Energy calibration using the $p(d, {}^3\mathrm{He})\pi^0$ reaction in pionic atom spectroscopy at BigRIPS

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In June 2014, we performed a missing-mass spectroscopy experiment on the ${}^{122,117}\mathrm{Sn}(d,{}^3\mathrm{He})$ reaction to measure the binding energies and widths of deeply bound pionic states[1]. In the experiment, excitation spectra of ${}^{121,116}\mathrm{Sn}$ near the π^- emission threshold were obtained from the measurement of ${}^3\mathrm{He}$ momenta, which were magnetically analyzed using BigRIPS as a spectrometer. The momenta are determined from two types of information: the central momentum and its deviation. The former is calibrated using the two-body reaction $p(d, {}^3\mathrm{He})\pi^0$ with a polyethylene target. The latter is determined precisely by position measurements at a dispersive focal plane. In this report, the details of the calibration are explained.

To precisely calibrate the central momentum in BigRIPS, we performed Monte-Carlo simulations and compared them with experimentally obtained ${}^3\mathrm{He}$ momenta and reaction angles. In the simulation, momenta and angles were obtained using the following three steps.

(a) Emittance of the primary beam

The position, angle, and momentum spread of the primary deuteron beam were taken into account. The measured emittance was $0.2 \times 2.0\pi$ mm·mrad (horizontal/RMS) and 0.03% (RMS)[3]. The momentum spread is one of the main sources for the missing mass resolution.

(b) Two-body reaction at the target

The distribution of reaction angles of ${}^3\mathrm{He}$ from the $d(p, {}^3\mathrm{He})\pi^0$ reaction was taken from previous experimental data[2] where the energy in the center-of-mass frame was the same as in our experiment. The corresponding momenta are obtained from two-body kinematical calculation.

(c) Analysis with a transfer matrix

The momenta and reaction angles produced in steps (a) and (b) were converted to the positions and angles at the focal plane using an experimentally measured transfer matrix. In the conversion, the effects of multiple scattering inside the target and in a 50 μm-thick stainless steel window located upstream of the focal plane were also considered. The obtained positions and angles are converted to the momenta and reaction angles using the transfer matrix, as done for the experimental data. The obtained momentum deviations (represented as δ) and reaction angles in the simulation were compared with those in the experiment. The simulation result reproduces the experimental data well, as shown in Fig. 1. In the comparison, we calculated χ^2 between two 2D histograms and determined the central momentum of BigRIPS by minimizing the χ^2.

As a result, we succeeded in suppressing the contribution from the energy calibration on the missing mass precision within 10 keV, which is negligibly small compared with other contributions such as the ambiguity of the primary beam energy. Thus, we established the energy calibration method using the $d(p, {}^3\mathrm{He})\pi^0$ reaction, which will improve the determination accuracy of the binding energy of the pionic atoms. The analysis is ongoing.

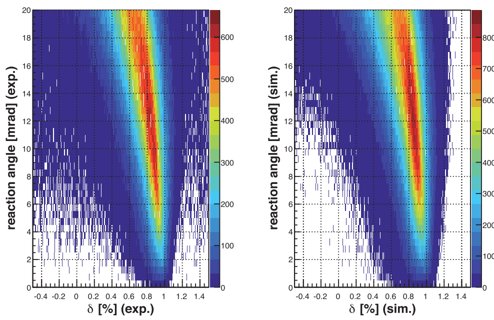

Fig. 1. δ - reaction angle plot from the $p(d, {}^3\mathrm{He})\pi^0$ reaction. (Left) Experimental data. (Right) Simulation result.

References

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