# Design of a Beam Switchyard for the ATLAS Multi-user Upgrade

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**Abstract**

This project includes designing a switchyard for the ATLAS multi-user upgrade and rearranging the beamline elements while considering the space constraints. By doing the measurements and then simulating beamline elements using TRACK and COSY, we were able to achieve the goal of combining the two beams from different ion sources, accelerating them together, and separating them at relatively low energy using a pulsed magnet.

# 1 Introduction

## 1.1 Motivation

The Argonne Tandem Linac Accelerator System (ATLAS) is a Department of Energy Nuclear Physics User Facility at Argonne. It is based on a superconducting ion linac and has been a single user facility since its inauguration in 1985. In order to enhance the experimental program at ATLAS and allow more beam time for applications, an upgrade project was recently approved to convert it into a multi-user facility. Serving two users simultaneously requires beam delivery to two different target stations at the same time. A beam switchyard for a dedicated material irradiation station at low energy (∼ 1 MeV/u) is required for the upgrade. The main goal of this project is to design a beam switchyard by optimizing the beam optics and the beamline elements while considering the existing space constraints.

## 1.2 Project Scope

The scope of the project includes the part of ATLAS from two ion sources to a dedicated irradiation station as shown in Figure 1. It is divided into six parts:

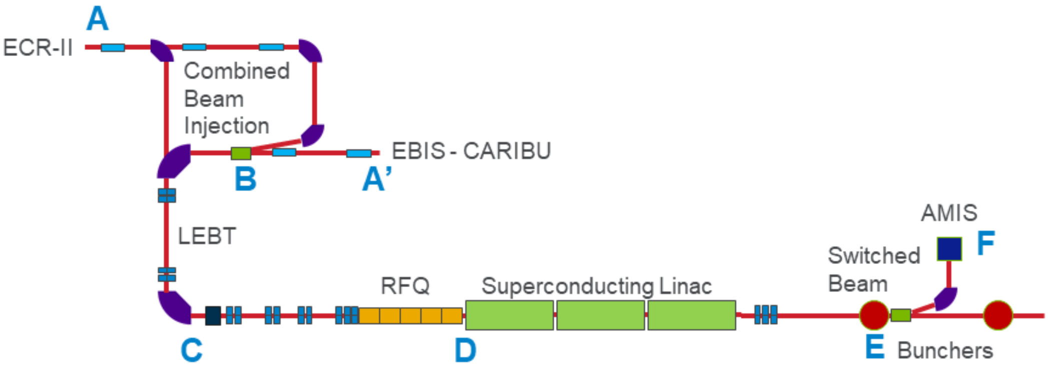

Figure 1: Complete beamline layout.

- A - B: From 14 GHz Electron Cyclotron Resonance ion source (ECR-II) to Combined Beam Injection. ECR-II can produce beams of highly charged heavy ions at high intensity and continuous in time.

- A' - B: From Electron Beam ion source (EBIS) to Combined Beam Injection. EBIS is developed to breed the CAlifornium Rare Isotope Breeder Upgrade (CARIBU) radioactive beams. It can provide charge breeding of any ions in the full mass range of periodic table with high efficiency, short breeding times, and sufficiently low mass-to-charge ratio. It delivers high charge state beams in short (∼ milliseconds) pulses adjustable in the range of 10-30 Hz.

- B - C: Low Energy Beam Transport (LEBT) system. Figure 2 shows how the pulsed magnet at the beginning of this part of the beamline switches between EBIS pulsed beam and ECR-II stable beam. The magnet is turned on during switching time to allow pulsed beams to pass, and it is turned off the rest of the time to allow stable beams to pass. The main purpose of the LEBT is to transport specific ion species and match it into the following Radio-Frequency accelerator.

- C - D: Radio-Frequency Quadruple (RFQ). Its purpose is to bunch, accelerate and focus a single-species beam of charged particles.
- D - E: Positive Ion Injector (PII), a superconducting linac. It consists of 16 niobium superconducting resonators and can provide a total equivalent voltage of approximately 12 MV.
- E - F: Switched Beam to ATLAS Material Irradiation Station (AMIS). Figure 2 shows how the pulsed magnet at the beginning of this part of the beamline switches between EBIS pulsed beam and ECR-II stable beam. AMIS will be installed as part of the planned ATLAS multi-user upgrade.

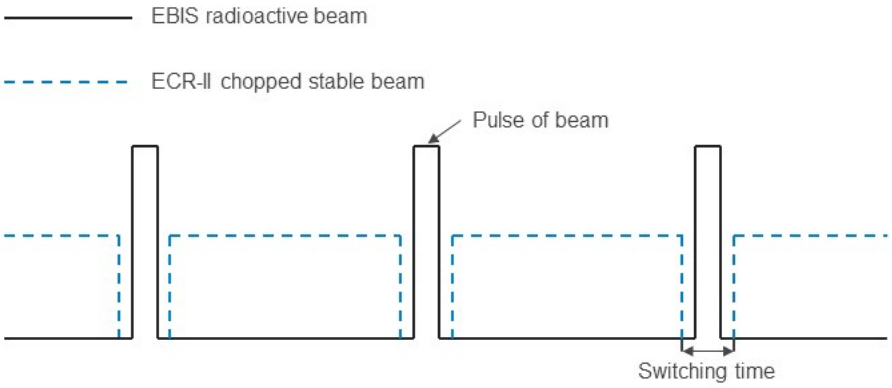

Figure 2: Illustration of switching between beams.

# 2 Methods

## 2.1 Tools

We used TRACK and COSY INFINITY for this project.
The code TRACK simulates beam dynamics of multi-component ion beams in linear accelerators. It has multiple features, including 3D electromagnetic fields in radio frequency resonators, fringing fields of magnets and multipoles, and realistic fields in solenoids.
COSY INFINITY is an arbitrary order beam optics code. It allows the study of accelerator lattices, beamlines, and many other devices. The elements can either be based on a large library of existing elements with realistic field configurations or described in detail by measured data. The options it supports include computation of high-order nonlinearities, analysis of aberration correction, and analysis of properties of repetitive motion via chromaticities.

## 2.2 Simulations

We measured the current configurations of the beamline and set the parameters of beamline elements like bending magnets and quadruples. We then simulated beam tracking and set up matching conditions in TRACK and COSY. By running their matching algorithms and manually adjusting the variables, we were able to get the desired results, and we made sure the two approaches agree.

# 3 Results

## 3.1 From ECR-II to Combined Beam Injection

The stable beam generated by ECR-II contains $^{48}Ca^{10+}$ particles. The beamline has two 90° bending magnets and two triplets. We achieve a waist at the end of this part of the beamline, and the emittance at the end is about the same as the emittance at the beginning. Figure 3 is RMS (the lower curve) and max beam size (the upper curve) vs distance, and Figure 4 is phase space distribution in x direction at the end of the beamline.

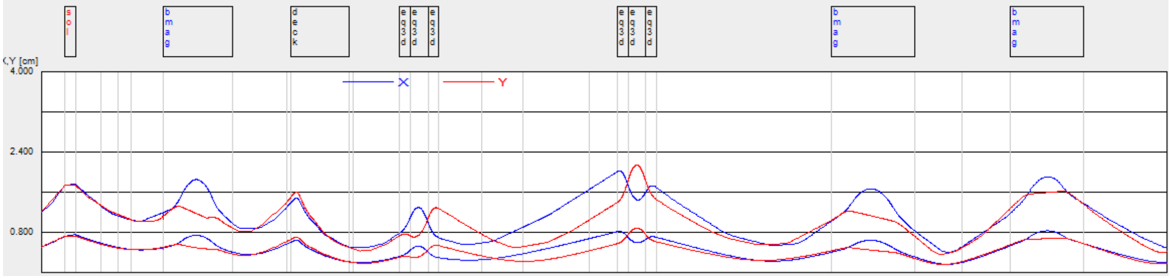

Figure 3: RMS (lower) and max beam size (upper) vs distance for ECR-II to Combined Beam Injection.

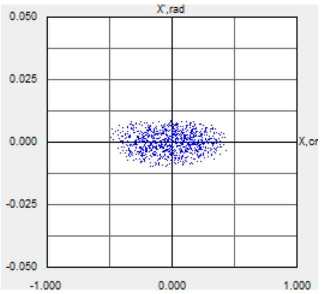

Figure 4: Phase space distribution in x at the end.

## 3.2 From EBIS to Combined Beam Injection

The radioactive beam generated by EBIS contains $^{132}Sn^{27+}$ particles. The beam goes through two triplets to get focused. We achieve a waist at the end of the beamline, and the emittance at the end is about the same as the emittance at the beginning. Figure 5 is RMS (the lower curve) and max beam size (the upper curve) vs distance, and Figure 6 is phase space distribution in x direction at the end of the beamline.

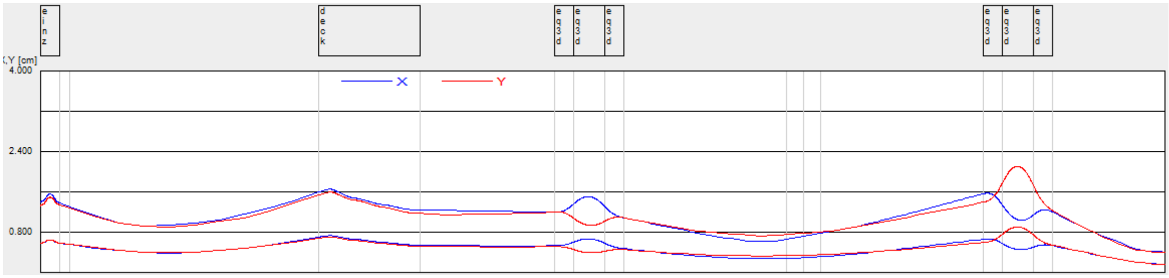

Figure 5: RMS (lower) and max beam size (upper) vs distance for EBIS to Combined Beam Injection.

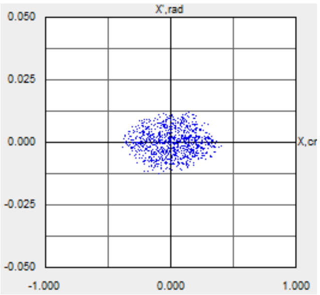

Figure 6: Phase space distribution in x at the end.

## 3.3 LEBT

The chopped stable beam from ECR-II and the pulsed radioactive beam from EBIS are combined in time at the beginning of LEBT system. A 30 Hz pulsed magnet is used to switch between the two beams before and after the accelerator. Therefore, two experiments can be carried out simultaneously with almost no loss of beam intensity. Figure 7 is RMS (the lower curve) and max beam size (the upper curve) vs distance, and Figure 8 is phase space distribution in x direction at the end of the beamline. The blue particles are $^{48}Ca^{10+}$, and the green particles are $^{132}Sn^{27+}$.

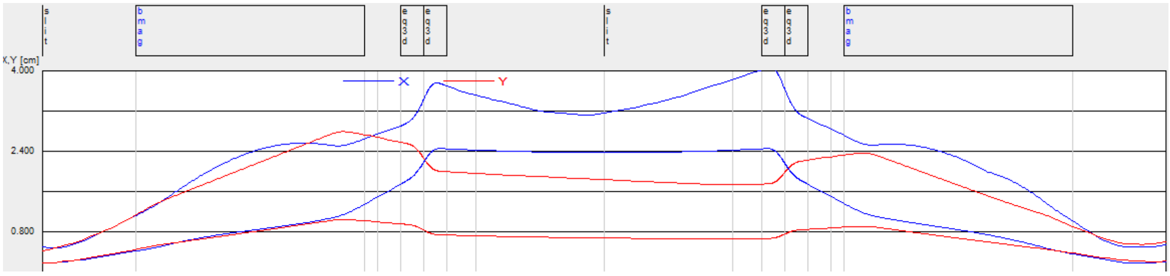

Figure 7: RMS (lower) and max beam size (upper) vs distance for LEBT.

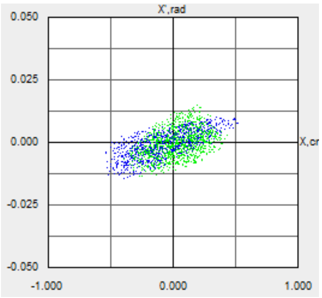

Figure 8: Phase space distribution in x at the end.

## 3.4 RFQ

The combined beam then goes through the RFQ and accelerates. The beams are separated in time, but both beams are accelerated and transported because they have nearly identical mass-to-charge ratio. Figure 9 is RMS (the lower curve) and max beam size (the upper curve) vs distance, and Figure 10 is phase space distribution in x direction at the end of the beamline. The blue particles are $^{48}Ca^{10+}$, and the green particles are $^{132}Sn^{27+}$.

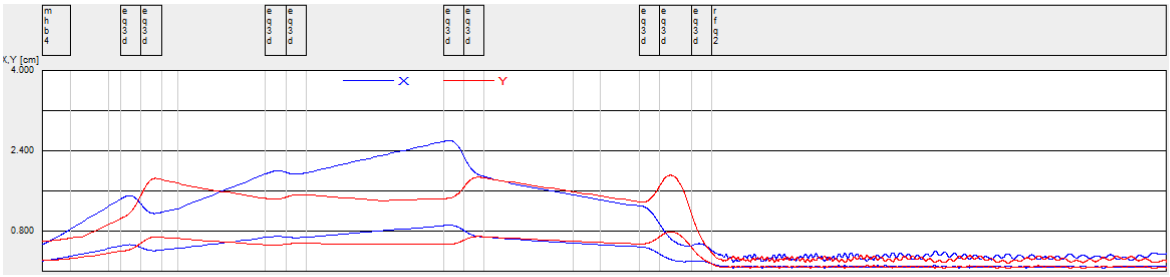

Figure 9: RMS (lower) and max beam size (upper) vs distance for RFQ.

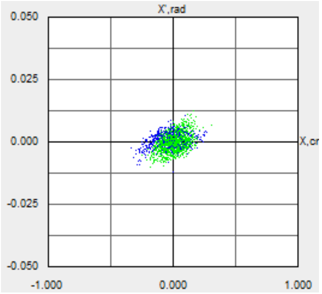

Figure 10: Phase space distribution in x at the end.

## 3.5 Superconducting Linac

The combined beam then goes through the PII, a superconducting linac. Figure 11 is RMS (the lower curve) and max beam size (the upper curve) vs distance, and phase space distribution in x direction at the end of the beamline is in Figure 12. The blue particles are $^{48}Ca^{10+}$, and the green particles are $^{132}Sn^{27+}$.

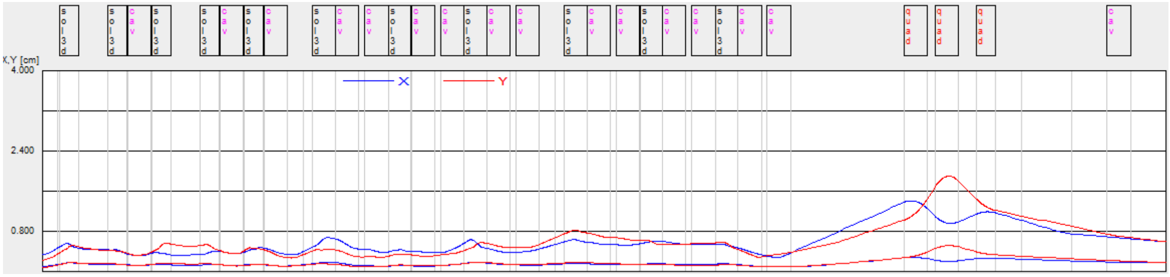

Figure 11: RMS (lower) and max beam size (upper) vs distance for Superconducting Linac.

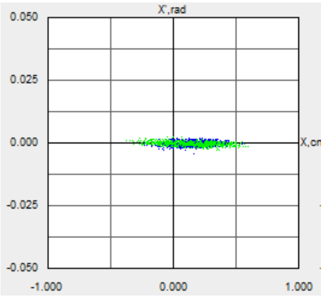

Figure 12: Phase space distribution in x at the end.

## 3.6 Switched Beam to AMIS

$^{48}Ca^{10+}$ from ECR-II and $^{132}Sn^{27+}$ from EBIS are at low energy, about 1.766 MeV/u, at the beginning of the beamline. The combined beam is separated by a pulsed magnet. Usually, $^{132}Sn^{27+}$ continues for further acceleration to higher energy for nuclear physics studies while $^{48}Ca^{10+}$ goes to AMIS for material irradiation studies. However, since the mass-to-charge ratio is the same for both particles, we used $^{132}Sn^{27+}$ for simulation. Figure 13 is RMS (the lower curve) and max beam size (the upper curve) vs distance, and phase space distribution in x direction at the end of the beamline is in Figure 14.

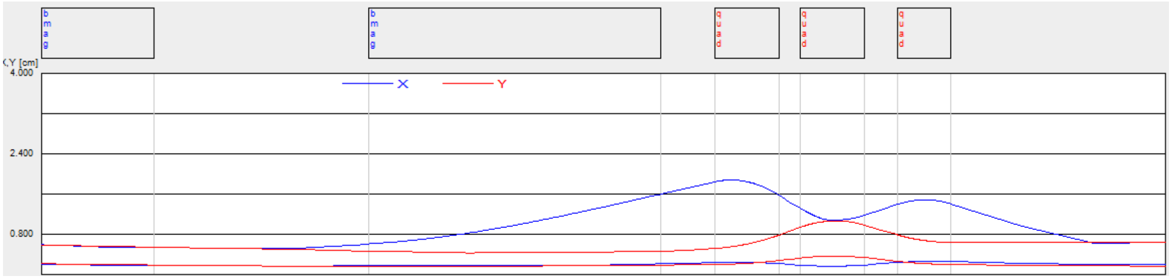

Figure 13: RMS (lower) and max beam size (upper) vs distance for Switched Beam to AMIS.

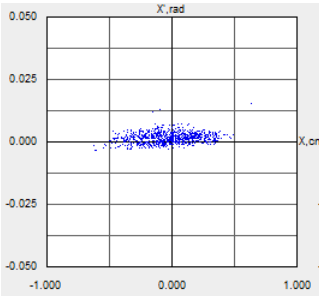

Figure 14: Phase space distribution in x at the end.

## 4 Conclusion and Future Work

We designed and simulated beamline elements in TRACK and COSY. The beamline is able to combine $^{48}Ca^{10+}$ particles from ECR-II and $^{132}Sn^{27+}$ particles from EBIS, accelerate them, and separate them after the first step of superconducting linac. The stable beam from ECR-II and the radioactive beam from EBIS are combined and separated using the pulsed magnet. There is no loss of intensity for the EBIS beam, while the ECR radioactive beam has a few percent loss of intensity.

In the future, we can improve the beam optics in the last part of the beamline, Switched Beam to AMIS. The emittance of the beam delivered to AMIS is four times of the emittance at the beginning of the beamline. This effect requires further study to understand, and we will improve the beamline by reducing the emittance of the beam. We would also like to replace the pulsed magnet with an electrostatic deflector, since the later one can switch between two beams just like the pulsed magnet, but the cost is much lower. Further design studies are in progress to determine if magnetic or electric fields will be used as the pulsed switchers.

## 5 Acknowledgements

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## References

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