Improved beam characteristics from the ATLAS upgrade

HB2014

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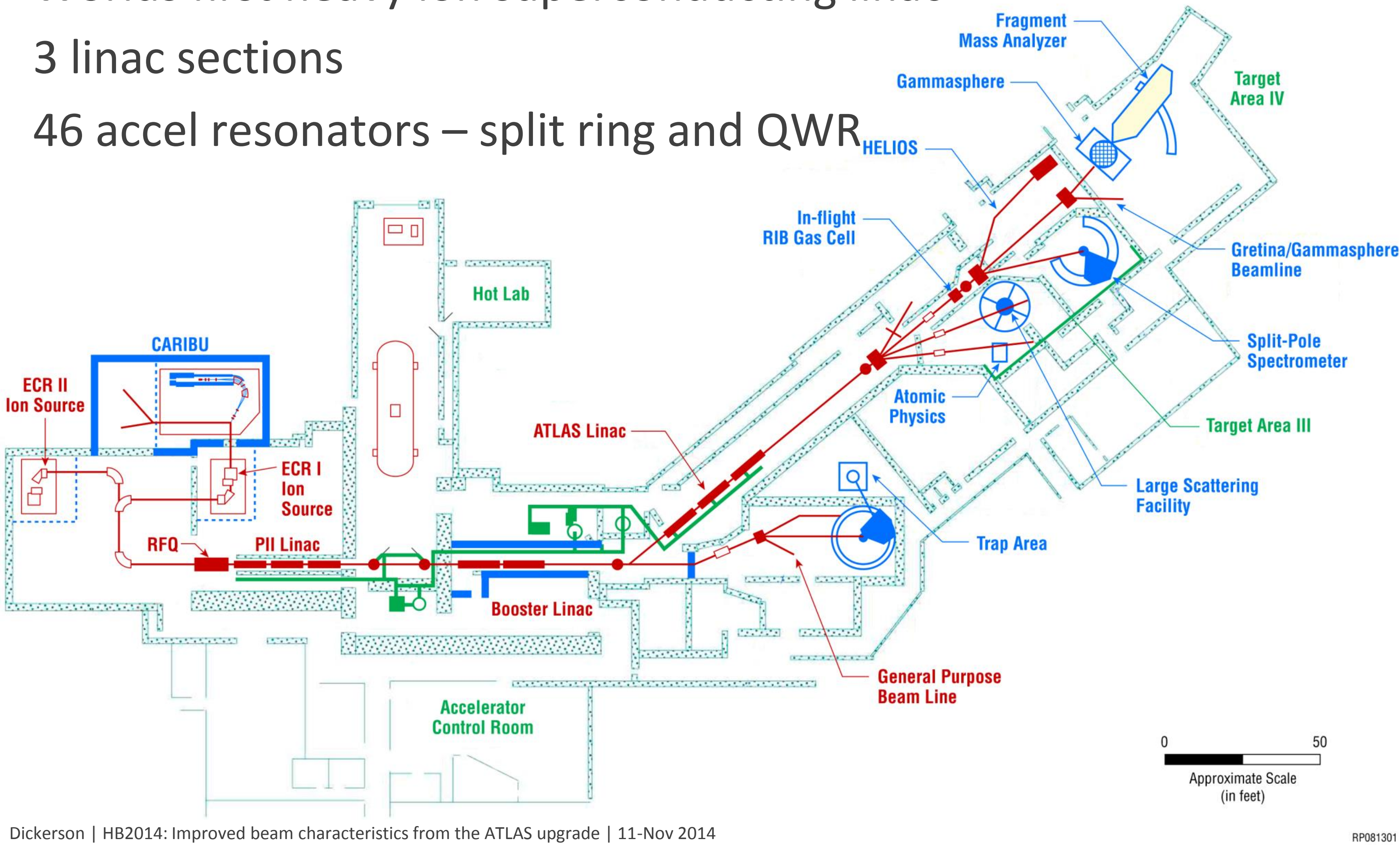
Outline

- ATLAS overview
- ATLAS upgrade
  - Motivation
  - Solutions
- Upgrade results
  - Efficiency
  - Intensity
- Summary

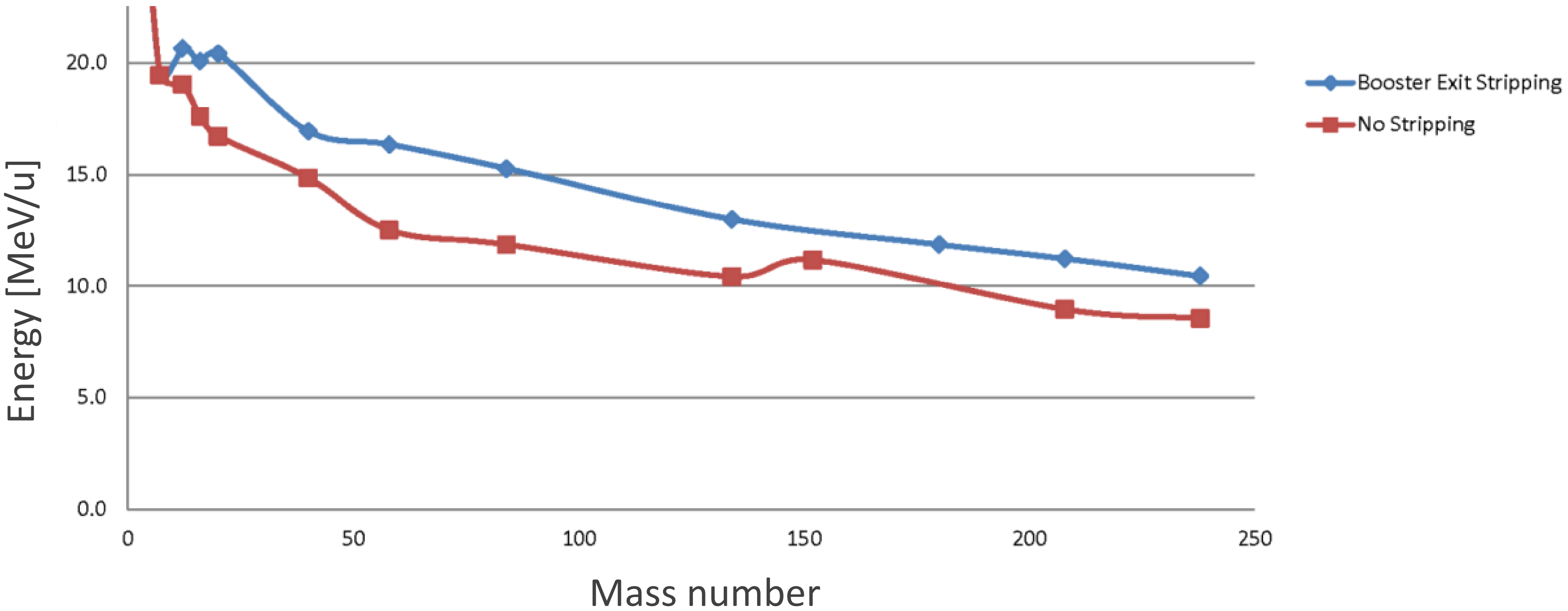
Argonne Tandem Linac Accelerator System (ATLAS)

- Worlds first heavy ion superconducting linac
- 3 linac sections
- 46 accel resonators – split ring and QWR



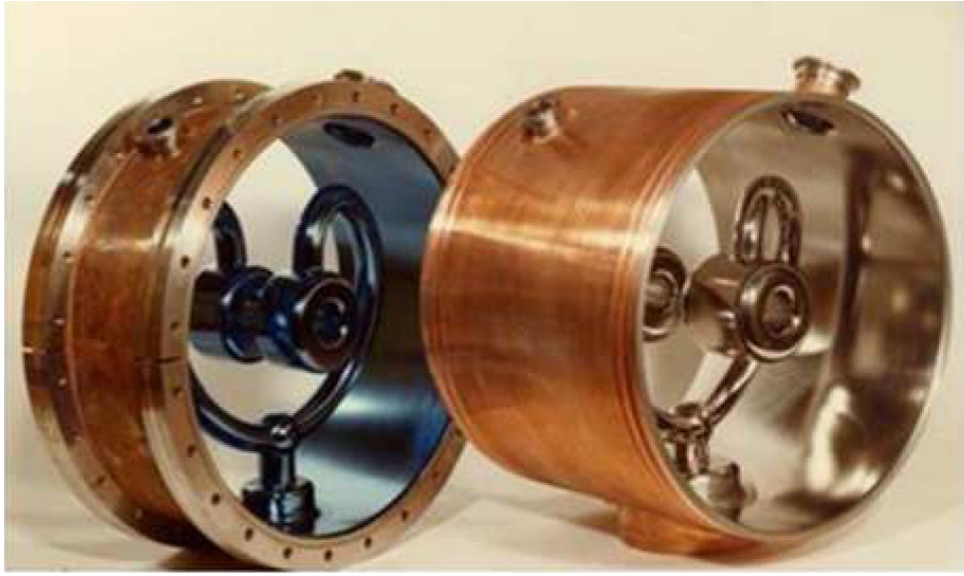
ATLAS parameters

- Typical beam emittances
  - $\varepsilon_{x,y\ rms}$ normalized = 0.03 π μm
  - $\varepsilon_{z\ rms}$ = 3 π ns-kev/u



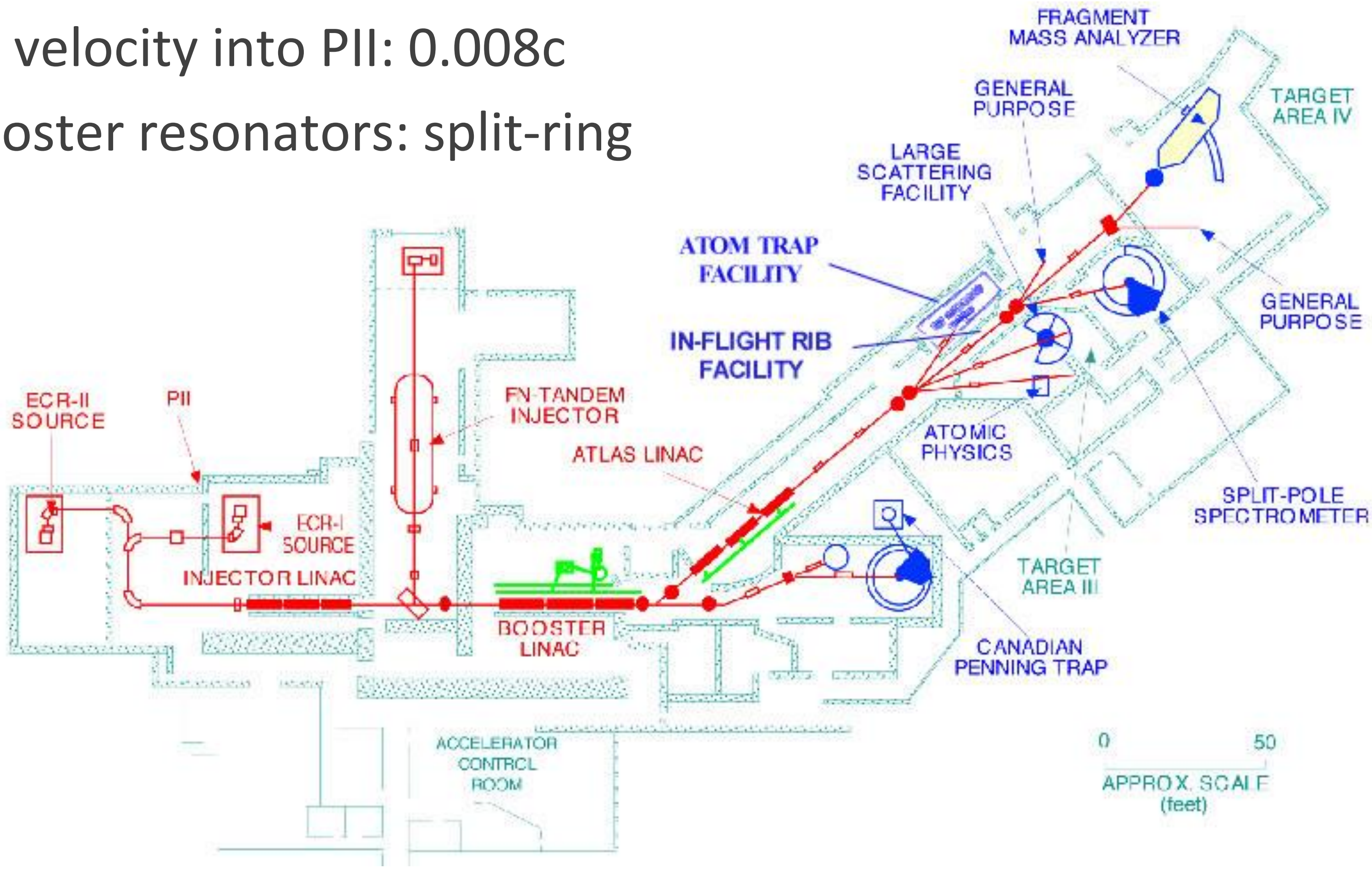
ATLAS Upgrade motivations

- Increase transport efficiency – especially for CARIBU beams
- Increase stable beam intensity to 10 pμA for secondary RIBs
- Previous limitations
  - Quality of beam suffered during low velocity acceleration – very low β_{OPT} PII cavities
  - Excessive steering from split-ring resonators limits intensity due to beam losses



Old configuration

- PII bunching – 4-harmonic buncher (12.125 MHz fundamental), 24.25 MHz buncher, chopper
- Beam velocity into PII: 0.008c
- All Booster resonators: split-ring



Solutions

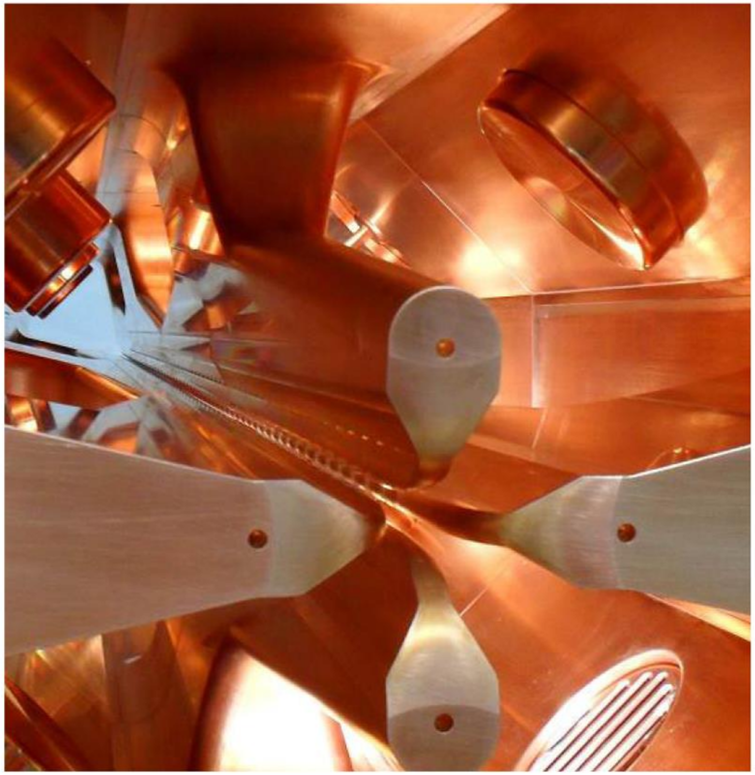
- Efficiency
  - Removed first three low β_{OPT} (0.008 and 0.015), small aperture (ø15 and ø19 mm) cavities from PII linac
  - Designed and installed RFQ to gradually accelerate, focus, and bunch beam into PII
  - Remove chopper and 24.25 MHz buncher
  - Create MEBT inside first PII cryostat
    - Installed electrostatic steerer
    - One resonator repurposed as a buncher
- Intensity
  - Remove split ring cavities
  - Replace with cryostats of QWR

CW RFQ – Operation since Jan 2013

- Sinusoidal and trapezoidal vane tip modulation

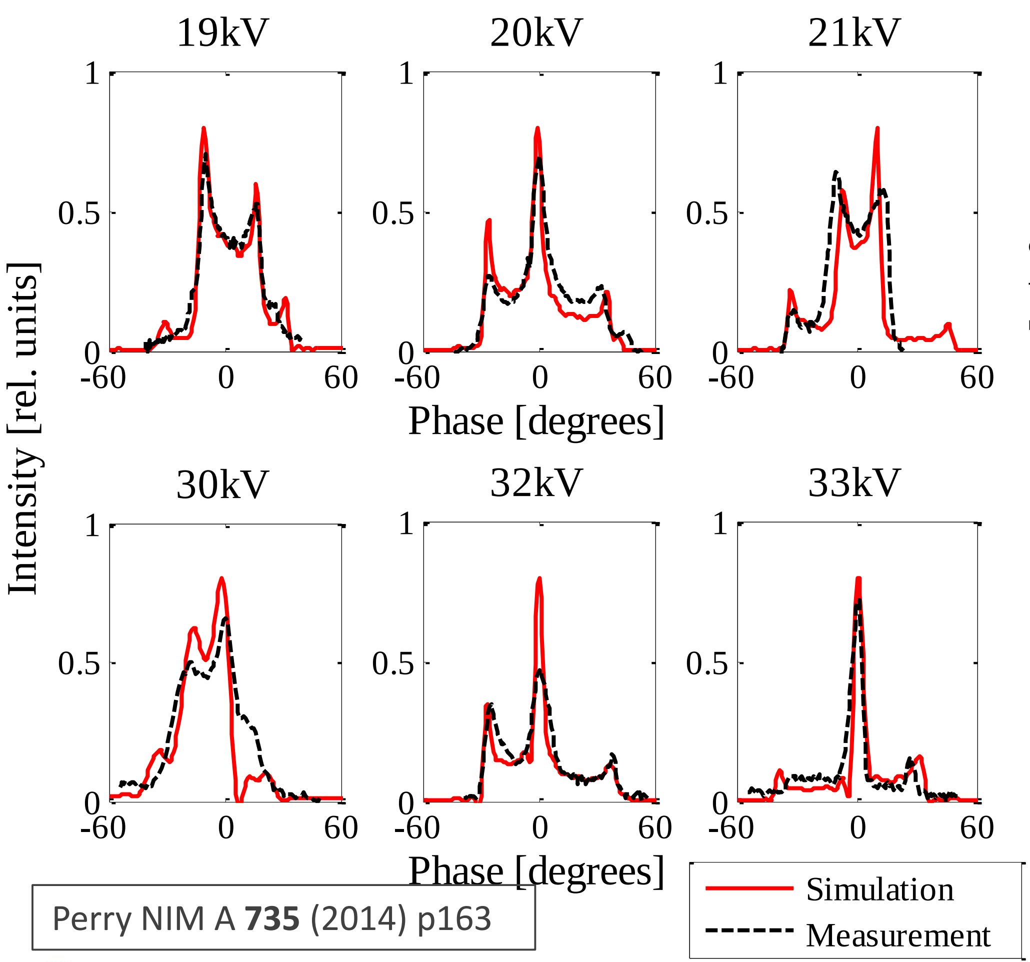
TABLE I. Basic parameters of the RFQ.

Parameter	Value
Input energy	30 keV/u
Output energy	296.5 keV/u
Frequency	60.625 MHz
Vane voltage	70 kV
rf power calculated by MW-STUDIO	52 kW
Average aperture radius	7.2 mm
Length	3.81 m
Transverse normalized acceptance	2π mm mrad
Longitudinal rms emittance	20π deg·keV/u (at 60.625 MHz) 0.9π nsec · keV/u
Bunching	External 4-harmonic



Bunch Shape, Energy Spread and Transverse Profile

- Results of the RFQ beam testing
  - Helium and Oxygen beams



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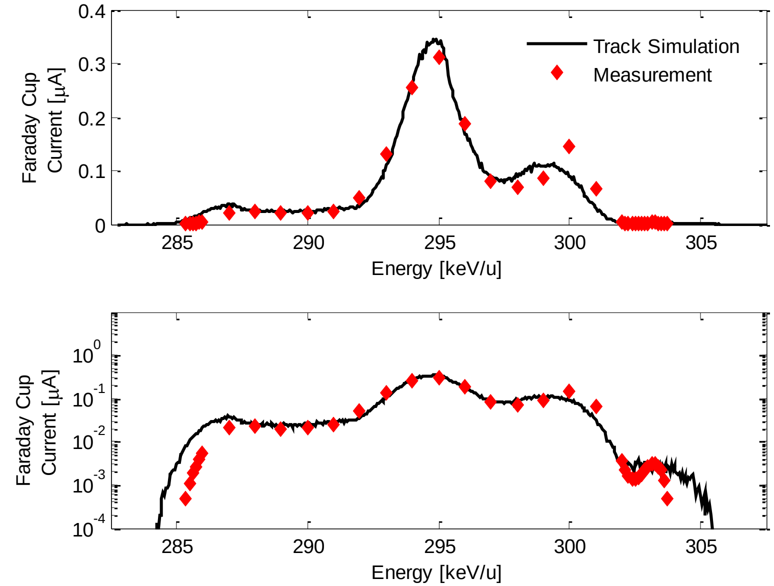
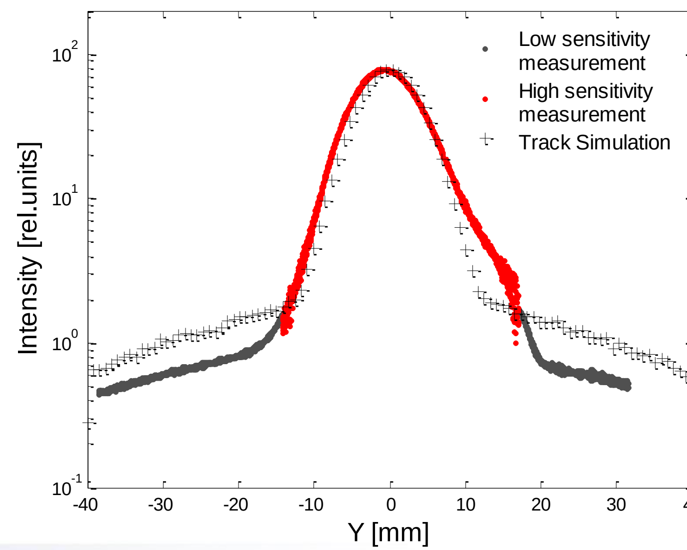
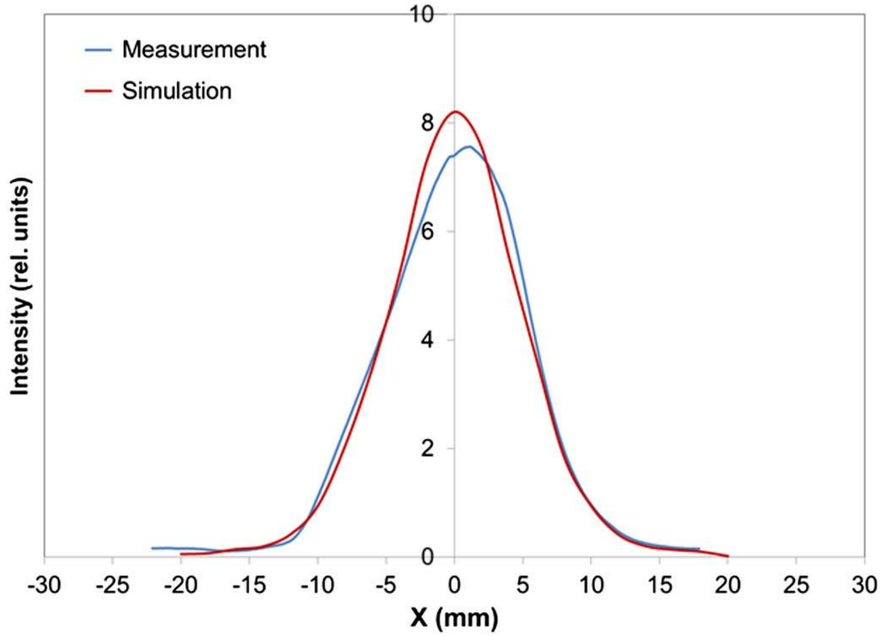
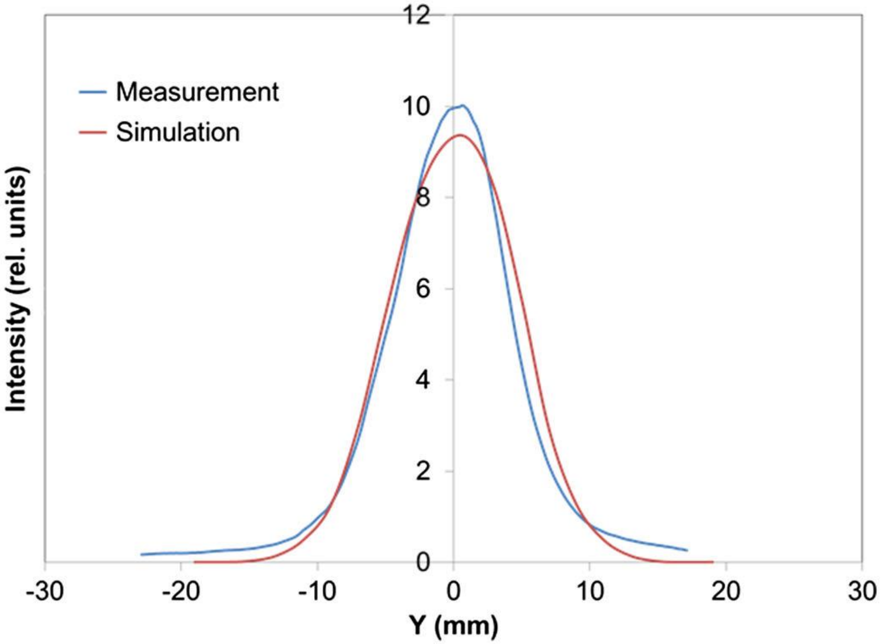




Output radial matcher

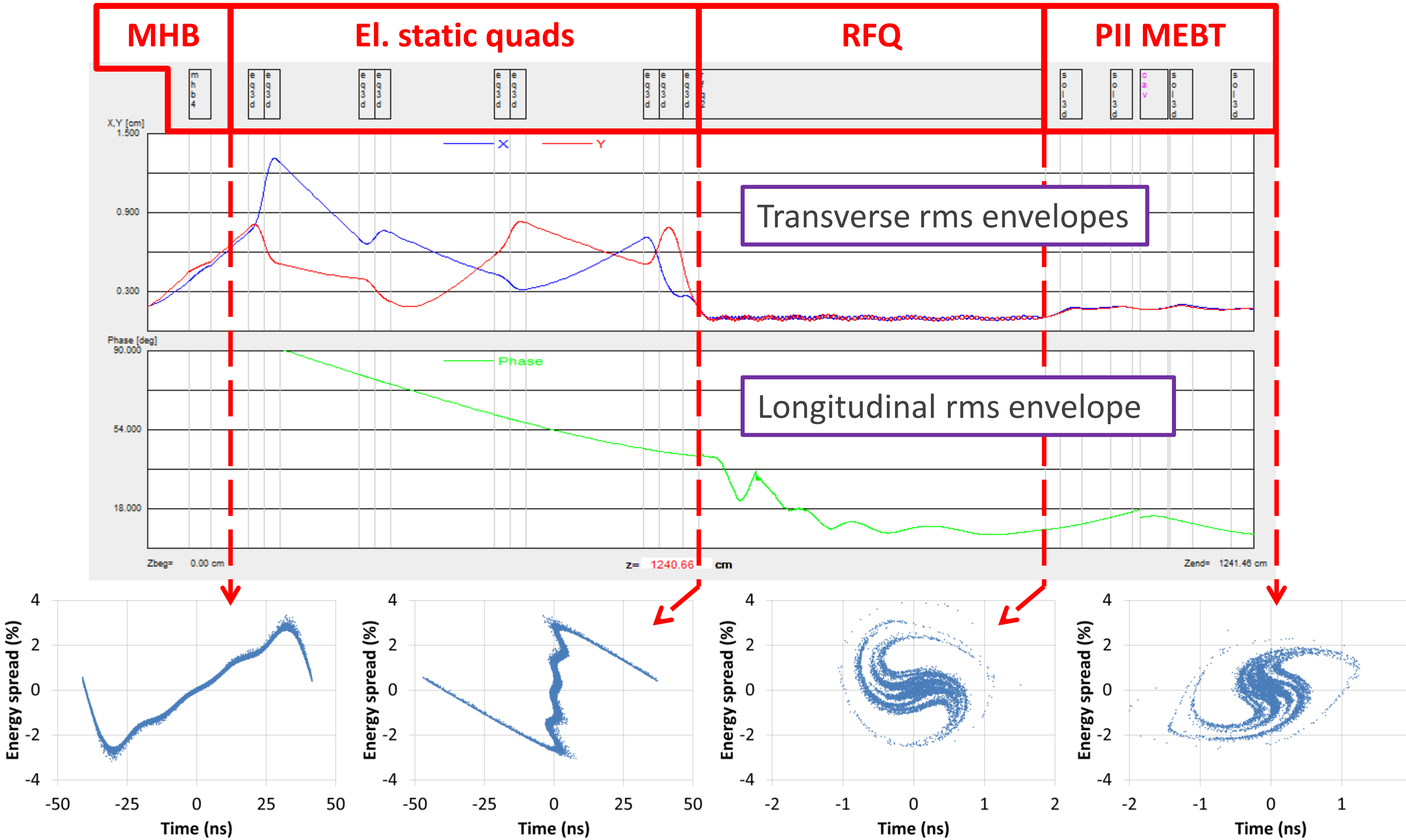
- RFQ forms axially symmetric output beam
- No additional matching needed for PII solenoid lattice





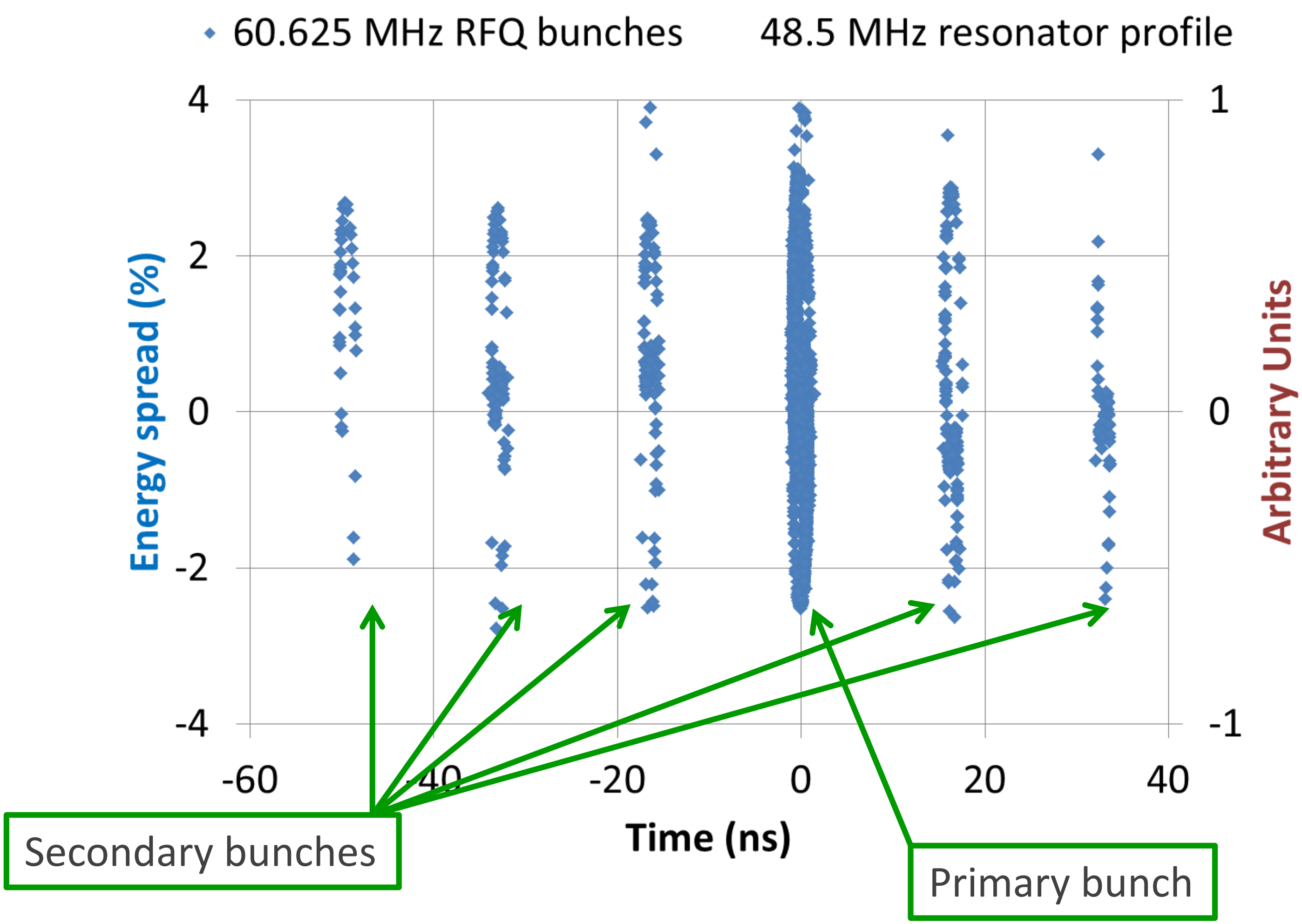
Ostroumov PRST-AB **15** (2012) 110101

Beam dynamics of new configuration



Removed beam chopper

- Due to favorable combination of operating frequencies



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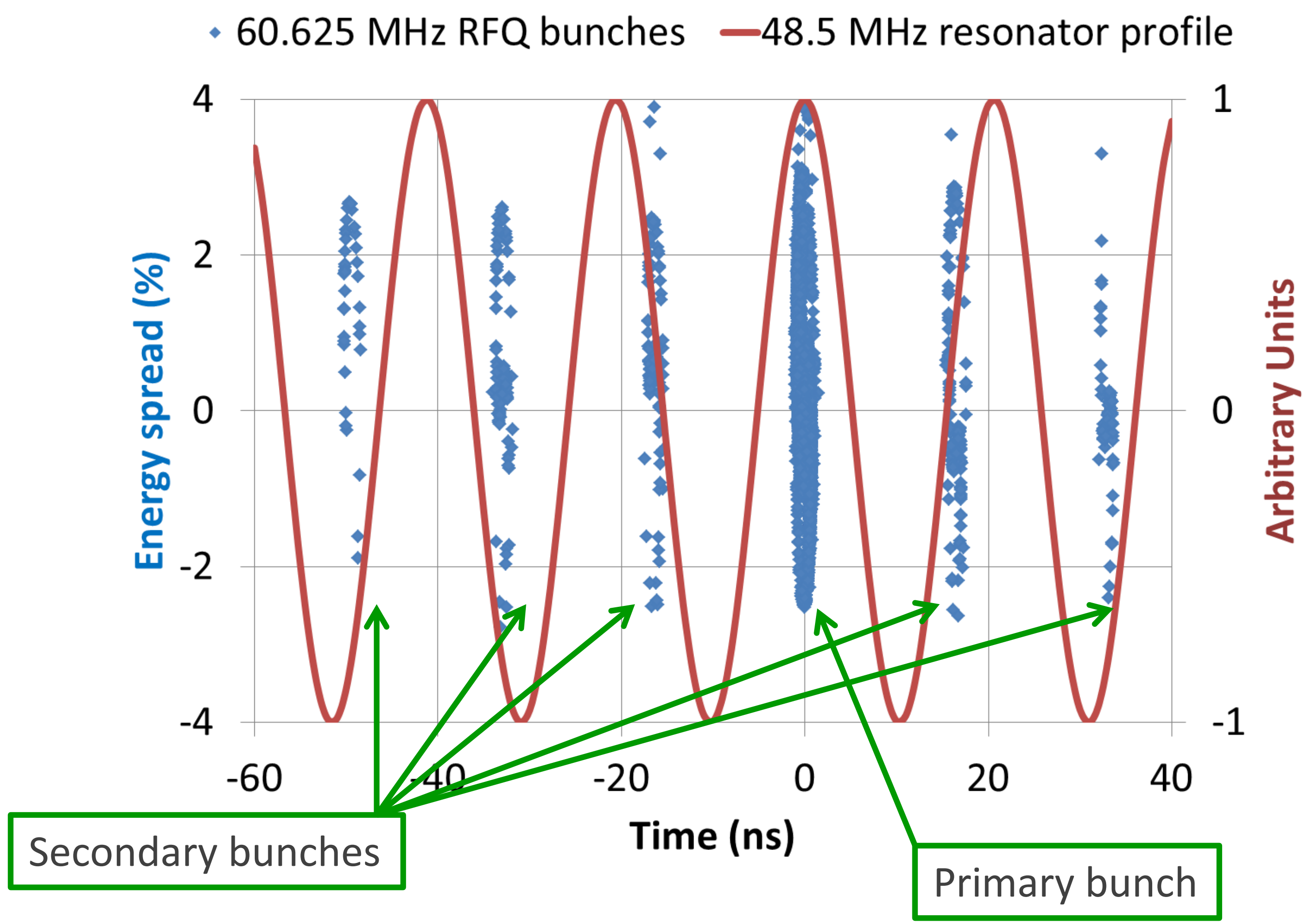
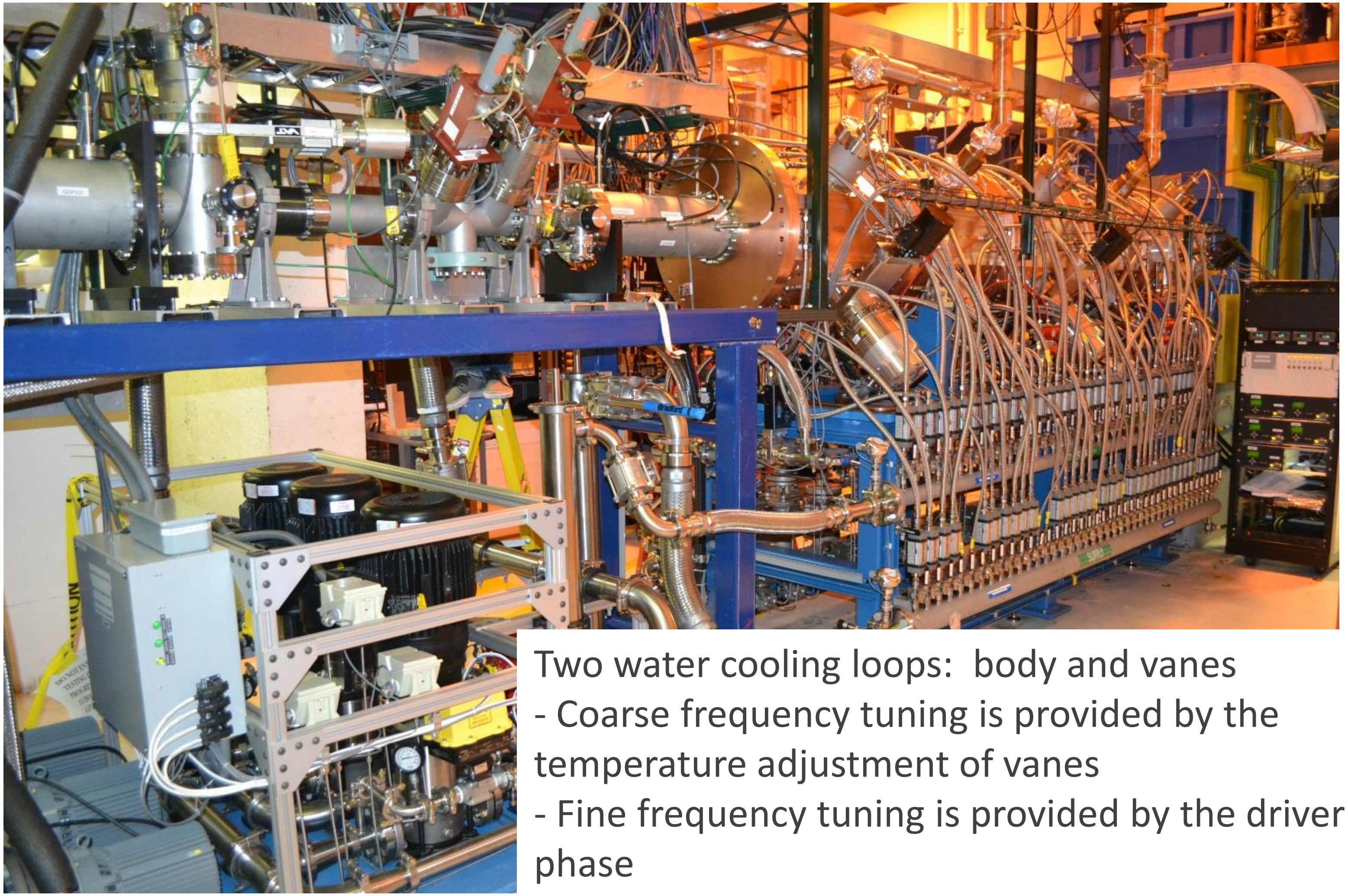


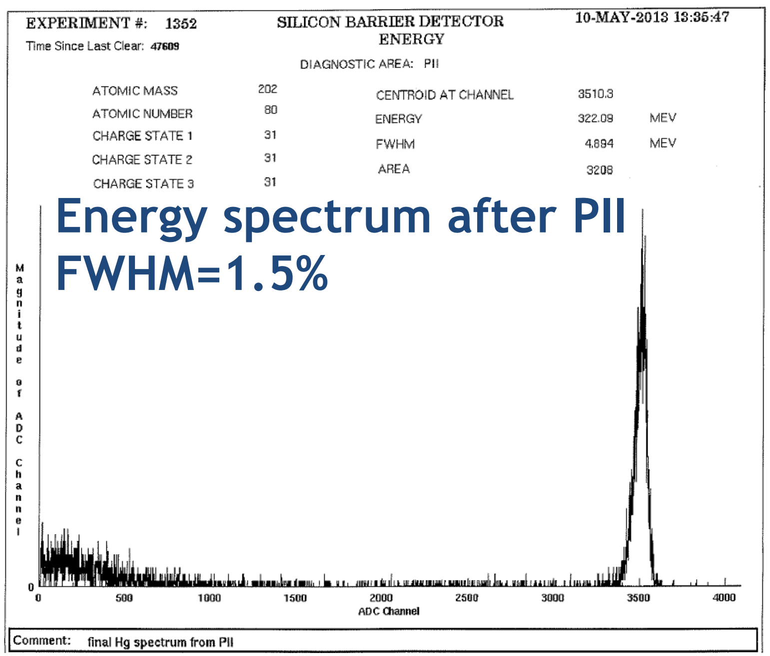
RFQ at Permanent Location

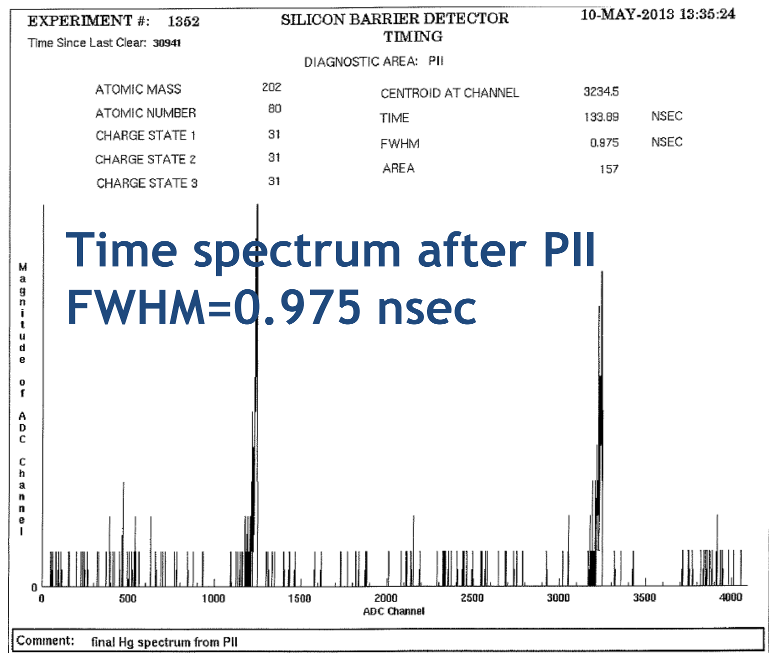


Two water cooling loops: body and vanes
- Coarse frequency tuning is provided by the temperature adjustment of vanes
- Fine frequency tuning is provided by the driver RF phase

Measured RFQ+PII Energy and Time Profile, $^{202}Hg^{+31}$

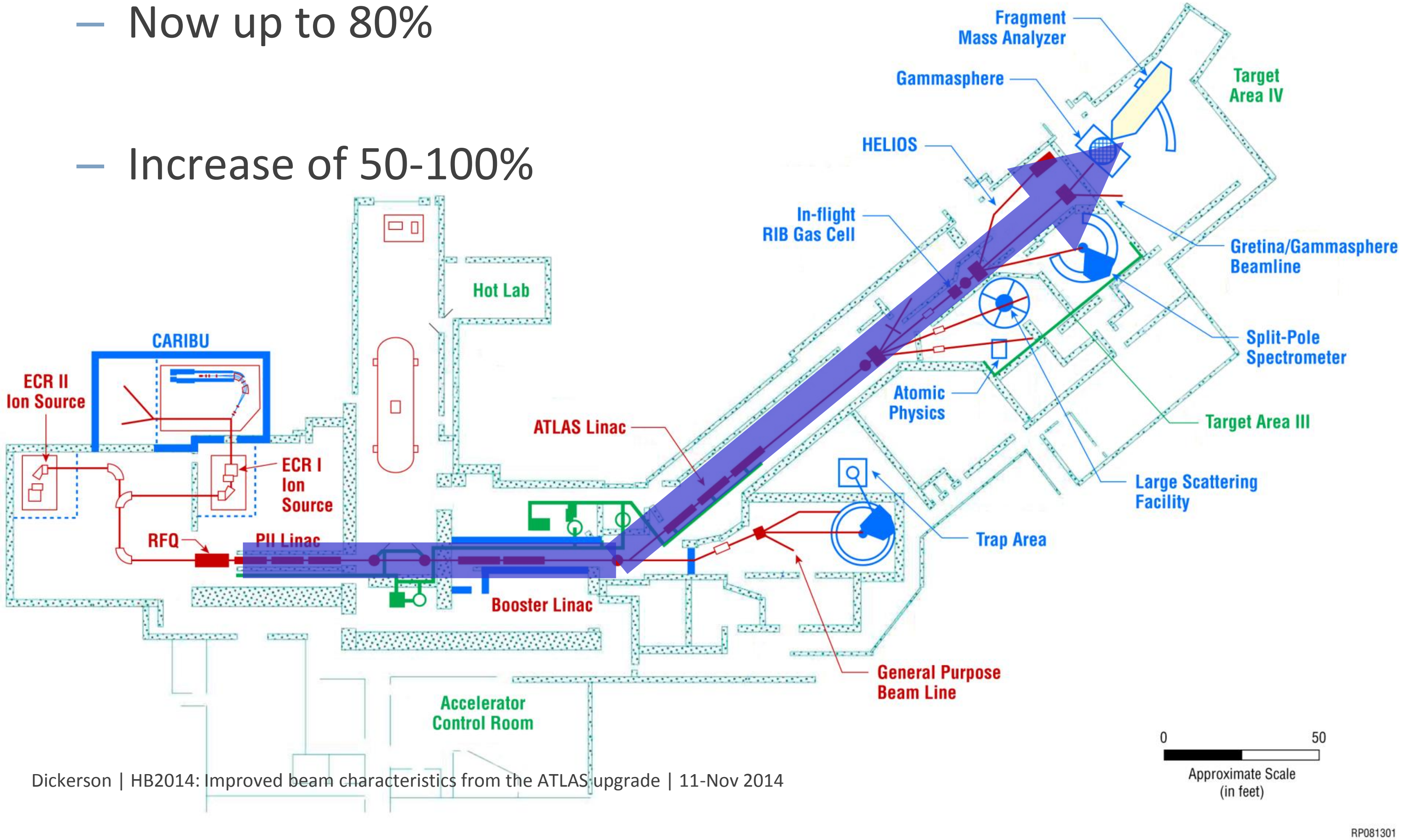
- Initial conditioning reached 74 kV inter-vane voltage after 5 hours conditioning
- Provides 83% acceleration efficiency through PII (~1.5 MeV/u) as designed
- Many ion beam species have been accelerated and used for experiments, from Li to U





Transmission efficiency

- From PII entrance to target
  - Previously 40-60%
  - Now up to 80%
  - Increase of 50-100%



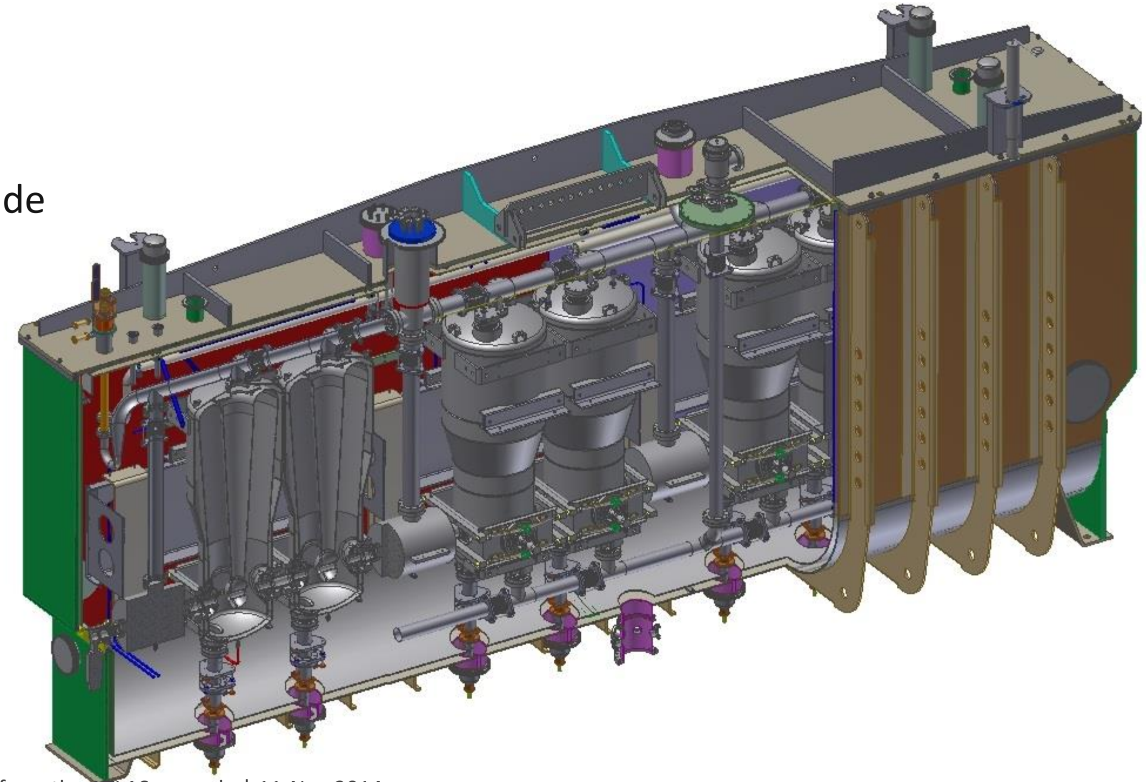
High intensity runs

- Goal: Intensity up to 10 pμA
- Mainly envisioned for in-flight RIB production (transfer reactions)
- Only QWR can be used (presently 28 resonators) to avoid excessive steering by split-rings
  - PII (early 1990s)
  - Energy upgrade cryostat at end of ATLAS linac (2009)
  - New Booster cryostat (2014)
- Energy up to ~10 MeV/u
- Made possible by replacing split-ring resonators . . .

Cryomodule of 7 QWRs and 4 SC Solenoids

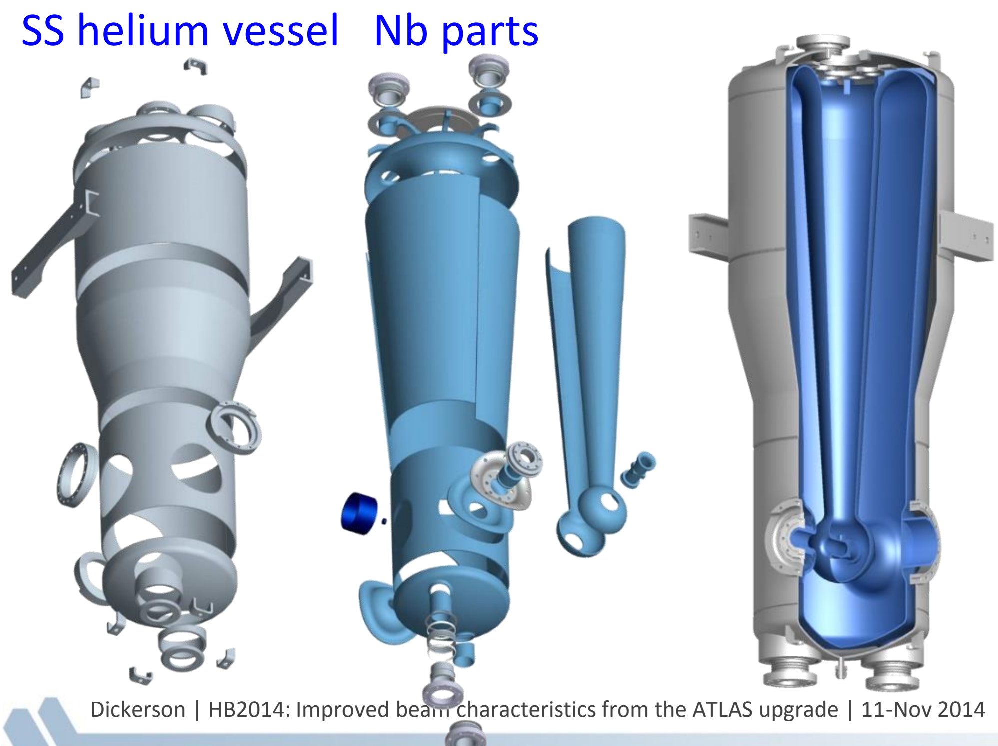
- Seven β = 0.077, 72.75 MHz quarter-wave cavities
- Four 9-Tesla superconducting solenoids
- Replaces 3 old cryomodules with split-ring cavities
- Total design voltage is 17.5 MV, 4.5K cryogenic load is 70 W

5.2 m long x 2.9 m high x 1.1 m wide



New 72.75 MHz QWR

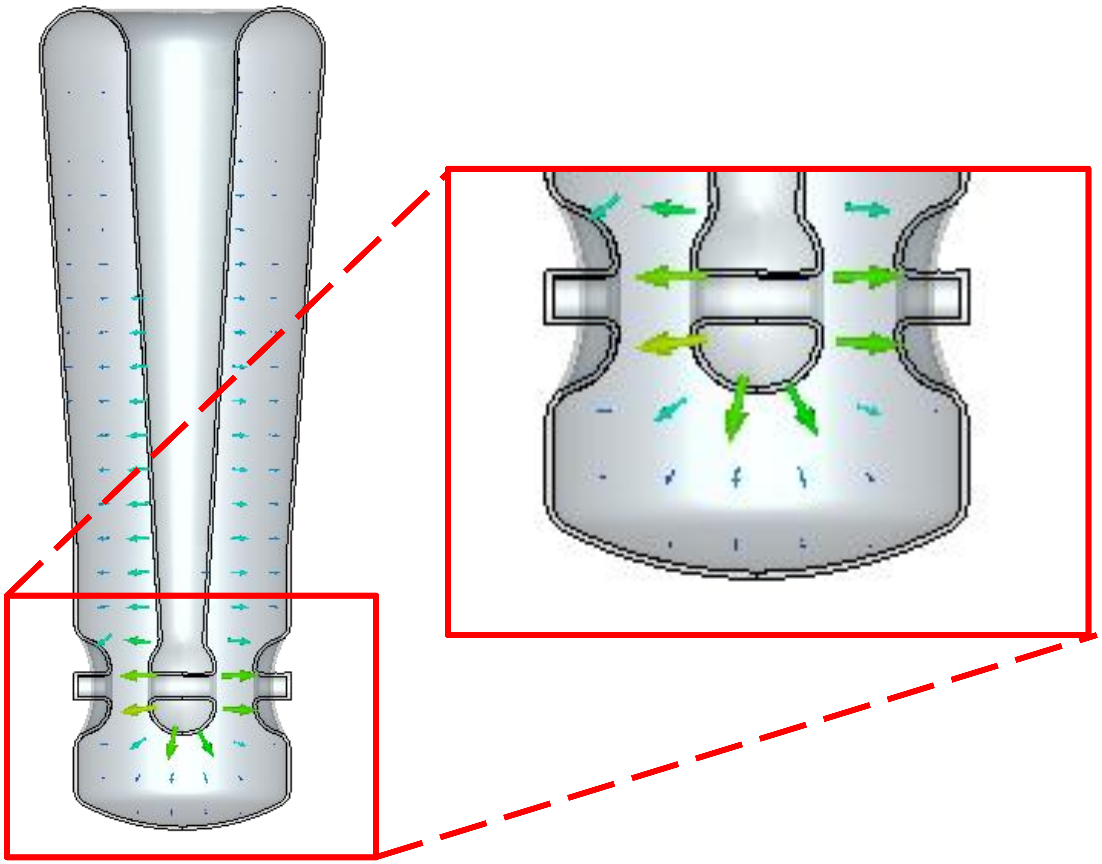
- Double conical highly-optimized design with steering correction
- Stainless steal helium jacket, brazed niobium–SS transitions
- Wire EDM instead of machining of EBW joints
- EP of the cavity after all fabrication work including He vessel is complete
- Central conductor was aligned to minimize microphonics



	Design
V, max. voltage gain, MV	2.5
E_{PEAK} , MV/m	40
B_{PEAK} , mT	60
G, Ohm	26
R_{sh}/Q, Ohm	575
Cryogenic load at 4.5K, W	<10

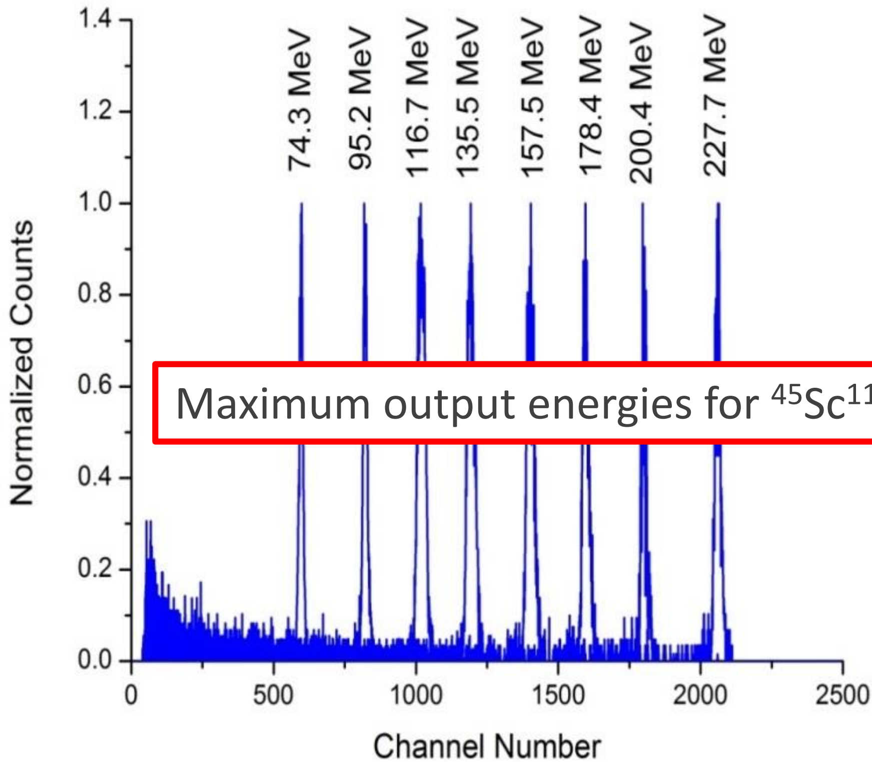
New resonator steering correction

- Faces of drift tubes angled by ~3 degrees
- E field compensates steering from B field on axis



Cryostat operation

- Since April 2014
- Amplitudes limited by LLRF ability to phase lock cavities
- 4 kW amplifier power available, ~2 kW used



Maximum output energies for $^{45}Sc^{11+}$

Average	Current Operation	Available
V_{EFF}	2.5 MV	3.75 MV
E_{PEAK}	40 MV/m	60MV/m
LHe, 4.5K	5 W	12 W

High intensity results and plans

- To date 7.5 pμA of ^{40}Ar at 1.5 MeV/u has been delivered to the entrance of Booster
- Currently there are no targets at ATLAS capable of accepting 10 pμA at 10 MeV/u (1.2 – 10 kW)
- We are developing a chicane separator (AIRIS) with a liquid film target to take advantage of ATLAS full intensity
- We have plans to test high intensity beam through Booster and ATLAS linacs in early 2015

Summary

- Radioactive beams are driving ATLAS upgrades
  - Low intensity CARIBU beams require high efficiency
  - Secondary in-flight beams require high intensity
- 50 – 100% efficiency increases from improvements in low energy bunching and acceleration
  - Removed problematic low β resonators
  - Design and installation of CW RFQ
  - MEBT integrated into first PII cryostat
- New cryostat will enable acceleration of 10 pμA to 10 MeV/u
  - Resonator design optimized to eliminate unwanted steering
  - World class accelerating gradients enable useful beam energies
- One more cryostat of QWR can replace performance of all remaining split-rings (3 cryostats, 18 resonators)