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Neutron decay of the Giant Pairing Vibration in ^{15}C

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Abstract. The neutron decay of the resonant states of light neutron-rich nuclei is an important and poorly explored property, useful to extract valuable nuclear structure information. The neutron decay of the ^{15}C resonances populated via the two-neutron transfer reaction ^{13}C(^{18}O,^{16}O n) at 84 MeV incident energy is studied using an innovative technique which couples the MAGNEX magnetic spectrometer and the EDEN neutron detector array. The data show that the recently observed ^{15}C Giant Pairing Vibration at 13.7 MeV mainly decays via two-neutron emission.

1. Introduction

The study of the decay modes of nuclear states populated in direct reactions is a powerful tool for understanding their microscopic structure. When the reaction populates unbound or weakly bound neutron-rich nuclei, the decay via neutron emission can be the dominant decay mode of the ground and excited states. In these cases the detection in coincidence of neutrons and charged ejectiles emitted in the reaction and the high-resolution measurement of the neutron energy are crucial tasks for spectroscopic investigations of the residual nuclei populated in the reaction.

The advent of large acceptance magnetic spectrometers has allowed a deeper exploration of stable and unstable nuclei up to high excitation energy with considerable resolution and good statistical significance, leading to the observation of new resonances in the unknown continuum. Examples are the Giant Pairing Vibrations (GPV), which are collective motion in the particle-particle space excited via two-neutron transfer reactions [1]. Signatures of such resonances in light nuclei have been recently shown and discussed in Refs. [2], [3], [4].

The neutron decay of the ^{15}C resonances up to 16 MeV excitation energy, populated via the ^{13}C(^{18}O,^{16}O n) reaction at 84 MeV incident energy has been studied in ref. [5]. In that paper, a new method to

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determine the neutron kinetic energy by time-of-flight (TOF) in exclusive experiments was presented. It involves the use of the MAGNEX magnetic spectrometer and the EDEN neutron detector array. A schematic view of the used facility is shown in Figure 1.

2. The experimental apparatus and the data reduction

The MAGNEX spectrometer consists of two magnetic elements: a large aperture quadrupole and a large bending magnet. It is characterized by large acceptance both in angle (solid angle $\Delta\Omega = 50$ msr) and momentum (relative momentum with respect to the central trajectory $\Delta p = -14\%, +10\%$). The features and performances of MAGNEX are described in Refs. [6], [7], [9], [10], [11]. The high-order aberrations originated by the large acceptance are calculated and corrected by means of a software ray-reconstruction described in Ref. [12]. The reaction ejectiles, momentum-analyzed by MAGNEX, are detected by the Focal Plane Detector (FPD). A detailed description of the MAGNEX FPD is reported in Ref. [13].

EDEN is an array of 36 cylindrical organic scintillators (NE213) by IPN-Orsay located around the MAGNEX scattering chamber. In the experiment, they were positioned at a distance ranging from 1.8 to 2.4 m from the target, covering a total solid angle of 270 msr. A detailed description of the detectors is given in Ref. [14]. The neutron-gamma discrimination is provided by pulse-shape analysis of the fast and slow components of the scintillation signal [15]. A timing signal is also an output of the module for each EDEN channel.

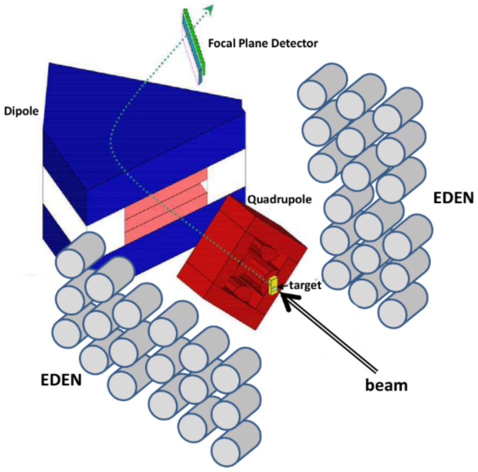

Figure 1. Schematic layout of the MAGNEX-EDEN coupling.

The experiment was performed at INFN-Laboratori Nazionali del Sud using a $^{18}O^{6+}$ beam delivered by the Tandem Van der Graff accelerator at 84 MeV incident energy impinging on a 50 µg/cm2 99% enriched ^{13}C target. The ^{16}O reaction ejectiles were momentum analyzed by MAGNEX. The angular range explored by MAGNEX was $3° < \theta_{lab} < 14°$ in the laboratory. The ejectiles were identified at the FPD as described in Ref. [16] and their momentum reconstructed by the ray-reconstruction technique [12]. The excitation energy spectra of the reaction products were obtained by the missing mass method $E_x = Q_0 - Q$ (where Q_0 is the ground to ground state reaction Q-value).

For each ion reaching the FPD, also the path length along the spectrometer was reconstructed event by event and consequently its time of flight TOF_{ion} extracted. In the TOF technique used, the start signal is given by the detection of the ejectiles at the focal plane of MAGNEX. The stop signal was provided by the EDEN time signal. In more details, the EDEN timing signal is sent to a high-stability delay line which introduces a delay of $\Delta T_{delay} = 400$ ns and then to the stop input of a Time to Digital Converter (TDC). The common start to the TDC is given by the logic OR of the timing signals of the MAGNEX silicon detectors. Thus, once the time-of-flight of the charged ejectiles along the spectrometer is known

(TOF_{ion}) by ray-reconstruction, the time-of-flight of the neutrons from the target point to the EDEN detector (TOF_{EDEN}) can be deduced by the relation:

$$TOF_{EDEN} = TOF_{ion} + T_{TDC} - \Delta T_{delay}$$

Then, the knowledge of the distances and angles of the EDEN array with respect to the target allows to determine the kinetic energy of the neutrons by relativistic relations and energy E_n in the reference frame of the decaying nucleus.

3. Study of the ^{15}C resonances

An example of the excitation energy spectrum (E_x) of ^{15}C measured by MAGNEX is shown in Fig. 2. Several narrow peaks corresponding to known low-lying bound and resonant states of ^{15}C are observed. Among them, the resonance at E_x = 13.7 MeV was associated to the Giant Pairing Vibration in Ref. [15].

Above the one-neutron separation energy of ^{15}C, S_n = 1.218 MeV, the neutron decay of the observed resonances was studied gating on the different peaks of the ^{15}C excitation energy spectrum (E_x) and plotting the correspondent neutron energy spectra (E_n). The background neutron spectra are subtracted as described in Ref. [5].

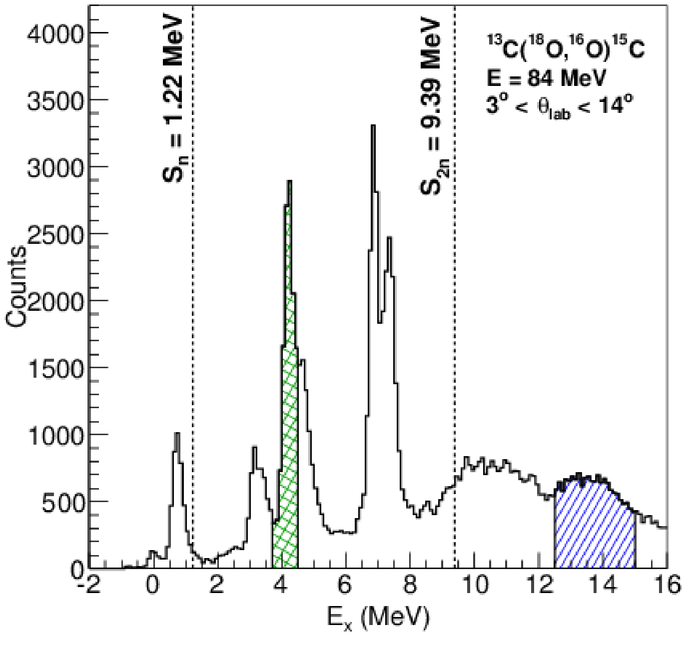

Fig. 2 ^{15}C Excitation energy spectrum for the ^{13}C(^{18}O,^{16}O) reaction at 84 MeV incident energy and 3° < θ_{lab} < 14°. The color filled areas are the two regions selected for the study of the neutron decay spectra in this paper.

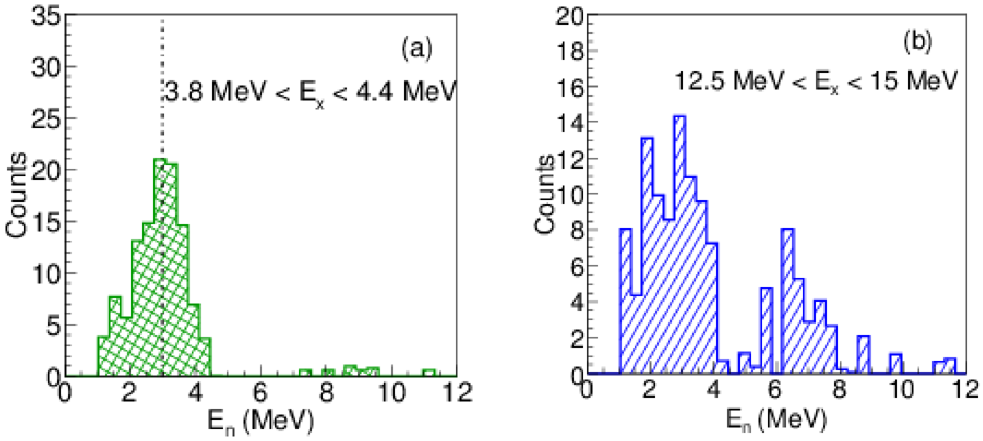

Fig. 3 Neutron energy spectrum gated on the ^{15}C excitation energy regions (a) 3.8 MeV $< E_x <$ 4.4 MeV and (b) 12.5 MeV $< E_x <$ 15 MeV.

Let us consider for example the ^{15}C excited state at E_x = 4.220 MeV. The neutron energies obtained by gating the excitation energy spectrum in the region 3.8 MeV $< E_x <$ 4.4 MeV is shown in Fig. 3(a). A structure in the neutron spectrum at around 3 MeV is well visible. Such an energy corresponds, within the uncertainty, to the energy of the neutrons decaying from the ^{15}C excited state at E_x = 4.220 MeV to the ^{14}C ground state, which is $E_n = E_x - S_n$ = 3 MeV. Similar spectra are obtained gating on the other states below S_n [5]. These results demonstrate that the investigated states in the continuum of ^{15}C mainly decay to the ^{14}C ground state.
The resonance in the ^{15}C spectrum at E_x = 13.7 MeV was associated to the Giant Pairing Vibration in Ref. [15]. Its decay to the ^{14}C ground state and the consequent emission of neutrons of energy distributed around $E_n = E_x – S_n$ = 13.7 - 1.22 = 12.5 MeV is ruled out by the measured neutron spectrum (see figure 3(b)). The most intense neutron distribution in coincidence with the GPV peak of ^{15}C can be explained by the decay to the ^{13}C ground state via a two-neutron emission. In this case, neutron energies ranging from zero to $E_n = E_x – S_{2n}$ = 4.3 MeV are expected and, in fact, observed. The simultaneous measurement of two-neutron coincidences is prevented by the low yields in the present experiment. However a dedicated experiment is foreseen as the next step of our research program.

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