The first direct measurement of the 65 keV resonance strength of the $^{17}O(p,\gamma)^{18}F$ reaction at LUNA

Riccardo Maria Gesuè[1] for the LUNA collaboration

[1] Gran Sasso Science Institute, INFN LNGS

contacts: gesue.riccardo@gssi.it

Astrophysical motivations

- A precise determination of proton capture reaction rates on oxygen is mandatory to predict the abundance ratios of the oxygen isotopes in stellar environments where hydrogen burning is active.
- The $^{17}O(p,\gamma)^{18}F$ reaction (Q= 5607 keV) plays a crucial role in AGB nucleosynthesis and in explosive hydrogen burning occurring in type Ia novae.
- In the the AGB scenario (20 MK < T < 80 MK) the main contribution to the reaction rate comes from the E_{cm} = 65 keV resonance.
- At novae temperatures (100 MK < T < 400 MK) the E_{cm} = 183 keV resonance dominates together with the direct capture (DC) component (Fig. 1).

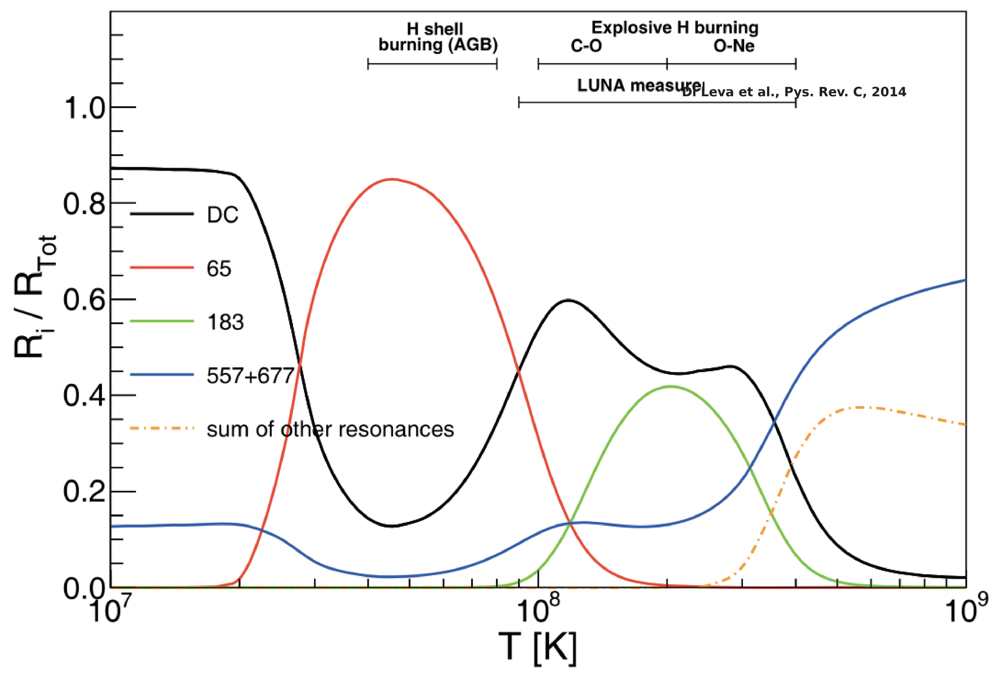

Fig.1: Fractional contribution of the reaction rate of the $^{17}O(p,\gamma)^{18}F$[1].

State of the art

- Recently LUNA performed precise determination of the E_{cm} = 183 keV resonance strength of the $^{17}O(p,\gamma)^{18}F$ reaction[1].
- The strength of the E_{cm} = 65 keV resonance is presently determined only through indirect measurements [2-5], with the adopted value of $\omega\gamma$ = (16±3) peV[5].
- Current adopted value of proton capture partial width Γ_p = (35.0 ± 6.8)x10^{-9} eV [6].
- The branching ratio of the de-excitation of the resonance is well known[7].

Critical points of the measurement

- Low expected counting rate: N = 0.31 reactions/C.
- The environmental and beam induced background must be reduced.
- The knowledge of the beam induced background (BIB) is crucial for the evaluation of the signal.
- The target must be well characterized in thickness and stoichiometry.
- The detection efficency must be maximized.
- Data analysis focused on a regime with S/N ≈ 1.

Target characterization

- Anodisation of tantalum backings in water enriched in ^{17}O and ^{18}O.
- Runs on top of $^{17}O(p,\gamma)^{18}F$ E_{cm} = 183 keV resonance:
  → ^{17}O abundance.
- Periodic scans of the $^{18}O(p,\gamma)^{18}F$ E_{cm} = 144 keV resonance:
  → ^{18}O abundance;
  → target degradation.
- At the energy of interest the plateau remains unchanged within the uncertainties after Q > 20C cumulated on target (Fig.4).
- Produced targets ~20keV and ~50keV thick (@Ep=80 keV, Fig.5).

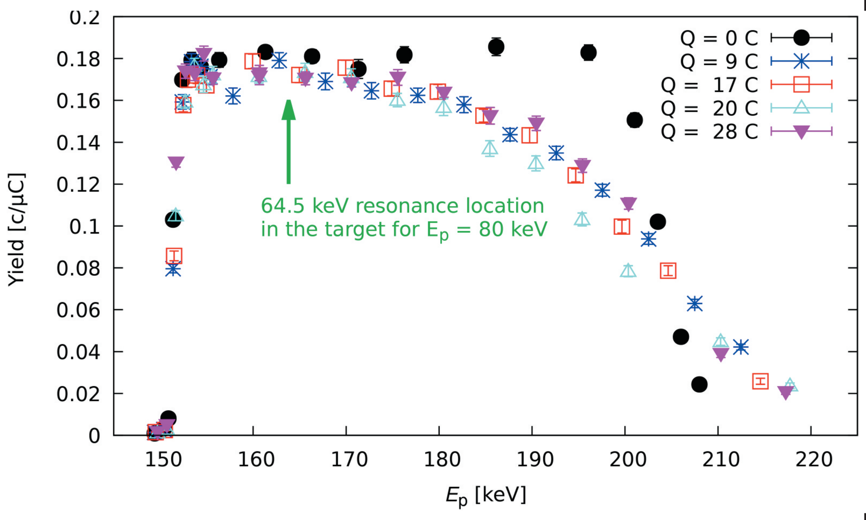

Fig.4: Example of a target scan.

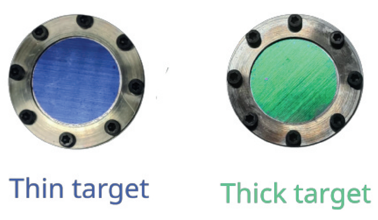

Fig.5: ***Left***: ~20keV thick target. ***Right***: ~50keV thick target .

Experimental setup

- Situated at LNGS below a 1400m thick overburden of rock:
  → Muon-induced background reduced by 6 orders of magnitude;
  → Neutron background reduced by 3 orders of magnitude.
- LUNA 400kV electrostatic accelerator can provide stable and intense (<I>=200 μA), proton or alpha beams with high energy resolution (30 eV) [8].
- 4π BGO detector segmented in 6 crystals, with high efficiency (74%@661 keV, Fig. 2).
- Alluminum target chamber and target holder to reduce absorption.
- Lead + borated polyethylene shielding for further background reduction of a factor 4.27 ± 0.09 in the ROI (5200keV - 6200keV) with respect to only lead shielding (Fig.3)[9].

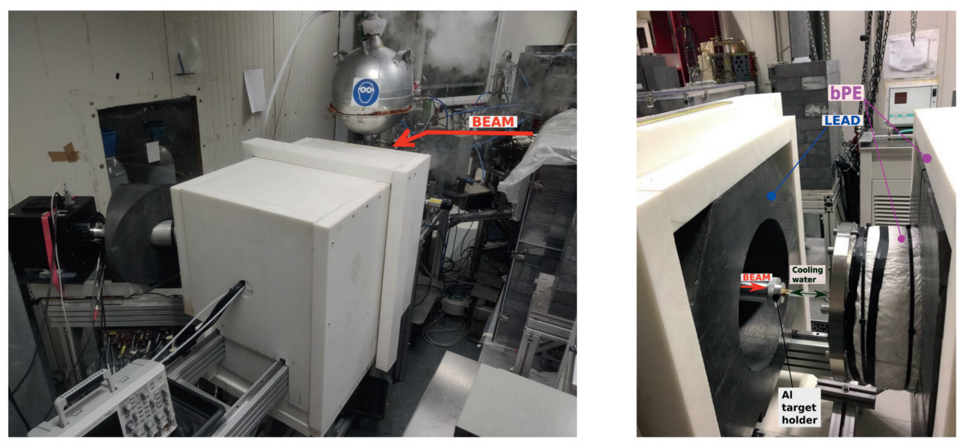

Fig.2: Detail of the shielding.

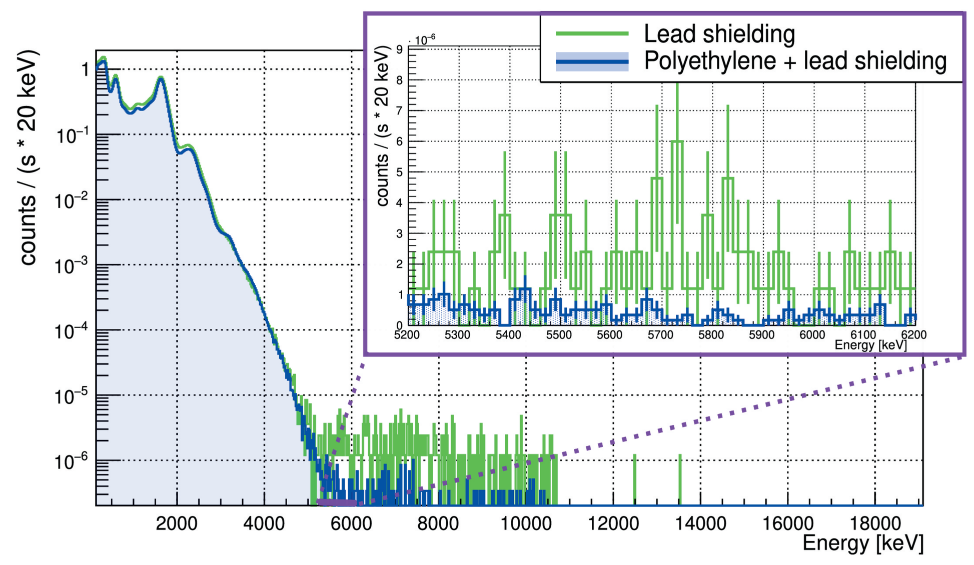

Fig.3: Environmental background reduction[9].

Measurement campaigns

- 4 campaigns in 2021-2022.
- 420C on top of 65keV resonance on ^{17}O targets.
- 300C on top of 65keV resonance on UPW targets to monitor BIB.

Simulation of the setup

- Geant4 simulations optimized on well-known spectra of ^{137}Cs,^{60}Co, ^{14}N+p@270keV (Fig.6).
- Difference with experiment ≲ 3% in all three cases.
- Simulations used to determine detector efficiency.
- DC contribution under the resonance determined simulating branching ratios of [1].

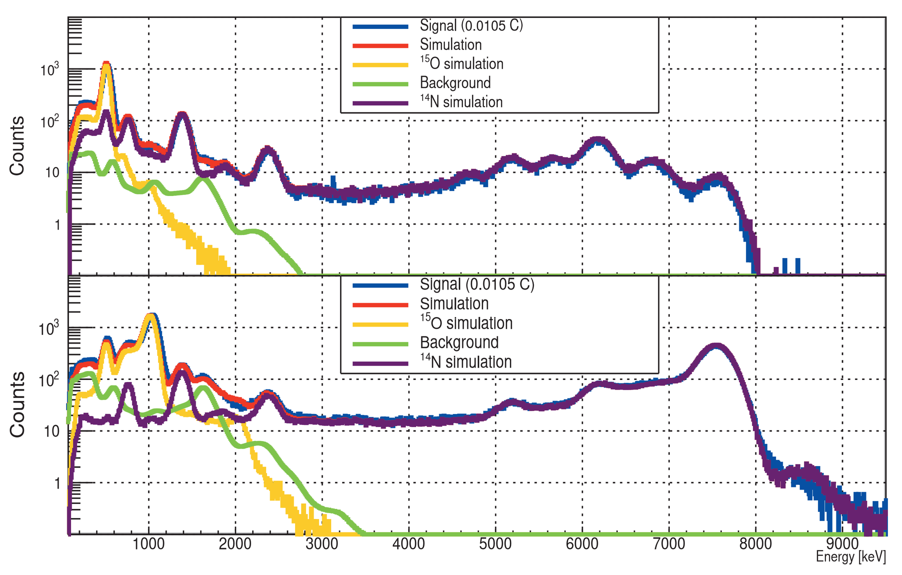

Fig.6: 14N+p@270keV simulation[9].

Data analysis

- Measurement objective are the net counts of the resonance, but p+D sum peak falls in the same ROI → BIB contribution due to D contamination (Fig.7).
- Use the detector segmentation and knowledge on ^{18}F branching ratio to isolate resonance events (Fig.8):
  → Select events in sum peak;
  → Among these select events with primary energy reading in one crystal.
- Apply the same gates on runs on UPW targets to subtract random coincidences.
- Apply the same gates on DC simulation to subtract its contribution under the resonance.

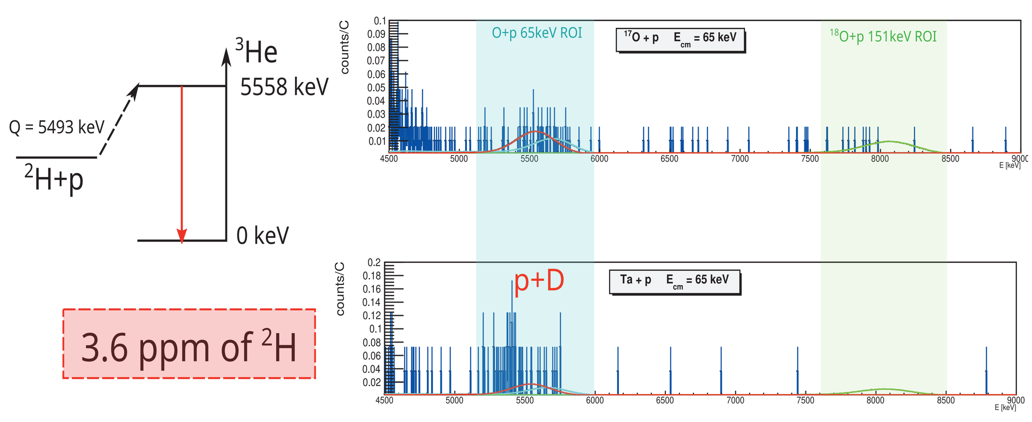

Fig.7: Deuterium contamination.

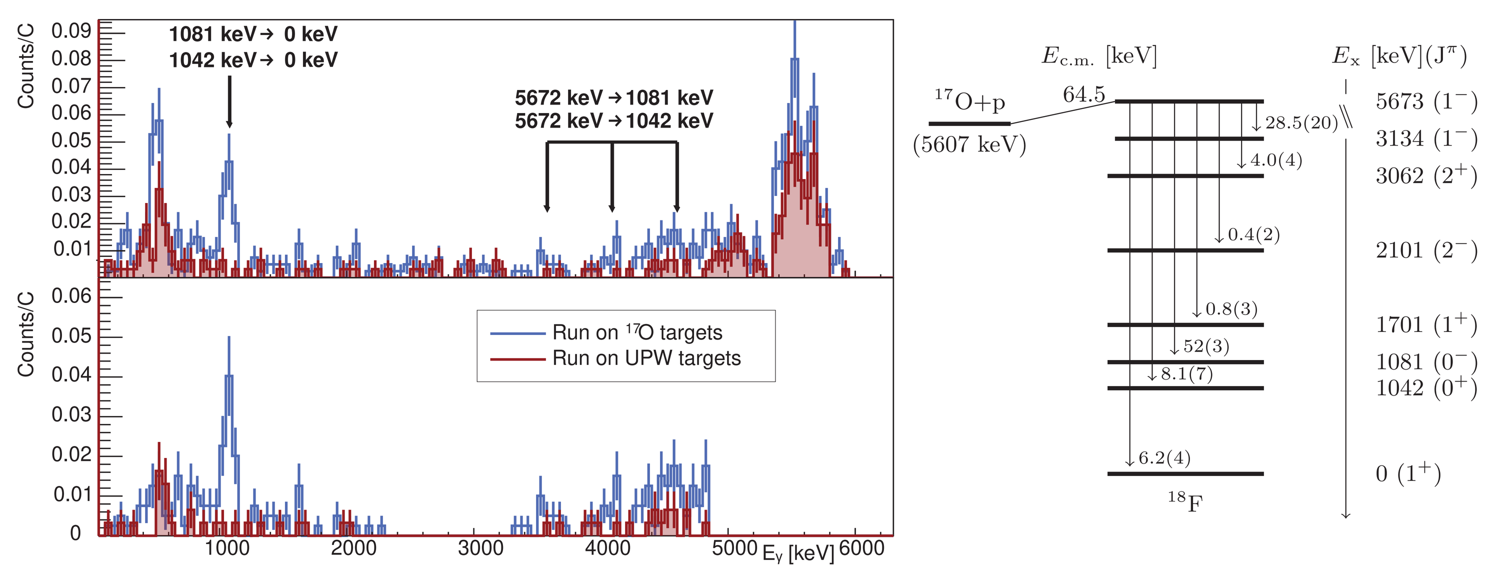

Fig.8: ***Right***: gate on sum peak of ^{17}O+p E_{cm} =65keV resonance[10]. ***Left***: level scheme of ^{18}F with primary branching ratios, as reported in [7].

Results

Reference	$\omega\gamma_{p,\gamma}$ [peV]	$\omega\gamma^{bare}_{p,\gamma}$ [peV]	Γ_p [neV]	Γ^{bare}_p [neV]
Previously adopted value		16(3)[5]	40(7)[6]	35(6)[6]
Present work [10]	34(8)	30(6)	39(9)	34(8)

- First direct measurement of the resonance strength, about a factor 2 higher than the values reported in literature.
- The Γ_p was calculated, in excellent agreement with previous LUNA result [6].
- Lowest strength value ever measured directly.
- Technical paper on setup published [9].
- Results paper published on PRL vol.133 issue 5 [10].

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