

The ATLAS Intensity Upgrade: Project Overview and Online Operating Experience

Presented by Richard Pardo Physics Division Argonne National Lab For R.C. Pardo, A. Barcikowski, Z. Conway, C. Dickerson, M. Hendricks, M. P. Kelly, S.H. Kim, Y. Luo, S. MacDonald, B. Mustapha, P. Ostroumov, C. Peters, M. Power, R. Scott, S. Sharamentov, R. Vondrasek, G. Zinkann



ATLAS (the Argonne Tandem Linac Accelerator Facility)

- ATLAS began operating as a National User Facility in 1985
 - First beams accelerated for research with RF superconductivity 1979
 - Initial configuration: only a tandem electrostatic accelerator for ions
 - Limited to A~80 due to stripping and velocity match issues
- Any research facility must constantly improve to remain relevant
 - A second beam injector: Positive Ion Injector (PII) completed in 1993
 - Expanded available isotopes to entire stable ion range, especially ²³⁸U
 - New ECR ion source (ECR-II) higher beam currents and flexibility: 1998

ATLAS is the only U.S. low-energy nuclear physics national user facility

- Primary focus is stable ions
- But, at least until FRIB, radioactive beams are quite important
 - 2 RIB techniques at ATLAS
 - In-Flight RIBs produced by reacting a stable ion beam with a intermediate target, on the way to the actual experiment's target and detector
 - CARIBU provides neutron-rich isotopes not available anywhere else in world
- Simultaneous push
 - high current stable beams
 - Very low-intensity RIBs



ATLAS Improvement Goals Since 2008

- Improve total facility efficiency
 - Goal: up to ~80%
 - From more typical 30-40% prior to upgrades
 - Transmission only limited by saw-tooth bunching at start
- > Handle high beam currents without significant losses
 - Maintain transmission from RIB beam intensity to very high current (~10 $\ensuremath{\text{p}\mu\text{A}}\xspace$) stable beams
- Improve shielding for seamless higher beam current operation
- Simplify operation
 - Speed setup times
 - Reduce resonator count while maintaining beam maximum energy

Completed ATLAS Improvements

- ATLAS Accelerator Improvements: 3 Major accelerator projects
 - 1. Energy Upgrade Project (2009)
 - New Cryostat of 7 quarter-wave resonators
 - Restore maximum beam energy
 - Improved optics, less steering
 - 2. Radio Frequency Quadrupole for ATLAS (2013)
 - Replaced 3 accelerating resonators in PII low-energy accelerator region
 - Replaced traveling wave chopper
 - Much improved total transmission through PII (65% \rightarrow 82%)
 - M/Q acceptance ≤ 7
 - Frequency control by active temperature feedback
 - 3. Efficiency & Intensity Upgrade Cryomodule and 'Booster' Area Reconfiguration (2014)
 - Tandem (original linac injector) retirement
 - Retire 3 split-ring resonator cryostats (16 resonators)
 - Significant improvement in transmission and high current performance

ATLAS Upgrades Facility Relationship

- Energy Upgrade Project Resonator & Cryomodule (2009)
- New 60.625 MHz CW RFQ (2013)
- Intensity Upgrade Project (2014)
 - New cryomodule and LHe distribution system upgrade
 - Beamline and booster reconfiguration
 - ATLAS Utilities Upgrade
- EBIS Charge Breeder (2016)



Radio Frequency Quadrupole Linac for PII

Original PII linac design

- First very low-velocity (β=0.009c) SC linac
- First resonator matched velocity 0.008c, 10 cm long.
 - Doubled beam energy in 10cm
 - Very tight longitudinal acceptance
 - Alternate phase focusing
 - Degraded beam emittance
 - Result: ~ 60-65% transmission through PII, 80% to target (best)

RFQ Project

- First CW RFQ in U.S. and one of a very few in the world
- Acceleration: 30.5 keV/u \rightarrow 295 keV/U
- M/Q < 7
- Combined with existing Saw-tooth buncher, capture 80-85% of DC source beam
- Eliminate emittance growth
- Improve transmission throughout ATLAS with reduced emittance (transverse and longitudinal)
- Retire first 3 SC very low- β (0.009c & 2@0.016c) resonators





Operating Experience with RFQ & PII reconfiguration

RFQ Parameters

- 1. Frequency: 60.625 MHz
- 2. Maximum vane voltage: 70kV
- 3. CW operation
- 4. Length: 3.81 m
- 5. Aperture: 7.2 mm
- 6. Multi-segment split-coaxial structure

Operational Performance

- 1. RFQ WORKS CW!! Over 8000 hours of operation with >92% reliability.
- 2. Excellent transmission
 - a) 80-82% through PII
 - b) Up to 100% after PII Exit \rightarrow Target
- 3. Operation at ~95% of full powera) m/q ~6.7 acceleration achieved
- 4. Novel frequency control through precise temperature setting in feed back loop
- 5. Maximum power required: ~60 kW



RFQ internal views









New Beamline Upstream of the PII



RFQ Performance after Installation

- In operation since January 2013
- Initial field level conditioning reached 74kV inter-vane voltage
 - Design Maximum is 70kV
- Calculated best beam transmission is 83%
- Tune the following beams

—	12/06/2012 - ⁴⁰ Ar ⁺¹¹	M/q = 3.6	Beam transmission 79.2%
_	01/07/2013 - ¹⁶ O ⁺²	M/q = 5.3	Beam transmission 81.8%
_	01/18/2013 - ²⁰ Ne ⁺⁸	M/q = 4.0	Beam transmission 78.7%
_	02/11/2013 - ⁸⁴ Kr ⁺¹³	M/q = 6.46	Beam transmission 80.0%

- Two 60kW RF amplifiers
 - Tetrode final stage
 - Short lifetime of tetrode tubes (6months to 1 year).
 - Cooling problem with tubes.
- Presently limited to M/Q ~6.7.
 - Appears to be outgassing due to local heating effects
 - Improved vacuum pumping is planned to be installed by end of 2015.

Two new cryostats of superconducting resonators 1. "Energy Upgrade" Cryostat: 2009

- > Replaced cryostat containing six old β =0.15 split ring resonators
 - High-β class of split-ring resonators had never worked well.
- First new resonators for ATLAS in ~20 years
 - Matched velocity of 0.14c
 - 109.125 MHz, 25 cm length
 - Incorporate new techniques of fabrication
 - Abandon explosive bonding to copper for cooling
 - Adopt liquid helium immersion
 - Separate vacuum system for resonator interior
 - Variable position RF coupler for improved conditioning
 - Drift-tube face tilt to compensate for non-symmetric field steering
 - Keep frequency and phase control from past design
 - Helium pressure slow-tuner
 - Voltage-controlled reactance (VCX) PIN diode fast tuner
 - Improved cryostat design built on PII linac designs
 - Gravity-fed helium to resonators
 - Super-insulation use
 - 'Strong-back' resonator and solenoid mounting

Internal cryostat construction

Cavity string suspended from the lid before loading into the box cryostat.



Energy Upgrade Cryostat

Apply new design concepts to ATLAS resonators Restore maximum beam energy to original design

- Consists of 7 QWRs, f=109 MHz, beta=0.14
 - New variable RF coupler
 - Slow tuner & PIN diode fast tuner maintained
- 1 solenoid (centered)
- Separate insulating vacuum
- UHV cavity vacuum

Energy Upgrade Cryostat Long Term Field Performance



2009 E(avg) = 5.2 MV/m 2015 E(avg) = 4.8 MV/m Fields are limited by choice of continuing use of VCX PIN diodes for phase stabilization

"Intensity Upgrade" Cryostat and Booster Rebuild

Replace 3 cryostats of twelve low- β (0.065c) and six high- β (0.105c) split-ring resonators

- New class of quarter-wave resonators ($\beta = 0.075c$)
 - Build on the techniques used in "Energy Upgrade Cryostat"
 - PLUS
 - Abandon VCX PIN diode fast tuner
 - Adopt a driven RF control system
 - No field limitations due to PIN diodes power handling capability
 - Now need 1-3 kW RF power rather than 150-200 watts
 - Further improve RF coupler to handle additional beam power
 - Continue to improve surface preparation techniques
 - Helium pressure slow-tuner

Redesign the middle "Booster" section of the ATLAS LINAC

- New liquid helium distribution system
- Additional shielding to handle planned increased beam intensity
- New beam optics configuration
- Retain only one cryostat of older split-ring resonators
- Retire tandem as part of PII-Booster beamline redesign

Resonator Clean Assembly

Completed in January 2013





Booster Re-configuration Project

- Major reconfiguration of the Booster region
 - Install new cryomodule with 7 resonators
 - 3 split-ring cryomodules retired (16 split-ring resonators)
 - New cryogenics distribution system
 - All new cabling and beam optics configuration
 - Retire tandem injector accelerator
- Six month full ATLAS shutdown (June-December 2013)





Booster Reconfiguration Project Overview

Tandem Vault

BEAM

from P

- Complete shielding and room redesign
 - Divides old Booster Area into 3 sections
 - New doorway required
- **PII-Booster beamline redesigned**
- 40° bend beamline reconfiguration
- New cabling to Booster system
 - Remove old cables and cable trays
- New RF amplifiers and new resonator electronics
 - For new cryomodule
 - New Master Oscillator system
- Computer interface modifications

Booster Upgrade Photo Sequence

Booster Before Reconfiguration June 10, 2013



Booster Upgrade Photo Sequence

Dis-assembly:



Booster room July 23, 2013



HIAT 2015 Yokahama, Japan September 9, 2015 R. Pardo

June 26, 2013



Phase II: Center ("Booster") Section Rebuild

November 2013

January 2014



Intensity Upgrade Cryostat Field Performance



March 2014: Initial E(avg) = 8.2 MV/m. Present average: 7.3 MV/m Limited by control problems at present.

Compare to the 2009 'Energy Upgrade' resonators with E(avg) = 4.8 MV/m

Summary

Improvement projects over past 6 years have transformed ATLAS

- ✓ Two cryostats of new resonators (14 resonators)
 - World record performance in field levels
 - No obvious deterioration in resonator performance with time
 - Improved transmission
 - Reduced beam emittance growth
- ✓ New RFQ linac
 - First operations CW RFQ in US
 - Reduced beam emittance growth
 - Improved transmission
 - Improved performance at high currents (space charge compensation)
 - Limited to M/Q ~6.7 at present

Ongoing projects will further transform facility

- ✓ EBIS charge breeder to replace ECR charge breeder (January 2016)
- ✓ AIRIS in-flight RIB facility will require high beam currents from LINAC
- ✓ Argonne Gas-filled Fragment Analyzer-AGFA
 - Heavy and super-heavy regime studies
 - Requires high stable-beam currents from ATLAS
- Plans for a multiuser mode now under development