ON THE ARIEL PRE-SEPARATOR

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Abstract

Two new independent target ion sources with dedicated pre-separators will be built in the ARIEL facility to triple the radioactive ion beam production at TRIUMF. A compact Nier-Johnson type of pre-separator has been designed to achieve a mass resolving power of 300 in order to minimize the undesired radioactive species contaminating the downstream beamlines. It consists of a 112° magnetic and a 90° toroidal electrostatic dipole with deflection in opposite direction. It also contains electrostatic quadrupole elements in between the dipoles. The electrostatic dipole compensates the energy dispersion of the magnetic dipole. This allows an achromatic mode of operation resulting in a high mass resolving power downstream to the electrostatic deflector even for beams with a high energy spread. We present the result of beam optics calculations for the ARIEL pre-separator.

INTRODUCTION

The ARIEL facility complements the existing ISAC facility, adding to it two driver beams: an additional proton beam from the existing 500 MeV H^- TRIUMF cyclotron, and an electron beam from our new electron linac [1].

The ARIEL facility consists of two target ion sources called ARIEL Proton Target West (APTW) and ARIEL Electron Target East (AETE). Each target ion source has its own pre-separator and they are optically identical. The pre-separator beamline will be used to transport the extracted beam from the ARIEL target ion source to outside the target hall [2]. Also it is used to pre-select the required ions to within one amu. This allows us to confine the radioactive contamination inside the target hall. The pre-separator has been designed to achieve a mass resolving power of 300 for a beam with a 4*RMS emittance 20 µm [3]. It has been designed to handle a beam with a maximum magnetic rigidity of 0.544 T m.

This pre-separator consists of a magnetic dipole and an electrostatic dipole for momentum and energy collimation and thus makes a Nier-Johnson type of configuration. Advantages of such a pre-separator with achromatic operation are: a) It allows rejection of neighbouring masses that are off energy, as can happen when a much more populous undesired isotope is stripped in the extraction region of the target ion source and gains less energy than the total potential difference, b) It has an energy collimation feature, c) The achromaticity will cancel energy-horizontal motion correlation and hence simplify tuning when small energy changes are being made.

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BEAMLINE LAYOUT

A schematic layout of the 4 m long ARIEL pre-separator optics is presented in Fig. 1. The pre-separator beamline consists of three optical modules according to optical functionality. The first module consists of a magnetic dipole element (MB8). The second module consists of a triplet (EQ9, EQ10 & EQ11) and the third module consists of an electrostatic toroidal dipole (EB12) with an electrostatic quadrupole (EQ12 & EQ13) at either side of the dipole. Optical functionality is discussed in the following section. The basic specification of this dipole is given in Table 1.

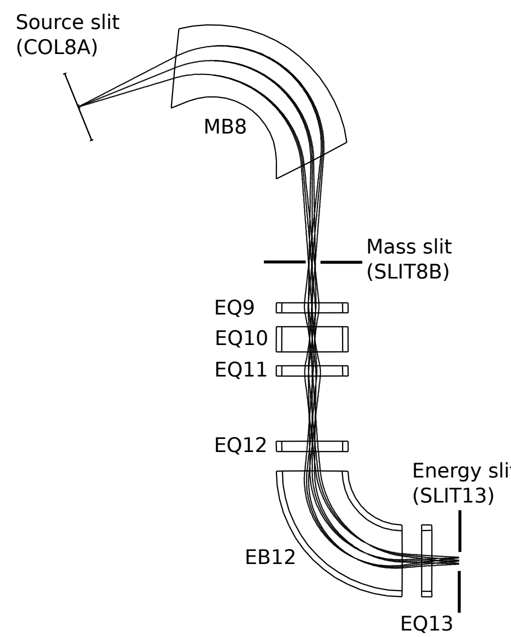

Figure 1: A schematic layout of the pre-separator in the target hall. The transverse displacements, including the gap in the electrostatic dipole, have been exaggerated for clarity.

Table 1: Dipole Specifications

Dipole	Radius	Angle	Pole gap	Edge angle
MB8	50.0 cm	112.0 °	6.0 cm	27.5 °
EB12	45.0 cm	90.0 °	5.0 cm	0.0 °

Matching into and out of the pre-separator have been described elsewhere [4]. The unseparated beam from the source arrives at COL8A, the location of the object slit, through a matching system. SLIT13 will be followed by 4 electrostatic quadrupoles to match to the periodic section with switches that transport to the High Resolution Separator (HRS) [5] or a bypass directly to experiments, as needed.

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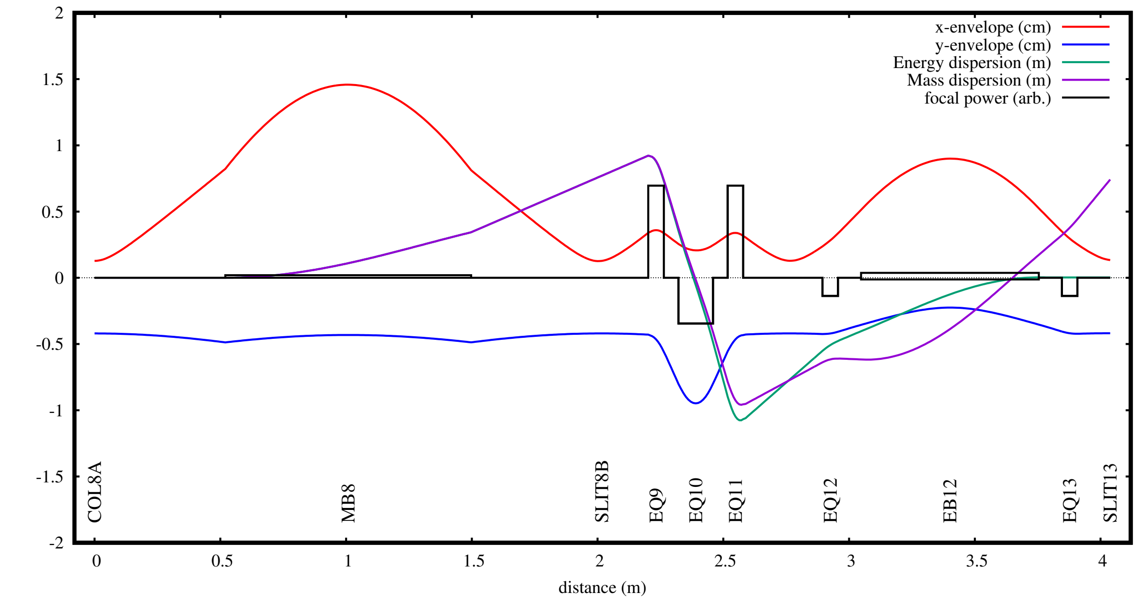

Figure 2: Calculated beam envelope (2*RMS, positive for x, negative for y) with energy and mass dispersion for an ion beam through the pre-separator with $\varepsilon_{4\mathrm{rms}} = 20\,\mu\mathrm{m}$.

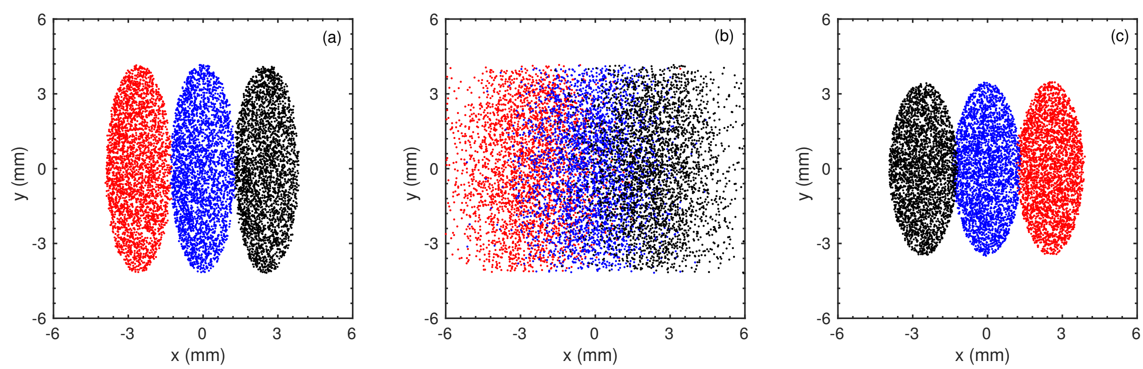

Figure 3: Calculated spatial profiles with $\delta_m = \pm\, 0.33\%$ and $\delta_E = 0.0083\%$ at SLIT8B (a), with $\delta_m = \pm\, 0.33\%$ and $\delta_E = 0.33\%$ at SLIT8B (b) and with $\delta_m = \pm\, 0.33\%$ and $\delta_E = 0.33\%$ at SLIT13 (c).

BEAM OPTICS

Initial beam optics have been designed using the code TRANSOPTR and the final design of the pre-separator has been benchmarked with the code COSY-∞ [6] up to third order.

A 112° dipole magnet (MB8) with bending radius of 500 mm is used in the pre-separator for the momentum selection at the location of SLIT8B. The dipole has an acceptance of 300 µm. The magnetic dipole provides a mass dispersion of 770 mm, which yields a mass resolving power of 300 for a beam with a 4*RMS emittance about 20 µm. The basic requirements of this dipole are given in Table 1. Detailed design requirements are presented in reference [7].

A 90° toroidal electrostatic dipole (EB12) is used in the pre-separator to compensate the energy dispersion due to the magnetic dipole (MB8). The toroidal electrostatic dipole (EB12) is modeled by using the code OPERA3D [8] and the calculated potential map is imported into the code COSY-∞ for optics calculations [9]. In order to have focusing in the non-bend plane, the dipole electrodes are curved in that plane. The ratio of the electrode radius in the bend plane to the non-bend plane is 0.5. The dipole has an acceptance of 250 µm. A detailed design of the toroidal electrostatic dipole is presented in reference [4]. A quadrupole is added at each end of the electrostatic dipole for edge focusing. In our case the electrostatic dipole with additional quadrupole optics gives a magnification near 1.

SLIT8B is an image of COL8A with a magnification of 1 and the mass dispersion is 0.77 m. Also SLIT13 is an image of COL8A with a magnification 1 and the energy dispersion vanishes at this location. In order to select a required m/q, an adjustable slit will be installed at the location of the first focal point (SLIT8B), which is 0.52 m downstream to the exit of the effective field boundary of the dipole magnet (MB8).

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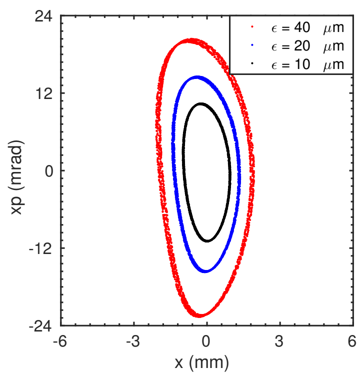

Figure 4: Calculated phase-space in the horizontal plane for various beam emittance contours with $\delta_E = 0.0083\%$ at SLIT13.

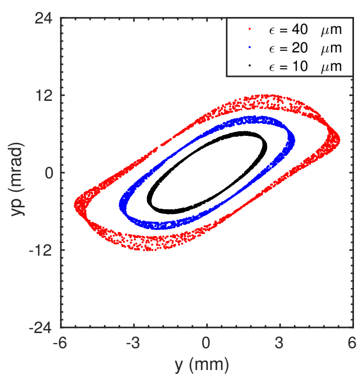

Figure 5: Calculated phase-space in the vertical plane for various beam emittance contours with $\delta_E = 0.0083\%$ at SLIT13.

Figure 1 shows the calculated ion trajectories through the beamline for three different masses with a mass difference of $\delta_m = \pm 0.33\%$. In the case of an extraction voltage of 60 keV, we have assumed an energy spread of 10 eV (i.e. $\delta_E = \pm 0.0083\%$). The TRANSOPTR calculated beam envelope and energy dispersion in the pre-separator are shown in Fig. 2. Calculated spatial profile at the location of the mass selection slit (SLIT8) is shown in Fig. 3(a).

One of the advantages of the ARIEL pre-separator is its Nier-like mass separator configuration with the combination of electrostatic (EB12) and magnet (MB8) dipoles. This provides a higher mass resolution ($\delta_m \approx \pm 0.33\%$) at the location of SLIT13 for a beam even with higher energy spread ($\delta_E > \pm 0.0083\%$). For example, a beam with energy spread about 200 eV at 60 keV is difficult to resolve (see Fig. 3(b)) at the mass selection slit (SLIT8B), whereas this is still possible to resolve (see Fig. 3(c)) at the energy selection slit (SLIT13).

Figures 4 and 5 show the calculated phase-space distributions (up to 3rd order) at the location of PM13 for various beam emittances. These calculations show that the emittance growth will be less than 1% in both horizontal and vertical planes for an initial beam emittance of 20 µm. If we assume an initial emittance of 40 µm, then the emittance growth will about 1% in the horizontal plane and 3% in the vertical plane. Higher order aberrations could be minimized further by increasing the radius of the EB12 and/or increasing the distance between the MB8 and EB12 but in our case these are limited because of the crane accessibility in the ARIEL target hall. The pre-separator layout is therefore a trade-off between the aberrations and space constraint in the ARIEL target hall.

Resolving Power

In the linear approximation:

1. Mass resolving power at the location of the mass slit (SLIT8B) for an initial beam emittance of 20 µm,

$$R_m = \frac{(x|\delta_m)}{2(x|x)W} \approx 300 \tag{1}$$

where $(x|\delta_m) = 0.77$ m is the mass dispersion,
$(x|x) = 1.0$ is the magnification, and
$W = 1.28 \times 10^{-3}$ m is the half width of the source slit (COL8A).

2. Energy resolving power at the location of the energy slit (SLIT13) for an initial beam emittance of 20 µm,

$$R_K = \frac{(x|\delta_E)}{2(x|x)W} \approx 327 \tag{2}$$

where $(x|\delta_E) = 0.77$ m is the energy dispersion,
$(x|x) = 0.92$ is the magnification, and
$W = 1.28 \times 10^{-3}$ m is the half width of the source slit (COL8A).

SUMMARY

Beam optics design for the ARIEL pre-separator achieves a mass resolving power of 300 for a given 4*RMS emittance of 20 µm. The pre-separator can operate in an achromatic mode with the specified beam optics and it has an advantage of energy collimation in addition to mass separation.

REFERENCES

[1] L. Merminga *et al.*, “ARIEL:TRIUMF advanced rare isotope laboratory”, in *Proc. IPAC'11*, San Sebastián, Spain, paper WEOBA01, 2011.

[2] M. Marchetto *et al.*, “The ARIEL radioactive ion beam transport system”, in *Proc. LINAC'16*, East Lansing, MI, USA, paper THPLR023, 2016.

[3] R. Baartman, “Emittance Convention”, TRIUMF, Vancouver, Canada, Internal report, TRI-BN-15-07, 2015.

[4] S. Saminathan and R. Baartman, “ARIEL pre-separator”, TRIUMF, Vancouver, Canada, Internal report, TRI-DN-16-07, 2016.

[5] J. A. Maloney, R. Baartman, and M. Marchetto, “New design studies for TRIUMF's ARIEL High Resolution Separator”, *Nucl. Instr. Meth.*, vol. 376, pp. 135–139, 2016.

[6] COSY-∞, `http://www.bt.pa.msu.edu/`

[7] S. Saminathan and N. Muller, “ARIEL Pre-separator Dipole Magnet”, TRIUMF, Vancouver, Canada, Internal report, TRI-DN-16-27, 2016.

[8] OPERA3D, `http://operafea.com/`

[9] J. A. Maloney *et al.*, “Electrostatic potential map modelling with COSY Infinity”, *Nucl. Instr. Meth.*, vol. 376, pp. 171–174, 2016.

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