Nuclear reactions of astrophysical interest with solid targets at LUNA

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GIANTS XI

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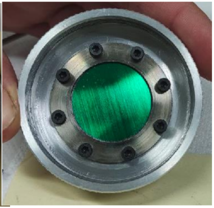
Outline

Why Solid Targets?

Thin, self-supporting metallic disk with the target material itself either **deposited** on the backing or **implanted** into it



Advantages

- Compact experimental setup
- Detector in closer distance
- Almost point-like source
- Convenient target exchange

Disadvantages

- Not for all elements
- Target thickness
- Stoichiometric ratio
- Backing contaminants

Previous Measurements at LUNA

	Reaction	Target	Type
Past	$^{14}N(p,\gamma)^{15}O$	TiN	Reactive Sputtering
	$^{25}Mg(p,\gamma)^{26}Al$	MgO	Evaporation
	$^{15}N(p,\gamma)^{16}O$	TiN	Reactive Sputtering
	$^{18}O(p,\gamma)^{19}F$	Ta_2O_5	Anodic Oxidation
	$^{6}Li(p,\gamma)^{7}Be$	Li	Evaporation
	$^{13}C(\alpha,n)^{16}O$	C	Evaporation
Present	$\boldsymbol{^{12}C(p,\gamma)^{13}N}$	C	Evaporation
	$\boldsymbol{^{13}C(p,\gamma)^{14}N}$	C	Evaporation
	$\boldsymbol{^{17}O(p,\gamma)^{18}F}$	Ta_2O_5	Anodic Oxidation
	$^{16}O(p,\gamma)^{17}F$	Ta_2O_5	Anodic Oxidation
Future	$^{23}Na(p,\alpha)^{20}Ne$	Na	Evaporation

See at Ciani talk (after lunch)

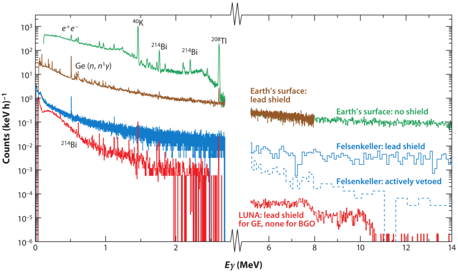
Laboratory for Underground Nuclear Astrophysics

Why?

- the muon flux reduced by **six orders of magnitude**
- necessary for very low cross-sections measurements

Where?

- located at LNGS laboratories in Abruzzo, Italy
- $\sim$ **1400 meters** under Gran Sasso mountain



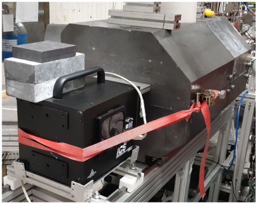
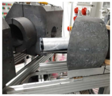
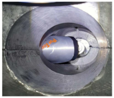
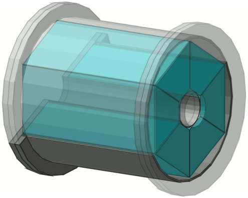
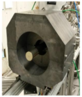
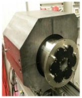
Solid Target Setup

HPGe

- **close geometry**
- excellent energy resolution
- used at **0 deg** and **55 deg**

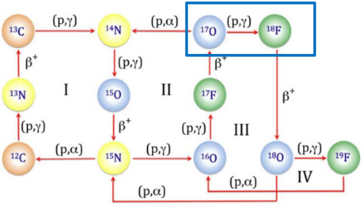
BGO

- almost **4π geometry**
- segmented in **6 crystals**
- permits coincidences

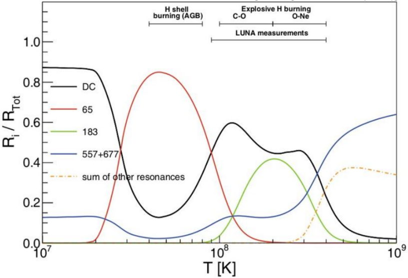







$^{17}O(p,\gamma)^{18}F$ - Resonance at 65 keV

- **$^{17}O(p,\gamma)^{18}F$** reaction takes part of the **CNO cycle**
- AGB nucleosynthesis footprint is the **oxygen isotopic ratio in presolar grains**
- Models still **struggle** to match the observations
- The **reaction rate** in the range of interest is **dominated** by the **resonance at 65 keV**



[Boeltzig et al , EPJ A (2016)]



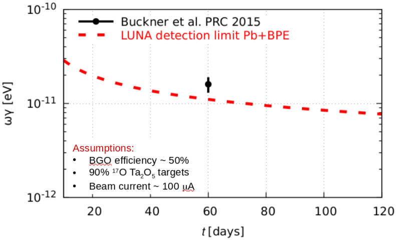
Measuring the 65 keV Resonance (1)

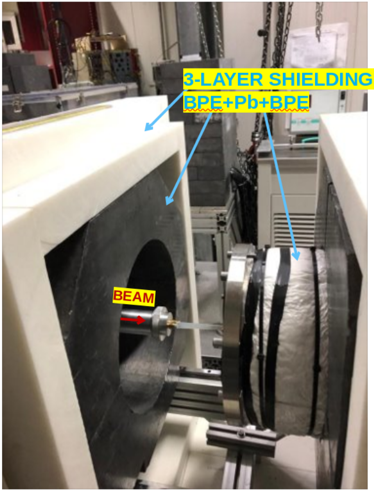
State of the Art

No measurements, estimated $\omega\gamma = (1.6 \pm 0.3) \times 10^{-11}$ eV

Improving Sensitivity

1. **new shielding**: background reduction by **factor of 5**
2. new **Al** holder and chamber: **20 %** increase in efficiency





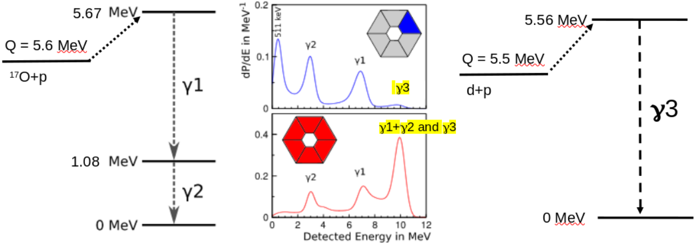
Measuring the 65 keV Resonance (2)

Problem

Ta backing contains d and $p + d$ reaction produces a **single γ-ray** which lies in the **same energy region** of $^{17}O(p,\gamma)^{18}F$

Solution

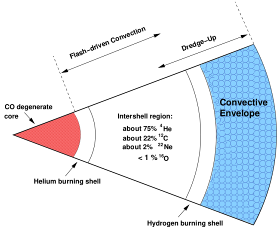
- 420 Coulombs on ^{17}O targets for resonance study
- 300 Coulombs on ^{nat}O targets for $p + d$ background
- **gating the events on the number of γ-rays**

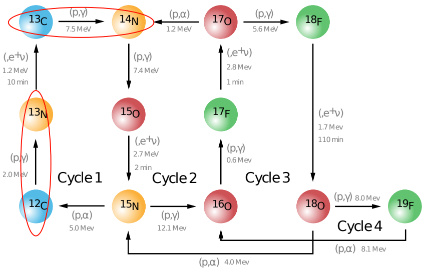


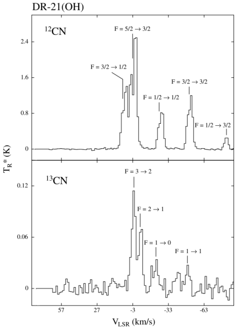
$^{12}C(p,\gamma)^{13}N$ and $^{13}C(p,\gamma)^{14}N$

Astrophysical Motivation

- First two reactions of the CNO cycle and **neutrino emitter**
- The $^{12}C/^{13}C$ ratio **readily derived** from the stellar spectra
- **Constrained reaction rate** in a wide energy range can help the **mixing models**



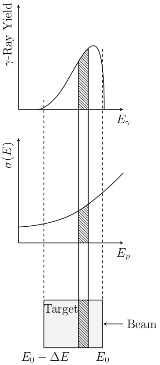


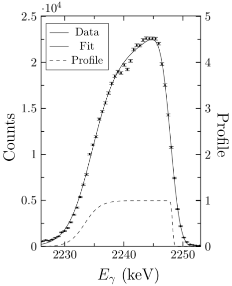


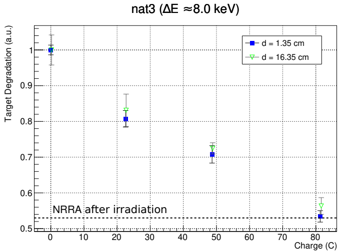
HPGe Campaign

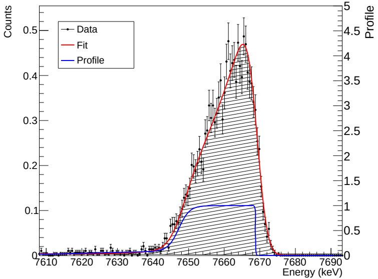
Peak Shape Analysis

- Full **parametrization** of primary γ-peaks
- Best-fit results for both **S-factor** and **target profile**









Introduction

Experimental Setup

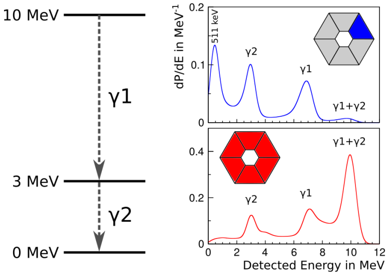
$^{17}O(p,\gamma)^{18}F$ Resonance

Proton Capture on Carbon

Conclusions

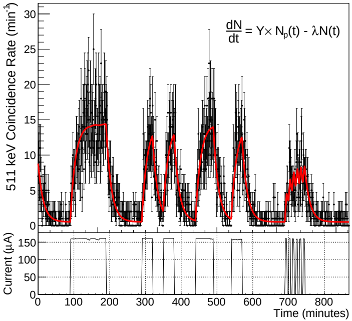
$^{13}C(p,\gamma)^{14}N$ ($Q \sim$ **8 MeV**)

- **Sum** spectrum for all crystals
- High Q-value, no background
- Target monitoring with HPGe at 55 deg

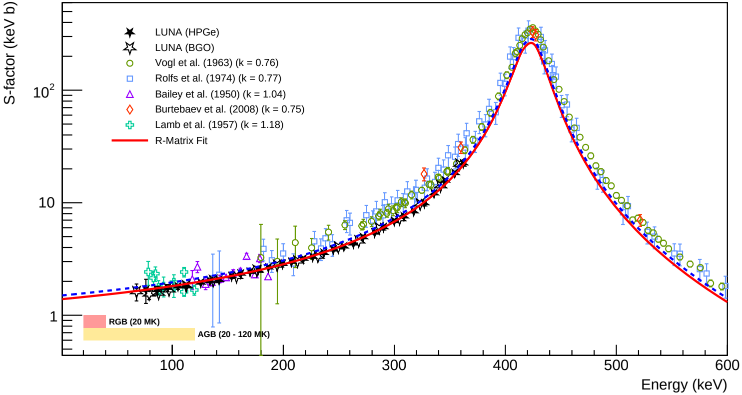


$^{12}C(p,\gamma)^{13}N$ ($Q \sim$ **2 MeV**)

- **Irradiation** and **counting** cycles in-situ
- Best-fit by iteratively solving differential equation

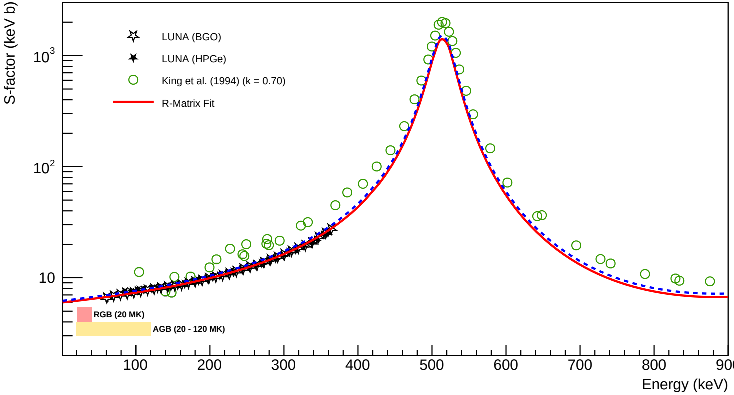


Results - $^{12}C(p,\gamma)^{13}N$



Only statistical uncertainty is plotted, systematic one is 6.8%

Results - $^{13}C(p,\gamma)^{14}N$

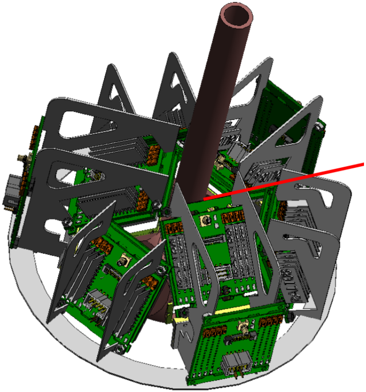


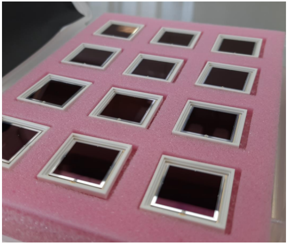
Only statistical uncertainty is plotted, systematic one is 7.1%

(Bonus) Future

$^{23}\mathbf{Na}(\boldsymbol{p},\alpha)^{20}\mathbf{Ne}$ study requires charged-particle detection!

$\rightarrow$ **new setup under construction** at Edinburgh!





Conclusions

- Solid targets offer **several advantages** (and few disadvantages)
- **Frequently employed at LUNA**
- Permit usage of **different experimental techniques**
- Soon a new setup for **charged-particle detection** will be mounted

Thank you for attention!