Argonne NATIONAL LABORATORY

Operation of the ATLAS Superconducting Accelerator for Heavy Ions

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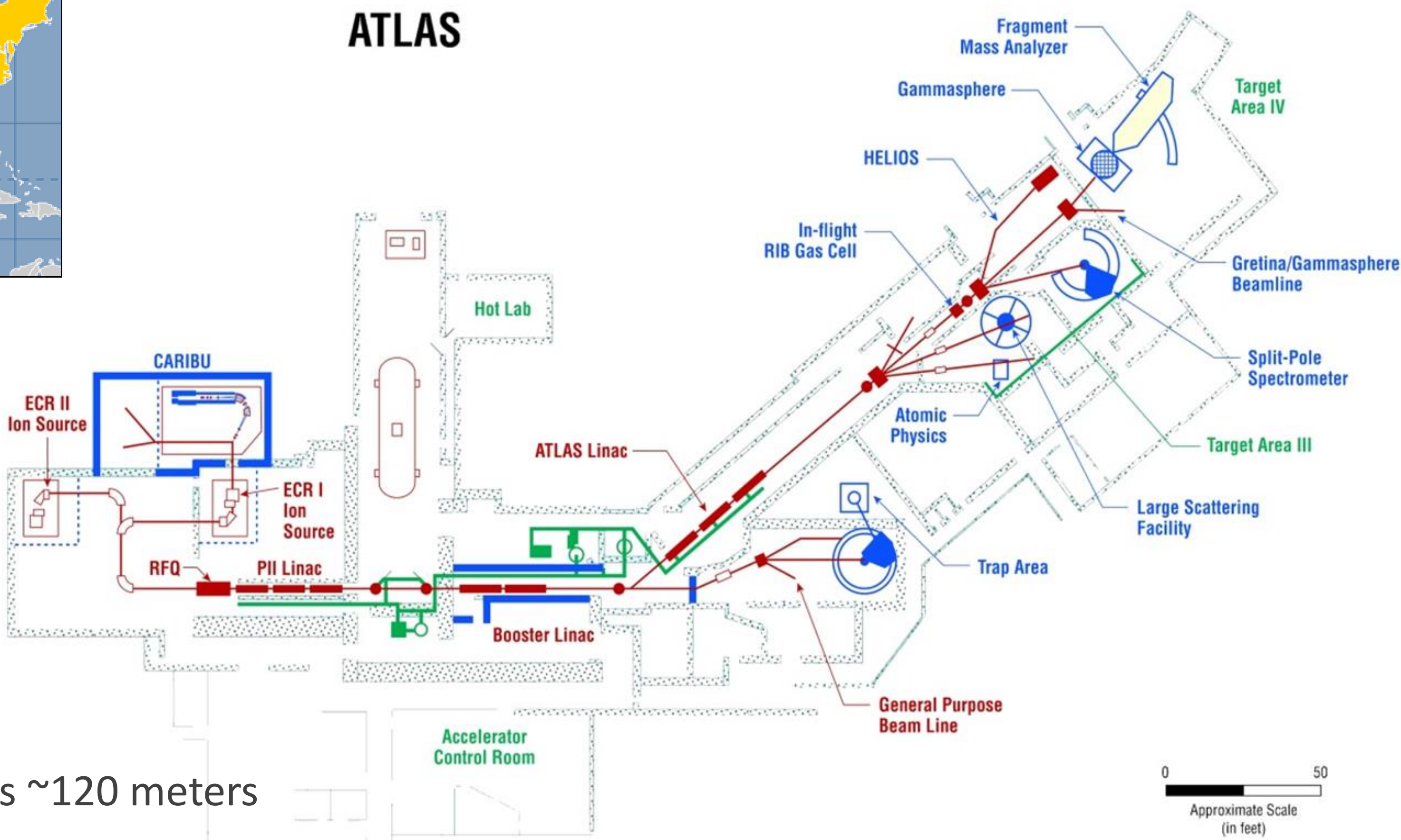
U.S. DEPARTMENT OF ENERGY

Outline

- Overview the ATLAS accelerator
- Staffing and beam diversity
- Accelerator startup
- Accelerator configuration logging and mass to charge scaling
- Tuning radioactive ion beams (RIB) from both in-flight production and CARIBU ion source, as well as associated diagnostics
- Maintenance
- Problems/Troubleshooting

Floor Plan and Location

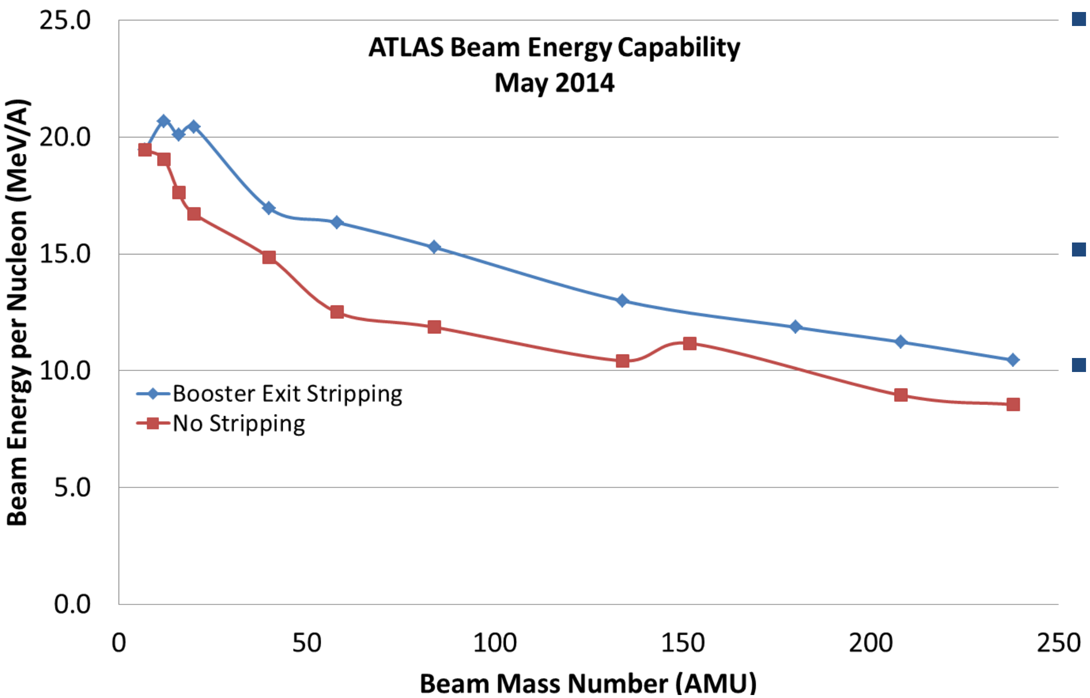
Argonne Tandem Linear Accelerating System



Total facility length is ~120 meters

Overview

- ATLAS is world's first superconducting (SC) heavy-ion accelerator
- It is DOE's designated National User Facility for stable, low energy, ion beams with a focus on nuclear physics research
- Made up of 3 distinct accelerator sections, totaling 50 SC RF resonators providing an effective total voltage of 52MV, coupled with 26 SC solenoids
- 21.6% of beam time is devoted to radioactive ion beams, either from CARIBU or "in-flight"

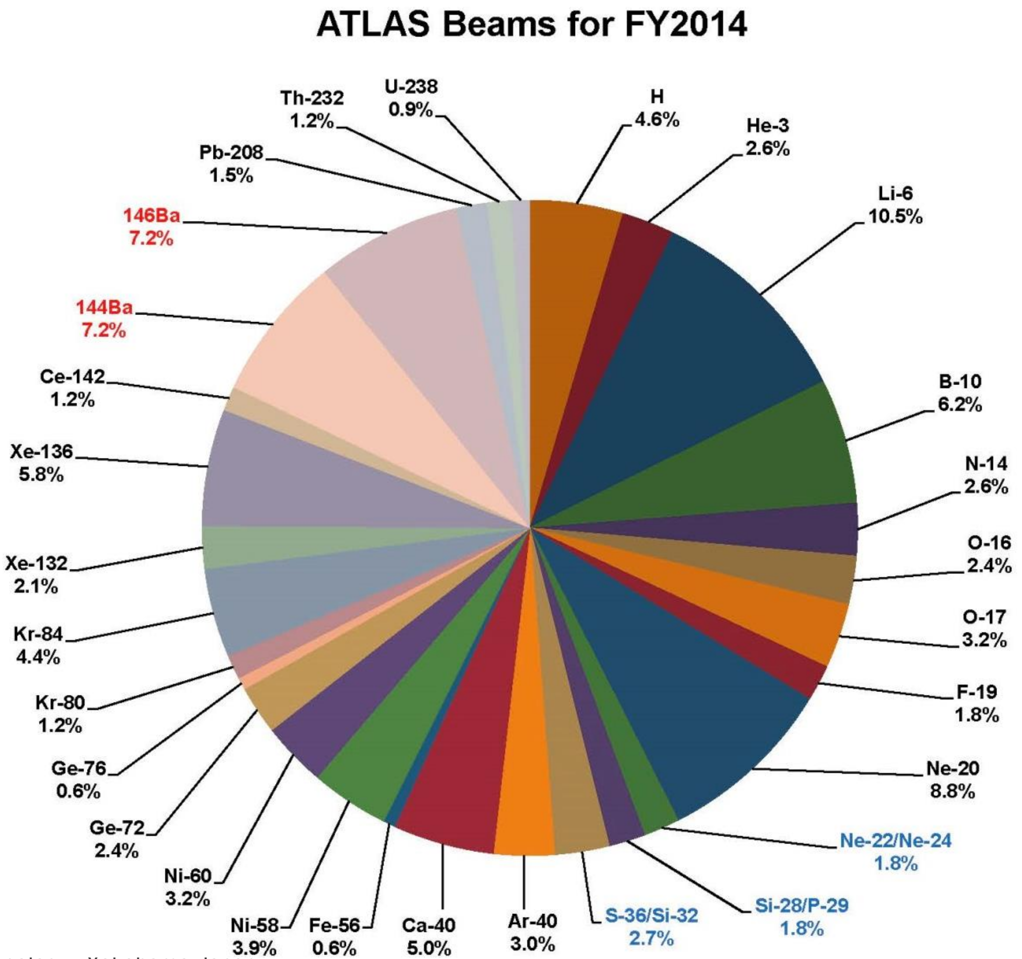


- Typical beam currents are in the range of 5 to 500 electrical nanoamps, however demonstrated 35 electrical microamps through PII
- ATLAS Operations budget is ~$10M/year
- 21 Full Time Employees

ATLAS Beams for FY2014

Stable ion species provided by ATLAS range from protons through uranium

- 29 unique ion species delivered in FY2014
  - 2 of those 29 were radioactive ion beams from CARIBU
  - 3 of those 29 were in-flight produced radioactive ion beams (RIB)



ATLAS Staffing and Operator Training

- 21 Full time employees & 2 part time employees
  - Divisional Groups: Physicists (2), Operations (8), Ion Source(2), Control System (2), Cryogenic (2), Mechanical (2), Electronic (3)
- 7 qualified operators keep the accelerator running 24 hours a day, 7 days a week
- Almost 50% of shifts are staffed by 2 operators, 1 operator is the chief shift operator, the other is safety watch.
- Every operator is required to work each shift at least once per 6 months
- When only one operator is on shift the safety watch is fulfilled by the experimenter
- On average 40 safety classes must be kept up to date for each operator
- New operator qualification consists of 6-8 "classroom session", the rest is on the job
- Operator qualification typically takes 6 months, made up of 2 exams and 1 practical

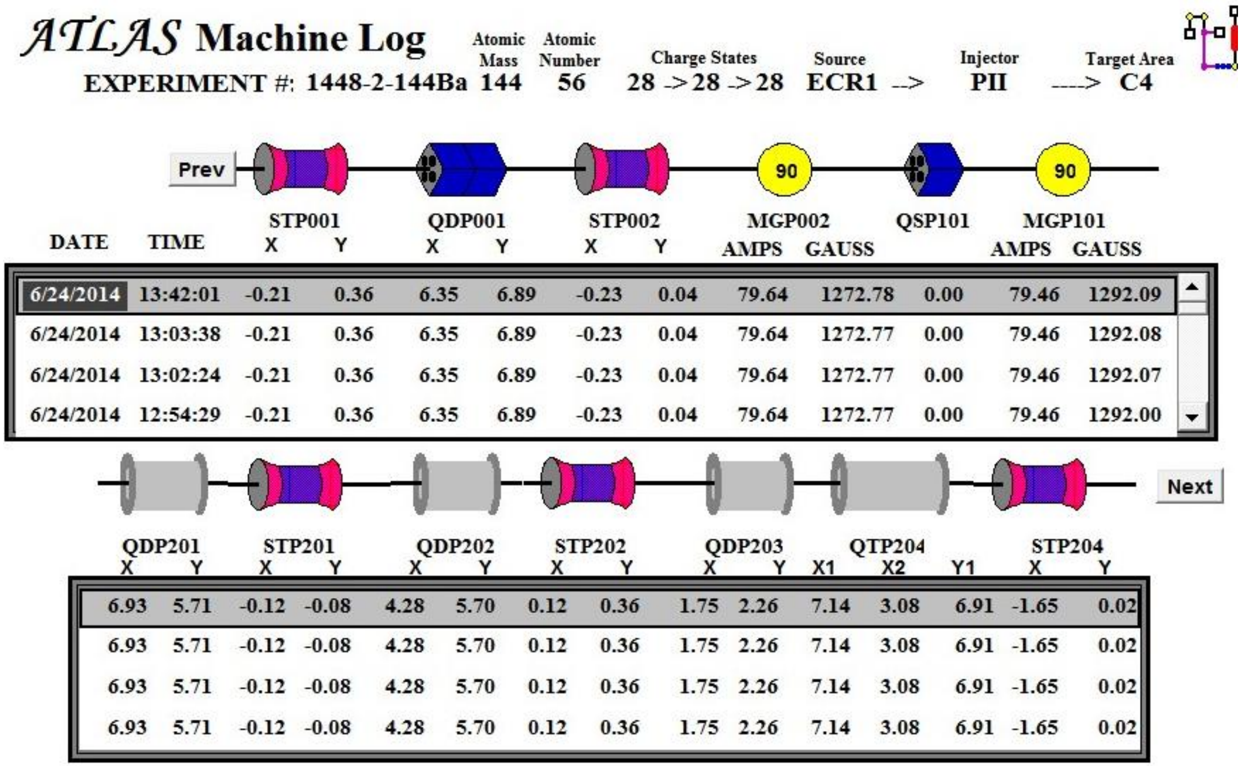
	Shift	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Sun.
Week 1	0000-0800	BB	GD BB	GD BB	GD BB	GD	GD	BB
	0800-1600	NP	RB NP	RB NP	RB NP	RB	RB	NP
	1600-2400	TR	TR SB	TR SB	TR SB	SB	SB	TR
Week 2	0000-0800	BB	GD BB	GD BB	GD BB	GD	GD	BB
	0800-1600	NP	RB NP	RB NP	RB NP	RB	RB	NP
	1600-2400	TR	TR SB	TR SB	TR SB	SB	SB	TR

New Experiment Startup and Beam Tuning

- "Authorization to Operate" form insures experiment is reviewed and authorized prior to delivering beam to the user.
- Reconfigure all elements of the accelerator for each experiment
- Two options for accelerator startup
  - Use a previous accelerator configuration from a computerized library
    - Useful for either exact configuration or scaled configuration
    - Saves time
  - Establish a new accelerator configuration
    - Time consuming
    - Typically achieves best beam quality

Accelerator Device Logging

- Offline computer (Paradox) records entire accelerator configuration and beam parameters
- Creating a library of old accelerator configurations
- Basis for scaling accelerator

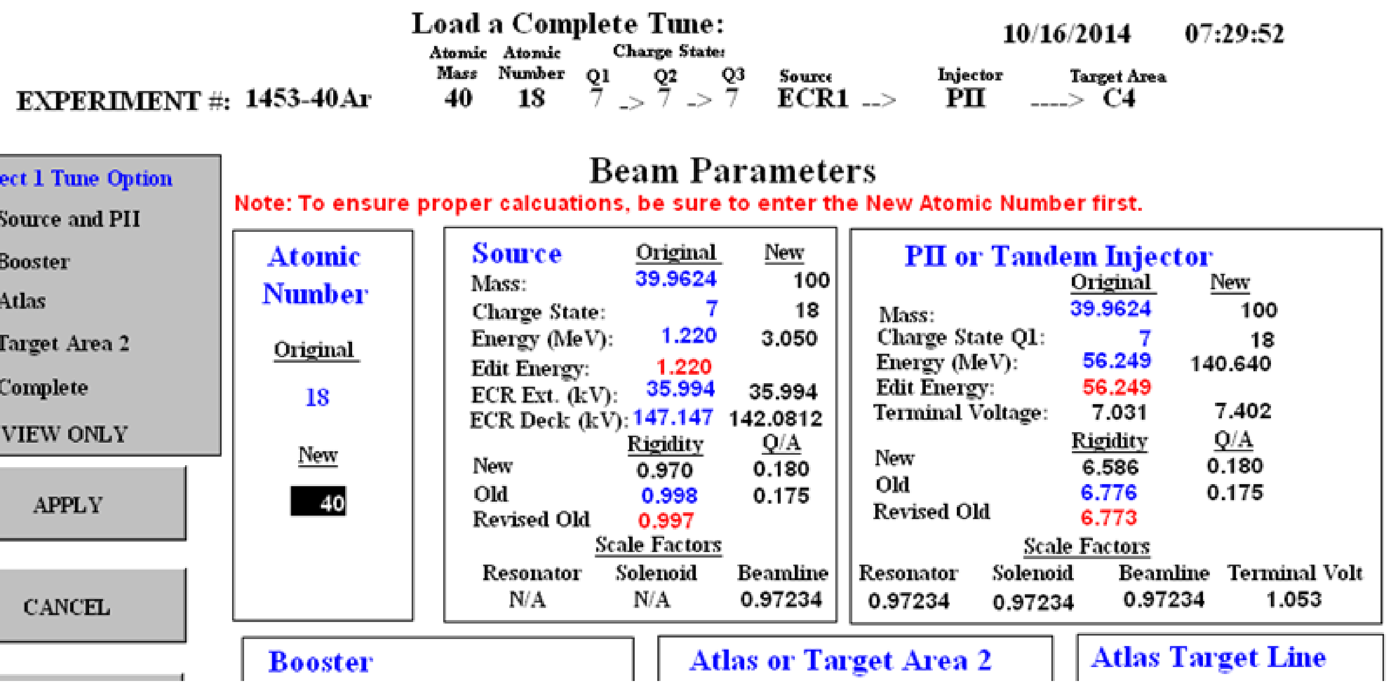


DATE	TIME	STP001 X	STP001 Y	QDP001 X	QDP001 Y	STP002 X	STP002 Y	MGP002 AMPS	MGP002 GAUSS	QSP101	MGP101 AMPS	MGP101 GAUSS
6/24/2014	13:42:01	-0.21	0.36	6.35	6.89	-0.23	0.04	79.64	1272.78	0.00	79.46	1292.09
6/24/2014	13:03:38	-0.21	0.36	6.35	6.89	-0.23	0.04	79.64	1272.77	0.00	79.46	1292.08
6/24/2014	13:02:24	-0.21	0.36	6.35	6.89	-0.23	0.04	79.64	1272.77	0.00	79.46	1292.07
6/24/2014	12:54:29	-0.21	0.36	6.35	6.89	-0.23	0.04	79.64	1272.77	0.00	79.46	1292.00

QDP201 X	QDP201 Y	STP201 X	STP201 Y	QDP202 X	QDP202 Y	STP202 X	STP202 Y	QDP203 X	QDP203 Y	QTP204 X1	QTP204 X2	QTP204 Y1	STP204 X	STP204 Y
6.93	5.71	-0.12	-0.08	4.28	5.70	0.12	0.36	1.75	2.26	7.14	3.08	6.91	-1.65	0.02
6.93	5.71	-0.12	-0.08	4.28	5.70	0.12	0.36	1.75	2.26	7.14	3.08	6.91	-1.65	0.02
6.93	5.71	-0.12	-0.08	4.28	5.70	0.12	0.36	1.75	2.26	7.14	3.08	6.91	-1.65	0.02
6.93	5.71	-0.12	-0.08	4.28	5.70	0.12	0.36	1.75	2.26	7.14	3.08	6.91	-1.65	0.02

Accelerator Scaling

- Paradox allows scaling of all accelerator devices
  - Resonators scaled by A/q
    - Scaling is limited to ±15% of saved configuration's mass to charge
      - Due to lack of linearity in setting resonator phase and amplitude
    - Scaling also limited by resonator amplitudes
- Scaling of magnetic devices based on magnetic rigidity
- Functionality critical for setup of CARIBU beams, or performing accelerator mass spectroscopy (AMS)



Accelerator Modifications - Since 2009

- Pioneered heavy ion accelerator technology in 1978, averaged 0.75MV accelerating voltage per resonator
- World record high 2.0MV accelerating voltage average per resonator
- Separate cavity and cryostat vacuum
- No degradation of quality or gradients since July 2009

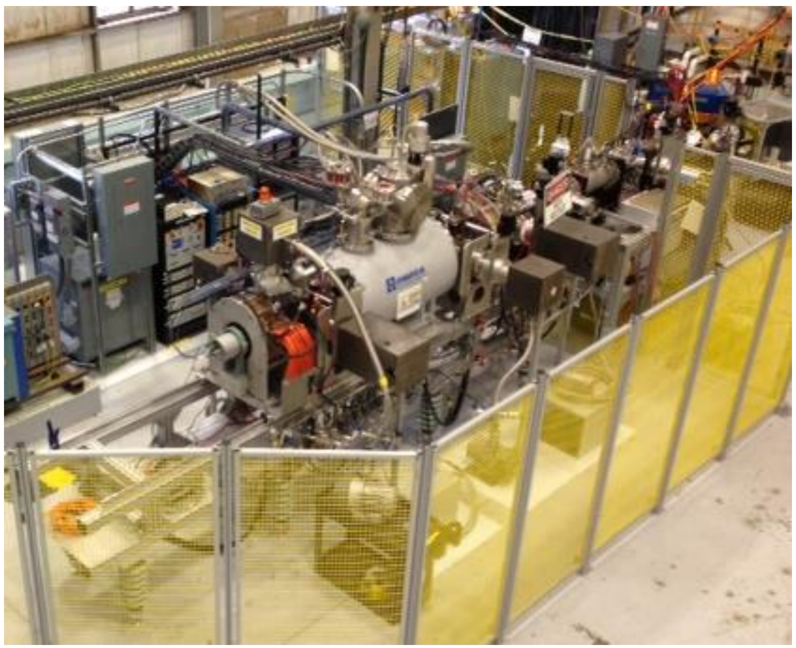
- Operates with greater than 90% reliability
- Bunches, focuses, and accelerates at the same time
- Beam emittance is maintained, and therefore allows good transmission

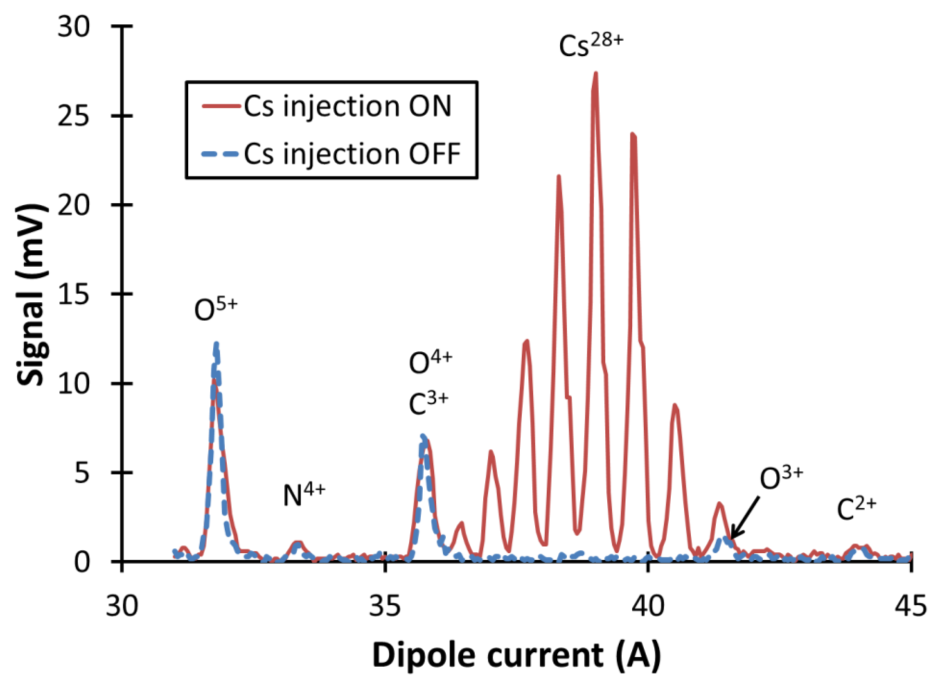
- World record 2.5MV accelerating voltage average per resonator
- Only 45W of power into 4.5K liquid helium system for entire cryostat during operation

Accelerator Modification (EBIS) - Early 2016

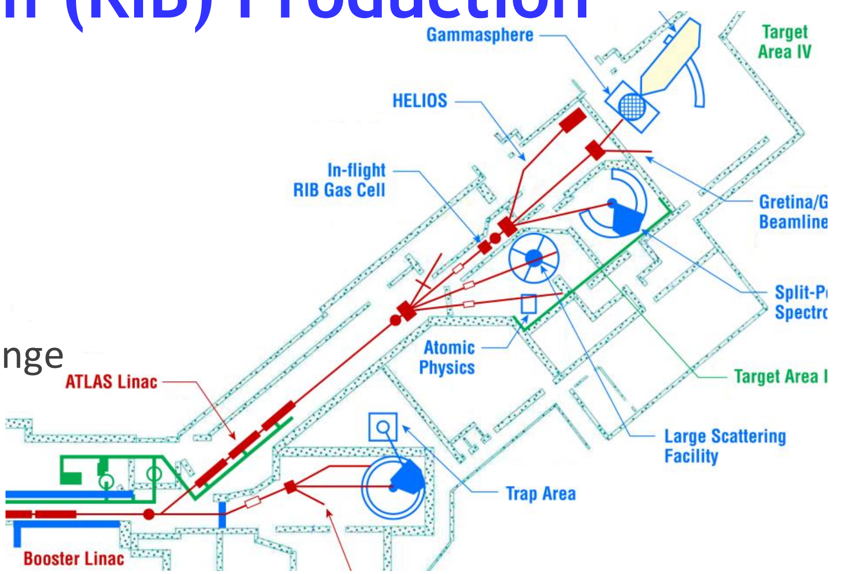
Electron **B**eam **I**on **S**ource (EBIS)

- Replaces existing ECR-Charge Breeder
- Approximately doubles charge breeding efficiency versus ECR-Charge Breeder
- Provides very clean background in the A/q range of CARIBU ion beams





In-Flight Radioactive Ion Beam (RIB) Production

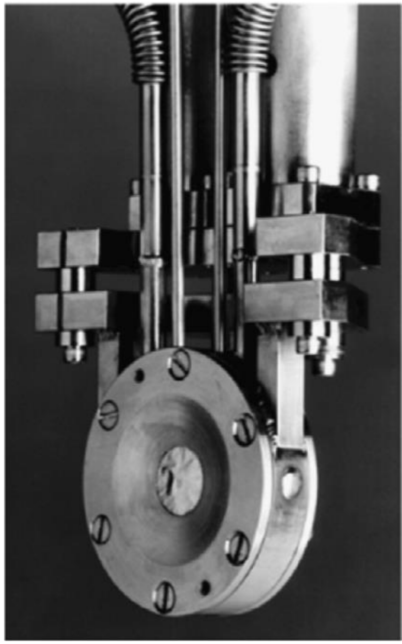


1. Tune stable beam to target
   A. Typically used to calibrate detector

2. Insert gas cell or Be foil into beamline
   A. Stable beam interacts with deuterium or Be to change proton/neutron ratio

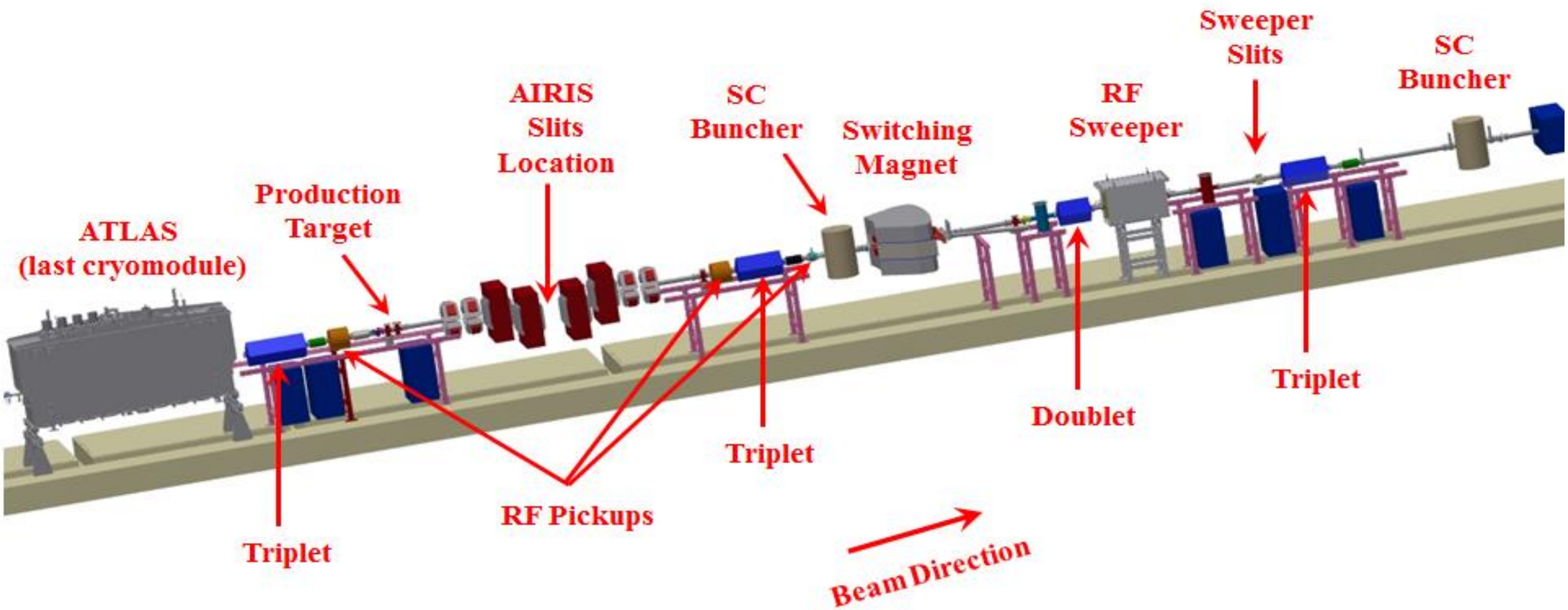
3. Retune stable beam to target
   A. Energy will be degraded some after passing through gas cell/Be foil

4. Tune RIB from gas cell to detector system
   A. Scale devices after target based on expected rigidity
   B. Solenoid after gas cell focuses scattered RIB
   C. Rebuncher before target: time focuses at production target
   D. Rebuncher after target: time focuses at RIB “sweeper”
   E. RIB “sweeper” in some cases can be used to remove undesirable beam with similar rigidity but different timing



Accelerator Modifications (AIRIS) - Before 2017

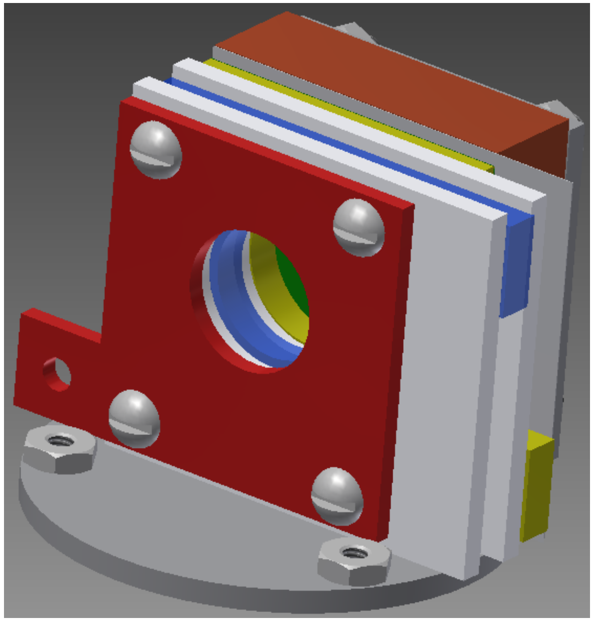
- **A**rgonne **I**n-flight **R**adioactive **I**on **S**eparator (AIRIS)
  - Dedicated mass separator
  - Improved transmission of RIB produced in-flight
  - Provides new regions of RIB's, higher mass and further from stability
  - RIB separation does not rely on beam transport optics, making it available to more target areas than current RIB production location
  - RF sweeper to remove beam tails

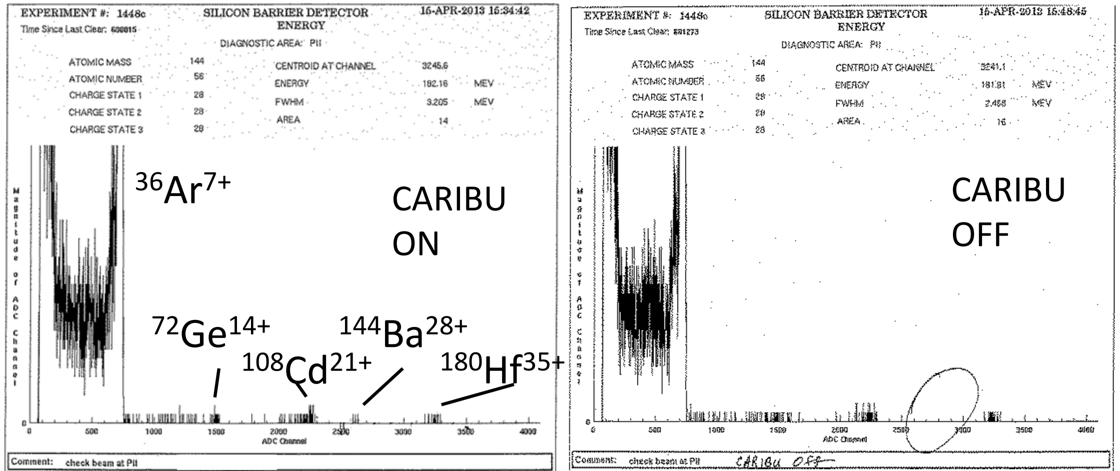


CARIBU Radioactive Beam Tuning

- Initial tuning with “guide beam” having a similar mass to charge ratio
- Scale entire accelerator for mass to charge ratio difference
- Use Beta Detectors and rate meter for final fine tuning
  - Radioactive beams intensities < 10^5 particles/second, use of specialized detectors and electronics necessary
  - ECR stable backgrounds force use of β decay to tune RIB
  - 8 different beta detectors located through the accelerator

Beta Detector





Maintenance

- One major *planned* maintenance period per year (~4 weeks in length)
  - Address annual safety testing and inspections
  - Cryostat repairs
  - Cryogenic system repairs
  - Any other major repairs

- Run to failure philosophy

- Minor maintenance work handled during startup day

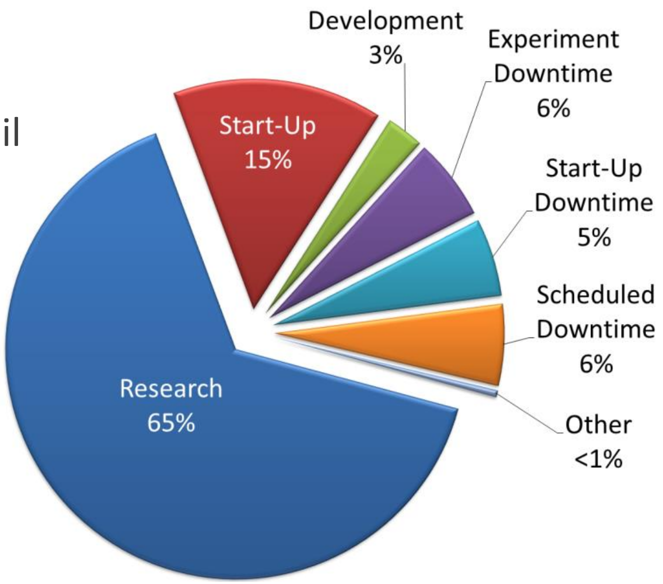
- ATLAS has been averaging 91.9% reliability over the last 6 years
  - Flexible accelerator design allows 'work around' failures on the fly.

- Recent upgrades to the accelerator have made reliability better, but those upgrades require more diverse expertise to achieve.

Troubleshooting - Problems

- Operators expected to handle (at least diagnose) almost any problem
  - Examples: resonator problems, He compressor trips, power supply exchange, water/air leaks/blockage, vacuum problems
  - Ask for assistance if the problem lasts longer than one hour
- Heavy reliance on system experts
  - All system experts are on call at all times
- Recent LHe plumbing failure inside a cryostat
  - Resulted in ~4 hours of downtime before beam delivery resumed
  - Loss of ~3MV from entire accelerator
  - 15-35% transmission loss through affected cryostat until repaired
  - Demonstrates nimble abilities of small knowledgeable workforce

Staffed hours for 2014



Summary

- 21 full time employees to operate and maintain the accelerator
- Accelerator in operation 24 hours, 7 days a week
- Operators perform maintenance tasks as well as tuning beam
- Accelerator configuration library and scaling saves time
- 3 major improvement projects in last 5 years; 2 additional improvements planned or in process within the next 2 years
- In-Flight Radioactive Ion Beam production is well understood and upcoming upgrade will improve yields, expand available species, and increase target areas
- CARIBU Radioactive beam tuning becoming standard; it is more complicated than stable beam tuning
- One scheduled 4 week maintenance period per year, run to failure philosophy, perform repairs as needed

THANK YOU