PROGRESS AND DESIGN STUDIES FOR THE ATLAS MULTI-USER UPGRADE*

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Abstract

With the recent integration of the CARIBU-EBIS into ATLAS for more pure and efficient charge breeding of radioactive beams, more effort is being devoted to study the design options for a potential multi-user upgrade. The proposed upgrade will take advantage of the pulsed nature of the EBIS beams and the cw nature of ATLAS, in order to simultaneously accelerate beams with very close charge-to-mass ratios. In addition to enhancing the nuclear physics program, beam extraction at different points along the linac will open up the opportunity for other possible applications. Different beam injection and extraction schemes are presented and discussed.

INTRODUCTION

In the past few years, the requested experimental beam time significantly exceeded the 5000-5500 hours that ATLAS can deliver every year. With the Californium Rare Isotope Beam Upgrade (CARIBU) online, the demand for beam time has more than doubled. Low intensity radioactive beams from CARIBU requires longer experimental run periods which further reduced the number of users served. We believe that there is an immediate need for multi-user capabilities at ATLAS. An analysis of ATLAS operation, when CARIBU beams are accelerated, shows that such an upgrade could deliver ~ 50% more beam time if certain experimental areas were appropriately equipped with instruments. Figure 1 shows the ATLAS floor plan with the possibility of serving two experimental areas simultaneously, namely Area II with beam energies of 4-7 MeV/u and Area III/IV with beams up to the full ATLAS energies.

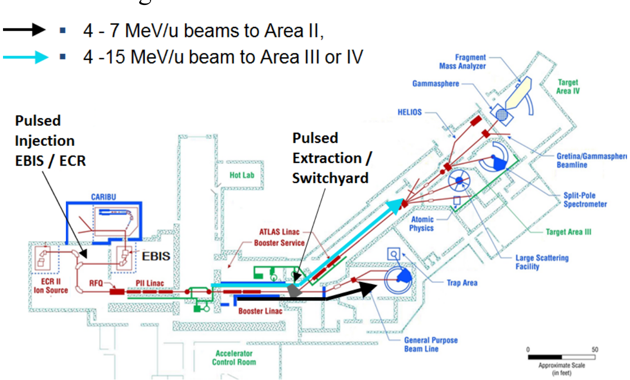

Figure 1: ATLAS floor plan showing the possibility of serving different experimental areas simultaneously.

The recently commissioned CARIBU-EBIS [1] will produce pulsed radioactive beams with ~ 3% duty factor. It will be possible to simultaneously inject stable beams from the ECR ion source in the remaining 97% of the cycle and take advantage of the cw nature of ATLAS. The two beams will have to be within 3% in charge-to-mass ratio. Figure 2 shows the expected time structure of the two beams and their combination.

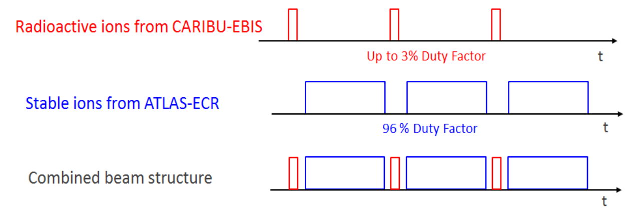

Figure 2: The expected time structure of the CARIBU-EBIS beam, the ECR beam and their combination for injection into ATLAS.

More details about the potential overlap of radioactive and stable beams that could be simultaneously accelerated as well preliminary design solutions for the upgrade were reported earlier [2]. We here report on the progress made in these design studies for both the beam injection at the LEBT and extraction of one of the beams at the Booster.

MODIFIED BEAM INJECTION IN THE LEBT

In order to combine two beams with very close charge-to-mass, one stable from the ECR and one radioactive from EBIS, the LEBT section has to be modified as shown in Figure 3. For the ECR line, an additional 90 deg bend and a 75 deg magnet are used to bring the beam to a 15 deg pulsed electrostatic deflector on the EBIS line. In addition, two sextupoles are required for second order corrections in the dispersive section between the dipoles.

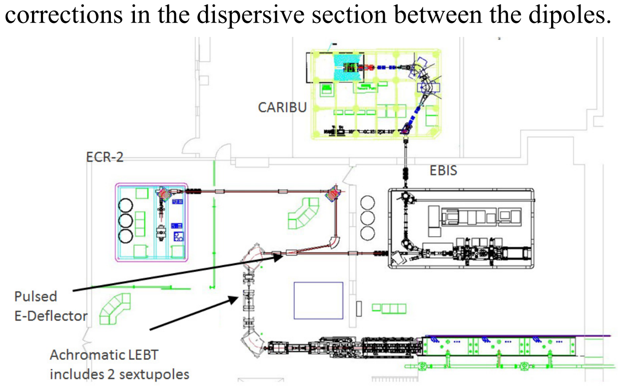

Figure 3: Modified LEBT to combine one stable beam from ECR and one radioactive beam from LEBT.

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Figure 4 shows the evolution of the transverse phase space of two combined beams, $^{132}Sn^{27+}$ from CARIBU-EBIS and $^{48}Ca^{10+}$ from the ECR, through the LEBT and first acceleration in the RFQ.

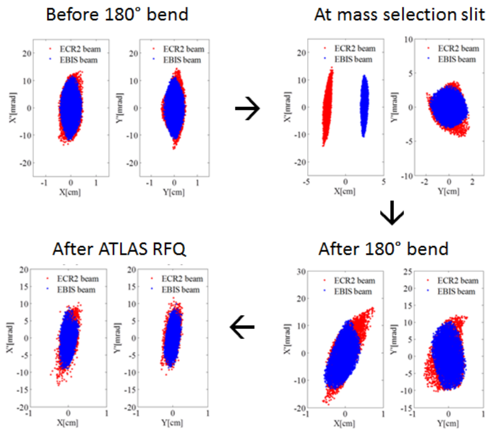

Figure 4: Evolution of the transverse phase space of two combined beams, $^{132}Sn^{27+}$ from CARIBU-EBIS (blue) and $^{48}Ca^{10+}$ from the ECR (red), through the LEBT and RFQ.

BEAM SWITCHYARD AFTER THE BOOSTER

The main requirements for the Booster beam switchyard are:

- Capability of switching in pulsed mode to send radioactive or stable beams to either Area II or Area III/IV
- Fits into the available space (significant constraint)
- Should accommodate the existing buncher cavity closer to the middle of the beam transport line
- Should accommodate existing beam diagnostics tools
- Desirable: achromatic beam transport to avoid transverse emittance growth and allow the simultaneous acceleration of two beams with slightly different q/A in the ATLAS section of the linac in the future

Investigated Options

As part of these studies two main options were investigated. In the first option (I), the straight line to Area II is preserved, while the ATLAS line is modified with a pulsed kicker magnet followed a septum. In the second option (II), a chicane is added to kick and transport the beam to Area II, while the ATLAS line is unchanged. For Option I, we have investigated several possible solutions or layouts, they are listed and commented on below:

- Buncher before the bend: In this case the buncher is closer to the Booster and becomes less effective. Also, the transverse beam optics are less favorable requiring large beam envelopes for appropriate matching
- Buncher after the bend: Here the buncher is closer to ATLAS requiring much higher voltage and strong focusing in short distance after the bend to fit the buncher aperture.
- Buncher in the middle of the bend: Being in a dispersive area, the buncher produced significant emittance growth. A real achromatic solution is not possible in this case.
- Buncher between two achromatic bends: This would be the best solution, but unfortunately it is not possible due to the limited space available and the small angles involved in the bends.

For option II, two solutions were investigated: a horizontal or a vertical chicane to Area II. Due to the buncher overall dimensions, the vertical dimension would require a larger combined deflection angle from the kicker and the septum, 20 deg instead of 15 deg for the case of the horizontal chicane. Therefore, the most feasible solution for this upgrade is the horizontal chicane to Area II while the ATLAS line remains unchanged.

Most Feasible Solution

Figure 5 shows the layout for the most feasible solution for the proposed ATLAS Multi-user upgrade: A horizontal chicane to Area II and un-modified ATLAS line. The chicane is made of a 5 deg kicker magnet followed by a 10 deg septum and three 15 deg regular magnets.

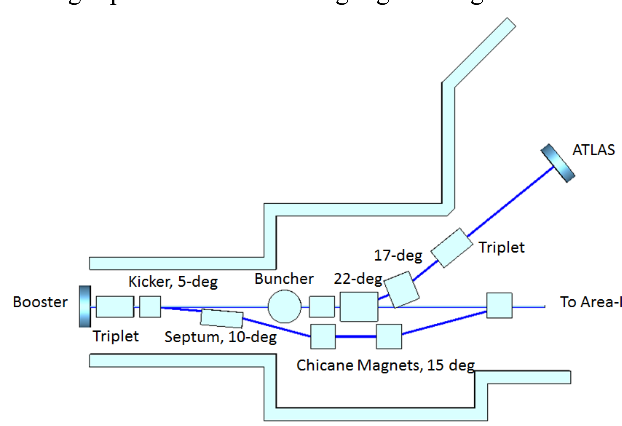

Figure 5: Layout of the most feasible solution for ATLAS-MUU: A horizontal chicane to Area II and un-modified ATLAS line.

The beam optics for this solution for both beam lines is shown in Figure 6. We notice in particular that the compact triplet at the Booster exit is essential for matching the beam to both lines.

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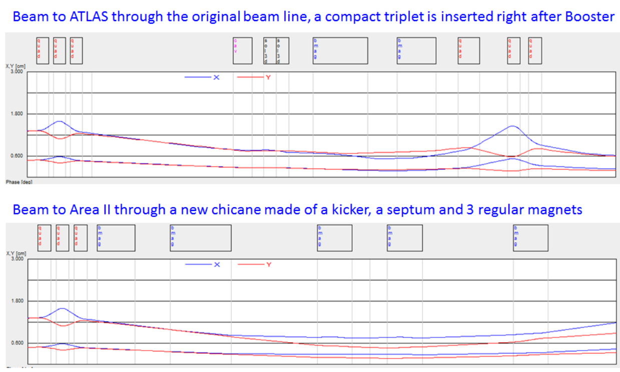

Figure 6: Beam envelopes for both the ATLAS line (top) and the new chicane to Area II (bottom).

KEY ELEMENTS OF THE UPGRADE

The key elements of the ATLAS multi-user upgrade are an electrostatic deflector and sextupoles in the LEBT to combine the two beams and a kicker and a septum magnet in the Booster switchyard to extract one of the beams while the other is injected into ATLAS for further acceleration. The design magnetic rigidity for the Booster switchyard is ~ 2.6 T.m. Due to the limited space available, the minimum angle for the kicker magnet is 5 deg, but the desired value is 10 deg. For a half meter long kicker, the magnetic field is ~ 1 T. Such field can only be provided by an Iron magnet. Ferrite magnets are usually limited to 0.15 T. In order to maximize the useful duty cycle of the machine, the required field rise and fall times should be ~ 1 ms or less. A preliminary study of the beam position stability on the target due to jitter in the kicker field shows that the required field flat-top stability should be better than 10^{-3}. In addition, to satisfy the different operating modes of the Booster switchyard, the kicker magnet should be able to operate with low duty factor to deflect radioactive beams and with high duty factor to deflect stable beams to Area II as needed. Table 1 presents the different operating modes of the Booster switchyard and Table 2 lists the preliminary design parameters for the kicker magnet.

Table 1: Possible Operating Modes for the BOOSTER SWITCHYard for Radioactive (RIB) and Stable Beams

Parameter	Value / Range	Unit
RIB pulse length	0.1-10	ms
RIB pulse rate	1-30	Hz
Pulse cycle length	33-1000	ms
Operating Mode#1 Example (Deflect radioactive beam)	1 ms ON 30 ms OFF	
Operating Mode#2 Example (Deflect stable beam)	30 ms ON 1 ms OFF	

Table 2: Preliminary Design Parameters for the Kicker Magnet

Parameter	Design Value	Unit
Design beam rigidity	2.6	T.m
Deflection angle	10	deg
Peak magnetic field	1	T
Magnet gap	4	cm
Magnet effective length	45	cm
Width of good field area	7	cm
Field rise/fall time	< 1	ms
Field flat-top stability	$< 10^{-3}$	
Operating modes and duty factor	3-97%, see table 1	

SUMMARY & OUTLOOK

Significant progress has been made in the design studies for the ATLAS multi-user upgrade. A feasible solution that satisfies most of the requirements despite the limited space available has been developed. A parameter feasibility study for the iron kicker magnet, a key component of the upgrade, is underway and will be completed soon. A full proposal for the multi-user upgrade will be developed at the end of these design studies.

Among the potential developments and upgrades in the future we name:

- The ATLAS injection line could be made into an achromat with the insertion of a single quad between the two dipoles. This will allow to transport and accelerate at least two beams with close A/q ratios to the highest energy.
- An RF switchyard could be added to separate and switch the beams to Area III and Area IV. Such an upgrade would benefit significantly from the development of a new 72 MHz cryostat in the Booster to replace the remaining old split ring modules.
- A possible beam extraction at lower energy after PII could be useful for some applications such as materials irradiation.
- If higher energy is desired for ATLAS beams, a second 109 MHz cryostat could be added to reach 25 MeV/u for light ions and 20 MeV/u for heavy ions.

REFERENCES

[1] P. Ostroumov *et al*, "Installation and on-line commissioning of EBIS at ATLAS", presented at LINAC 16, East Lansing, MI, USA, Sept. 2016, paper FR1A02, this conference.

[2] B. Mustapha *et al*, "Simultaneous acceleration of radioactive and stable beams in the ATLAS Linac", in *Proceedings HB-2014*, East Lansing, MI, USA, p. 334.