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Status and plans for radioactive beams at ATLAS

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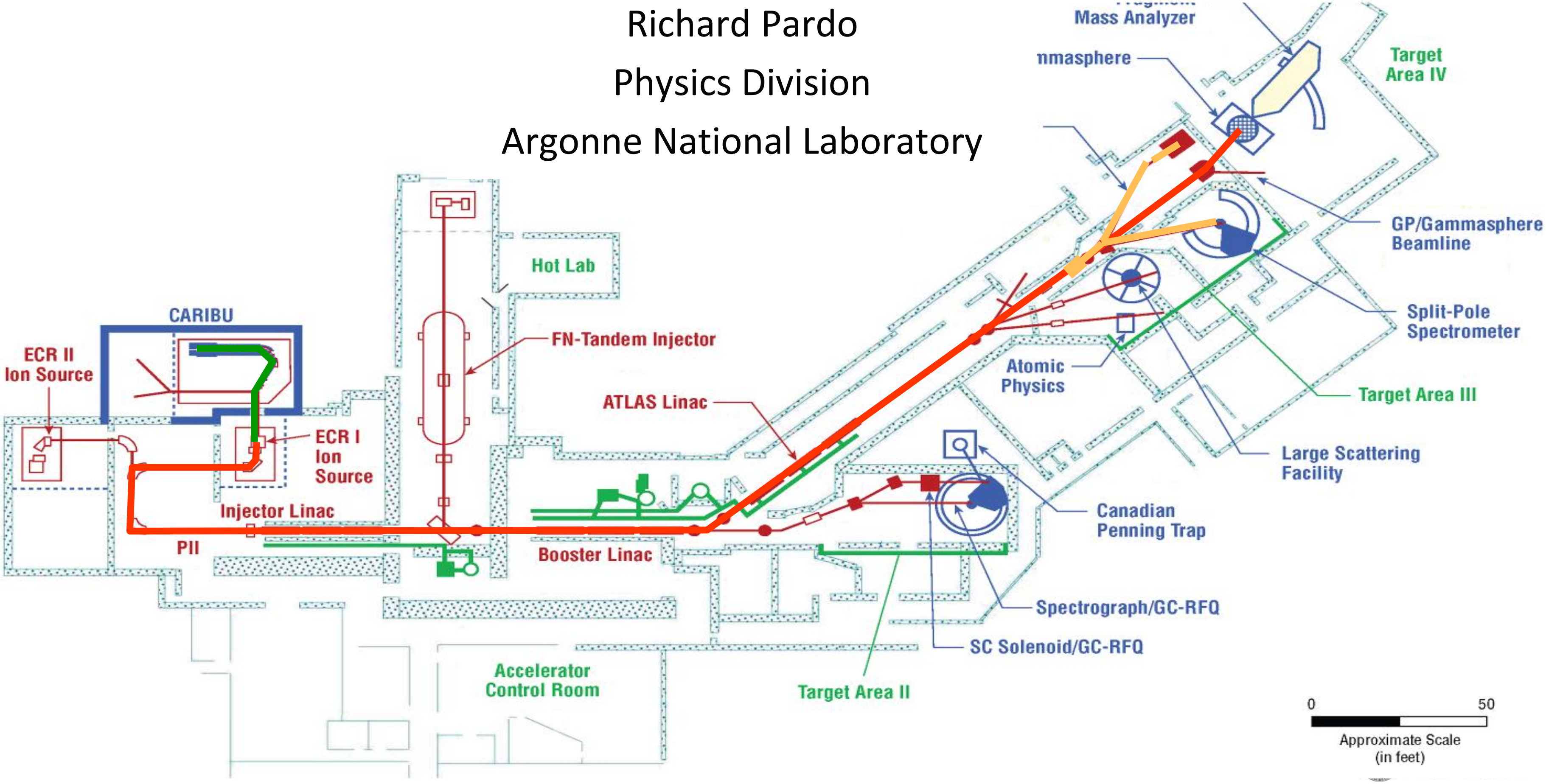


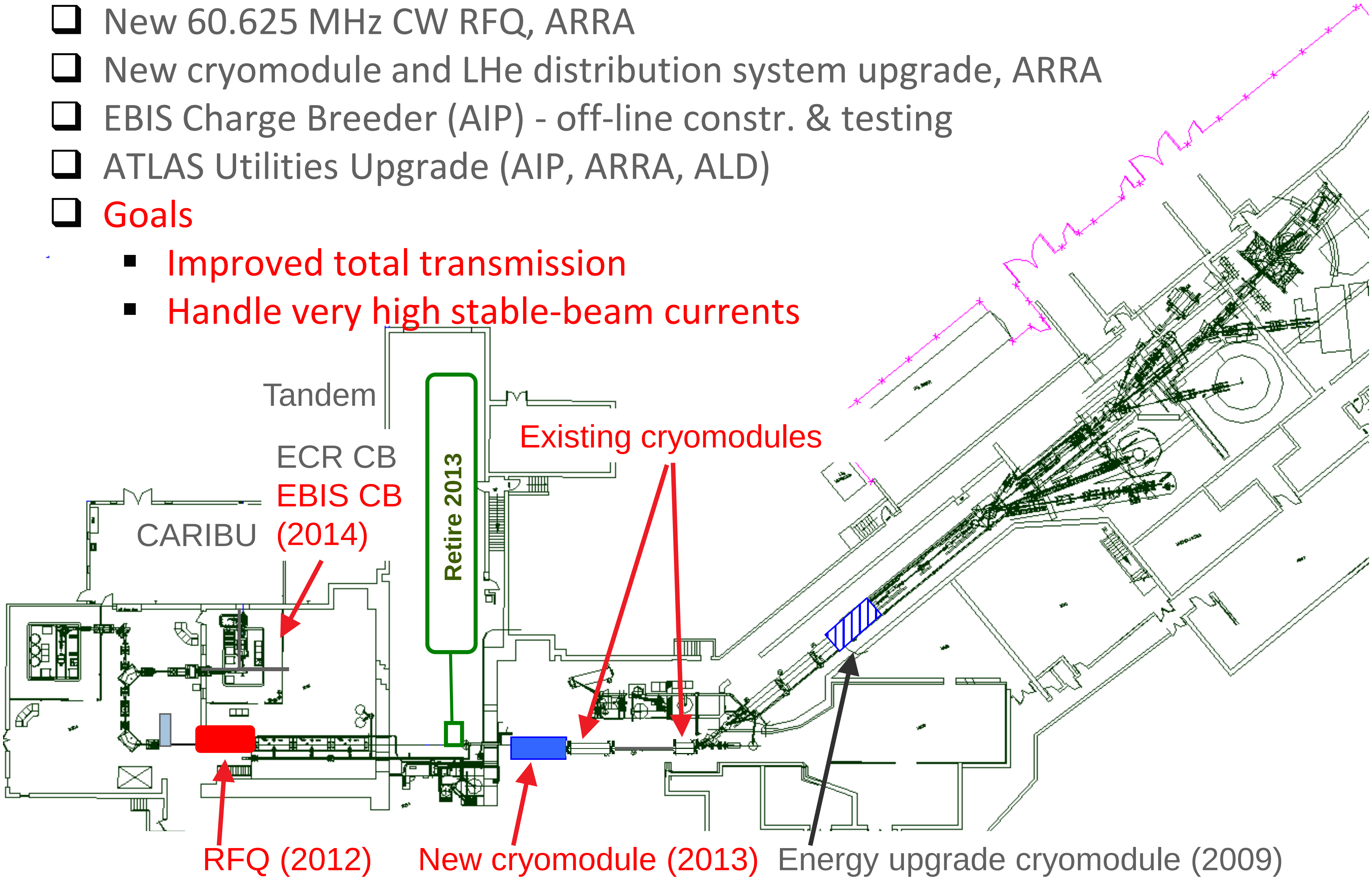
ATLAS Overview

ATLAS: Argonne Tandem LINAC Accelerator Facility

- ATLAS is the national user facility for low-energy heavy-ion stable beam physics in the United States
  - Began operation in 1985
- Also provides RIB beams as part of research program
- Major two stage upgrade of accelerator facility is underway
  - Improve total transmission from source to target
  - Improve high intensity operation (better handle space charge)

ATLAS Efficiency and Intensity Upgrade

- New 60.625 MHz CW RFQ, ARRA
- New cryomodule and LHe distribution system upgrade, ARRA
- EBIS Charge Breeder (AIP) - off-line constr. & testing
- ATLAS Utilities Upgrade (AIP, ARRA, ALD)
- Goals
  - Improved total transmission
  - Handle very high stable-beam currents

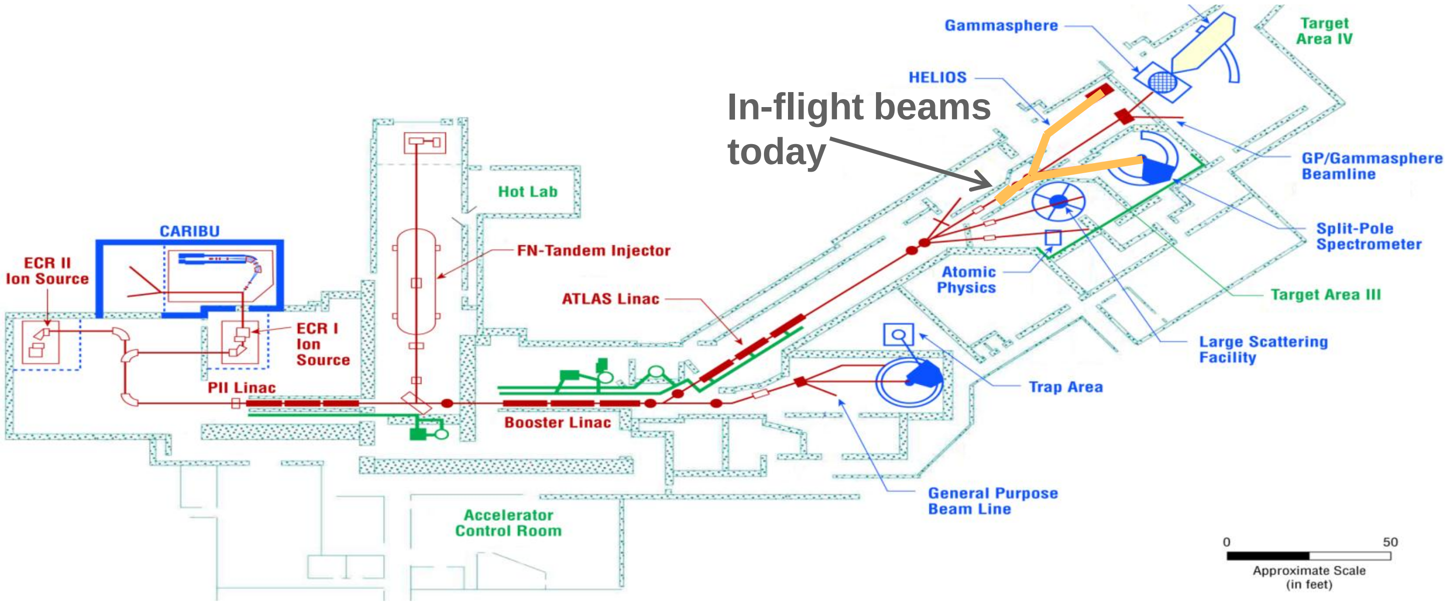


ATLAS Radioactive Beam Program

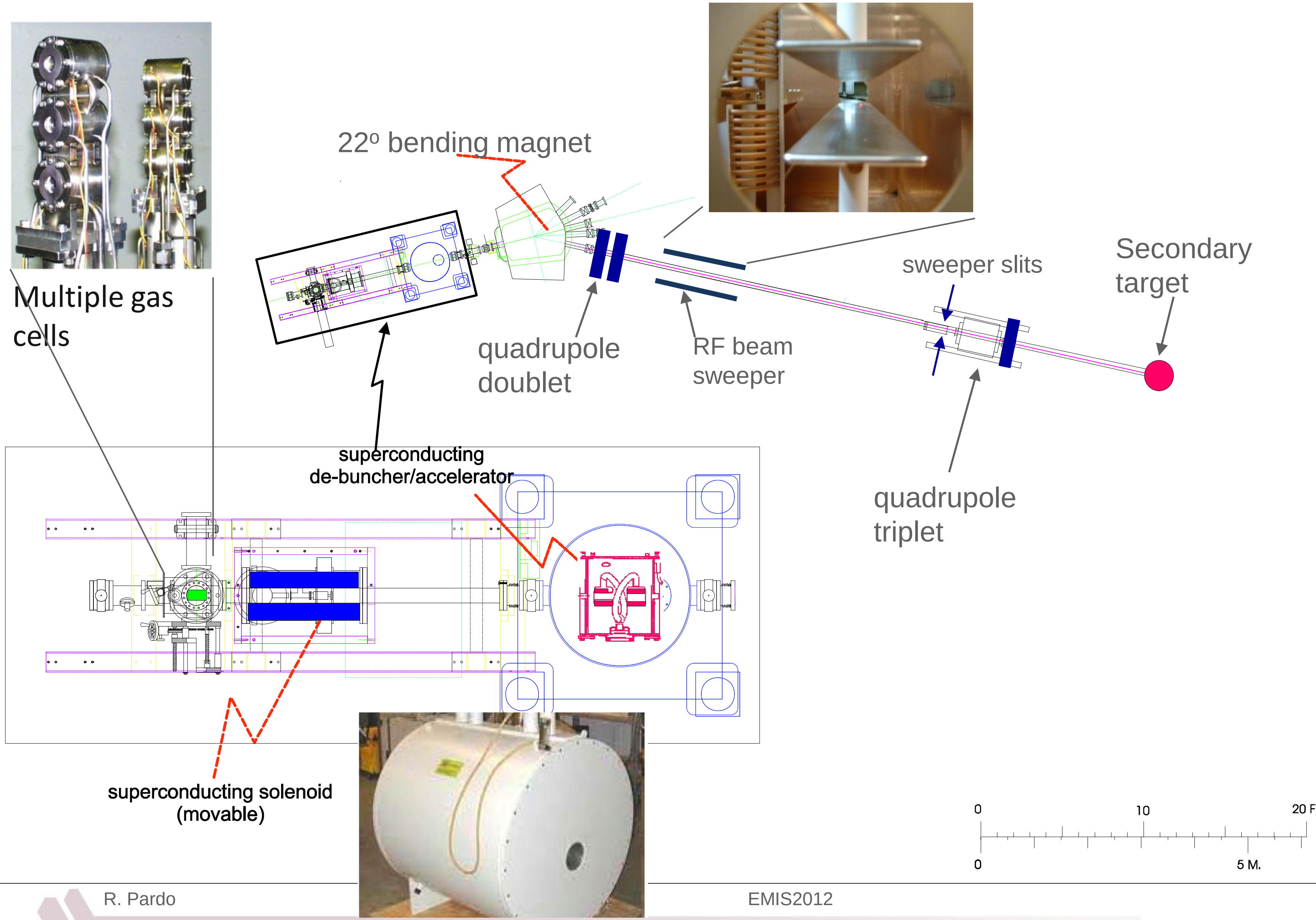
- First radioactive beams from ATLAS developed and used in 1994
- Two approaches developed in the 90s
  1. 'Two-Accelerator' Technique
     - Long-lived activity produced elsewhere
     - Material prepared for ion-source and acceleration
     - ^{18}F, ^{44}Ti, ^{56}Ni & ^{56}Co
     - Limited applications
  2. ATLAS In-Flight Beams
     - Existing Program
     - Proposed facility upgrade: AIRIS
  3. CARIBU
     - Overview
     - Results with the CARIBU program
     - Beginning research program

ATLAS Radioactive Beam Program:

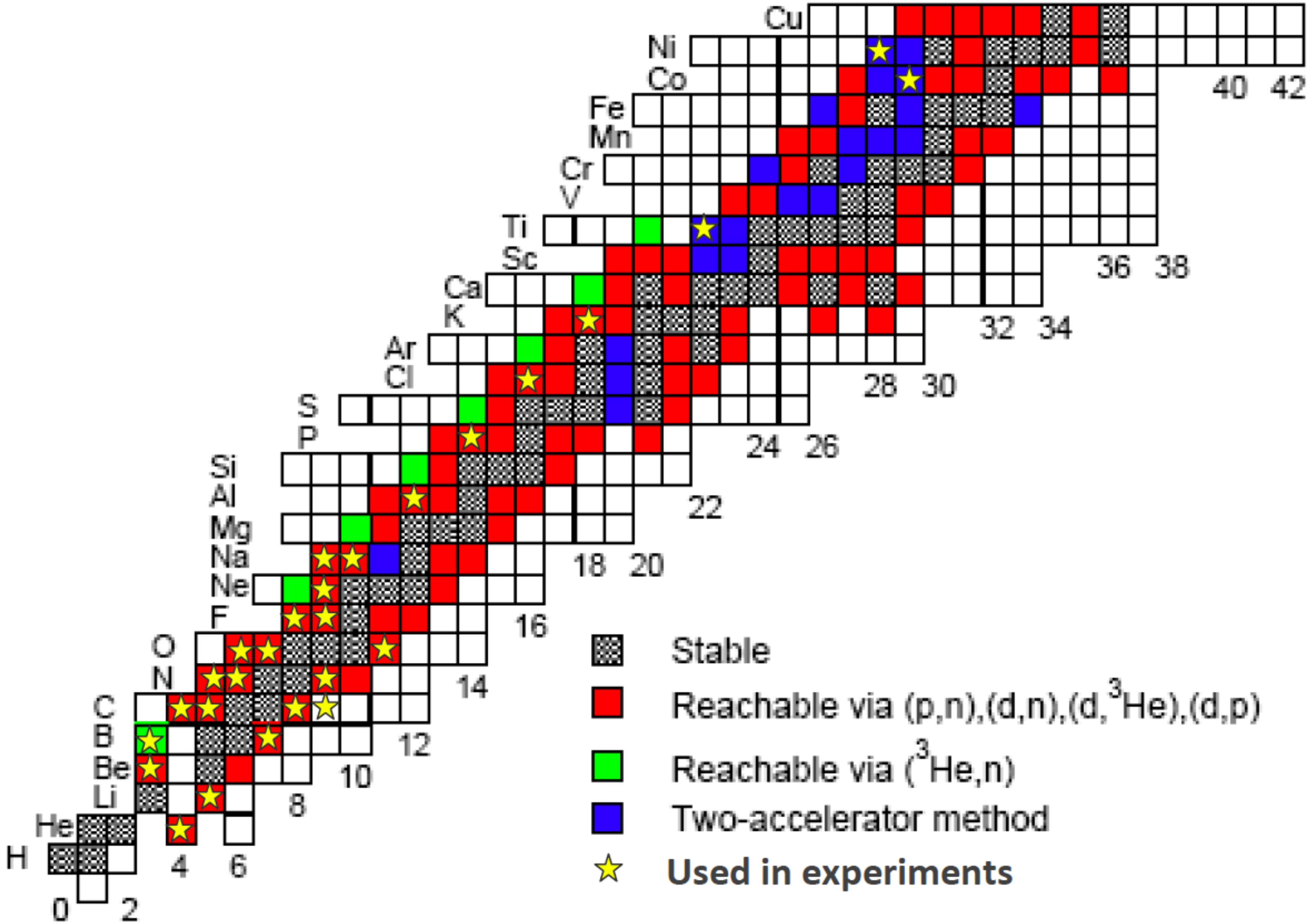
- In-Flight Production Program
  - Production of ^{17}F first demonstrated in 1989
    - $d(^{16}O, ^{17}F)n$ and $p(^{17}O, ^{17}F)n$
  - Present geometry began operation in 1997
  - RF Sweeper on one beamline added in 2008
- Produced by 0, 1, 2 nucleon transfer
- Low efficiency: 1-10%



In-Flight Secondary Beamline to Area III Spectrograph



In-flight RIBs at ATLAS (1998 to the present)

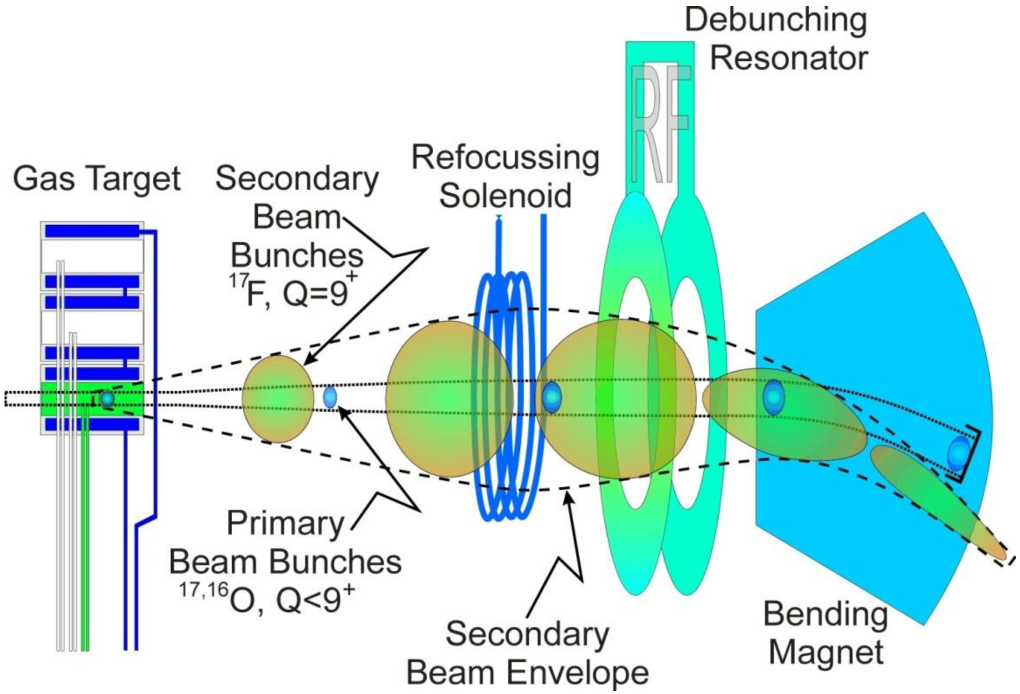


In-Flight Secondary Production and Purification System

Over 25 RIB isotopes used in experiments

Approximately 14% of all beam time in past decade.

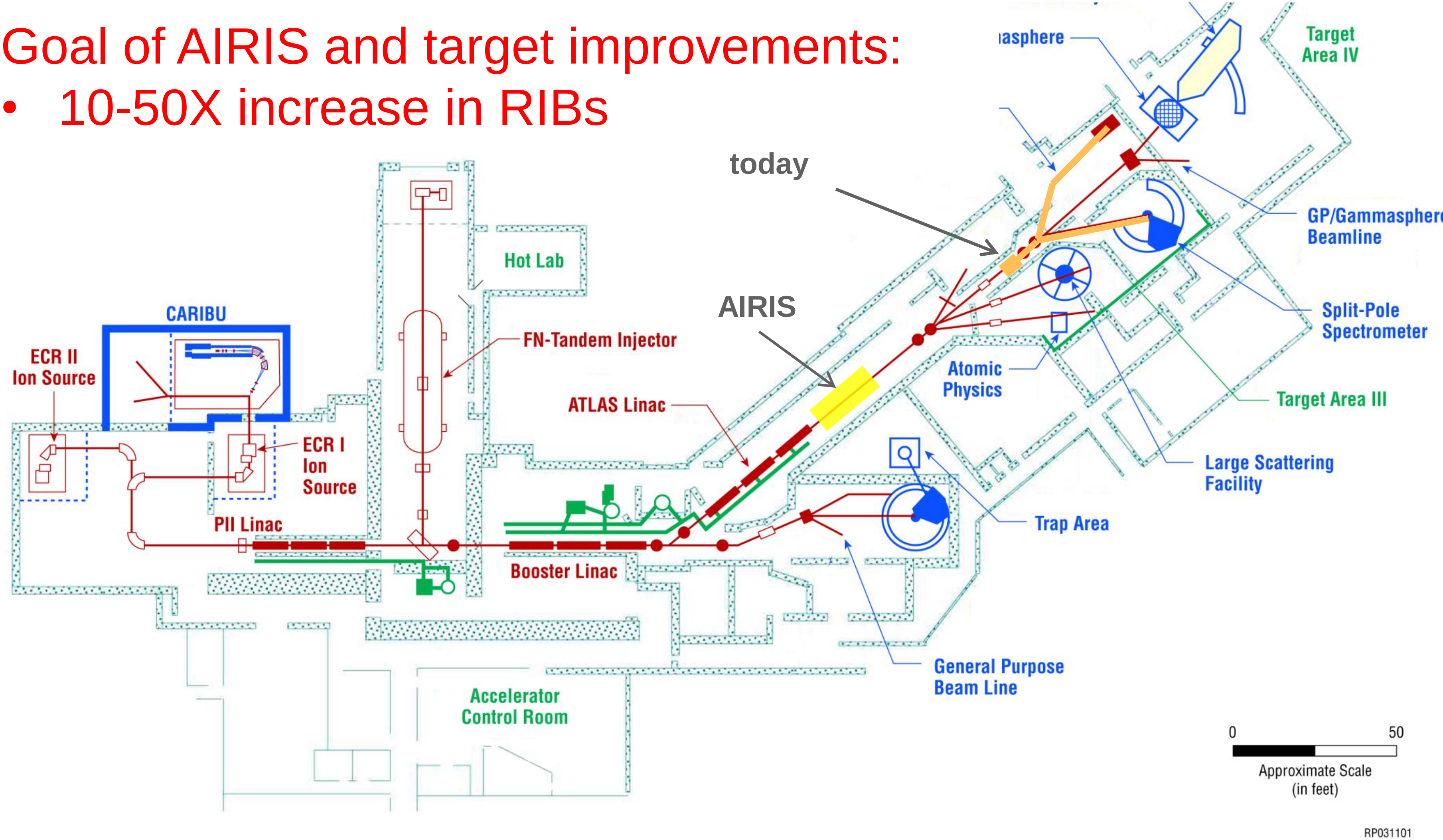
Ion	Reaction	Intens. #/s/pnA	Open Angle	Prod. Energy	Max. Rate , #/s
^{6}He	$d(^{7}Li,^{6}He)^{3}He$	150	19°	75 (MeV)	1×10^{4}
^{8}Li	$d(^{7}Li,^{8}Li)p$	2000	11°	71	1.5×10^{5}
^{8}B	$^{3}He(^{6}Li,^{8}B)n$	10	13°	27	few
^{10}C	$p(^{10}B,^{10}C)n$	543	4.5°	120	$5x10^{4}$
^{11}C	$p(^{11}B,^{11}C)n$	2300	4.5°	105	2×10^{5}
^{12}B	$d(^{11}B,^{12}B)p$	~2500	7.4°	110	
^{13}B	d(14C,13B)3He	1200	7.4°	240	1×10^{5}
	$^{9}Be(^{14}C, ^{13}B)^{10}B$	1200	40°	240	1×10^{5}
^{12}N	$^{3}He(^{10}B,^{12}N)n$	<25	9.5°	73/100	
^{14}O	$p(^{14}N,^{14}O)n$	1200	2.9°	170	1×10^{5}
^{15}C	$d(^{14}C,^{15}C)p$	24000	5.4°	96	$1\text{-}2x10^{6}$
^{16}N	$d(^{15}N,^{16}N)p$	30000	5.4°	70	3×10^{6}
^{17}F	$d(^{16}O,^{17}F)n$ $p(^{17}O,^{17}F)n$	20000 20000	4.5° 1.7°	~90	2×10^{6}
^{19}O	$d(^{18}O,^{19}O)p$	10000	4.7°	145	$2x10^{5}$
^{20}Na	$^{3}He(^{19}F,^{20}Na)2n$	~1		148	
^{21}Na	$d(^{20}Ne,^{21}Na)n$ $p(^{21}Ne,^{21}Na)n$	4000 8000	4.0° 2.6°	113 113	2×10^{6}
^{25}Al	$d(^{24}Mg,^{25}Al)n$ p(25Mg,25Al)n	1000 2000	3.7° 2.2°	204 180	
^{27}Si	$p(^{27}Al,^{27}Si)n$	4000	1.4°	270	$2x10^{5}$
^{31}S	$p(^{31}P,^{31}S)n$	1000	1.1	340	Test only
^{37}K	$d(^{36}Ar,^{37}K)n$	1200	2.2°	280	5×10^{4}



Present ATLAS In-Flight Facility and Proposed Upgrade: The Argonne In-flight Radioactive Ion Separator (AIRIS)

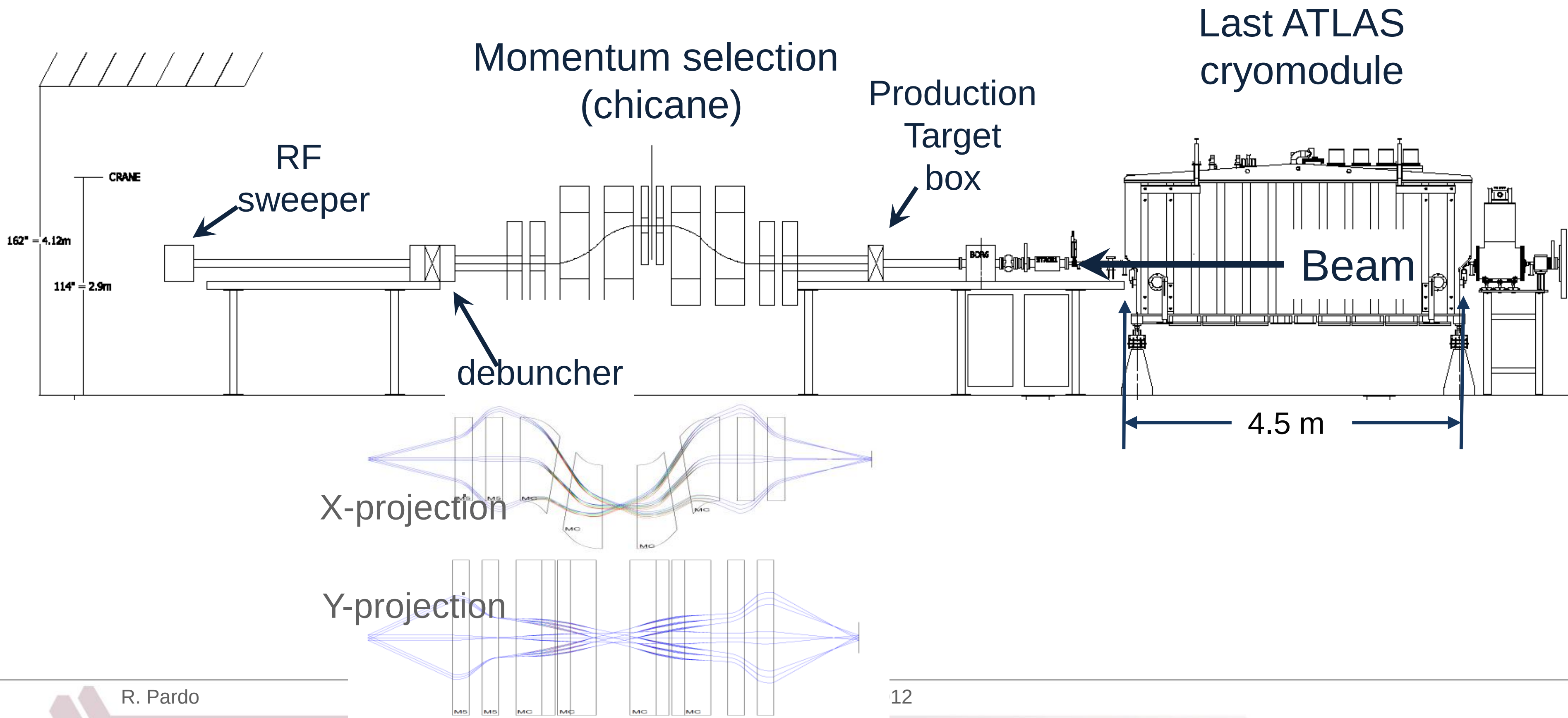
Goal of AIRIS and target improvements:

- 10-50X increase in RIBs



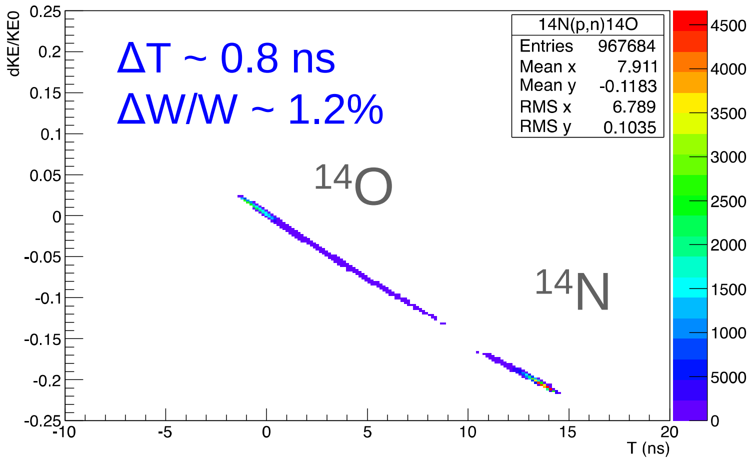
AIRIS – conceptual layout

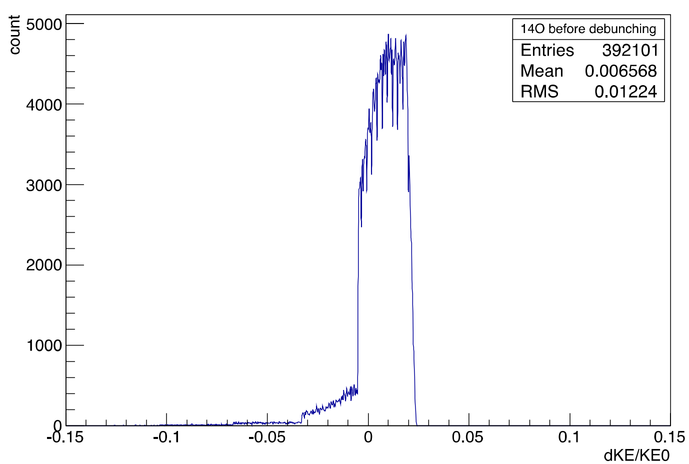
- Four dipoles , four multipole elements
- Expected transmission efficiency: 65-75% (compared to 2-4% today)
- Position of Debuncher and Sweeper not yet optimized
- Simulations with COSY using LISE++ and TRIM outputs



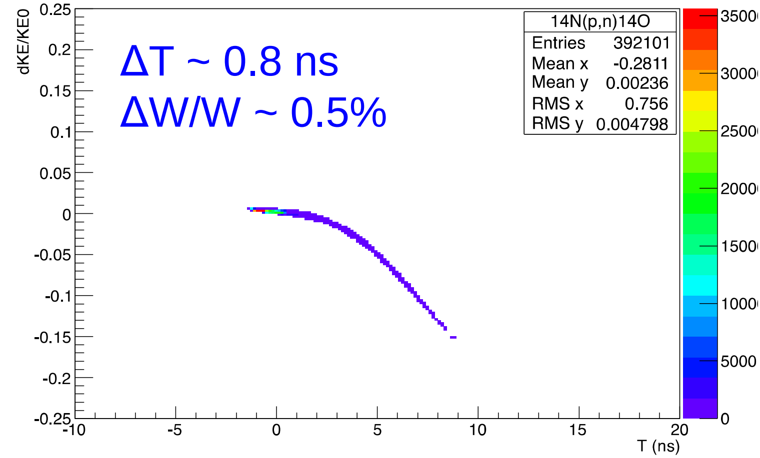
Example results of case: $^{14}N(p,n)^{14}O$ @140 MeV debuncher & sweeper effect

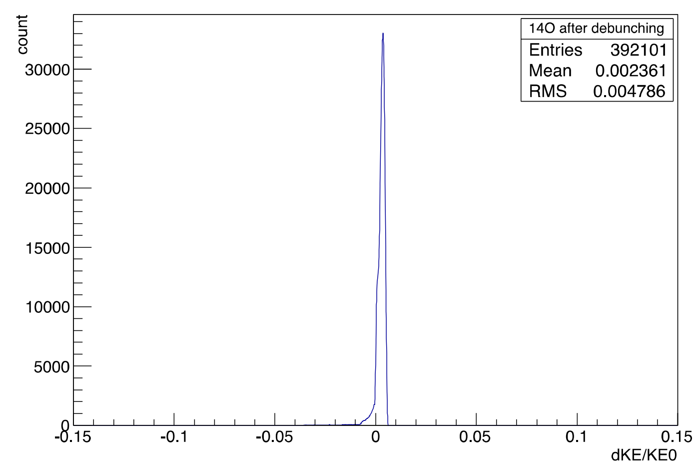
Before debuncher and sweeper





After debuncher and sweeper





AIRIS Summary

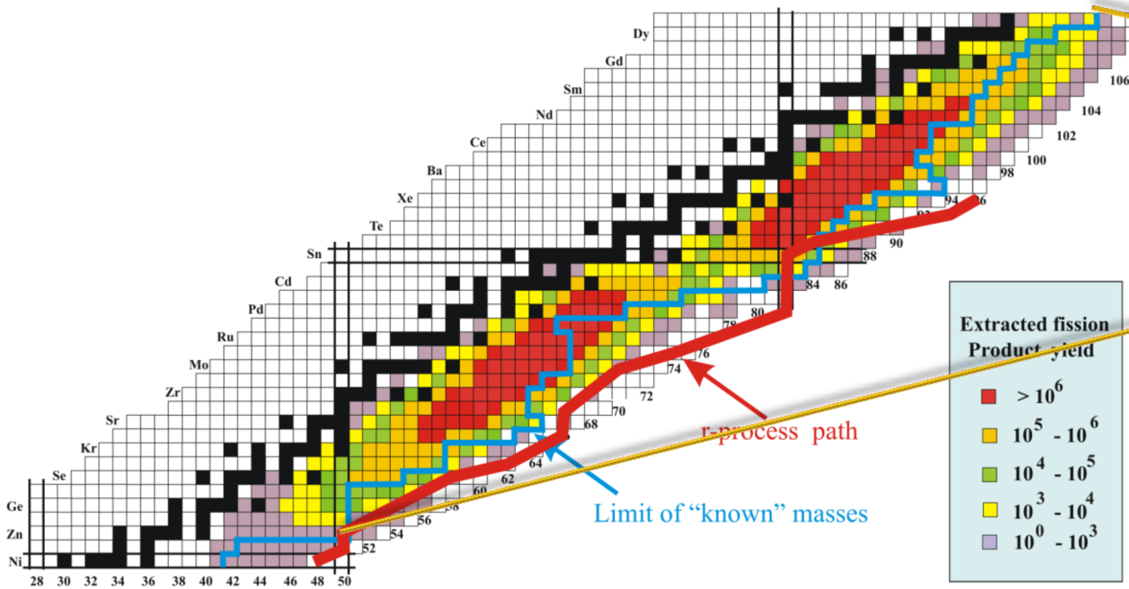
- Design work continues
  - Beamline design to target stations now underway.
  - Study additional reaction cases
  - Optimize scale and higher order corrections
- Expect a factor of 10-30 X improvement in beam currents
  - For same primary beam
  - RIB collection efficiency is 65-80%
- Total cost estimate (including beamline changes) ~$5.5 M
- Earliest possible installation time: FY 2017
  - Actual timescale depends on funding

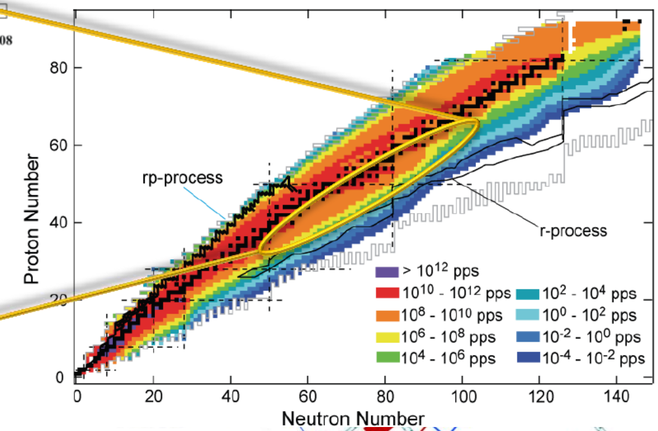
CARIBU: The Californium Rare Ion Breeder Upgrade For ATLAS

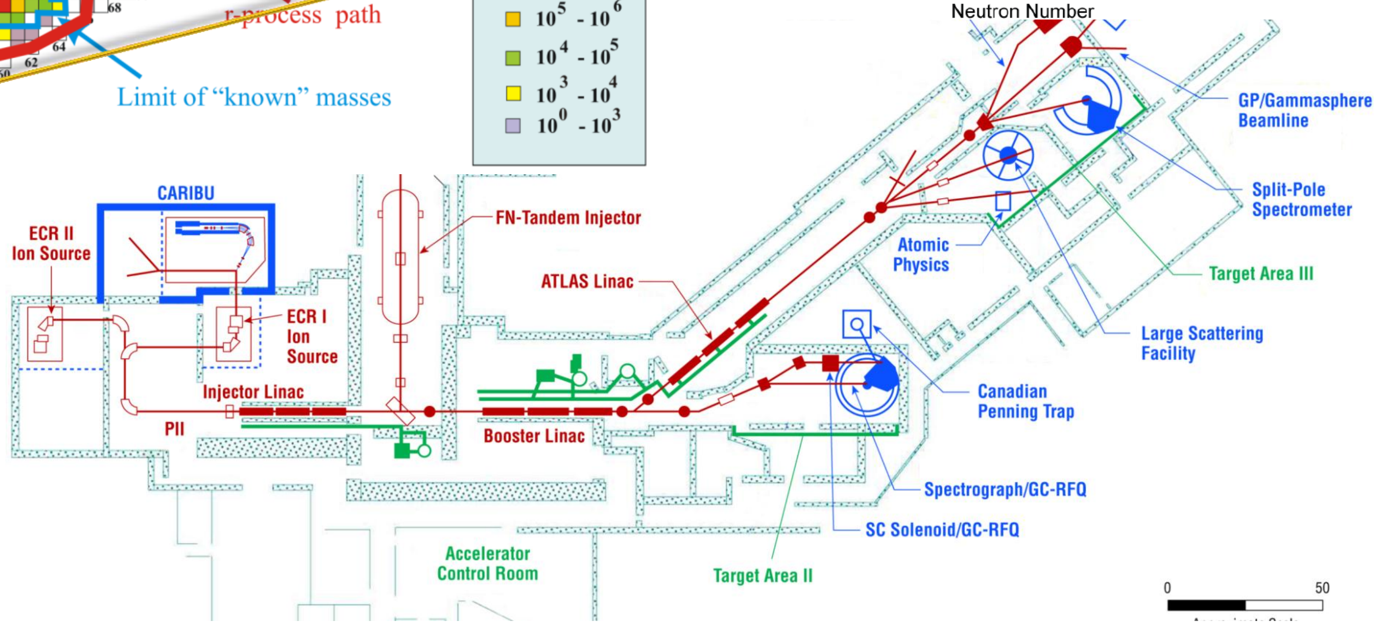
- I Ci ^{252}Cf fission source
- Fission products thermalized in high purity helium gas catcher system
- Mass analyzed to select species of interest (1:20,000)
- Beam provided to either:
  - Stopped beam research facility
    - Penning trap mass measurement
    - X-array and tape station for beta studies
  - Delivered to ATLAS experimental facility with similar properties to stable beams
    - Except intensity and background
    - Accelerated to as high as 15 MeV/u
    - Charge bred in ECR Ion Source (later EBIS)

CARIBU: The Californium Rare Ion Breeder Upgrade

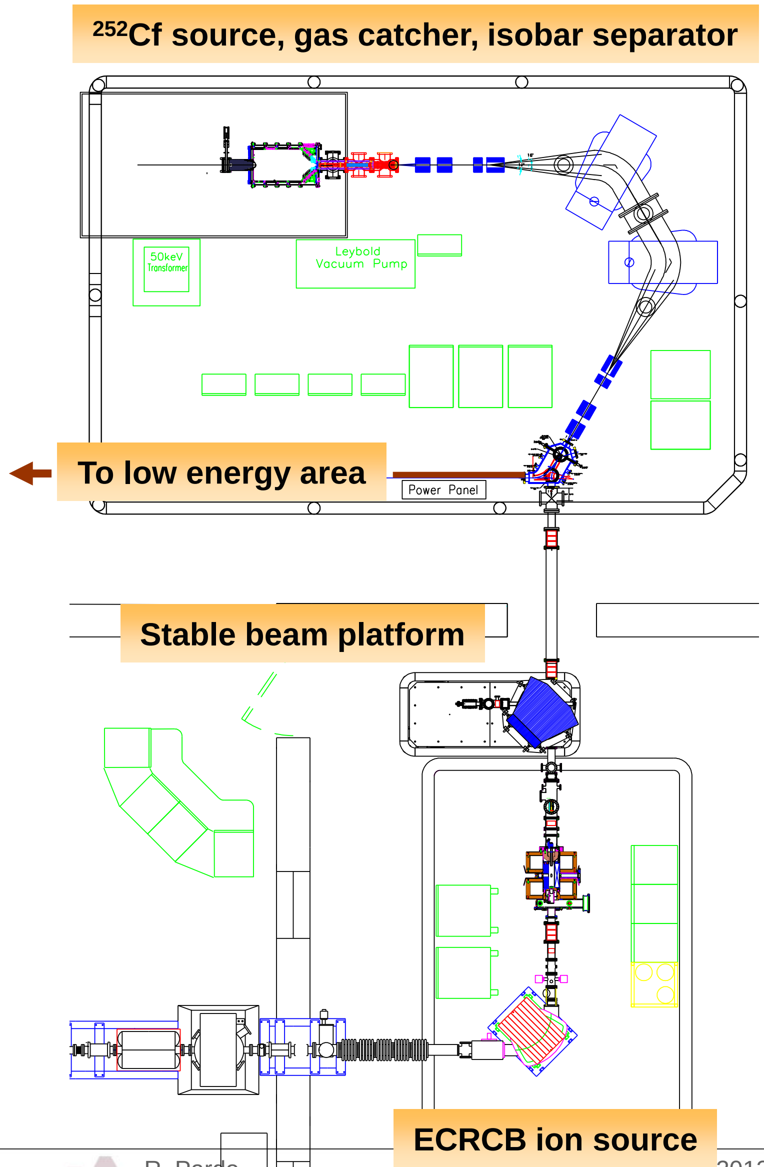
- $T_{1/2}$=2.6 a 3.1% fission branch
- ^{252}Cf fission yield is complimentary to uranium fission

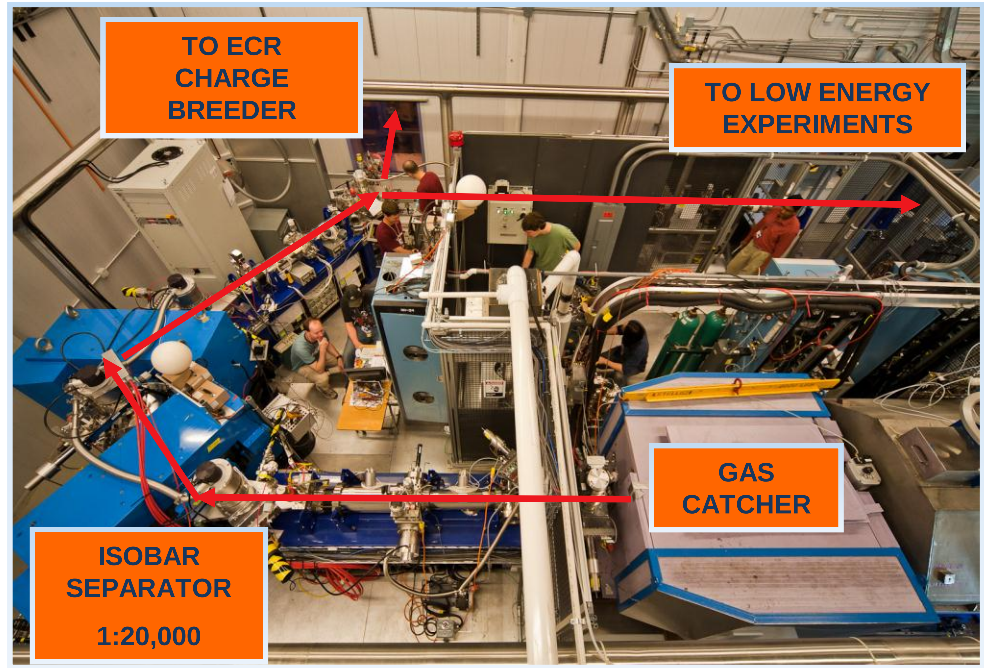


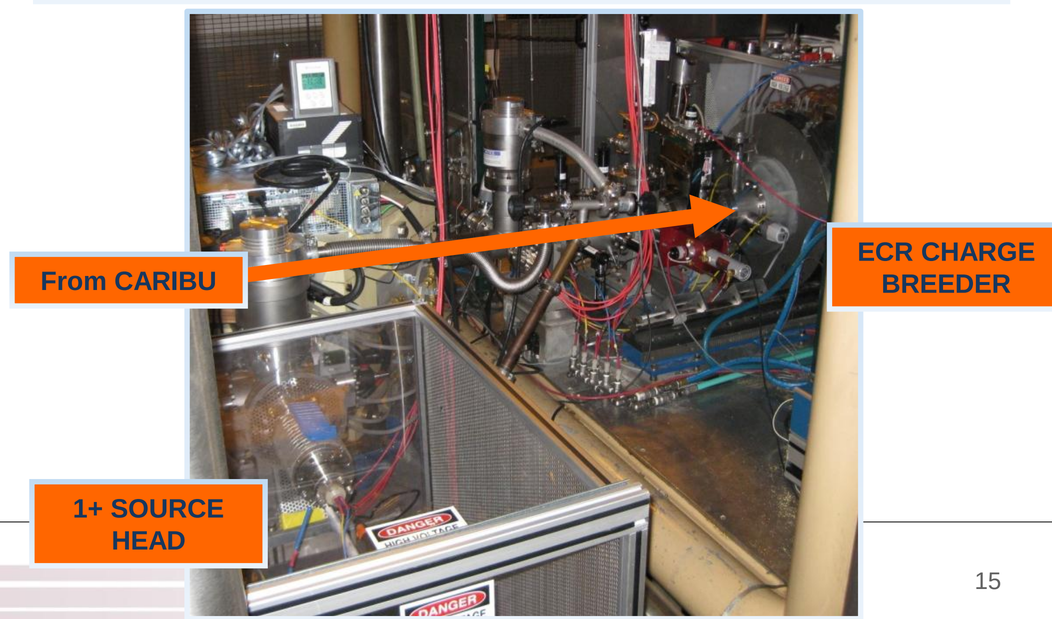




CARIBU - Californium Rare Ion Breeder Upgrade

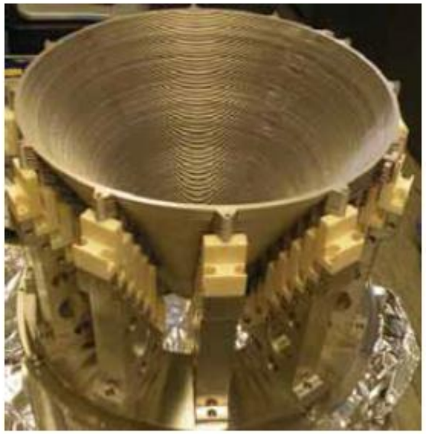


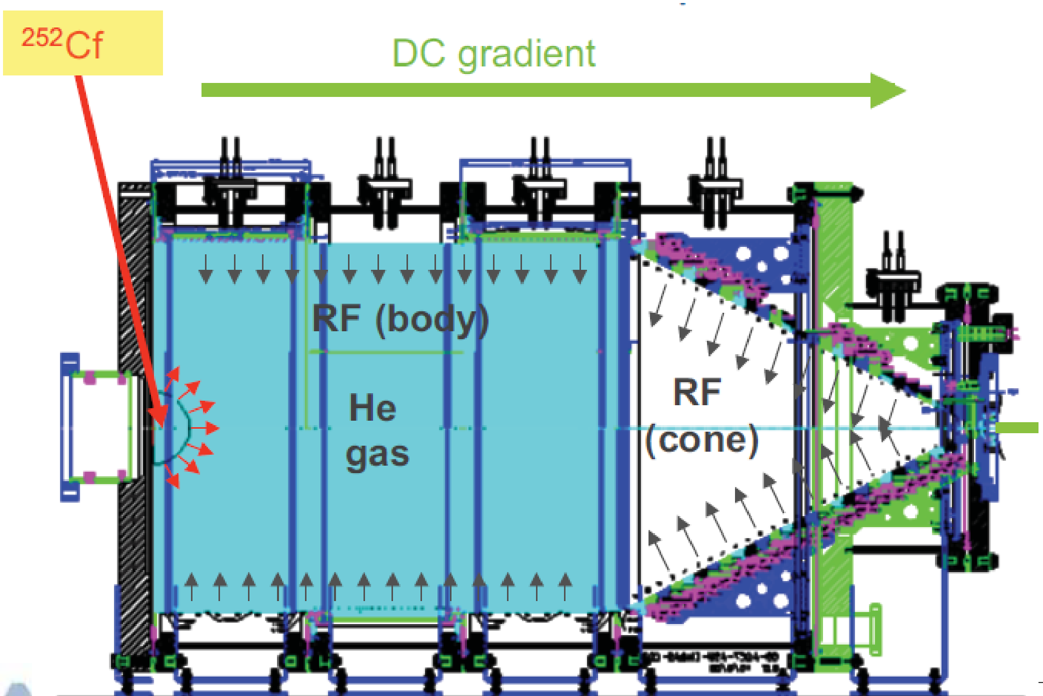




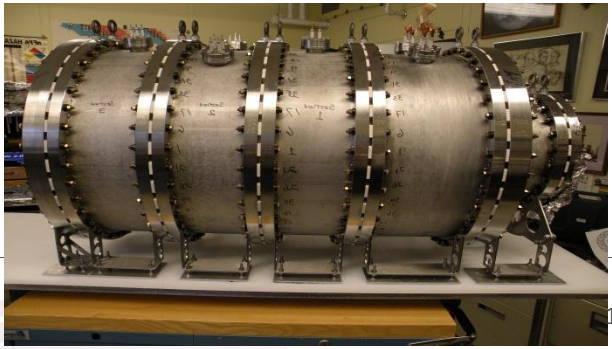
CARIBU gas catcher

- 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



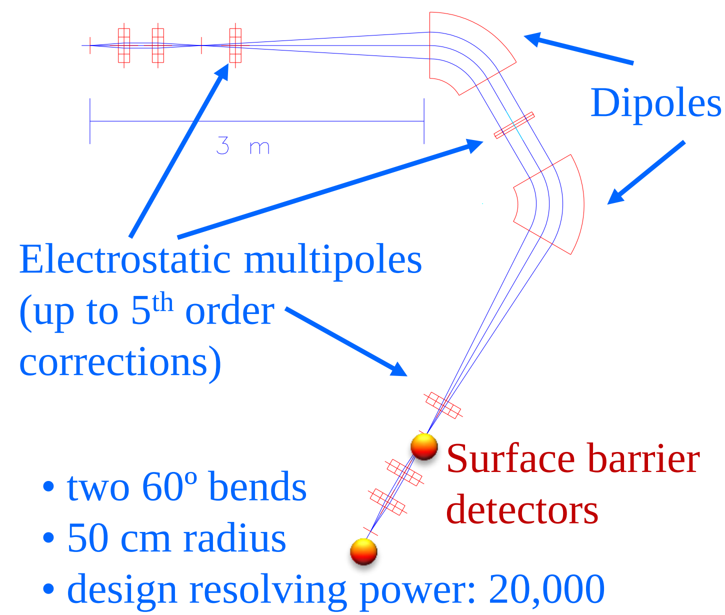


- Mean extraction time is <10 msec
- Overall efficiency of 20%
- Extraction is element independent
- Emittance: 3 π·mm·mrad
- Energy spread: ~1 eV

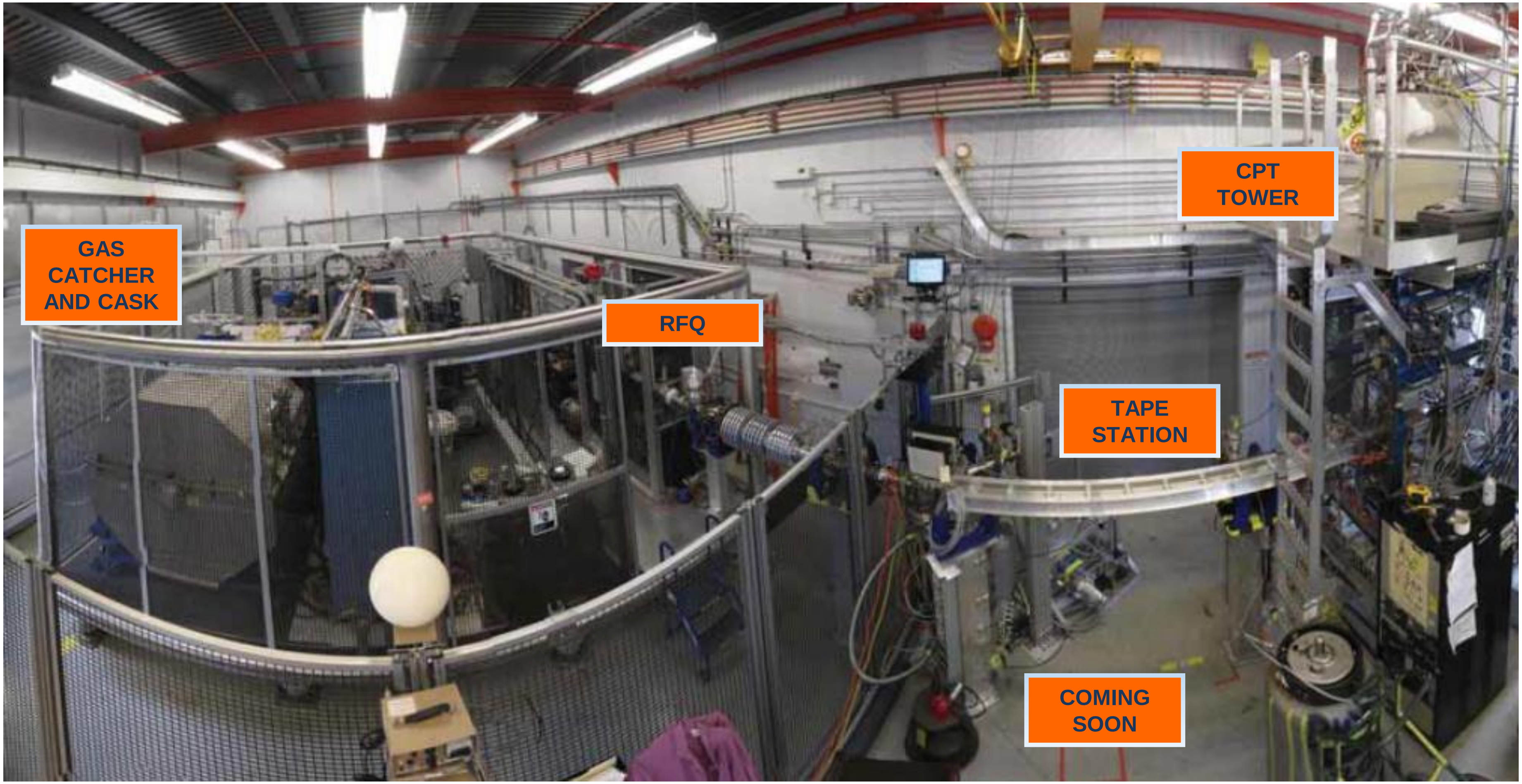


Purification of radioactive beam

- 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 1:8,000 more typical
- Takes advantage of low emittance and low 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



CARIBU in-room low-energy beamline

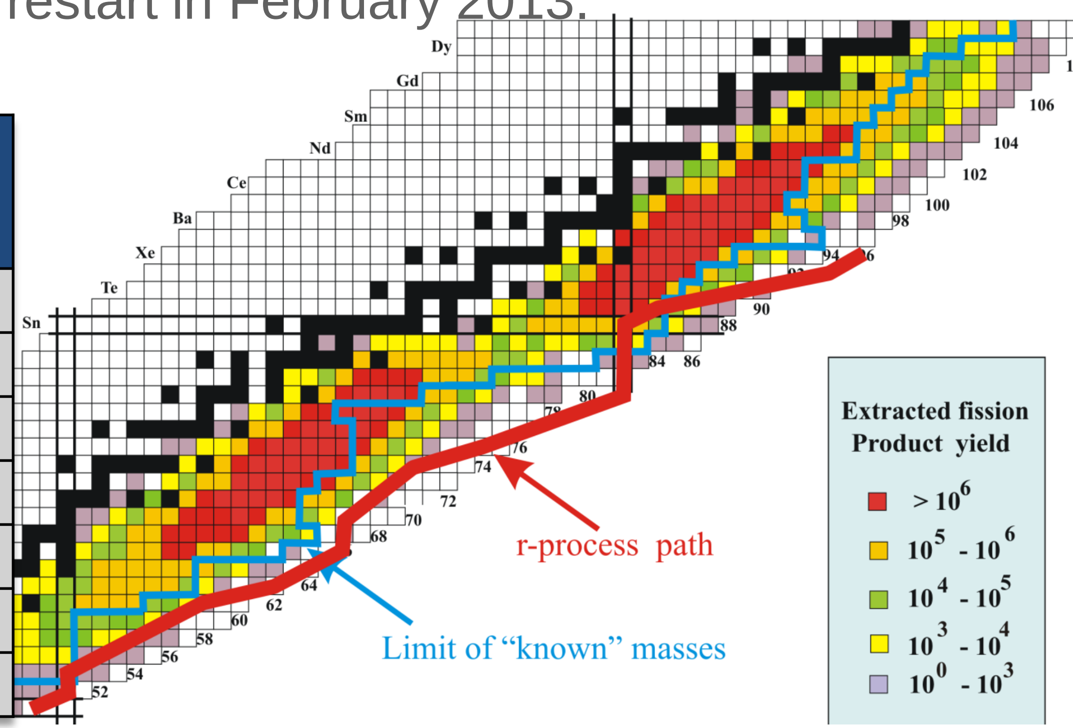


CARIBU expected beam yields with 1 Ci Source

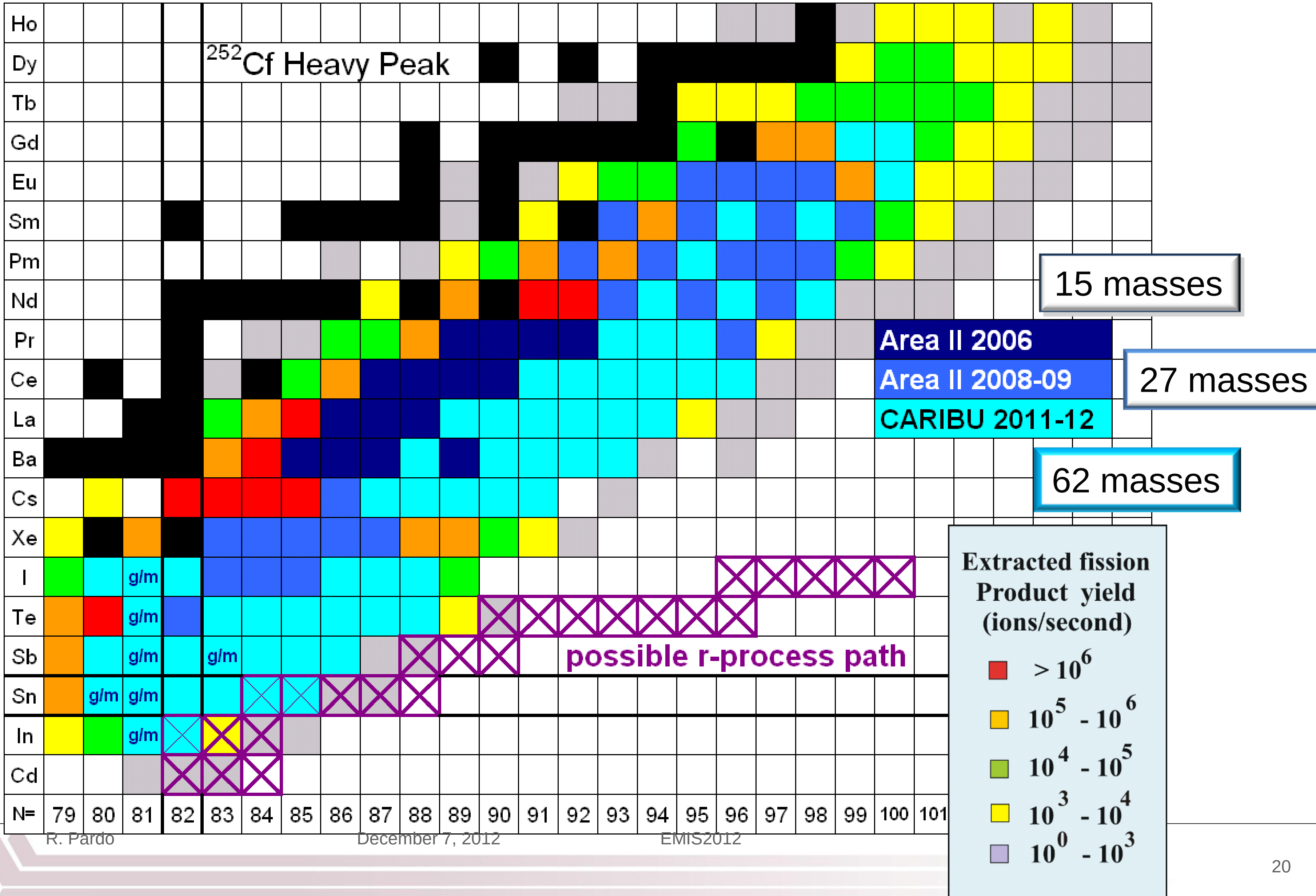
- 0.35 Ci source installed in CARIBU in September 2012
  - Not 1 Ci
  - Thicker than desired
- Stopped beam program has used CARIBU the most
- One accelerated beam run in late September 2012
  - COULEX of ^{141}Cs to 6 MeV/u
  - Maximum intensity: 10^4 /s at GAMMASPHERE
- Await completion of RFQ to restart in February 2013.

Optimum yields for 1 Ci source

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

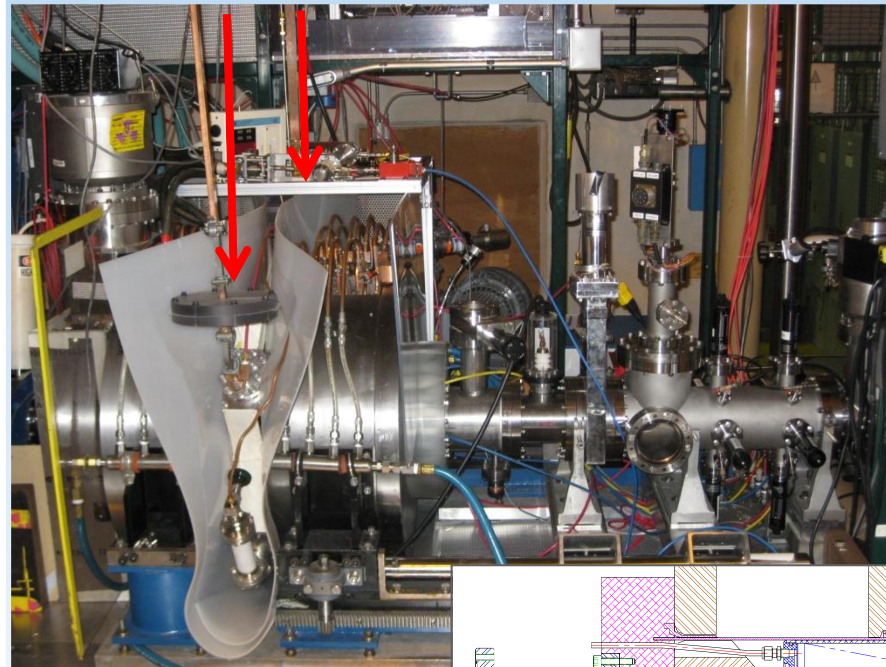


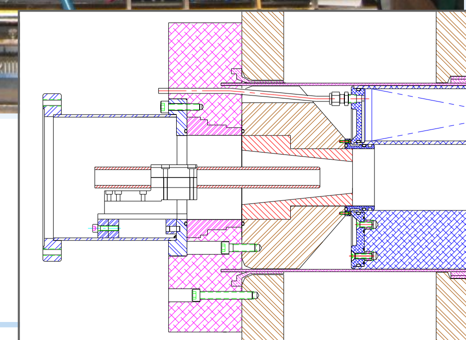
CPT measurement campaigns



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: $2x10^{-8}$ mbar
    - Operation: $7x10^{-8}$ mbar
    - Extraction pressure: $4x10^{-8}$ mbar
- Movable grounded tube
  - 2.5 cm of travel
- 50 kV high voltage isolation
  - Now operates routinely at 35 kV

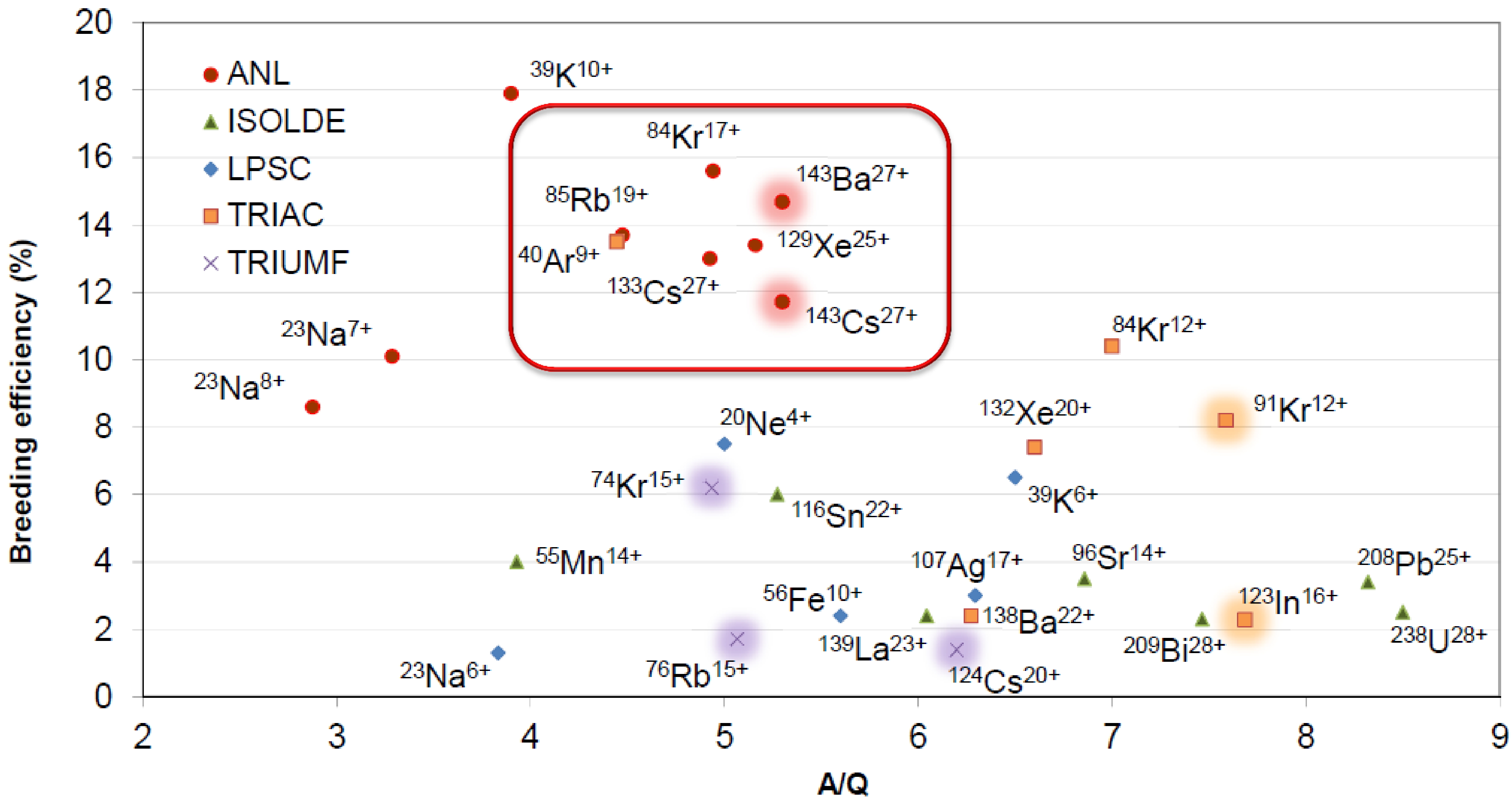




	Design value	Running condition
B_{inj}	1.31 T	1.16 T
B_{min}	0.31	0.27
B_{ext}	0.85	0.83
$B_{(radial)}$		0.86 T
Last closed surface		0.61 T

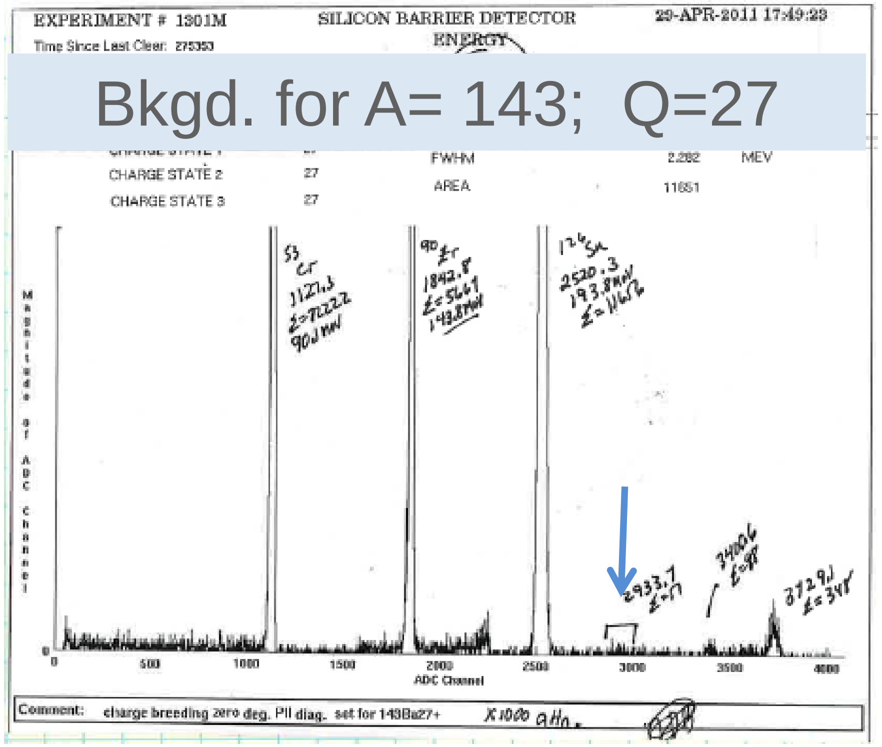
CARIBU ECRCB performance leads world

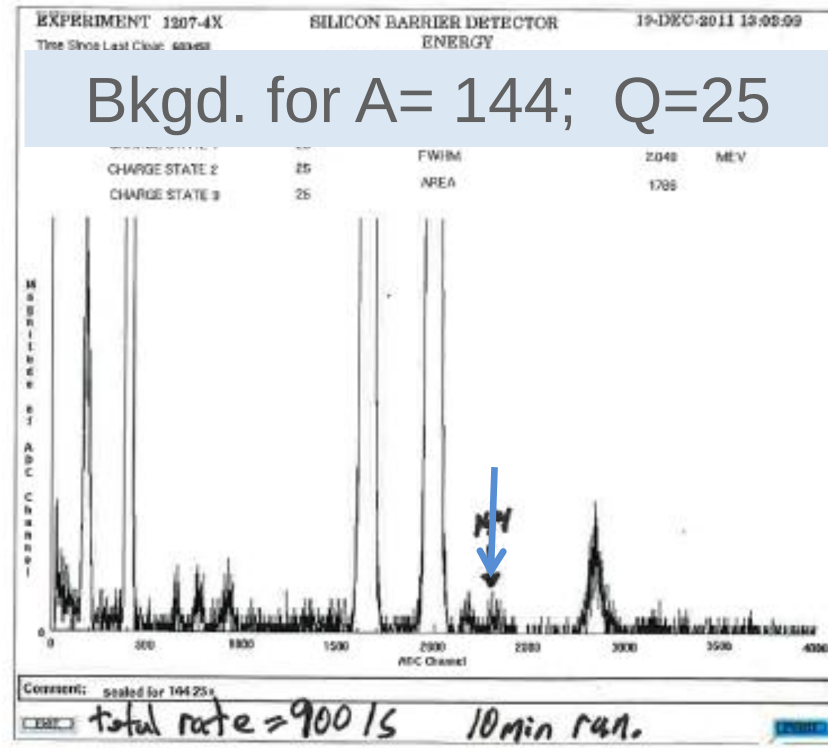
- Original CARIBU goals were 5% for solids, 10% for gases
- Now achieve >10% for all species (RIBs and stable, solids and gases)



ECRCB Beam contaminants are significant

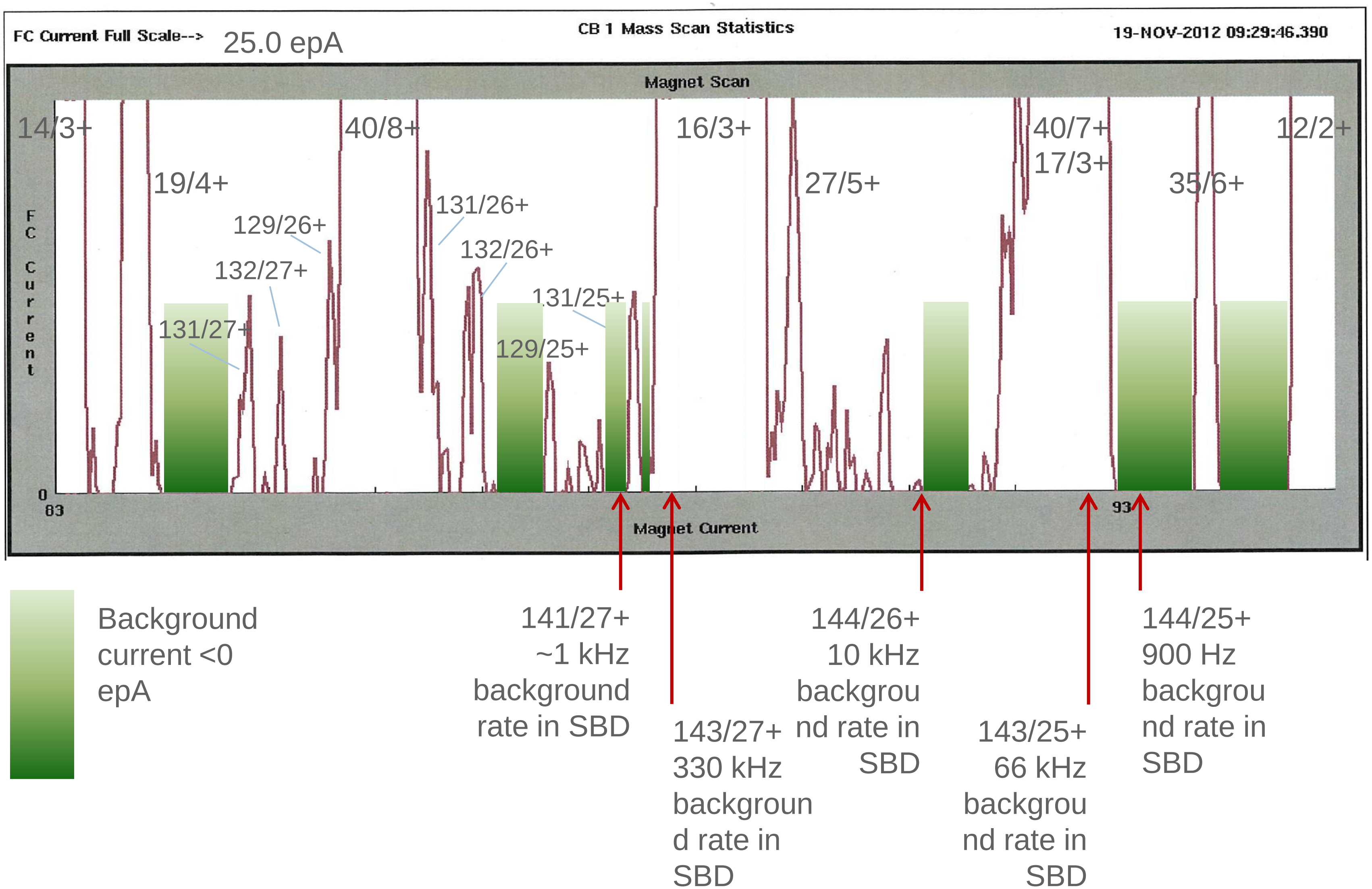
- The ECRCB has a large amount of background which has to be reduced
- Proper choice of Q can yield a relatively clean spectrum





- 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

ECRCB Beam Cleaner regions



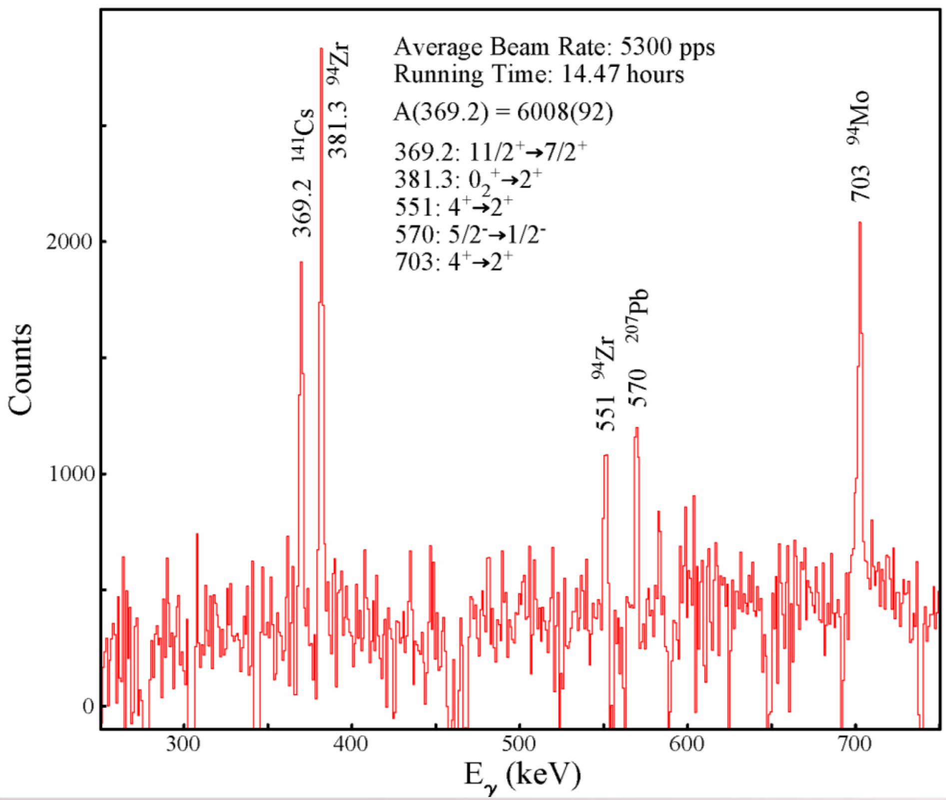
Background current <0 epA

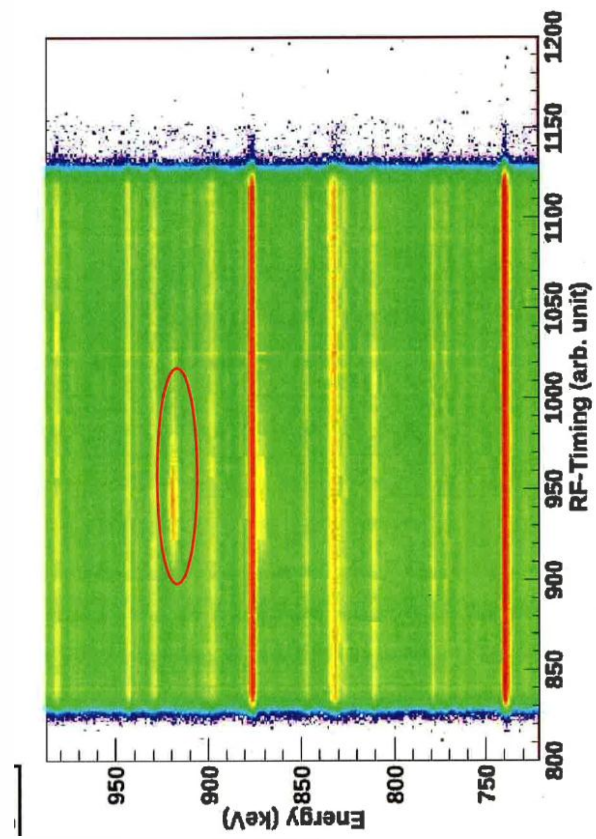
First Coulomb excitation with CARIBU beams

Formal project commissioning goal achieved in May 2011 with 50 mCi source.

First accelerated beam experiment occurred in September 2012 with 350 mCi source.

- ^{141}Cs at 846 and 601 MeV on thick target into Gammasphere with 10^4 /s.
    - Experiment performed 2 weeks after new source (350 mCi) installation
    - Coulomb excitation line at 369.2 keV along with other gamma rays
    - (m/q) degenerate stable beams of ^{94}Zr and ^{94}Mo, ~5 x ^{141}Cs level





Next Steps for CARIBU

- Understand 350 mCi source thickness question
  - Electro-deposition is making too thick total target
- 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 (steering differences)
- Improve the beam purity from the ECRCB
  - Quartz liner test
  - Changed over to high purity aluminum components
  - Remove the grounded injection tube
  - Aluminum coat the iron plug
- Build an EBIS to replace the ECRCB
  - Under construction
  - First beam tests off-line summer(?) 2013