Towards a direct measurement of the E_{cm}= 65 keV resonance strength in $^{17}O(p, \gamma)^{18}F$ at LUNA

G.F. Ciani[1], **D. Piatti**[2] **for the LUNA collaboration**

[1] Università degli Studi di Bari, Dipartimento interateneo di fisica "M. Merlin" & INFN Bari
[2] Università degli Studi di Padova, Via Marzolo 8 35136 Padova (Italy) & INFN Division of Padova, Via Marzolo 8 35136 Padova (Italy)

E-mail: giovanni.ciani@ba.infn.it

Abstract. The $^{17}O(p, \gamma)^{18}F$ reaction plays a crucial role in several stellar scenarios where the hydrogen burning phases takes place. In particular, in the temperature energy range of interest for AGB nucleosynthesis (20 MK< T <80 MK) the main contribution to the astrophysical reaction rate comes from the elusive 65 keV resonance. Indeed, this resonance strength is at the moment determined only through indirect measurements, with a reported value of $\omega\gamma$ = $(1.6 \pm 0.3) \times 10^{-11}$ eV. With typical experimental quantities for beam current, isotopic enrichment and detection efficiency, this strength yields an expected count rate of less than one count per Coulomb, making the direct measurement of this resonance extremely challenging. The Laboratory for Underground Nuclear Astrophysics (LUNA) 400kV accelerator installed in Laboratori Nazionali del Gran Sasso (Italy) provides a unique possibility to directly measure this low resonance thanks to the reduction of cosmic ray background by six orders of magnitude with respect surface laboratories and thanks to an intense, narrow proton beam. To improve the experimental sensitivity, the environmental background was further reduced designing a lead and borated (5%) polyethylene shielding and the absorption of $\gamma - rays$ emitted by the reaction was minimised by the installation of target chamber and holder made of aluminum.
With about 400 Coulomb accumulated on Ta_2O_5 targets, with nominal ^{17}O enrichment of 90%, the LUNA collaboration has performed the first direct measurement of the 65 keV resonance strength.

1. Introduction

Precise determination of proton capture rates on oxygen isotopes, in particular for the $^{17}O(p,\gamma)^{18}F$ and the $^{17}O(p,\alpha)^{14}N$ reactions, are necessary to calculate the abundance ratios of the oxygen isotopes in a stellar environment where hydrogen burning is active. The $^{17}O(p,\gamma)^{18}F$ reaction plays a key role in AGB nucleosynthesis, but is also of importance in explosive hydrogen burning occurring in novae.

At temperatures below 1 GK, the main contributions to the astrophysical reaction rate come from two narrow resonances at E_{cm} = 65 and 183 keV and from non-resonant contributions, which include a direct capture (DC) component and the tails of two broad resonances at E_{cm} = 557 keV and 677 keV. Figure 1 shows the fractional contributions to the reaction rate of each component as a function of the temperature. The main contributions to the reaction rate in the temperature range of interest for quiescent H burning and AGB nucleosynthesis (20 MK $\leq$ T $\leq$ 80 MK) stem from the E_{cm} = 65 keV resonance and to a lesser extent from the non-resonant component.

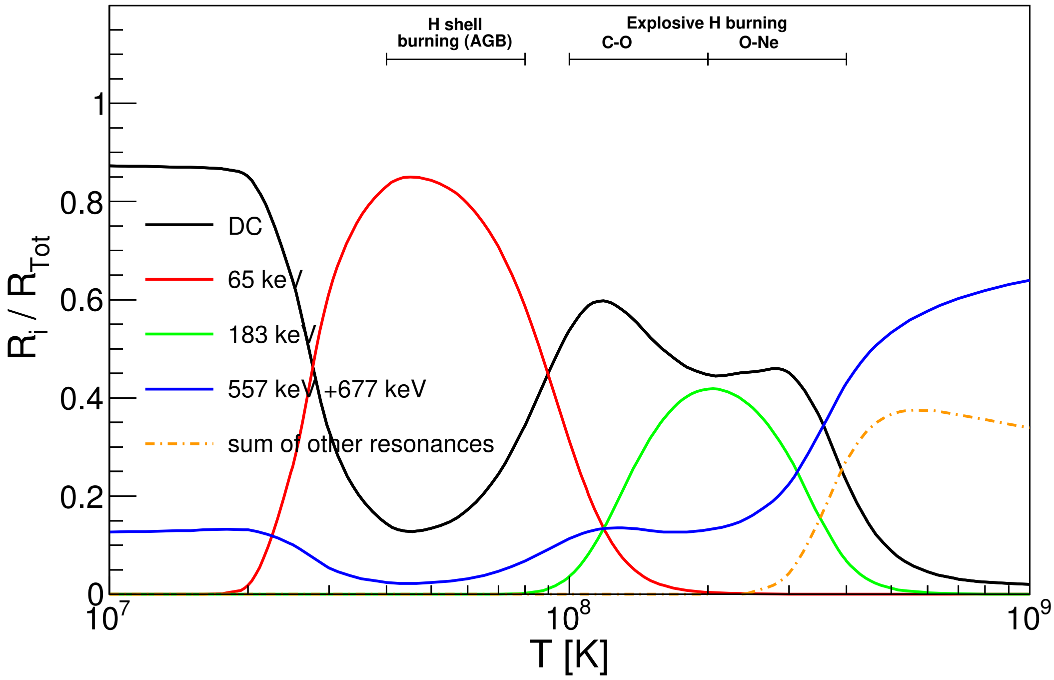

Figure 1: Fractional contributions of the low-energy resonances and the direct component (DC) to the reaction rate of ^{17}O(p,γ)^{18}F, as a function of temperature [3]

A recent direct measurement of the 65 keV resonance in the $^{17}O(p,\alpha)^{14}N$ reaction ($Q = 1192$ keV) at LUNA[1] had a paramount impact in determining that oxygen-rich pre-solar grains of group II are most likely formed at the base of the convective envelope during the late evolution of intermediate-mass stars of 4-8 solar masses [2]. For this reason, an accurate measurement of the resonance strength could improve the reaction rate determination and would help to constrain RGB and AGB models evolution. The strength of the E_{cm} = 65 keV resonance is presently determined only through indirect measurements, the Γ_γ and Γ_α were provided by measurement of the ^{14}N(α,γ)^{18}F and ^{14}N(α,α)^{14}N reaction respectively [4, 5]. The Γ_p is derived from the $\omega\gamma$ of the $^{17}O(p,\alpha)^{14}N$ channel resulting in the adopted $\omega\gamma_{(p,\gamma)} = (16 \pm 3)$ peV [6].

Such a low resonance strength translates in an expected rate as low as one reaction per Coulomb, thus a direct measurement of the E_{cm} = 65 keV resonance strength required both a high sensitivity setup and a devoted technique to monitor and subtract potential beam-induced background and LUNA already tried to measured such weak resonances in the past with a gas target[7]. In following sections the setup, and the analysis approach will be described.

2. The experimental setup

The measurement was performed at LUNA laboratory, located in the deep underground facility of Laboratori Nazionali del Gran Sasso (LNGS, Italy) [8]. Thanks to the 1400m overburden rock of Gran Sasso mountain, here the muon and neutron background are reduced by a factor 10^6[9] and 10^3[10] with respect to the surface laboratories, respectively.
In order to increase signal to background ratio, the detection efficiency was maximized using an high efficiency detector and selecting materials to minimize γ-ray attenuation. A segmented 4π BGO detector was used. The detector is segmented in six optically independent crystals,

which coupled with a listmode DAQ for the reading of single crystal and the construction of an add-back spectrum, adding coincident events in the individual crystals [11]. Both the scattering chamber and the target holder were designed in aluminum, reducing gamma attenuation and providing an increase in efficiency of more than 20% with respect to previous setup made of stainless-steel and brass. Gamma detection efficiency has been calculated both using a devoted Monte Carlo code based on GEANT4 [12] and validated using standard calibration sources (^{60}Co and ^{137}Cs) Just for reference, with these improvements the detector efficiency is about 74% at 661 keV ^{137}Cs γ-line.
A three layer shielding made by 1 cm thick layer of borated(5%) polyethylene (BPE), 15 cm thick lead shielding and 5 cm thick borated (5%) polyethylene envelope was installed around the detector to further reduce the background contribution coming from environmental background and neutron capture events. A drawing of the setup is shown in Figure 2.

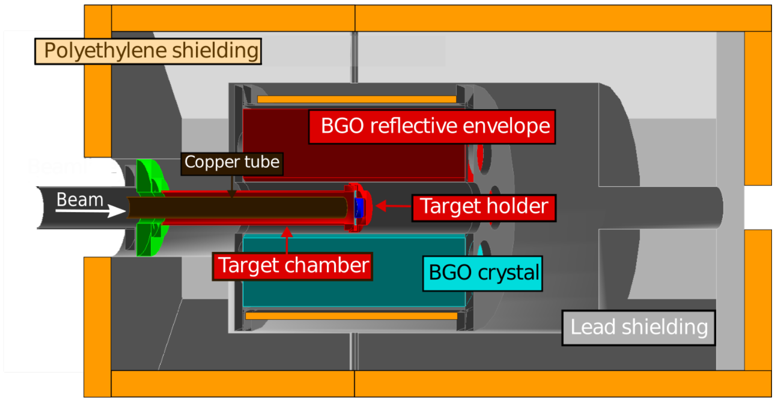

Figure 2: Section of the 3D model of the detector setup.

The BPE absorber reduced the background by a factor 4.3 ± 0.1 in the region of interest (ROI) of our measurement (5.2 - 6.2 MeV), with respect the shielding with only lead [11]. The high stability and high intensity (200 μA) 80 keV proton beam provided by LUNA400kV accelerator was delivered through a Cu pipe to the target. The copper tube was used as cold finger, to prevent carbon build-up, and with applied - 300 V as secondary electron suppressor. The Ta_2O_5 solid targets were produced by anodization of tantalum backings in water solution with 90% ^{17}O, 5% ^{18}O and 5% ^{16}O. The target was water cooled to dissipate about 100 W beam power and minimize target degradation. Furthermore, possible target modifications under the intense proton beam are monitored by the periodic scan of the E_p = 151 keV narrow resonance of the $^{18}O(p,\gamma)^{19}F$ reaction[14].

3. Data analysis and future prospectives

For the evaluation of the E_{cm} =65 keV resonance strength, about 400 C were accumulated on about 20 Ta_2O_5 targets. Moreover, 400 Coulombs were accumulated on target smade using ultra-pure water with natural abundance of oxygen and therefore a negligible amount of ^{17}O for the evaluation of beam induced background. The main source of beam induced background cames from deuterium contamination in the tantalum: the reaction p(d,γ)^{3}He (Q = 5495 keV) emits single γ-rays by direct capture reaction to the ground state in the same ROI of the ^{17}O(p,γ)^{18}F. For the beam induced background subtraction, two indepentent approaches will be applied.
One is based on the BGO detector segmentation and on the precise knowledge of the E_x = 5672 keV de-excitation cascade branching ratios [13], an unequivocal signature of the reaction of interest.
The technique, thanks to the data acquisition in list mode, isolates γ-rays transition with at

least multiplicity 2, contributing to the sum peak, in the ROI between 5200 and 6200 keV in the add-back spectra, and with energies matching the $E_\gamma = 5672\,\mathrm{keV}$ de-excitation cascade. In this way events with multiplicity 1 were discarded. This allows an almost complete background subtraction while losing only a small amount of events of interest, since the probability of de-excitation to ground state transition of E_{cm} = 65 keV is 6%.
Residual spurious coincidences by beam induced background were subtracted applying the same analysis on ultra-pure water target spectra.
In addition, a second technique has been developed by comparison between on-resonance spectra acquired with ^{17}O target and ultra-pure water targets. The excess of counts observed in the former is due to the resonant signal, from which a resonance strength could be derived in a Monte Carlo based approach developed by Rolke [15]. 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. Further details on the setup and on the technique used can be found in a technical paper recently published [16], while the final results on the resonance strenght will be published in a following paper.

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