

Introduction of the new LUNA experimental setup for high precision measurement of the $^{13}\text{C}(\alpha,n)^{16}\text{O}$ reaction for astrophysical purposes

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Abstract. The $^{13}\text{C}(\alpha,n)^{16}\text{O}$ reaction is the prevalent neutron source for the main *s*-process. The direct measurement of this reaction at stellar temperature ($kT=8$ keV) has so far not been possible due to the very low cross section at the corresponding energy. The extrapolation of the astrophysical *S*-factor of this reaction into the Gamow window ($E_{\alpha,c.m.}=140\text{-}230$ keV) is complicated by the large uncertainties of the low-energy experimental data and the existence of a state of ^{17}O near the α -threshold that can have a large effect on low energy cross section. The aim of this paper is to introduce the new LUNA experimental setup, dedicated to the investigation of $^{13}\text{C}(\alpha,n)^{16}\text{O}$ reaction below $E_{\alpha,\text{lab}}=400$ keV.

1 Introduction

The $^{13}\text{C}(\alpha,n)^{16}\text{O}$ reaction is very important in astrophysical context. This reaction is the dominant neutron source for the synthesis of the main *s*-process component of heavy elements in thermally pulsing, low-mass asymptotic giant branch (AGB) stars [1]. Several papers can be found in literature using direct [2-6] and indirect [7-10] methods to investigate the behaviour of the $^{13}\text{C}(\alpha,n)^{16}\text{O}$ reaction. However, the extrapolation of the astrophysical *S*-factor of this reaction into the Gamow window ($E_{\alpha,c.m.}=140\text{-}230$ keV) is challenging due to the contested effect of a resonance of ^{17}O located near the threshold and high uncertainties of the experimental data in the low-energy region.

The aim of the new project at the LUNA 400 kV accelerator is the determination of cross section of the $^{13}\text{C}(\alpha,n)^{16}\text{O}$ reaction approaching, in energy, the Gamow window with an accuracy of about 10% being performed in the Laboratori Nazionali del Gran Sasso (LNGS), Italy. The LNGS Underground Laboratory provides an ideal environment to establish the direct measurement of this reaction at low energy thanks to the reduction of neutron background with 3 orders of magnitude compared with other experiment performed on the Earth surface. This paper gives an overview of the design and of the features of the experimental setup. Moreover, the characterization of the environmental neutron and gamma-ray background and preliminary results of the efficiency calculation using Geant4 code [11] are presented.

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2 Experimental setup

The LUNA setup for the investigation of the $^{13}\text{C}(\alpha,n)^{16}\text{O}$ reaction is shown in figure 1. The setup includes 18 ^3He counters under a pressure of 10 atm (6 counters with 25 cm and 12 with 40 cm active length) with stainless steel body material. As ^3He has a very high cross section for capturing thermal neutrons through the reaction $^3\text{He}(n,p)^3\text{H}$ ($\sigma=5330$ barn, $Q=764$ keV), effective thermalisation of the emitted neutrons from the $^{13}\text{C}(\alpha,n)^{16}\text{O}$ reaction is required. Therefore, counters are embedded in a polyethylene moderator arranged in two cycles. Additionally the polyethylene block will be coated with borated-polyethylene for further reduction of count rates from the environmental neutron background.

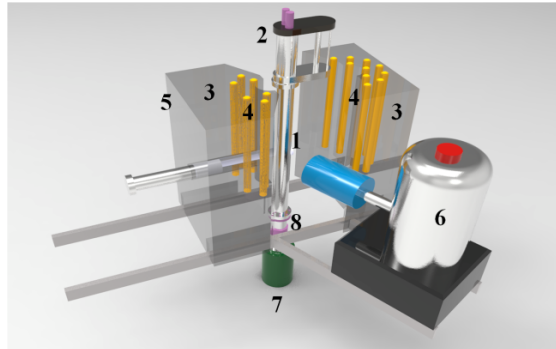


Fig. 1. Design of the experimental setup: 1-Vacuum chamber, 2-Linear motion feedthrough, 3-Polyethylene moderator composed of the two separable parts (left and right side with respect to the vacuum chamber), 4- ^3He counters embedded in the moderator, 5-Borated-polyethylen shield, 6-HPGe detector, 7-Vacuum pump, 8-Electrical vacuum break.

In the energy range of the LUNA-400, the $^{13}\text{C}(p,\gamma)^{14}\text{N}$ reaction is suitable for the monitoring of the target degradation before and after the alpha irradiation. Therefore, the setup is designed to allow the use of a High-Purity Germanium (HPGe) detector in close geometry during the experiment. In regular intervals the $^{13}\text{C}(\alpha,n)^{16}\text{O}$ measurement can be interrupted, the moderator opened and the target degradation can be checked observing the $^{13}\text{C}(p,\gamma)^{14}\text{N}$ reaction with the HPGe detector.

Multi-stage target holder is applied to minimize the possible contamination and simplify the target changing procedure during the experiment. Moreover, cooling loop is integrated in the target holder for effective removing the dissipated beam power.

2.1. Characterization of environmental background

Left and right panels of figure 2 present the comparison of measured gamma-ray and neutron environmental background on surface and in LNGS Underground Laboratory. The violet bars include the region of the thermal neutron peak. Signals beyond this region are due to alpha intrinsic background. Underground neutron measurement using the counters agrees with the most recent literature value [12]. The intrinsic background of ^3He counter is in the range of $10^{-8} \text{ cm}^{-2} \text{ s}^{-1}$, which is essential for the measurement of the $^{13}\text{C}(\alpha,n)^{16}\text{O}$ reaction at low bombarding energy range.

2.2. Simulation of neutron detection efficiency

The geometry of the experimental setup is optimized, using Geant4 simulation, to reach the highest neutron detection efficiency in the energy region of our interest ($E_{\alpha} \sim 2.1\text{-}2.5$ MeV). The estimated neutron detection efficiency of the setup is $\epsilon_{\text{tot-n}} \sim 40\%$. However for

the validation of the Geant4 simulation and the determination of absolute neutron detection efficiency, the measurement using calibrated neutron source and/or particle induced neutron threshold nuclear reaction are required.

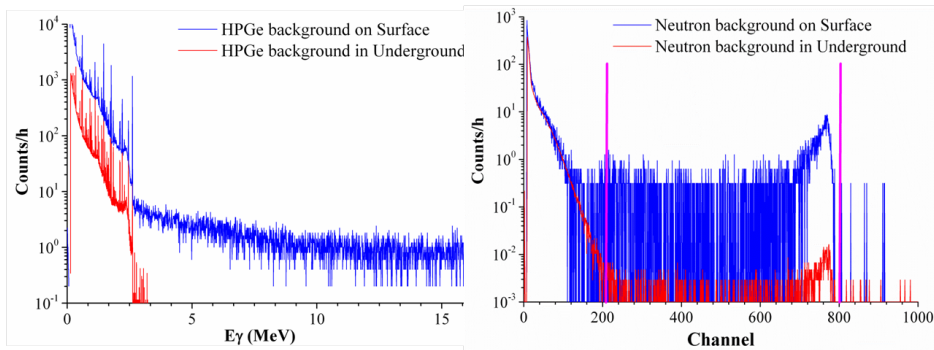


Fig. 2. Left panel: Gamma-ray environmental background measured on surface (blue line) and in the LNGS Underground Laboratory (red line) with HPGe detector – Right panel: Environmental neutron background measured on surface (blue line) and in the LNGS Underground Laboratory (red line) with a ³He counter. The violet bars include the region of the thermal neutron peak. Signals beyond this region are due to alpha intrinsic background.

3 Summary and outlook

In the LNGS Underground Laboratory, a new high efficiency setup is designed and developed to investigate the low energy yield of the ¹³C(α ,n)¹⁶O reaction close to its Gamow window. Neutron and gamma-ray environmental background are characterized and the commissioning phase of the experimental arrangement is in progress.

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