

## Preliminary results for the $^{19}\text{F}(p,\alpha)^{16}\text{O}$ reaction cross section measured at INFN-LNS

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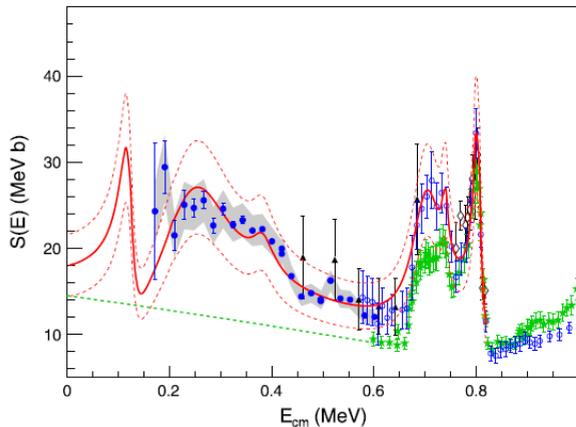
**Abstract.** The  $^{19}\text{F}(p,\alpha)^{16}\text{O}$  reaction is an important fluorine destruction channel in the proton-rich outer layers of asymptotic giant branch (AGB) stars and it might also play a role in hydrogen-deficient post-AGB star nucleosynthesis. At present, theoretical models overproduce F abundances in AGB stars with respect to the observed values, thus calling for further investigation of the nuclear reaction rates involved in the production and destruction of fluorine. In the last years, new direct and indirect measurements improved significantly the knowledge of  $^{19}\text{F}(p,\alpha)^{16}\text{O}$  cross section at deeply sub-Coulomb energies (below 0.8 MeV). However, those data are larger by a factor of 1.4 with respect the previous data reported in the NACRE compilation in the energy region 0.6-0.8 MeV. Using the Large High resolution Array of Silicons for Astrophysics (LHASA), we performed a new direct measurement of the  $^{19}\text{F}(p,\alpha)^{16}\text{O}$ . The goal of this experiment is to reduce the uncertainties in the nuclear reaction rate of the  $^{19}\text{F}(p,\alpha)^{16}\text{O}$  reaction. Here, experimental details, the calibration procedure and angular distributions are presented.

### 1 Astrophysical motivation and state of the art

Fluorine nucleosynthesis takes place in the hydrogen-helium intershell region of Asymptotic Giant Branch (AGB) stars this being the region where the s-process elements are produced. Since fluorine is produced in the He-intershell and then brought up to the surface together

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**Figure 1.** S-factor of the  $^{19}\text{F}(p,\alpha)^{16}\text{O}$  reaction available in literature [4]. The full and empty blue circles are from Lombardo et al. [4], the black triangles show the data of Breuer et al. [5], the green stars the data of Isoya et al. [6] and the empty diamonds the data of Caracciolo et al. [7]. The red line represents the results of the R-matrix calculation based on THM measurement, as reported in Indelicato et al. [8].

with s-process elements, its abundance is used as probe for AGB models and nucleosynthesis and is one of the most important input parameters for the analysis of s-process in AGB star conditions [1,2,3].

More recently, a direct measurement carried out in the energy range  $E_{CM} = 0.2 - 1$  MeV [3] was reported. In the energy region  $E_{CM}$  higher than 0.8 MeV, the new results agree with the data included in the NACRE compilation. Below 0.8 MeV, the data of Lombardo et al. [4] agrees with the data of Breuer et al. [5]. This experimental data sets are larger by a factor of about 1.4 compared to the data of Isoya et al. [6]. The low energy region is explored by means of the Trojan Horse Method (THM) by La Cognata et al. and by Indelicato et al. [8,9]. Figure 1 reports a summary of the S-factors from available data present in literature for the  $^{19}\text{F}(p,\alpha)^{16}\text{O}$  reaction.

## 2 Experimental details

This experiment was performed at INFN - Laboratori Nazionali del Sud, Catania (Italy). The 15 MV Tandem Van der Graaff provided a  $^{19}\text{F}$  beam in the energy range from 9 up to 18.5 MeV with a spot size on target of 1 mm and intensities around 1 - 5 nA. Thin self-supported polyethylene targets ( $\text{CH}_2$ ) of about  $100 \mu\text{g}/\text{cm}^2$  were placed at  $90^\circ$  with respect to the beam direction and were frequently changed to avoid degradation. A picture of the experimental set-up is shown in Figure 2.

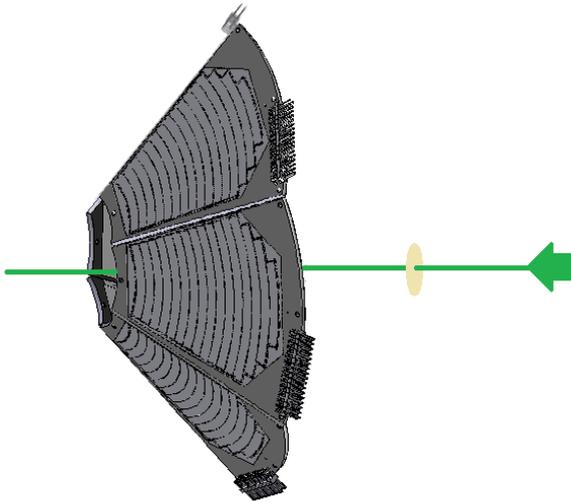
In order to calculate the cross section, it is necessary to calculate the number of particles in the beam, the number of particles in the target and the number of reactions. Since the angular coverage of the experimental setup is approximately 15% of the total solid angle, the number of reactions is calculated by integrating the angular distribution for each energy.

$$\sigma = \frac{N_R}{N_b N_T} \quad (1)$$

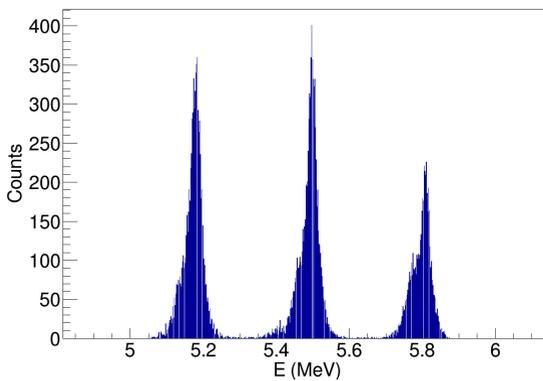
The following subsections will focus on determining this quantities.

### 2.1 Beam monitoring

Beam current was measured by means of a Faraday cup placed behind the target and a -300 V suppression voltage was applied to reduce secondary electron effects. The reaction



**Figure 2.** LHASA - the experimental set-up used for the study of  $^{19}\text{F}(p,\alpha)^{16}\text{O}$  reaction cross section. The beam is shown in green and the target in yellow.



**Figure 3.** Monitor calibration with a triple alpha source.

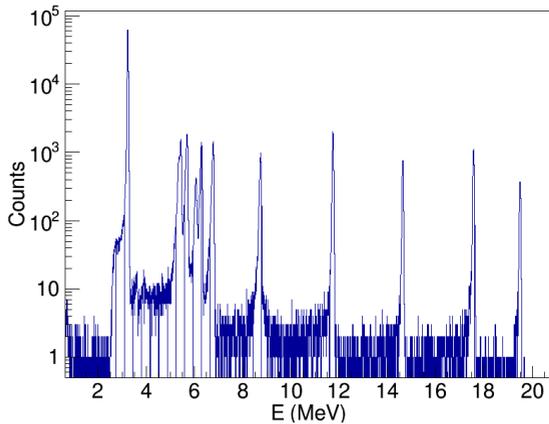
chamber was operated under high vacuum condition. “The number of particles in the beam are calculated by dividing the charge collected in the Faraday cup by the charge state of the beam after the target.

## 2.2 Target monitoring

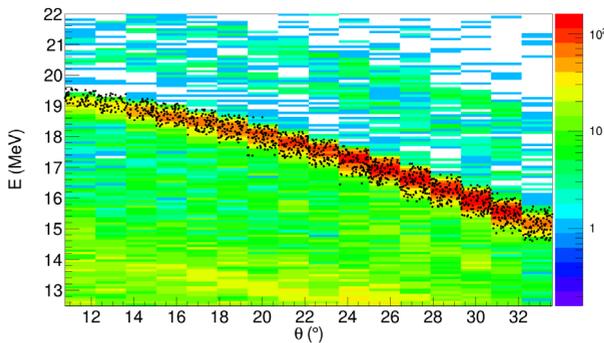
An online monitoring system of the target was used. A photodiode was placed at  $45^\circ$  with respect to beam direction, which was used to monitor the  $\text{CH}_2$  target thickness. Since the Rutherford cross section is experimentally well known at this energies, it is used for calculating the number of particles in the target. The monitor was calibrated with a triple alpha source (see Figure 3).

## 2.3 Experimental set-up

The LHASA detector array, which consist of six Micron Ltd. YY1 [10] silicon strip detectors and up to 96 channels of associated electronics, was chosen because of the good resolution and angular coverage (from  $10^\circ$  to  $32^\circ$ ). The experimental setup is shown in Figure 2. Each



**Figure 4.** Detector calibration with  $\alpha$ -source energy range 3-9 MeV and  ${}^6\text{Li}$  elastic and inelastic scattering in the energy range 12-20 MeV.



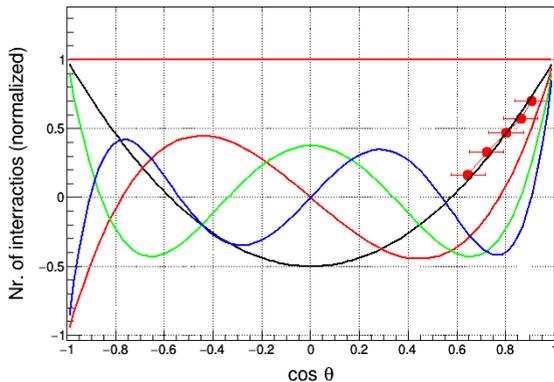
**Figure 5.** The  ${}^{19}\text{F}(p, \alpha_0){}^{16}\text{O}$  reaction at 18.5 MeV with red and simulations with black.

detector sector has 16 strips and is 300  $\mu\text{m}$  thick, with an energy resolution of 3%. The detector mounting system was fixed inside the vacuum chamber such that the position of the center of the array is perfectly aligned with the beam line. For this alignment, the optical system available at INFN-LNS was used. All the signals coming from the detectors were delivered to the preamplifiers, with the aim to increase the signal-to-noise ratio and to shape the signal in the best possible way, improving resolution. Processed signals are then collected by the ADC (Analogic to Digital Converter), that digitalized the signals. Those were then ready to be stored in the PC disk.

### 3 Calibration procedure and simulations

Energy calibration of the detectors was performed by means of  ${}^6\text{Li}$  elastic and inelastic scattering in the energy range 12-20 MeV through the interaction with a gold and carbon target and by using a  ${}^{228}\text{Th}$   $\alpha$ -source. All of the peaks are shown in Figure 4.

The calibration was checked with simulations done with LISE++ program [11] and with GEANT4 simulations [12], which are fully independent of the data. The results show excellent agreement with the data and indicate that the calibration was done properly (see Figure 5).



**Figure 6.** The angular distribution for the  $^{19}\text{F}(p,\alpha)^{16}\text{O}$  reaction at 700 keV in the center-of-mass system. The experimental points (with red) are overlapped with scaled Legendre polynomial of orders from one to five.

## 4 Data analysis and preliminary results

To continue with the calculation of the cross section, it is necessary to calculate the number of interactions. By integrating the number of reactions in each strip, it is possible to determine the angular distribution for the  $^{19}\text{F}(p,\alpha)^{16}\text{O}$  reaction. Integrating the angular distribution, for a given energy, the reaction yield is calculated. In Figure 6 it is shown how the experimental points at 700 keV in the center-of-mass system are well described by a second order Legendre polynomial. This means that the resonance situated at 696 keV in the center-of-mass system, which is due to the population of 13.529 MeV excited level of  $^{20}\text{Ne}$ , is  $2^+$  state, exactly like it is stated in the literature [8].

## 5 Conclusions

Recently, two experimental works concerning the  $^{19}\text{F}(p,\alpha)^{16}\text{O}$  reaction cross section have been reported. There is a discrepancy of a factor of 1.4 between the new data and the NACRE compilation.

In an attempt to resolve this discrepancy, here, a new experiment was presented with the aim of reduce the uncertainties in the nuclear reaction rates in the energy region from 0.6 MeV up to 0.8 MeV in the center-of-mass system. Preliminary results are in agreement with previous assignment of the spin and parity,  $J_\pi=2^+$ , of the resonance situated at 696 keV in the center-of-mass system, which is due to the population of the 13.529 MeV excited level of  $^{20}\text{Ne}$  [8].

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## References

- [1] S. Cristallo et al., 2009, *ApJ*, 696, 797
- [2] H. Jonsson et al., 2017, *ApJ*, 835, 50
- [3] G. D'Agata et al., 2018, *ApJ*, 860, 61
- [4] I. Lombardo et al., 2015, *Phys. Lett. B*, 748, 178
- [5] G. Breuer, 1959, *ZPhys.*, 154, 339
- [6] A. Isoya, 1959, *Nucl. Phys. A*, 7, 126
- [7] R. Caracciolo et al., 1974, *Lett. Nuovo Cim.*, 11, 33
- [8] I. Indelicato et al., 2017, *ApJ*, 845, 19
- [9] M. La Cognata et al., 2011, *ApJ L*, 739, L54
- [10] Micron Ltd. website: <https://www.micron.com/>
- [11] Tarasov and D. Bazin, 2008, *Nucl. Instr. Meth. B*, 266, 4657
- [12] D. Lattuada et al., 2017, *EPJ Web of Conf.*, 165, 01034