

Angular Distribution and Cross Section Measurement of the ${}^6\text{Li}({}^3\text{He},n){}^8\text{B}$ Reaction at 5.8 MeV

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Abstract. The reaction ${}^6\text{Li}({}^3\text{He},n){}^8\text{B}$ was studied at Laboratori Nazionali di Legnaro in the framework of the EUROnu Design Study for a Beta Beam facility at CERN. The ${}^8\text{B}$ production cross section was determined through neutron angular distribution by using the time-of-flight technique. Thanks to the high statistics achieved, the neutron angular distribution for the population of the ${}^8\text{B}$ first excited state has been measured for the first time. Discrepancies with other available data sets for ${}^8\text{B}$ ground state population are discussed and interpreted in the framework of DWBA calculations. Further measurements at beam energies above 10 MeV are needed to clarify the behaviour of the angular distribution.

1 Introduction

The precise knowledge of cross section and angular distribution of different nuclear reactions is a key issue for the estimates of beam production rates and transmission of new facilities for radioactive ion beams. One example is given by the design of a Beta Beam facility at CERN for the study of neutrino oscillations in the contest of the EUROnu Design Study [1]. A Beta Beam facility produces a pure electron neutrino beam with no contamination of other neutrino types. The facility accelerates beta active isotopes to high energies and accumulates them in a storage ring where they decay and generate pure electron neutrinos. The challenges of the facility design are related to the production of radioactive isotopes, with suitable decay times and Q-values, in a sufficiently high quantity to produce the required neutrino flux. Within this context, the possibility of synthesizing in a small production and accumulation ring the ${}^8\text{B}$ and ${}^8\text{Li}$ isotope pair, that decays β^+ and β^- respectively, with high Q-value was studied within the EUROnu BETABEAM working package. The two reactions ${}^6\text{Li}({}^3\text{He},n){}^8\text{B}$ and ${}^7\text{Li}({}^2\text{H},p){}^8\text{Li}$ in reverse kinematics have been proposed in 2006 by Rubbia et al. [2]. In the original idea of the paper an internal gas target would serve as a stripper and an absorber for

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ionization cooling of the circulating beam. In a later paper by David Neuffer [3] the advantage of using a direct kinematics was also discussed. The total cross section of the ${}^6\text{Li}({}^3\text{He},n){}^8\text{B}$ reaction was measured in the past using the positron decay technique [4,5]. On the other hand, the only available neutron angular distribution measurement [6] reported a larger value for the integrated cross section by about a factor 3. Moreover, the experimental uncertainties of these existing works are quite large going up to the 30% relative error. More accurate measurements are therefore needed, to shed light on the large discrepancies evidenced in the available experimental data.

2 Experimental set-up and data analysis

The experiment was performed at the CN 7 MV Van De Graaf accelerator of the Laboratori Nazionali di Legnaro. The ${}^6\text{Li}({}^3\text{He},n){}^8\text{B}$ reaction was studied using a 6.1 MeV pulsed ${}^3\text{He}$ beam onto a LiF 500 $\mu\text{g}/\text{cm}^2$ thick target housed in a thin walled spherical scattering chamber. The LiF target was 95% enriched in ${}^6\text{Li}$ and evaporated on a 500 $\mu\text{g}/\text{cm}^2$ thick Au backing. To minimize Li evaporation the target was cooled during the experiment and the gold backing was mounted towards the beam. The resulting beam energy after passing the Au at the middle of the LiF target was 5.8 MeV. The emitted neutrons were identified with the time-of-flight technique by using 8 large volume (5''x 5'') cylindrical BC501 liquid scintillation detectors of the RIPEN modular array [7]. The detectors were placed at a distance of 2 m from the target spanning an angular range from 15 to 140 degrees. The time reference signal for neutron Time of Flight (TOF) was given by the passage of the beam through a capacitive pick-up at the entrance of the chamber. A collimated $\Delta E(15 \mu\text{m})\text{-}E(200 \mu\text{m})$ Silicon Telescope was placed inside the scattering chamber at 150 degrees and at the distance of 56.5 mm from the target for absolute cross section normalization through the measurement of the elastically backscattered ${}^3\text{He}$ beam particles on Au.

A custom data acquisition code was used to handle commercial VME digitizers (12 bit, 250 Ms/s). Moreover, a dedicated off-line analysis code, based on the ROOT package, was developed. This tool performs the pulse shape processing of the raw data, the events reconstruction and provides a graphical user interface also for the on-line monitoring.

Neutrons and background gamma rays were discriminated through, the Zero-Crossing method [8], based on the different pulse shape of the signals related to a neutron or a gamma interaction in liquid scintillators. A neutron detection threshold of about 150 keVee was achieved. This threshold corresponds to a minimum neutron energy of about 0.5 MeV. The detection threshold determine the efficiency of the BC501 detectors that can be calculated by a Monte Carlo code as reported in ref. [7].

In Fig. 1 the neutron Time-of-Flight spectrum at 15 degrees is shown after the proper neutron signal selection with the Zero-Crossing Method. Three main peaks are evidenced in the spectrum. Two of them are attributed to the population of the ${}^8\text{B}$ in its ground and first-excited [9] states. The third one is related to the neutrons from the reaction ${}^{12}\text{C}({}^3\text{He},n){}^{14}\text{O}$ due to the Carbon build-up on the target. These peaks rise above an overall continuum due to the three-body reaction ${}^6\text{Li}({}^3\text{He},np){}^7\text{Be}$. Continuum and uncorrelated background have been subtracted by using the Sensitive Nonlinear Iterative Peak clipping algorithm developed within the ROOT software. After this subtraction the ${}^8\text{B}$ peaks are well separated from the spurious contribution from target contamination; also the small contribution from ${}^9\text{B}$ [10] populated in the reaction of the beam with the 5% of ${}^7\text{Li}$ present in the target is visible. The correct identification of these contamination peaks has been confirmed by direct measurements on ${}^{12}\text{C}$ and ${}^7\text{LiF}$ targets. Two-body kinematics calculations provided the final check for the correct identifications of the ${}^8\text{B}$ peaks at all angles. From the area under the peaks of interest one can calculate the differential cross section at the considered angles after correction for the detection efficiency and normalization to the Rutherford scattering on the Au backing.

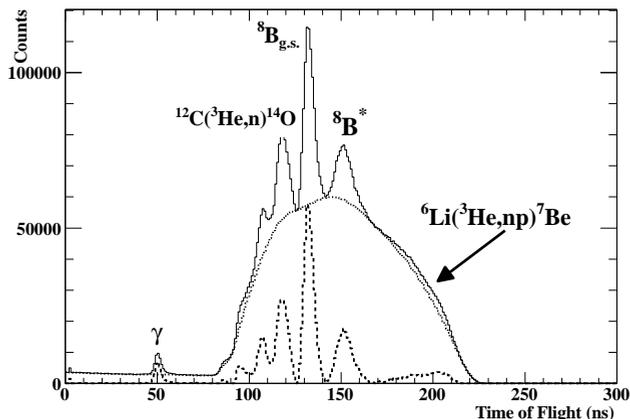


Figure 1. Neutron time-of-flight spectrum at 15 degrees in the laboratory reference frame from the reaction ${}^6\text{Li}({}^3\text{He},n){}^8\text{B}$ at 5.8 MeV.

3 Results and Discussion

The measured neutron angular distribution in the Center of Mass frame is shown in Fig. 2 for both ground and first-excited state ${}^8\text{B}$ population. The main error source comes from the target thickness. Other uncertainties come from BC501 detection efficiency and from solid angle subtended by the detectors. The overall uncertainties are about 10%. We stress the fact that, in the present experiment, the angular distribution for the population of the first excited state of ${}^8\text{B}$ has been measured for the first time with high statistics. In Fig. 2 our data are compared with the results from the work of ref. [6] at the slightly lower bombarding energy of 5.6 MeV showing a very nice agreement.

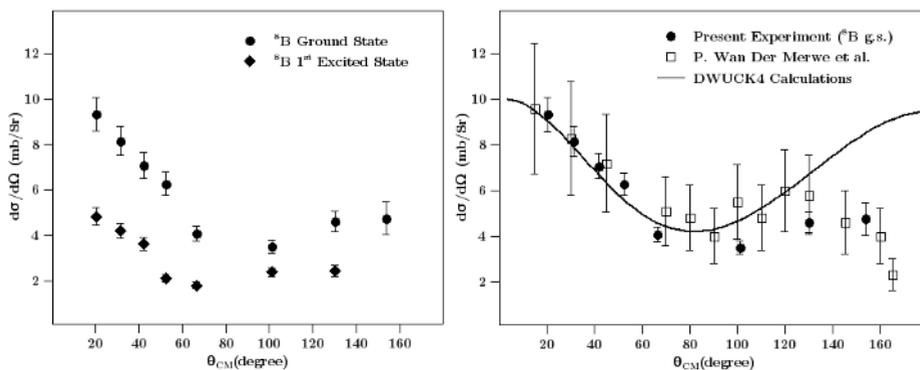


Figure 2. Left: Measured Neutron angular distribution in the center of mass frame of the ${}^6\text{Li}({}^3\text{He},n){}^8\text{B}$ reaction. Right: The present results for the ${}^8\text{B}$ ground state are compared with the data of ref. [6] and with DWBA calculations with the code DWUCK4.

Preliminary theoretical calculations were performed for the ground state of ${}^8\text{B}$ by means of Zero Range Knock-out Distorted Wave Born Approximation using the code DWUCK4 [11] and are compared with the experimental data in Fig. 2. Calculations show a reasonably good agreement with experimental data at forward angles while the backward neutron emission is over estimated. In ref. [6] a discussion can be found explaining a possible origin of this disagreement depending on the different reaction mechanisms involved (i.e. knock-out and/or nucleon transfer). The integrated measured cross section is 58 ± 7 mb to be compared with the 20 mb value extracted by the positron

counting experiments [4,5]. To investigate this difference using the two methods we performed DWUCK4 calculations extending the projectile energy up to 25 MeV as shown in Fig. 3

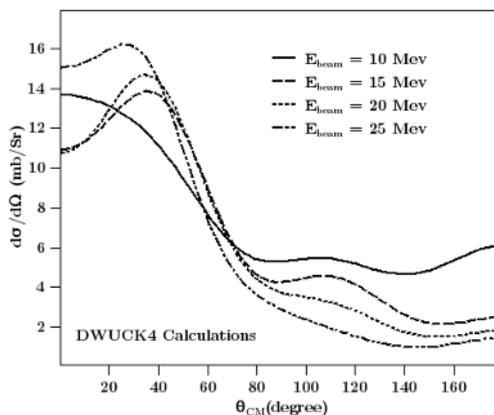


Figure 3. Neutron angular distribution for the ${}^6\text{Li}({}^3\text{He},n){}^8\text{B}$ reaction at different projectile energies calculated with the DWUCK4 code.

From the figure, we observe that the neutron angular distribution is focused at the forward angles when increasing the projectile energy but the calculated total cross section is not changing very much going from 75 mb of our case to 66 mb at 25 MeV with a maximum of about 85 mb at 10 MeV. The results of these calculation are thus in strong disagreement with the experimental results reported in ref. [4,5] where the measured cross section is monotonically decreasing in the considered bombarding energy range from 20 to about 3 mb

4 Conclusions and Outlook

The angular distribution and the cross section of the ${}^6\text{Li}({}^3\text{He},n){}^8\text{B}$ reaction have been measured using the neutron time-of-flight method. The result of this experiment is in agreement with earlier measurement using the same technique [6] showing the same discrepancy with the data coming from positron counting [4,5] and reported in the original paper by C. Rubbia et al. [2]. Preliminary calculations based on the Zero Range Knock-out Distorted Wave Born Approximation show an increasing disagreement with available experimental data when the beam energy increases. In order to understand the origin of this disagreement, experiments at bombarding energies above 10 MeV have to be performed.

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