Commissioning Experience with CARIBU

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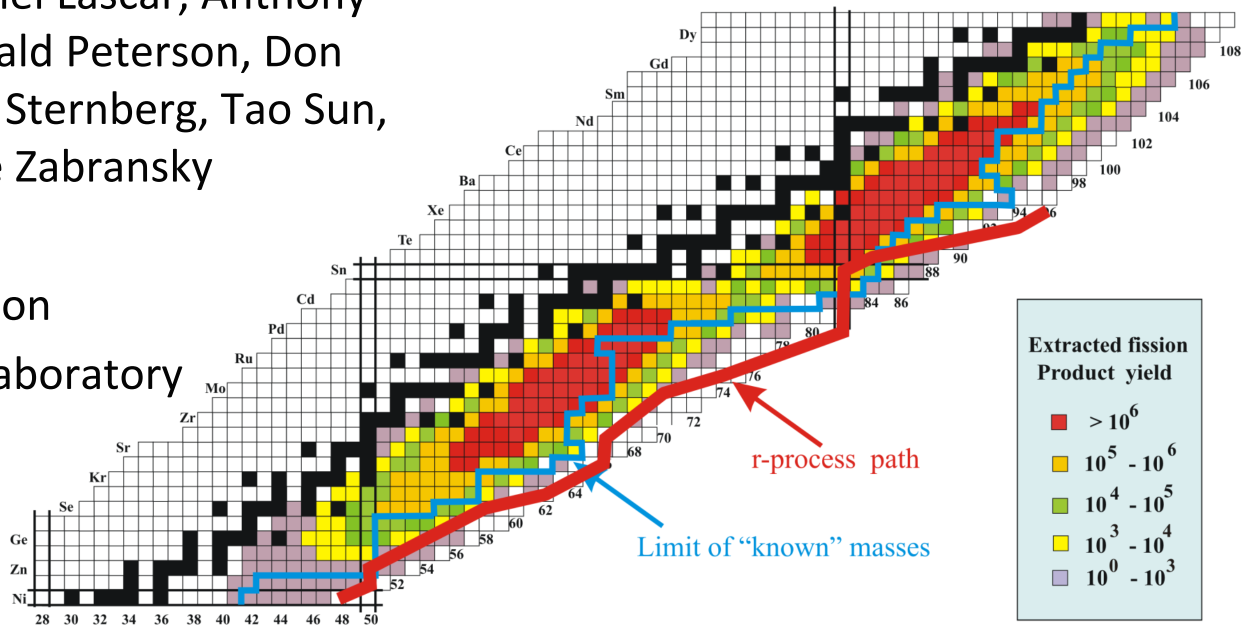


- CARIBU overview
- Results with the CARIBU program
- Future prospects

The pursuit of radioactive ion beams

- Science is driving the development of ever more capable radioactive beam facilities
  - Present day facilities are in the $10^4 \rightarrow 10^8$ pps range
  - Future facilities will deliver beam intensities of $10^{10} \rightarrow 10^{13}$ pps
  - Large projects, very expensive, long timeline

ECR

LPSC Grenoble

TRIAC Tokai Radioactive Ion Accelerator Complex

TRIUMF

Argonne NATIONAL LABORATORY

SPES exotic beams for science

GANIL Spiral2 laboratoire commun CEA/DSM CNRS/IN2P3

ATM CYCLOTRON INSTITUTE TEXAS A&M UNIVERSITY

Variable Energy Cyclotron Centre
1/AF, Bidhan Nagar, Kolkata-700 064

EBIS

REX-ISOLDE

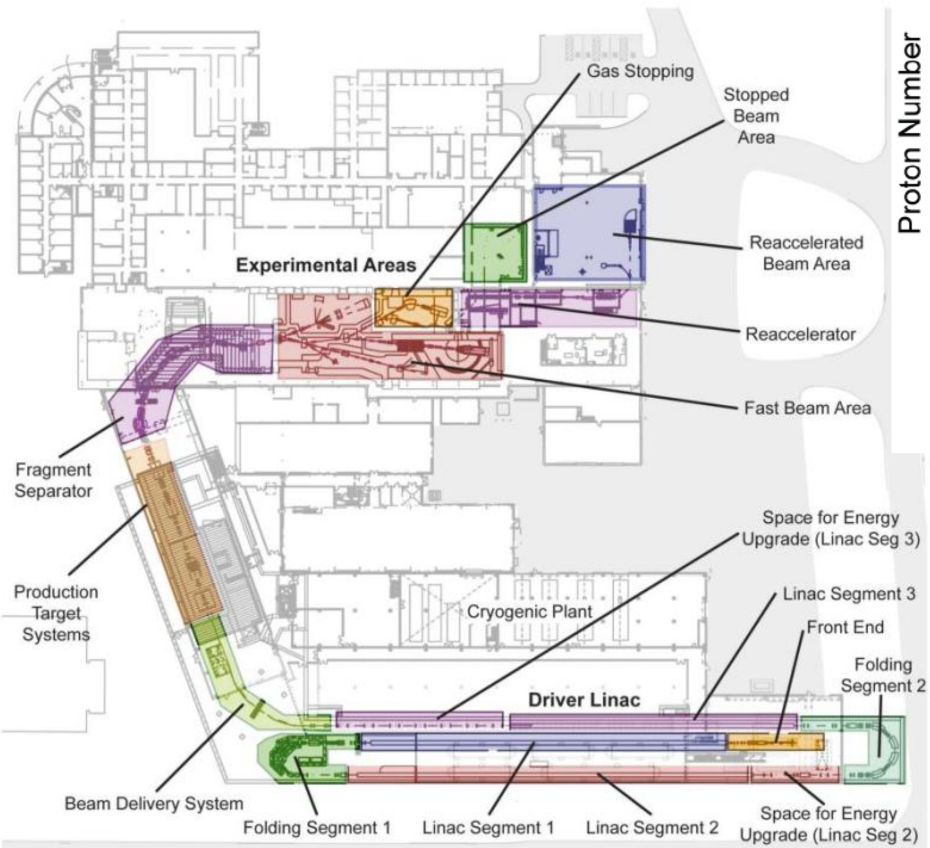
sparc

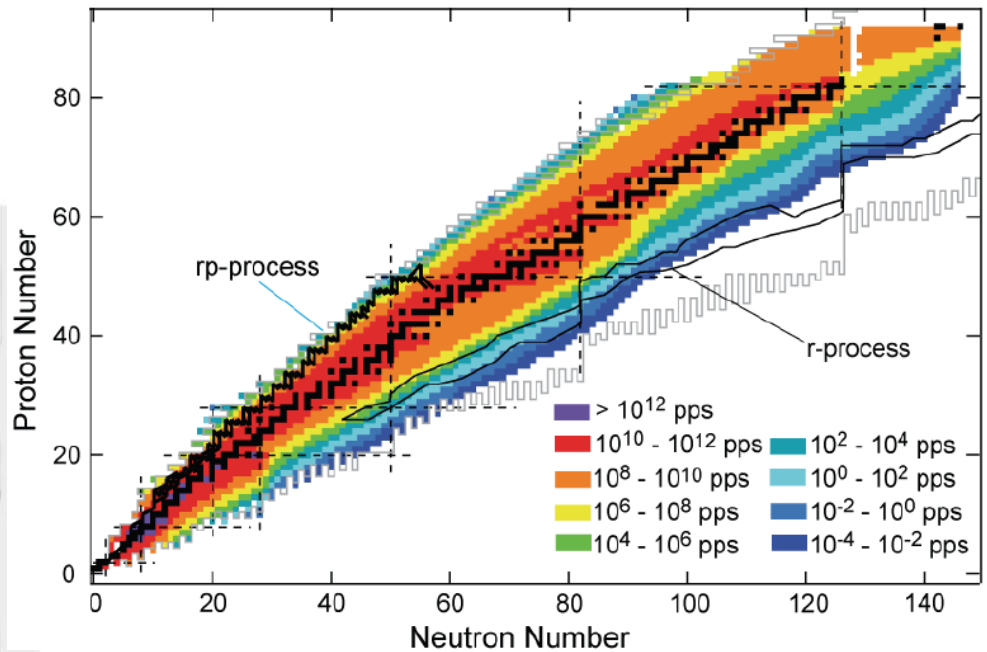
FACILITY FOR RARE ISOTOPE BEAMS

HIE ISOLDE

FRIB at MSU

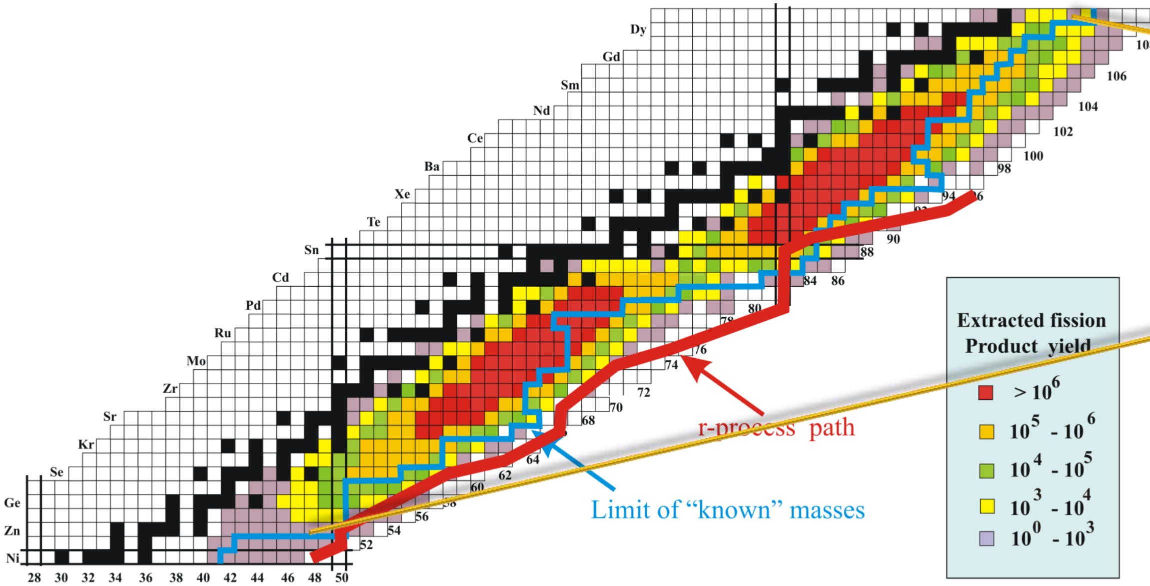
FACILITY FOR
RARE ISOTOPE BEAMS

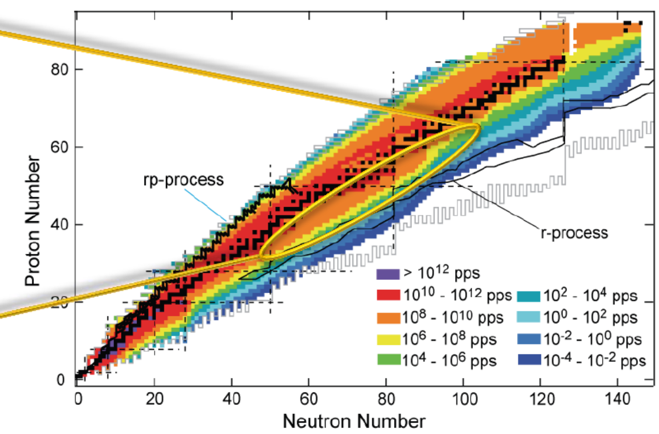


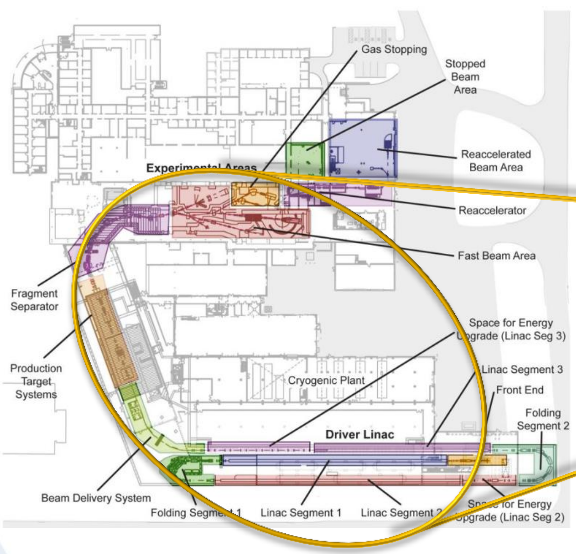


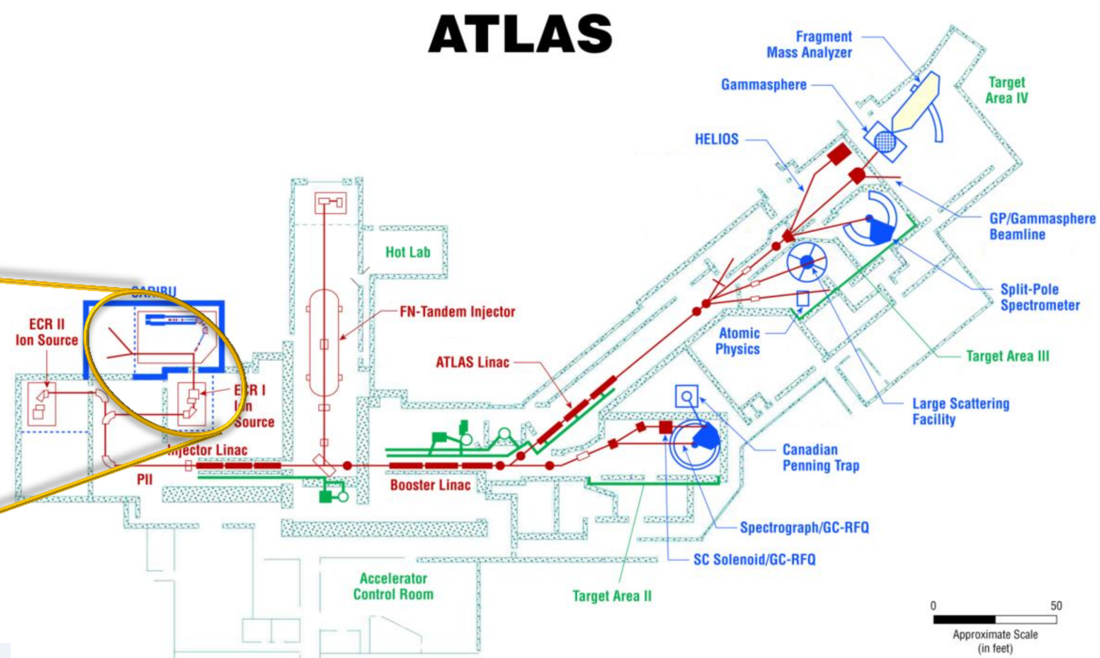
- Beams produced via fragmentation
  - Broad reach with high beam intensities
- Expected to come on line in 2021
  - What can we do in the mean time?

CARIBU at Argonne National Laboratory





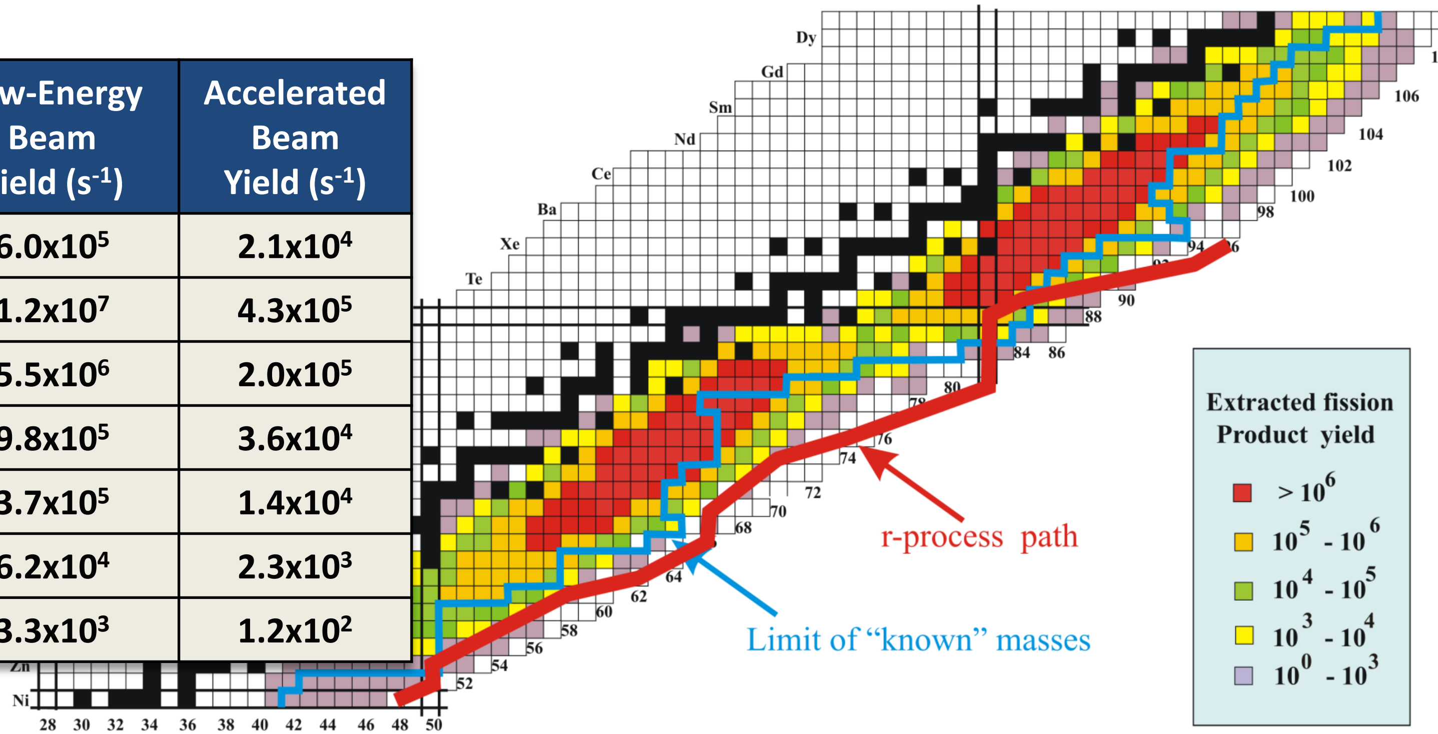




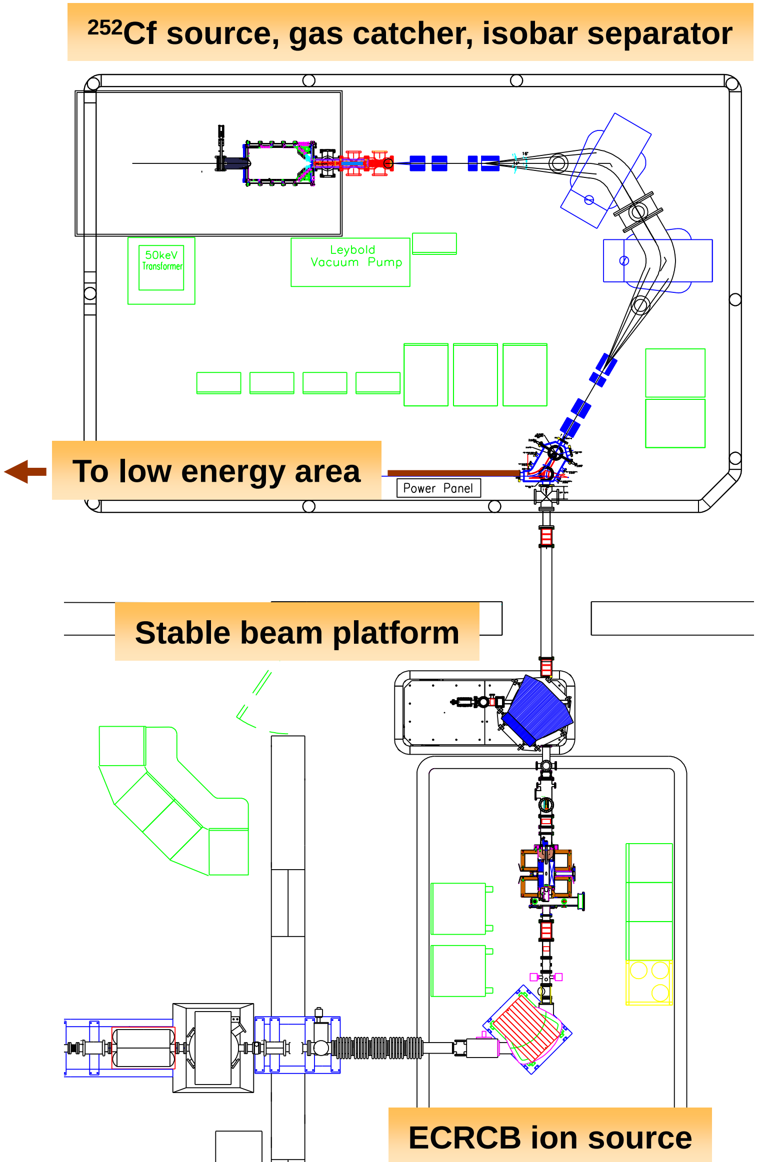
CARIBU expected beam yields

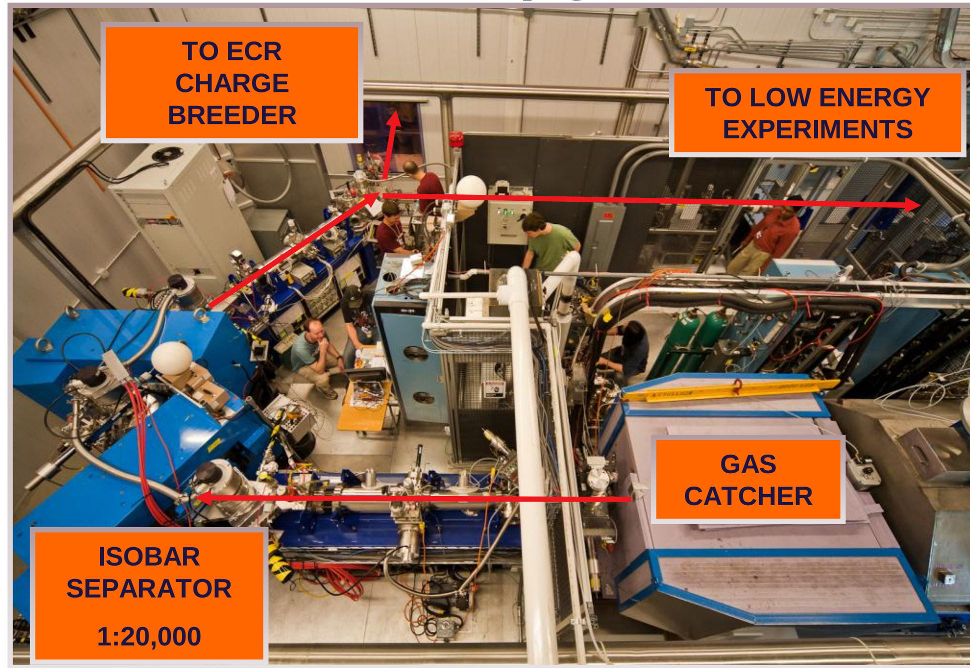
- 1 Ci ^{252}Cf fission source provides radioactive species
  - $T_{1/2}$=2.6 a 3.1% fission branch
  - Maximum approved source strength of 1.0 Ci, installation planned late summer 2012
- ^{252}Cf fission yield is complimentary to uranium fission
- Stopped beams - Masses, decay spectroscopy, laser spectroscopy
- Post-acceleration energy up to 15 MeV/u - Single particle structure, gamma-ray spectroscopy

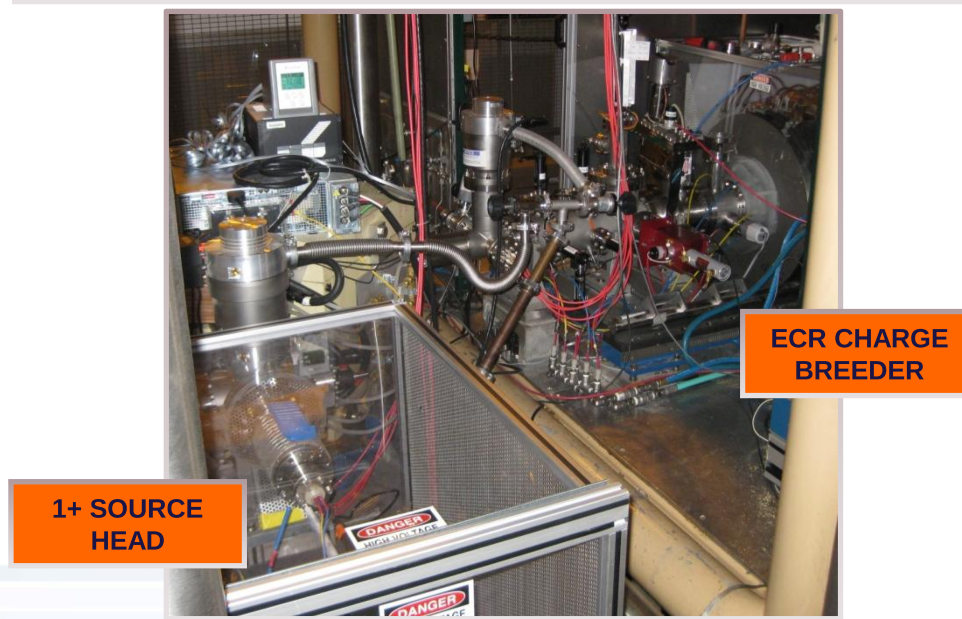
Isotope	Half-life (s)	Low-Energy Beam Yield (s^{-1})	Accelerated Beam Yield (s^{-1})
^{104}Zr	1.2	6.0×10^5	2.1×10^4
^{143}Ba	14.3	1.2×10^7	4.3×10^5
^{145}Ba	4.0	5.5×10^6	2.0×10^5
^{130}Sn	222.	9.8×10^5	3.6×10^4
^{132}Sn	40.	3.7×10^5	1.4×10^4
^{110}Mo	2.8	6.2×10^4	2.3×10^3
^{111}Mo	0.5	3.3×10^3	1.2×10^2



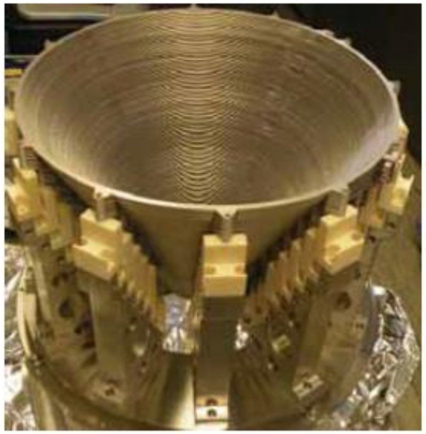
CARIBU – Californium Rare Ion Breeder Upgrade



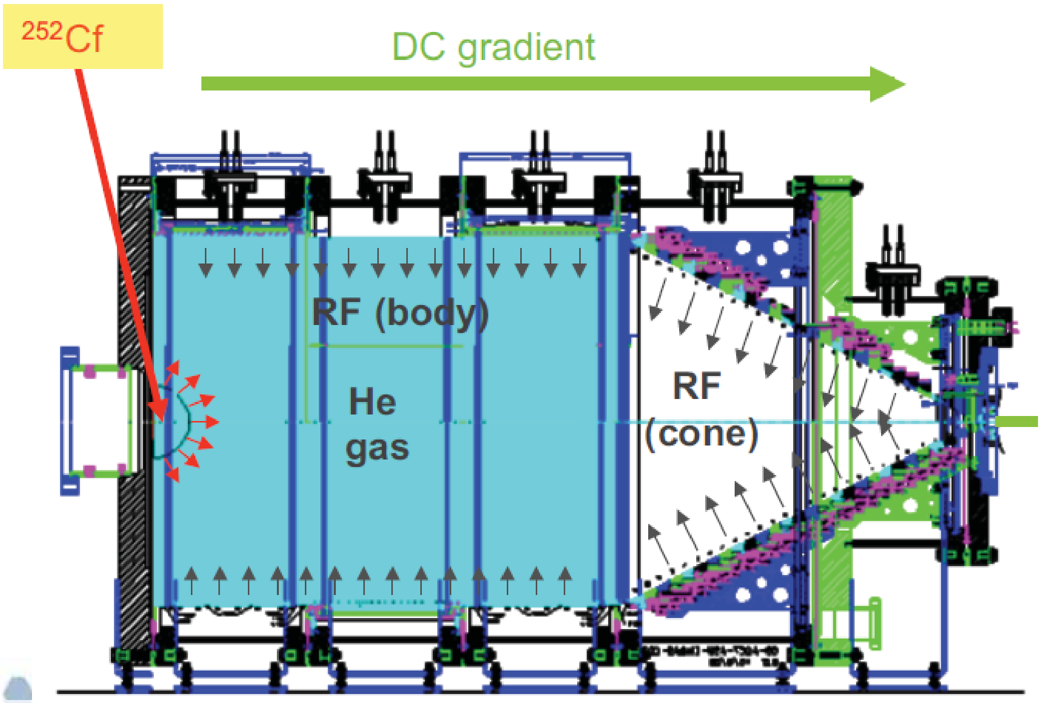




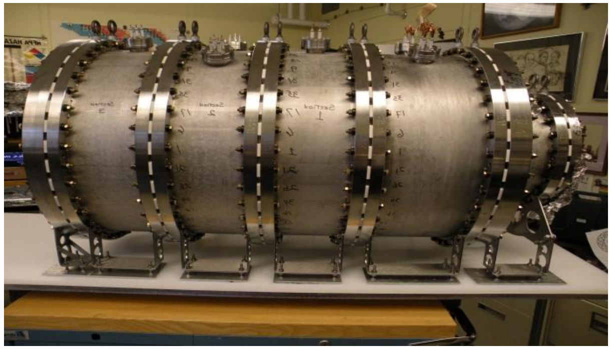
CARIBU gas catcher



- Large volume - 50 cm diameter and 1.5 m length
- UHV construction - stainless steel and ceramic
- Ultra pure helium - operating pressure of 150 mbar
- Radioactive ions transported by RF + DC + gas flow
- Extraction in 2 RFQ sections with µRFQs

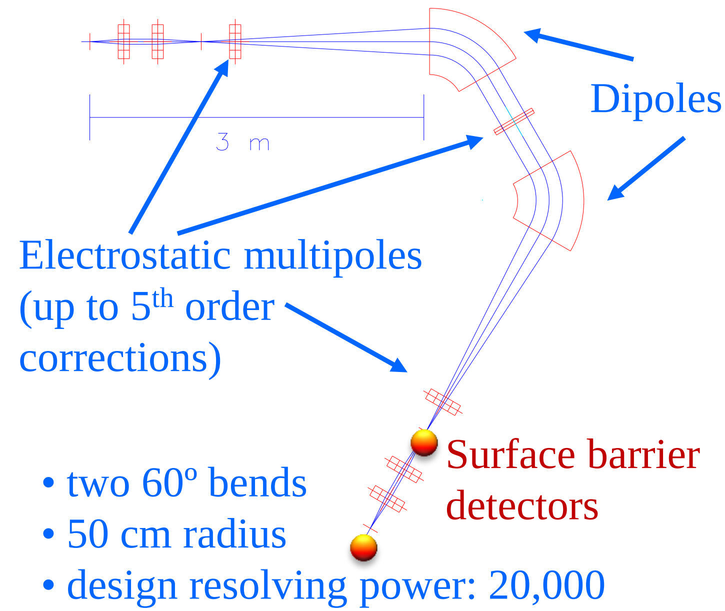


- Mean extraction time is <10 msec
- Overall efficiency of 20%
- Extraction is element independent
- Emittance: 3 π·mm·mrad
- Energy spread: ~1 eV

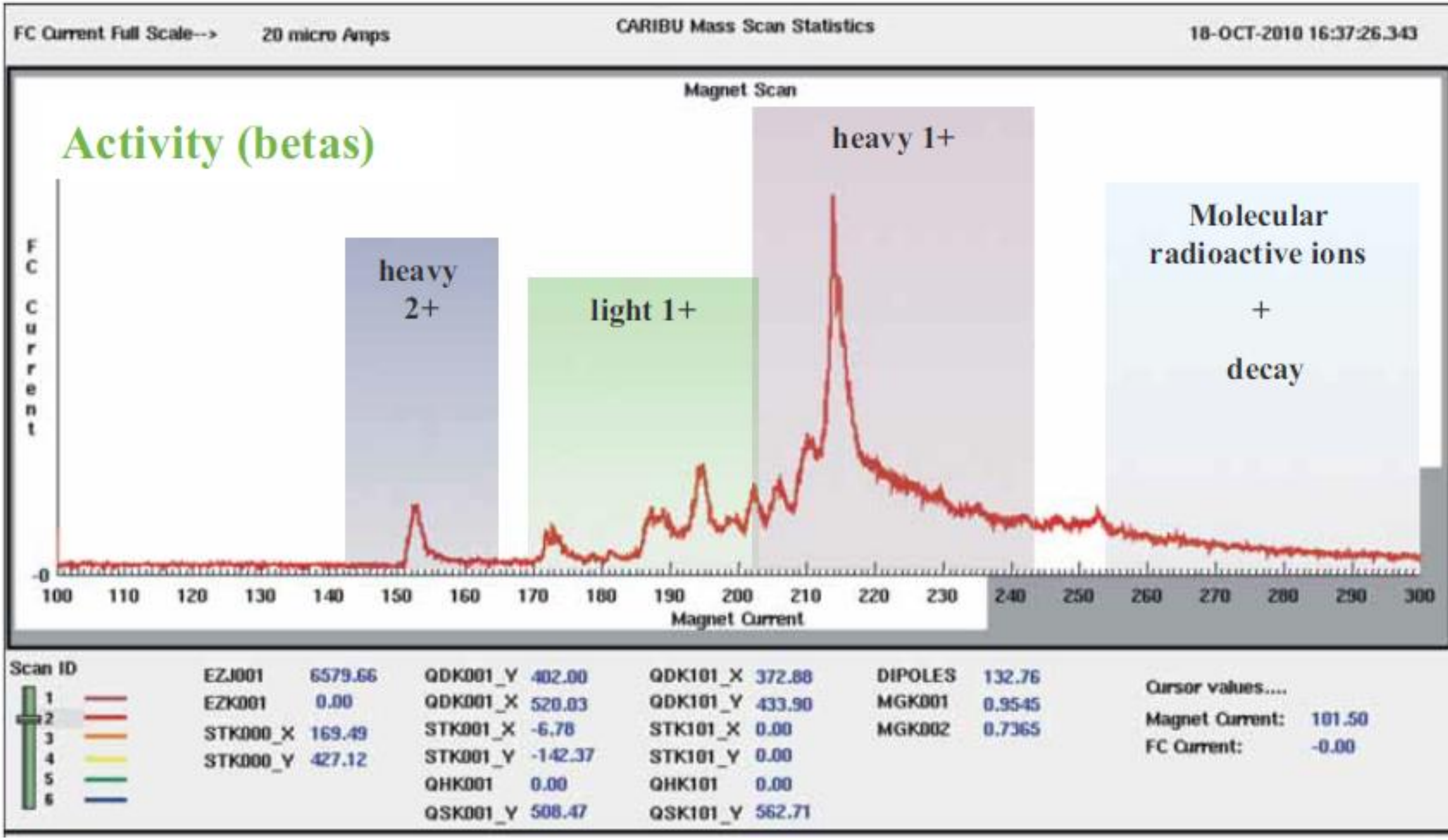


Purification of radioactive beam

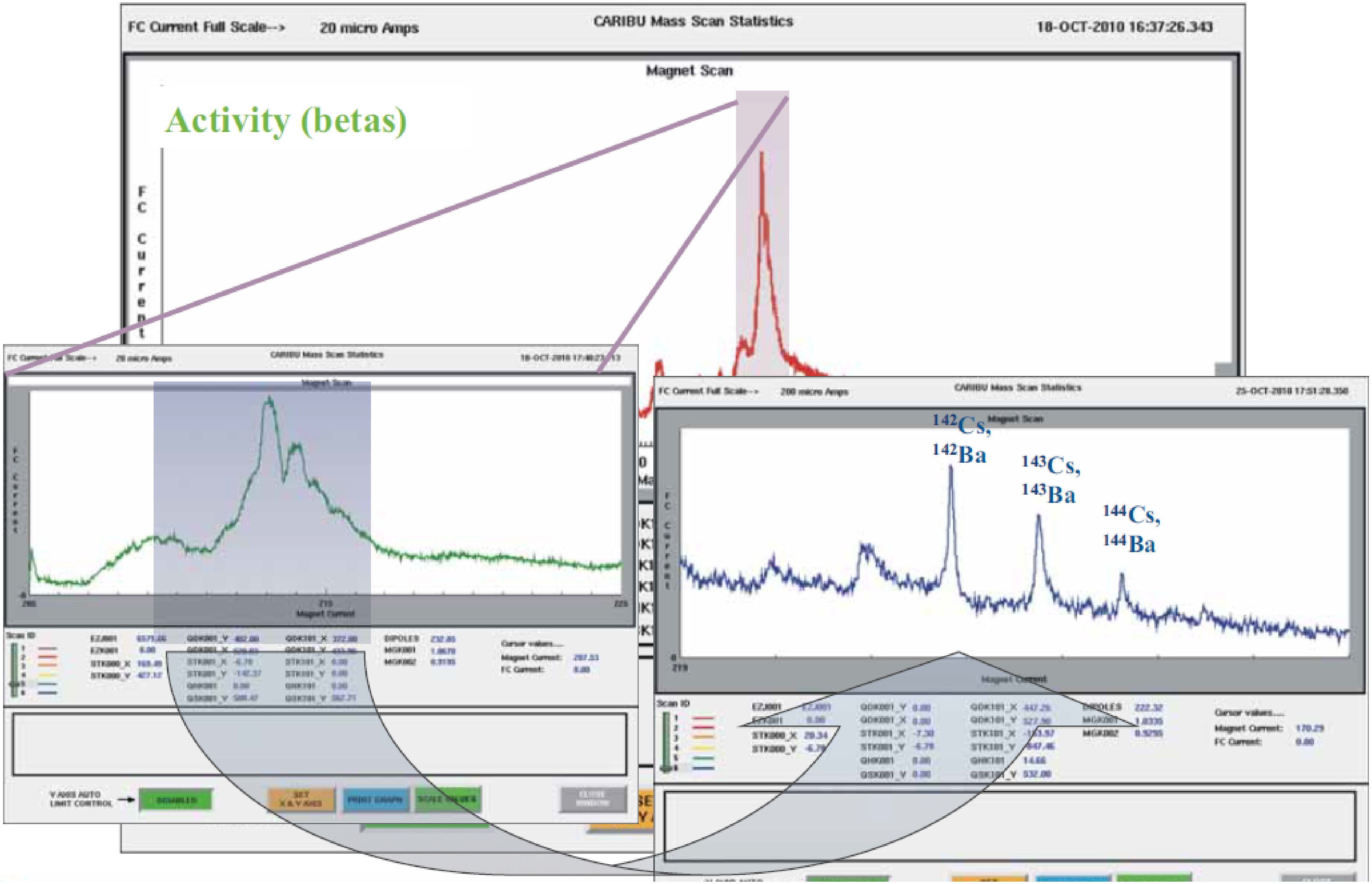
- Contamination from neighboring masses is handled with 'compact' isobar separator
- Resolution required to remove….
  - Neighboring masses R = 250
  - Molecular ions R = 500 - 1000
  - Isobars R = 5000 – 50,000
  - Have achieved 1:10,000 resolution with 1:7,000 more typical
- Take advantage of low emittance and energy spread of extracted beams
- Matching sections at entrance and exit form ribbon beam
- All optics except for bending magnets are electrostatic so that tune is mass independent
- And it all fits on a high voltage platform



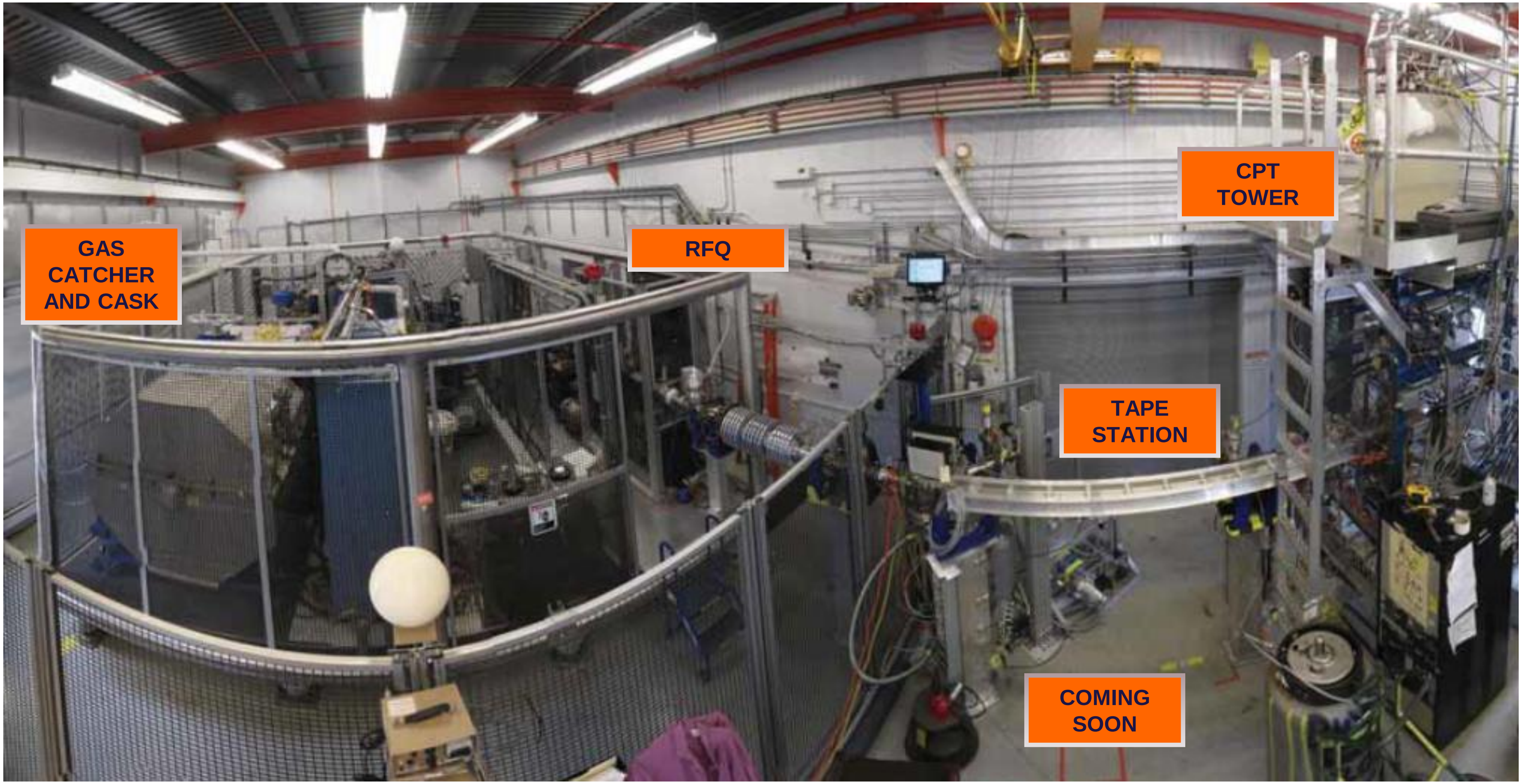
Beam identification



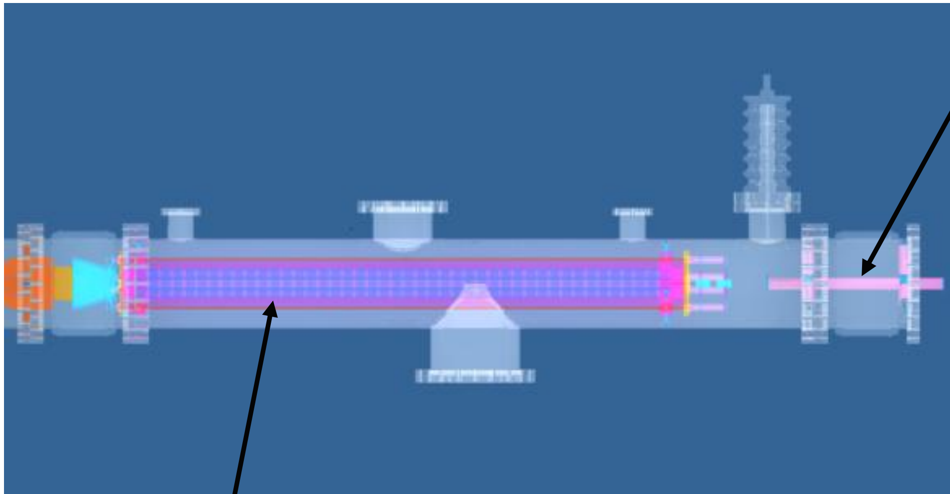
Zooming in on specific activity



CARIBU in-room low-energy beamline



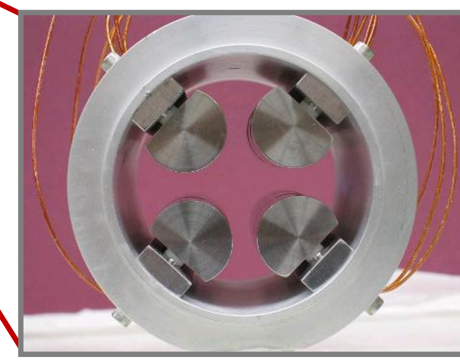
The Canadian Penning Trap (CPT) at CARIBU



Elevator lowers ion potential from 50 kV → 2 kV

Gas filled RFQ provides cooled, bunched beams to stopped beam experiments

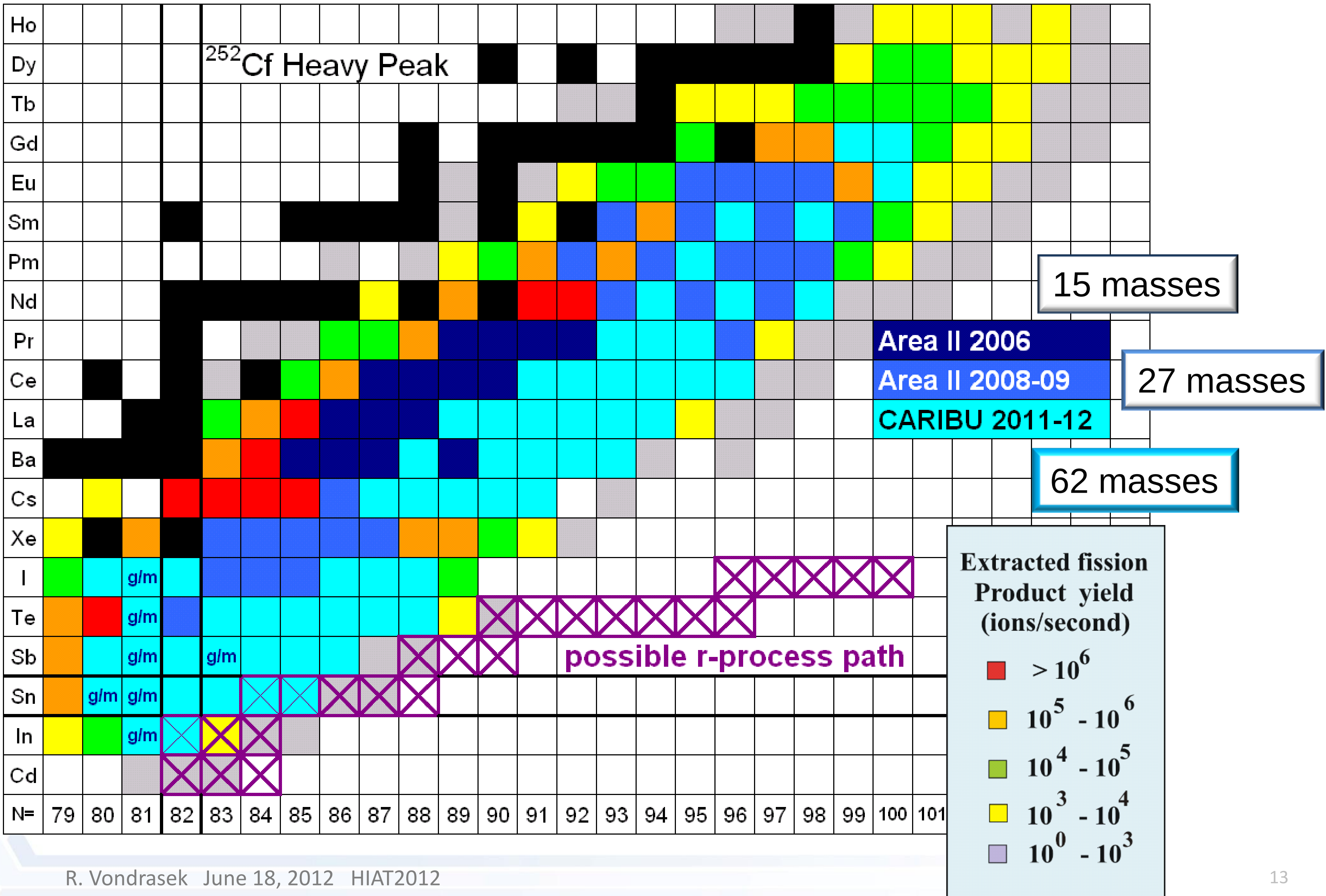
Penning Trap



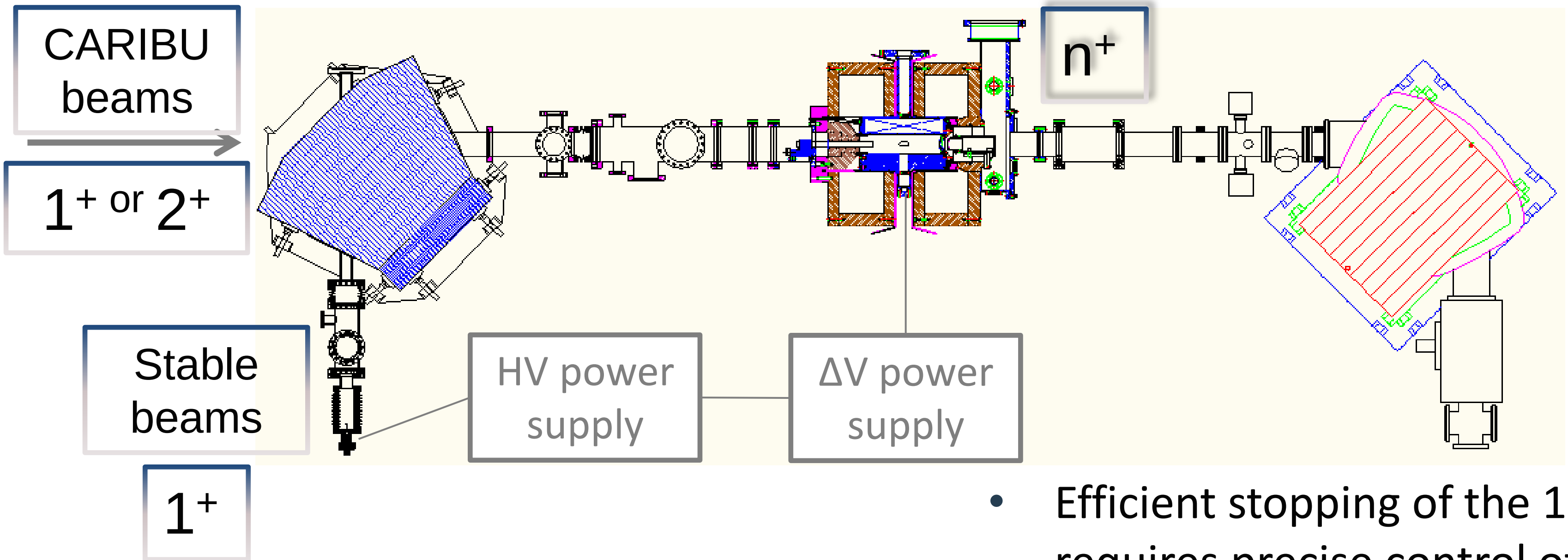
Linear RFQ trap

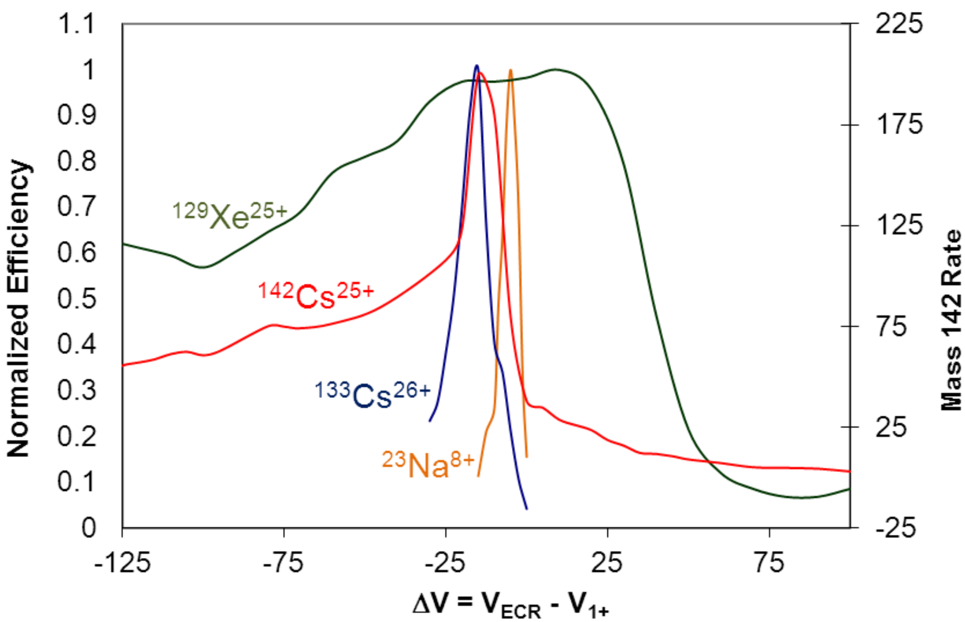
- Trap was previously in AREA 2 utilizing in flight beams and a smaller fission source
- Trap was moved to CARIBU room in 2010

CPT measurement campaigns



Charge breeding with an ECR source

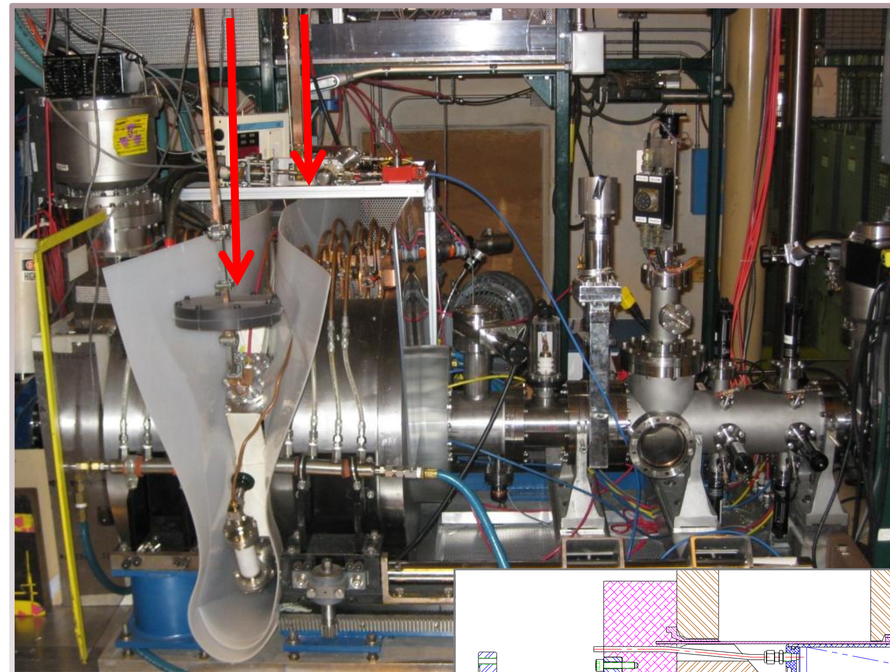


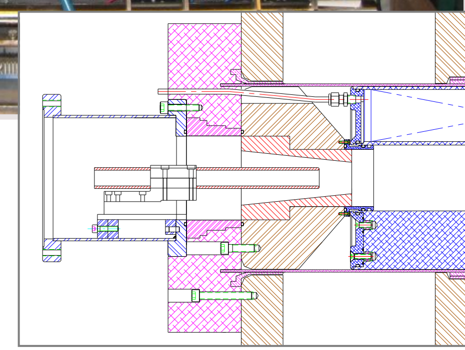


- Efficient stopping of the 1+ ions requires precise control of the ΔV
- Position of ΔV peak depends upon the source of the 1+ ions
  - Surface source, RF, CARIBU
- Narrow tuning range for condensable elements, wide window for gases
- Beamline tunes for stable and radioactive beams are not exactly the same

ECR charge breeder

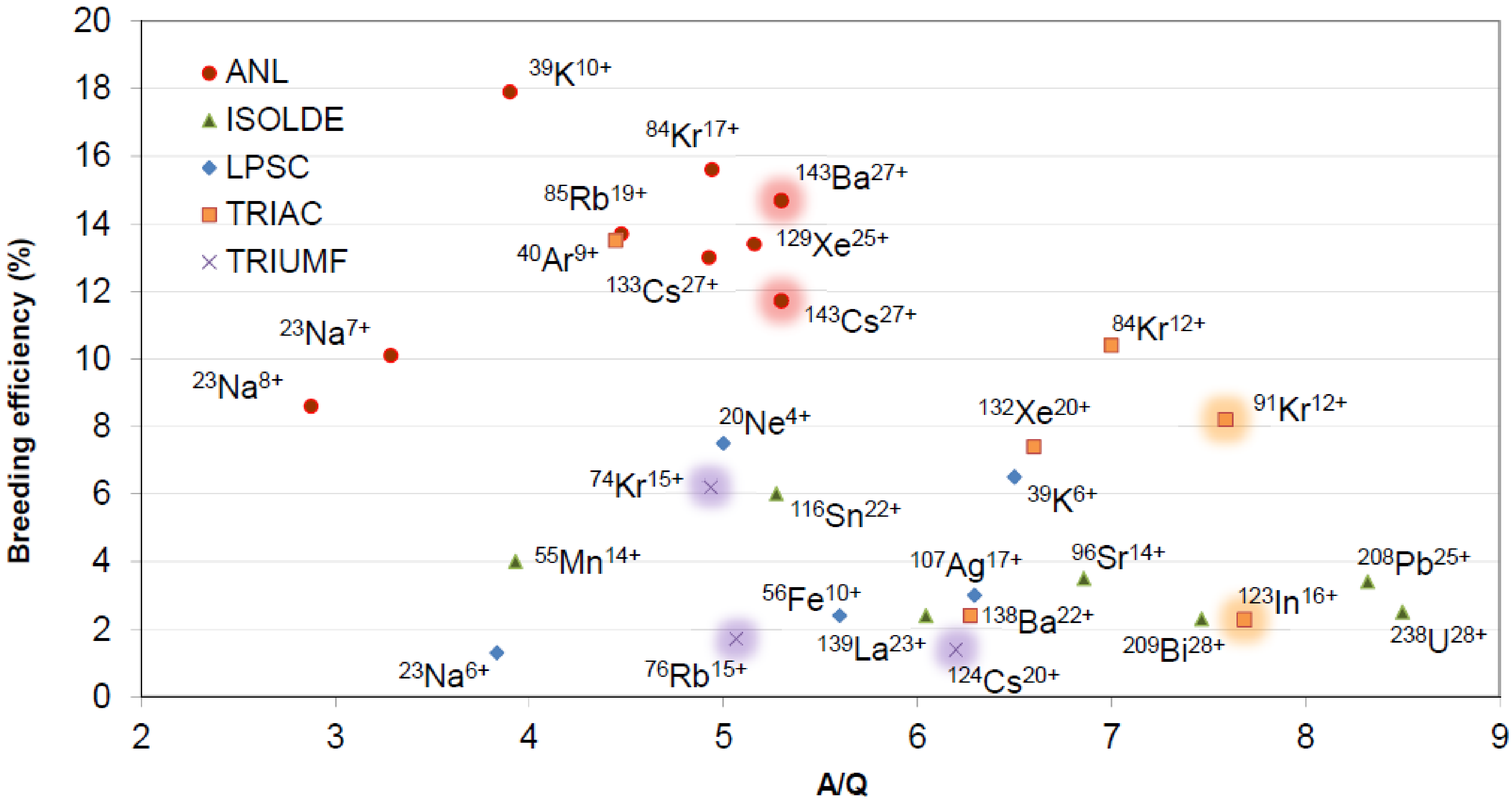
- Multiple frequency operation
  - Klystron: 10.44 GHz, 2 kW
  - TWTA: 11→13 GHz, 0.5 kW
- Open hexapole structure
  - RF is injected radially
  - Uniform iron in the injection region for symmetrical fields
  - Improved pumping to the plasma chamber region
    - Base pressure: 2×10^{-8} mbar
    - Operation: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



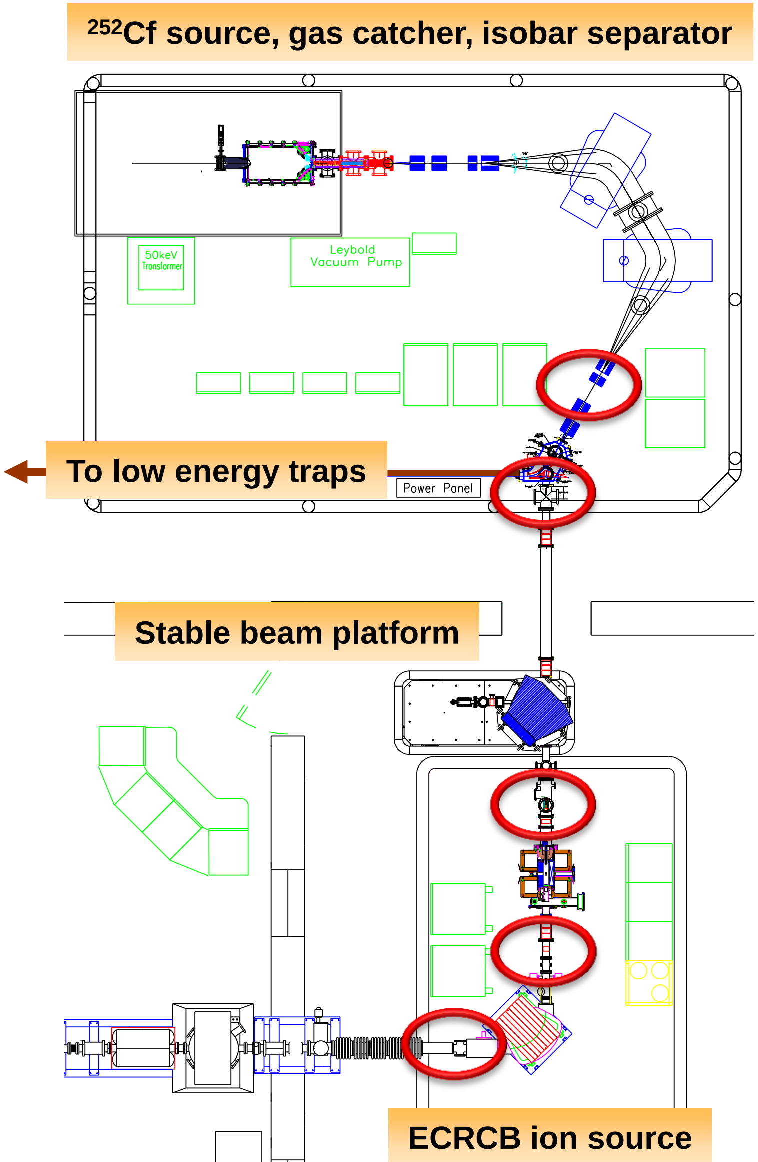


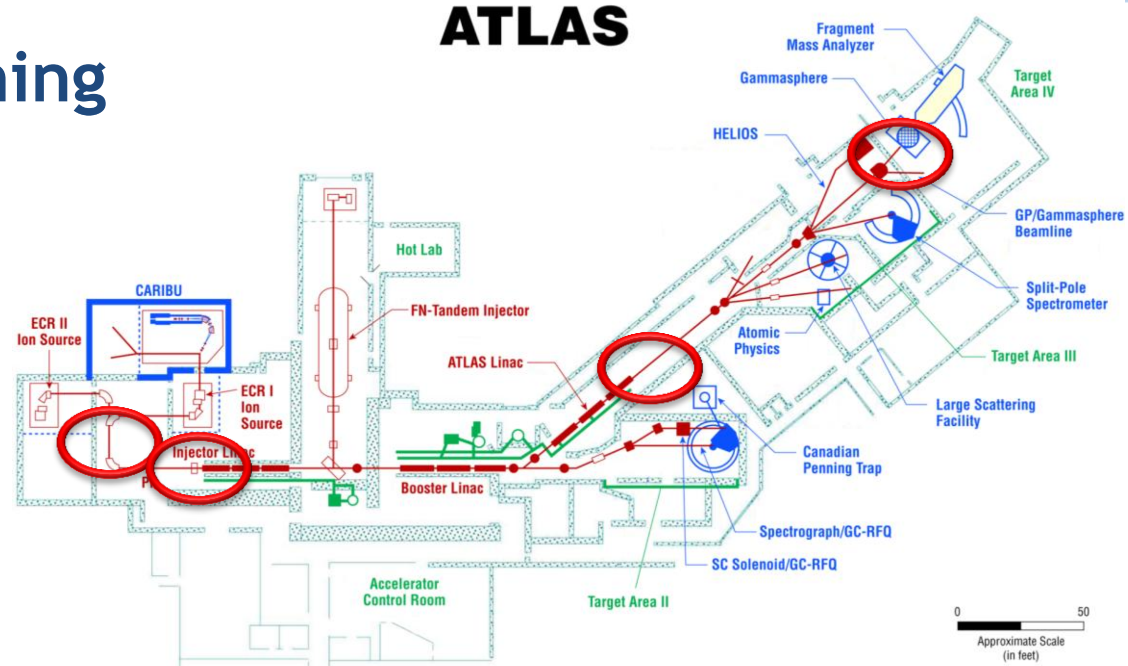
	Design value	Running condition
B_{inj}	1.31 T	1.16 T
B_{min}	0.31	0.27
B_{ext}	0.85	0.83
$B_{(radial)}$		0.86 T
Last closed surface		0.61 T

Worldwide charge breeding results



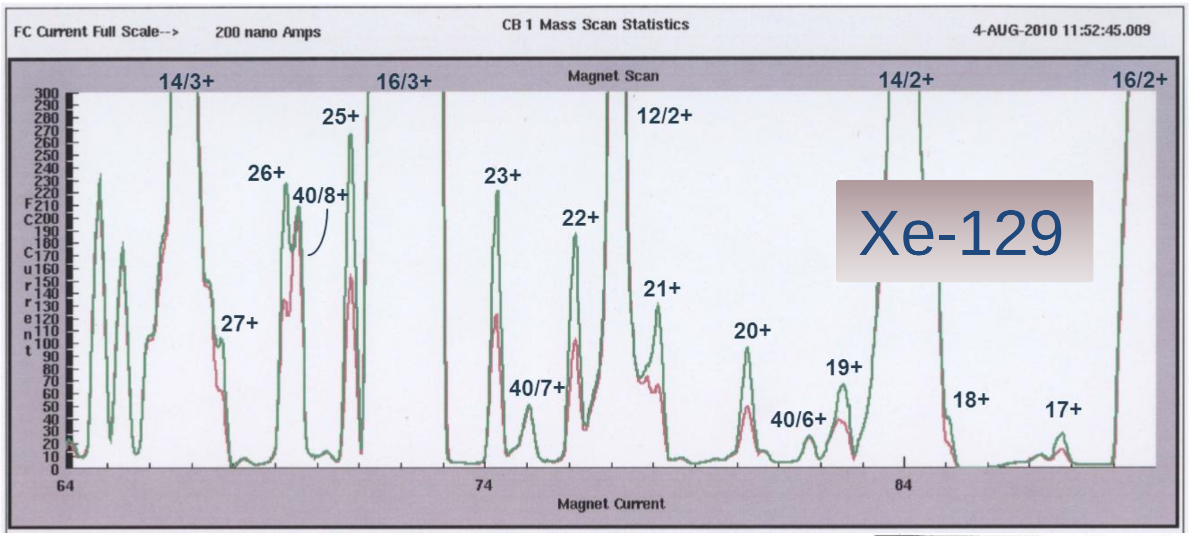
Radioactive beam tuning





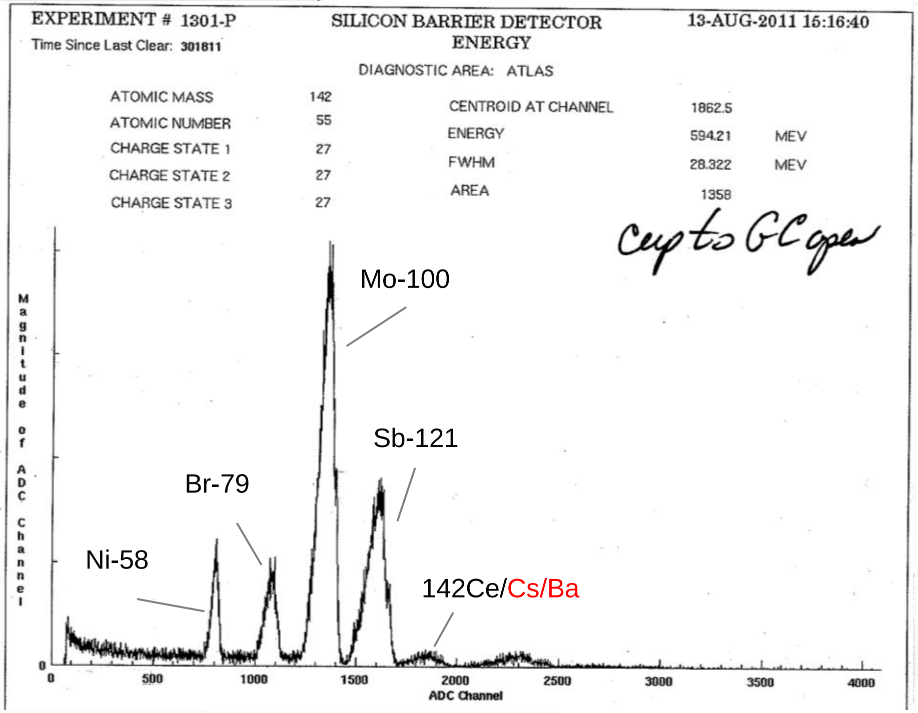
- Have many years of experience using guide beams in support of AMS program
- Accelerator is first tuned with a stable guide beam from the ECRCB which has a similar q/m as the radioactive beam
- All machine elements are then scaled to the desired q/m with no tuning after scaling
- Beta decay of the fission products are monitored on surface barrier detectors placed at key locations

Beam contaminants



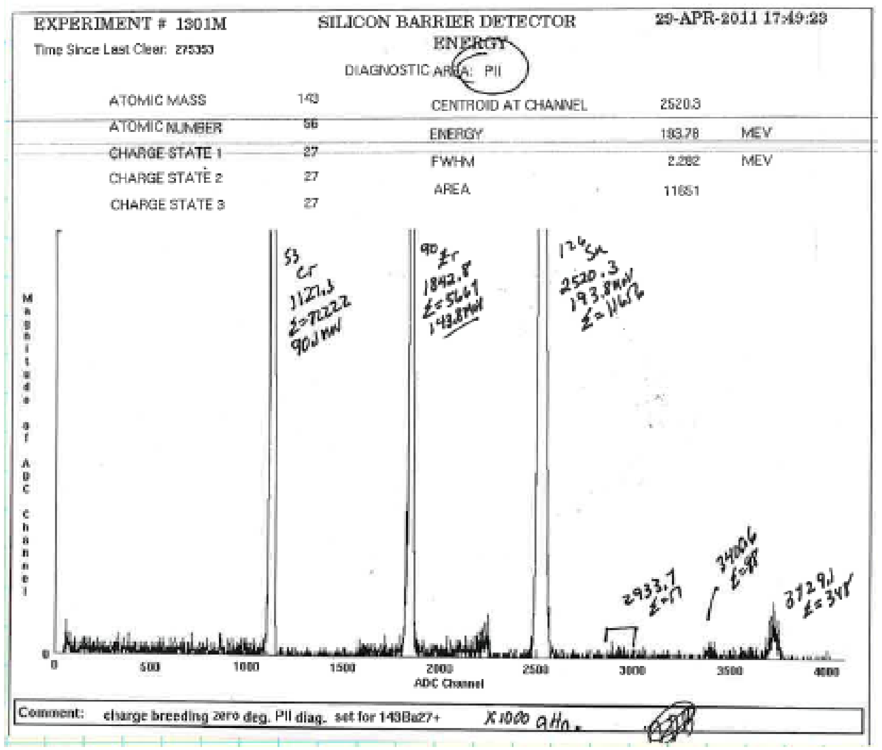
- The ECRCB has a large amount of background which has to be filtered out
  - Magnetic analysis has resolution of 1:500
  - Remaining contaminants are seen on energy spectrum

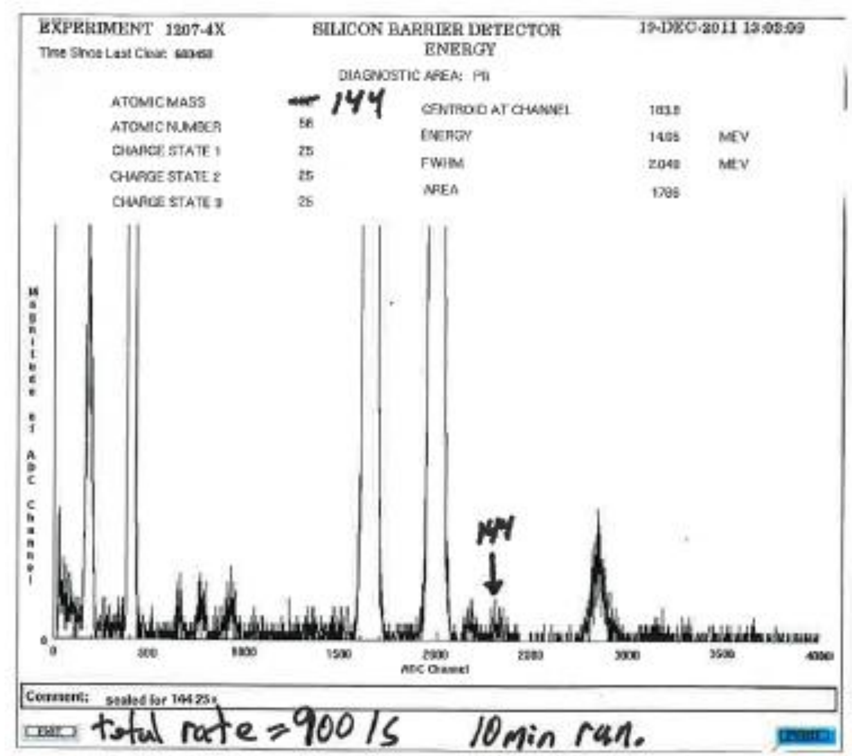
- Peak of interest is a mix of stable cerium and radioactive cesium and barium
  - For other settings have seen Fe, Ni, As, Ge
- This contamination hinders beam tuning, limits the detection capability, and complicates the experimental set up



Beam contaminants

- But there are many q/m combinations which can yield a relatively clean spectrum





- A = 143, Q = 25+
  - Total rate: 66,000 Hz
- A = 143, Q = 27+
  - Total rate: 330,000 Hz
- A = 144, Q = 25+
  - Total rate: 900 Hz
- A = 144, Q = 26+
  - Total rate: 10,000 Hz

Beam commissioning

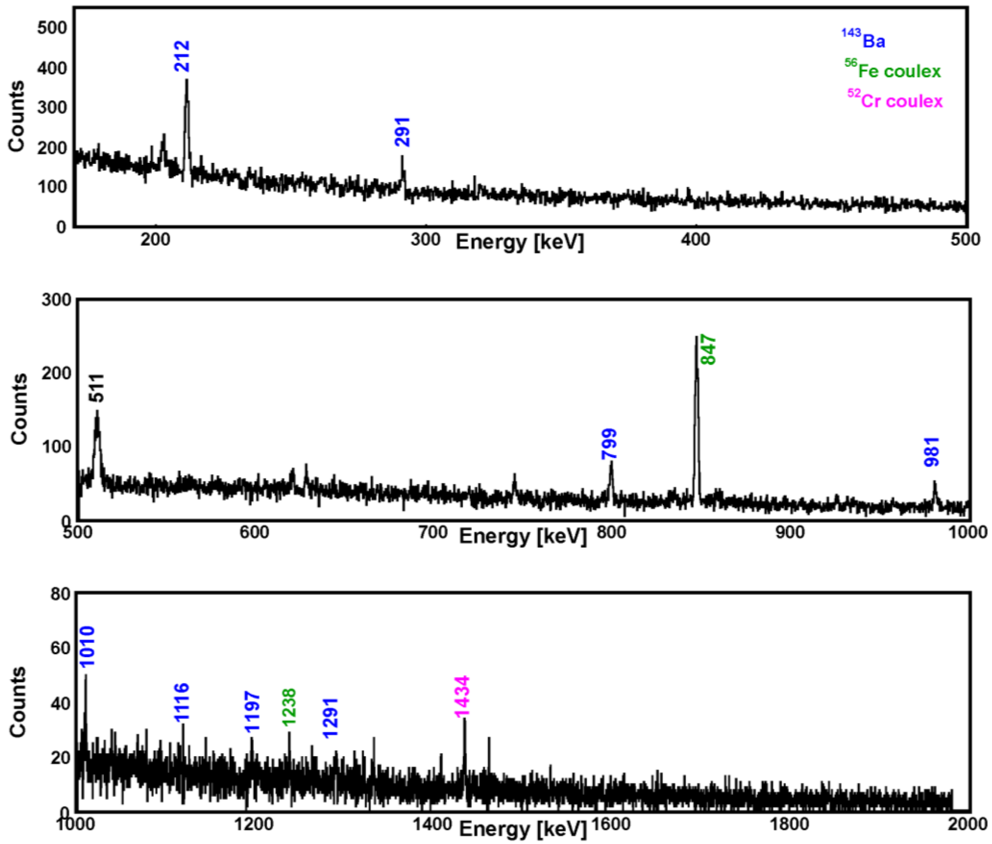


Figure 1. Background-subtracted gamma-ray spectrum at the ATLAS high energy diagnostics area showing ^{143}Ba gamma rays as well as gamma rays from stable beam coulomb excitation of the stainless steel beamstop material.

- Commissioning goal was a beam of $^{143}Ba^{18+}$ accelerated to 6.0 MeV/u
- Achieved commissioning with a beam of $^{143}Ba^{27+}$ at 6.1 MeV/u
  - Verified with gamma ray spectrum
- High energy rate was 900 Hz
  - Breeding efficiency of 12%
  - Total transmission from source was 12%
- What were the bottlenecks?
  - Gas catcher operation
    - Vacuum interlock
    - Bake-out cycle
  - Isobar stability
    - Power supply feedback does not stay in lock
  - Machine transmission
    - Better diagnostics

Next activities for CARIBU

- Install 500 mCi source
  - Immediate factor of 10 increase in available beam rates
  - Greater radiological headaches but have learned with 50 mCi source
- Improve isobar separator resolution without loss of transmission
  - Solve magnet stability issue and learning curve
- Better understanding of the difference between stable and radioactive beam tunes with regard to the charge breeder
- Improve the beam purity from the ECRCB
  - Quartz liner has been installed
  - Changed over to high purity aluminum components
  - Remove the grounded tube
  - Aluminum coat the iron plug
- Build an EBIS to replace the ECRCB

CARIBU EBIS upgrade

- Provides two important gains versus ECR charge breeding at CARIBU
  - Higher charge breeding efficiency demonstrated for pulse injection operation (ANL tests at BNL EBIS)
    - EBIS can accept 10^{10} pps
  - Stable beam background suppression
- Optimized all parameters of EBIS source in order to achieve optimal charge breeding
  - Pulsed injection and extraction following RFQ buncher
  - Operation with 2 e-guns
    - Standard operation
    - Electronic closed shell
- Sergey Kondrashev - Wednesday