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

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Abstract. A precise determination of proton capture rates on oxygen is mandatory to predict the abundance ratios of the oxygen isotopes in a stellar environment where hydrogen burning is active. The ^{17}O(p,γ)^{18}F reaction, specifically, plays a crucial role in AGB nucleosynthesis as well as in explosive hydrogen burning occurring in type Ia novae. At temperatures of interest for the former scenario (20 MK ≤ T ≤ 80 MK) the main contribution to the astrophysical reaction rate comes from the $E_{\mathrm{c.m.}}$ = 65 keV resonance. The strength of this resonance is presently determined only through indirect measurements, with an adopted value of $\omega\gamma = (1.6 \pm 0.3) \times 10^{-11}$ eV. Thanks to the low background environment of the Laboratori Nazionali del Gran Sasso, the intense and stable beam provided by the LUNA 400 kV accelerator and the experience in oxygen target production, the LUNA collaboration is aiming the first direct measurement of the above mentioned resonance strength. In the present work details of challenging direct measurement planned at LUNA will be described.

1 Introduction

The ^{17}O(p,γ)^{18}F reaction (Q = 5607.1(5)[1]) participates in the NO section of the CNO cycle, which is the main H-burning cycle in H-shell of giant stars or in explosive scenarios as type Ia novae.

Oxygen isotopic ratios in H-burning shell of Red Giant Branch (RGB) and Asymptotic Giant Branch (AGB) stars only depend on the rate of proton capture reaction on oxygen. Variations of the isotopic ratio occur at the surface as result of convective instabilities in the stellar envelope. This isotopic ratio can be observed in stellar IR spectra [2] and it probes the depth attained by the mixing episodes as well as the additional processes that may contribute to the chemical surface variation [3] Moreover, the oxygen isotopic ratio is measured in pre-solar meteoritic grains [4] providing high-precision snapshots of the progenitor isotopic composition as well as of nuclear and stellar parameters.

In both cases the reliability of probing the deep mixing and of the pre-solar grain origin depend on our knowledge of the rates of the nuclear reactions involved.

The ^{17,18}O(p,γ)^{18,19}F and ^{17,18}O(p,α)^{14,15}N reaction cross sections have been measured at the Laboratory for Underground Nuclear Astrophysics (LUNA), located deep underground at

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Laboratori Nazionali del Gran Sasso (LNGS) where muonic background is reduced by 6 orders of magnitude with respect to the surface experiments [5]. Results obtained by the LUNA collaboration [6–11] had paramount impact on the interpretation of the oxygen isotopic ratio observed in giant stars and in stardust grains [12, 13]. Moreover, a study of the ^{16}O(p,γ)^{17}F reaction is also planned at LUNA 400 kV.

The ^{17}O(p,γ)^{18}F reaction study completed at LUNA was mainly focused at Gamow energies for classical novae, 160 keV ≤ $E_{\rm c.m.} \leq 370$ keV. At temperature of interest for the AGB star H-burning shell (20 MK ≤ T ≤ 80 MK), however, the main contribution to the astrophysical reaction rate comes from the $E_{\rm c.m.}$ = 65 keV resonance. An accurate measurement of the resonance strength can improve the reaction rate determination and will help constraining the RGB and AGB models.

The strength of the $E_{\rm c.m.}$ = 65 keV resonance is presently determined only through indirect measurements [14–16]. In a recent reevaluation by Fox et al. [17], the $\omega\gamma$ was calculated from the reported resonance strengths of ^{17}O(p,α)^{14}N, ^{14}N(α,γ)^{18}F and from the Γ_α partial width obtained by the ^{14}N(α,α') scattering data [14]. The value reported by Fox et al. [17] for the resonance strength $\omega\gamma = (1.6 \pm 0.3) \times 10^{-11}$ eV. Recent measurements of the ^{17}O(p,γ)^{18}F reaction performed at LUNA using both the prompt γ-ray detection and the activation method led to a precise determination of the $E_{\rm c.m.}$ = 183 keV resonance strength [7], while a direct measurement of the $E_{\rm c.m.}$ = 65 keV resonance strength remained prohibitive because of background and efficiency limitations.

2 Experimental Setup

Starting from the resonance strength reported in [17], the expected yield is less then 1 count/C. For this reason the setup must be optimized in terms of background reduction to overcome a disfavoured signal-to-noise ratio.

In order to minimize the γ-ray absorption the scattering chamber and target holder of the setup are made of aluminum. To maximize the detection efficiency a 4π BGO detector is installed all around the target. Solid targets are produced by anodization of tantalum backings in enriched, 90% ^{17}O, water with well-known stochiometry, Ta_2O_5 [18]. In order to characterize and monitor target thickness they will be doped in ^{18}O (at the level of 5%). This will allow to periodically scan the $E_{\rm c.m.} = 143$ keV resonance of the ^{18}O(p,γ)^{19}F reaction as monitor for target degradation. Finally in order to further reduce the environmental background the whole setup is surrounded by a shielding made of borated polyethylene and lead, as neutron and gamma absorber, respectively [19]. Figure 1 shows the upgraded setup.

3 Preliminary Results

Tests have been performed to fine tune and characterize the present setup.
Preliminary GEANT4 simulations show a 30% improvement in the detection efficiency at the E_γ = 662 keV with respect to the previous setup configuration, with a steel chamber and a brass target holder. The comparison is shown in Figure 2.
The 30 day long observed background count rate in the region of interest is (0.08 ± 0.01) counts per hour, reduced by a factor of (4.2 ± 0.8) with respect to using the BGO unshielded [20]. The average current for proton beam energy of about 75 keV is $I_{\rm b} = 100\,\mu A$. According to the above preliminary evaluations the detection limit was calculated following [21] and a resonance strength of the order of 10^{-11} eV can be detected.
LUNA now has the good opportunity of directly measuring this resonance in spite of its low

strength, with expected large impact on the $^{17}O(p,\gamma)^{18}F$ reaction rate and our understanding of AGB nucleosynthesis processes.

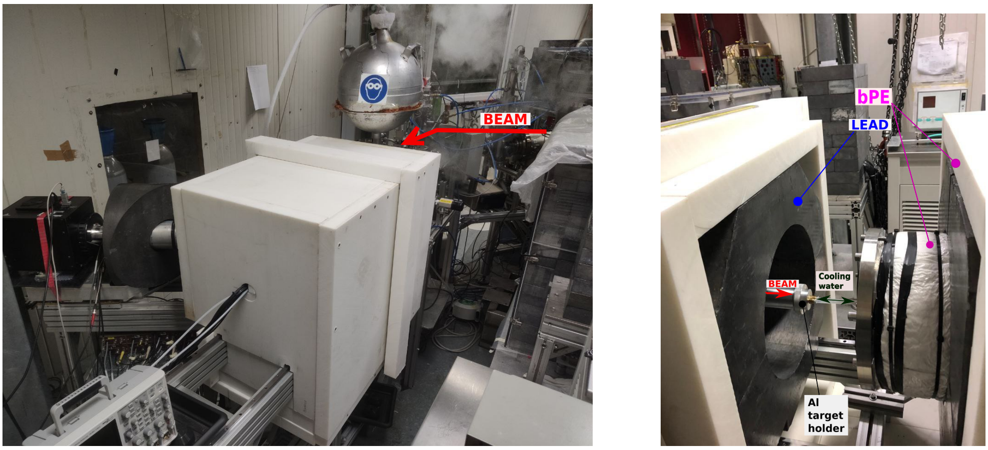

Figure 1: Present setup for the $^{17}O(p,\gamma)^{18}F$ cross section measurement at LUNA. Left: the external borated Polyethylene shielding. Right: the three-layer shielding opened to show the aluminum chamber and target holder to which the water cooling is connected. Part of the BGO detector is also visible inside the shielding.

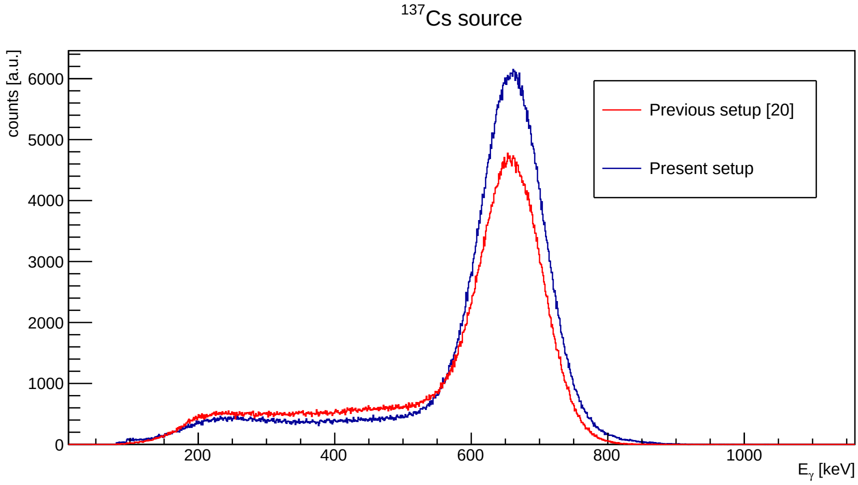

Figure 2: Comparison between ^{137}Cs spectrum simulated with present setup, blue line, and with previous setup, red line.

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