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Precision pionic-atom spectroscopy at RIKEN-RIBF: Test report on primary beam dispersion matching

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Abstract. We performed a test experiment at the RI beam factory (RIBF). In the test experimnt, a ^{14}N beam with an energy of 250 MeV/nucleon was used. We realized the dispersion matching between the beam transfer line and the BigRIPS spectrometer. The position resolution improved by a factor of two after the dispersion matching was applied. The resolving power of the BigRIPS was estimated to be 3860 (FWHM) from the obtained resolution which was 0.83 mm (FWHM). This resolving power corresponds to an experimental resolution of 190 keV (FWHM) for the emitted ^{3}He at 365 MeV from the (d,^{3}He) reaction in the deeply bound-pionic atom spectroscopy.

1. Introduction
We are planning to perform precision pionic-atom spectroscopy[1] at the RIKEN-RIBF. The objective of the experiment is to achieve the highest ever precision in the deeply bound-pionic-atom spectroscopy by exploiting the (d,^{3}He) reaction, and thus, to precisely determine the in-medium isovector interaction strength between the pion and the nucleus. By applying the dispersion matching technique[3] between the beam transfer line (from the SRC to the target) and the BigRIPS spectrometer[4] (from the target to the F5 focal plane), we expect to achieve an experimental resolution of 200 keV (FWHM) (see Table 1), with which it is possible to simultaneously observe both the 1s and 2s states of the pionic Sn atom; the 2s state was not observed in the previous pionic-atom spectroscopy performed at the GSI in 2001 (see Figure 1). In May 2009, we performed a test experiment to establish a method for realizing the dispersion matching and for measuring the resolution.

2. Test experiment
We used a ^{14}N beam with an energy of 250 MeV/nucleon; the beam was provided by the SRC. The beam energy was chosen such that the beam rigidity was identical to that of the deuteron beam for use in the pionic-atom spectroscopy. The beam positions and the directions in each focal plane were measured by using PPAC[5] detectors. The PPAC position resolution was estimated to be 1.5 mm (FWHM) on the basis of ray fitting of the incident beam. The beam emittance was measured to be 39π mm·mrad (FWHM) and 22π mm·mrad (FWHM) in the F3 achromatic focal plane in the horizontal and vertical directions, after subtracting the PPAC resolution.

The dispersion matching condition is described as

$$b_{16}s_{11} + b_{26}s_{12} + s_{16} = 0 \tag{1}$$

Table 1. Comparison of experimental conditions at GSI and the RIBF. The momentum spread of the deuteron beam at the RIBF is about three times wider than that at GSI. By applying the dispersion matching to minimize its effect, we will achieve about a factor of two better resolution of 200 keV (FWHM) compared to the previous (400 keV).

	GSI	RIBF
Intensity	10^{11} /s	10^{12} /s
Target	20 mg/cm^2	10 mg/cm^2
$\Delta p_d/p_d$	0.03%	0.1%
Resolution	400 keV	200 keV

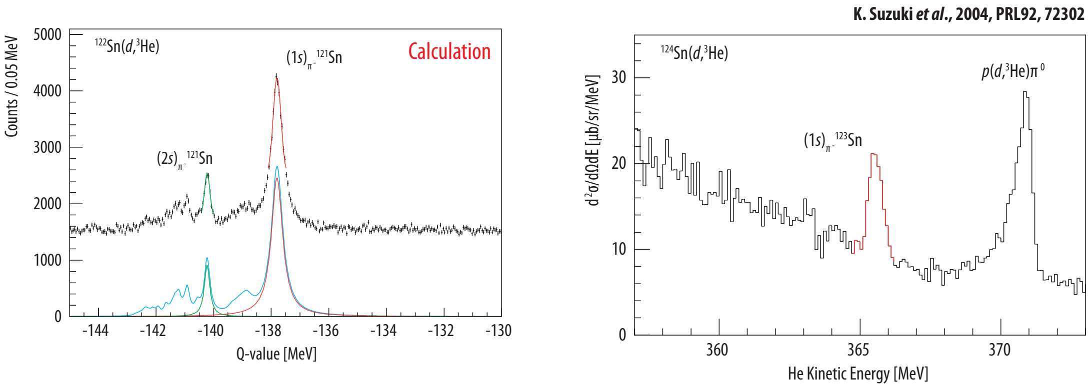

Figure 1. Left: A simulated spectrum of the deeply bound-pionic-atom spectroscopy at the RIBF. We can simultaneously observe both 1s and 2s states of the pionic Sn atom with the resolution of 200 keV (FWHM). Right: The deeply bound-pionic 1s state measured with the resolution of 400 keV (FWHM) at GSI in 2001[2]. A large skewed peak close to 371 MeV is the built-in calibration line from the $p(d,^3\text{He})\pi^0$ reaction.

where b_{ij} and s_{ij} denote R-matrix elements for the beam transfer line and the BigRIPS spectrometer (F0-F5), respectively (see Figure 2). The elements in the matching condition (1) were selected such that $b_{16} = 46$ mm/%, $b_{26} = 0.0$ mrad/%, $s_{11} = -0.69$, $s_{12} = 0.0$ mm/mrad, and $s_{16} = 32$ mm/%. We installed Al degraders in order to measure the dispersion values b_{16} and s_{16}. The measured dispersion values were consistent with the selected values.

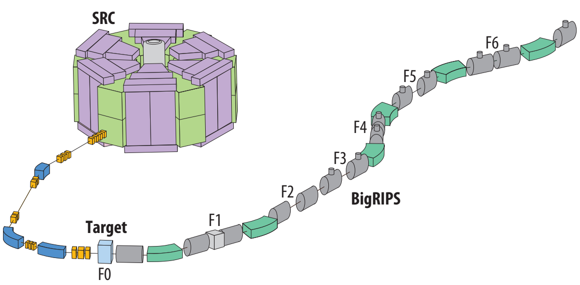

Figure 2. A schematic view of the RIKEN-RIBF. We applied the dispersion matching technique between the beam transfer line (from the SRC to the target) and the BigRIPS spectrometer (from the target to the F5 focal plane).

3. Results

Figure 3 shows the histograms of the horizontal position in the F5 focal plane before and after the dispersion matching was applied; the hatched and the unhatched histograms correspond to the position before and after the dispersion matching, respectively. The position resolution improved by a factor of two after the dispersion matching was applied. The obtained resolution was 0.83 mm (FWHM), after the PPAC resolution was subtracted. The resolving power of the BigRIPS was estimated to be 3860 (FWHM). The obtained resolving power yields an experimental resolution of 190 keV (FWHM) for the emitted ^{3}He at 365 MeV from the (d,^{3}He) reaction in the deeply bound-pionic-atom spectroscopy.

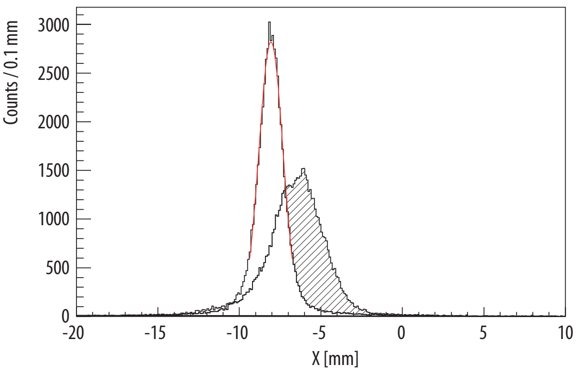

Figure 3. Histograms of the horizontal position in the F5 focal plane before and after the dispersion matching was applied; the hatched and the unhatched histograms correspond to the position before and after the dispersion matching, respectively.

4. Conclusion

We have obtained dispersion matching at the RIKEN-RIBF. The position resolution improved by a factor of two with the dispersion matching. The resolving power of the BigRIPS was estimated to be 3860 (FWHM). The obtained resolving power yields an experimental resolution of 190 keV (FWHM) for the emitted ^{3}He at 365 MeV from the (d, ^{3}He) reaction in the deeply bound-pionic-atom spectroscopy.

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