

# Underground Nuclear Astrophysics at LNGS

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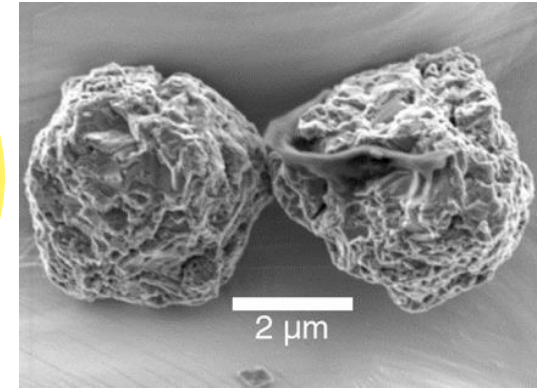


Observational  
Astronomy

Neutrino  
Physics

Nuclear  
Astrophysics

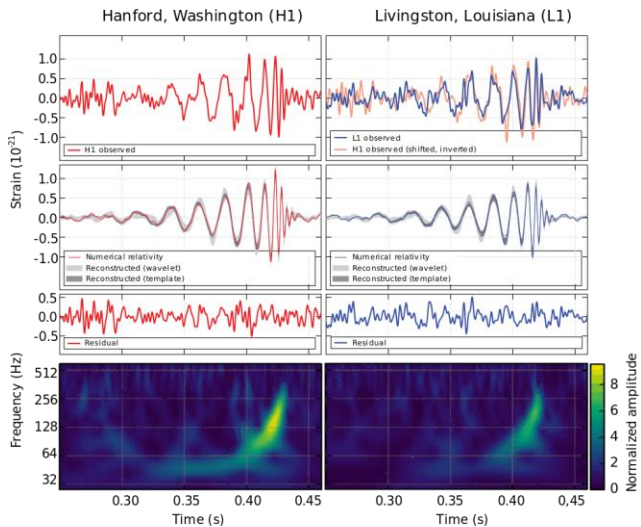
Meteoritic  
Grains



Cosmology

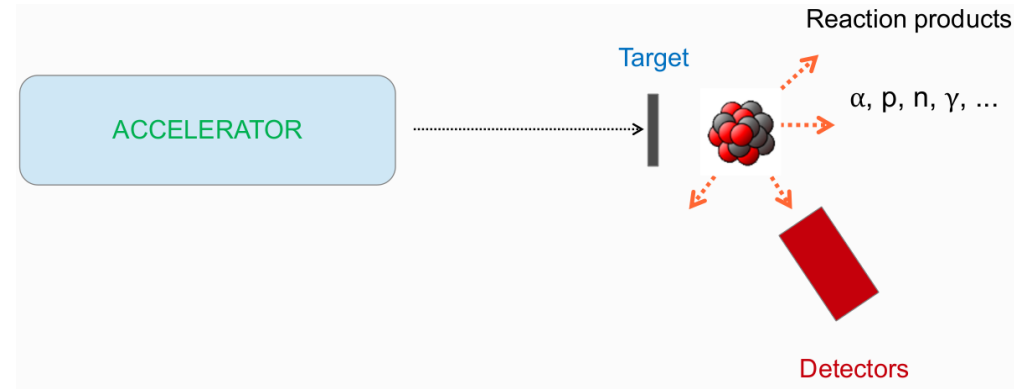
Stellar  
Model

Nuclear  
Physics



# Reaction Rate = reactions per unit of volume and time

Direct measurement



$$= N_B \times N_T \times \text{efficiency}(E) \times cs(E)$$

$10^{12} - 10^{14}$  pps  
(1uA - 100uA)

$10^{18}$  atoms/cm<sup>2</sup>  
(solid target)

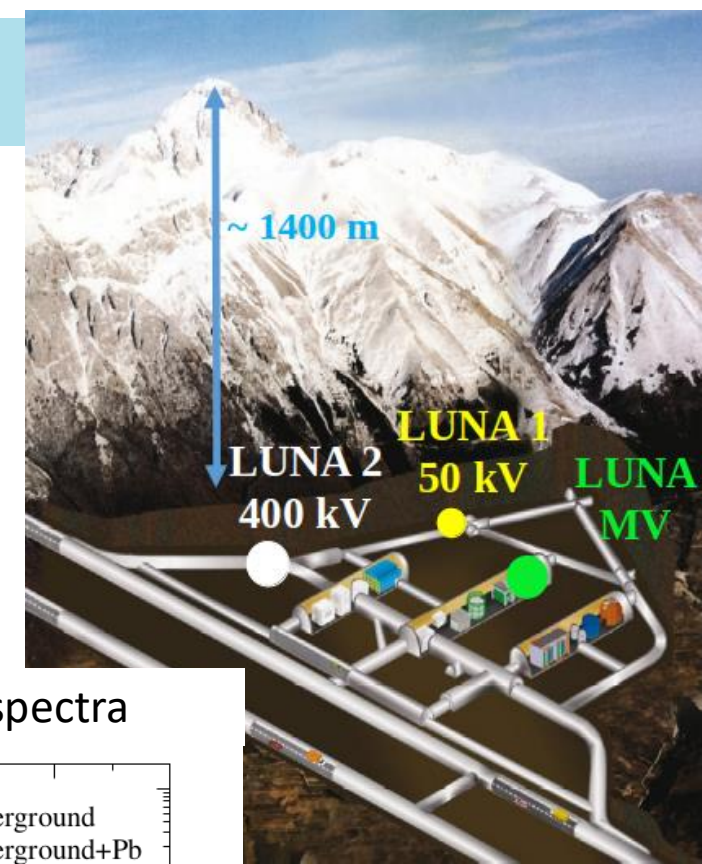
1%-10% HPGe detectors  
up to 60% for scintillators

$10^{-12}$  barns (=  $10^{-36}$  cm<sup>2</sup>)  
at energies of interest

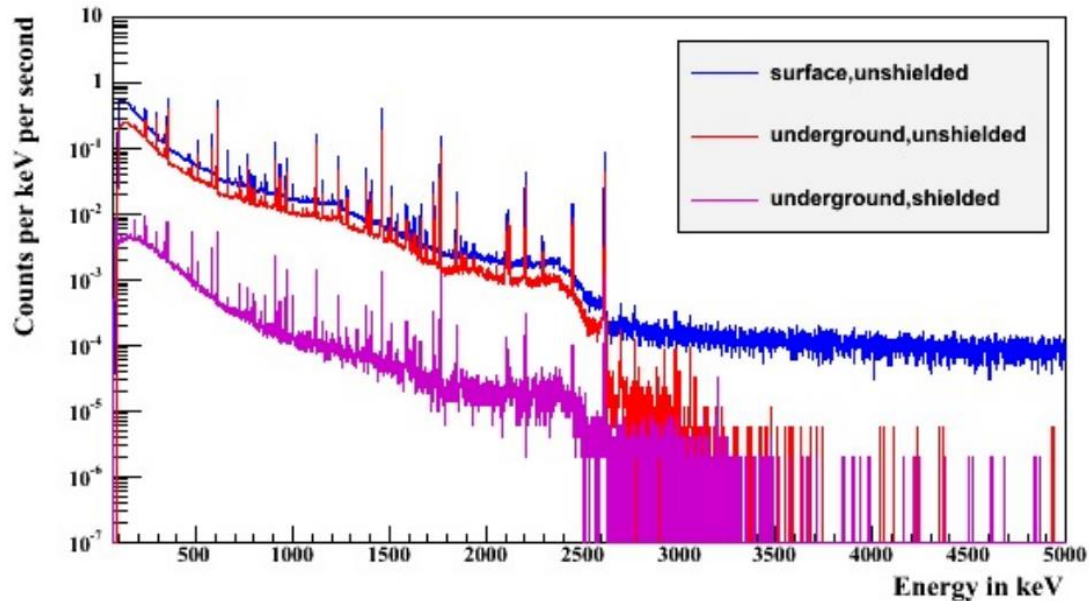
## Observed Count Rate = 1-10 c/d -> S/N << 1

# Laboratory for **U**nderground **N**uclear **A**strophysics

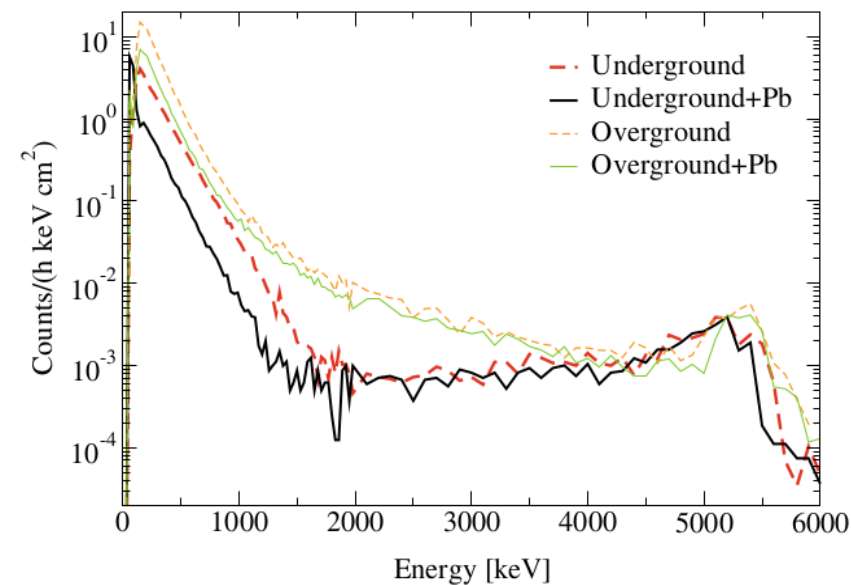
- LUNA is located at LNGS
- Natural shielding of 1400 m of rock (= 4000 m w.e.)
- Background suppression:



Muon:  $\times 10^{-6}$ ; Neutron:  $\times 10^{-3}$



Up to a factor 15 in particle spectra



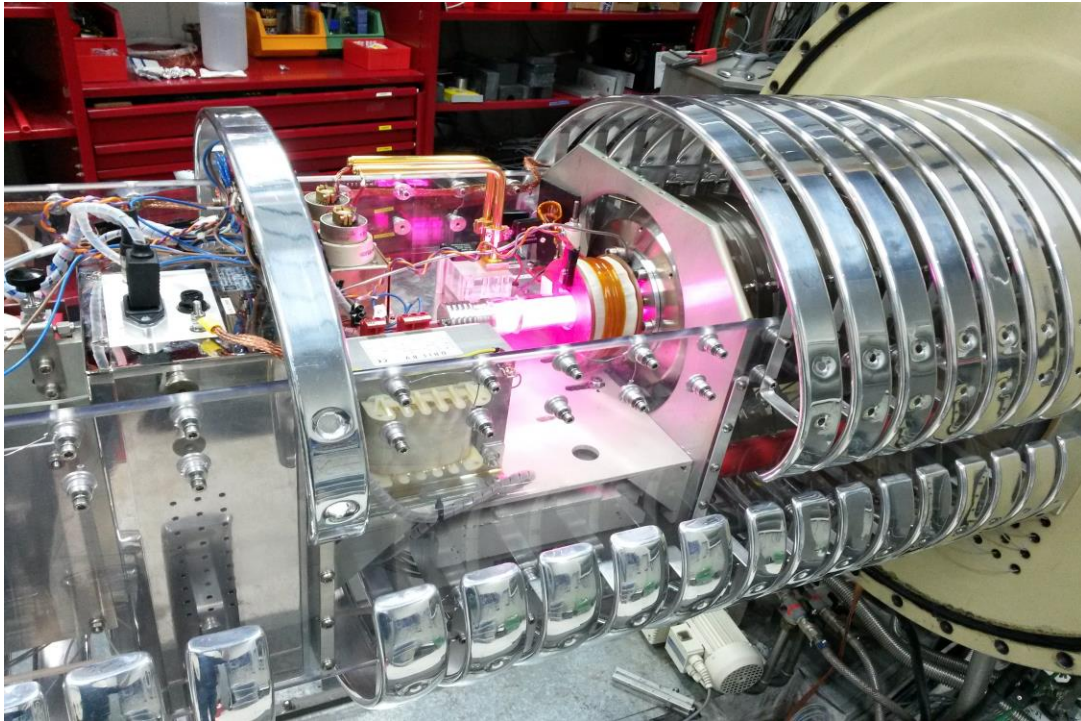
# LUNA50 – BBN and pp chain

- Activity 1991 – 2001
  - Homemade accelerator
  - $H^+$  and  $He^+$  beams
  - Energy range: up to 50 keV
  - BBN and pp-chain key reactions:
    - $p+D \rightarrow$  Solar H-burning
    - ${}^3He({}^3He,2p){}^4He$
    - ${}^3He(\alpha,\gamma){}^7Be$
    - ${}^2H(\alpha,\gamma){}^6Li$
- } Solar neutrino flux  
} BBN



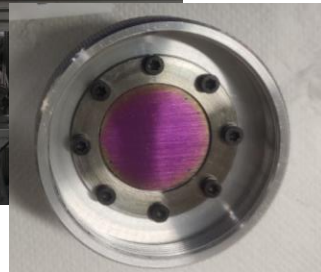
# LUNA400 – BBN, CNO cycle(s) and s-process

- Activity 2001 -
- HVEE accelerator
- H<sup>+</sup> and He<sup>+</sup> beams
- Energy range 50 –400 keV
- Beam intensity: 1mA and 500  $\mu$ A
- Solid and Gas target beamlines

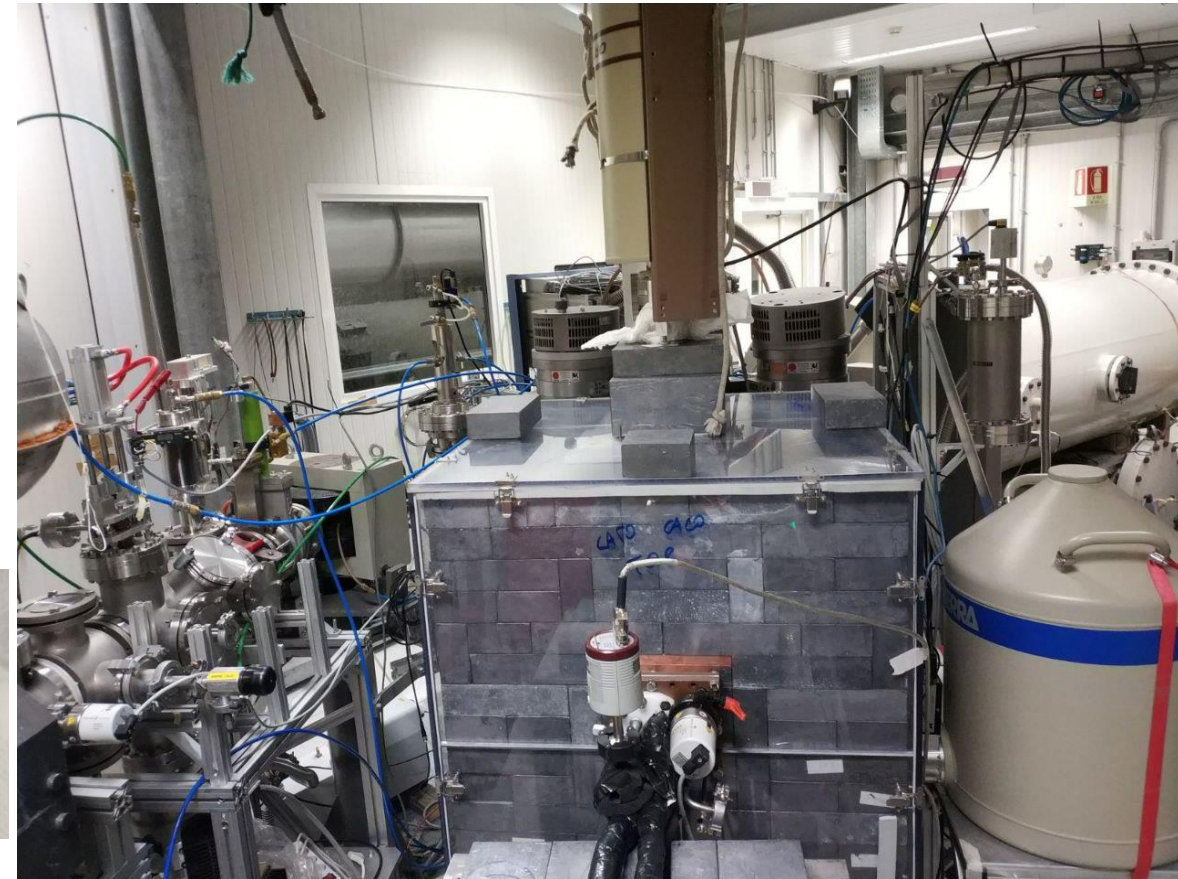


- $^{14}\text{N}(p,\gamma)^{15}\text{O}$  -> increase of 0.7-1Gyr Globular Cluster Age
- $^{17}\text{O}(p,\alpha)^{14}\text{N}$  -> Origin of meteoritic grains unveiled
- $^{22}\text{Ne}(p,\gamma)^{23}\text{Na}$  -> 3 new resonances observed
- $^6\text{Li}(p,g)^7\text{Be}$  -> claimed resonance excluded
- p+D -> Universe baryon density

# LUNA400 – Ongoing



- $^{17}\text{O}(p,\gamma)^{18}\text{F}$  reaction 69 keV resonance
- $\omega_{\text{lit}} = 10^{-11}$  ev  $\rightarrow$  0.1 c/C!!!!
- $\text{Ta}_2\text{O}_5$  solid target
- $4\pi$  BGO detector
- Pb+bPe shielding
- Al chamber and target holder



- $^{20}\text{Ne}(p,\gamma)^{21}\text{Na}$  366 keV resonance and Direct Capture
- Windowless gas target + 2 HPGe detectors
- Pb+Cu shielding + Rn box
- Calorimeter to get beam current

- After 20 years LUNA400 is still an outstanding tool for nuclear astrophysics investigations
- New proposal approved:
  - $^{23}\text{Na}(p,\alpha)^{20}\text{Ne} \rightarrow$  O-Na anticorrelation puzzle in Globular Cluster
  - $^{27}\text{Al}(p,\alpha)^{24}\text{Mg} \rightarrow$  Mg-Al anticorrelation puzzle in GC
  - $^{16}\text{O}(p,\gamma)^{17}\text{F} \rightarrow$  AGB and RGB star nucleosynthesis
  - $^{21}\text{Ne}(p,\gamma)^{22}\text{Na} \rightarrow$   $^{22}\text{Ne}$  puzzle in presolar grains



# LUNAMV – beyond He burning and s-process

- Installation ongoing!!!
- $H^+$ ,  $He^+$ ,  $^{12}C^+$ ,  $^{12}C^{++}$
- Expected intensity: 1000, 500, 150, 100  $\mu A$
- Energy range: 0.3 - 3.5 MeV
- Solid and Gas target



- $^{14}N(p,\gamma)^{15}O$
  - $^{12}C+^{12}C \rightarrow$  trigger of C burning  $\rightarrow$  determines mass limit between white dwarfs and supernovae
  - $^{22}Ne(\alpha,n)^{25}Mg$
  - $^{13}C(\alpha,n)^{16}O$
- Key role for s-process in AGB and massive stars

# LUNA Collaboration

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«The amazing thing is that every atom in your body came from a star that exploded. And, the atoms in your left hand probably came from a different star than your right hand. It really is the most poetic thing I know about physics: You are all stardust.»

Lawrence M. Krauss

THANK YOU