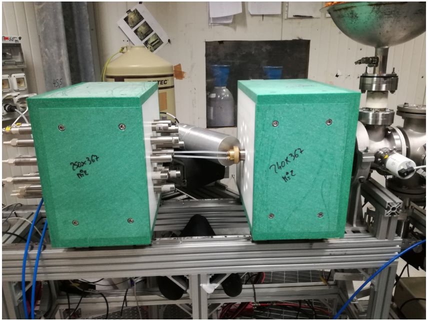
Direct low-energy measurement of the $^{13}C(\alpha, n)^{16}O$ cross section at LUNA

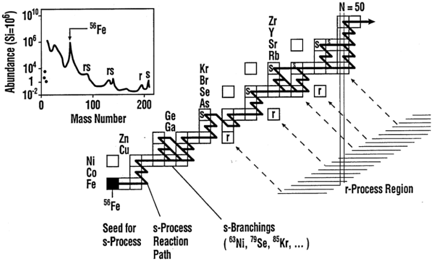


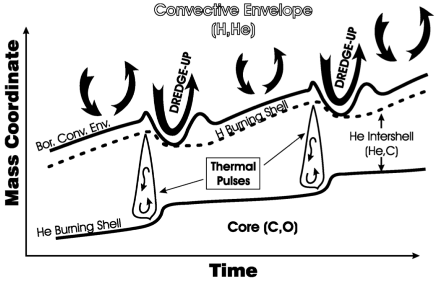
IAEA (α, n) data meeting

Andreas Best

INFN Naples
University of Naples "Federico II"

Main s process

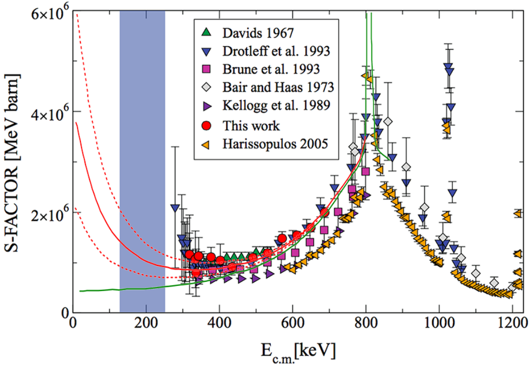




Kaeppeler et al. 2011 Straniero et al. 2006

- $\lambda_{(n,\gamma)} \ll \lambda_{\beta^-}$: nucleosynthesis follows valley of stability
- Takes place in "^{13}C pocket" in thermally pulsing AGB stars
- $^{13}C(\alpha, n)^{16}O$ main neutron sources for s process
- $^{13}C(\alpha, n)^{16}O$: T $\approx$ 90 MK, energy range 140 - 230 keV
- Also possible neutron source for i-process ($\sim$ 280 MK, 285 - 510 keV)
- $^{22}Ne(\alpha, n)^{25}Mg$ small contribution during late stages of main s process

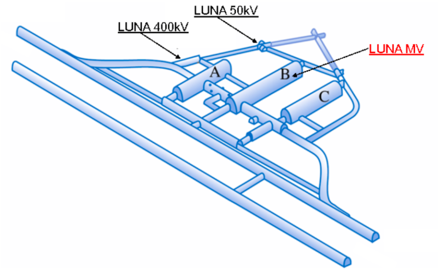
State of the art

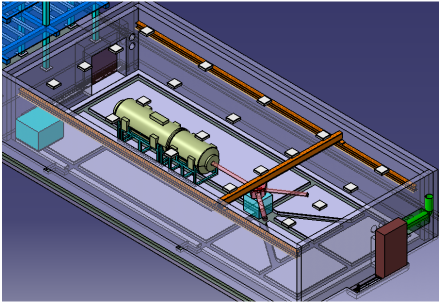


Heil et al. 2008

- Heil et al.: down to 317 keV, large uncertainties below 400 keV
- Drotleff et al.: $E_{cm,min} = 279$ keV, large uncertainties below 350 keV
- Environmental background
  - Heil 340 counts/hour
  - Drotleff 290 counts/hour
- At higher energies strong differences in normalization
- Trojan horse data anchor to ANC/high-energy c.s.

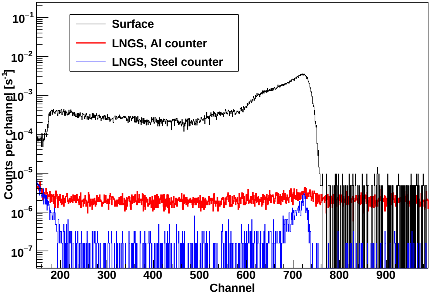
LUNA / MV campaigns

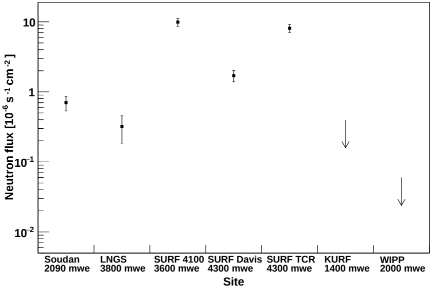




- Can cover 50 - 3500 keV with two accelerators
- Same setup(s) for both campaigns, energy overlap 350 - 400 keV
- Opportunity to calibrate using more reactions at higher energies
- p/α beam currents order of hundreds of μA

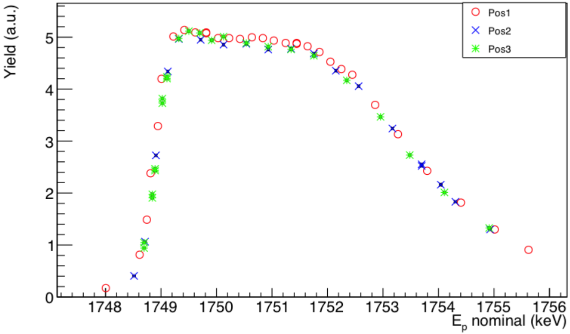
Advantages of going underground





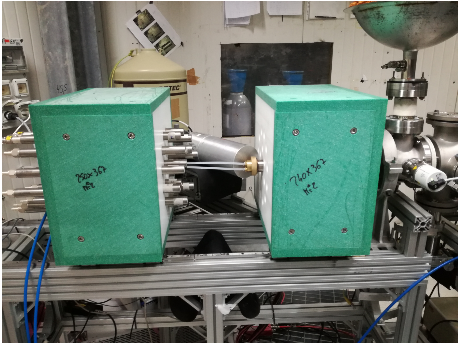
- Direct low-energy measurements limited by natural background
- LNGS ≈ 3400 m.w.e. underneath Gran Sasso mountain chain
- Cosmic-ray induced neutrons efficiently shielded against
- Residual flux from (α, n) and fission in rocks
- Neutron flux underground suppressed by ≈ 1000 w.r.t. surface

Setup - Targets



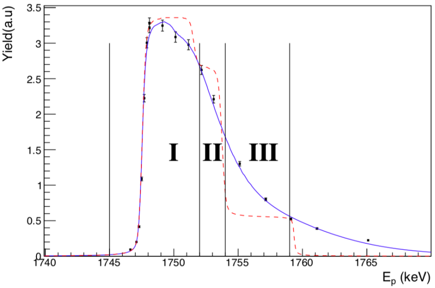
- 99% enriched ^{13}C on Ta disks
- Electron gun evaporation, thickness $\approx$ 60 keV
- Stoichiometry and enrichment tested at ATOMKI using ^{12,13}C(p, γ)^{13,14}N resonances

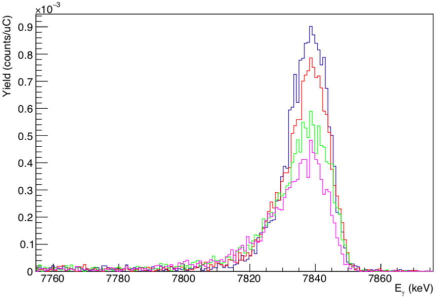
Setup - Detector



- 6×25 cm, 12×40 cm long, 10 bar ^{3}He counters in polyethylene
- Efficiency $\approx 30\%$ (^{51}V(p,n)^{51}Cr, AmBe)
- 2" 5% borated PE shielding
- 1-2 counts/hour total (internal+external) background
- Csedreki et al. NIM A A 994 (2021) 165081

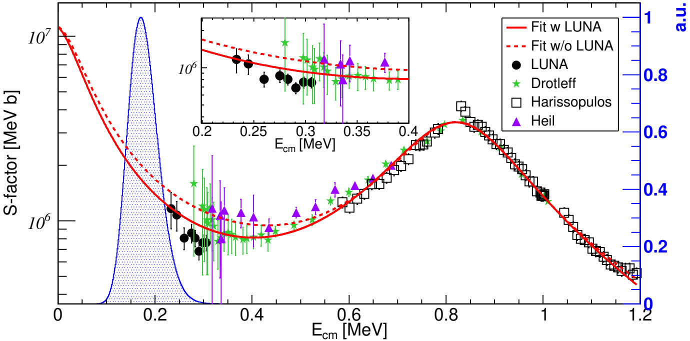
Measurement strategy





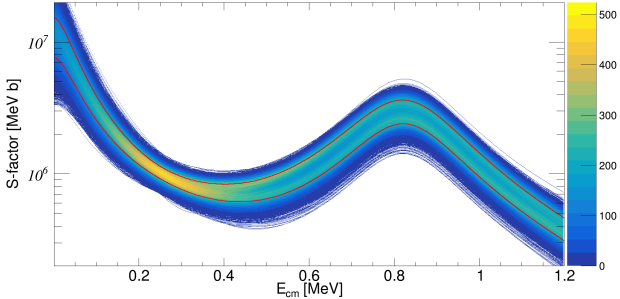
- Solid target (^{13}C on Ta) $\rightarrow$ degradation under beam
- Normally, use resonance yield profile to monitor target
- No ^{13}C resonances in LUNA 400 energy range!
- Switch to H^+ beam, measure ^{13}C(p,γ) gamma ray shape
- Ciani et al., EPJ A 56 (2020), 75

Results



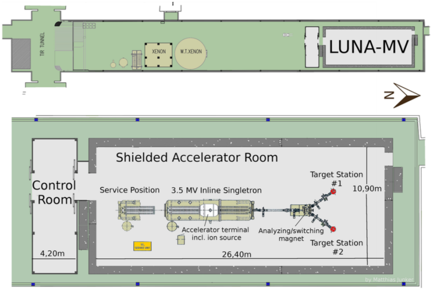
- Covered 235 - 300 keV, 50 keV lower than before
- ≈ 100 C for lowest point
- Problem remains connection to different normalizations
- Ciani et al. PRL 127, 152701 (2021)

R matrix



- Adopted two normalizations: Harissopulos, Drotleff&Heil
- LUNA data kept fixed, others rescaled
- MC R matrix fits for each set for combined reaction rate PDF

Program with new accelerator



- Expected to start operation in 2022
- "High priority" in program
- Remeasure low energy points (> 350 keV) to check systematics
- Map out higher energy region, cross-check with upcoming data

Summary

- Unprecedented ultra-low internal+external background
- Low-energy campaign completed, measured into s process Gamow window
- Connect to high energy region (and cover i process window)
- Treasure trove of new data, both high and low energy
- Need new, global R matrix analysis