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Direct cross section measurement for the $^{18}\mathbf{O}(\mathbf{p},\gamma)^{19}\mathbf{F}$ reaction at astrophysical energies at LUNA

F. R. Pantaleo[1,2,⋆] and *A.* Best[3,4], *G.* Imbriani[3,4], *R.* Perrino[2,⋆⋆]
for the LUNA Collaboration

[1] *Universita' degli Studi di Bari, Dipartimento Interateneo di Fisica "M. Merlin", Bari, Italy*
[2] *Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Bari, Italy*
[3] *Universita' degli Studi di Napoli, Dipartimento di Fisica "E. Pancini", Napoli, Italy*
[4] *Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Napoli, Italy*

Abstract. $^{18}O(p,\gamma)^{19}F$ plays an important role in the AGB star scenarios. The low energy cross section could be influenced by a hypothetical low energy resonance at 95 keV and by the tails of the higher energy broad states. The 95 keV resonance lies in the energy window corresponding to the relevant stellar temperature range of 40-50 MK.
Measurements of the direct cross section were performed at the Laboratory for Underground Nuclear Astrophysics (LUNA), including the unobserved low energy resonance, the higher energy resonances and the non-resonant component, taking advantage of the extremely low environmental background. Here we report on the experimental setup and the status of the analysis.

1 Introduction

The $^{18}O(p,\gamma)^{19}F$ reaction ($Q \simeq 7.99$ MeV) represents the bridge between the CNO cycle and other cycles involved in the production of heavier nuclei, which are active during shell H burning.
A $^{18}O/^{16}O$ isotopic ratio equal to $2.09^{+0.13}_{-0.12} \cdot 10^{-3}$ is present in matter within our solar system [1]. Investigations of oxygen isotopic ratios through pre-solar grains, gathered over the years from primitive meteorites and interplanetary dust particles, found a value $\leq 1.5 \cdot 10^{-3}$ [2], reflecting a substantial ^{18}O depletion compared to the solar system value.

It has been suggested that the low-mass asymptotic giant branch (AGB) stars are an ^{18}O depletion site [3] due to *cool bottom processing* (CBP) [2], in which the $^{18}O + p$ reaction occurs.
Within the CBP temperature regime (40 MK), the $^{18}O(p,\gamma)^{19}F$ reaction rate may be influenced by an unobserved low-energy resonance at $E_{res} = 95 \pm 3$ keV, that corresponds to the E_X=8084 keV±3 keV [4] level in the ^{19}F nucleus. The 95 keV resonance strength is disputed by [5] and [6]. An experimental upper limit of the 95 keV resonance strength [5] could have a negligible impact on the $^{18}O(p,\gamma)^{19}F$ reaction rate over the entire temperature range (see Fig. 1(a)), otherwise a larger resonance strength estimated by [6] could have a dominant contribution to the reaction rate over the AGB stars temperature range (see Fig. 1(b)).

⋆e-mail: francesca.pantaleo@ba.infn.it
⋆⋆permanent address: INFN Lecce, Italy

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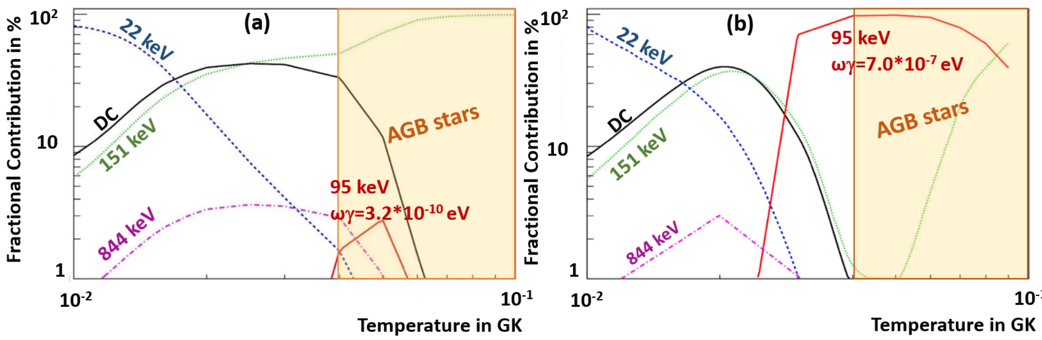

Figure 1. Reaction rates contributions in the AGB range of stars, (a) follows as [5] and (b) follows as [6].

A direct observation of the disputed resonance is desirable, and measurements of the non-resonant cross section at lower energies can support the extrapolation of the non-resonant contribution towards lower energies of astrophysical interest.

Further measurements regarding the off-resonant and on-resonant higher energy range, were done in order to improve our knowledge of levels in the ^{19}F compound nucleus that are relevant to nuclear astrophysics and to complete available data known in literature [7], [8], [9].

2 Experimental setup

The $^{18}O(p,\gamma)^{19}F$ reaction was investigated using the accelerator at the LUNA2 facility [10], which provides very accurate and reproducible ion beams of protons in the energy range of 50 keV $\leq E_p^{lab} \leq$ 400 keV with a maximum current (on-target) approximately equal to 300 μA. The facility has two beamlines, one dedicated to solid target and the other one to gas target experiments. The solid target beamline has been used for studying the reaction of interest for the present work.

The Ta_2O_5 targets were prepared by anodic oxidation [11] of thin tantalum disks (0.3 mm x 40 mm diameter) with an isotopic enrichment 99% in ^{18}O. These targets have to meet a number of specific requirements: thickness must be uniform and such to sustain the high beam currents over extended times; known and constant stoichiometry, to allow for accurate beam energy loss calculation; known and possibly enriched isotopic composition, to allow for measurable yields.

A high efficiency BGO summing crystal detector was used for total cross section measurement. The experimental setup also hosts a High Purity Germanium (HPGe) detector, positioned at 55° with respect to the beam direction, which provides a much lower detection efficiency compared to the BGO detector but a greatly improved energy resolution in order to measure branchings and higher energy resonances.

The BGO and the HPGe setup are shielded by 10 cm and 15 cm of lead in order to reduce the environmental background contributions, respectively.

3 Measurements

The experimental campaign was split in two phases. The first phase is characterized by a high efficiency BGO summing crystal detector. During the second phase a high energy resolution HPGe

detector was used. Both approaches used a solid target setup and covered the common range of data taking (140-400 keV). The first phase extended the range of measurements to energies down to 89 keV, to probe the existence of the hypothetical low energy resonance using the high efficiency BGO summing crystal detector.
Five resonances were measured within 89-400 keV. For the first time a measurement was done in order to estimate the resonance strength for the low-energy resonance at $E_{res} = 95 \pm 3$ keV , and in addition measurements were done to reduce the error on the 151 keV, 216 keV, 274 keV and 334 keV resonance strengths. Two experimental spectra acquired at 95 keV and at the energy of the strongest resonance of $^{18}O(p,\gamma)^{19}F$ reaction 151 keV, are shown in Figures 2.(a) and (b). A signal was observed at 95 keV with the BGO setup, (see Fig. 2(c)). Clear individual transitions for the 151 keV resonance demonstrate resolution of the HPGe detector (see Figs. 2.(b) and (d)).

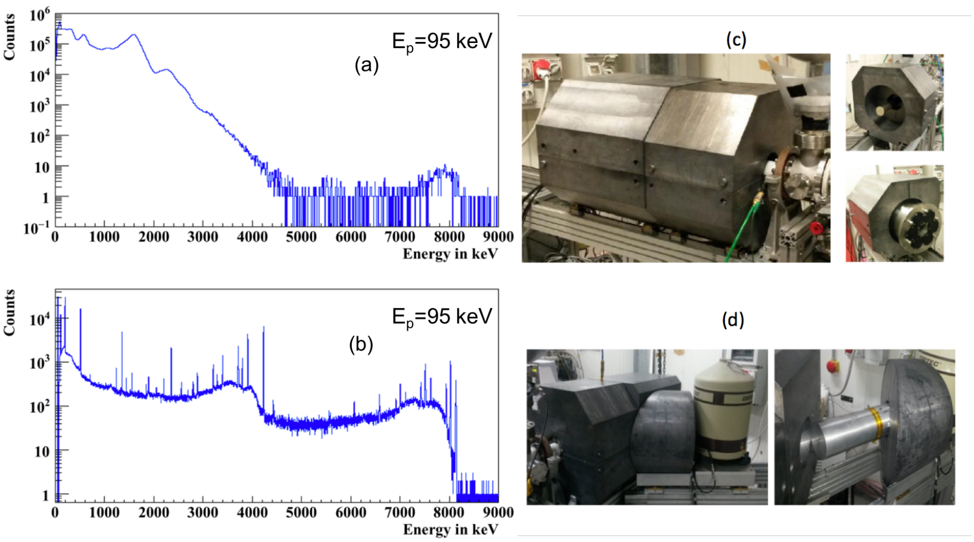

Figure 2. Experimental spectra are shown: (a) acquired at 95 keV, the energy of the low energy resonance, (b) acquired at 151 keV, the energy of the strongest resonance of $^{18}O(p,\gamma)^{19}F$ reaction. Detector setups are shown: (c) BGO and (d) HPGe.

The excitation function including all BGO measurements is shown in Fig. 3, except data lower than about 100 keV because the analysis of the low energy part is ongoing.

Several measurements of environmental backgrounds were done during the two phases, and beam induced background measurements were performed only during the first phase in order to understand the influence of the different contaminants. With Q values of 8.0 MeV, the signals are in regions at which the background rate is greatly reduced thanks to the underground location of LUNA.
It is dominated by radiative capture of thermal neutrons in the detector materials, but it is only on the order of 10^{-4} counts per MeV per second.

4 Analysis and Conclusions

The data analysis for the two experimental phases is ongoing and will be finalized soon.
The first focus is the low-energy resonance, and the estimates of the strengths regarding the other

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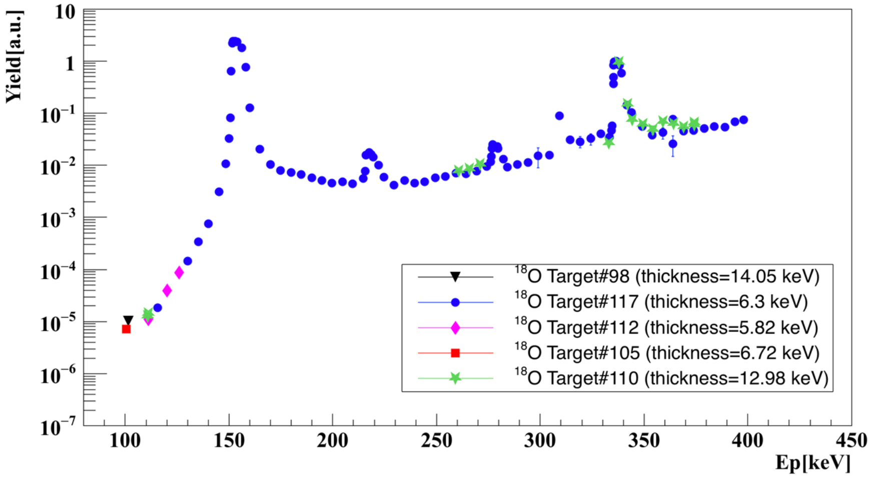

Figure 3. Excitation function from the BGO measurements.

resonances are ongoing, with the BGO data sets.
A preliminary analysis regarding the low-energy resonance with tail effects coming from the 151 keV resonance and the direct capture contributions is ongoing. Data analysis from complete HPGe data sets is also ongoing. In particular the determination of the γ-ray branchings and resonance strengths regarding on-resonance energy component are almost finalized. The γ-ray branchings regarding the 216 keV proton energy resonance were calculated for the first time at LUNA. For the remaining resonances at 151 keV, 274 keV, 334 keV proton energies, the γ-ray branchings obtained at LUNA were compared with previous published data [7].

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