Study of spin-isospin response of $^{11}$Li and $^{14}$Be drip line nuclei with PANDORA

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The spin-isospin responses of $^{11}$Li and $^{14}$Be neutron drip line nuclei were measured in charge-exchange ($pn$) reactions. Until recently, only the spin-isospin collectivity in stable isotopes was investigated [1]. There is no available data for nuclei with large isospin asymmetry factors, where $(N - Z)/A > 0.25$. The ($pn$, n) reactions at intermediate beam energies ($E/A > 100$ MeV) and small scattering angles can excite Gamow-Teller (GT) states up to high excitation energies in the final nucleus, without Q-value limitation [2–4]. The combined setup of PANDORA neutron detector [5] and SAMURAI spectrometer [6] with a thick liquid hydrogen target (LHT) allowed us to perform the experiment with high luminosity. In this setup [7], PANDORA was used for the detection of the low-energy recoil neutrons while SAMURAI was used to tag the decay channel of the reaction residues.

A secondary cocktail beam of unstable $^{11}$Li and $^{14}$Be was produced via the fragmentation reaction of a 230 MeV/u $^{18}$O primary beam on a 14-mm-thick $^9$Be target. In the experimental setup around the SAMURAI spectrometer, two 1-mm-thick plastic scintillators (SBT1,2) were installed for the detection of beam particles. Figure 1 shows the overview of the experimental setup.

Figure 1. Recoil neutron energy spectrum as a function of scattering angle in the laboratory frame.

The SBTs were used to produce the beam trigger (threshold was set to $Z \geq 2$). The beam PID was performed on an event-by-event basis by measuring the energy loss in SBTs and the ToF of the beam particles in BigRIPS between F7 and F13. The secondary cocktail beam consisted of $^{11}$Li at 182 MeV/u with intensity of $2.5 \times 10^7$ particle/s and $^{14}$Be at 198 MeV/u with intensity of $1 \times 10^7$ particle/s with purity of 48% and 19%, respectively. The triton contamination was below 30%. The neutron detector setup on the left and right sides of LHT consisted of 27 PANDORA and 13 WINDS [8] plastic scintillator bars. The neutron kinetic energies were deduced by the time-of-flight (ToF) technique. PANDORA was optimized to detect neutrons with a kinetic energy of 0.1–5 MeV by measuring the related ToF in the range of 50–300 ns on 1.25 m flight path. The ToF time reference was taken from SBTs. The left and right wings with respect to the beam line covered the laboratory recoil angular region of $47^\circ$–$113^\circ$ and $62^\circ$–$134^\circ$, respectively, with 3.25$^\circ$ steps. The light output threshold was set to be 60 keV$_{ee}$.

The reaction residues entered into SAMURAI after passing through the forward drift chamber, FDC0. The magnetic field of the spectrometer was set to 2.75 T. At the focal plane of SAMURAI, a wall (HODF24 detector) of 24 plastic scintillator bars with dimensions of $100W \times 100H \times 10D$ mm$^3$ was installed, to measure the trajectories, energy loss, and ToF (from SBTs) of the reaction residues. Further downstream, an additional wall, HODP, with 16 plastic bars (same as HODF24 bars) was installed. Those 2 bars of HODF24 which were hit by the unreacted beam were excluded from trigger. Figure 2 shows a typical PID spectrum detected in HODF24 for events generated by the $^{11}$Li or $^{14}$Be beams. The reaction products and decay particles can be clearly identified. NEBULA was used to detect the fast decay neutrons of the reaction products (decays by $1n$ and $2n$ emissions).

Figure 2. A PID spectrum in the focal plane of SAMURAI spectrometer, measured by one bar (bar ID=7) of HODF24.
The digital data-acquisition (DAQ) of PANDORA [9] was combined with standard DAQ of SAMURAI. Data from PANDORA bars (each with a signal from both ends) were read out with duplicated readout; CAEN V1730 modules were used for charge and pulse shape discrimination information while an analog circuit (discriminators and CAEN V1290 TDC modules) was used for timing and triggering.

For the digital DAQ we daisy chained six CAEN V1730B and one CAEN V1730D waveform digitizers using an optical connection. The unpublished software of digiTES, based on Digital Pulse Processing for the Pulse Shape Discrimination (DPP-PSD) firmware [10] was used to manage different modules in the daisy chain condition and control the digitizers. A LUPO (Logic Unit for Programmable Operation) module [11] was used to generate a 62.5 MHz signal to synchronize timestamps of the seven modules, as well as to share clock with another LUPO in the DAQ system. The acquisition in the digitizers was not based on the self-triggering of each channel. The local triggering option of the two-two coupled channels, in V1730 two neighboring channels are paired, was used to ensure the coincidence between the top and bottom photomultiplier of PANDORA. The digitizers were configured so that the validation of the local triggers came from an external trigger based on the costumer configured software criteria. In order to manage the coincidence requirements between the two separate acquisition systems, the first channel (ch 0) of each digitizer was dedicated to a logic signal. This external trigger was validating the PANDORA self-triggers in an about 1-µs-wide time window.

The neutron-gamma discrimination of PANDORA is based on comparison of integrated charges measured over two different time regions of the input signal. The PSD parameter is defined as

$$\text{PSD} = \frac{Q_{\text{Long}} - Q_{\text{Short}}}{Q_{\text{Long}}},$$

where $Q_{\text{Long}}$ and $Q_{\text{Short}}$ are the charges integrated in long (width = 450 ns) and short (width = 42 ns) gates, respectively. The arithmetic mean of two single-end readouts of each PANDORA bar ($PSD_{\text{bottom}}$ and $PSD_{\text{top}}$) was defined as, $PSD_{\text{mean}}$ [5], an additional parameter to the ToF for each event. The combination of the measured neutron ToF with the new PSD parameter improved the discrimination of neutron- and gamma-like events Figure 3 shows the two-dimensional plot of $PSD_{\text{mean}}$ vs. total light output of a PANDORA bar for events associated with $^9\text{Li}$ beam. Clear separation of neutron-like events even at the low-light output region is observed.

Figure 4 shows the plot of kinetic energy as a function of laboratory scattering angle in the laboratory frame.

The $^9\text{Li} + d$ decay channel of $^{11}\text{Be}$ is observed for the first time. Reconstruction of the excitation-energy spectrum up to about 30 MeV, including the GT giant resonance region, is ongoing.

References