NEUTRON-RICH BEAMS FROM ^{252}CF FISSION AT ATLAS – STATUS of THE CARIBU PROJECT

The 11th International Conference on Heavy Ion Accelerator Technology

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Outline

CARIBU - CAlifornium Rare Ion Breeder Upgrade

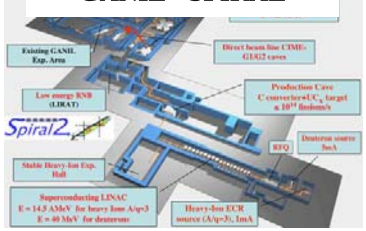
- CARIBU in the context of low-energy nuclear physics research
- Project Description, Status & Expected Performance
  - Technical approach
    - *Source and radiological issues*
    - *Gas catcher/RFQ cooler*
    - *ECR Charge-breeder*
    - *Isobar separator - beam purity*
    - *Low-Intensity Diagnostics*
- Commissioning Plans

Low-energy nuclear physics research

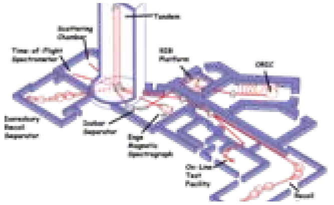
Continued progress in nuclear physics and associated fields needs radioactive beams

Proton-rich side reached by existing facilities

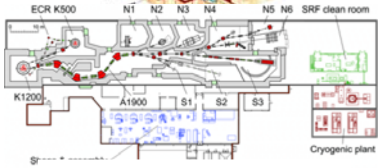
GANIL - SPIRAL



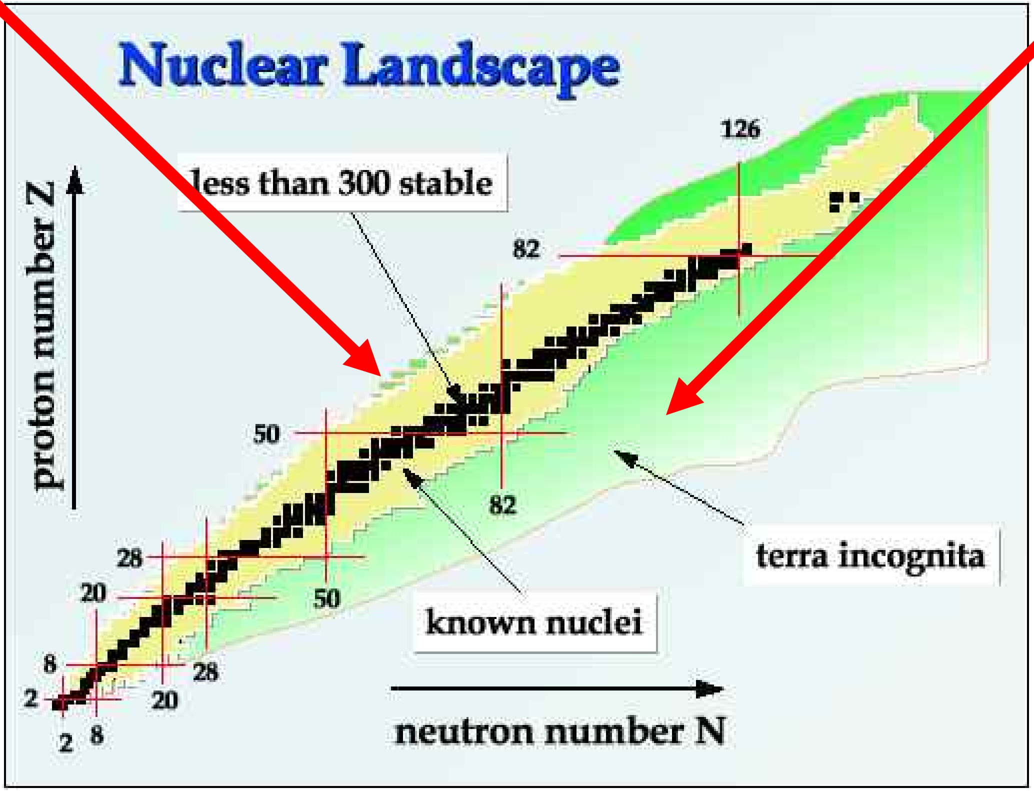
ORNL - Holifield



TRIUMF - ISAC

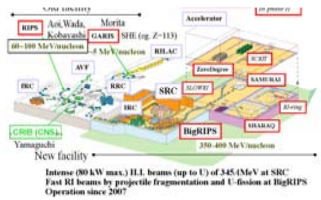


MSU - NSCL

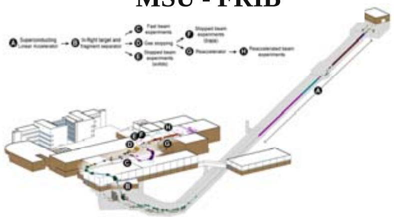


Neutron-rich side will be the focus of new facilities

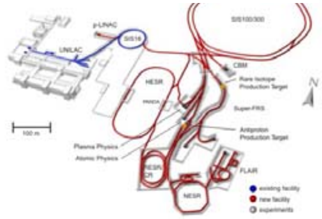
RIKEN _ RIBF



MSU - FRIB



GSI - FAIR



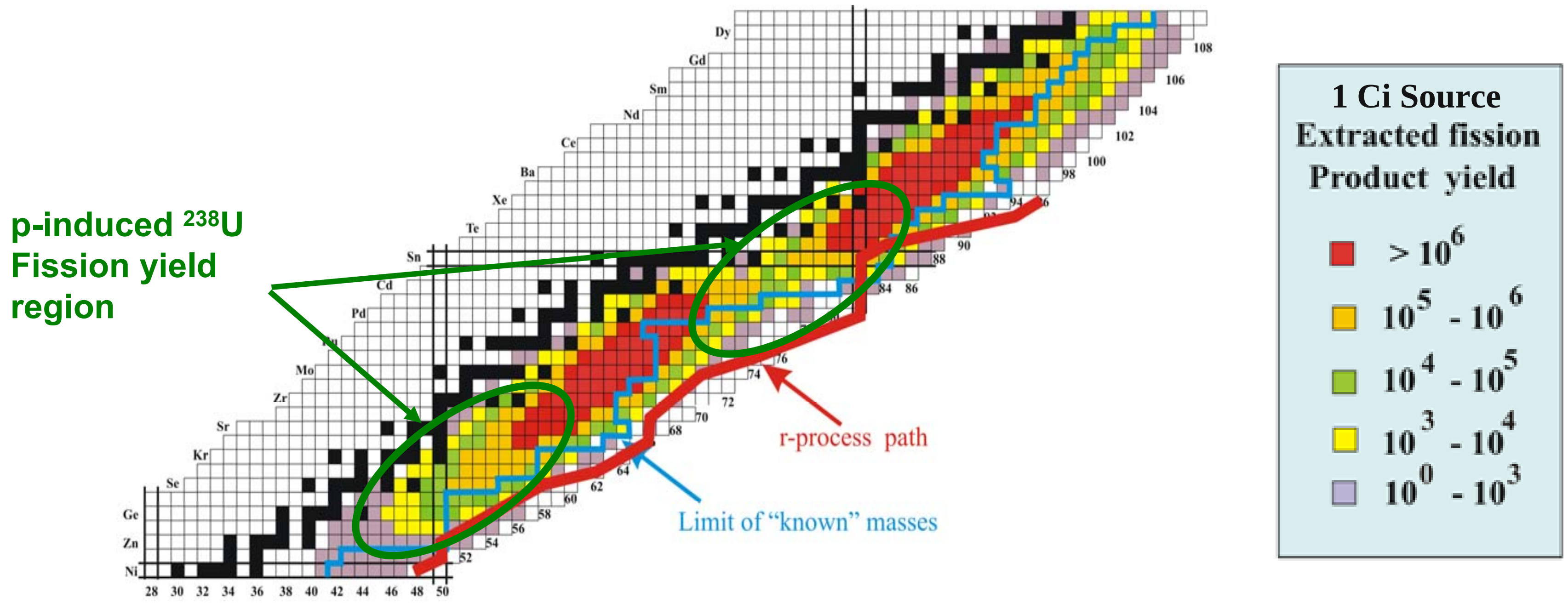
n-rich region is the next frontier

A Californium Fission Source for ATLAS

- ^{252}Cf fission yield is complementary to uranium fission
- Provides access to unique, important areas of the N/Z plane
- Significant yield extends into the r-process region
- Technology and experience useful for FRIB

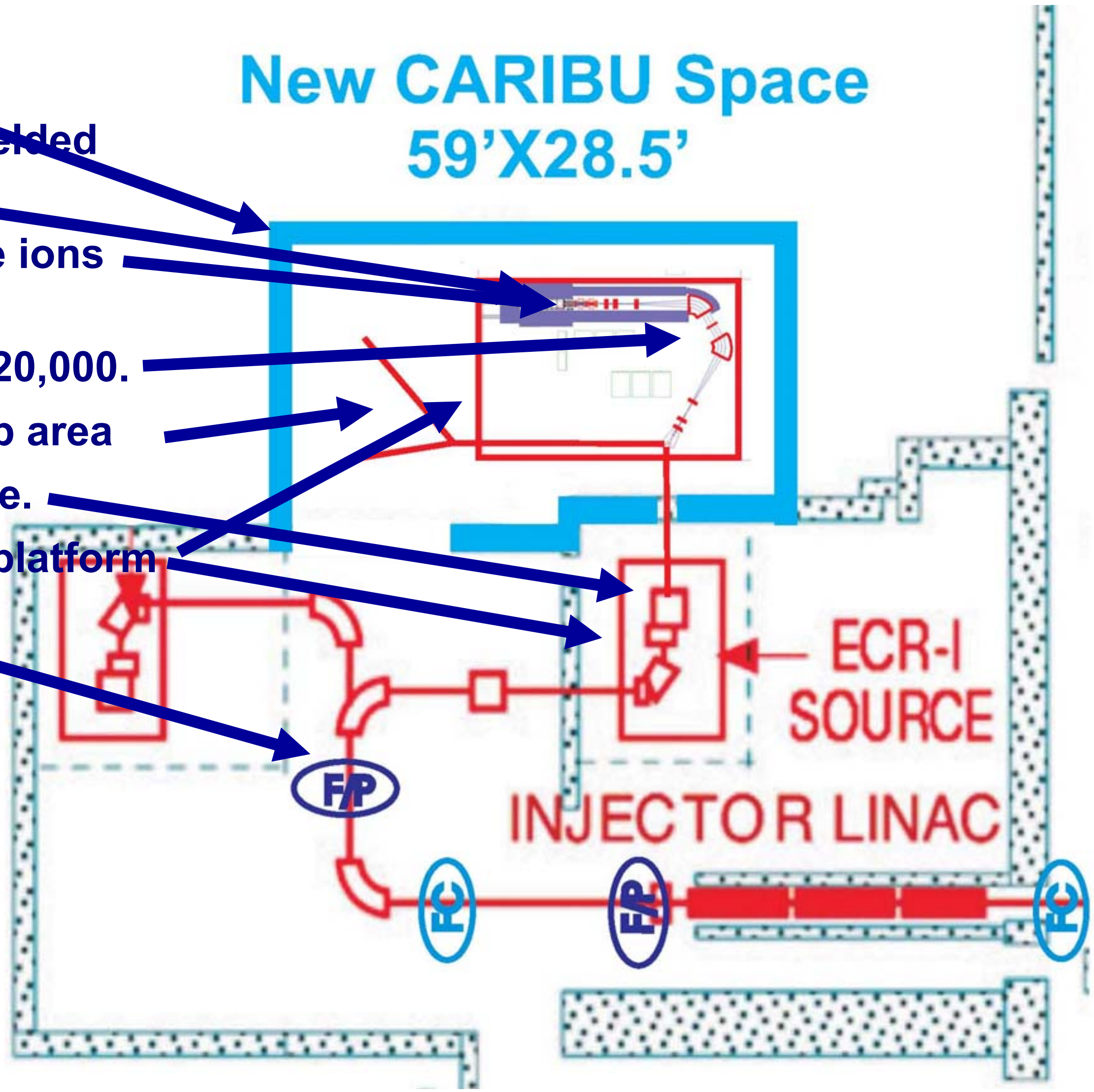
^{252}Cf spontaneous fission yield

$T_{1/2}$=2.6 a 3.1% fission branch



^{252}Cf Fission Source System

- New ~1600 ft^2 building.
- 1 Ci ^{252}Cf fission source in shielded cask.
- Gas catcher/RFQ to thermalize ions and create beam.
- Isobar separator with δm/m:1/20,000.
- Un-accelerated ion & atom trap area
- ECR charge breeder ion source.
- Mounted on HV (up to 200kV) platform
- Weak beam diagnostics.



Examples of Yields for Representative Species

Calculated maximum beam intensities for a 1 Ci ^{252}Cf fission source using expected efficiencies.

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

~65 species have accelerated intensities of over 10^5

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

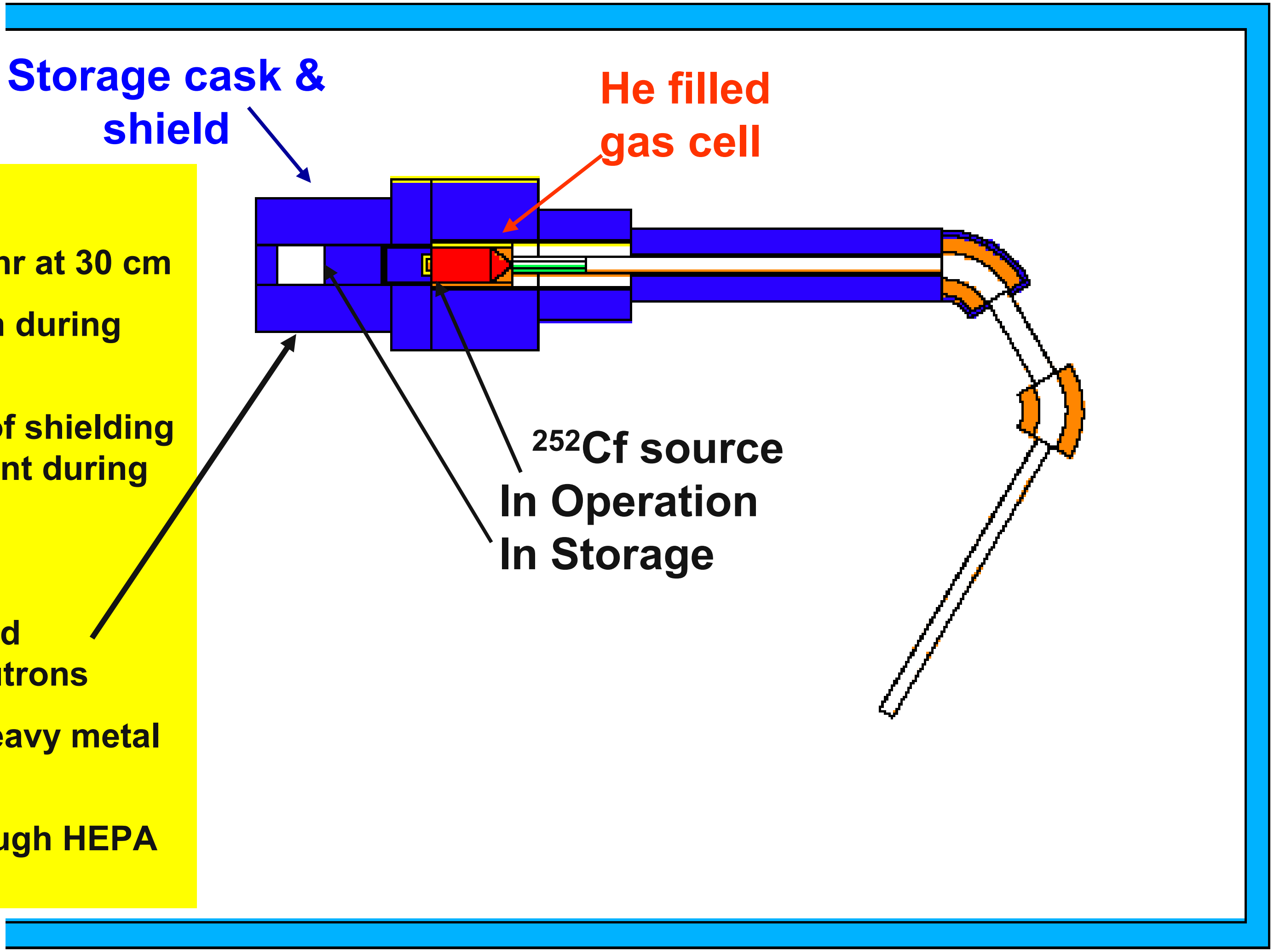
Californium source characteristics

- CARIBU will (eventually) use fission fragments from a 1 Ci source of ^{252}Cf.
  - Start with two weaker sources – ~2 mCi and ~80 mCi
- ^{252}Cf is produced at the High Flux Reactor at Oak Ridge and will be produced by ORNL as an open source electroplated on a polished SS plate.
- ^{252}Cf has a fairly short lifetime of 2.645 yrs so that source thickness is small
  - 1 Ci of ^{252}Cf is 1.9 mg; over an 1.9 cm diameter circle this yields a density of ~660 $\mu g/cm^2$
- A 1 Ci source has significant radiation and radioactivity emissions
  - 46 rem/hr neutrons at 30 cm
  - 5 rem/hr γ-rays at 30 cm
  - Radioactive and noble gas emissions must be trapped or exhausted

CARIBU Shielding

Required: Access to equipment near source for extended periods.

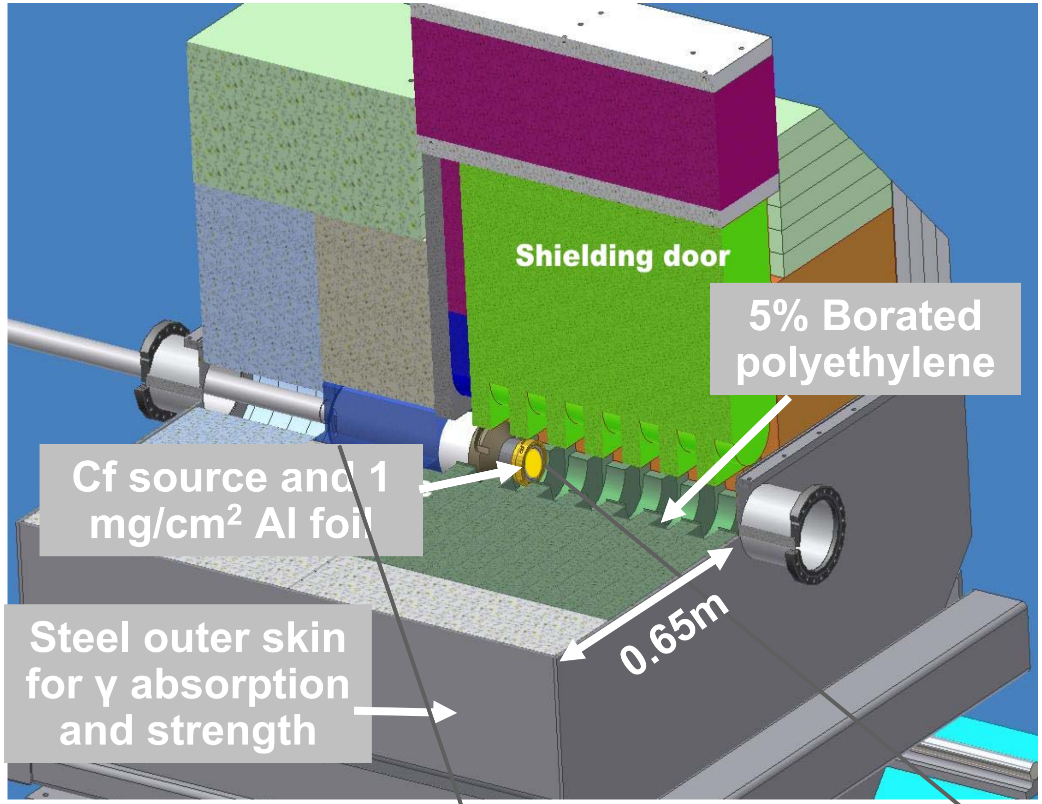
- Shielding Design Goals
  - Less than 1 mrem/hr at 30 cm
  - Fully shielded even during source installation
  - Manual operation of shielding and source movement during installation
- Shield requirements:
  - ~0.65 m. 5% borated polyethylene for neutrons
  - Additional 5 cm. heavy metal shielding for γ-rays
- Exhausting system through HEPA filters for volatile species.



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.

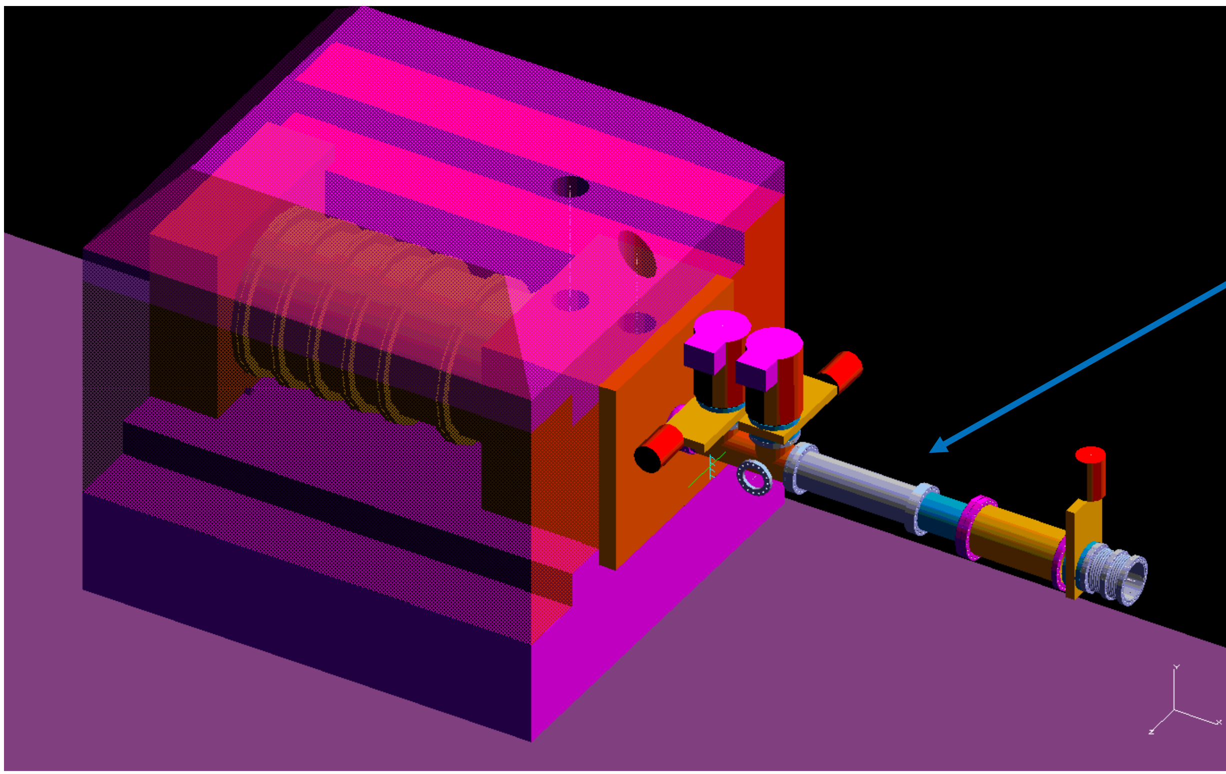
Californium source and gas catcher relationship

- 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.

Gas catcher shielding

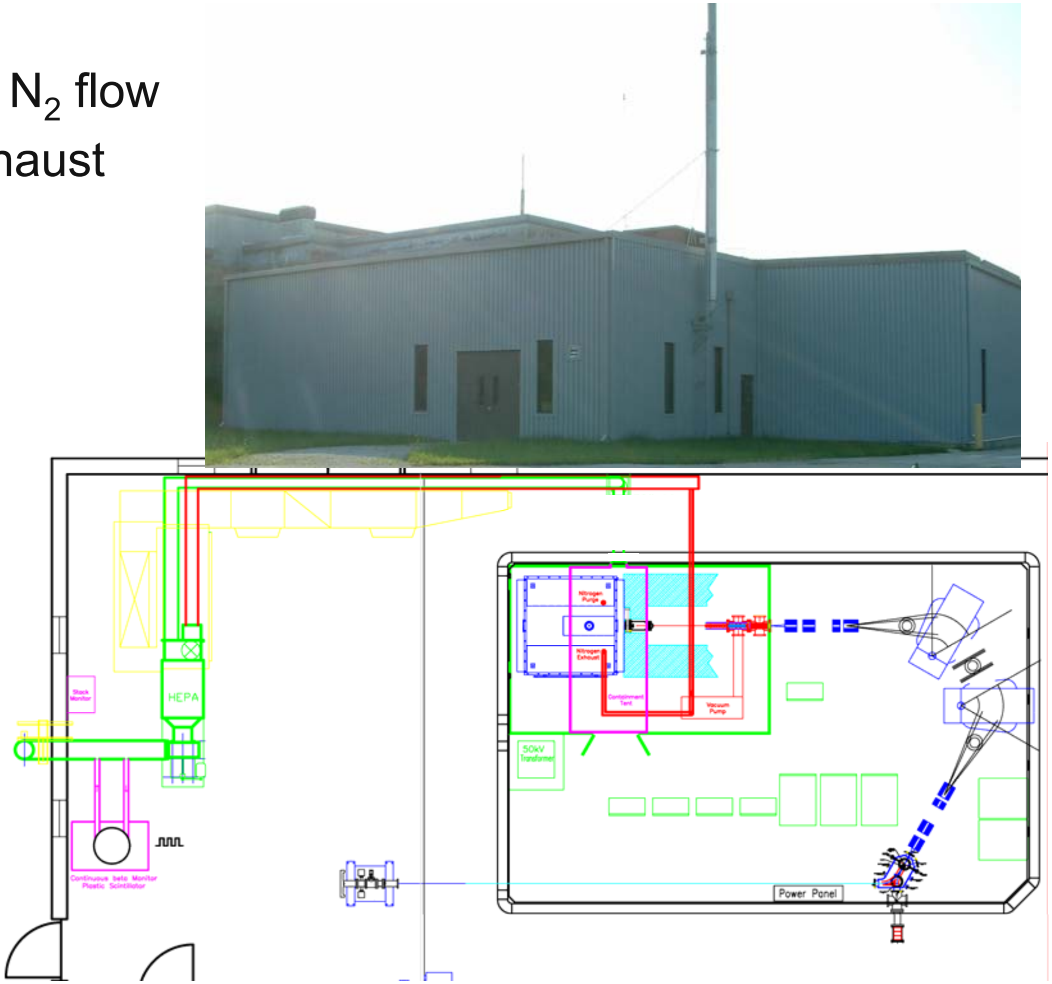
- **Gas catcher shielding**
  - ***Interlocked pieces to remove line of sights***
  - ***Removable to provide access for maintenance***
  - ***Leave ports for pumping and RF feeding access***
  - ***Polyethylene enclosed in metal shield to minimize fire hazard***
  - ***Whole shielding assembly sitting at 50 kV above platform***

Additional shielding will be installed around beamline



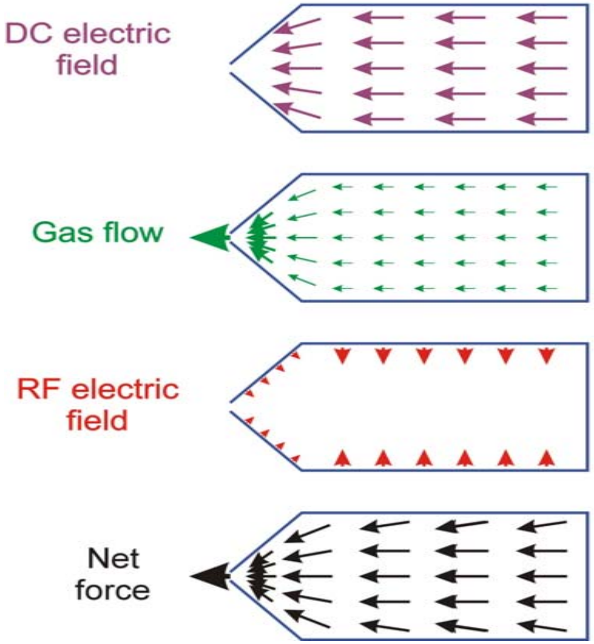
Monitoring and exhausting radioactive volatiles

- CARIBU building is kept at negative pressure by HEPA exhaust system
  - Contains any spill/leakage
- Cask storage space purged by N_2 flow
- Combined with gas catcher exhaust
  - 100 second holdup time
  - Charcoal traps for iodine
  - Additional small HEPA
    - *Particulate trap*
- Continuous exhaust monitor
  - Exhaust ß activity logged
- Work area n/γ monitored

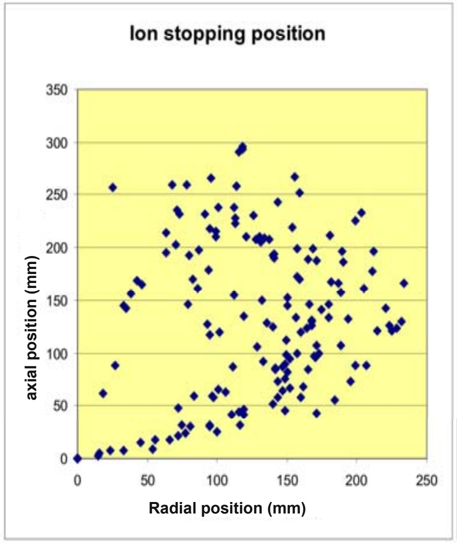


CARIBU gas catcher requirements (1)

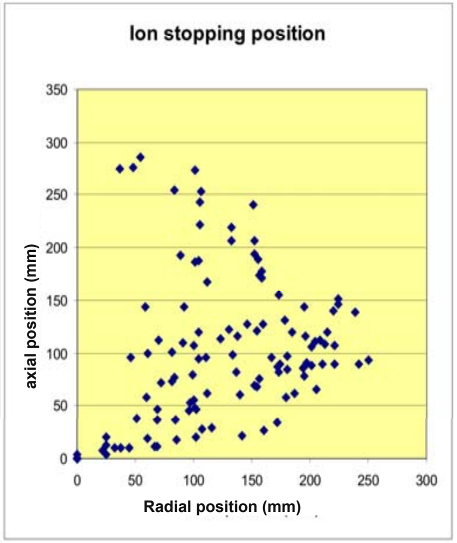
- **Detailed simulations of fission fragment stopping in the gas catcher, incorporating contaminants in the californium source, source size, protective foil, spherical degrader thickness and size, and proper energy-mass distribution for different fragments indicate that**
  - **a 50 cm gas catcher diameter is required**
  - **3 different degraders can cover the full fission fragment mass range**
    - ***degrader is a half sphere of 4 cm radius (~11 mg/cm² Al thickness)***
    - ***degrader will be removable locally***



^{104}Mo



^{144}Xe



CARIBU gas catcher requirements (2)

- **The 1 Ci ^{252}Cf source will generate significant ionization in the gas catcher:**
  - **~ 10^9 fission per second with two fission fragments per fission (one emitted towards the gas catcher volume)**
    - **Fission fragments lose roughly 5 MeV in gas volume (most energy lost in degrader)**
  - **~ 4 X 10^{10} alpha particles per second, half of which go through the gas catcher**
    - **Alphas lose roughly 0.5 MeV in gas volume (most go through the gas and hit the enclosure where they deposit the rest of their energy)**
  - **Both sources contribute almost equally to ionization density**
  - **Build up of beta decaying activity has a negligible effect**
  - **Total ionization density ~ 1.5 X 10^{16} eV/s over a 160,000 cm^3**
    - ***~ 9 X 10^{10} eV/cm^3.s → high intensity operation***

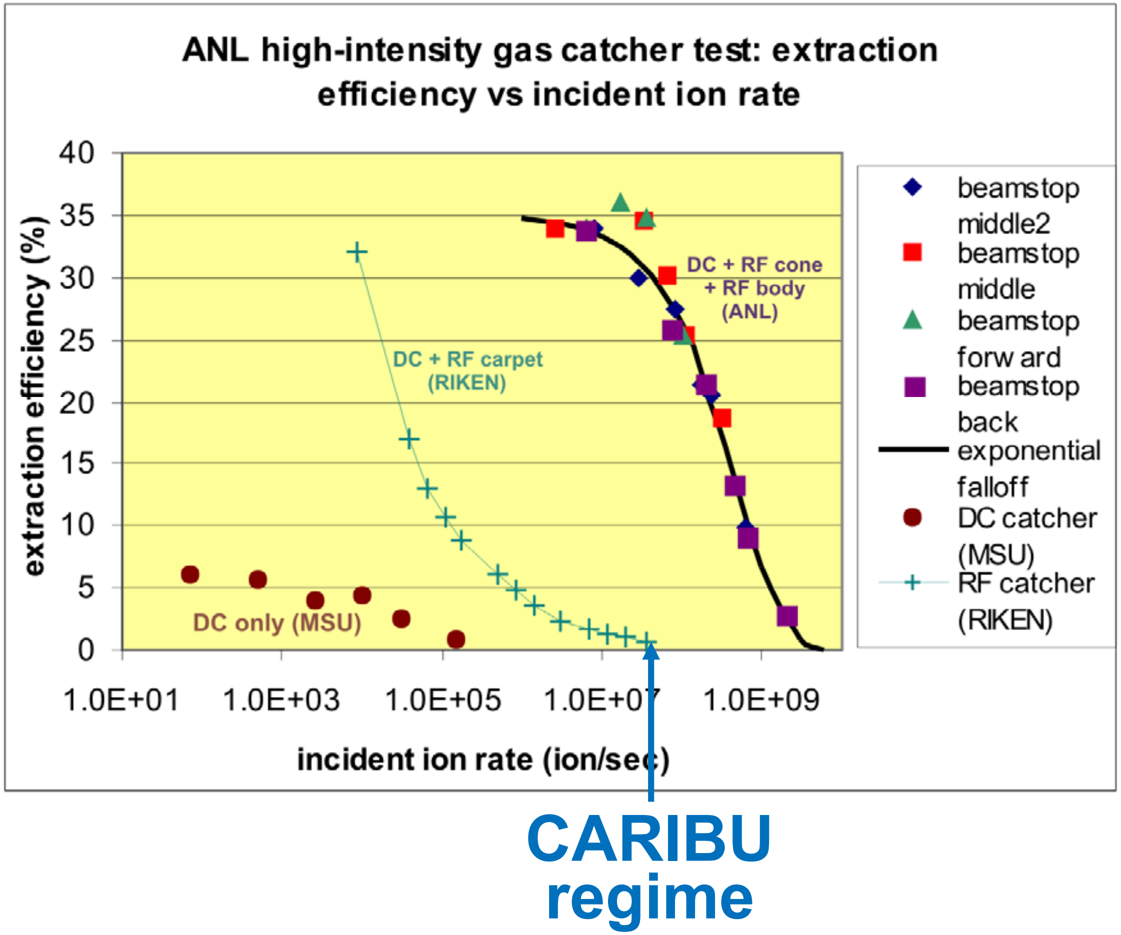
~ 10-100 times higher ionization than normal CPT operation

~ 10 times below FRIB-like ionization density

Gas catcher operation at FRIB/CARIBU intensity

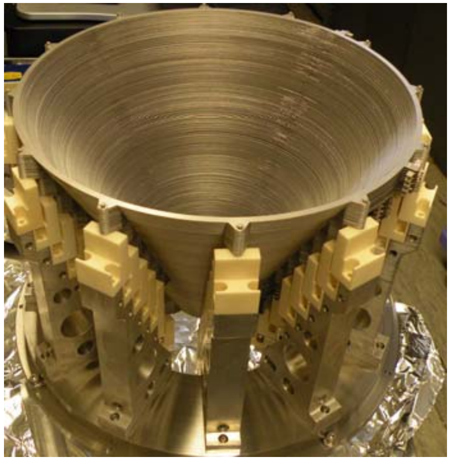
Series of high intensity tests at ATLAS in late 2006 confirmed redesigned gas catcher.

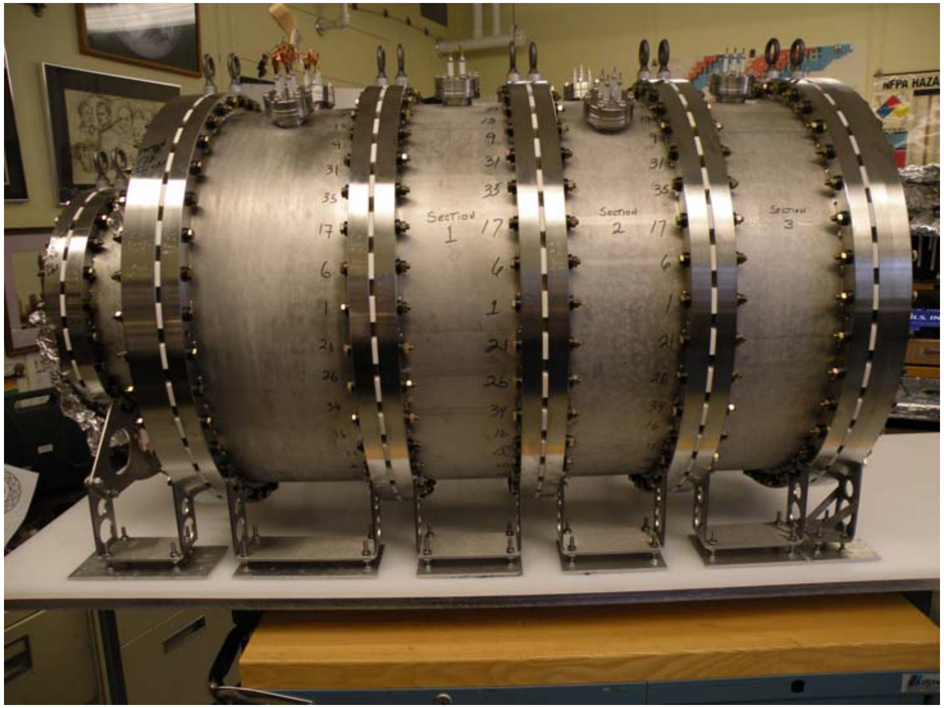
- **High efficiency obtained at up to 10^9 incoming particles per second**
- **Extracted ions identified as ions, not molecular ions**
- **All modifications had a clearly identifiable positive effect**



CARIBU gas catcher

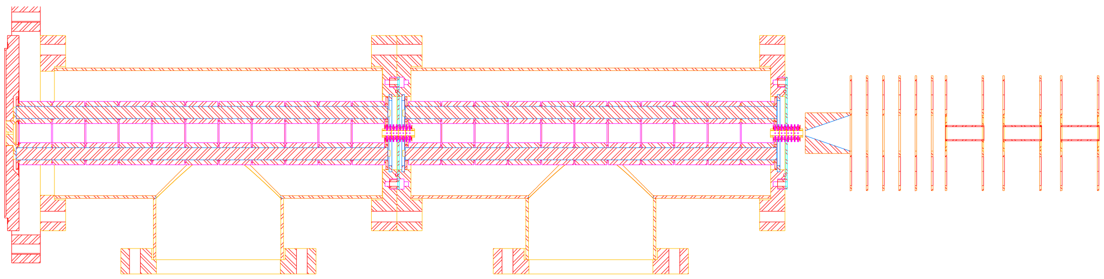
- Device similar to ANL-proposed FRIB gas catcher
  - Same operating principle (RF + DC + gas flow)
  - Similar construction
  - Similar length
  - Twice the diameter (50 cm inner diameter)





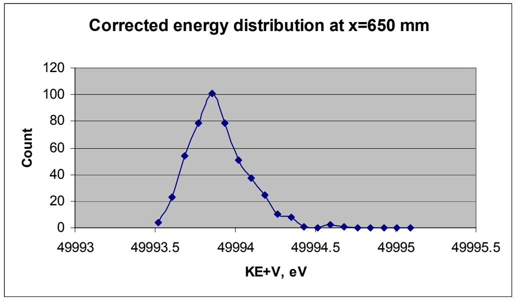
RFQs for gas cooler

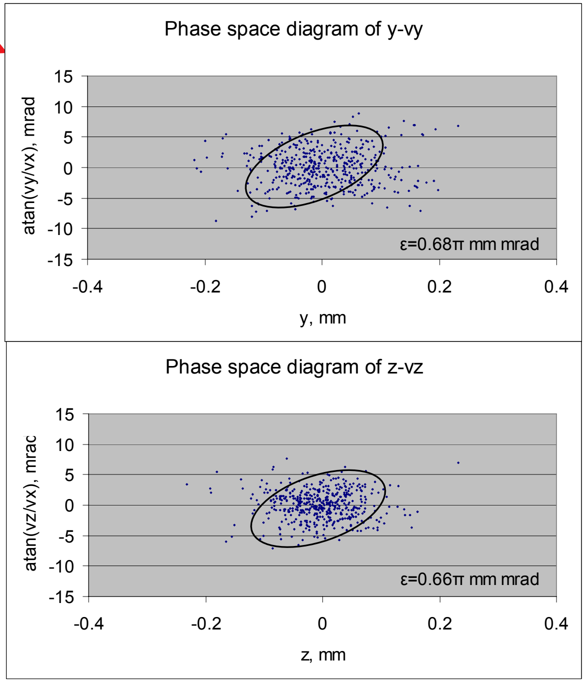
- Design criteria
  - Accept and transport all heavy-ions from gas catcher
    - *Large initial RFQ aperture of 15 mm*
  - Pressure in the acceleration region (at the end of the cooler) must be $<10^{-5}$ mbar
    - *Two large sections of RFQ cooler and two μRFQs for differential pumping*
  - Minimal final emittance and energy spread < 1 eV
    - *Matching of RFQs (and μRFQs) sections to minimize reheating during transitions*
    - *Individual lengths tuned to assure thermalization*
    - *Conical extraction structure to minimize field penetration*
  - Total length: Less than 1 meter

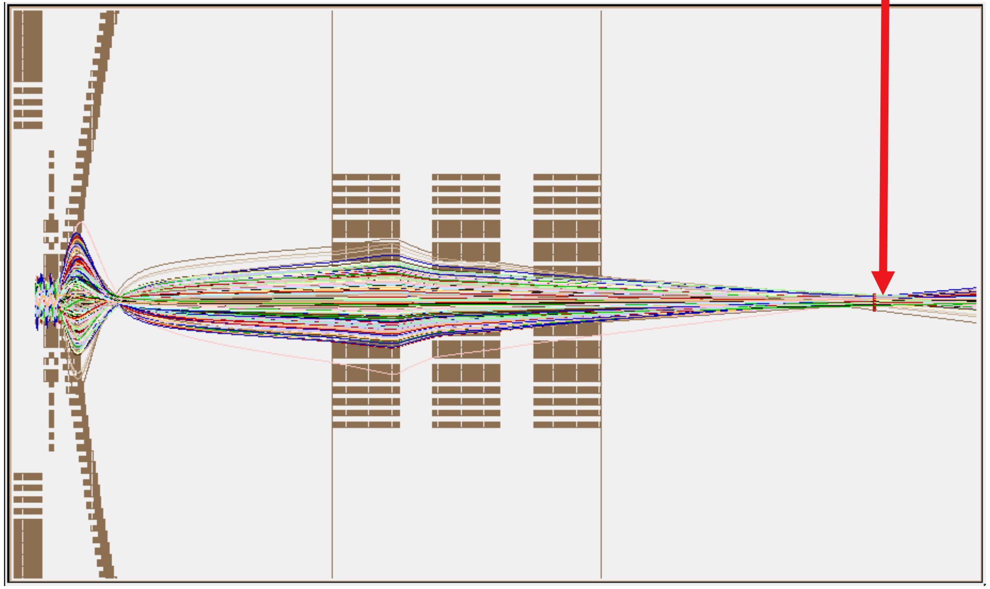


RFQ cooler simulations

- **Energy spread ~ 0.5 eV**
- **Emittance ~ 1π mm•mrad**
- **Differential pumping sufficient**
- **Acceleration by 50 kV DC potential yields spot size diameter below 1 mm**
- **Total length just below 1 m**







Calculations by Tao Sun using SIMION

CARIBU gas catcher status

- Gas Catcher/RFQ cooler installation on platform underway
  - Vacuum systems in place
  - RF tank circuits being tuned
  - First ions (stable) late June 2009

CARIBU gas catcher status

- Gas Catcher/RFQ cooler isolated from main platform and biased to 50 kV.
- Status of installation on June 1, 2009

CARIBU gas catcher status

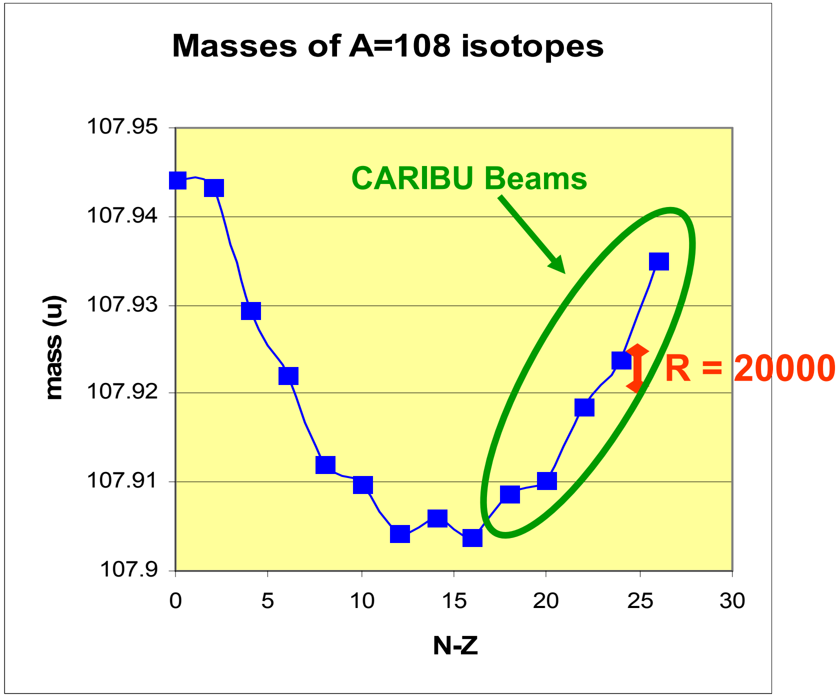
- Gas Catcher/RFQ cooler isolated from main platform and biased to 50 kV.
- Status of installation on June 1, 2009

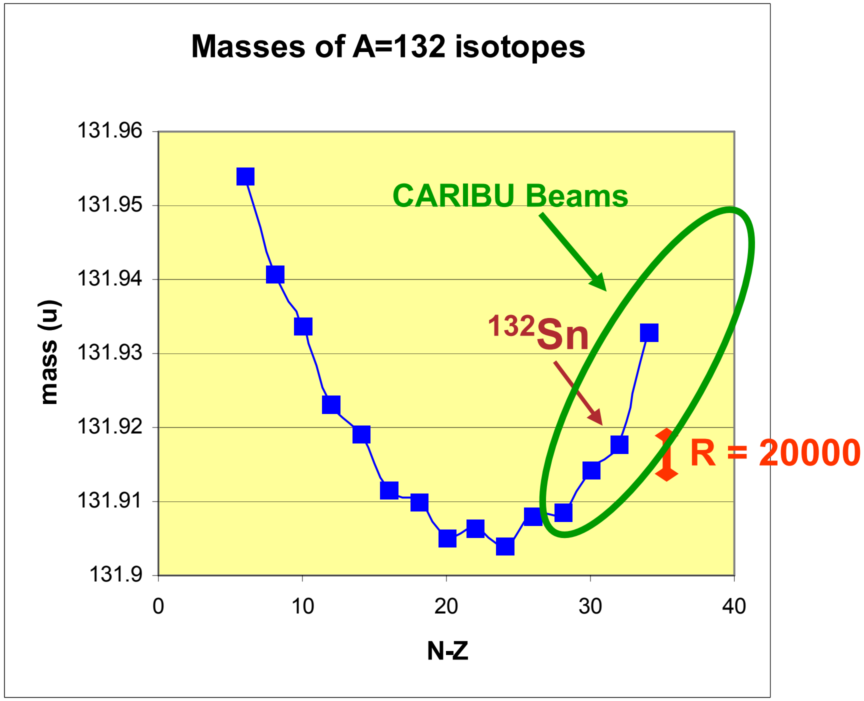
CARIBU gas catcher status

- Gas Catcher/RFQ cooler isolated from main platform and biased to 50 kV.
- Status of installation on June 1, 2009

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

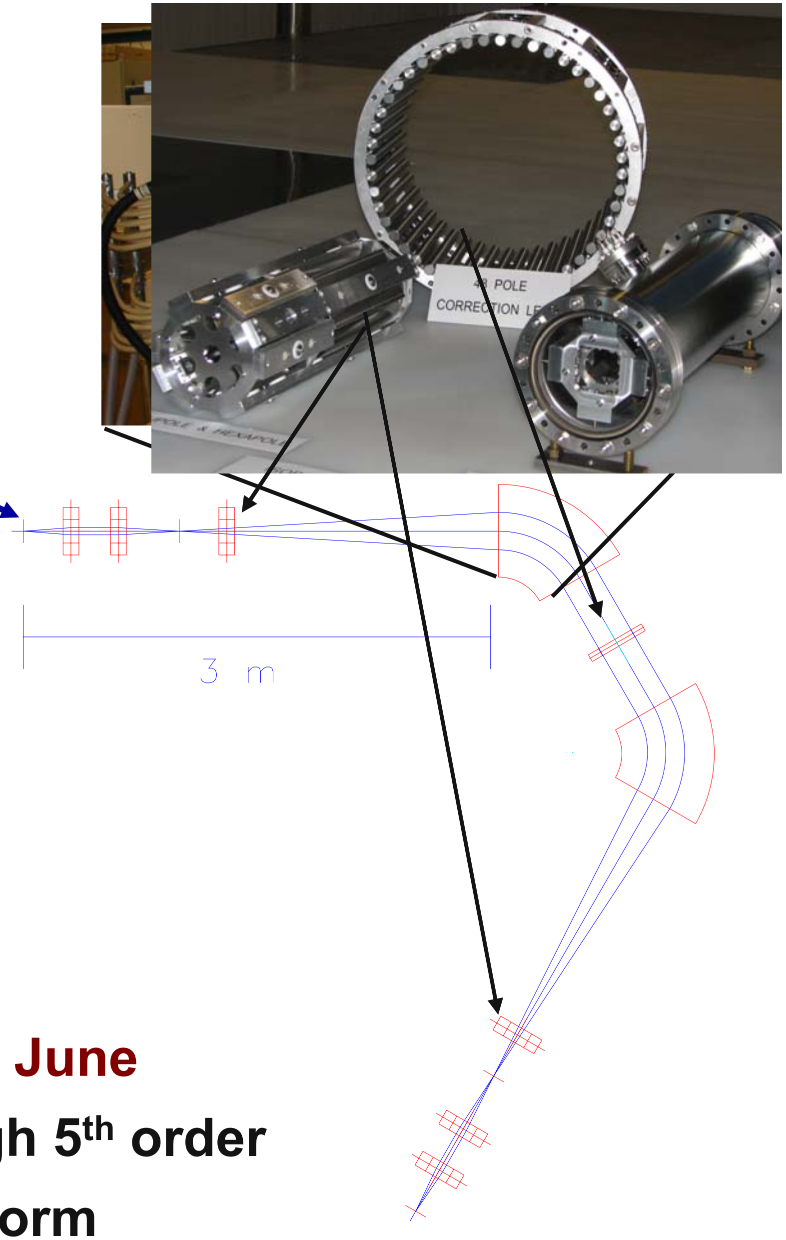




"Compact" isobar separator

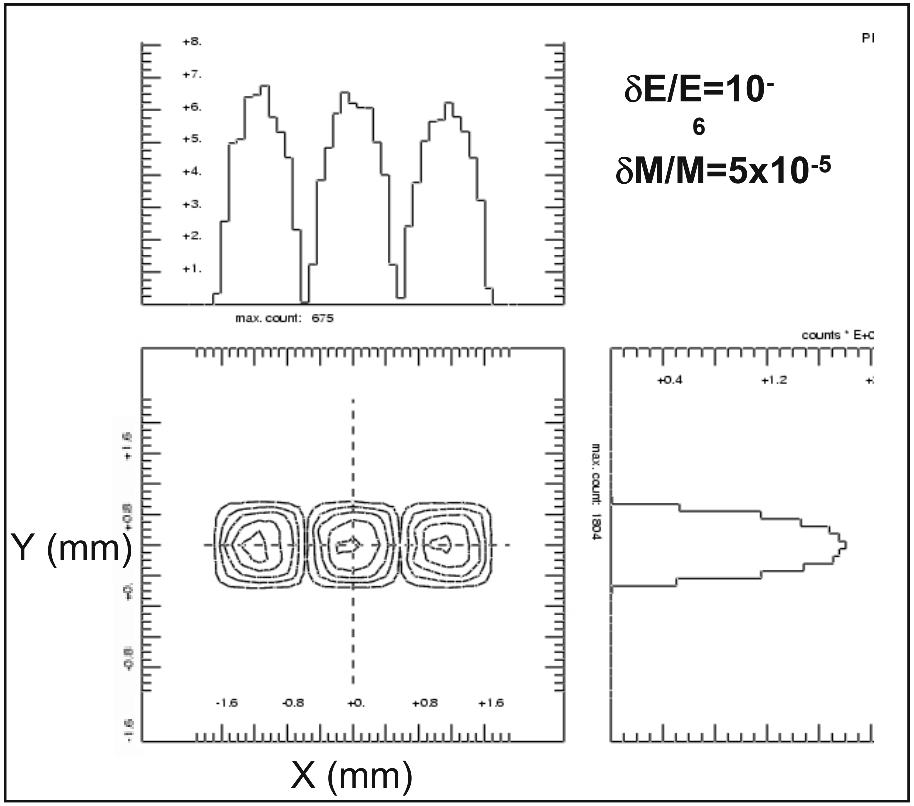
- **Takes advantage of low emittance and energy spread of extracted beams:**

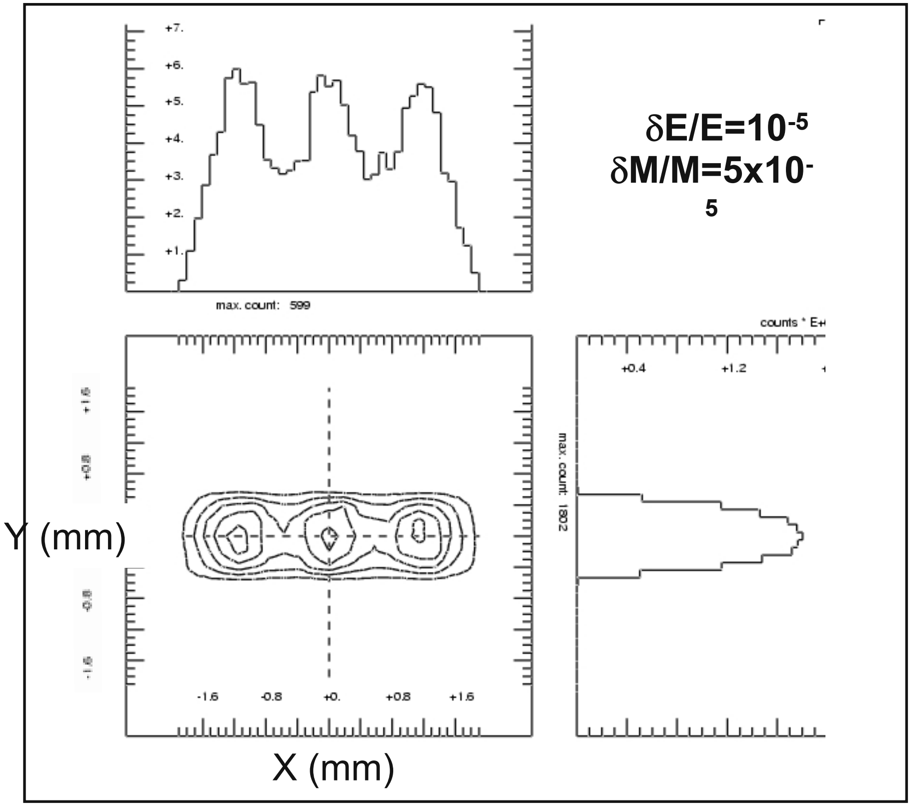
> **Beam Properties from gas catcher:**
> **$\varepsilon \approx 3\ \pi$ mm•mr $\quad \delta E \approx 1$eV**
> **1 mm dia. (circular) beam**
> **$\theta_{max}, \varphi_{max} = \pm 6$ mr**



- **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**
- **Magnet delivery 1.5 years late, expect in June**
- **3 electrostatic multipoles correct through 5th order**
- **Small enough footprint to fit on HV platform**

X and Y Projections at Focal Plane





@50keV: $\delta E = 0.05$ eV

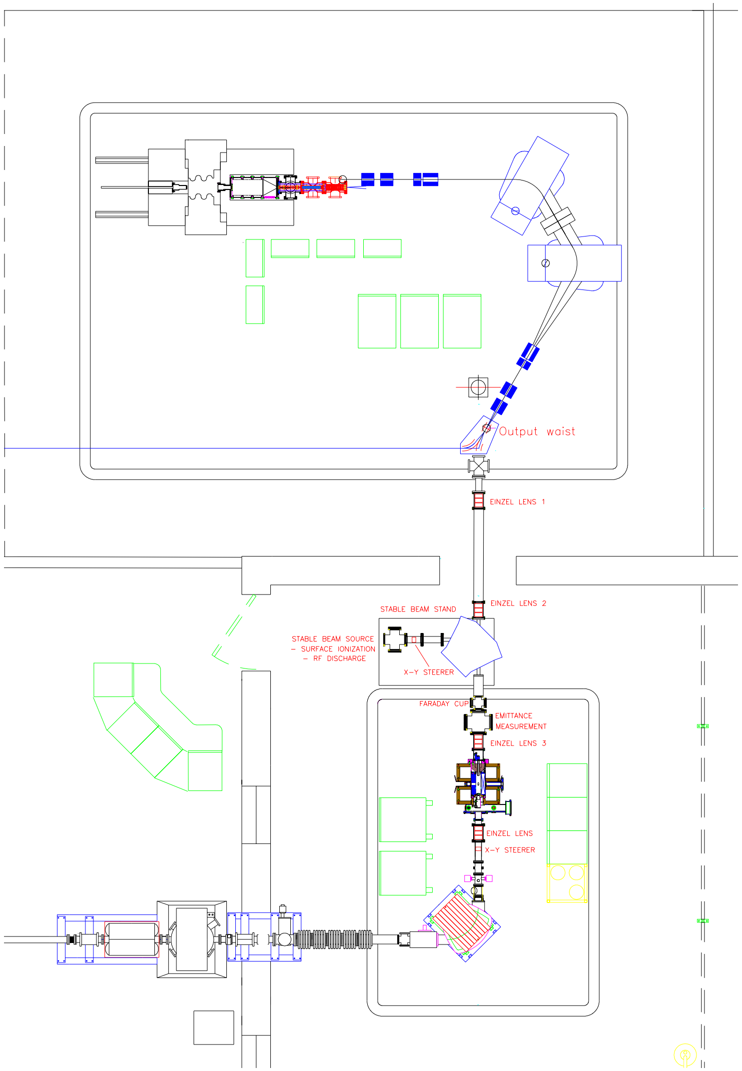
@50keV: $\delta E = 0.5$ eV

- Separator has no energy compensation.
- Relies on very low energy spread from gas catcher

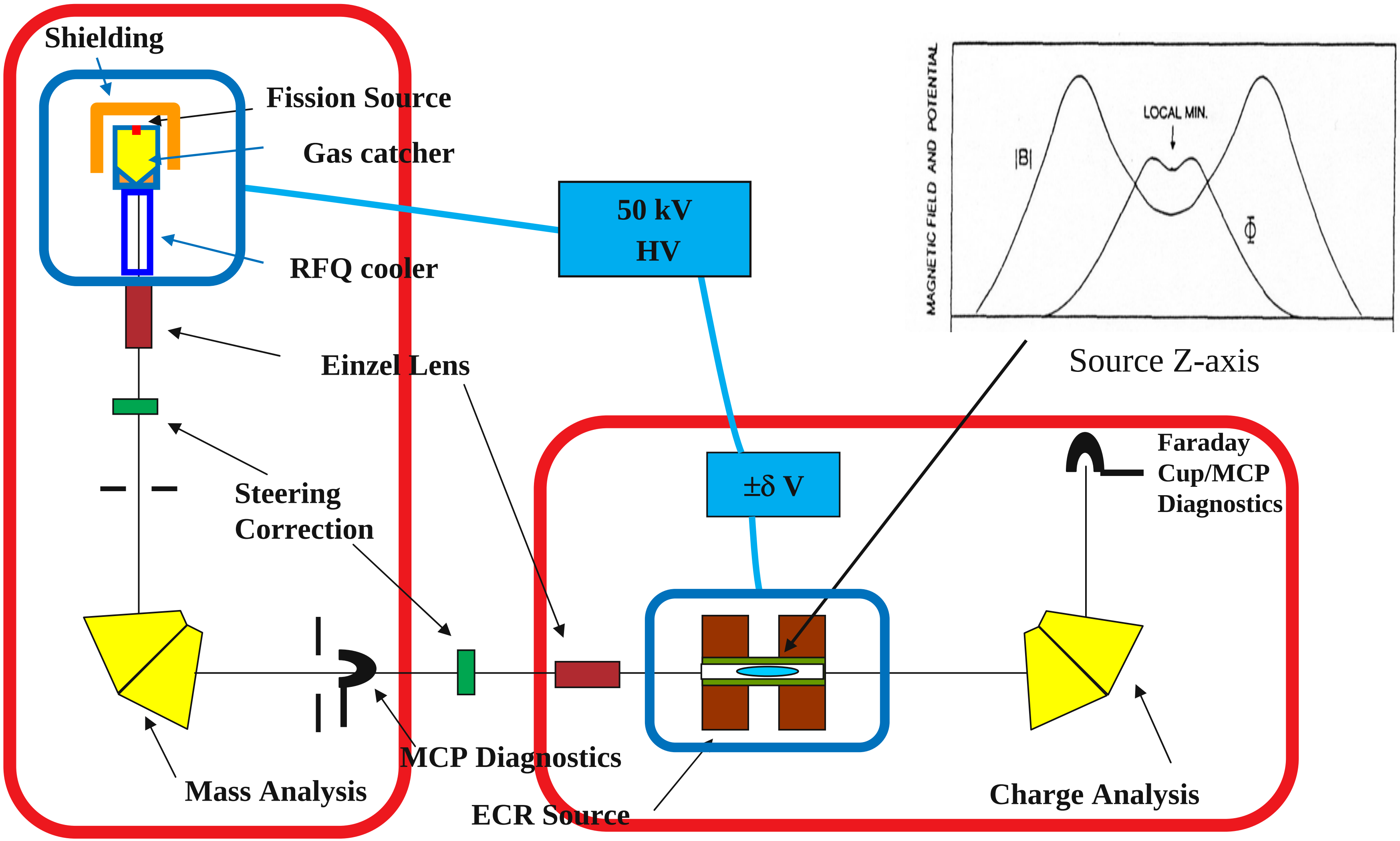
1+ → *n+ Implementation with ECR-I – CARIBU*

Acceleration in ATLAS requires the ion's q/m ≥ 0.15

- Radioactive beams from a 1.0 Ci ^{252}Cf fission source
  - Fission products are collected and thermalized in a helium gas catcher
- High resolution mass analysis (1:20,000) limits the number of isobars in the 1+ beam
- Transported to the ECR charge breeder source and stopped in plasma.
  - To achieve required mass resolution, source must operate at 50 kV (0.5 V stability)
  - High efficiency into one charge

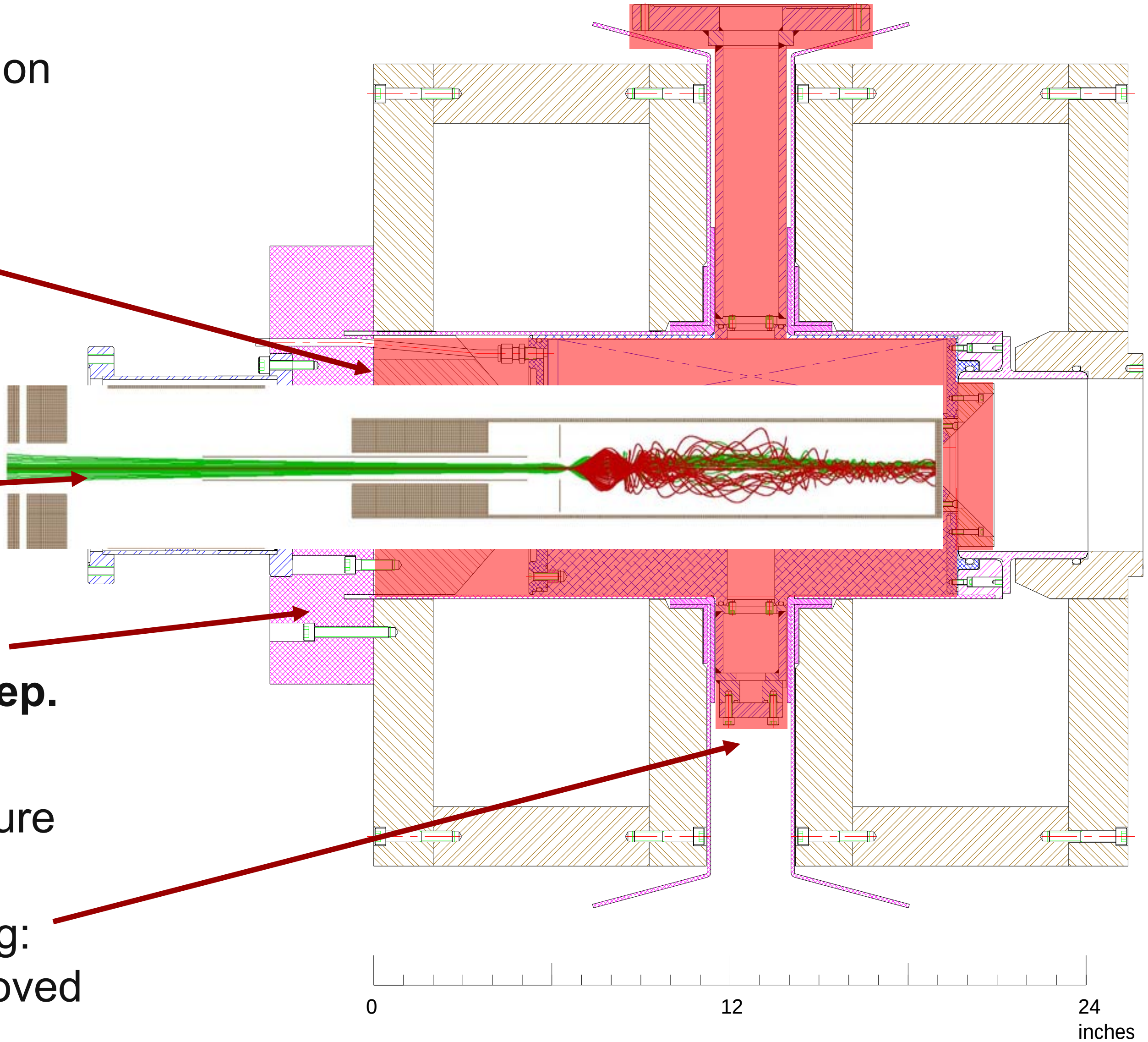


CARIBU ECR Charge-Breeder System



ANL ECR-I modified to function as a Charge Breeder

- Necessary to increase ion charge state for acceleration in ATLAS. (q/m > 0.15)
- Injection side iron modifications to allow injection tube and optics
- Injection capture optics modeled with SIMION & GEM codes of Far-Tech, Inc.
- High voltage isolation
  - **Increase to 50 kV as required by isobar sep.**
- RF injection
  - Open hexapole structure allows radial injection
  - Two frequency heating: 10 & 14 GHz for improved efficiency



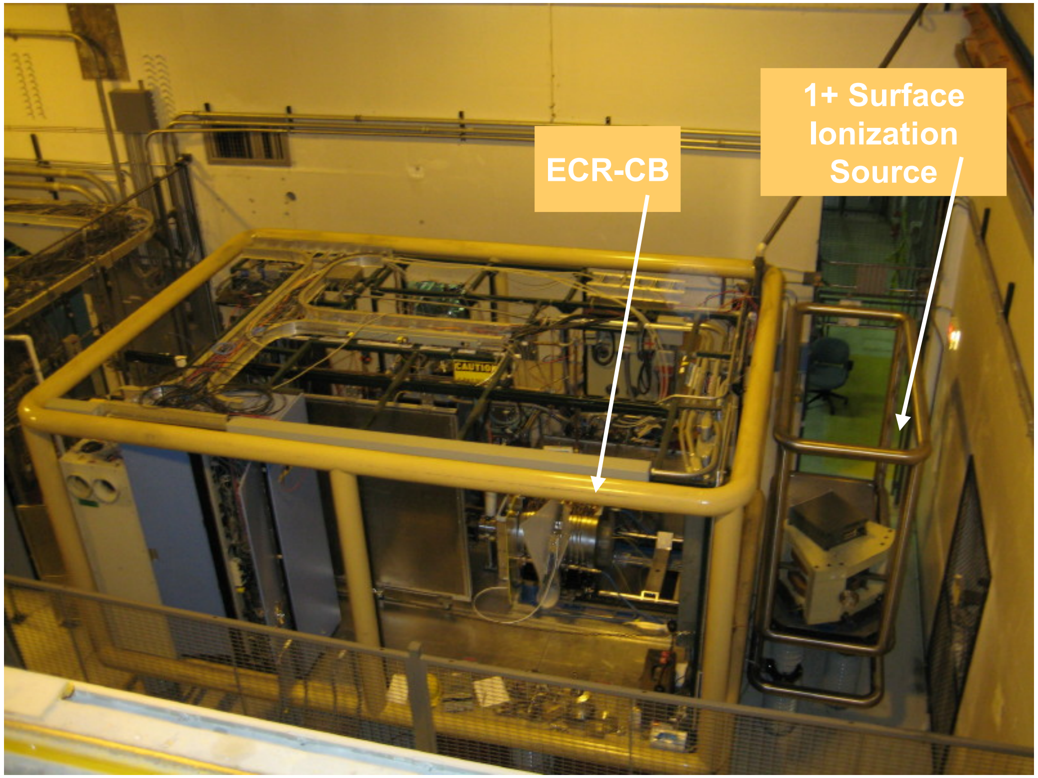
ECR Charge Breeder Status

- **Initial operation of rebuilt source: January 2008**
- **Charge Breeding Studies with alkali metal began in May 2008**
- **Long-term charge breeding efficiency goal:**
  - **5% solid materials**
  - **10% gases**

Breeding Efficiency in August 2008

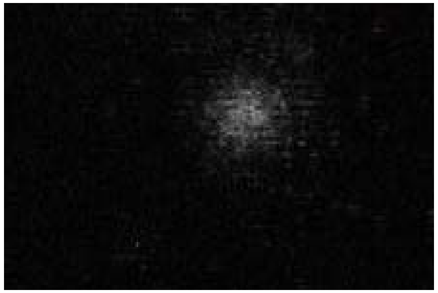
Ion Species	Efficiency Single/Two Freq.
$^{133}Cs^{16+}$	0.9%/1.4%
$^{133}Cs^{18+}$	1.0%/1.5%
$^{133}Cs^{20+}$	2.4%/2.9%
$^{133}Cs^{23+}$	0.5%/1.1%

Hear R. Vondrasek's Presentation for latest Rb Efficiency Results

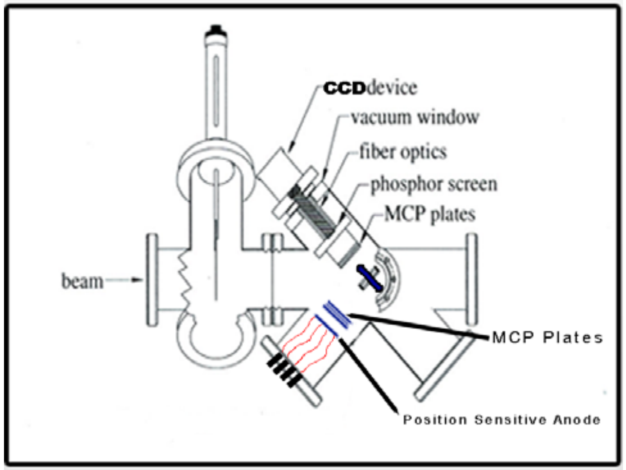


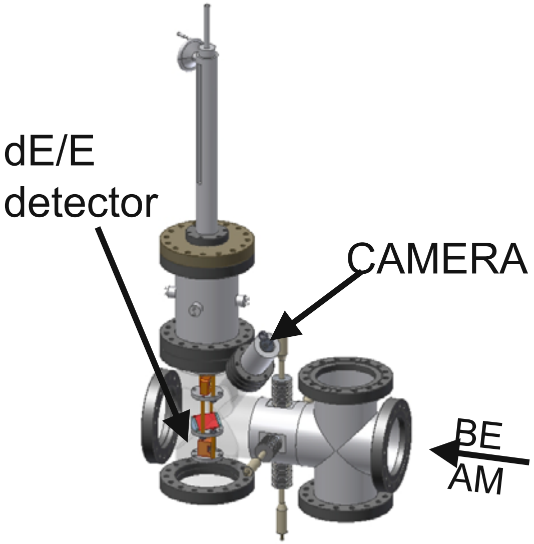
Weak Beam Diagnostics

- **Beam Profile & Current integration**
  - ANL-designed Beam Profile Monitoring Device
    - *Secondary electrons → MCP → phosphor screen →CCD image*
  - Commercial (Quantar Technologies) position sensitive device
    - *Secondary electrons → MCP using a 2D charge division anode*
  - Phosphor surface → high sensitivity CCD camera (profile only)
    - *Gd_2O_2S:Tb and Y_2O_2S:Tb*
- **Longitudinal beam quality and mass determination/beam contamination**
  - Silicon detectors in dE/E format
- **Tape station: ß counting**
  - Decay constant and istope identification



1000 ions/s
Single frame capture





CARIBU Project Status

- ECR Charge Breeder commissioned
  - Charge state distributions are as expected
  - Minimum efficiency goals met (with stable beams)
  - Approaching CARIBU long-term efficiency goals
- Installation of Gas Catcher/RFQ underway
  - First stable ion extraction, late June or July
- Dipole magnets shipment now (June 2009)
  - Commissioning and calibration in July and August 2009
- Weak beam diagnostics available for commissioning
  - Four of six stations in place
  - First radioactive beam using 2.2 mCi source ~July 2009.
- Commissioning: September 2009.

Summary

CARIBU is an exciting, cost effective enhancement to the capabilities of the ATLAS facility that provides the tools necessary for cutting-edge nuclear physics research.

- ***The ^{252}Cf fission source project compliments other existing facilities.***
  - **Provides tools to address an important class of physics questions during the era leading up to a national exotic beam facility.**
  - **Interesting array of radioactive beams.**
  - **Energy regime not generally available at other RIB facilities.**
  - **Leverages the expertise and technologies available at ATLAS.**
  - **The proposed upgrade has great synergy with future RIB facilities on both the technical and physics fronts.**
- ***Serves as a bridge to higher intensity facilities.***
- ***First beams are planned in Fall 2009 with an 80 mCi source.***
- ***1 Ci source not available until near end of calendar 2009.***