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Improved results on the extraction of ^{11}B(p,α_0)^{8}Be S(E)-factor via the Trojan Horse Method

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Abstract. This work is focused on a recent analysis of the ^{11}B(p,α_0)^{8}Be reaction by means of the Trojan Horse Method (THM) applied to the ^{2}H(^{11}B,α_0 ^{8}Be)n process. This approach allows one to extract the S(E) factor for the astrophysically relevant ^{11}B(p,α_0)^{8}Be reaction right in the region of the relevant Gamow peak (~10 keV) where both electron screening and extrapolations could influence the available direct data. The experimental approach and the preliminary data of such investigation will be discussed.

Key words. Stars: abundances – Nuclear Physics: Cross section measurements – Nuclear Physics: Indirect methods

1. Introduction

Boron plays a significant role together with lithium and beryllium in the framework of light-element Li, Be and B depletion in young F-G stars as probe for internal stellar structure. The residual abundances of these elements in such atmospheres should reflect the effect of *non-standard* mixing processes, hav-

Send offprint requests to: C. Spitaleri ing the effect of transporting the atmospheric material from the external stellar layers down to the base of the convective zone and close to the nuclear destruction zone where the nuclear burning of Li, Be or B could be triggered (Boesgaard et al. 2004, 2005).

Because of their different fragility against (p,α) destruction, Li, Be and B are mainly burned at internal temperatures ranging from $2*10^6$ K to $5*10^6$ K, so their abundances represent a tool for stellar interior understanding (Stephens et al. 1997). At these temperatures, the energetic window relevant for astrophysics for those reactions is fixed between 5-15 keV's, making difficult a direct cross section investigation, since at such energies the nuclear cross section exponentially droops to ultra-low even vanishing values (Rolfs & Rodney 1988).

The application of the Trojan Horse Method (THM) (Spitaleri et al. 1999; Pizzone et al. 2005; Lamia et al. 2007; La Cognata et al. 2007) to astrophysically relevant reactions made possible to by-pass several problems in the determination of their astrophysical S(E)-factor, overcoming the typical difficulties of a direct investigation, i.e. electron screening and Coulomb penetrability effects. Because of that in a direct measurement the energetic window of relevance for astrophysics is often reached by means of an *extrapolation* procedure from higher energy experimental data. The indirect study of the $^{11}B(p,\alpha_0)^8Be$ has been performed by applying the THM to the $^2H(^{11}B,\alpha_0{}^8Be)n$ three-body reaction induced at about 27 MeV.

2. The experiment

The $^2H(^{11}B,\alpha^8Be)n$ experiment was performed at LNS of Catania with the aim of studying the $^{11}B(p,\alpha)^8Be$ in the two-channels $^{11}B(p,\alpha_0)^8Be$ and $^{11}B(p,\alpha_1)^8Be$. In particular while the α_0 channel implies the study of the alpha-particles leading the beryllium in its ground state, the α_1 channel implies the study of the alpha-particles leading the beryllium in its first excited state. The detection set up displaced inside the scattering chamber, consisted of four Dual Position Sensitive Detector (DPSD), made of two 50x10mm^2 silicon detectors mounted one above-the-other and separated by an empty 1mm space. Two Position Sensitive detectors (PSD) were further used with the aim to detect the alpha- particles coming from the α_0 channel. The angular position of such detection setup was chosen in order to investigate the quasi-free angular region, i.e. the kinematical region where a strong contribution of the quasi-free reaction mechanism is expected. The SMP Tandem Van de Graaf accelerator provided a 27 MeV ^{11}B beam with a spot size on target of about 1.5 mm and intensities up to 2-3 nA, impinging on a Deuterated polyethylene targets (CD_2).

3. Data analysis

3.1. Selection of the reaction channel

The first stage of data analysis was the study of the $^2H(^{11}B,\alpha_0{}^8Be)n$ reaction aimed to extract the astrophysical S(E)-factor of the $^{11}B(p,\alpha_0)^8Be$ reaction in the energetic region for astrophysics. For the purposes of the present experiment, the selection of the events coming from the alpha-decay of ^8Be from its ground state was fulfilled through an off-line selection of two alphas hitting in coincidence upper and lower part of a DPSD array. By detecting the energies and the angles of these particles, it was possible to reconstruct the experimental relative energies, as explained in (Lamia et al. 2008). After that, only the events falling inside the peak corresponding to the $^8Be_{g.s.}$ were taken into account. A selection of the three body $^2H(^{11}B,\alpha_0{}^8Be)n$ channel was made by reconstructing the experimental Q-value, in the hypothesis that a further alpha-particle was detected. The presence of a well separated peak around 6.4 MeV in Fig.1 must be compared with the theoretical Q-value of 6.36 MeV for the $^2H(^{11}B,\alpha_0{}^8Be)n$ reaction. The agreement, within the experimental uncertainties, is a signature of our good calibration and a precise selection of the three-body channel.

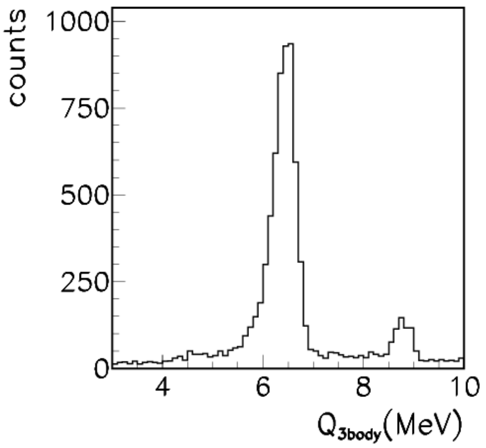

Fig. 1. Experimental Q-value for the three-body $^2H(^{11}B,\alpha_0{}^8Be)n$ reaction. The experimental value must be compared with the theoretical one (Q=6.36 MeV).

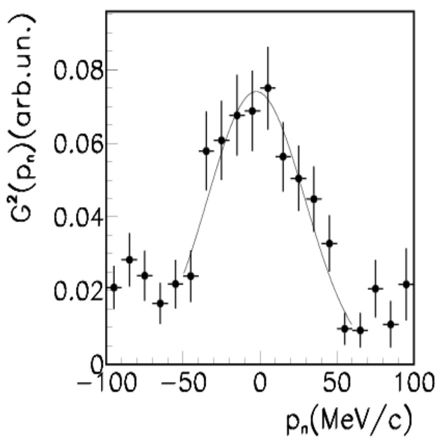

Fig. 2. Experimental distribution (points) for the neutron-momentum values compared with the theoretical Hulthén distribution (full line).

3.2. Selection of the reaction mechanism

To provide a strict experimental selection of the reaction mechanism contributing to the three body channel of our interest, it is important to study the experimental momentum distribution for the undetected neutron in the $^2H(^{11}B,\alpha_0{}^8Be)n$ reaction. In the "quasi-free" (QF) hypothesis, the neutron should maintain in the exit channel the same momentum distribution for the p-n relative motion inside the deuteron that it had before interaction with the impinging particle. Selecting then a small energy region where the two-body cross section can be assumed almost constant and by following the Plane Wave Impulse Approximation (PWIA) description for quasi-free processes (Jain et al. 1970), the three-body coincidence yield corrected for the phase-space factor will be proportional to the momentum distribution (Lamia et al. 2008). The experimental result is shown in Fig.2, where the coincidence yield corrected for the phase-space factor is reported. The good agreement between the experimental data (black points) and the theoretical Hulthén function (full black line) for the p-n motion inside the deuteron represents the experimental evidence that the neutron acted as "spectator" during the break-up occurred in the $^2H(^{11}B,\alpha_0{}^8Be)n$ reaction. After the selection of the QF-mechanism on the three-body $^2H(^{11}B,\alpha_0{}^8Be)n$ channel, it was possible to study the astrophysical reaction $^{11}B(p,\alpha_0)^8Be$ by following the experimental procedure adopted in (Lamia et al. 2008).

4. Results and discussion

By selecting then only the events for which $-40<p_n<40$ MeV/c, it was possible to extract the nuclear part of the $^{11}B(p,\alpha_0)^8Be$ reaction cross section by means of the THM as shown in Fig.3. The correspondent S(E)-factor will be estimated by means of the standard formula (Rolfs & Rodney 1988) and by following the same procedure described in Lamia et al. (2008); Spitaleri et al. (2009). The reaction proceeds through the formation of the 16.106 MeV ($J^\pi=2^+$) level of ^{12}C, representing a l=1 resonance in the ^{11}B-p channel, as confirmed from the direct data reported in Becker et al. (1987). By fitting the experimental data through a second order polynomial and a Gaussian function, it will be possible to evaluate the non-resonant astrophysical S(E)-factor. Such procedure is still under study while a previous estimation of the

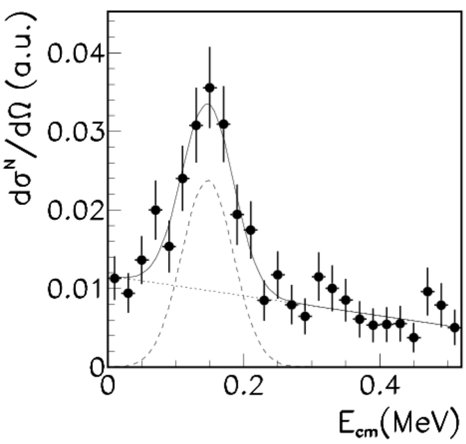

Fig. 3. Nuclear part of the $^{11}B(p,\alpha_0)^8Be$ reaction cross section by means of the THM. The full-line represent the fit on the experimental data. The non-resonant l=0 contribution (dotted line) and the resonant l=1 contribution (dashed line) are also shown.

S(0) value reported in Lamia et al. (2008) and Spitaleri et al. (2009) is in agreement with the value obtained by extrapolation on direct data (Becker et al. 1987). Such investigation allows then to give a measure of the astrophysical S(E)-factor in correspondence of the energetic window of relevance for astrophysics where, up to now, only an extrapolation was present. However a deep investigation is still required for such data and in particular they will be included in an incoming comprehensive scientific work.

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