The challenging direct measurement of the $65\,keV$ resonance strength of the $^{17}\mathrm{O}(p,\gamma)^{18}\mathrm{F}$ reaction at LUNA

Riccardo Maria Gesuè[1]* for the LUNA collaboration

[1]Università degli Studi di Napoli and INFN Division of Napoli, Via Cintia, 80126 Napoli (Italy)

Abstract. The $^{17}\mathrm{O}(p,\gamma)^{18}\mathrm{F}$ reaction plays a crucial role in AGB nucleosynthesis as well as in explosive hydrogen burning occurring in type Ia novae. At the temperatures of interest for the former scenario ($20\,\mathrm{MK} < \mathrm{T} < 80\,\mathrm{MK}$) the main contribution to the astrophysical reaction rate comes from the poorly constrained $E_R = 65\,\mathrm{keV}$ resonance. The strength of this resonance is presently determined only through indirect measurements, with an adopted value $\omega\gamma = (16 \pm 3)\,\mathrm{peV}$.
A new high sensitivity setup was installed at LUNA, located at LNGS. The underground location of the LUNA 400kV accelerator guarantees a reduction of the cosmic ray background by several orders of magnitude. The residual background was further reduced installing a devoted shielding. On the other hand, to increase the efficiency, the 4π BGO detector was coupled with Al target chamber and holder. With more than 400 C accumulated on Ta_2O_5 targets, nominal $^{17}\mathrm{O}$ enrichment of 90%, the LUNA collaboration has performed the first direct measurement of the 65 keV resonance strength.

1 Introduction

The $^{17}\mathrm{O}(p,\gamma)^{18}\mathrm{F}$ reaction takes part in the CNO cycle, active in the giant stars H-burning shell or in explosive burning scenarios (i.e. type Ia novae). The precise knowledge of the $^{17}\mathrm{O}(p,\gamma)^{18}\mathrm{F}$ nuclear reaction rate at typical temperatures of H-shell burning in AGB stars ($20\,\mathrm{MK} \leq T \leq 80\,\mathrm{MK}$) is needed to address several astrophysical problems regarding the Oxygen isotopic ratio [1]. The post first dredge-up (FDU) Oxygen ratios predicted by theoretical models [2], often differ form observed surface abundances of low-mass giant stars ($M < 2M_{\odot}$) at the tip of the RGB on the Hertzsprung-Russell diagram. Moreover, in a group of pre-solar grains, are observed a moderate $^{18}\mathrm{O}$ depletion and a high $^{17}\mathrm{O}$ enrichment that cannot be retrieved by models. In this context the $^{17}\mathrm{O}(p,\gamma)^{18}\mathrm{F}$ reaction rate plays a key role, directly affecting the $^{17}\mathrm{O}$ depletion and $^{18}\mathrm{O}$ production ($^{18}\mathrm{F}$ decays with a $T_{\frac{1}{2}} = 109.77'$ in $^{18}\mathrm{O}$).

The past $^{17}\mathrm{O}(p,\gamma)^{18}\mathrm{F}$ reaction study performed at Laboratory for Underground Nuclear Astrophysics (LUNA) was mainly focused at Gamow energies for classical novae ($160\,\mathrm{keV} \leq E_{cm} \leq 370\,\mathrm{keV}$), using both the prompt γ-ray detection and the activation method, leding to a precise determination of the $E_R = 183\,\mathrm{keV}$ resonance strength [3] (resonance energies are expressed in the center of mass). However, the main contribution to the astrophysical reaction rate at temperatures of interest for the AGB star H-burning shell comes from the $E_R = 65\,\mathrm{keV}$

*e-mail: riccardo.gesue@na.infn.it

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resonance. An accurate measurement of the resonance strength can improve the reaction rate determination and will help to constrain the RGB and AGB models. The strength of the E_R = 65 keV resonance is presently determined only through indirect measurements [4–6] providing the Γ_γ and Γ_α, while the Γ_p is derived from the $\omega\gamma_{(\alpha,\gamma)}$ [7]. The adopted value is $\omega\gamma = (16 \pm 3)$ peV.

Since the expected rate is as low as one reaction per Coulomb [8], a direct measurement of the E_R = 65 keV resonance strength required both a high sensitivity setup and a devoted technique for beam-induced background (BIB) suppression. In following sections the setup, the analysis and the preliminary results found will be described.

2 Experimental setup

The measurement was performed at LUNA, located in the deep underground facility of Laboratory Nazionali del Gran Sasso (LNGS). Thanks to the 1400 m overburden of rock, here the muon cosmic ray background is reduced by six orders of magnitude with respect to the surface [9]. Such a low cosmic-ray background in turn allows the deployment of thick passive shielding to absorb the natural radioactivity signals. In particular, a 15 cm thick lead shielding used for γ absorption was surrounded with a 5 cm borated (5%) polyethylene for n absorption: the polyethylene reduced the detected background of a factor 4 in the region of interest (ROI) of our measurement (5.2 - 6.2 MeV), with respect to using only lead. The LUNA 400kV accelerator [10] was able to provide a high stability 200 μA current on target at projectile energy E_p = 80 keV. The high efficiency (74% at 661 keV) Bismuth-Germanium-Oxide (BGO) detector was installed around the reaction chamber, covering a 4π angle around the target. The detector is made of six optically independent crystals, which coupled with a DAQ that records the time stamp of each reading allows both single crystal spectra and the construction of the add-back spectrum, namely by adding coincident events in the individual crystals. In order to minimize the γ-ray absorption, Aluminium was used as construction material for the scattering chamber and the target holder. A 3D model of the detection setup is shown in Fig.1.

The measurement was performed using Ta_2O_5 solid targets produced by anodization of tantalum backings in 90% ^{17}O enriched water. Targets were doped with 5% ^{18}O, thus allowing the periodical scan of the E_R = 143 keV $^{18}O(p,\gamma)^{19}F$ resonance to monitor target degradation and thickness.

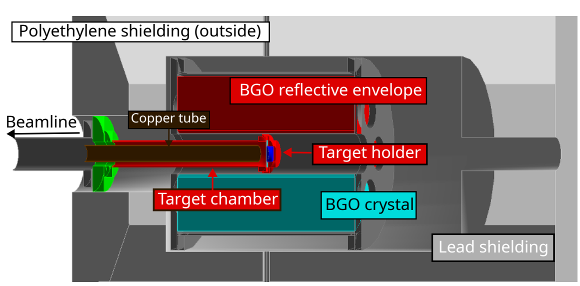

Figure 1. Section of the 3D model of the detector setup used in the Geant4 simulation.

3 Analysis and preliminary results

During five measurement campaigns, about 400 C were cumulated on ^{17}O targets. An accurate Montecarlo simulation of the setup was crucial for the analysis of the acquired data. The simulation was developed using the Geant4 toolkit [11] and it was optimized on the well-known spectra of ^{60}Co and ^{137}Cs sources, and ^{14}N$(p,\gamma)^{15}$O E_R = 270 keV resonance. See Fig.2 for a comparison between simulation and measurement of ^{14}N$(p,\gamma)^{15}$O. The average residuals between simulated and measured spectra after normalisation was below 3% in all three cases. This value also represents the precision at which the detection efficiency can be determined from the simulations.

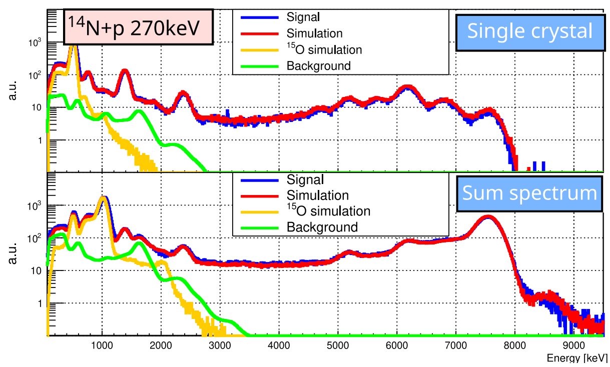

Figure 2. Comparison of simulated (red) and measured (blue) spectra of ^{14}N$(p,\gamma)^{15}$O 270 keV resonance. In green and yellow are represented environmental background and ^{15}O decay spectra respectively, included in the simulation.

A low (3 p.p.m.) deuterium contamination on the Ta backing produced a single γ peak at the same energy of the ^{17}O$(p,\gamma)^{18}$F 65 keV resonance peak. In Fig.3 the BIB peak is clearly visible and due to a contamination in the Ta backing. In order to subtract this BIB an innovative technique was developed which made use of our knowledge of the E = 5672 keV de-excitation branching ratios and of the BGO detector segmentation. The technique iso-

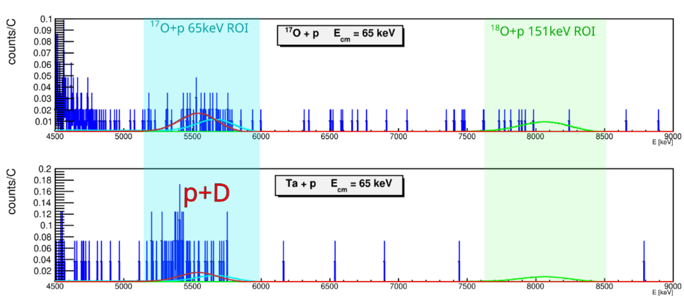

Figure 3. Spectra acquired shooting a E_{lab} = 80 keV proton beam on ^{17}O (top) targets and naked Ta backings (bottom). The $p+d$ peak in the bottom spectrum indicates a contamination in the Ta backings estimated at 3 p.p.m. level. The coloured peaks are shown to guide the eye.

lates multiplicity 2 and 3 transition γ-rays with the expected energies for the 5672 keV de-excitation chain from the multiplicity 1 BIB. This allows an almost complete background subtraction while losing only a small amount of resonance γ, since the probability of ground state transition (multiplicity 1) is 6%. The analysis lead to a preliminary $\omega\gamma$ determination of about double the value of the indirect estimates.

At the time of writing this proceeding, the last acquired data is being analysed and an in-depth evaluation of the uncertainties is being performed. A technical paper on the detector, setup and analysis technique is ongoing, while the final results will be published in a separate paper.

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