ATLAS 25th Anniversary Celebration
October 22-23, 2010

ATLAS Upgrade Plans – Technology

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October 23, 2010


The Future
NEXT EXIT

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- ATLAS Efficiency and Intensity Upgrade
  - Beam Intensity limitations in the ATLAS
  - Description and Layout of the Fully Funded Upgrade Projects
- CW Radio Frequency Quadrupole (RFQ) development
- New Low-beta Cryomodule Development
- Charge Breeder for CARIBU based on Electron Beam Ion Source
- Future plans for the ATLAS Upgrade

Efficiency and Intensity Limitations of the Current ATLAS

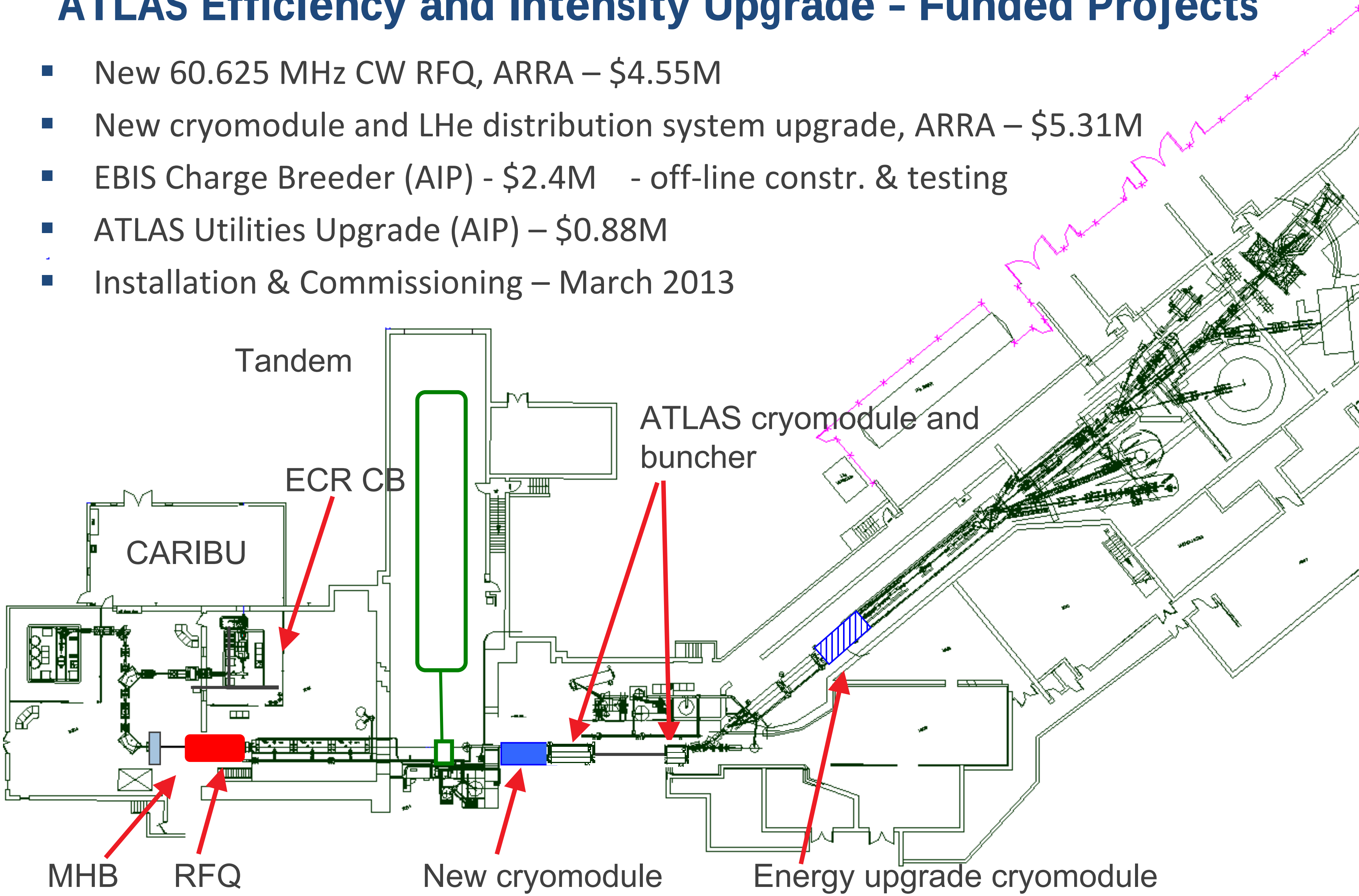
- Previous generation ECR
- ECR charge breeder for CARIBU: low efficiency, long breeding time
- Low Energy Beam Transport: emittance growth, beam losses
- Multi-Harmonic Buncher
  - Low voltage, strong space charge effects
  - As a result not efficient for high current beams (>10 pμA)
- Low transverse acceptance of the first PII cryostat
  - The aperture diameter of the first cavity is 15 mm, the second cavity – 19 mm
  - The transverse acceptance is ~0.6 π mm-mrad, normalized
- Longitudinal emittance
  - Strong transverse-longitudinal coupling in the first cavities at high field
  - Non-adiabatic motion in the phase space, low acceptance, emittance growth for high-intensity beams and beam losses
- Beam steering in the split-ring cavities, especially for light ions
- Space limitation for new experimental equipment, for example, new in-flight separator
- RF system, Cryogenics, Radiation Shielding, Control system, Beam diagnostics

Scope of the Funded ATLAS Efficiency and Intensity Upgrade Projects and Proposals for Future Upgrades

- Deliver $\geq$7 MeV/u high-intensity (~10 pμA) ion beams for experiments
- The maximum beam energy of medium intensity beams (~1 pμA) will be increased to ~11 MeV/u for A/q=7 without any additional stripping and to over 20 MeV/u for beams with A/q<3 (such as $^{40}Ar^{14+}$).
- Increase the efficiency of CARIBU charge breeding by using an EBIS up to 25%
- Increase the overall transmission of any ion beam, including CARIBU radioactive beams, to 80% of the intensity of DC beams from the source/breeder.
- Replace the ATLAS ECR-II ion source with a 'third generation' superconducting ECR source.
- Add new in-flight separator to produce high-intensity in-flight secondary beams
- Upgrade ATLAS technical systems (RF, Beam Instrumentation, Controls, ARIS) and radiation shielding to handle higher intensity beams
- Improve efficiency of the LHe distribution system
- Remove Tandem and create space for low-energy experiments with radioactive beams
- Move and extend SRF facility

ATLAS Efficiency and Intensity Upgrade - Funded Projects

- New 60.625 MHz CW RFQ, ARRA – $4.55M
- New cryomodule and LHe distribution system upgrade, ARRA – $5.31M
- EBIS Charge Breeder (AIP) - $2.4M - off-line constr. & testing
- ATLAS Utilities Upgrade (AIP) – $0.88M
- Installation & Commissioning – March 2013

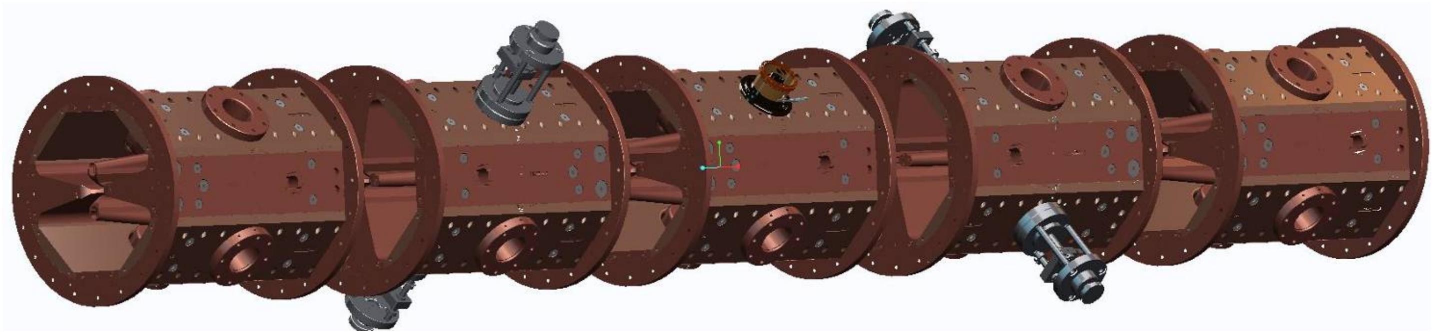


ARRA RFQ Project

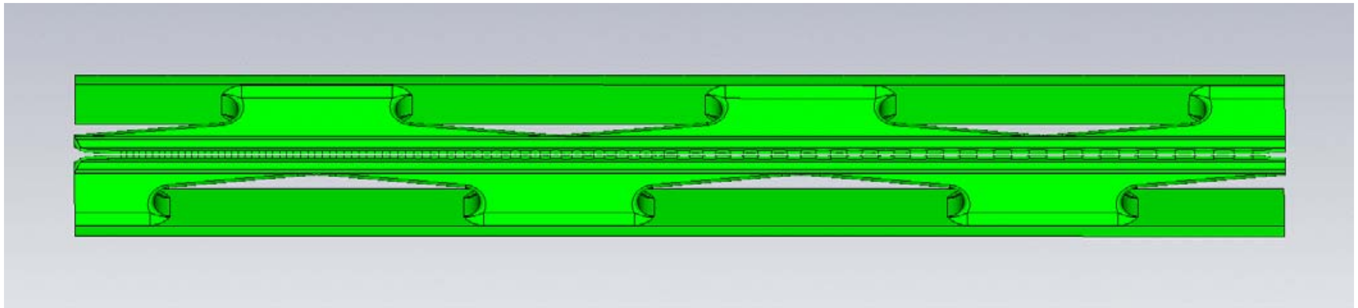
- CW regime of operation
- 60.625 MHz, 5^{th} harmonic, 3.9-meter length
- Any ions in the $1/7 \leq q/A \leq 1$ range
- 83 % efficiency of beam capture for acceleration
- OFE copper, high-temperature furnace brazing
- 5 segments of 30”-length each
- Total calculated RF power - 53kW
- New features
  - Forms axially-symmetric beam
  - Very low longitudinal emittance
  - Increased efficiency of acceleration by using trapezoidal vane tip modulation

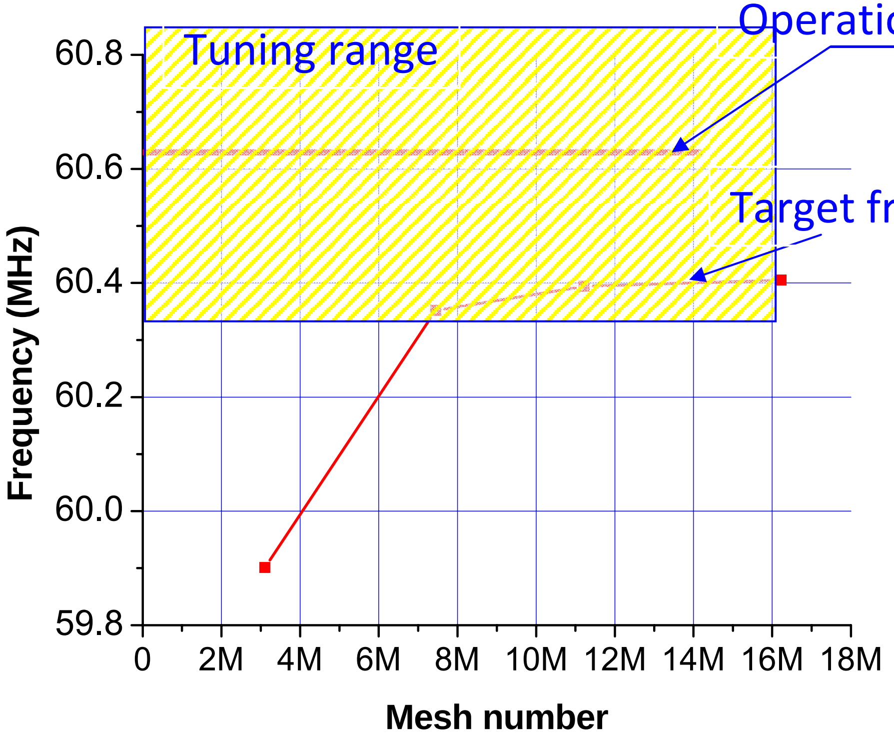
Prototype segment (2006)

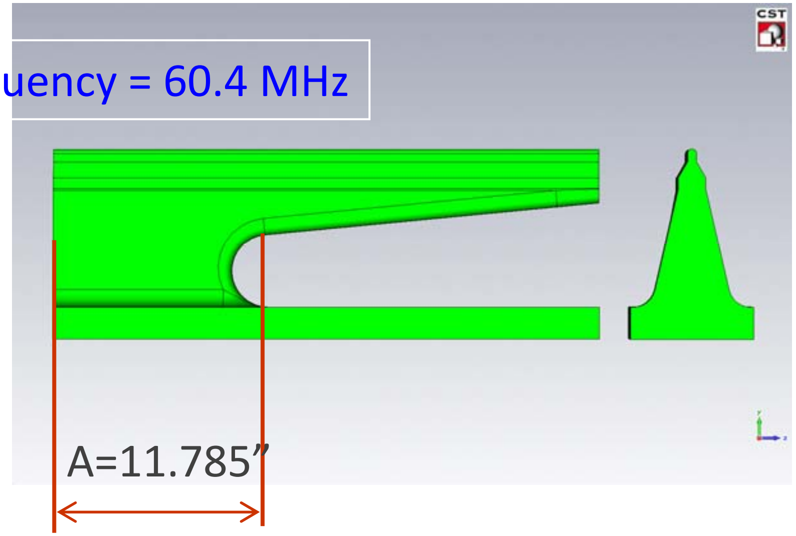
Exploded view of 5 segment RFQ



Frequency of the 5-segment RFQ, MWS Model with Modulated Vanes





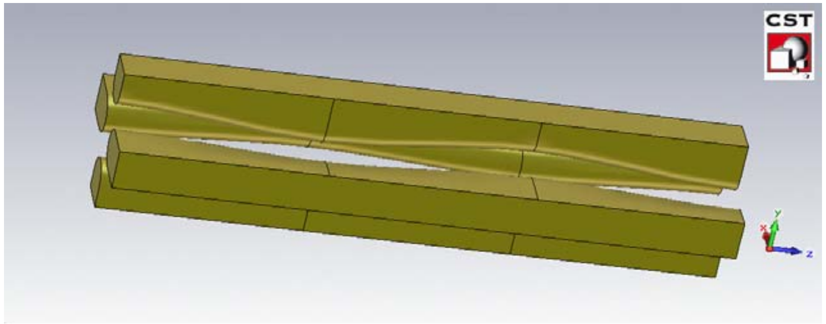


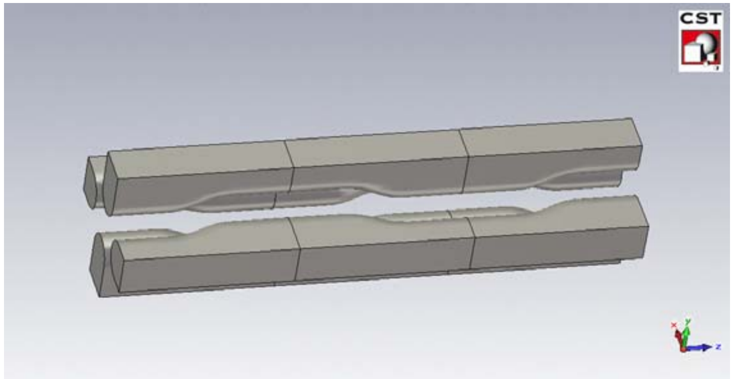
Increased Efficiency of the RFQ Accelerating Field

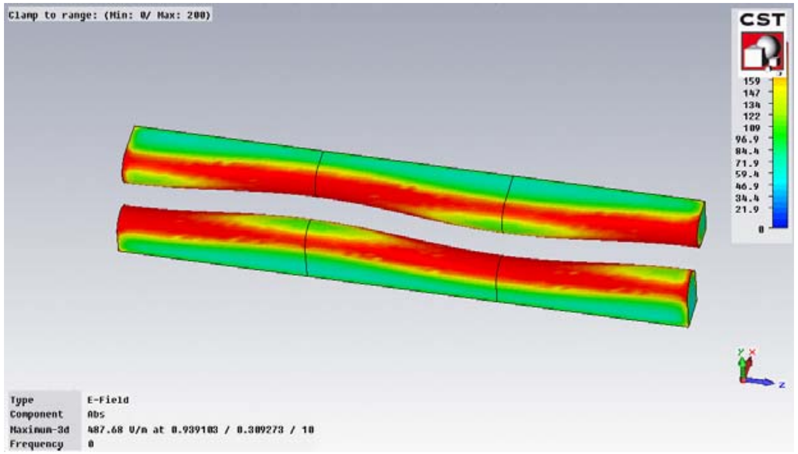
- Conventional approach

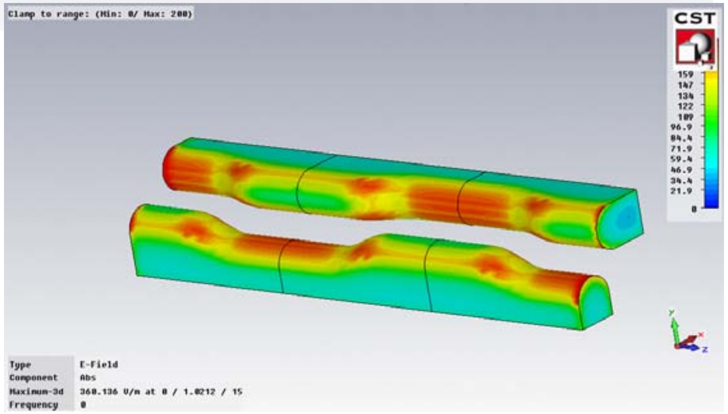
ANL approach

Based on design developed at IHEP, Protvino (Russia)

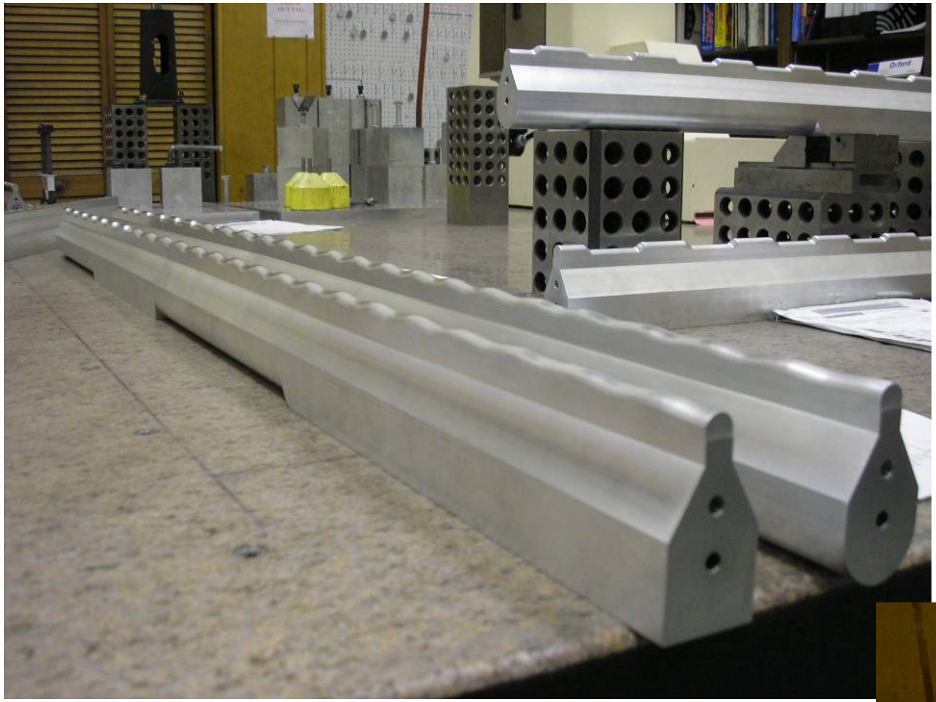






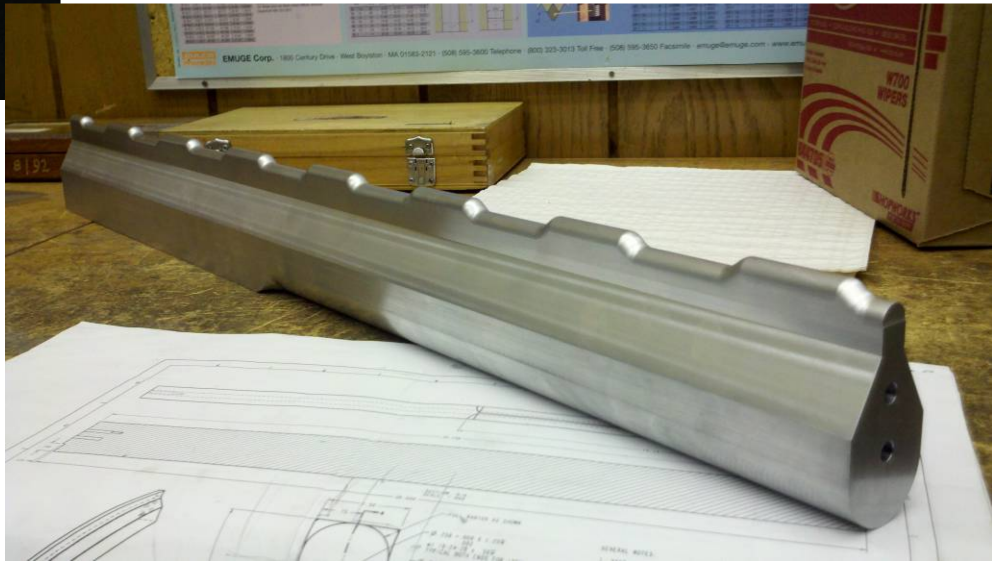


Vane Tip Modulation



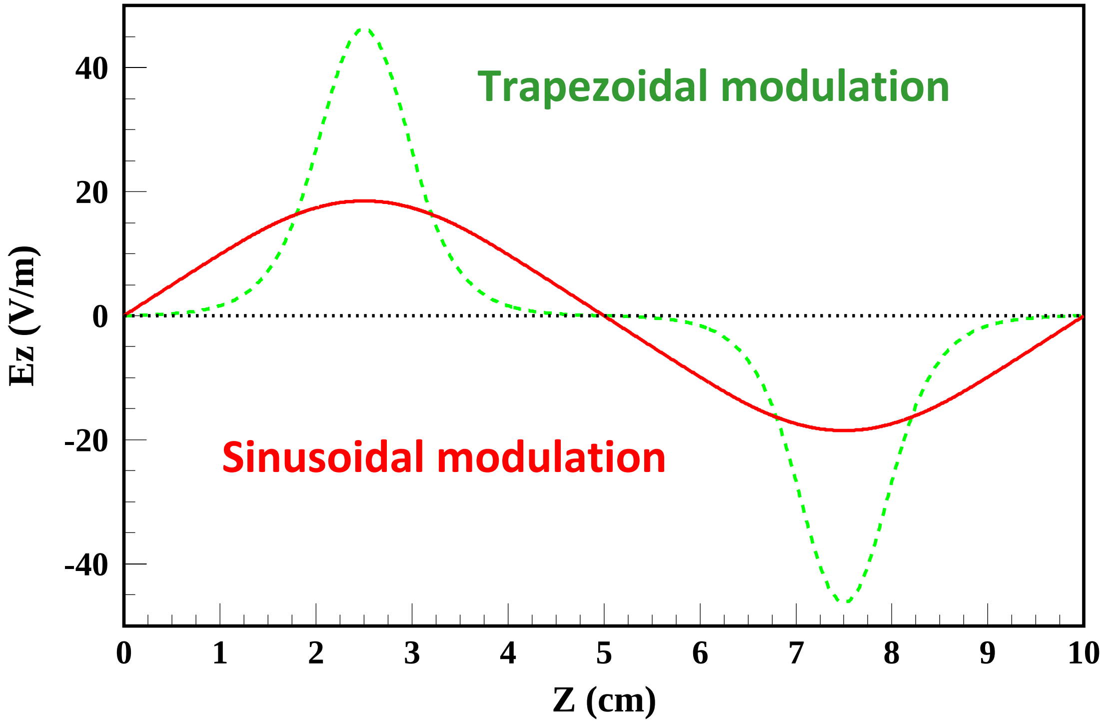
Initial section is sinusoidal

Accelerating section is trapezoidal



Accelerating Field in the RFQ

- Increased effective accelerating field due to the higher transit time factor
  - ATLAS RFQ: energy increase from 250 keV/u to 295 keV/u
  - Equivalent voltage gain in the modified section is 400 kV
  - The same RF power

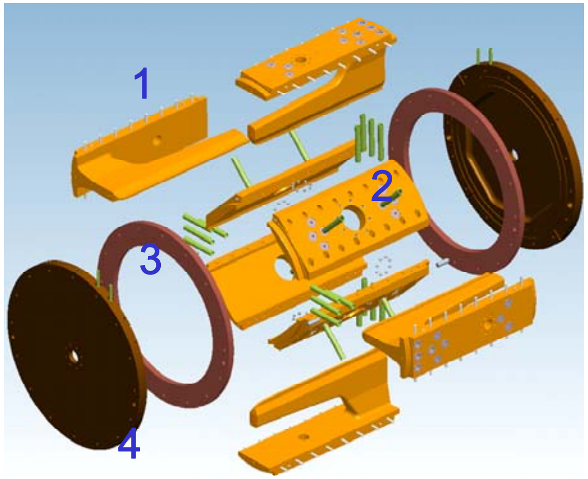


RFQ Fabrication Technology

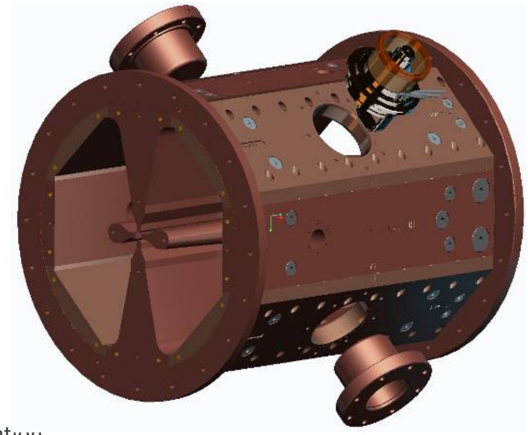
1. Forge OFE copper to near-net-shape (Weldaloy)
2. Rough machine components (Walco)
3. Drill coolant passages (Carlson)
4. Braze coolant passage plugs & tubes (ANL)
5. Finish machine components (Walco)
6. Machine vane tips (Walco)
7. Pre-braze assembly to check fit and frequency (Walco)
8. Braze segment (California Brazing)
9. Final machine (Walco)
10. CMM is used after each step

All these vendors have experience with the fabrication of the RIA Prototype RFQ

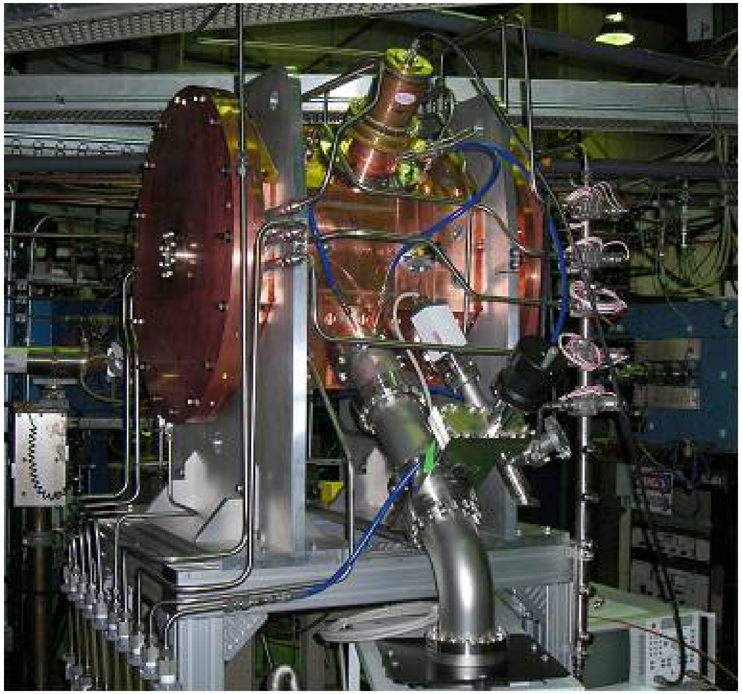
Exploded View RFQ segment



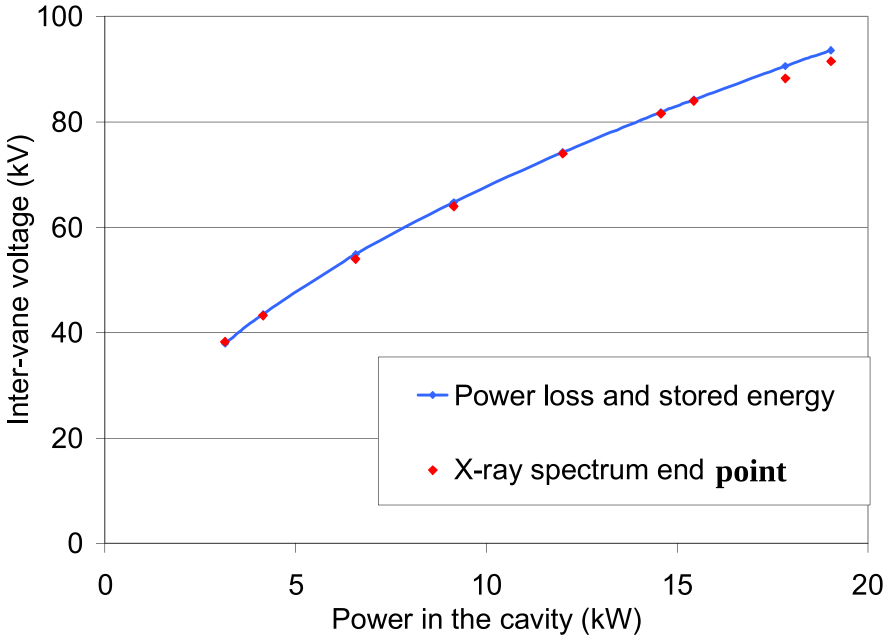
1. Vanes (4)
2. Quadrant Plates (4)
3. Body Flanges (2)
4. End Caps (2)



High power Tests of the RIA Driver Linac RFQ

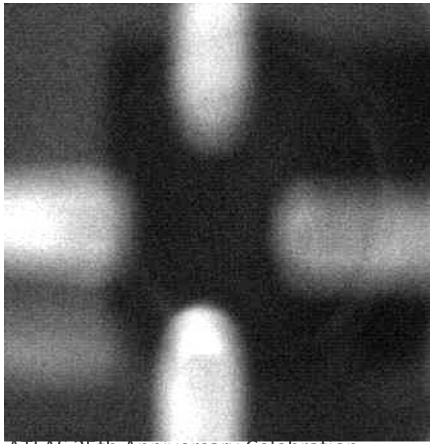


92 kV = 2×Kilpatrick



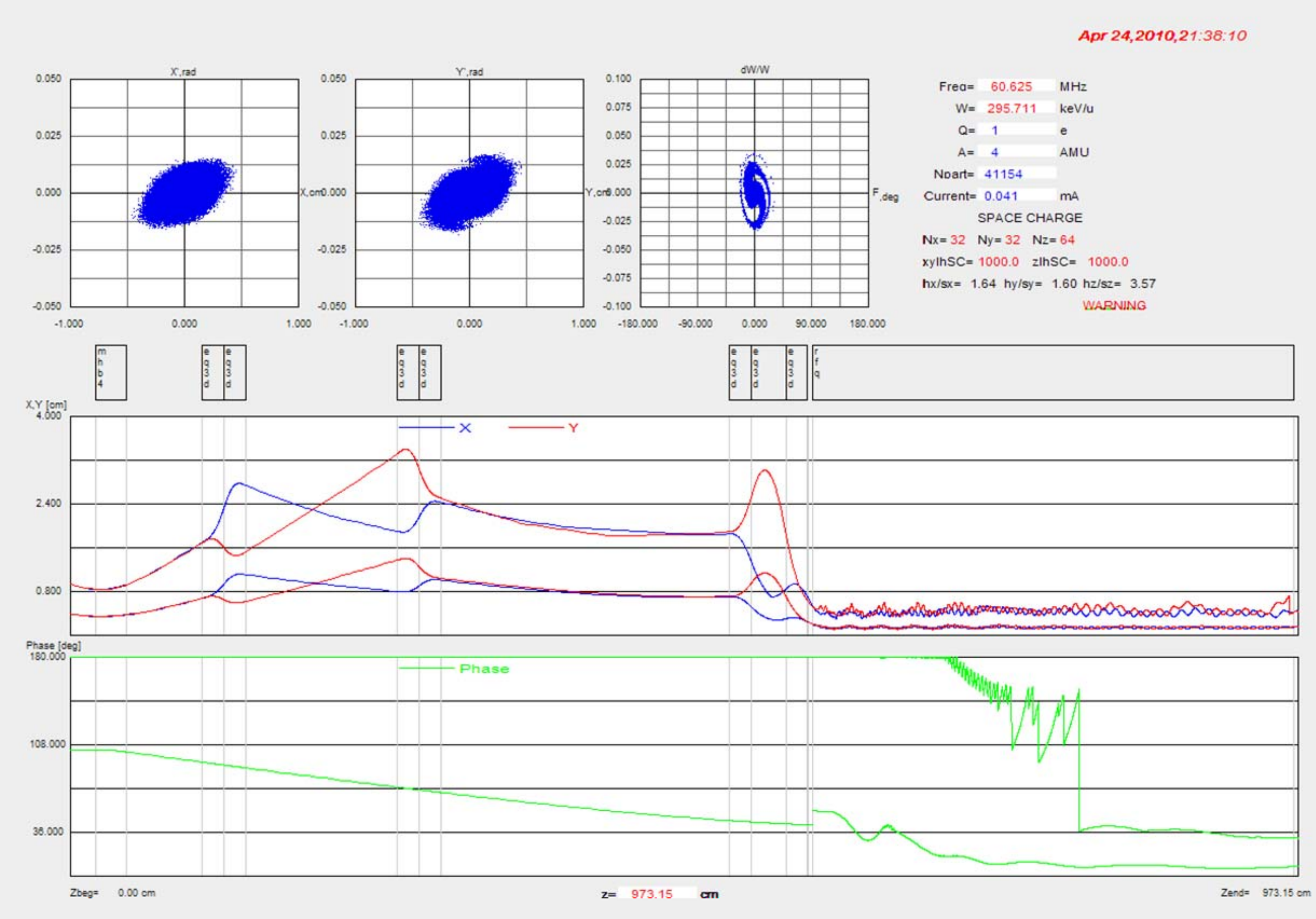
Study of the vane

tips displacement



RFQ Beam Dynamics

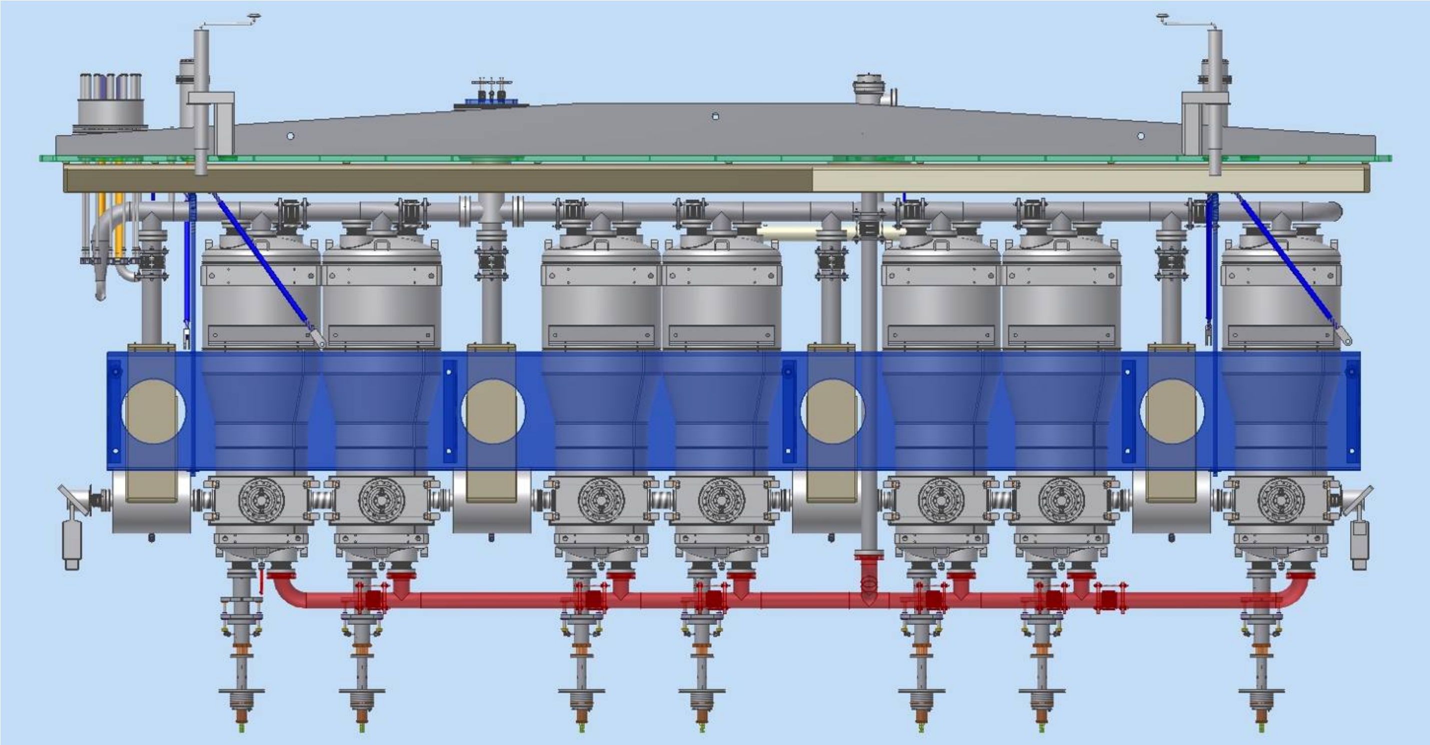
- ✓ A/q=4
- ✓ 10 pμA, 295 keV/u
- ✓ 80.5 % Capture &Acceleration efficiency
- ✓ ~ 0.8 ns×keV/u normalized longitudinal rms emittance
- ✓ Symmetric output beam for direct injection to PII



New Cryomodule

Total design voltage is 17.5 MV

5.12-meter long, separate vacuum, improved AEU design

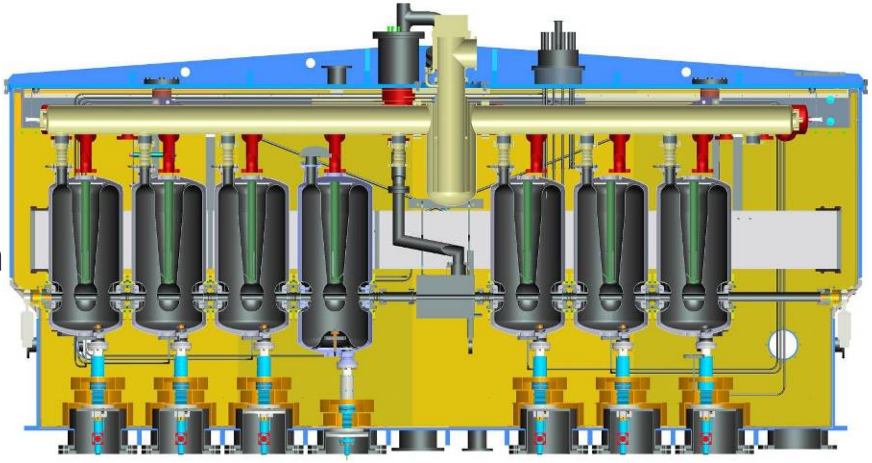


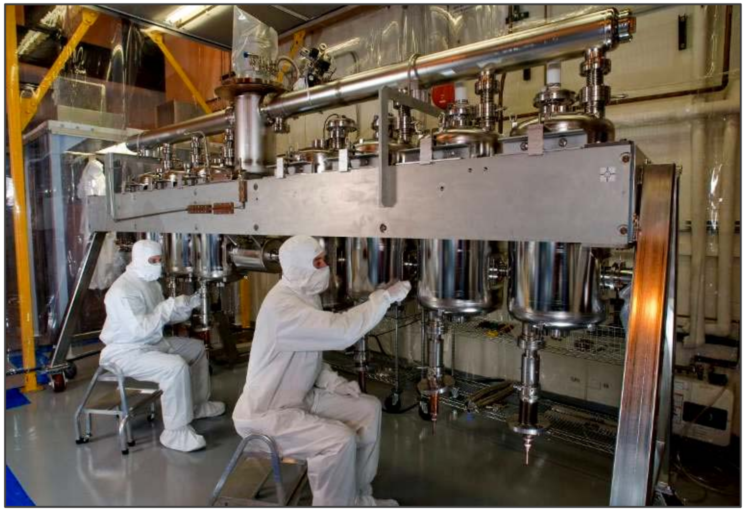
Engineering 3D model of the cavity-solenoid string

ATLAS Energy Upgrade Cryomodule is On-line since July 2009

- 7 quarter wave SC resonators
- Innovative features
  - Advanced EM and Mech. design
  - Steering corrected drift-tubes
  - State-of-the-art surface processing and clean assembly
  - Separate cavity & cryostat vacuum
- ATLAS energy increase 30-40%
  - Highest real-estate gradient 14.7MV/4.6m
- Technical basis for the development of a new cryomodule – ARRA project

beam

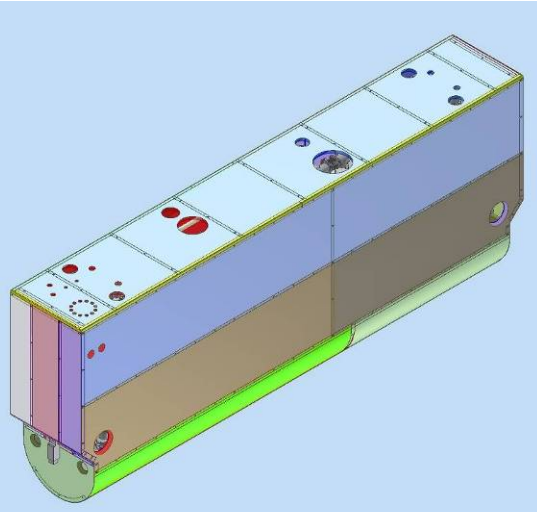




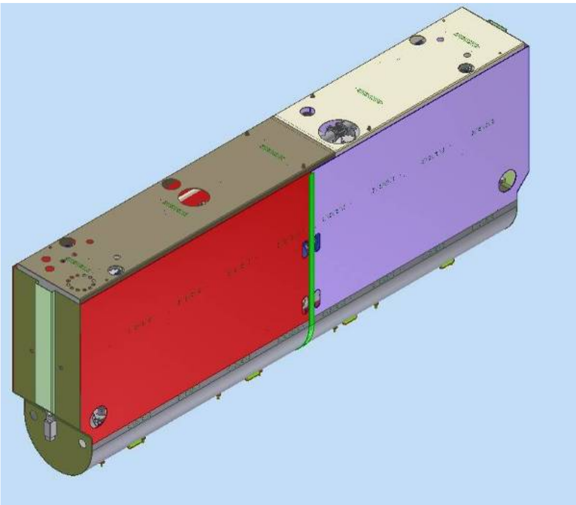
Cavity performance as measured off-line without VCX tuners:
Max. Accelerating Voltage = 3.75 MV/cavity,
E_{PEAK} = 48 MV/m, B_{PEAK} = 88 mT

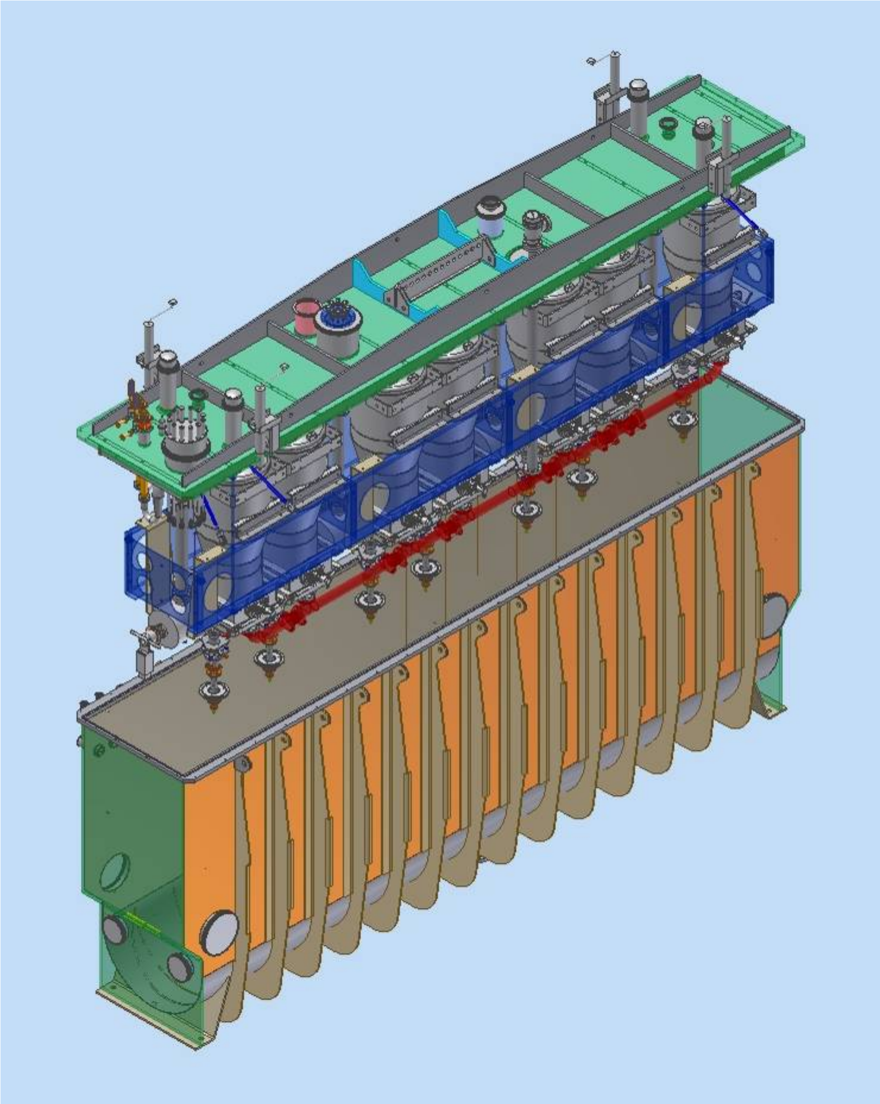
Major Components of the Cryomodule

- Magnetic shield



- Thermal shield

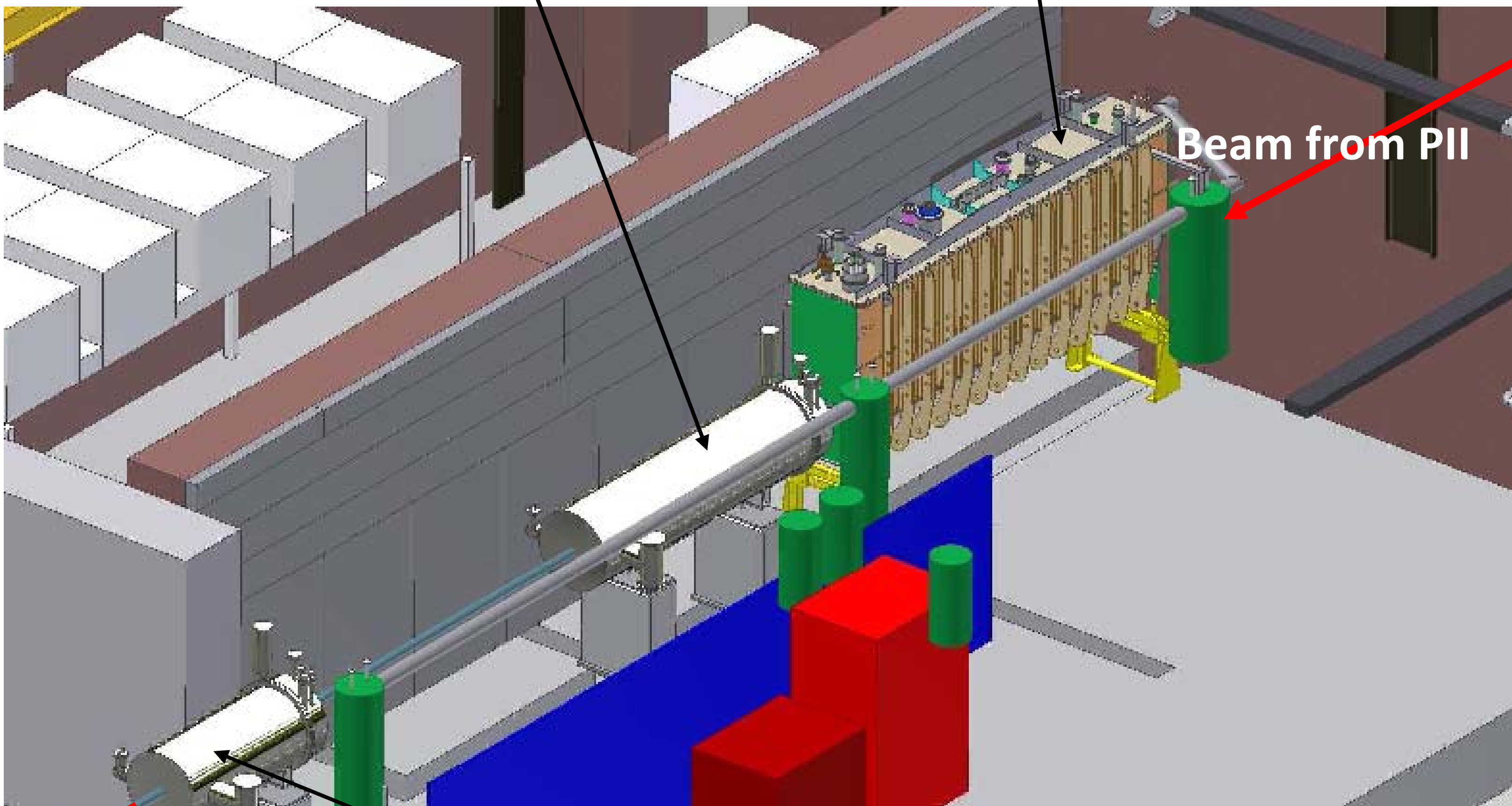




Booster Area with New Cryomodule

Existing cryomodule

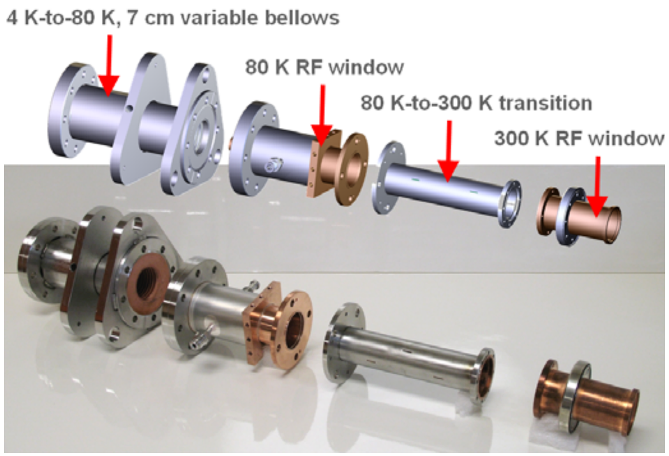
New cryomodule



Beam to the bending magnet

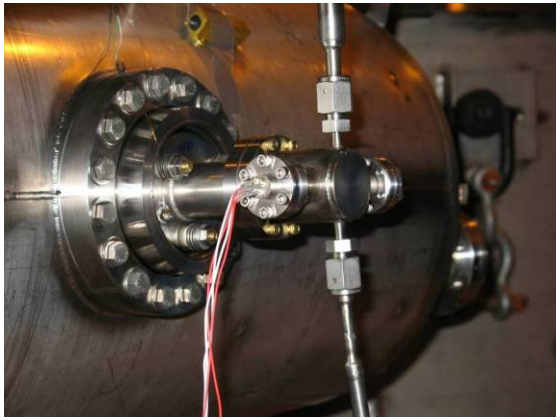
Rebuncher and SC solenoid in the existing cryostat

Cryomodule Project Hardware



- High power coupler

- Piezoelectric fast tuner



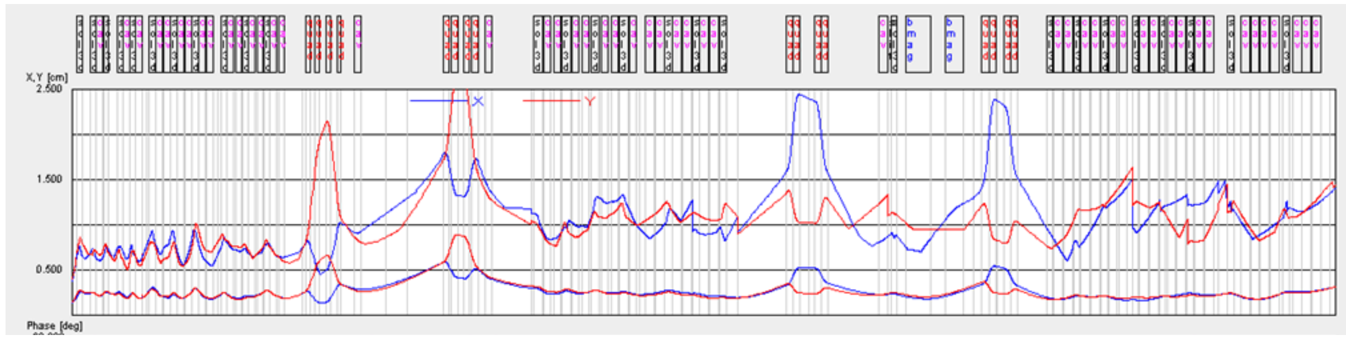
- RF test of the QWR prior final EBW. Photo is taken on Sep. 30th, 2010

Niobium Parts are Being Fabricated for Production Cavities

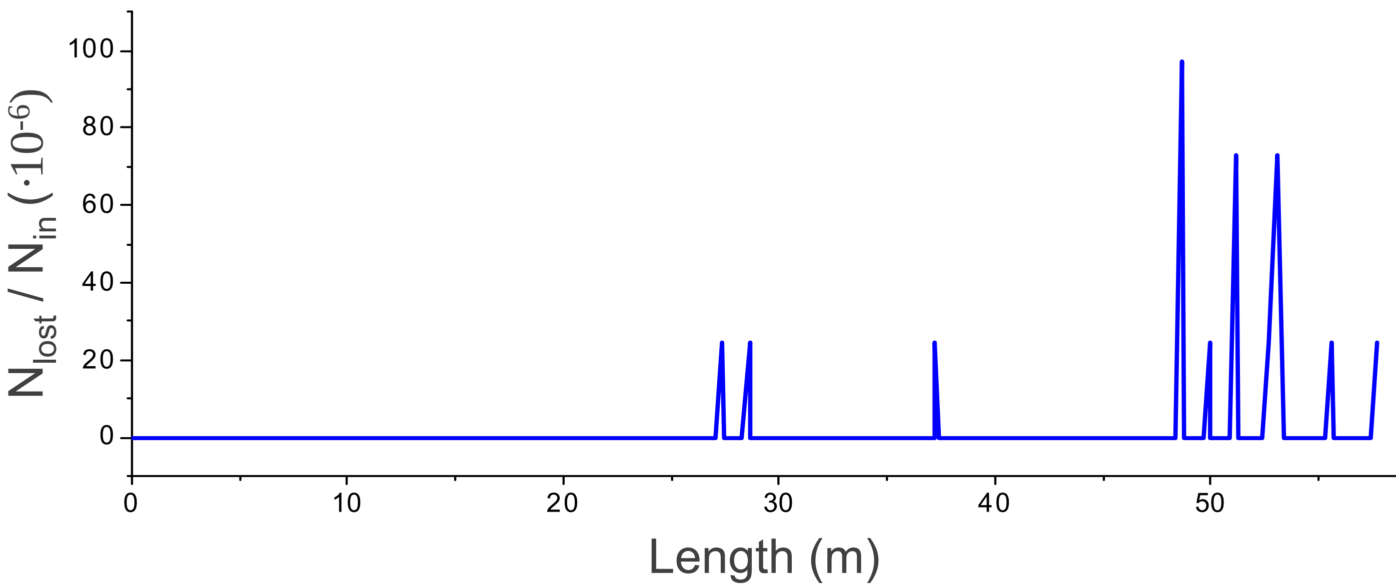
q/A=1/7 Ion Beam Envelopes , Beam Loss (<0.05%) Distribution

Beam Line →

Transverse RMS & Max. Beam Size →



Lost particles →



ATLAS Beam Energies after the ARRA Projects are Complete

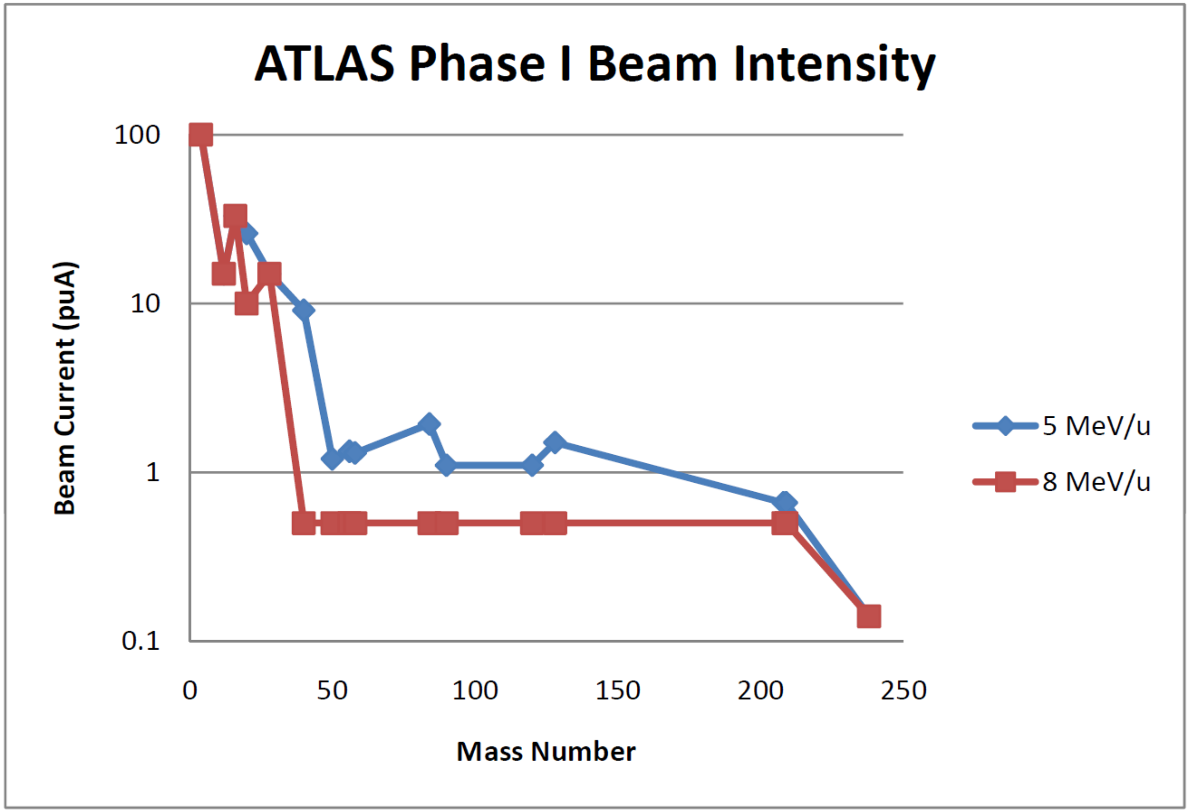
Note: High intensity (~10 pμA) beam energy is after the new ARRA cryomodule

Low intensity (~1 pμA) beam energy is the full energy

Q/A	High Intensity beam energy (MeV/u)		Low Intensity beam energy (MeV/u)	
	Design	High performance	Design	High performance
1/2	11.4	13.5	21	22.6
1/3	8.6	10.2	15.8	17.2
1/4	7.0	8.3	12.6	13.8
1/5	5.9	7.1	10.5	11.6
1/6	5.2	6.2	9.0	10.0
1/7	4.6	5.5	7.8	8.8

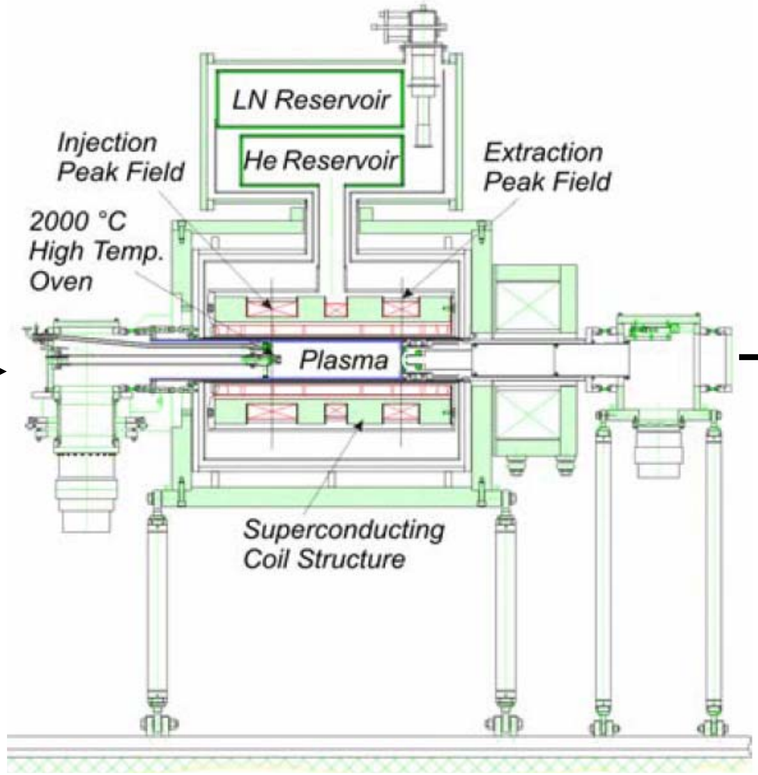
ATLAS Beam Intensities after the ARRA Projects are Complete

- Beam intensity is limited by radiation shielding for light ions
- Beam intensity is limited by the ECR performance for heavier ions

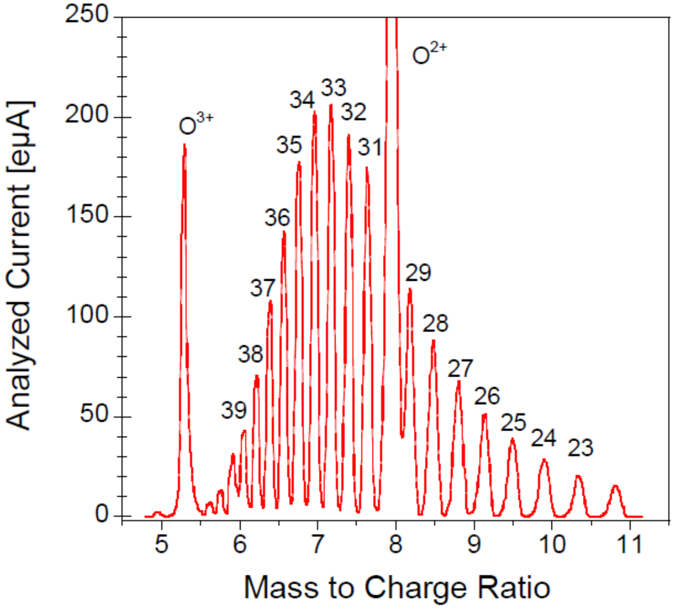


ECR Charge Breeder, Efficiency ~10%

1+ ion, DC



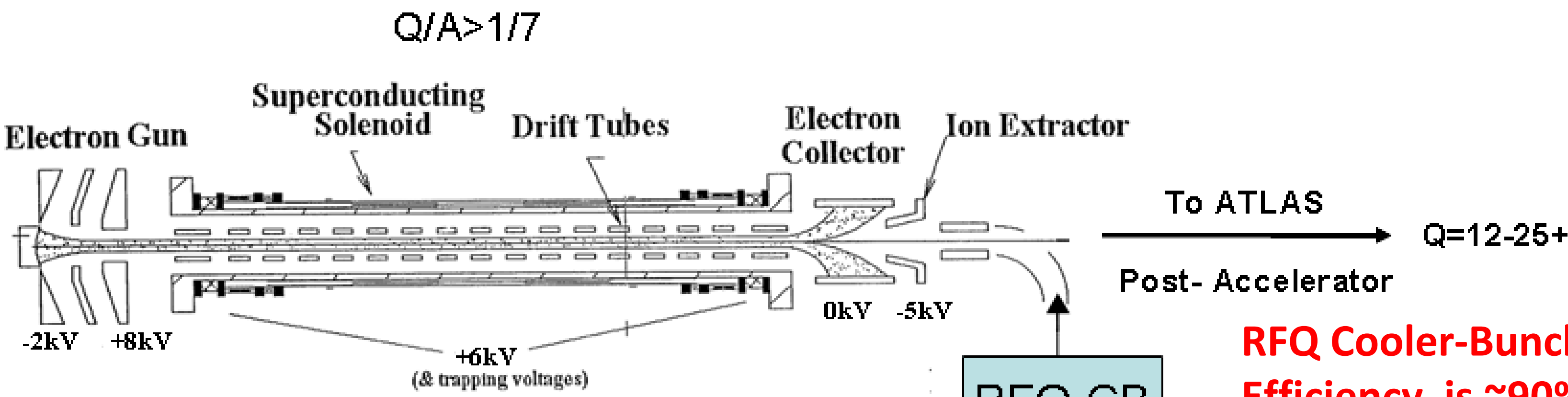
n+ ion, DC

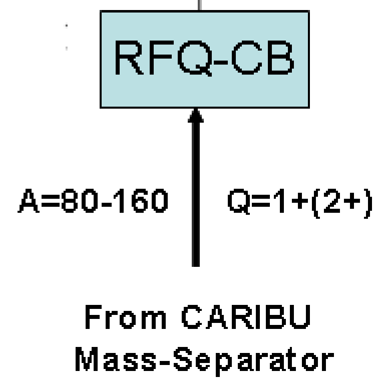


Charge Breeder for CARIBU Based on Electron Beam Ion Source

- **EBIS CB vs ECR CB**
  - Breeding efficiency – factor of 2-3 higher, CERN-ISOLDE has demonstrated 35% breeding efficiency for some ion species (^{65}Cu)
  - Breeding time - < 30 msec, an order of magnitude better
  - Emittance of the high Q+ ions – low
  - Improved isotope beam purity
  - Short pulses of very low intensity beams result to good signal/noise ratio for the experiments
  - Much more relaxed voltage matching between CARIBU and EBIS-CB HV decks
- Key component of the ATLAS charge breeding set-up is a high-efficiency (~90%) cooler-buncher upstream of the EBIS. This combination is perfectly suitable for relatively low intensity RIBs (below 10^7 ions/sec) produced by CARIBU. The state-of-the art cooler-buncher technology is available in the Physics Division.
- Traditional fast (~10 μsec) pulsed injection-extraction of ion beams will be used, pulse repetition rate is 30 Hz
- Large acceptance for ion beams, the diameter of the e-beam is ~ 600 μm
- We are developing two electron guns 2 A and 0.2 A, both with very high density ~600-700 A/cm^2 (factor of 5 higher than at CERN REXEBIS)
- EBIS-CB will be similar to BNL EBIS which has demonstrated the best performance to-date

EBIS Charge Breeder for CARIBU, Layout



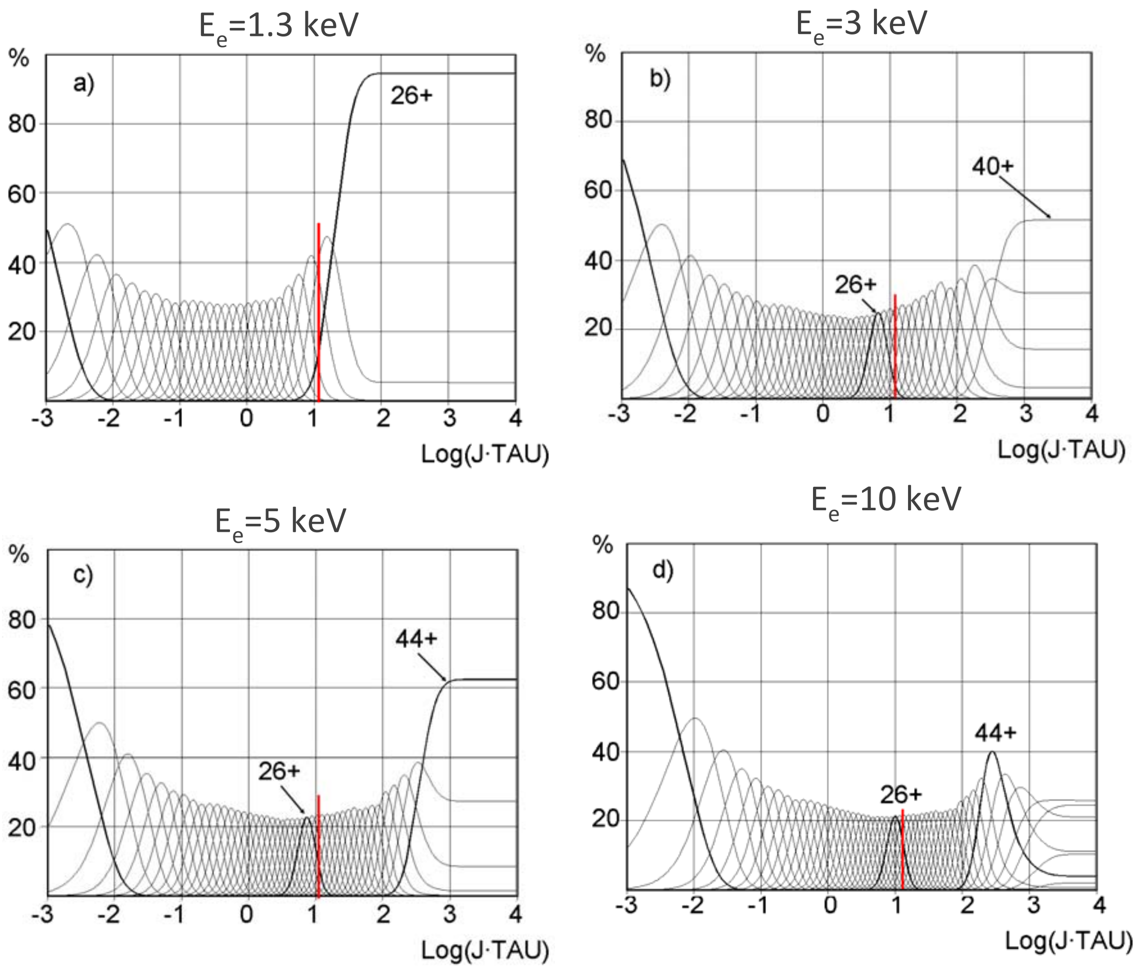


RFQ Cooler-Buncher Efficiency is ~90%

Electron beam current	Up to 2 A DC
Electron beam energy	Up to 10 kV
Electron beam current density	Up to 600 A/cm^2
Breeding time	30-40 ms
Efficiency	> 20%

The state-of-the-art BNL Test EBIS is the best choice as a prototype of the EBIS-CB

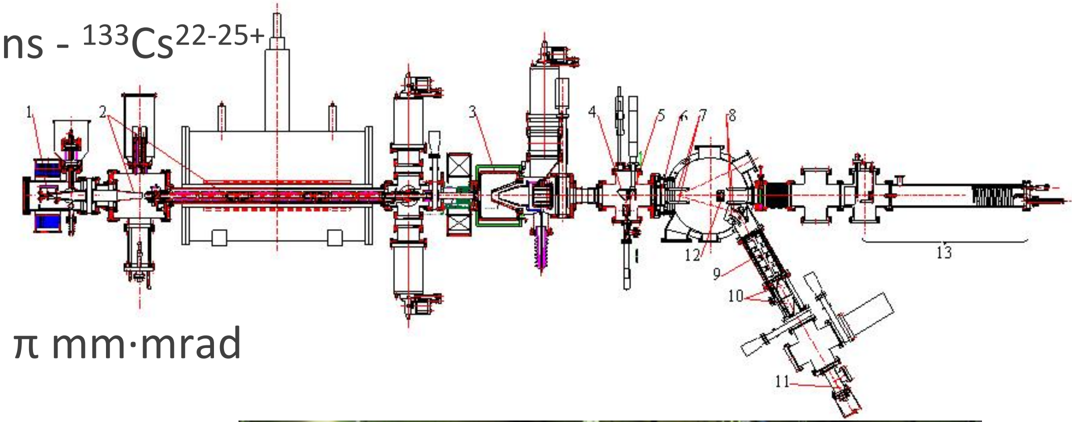
Charge State Evolution of ^{131}Xe (CBSIM code)



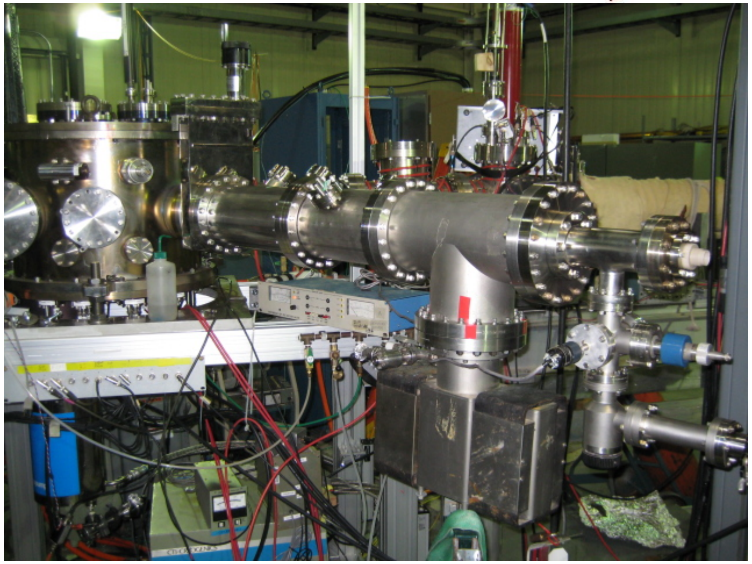
Red line – Log(J·τ) = 1.18
(J = 500 A/cm^2, τ = 30 ms)

- Lower electron beam energies provide higher abundances of ions
- Lower rep-rates are beneficial for higher abundances of ions

Breeding Efficiency Measurements at BNL T-EBIS

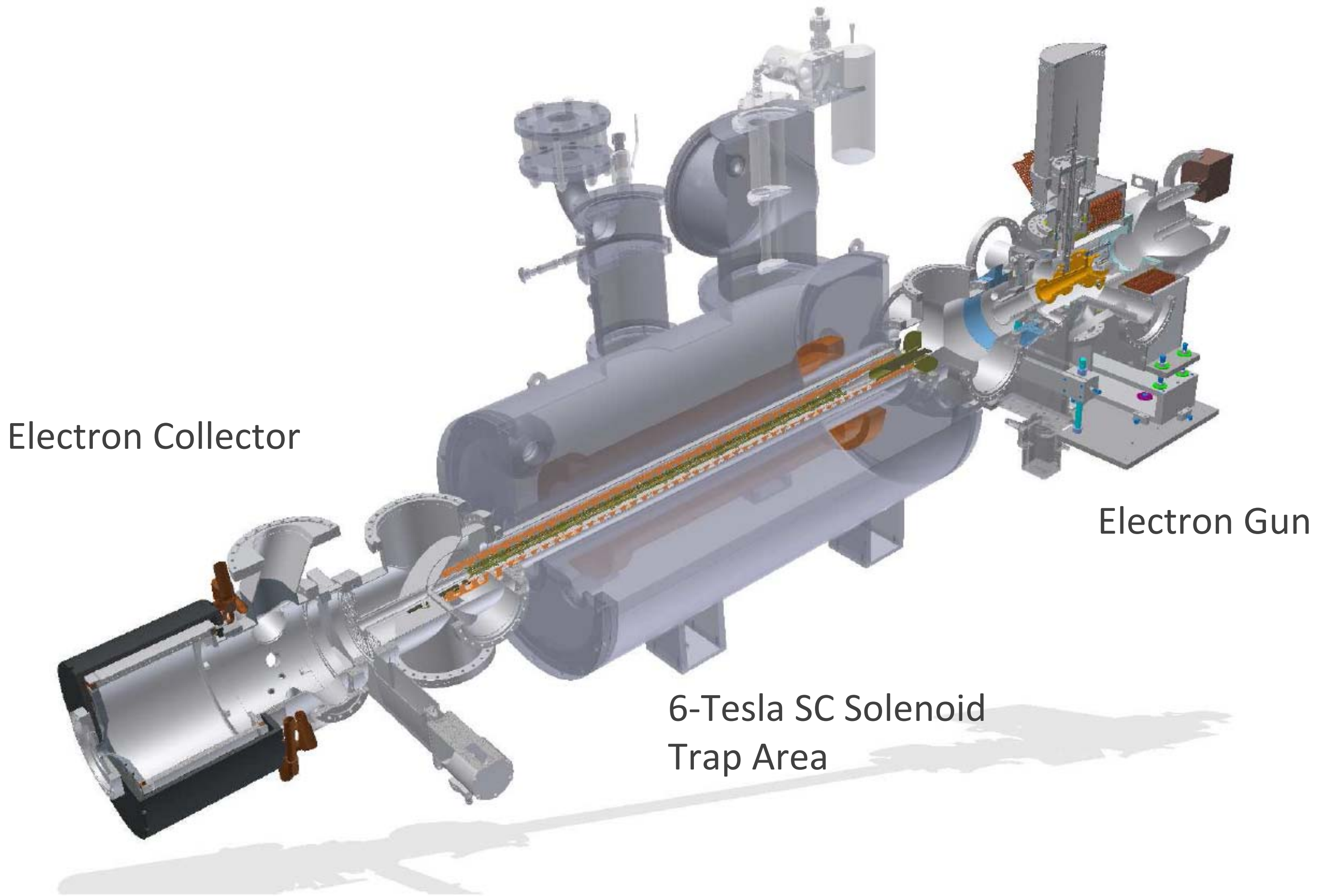


- Injected ions - $^{133}Cs^{+}$ ↔ extracted ions - $^{133}Cs^{22\text{-}25+}$
  - pulse duration – about 10 μs
  - current – 0.1-1 μA
  - number of ions per pulse – 10^7-10^8
  - 4 rms normalized emittance is ~0.02 π mm·mrad
- Charge breeding efficiency
  - electron beam size (by adjusting the ratio of solenoid and e-gun magnetic fields)
  - electron beam current (by adjusting cathode-anode voltage)
  - electron beam energy (by adjusting drift structure electrodes potentials)

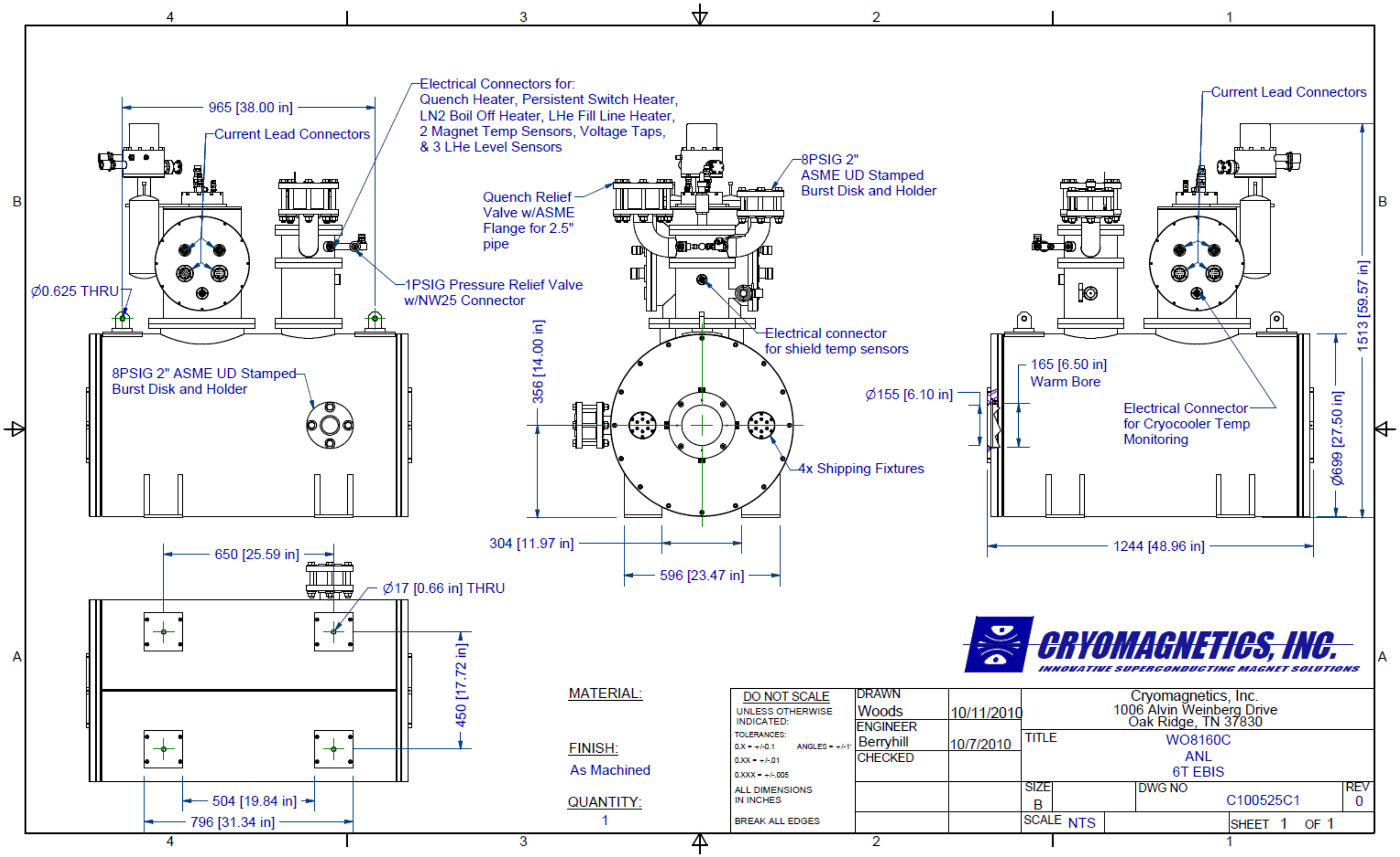


- Optimization of breeding efficiency on ion beam injection parameters (energy, size, angle)
- Comparison of experimental results with results of numerical simulations

3D Model of the CARIBU-EBIS Assembly

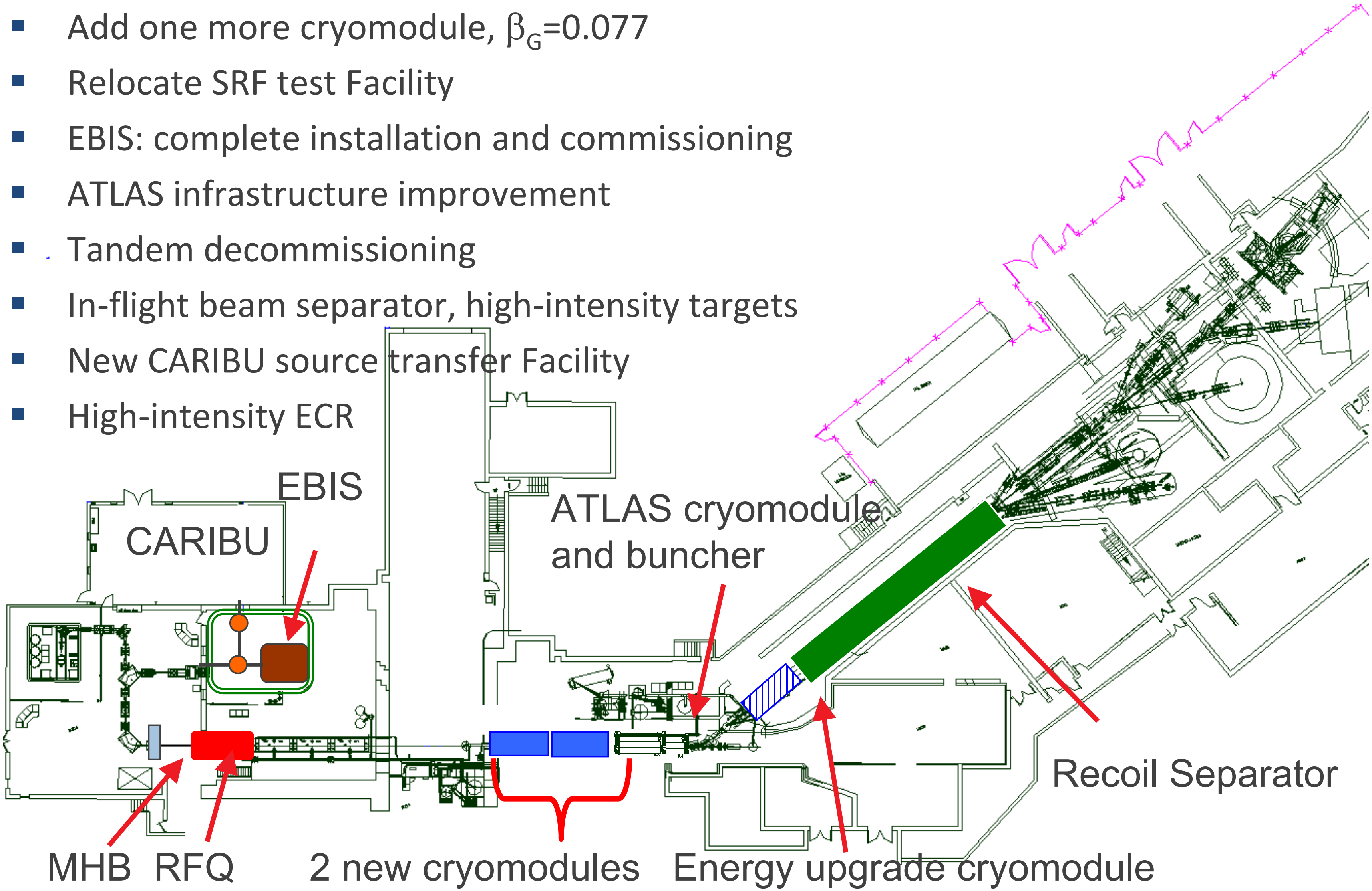


6-Tesla SC Solenoid is Being Procured



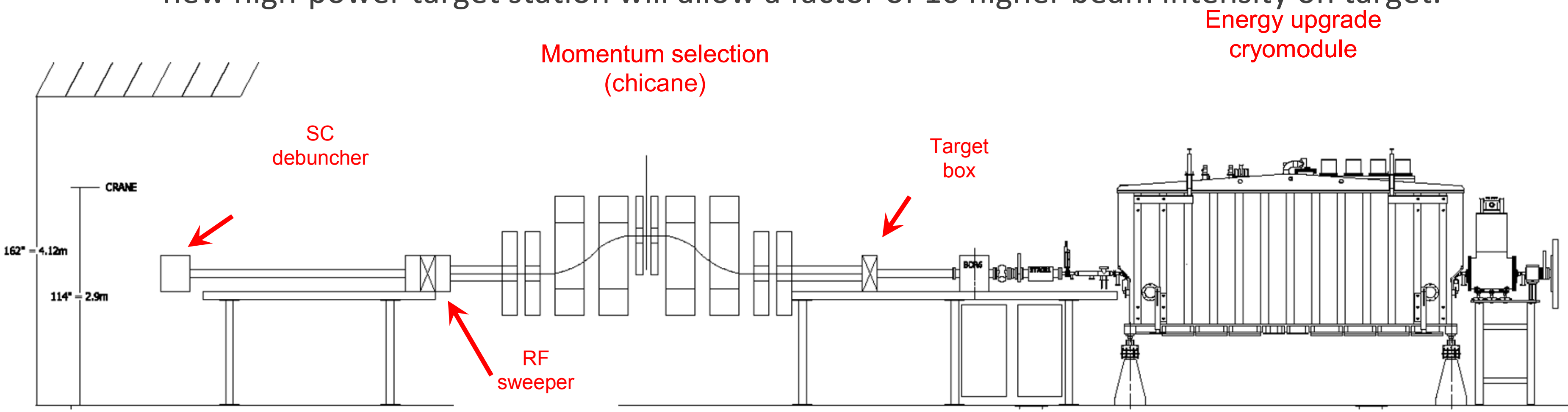
ATLAS Layout Beyond the Funded Projects

- Add one more cryomodule, β_G=0.077
- Relocate SRF test Facility
- EBIS: complete installation and commissioning
- ATLAS infrastructure improvement
- Tandem decommissioning
- In-flight beam separator, high-intensity targets
- New CARIBU source transfer Facility
- High-intensity ECR



In-Flight Separator

- Angular acceptance of ± 50 mrad in both x and y, a momentum acceptance of ± 5% and a maximum rigidity of 1.5 Tm
- The RF sweeper adds time-of-flight selection to the achromatic momentum selection, effectively providing a coarse mass selection for the recoils
- The SC debuncher reduces the energy spread of the recoil beam
- 2 orders of magnitude gain in intensity for the in-flight produced secondary beams
  - Improve the collection efficiency of the recoils by a factor of at least 10 over the existing system
  - new high-power target station will allow a factor of 10 higher beam intensity on target.



Conclusions

- ATLAS future is considered as the National User Facility for Intense Stable Ion Beams
- Appreciable funds have been assigned for the ATLAS Upgrade
- ~10 pμA ~6 MeV/u medium mass ion beams will be available in the beginning of 2013
- Higher energy and higher intensity (by the factor of 2-3) heaviest ion beams will be available in 2013