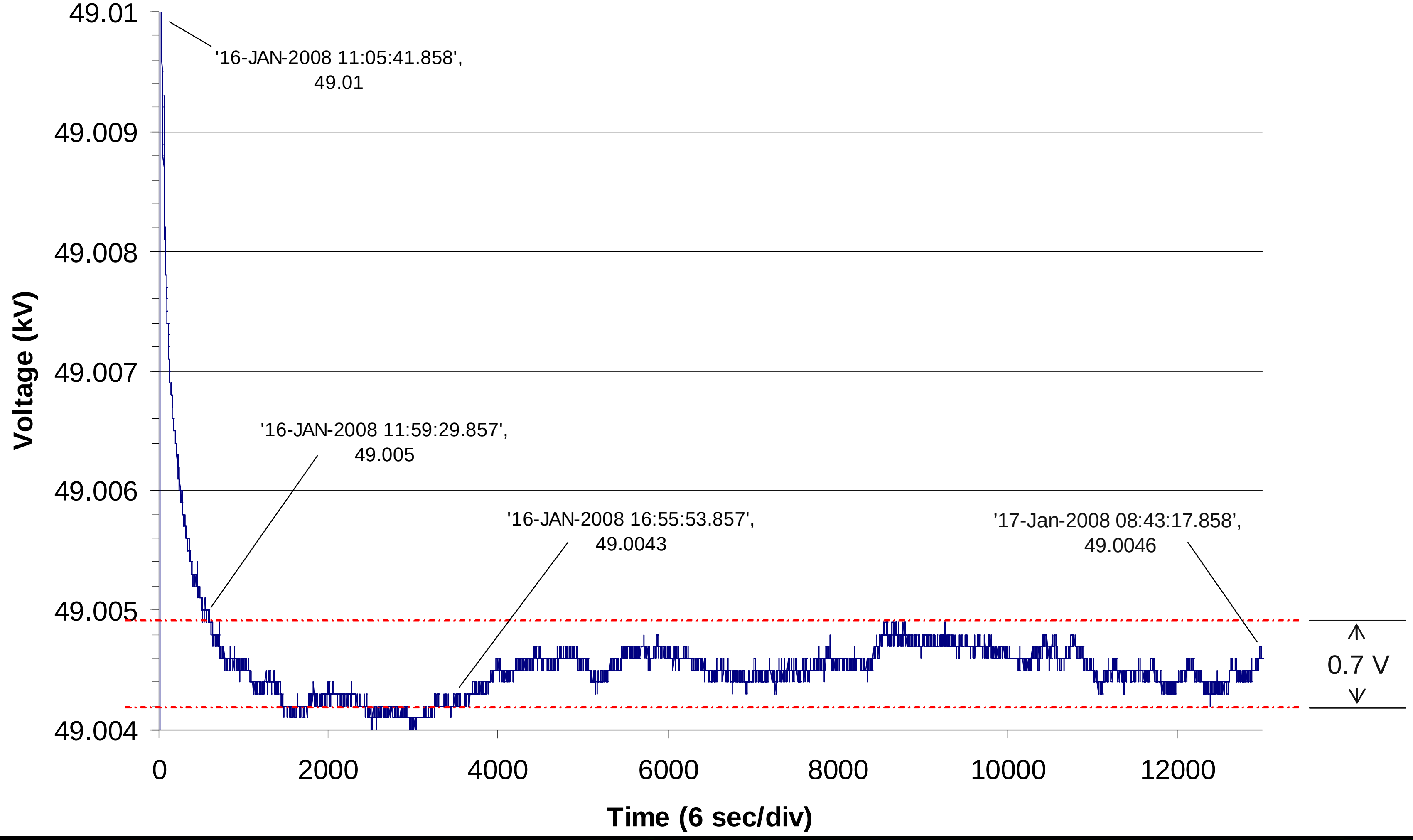


High stability power supply

- Power supply specifications for charge breeder
  - 65 kVDC, 5 mA
  - Stability: <± 0.001%/K+20 mV (<± 0.67V → 1.34 V window)
    - *Supply passed factory acceptance test*
    - *In house testing shows <± 0.500 V deviations at 50 kV*
  - Ripple: < 0.005%+20 mV p-p (≤ 3.45 V p-p)
    - *Supply passed factory acceptance test*
    - *In house testing shows < 0.500 V p-p ripple at 65 kV*
      - Gas catcher power supply will have < 0.001%+20 mV p-p ripple specification (≤ 0.67 V p-p)

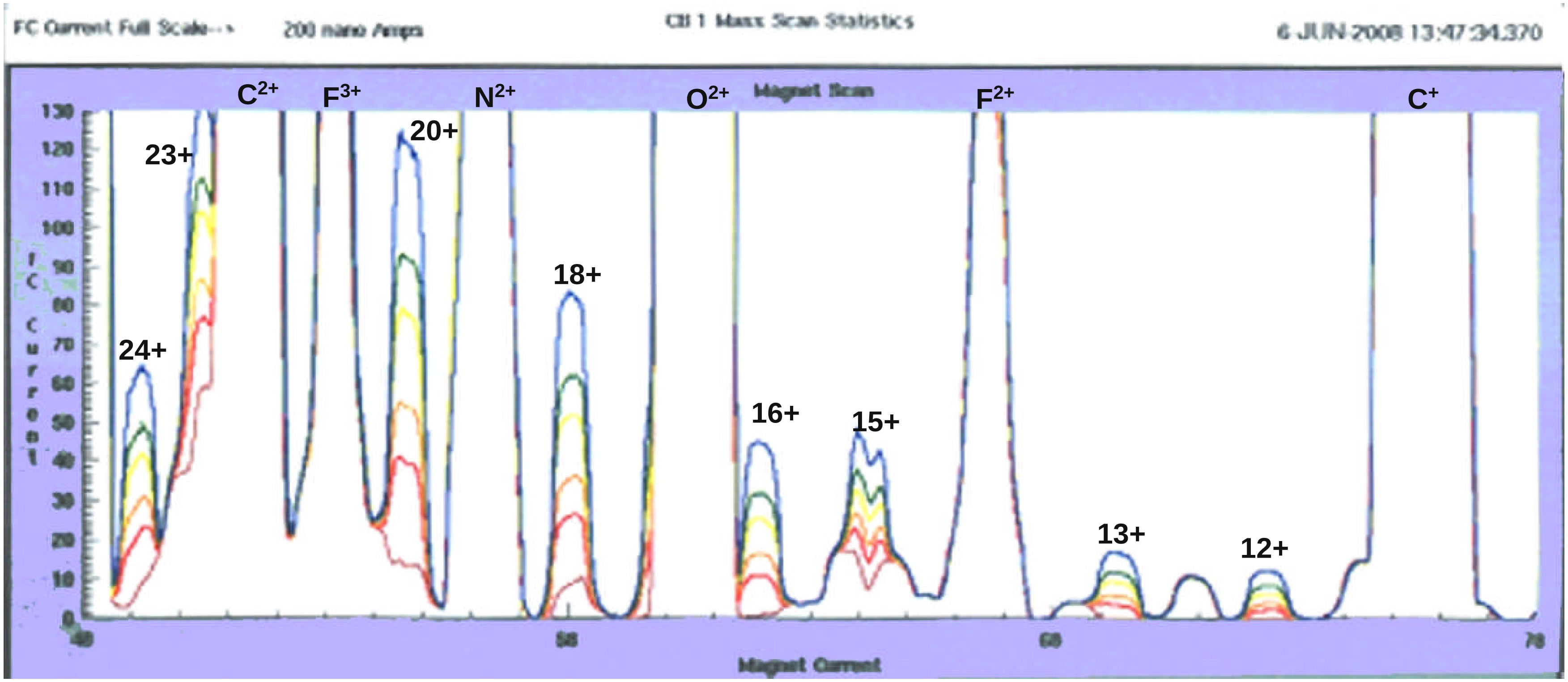
In house stability test

- Took ~1 hour for supply to warm up and voltage to settle within 1.0 V window
- Voltage stayed within 1.0 V window for 24 hours



Cesium charge breeding spectrum

- We achieved our 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



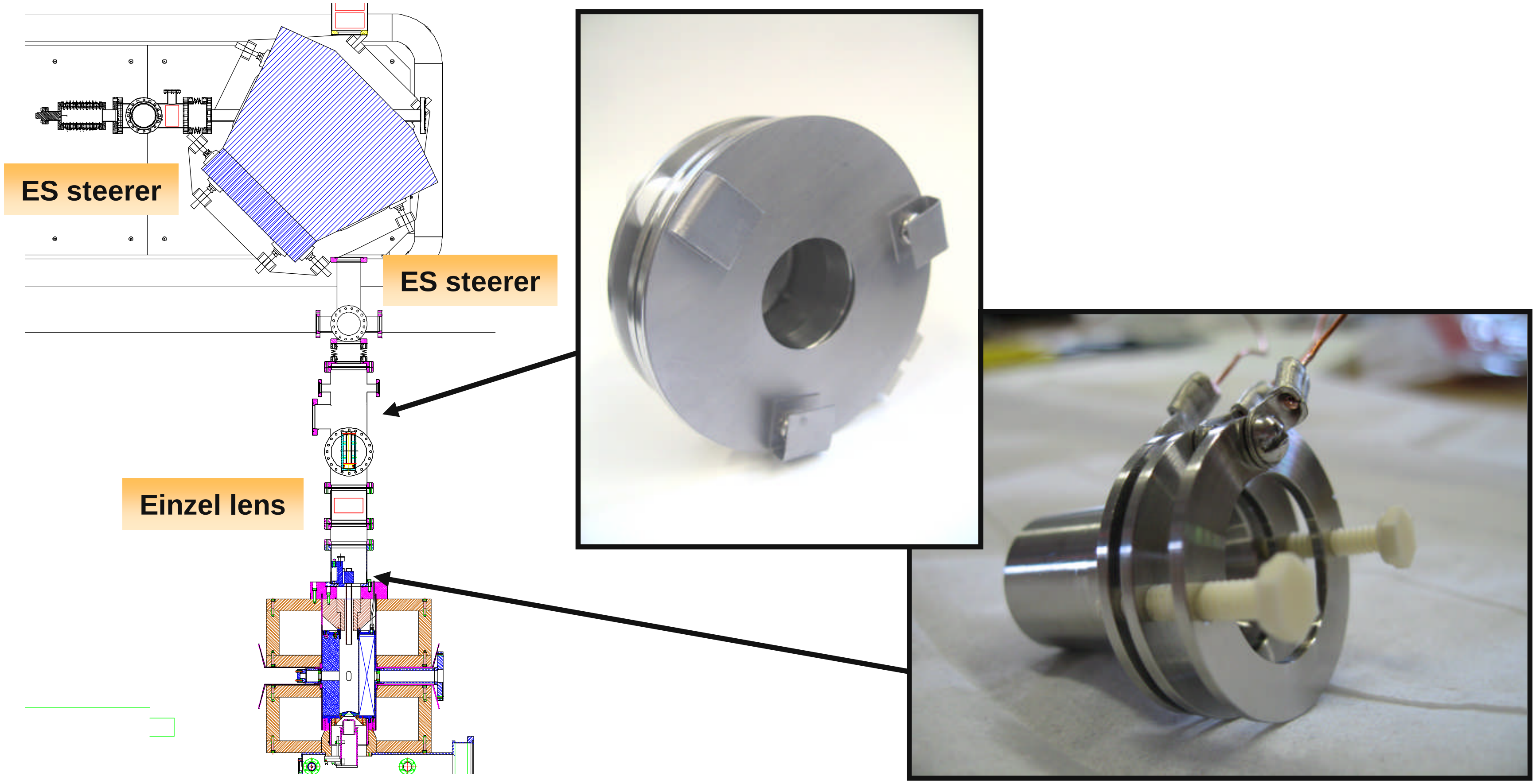
Charge bred cesium beam – "initial results"

Charge state	Efficiency	Efficiency after tuning 1+ line
12+	1.4	
13+	1.8	
16+	2.4	
18+	3.8	7.1
20+	6.8	9.0
24+	2.2	

- Previous results at TRIUMF using a Phoenix ECR charge breeder had 2.7% efficiency into $^{133}Cs^{18+}$
- So what can be wrong?
  - Beam currents are not being measured correctly – 1+ or n+
  - Background measurement is not accurate

Beam current measurement

- Using a brand new Thermionics faraday cup
- Picoammeters were calibrated and in good working order
- Built a second small faraday cup and installed it at the front of the transfer tube to check the accuracy of the Thermionics faraday cup measurement



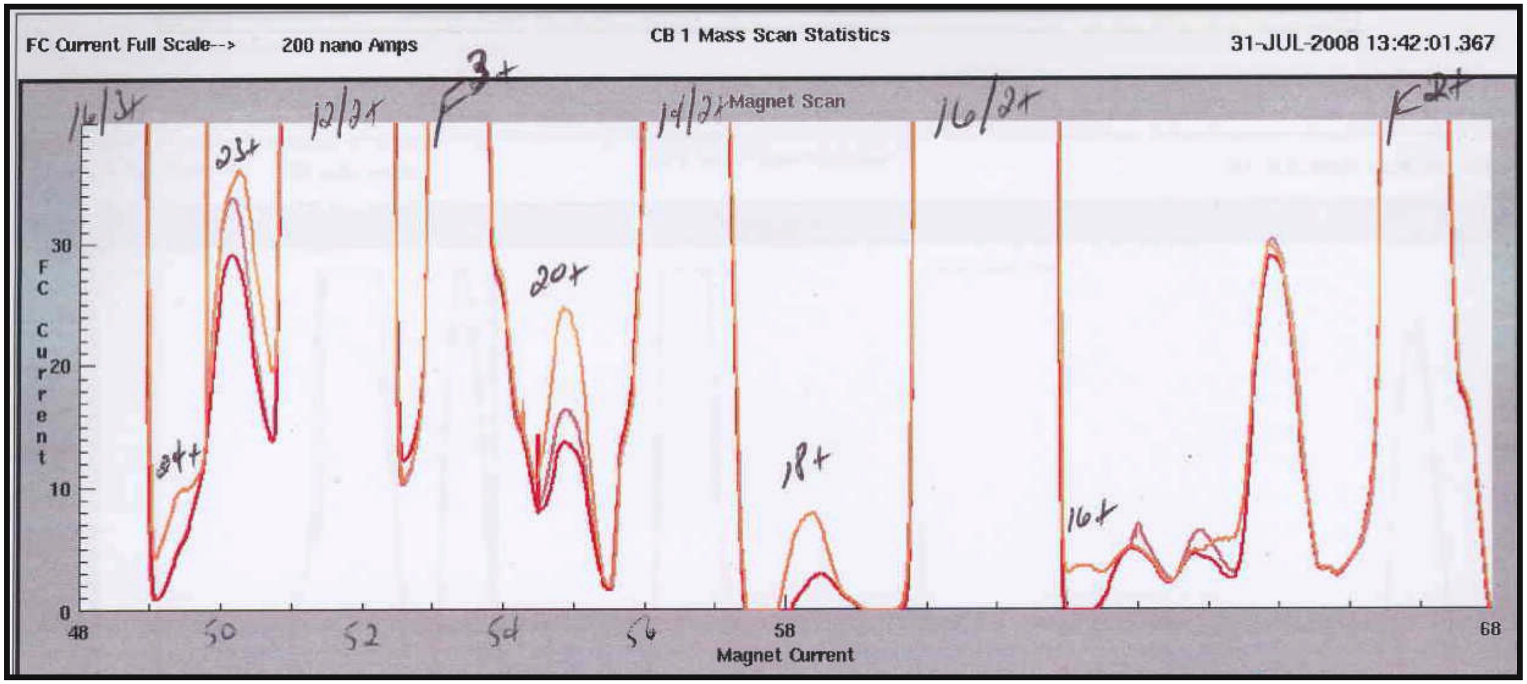
Beam current measurement

- Turned the surface ionization source back on to the same settings as the "9.0% efficiency" run
  - Thermionics cup : 34 nA
  - Small faraday cup: 125 nA
- Problem one: faraday cup was not reading properly
  - Traced to an insulating layer on the tantalum charge collector generated during welding
    - *Replaced tantalum piece with a stainless steel charge collector*
      - Cup readings in agreement

Charge state	Efficiency	'Normalized' Efficiency
18+	7.1	1.9
20+	9.0	2.4

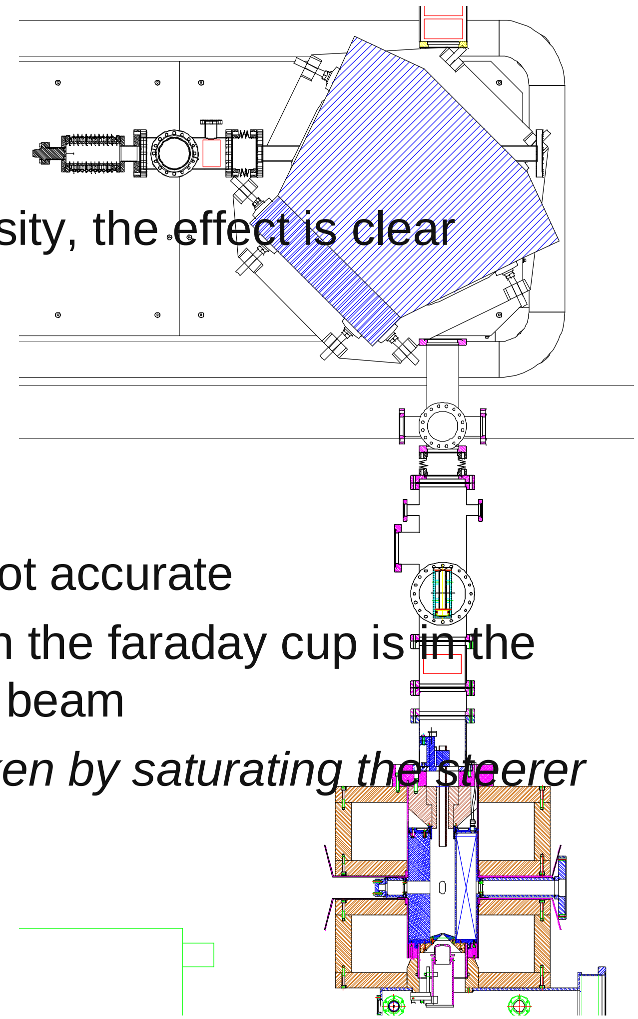
Background measurement

- Orange trace is with Cs^+ injection
- Brown trace is with Cs^+ stopped using an electrostatic steerer just after the 1+ source but before the analyzing magnet
  - Confirmed that saturating the steerer generates the same background spectrum as shutting off the 1+ source
- Red trace is with the Cs^+ stopped using the faraday cup after analysis
  - Clearly see a difference in the background levels of 20+ and 23+



Background measurement

- The difference in the background level is due to outgassing in the 1+ analyzing magnet and low energy line which is generated by the beam coming out of the injection side of the ECRCB
  - $^{133}Cs^{20+}$ very similar m/q as $^{40}Ar^{6+}$
  - $^{133}Cs^{23+}$ very similar m/q as $^{40}Ar^{7+}$
- 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*
- Problem two: background measurement was not accurate
  - Due to gas loading that is not present when the faraday cup is in the beamline and intercepts the outgoing ECR beam
    - *Background measurement has to be taken by saturating the steerer*



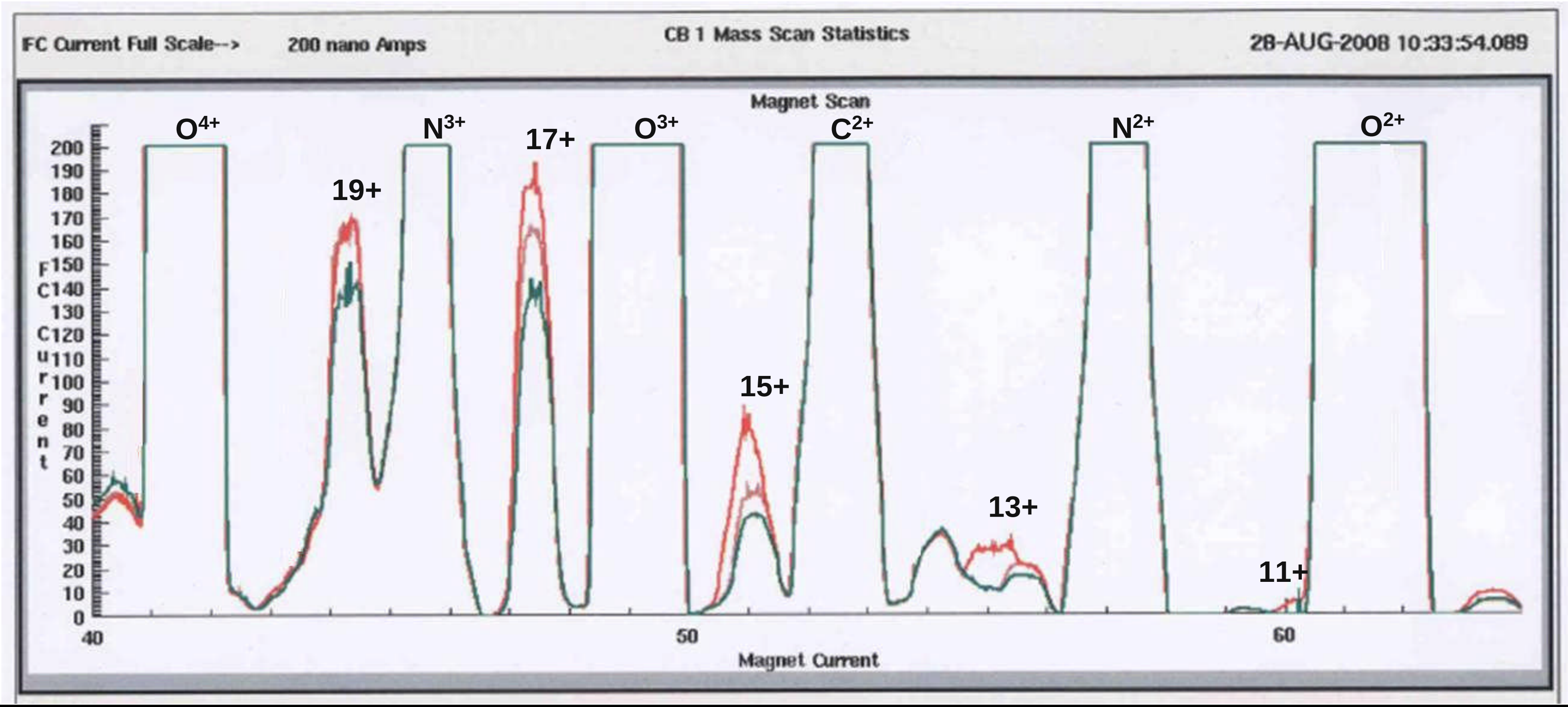
Real results of charge bred cesium

- We now have no idea how to ‘normalize’ the previous experimental results
  - Repeat all of the measurements
    - *Surface ionization source electrical isolation began to degrade*
    - *Poor beam optics as a result but we still collected some data*
- 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
  - 175 W at 10.44 GHz
  - 75 W at 12.27 GHz

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

- Mass spectrum of ECR ion source output with and without Rb^+ injection
  - Charge bred rubidium is in red
  - Source background, with Rb^+ injection stopped by electrostatic steerer, is shown in brown
  - Source background, with Rb^+ injection stopped by faraday cup, is shown in green



Results of charge bred rubidium

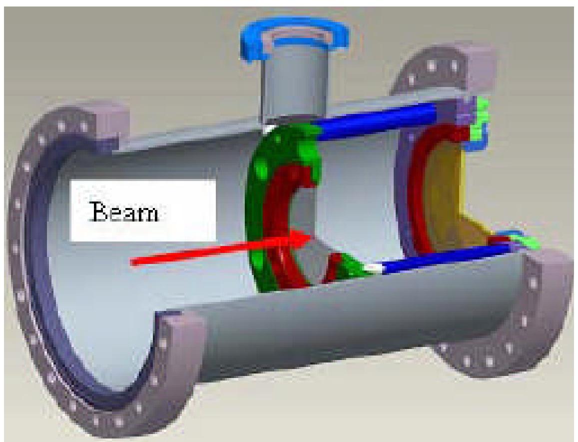
Charge state	Efficiency
10+	0.7
11+	0.8
13+	1.8
15+	3.6
17+	0.8

- Optimized on $^{85}Rb^{15+}$ with oxygen support gas and 270 W at 10.44 GHz

"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 (n80 mm) which is viewed by CCD camera
- Beam energy of 75 keV/q and current density of <1.0 eµA/cm^2 with Bi beam

See Sergei Kondrashev's talk on Thursday morning



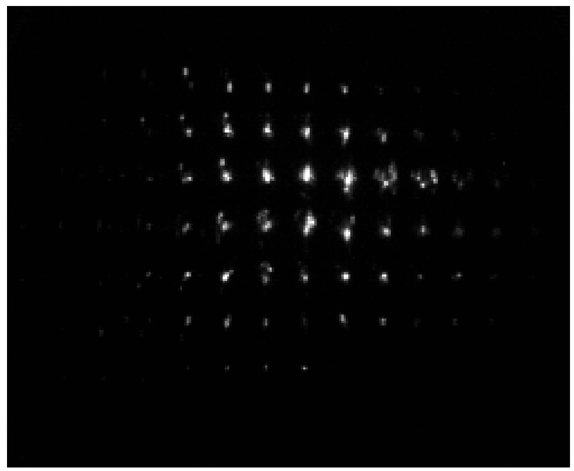


Figure 6: Pepper pot image of $^{129}Xe^{14+}$ ion beam.

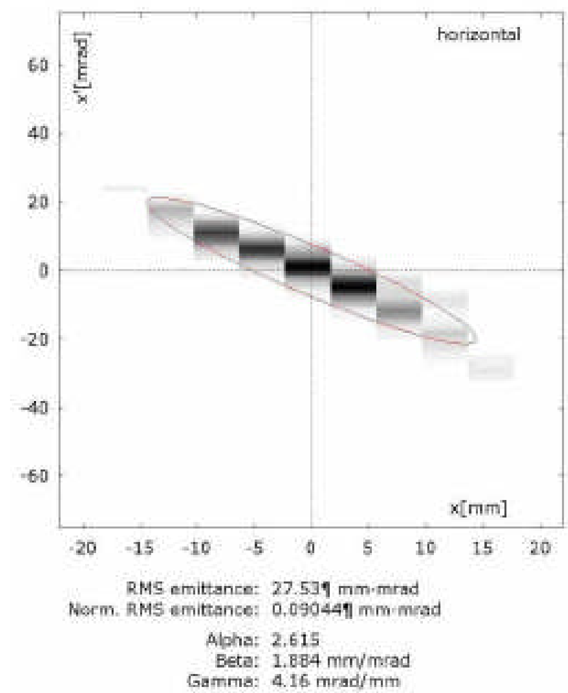


Figure 7: Horizontal phase space plot of the $^{129}Xe^{14+}$ ion beam.

TUPAS003 Proceedings of PAC07, Albuquerque, New Mexico, USA

EXPERIMENTAL RESULTS ON MULTI-CHARGE-STATE LEBT APPROACH*

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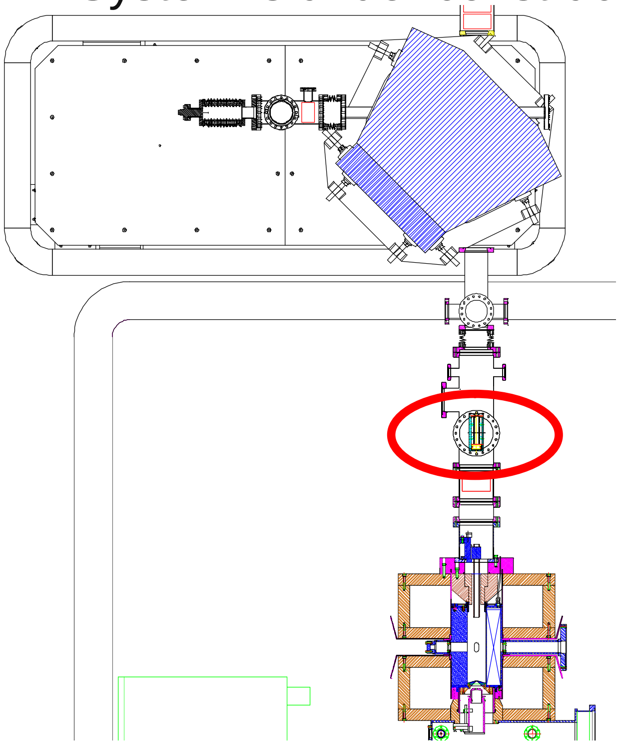
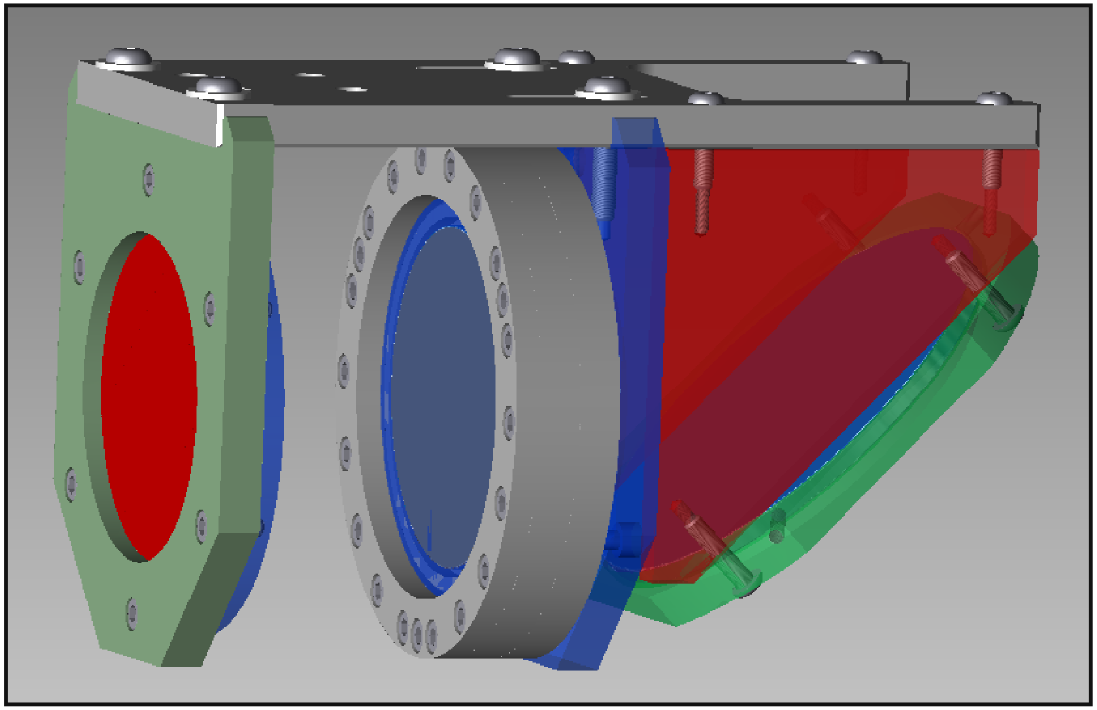
“Pepper Pot” emittance system for ECR charge breeder

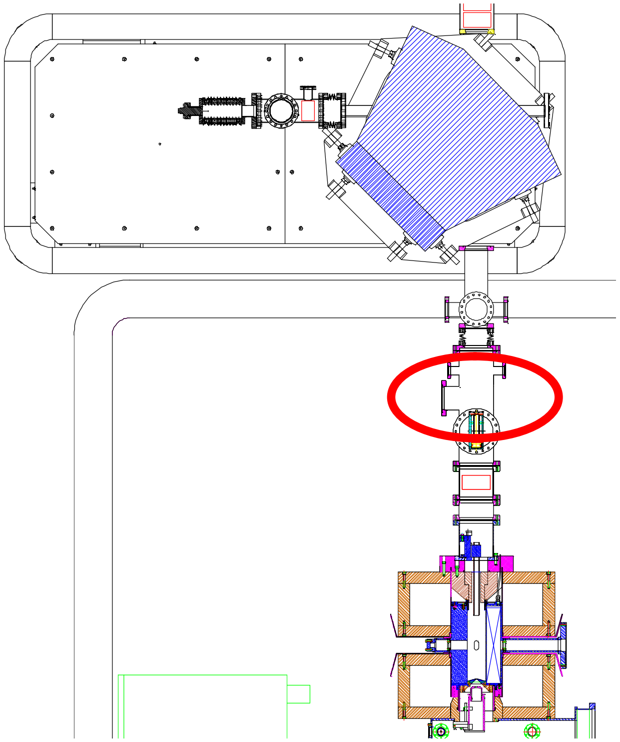
- Mask has 20 µm laser drilled holes, 0.5 x 0.5 mm spacing, 40 mm diameter
- Behind the mask is a CsI crystal (n40 mm)
  - Scintillator tested with a 300 nA, 10 kV beam
- Distance between the mask and the scintillator is variable
- Improved sensitivity possible with the addition of a micro channel plate/phosphor
- System is under construction





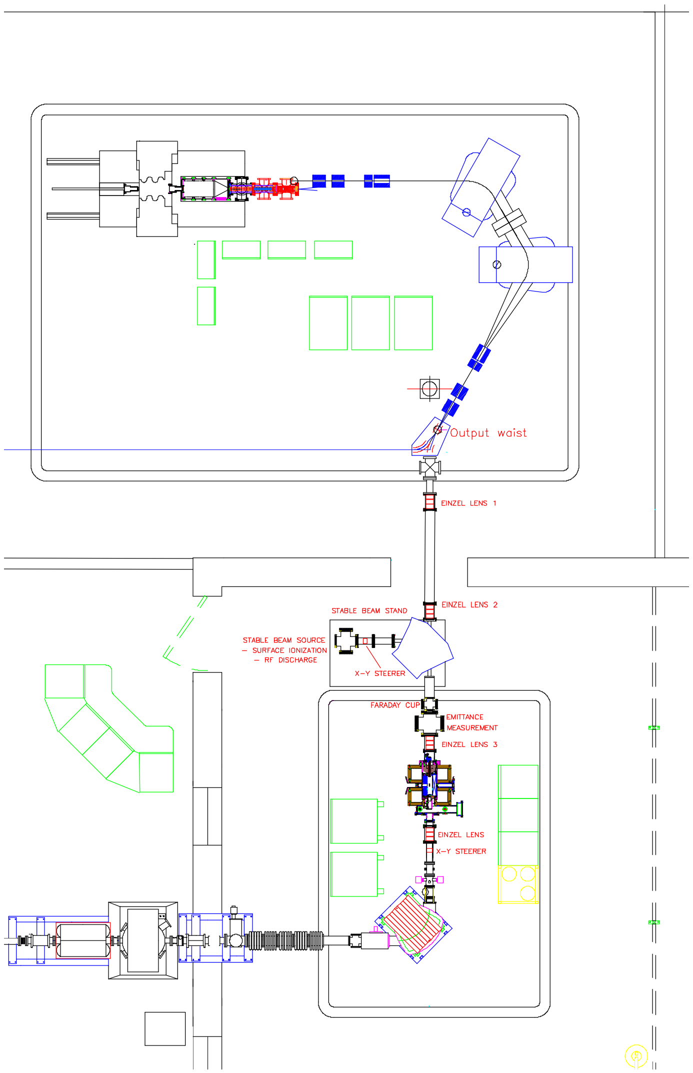
New fully rear-shielded faraday cup

- Presently using a standard Thermionics faraday cup
- The back of the charge collection cup is not shielded and “sees” the beam coming from the injection side of the ECRCB
  - This means we have to shut off the ECRCB to measure the 1+ beam current
- New cup design is fully shielded and will allow beam measurements without turning off ECRCB



The CARIBU project - status

- High voltage platform and shield cask are complete
- Isobar separator magnets are in final testing
  - Shipment is expected in October
  - Focusing elements are complete
- Gas catcher construction is nearing completion
- ECRCB commissioning is complete
- CARIBU operation ramps up in 3 steps
  - First ^{252}Cf source – 3 mCi shipped last week
  - Second source 80 mCi, order placed to ORNL
  - 1.0 Ci source for full operation will not be available until at least September, 2009
    - *US production awaits funding from Congress*
- The CARIBU project can be commissioned with the 80 mCi source. The goal is to complete commissioning by March 31, 2009.



Future plans for the charge breeder

- Continue with beam development using rubidium source
  - More work with multiple frequency heating
- Install RF discharge source to develop source performance with gases
- Replace stainless steel transfer tube with one made of soft iron and nickel coated
  - Improves magnetic field on injection side of ECRCB
- Improve pumping at injection region
  - Have seen some evidence that a lower pressure will improve the efficiency
  - Recently modified the chamber to accept another turbo pump
- Eliminate sources of outgassing
  - Bake out the 1+ transport line
  - Beamline collimators to inhibit backstreaming into ECRCB
- 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