Mass Separator for the ISAC project at TRIUMF

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Abstract

Presently, a radioactive ion beam facility, ISAC, is being built at TRIUMF. A 100 μA beam from the 500 MeV cyclotron produces radioactive species in a thick target. They are ionized in an ion source and singly charged ions are extracted with a 60 kV Voltage. The typical energy is 2 keV/u. The ions pass through a mass separator and are then transported immediately to a low energy experimental area or injected into an accelerator sequence consisting of an RFQ and a linac for acceleration up to 1.5 MeV/u. This paper describes the optics design of the mass separator. It can accept beam from two target stations and will be used with many different types of ion sources. The mass separator gives a mass resolution of 10,000 for an ion source with a small energy spread and a horizontal phase space area of 8 mm-mr.

1 INTRODUCTION AND SUMMARY

The ISAC project aims to produce radioactive ion beams from thick targets using an on line ion source. Usually, short lived isotopes are produced in much smaller quantities than the longer lived or stable isotopes. Therefore, the mass separator plays a crucial role in the rejection of the background caused by the unwanted species. Not only should it have a good mass resolution but also the tails of the intensity distribution as function of the position in the focal plane should be as short as possible. Since the intensities of the wanted isotopes may be small, it is important to have a large solid angle and position acceptance if the ion source emittance is large. Acceptance and resolution are roughly inversely proportional to each other. In many cases ion sources may have large emittances. It is then still possible to obtain a good resolution by using slits to restrict the horizontal acceptance at the expense of intensity. In such cases it is not advisable to also restrict the vertical emittance because that would lead to additional loss of intensity. Therefore, the separator is designed in such a way that a large vertical emittance is maintained even in situations where a high resolution is required. The mass separator was designed to give a FWHM resolution of about 10,000 in practical circumstances for a modest emittance in the separation plane and for ion sources with an energy spread that does not exceed a few electron volts.

This paper describes the ion optics design. Special attention was paid to minimizing the higher order aberrations by a suitable choice of the first order optics.

From the point of view of construction it seemed important to use as much as possible standard, well understood beam line elements. Therefore, we used standard bending magnets with flat pole faces. Higher order aberrations are small due to the high degree of symmetry in the first order optics. Second and third order order corrections are obtained using weak sextupoles and octupoles and are facilitated by placing the multipoles at optimal locations where they couple exclusively to only one or two aberrations.

Section 2 gives a more detailed description of the separator. The higher order optics is discussed in section 3. The results of Monte Carlo calculations are given in section 4.

The best result for a source with zero energy spread is a resolution of 25,000 for 8 mm-mr horizontal by 80 mm-mr vertical phase space areas. This shows that it is possible to correct the aberrations very well to the extent that the resolution is close to the first order resolution even for a higher order calculation. At the same time the extent of the tails can be limited.

A conclusion is that the actual resolution that can be obtained with the separator will not depend on the intrinsic higher order optics but will be determined by other effects e.g. the stability of the beam elements, the energy spread in the source, and the separator environment. It is anticipated that, in practice, a mass resolution of about 10,000 can be obtained under many circumstances.

2 LAYOUT OF THE SEPARATOR AND FIRST ORDER OPTICS

The layout is shown in Fig. 1 and the beam envelope in Fig. 2.

The separator consists of three sections. Section 1 transports and focusses the beam horizontally at HF1 and vertically in the center of B1. It consists of electrostatic quadrupoles. Depending on the type of source a small triplet is placed very close to the source to capture a large solid angle. Quadrupoles QM3 to QM6 have the same but alternating strength and act as a minus unit transport system. The tuning to match different sources to the separator is done with the two doublets QM1/QM2 and QM7/QM8. A horizontal slit at HF1 determines the size of the object seen by the separator.

Section 2 between HF1 and HF2 acts as a low resolution pre-separator. It consists of a 60 degree bend which can accept beam from either the East or the West target stations. Beams enter and exit B1 along the normal to the poleface. B1 focusses horizontally with -1 magnification between HF1 and HF2 in quadrupole QS1. The beam can be

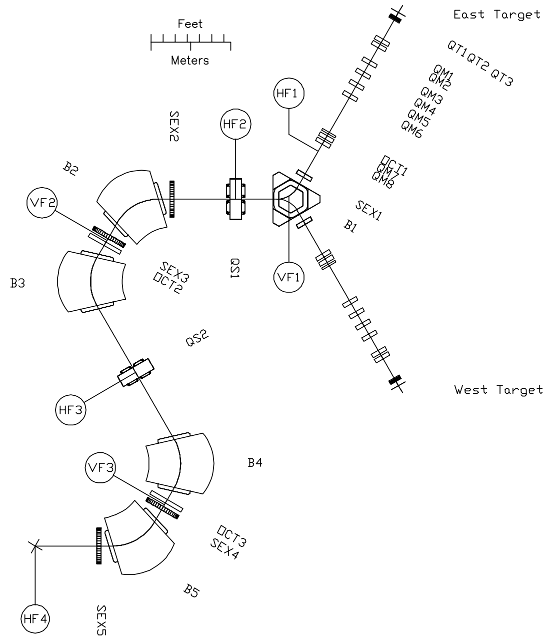

Figure 1: Separator layout

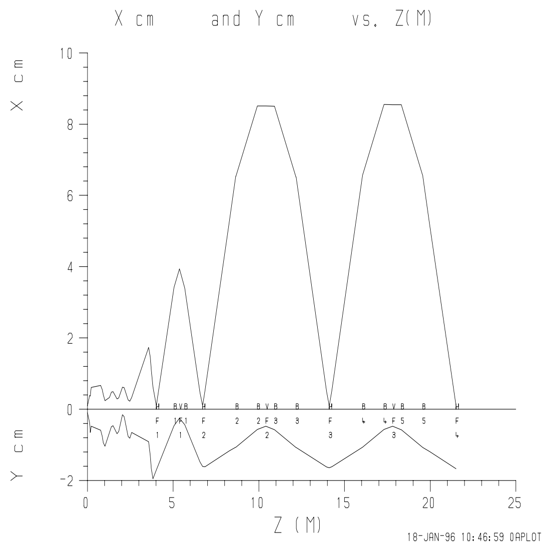

Figure 2: Beam envelopes in separator

monitored immediately in front of HF2 by observing masses that differ slightly from the wanted mass but are usually more abundant. A succeeding slit performs a coarse selection of the wanted mass. Since the mass dispersion at HF1 is 0.6 cm per percent ΔM/M the first order mass resolving power of section 2 is 3,000 for a spot size of ± 0.1 mm at HF1.

Section 3 between HF2 and HF4 is the high resolution separator. It consists of four identical 60 degree bending magnets with flat pole faces which make an angle of 17.16 degrees with the normal to the central trajectory. This value achieves point to point focussing between HF2 and HF3 in both the horizontal and the vertical plane. The section HF3 to HF2 is identical to the section HF2 to HF3 but bends in the opposite direction so that the dispersions will add. The mass dispersion for section 3 alone is 5.2 cm per percent ΔM/M. The total mass dispersion of the whole separator is 5.8, resp. 4.6 cm per percent ΔM/M for the East target, resp. the West target, corresponding to first order mass resolutions of 29,000 and 23,000 for a ± 0.1 mm spot at HF1.

In an earlier design, there were simultaneously horizontal and vertical foci at HF1, HF2, HF3 and HF4. This resulted in a small vertical angle acceptance which was partly due to the difficulty of correcting the higher order optics aberrations. In the present design horizontal and vertical foci do not coincide but QS1 focusses the beam vertically midway between B2 and B3 and QS2 gives a vertical focus midway between B4 and B5.

3 HIGHER ORDER CORRECTIONS

The first order resolution mentioned above is the performance limit. In reality, higher order effects widen the peaks in the focal plane. In practice, it is often possible to correct the most important second and third order terms but the influence of the forth and fifth order terms can only be limited by limiting the beam emittance and, especially, the input angles. The horizontal spots at the horizontal foci have to be corrected for aberrations due to the horizontal angle θ and due to the vertical angle ϕ. The sextupoles SEX3 and SEX4 and the octupoles OCT2 and OCT3 at the vertical foci influence only the θ aberrations. The sextupoles SEX2 and SEX5 influence both types of aberrations. SEX2 equals minus SEX5. SEX3 equals minus SEX4 and OCT2 equals OCT3. This symmetry reduces the number of knobs that need to be tuned. First the ϕ aberrations are corrected with SEX2/SEX5 and then the θ aberrations with SEX3/SEX4 and OCT2/OCT3.

The ray tracing program ZGOUBI [1] was used to do the higher order calculations up to fifth order for beam line elements with realistic fringe fields. Figures 3 and 4 show the effect of sextupoles SEX4 and SEX5 on the horizontal coordinate at HF4 as function of θ and ϕ. Both sextupoles are important for the θ aberrations but only SEX5 is important for the small ϕ aberrations.

4 RESULTS OF MONTE CARLO CALCULATIONS

Monte Carlo calculations were done for 20,000 particles for the initial square phase space of $x_i = \pm 0.25$ mm by $\theta_i = \pm 30$ mr and $y_i = \pm 1.0$ mm by $\phi_i = \pm 30$ mr. A horizontal slit 80 cm downstream of HF1 can be used to restrict the horizontal angle acceptance, while a vertical slit 30 cm upstream of HF2 limits the vertical angle acceptance.

Fig. 5 was obtained by limiting both the θ acceptance and the and the ϕ acceptance to ± 20 mr. A horizontal slit at

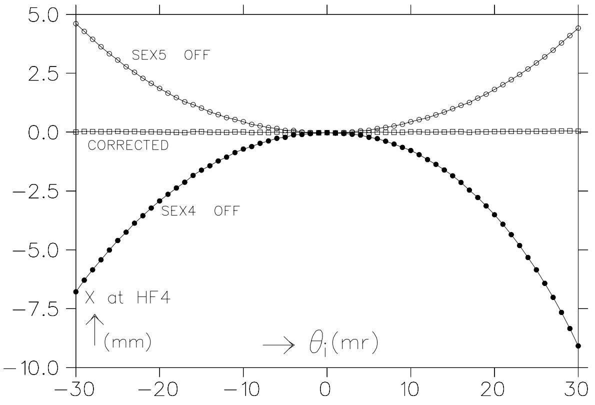

Figure 3: The influence of sextupoles SEX4 and SEX5 on the horizontal displacement in the final focal plane as function of the launching angle θ_i at the source.

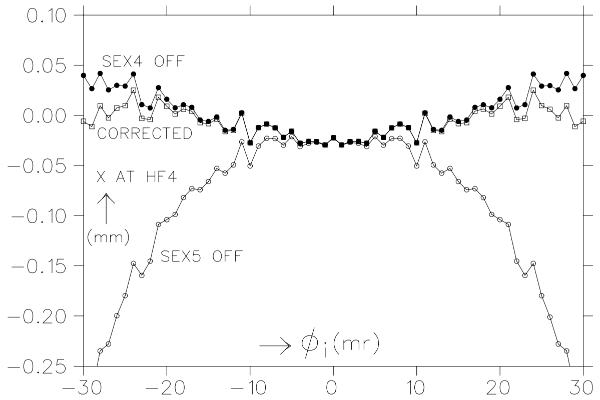

Figure 4: The influence of sextupoles SEX4 and SEX5 on the horizontal displacement in the final focal plane as function of the launching angle ϕ_i at the source. SEX4 has almost no influence on ϕ-related aberrations.

HF1 has a full aperture of 0.2 mm. The energy spread in the source was exactly zero. The acceptance area in the horizontal plane is 8 mm-mr. In the vertical plane it is 80 mm-mr. The figure shows three peaks of different masses such that M/ΔM is $\pm 25,000$. They are well separated so that the FWHM mass resolution is better than 25,000. The peaks have a very good shape and there are almost no tails. This fact is, especially, important for the separation of the wanted masses from neighbouring masses that are much more abundant.

Further calculations showed that it is easy to transport a very large phase space area of 80 mm-mr in both the separation plane and the vertical plane. In that case the FWHM mass resolution is 1,450.

5 REFERENCES

[1] ZGOUBI user's guide, version 3, F. Meot and S. Valero, Laboratoire National Saturne Note LNS/GT/93-12

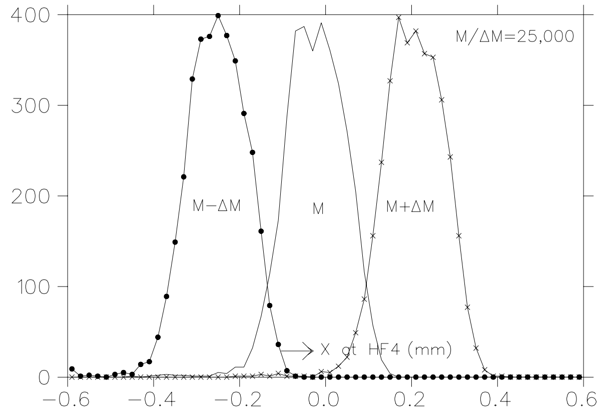

Figure 5: Mass resolution from higher order calculations.