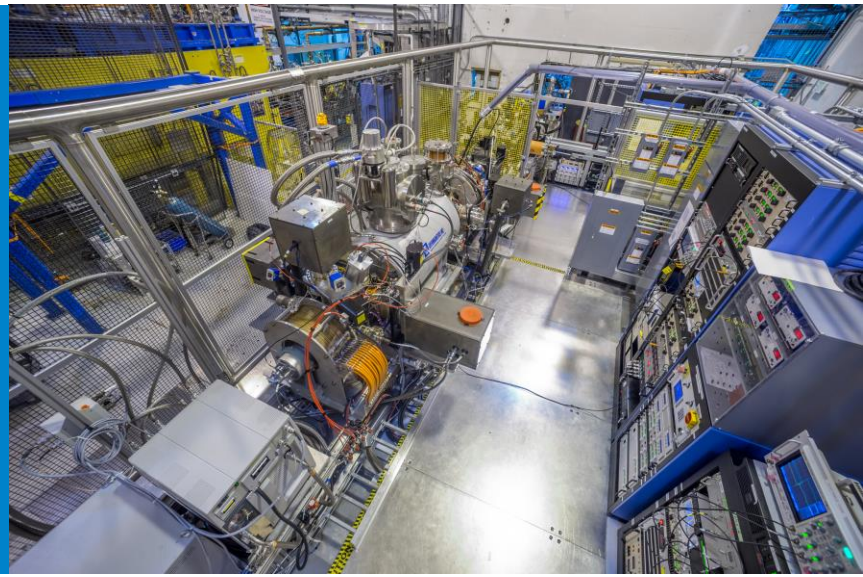
OCTOBER 17, 2017

Argonne NATIONAL LABORATORY

CHARGE BREEDING OF RADIOACTIVE ISOTOPES AT THE CARIBU FACILITY



RICHARD VONDRASEK
Physics Division

C. Dickerson, M. Hendricks, P. Ostroumov (Michigan State University), R. Pardo, G. Savard, R. Scott, G. Zinkann

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CHARGE BREEDING OF RADIOACTIVE ISOTOPES AT THE CARIBU FACILITY

- CARIBU - CALIFORNIUM RARE ION BREEDER UPGRADE
- EBIS CHARGE BREEDER
- EBIS PERFORMANCE
- FUTURE PLANS

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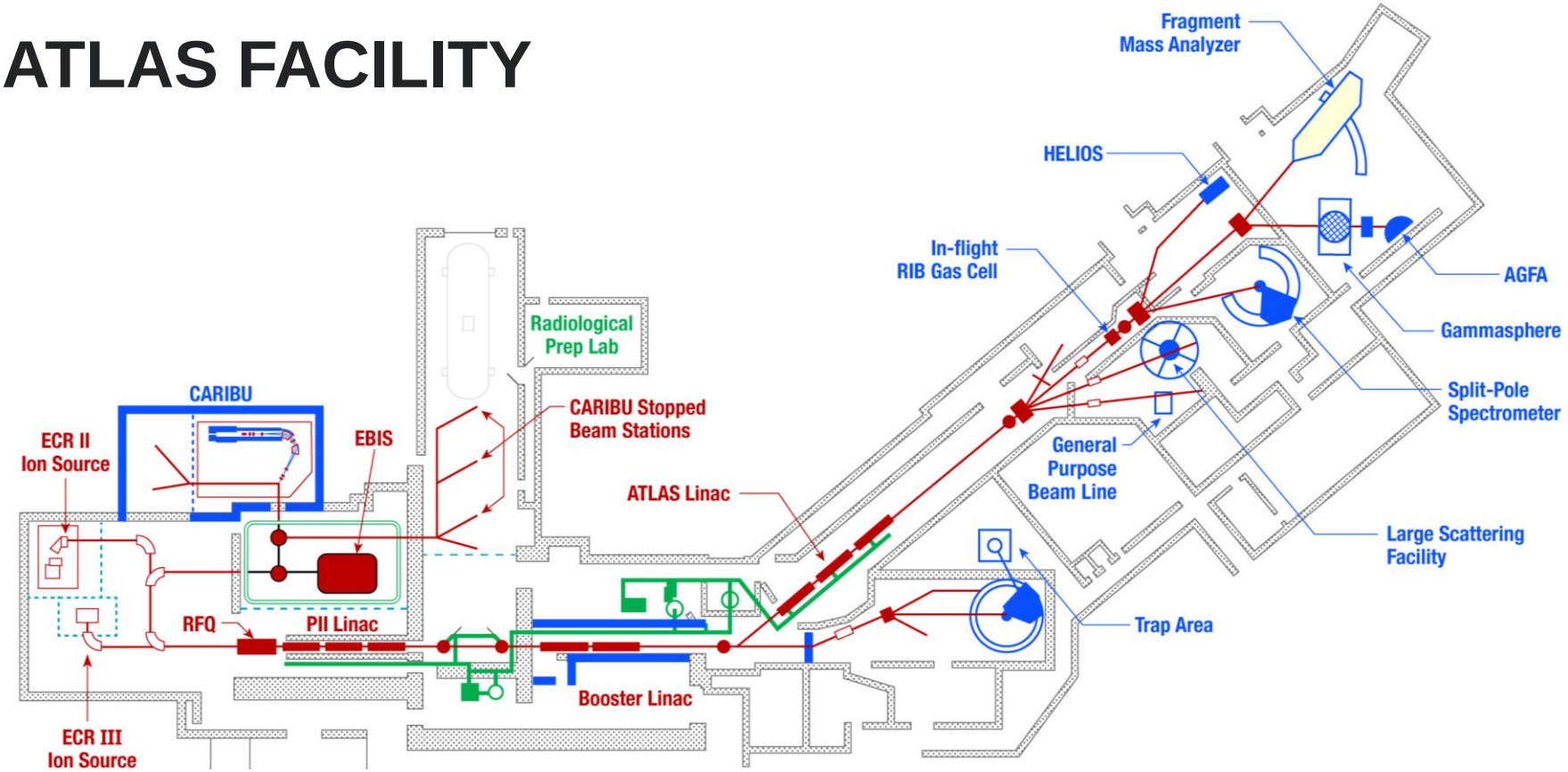
ATLAS FACILITY

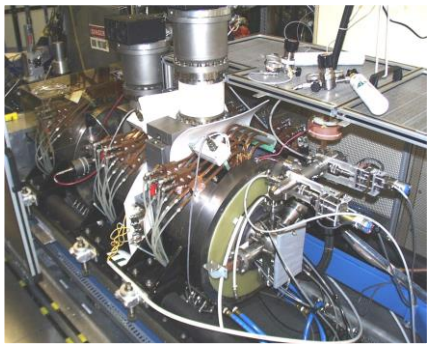


- ATLAS is a National User Facility delivering stable, low energy, ion beams with a focus on nuclear physics research
- ATLAS has a rich history of radioactive beam research
  - Irradiated source materials
  - In-flight beam production
  - CARIBU – reacceleration of Cf fission fragments

ATLAS FACILITY
Front End

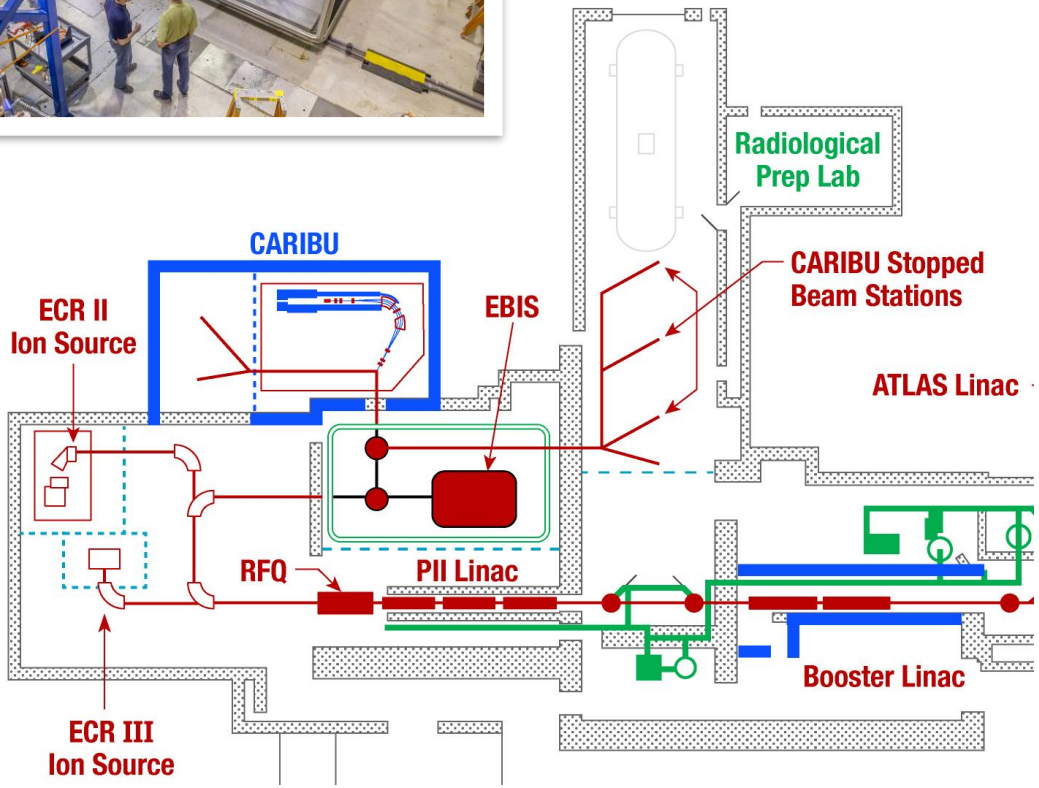
CARIBU

EBIS

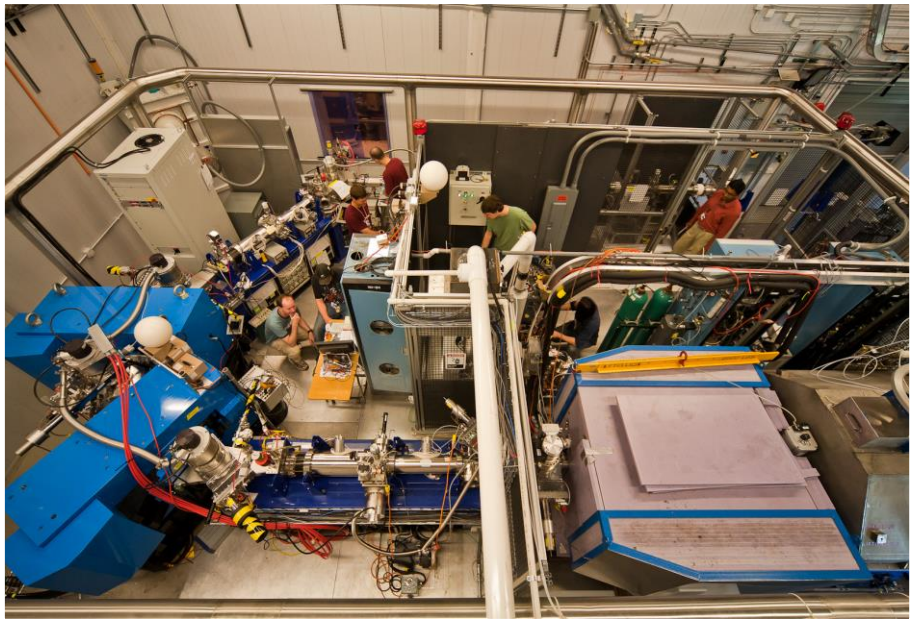


ECR2

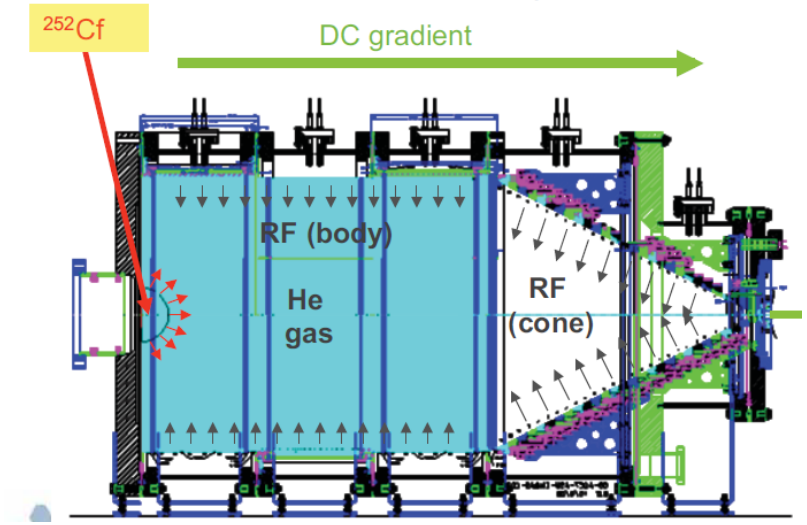
ECR3

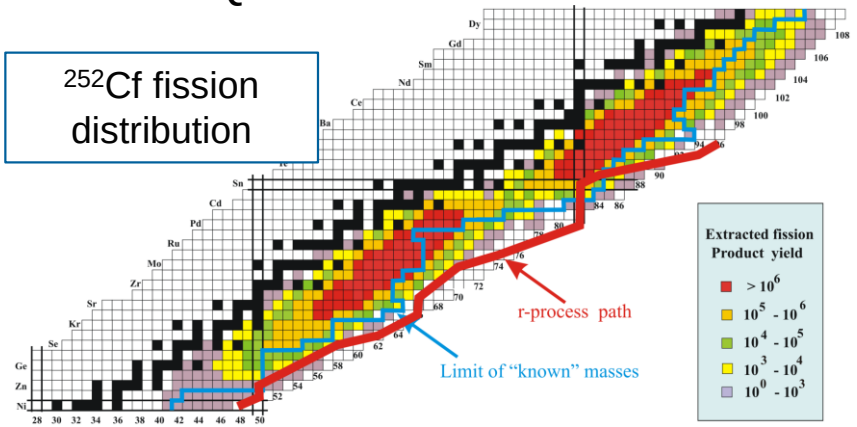


CAlifornium Rare Ion Breeder Upgrade (CARIBU)



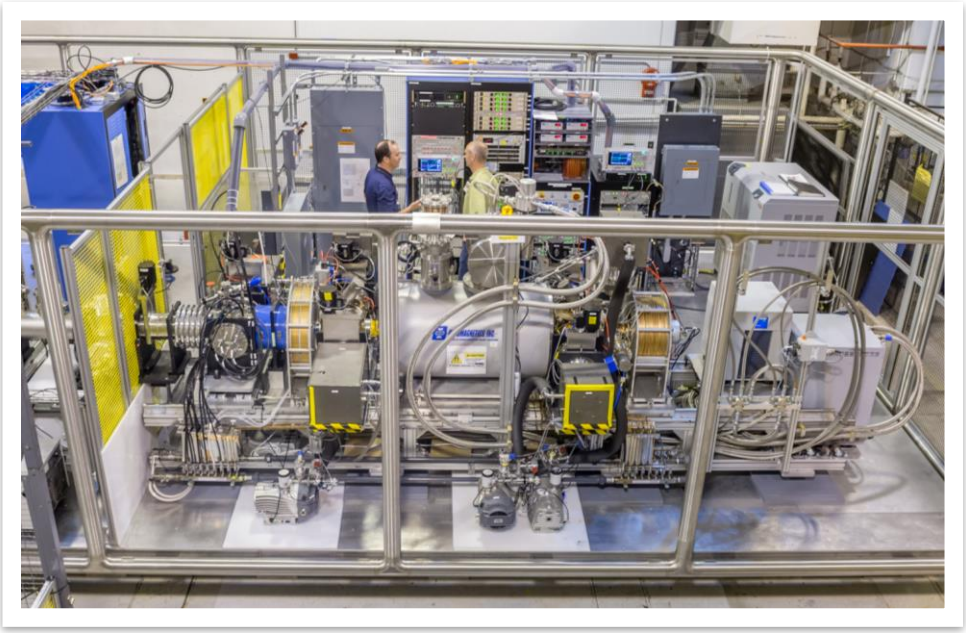
- ^{252}Cf fission source provides radioactive species
  - 1.7 Ci source
  - $T_{1/2}$=2.6 yrs
- Thermalized in a large volume helium gas catcher
  - 0.5 m diameter, 1.2 m length
- Energy spread - 1 eV
- Emittance - 3·π·mm·mrad
- Isobar separator - 1:20,000 design resolution
- RFQ cooler/buncher and MR-TOF





EBIS CHARGE BREEDER

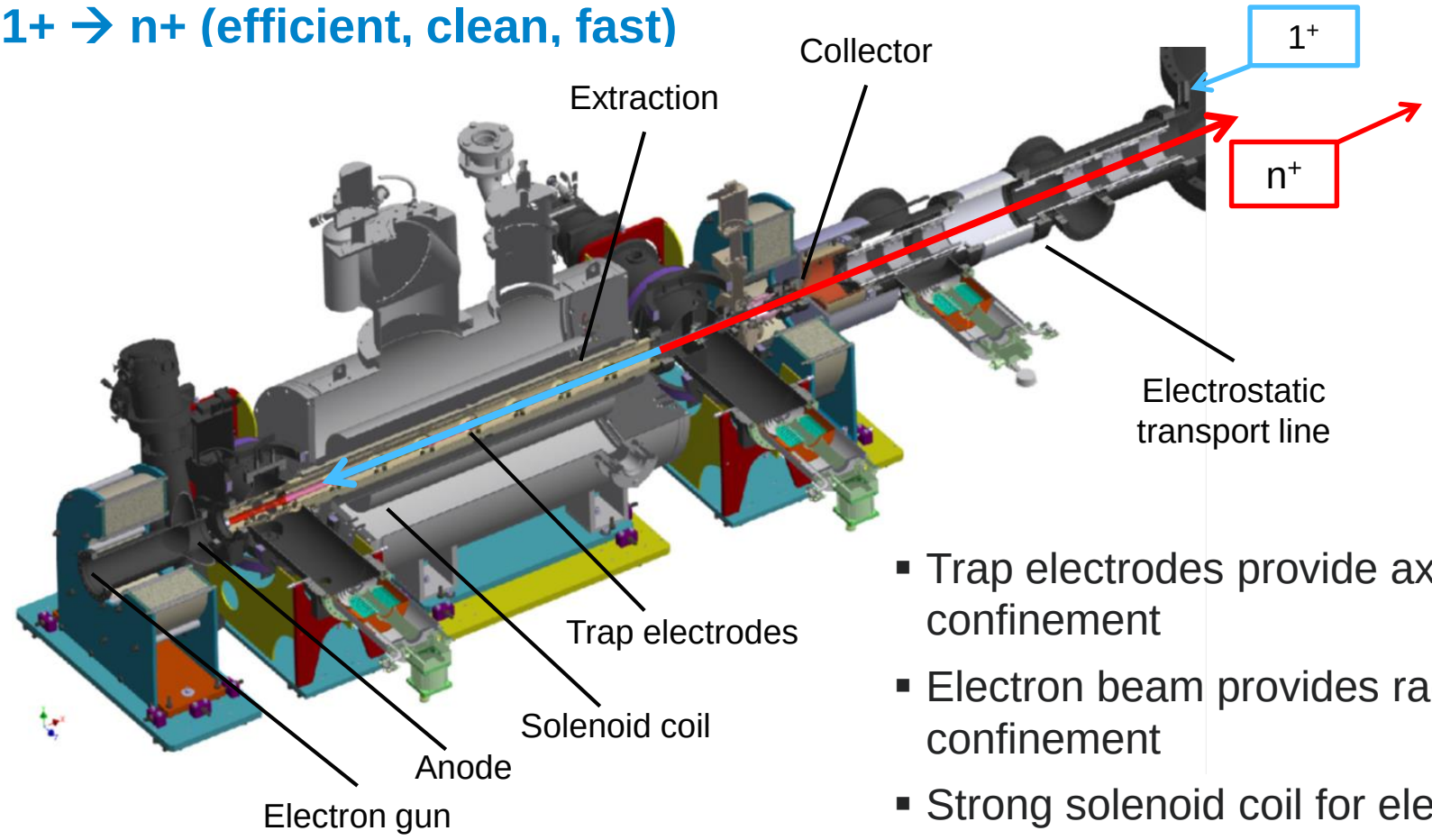
- Developed in collaboration with BNL and is based upon the TestEBIS design
- 2014-15 - Commissioned off-line
- October 2015 – Replaced the ECRCB at the ATLAS front end
- May 6, 2016 - First extracted beam (O-16)
- September 9, 2016 - First accelerated radioactive charge bred beam (Cs-142)

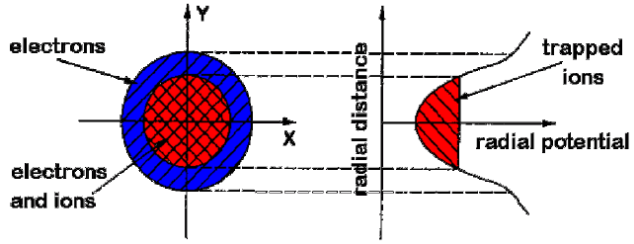


EBIS Operating Parameters	
Solenoid field	5.5 T
Magnetic field on cathode	0.15 T
IrCe cathode diameter	4.2 mm
Electron beam current	1.12 A
Electron beam diameter in trap	0.692 mm
Electron beam density in trap	296 A/cm^2
Electron beam energy in trap	8118 eV
Trap length	0.532 m
Trap capacity	11 nC
Injection time	10-40 µs
Repetition rate	10 Hz
Duty cycle	33 %
EBIS bias	20 kV
Pressure	<1x10^{-10} Torr

EBIS CHARGE BREEDING

1+ → n+ (efficient, clean, fast)

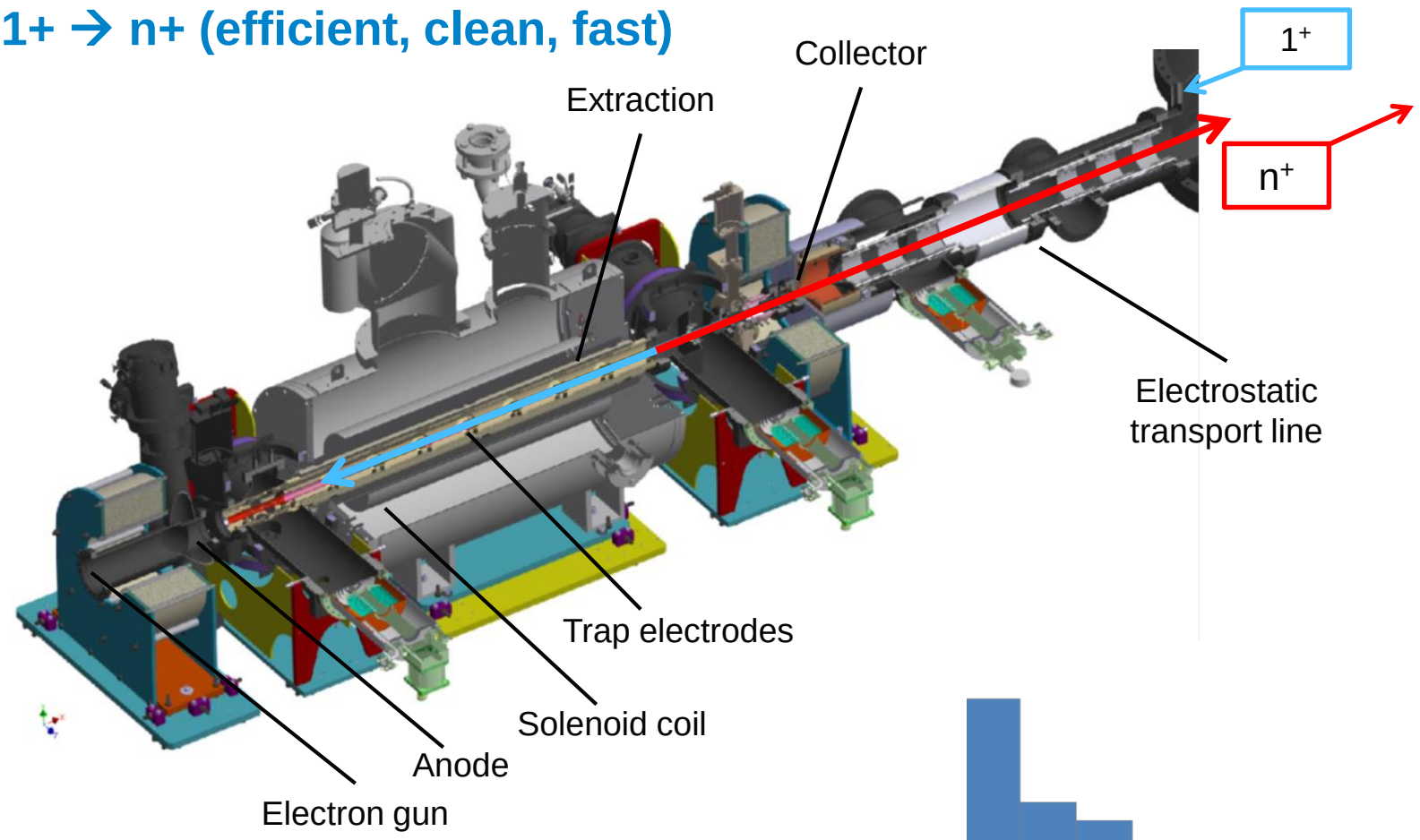


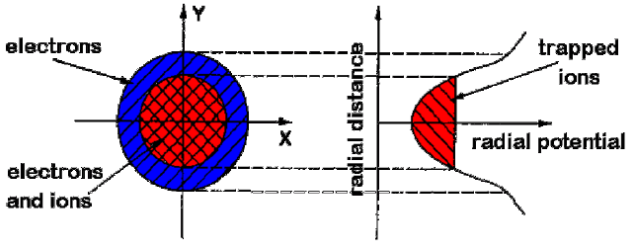


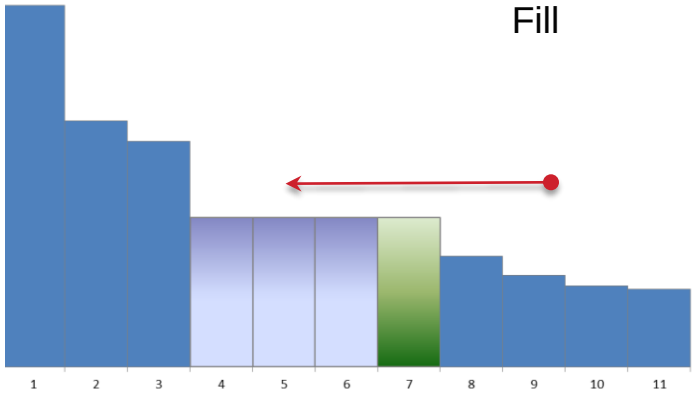
- Trap electrodes provide axial ion confinement
- Electron beam provides radial ion confinement
- Strong solenoid coil for electron beam compression
- Highly charged ions produced by interaction with electron beam

EBIS CHARGE BREEDING

1+ → n+ (efficient, clean, fast)



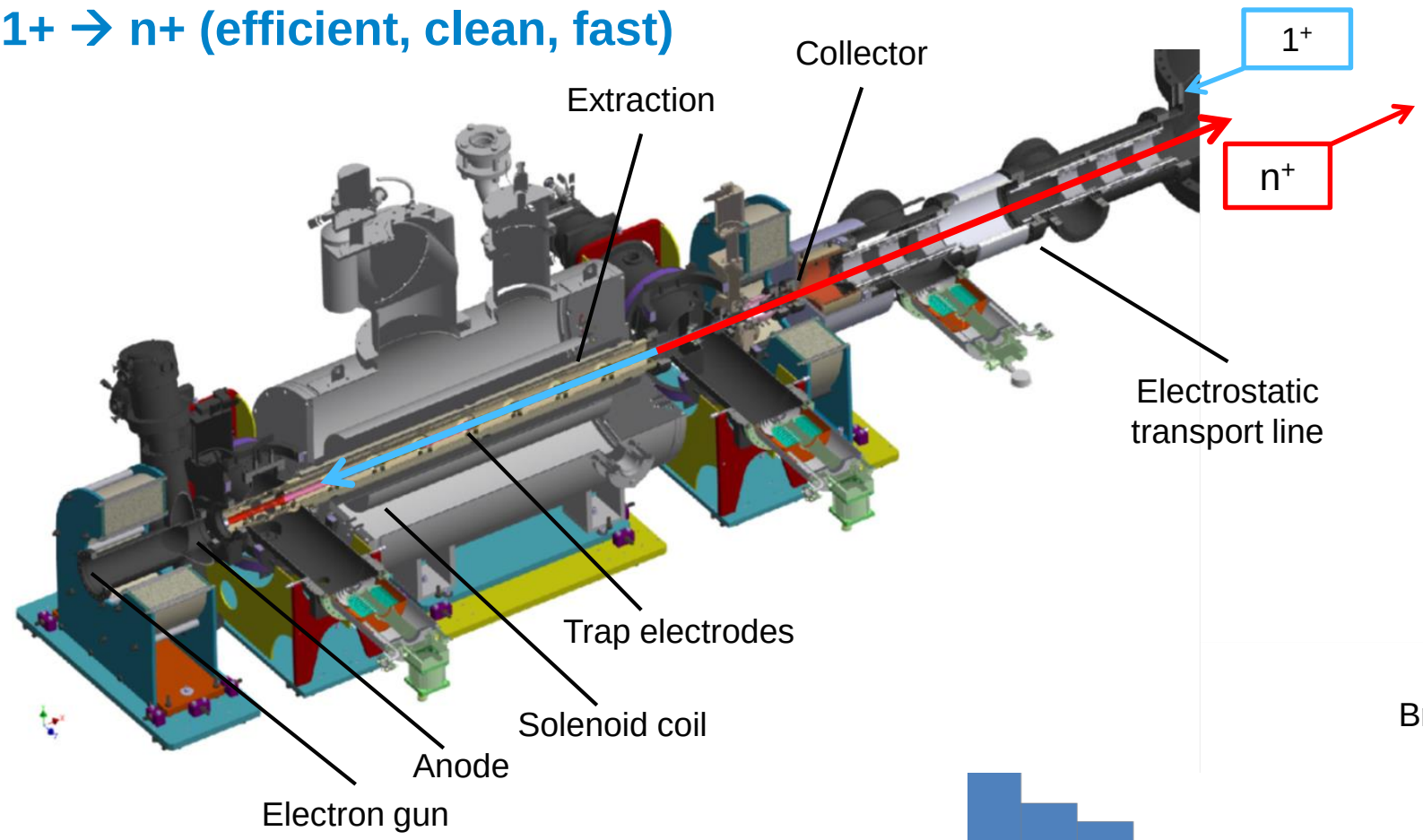


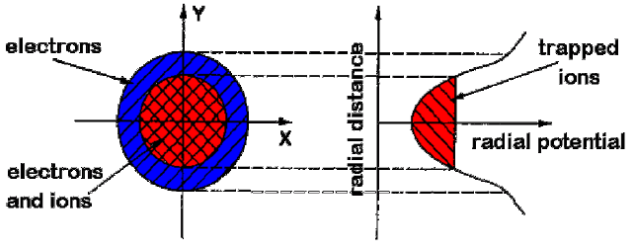


See Clay Dickerson's poster Tu73

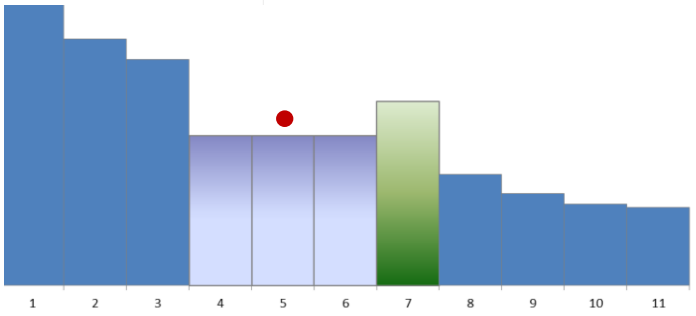
EBIS CHARGE BREEDING

1+ → n+ (efficient, clean, fast)





Breed



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EBIS CHARGE BREEDING

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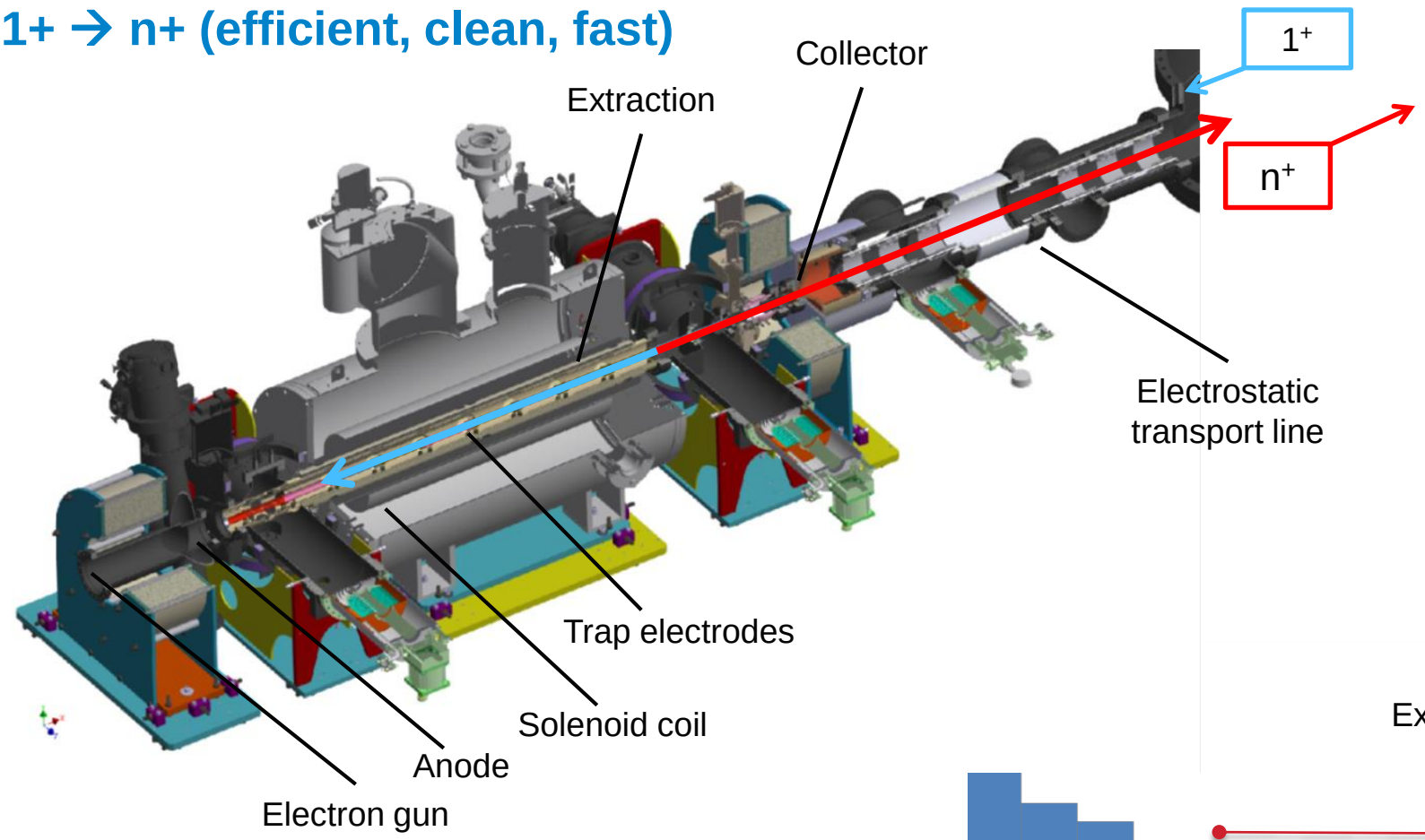
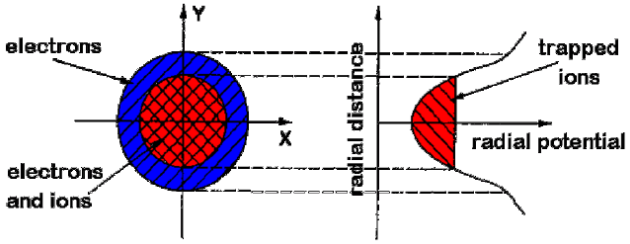
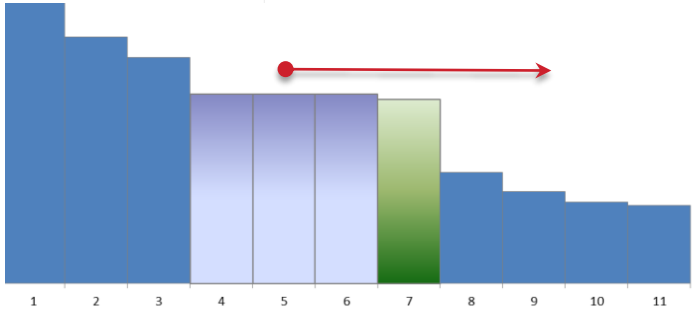




Extract



See Clay Dickerson's poster Tu73

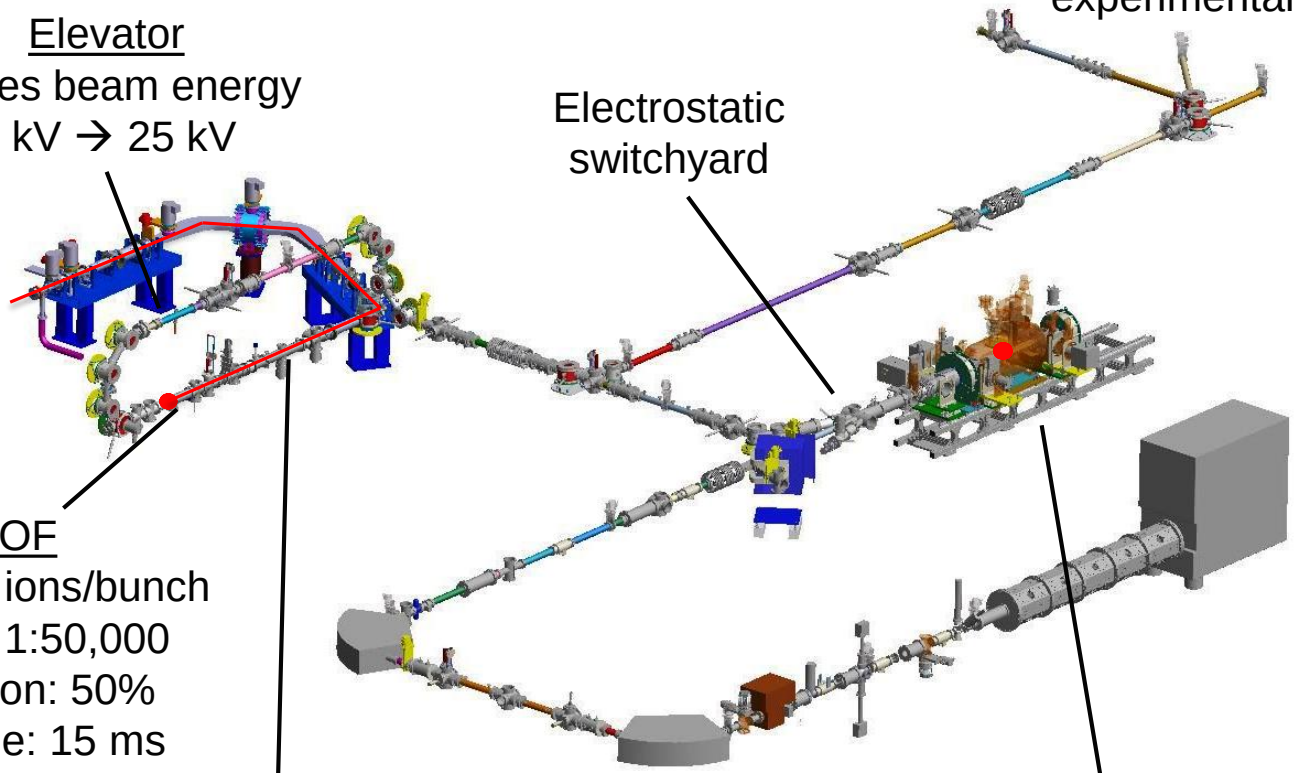
EBIS CHARGE BREEDING CYCLE

CARIBU → EBIS → ACCELERATOR

Stopped beams experimental area

Elevator
Raises beam energy
2 kV → 25 kV

Electrostatic switchyard



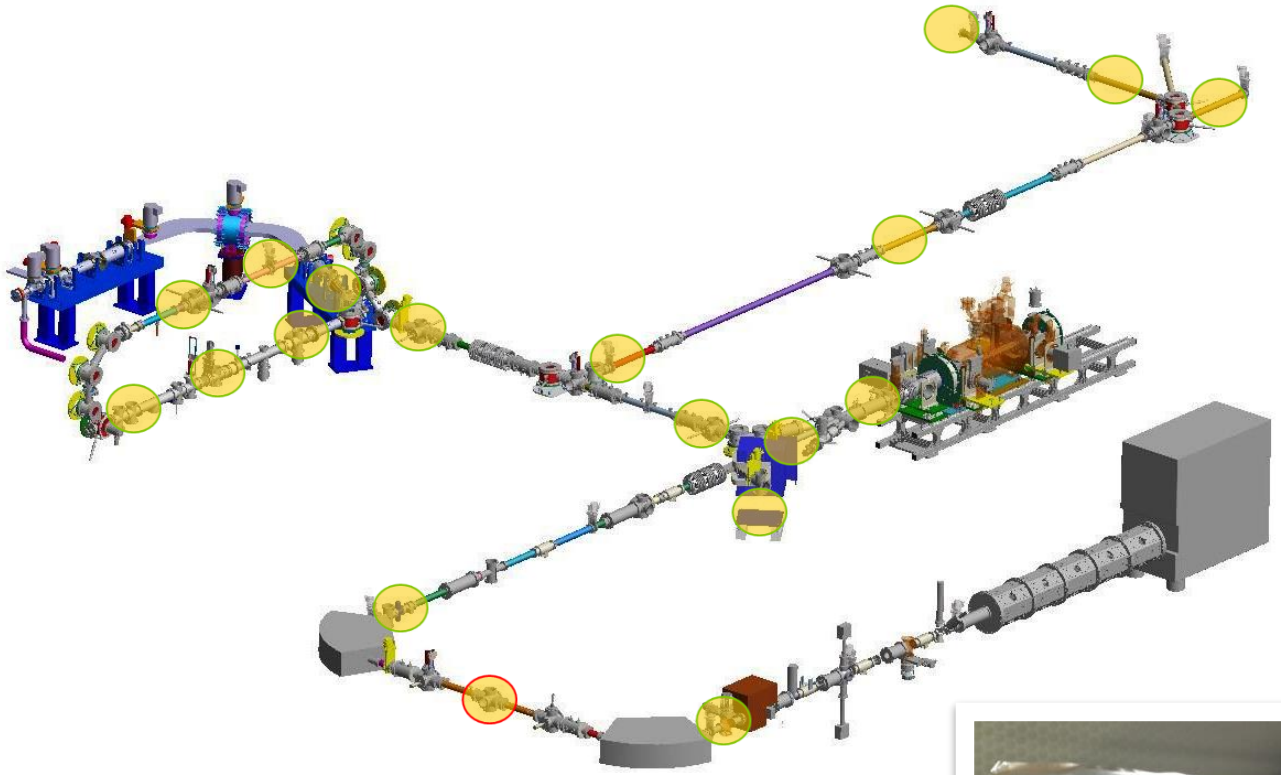
MR-TOF
Capacity: 10^4 ions/bunch
Resolution: 1:50,000
Transmission: 50%
Hold-up time: 15 ms

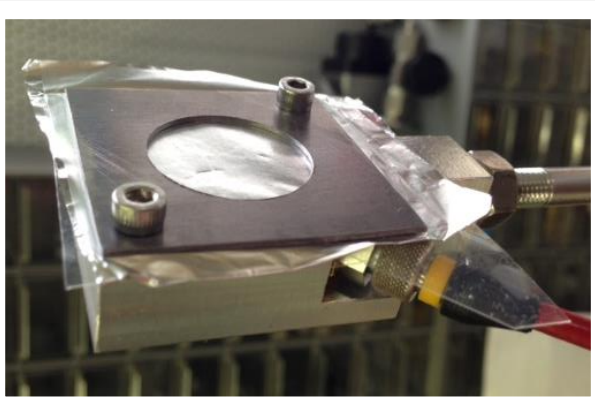
RFQ cooler/buncher
Capacity: 10^6 ions/bunch
Accumulation: 30 ms
Transmission: 70% (2+)
<70% for 1+
Pulse width: 2 µs

EBIS
Breeding time: 20 ms
Frequency: 10 Hz
Total efficiency: 90%

EBIS CHARGE BREEDING CYCLE

Beam detection

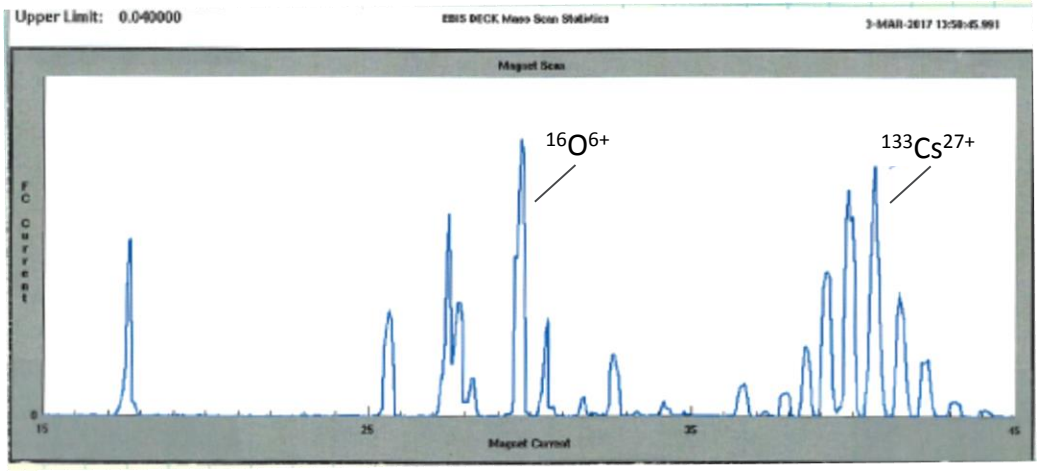


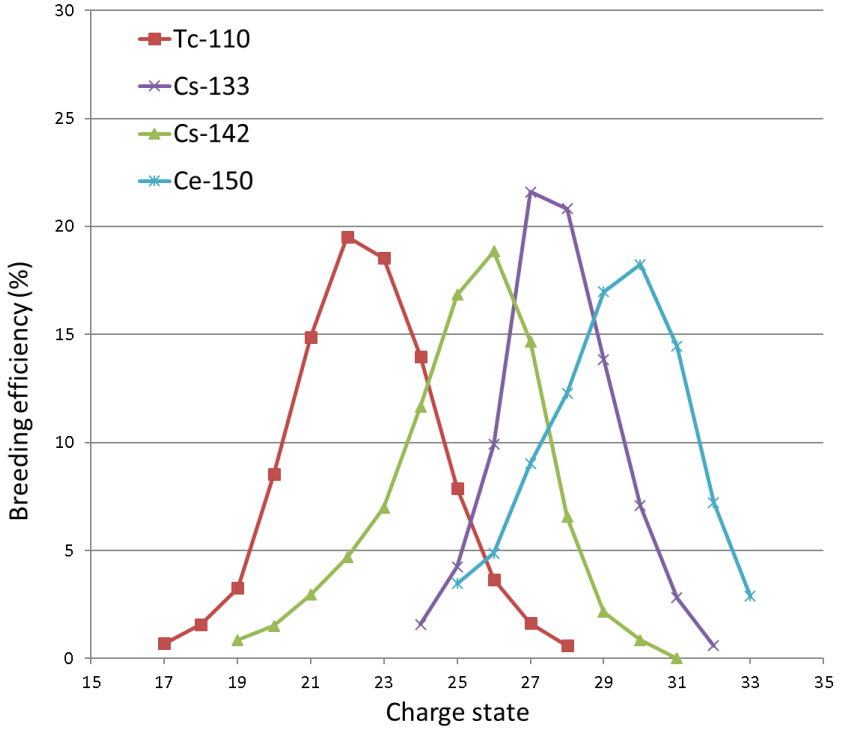


- RIB is detected via beta decay using silicon barrier detectors with aluminum cover foil
  - Identical assemblies for accurate transmission
  - Post-EBIS all locations have faraday cups as well
  - First magnetic analysis off of deck used as benchmark position for accelerator transmission

EBIS CHARGE BREEDER PERFORMANCE

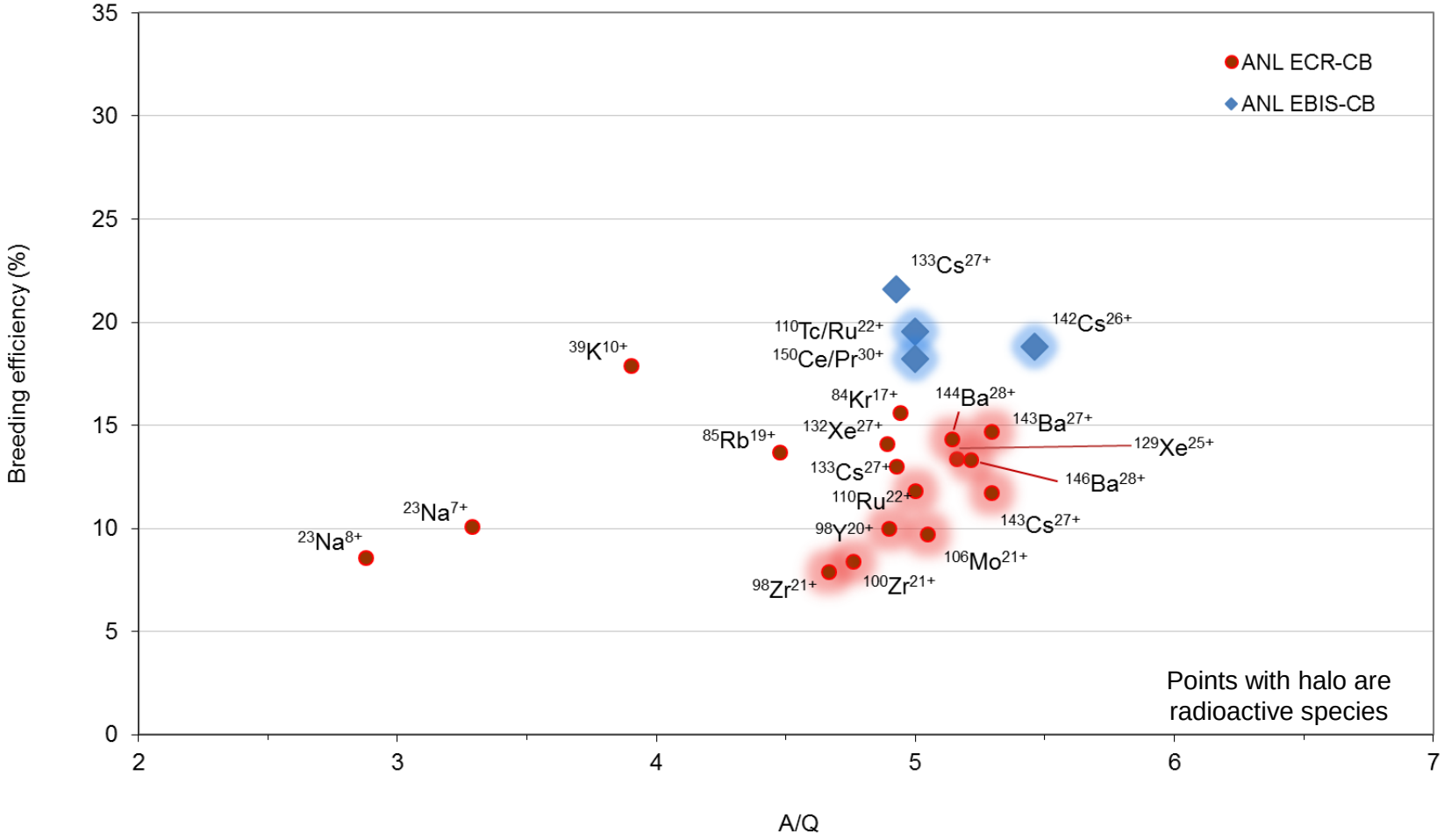
- Source performance benchmarked with Cs-133
  - Efficiency (EBIS only) for $^{133}Cs^{27+}$: 21.6%
  - Global efficiency: 95%
  - Rep rate: 10 Hz
  - Breeding time: 23 ms
  - Injected pulse (Cs^{+}): 40 µs
  - Extracted pulse width: 1.0 ms
- Radioactive beams Tc-110, Cs-142, and Ce-150
  - Same settings as stable beam with adjustments to trap timing
  - Efficiency (EBIS only) for $^{142}Cs^{26+}$: 19%
  - Global efficiency: 89%
  - Rep rate: 10 Hz
  - Breeding time: 19 ms
  - Injected pulse: 10 µs
  - Extracted pulse width: 1.0 ms





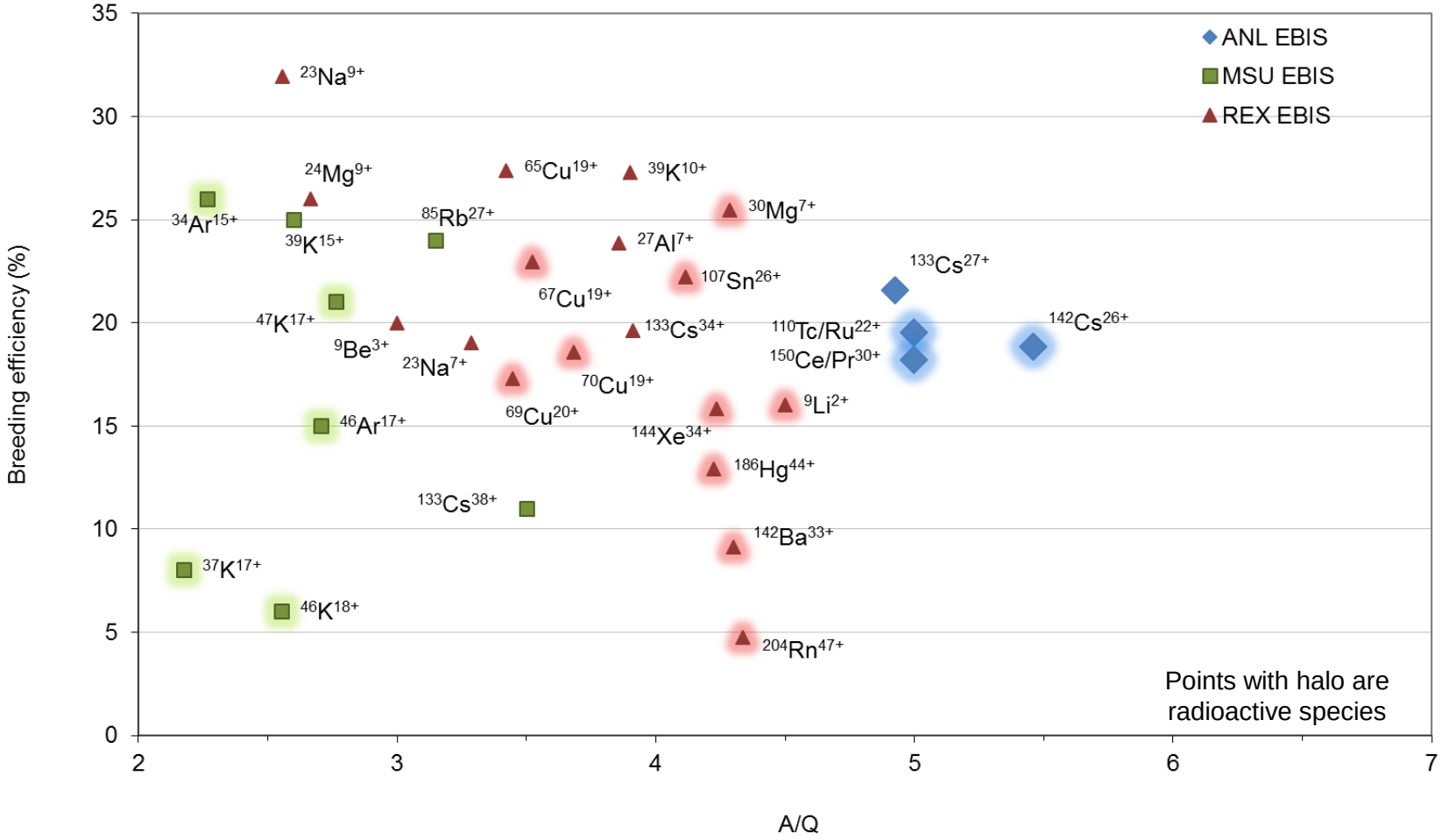
EBIS CHARGE BREEDER EFFICIENCY

Compared to ANL ECR charge breeder



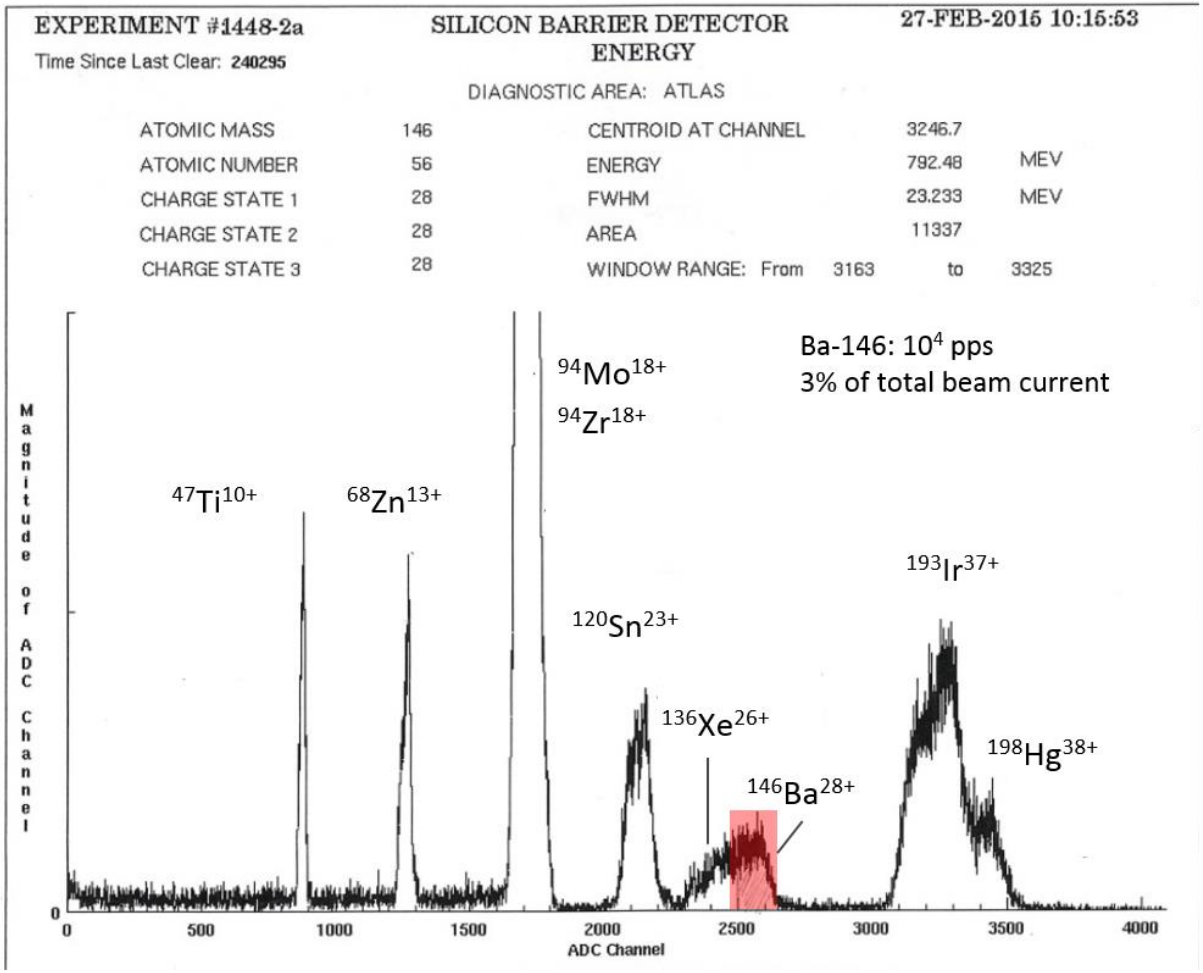
EBIS CHARGE BREEDER EFFICIENCY

Compared to REX EBIS and MSU EBIS – EBIS ONLY



BEAM CONTAMINATION

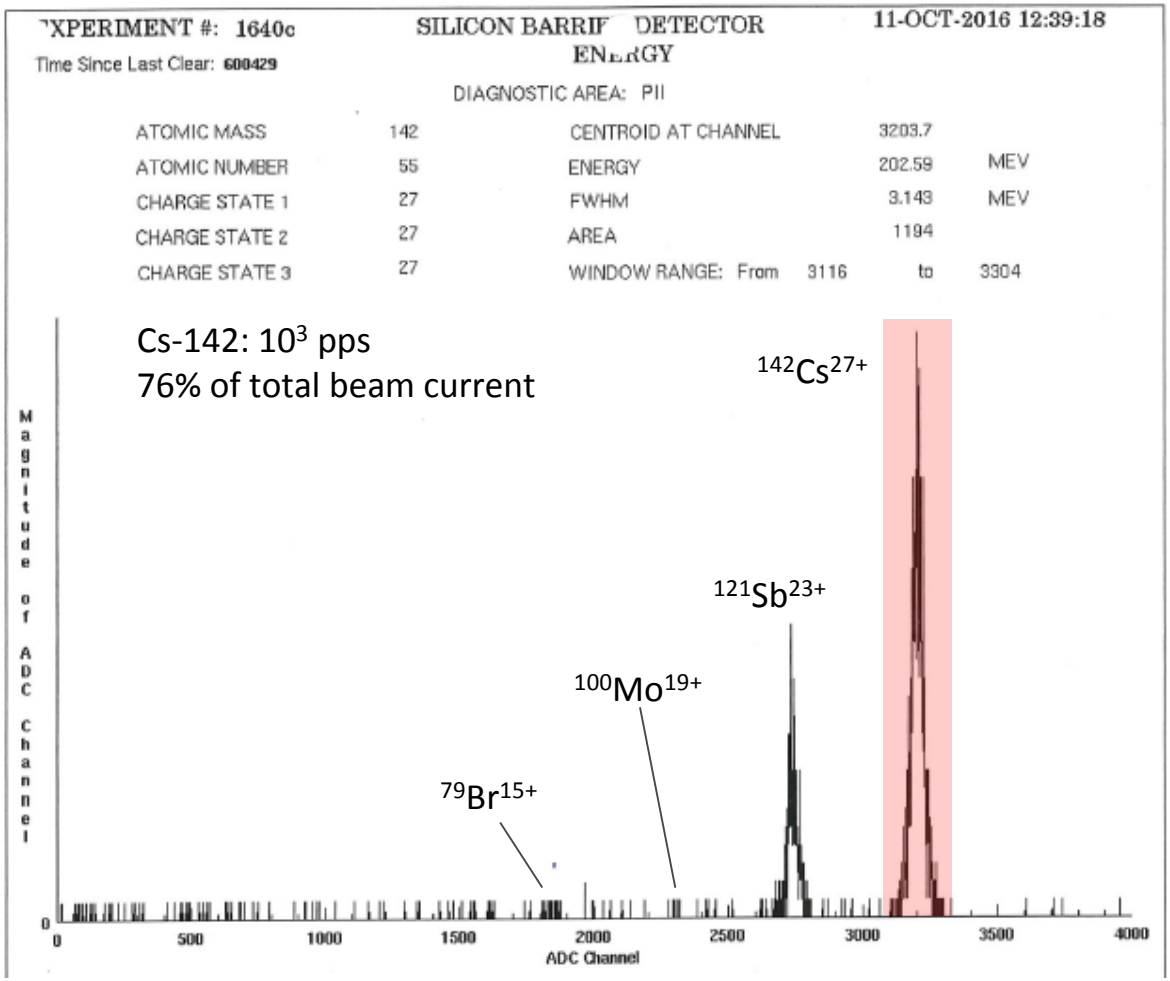
ANL ECR vs. ANL EBIS



BEAM FROM ECR CHARGE BREEDER

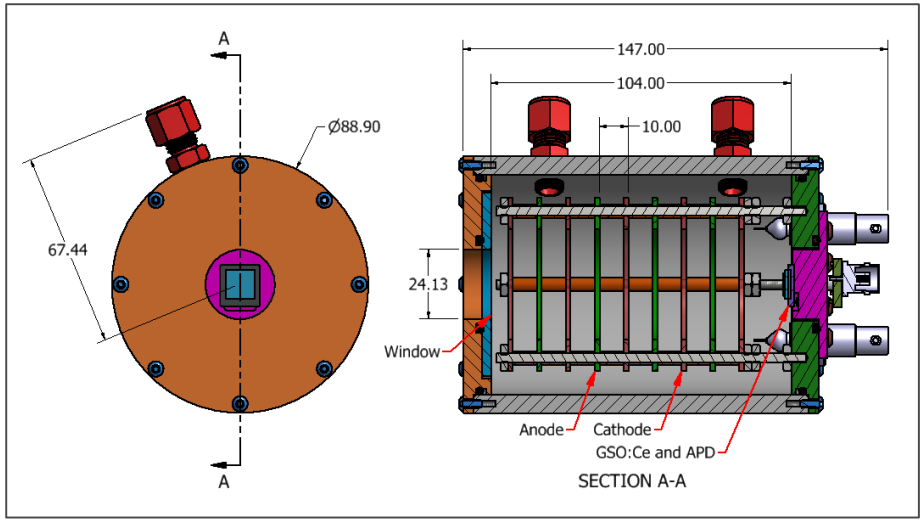
BEAM CONTAMINATION

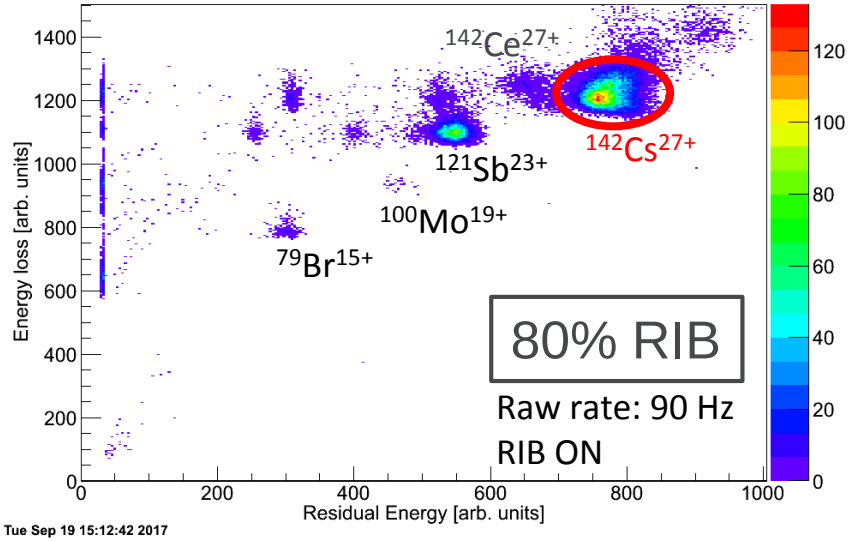
ANL ECR vs. ANL EBIS



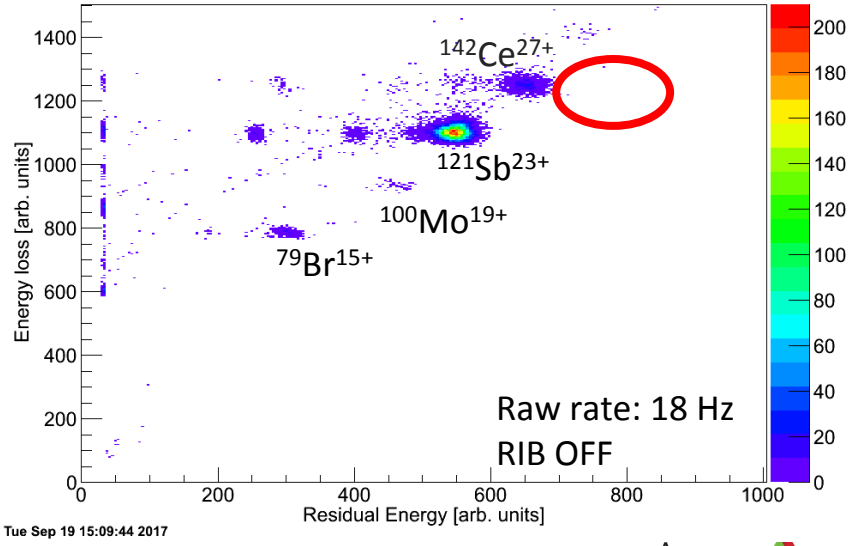
BEAM FROM EBIS CHARGE BREEDER

RADIOACTIVE BEAM DETECTION

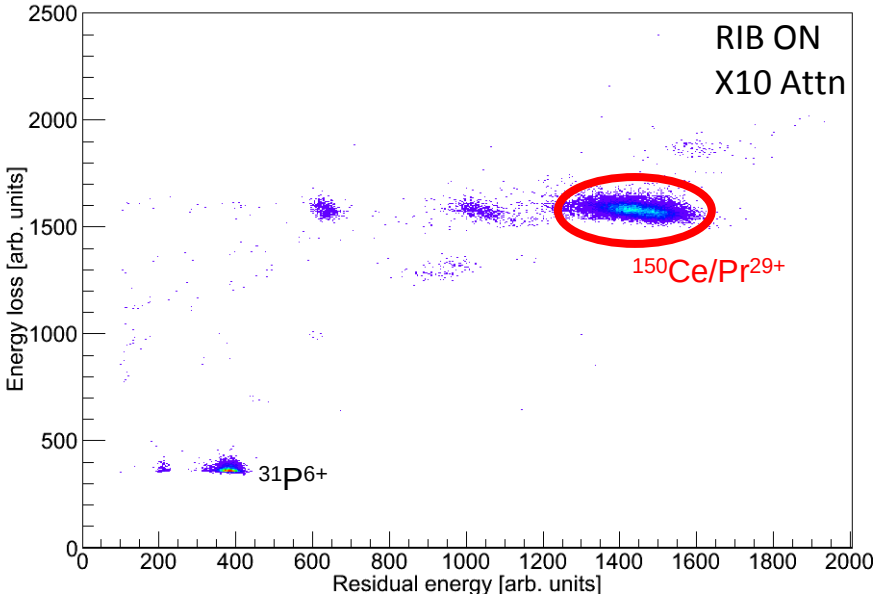


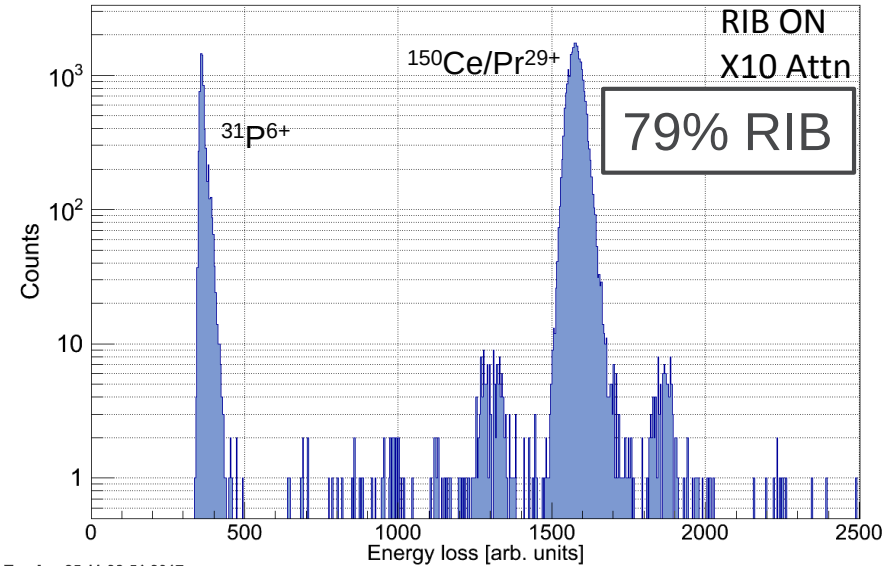


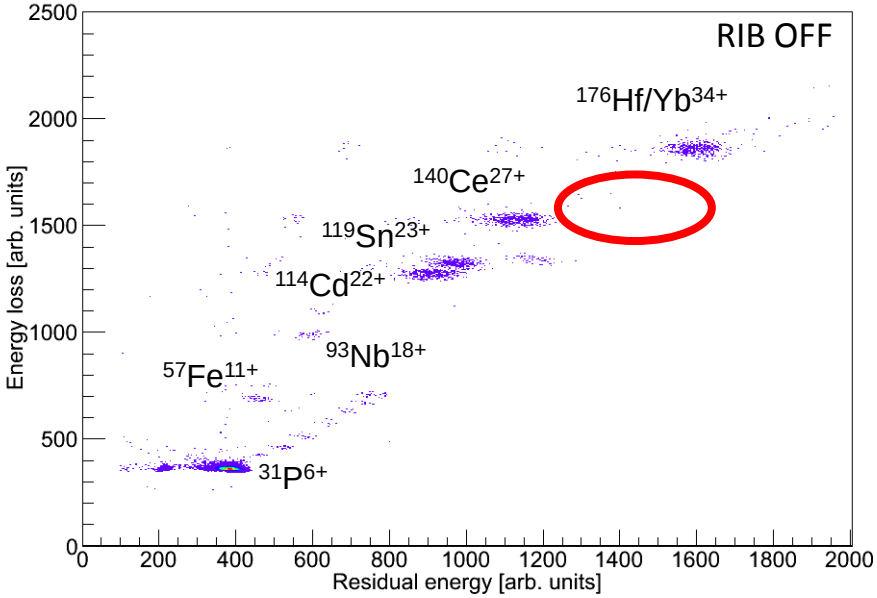
- Fast and compact gas ionization chamber
  - Direct measurements of CARIBU RIBs for tuning and identification
  - Avoids time lag inherent to beta decay detection method
  - Can be positioned at many places along accelerator
  - Prototype performance limited at rate of 2 x 10^4 ions/sec

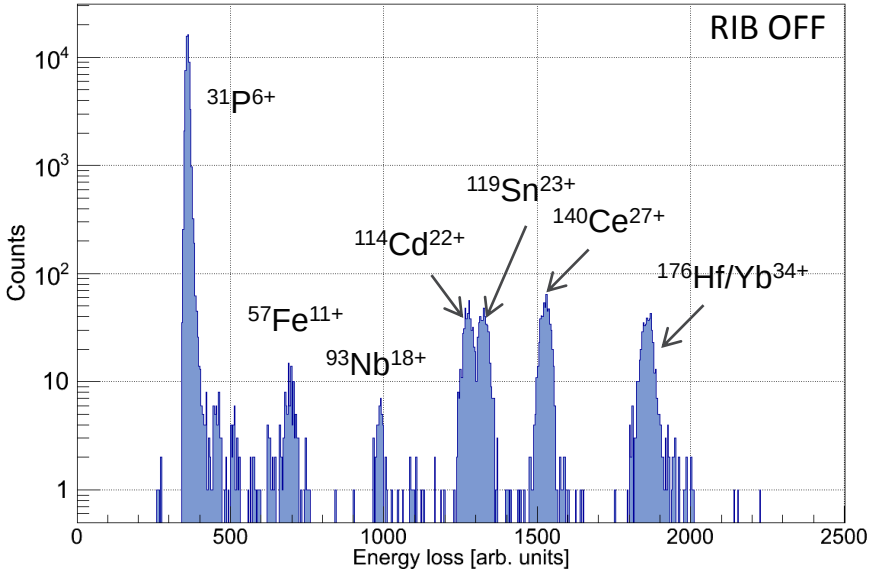


EBIS BACKGROUND – MASS150



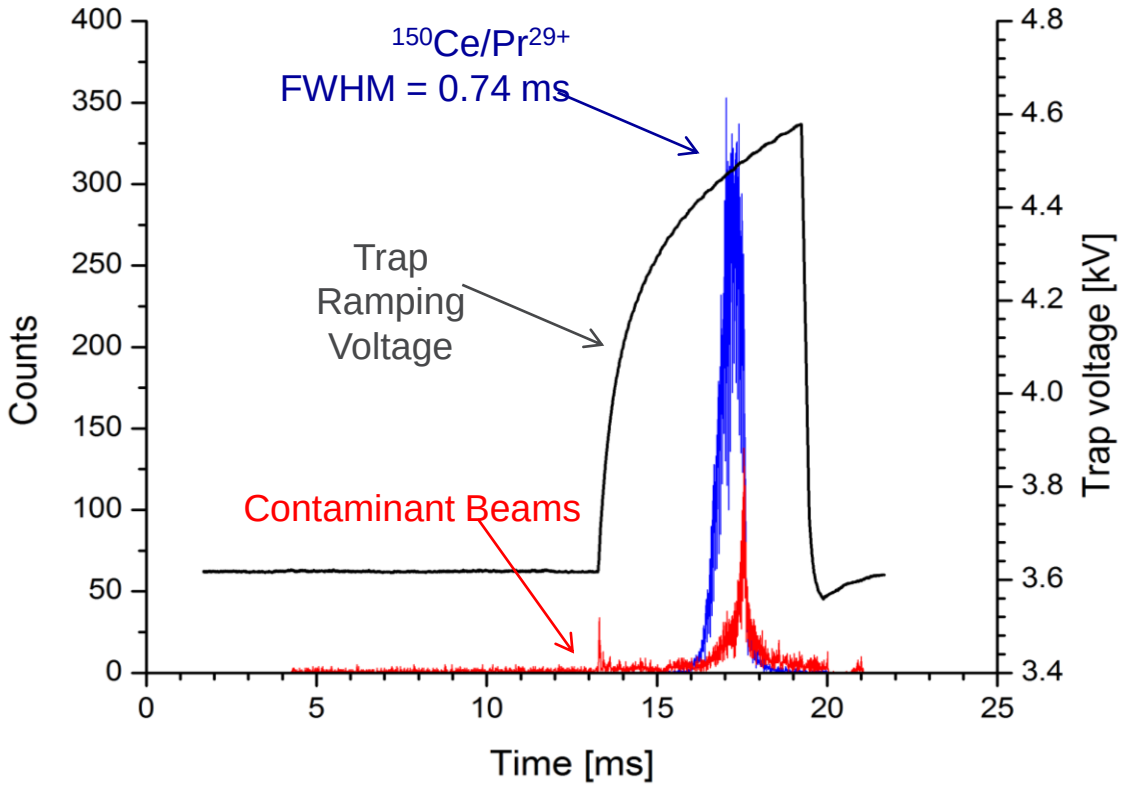






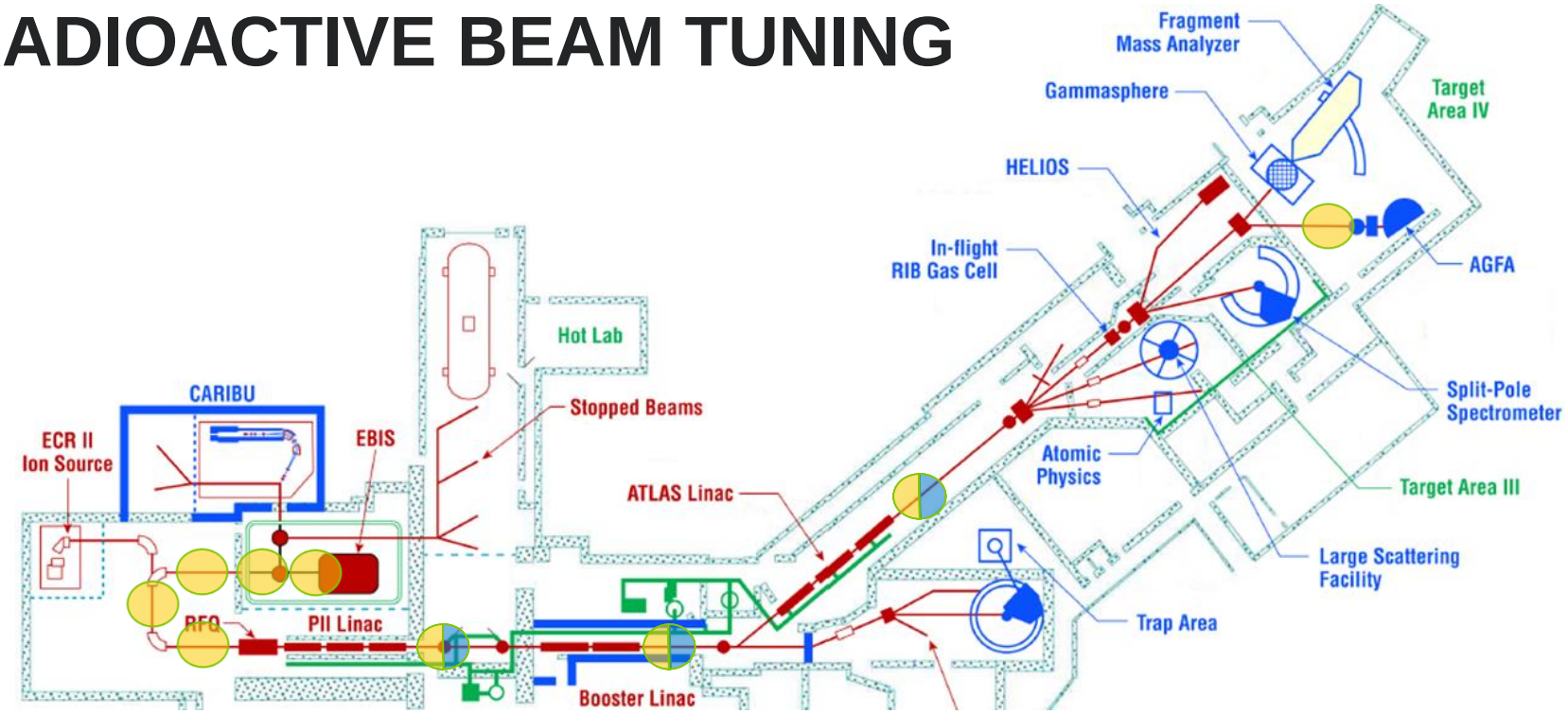
EBIS PULSE TIMING

Trap-over-barrier extraction



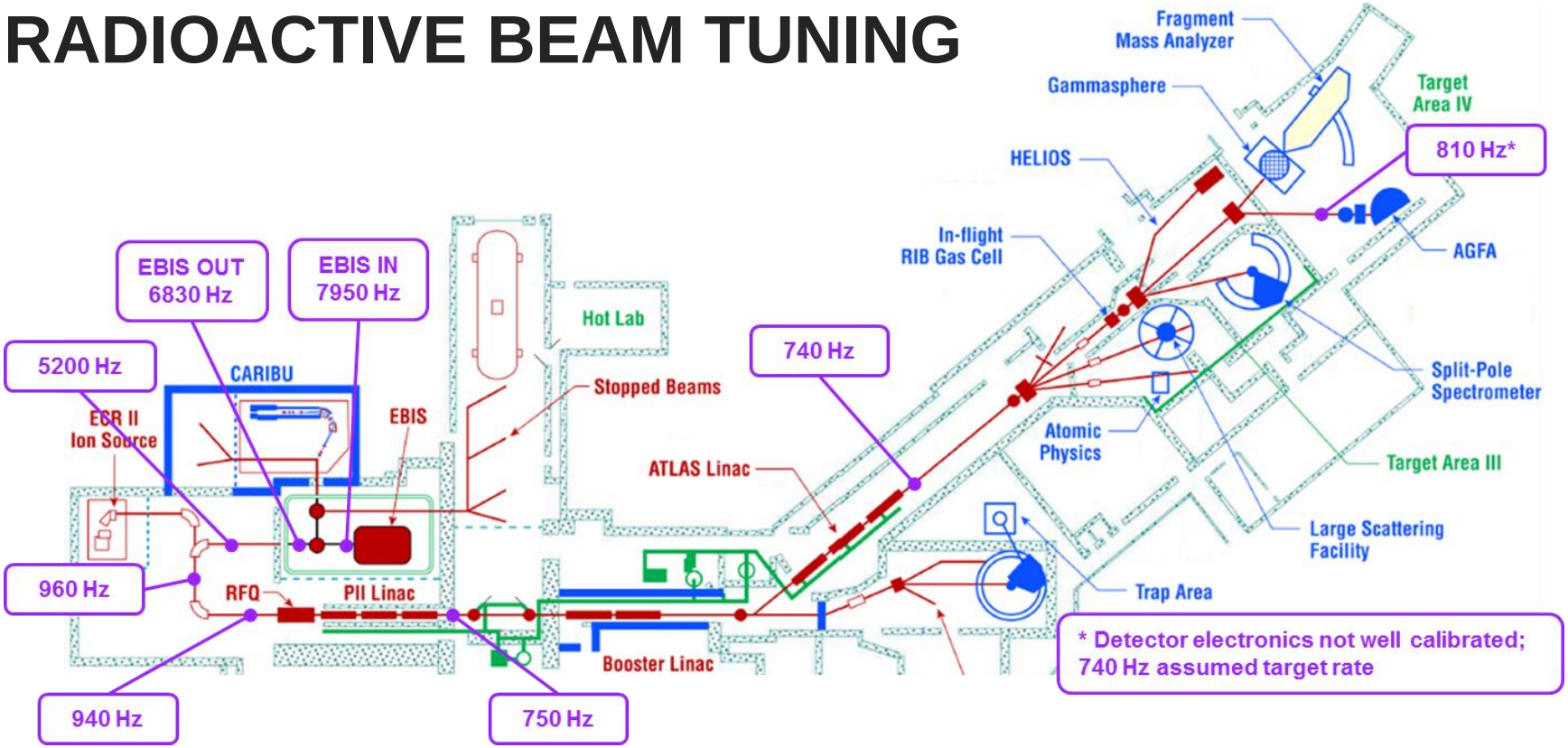
- Normal barrier only pulse is ~20 µs
- Trap-over-barrier: three trap electrodes raised above barrier potential
- Pulses as long as 3 ms have been produced
- Reduces instantaneous rate onto target detectors

RADIOACTIVE BEAM TUNING



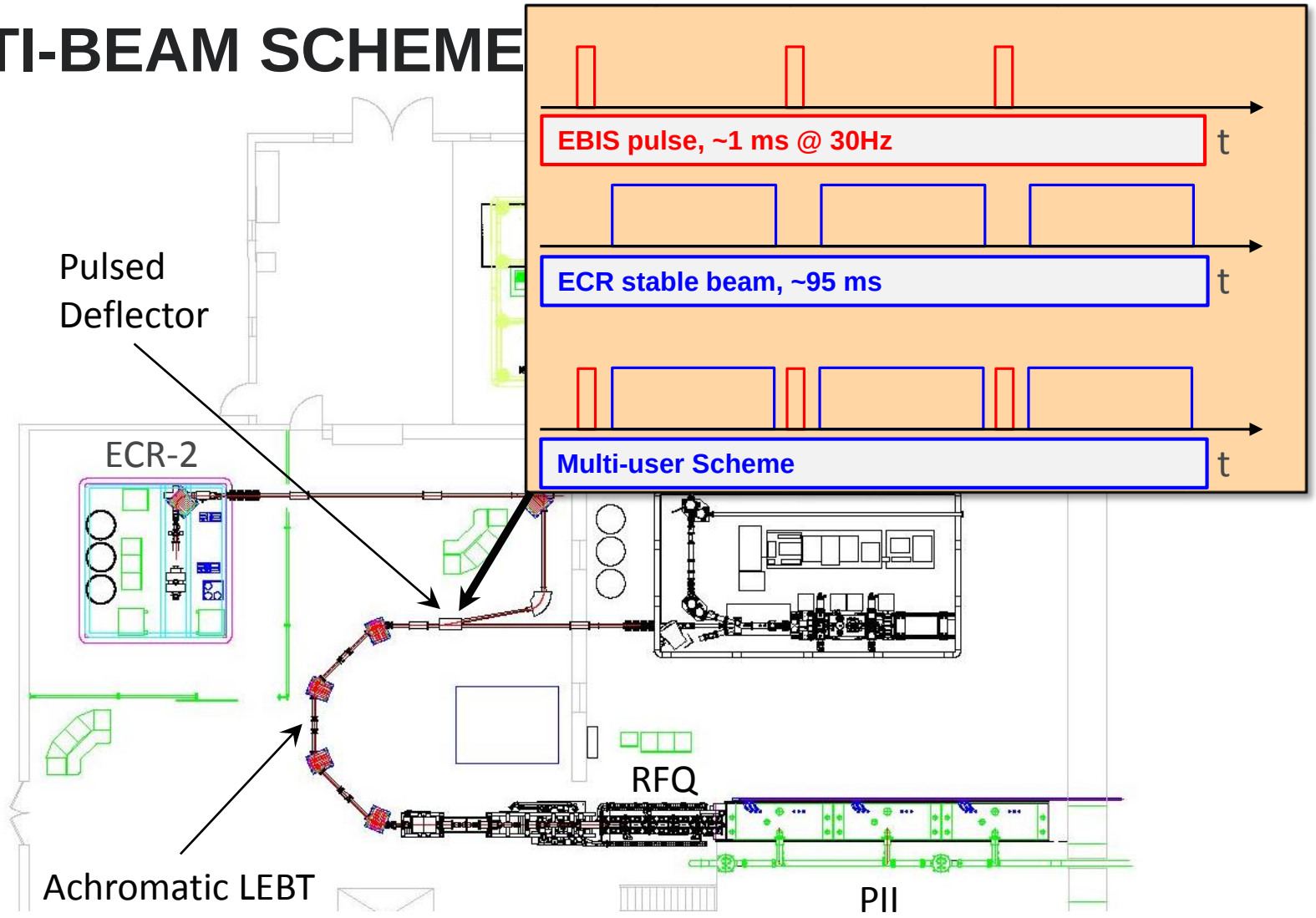
- Tune machine with stable pilot beam of $^{133}Cs^{26+}$
- Pilot beam measured on faraday cups
  - Typically 30-50 epA
- Stop Cs^{+} beam and inject low charge state RIB into EBIS
- Scale entire machine over to RIB of interest
- Beta rates measured with silicon barrier detectors with aluminum cover foils

RADIOACTIVE BEAM TUNING



- Stable pilot beam of $^{133}Cs^{26+}$ with transmission of 73%
- Transmission with $^{150}Ce/Pr^{29+}$ was 77%
- EBIS IN-to-target efficiency: 740/7950 = 9.3%
- Absolute rate on target ~3000 Hz (detector efficiency ~25%)
  - Cf-252 source is several years old
  - Is also very thick and self-shields
  - New source is being fabricated

MULTI-BEAM SCHEME



- The simultaneous acceleration of two beam species
  - One stable from the ECR and one radioactive from CARIBU-EBIS
  - A/q required to be within 1% of each other

ACKNOWLEDGEMENTS

This is the work of many people…

J. Clark, R. Pardo, G. Savard – ANL CARIBU

C. Dickerson, S.A. Kondrashev, P.N. Ostroumov, E. Beebe, A. Pikin, C. Peters, M. Powers, D. Santiago-Gonzalez, S. Sharamentov – EBIS development

B. Mustapha – Beam optics Multi-user Upgrade