An achromatic mass separator design for ions from the EBIT charge breeder at the NSCL

AN ACHROMATIC MASS SEPARATOR DESIGN FOR IONS FROM THE EBIT CHARGE BREEDER AT THE NSCL*

M. Portillo#, G. Bollen, S. Chouhan, O. Kester, G. Machicoane, J. Ottarson, S. Schwarz, A. Zeller, NSCL, MSU, East Lansing, MI 48824

Abstract

The NSCL at Michigan State University is implementing a system called the ReA3 to reaccelerate rare isotope beams from projectile fragmentation to energies of about 3 MeV/u [1]. The re-acceleration system uses an Electron Beam Ion Trap (EBIT) to provide a compact and cost efficient system [2]. We discuss the design parameters for a *M/Q* separator that is to be used to separate highly charged ions from the EBIT. The separator is designed to accept ions at 12 keV/u with mass to charge ratios in the range of *M/Q*=2.5 to 5 amu. The goal is to separate selected rare isotope species from any residual ions before injecting them into the ReA3 linear accelerator system. Using ray tracing simulations with SIMION, as well as higher order map calculations with COSY INFINITY, the performance of the separator has been evaluated in terms of the expected mass resolution and overall acceptance. The separator consists of a magnetic sector and a series of electrostatic devices to obtain a first order achromatic tune. For comparison, similar performance values will be derived as those for a similar separator constructed at REX-ISOLDE.

INTRODUCTION

Wu and others had described the design of the reaccelerator at the NSCL in previous proceedings [3]. Since then there has been further progress in the details of the design and fabrication of the first sections of the EBIT charge breeder [4] and ReA3 injections system [5].

A large portion of the chemical selectivity needed to generate the isotope species of interest is to be accomplished at the level of the in-flight separator before the ions have been stopped in the gas cell. Furthermore, chemical and mass separation techniques will be used before injecting the ions into the EBIT. This makes the mass resolving power requirement on the separator less stringent than what is needed for example of separators used at Isotope Separator On-Line (ISOL) facilities where desired resolving powers range from 10^3 to 10^4, depending on the emittance from the ion source [6,7].

For this application, we have estimated that a mass resolving power of R~100 for beams of emittances of as high as 120 π-mm-mr would be adequate for most beams of interest. A large emphasis has been given to obtaining achromatic mass separation since the electron impact processes in EBIT type breeders tend to create beams of non-negligible energy spreads. Consequently, we have adopted an achromatic mass separation scheme similar to that used at the REX-ISOLDE facility [8]. Since the REX-ISOLDE separator plays a very similar role at their accelerator facility, we will make design comparisons and use similar figures of merit.

MASS SEPARATOR LAYOUT

The layout of the mass separator with respect to the EBIT and the injection section of the RFQ is shown in Figure 1. Beam observation boxes (BOB) are located at BOB-1 through BOB-6 where the first one marks the matching point between the EBIT and the separator. The dashed inset box at the center of the figure contains plots of rays propagating through the separator between BOB-1 and BOB-4. The plots have been calculated with COSY INFINITY version 9 [9].

Between BOB-1 and -2 is the so-called "double bender" section, which can be used to inject ions towards the EBIT from above or below. Cylindrical bends of 33 mm gap are used to electrostatically divert ions coming from the top or bottom over a 75° bend and 250 mm radius. A 15° pulsed kick can be turned on to merge the beam onto the optic axis of the EBIT with either radioactive ions from bellow or stable ions from a test ion source above. During injection the EBIT will be at ground potential while ions are being trapped for cycles of as long as ~100 ms or less, depending on the optimum breeding time.

Following the breeding cycle, the EBIT will then be pulsed up to as high as 60 kV to accelerate the highly charged ions into the separator at an optimum energy of 12 keV/u, which is needed for injection into a multi-harmonic buncher (MHB) and RFQ. During this time the 15° kicker is switched off or used as a vertical steerer. The triplet after BOB-1 switches potentials to "extraction-mode" such that optimum focus at BOB-2 is established in conjunction with the other triplet.

Electrostatic Sector Spectrometer

Between BOB-2 and –3 is an electrostatic bend section consisting of two 45° bends at 681 mm radius that are oriented symmetrically about the center of the quadrupole at the midpoint. Since the bends are cylindrical, only the central quadrupole provides vertical focusing in this section. At the focus position there is an adjustable horizontal slit for defining the energy acceptance *ΔE/E*. First order optics calculations predict a magnification of about (x,x)=0.4 and an energy dispersion of about (x,δ_E)=10 mm/%, which is depicted in the plot by a ray having and energy difference of δ_E=2% away from the reference trajectory.

*The US National Science Foundation funds operation of the NSCL as a national user facility under cooperative agreement PHY 06-06007.
#portillo@nscl.msu.edu

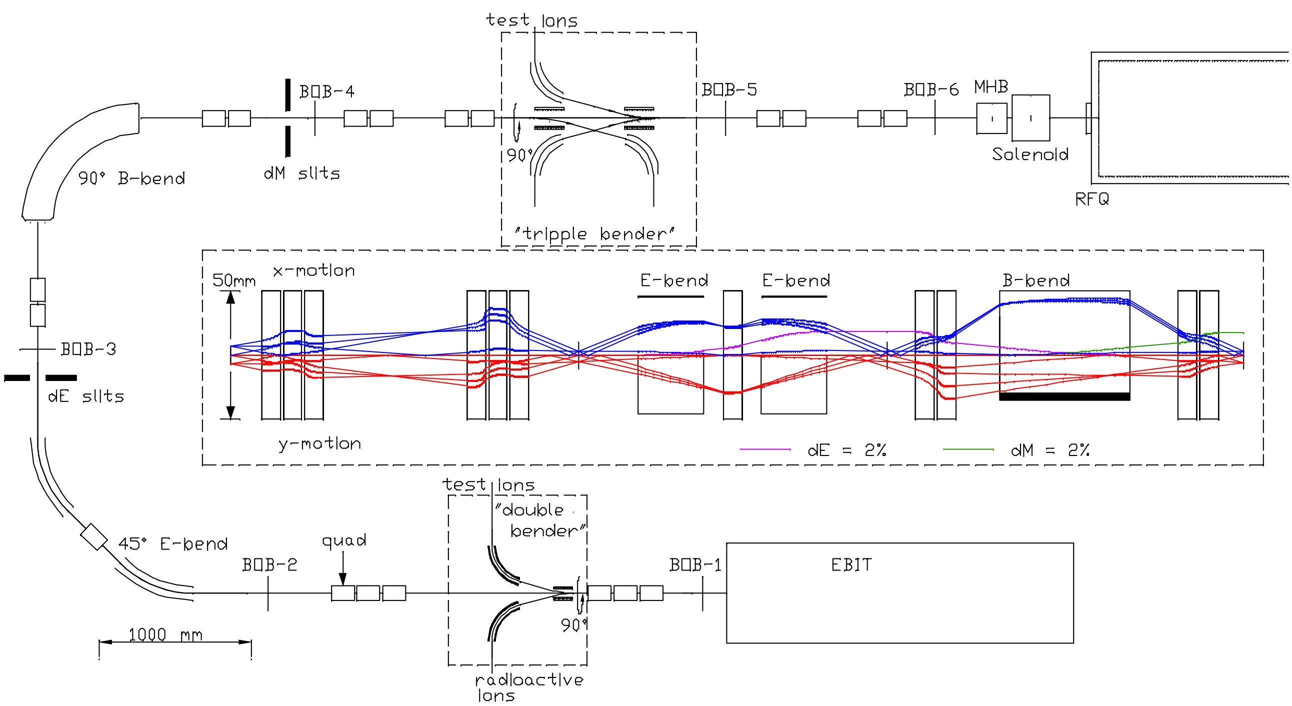

Figure 1: Layout of the ReA3 mass separator with respect to the EBIT charge breeder and RFQ. Locations BOB-1 through BOB-5 are the positions of each beam-observation-box. See text for more details.

Magnetic Sector Spectrometer

The section that follows consists of two quadrupole doublets and a magnetic bend oriented symmetrically about the center between BOB-3 and –4. A uniform field 90° bend sector magnet with water-cooled coils is used for dispersing the masses along a 681 mm radius. Although the vertical gap of the dipole is 60 mm, the walls of the vacuum vessel allow only 50 mm clearance for the beam. Field measurements with a Hall probe have been carried out and compare well with the predictions of the of the design simulations with Opera-3D. The quadrupole doublet strengths are optimized to focus the beam at the position of the adjustable horizontal slits at BOB-4, were the mass acceptance $\Delta M/M$ is defined. The tune is optimized to obtain a mass dispersion of (x,δ_M)=10 mm/% and cancels out the energy dispersion terms (x,δ_E) and (a,δ_E), hence, yielding first order achromiticy. The plot shows a ray having a mass difference of δ_M=2% away from the reference trajectory. At this point the horizontal magnification is still about (x,x)=0.4, while the vertical magnification is about (y,y)=0.7.

ReA3 Injection Section

The section that follows allows the beam phase space to be re-oriented with stigmatic focusing through to the MHB and RFQ section for subsequent acceleration to high-energy experiments.

Also added along this section is the so-called triple bender section used for diverting highly charged ions to other experiments or, alternatively, inject ions from two possible sources. The ions from above will be injecting stable ions that serve as a pilot beam for the high-energy section. From below is a channel reserved for injection into the accelerator from possibly an alternate future breeder. The three bends in this chamber are spherical and have larger gaps than those in the "double bender." This is to allow for larger phase space beams of the type expected from some high charge breeders. The 75° bends have 80 mm gaps at a radius of 250 mm and are design to operate at potentials as high as ±20 kV, symmetrically biased. The two 15° bends have a gap of 120 mm and are design to operate at up to ±10 kV over a length of 191 mm.

BEAM CHARACTERISTICS

The acceptance of the separator has been designed to be similar to that of the accelerator, which is expected to be up to 0.6 π- mm-mr. At 12 keV/u the emittances can thus be as high as ~120 π-mm-mr.

Comparison of characteristics of the ReA3 and REX-ISOLDE mass separator designs are listed in Table 1. Notice that the ReA3 separator requires over twice the velocity to be accepted by their corresponding acceleration stages down stream. This will require more stringent requirements on the acceleration potential, as well as needed field strengths for focusing and bending. For ReA3 the magnetic bend radius is scaled up by about 36% in order to obtain higher dispersion. Furthermore, the full aperture size of the quadrupoles are double the size to achieve higher acceptance transverse acceptance. The angular acceptance for the ReA3 separator is about ±17 mrad along both the x- and y-planes as can be seen by the plot in Figure 1. Monet Carlo simulations also predict that the beam size is restricted to within about ±20 mm along both planes.

In order to compare the performance in terms of mass resolving power, calculations with COSY have been carried out to simulate the particle distributions at the exit of the separator at position BOB-4. The top-most plot in Figure 2 shows the resulting distribution of particles along the *a* vs *x* phase space. The three groups of particles have a mass difference of δ_m=1/150 and each has 5000 particles.

The initial phase space distributions are Gaussian and have been modeled with a Monte Carlo code. After this the final positions are evaluated using 5th order maps. The effects of the higher order aberrations can be clearly seen by the filamentation of the distributions at the outermost divergences. An ellipse having half-widths 2.2 mm by 31 mrad is plotted here to represent the expected 1st order boundary within which about 95% of the particles would reside if not for the higher order effects. At the bottom of the same figure is a corresponding plot of the distribution along the *x*-axis with 0.4 mm wide binning.

Within the half-width range of the central particles, the transmission of particles is 87%, while contamination from adjacent masses is almost 2% for any of the two. Since the impurities from the adjacent masses are of major concern, future efforts in correcting higher order aberrations may need to be considered. The value of such an effort will depend on the emittances that ultimately result out of the EBIT, which will be an evolving process in itself.

SUMMARY AND OUTLOOK

The ReA3 separator as of date is still under construction and scheduled for commissioning starting in June 2009. Most of the needed components have been fabricated at the NSCL, and where possible purchased from outside vendors. For the design specifications, simulations with 3D codes such as SIMION [10] and Opera-3D [11] have been carried out and applied to the design of the optical elements. As in the analysis for the REX-ISOLDE separator, simulations with COSY have been used for the ReA3 design to determine the optimal optical layout and expected performance in terms of mass resolving power and acceptance. A comparison of the characteristics of the two separators has been described.

Table 1: Comparison of Mass Separator Characteristics

Characteristics	REX-ISOLDE	ReA3
required energy [keV/u]	5	12
Q/M range	0.2 to 0.34	0.2 to 0.4
acceleration potential [kV]	14.7 to 25	30 to 60
magnet bend radius [mm]	500	681
mass dispersion [mm/%]	5	10
quadrupole full-aperture [mm]	50	100
emittance at *R*=150 [π-mm-mr]	40	70

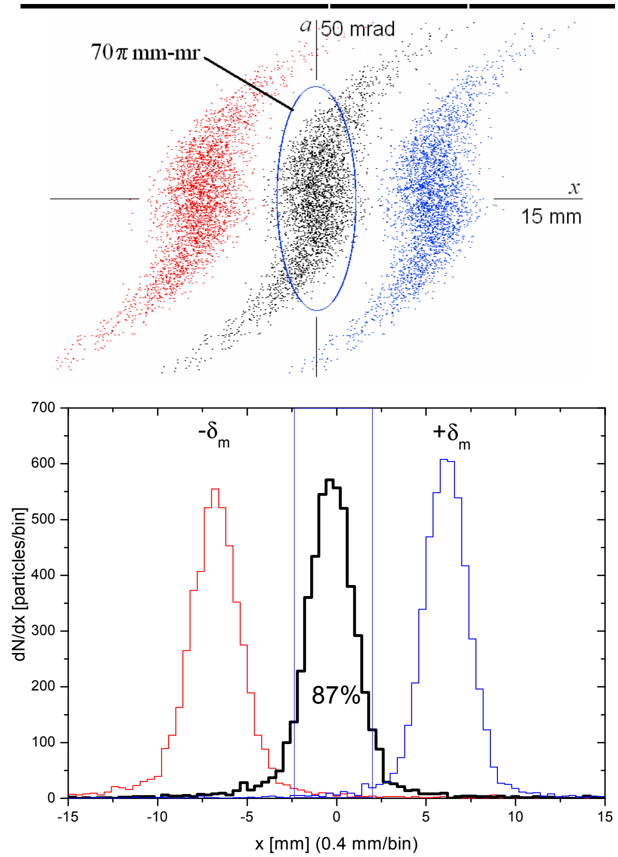

Figure 2: (top) Simulated particle distributions along *a* vs *x* as described in the text. (bottom) Integrated sum of particles along the *x*-axis for the same plot.

REFERENCES

[1] http://www.nscl.msu.edu/future/isf
[2] S. Schwarz, et. al., Rev. Sci. Instrum. 79, (2008) 02A706.
[3] X. Wu, et. al. "Beam Dynamics Studies for the Reaccelerator of Low Energy RIBS at the NSCL." PAC'07, Albuquerque, June 2007, TUPAS053, p. 1769 (2007) http://www.JACoW.org.
[4] O. Kester, et. al., these proceedings.
[5] X. Wu, et. al., these proceedings.
[6] P.G. Bricault, et. al.,NIMB 126 p. 231 (1997).
[7] E. Kluger, et. al.,NIMD 70 p. 41 (1992).
[8] D. Habs, et. al. "The q/m Separator for REX-ISODE." EPAC'98, Stockholm, Sweden, June 1998, p. 2132 (1998).
[9] K. Makino and M. Berz, NIMA 558 (2005) 346.
[10] D.A. Dalh, et. al., Rev. Sci. Instrum. 61 p. 607 (1990).
[11] Opera-3D/2D users guide, Vector Fields Limited, England.