ID #106

The SOCIAL project: Measurement of the $^{14}N(p,\gamma)^{15}O$ cross section

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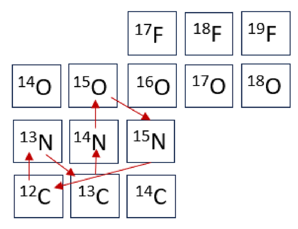
Abstract

Solar neutrinos play a significant role in constraining physical conditions in the interior of the Sun and are a unique tool to investigate its core composition. The $^{14}N(p,\gamma)^{15}O$ cross section is the dominant nuclear error source on neutrino flux predictions. At solar energies (15 - 50 keV) such a cross section is too low to be measured directly, therefore current estimates are based on extrapolations of higher energy data. The SOCIAL project aims at determining the $^{14}N(p,\gamma)^{15}O$ reaction rate at astrophysical energies with 5% precision, as requested by Solar models. We take advantage of the much suppressed gamma-ray background achievable in the underground Gran Sasso laboratory to measure $^{14}N(p,\gamma)^{15}O$ partial cross section in the 100-370 keV energy range. We deliver an intense proton beam from the LUNA accelerator to a solid nitrogen target. Gamma-rays are detected with a high-efficiency 4π-BGO detector composed by 6 independent segments. The data analysis technique will lead to determine the total and the partial cross sections for individual gamma transitions. An overview of the experimental setup and the preliminary data analysis are presented.

Motivation

CNO hydrogen burning in the Sun can be used as a tool to infer the chemical composition of the solar core, through the detection of neutrinos from the β+ decay of ^{13}N and ^{15}O. The rate of the carbon-nitrogen-oxygen (CNO) cycle of hydrogen burning is controlled by the $^{14}N(p,\gamma)^{15}O$ reaction which therefore determines both the energy production rate and the solar neutrinos flux from the CNO cycle.



Experimental setup

- The LUNA-400 accelerator provides proton beams with energies up to 400 keV.
- The system is kept in vacuum by a primary and a turbomolecular pump, reaching pressures of 10^{-7} mBar.
- TiN sputtered targets + Ti inter-layer + Ta backing produced @INFN-LNL (t=70-100-140 nm)
- 4π-BGO detector composed by 6 independent segments + lead shielding (10 cm thickness) all around.

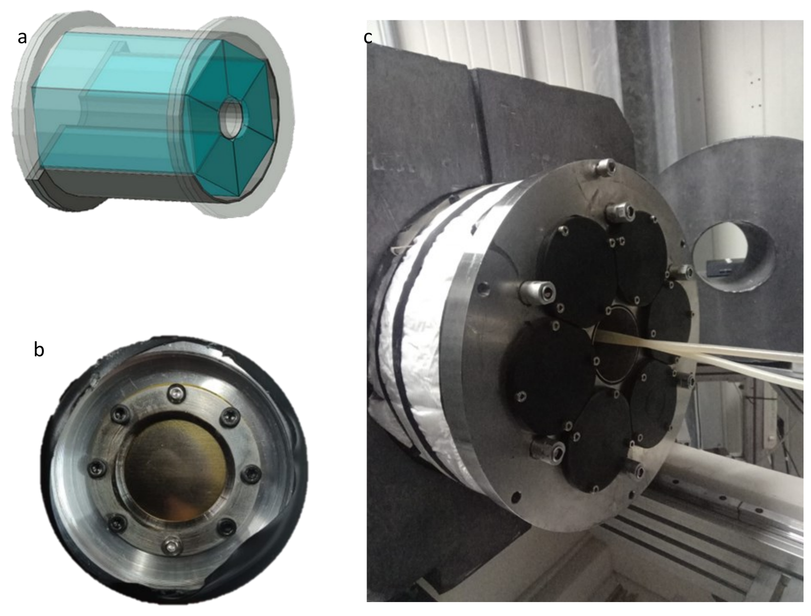


Figure 2: a) Scheme of the BGO detectors and lead shielding, b) picture of the target and the target holder, c) picture of BGO detectors and lead shielding

Target scan analysis

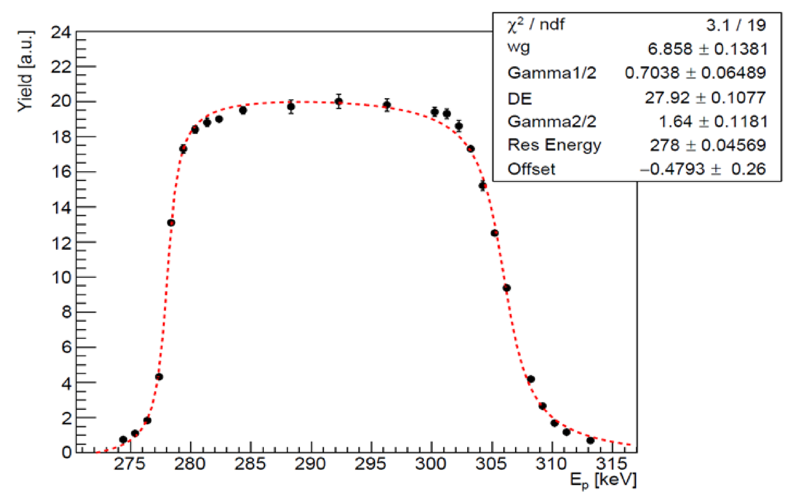


Figure 3: measured yield and scan fit for target 159_1 with nominal thickness 140 nm and measured 27.9 +- 0.1 keV

$$Y = N * [\tan^{-1}\frac{E-E_r}{\Gamma_1} - \tan^{-1}\frac{E-E_r-\Delta E}{\Gamma_2}] + h$$

Target stability is checked every day performing scans of the well known resonance at Ep= 278 keV.

Target	Measured thickness (keV)	Accumulated Charge (C)
Dep158_3	20,2 +- 0,2	245
Dep159_1	27,9 +- 0,1	96
Dep159_2	27,2 +- 0,1	62
Dep165_1	14,11 +- 0,07	81
Dep166_1	20,02 +- 0,09	193
Dep166_2	20,03 +- 0,08	68
Dep165_2	14,2 +- 0,07	126
Dep165_3	13,98 +- 0.09	130

State of the art

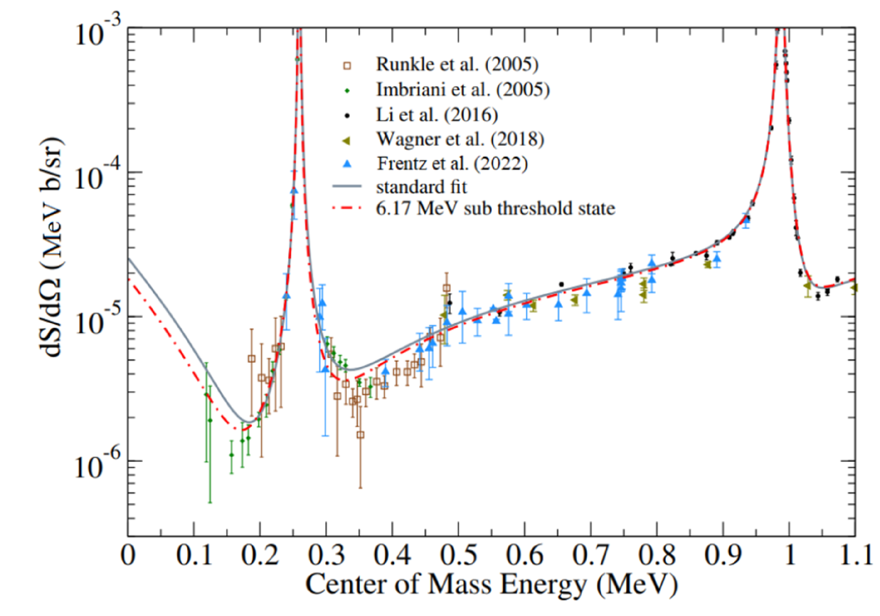


Figure 1: Data available in literature of the partial BR for the GS transition. The lowest energy measured is 118 keV in the center of mass (Adopted from B. Frentz et al. Phys. Rev. C 106 (2022), p. 065803.)

Even if the cross section has been measured many times, extrapolations to solar energies still carry considerable uncertainties (8.4%, as quoted in SFIII). Moreover, significant discrepancies between experimental data and R-matrix fits are present on the tails of the 259 keV resonance.

The lowest energy measured is 118 keV in the center of mass.

Analysis procedure — gamma summing technique

- Calculate the sum spectrum summing the energy for events in coincidence in the 6 segments .
- study energy distribution of events contributing to the sum peak (gated spectrum).
- fit the gated spectrum using simulated template spectra for each gamma cascade to derive branching ratios.

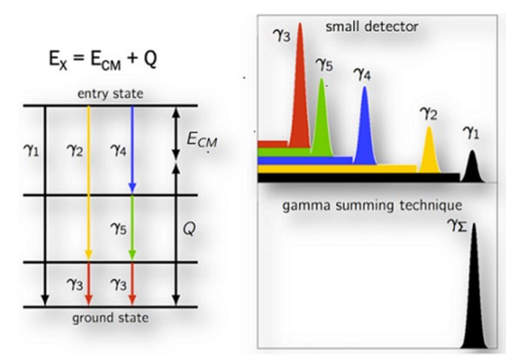


Figure 4: Gamma summing technique

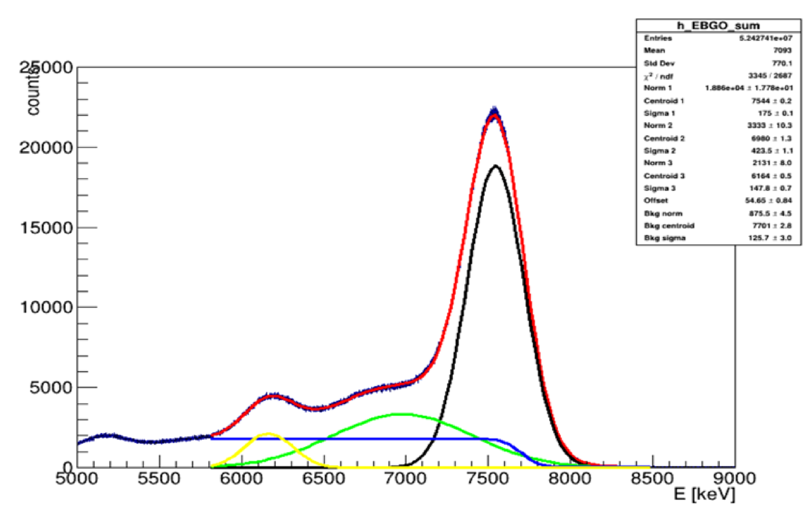


Figure 5: Sum spectrum and fit of the sum peak (red) for Ep= 250 keV. The peak has been fit with 3 gaussians and an error function that mimic the continuum compton.

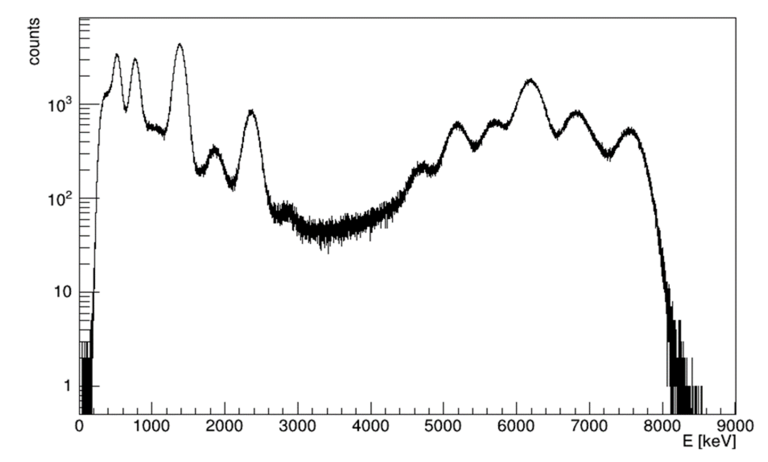


Figure 6: Gated spectrum obtained selecting events in the sum peak (black) and simulation of the partial branching that should be used to fit the experimental data .

Preliminary results

- First campaign (February 2024):
  - Targets: 100nm and 140nm
  - Energies measured: from 400 keV down to 200 keV (30 keV steps)
- Second campaign (April 2024):
  - Targets: 70nm and 100nm
  - Energies measured: from 400 keV down to 180 keV (30 keV steps)
- Third campaign (June 2024):
  - Targets: 70nm
  - Energy measured: 150 keV
- Fourth campaign in progress (September 2024)

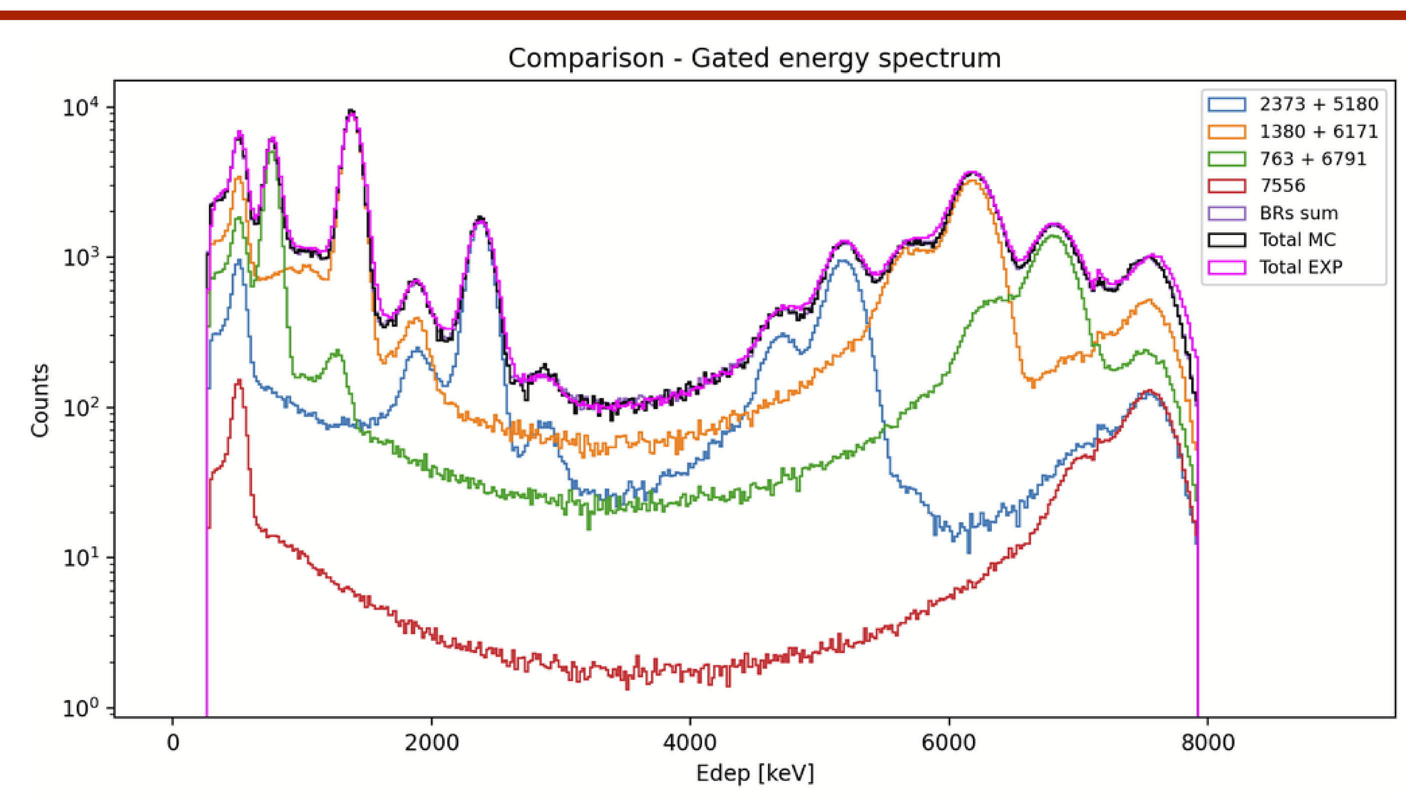


Figure 7: Comparison between experimental data for the gated spectrum (pink) for Ep=278 keV (resonance) and the simulations for the 4 main branchings and the total simulation (black and purple).