PROPOSAL FOR SIMULTANEOUS ACCELERATION OF STABLE AND UNSTABLE IONS IN ATLAS†

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Abstract

The Argonne Tandem Linac Accelerator System (ATLAS) is the only national user facility for low-energy stable heavy ion beams. With the recent commissioning of the Californium Rare Isotope Breeder Upgrade (CARIBU), ATLAS will also be used to accelerate radioactive beams. We here propose to convert ATLAS into a multi-user facility by simultaneously accelerating stable beams from the ECR ion source and radioactive beams from an Electron Beam Ion Source (EBIS) charge breeder under development for CARIBU. Radioactive beams produced from EBIS will contain several charge states of the same isotope, and could be injected into ATLAS in short (~10μs) pulses. We propose modifications of the existing ATLAS low energy beam transport line that will allow the simultaneous injection and acceleration of one or more charge states from EBIS and a stable ion beam from the ECR. Beam dynamics simulations using the code TRACK confirmed the feasibility of these modifications. The realization of this concept will increase the available beam time, the intensity of radioactive beams and improve the quality of the delivered beams as well.

INTRODUCTION

The Argonne Tandem Linac Accelerator System (ATLAS) is the only national user facility for low-energy stable heavy ion beams. On a yearly basis ATLAS provides beam time in excess of 5000 hours to domestic and international users.

Recently, the californium rare isotope breeder upgrade (CARIBU) had been successfully commissioned at ATLAS [1]. CARIBU will produce, at full capacity, beams of ~80-160 amu fission fragments from a 1 Curie ^{252}Cf source. After thermal stabilization and mass separation, the fragments will be charge bred in a charge breeder based on an electron beam ion source (EBIS) [2]. This type of charge breeders yield higher breeding efficiencies with fewer contaminations and shorter breeding times compared to electron cyclotron resonance (ECR) based charge breeders. After charge breeding in EBIS, the radioactive beams will be injected into ATLAS, used as a post accelerator.

When radioactive beams from CARIBU become available, the already high demand for ATLAS beam time is expected to further increase. It may therefore be necessary to upgrade ATLAS into a multi-user facility - capable of simultaneously accelerating multiple beams and delivering them to different experiments. The feasibility of the proposed upgrade project relies heavily on two features:

a. The accelerator structure of ATLAS, consisting of individually-phased superconducting cavities, is extremely versatile, as was best demonstrated in the simultaneous acceleration of 8 charge states of Uranium through the booster linac section [3]. This enables the acceleration of stable and radioactive beams with charge to mass ratios differing by as much as 5%. Amongst the beams available for injection into ATLAS are numerous examples that meet this criterion, as shown in Table 1 below.
b. The radioactive beam from CARIBU EBIS will be pulsed with a pulse repetition rate of ~30Hz and a pulse length of ~10μs for a duty cycle of 0.03%. During the remaining time it will be possible to feed the accelerator with the appropriate stable beam.

Table 1: Some Beams with Similar Charge-to-Mass Ratios which can be Accelerated Simultaneously in ATLAS

Nominal Charge/mass	Stable Beams from ECR2	Radioactive beams from EBIS
0.15	$^{20}Ne^{3+}$, $^{86}Kr^{13+}$ $^{238}U^{36+}$, $^{133}Cs^{20+}$	$^{86}As^{13+}$, $^{106}Nb^{16+}$ $^{93}Kr^{14+}$, $^{93}Rb^{14+}$
0.16	$^{208}Pb^{33+}$, $^{56}Fe^{9+}$	$^{100}Y^{16+}$, $^{87}Br^{14+}$
0.18	$^{128}Xe^{23+}$, $^{84}Kr^{15+}$	$^{111}Tc^{20+}$, $^{138}Te^{25+}$
0.20	$^{20}Ne^{4+}$, $^{90}Zr^{18+}$	$^{131}Sn^{26+}$, $^{124}Cd^{25+}$
0.23	$^{56}Fe^{13+}$	$^{105}Ru^{24+}$, $^{101}Mo^{23+}$ $^{91}Sr^{21+}$,$^{83}Se^{19+}$

In order to achieve multi-user capability, 3 main points were identified:

- Injection of beams from two sources into the ATLAS Low Energy Beam Transport (LEBT).
- Modification of the ATLAS LEBT, which contains a 180 degrees bend, to accommodate for the transport of two beams with slightly different charge-to-mass ratios while introducing minimal emittance growth.

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- Extraction of the beams after acceleration in ATLAS and their delivery to the designated experimental areas.

The primary challenge presented would be addressing the above points in a cost effective way and within the constraints of the available infrastructure.

LEBT MODIFICATION

A general layout of the proposed ATLAS LEBT is depicted in Figure 1. The orientation of the EBIS charge breeder platform with respect to the ATLAS accelerator beam line dictates a total 180° bend of the radioactive beam. In order to accommodate the transport of multiple beams with different charge-to-mass ratios simultaneously, it is necessary to make the transport line achromat. This may be accomplished by using the Double Bend Achromat (DBA, also known as the Chasman Green lattice) [4]. In the DBA, each 90° bend is composed of two 45° bending magnets and an intermediate quadrupole lens. Using the mirror symmetry with respect to a plane through the middle of the quadrupole, it can be shown that the lattice is doubly achromatic in first order if the quadrupole strength k_0 satisfies the equation:

$$k_0 tan\left(\frac{k_0 Q}{2}\right) =$$

$$= \frac{(1-cos\theta)tan(u)+sin(\theta)}{\rho\left\{1-cos(\theta)+\frac{S_1}{\rho}\left[(1-cos(\theta))tan(u)+sin(\theta)\right]\right\}}$$

where Q is the quadrupole length and S_1 the distance from the bending magnet to the quadrupole. ρ, θ *and* u are the bending magnet's radius, bend angle and exit edge angle respectively.

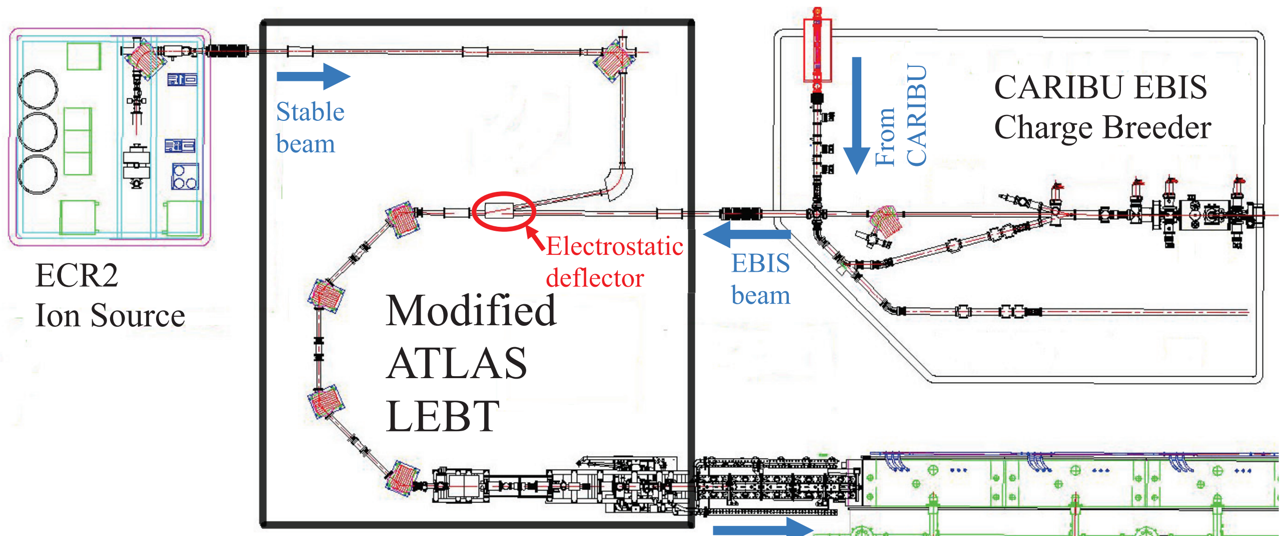

Figure 1: General layout of the proposed ATLAS low energy beam transport (LEBT) beam line. Arrows indicate the beam directions of the stable beam produced by ECR2, and the radioactive beam from EBIS.

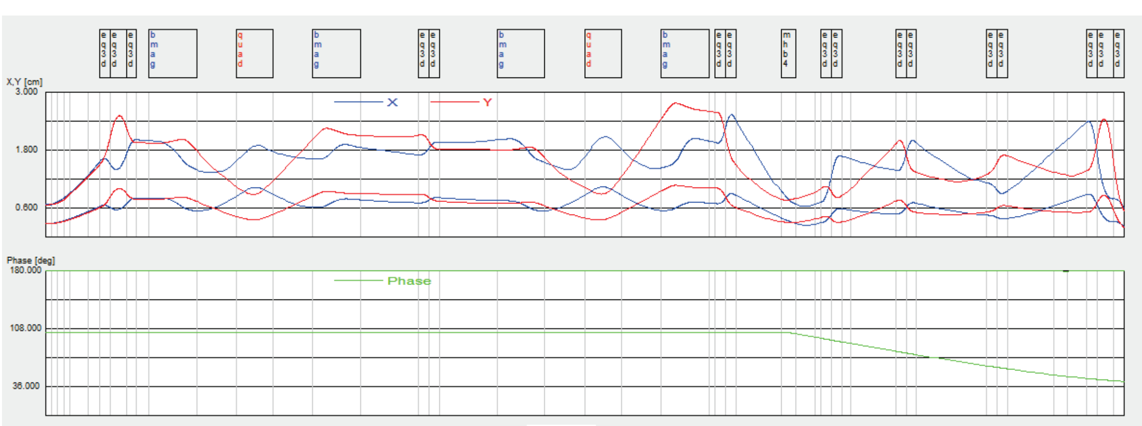

Figure 2: TRACK simulation results for the simultaneous transport of $^{132}Sn^{27+}$ from EBIS and $^{48}Ca^{10+}$ from ECR2. The RMS emittance growth in the 180° achromat bend is 1%.

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Furthermore, double focusing can be achieved by the appropriate choice of S_1 and u.

In addition to creating the achromat lattice, we also propose to replace all the magnetic focusing elements in the LEBT with electrostatic lenses. The latter are more compact and hence preferable to magnetic lenses in the low energy regime. The maximum of the dispersion function is obtained inside the intermediate quadrupole lens and is given by:

$$D_{max} = -\frac{1}{2k_0}\frac{sin(\theta)}{sin\left(\frac{k_0 Q}{2}\right)}$$

Hence these quadrupoles will have a 5 cm aperture radius which is larger than the standard used until now.

The code COSY Infinity [5] was used to evaluate the transfer matrix of the lattice and confirm its achromaticity in linear order, as well as the effects due to nonlinear terms. The beam dynamics code TRACK [6] was then used to simulate the simultaneous acceleration of $^{132}Sn^{27+}$ ions available from EBIS charge breeder and $^{48}Ca^{10+}$ ions available from ECR-2. The beams were first transported in the modified LEBT (Figure 2) and then injected into the ATLAS Radio Frequency Quadrupole (RFQ) accelerator and subsequent superconducting accelerator.

INJECTION AND EXTRACTION

The EBIS charge breeder will output approximately 30 batches of particles every second, each approximately 10μs long. In order to inject these batches and the batches produced from the ECR ion source into the same beam line, an electrostatic deflector (switch) will be used (as shown in Figure 1. The electrostatic deflector is to deflect the stable beam into the downstream beam line, but it will be synchronized to switch off with the arrival of the EBIS beam batches, so they continue downstream without deflection.

The design of the deflector will rely on the CARIBU EBIS electrostatic deflector and its ‘diagonal cut’ design. As shown in [2] this deflector design produces minimal emittance growth. However, due to the higher energy of the particles a higher deflecting voltage (evaluated at ~50kV) will be used for our purpose. If a total switching time (rise and fall) of 2ms is allowed then the requirements from the power supply are relatively relaxed, and a 94% duty cycle of the stable beam is still possible.

The Extraction of one of the beams and its subsequent delivery to the designated experimental hall is more complex due to the higher energy after acceleration and limited space available. The extraction will take place after acceleration in the Positive Ion Injector (PII) and the Booster, where the particles reach energies greater than 5.5MeV/u. A combination of a kicker magnet and a septum magnet will be used for the extraction.

SUMMARY

We propose a cost effective redesign of the ATLAS LEBT to accommodate the transport of multiple beams simultaneously. TRACK simulations show that with a modified LEBT, based on the Double Bend Achromat lattice, multiple beams with a charge-to-mass ratios differing by up to ~3% can be transported from two sources and accelerated in ATLAS. This will make ATLAS capable of multi-user operation, a capability which is important in light of the high demand for beam time, which is expected to further increase once radioactive beams from the EBIS CARIBU become available.

In addition to that, the radioactive beams from CARIBU EBIS will contain a range of charge states. If the LEBT is modified in accordance to our proposal, two of these charge states can be transported simultaneously and injected into different RF buckets in the RFQ. This will increase the intensity of the radioactive beams delivered to users.

Lastly, TRACK simulations indicate that transporting the CARIBU EBIS beam in the present LEBT may result in significant beam quality degradation. This is due to the high dispersion in the current layout and the energy spread of the beams produced by EBIS.

Further work on the injection, extraction and acceleration of multiple beams is still required.

REFERENCES

[1] G. Savard et al., “Radioactive beams from gas catchers: The CARIBU facility”, Instruments and Methods in Physics Research B 266, 4086 (2008).

[2] C. Dickerson et al., “Simulation and design of an electron beam ion source charge breeder for the californium rare isotope breeder upgrade”, Physical Review special topics - accelerators and beams 16, 024201 (2013).

[3] P. N. Ostroumov et al., “Simultaneous Acceleration of Multiply Charger Ions through a Superconducting Linac”, Physical Review Letters 86, 2798 (2001).

[4] H. Wiedemann, "Particle Accelerator Physics I – Basic Principles and Linear Beam Dynamics", 2nd ed., Springer-Verlag Berlin Heidelberg New-York, 2004.

[5] http://www.bt.pa.msu.edu/index_cosy.htm

[6] The beam dynamics code Track [http://www.phy.anl.gov/atlas/TRACK]