Ion-optical study of additive and subtractive modes of BigRIPS

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One of the important features of the in-flight fragment separator BigRIPS[1)] is a two-stage separation scheme. Rare-isotope (RI) beam is produced and separated in the first stage (F0-F2) with an energy-loss degrader at the momentum dispersive focus F1. Particle identification and momentum analysis are performed event-by-event in the second stage (F3-F7) with the momentum dispersive foci F4, F5, and F6.[1,2)] Another energy-loss degrader placed at F5 is often used to separate unwanted isotopes produced in the first degrader at F1 as a result of the charge state change or the secondary reaction.

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 added, the horizontal spatial distance at the final focus F7 would increase. Because widths also increase, improvement of the final resolving power will depend on the experimental condition.

The additive and subtractive modes can be switched by changing the sign of the magnification of a matching section F2-F3 in between the two stages. In a previous report,[3)] we have introduced a new ion-optical system for the additive mode. The F2-F3 magnification is reversed compared to the standard (subtractive) mode by adding one focus in the horizontal direction at the mid-point between F2 and F3. We performed machine studies to examine the two modes in this year.

In April 2015, we compared the additive and subtractive modes under the same conditions for the first and second stages. Only the matching section F2-F3 was changed. Isotopes around ^{132}Sn produced in a ^{238}U^{86+} + Be 5 mm reaction at 345 MeV/nucleon were used to measure the optical properties. 5-mm- and 3-mm-thick wedge-shaped aluminum degraders were placed at F1 and F5, respectively. Magnetic rigidity of the first dipole (D1) was 7.1 Tm and the other dipoles (D2-D6) were tuned so that the ^{132}Sn isotope came at the center at each focus.

Table 1 shows the measured mass dispersions at F2, F3, and F7 together with the LISE^{++} simulation. We can see that the mass dispersion became large at F7 in the additive mode as expected. However, there are some discrepancies in the additive mode between the measured and calculated values compared to those of the subtractive mode. These discrepancies may come from the discrepancies in the F2-F3 transfer matrix elements. For example, the measured and calculated magnifications were 0.78 and 1.01, respectively, while they agreed in a few % in the subtractive mode. The reason for the difference is under consideration. We also found that the telescopic condition was not fulfilled due to the very large $(a|x)$ value in the additive mode. The measured and calculated values were 1.89 and 2.14 mrad/mm, respectively. According to this $(a|x)$ term, isotopes that come off-center at F2 have large angles at F3 and the track reconstruction in the second stage would become worse. The transmission is also affected. The ^{132}Sn yield in the additive mode was about 30% less than that in the subtractive mode. Events with a large angle caused by the large $(a|x)$ term may be lost after F2. Reduction of the $(a|x)$ term is under consideration.

Table 1. Mass dispersion in mm/ΔA at F2, F3, and F7. See text for the RI beam setting in this measurement.

	subtractive		additive	
	measured	LISE^{++}	measured	LISE^{++}
F2	5.82	6.05	5.54	6.05
F3	-6.33	-6.41	4.72	6.11
F7	0.23	-0.71	12.1	18.5

Purities of the ^{132}Sn isotope are almost the same in both additive and subtractive modes, being 8% and 6% for the F1 slit at ±2 mm and ±64.2 mm, respectively, when the F2 and F7 slits are optimized for ^{132}Sn. The purities are dominated by the contamination from the same isotones, which occupy almost the same position at F2 in our case. The additive mode gives the same separation for such isotones as the subtractive mode. Therefore, the purities were not improved in the additive mode as we had expected. Altering the combination of energy and degrader thickness is required for isotone separation.

In November 2015, we performed another machine study for the two-stage separation. We applied the same conditions for the first stage as in April. Thickness of the aluminum degrader at F5 was changed (0 mm, 2 mm, 3 mm, and 5 mm) to investigate systematically the isotope separation in the subtractive mode. The measured mass dispersions at F7 varied from −7 to 11 mm/ΔA as a function of the F5 degrader thickness and were well reproduced with LISE^{++} simulations. Detailed analysis, including transmission, purity, and so on, is in progress.

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References
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