Q-value resolution improvements in the spectroscopy of deeply bound pionic atoms using BigRIPS

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In June 2014, we performed missing-mass spectroscopy on the deeply bound pionic atoms to measure their binding energies and widths.[1,2] The Q values of the ^{122,117}Sn(d,^{3}He) reactions were measured using BigRIPS near the π^- emission threshold. We succeeded in accumulating a sufficient number of events and achieved the best Q-value resolution in the spectroscopy of the Sn(d,^{3}He) reaction thus far. In this paper, we report how we achieved the resolution.

We improved two aspects. First, the emittance and momentum spread of the primary beam were reduced by optimizing accelerator parameters. Second, the optics of the beam-transfer line was adjusted to realize optimum dispersion matching. Here, the "beam-transfer line" indicates the beam line from the exit of SRC to the F0 focal plane in BigRIPS.

The emittance and momentum spread were monitored using the beam position and angle at the achromatic focal plane F3 and the dispersive focal plane F5 in BigRIPS. According to these measurements, the voltage and phase of the flat top cavity of SRC, the phase of the RF of RRC, and the voltage of the re-buncher were optimized. We also optimized the phase slit inside and the double slits downstream of the AVF cyclotron. After optimization, we achieved an emittance of 0.2 × 2.0 πmm·mrad (horizontal) and a momentum spread of 0.027% (σ), which are dramatic improvements from those achieved in the pilot experiment: an emittance of 0.7 × 3.0 πmm·mrad and momentum spread of 0.04% (σ).

To adjust the dispersion at F0, a new method was developed using position information at the F3 and F5 focal planes. In our experiment, we developed new ion optics with finite dispersion at F0 to realize the dispersion-matching condition.[3] However, there are no high-precision position/angle detectors in the beam-transfer line to tune the optics. In the new method, the momentum deviation of the particle and the position at F0 can be deduced through position measurements at F3 and F5 using the following equations:

$$x_0 = x_3/(x|x)_{03},$$
$$\delta = (x_5 - (x|x)_{35}x_3)/(x|\delta)_{35}.$$

Here, x_0, x_3, and x_5 are the positions at the F0, F3, and F5 focal planes in BigRIPS, respectively. $(x|x)_{03}$ and $(x|x)_{35}$ are the magnifications from F0 to F3 and from F3 to F5, respectively. $(x|\delta)$ represents dispersion. Because of achromatic transport from F0 to F3, $(x|\delta)_{03}$ is assumed to be 0. These transfer matrix elements of BigRIPS were measured in advance by setting the optics of the beam-transfer line to the standard mode, in which the F0 focal plane was achromatic. Figure 1 shows the 2D plot of the deduced δ and x_0. By using this method, we could measure and improve the new optics in the beam-transfer line.

As a result, we succeeded in improving the Q-value resolution. The peaks in the online spectrum of the present experiment were clearly narrower than those of similar past experiments. The precise analysis is in progress.

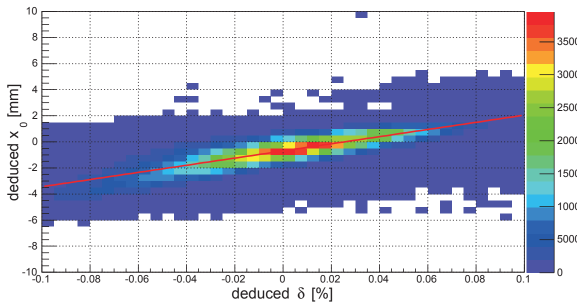

Fig. 1. Scatter plot of x_0 versus δ deduced from x_3 and x_5. The slope corresponds to the dispersion at F0.

References
1) K. Itahashi et al.: *RIBF Proposal* **No.054** (2008).
2) K. Itahashi et al.: *RIBF Proposal* **No.054R1** (2013).
3) T. Nishi et al.: Nucl. Instrum. Methods. in Phys. Res. B 317 290-293 (2013).

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