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Low energy cross section of $^{18}\text{O}(p,\gamma)^{19}\text{F}$

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Abstract. The observation of oxygen isotopes in giant stars sheds light on mixing processes operating in their interiors. Due to the very strong correlation between nuclear burning and mixing processes it is very important to reduce the uncertainty on the cross sections of the nuclear reactions that are involved. In this paper we focus our attention on the reaction $^{18}\text{O}(p,\gamma)^{19}\text{F}$. While the $^{18}\text{O}(p,\alpha)^{15}\text{N}$ channel is thought to be dominant, the (p,γ) channel can still be an important component in stellar burning in giants, depending on the low energy cross section. So far only extrapolations from higher-energy measurements exist and recent estimates vary by orders of magnitude. These large uncertainties call for an experimental reinvestigation of this reaction.

We present a direct measurement of the $^{18}\text{O}(p,\gamma)^{19}\text{F}$ cross section using a high-efficiency 4π BGO summing detector at the Laboratory for Underground Nuclear Astrophysics (LUNA). The reaction cross section has been directly determined for the first time from 140 keV down to 85 keV and the different cross section components have been obtained individually. The previously highly uncertain strength of the 90 keV resonance was found to be three orders of magnitude lower than an indirect estimate based on nuclear properties of the resonant state and a factor of 20 lower than a recently established upper limit. This result excludes the possibility that the 90 keV resonance can contribute significantly to the stellar reaction rate.

In addition the strengths and branching ratios of resonances between 150 and 400 keV have been determined with much improved precision and sensitivity using a HPGe detector, including a first measurement of branching ratios of the 216 keV resonance. Preliminary results are presented.

1. Introduction

The relative strength of the reactions $^{18}\text{O}(p,\alpha)^{15}\text{N}$ and $^{18}\text{O}(p,\gamma)^{19}\text{F}$ influences a variety of stellar observations: two examples are the ^{19}F enhancement in thermally pulsing stars [1] and the possibility to use the $^{16}\text{O}/^{18}\text{O}$ ratio in stellar atmospheres as a probe for mixing processes in their interiors [2]. Significant attention has been devoted to



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the $3/2^+$ $E_x = 8080$ state in ^{19}F that corresponds to a resonance with $E_{cm} = 90$ keV in the two reaction channels; but only the α channel has been directly measured so far (see [3] and references therein). The strength of the 90 keV resonance in the $^{18}\text{O}(p,\gamma)^{19}\text{F}$ channel has so far eluded a direct determination, with one recent attempt being able to produce an upper limit [4] weak enough to exclude any astrophysical importance. Shortly thereafter though a calculation of the resonance strength using nuclear parameters of the state resulted in a possibly very high strength of the 90 keV resonance, high enough to dominate the reaction rate over a large temperature range and to have a strong impact on stellar calculations [5]. In order to resolve this issue a new direct measurement has been performed with the LUNA 400 accelerator at the deep underground Gran Sasso National Laboratory in Italy. The 1400 meter rock overburden provides a very strong background suppression, allowing the measurement of very low nuclear cross section that are unreachable in laboratories on the surface of the Earth [6]. The LUNA 400 accelerator provided proton beams with energies between 50 and 400 keV and currents of up to a few 100 μA . The measurement was performed in two phases at the “solid target” beamline: the low-energy cross section was measured in a first campaign using a high-efficiency 4π BGO detector [7], then a high-resolution HPGe detector was used to measure branchings and strengths of higher-energy resonances. The targets were produced using the well-known anodization of tantalum with water enriched with 99% ^{18}O . Preliminary results of both campaigns are presented here.

2. Data analysis and results

2.1. Low-energy campaign

The goal of this part of the campaign was to determine the strength of the 90 keV resonance and provide a direct measurement of the direct capture cross section. Therefore, the BGO measurements focused on the region below a strong resonance at $E_p = 151$ keV, covering the energy range between 85 and 155 keV. The total reaction cross section in this region is composed of three different components: the direct capture component and the 90 and 151 keV resonances. In order to disentangle the three contributions to the reaction yield a least-squares analysis of the measured yield $Y(E)$ was performed, using the relation between cross section and yield:

$$Y(E) = \int_{E-\Delta E}^E \frac{\eta_1 \sigma_{BW_1}(E) + \eta_2 \sigma_{BW_2}(E) + \eta_3 \sigma_{DC}(E)}{\epsilon(E)} dE, \quad (1)$$

where the η_i are the detection efficiencies of the BGO for the gamma decay pattern of the different components and the σ_{DC} and σ_{BW} are the direct capture and the resonant (Breit-Wigner) cross sections. ϵ is the stopping power of the target material. The detection efficiencies were determined using simulations with Geant4 [8].

Results are shown in fig. 1. As can be seen, we were able to directly measure the resonance strength (details in [9]). Its value is in agreement with the upper limit, confirming that the resonance does not play a role in astrophysics.

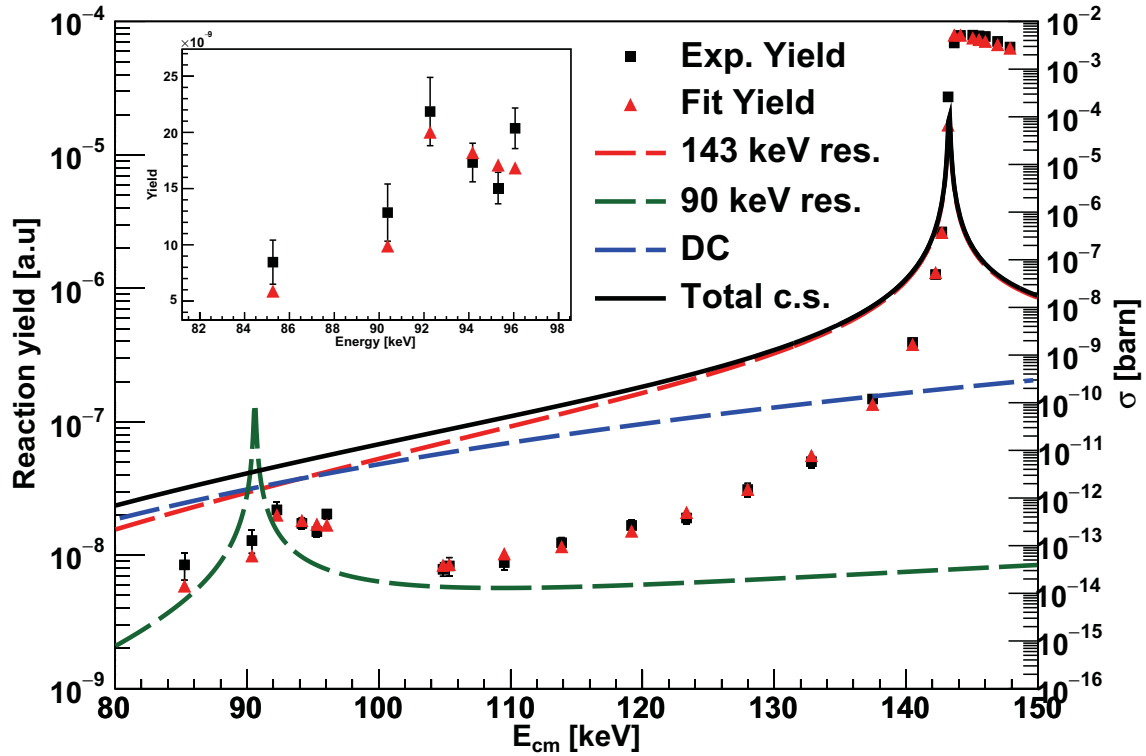
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Figure 1. Cross section components and measured yields of the low-energy region of the reaction $^{18}\text{O}(p,\gamma)^{19}\text{F}$. Figure from [9], ©2019 the authors of [9] - CC BY 4.0.

2.2. Germanium phase

Between the 90 keV resonance and 400 keV (the upper limit of the reachable energy at LUNA 400) there are four resonances that are strong enough to be measured using a HPGe detector: they are located at proton energies of 151, 216, 278 and 334 keV. Their strengths have previously been determined, but only limited information on the gamma decay branchings is available so far [10]. At LUNA, we performed long runs in-resonance and obtained high statistics spectra of all four resonances. Many new transitions were observed, and in the case of the 216 keV resonance we were able to measure the branchings for the first time (seven transitions were observed [11]). A spectrum taken in the 216 keV resonance is displayed in fig. 2. A detailed publication on this campaign is in preparation.

3. Conclusions

In summary, a direct determination of both the 90 keV resonance strength and the low energy direct capture cross section has been performed for the first time at LUNA 400. We confirmed a low strength of the resonance, ruling out a possible astrophysical importance of the state. The direct capture cross section is in good agreement with [10]. In addition we performed high-statistics measurements of the $E_p = 151, 216, 174$ and

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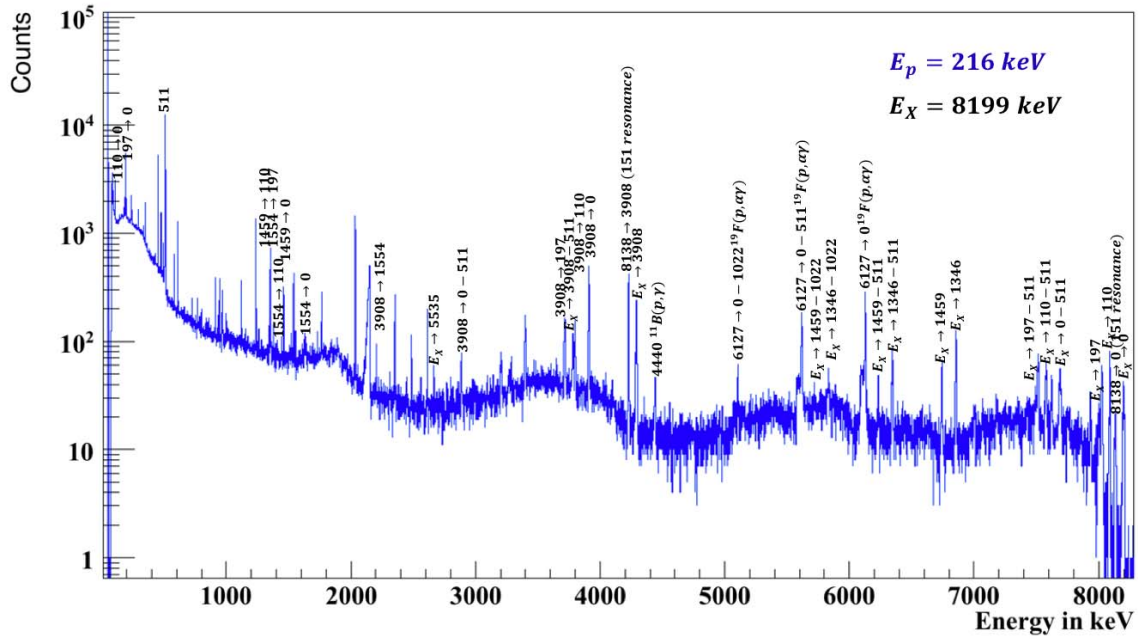


Figure 2. On-resonance spectrum of the 216 keV resonance [11].

332 keV resonances, greatly improving our knowledge of the gamma decay branchings of these states.

Acknowledgments

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