

PUSHING THE INTENSITY ENVELOPE AT THE ATLAS LINAC*

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Abstract

The ATLAS linac at Argonne National Laboratory has recently been upgraded for higher beam intensity and transport efficiency. A new 60 MHz RFQ replacing the first few cavities of the Positive Ion Injector (PII) section and a new superconducting module replaced three old cryomodules of split-ring resonators in the Booster section of the linac. Following the installation of the new RFQ, we performed a high-intensity run using a $^{40}\text{Ar}^{8+}$ beam. A beam current of 7 pA was successfully injected and accelerated in the RFQ and PII section of the linac to an energy of 1.5 MeV/u. The results of this run are presented and the limitations to reach higher currents are discussed. A second run is planned to try to push the beam current higher and farther into the Booster and ATLAS sections of the linac. Finally, a future intensity upgrade plan, motivated by the inflight production of radioactive beams using the AIRIS separator and the proposed multi-user upgrade with potential stable beam applications is presented and discussed. The ultimate goal of this upgrade plan is to reach 10 pA or higher for most beams at the full ATLAS energy.

THE RECENT ATLAS UPGRADE AND IMPROVEMENT IN BEAM CHARACTERISTICS

The Argonne Tandem Linear Accelerator System (ATLAS) was the first superconducting linac for ion beams in the world [1]. It has been operating and delivering ion beams for over thirty years at different capacities. Over the same period, ATLAS has undergone

several upgrades [2]. The most recent is the Efficiency and Intensity upgrade [3].

The Efficiency and Intensity upgrade consisted of a new RFQ [4] and a new superconducting module [5]. The RFQ replaced the first three superconducting cavities of the Positive Ion Injector (PII) to avoid deterioration of the beam quality due to fast acceleration of low energy beams. The RFQ uses the existing multi-harmonic buncher (MHB) as a pre-buncher. Two notable features of the ATLAS RFQ are trapezoidal modulations in the accelerating section and a compact output matcher to produce an axially-symmetric beam for direct beam injection into the PII which uses solenoidal focusing [6]. The new cryomodule replaced three old modules with split-ring resonators [7]. The split-ring cavities steer the beam resulting in beam loss and the subsequent quench of solenoids. The new cryomodule is made of 7 quarter-wave resonators (QWR) and 4 superconducting solenoids. The QWRs were designed and built with steering correction [8]. The new module should be able to accelerate 10 to 100 times higher intensity stable beams without significant beam loss.

Both the new RFQ and cryomodule have been successfully commissioned and are now being used for routine ATLAS operations. The improved beam quality from the RFQ, both transverse and longitudinal, has increased the transmission by 50 to 100% for all beams accelerated in ATLAS [9]. The overall transmission is now routinely over 80%, which is dictated by the MHB used to produce a small longitudinal emittance for more efficient beam transport and acceleration in ATLAS [10]. Figure 1 shows the current layout of ATLAS after the recent intensity and efficiency upgrade.

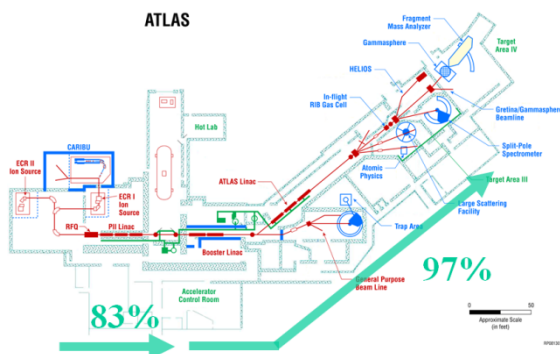


Figure 1: ATLAS layout after the recent Intensity and Efficiency Upgrade showing typical beam transmission through the different linac sections.

HIGH INTENSITY RUN AT ATLAS

A high-intensity run was performed at ATLAS in February 2014, just before the installation of the new cryomodule. The goal of this run was to inject and accelerate 10 pA of a heavy-ion beam through the RFQ+PII section of ATLAS.

An $\sim 120 \text{ pA}$ $^{40}\text{Ar}^{8+}$ beam was produced at the ECR-2 ion source. The LEPT, RFQ and PII were first tuned with low current beam using attenuators to control the beam intensity and collimating slits to control the beam emittance. A transmission of 80% or more through the RFQ+PII is essential. A lower transmission would mean a substantial beam loss that will prevent ramping up the beam current. The beam intensity was increased by gradually removing beam attenuators, opening slits and adjusting the gas in the ECR. The final results were: 72 pA injected into the RFQ+PII section with 58 pA transmitted and accelerated (consistent with the simulated MHB-RFQ transmission) to the full 1.5 MeV/u energy. That is a 7.2 pA $^{40}\text{Ar}^{8+}$ beam, which is a significant

* This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract number DE-AC02-06CH11357. This research used resources of ANL's ATLAS facility, which is a DOE Office of Science User Facility.
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improvement over the previous maximum of 2 μA for this beam.

Among the limitations preventing us from reaching higher currents are: (i) The current ECR source produces enough beam current but with such a large emittance that it requires significant collimation to be effectively transported through the LEBT and injected into the RFQ, (ii) beam loss in PII due to the large emittance and not enough steering correction to control the beam center, as well as (iii) the loss of the RFQ satellite bunches in PII due to the frequency change. Both of these effects lead to solenoid quenching and resonator heating in PII, which are the main limiting factors. A second run is planned in the near future to try to push the beam current higher and farther into the Booster and ATLAS sections of the linac.

OPPORTUNITY FOR A FUTURE INTENSITY UPGRADE AT ATLAS

The Argonne In-flight Radioactive Isotope Separator (AIRIS) [11] project has recently been approved, by the US Department of Energy's (DOE) Office of Nuclear Physics, to be built and installed at the ATLAS facility. AIRIS, shown in Figure 2, will use stable beams from ATLAS to produce secondary radioactive beams (RIBs) using transfer reactions. Secondary beams with masses up to 50 with energies variable over the full ATLAS energy range will be available to the same experimental areas served by ATLAS stable beams. The existing radioactive beam facility [12] has been limited to primary beam intensities of about 100 pA by both the gas cell target used to produce the secondary beams and the insufficient 20 year old radiation shielding in the production area. AIRIS is a dedicated device, where a liquid film target will be used along with the appropriate radiation shielding. The starting primary beam intensity for AIRIS is 1 μA , that is ten times the current limit. However, the production of radioactive beams at AIRIS could benefit significantly from an intensity upgrade of ATLAS. A 10 μA primary beam current will shorten the run time for typical RIBs and allow the production of more rare isotope beams at rates useful for experiments.

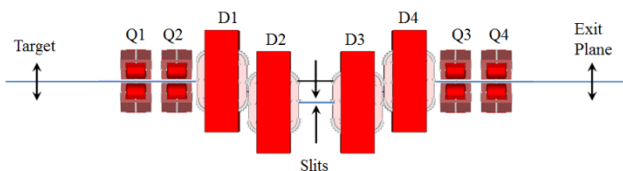


Figure 2: Layout of AIRIS, recently approved for construction and installation at ATLAS.

On the other hand, with the upcoming installation of the recently commissioned CARIBU-EBIS charge breeder [13], it will be possible to simultaneously accelerate one radioactive and one stable beam in ATLAS. The EBIS produces a 10 μs to 1 ms beam pulse with a repetition rate of up to 30 Hz, or 3% of the duty cycle. ATLAS, being a

CW machine, enables the possibility of injecting stable beams during the remaining 97% of the duty cycle. Considering the fact that a stable beam with a charge-to-mass ratio close to that of the CARIBU beam is usually used as a guide beam to tune the linac, it would be straightforward to inject any stable beam with a charge-to-mass ratio within 3% without retuning the machine. Such a multi-user capability could also benefit from an intensity upgrade at ATLAS where we can envision splitting an intense stable beam to serve different experimental areas simultaneously, including possible applications. In particular, this could be done right after the PII section of the linac for high-intensity beam irradiation experiments, or at the end of the linac for isotope production, which requires high intensity beams at the full ATLAS energy. Figure 3 shows the proposed layout for the ATLAS multi-user upgrade with beam splitting to the different experimental areas.

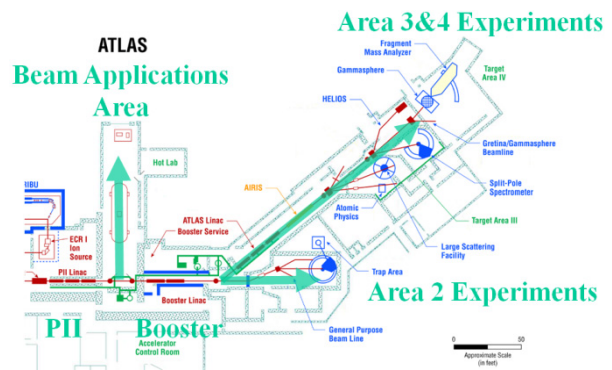


Figure 3: Layout of the proposed ATLAS multi-user upgrade with possible beam splitting after PII for beam applications and after Booster for the different experimental areas.

THE PATH TO HIGHER BEAM INTENSITY AT ATLAS

The ultimate goal of a future intensity upgrade is to deliver 10 μA or more for most beams at the full ATLAS energy. The proposed approach to reach this goal is:

- 1) Install a new VENUS-type [14] superconducting ECR ion source to provide the required input current for all beams within acceptable emittances.
- 2) Adopt achromatic beam transport to limit emittance growth in the LEBT, using more compact electrostatic focusing. This will be implemented with the upcoming CARIBU-EBIS installation and integration into ATLAS [15].
- 3) Locate where the RFQ satellite bunches are lost and, if needed, install beam collimators inside or between cryomodules to intercept them and avoid quenching of solenoids and cavities.
- 4) Add beam steering elements in PII to better control beam center. Few existing solenoids could be replaced by solenoids with steering correctors.
- 5) Install a second re-buncher after PII. Using a single re-buncher is enough for low current operations,

but the second re-buncher will be needed for high intensity runs.

- 6) Replace the remaining three split-ring cryomodules with at least one new QWR cryomodule, similar to the recent 72 MHz module. The split-rings are limiting the beam current in ATLAS to 2-3 μA due to their intrinsic beam steering.
- 7) A second high-beta QWR cryomodule, similar to the existing 109 MHz module [16], may be needed to achieve the energy goal for heavy ions..
- 8) Install high-power diagnostics throughout the linac.

With such a plan, we believe we could achieve the desired goal of higher beam intensity at ATLAS.

SUMMARY

Following the recent ATLAS Intensity and Efficiency Upgrade [3], we have performed a high-intensity run in the RFQ+PII section. A 7.2 μA $^{40}\text{Ar}^{8+}$ beam was successfully transported and accelerated to 1.5 MeV/u. This is a significant improvement over the previous limit of 2 μA for this particular beam. Work is ongoing to increase the available beam current, and we have identified several limitations and presented possible solutions. This first run was performed prior to the installation of the new intensity upgrade QWR cryomodule. We are planning a second high-intensity run in the near future to attempt to push the beam current higher and farther into the Booster and ATLAS sections of the linac.

With the upcoming AIRIS project and the proposed ATLAS multi-user upgrade, we see an opportunity for a future intensity upgrade of ATLAS. The goal of such an upgrade is to be able to deliver 10 μA or higher for most beams at the full ATLAS energy. This would allow higher intensity radioactive beams from AIRIS. It would also allow potential high-intensity stable beam applications that could run simultaneously with the experimental nuclear physics program following the ATLAS multi-user upgrade.

REFERENCES

- [1] L.M. Bollinger et al., “The Argonne Superconducting heavy-ion linac”, Proceedings of the Conference on Proton Linear Accelerators, Chalk River, Ontario, 14-17 September 1976, AECL-5677, p95 (1976).
- [2] K.W. Shepard et al., “Superconducting Low-Velocity Linac For The Argonne Positive-Ion Injector”, Proceedings of the 1989 IEEE Particle Accelerator Conference, Chicago, Illinois, March 20-23, 1989, IEEE Publishing Vol. 2, p974 (1989).

- [3] P.N. Ostroumov et al., “Completion of Efficiency and Intensity Upgrade of the ATLAS Facility”, Proceedings of the 2014 Linear Accelerator Conference (LINAC-14), Geneva, Switzerland, August 31 - September 5, 2014.
- [4] P.N. Ostroumov et al., “Development and beam test of a continuous wave radio-frequency quadrupole accelerator”, Phys. Rev. ST-AB 15 (2012) 110101.
- [5] M.P. Kelly et al., “Commissioning of the 72 MHz Quarter-Wave Cavity Cryomodule at ATLAS”, Proceedings of the 2014 Linear Accelerator Conference (LINAC-14), Geneva, Switzerland, August 31 - September 5, 2014.
- [6] B. Mustapha et al., “A full three-dimensional approach to the design and simulation of a radio-frequency quadrupole”, Phys. Rev. ST-AB 16 (2013) 120101.
- [7] K.W. Shepard et al., “Split-ring Resonator for the Argonne Superconducting Heavy-ion Booster”, IEEE Trans. Nucl. Sci. NS-24, p1147 (1977).
- [8] B. Mustapha and P.N. Ostroumov, “Electro-Magnetic Optimization of a Quarter-Wave Resonator”, Proceedings of the XXV Linear Accelerator Conference (LINAC-10), Tsukuba, Japan, September 12-17, 2010.
- [9] C. Dickerson et al., “Improved beam characteristics from the ATLAS upgrade”, HB-2014, East Lansing, MI, November 10-14, 2014.
- [10] B. Mustapha P. N. Ostroumov and J. A. Nolen, “A Driver Linac for the Advanced Exotic Beam Laboratory: Physics Design and Beam Dynamics Simulations”, Proceedings of PAC-07 Conference, Albuquerque, New Mexico, June 25-29, 2007, p1601.
- [11] S. Manikonda et al., “Argonne In-flight Radioactive Ion Separator”, Proceedings of HIAT-2012, Chicago, IL, USA.
- [12] B.B. Back et al., “Astrophysics experiments with radioactive beams at ATLAS”, AIP Advances 4, 041005 (2014).
- [13] P. Ostroumov et al., “Fast and efficient charge breeding of the Californium rare isotope breeder upgrade electron beam ion source”, Rev. of Sci. Instr. 86, 083311 (2015)
- [14] The VENUS ECR ion source, @ <http://cyclotron.lbl.gov/ionsources/venus>
- [15] P. Ostroumov et al., “Off-line Commissioning of EBIS and Plans for Its Integration into ATLAS and CARIBUEBIS”, Proceedings of the ICIS-2015 Conference, New York, NY, August 23-28, 2015.
- [16] J.D. Fuerst, “The ATLAS Energy Upgrade Cryomodule”, Proceedings of SRF 2009, Berlin, Germany.