DESIGN AND SIMULATION OF THE ARGONNE INFLIGHT RADIOACTIVE ION SEPARATOR (AIRIS)*

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Abstract

A new inflight radioactive ion separator (AIRIS) is being designed for the ATLAS facility at Argonne. AIRIS will be used to separate and produce secondary radioactive beams from the interaction of ATLAS primary beams in a production target. AIRIS will be at least 10 times more efficient than the existing radioactive beam capability. We have made significant progress in the design and simulations of AIRIS including full 3D models of all the elements to consider their real dimensions and produce realistic 3D fields. The resolving power of the device has been studied for several reaction cases using realistic cross sections and kinematics. In addition to the magnetic separation of the device, an RF sweeper is being designed to take advantage of the time separation of the different beams and reject the primary beam tail and other potential contaminants in order to produce higher purity secondary beams. The latest AIRIS design and simulation results will be presented and discussed.

AIRIS AT ATLAS

The Argonne Tandem Linac Accelerator System is undergoing an efficiency and intensity upgrade [1]. Most of the stable beams will have their intensities increased by one to two orders of magnitude. To take advantage of this intensity upgrade and enhance the radioactive beam capabilities at ATLAS, a new inflight radioactive beam production and separation system is being proposed. The new system will consist of a production target placed at the end of ATLAS followed by an ion separator called AIRIS. Figure 1 shows the location of AIRIS downstream of ATLAS and upstream of any experimental area. The main constraint on the AIRIS design is to preserve stable beam operations by moving the target out and using AIRIS as a transport line. For this purpose, AIRIS should have the same beam axis as ATLAS and the existing beamline. A broadband design has been proposed and developed for AIRIS [2]. It consists of four dipoles and four multipoles (quadrupoles) as shown in Figure 1. The original design was developed and simulated using COSY [3]. In this work, we have performed detailed simulations and parameter feasibility studies using the code TRACK [4], which has led to the new design parameters listed in Table 1. The dimensions and spacing of the elements have changed but not the overall layout.

Table 1: AIRIS Design Parameters

Parameter	Value
Number of dipoles	4
Dipole bend angle, deg	22.5
Dipole radius, m	1
Dipole full gap, cm	10
Max. dipole field, T	1.75
Number of quadrupoles	4
Quadrupole length, cm	30
Quadrupole full aperture, cm	15
Max. quadrupole field, T	1.0
Shortest drift, cm	20
Total chicane length, m	7.1
Angular acceptance, mrad	50
Dispersion at mid-plane, mm/%	1.2

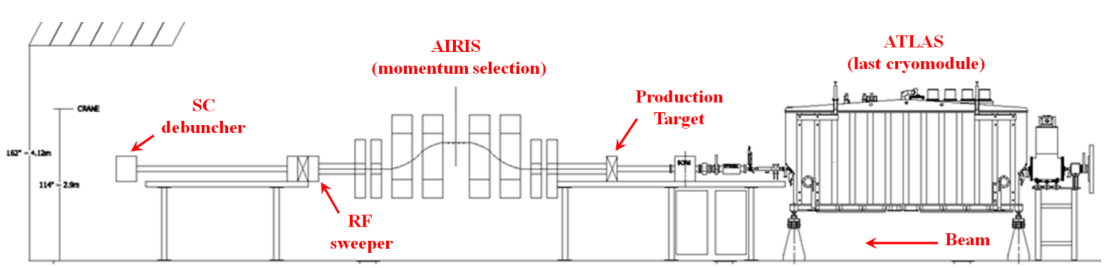

Figure 1: AIRIS, designed to be installed downstream of ATLAS and upstream of experimental areas for the production and separation of radioactive beams. An rf sweeper and a SC debuncher are included.

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TRACK FOR ION SEPARATOR DESIGN AND SIMULATION

The beam dynamics code TRACK has recently been modified for more accurate transfer matrix calculation of any element up to the second order in particle coordinates. These calculations were benchmarked against COSY's results with excellent agreement, as will be shown later. Combining the new features with the existing TRACK capabilities, we were able to study the AIRIS design in more detail, which allowed us to produce more realistic element parameters. TRACK can now be used for the design and simulation of any ion separator.

Benchmarking Against COSY

Figure 2 shows a comparison of transverse beam emittance along AIRIS calculated for a 14 MeV/u $^{14}O^{8+}$ beam using ray-tracing in TRACK and different order matrices in COSY. We clearly see that from 2^{nd} to 5^{th} order, COSY's results converge towards TRACK's results, which should be equivalent to infinite order.

Integration Steps in Bending Magnets

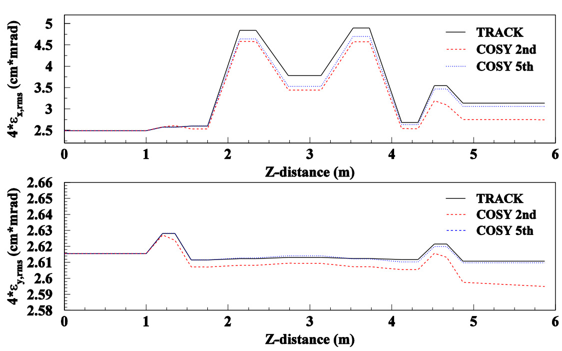

Figure 2: Transverse beam emittance along AIRIS calculated with TRACK and COSY at different orders.

Due to the curvature of a charged particle trajectory in a bending magnet, we expect a dependence of ray-tracing

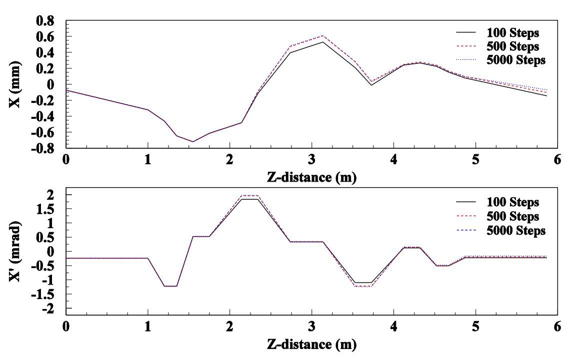

Figure 3: Horizontal (dispersive) beam centroid along AIRIS calculated in TRACK with different number of integration steps in the dipoles.

results in TRACK to the number of integration steps used for tracking. Figure 3 shows the dispersive horizontal beam centroid along AIRIS calculated in TRACK with increasing number of integration steps in the dipoles. We can see an improvement in the precision from 100 to 500 steps where it seems to saturate because we don't see a significant change when using 5000 steps.

TRACK's 2^{nd} Order Matrix for Correction

Using the 2^{nd} order matrix calculation in TRACK and an internal optimization procedure, developed for high-order beam correction, we were able to optimize the sextupole component strength for a 2^{nd} order correction. The results are shown in Figure 4.

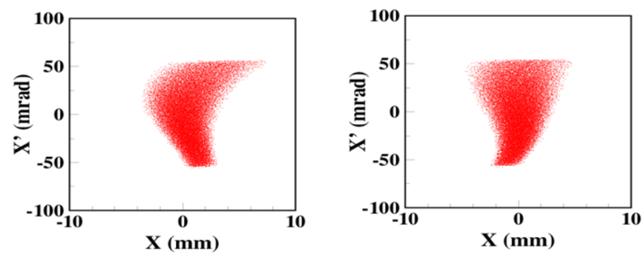

Figure 4: Horizontal beam phase space in AIRIS's mid-plane before and after 2^{nd} order correction in TRACK.

Acceptance Calculation for Contaminants

TRACK already has an acceptance calculation procedure which could be easily applied to any potential contaminant to the radioactive beam selected in AIRIS. Figure 5 shows different regions of AIRIS acceptance in angle and energy, calculated with different mid-plane selection slit openings, for the $^{14}N^{7+}$ primary beam tail which is a potential contaminant to the $^{14}O^{8+}$ beam of interest. Such a calculation identifies the area of overlap with the primary beam and how to reject it.

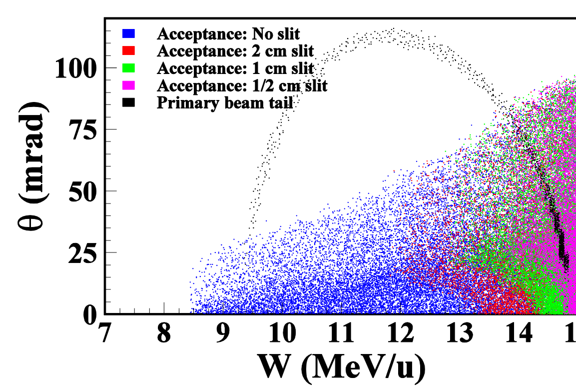

Figure 5: Regions of AIRIS acceptance (colors) calculated with TRACK for the $^{14}N^{7+}$ primary beam tail (black) with different mid-plane selection slit openings.

Multi-Beam and Multi-Charge States

TRACK was the first beam dynamics code to support simultaneous tracking of multiple beams and, in particular, multi-charge state beams. It was used to prove and demonstrate the simultaneous acceleration of multiple charge states of a uranium beam in ATLAS [5]. Figure 6 shows one example of multi-beam simulation and one example of multi-charge state simulation applied to study the overlap of the different beams and select the beam of interest at the AIRIS mid-plane.

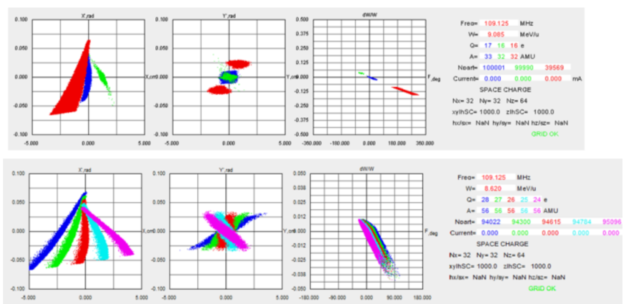

Figure 6: (top) Multi-beam phase space plots at AIRIS mid-plane for the $^{33}Cl^{17+}$ beam of interest and the $^{32}S^{16+}$ primary beam core and tail. (bottom) Multiple charge states of a ^{56}Ni beam at AIRIS mid-plane.

From Hard-Edge to 3D-Field Models

TRACK has internal models for most elements. These models range from simplified hard-edge to models with more realistic fringe fields. TRACK also supports external 3D fields calculated with other software. Although not always required, 3D field models could reveal more realistic non-linear effects. Figure 7 shows the $^{14}O^{8+}$ phase space in the AIRIS end plane simulated with hard-edge and 3D models for the dipoles and quadrupoles. We clearly see more beam distortions and tail formation in the 3D field case.

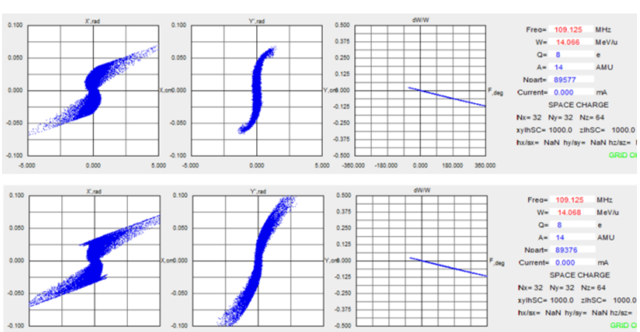

Figure 7: $^{14}O^{8+}$ phase space plots at the AIRIS end-plane calculated using hard-edge models (top) and 3D-field models (bottom) for the dipoles and quadrupoles.

3D MODELING OF AIRIS

In order to produce a more realistic model for AIRIS and check the feasibility of its elements, we have developed preliminary 3D designs for the dipoles and quadrupoles. For this purpose, EM-Studio of the CST package [6] was used and Figure 8 shows the full 3D model for AIRIS. The 3D modelling was essential to modify the AIRIS design parameters considering limitations on element dimensions, spacing and fields.

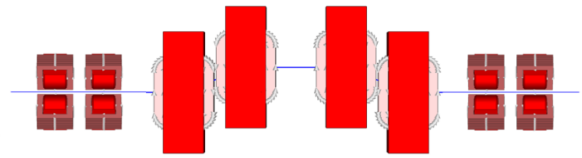

Figure 8: Full 3D model of AIRIS showing the dipoles and quadrupoles.

EXAMPLE OF AIRIS RESOLVING POWER

In order to study AIRIS's resolving power, we have simulated several radioactive beams. Realistic nuclear reaction models [7, 8] were used to generate the distributions for the secondary beam of interest, the scattered primary beam and the potential contaminants produced in the same reaction. Figure 9 shows an example of AIRIS performance in separating the secondary $^{56}Ni^{28+}$ beam of interest from the primary beam and other contaminants produced in the interaction of a 10 MeV/u ^{54}Fe beam on a carbon target.

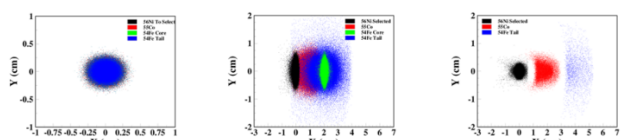

Figure 9: Separation of the $^{56}Ni^{28+}$ beam of interest from the primary beam and other contaminants. (left) All beams superposed at the target. (center) Clear separation of $^{56}Ni^{28+}$ (black) from the $^{54}Fe^{26+}$ primary beam core (green) at the AIRIS mid-plane. (right) Clear separation of $^{56}Ni^{28+}$ (black) from other contaminants, $^{55}Co^{27+}$ (red) and $^{54}Fe^{26+}$ primary beam tail (blue), at the AIRIS end-plane.

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