LUNA: present status and future prospects

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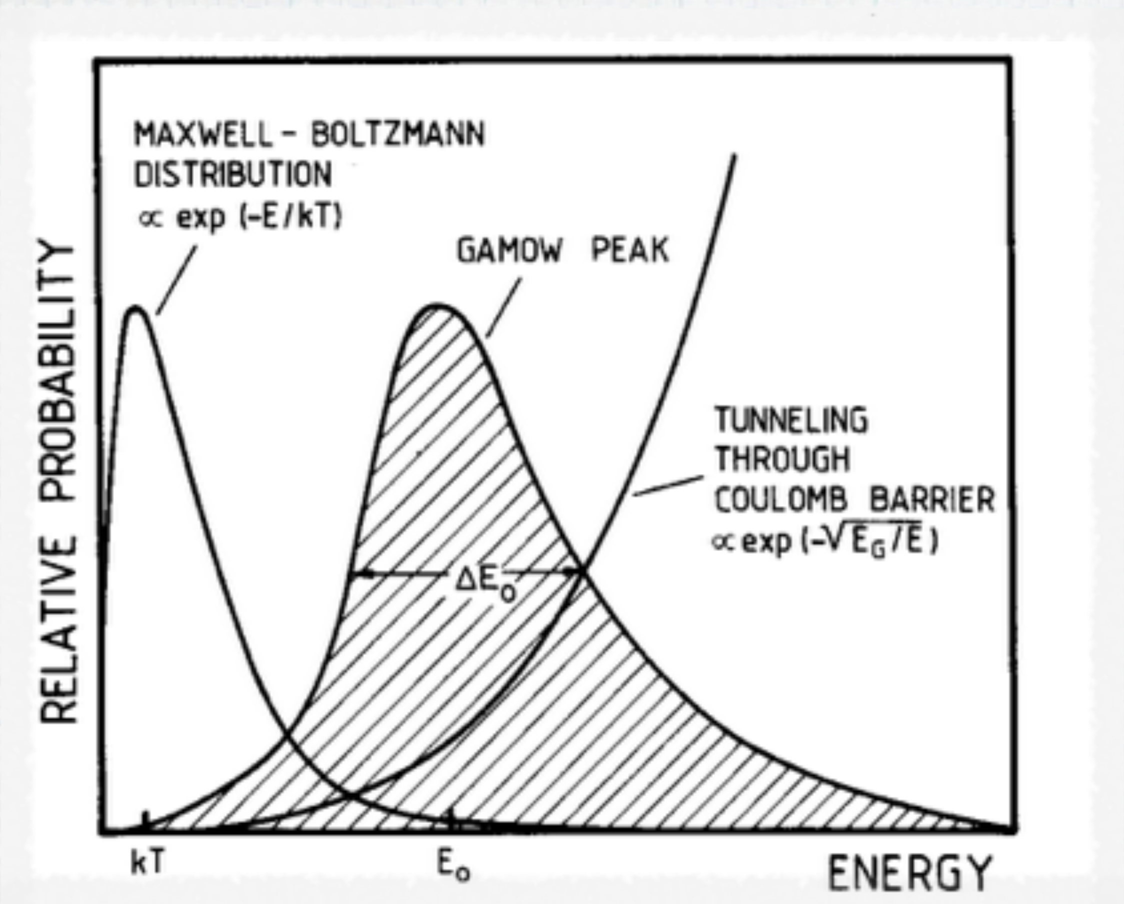
Reaction Rate for charged particles

$$\sigma(E) = \frac{S(E)}{E} \exp\left(-31.29 \cdot Z_1 \cdot Z_2 \cdot \sqrt{\frac{\mu}{E}}\right)$$

ASTROPHYSICAL FACTOR

GAMOW FACTOR

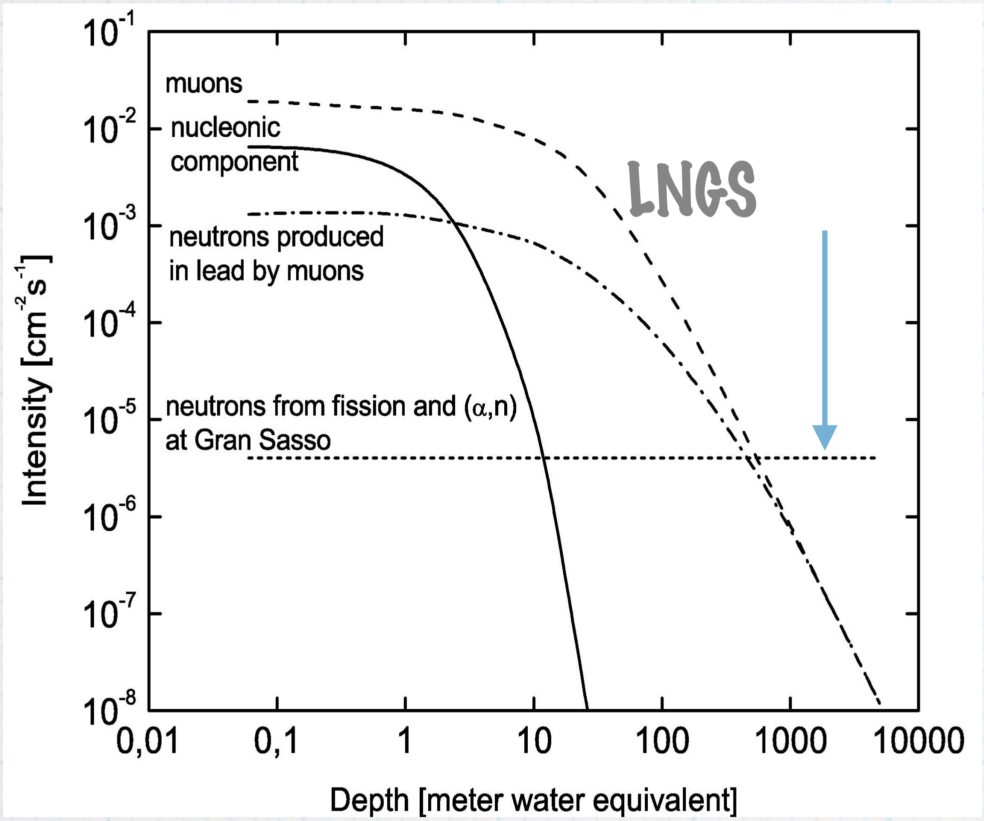


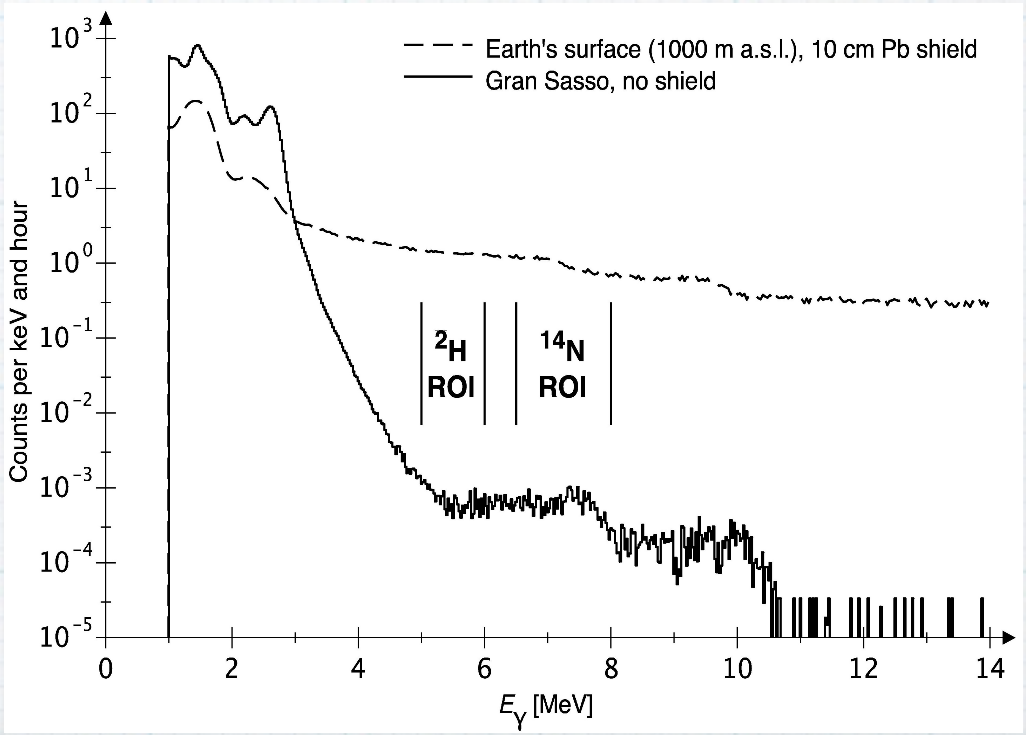
Nuclear reactions that generate energy and synthesise elements take place inside the stars in a relatively narrow energy window: the Gamow peak

Gamow Energy for H-burning reactions: few to several tens keV

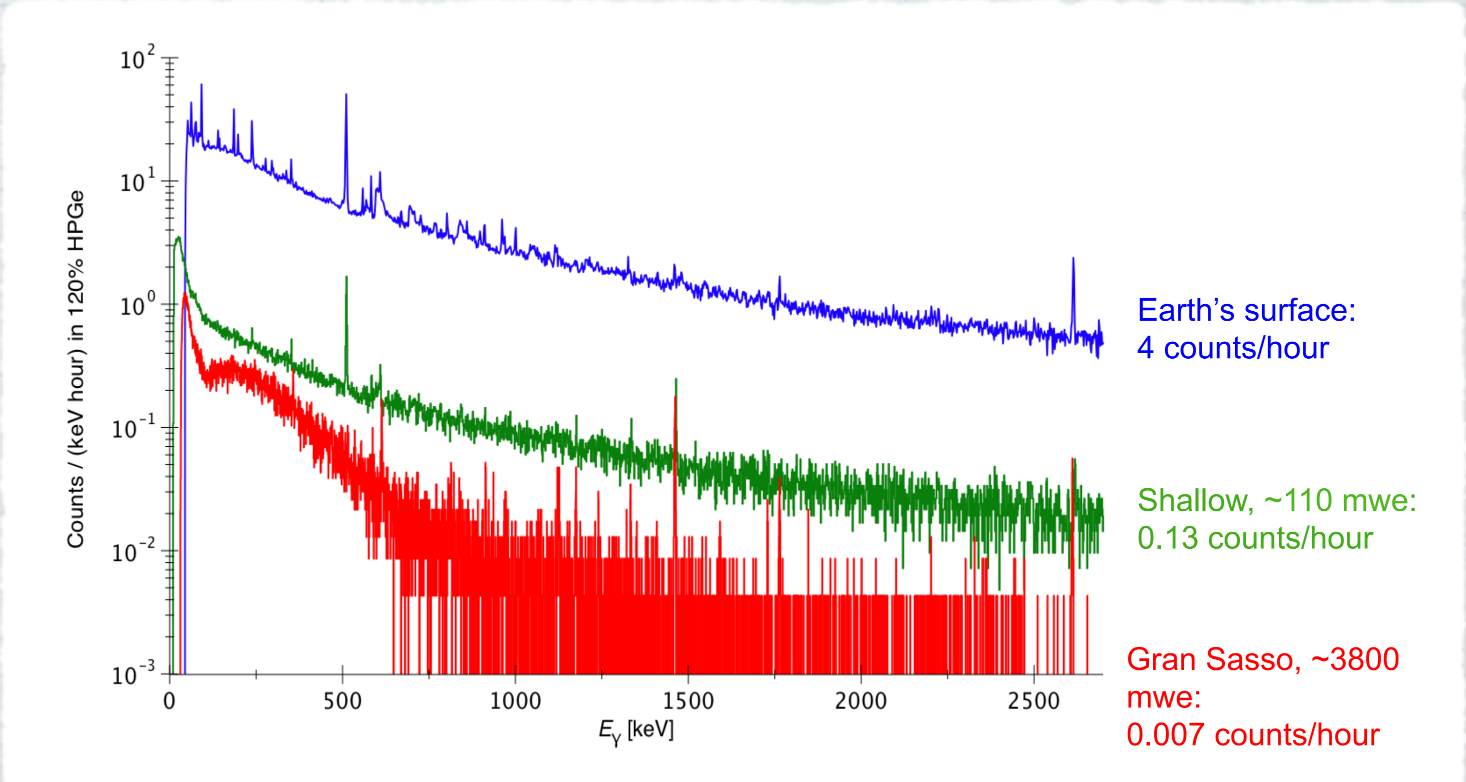
pbarn < σ < nbarn

Why going in underground

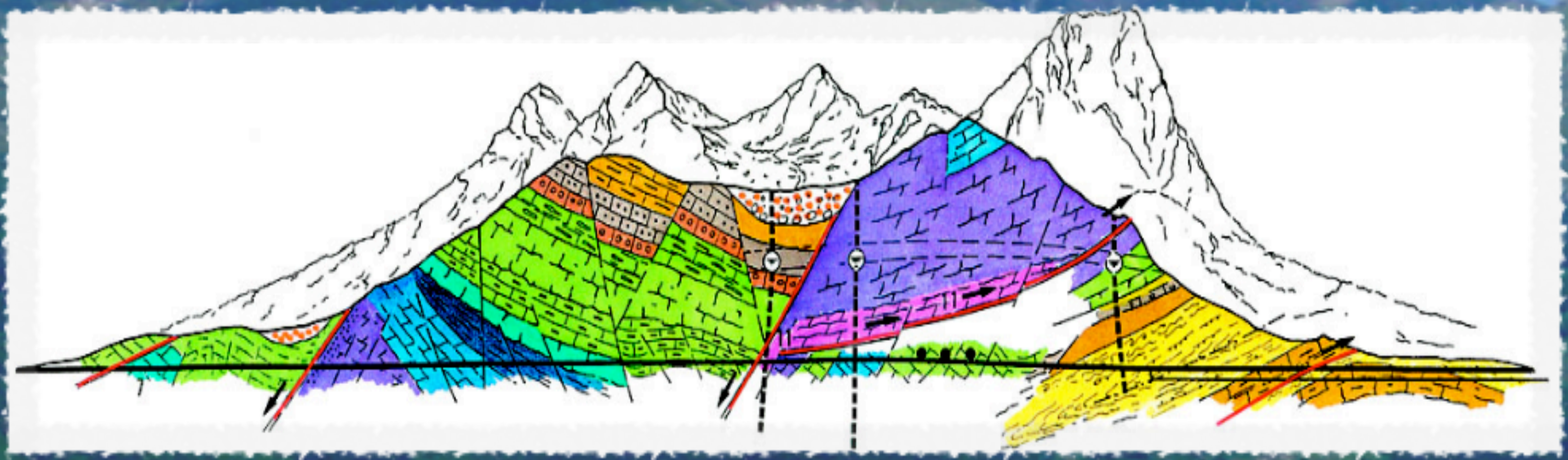




Below 3 MeV the background should be reduced by using a proper shielding but still the underground is fundamental for optimal results

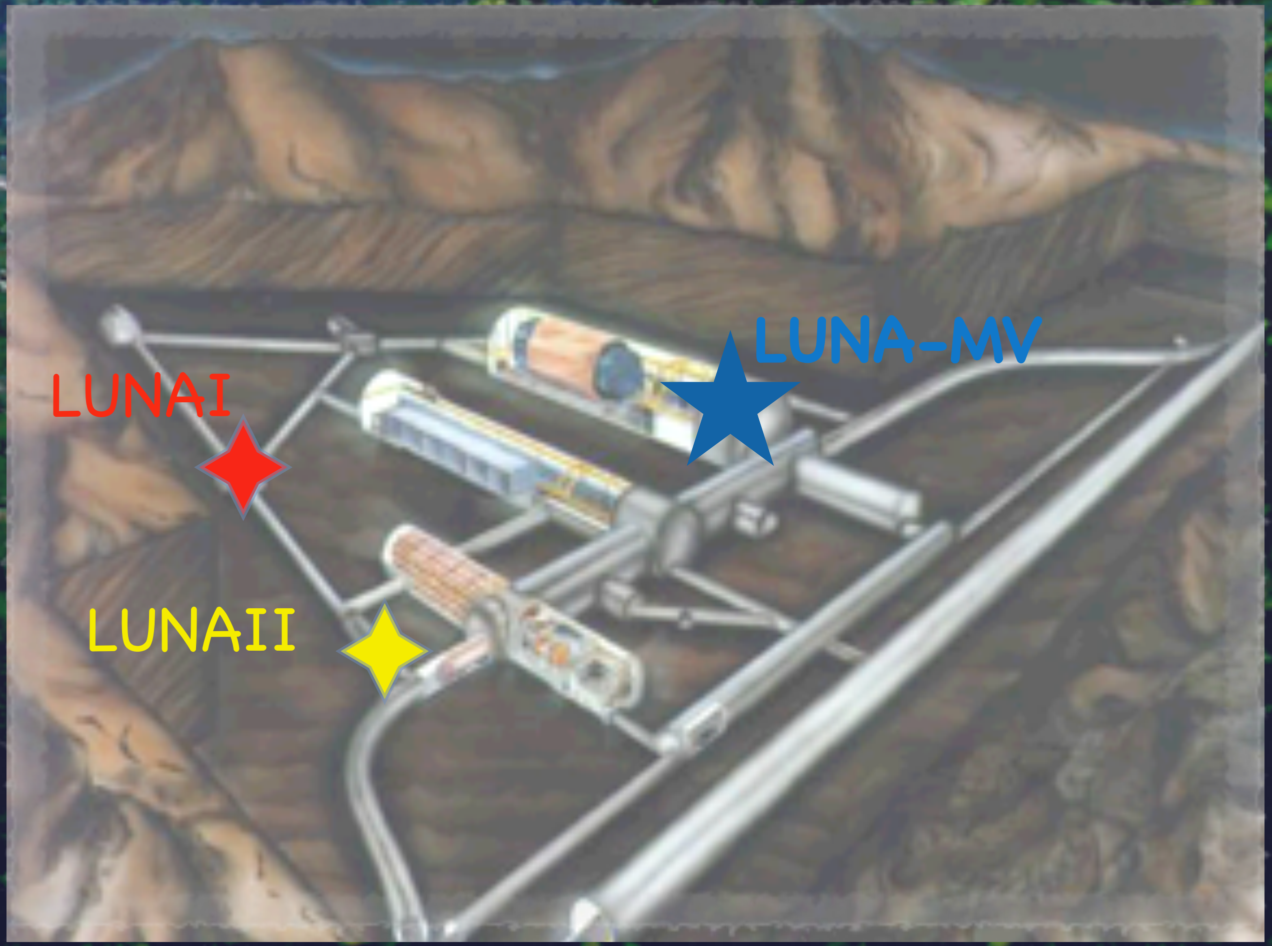


Laboratori Nazionali del Gran Sasso

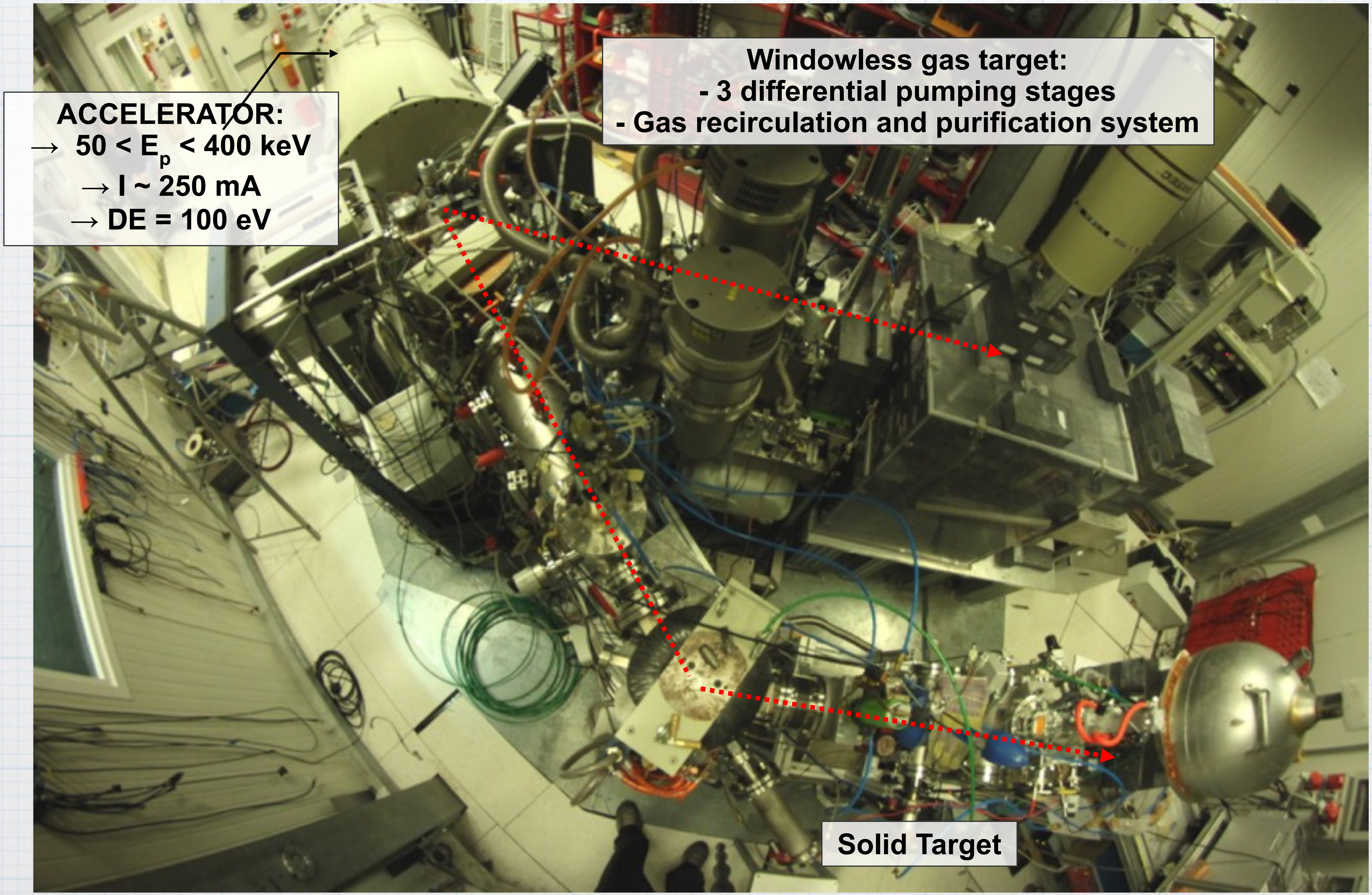


- 1400 m rock overburden (=3800 m w.e.)
- Flux attenuation: n 10^{-3} ($CaCO_3$)
  μ 10^{-6} (1/m2 h)

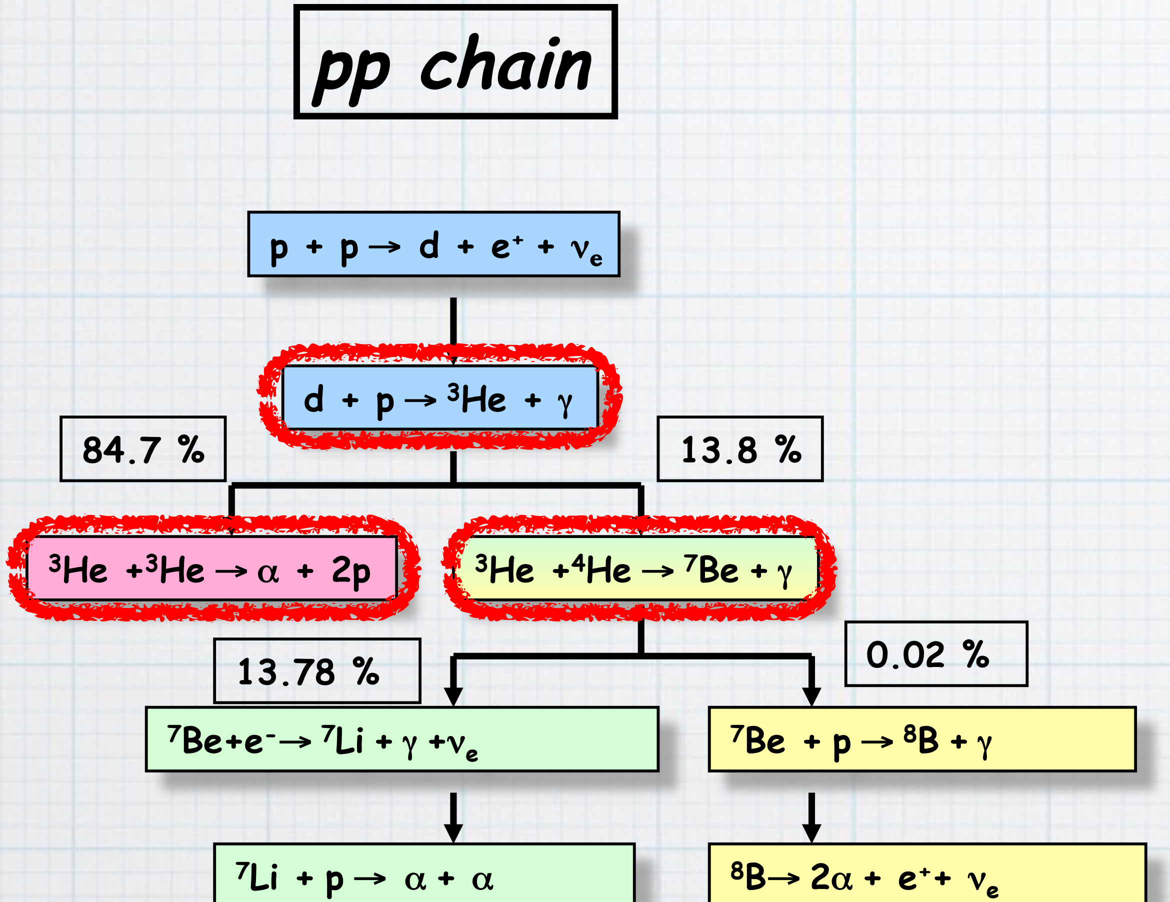
- underground area 18000 m2
- support facilities on the surface

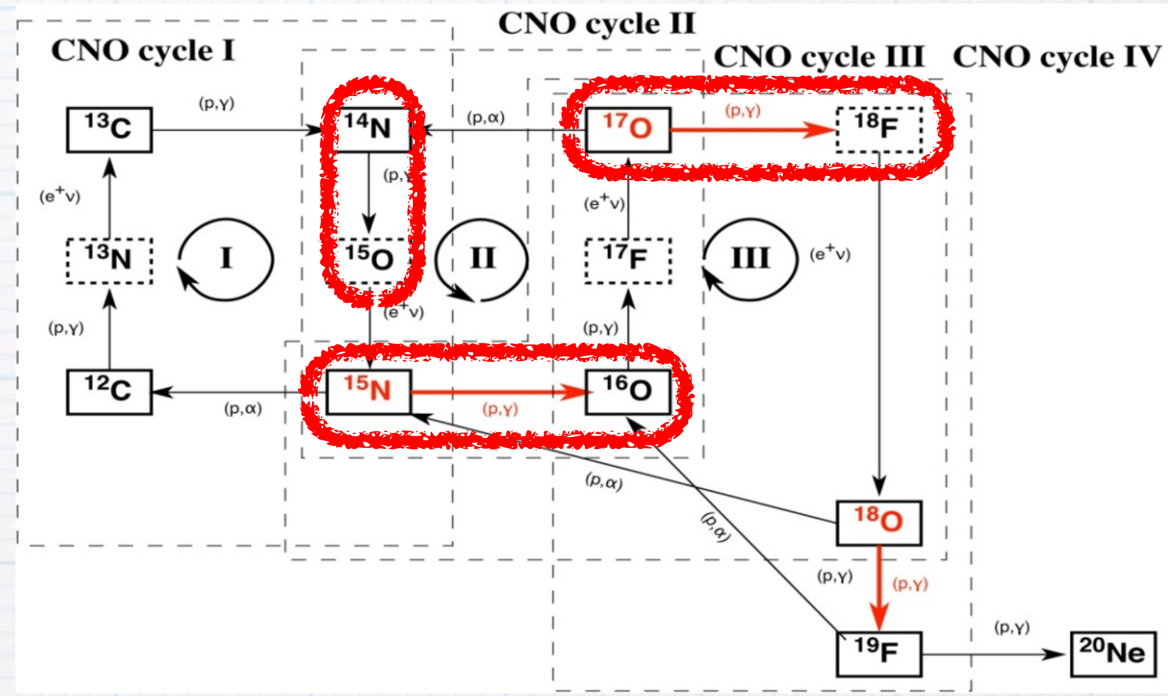


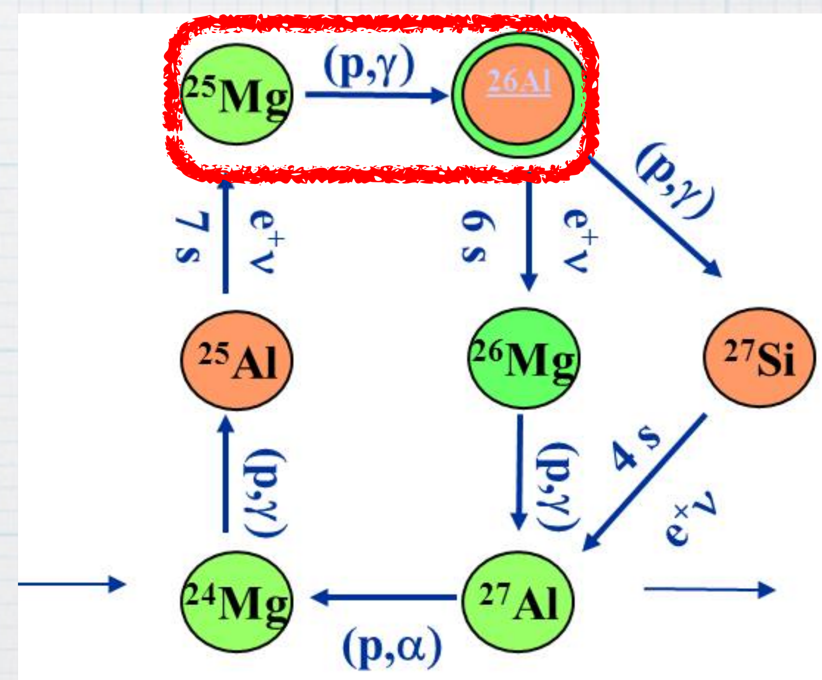
Laboratory for Underground Nuclear Astrophysics



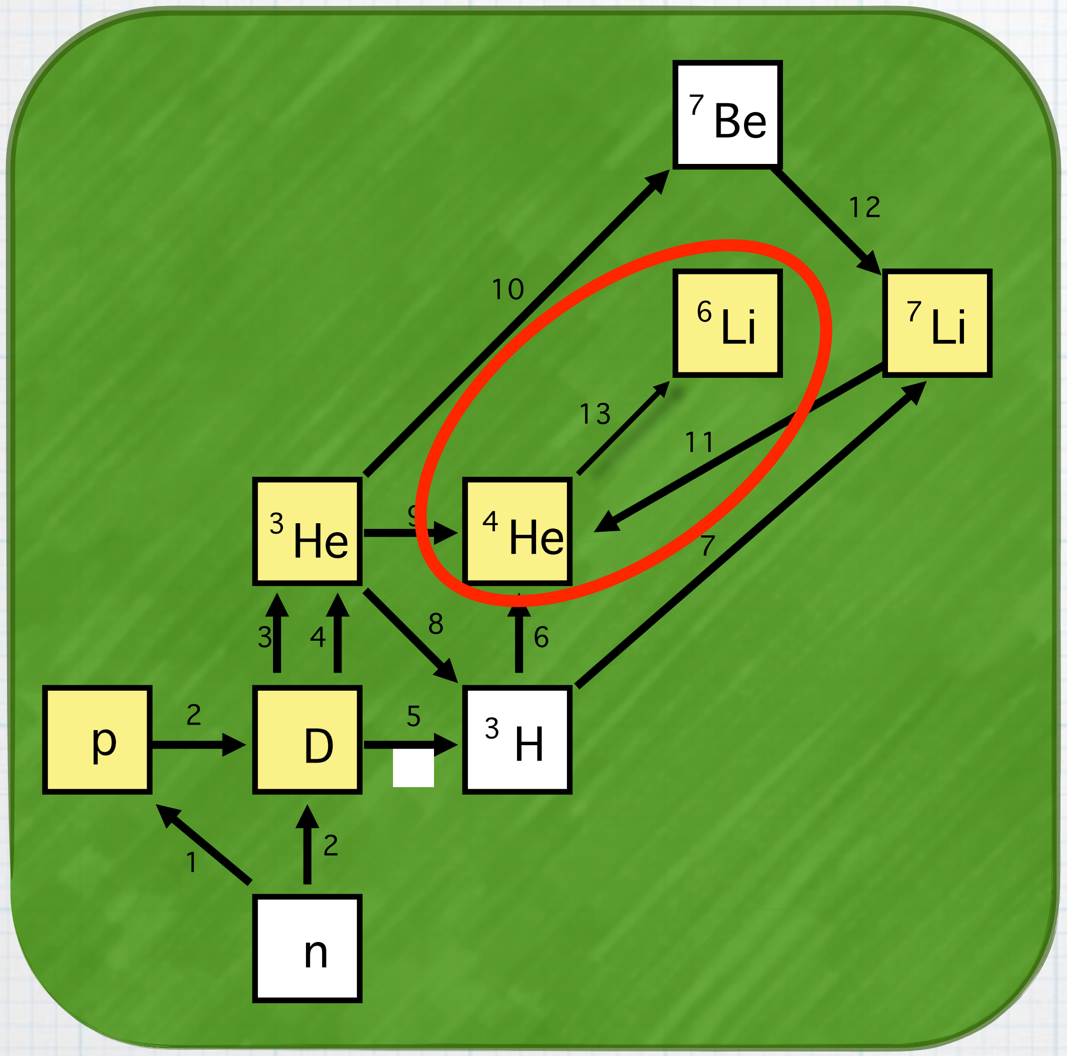
H-burning at LUNA





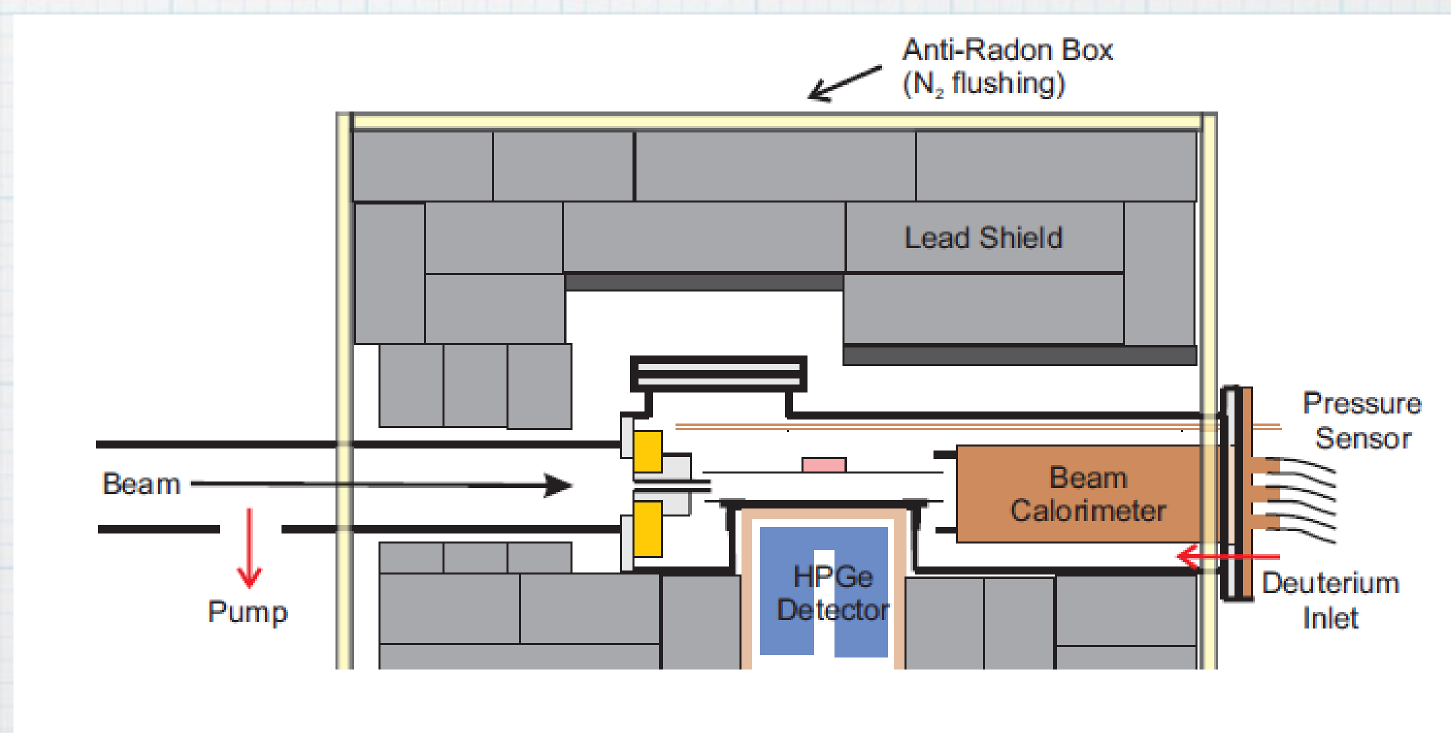


Recent Results: d(α,γ)^{6}Li

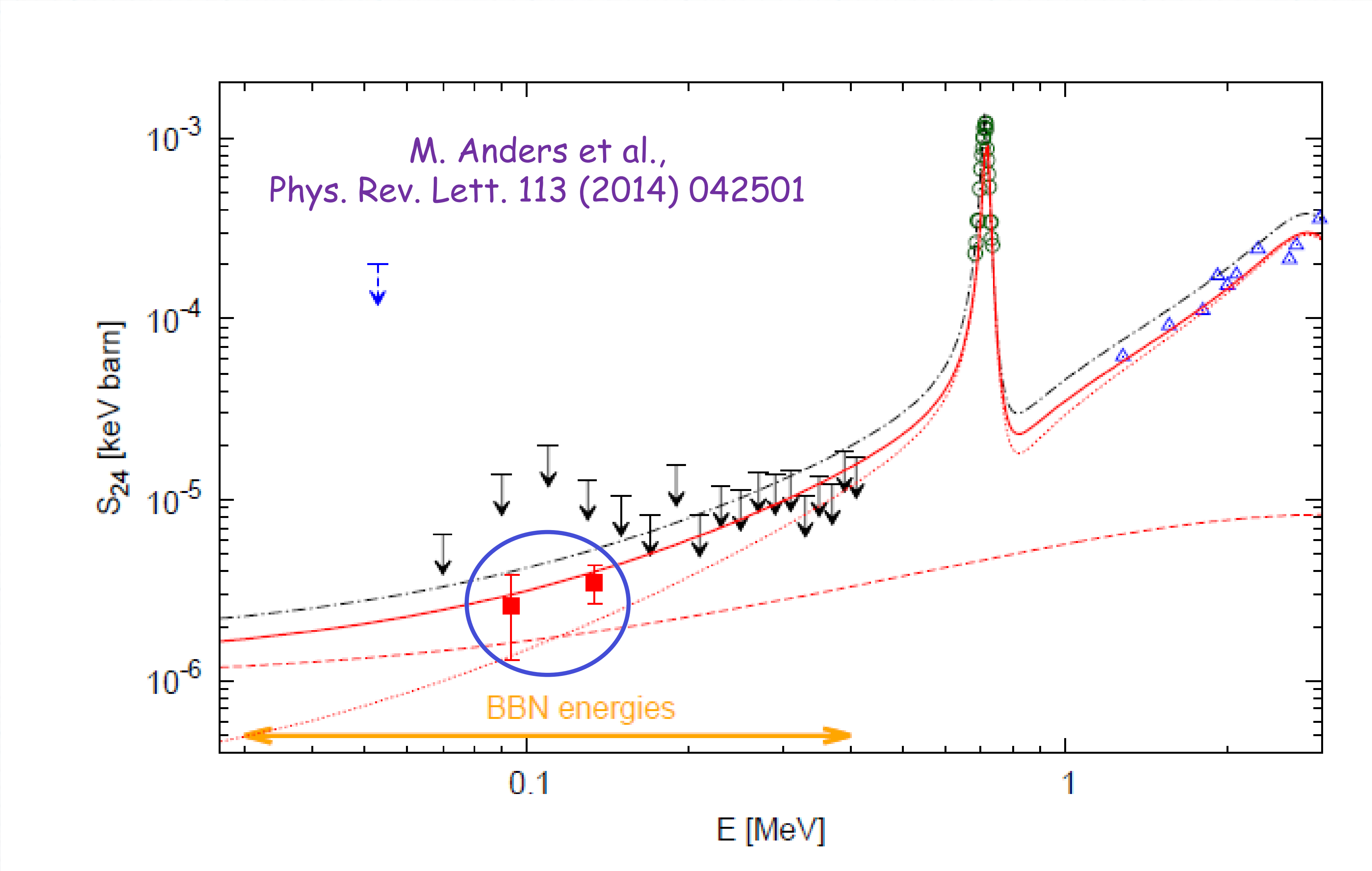


The amount of ^{6}Li predicted by BBN is about 1000 lower than the observed one in metal poor stars

BBN predicts ^{6}Li/^{7}Li = 2 * 10^{-5} much below the detected levels of about ^{6}Li/^{7}Li= 5 * 10^{-2}



Recent Results: $d(\alpha,\gamma)^6Li$



From the new data on the $^2H(\alpha,\gamma)^6Li$ reaction: $^6Li/^7Li = (1.5 \pm 0.3) * 10^{-5}$

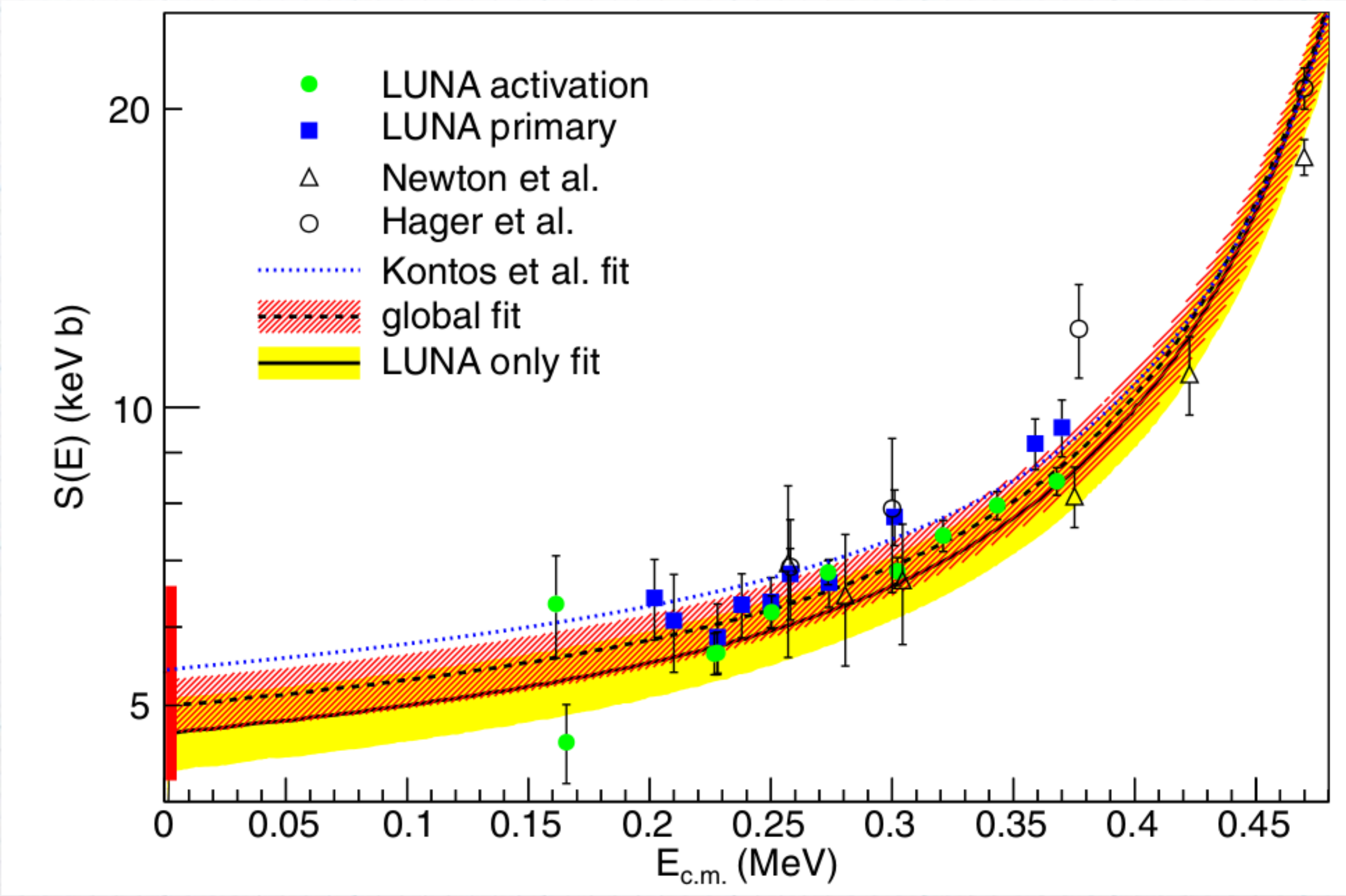
Standard BBN production as a possible explanation for the reported ^6Li detections is ruled out. "Non standard" physics solutions?

Recent results: $^{17}O(p,\gamma)^{18}O$

17O+p is very important for hydrogen burning in different stellar environments:

- Red giants
- Massive stars
- AGB
- Novae

$\omega\gamma$(183keV) = 1.67 ± 0.12 μeV
new transitions observed

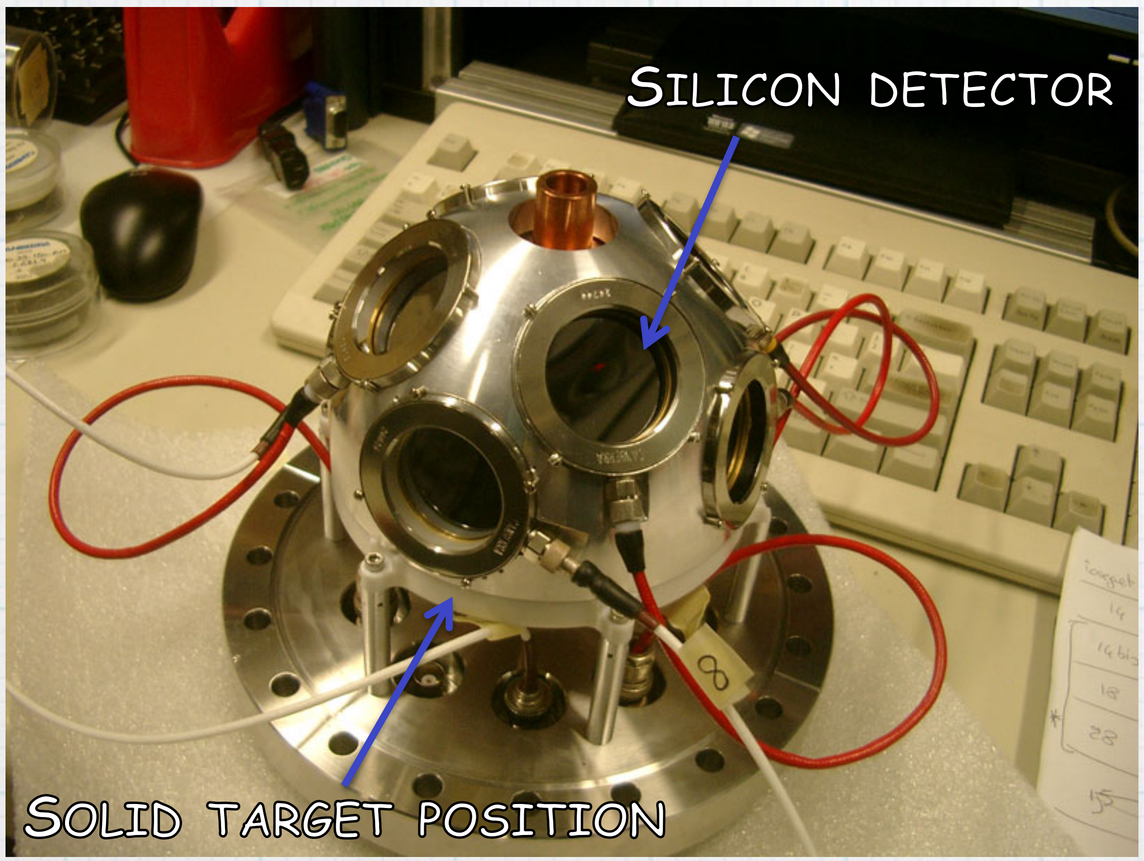


The new reaction rate allows to calculate abundances of ^{18}O, ^{18}F, ^{19}F and ^{15}N using nova models with 10% precision

D. Scott et al., Phys. Rev. Lett. 109 (2012) 202501
A. Di Leva et al., Phys. Rev. C 89 (2014) 015803

upcoming results

$^{17/18}O(p,\alpha)^{14/15}N$



In AGB stars (T=0.03-0.1 GK)
CNO cycle takes place in H burning shell

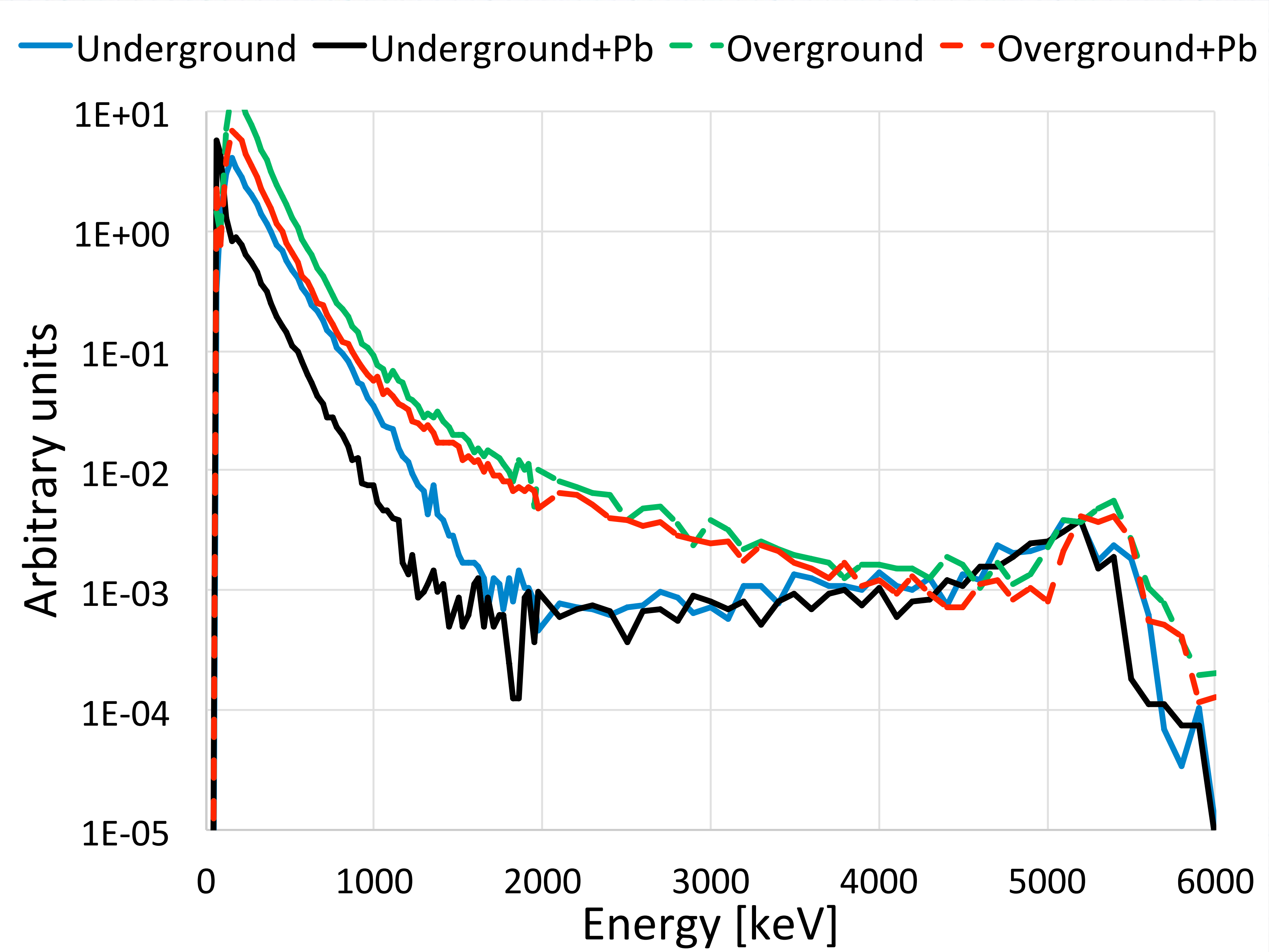
Measured 17O/16O and 18O/16O abundances in pre-solar grain give information on AGB surface composition

Information on mixing processes if cross sections are well known

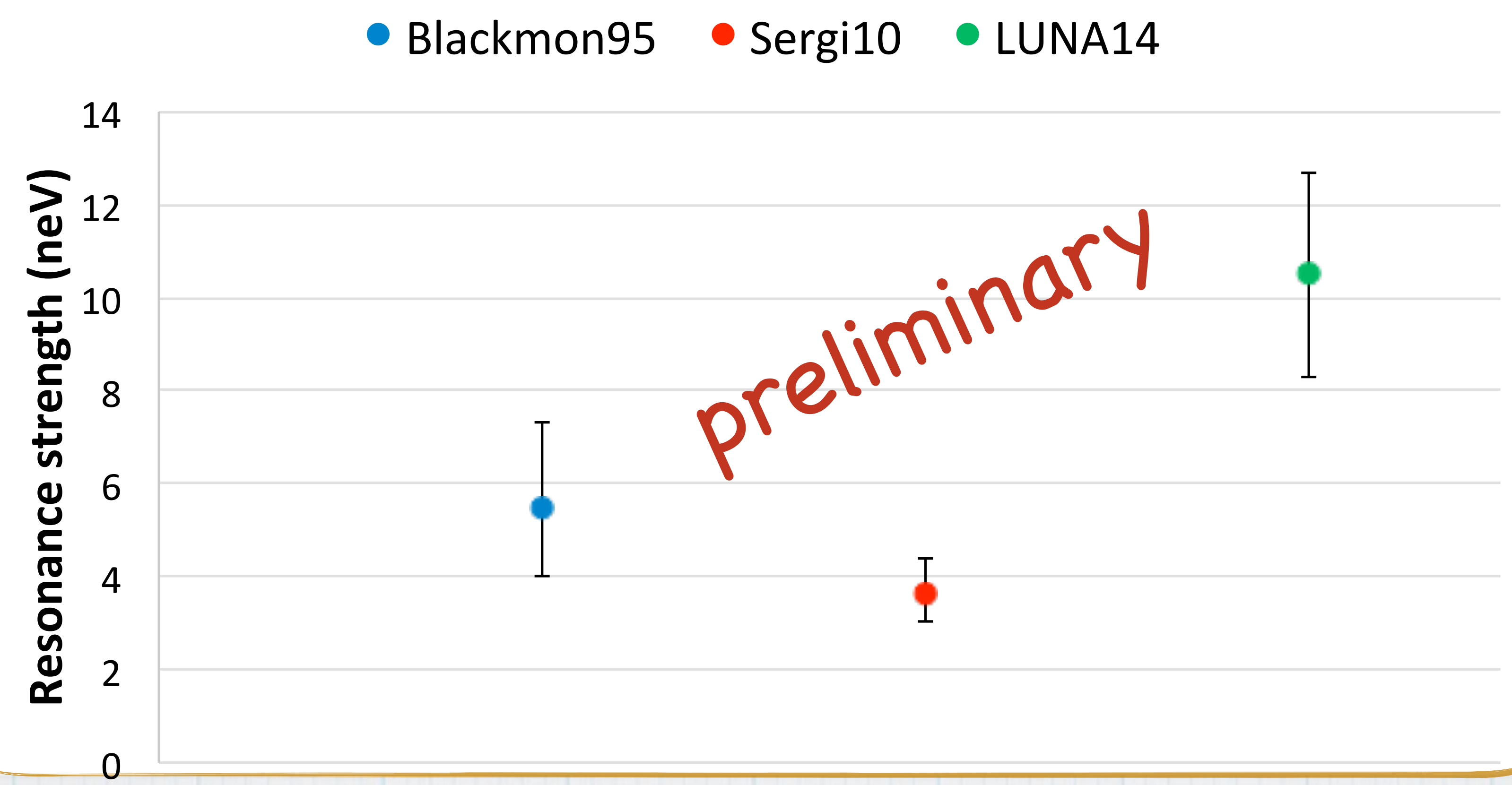
proton beam from LUNA 400 kV
enriched ^{17}O or ^{18}O targets
8 silicon detectors
foils of Al Mylar to stop backscattered protons low alpha particle energy
(200-250 keV for $^{17}O(p,\alpha)^{14}N$ reaction)

upcoming results

background reduction at LNGS



$^{17}O(p,\alpha)^{14}N$ preliminary results

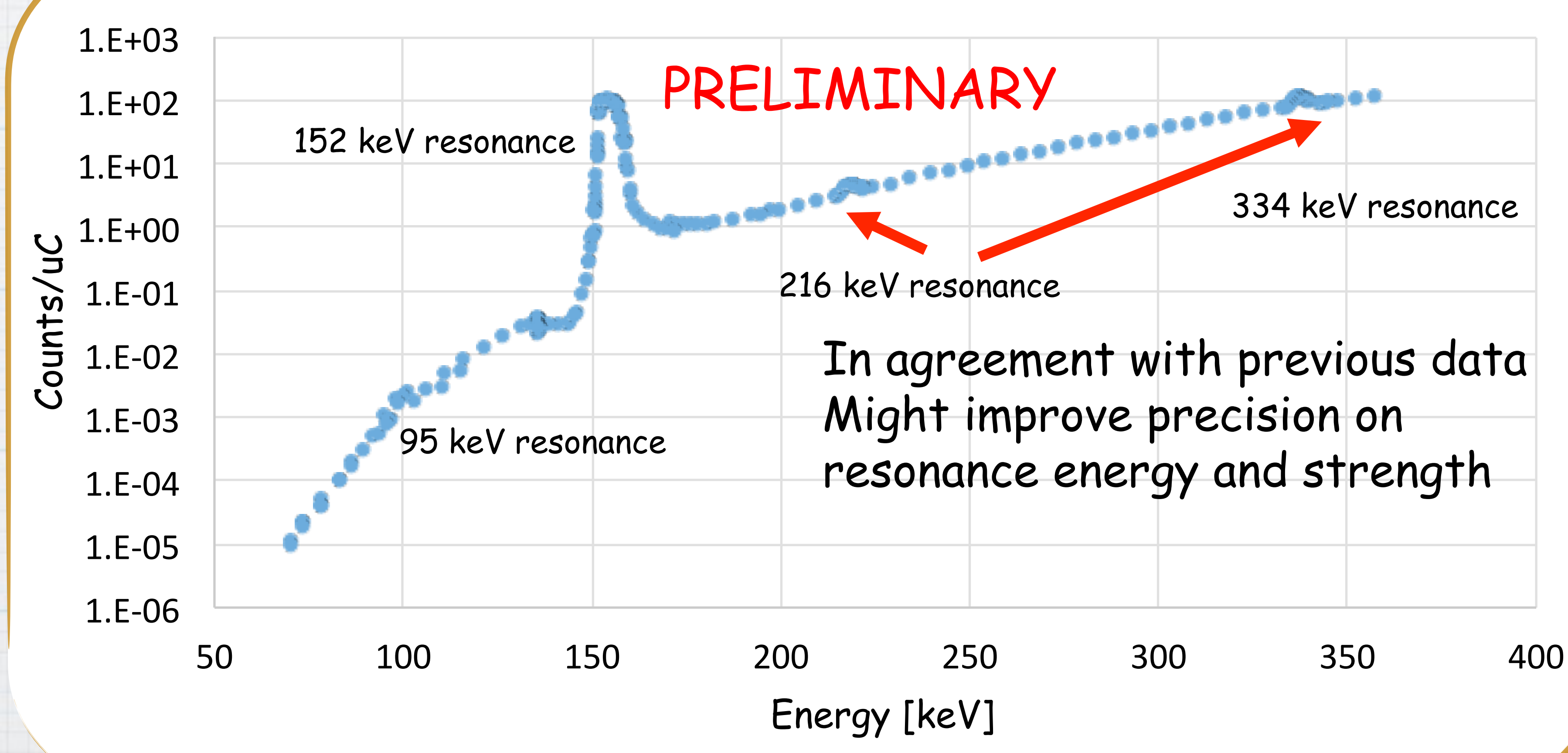


Very preliminary analysis favours a larger strength value compared with literature

If confirmed, it would have an astrophysical impact

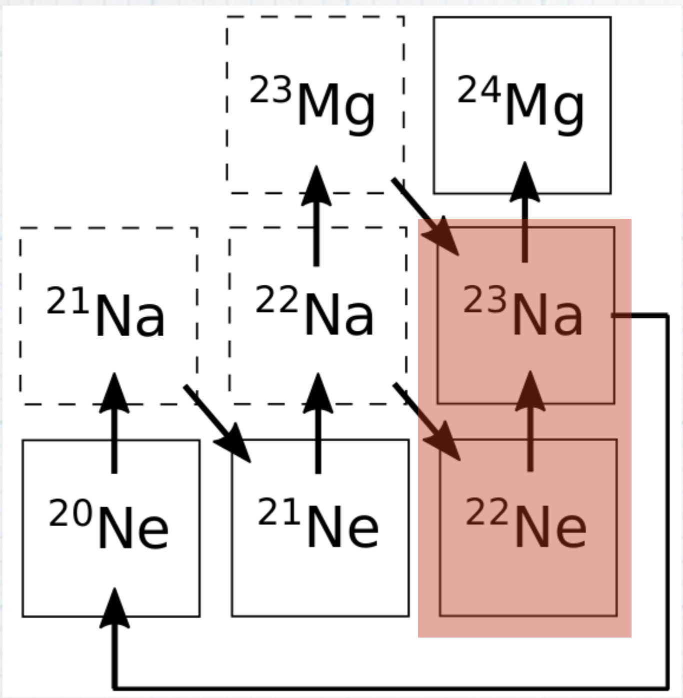
Analysis is still ongoing

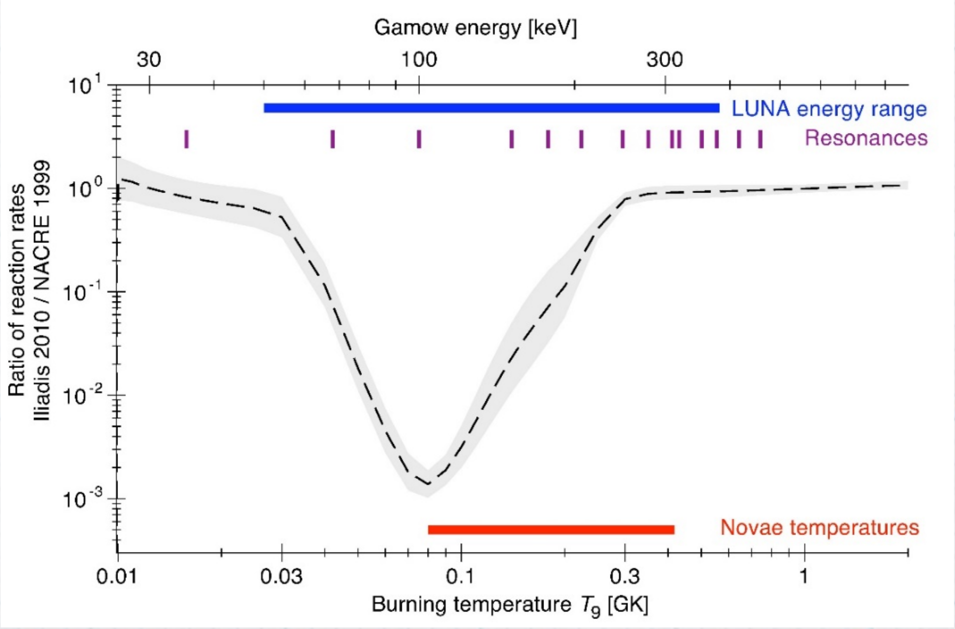
$^{18}O(p,\alpha)^{15}N$ preliminary results



95 keV resonance strength: precision about 10% (20-30% literature)
energy determined with 0.5 keV precision (2.2 keV literature)
60 keV measured with about 20% statistical uncertainty

upcoming results
$^{22}Ne(p,\gamma)^{23}Na$



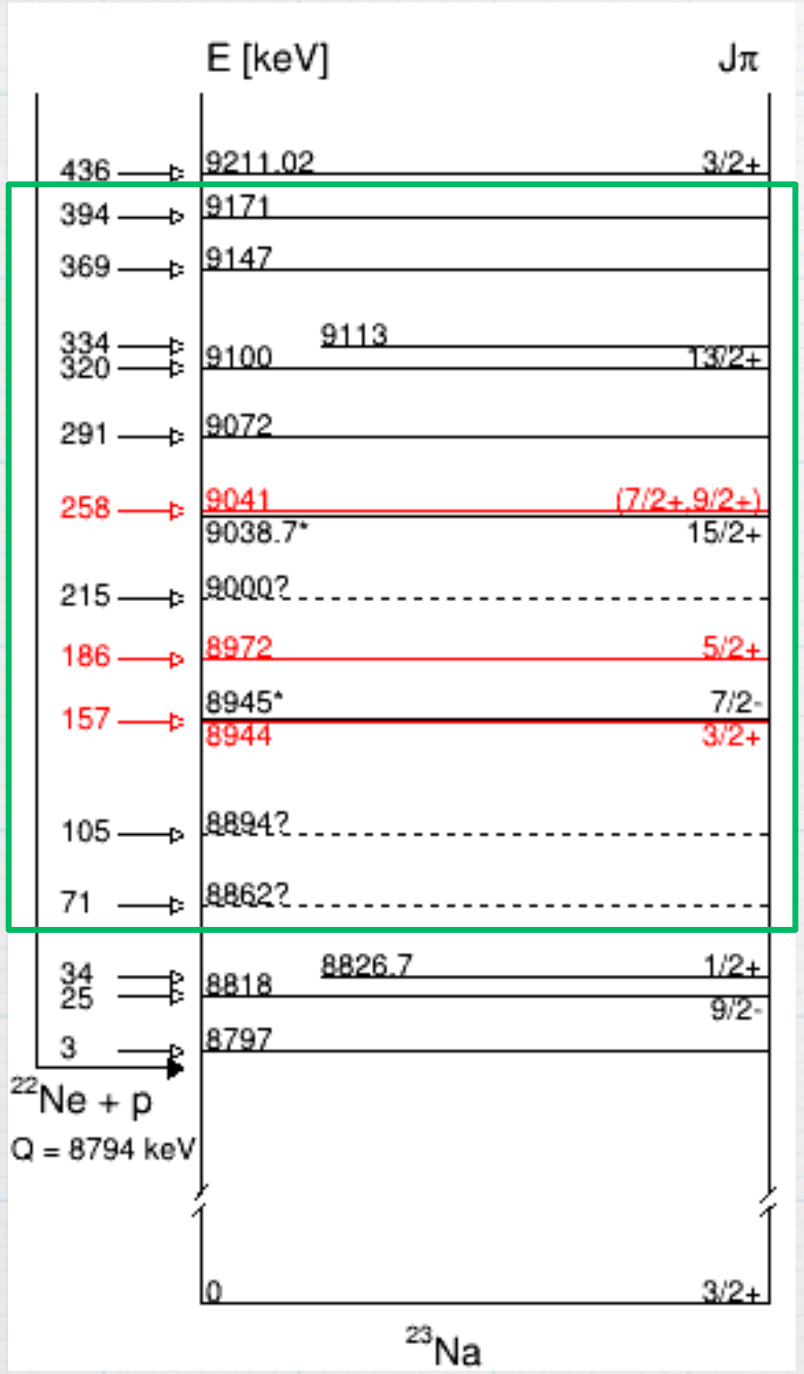


The Neon - Sodium cycle strongly influences the abundance of Ne, Na, Mg and Al isotopes in:

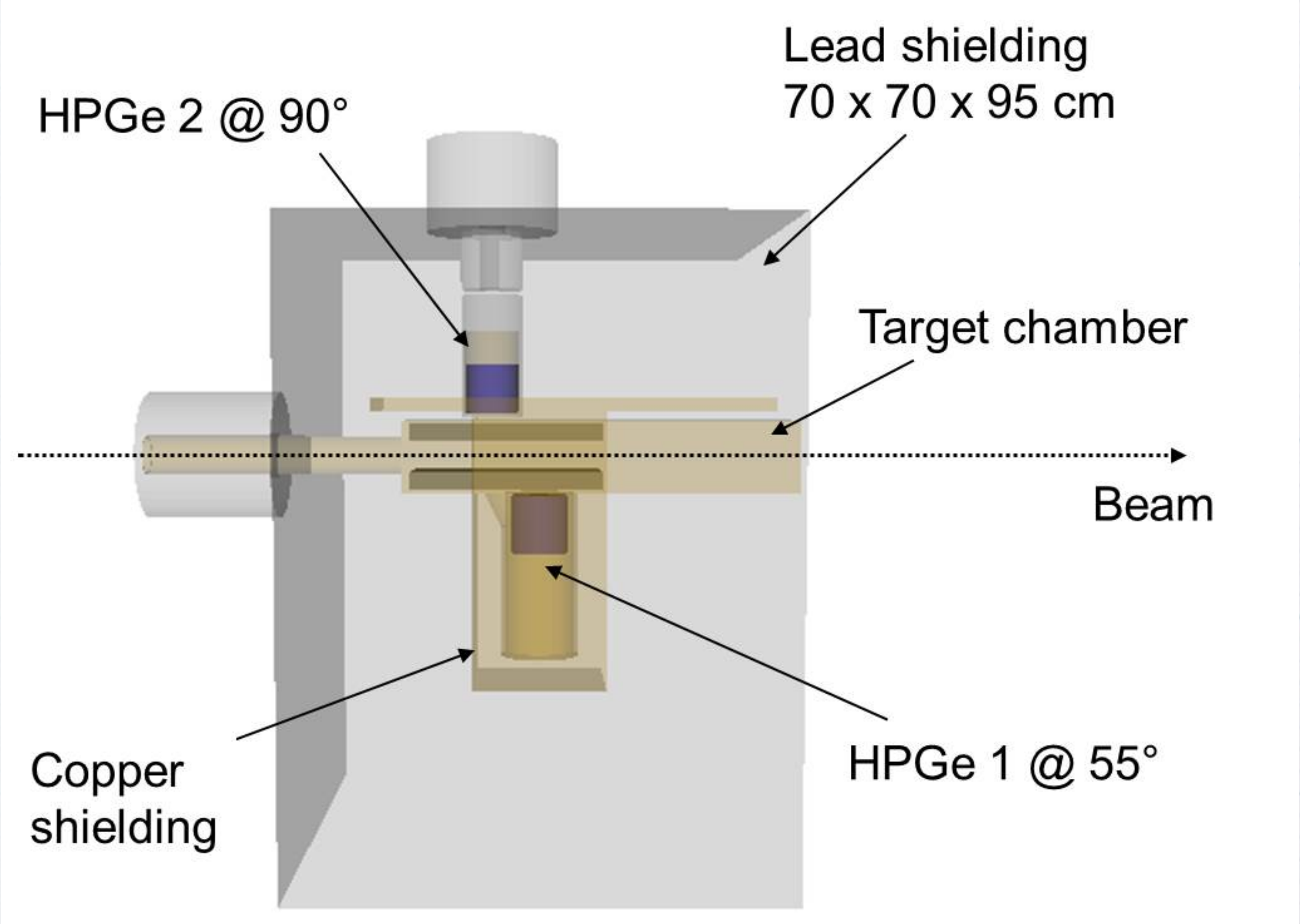
Shell hydrogen burning in Red Giant Branch and Asymptotic Giant Branch stars (Na-O anticorrelation problem)

Explosive H burning in classical novae and type Ia supernovae

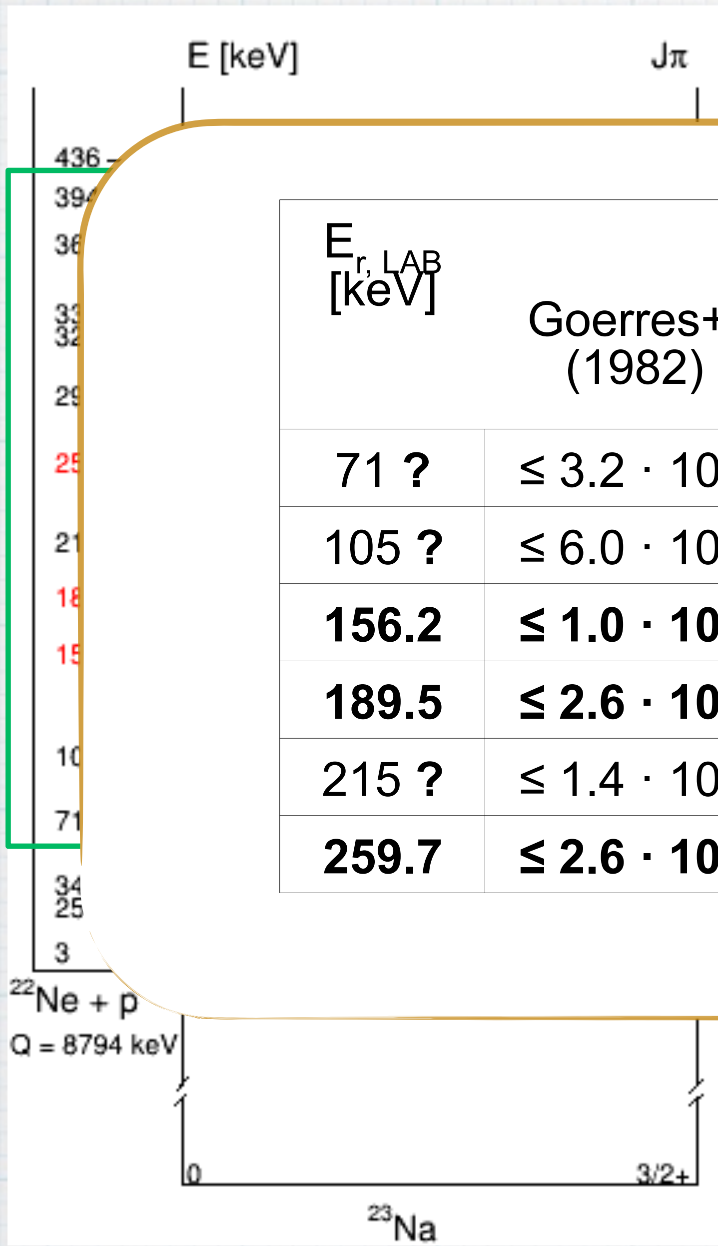
upcoming results
$^{22}Ne(p,\gamma)^{23}Na$



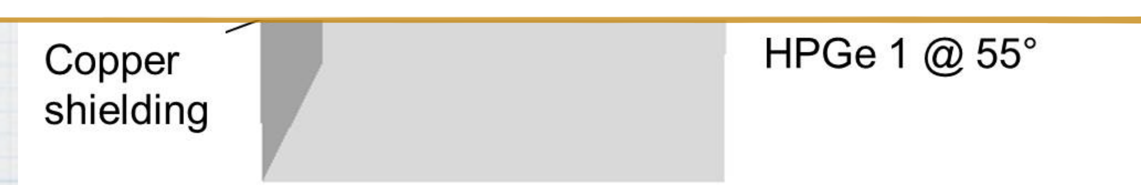
Three resonances observed for the first time



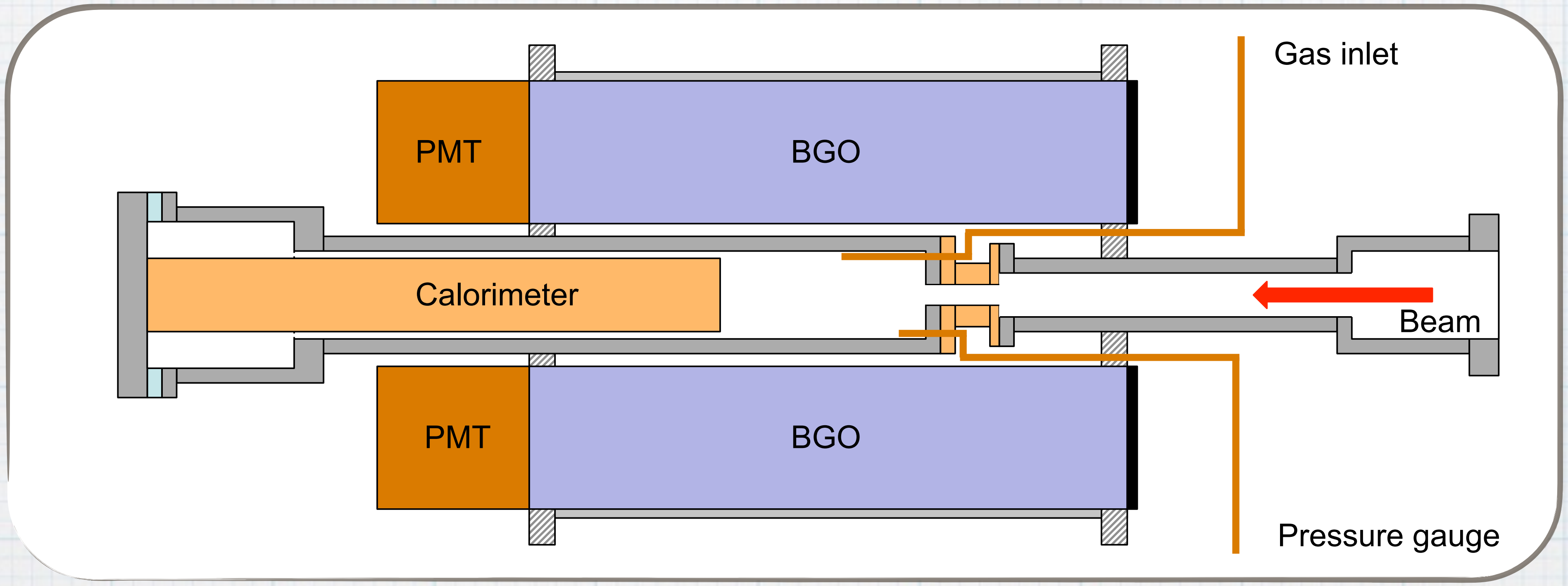
upcoming results
$^{22}Ne(p,\gamma)^{23}Na$



$E_{r,\ LAB}$ [keV]	wg [eV]			
	Goerres+ (1982)	NACRE	Iliadis+ (2010)	LUNA
71 **?**	$\leq 3.2 \cdot 10^{-6}$	$\leq 4.2 \cdot 10^{-9}$	-	$\leq 3.4 \cdot 10^{-9}$
105 **?**	$\leq 6.0 \cdot 10^{-7}$	$\leq 6.0 \cdot 10^{-7}$	-	$\leq 7.0 \cdot 10^{-9}$
156.2	$\mathbf{\leq 1.0 \cdot 10^{-6}}$	$\mathbf{(6.5 \pm 1.9) \cdot 10^{-7}}$	$\mathbf{(9.2 \pm 3.7) \cdot 10^{-9}}$	$\mathbf{(1.5 \pm 0.1) \cdot 10^{-7}}$
189.5	$\mathbf{\leq 2.6 \cdot 10^{-6}}$	$\mathbf{\leq 2.6 \cdot 10^{-6}}$	$\mathbf{\leq 2.6 \cdot 10^{-6}}$	$\mathbf{(1.87 \pm 0.05) \cdot 10^{-6}}$
215 **?**	$\leq 1.4 \cdot 10^{-6}$	$\leq 1.4 \cdot 10^{-6}$	-	$\leq 2.4 \cdot 10^{-8}$
259.7	$\mathbf{\leq 2.6 \cdot 10^{-6}}$	$\mathbf{\leq 2.6 \cdot 10^{-6}}$	$\mathbf{\leq 1.3 \cdot 10^{-6}}$	$\mathbf{(6.9 \pm 0.2) \cdot 10^{-6}}$



ongoing:
$^{22}Ne(p,\gamma)^{23}Na$ - BGO phase



Goal of the BGO phase: reduce further the upper limits on resonances at 71 and 105 keV, direct capture

setup already mounted and calibrated
data taken until autumn 2015

ongoing: $^{18}O(p,\gamma)^{19}F$ and $^{23}Na(p,\gamma)^{24}Mg$

Goal of $^{18}O(p,\gamma)^{19}F$ measurement: 95 keV resonance and DC component. BGO detector first, HPGe if feasible

Goal of $^{23}Na(p,\gamma)^{24}Mg$ measurement: 144 keV resonance and DC component.

BGO detector first. HPGe if feasible
A fully shielded setup with 15 cm lead is used

future reaction

$^{13}C(\alpha,n)^{16}O$ – neutron source (LUNA MV)

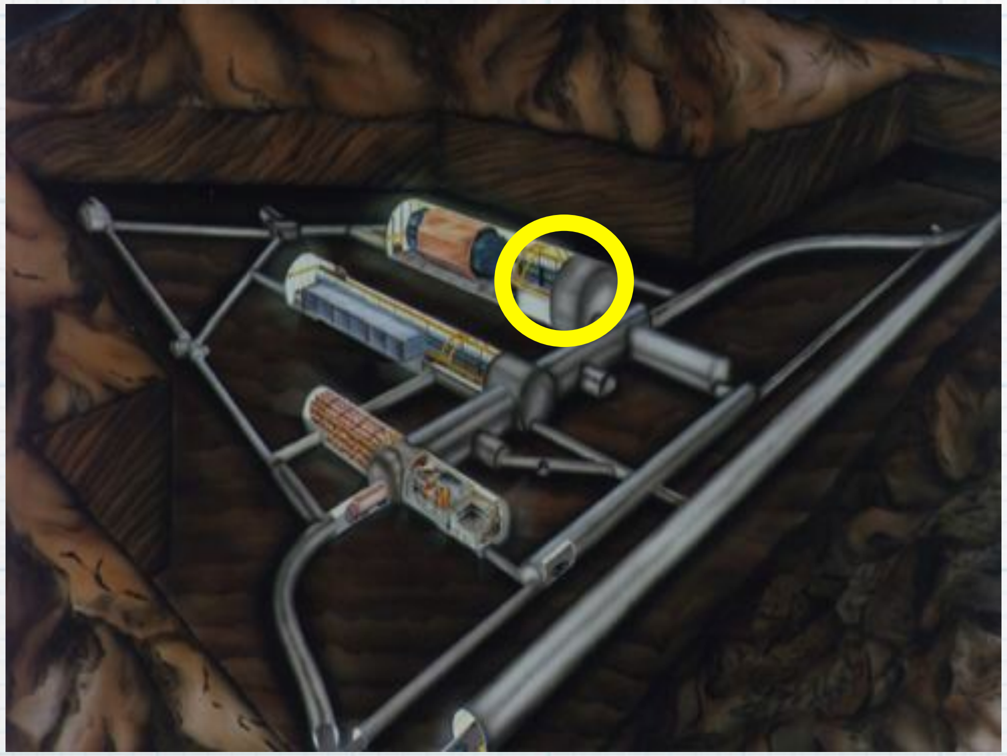
$^{12}C(p,\gamma)^{13}N$ and $^{13}C(p,\gamma)^{14}N$ – relative abundance of ^{12}C-^{13}C in the deepest layers of H-rich envelopes of any star

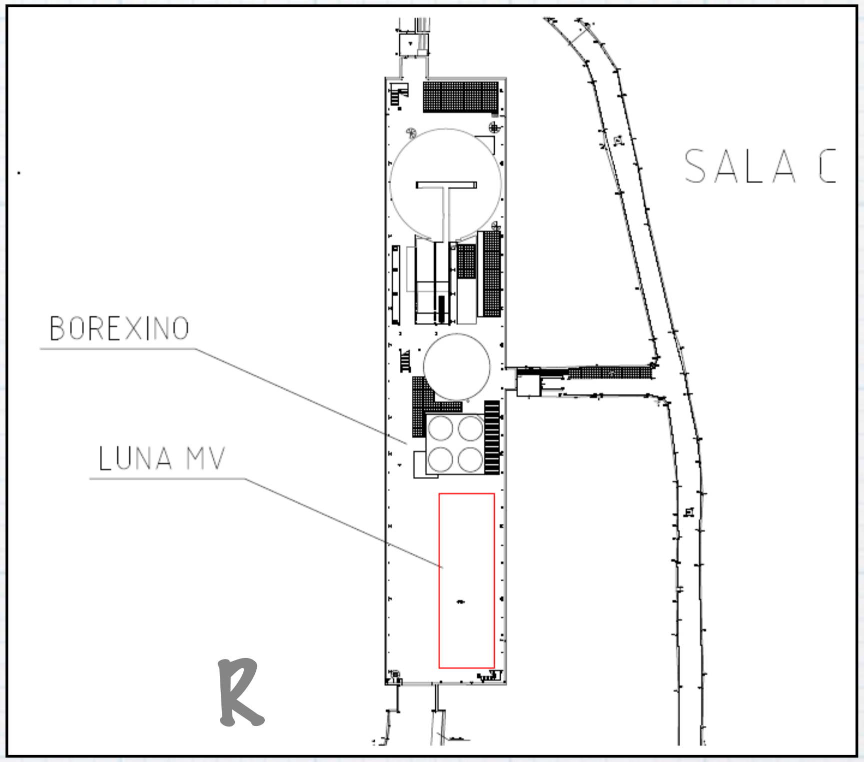
$^{2}H(p,\gamma)^{3}He$ – ^{2}H production in BBN (feasibility test already performed)

$^{22}Ne(\alpha,\gamma)^{26}Mg$ – competes with $^{22}Ne(\alpha,n)^{25}Mg$ neutron source (LUNA MV)

$^{6}Li(p,\gamma)^{7}Be$ – improves the knowledge of $^{3}He(\alpha,\gamma)^{7}Be$ key reaction of p-p chain (LUNA MV)

LUNA-MV





LUNA MV accelerator will be installed in the south part of Hall C of LNGS laboratory (OPERA location)

Provisionary dimensions of the hall: 27x11x5 m3
OPERA decommissioning started in Jan 2015. Should be finished by October 2016

LUNA-MV

Accelerator:

Intense H^+, $^4He^+$, $^{12}C^+$ e $^{12}C^{++}$ beams in the energy range: 350 keV-3.5 MeV.
One beam line with all necessary elements (magnets, pumps, valves,...).

Total budget about 3.9 Meuro: from LUNA MV «Premium projects» (total 5.3 Meuro) of the Italian Research Ministry

Tender published last April on European official gazette. Two factories are qualified and have been officially invited to produce an offer before September 2015.

Tender assignment: 50% tecnical performances (beam intensity, beam quality, maintenance, additional components, ...) , 50% price

Timeline:

Contract signed by 12/2015.
Accelerator built and tested by the producing company by 11/2017.
Accelerator delivered to LNGS by 01/2018
Accelerator installed and tested at LNGS by 07/2018. Then first experiments

LUNA-MV

$^{13}C(\alpha,n)^{16}O$ and $^{22}Ne(\alpha,n)^{25}Mg$: neutron sources for the s-process (formation of heavy elements)

$^{12}C(\alpha,\gamma)^{16}O$: key reaction of Helium burning: determine C/O ratio and stellar evolution

$^{12}C+^{12}C$: energy production and nucleosynthesis in Carbon burning. Global chemical evolution of the Universe

Reactions occurring at higher temperature than those belonging to Hydrogen burning or BBN

The LUNA collaboration

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Thank you!