ARGONNE IN-FLIGHT RADIOACTIVE ION SEPARATOR*

S. Manikonda†, J. Nolen, B. Back, K.-E. Rehm, M. Alcorta, R. Pardo
G. Savard, D. Seweryniak, B. Erdelyi, C.R. Hoffman
ANL, Argonne, IL 60439, USA

Abstract

The Argonne In-flight Radioactive Ion Separator (AIRIS) is a new device that is being designed as a part of proposed future upgrade of the ATLAS facility at Argonne. AIRIS is a large recoil separator for the in-flight radioactive beam that will provide at least 10 times more collection efficiency than the existing system. In combination with other proposed ATLAS upgrades it will provide a 2 orders of magnitude gain in the intensity for the in-flight produced secondary beams compared to the existing facility. The resulting unprecedented intensities for the recoil beam open new opportunities in several physics domains, e.g.: gamma ray spectroscopy after secondary reactions, reactions for rp-, γp-, αp- processes and CNO cycle. The proposed design for the AIRIS device is based on four multipole magnets and four dipole magnets arranged in a so called broadband spectrometer configuration. This arrangement will be followed by two RF cavities to provide further selection. The advantages of such a design as well as key device parameters will be discussed in detail. We will also demonstrate the performance of the device for few representative reaction cases that can be studied using AIRIS.

INTRODUCTION

ATLAS at Argonne is undergoing an efficiency and intensity upgrade. The proposed upgrade is being done in two stages, details are presented in [1, 2, 3]. One of the upgrades being proposed in the second stage of the upgrade is the installation of a large recoil separator for the in-flight radioactive beam program resulting in a better separation of the desired rare isotope beam from the primary production beam. The schematic layout of the proposed device, the **A**rgonne **I**n-flight **R**adioactive **I**on **S**eparator (**AIRIS**), is shown in Fig. 1. AIRIS, along with other intensity and efficiency upgrades, will result in two orders of magnitude increase in the intensity of the in-flight rare isotope beams, and the availability of higher energies also augments the range of rare ions that can be produced with this technique. The physics that is proposed to be studied includes nuclear structure studies and study of nuclear astrophysics processes. This paper summarizes the current status of design studies for AIRIS.

AIRIS DESIGN

AIRIS design is comprised of a magnetic chicane that is preceded by a target station and followed by a RF sweeper and a superconducting debuncher section, as shown in Fig. 1. The selection of recoil beams of interest will be done by appropriately placing slits and beam blockers at the central image of the magnetic chicane. Further selection will happen along the second half of the chicane and at the end slit placed at the final image. Further purification of the recoil beam will be done in the RF sweeper where the tail of the primary beam whose rigidity overlaps with the recoil beam are separated in time and can easily be separated. Finally the recoil beam will go through the debuncher section that will reduce the energy spread and will allow efficient beam transport to experimental stations.

It is a design goal for AIRIS to work for recoil beams of up to 1Tm. It is envisioned that up to 1 pμA stable beams will be used and will require development of new suitable production targets based on rotating target wheels or liquid oil films. The recoil beam will have angular spread of ± 50 mrad in X and Y, momentum spread of ±5% and have beam spots of ±5 mm x ±5 mm.

Table 1 summarizes key parameters for the AIRIS device.

Table 1: AIRIS parameters

Parameter	Units	Value
Magnetic chicane length	m	5.87
Dispersion at the central image per percent of kinetic energy deviation	mm	1.2
Angular acceptance	mrad	50
Minimum drift space	cm	15
Multipole parameters		
Number of multipole magnets		4
Half aperture	cm	10
Multipole magnet length	cm	20
Maximum quadrupole poletip field	T	1.5
Maximum sextupole poletip field	T	0.05
Dipole parameters		
Number of dipoles		4
Maximum dipole field	T	1
Dipole bend angle	deg	22.5
Dipole radius of curvature	m	1
Dipole half gap	cm	5
Debuncher parameters		
Maximum Debuncher cavity field	MV/m	4
Debuncher frequency	MHz	72
Debuncher length	cm	10
Debuncher half aperture	cm	2

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† manikonda@anl.gov

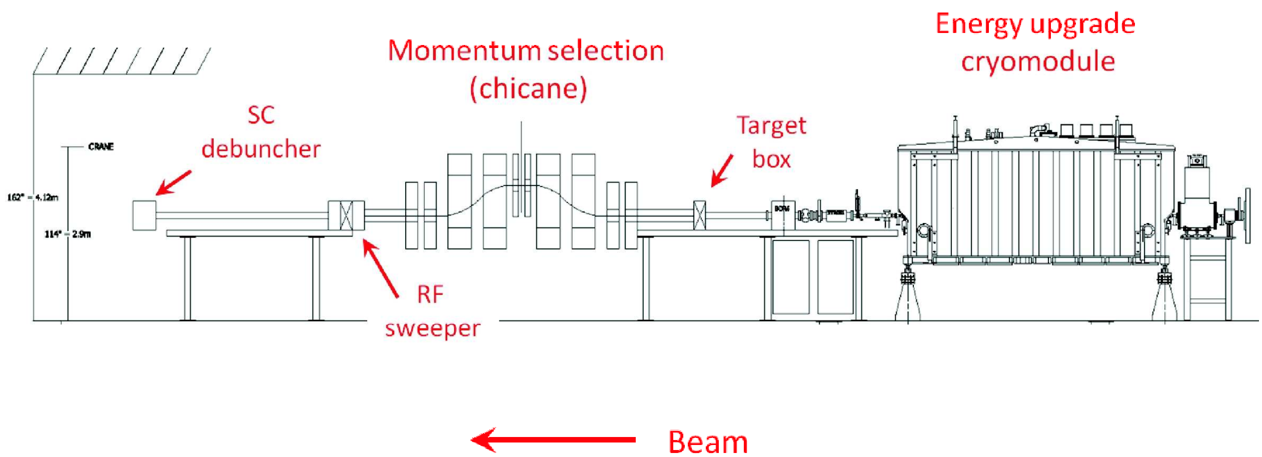

Figure 1: The schematic view of the AIRIS layout in ATLAS.

The First Order Layout Of Magnetic Chicane

The proposed design for the magnetic chicane is based on four multipole magnets and four dipole magnets arranged in a so-called broadband spectrometer configuration. First order design studies have been performed for the proposed design using COSY Infinity [4, 5]. Fig. 2 shows the first order optics for the device. The center of magnetic chicane is a dispersive image where most of the primary beam can be separated. Magnetic chicane is tuned to the desired recoil beam rigidity and provides a separation of 1.2 mm per percent of kinetic energy deviation at the central image. At the final image the system is dispersion-less, but not achromatic.

Fringe fields for multipole magnets and the dipole magnets have been included for realistic simulations of optics. The COSY Infinity's fringe field model that uses symplectically scaled fields of real magnets has been used for the purpose [6].

Aberration corrections are important due to the large angular and energy acceptance of the momentum chicane. Only second order aberration correction at the central image has been performed using the four available multipole magnets and by introducing sextupole component in the four dipole magnets. This assumes a mirror symmetric layout for the sextupoles about the center of chicane. It also possible to consider layout where first and second half of the chicane are independently tuned to reduce aberration at the central image and the final image. But in practice it did not yield better results than the mirror symmetric layout. For this paper we will consider mirror symmetric layout for studying transmission efficiency of the device in the following section.

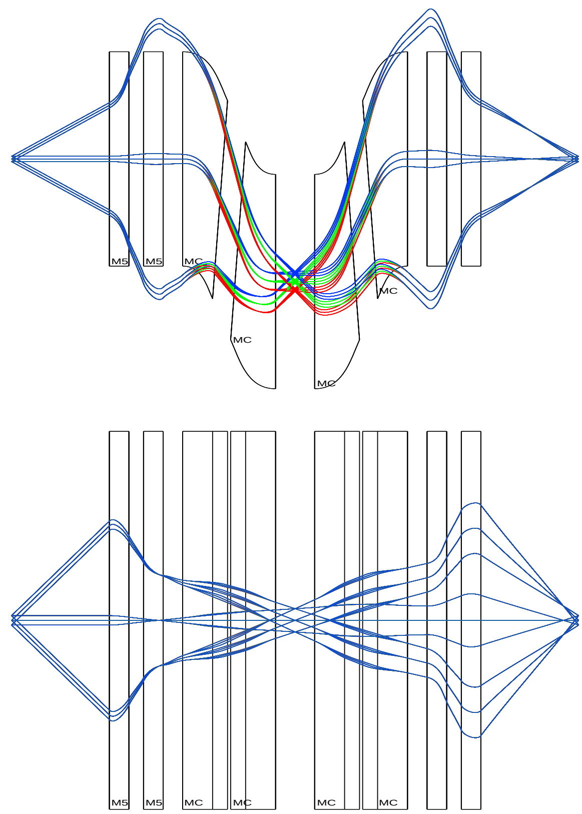

Figure 2: The schematic view of the layout showing the X-projection (left), Y-projection (right) of first order layout.

TRANSMISSION EFFICIENCY OF AIRIS

Simulation of transmission efficiency requires the detailed reaction kinematics of the specific reaction being studied. As test cases for the calculations, beams such as ^{14}O, ^{19}O, ^{33}Cl that have been produced in the existing In-Flight facility [7] were chosen. In this contribution we will concentrate on ^{14}O beams, which were generated via inverse (p,n) reactions. The physics cases for these proton-rich beams cover the study of the (α,p) process occurring during on the surface of neutron stars during X-ray bursts [8].

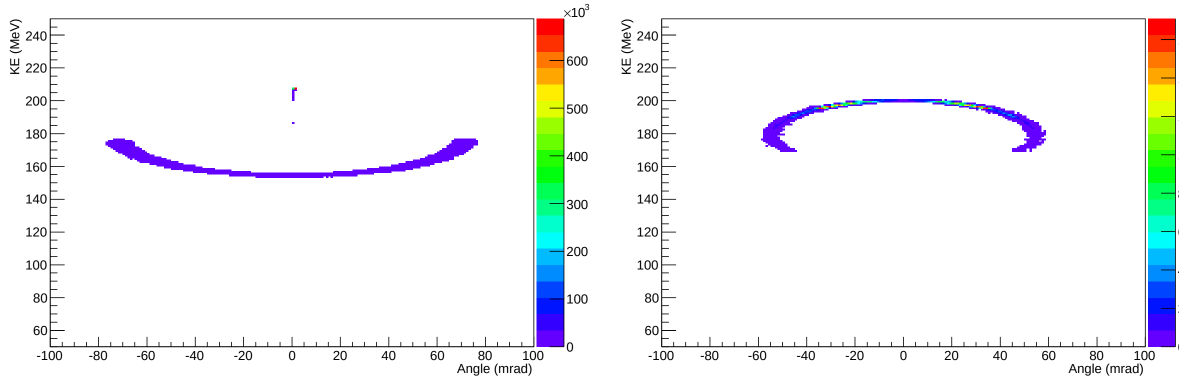

Figure 3: Angle energy distribution for primary beam ^{14}N (left) and recoil beam ^{14}O (right). Beam center and beam tail have been simulated separately. The intense beam center is several orders of magnitude greater than the beam tail.

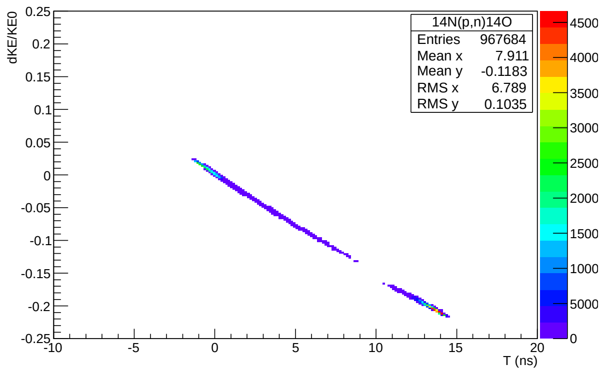

Figure 4: Longitudinal phase space plot of the recoil and remaining beam tail that is now well separated in time.

The angle-energy correlated distribution of the recoils and primary beams were simulated using LISE++ [9] and SRIM codes [10]. LISE++ was used to simulate angle-energy correlation for the recoil beams and the low energy tail of the primary beam that overlaps in rigidity with the recoil beam. The SRIM code provides the angle-energy correlated distribution for the intense beam center that is several orders of magnitude larger than the beam tail.

^{14}O beams are produced via the (p,n) mechanism using ^{14}N primary beams on a 1.5mg/cm^2 CH_2 target. The 10 MeV/nucleon and 15 MeV/nucleon ^{14}N beam were considered for simulations. The angle-energy distributions are simulated using experimental differential cross sections taken from the literature. For the intense beam center realistic profile for angle-energy distribution was considered but the number of particles was only limited to 10^6 due to limited computing resources. For the case of 15 MeV/nucleon ^{14}O beams the angle energy distribution of the ^{14}N and the ^{14}O are shown in Fig. 3. To select recoils of interest, 5 mm slits are placed at the center and end of magnetic chicane. The central rigidity of the magnetic chicane is tuned such that it allows maximum transmission for the recoils while rejecting a large portion of the beam tail. Transmission calculations were performed using 5th order Taylor transfer maps with fringe fields. The results are summarized in Table 2 for 10 MeV/nucleon case and Table 3 for 15 MeV/nucleon case.

Table 2: Transmissions for the case of 10 MeV/nucleon ^{14}O beam

	Ions	**Transmission (%)**
Recoil, ^{14}O	1×10^6	64
Beam tail, ^{14}N	2.5×10^6	7.6

Table 3: Transmission for the case 15 MeV/nucleon ^{14}O beam

	Ions	**Transmission (%)**
Recoil, ^{14}O	5×10^5	78.4
Beam tail, ^{14}N	5×10^6	11.5

RF sweeper is used to further separate the beam tail from recoils of interest. Longitudinal phase space at the end of chicane is shown in Fig. 4, where the beam tail (^{14}N) and the recoil of interest (^{14}O) are separated in time and can be easily be separated using a RF sweeper whose frequency is harmonic of beam bunch frequency, 12.125 MHz.

Debunching of the transmitted beams is essential to efficiently transport the beams after AIRIS. Debuncher parameters are summarized in Table 1. Fig. 5 show the longitudinal phase space and spread in kinetic energy deviation of the recoil beam (^{14}O) at the entrance and exit of the debuncher. For this specific case the spread in kinetic energy deviation is reduced by factor of 10.

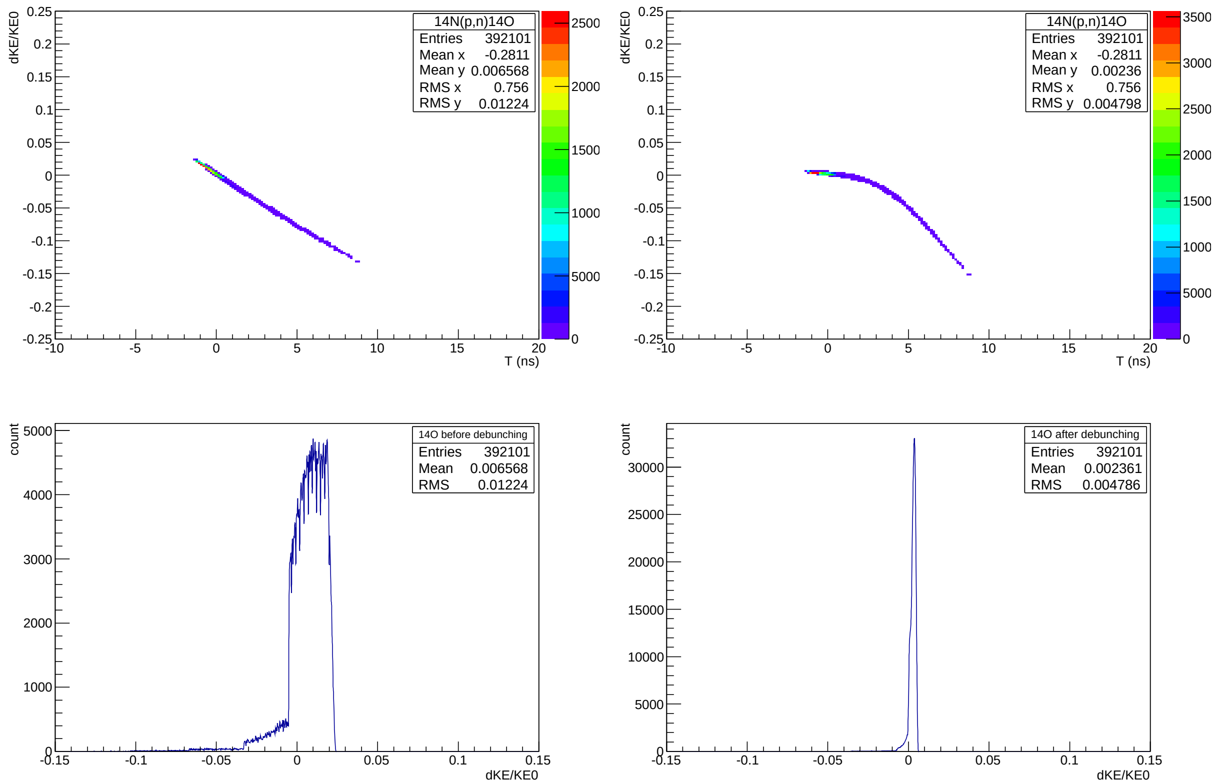

Figure 5: Plot on top left and top right show the longitudinal phase space of the recoil beam (^{14}O) at the entrance and exit of the debuncher. Plots on bottom left and bottom right show the spread in kinetic energy deviation at the entrance and exit of debuncher.

CONCLUSIONS

A new design for AIRIS has been presented. For the example case of ^{14}O beams, produced via the (p,n) reaction mechanism, a detailed simulation studies have been performed to shown that ^{14}O beams can be well separated and transmitted with high efficiency using the present design. Simulation studies to determine the separation and transmission for other radioactive beams of interest are on going.

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