Measurement of deuteron beam polarization at RIKEN RIBF

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The polarized ion source[1)] constructed in the 1990s, was capable of generating polarized deuteron beams and was widely utilized for measuring various spin observables through spin-axis control. Recently, it has contributed to studies of three-nucleon forces via deuteron-proton scattering, with further advancements in these studies are anticipated.

Owing to prolonged operational interval and a water leakage incident in 2023, concerns have arisen regarding the potential degradation of the ion source's performance. This report presents measurements conducted to verify the refurbish of the polarized ion source. The deuteron beam was accelerated up to 7 MeV/nucleon, and detailed measurements were performed using the polarimetry of $^{12}\mathrm{C}(\vec{d},p)^{13}\mathrm{C}_{\mathrm{gnd.}}$ with a positive Q-value of +2.7 MeV. These measurements serve to demonstrate the recovery of the polarized ion source and support its full restoration.

The measurement was conducted in September 2024. Experimental conditions are summarized in Table 1. A polarized deuteron beam, accelerated by the AVF cyclotron to 7 MeV/nucleon, bombarded natural carbon target in a beamline polarimeter, newly installed at the C-22 course, located just downstream of the AVF cyclotron.

Scattered particles were detected by two sets of ΔE-E detectors, consisting of thin plastic scintillators ($22^W \times 35^H \times 0.5^t$ mm^3) and NaI(Tl) scintillators ($31^W \times 31^H \times 58^t$ mm^3), positioned symmetrically on each side of the beam axis at a laboratory angle of 60 degrees. Angular acceptance was defined by a collimator positioned in front of the ΔE-E detector, located 90 mm from the target, featuring a circular aperture with a diameter of 6.3 mm. Data were collected using both polarized and unpolarized deuteron beams referenced against the theoretical maximum polarization values as $(p_y, p_{yy}) = (0,0)$, $\left(+\frac{1}{3},-1\right)$, $\left(-\frac{2}{3},0\right)$, and $\left(+\frac{1}{3},+1\right)$. Here, the y-direction is defined as $\hat{\boldsymbol{y}} = \boldsymbol{k}_i \times \boldsymbol{k}_f$, where $\boldsymbol{k}_i$ and $\boldsymbol{k}_f$ represent momenta of incident and scattered particle, respectively. Those four modes were changed cyclically at intervals of 5 s by switching the RF transition units of the PIS.

Figure 1 shows two-dimensional plots of the detectors' light outputs, with labels 1, 2, and 3 corresponding to the $^{12}\mathrm{C}(\vec{d},p)^{13}\mathrm{C}_{\mathrm{gnd.}}$, $^{12}\mathrm{C}(\vec{d},p)^{13}\mathrm{C}^*$(3.089, 3.684, 3.854 MeV), and $\vec{d}$+^{12}C elastic scattering, respectively. The polarizations were extracted by analyzing the yield asymmetries of $^{12}\mathrm{C}(\vec{d},p)^{13}\mathrm{C}_{\mathrm{gnd.}}$, as summarized in Table 2. The obtained values for modes#1 and #2 ranged from 70–80% of the theoretical maximum values, aligning with results from the previous experiments.[2)] The polarization of mode#3 was suboptimal, and optimized parameterization will take place during the measurement in spring 2025.

From these obtained results, we conclude that the PIS is successfully recovered.

Table 1. Experimental conditions.

Beam	pol.-d
Energy	7 MeV/nucleon
Intensity	∼20 particle nA
Polarimetry reaction	$^{12}\mathrm{C}(\vec{d},p)^{13}\mathrm{C}_{\mathrm{gnd.}}$
Target	$^{\mathrm{nat}}\mathrm{C}$, 0.5 mg/cm^2
Detector	ΔE(Plastic, 0.5 mm)-E(NaI(Tl), 58 mm)
Measured angle $\theta_{\mathrm{lab.}}$	60 deg.
Angular acceptance	$\Delta\theta$: ±2.0 deg., $\Delta\phi$: ±2.0 deg.

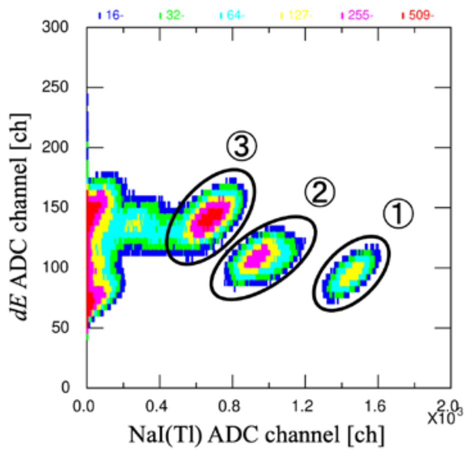

Fig. 1. Two-dimensional plots of light outputs from the ΔE-E detectors. The horizontal and vertical axes represent energy information on E and ΔE detector, respectively.

Table 2. Deuteron beam polarization on each mode.

mode#1	mode#2	mode#3
$(p_y,p_{yy}) = \left(+\frac{1}{3},-1\right)$	$(p_y,p_{yy}) = \left(-\frac{2}{3},0\right)$	$(p_y,p_{yy}) = \left(+\frac{1}{3},+1\right)$
$p_y = 0.222 \pm 0.011$	$p_y = -0.556 \pm 0.013$	$p_y = 0.260 \pm 0.014$
$p_{yy} = -0.741 \pm 0.039$	$p_{yy} = 0.021 \pm 0.048$	$p_{yy} = 0.565 \pm 0.052$

References
1) H. Okamura *et al.*, AIP Conf. Proc. **293**, 84 (1994).
2) K. Sekiguchi *et al.*, Phys. Rev. C **65**, 034003 (2002).

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