CARIBU Application's workshop,
Argonne National Laboratory,
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CARIBU Status and Schedule

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Outline

- Brief description of CARIBU
  - Production of isotopes and separation
  - low-energy buncher and beamline

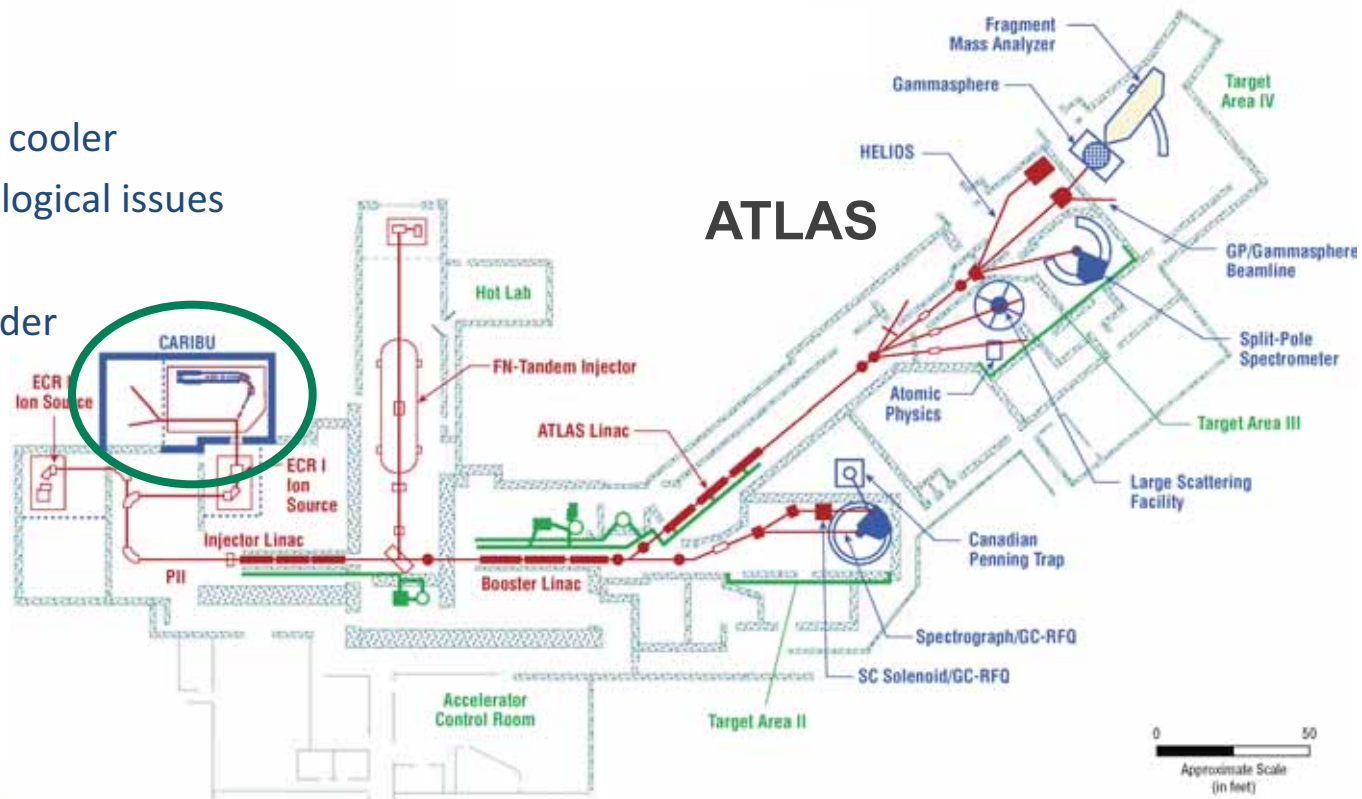
- CARIBU status and current developments for low-energy beams

CARIBU - Californium Rare Ion Breeder Upgrade

Use heaviest isotope "available" , ^{252}Cf, to produce neutron-rich isotopes

- Project goal: Provide neutron-rich radioactive beams to user community
  - Low-energy
    - Masses, decay spectroscopy, laser spectroscopy, …
  - Reaccelerated through ATLAS at up to 15 MeV/u
    - Single particle structure, gamma-ray spectrosc

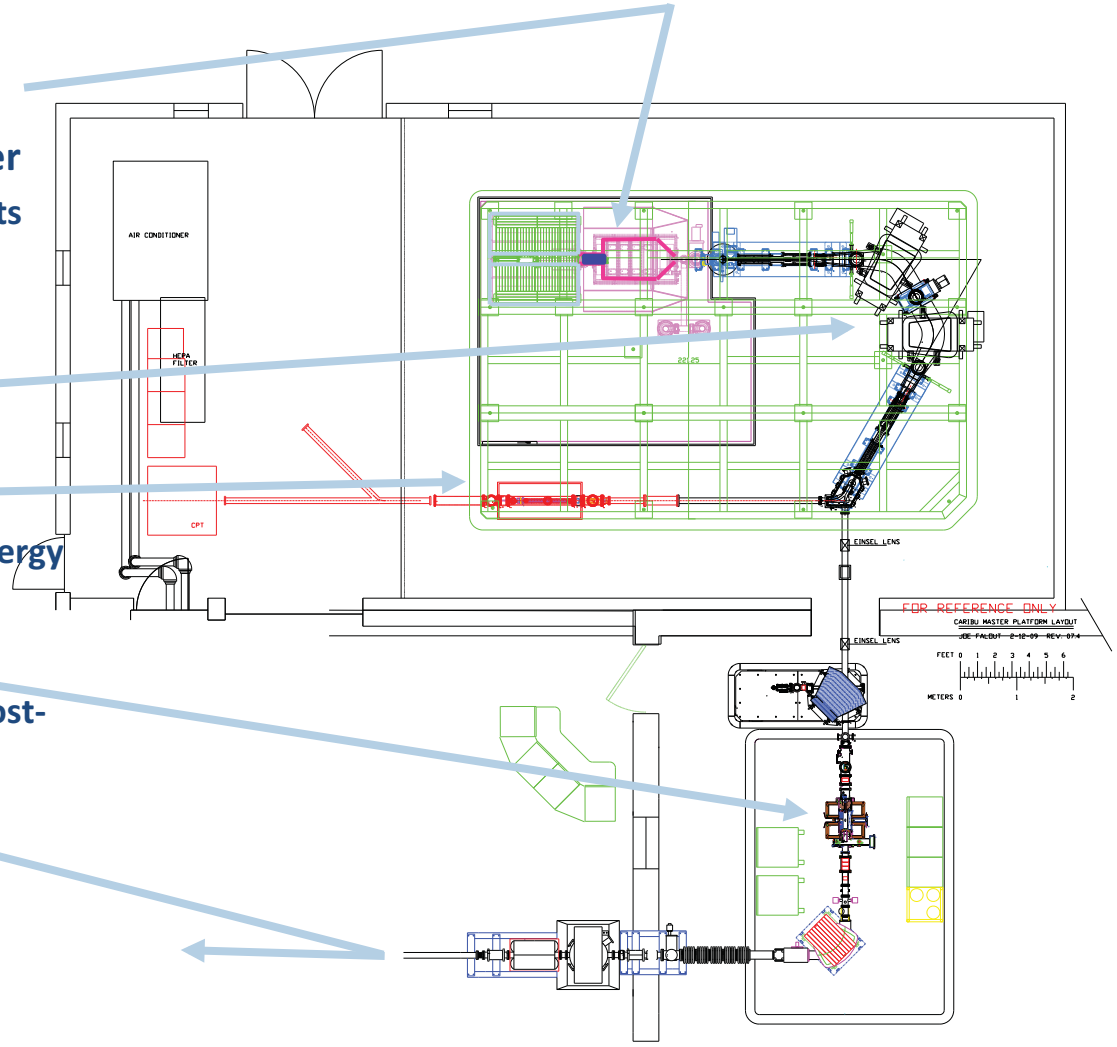
- Project Description
  - Gas catcher/RFQ cooler
  - Source and radiological issues
  - Isobar separator
  - ECR Charge-breeder
  - Diagnostics
  - Experimental equipment



Neutron-rich beam source: CARIBU "front end" layout

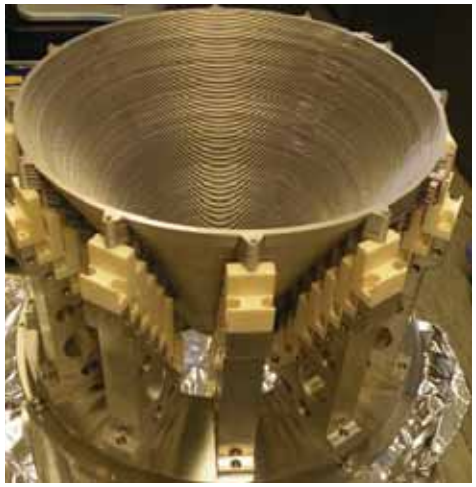
Main components of CARIBU

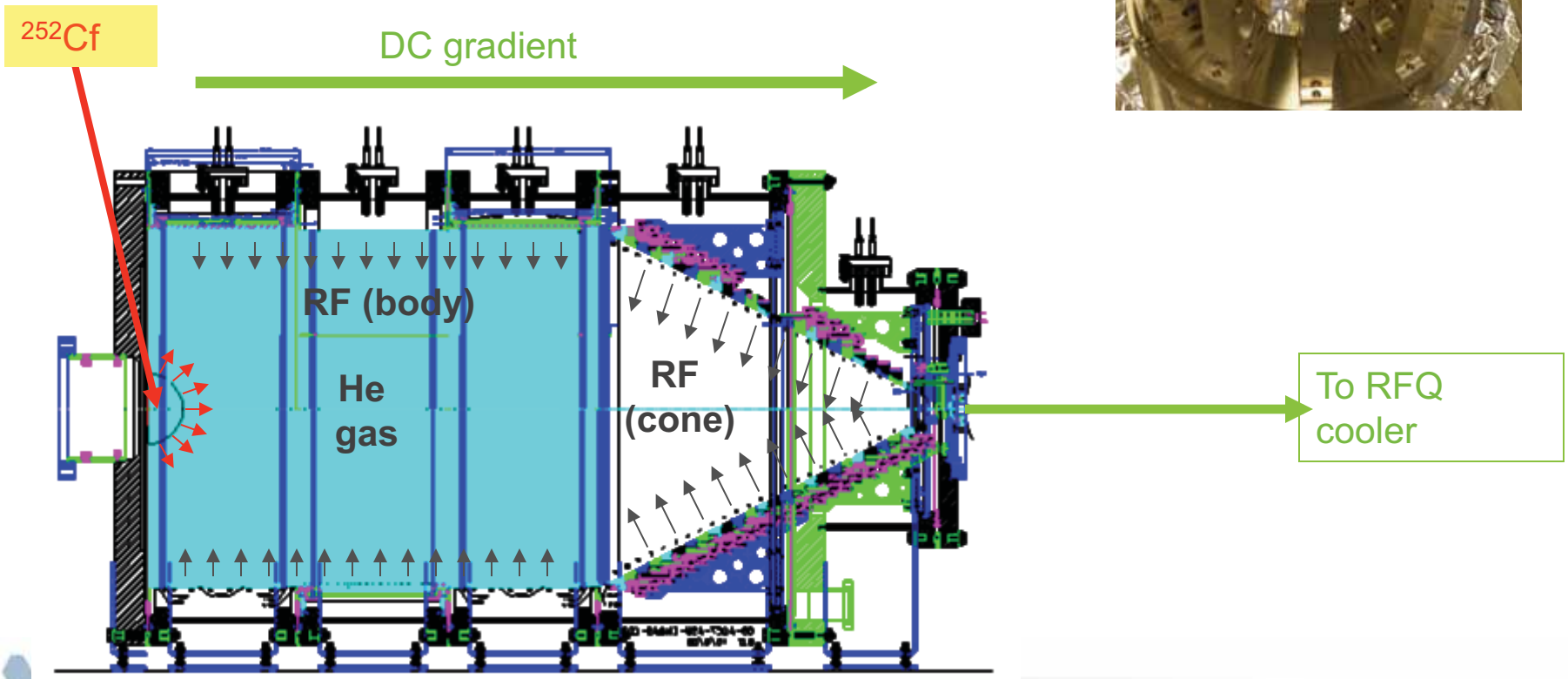
- "ion source" is ^{252}Cf source inside gas catcher / RFQ cooler
  - Thermalizes fission fragments
  - Extracts all species quickly
  - Forms low emittance beam
- Isobar separator
  - Purifies beam
- Low-energy buncher
  - Matches property to low-energy application
- Charge breeder
  - Increases charge state for post-acceleration
- Post-accelerator
  - ATLAS with energy upgrade



CARIBU gas catcher: transforms fission recoils into a beam with good optical properties

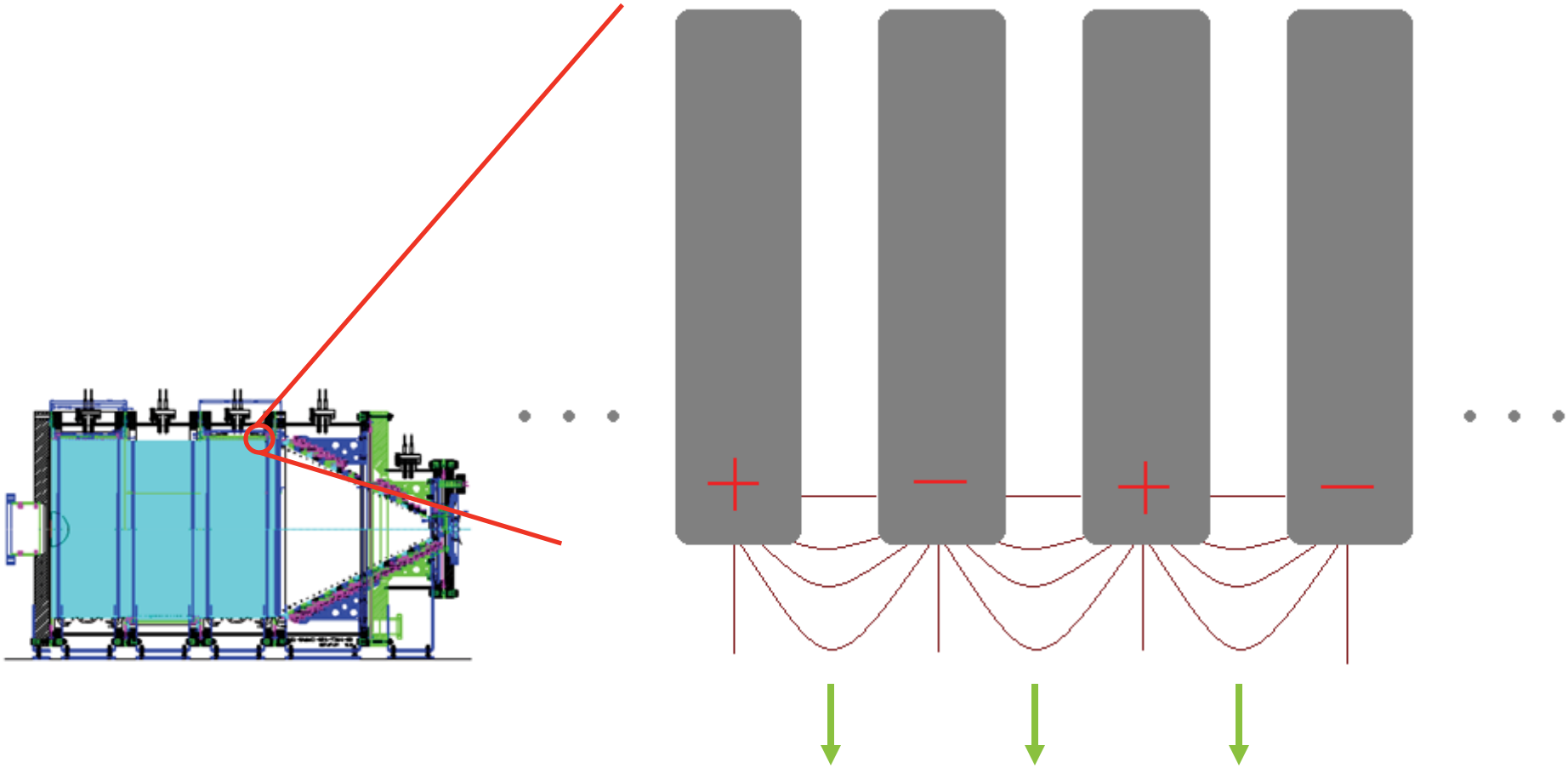
- **Device similar to ANL RIA/FRIB gas catcher prototype**
  - **Radioactive ion transport by RF + DC + gas flow**
  - **Stainless steel and ceramics construction**
  - **Similar length**
  - **Twice the diameter (50 cm inner diameter)**
  - **Extraction in 2 RFQ sections with µRFQs**





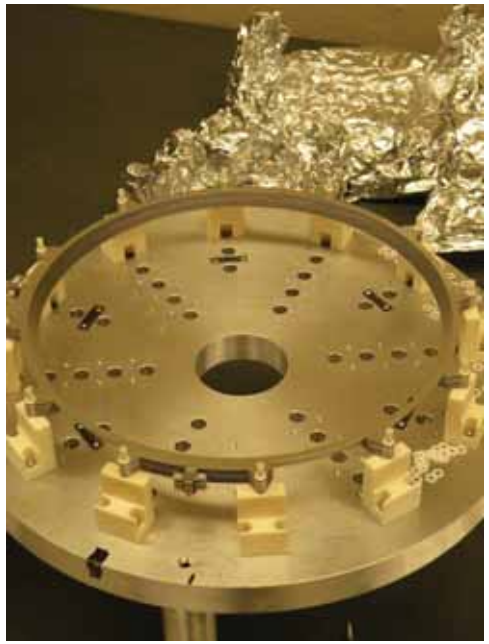
RF carpet

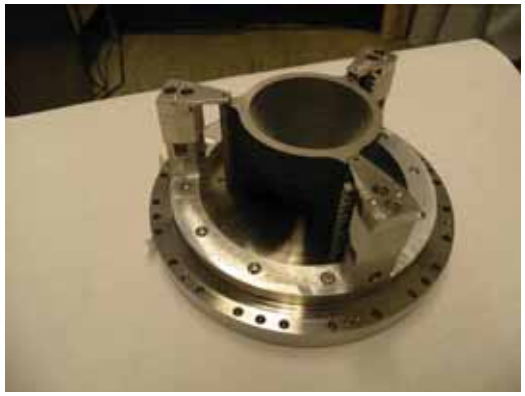
RF applied to ring electrodes in alternating phases @ ~ MHz

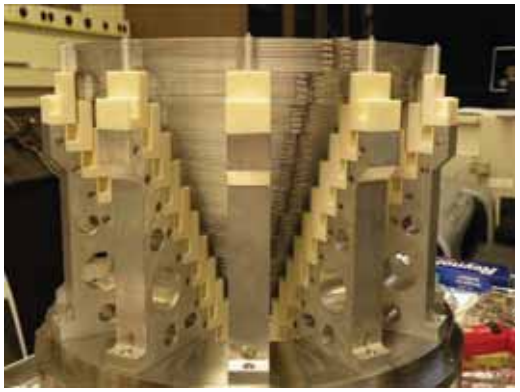


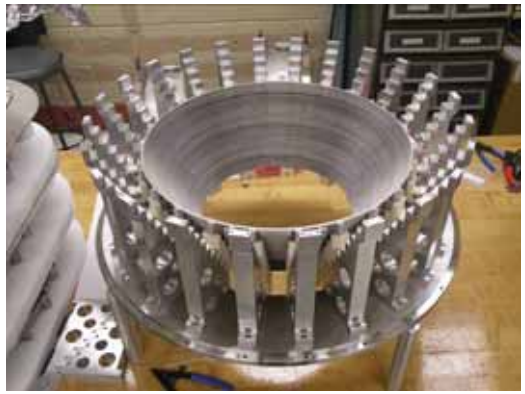
Average force is toward weaker field - IN

CARIBU Gas Catcher RF Cone preparation

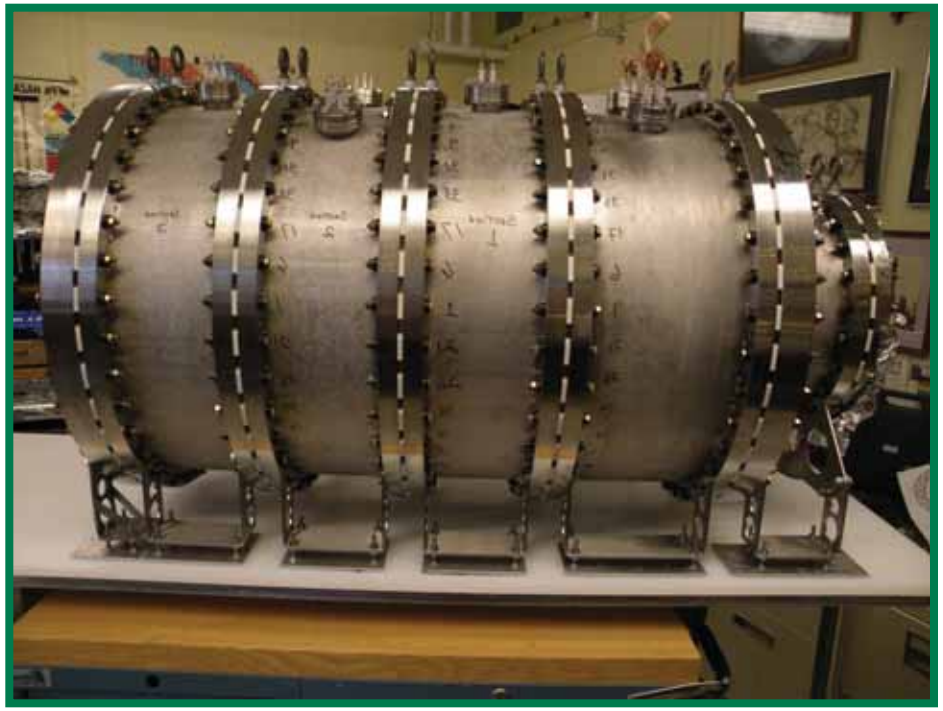






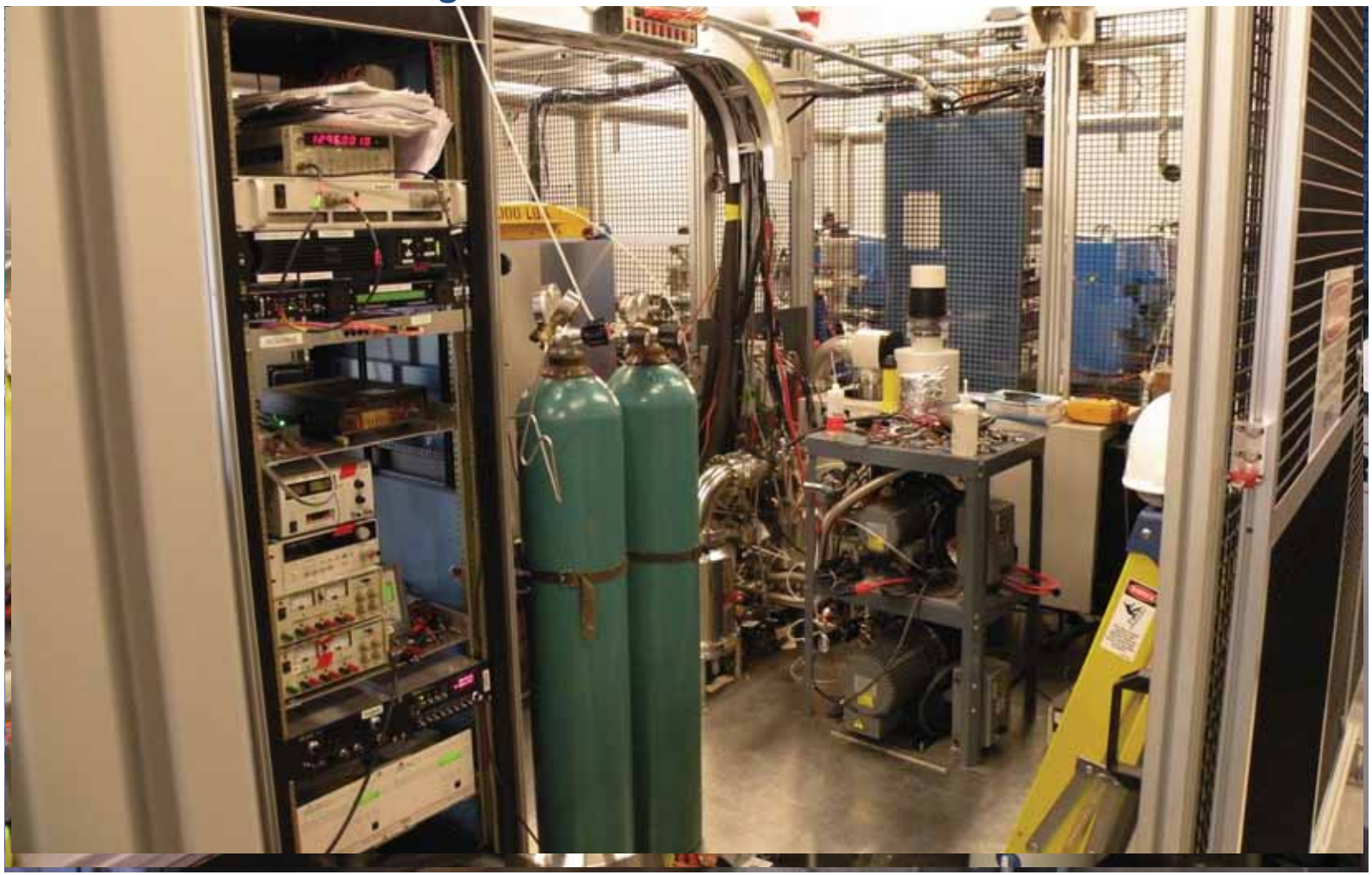


Ion extraction and beam formation: CARIBU gas catcher, RFQs and acceleration section completed and assembled



The very large high-intensity gas catcher for CARIBU

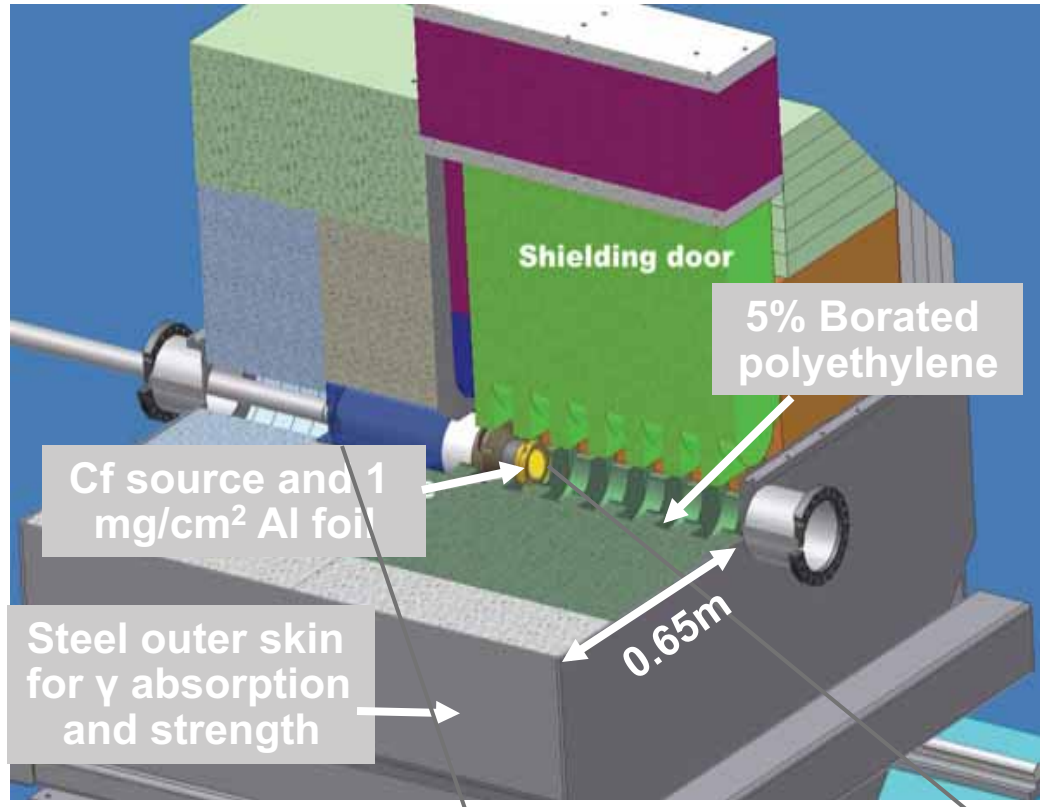
- Gas Catcher/RFQ cooler isolated from main platform and biased to 50 kV.
- Installed inside secondary enclosure with pumping, cooling and gas distribution
- Under 12000 lbs of shielding



CARIBU Shield Cask

Required: Access to equipment near source for extended periods.

- Unshielded 1Ci ^{252}Cf source
  - 46 rem/hr neutrons
  - 5 rem/hr γ-rays
- Work area radiation goal is:
  - 1 mrem/hr @ 30 cm
- The CARIBU source is installed in a shielded cask.
  - Store & transport ^{252}Cf source
  - Tungsten for γ absorption
  - Borated polyethylene for neutrons
  - Outer steel for secondary γ, fire suppression, & strength for transport



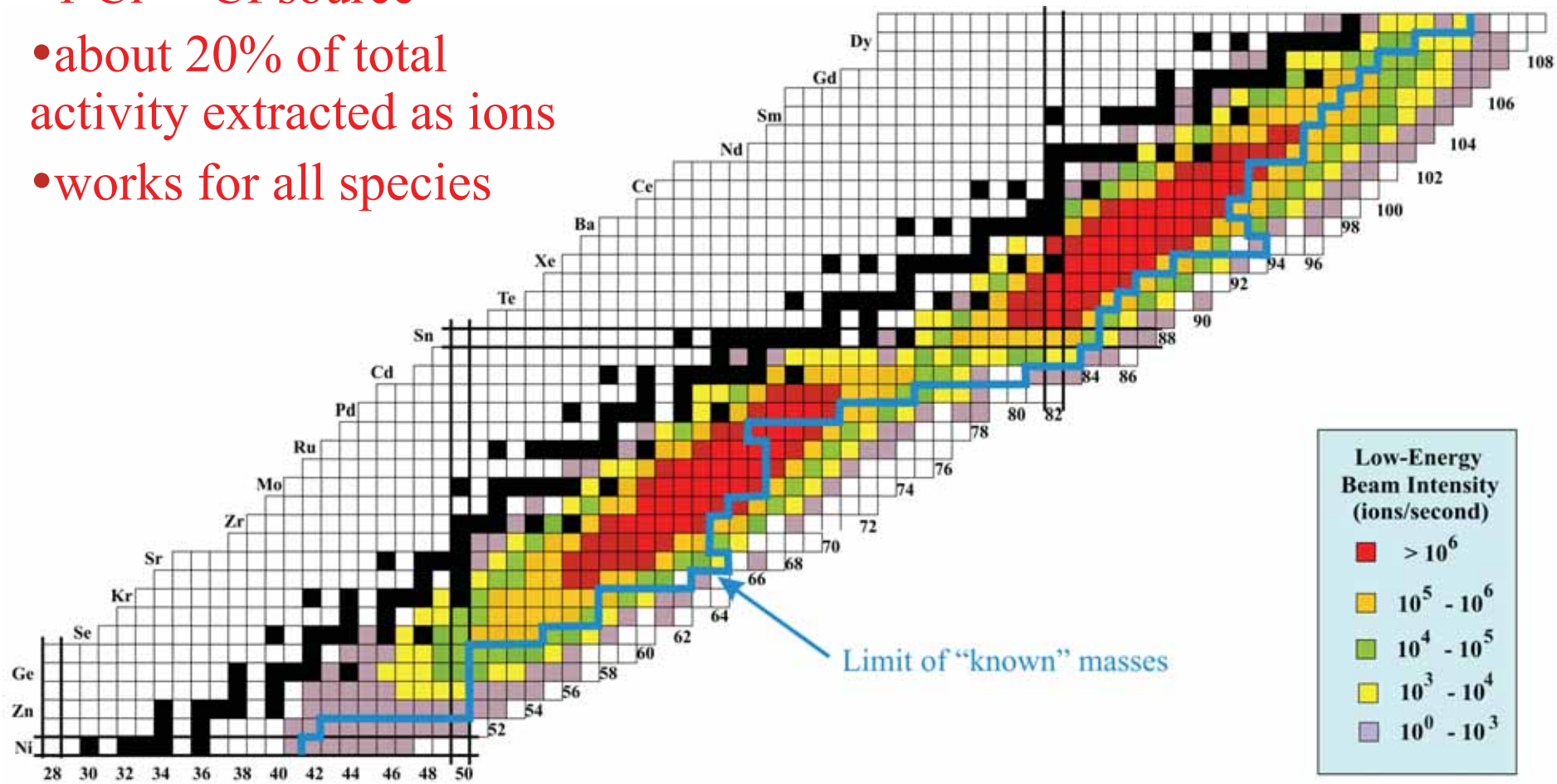
- For the 1 Ci source, 1.9 mg of material is deposited in a ~2cm diameter disk on a stainless steel plate.
- The plate is mounted on a shielded plug which provides shielding for emergency work.

Californium source and gas catcher relationship

- For installation in the gas catcher, the source and shielding plug are pushed from the storage location into position at the end of the helium gas catcher.
- The assembly is sealed to the gas catcher, the source being inside the gas catcher.

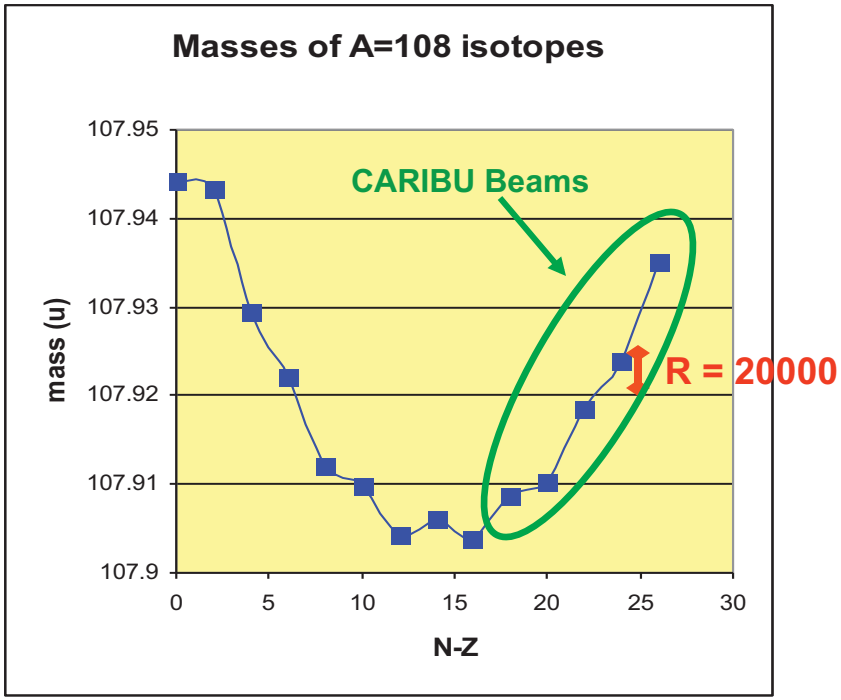
Extracted isotope yield at low energy (50 keV)

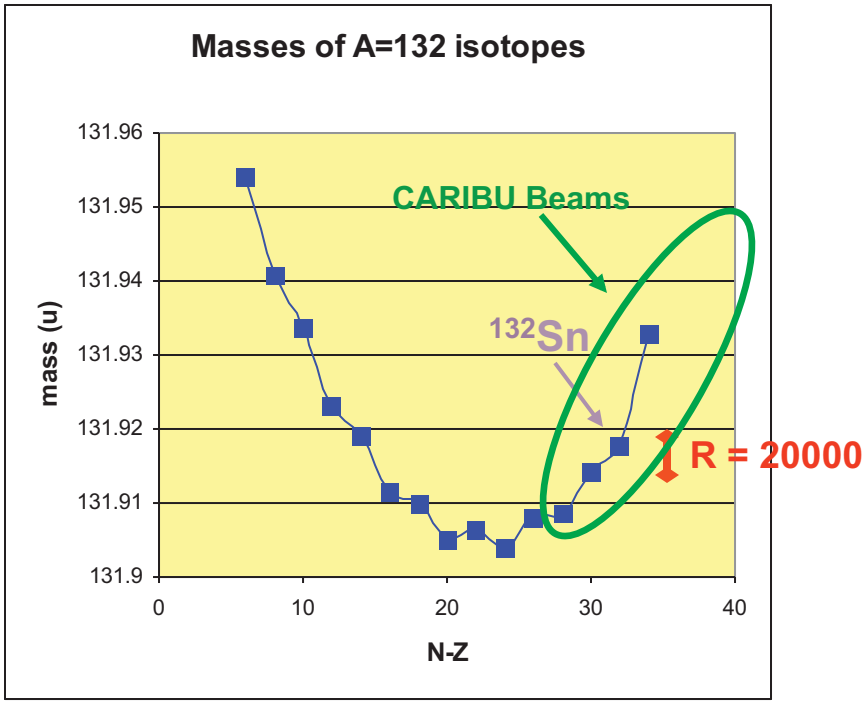
- 1 Ci ^{252}Cf source
- about 20% of total activity extracted as ions
- works for all species



Purification of radioactive ion beam

- Contaminant of neighboring masses are handled easily by most experiments. Same mass contaminants are more difficult.
- The resolution required to remove contamination is:
  - neighboring masses — R = 250
  - molecular ions — R = 500 - 1000
  - isobars — R = 5000 – 50000 (far/close to stability)
  - isomers — R = 10^5 - 10^6





"Compact" isobar separator

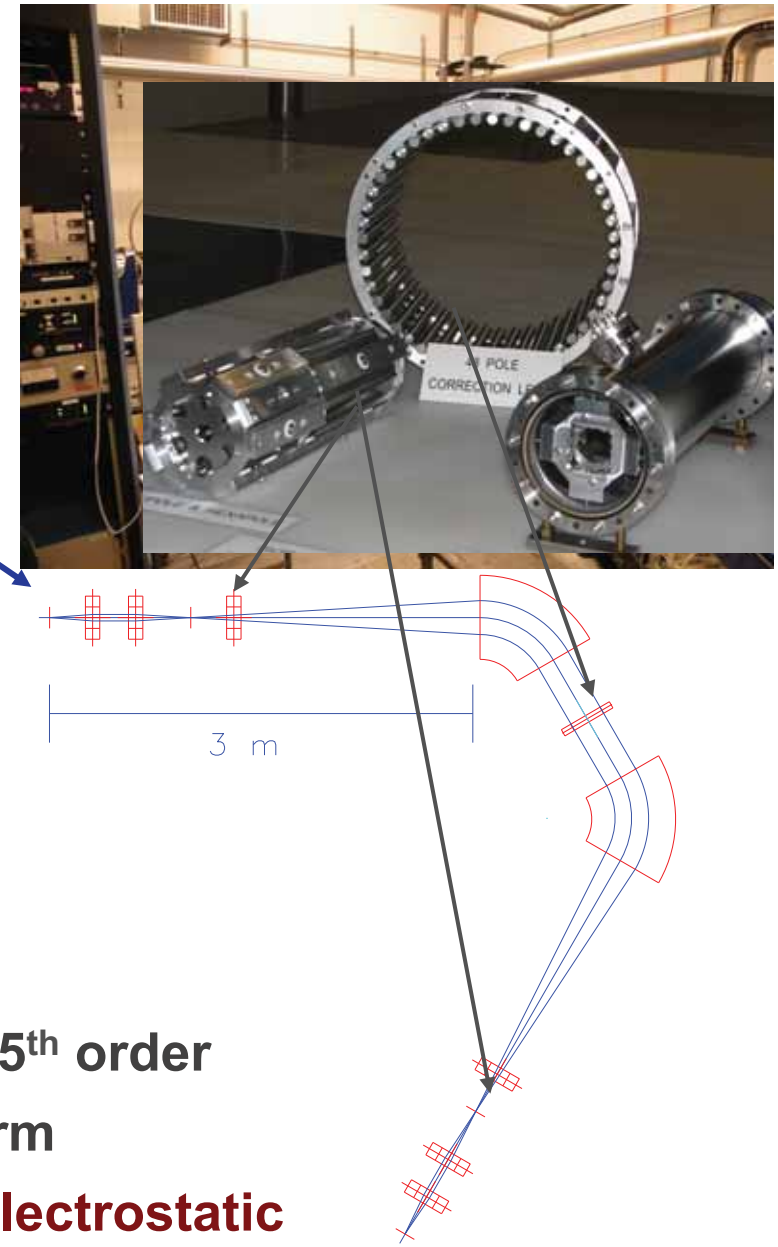
- Takes advantage of low emittance and energy spread of extracted beams:

Beam Properties from gas catcher:

$\varepsilon \approx 3\ \pi$ mm•mr $\delta E \approx 1$eV

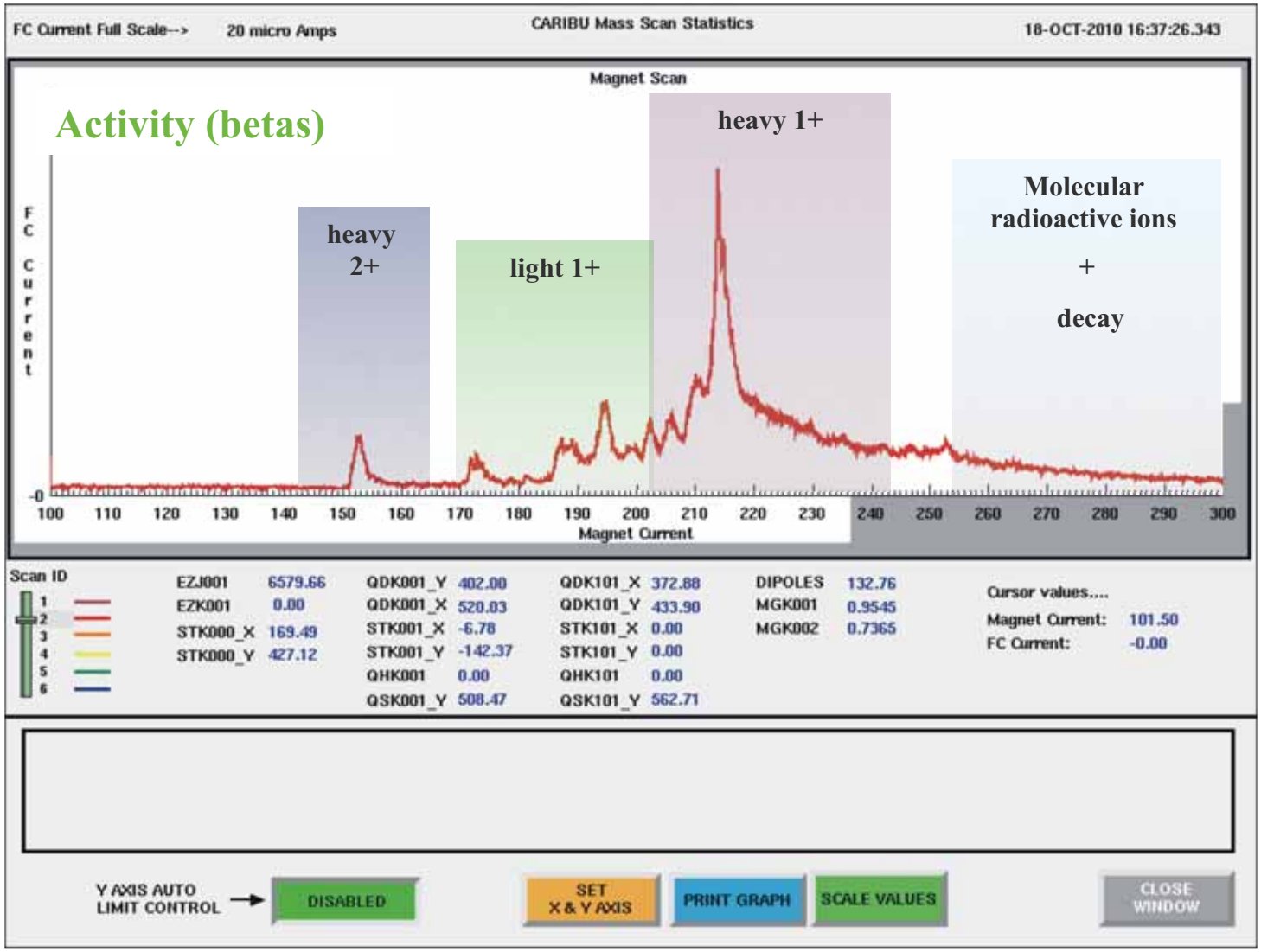
1 mm dia. (circular) beam

$\theta_{max}, \varphi_{max} = \pm 6$ mr

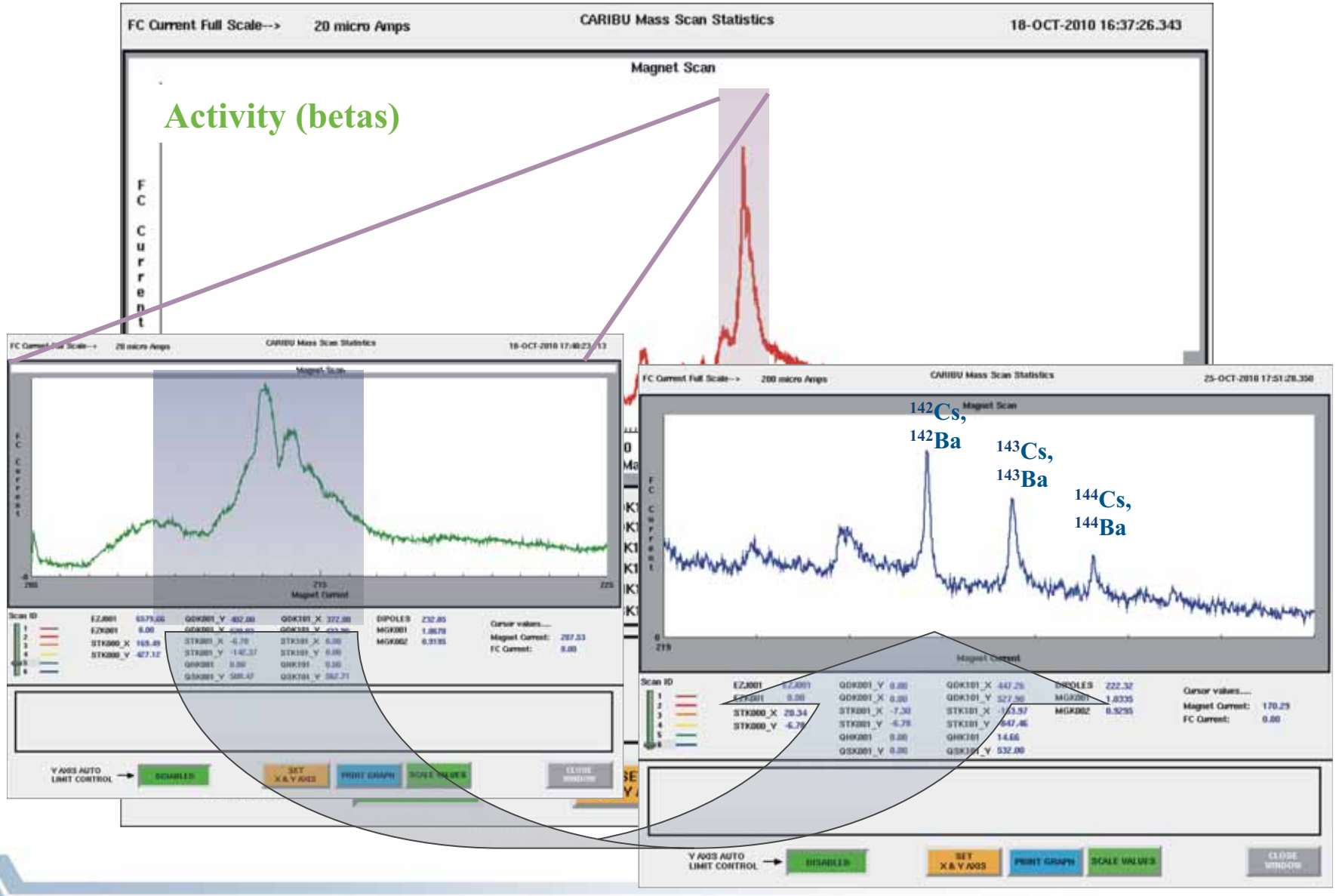


- Matching sections at entrance and exit transform beam to a ribbon beam.
- 2 x 60 degree bends
- R = 50 cm
- Dispersion 22.8 meters
- First order mass resolution: 1/20,000
- 3 electrostatic multipoles correct through 5th order
- Small enough footprint to fit on HV platform
- All optics, except for bending magnet, is electrostatic so that tune is essentially mass independent

Going from mass to specific activity

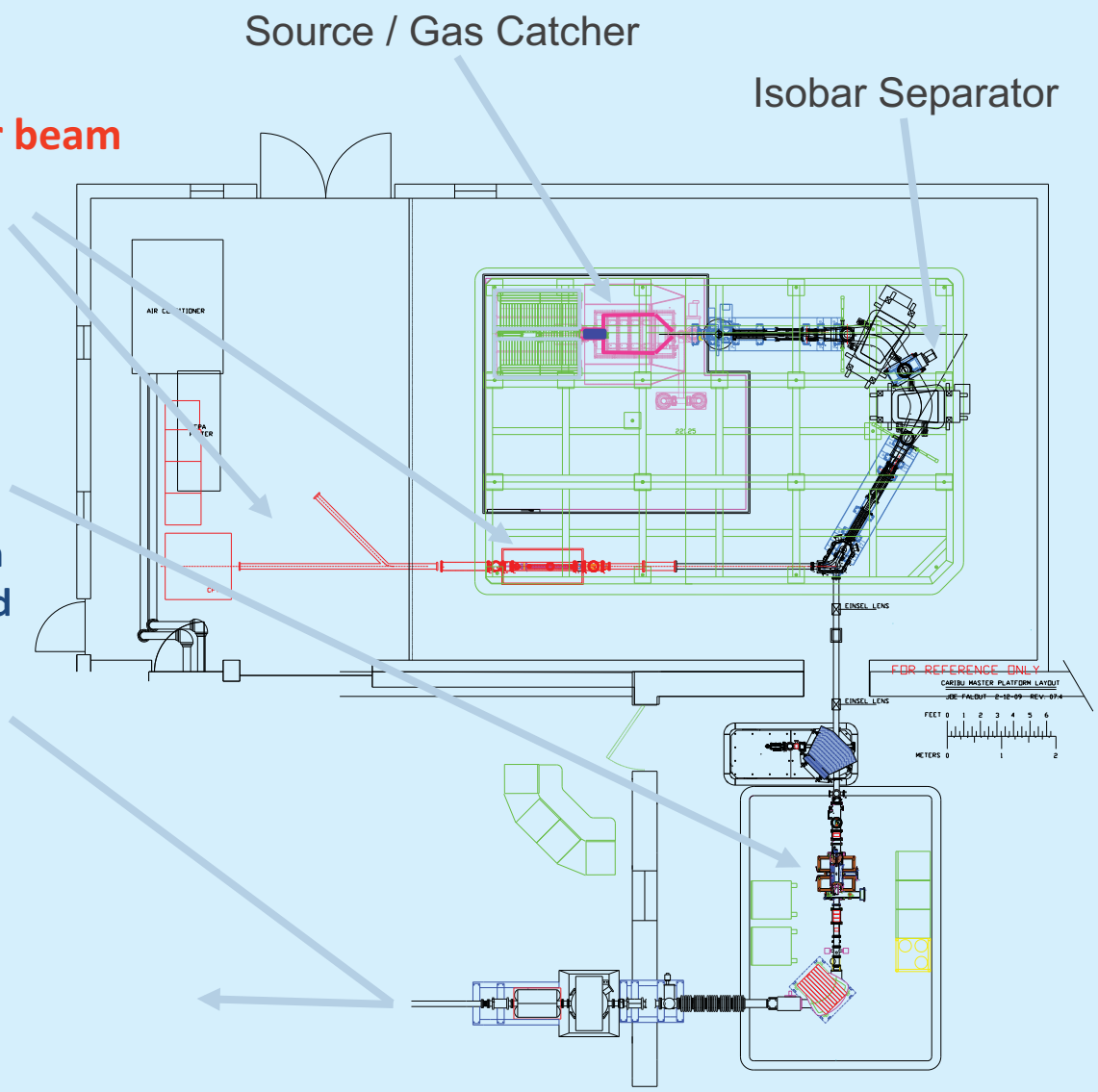


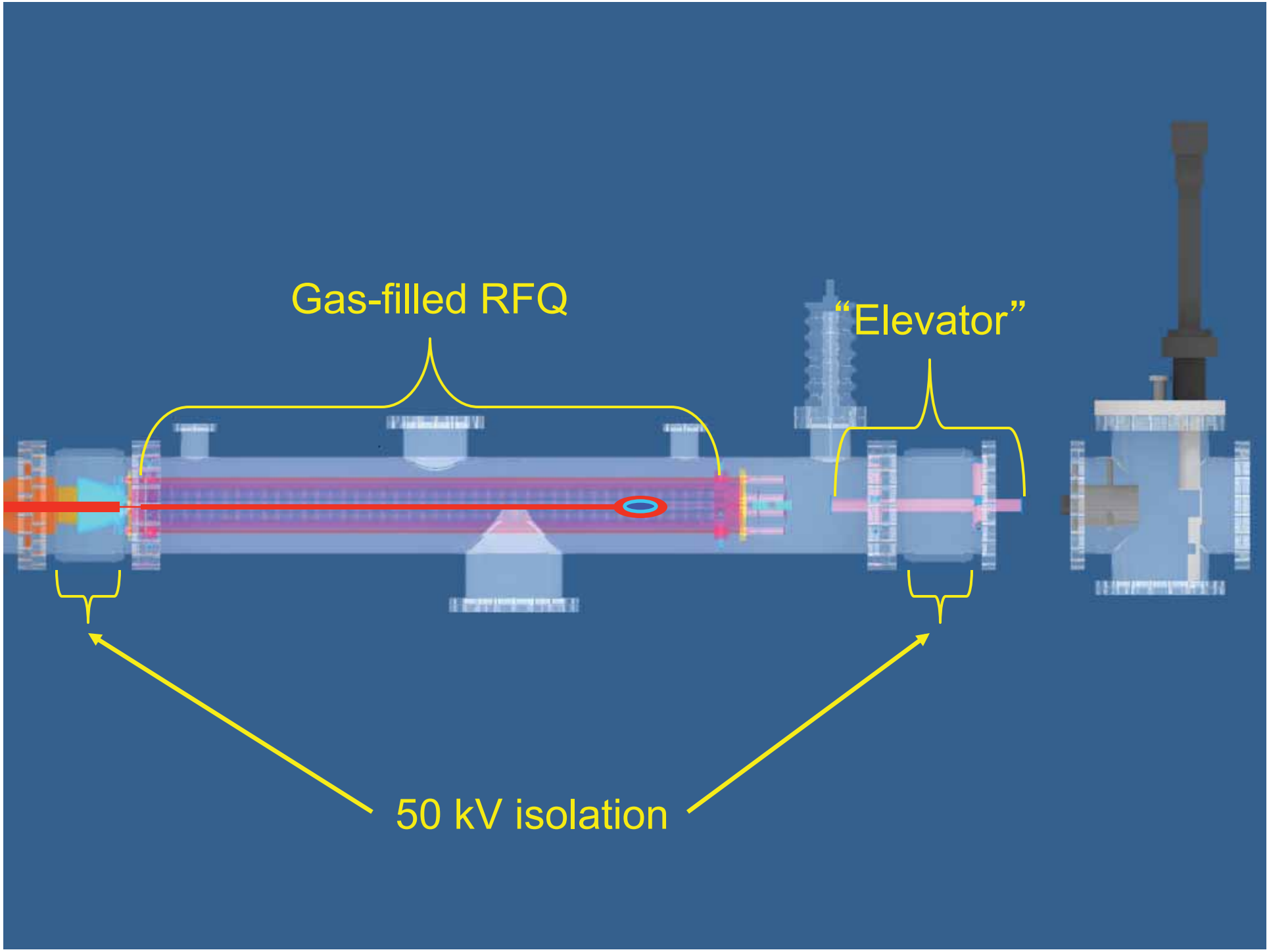
Zooming in on specific activity



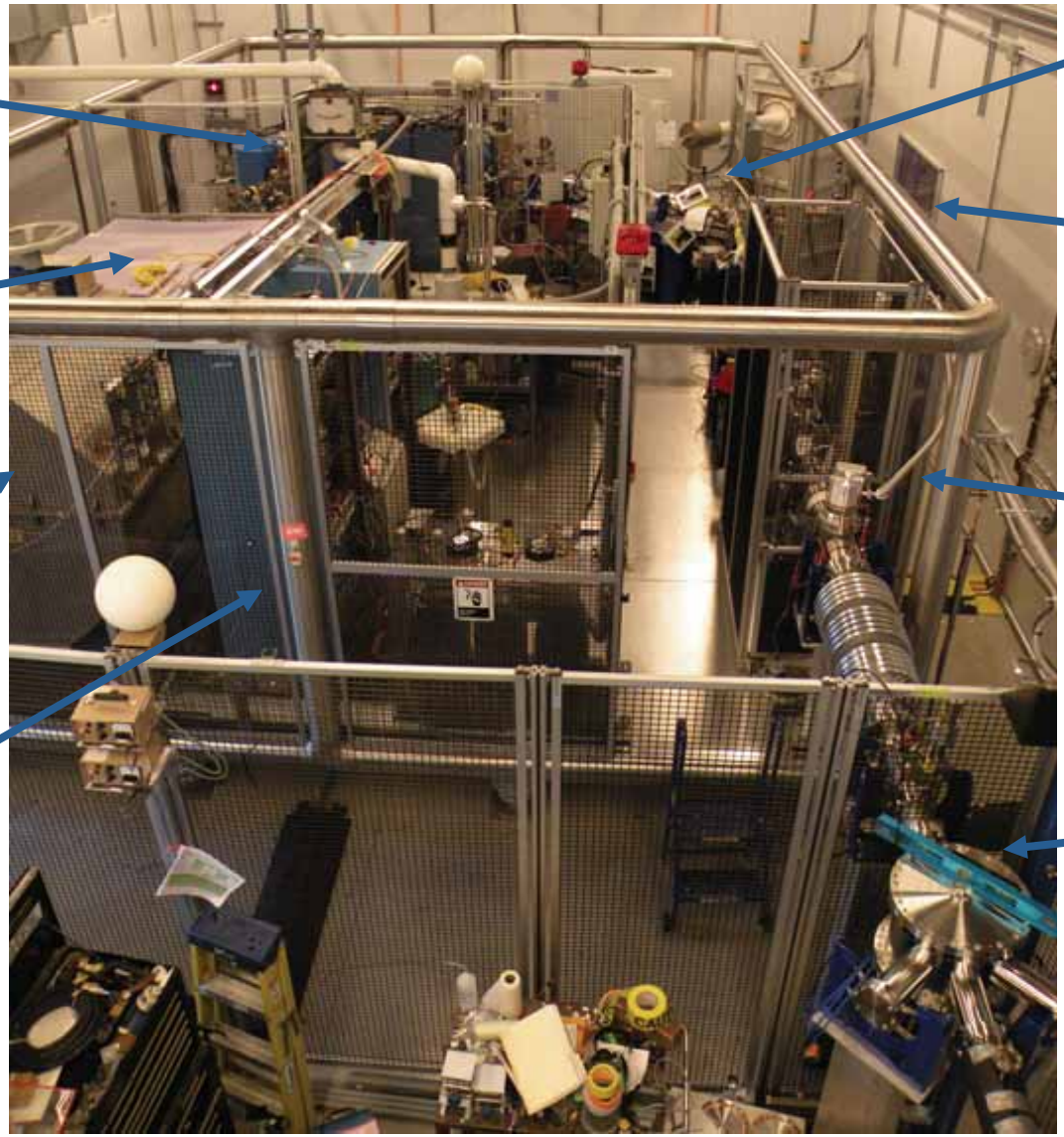
Beam Delivery

- After isobar separation, two options for beam use
- Low energy experiments after beam bunching
  - Mass measurement
  - Laser Spectroscopy
  - Beta decay studies
- Reaccelerated Beams
  - Use ECR-1 as charge breeder
  - Inject ions into ATLAS in high charge state (q/m > 0.15) and energy (~100-200 keV)



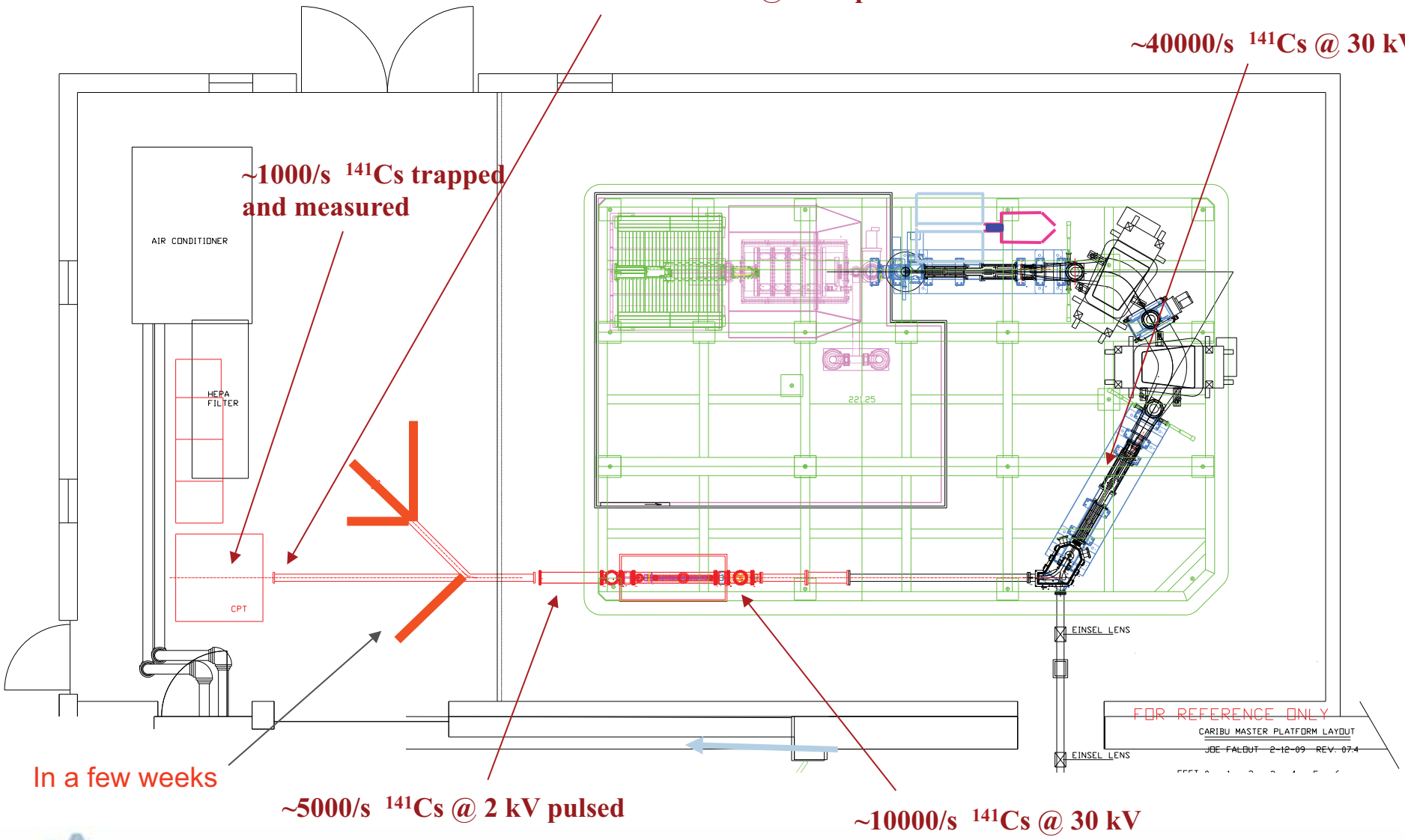

Gas-filled RFQ
“Elevator”
50 kV isolation

CARIBU completed



CARIBU building …. “warped”

Transport of radioactive ions to low-energy systems demonstrated



Status of CARIBU

- CARIBU facility construction is completed
- 100 mCi source is in and in operation, 1Ci source will be available (hopefully) later this year
- Mass separated radioactive beams have been transported to the low-energy experimental area and to the ECR charge breeder, bred to higher charge state with high efficiency and accelerated to 6 MeV/u
- First large piece of experimental equipment (CPT spectrometer) is ready to operate at CARIBU, others (tape station, X-array, total absorption spectrometer and EXO test system) will soon follow
    - First experiments have started at the CPT
- Some CARIBU beams available for "demonstration" experiments, LOI requested for outside users willing to bring new experimental equipment, open in next PAC

Current work

- All beams are coming out …. they have to be identified, contaminants characterized, …
  - Will be done with CPT and tape station when available
    - A few months of solid work needed …then transient work as new beams become available

- All equipment is working, but many efficiencies are below what they should be, resolution is still low, cleanliness not yet up to par, experience and automation are still missing. Currently concentrating on
  - Transmission … losing factor of 10 – 50 in first transport to CPT
    - » an issue with buncher identified and fixed
    - » additional diagnostics for tuning being added
  - Resolution … after some work, were able to send beam to CPT with resolution of about 3900
    - » leaning curve
    - » Improved field control system of magnets in the works
    - » Improved diagnostics

Yield is important but for most applications resolution is critical. Transmission will be improved quickly, stable operation at higher resolution (> 10000) might take a while … start with experiments where this is less critical.

Yields for Representative Species

Expected ^{252}Cf fission source strength:

- 2.5 mCi — March 2010 (mostly development work)
- 100 mCi — started fall 2010 for testing, for research in next PAC
- 1 Ci source — sometimes in 2011 … hopefully

Isotope	Half-life (s)	Low-Energy Beam Yield (s^{-1})	Accelerated Beam Yield (s^{-1})
^{104}Zr	1.2	1.5×10^3 / 6.0×10^4 / 6.0×10^5	5.3×10^1 / 2.1×10^3 / 2.1×10^4
^{143}Ba	14.3	3.0×10^4 / 1.2×10^6 / 1.2×10^7	1.1×10^3 / 4.3×10^4 / 4.3×10^5
^{145}Ba	4.0	1.4×10^4 / 5.5×10^5 / 5.5×10^6	5.0×10^2 / 2.0×10^4 / 2.0×10^5
^{130}Sn	222.	2.5×10^3 / 9.8×10^4 / 9.8×10^5	9.0×10^1 / 3.6×10^3 / 3.6×10^4
^{132}Sn	40.	9.3×10^2 / 3.7×10^4 / 3.7×10^5	3.5×10^1 / 1.4×10^3 / 1.4×10^4
^{138}Xe	846.	2.5×10^4 / 9.8×10^5 / 9.8×10^6	1.8×10^3 / 7.2×10^4 / 7.2×10^5
^{110}Mo	2.8	1.6×10^2 / 6.2×10^3 / 6.2×10^4	5.8×10^0 / 2.3×10^2 / 2.3×10^3
^{111}Mo	0.5	8.3×10^0 / 3.3×10^2 / 3.3×10^3	0.3×10^0 / 1.2×10^1 / 1.2×10^2

~65 species have accelerated intensities of over 10^5 /s

>150 additional species have accelerated intensities of over 10^4 /s