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Investigating the structure of ^{11}B using particle-γ coincidences

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ABSTRACT

The structure of ^{11}B was investigated at Legnaro National Laboratories of INFN using the ^{6}Li(^{6}Li,pγ) fusion-evaporation reaction. Emitted protons feeding excited states of ^{11}B were detected by the GALTRACE silicon telescopes in coincidence with γ rays measured by the GALILEO HPGe array. The level and γ-decay scheme of ^{11}B was reconstructed on an even-by-event basis by combining particle and γ-ray spectroscopy techniques. In particular, the γ decay from the possible near-threshold proton resonance was searched for, providing first results on its γ-ray branch with a 5σ and 3σ confidence level. Results are discussed along with predictions of the Shell Model Embedded in the Continuum (SMEC).

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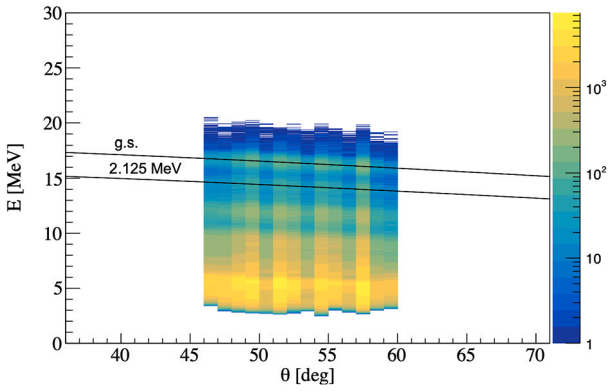

Fig. 1. Kinetic energy as a function of proton emission angles as measured in the present experiment. The expected kinematic lines for the ground state and the first excited state of ^{11}B are also shown. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

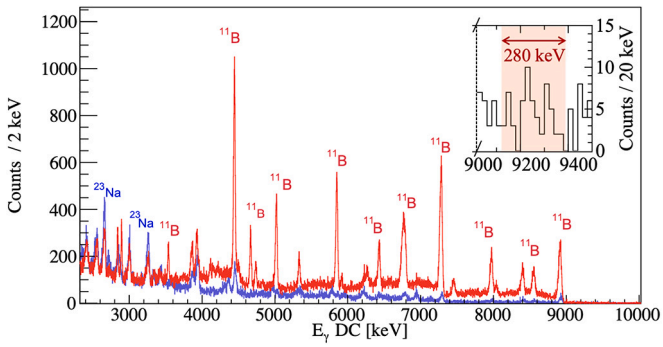

Fig. 2. Doppler corrected γ-ray spectrum measured in coincidence with protons stopped in the ΔE layer (blue) and punching through it (red) (see text for details). (Inset) Zoom on the region of interest of the γ-decay of the near-threshold resonance.

1. Introduction

Narrow near-threshold resonances located above particle-separation energies play a key role in understanding the structure and dynamics of light nuclei [1–9], such as the onset of collectivization and clusterization phenomena, the coupling between bound and scattering states in the continuum [10] and their impact in the abundance of elements in the Universe [11]. In ^{11}B, a near-threshold proton resonance was postulated based on the possible observation of the β^--delayed proton emission process in the ^{11}Be nucleus [12–14], yet with contradictory results. In this context, a recent experiment poses extra doubts on the originally-proposed β^--delayed proton emission branch [15]. If existing, such a resonance should have a dominant (^{10}Be ⊗ p) core-proton coupled configuration and can only be located within 280 keV above the proton separation energy of ^{11}B at $S_p = 11.229$ MeV. Its observation was claimed in two independent experiments [16,17] but not observed in a more recent experiment reported in Ref. [18]. Theoretical calculations, such as the Shell Model Embedded in the Continuum (SMEC) [10,19,20], predict a $1/2^+$ near-threshold state located 142 keV above the proton separation energy [19], with an E1 γ-ray branching to the $1/2^-_1$ state at 2125 keV of $0.98^{+167}_{-69}\times10^{-3}$ with respect to the particle-decay modes [20]. In this work, for the first time, the γ decay of the possible near-threshold proton resonance was searched for [21].

2. Experiment and results

Ground and excited states of ^{11}B were populated at Laboratori Nazionali di Legnaro of INFN using a fusion-evaporation reaction induced by a 7-MeV ^{6}Li beam impinging on a ^{6}LiF target 0.5-mg/cm^2 thick. The channel of interest was selected by detecting the emitted protons from the ^{12}C compound nucleus with 3 silicon detectors from the TRACE project [22]. They are pixel-type silicon layers mounted in a ΔE-E telescopic configuration, covering an angular range between 47° and 59°. Charged particles hitting the detectors were identified either using the ΔE - E method or Pulse Shape Analysis techniques for low-energy particles stopped in the first silicon layer [23,24]. The reaction kinematics of ^{11}B was reconstructed by correlating the kinetic energy and the emission angles of identified protons, as shown in Fig. 1. In the picture, the expected kinematic lines for the ground state and the first excited state at 2.125 MeV of ^{11}B are also displayed.

Protons were measured in coincidence with γ rays by the GALILEO array [25], consisting of 10 HPGe triple-cluster detectors at backward angles and 20 single, coaxial HPGe crystals at forward angles, all equipped with BGO anti-Compton shields. The Doppler-corrected, γ-ray spectrum is shown in Fig. 2 for protons stopped in ΔE layer (blue) and those reaching the second layer (red). Peaks

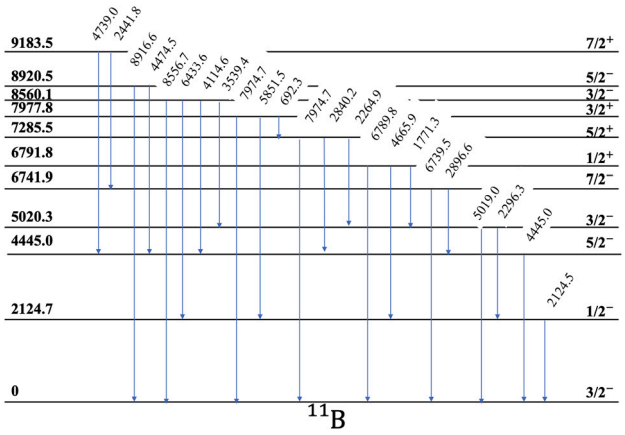

Fig. 3. Level and γ-decay scheme of ^{11}B as measured in this work.

belonging to ^{11}B are labeled accordingly, as well as those coming from ^{23}Na produced in the fusion of the beam with ^{19}F nuclei present in the target material. The levels and γ-decay scheme of ^{11}B was reconstructed by using γ-γ coincidences and was found to be consistent with the literature [26], as presented in Fig. 3.

The γ decay of the possible near-threshold state in ^{11}B was searched for by inspecting the 280-keV wide, 9100-9380 keV energy range. No evidence of a clear γ-ray peak was found in the region of interest (see inset of Fig. 2), hence a statistical analysis was performed to seek a significant excess of counts over the background by using a moving window [27], as described in detail in Ref. [21]. A global confidence level of 5σ was imposed, corresponding to a local confidence level of 5.4σ for each sampling window, yet no significant excess of counts was found. Therefore, an upper limit for the γ-ray decay was established with respect to the measured number of counts in the 8917-keV γ-ray peak, assuming the same population cross section for the hypothetical resonance. On average, an upper limit of 2.37×10^{-3} was found for the γ decay from the near-threshold proton resonance region to the $1/2^-_1$ state in ^{11}B. However, by lowering the global significance down to 3σ, corresponding to a local confidence level of 3.6σ, a significant excess of counts was observed for $E_\gamma = 9300(20)$ keV, corresponding to an excitation energy $E_{res} = 11429(20)$ keV. This result is consistent with $E_{res} = 11440(40)$ keV and $E_{res} = 11400(20)$ keV, reported in Refs. [16,17]. Therefore, assuming a 3σ global significance, the measured γ-ray branching to the $1/2^-_1$ state is then $BR_\gamma = 1.12(35)\times10^{-3}$. This result is compared with SMEC calculations [19,20], where, for $1/2^+$ spin-parity states, couplings to the $[^{10}\mathrm{Be}(0^+) \otimes \pi(s_{1/2})]$ and the $[^{10}\mathrm{B}(3^+) \otimes n(d_{5/2})]$ channels were considered. A near-threshold state at 142 keV above the proton separation energy was predicted, corresponding to a resonance energy of 11371 keV with a wave function dominated by the (^{10}Be $\otimes$ p) core-proton coupled configuration. The calculated γ-ray branching of $0.98^{+167}_{-69}\times10^{-3}$ with respect to the particle-decay modes agrees well with our result for a global 3σ confidence level.

3. Conclusions and perspectives

In conclusion, an experiment was carried out at Legnaro National Laboratories of INFN to investigate the structure of ^{11}B using the ^{6}Li(^{6}Li,pγ) reactions and particle-γ coincidence techniques by coupling the TRACE silicon detectors and the HPGe GALILEO array. The level and γ decay scheme of ^{11}B was obtained using γ-γ coincidences after reconstructing the kinematics of the reaction. A first result for the γ decay of the near-threshold proton resonance was obtained, which agrees well with SMEC predictions. In the near future, a new experiment with the state-of-the-art AGATA tracking array [28] and an upgraded particle detection setup is being planned, with the aim of increasing the experimental sensitivity by a factor of ≈10. This improved experimental condition should allow us to reach more firm conclusions on the γ decay from the near-threshold resonance state in ^{11}B.

CRediT authorship contribution statement

S. Bottoni: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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