A COMPACT HIGH-RESOLUTION ISOBAR SEPARATOR FOR THE CARIBU PROJECT*

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Abstract

A compact high-resolution isobar separator for the CARIBU project at Argonne National Laboratory is currently under construction. It has a first-order mass resolution of 22,400:1, and a > 95% transmission for the 50 keV low-emittance beam from a gas catcher-cooler combination.

INTRODUCTION

The CARIBU (Californium Rare Ion Breeder Upgrade) project will serve as a source of ions to provide beams of short-lived neutron-rich isotopes for the ATLAS accelerator facility at Argonne National Laboratory. The isotopes will be obtained from a 1 Ci ^{252}Cf fission source placed in a large gas catcher. After cooling by means of an open RFQ structure, the radioactive ions will be accelerated to an energy of 50 keV, mass analyzed, and transferred to an ECR ion source for charge breeding, before being further accelerated in the ATLAS superconducting linac. Because of the universality of the gas catcher/cooler technique, no mass or elemental selection occurs at this stage, and it is necessary to purify the beam by means of mass selection, preferably at the isobar level. The emittance properties of the beam extracted from the gas catcher/cooler are excellent, with an energy spread below 1 eV and transverse emittance of roughly 3π mm-mr for 90% of the beam [1]. This means that a purely magnetic high-resolution isobar separation is feasible. A mass resolution >20,000:1 should be effective for isobar separation of neutron-rich isotopes far from beta-stability.

DESIGN CONSIDERATIONS FOR THE ISOBAR SEPARATOR

The following requirements were established for the Isobar Separator:

- mass resolution M/ΔM ≥ 20,000:1,
- high transmission (> 95%),
- compact (must fit on HV platform),
- no energy compensation (means no electric dispersive elements),
- match the beam emittance from the gas catcher (transverse: < 3π mm-mr, longitudinal: ΔE < ±1 eV at 50 keV, for 90% of the beam),
- simple configuration for ease of tuning,
- focusing and corrective elements must be electrostatic, so that settings are independent of mass.

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The resulting separator design is shown in Figure 1. The first-order design consists of two 60º bending magnets with ρ=0.5 m, two quadrupole doublets, and two quadrupole singlets, in a symmetric combination. This design achieves a first-order mass resolution of 22,400.

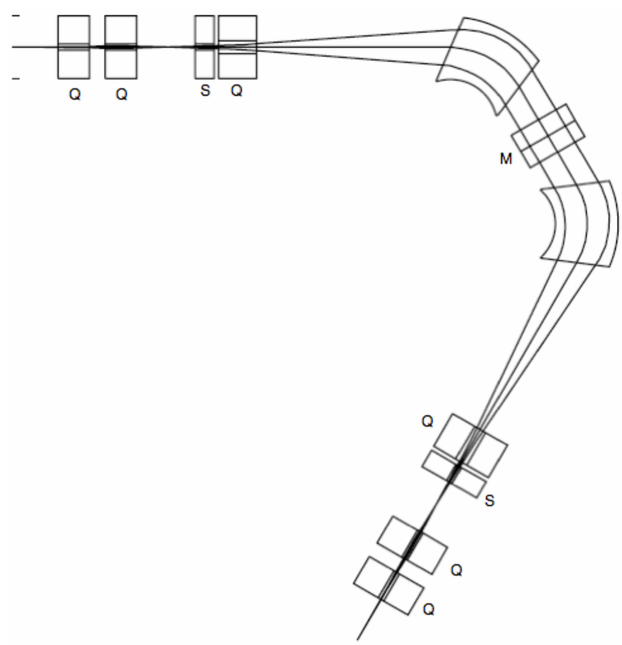

Figure 1: Layout of the Isobar Separator, showing the two 60º bending magnets with ρ=0.5 m, two quadrupole (Q) doublets, two quadrupole singlets, two sextupole (S) singlets, and an electrostatic multipole (M).

ION OPTICS DISCUSSION

Figure 2 shows the optics of the Isobar Separator in the x- (dispersive) and y- (non-dispersive) planes. Note the different scales for the two planes. The symmetric design of the separator helps to minimize aberrations. The beam enters from the left through a 1-mm diameter aperture, with θ_{max}, φ_{max} = ±6 mr. It then passes through the first quadrupole doublet, which has an x-magnification (x,x) of 0.19 and a y-magnification (y,y) of -3.4. This produces a ribbon-shaped beam, narrow in the dispersive direction and with reduced y-angles, which minimizes φ-aberrations. The next quadrupole (denoted below as the focusing quadrupole) diverges in x and converges in y, giving a small vertical size when entering the first bending magnet, thus minimizing y-aberrations. The diverging x-envelope assures that the beam will occupy a large area of the magnet, producing a high mass dispersion. Inclined faces on the entrance and exit edges of the magnet combine to produce a parallel beam in x upon exiting the magnet and a crossover in y at the center of the Isobar Separator. This is accomplished by requiring the focus conditions $(\theta,\theta) = (y,\varphi) = (\varphi,y) = 0$ at the center point. The remaining half of the Isobar Separator is the reverse of the first half, and transforms the ribbon-shaped beam back to a circular cross-section. This allows a 1-mm size mass-selection slit to be used at the focal plane.

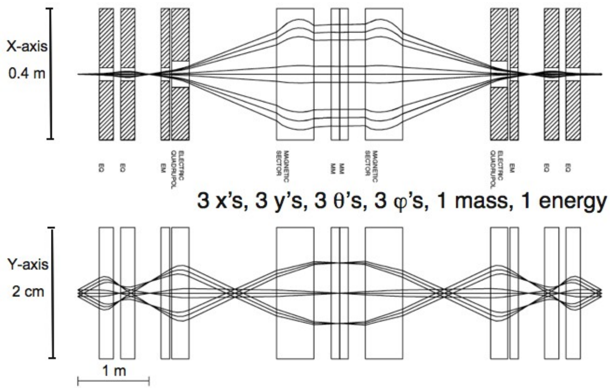

Figure 2: Ion optics of the Isobar Separator in the x- (dispersive) and y- (non-dispersive) planes. Note the different scales in the 2 planes.

The program COSY INFINITY [2] has been used to calculate the final version of the beam optics. Aberration correction up to 5th order is accomplished by means of two sextupole singlets placed adjacent to the two quadrupole singlets, and a 48-element electrostatic multipole lens with sextupole, octupole, decapole, and dodecapole components, placed between the two bending magnets. The dominant correction is of second order, and is mainly due to large horizontal angles.

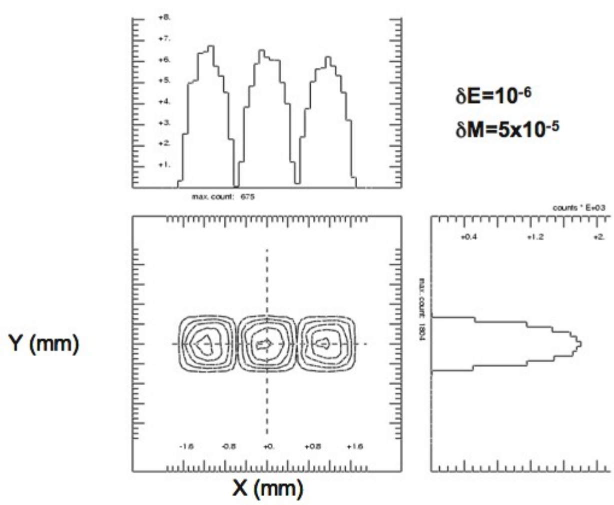

Figure 3: Calculated mass spectrum in the dispersive plane (X-direction) and non-dispersive plane (Y-direction) for 3 isobars differing in mass by 1 part in 20,000. Energy spread $\Delta E/E = \pm 1\times 10^{-6}$.

Figure 3 shows a calculated mass spectrum in the dispersive plane (x-direction) and non-dispersive plane (y-direction) for 3 isobars differing in mass by 1 part in 20,000. Maximum input angles are ±6 mr, and the initial beam spot is 1 mm in diameter. The energy spread has been set to $\Delta E/E = \pm 10^{-6}$ in order to indicate the intrinsic resolution of the separator.

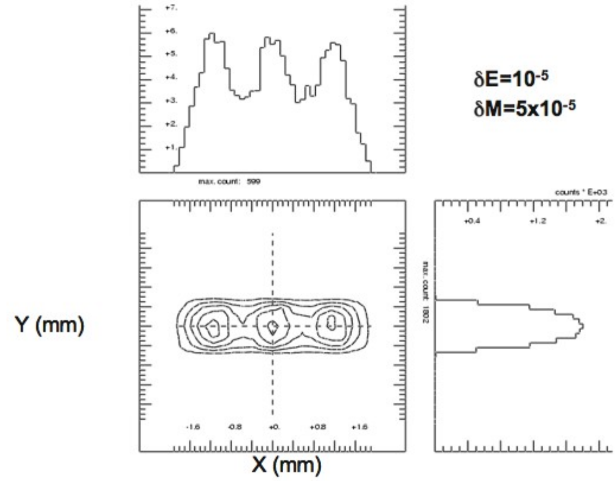

Figure 4: Calculated mass spectrum for 3 isobars differing in mass by 1 part in 20,000. Energy spread $\Delta E/E = \pm 1\times 10^{-5}$.

Figure 4 shows a calculated mass spectrum for the same input conditions as for Figure 3, except that the energy spread has been set to $\Delta E/E = \pm 1\times 10^{-5}$ in order to demonstrate the effect of a finite energy spread on the mass resolution.

Table 1: Physical Properties of the Bending Magnets

Element	Radius	Pole Gap	Pole Edge Angle	Pole Width
60° magnet	0.5 m	8 cm	23°	0.62 m

Table 2: Physical Properties of the Electrostatic Focusing Elements

Electrostatic Element	Length	Diameter
Matching quadrupole	20 cm	4 cm
Focusing quadrupole	24 cm	8 cm
Sextupole	12 cm	4 cm
Multipole	30 cm	40 cm

Table 1 shows the physical properties of the 60° bending magnets. Table 2 gives the properties of the electrostatic focusing elements.

The multipole lens has a 48-rod squirrel-cage construction, with 1.9 cm diameter rods. It is used for sextupole, octupole, decapole, and dodecapole corrections. Figure 5 shows a schematic drawing of the multipole lens. Table 3 shows the maximum voltages needed to excite the various multipoles, as well as the tolerances on each voltage. The tolerances have been determined in simulations by requiring that the transmission fraction remained > 95%. As can be seen, the decapole and dodecapole components are quite weak and non-critical.

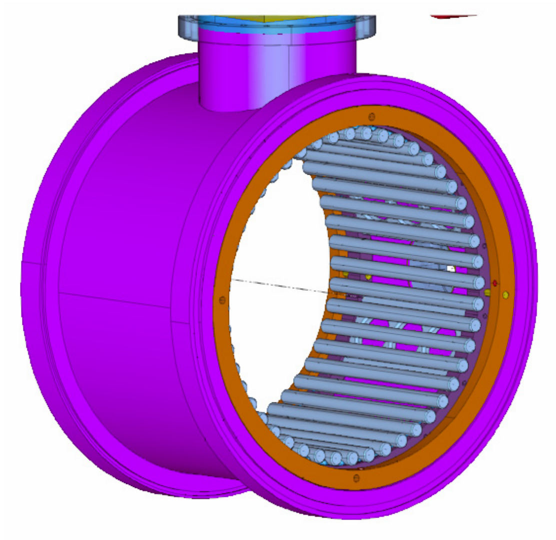

Figure 5: Schematic of 48-element electrostatic multipole lens.

Table 3: Voltages and Tolerances for the Various Multipoles in the Electrostatic Multipole Lens

Multipole Component	Voltage ± tolerance
Sextupole	~ 500 ± 1 V
Octupole	~ 20 ± 1 V
Decapole	~ 2 ± 1 V
Dodecapole	~2 ± 1 V

COMMISSIONING OF THE SEPARATOR

As part of the separator commissioning process, it is intended to tune the focusing quadrupole with reversed voltages such that an x-focus is obtained at the center of the separator. The matching quadrupole doublet voltages will remain unchanged. Figure 6 shows the dispersive and non-dispersive optics for this configuration.

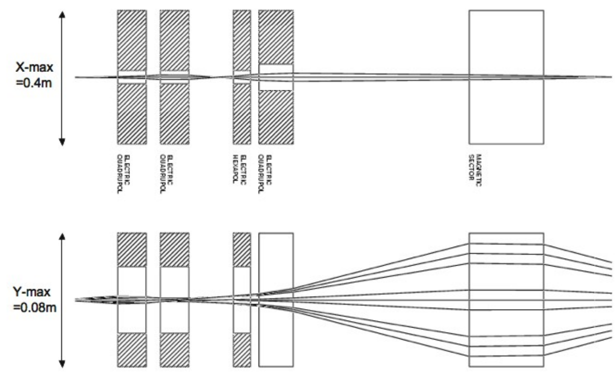

Figure 6: Dispersive and non-dispersive ion optics for the first half of the separator with reversed focusing quadrupole voltages.

The mass dispersion under these conditions is a factor of 58 smaller than that for the full separator with non-reversed focusing quadrupole voltages. This makes the demands on energy stability much less stringent (< 5-10 eV), and allows the use of stable beams for calibration purposes, i.e., ^{82,83,84,82}Kr (12%, 11%, 57%, 17%). A diagnostic station will be mounted inside the vacuum chamber of the multipole lens for these test runs.

CURRENT STATUS (APRIL 2009)

All electrostatic elements have been designed and constructed in our laboratory, and are presently being installed. The bending magnets are expected to be delivered from the manufacturer in May 2009.

REFERENCES

[1] F. Herfurth et al., Nucl. Instrum. Meth. A469 (2001), 254.

[2] Program COSY INFINITY, Version 8.1, http://bt.pa.msu.edu/index_cosy.htm.