# Isotope separation with new ion-optics mode

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Two-stage structure is an important feature of the in-flight fragment separator BigRIPS.[1)] The first stage, which consists of two dipoles (D1 and D2) and four superconducting triplet quadrupoles (STQs) (STQ1-4), is located between the production target F0 and achromatic focus F2 with the momentum dispersive focus F1. The second stage, which consists of four dipoles (D3-D6) and eight STQs (STQ7-14), is located between the achromatic foci F3 and F7 with the momentum dispersive foci F4, F5, and F6. The stage between F2 and F3, which consists of two STQs (STQ5-6), acts as a matching section. Rare-isotope (RI) beam is produced and separated in the first stage with an energy-loss degrader at F1, and particle identification and momentum analysis are performed in the second stage.[1,2)] Another energy-loss degrader placed at F5 is often effective when unwanted isotopes are transmitted as a result of the charge state change or the secondary reaction in the first degrader at F1. The thicknesses and shapes of the degraders at F1 and F5 are chosen so as to optimize the RI beam according to the experimental requirements.

The two stages act independently and their isotopic separation power can be added or subtracted, depending on the experimental condition. When the separation powers of the two stages are subtracted, the horizontal spatial distance of the separated isotopes becomes small at the final focus F7. Adding the isotopic separation powers of the two stages would increase the horizontal spatial distance. Because widths also increase, improvement of the final resolving power will depend on the experimental condition.

The ion-optical solution for adding the separation power can be realized by having either one or three foci in the matching section F2-F3, which have two foci (F2 and F3) in the standard mode. At least one focus in the standard mode is abandoned in the former case. It is not desirable because both F2 and F3 are important for slits and diagnostics of the RI beam. Therefore, here we present the solution having three foci.

Figure 1 shows the horizontal ($X$) and vertical ($Y$) tracks of the beam from F0 to F7 obtained from the solution of the first-order ion-optical calculation. In this solution, ion-optical conditions of the two stages (F0-F2 and F3-F7) are the same as the ones in the standard mode. Only the matching section F2-F3 is modified to have an additional focus in the $X$ direction at the midpoint "F2.5" between F2 and F3, while the beam is not focused in the $Y$ direction at F2.5 to reduce excitation

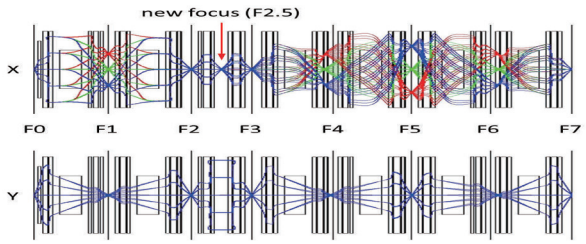


Fig. 1. Horizontal ($X$) and vertical ($Y$) tracks of the beam in the new mode.

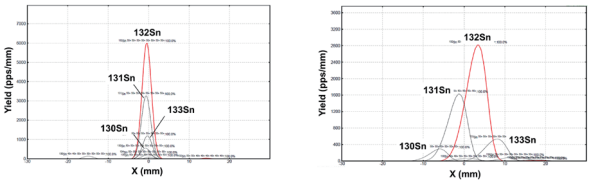


Fig. 2. Comparison of tin isotope distribution at F7 between the standard mode (left) and new mode (right) simulated with LISE$^{++}$.

currents of STQ5 and STQ6. Reversing the polarity of all quadrupoles of the two STQs is also necessary to reduce the currents. The maximum magnetic rigidity ($B\rho$) of 8.7 Tm is achieved in this solution. The value is almost the same as the maximum $B\rho$ of the second stage (8.8 Tm). There is a trade-off between achieving high $B\rho$ and large acceptance.

Figure 2 shows an example of horizontal distributions of tin isotopes at F7, simulated by LISE$^{++}$, in a $^{238}$U + Be 4 mm reaction at 345 MeV/nucleon using 3 mm- and 2.2-mm-thick aluminum degraders at F1 and F5, respectively. The spectrometer is tuned for $^{132}$Sn with D1 $B\rho = 7.49$ Tm. The left and right panels show the results in the standard and new modes, respectively. In the standard mode, all isotopes accumulate in the center ($X = 0$) because of the subtraction of the separation power. In contrast, the isotope separation is improved in the new mode.

Note that the difference between the two modes is small for separation of isotones because they often collect at approximately the same position at F2. Altering the combination of energy and degrader thickness is required for isotone separation.

A machine study for the new ion-optical mode proposed here had been scheduled in November 2014, but was cancelled. We expect to perform this study in the next year.

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References

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