Simultaneous Acceleration of Stable and Radioactive Beams in ATLAS

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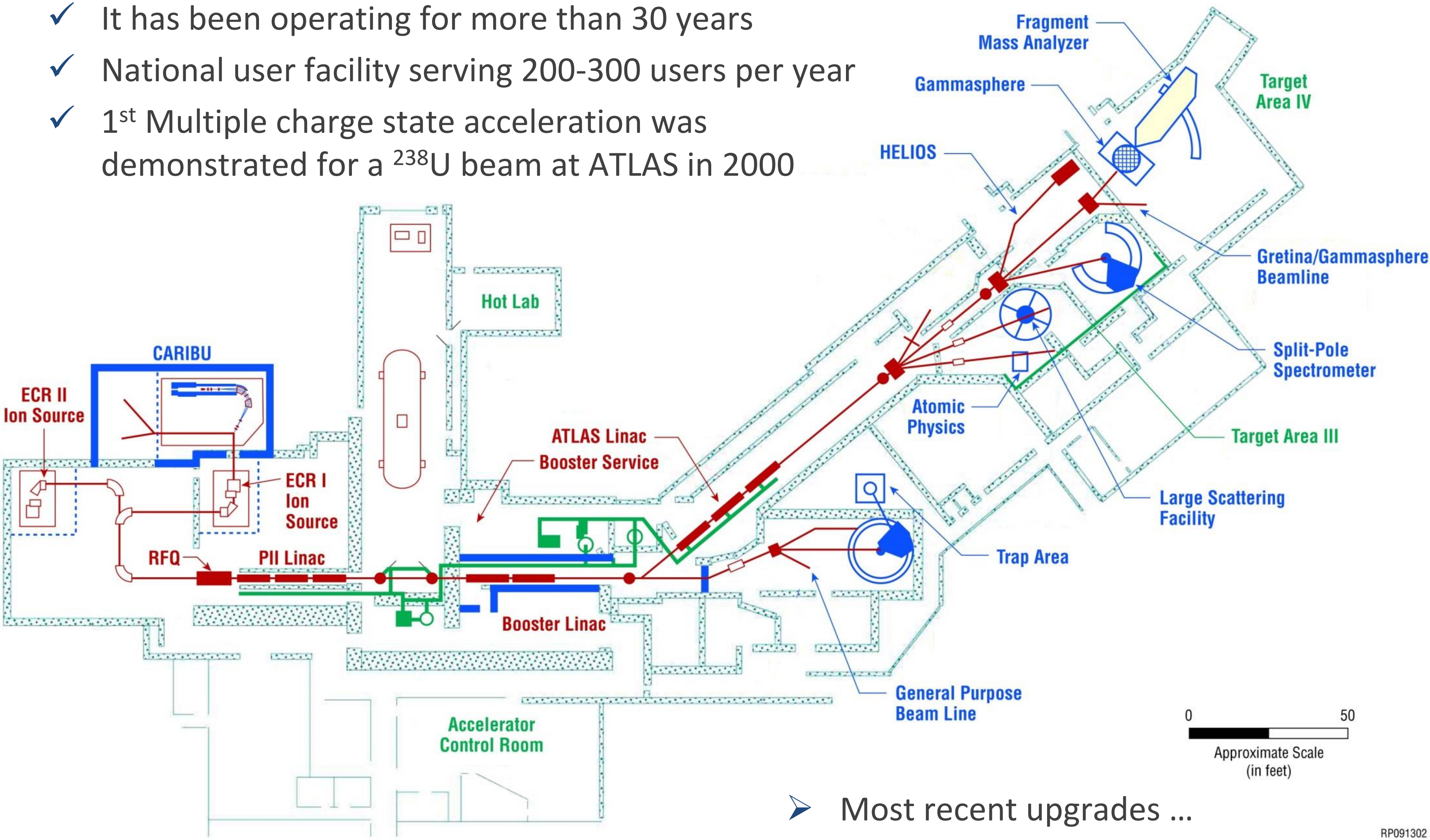
Outline of the Talk

- A brief Introduction to the ATLAS Linac at Argonne
- Recent ATLAS Upgrades:
  - Radioactive beams from CARIBU
  - Efficiency & Intensity Upgrade: New RFQ and Cryomodule
- Increasing beam demand and the need for multi-user capabilities
- EBIS charge breeder and simultaneous acceleration of stable and radioactive beams
- The injection: A pulsed deflector and an achromat
- The extraction: A kicker and a septum magnet
- Staging of the ATLAS multi-user upgrade
- Summary

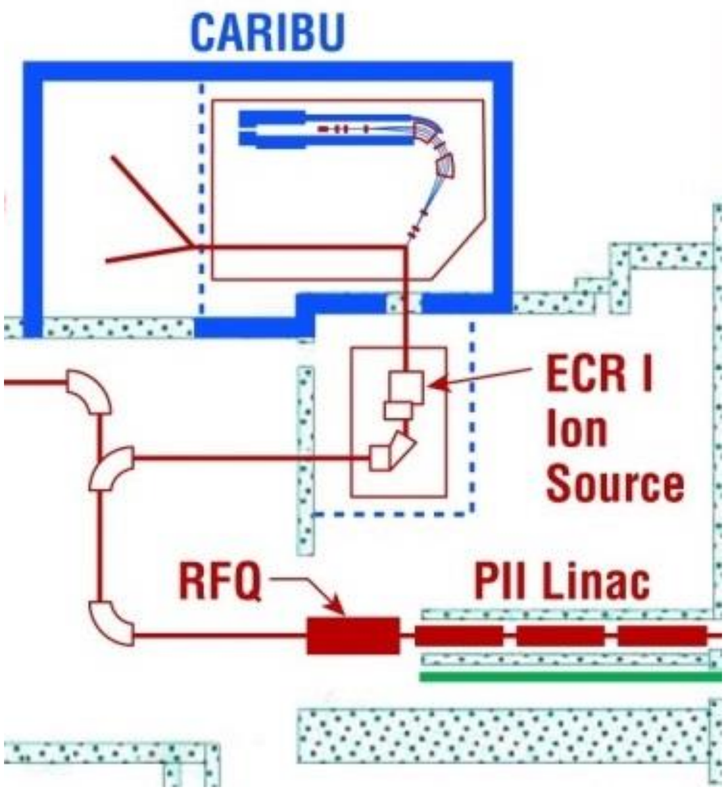
ATLAS: Argonne Tandem Linac Accelerator System

- ✓ 1st Superconducting heavy-ion linac in the world
- ✓ It has been operating for more than 30 years
- ✓ National user facility serving 200-300 users per year
- ✓ 1st Multiple charge state acceleration was demonstrated for a ^{238}U beam at ATLAS in 2000

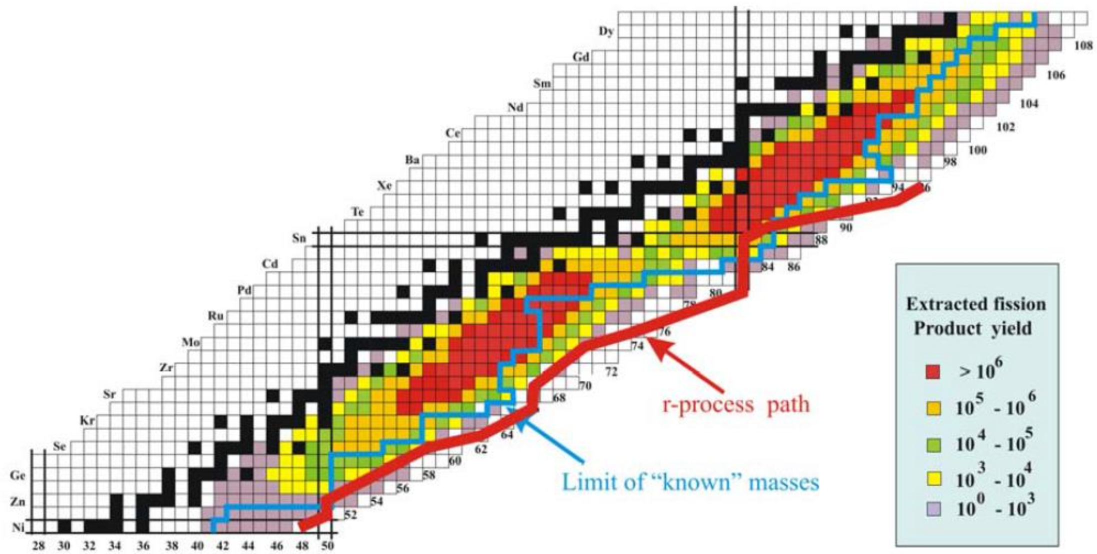


- ➢ Most recent upgrades …

CARIBU: CAlifornium Rare Isotope Breeder Upgrade



Map of radioactive beams from a ^{252}Cf source



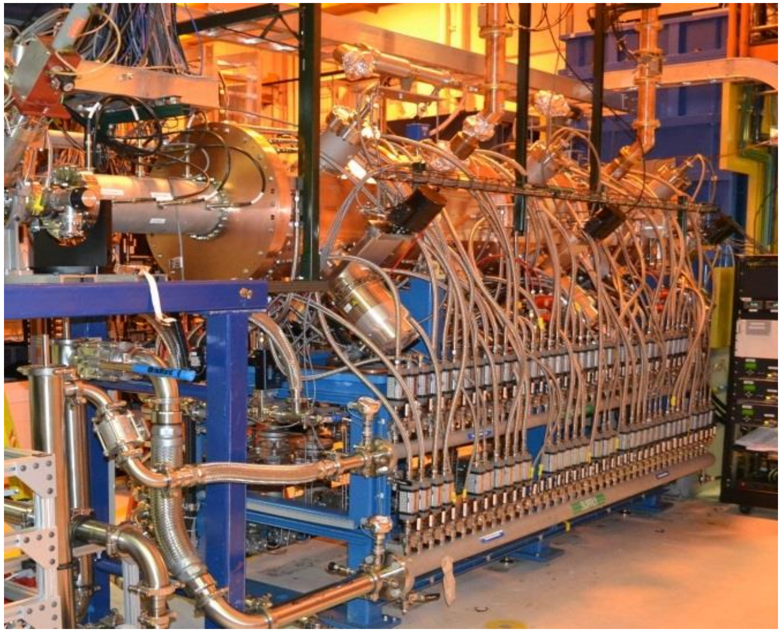
G. Savard et al, ANL

- ✓ Radioactive beams from a Californium Source
- ✓ The ions are collected, separated and cooled to form a beam
- ✓ An ECR Charge breeder is now used for injection and acceleration in ATLAS
- ✓ An EBIS charge breeder was developed for higher efficiency and better purity
- ✓ The EBIS was successfully tested offline and it's ready for installation next year

Efficiency & Intensity Upgrade: New RFQ and SC Module

New CW 60 MHz RFQ

- ✓ Split-coaxial with trapezoidal modulations
- ✓ Output matcher for axis symmetric beam
- ✓ In routine operation since early 2013



New SC Module

- ✓ 7 β ~ 0.77 QWR and 4 solenoids
- ✓ Capable of delivering 17.5 MV
- ✓ Replaced 3 old SC modules
- ✓ In routine operation since early 2014

- ✓ New RFQ: Transmission increased from 50% to 80% → Efficiency & Reliability
- ✓ New SC Module: Acceleration of 10x more intense beams → Intensity

Increasing Demand for ATLAS Beam Time

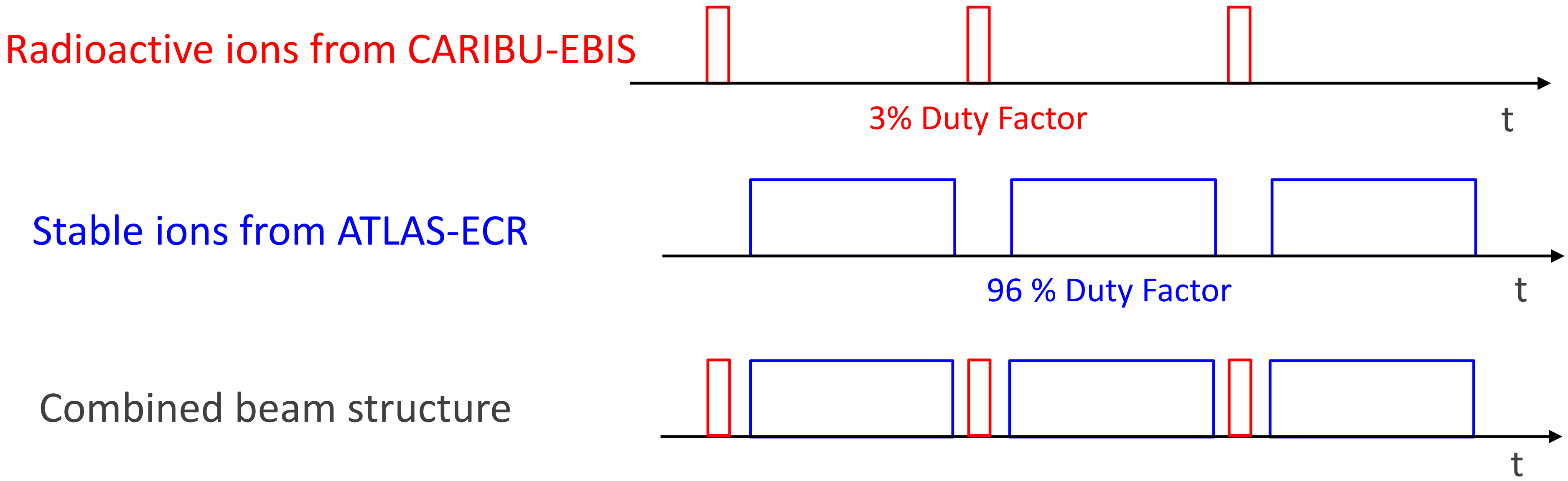
- In the past 2 years, the requested experimental beam time significantly exceeded the 5000-5500 hours that ATLAS can deliver yearly.

- With CARIBU online, the demand for beam time is at least doubling ...

- Low intensity radioactive beams from CARIBU will require longer experimental run periods, further reducing the number of users served.

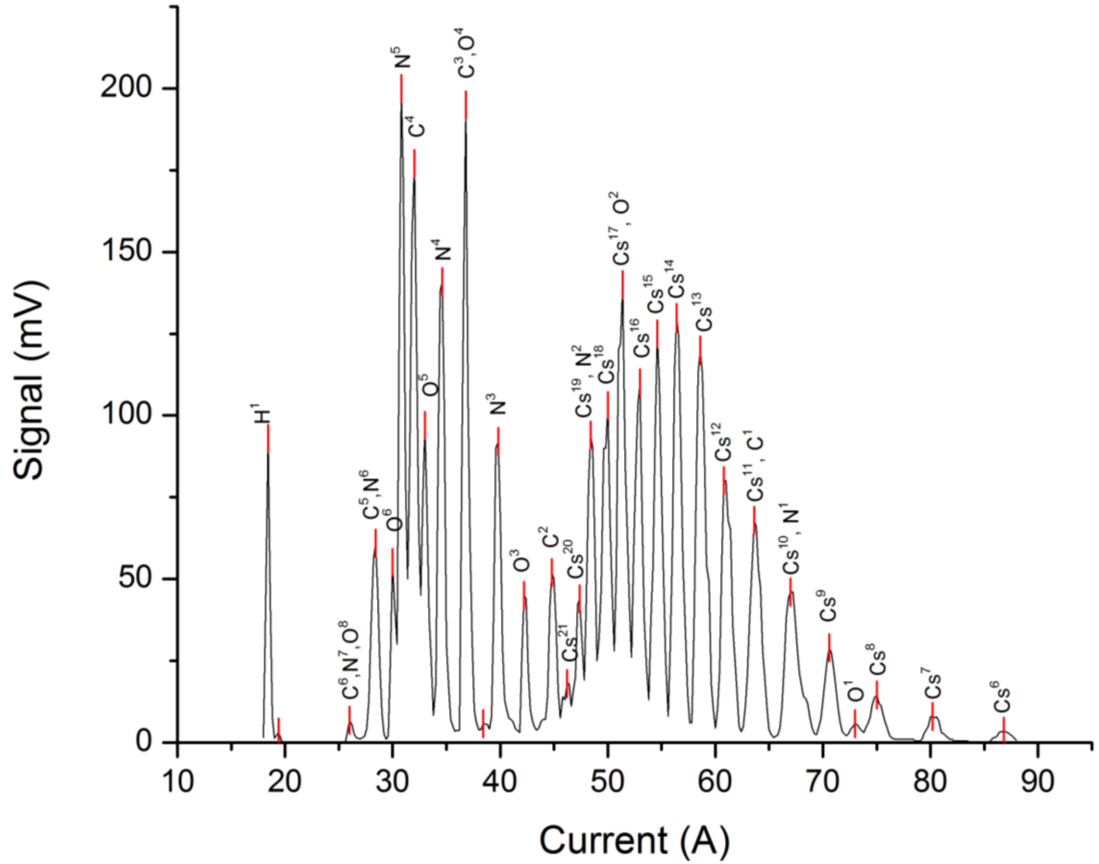
- There is an immediate need for multi-user capabilities

EBIS Charge Breeder & Possible Two-Beam Acceleration



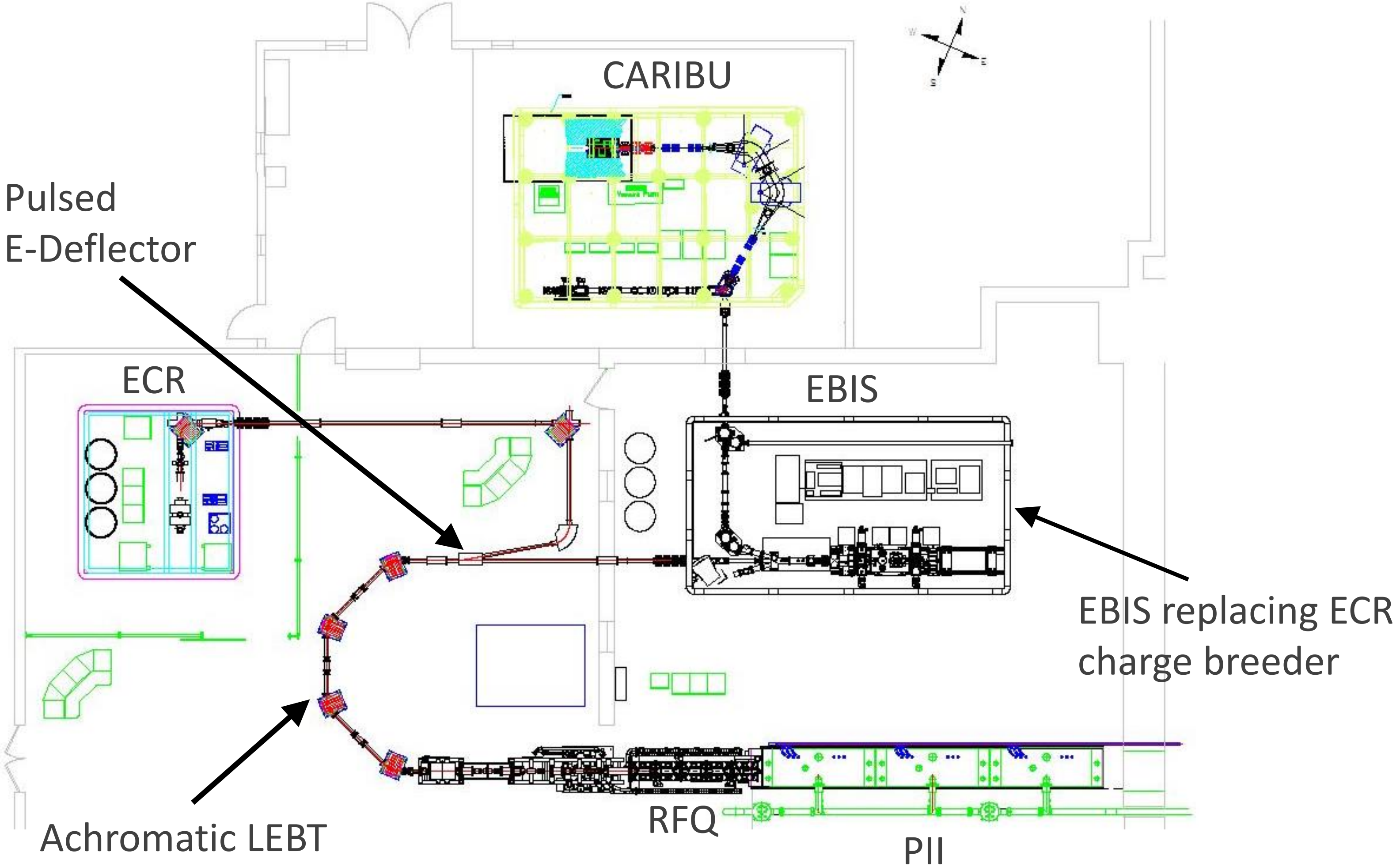
- ✓ EBIS beam is ~ 10 μs to 1 ms pulse with 30 Hz repetition rate → < 3 % DF
- ✓ DC beam from ECR could be injected into ATLAS in the remaining 97% DF
- ✓ CARIBU Beam masses range from 80 to 170 with Z ranging from 30 to 70
- ✓ The highest charge-to-mass ratio they could be ionized to is 1/4.
- ✓ ATLAS accelerates any beam with a charge-to-mass ratio > 1/7
- ✓ The useful charge-to-mass ratio range for the multi-user capability is 1/7 to 1/4
- ✓ If EBIS is operated at 10 Hz, higher q/A ≈ 1/3 can be achieved

EBIS Charge Breeder: Successful Off-line Commissioning



- ✓ Measured Cs transmission efficiency: > 70 % with > 15% breeding efficiency into a single charge state
- ✓ Will be ready for online installation at CARIBU in 2015 – already funded
- ✓ Will enhance both the intensity and purity of CARIBU beams

Modified Injection to Combine two Beams

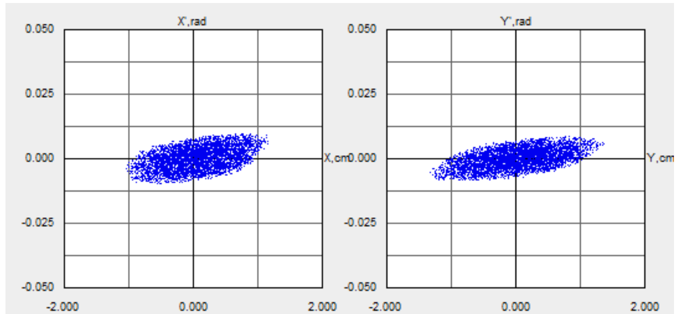


- ✓ New achromatic LEBT to transport beams of slightly different q/A
- ✓ Pulsed electrostatic deflector to combine stable beam from ECR and RIB from EBIS

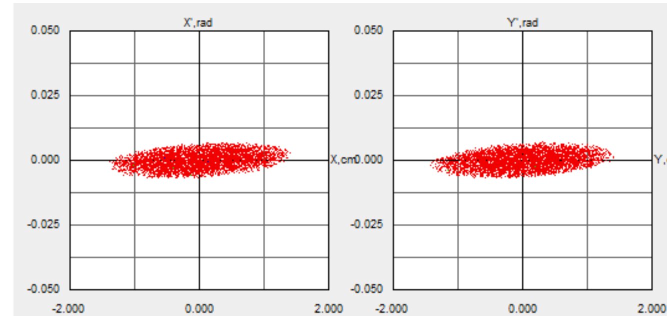
Example: $^{132}Sn^{27+}$ from EBIS and $^{48}Ca^{10+}$ from ECR

Two separate beams at their sources

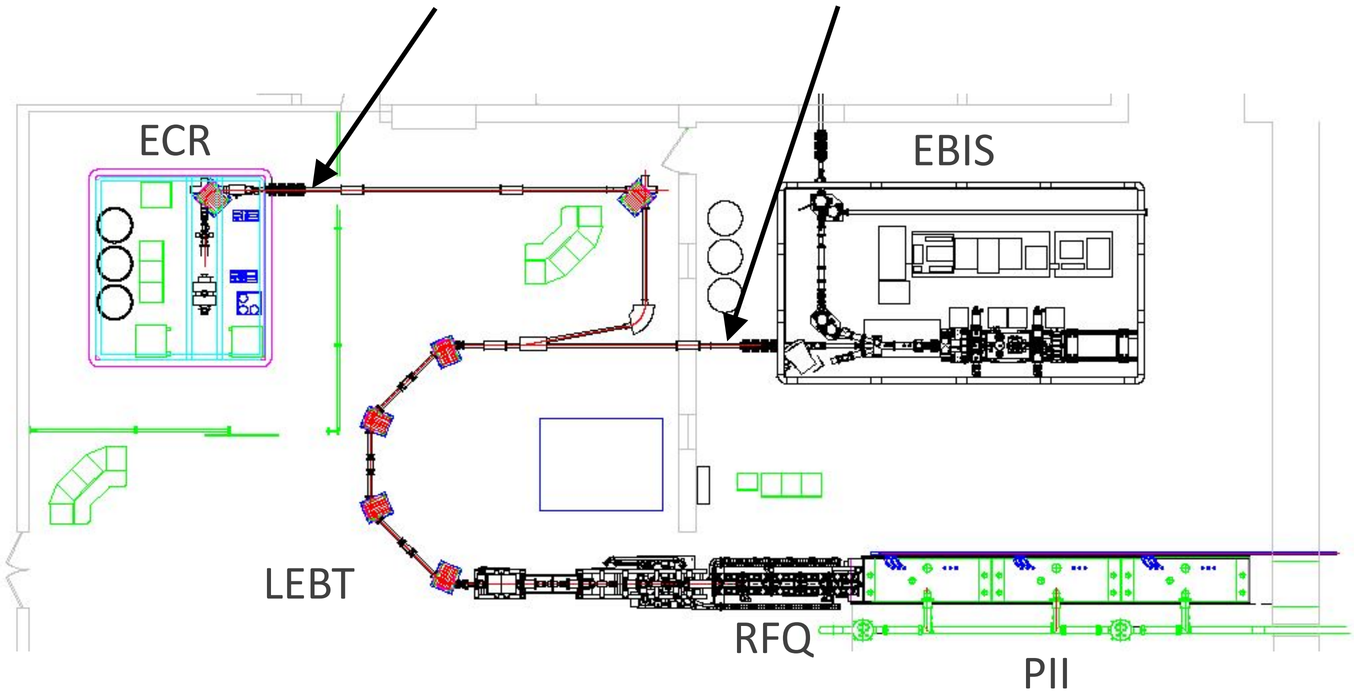
$^{48}Ca^{10+}$



$^{132}Sn^{27+}$



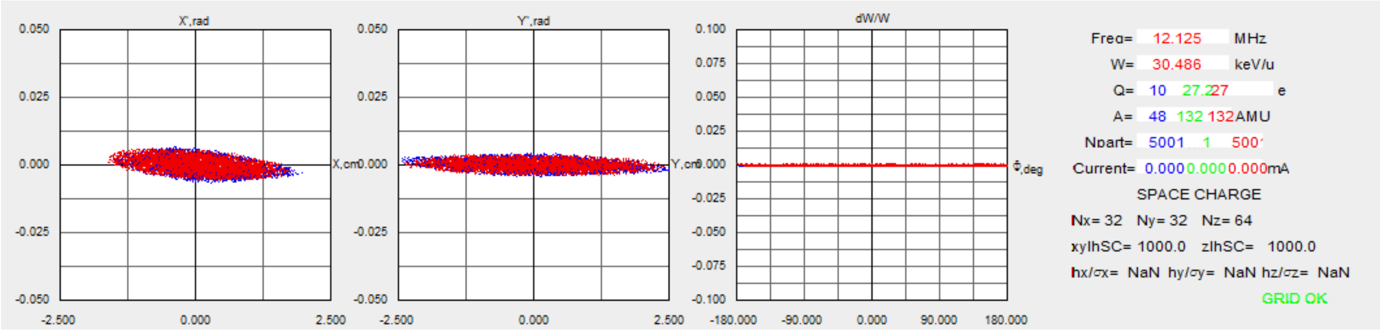
Separate platforms → Independent voltage adjustment for RFQ injection

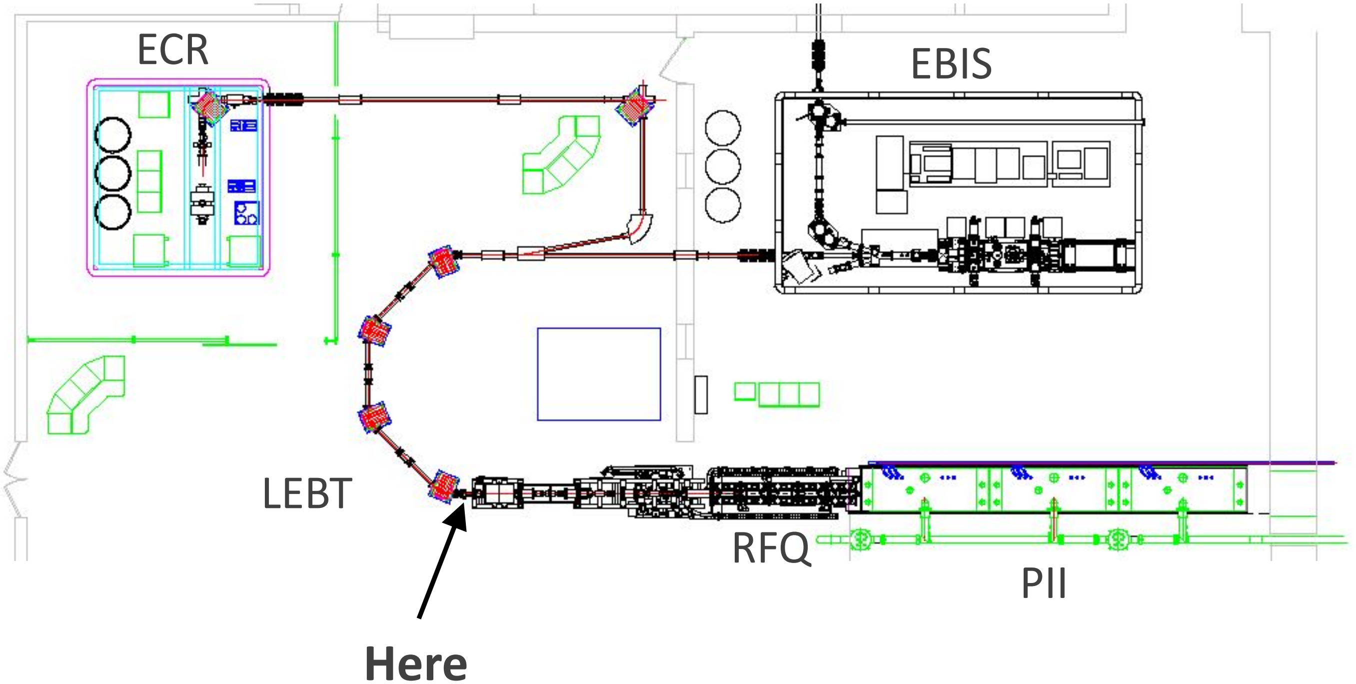


Example: $^{132}Sn^{27+}$ from EBIS and $^{48}Ca^{10+}$ from ECR

$^{48}Ca^{10+}$ $^{132}Sn^{27+}$

Combined beams in the LEBT

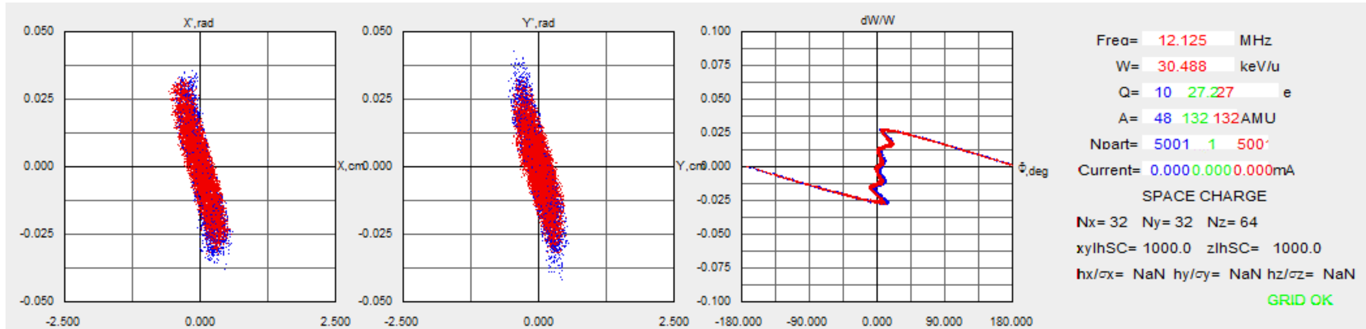


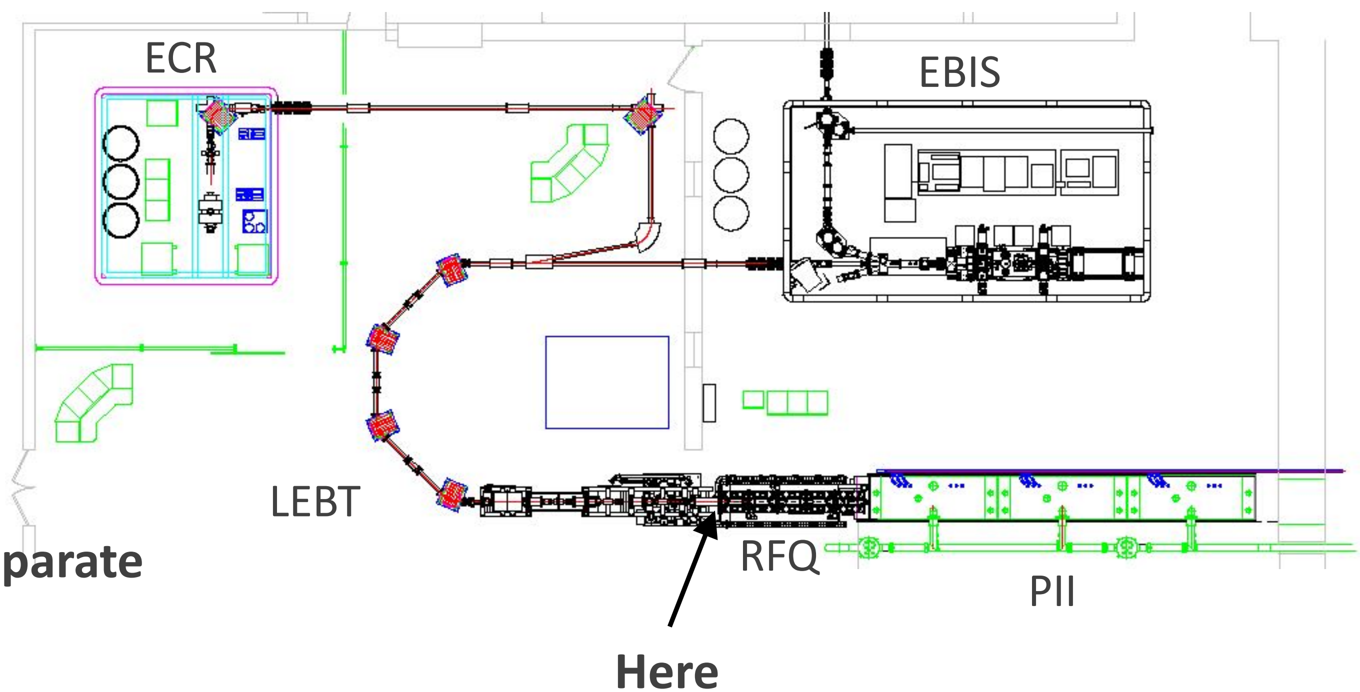


Example: $^{132}Sn^{27+}$ from EBIS and $^{48}Ca^{10+}$ from ECR

$^{48}Ca^{10+}$ $^{132}Sn^{27+}$

Two beams injected into the RFQ @ 30 keV/u



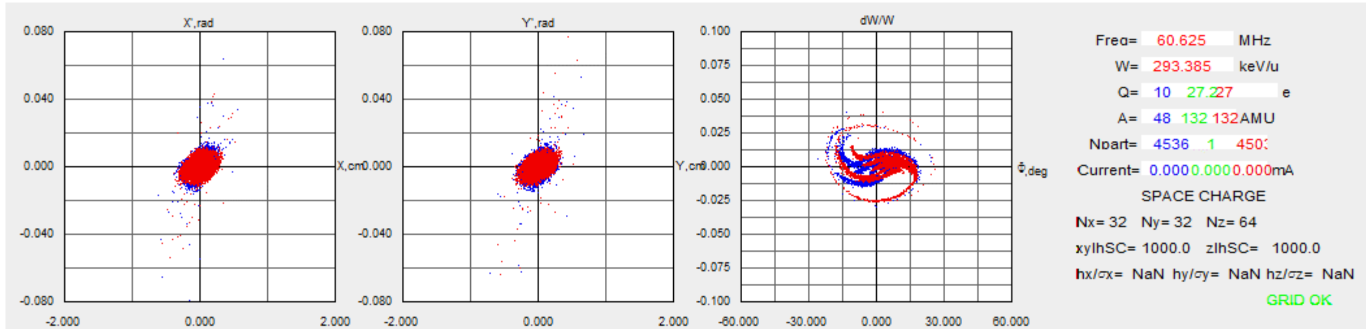


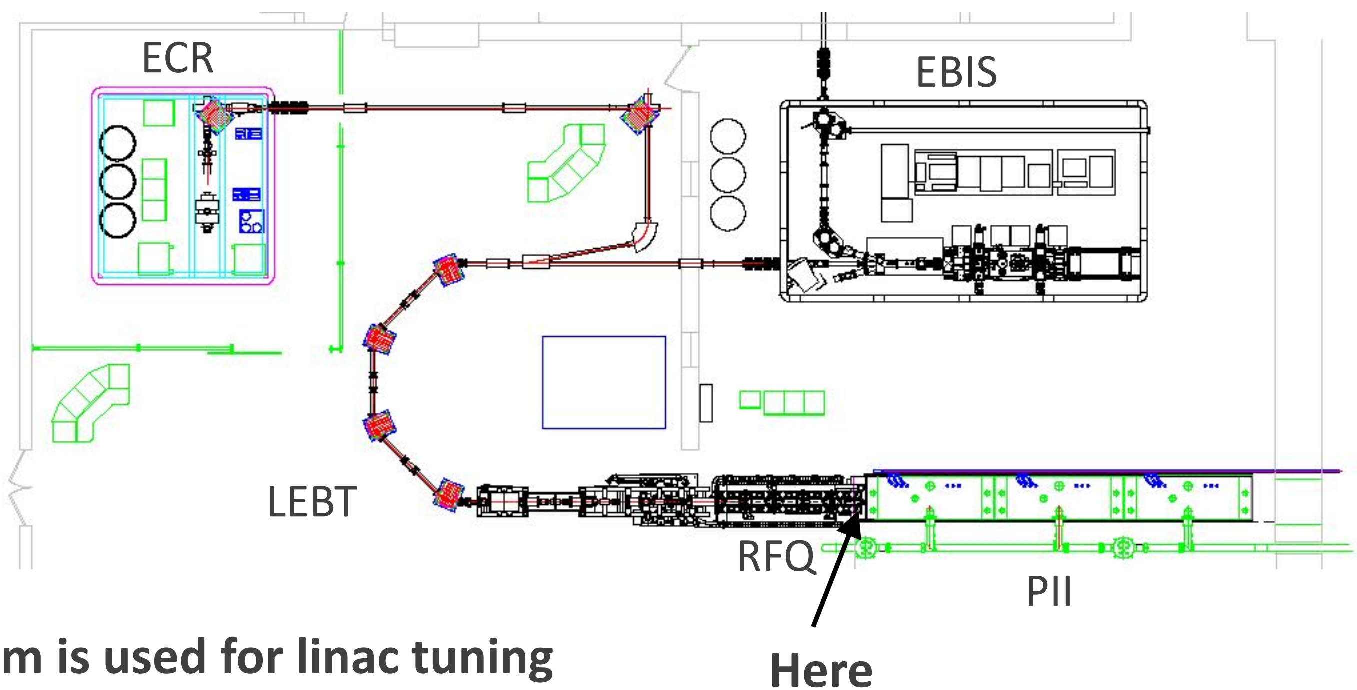
Injection into separate RF buckets

Example: $^{132}Sn^{27+}$ from EBIS and $^{48}Ca^{10+}$ from ECR

$^{48}Ca^{10+}$ $^{132}Sn^{27+}$

Two beams
out of RFQ into PII
@ ~ 300 keV/u



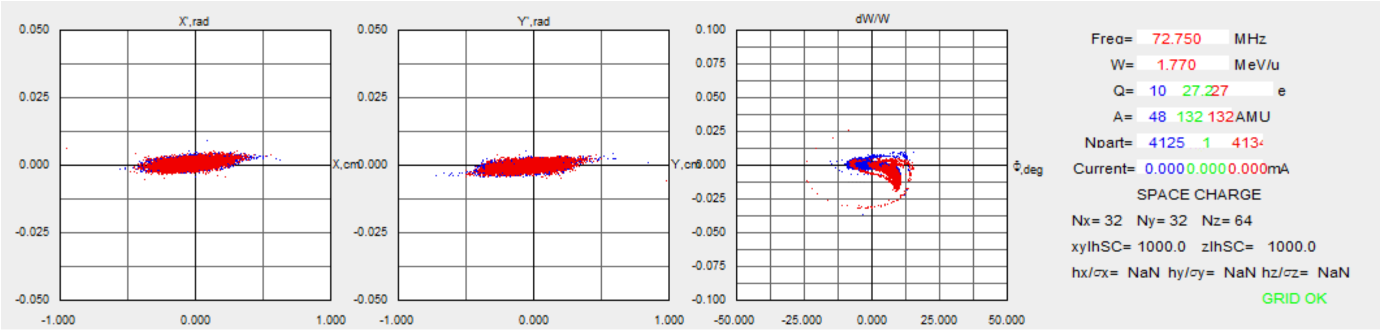


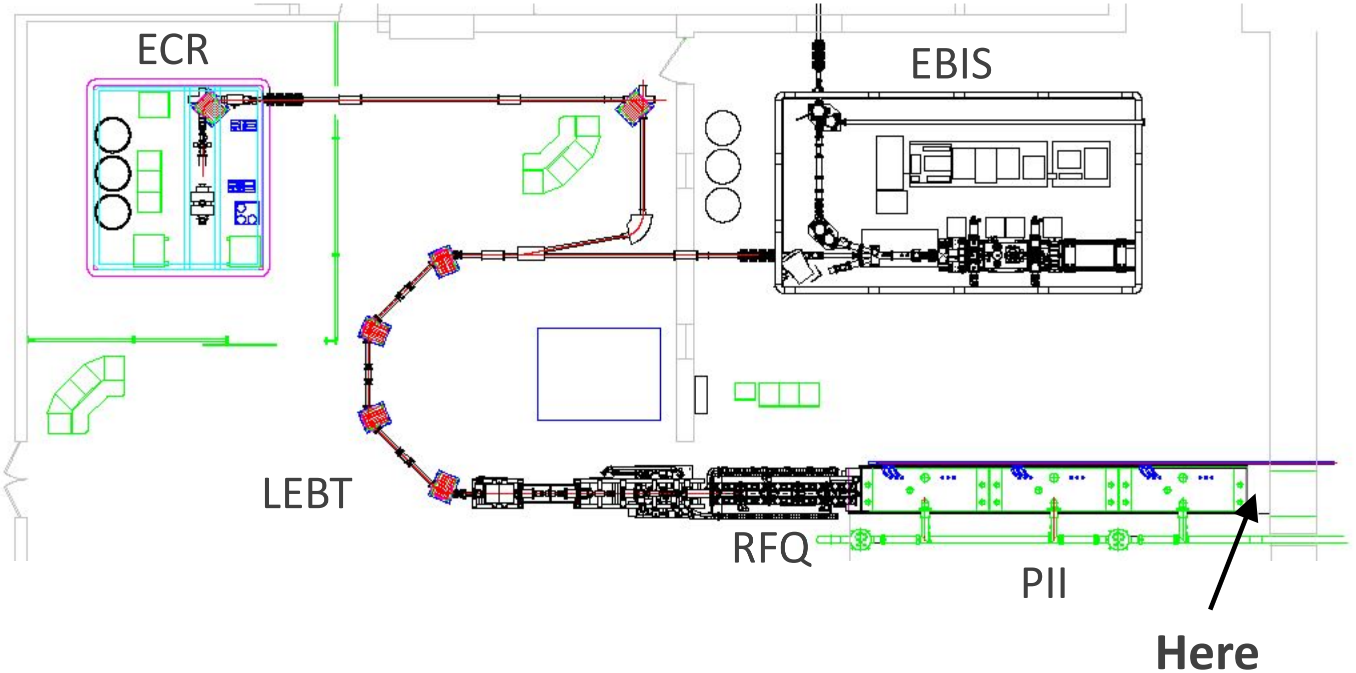
The stable beam is used for linac tuning

Example: $^{132}Sn^{27+}$ from EBIS and $^{48}Ca^{10+}$ from ECR

$^{48}Ca^{10+}$ $^{132}Sn^{27+}$

Two beams out of PII into Booster @ ~ 1.5 MeV/u

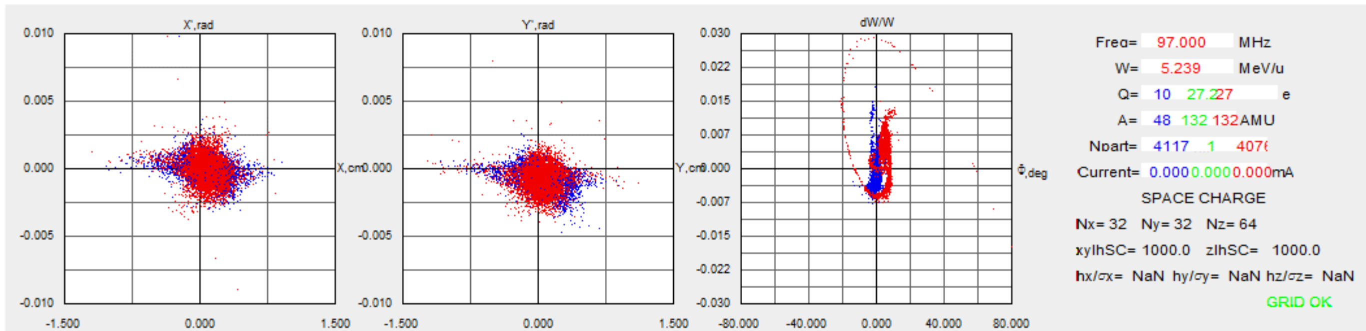


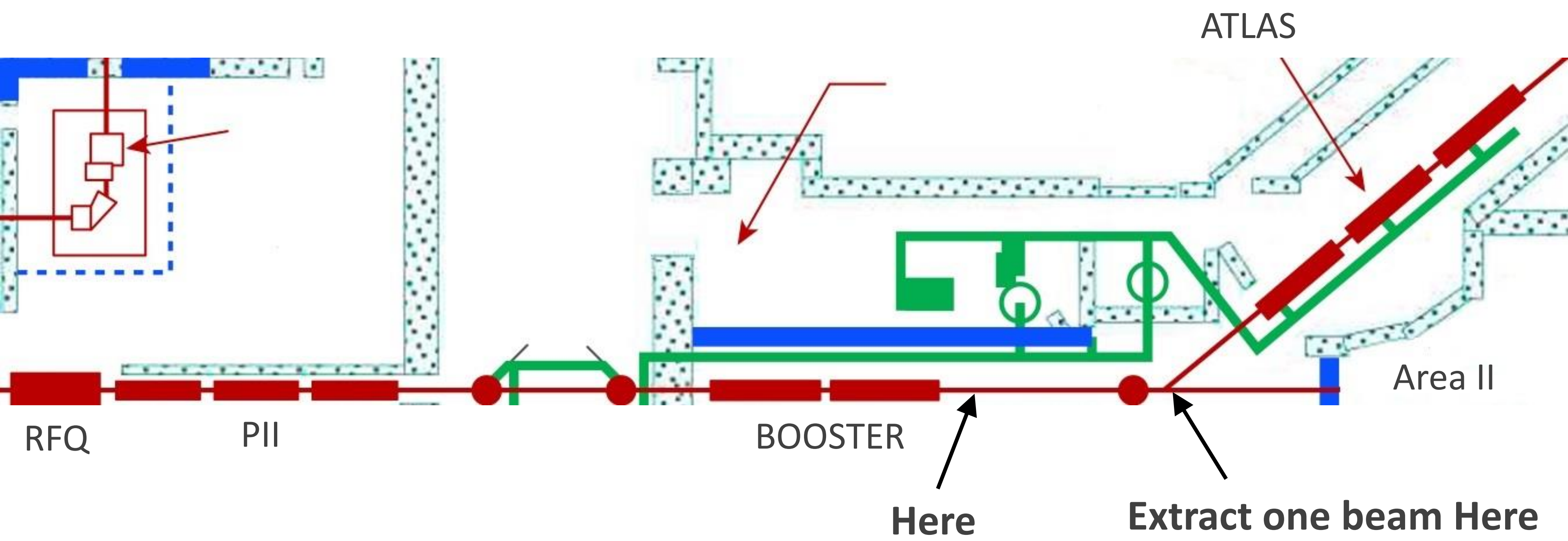


Example: $^{132}Sn^{27+}$ from EBIS and $^{48}Ca^{10+}$ from ECR

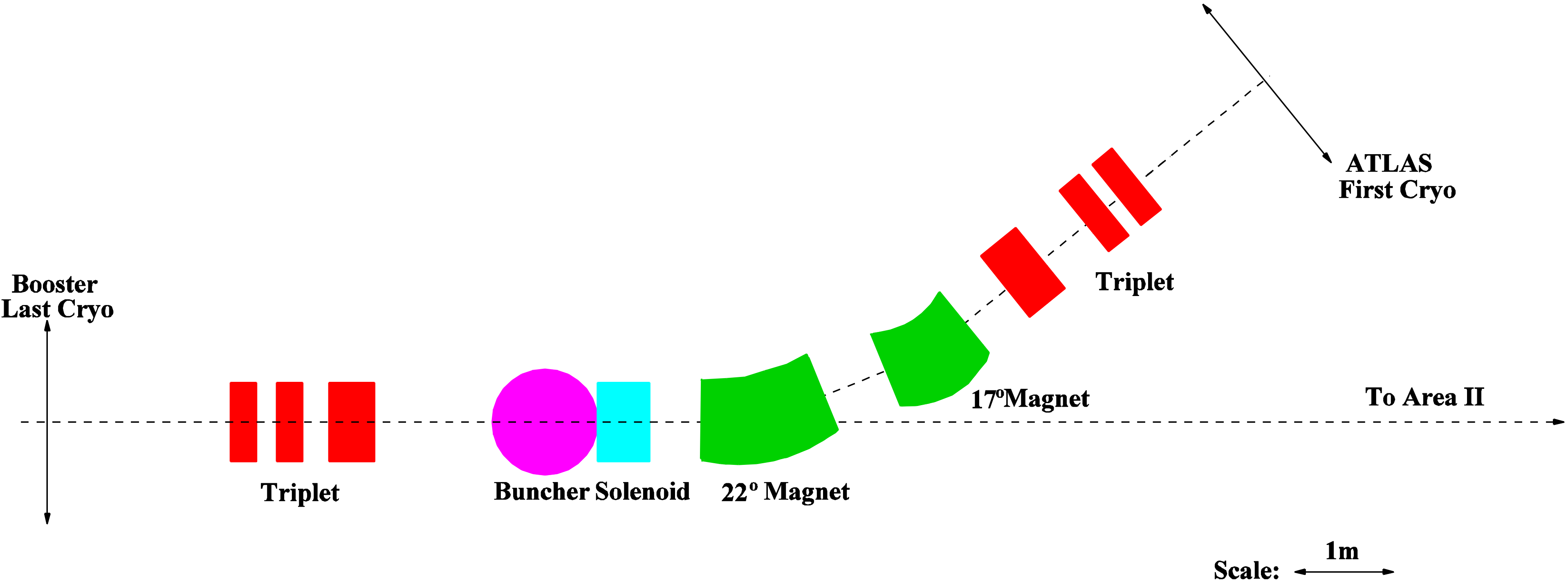
$^{48}Ca^{10+}$ $^{132}Sn^{27+}$

Two beams out of Booster @ 5.9 MeV/u



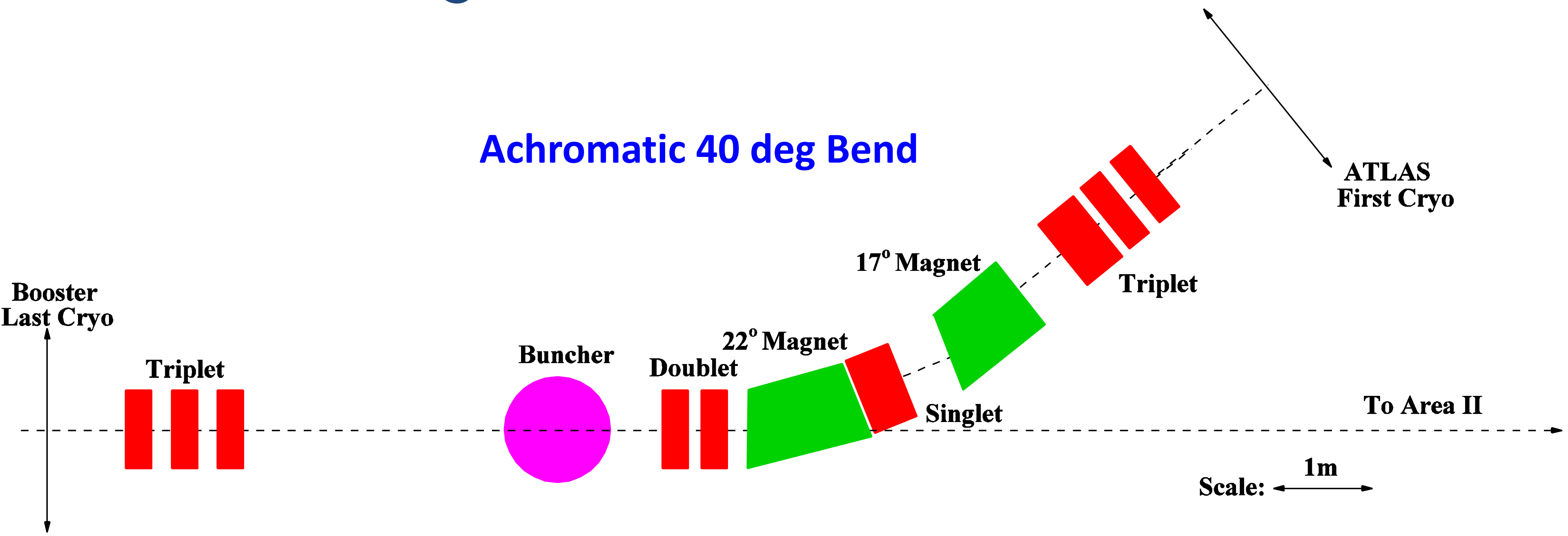


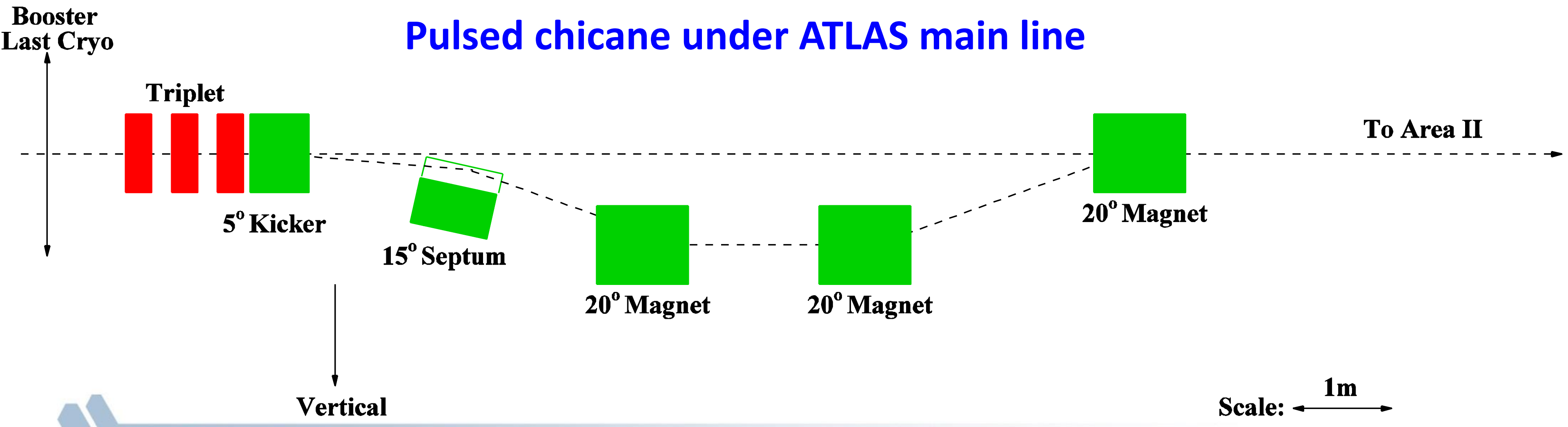
Existing 40 deg Bend Area



- ✓ Non Achromatic, not suited for multiple beam transport
- ✓ Difficult to tune

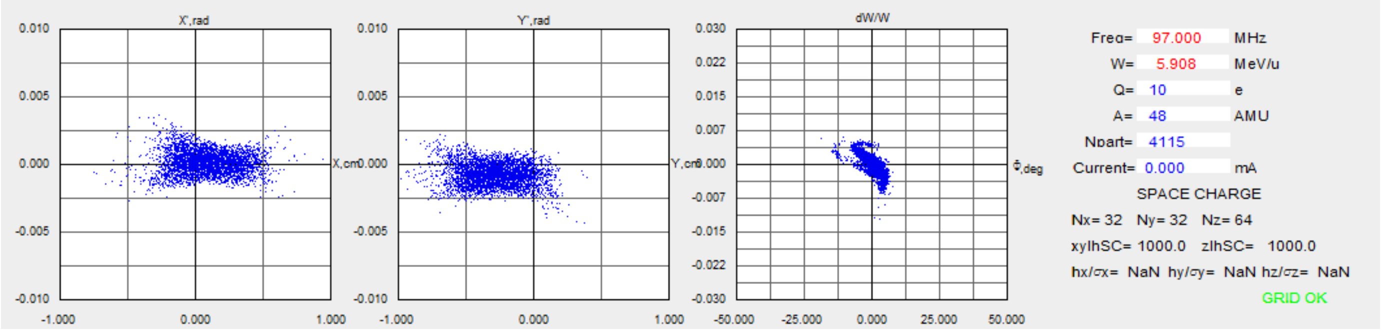
Modified 40 deg Bend Area for One Beam Extraction

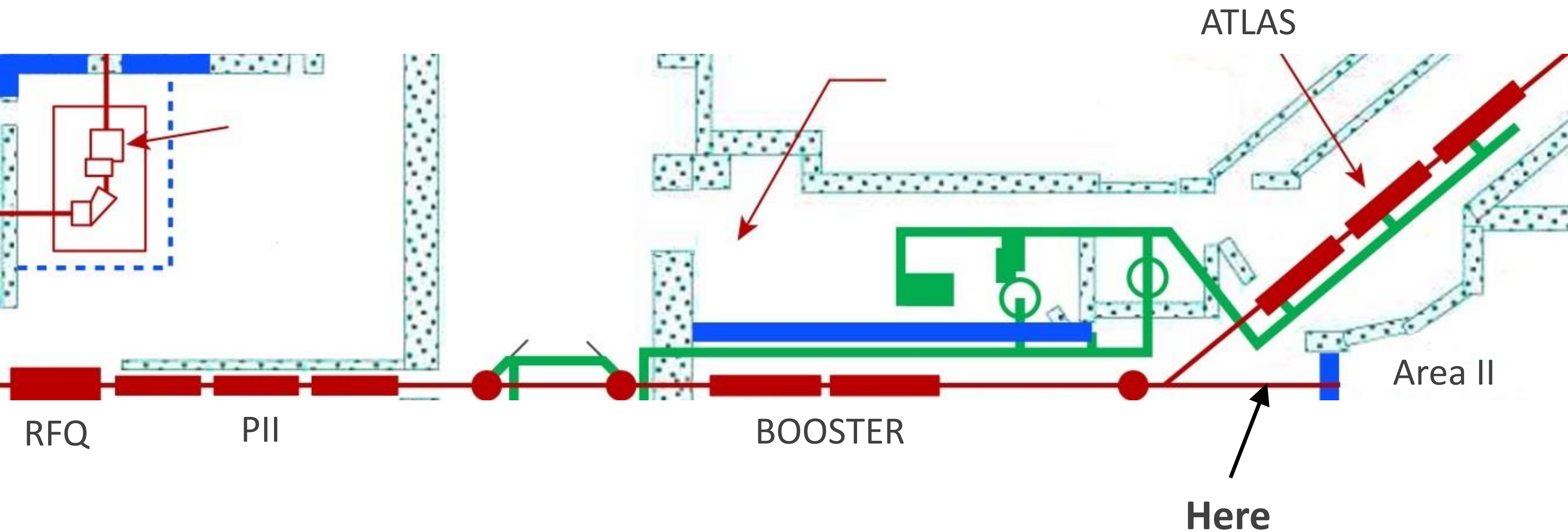




Example: $^{132}Sn^{27+}$ from EBIS and $^{48}Ca^{10+}$ from ECR

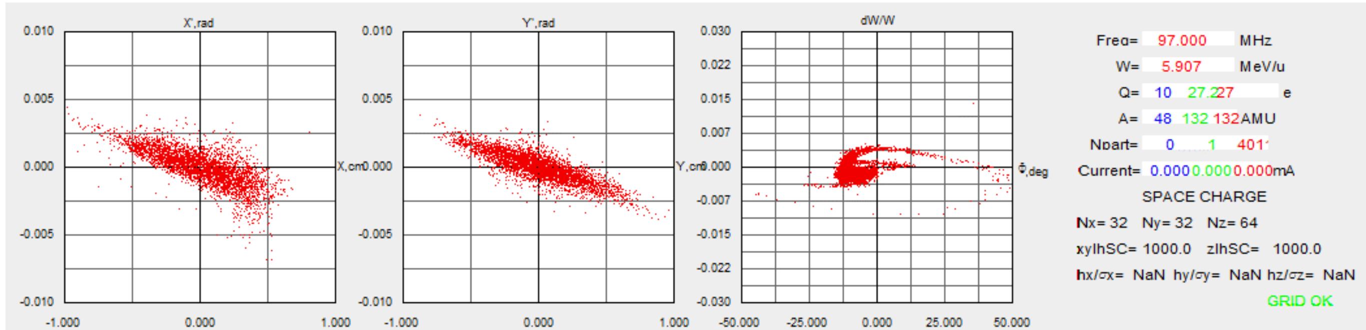
$^{48}Ca^{10+}$ at 5.9 MeV/u extracted and sent to Area II

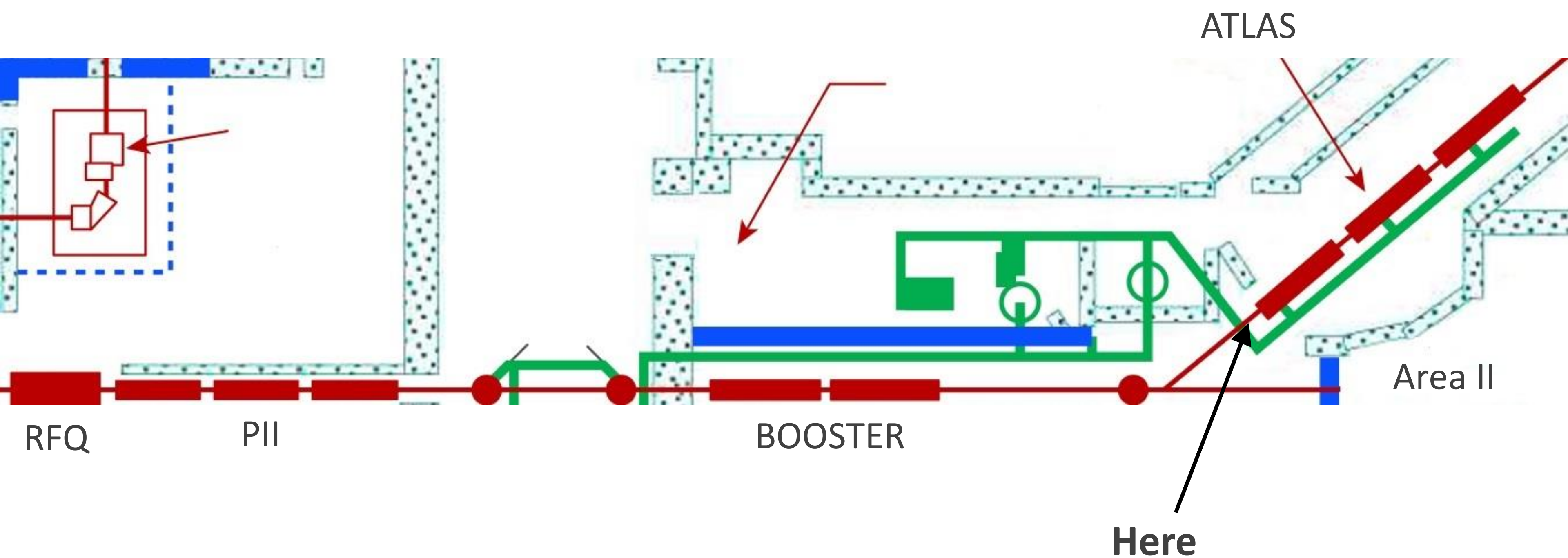




Example: $^{132}Sn^{27+}$ from EBIS and $^{48}Ca^{10+}$ from ECR

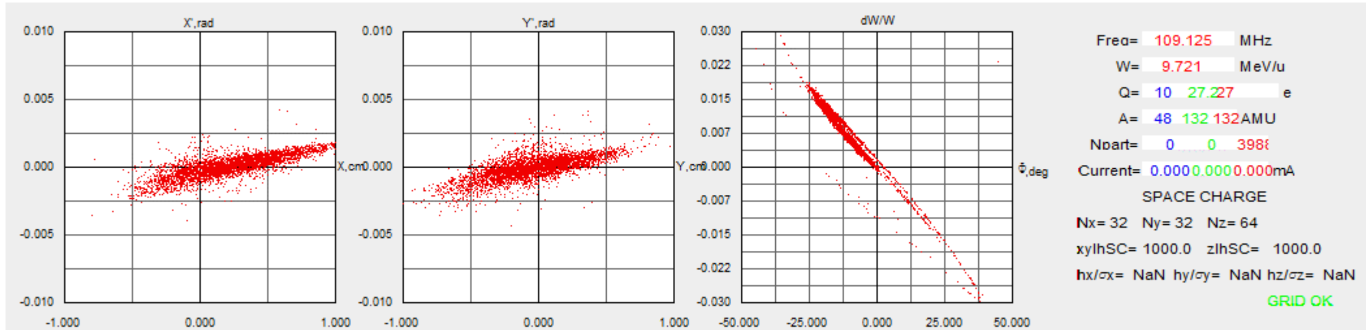
$^{132}Sn^{27+}$ at 5.9 MeV/u injected into ATLAS

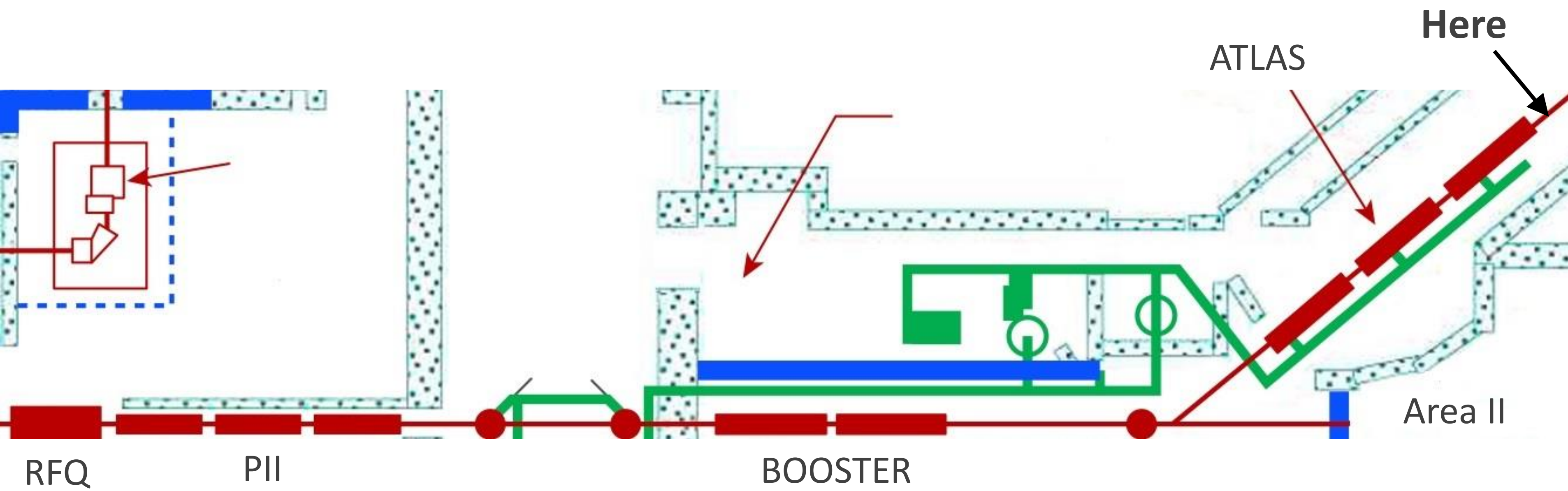




Example: $^{132}Sn^{27+}$ from EBIS and $^{48}Ca^{10+}$ from ECR

$^{132}Sn^{27+}$ at 10 MeV/u out of ATLAS to Areas III or IV





Examples of Possible Simultaneous Stable and RIB Beams

Q/A	Stable ATLAS beams	CARIBU beams
0.25000	$^{20}Ne^{5+}$, $^{28}Si^{7+}$, $^{36}Ar^{9+}$	$^{84}Se^{21+}$, $^{88}Kr^{22+}$, $^{92}Sr^{23+}$, $^{101}Mo^{25+}$, $^{105}Ru^{26+}$
0.24138	$^{58}Ni^{14+}$	$^{83}As^{20+}$, $^{95}Y^{23+}$, $^{104}Tc^{25+}$, $^{112}Pd^{27+}$, $^{117}Cd^{28+}$
0.24000	$^{50}Ti^{12+}$	$^{88}Br^{21+}$, $^{91}Rb^{22+}$, $^{101}Zr^{24+}$, $^{105}Ru^{25+}$, $^{117}Cd^{28+}$
0.23809	$^{63}Cu^{15+}$	$^{89}Rb^{21+}$, $^{97}Sr^{23+}$, $^{105}Mo^{25+}$, $^{109}Rh^{26+}$, $^{113}Ag^{27+}$
0.23596	$^{89}Y^{21+}$	$^{89}Kr^{21+}$, $^{97}Sr^{23+}$, $^{102}Zr^{24+}$, $^{111}Rh^{26+}$, $^{119}Cd^{28+}$
0.23214	$^{56}Fe^{13+}$	$^{94}Kr^{22+}$, $^{100}Sr^{23+}$, $^{113}Rh^{26+}$, $^{126}Sn^{29+}$, $^{143}Ce^{33+}$
0.22917	$^{48}Ti^{11+}$, $^{74}Ge^{17+}$	$^{92}Kr^{21+}$, $^{105}Nb^{24+}$, $^{109}Tc^{25+}$, $^{119}Pd^{27+}$, $^{149}Nd^{34+}$
0.22857	$^{35}Cl^{8+}$	$^{100}Y^{23+}$, $^{109}Tc^{25+}$, $^{127}Sn^{29+}$, $^{132}I^{30+}$, $^{159}Gd^{36+}$
0.22500	$^{40}Ca^{9+}$, $^{102}Ru^{23+}$, $^{120}Sn^{27+}$	$^{89}Br^{20+}$, $^{112}Rh^{25+}$, $^{139}Xe^{31+}$, $^{157}Sm^{35+}$, $^{156}Eu^{35+}$
0.22368	$^{76}Ge^{17+}$	$^{90}Br^{20+}$, $^{99}Sr^{22+}$, $^{135}Te^{30+}$, $^{128}Cs^{31+}$, $^{161}Gd^{36+}$
0.22034	$^{59}Co^{13+}$	$^{91}Rb^{20+}$, $^{105}Zr^{23+}$, $^{123}Cd^{27+}$, $^{131}Te^{29+}$, $^{146}Pr^{32+}$
0.20513	$^{78}Kr^{16+}$	$^{93}Y^{19+}$, $^{102}Mo^{21+}$, $^{132}Sn^{27+}$, $^{141}I^{29+}$, $^{162}Eu^{34+}$
0.20408	$^{98}Mo^{20+}$	$^{98}Sr^{20+}$, $^{108}Mo^{22+}$, $^{117}Pd^{24+}$, $^{136}Sb^{28+}$, $^{161}Sm^{33+}$
0.20312	$^{64}Zn^{13+}$	$^{83}Se^{17+}$, $^{93}Y^{19+}$, $^{117}Ag^{24+}$, $^{132}I^{27+}$, $^{166}Tb^{34+}$

More Examples of Possible Simultaneous Beams …

Q/A	Stable ATLAS beams	CARIBU beams
0.20000	$^{40}Ar^{8+}$, $^{60}Ni^{12+}$, $^{90}Zr^{18+}$, $^{130}Te^{26+}$	$^{85}Se^{17+}$, $^{110}Mo^{22+}$, $^{124}In^{25+}$, $^{141}I^{28+}$, $^{159}Pm^{32+}$
0.18939	$^{132}Xe^{25+}$	$^{105}Ru^{20+}$, $^{126}In^{24+}$, $^{137}I^{26+}$, $^{153}Pr^{29+}$, $^{165}Tb^{31+}$
0.17968	$^{128}Xe^{23+}$	$^{95}Y^{17+}$, $^{105}Tc^{19+}$, $^{134}Sn^{24+}$, $^{144}Xe^{26+}$, $^{149}La^{27+}$
0.17857	$^{84}Kr^{15+}$	$^{100}Nb^{18+}$, $^{111}Tc^{20+}$, $^{117}Cd^{21+}$, $^{141}Xe^{25+}$, $^{147}La^{26+}$
0.17721	$^{79}Br^{14+}$, $^{107}Ag^{19+}$	$^{96}Rb^{17+}$, $^{107}Nb^{19+}$, $^{119}Cd^{21+}$, $^{135}Te^{24+}$, $^{151}Nd^{27+}$
0.17500	$^{80}Se^{14+}$	$^{91}Kr^{16+}$, $^{97}Zr^{17+}$, $^{109}Ru^{19+}$, $^{131}Sb^{23+}$, $^{143}Ba^{25+}$
0.15546	$^{238}U^{37+}$	$^{83}Se^{13+}$, $^{90}Kr^{14+}$, $^{97}Sr^{15+}$, $^{103}Zr^{16+}$, $^{141}I^{22+}$
0.15116	$^{86}Kr^{13+}$	$^{86}Se^{13+}$, $^{92}Rb^{22+}$, $^{100}Sr^{23+}$, $^{105}Zr^{24+}$, $^{106}Nb^{24+}$
0.15000	$^{180}Hf^{27+}$	$^{87}Br^{13+}$, $^{94}Kr^{14+}$, $^{100}Sr^{15+}$, $^{101}Y^{15+}$, $^{107}Nb^{16+}$
0.14904	$^{208}Pb^{31+}$	$^{88}Se^{13+}$, $^{88}Br^{13+}$, $^{94}Rb^{14+}$, $^{100}Y^{15+}$, $^{107}Nb^{16+}$
0.14832	$^{209}Bi^{31+}$	$^{87}Se^{13+}$, $^{87}Br^{13+}$, $^{95}Rb^{14+}$, $^{102}Y^{15+}$, $^{108}Nb^{16+}$
0.14721	$^{197}Au^{29+}$	$^{89}Se^{13+}$, $^{89}Br^{13+}$, $^{95}Rb^{14+}$, $^{102}Y^{15+}$, $^{108}Nb^{16+}$
0.14286	$^{133}Cs^{19+}$	$^{84}As^{12+}$, $^{98}Rb^{14+}$, …

Stable and RIB Beams have q/A within 1% → A lot of flexibility

Stage I of the ATLAS Multi-User Upgrade

- Will allow:
  - The simultaneous acceleration of two beams
  - One stable from ATLAS-ECR and one radioactive from CARIBU-EBIS
  - One to the Booster energy and one to the full ATLAS energy

- Will require:
  - Installing the newly developed EBIS charge breeder, coming in 2015
  - Building an achromatic LEBT upstream of the RFQ
  - Building a pulsed switchyard for one beam extraction at the end of Booster

Stage II of the ATLAS Multi-User Upgrade

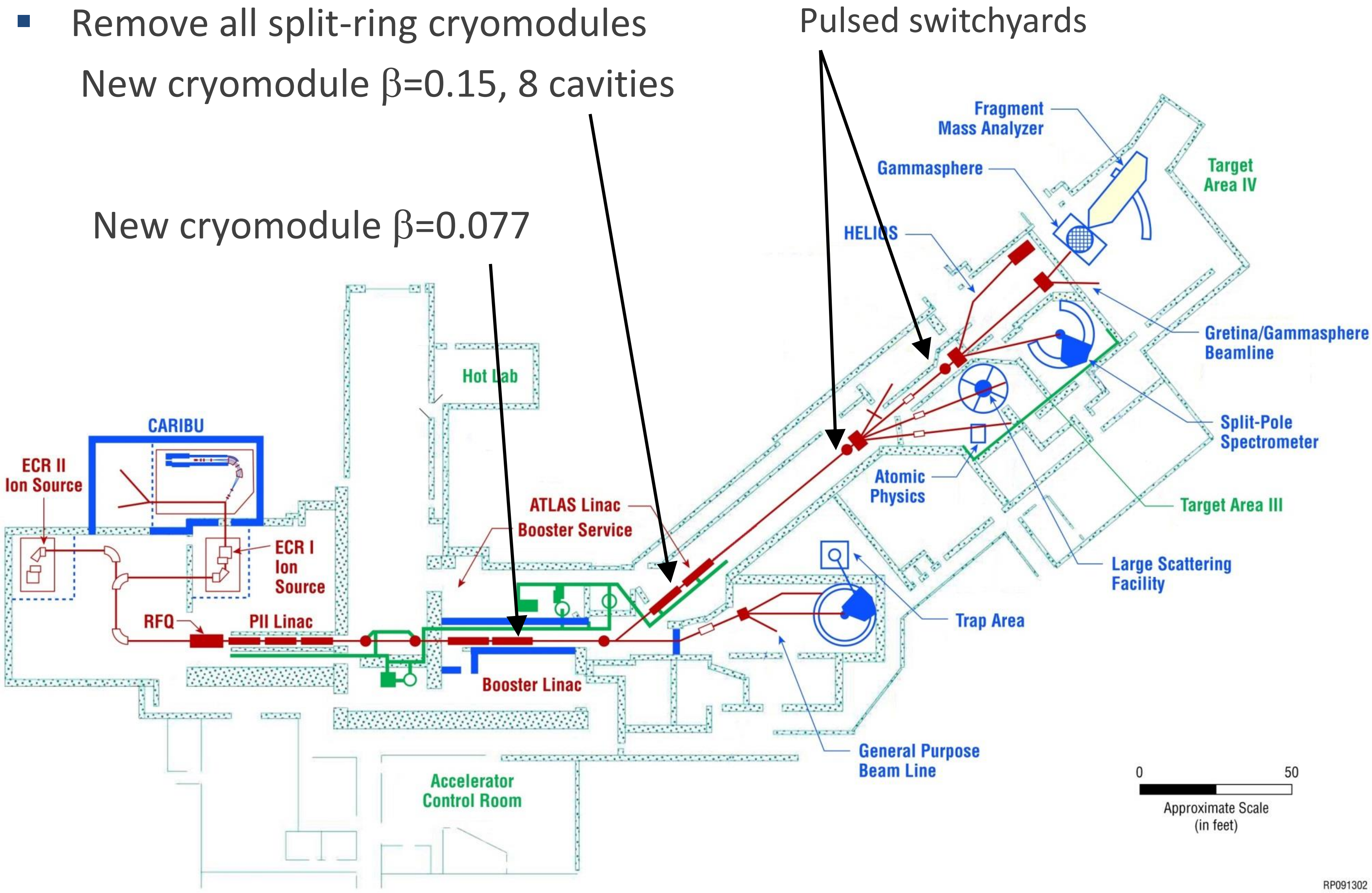
- Will allow:
  - Simultaneous acceleration of two beams (one stable and one radioactive) to the full energy of ATLAS
  - The acceleration of higher intensity stable beams to the full ATLAS energy

    → Higher intensity inflight radioactive beams from the future AIRIS separator

- Will require:
  - Replacing three old split-ring cryostats with at least one new QWR cryostats.
  - Modifying the 40-deg bend to be achromatic
  - Reconfiguring the shielding to accommodate higher intensity beams in ATLAS
  - Creating pulsed switchyards downstream of ATLAS

Stage II of Multi-User Upgrade

- Remove all split-ring cryomodules



Stage III of the ATLAS Multi-User Upgrade

- Will allow:
  - The simultaneous acceleration of three beams; two stable and one radioactive to either Booster or ATLAS energy to serve 3 different experiments simultaneously
  - Even higher intensity ATLAS beams, both stable from a new SC ECR and radioactive by combining multiple charge states
  - Intensities of stable beams will be a factor of 5-10 higher than now

- Will require:
  - Replacing one of the existing ECRs with a new high-performance SC ECR source
  - Developing and installing a chopper system in the LEBT to inject two stable beams with close q/A into two separate RF buckets of the RFQ
  - Modifying the injection for multiple-charge-state radioactive beams from EBIS
  - Developing and installing two RF switchyards for Areas II and III
  - Modifying experimental beam lines to allow the transport of multiple-charge-state and larger emittance beams

Summary

- With the EBIS online installation it will possible to simultaneously accelerate stable and radioactive beams in ATLAS and increase the available beam time for the users

- Phase I of the Multi-User Upgrade can be implemented within 2 years at low cost → serving two experiments at the same time

- Phase II: Replacement of remaining 3 split-ring cryomodules with one or two QWR cryomodules → acceleration of two beams to the highest available energies, including dual charge state beam from CARIBU-EBIS

- Phase III: A new SC ECR source and RF injection and extraction system → serve three experimental areas simultaneously with more flexibility