The ^{19}F(p, $\alpha_{1,2}$) reaction studied via Trojan Horse Method in astrophysical range of interest

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Abstract. The complex reaction network connected to the ^{19}F stellar abundance is very sensitive to the physical condition in stars. To overcome difficulties present in the direct measurements, mainly the very low cross section in the astrophysical energy range due to the Coulomb repulsion, an indirect measurement of the ^{19}F(p, α) reaction, with the Trojan Horse Method (THM), was performed at INFN-LNS. While the method had been successfully used to study α_0 channel, in the present analysis focus was given to the $\alpha_{1,2}$ channels, where better knowledge of the reaction rates at low energies is required, obtainable by employing the THM method.

1 Introduction

The complex reaction network governing the production and destruction of the ^{19}F in stars is determined by the physical condition in stars [1]. Discrepancies in the observed galactic abundance of the ^{19}F in the vicinity of Asymptotic Giant Branch (AGB) stars [2], which are believed to be the main production sites of galactic fluorine, motivate the research for better knowledge of the reaction rates involving the main destruction channels of fluorine: (α, p) [3, 4] in He-burning shell and (p, α) [5–7] in H-burning shell, both studied previously by THM [8]. The (p,γ) channel, important for the latter and as breakout reaction for the CNO cycle, was measured recently [9]. Recent direct measurements of the (p, α) reaction [10, 11] suggest that large effort in the knowledge of the reaction rates still needs to be given to the α_1 [10] and α_2 [11] channels. This is particularly true in the very low energy range, where the proposed 11 keV state [11] may have significant implications for the reaction rate as large increase was deduced, compared to the standard Nuclear Astrophysics Compilation of Reaction Rates (NACRE) [12]. For the latest results and state of the art concerning the α_0 channel, one is referred to a recent results from direct measurement [13] and a review article [14]. The commonly used notation $\alpha_{0,1,2,...}$ labels the exit channels corresponding to different states of the ^{16}O nucleus, where 0 represents the ground state (0 MeV, 0^+), 1 corresponds to the first excited state (6.05 MeV, 0^+), 2 to the second excited state (6.13 MeV, 3^-), and so on.

2 Overview of the experimental setup

The indirect measurement of the ^{19}F(p, α)^{16}O reaction was performed at Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (INFN-LNS) in Catania, using the 55 MeV ^{19}F beam and CD_2 target, where the deuteron served as THM nucleus. In the data reduction phase, proper quasi-free contribution of the ^{19}F(^{2}H, α^{16}O)n reaction was deduced, based on the vanishing momentum of the spectator neutron ($p_s \approx 0$), following the procedures described in [5–7].

The experimental setup, shown on Figure 1, was optimized for the kinematically complete measurement of the aforementioned quasi-free three-body reaction, where spectator neutron was left undetected. The pressure of the gas was ≈ 52.5 mbar throughout the experiment.

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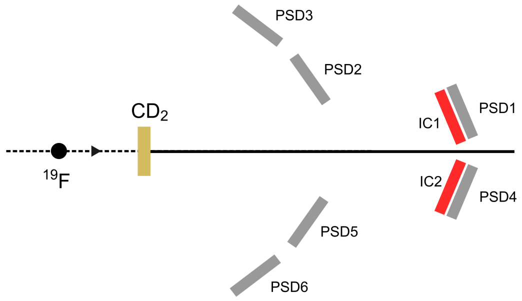

Figure 1. Experimental setup used at INFN-LNS, consisting of six Position Sensitive Detectors (PSD) and two Ionization Chambers (IC) filled with Isobutane gas.

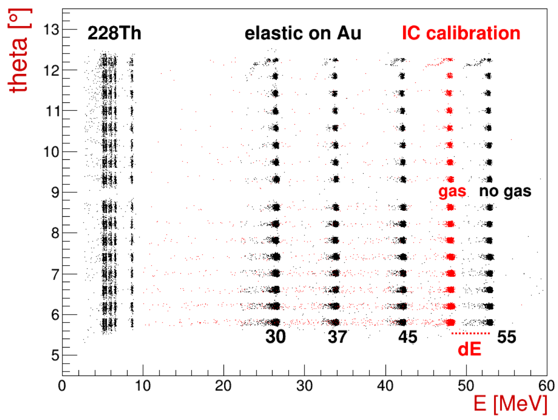

Figure 2. The exemplary spectrum of calibrated values of θ vs. E for PSD1, showing α-peaks from the ^{228}Th source and elastic scattering peaks of ^{16}O beam (E = 55, 45, 37, 30 MeV) on ^{197}Au target (^{12}C scattering data not shown here) with (red points) and without the gas (black points) in the IC1.

3 Analysis overview and preliminary results

The data collected during the experimental campaign was separated in the analysis into three independent case studies. These cases are categorized by the pairs of detected nuclei (α=a, ^{16}O=o) as follows: a2o4 (α in detector 2 and ^{16}O in detector 4, *case (1)*), o1a5 (^{16}O in detector 1 and α in detector 5, *case (2)*) and a1o4 + o1a4 (α and ^{16}O in detectors 1 and 4 respectively, *case (3)*), with detector numbering shown in Figure 1. In this way a shared effort was put to collective analysis checkpoints, to speed up the calibration (example spectrum shown on Figure 2) and quality control (QC) of the data, while keeping independent datasets as cross-check for the obtained results. For particle identification (PID) of the ^{16}O nuclei, the standard ΔE-E technique was used in all three cases, as well as for PID of detected α nuclei in the case *(3)*, whereas for the cases *(1)* and *(2)*, the exit channel of interest was identified through kinematic conditions.

After multiple cross-checks performed for the quality of the calibration, needed mainly due to the low sensitivity of the IC as precise energy loss (eloss) detector, solution was found to use the calibrated value of eloss for ^{16}O and calculated (SRIM) value for α in the analysis case *(3)*. On the other hand, for the cases *(1)* and *(2)*, better precision in the calculations was found by use of the parameters of detected α (E, θ) and only the angle (θ) of ^{16}O, an approach made possible after the correct identification of the exit channel of the reaction of interest (Q-value fixed). For the quality-control of the data, a detailed analysis of the two-body reaction ^{19}F(^{1}H, α)^{16}O was performed, as well as three-body one: ^{19}F(^{2}H, ^{16}O)^{5}He, which proceeds through creation of the ^{5}He nucleus in the ground state, which consequently decays via emission of neutron.

Likely one of the most important checks performed was the analysis of the ^{19}F(^{2}H, $\alpha_0{}^{16}$O)n exit channel, with ^{16}O nucleus in the ground state. This reaction proceeded through the creation of the compound nucleus ^{20}Ne in excited states. The α-decaying states in 5.5 - 8.5 MeV excitation energy range were used as QC of the analysis procedure (shown for the case *(3)* in Figure 3) with excellent agreement of the observed values with the ones from the literature [15]. The detailed analysis of the ^{19}F(^{2}H, $\alpha_{1,2}{}^{16}$O*)n channel is in progress.

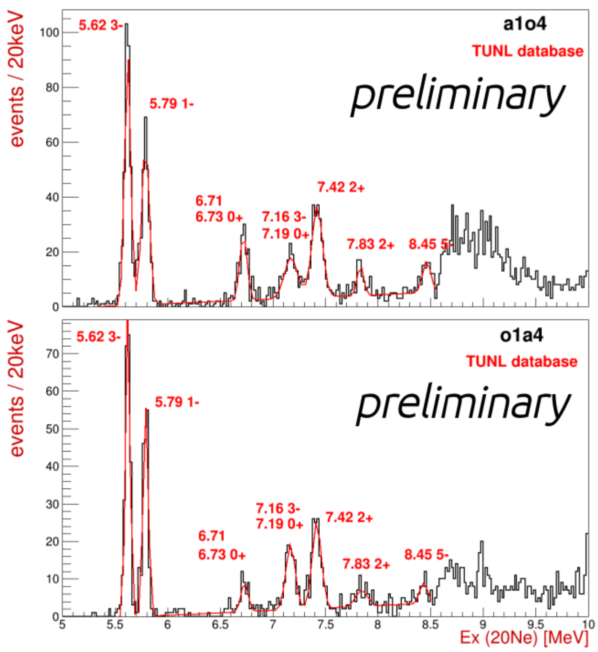

Figure 3. The excitation energy spectra of the ^{20}Ne nucleus for the a1o4 (upper panel) and o1a4 (lower panel) datasets (*see text for details*), used to access the quality of calibration and the analysis procedure.

4 Conclusion

Indirect measurement of the ^{19}F(p, α)^{16}O reaction was performed at INFN-LNS in Catania to obtain experimental data in the energy range of astrophysical interest. Using the Trojan Horse Method, quasi-free contribution of the ^{19}F(^{2}H, α^{16}O)n reaction was deduced, based on the vanishing momentum of the spectator neutron ($p_s \approx 0$). The method, sucesfully used previously in the study of the ^{19}F(p, α_0)^{16}O reaction in astrophysical energy range of interest [5–7], is employed in similar manner to obtain the data for the $\alpha_{1,2}$ recation channels also. An overview of the experimental setup and preliminary results for the α_0 channel, used as one of the quality control check-points of the analysis procedure, were given, while the detailed analysis of the ^{19}F(^{2}H, $\alpha_{1,2}$^{16}O*)n channel is in progress.

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