Going Underground To Study Stars

Underground direct study of the $^{17}O(p,\alpha)^{14}N$ reaction at the LUNA accelerator

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1. Motivation

Asymptotic Giant Branch (AGB) stars are the site of several mixing and recirculating processes that transport matter from their hot cores to their cooler surfaces, and *vice versa*. Some of these mixing processes are still not well-understood [1]. Constraining them would improve our understanding of stars that are in or will enter the AGB phase, including our own Sun. An ideal way to trace these poorly-understood mixing processes is the rare, stable ^{17}O isotope [2]. Its abundance is strongly sensitive to the strength of a resonance [3] at E_{proton}=70keV in the nuclear reaction $^{17}O(p,\alpha)^{14}N$ (Q_{val}=1.2MeV). This resonance was the focus of our investigation.

3. The experimental setup

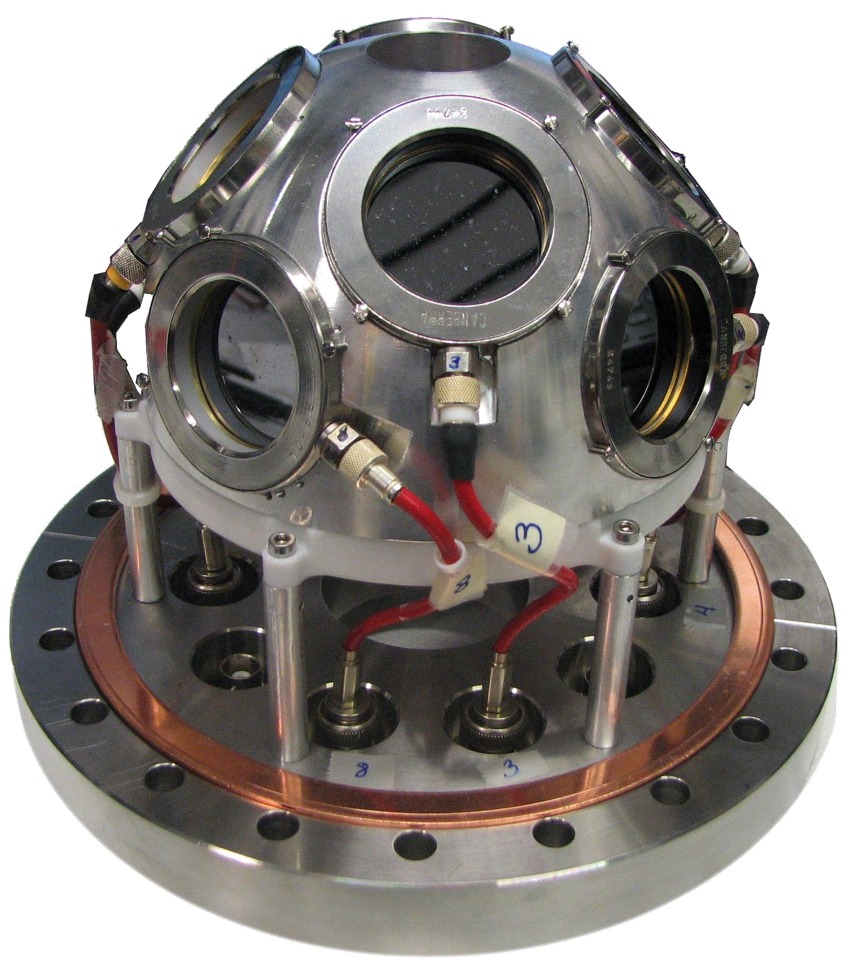

Fig.1: The reaction chamber.

Fig.2 (top) the aluminium dome. (bottom) the copper dome. See text for details

The reaction chamber (Fig.1) consists of two concentric domes. The proton beam enters from the top and reacts with a solid $Ta_2{}^{17}O_5$ target placed at the centre of the two domes. Eight silicon detectors, housed on the outer aluminium dome, detect the alpha particles produced by the reaction. Thin (2.4μm) aluminised Mylar foils were mounted on the inner copper dome (Fig.2) in front of each detector to stop protons elastically scattered off the solid target. These protons would otherwise increase the background and damage the detectors. Aluminised Mylar foils had to be thick enough to stop the protons, yet thin enough to let the alpha particles through with detectable energies. Finding a compromise was challenging. See ref. [5] for further details on the setup's commissioning.

5. What next?

The analysis of our data has been completed and the results are expected to be published forthwith [6]. The abundance of the ^{17}O isotope, a key parameter in several stellar models, is extremely sensitive to the strength of the E_{proton}=70keV resonance in $^{17}O(p,\alpha)^{14}N$. This strength is therefore an important input in the astrophysical computer models of several stellar sites, in particular massive AGB stars. At present, discrepancies in the abundance of ^{17}O are found between calculations and astrophysical observations [1,2]. Our measurement will affect the abundances predicted by stellar models and may potentially improve the agreement between computer models and astrophysical observations.

References

[1] K.M. Nollett *et al*., Astrophys. J 582 (2003) 1036
[2] M. Lugaro *et al*., Astron. Astrophys. 461 (2007) 657
[3] J. Blackmon *et al*., Phys. Rev. Lett. 74 (1995) 2642
[4] C. Broggini *et al*., Ann.Rev.Nuc.Part.Sci. 60 (2010) 53
[5] C.G. Bruno *et al*., Eur. Phys. J. A 51 (2015) 94
[6] C.G. Bruno *et al*., Phys. Rev. Lett., *submitted*

The LUNA collaboration

The LUNA-400kV linear accelerator is currently (2016) the only working underground accelerator in the world. It has been used by the LUNA collaboration since 2003 [4]. More info and full list of collaborators:

http://luna.lngs.infn.it

2. Why underground?

The Earth is constantly bombarded by charged particles known as cosmic rays, which are one of the main sources of background in surface-based detectors. Our experiment was carried out at the LUNA underground accelerator [4] in the Gran Sasso Laboratory (LNGS), Italy. Shielded by more than 1400m of rock, LNGS is ideal for the study of rare events such as the E_{proton}=70keV resonance (~1 cnt/h expected). How effective is moving underground? To find out, we carried out a comparison [5] of the background in Edinburgh and in LNGS (Fig.3). At the energies of interest for our study (~200 keV), we measured a background reduction underground up to a factor of 15, which proved essential to carry out this challenging experiment.

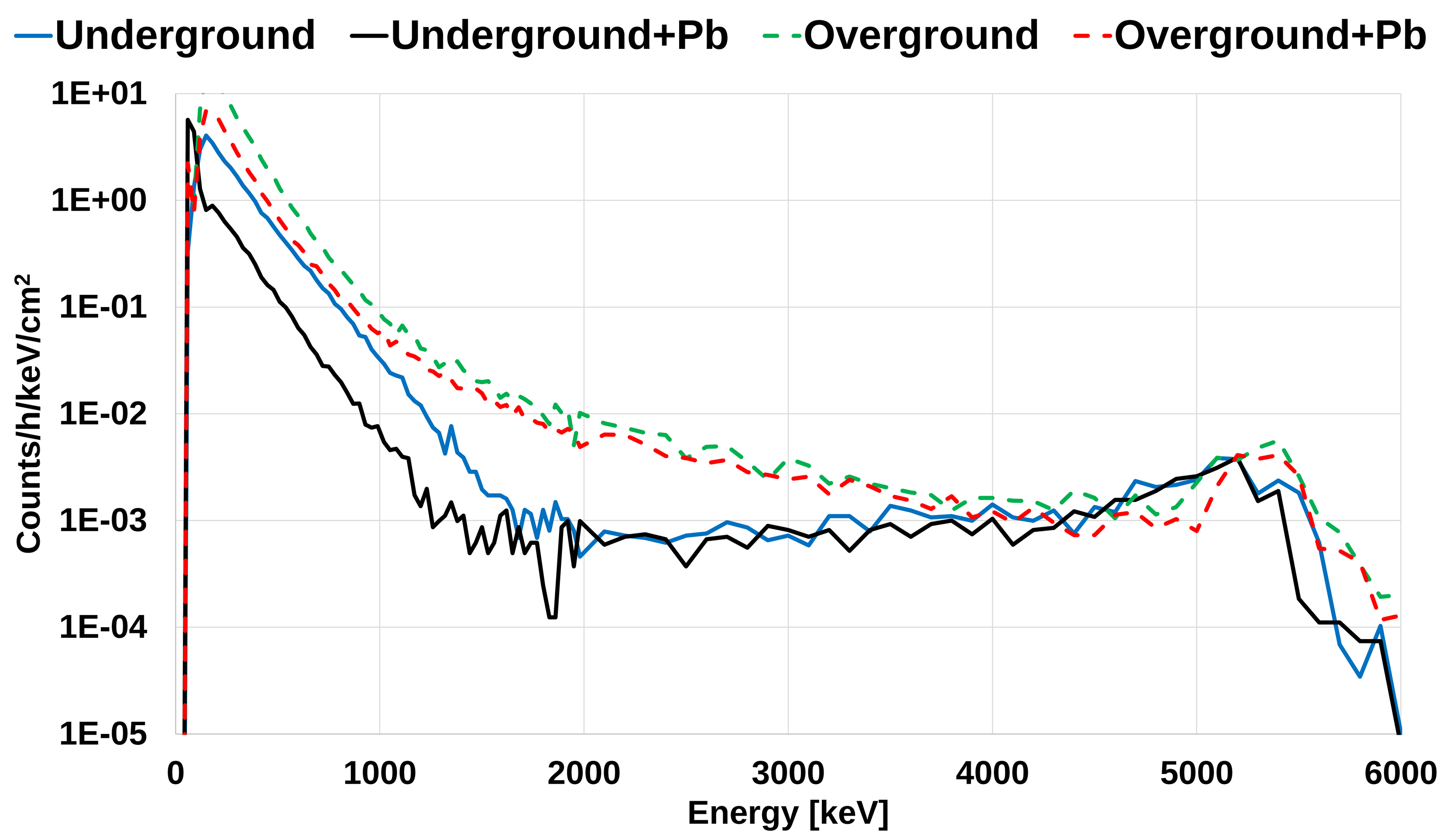

Fig.3: Background spectra taken underground in the Gran Sasso Laboratory, Italy, with (black) and without (blue) a 5cm lead shielding, against background spectra taken overground in Edinburgh, UK, with (red) and without (green) the lead shielding. See text for details.

4. Results

We observed a clear signal for the resonance at E_{proton}=70keV in $^{17}O(p,\alpha)^{14}N$ (Fig.4). Calculations indicate it is twice as strong as previously reported [3]. We carried out this challenging measurement exploiting a well-known resonance at E_{proton}=193keV in $^{17}O(p,\alpha)^{14}N$. This latter resonance is five orders of magnitude stronger [5] than that at 70keV and was used to estimate precisely the region of interest for the alpha particles produced at E_{proton}=70keV. This approach, combined with the background reduction afforded by the underground environment, allowed us to achieve an outstanding precision and accuracy. Because of the low counting rate for our signal of interest, almost 300 hours of natural background measurement as well as 200 hours of beam on target were needed to observe the signal peak shown in Fig.4 (bottom).

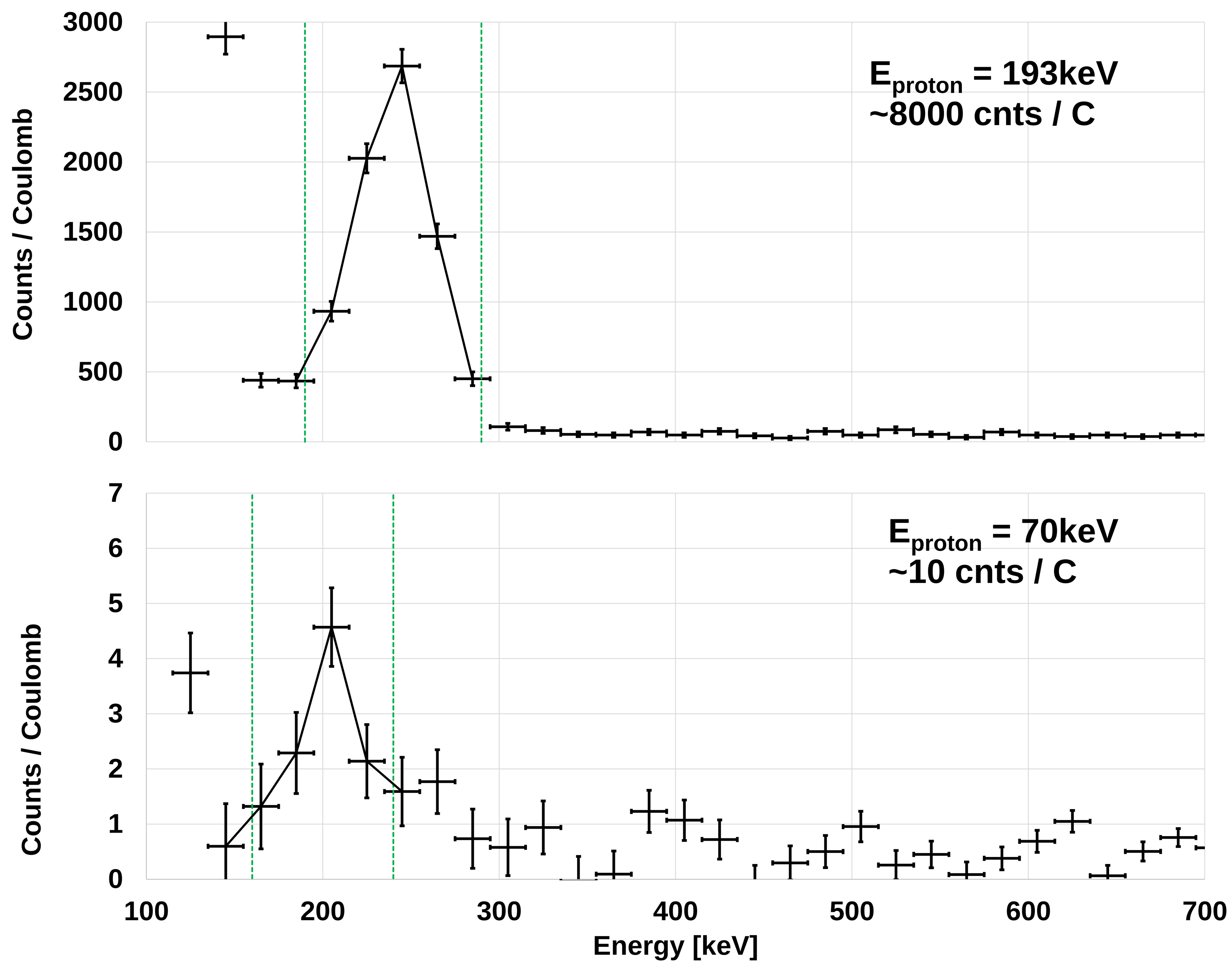

Fig.4. Alpha-particle peaks from the Ep=193keV resonance (top) and Ep=70keV resonance (bottom) in $^{17}O(p,\alpha)^{14}N$. The horizontal error bars indicate the bin size. The green vertical bars indicate the region of interest for the signal. This region was defined at Ep=193keV and shifted [6] at Ep=70keV to account for the lower energies of the alpha particles. The black lines are just guides for the eye.

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