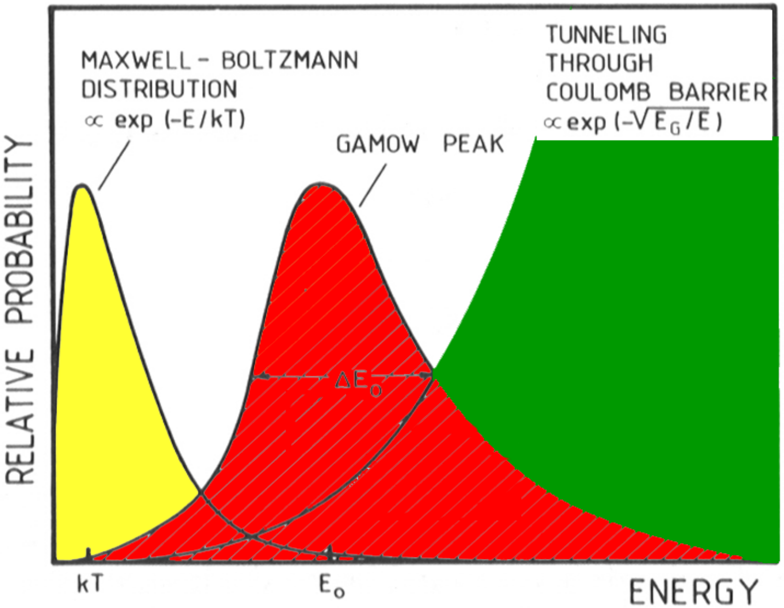
LUNA3 (CSN3) e LUNA-MV (progetto premiale)

Sandra Zavatarelli

INFN – Sezione di Genova

Resp. Loc. LUNA

Astrofisica nucleare underground: perche'?



Sun:
kT = 1 keV
$E_C \approx$ 0.5-2 MeV
$E_0 \approx$ 5-30 keV
for reactions of H burning

kT but also $E_0 \ll E_C$!!

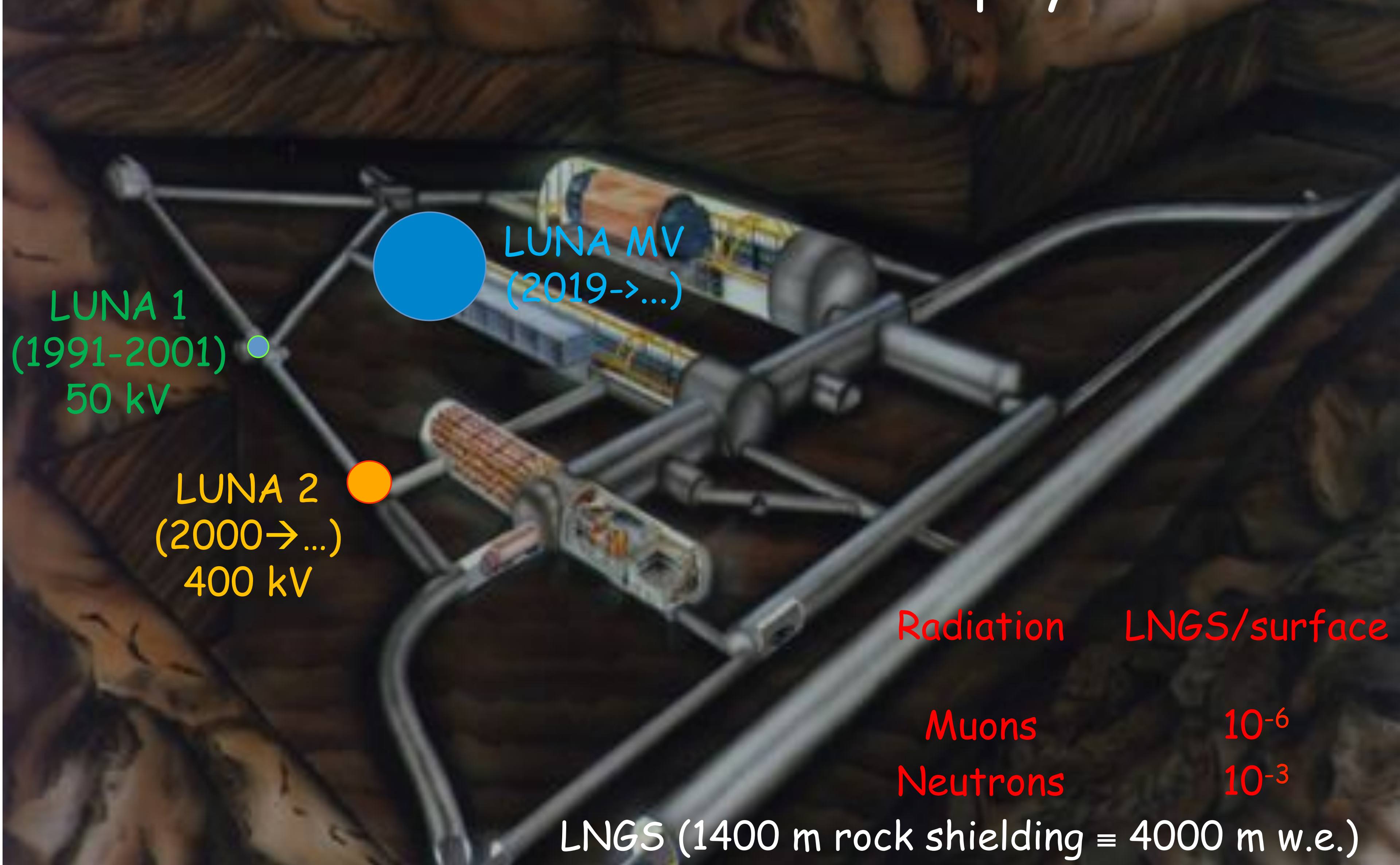
$$\sigma(E) = \frac{1}{E}\exp(-31.29 Z_1 Z_2 \sqrt{\mu/E})\, S(E)$$

Astrophysical factor

Cross sections in the range of pb-fb at stellar energies

with typical laboratory conditions reaction rate R can be as low as few events per month

Laboratory for Underground Nuclear Astrophysics

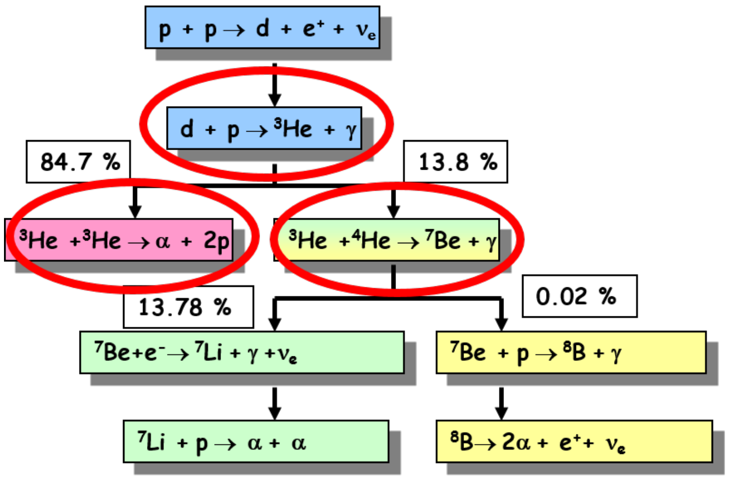


Radiation	LNGS/surface
Muons	10^{-6}
Neutrons	10^{-3}

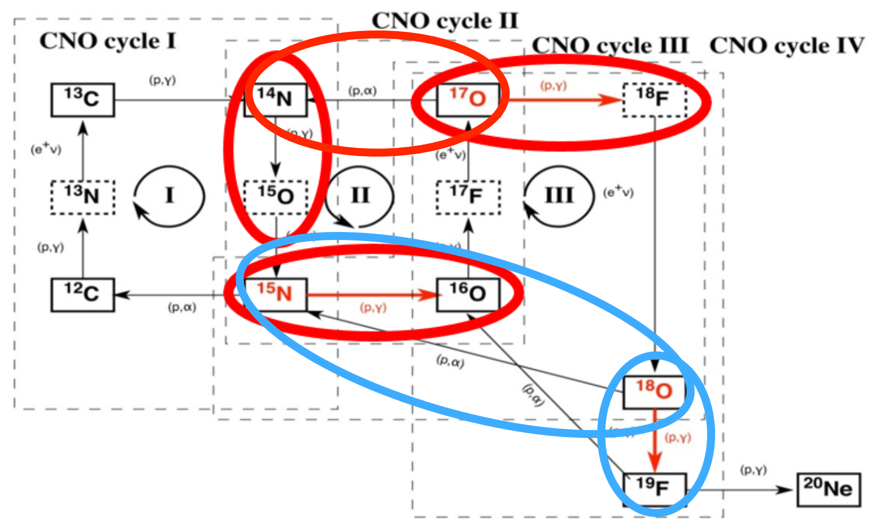
LNGS (1400 m rock shielding ≡ 4000 m w.e.)

25 anni a LUNA: la combustione dell'idrogeno

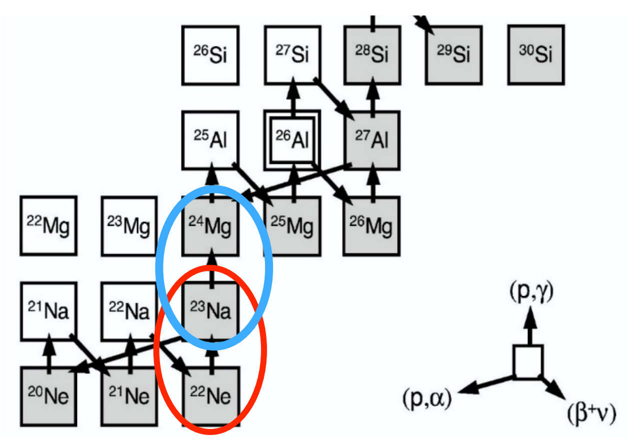
pp chain



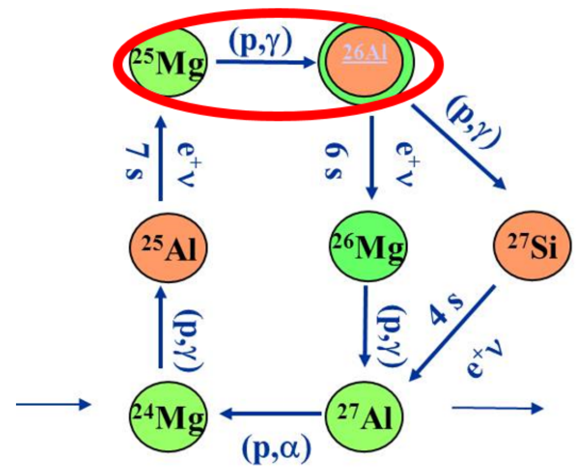
CNO cycle



Ne-Na cycle

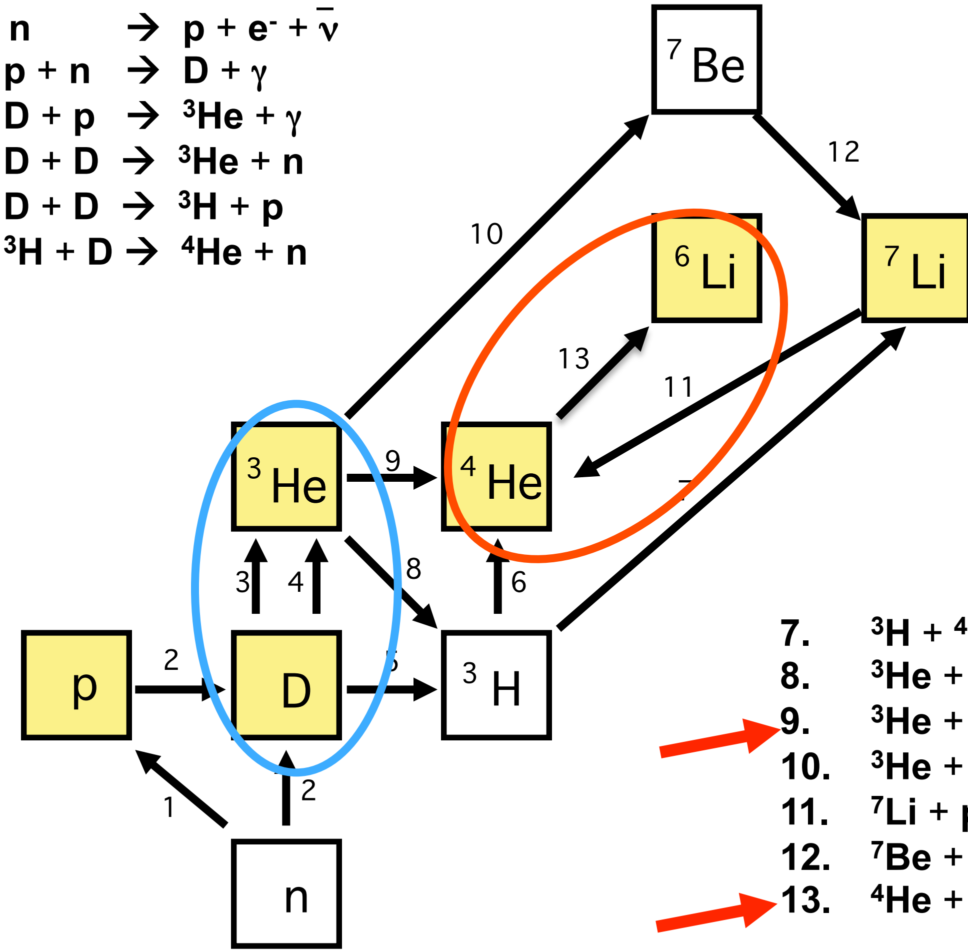


Mg-Al cycle



…e Nucleosintesi del Big Bang

1. n → $p + e^- + \bar{\nu}$
2. p + n → D + γ
3. D + p → $^3He + \gamma$
4. D + D → ^3He + n
5. D + D → ^3H + p
6. ^3H + D → ^4He + n



7. $^3H + ^4H$ → $^7Li + \gamma$
8. ^3He + n → ^3H + p
9. ^3He + D → ^4He + p
10. $^3He + ^4He$ → $^7Be + \gamma$
11. ^7Li + p → $^4He + ^4He$
12. ^7Be + n → ^7Li + p
13. ^4He + D → $^6Li + \gamma$

Program (@ LUNA400) 2016-2019: a bridge toward LUNA MV

^{2}H(p,γ)^{3}He – ^{2}H production in BBN ✓

^{6}Li(p,γ)^{7}Be – abundances of Li isotopes (BBN); improves the knowledge of ^{3}He(α,γ)^{7}Be key (p-p chain) ✓

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^{22}Ne(α,γ)^{26}Mg – competes with ^{22}Ne(α,n)^{25}Mg neutron source in massive stars(*LUNA 400 + MV*)

^{13}C(α,n)^{16}O – neutron source in AGB (*LUNA 400 + MV*)

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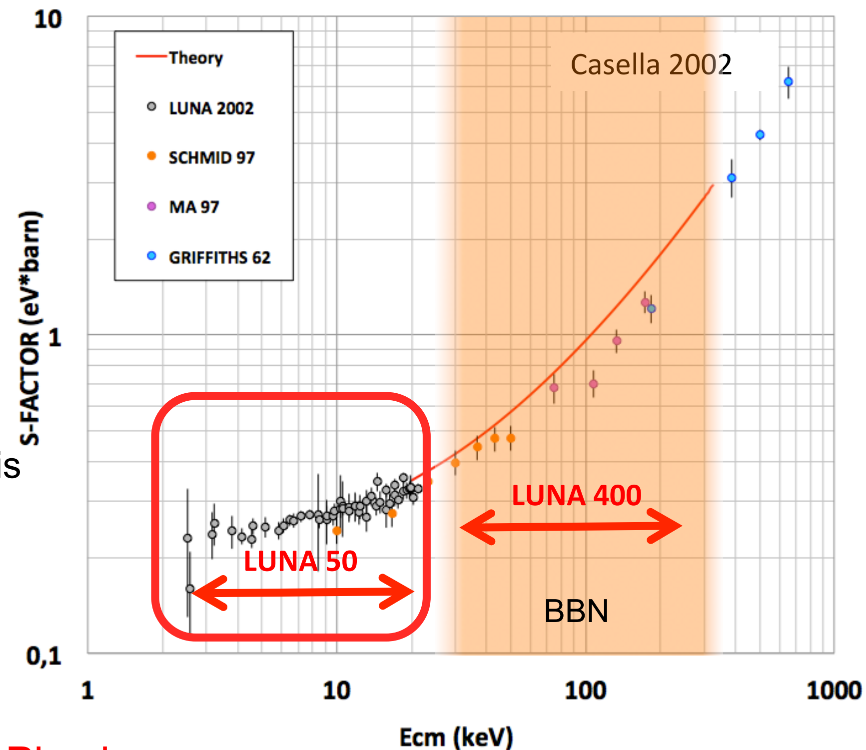
^{12}C(p,γ)^{13}N and ^{13}C(p,γ)^{14}N – relative abundance of ^{12}C-^{13}C in the deepest layers of H-rich envelopes.

$^{2}H(p,\gamma)^{3}He$ - ^{2}H production in BBN

Reaction	Rate Symbol	$\sigma_{^2H/H} \cdot 10^5$
$p(n,\gamma)^2H$	R_1	± 0.002
$d(p,\gamma)^3He$	R_2	± 0.062
$d(d,n)^3He$	R_3	± 0.020
$d(d,p)^3H$	R_4	± 0.013

(Di Valentino et al. 2014, $\Omega_b h^2 = 0.02207$)

-The error budget of computed abundance of deuterium is mainly due to the $D(p,\gamma)^3He$ reaction
-measurements (9% error) NOT in agreement with recent "Ab-Initio" calculations.



Measurement goal:

-Cross section measurement at $30<E_{cm}(keV)<260$ with ~ 5% accuracy
-Differential cross section measurement at $100<E_{cm}(keV)<260$

Physics:

-Cosmology: measurement of Ω_b.
-Neutrino physics: measurement of N_{eff}.
-Nuclear physics: comparison of data with "ab initio" predictions.

D/H ratio and cosmology

-BBN provides a precise estimate of Baryon density Ω_b, through the comparison of $(D/H)_{BBN}$ and $(D/H)_{obs}$:

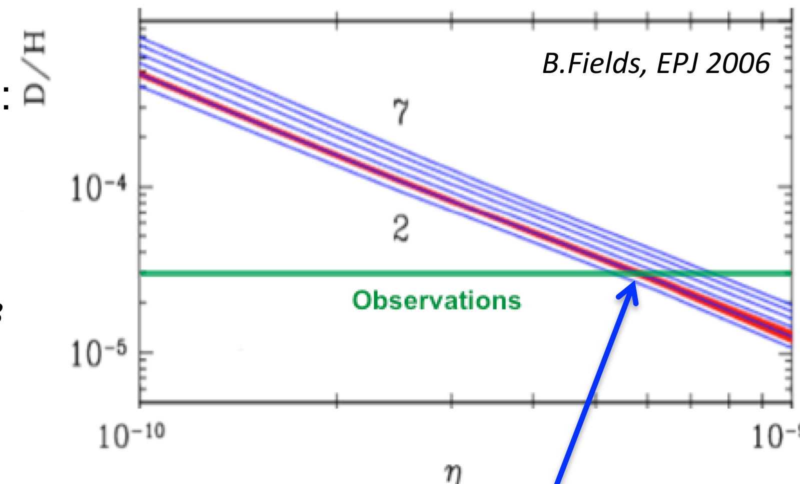
D(p,γ) data fit

$100\Omega_{b,0}h^2(BBN)=2.26\pm0.03\pm0.02$

$100\Omega_{b,0}h^2(BBN)=2.16\pm0.01\pm0.02$

D(p,γ) "ab-initio" *D/H observations*

R. Cooke et al., Ap. J. 830 (2016) 148

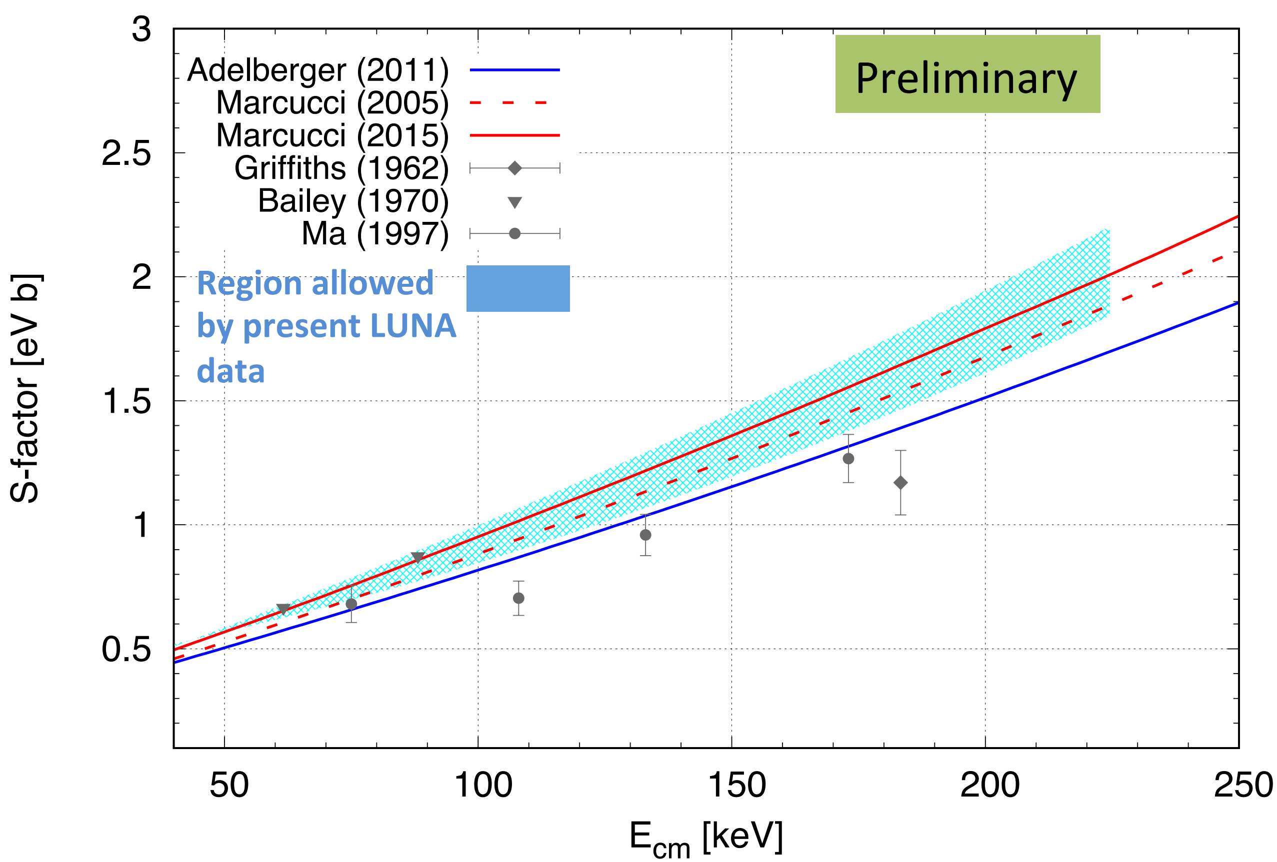


From CMB data:

$100\Omega_{b,0}h^2(CMB)=2.22\pm0.02$ (PLANCK2015)

-Deuterium abundance also depends on the density of relativistic particles (photons and 3 neutrinos in SM). Therefore it is a tool to constrain the "dark radiation".

Results: astrophysical factor

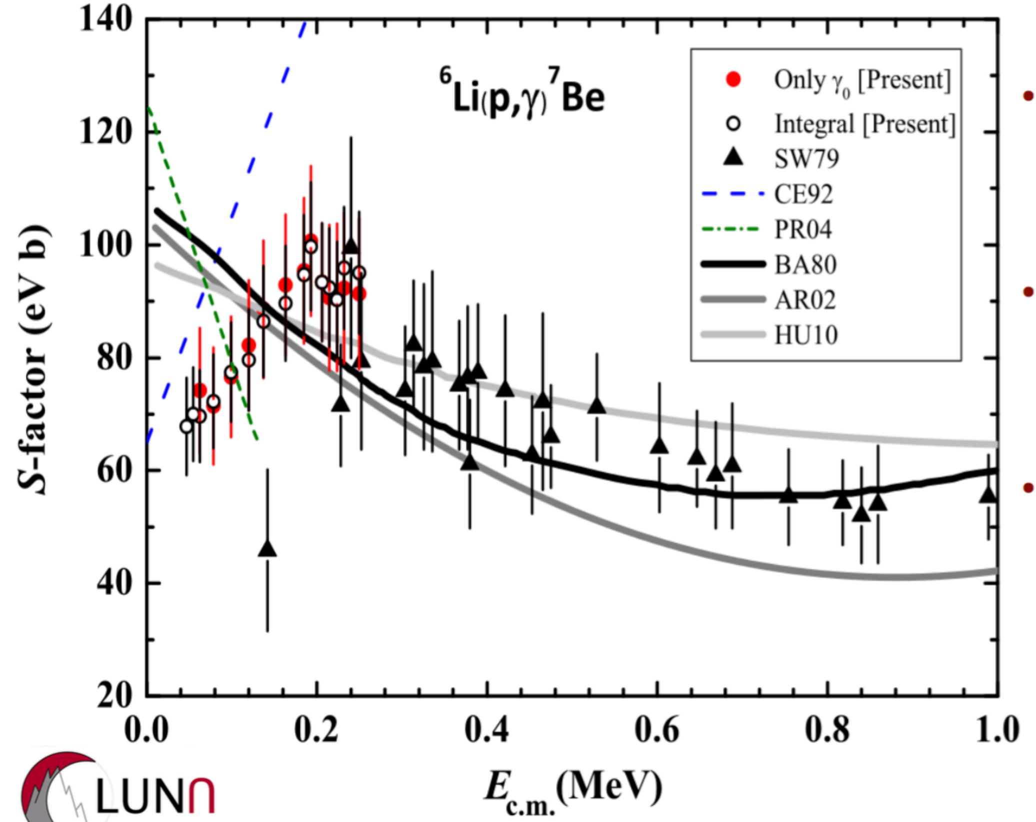


$^{6}Li(p,\gamma)^{3}He$

^{6}Li originates from the spallation and fusion reactions in the ISM.

Pre-main and main sequence stars efficiently **destroy ^{6}Li via $^{6}Li(p,\gamma)^{7}Be$ and $^{6}Li(p,\alpha)^{3}He$** ($T > 3 \cdot 10^{6}$ K)

^{6}Li is an important **tool to understand the early evolution of a star**



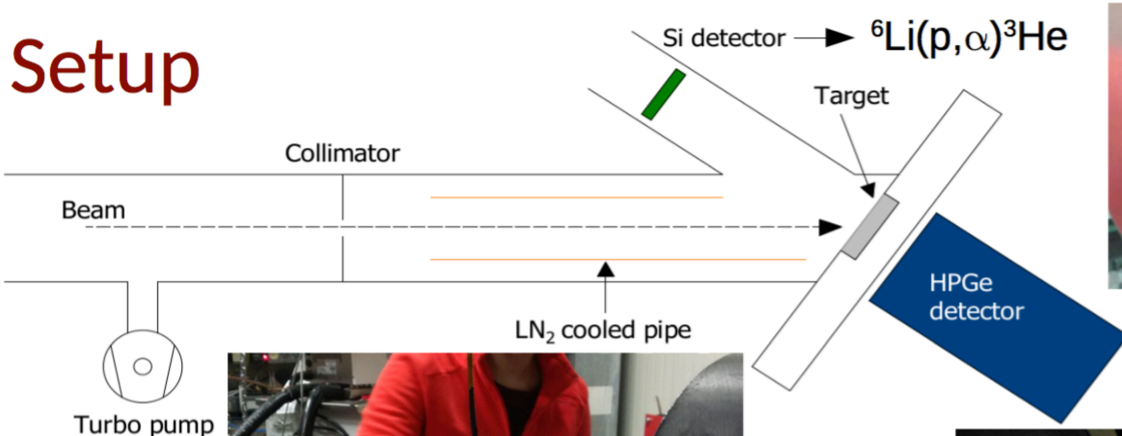
He et al., Phys. Rev. Lett. B (2013)

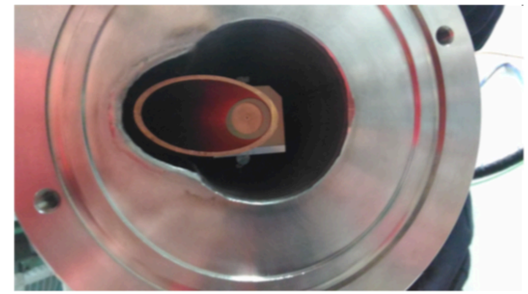
LUNA

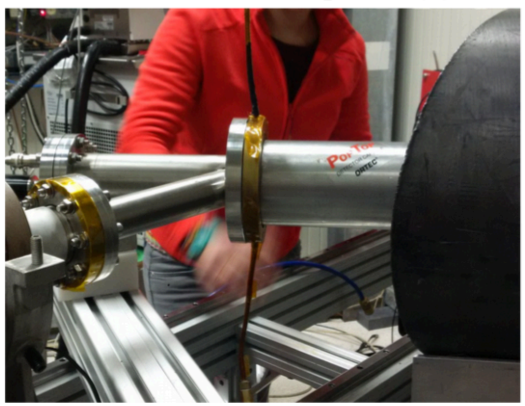
LUNA

$^{6}Li(p,\gamma)^{3}He$

Setup





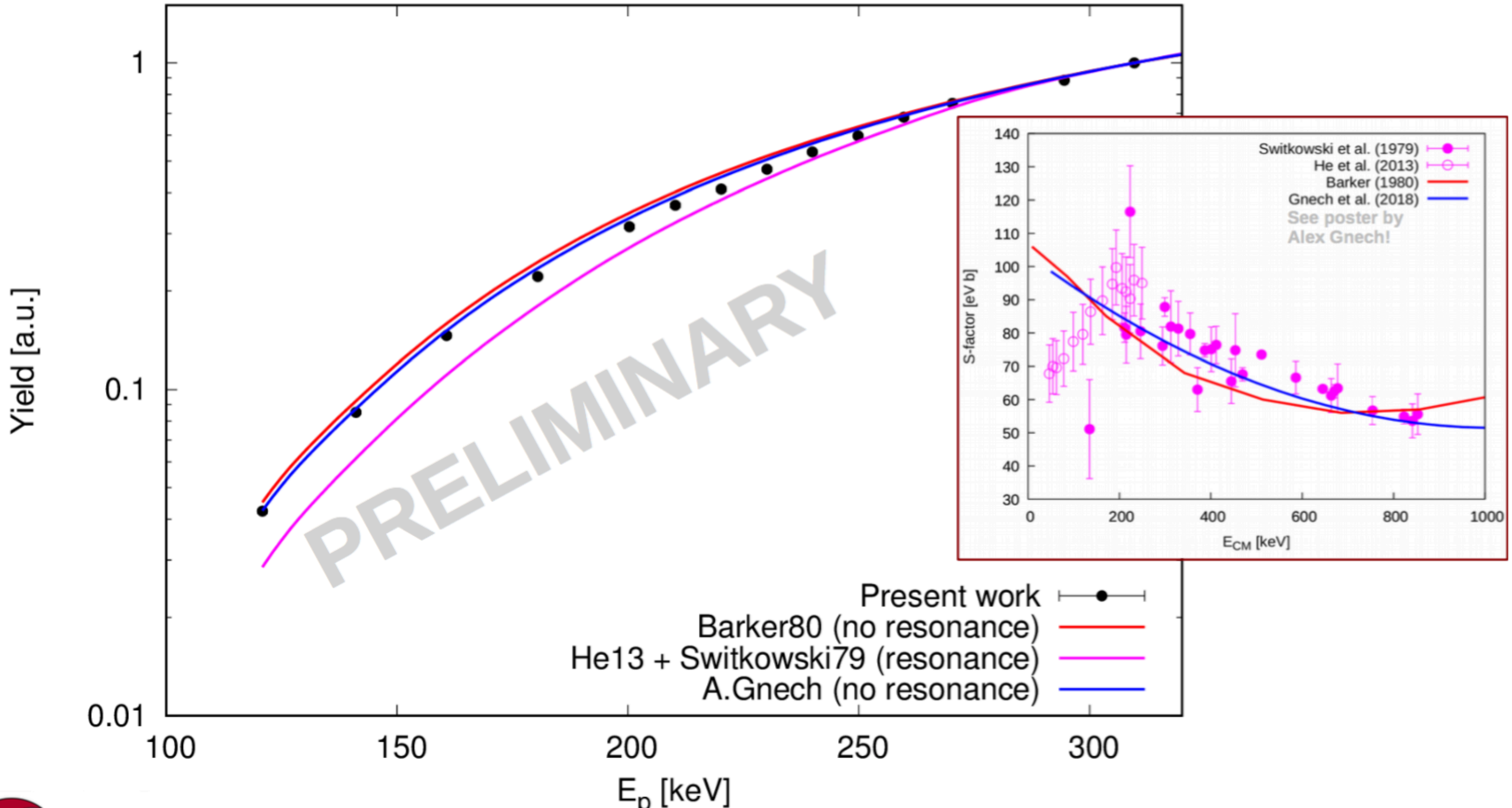


- Cold Finger + secondary e^{-} suppression
- Water cooled target
- HPGe at -55° and Si at +125° w.r.t. beam direction
- HPGe at 1.7 cm and Si at 10 cm w.r.t. target

LUNA

$^{6}Li(p,\gamma)^{3}He$

Total Yield



LUNA

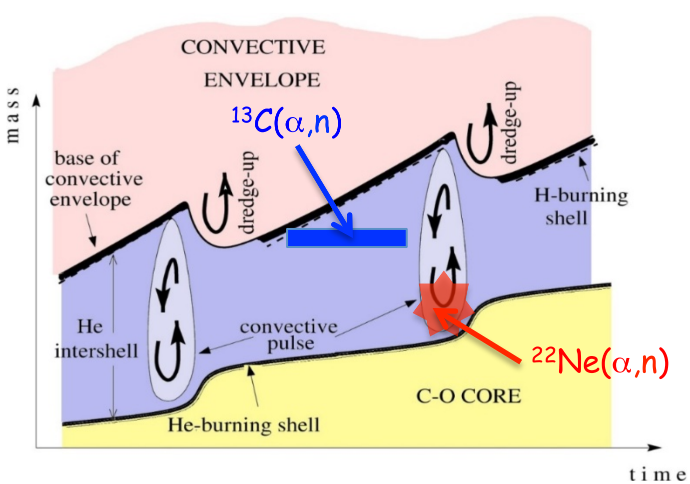
Le sorgenti di neutroni per il processo s: $^{13}C(\alpha,n)^{16}O$ e $^{22}Ne(\alpha,n)^{25}Mg$

Nucleosynthesis of half of the elements heavier than Fe

Main s-process ~90<A<210

TP-AGB stars

shell H-burning	He-flash
$T_9 \sim 0.1$ K	$0.25 \leq T_9 \sim 0.4$ K
10^7-10^8 cm^{-3}	10^{10}-10^{11} cm^{-3}
$^{13}C(\alpha,n)^{16}O$	$^{22}Ne(\alpha,n)^{25}Mg$

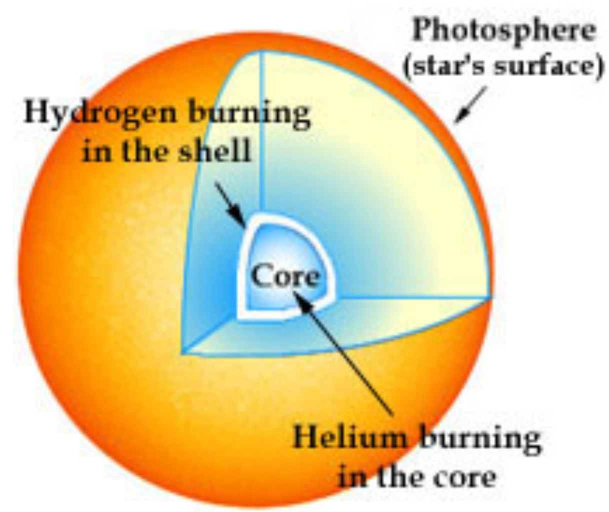


Weak s-process A<~90

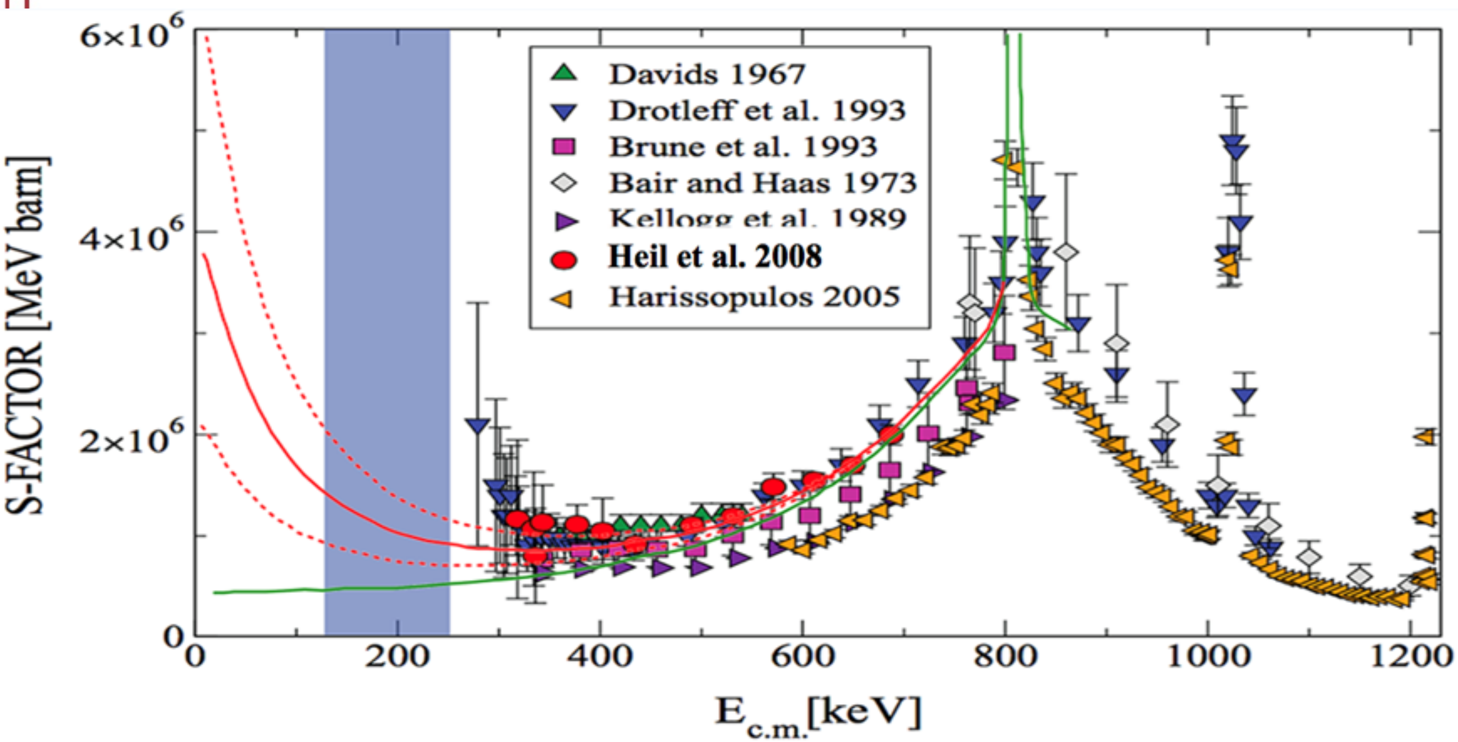
massive stars > 10 M_{Sun}

core He-burning	shell C-burning
3-3.5·10^8 K	~10^9 K
10^6 cm^{-3}	10^{11}-10^{12} cm^{-3}

$^{22}Ne(\alpha,n)^{25}Mg$



$^{13}C(\alpha,n)^{16}O$



$^{13}C(\alpha,n)^{16}O$ is the major neutron source for the main component of the *s process* in low mass (1-3 M☉) AGB stars, whose temperature is around 1-2 × 10^8 K.

This translates into the effective energy range: 120-250 keV.

No direct data covering this energy range is available yet.

Astrophysical requirement: uncertainty on S(E) < 10%

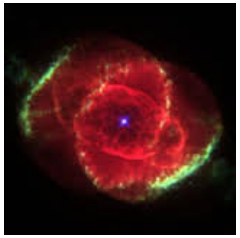
$^{13}C(\alpha,n)^{16}O$: expected reaction rate

Target enrichment in ^{13}C: 99%, I_{α} = 200 μA

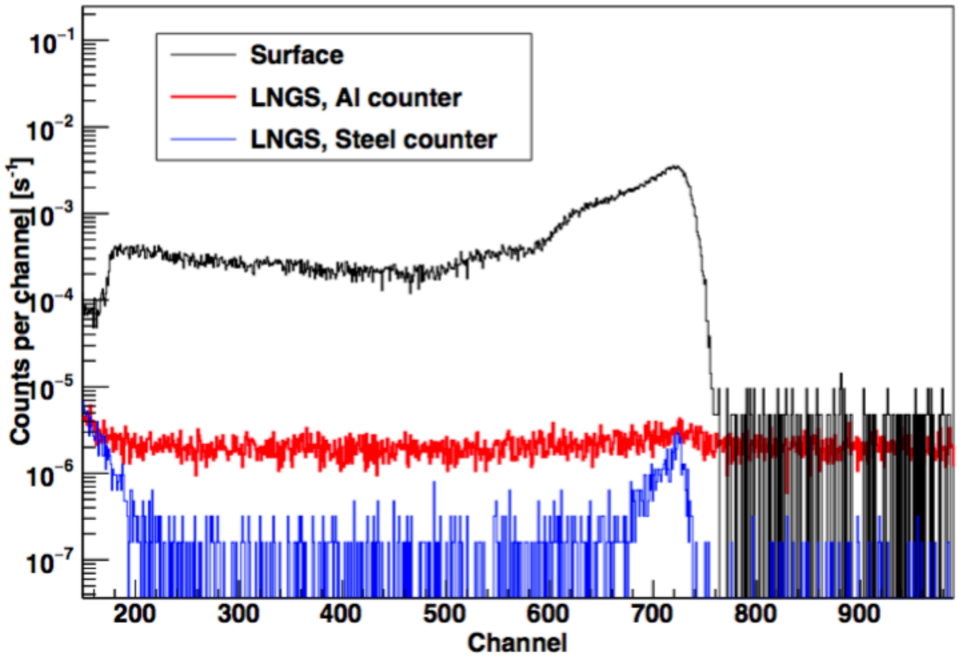
N_t = 10^{18} $2\ 10^{17}$ at/cm^2

Elab [keV]	Ecm [keV]	Rate [neutr/h]	Rate [neutr/h]
400	306	339	121
375	287	103	38.5
350	268	28	10.9
300	229	1.3	0.6
275	210	**0.2**	**0.1**
250	191	**0.02**	**0.01**

beam time:
≈ 2 months
if bck =0

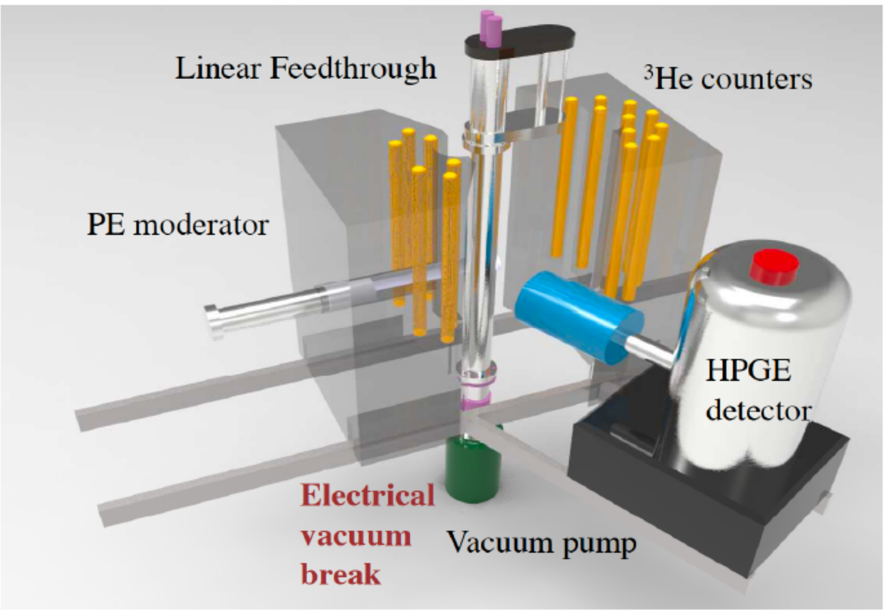


Low Background ^{3}He counters



- At lowest energy about 1:1 signal:background
- Total bg rate $\approx$ 4 counts/hour
- Composed of neutrons and α emitted into counter from wall

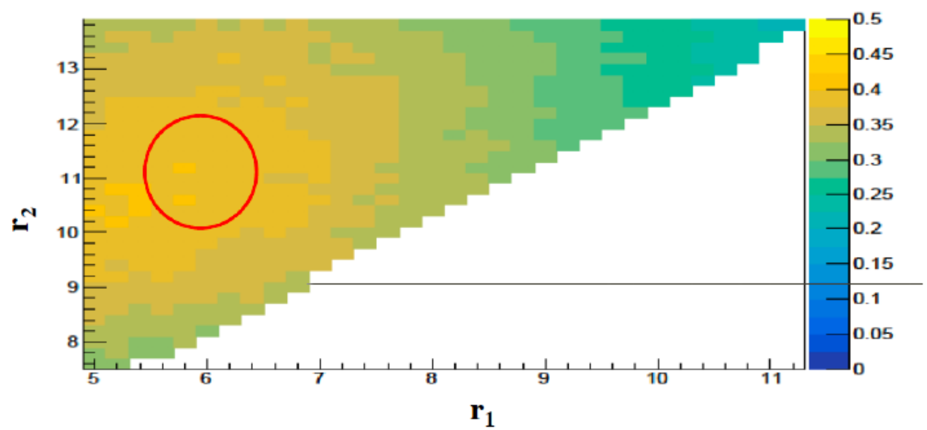
$^{13}C(\alpha,n)^{16}O$: set-up of the new undegroud experiment



Order concluded: delivery by the end of September

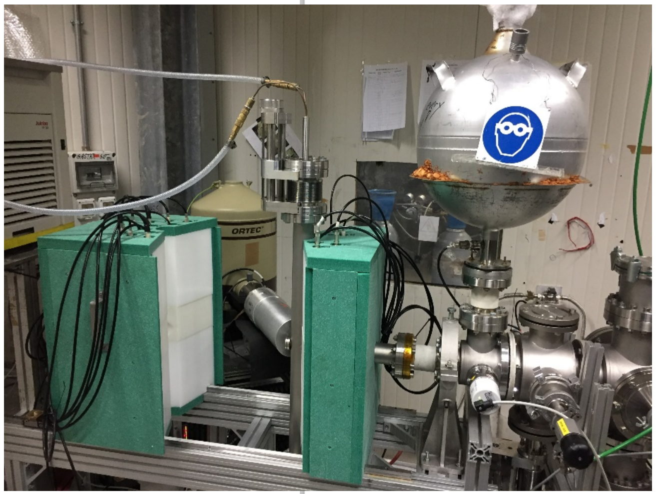
Counters arranged in two rings
INNER: 6 tubes (25 cm active lenght) at r1 from the target
OUTER: 12 tubes (40 cm active lenght) at r2

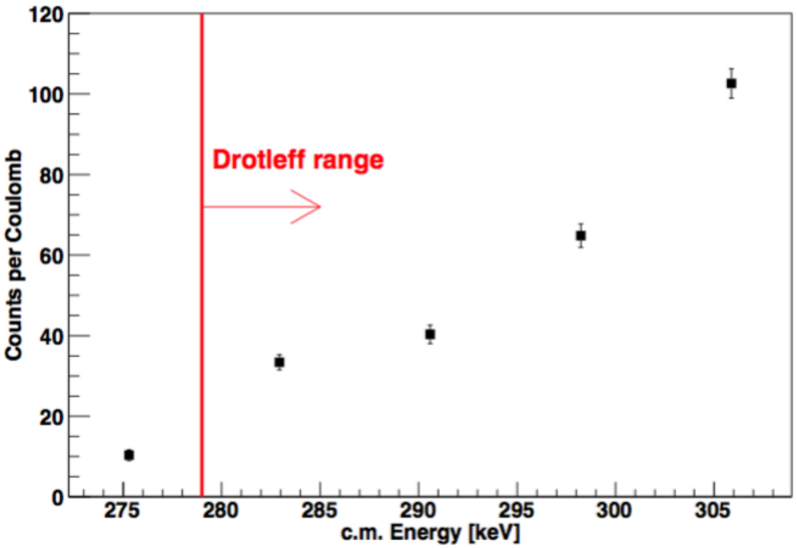
Geant4 simulations in order to maximise the efficiency (40%)



Detection efficiency ≈ 40%

$^{13}C(\alpha,n)^{16}O$: measured yield



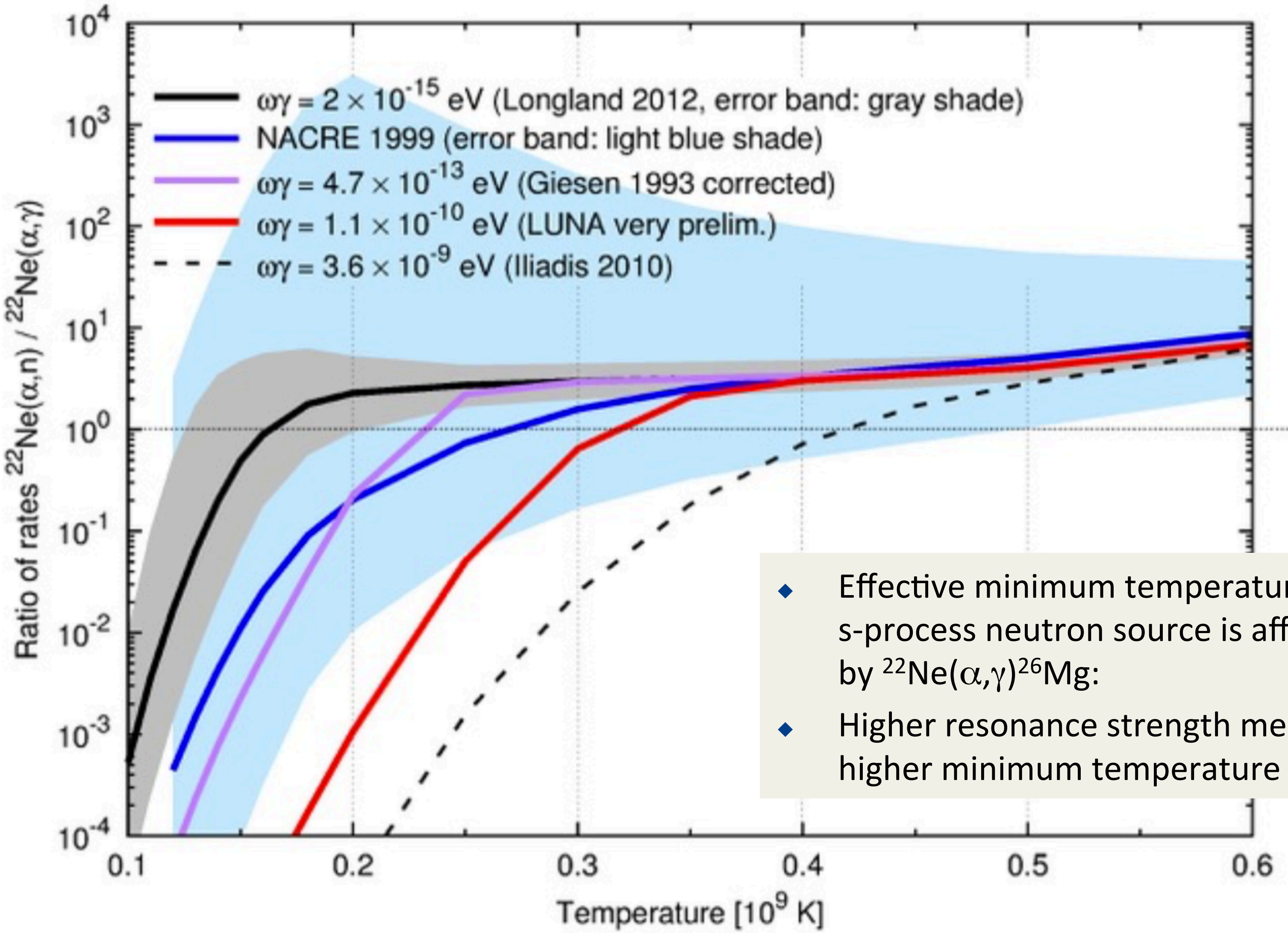


E_α [keV]	Charge [C]	Raw counts
400	11	1375
390	16.7	1408
380	17	1177
370	13.7	569
360	20.4	474

- First beam time concluded in March
- Total charge on target 80 C
- Counting statistics better than 10 %
- Measured below Drotleff et al. range

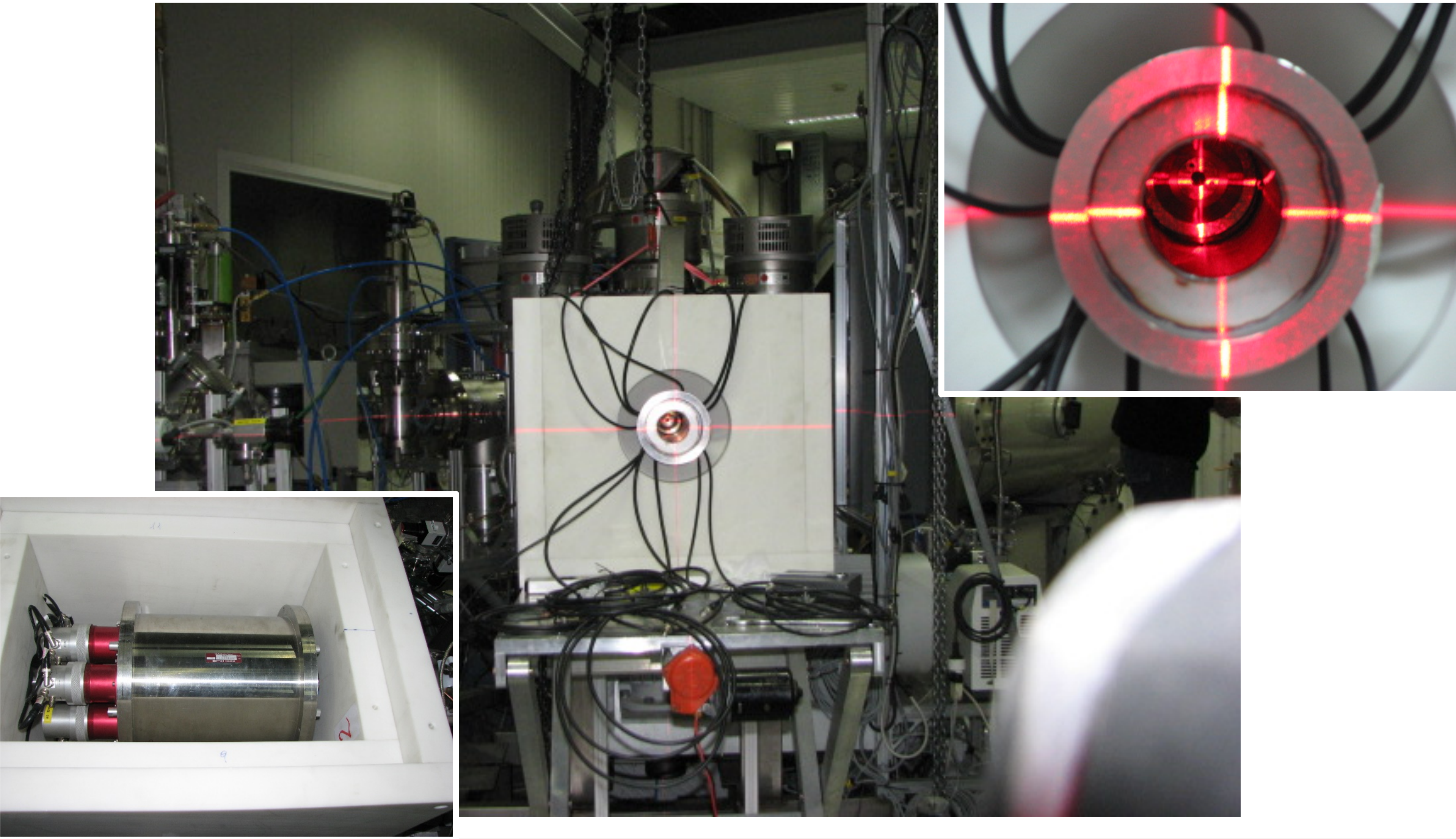
$^{22}Ne(\alpha,\gamma)^{26}Mg$

THE LUNA400: THE RATE WITH THE NEW UPPER LIMIT



- Effective minimum temperature for s-process neutron source is affected by $^{22}Ne(\alpha,\gamma)^{26}Mg$:
- Higher resonance strength means higher minimum temperature

THE NEW SETUP: MOUNTED AND TESTED IN APRIL 2018, BEAM TIME IN OCTOBER 2018



LUNA400: produzione scientifica 2018

The branching ratio of the 189.5 keV $^{22}Ne(p,\gamma)^{23}Na$ resonance
European Physical Journal - A 54 (2018) 44

Improved background suppression for radiative capture reactions at LUNA with HPGe and BGO detectors
J. Phys. G: Nucl. Part. Phys. 45 (2018) 025203

Improved $^{18}O(p,\alpha)^{15}N$ reaction rate by underground measurements at LUNA
PRL, submitted

Direct capture cross section and the Ep = 71 and 105 keV resonances in the $^{22}Ne(p,\gamma)^{23}Na$ reaction
PRL or Nature Physics, to be submitted in a few days

Effect of beam energy straggling on resonant yield in thin gas targets: the cases $^{22}Ne(p,\gamma)^{23}Na$ and $^{14}N(p,\gamma)^{15}O$
Europhysics Letters, to be submitted in a few days

Low energy cross section of the reaction $^{18}O(p,\gamma)^{19}F$
PRL or PLB, in the hands of the LUNA EB, submission whitin July 2018

& something on $D(p,\gamma)$ and $^{6}Li(p,\gamma)$ within the end of the year

LUNA MV- scientific program (2019 → 2023)

$^{14}N(p,\gamma)^{15}O$: High scientific interest for revised data covering a wide energy range (400 keV- 1.2 MeV). Scientific results of high impact but reduced risk immediately after commissioning phase (6 months)

$^{12}C+^{12}C$: solid state target. Gamma & particle detectors (30 months)

$^{13}C(\alpha,n)^{16}O$: enriched ^{13}C solid target & neutron detector (8 months)
Data taking at LUNA 400 kV ongoing.

$^{22}Ne(\alpha,n)^{25}Mg$: enriched ^{22}Ne gas target & neutron detector (8 months)

Next steps (not before 2024...):

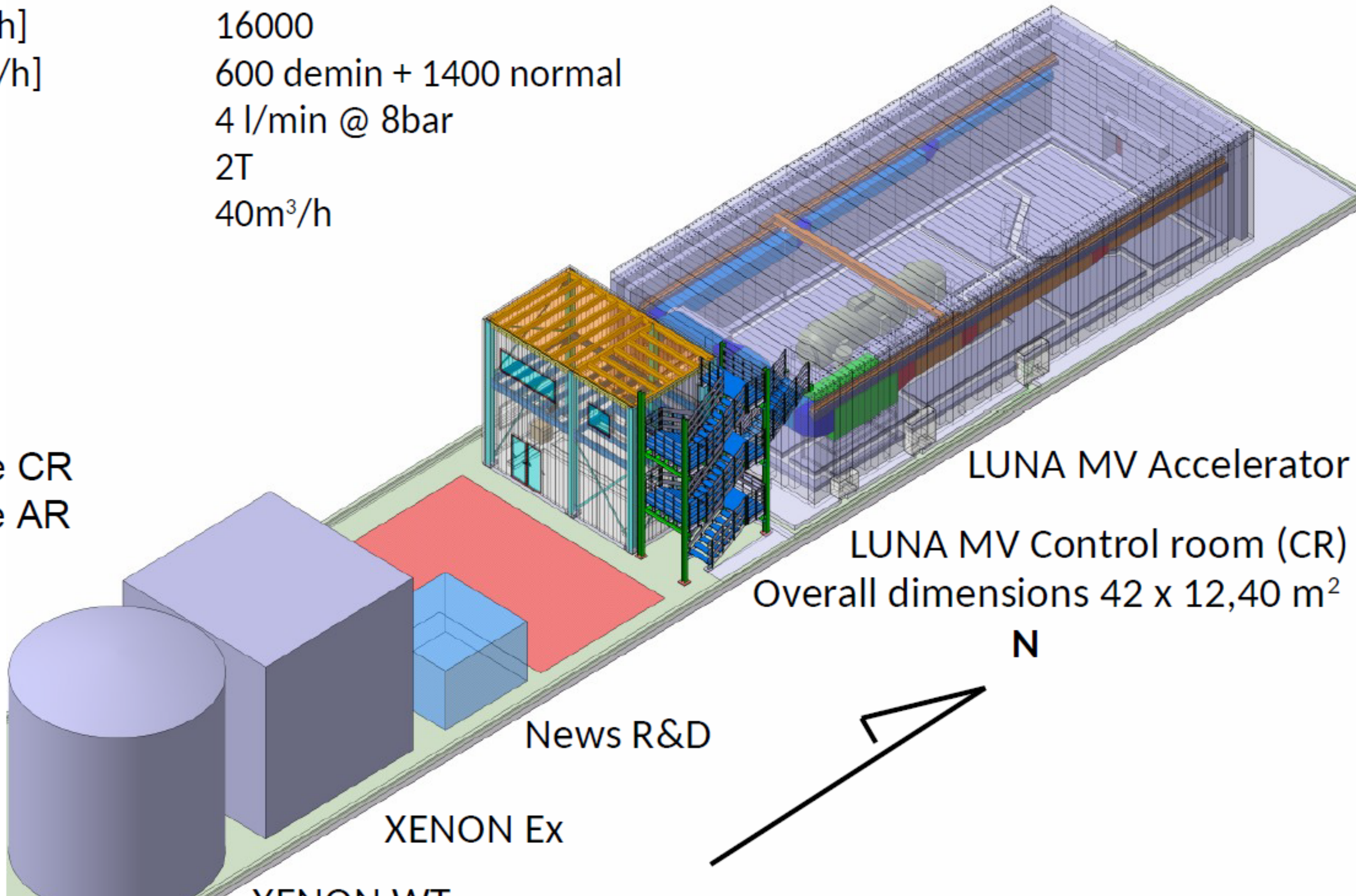
$^{12}C(\alpha,\gamma)^{16}O$: ^{12}C solid target depleted in ^{13}C and α beam OR α jet gas target and ^{12}C beam (36 months ??).

The new LUNA-MV site in Hall B

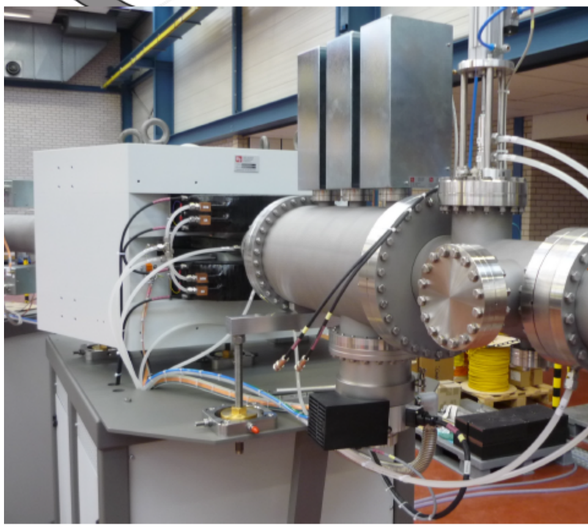
Electrical Power [kW]	45 normal + 165 UPS
Cooling AR [kW]	75 Water + 70 Air
Cooling CR [kW]	5 Air
Ventilation [m^3/h]	16000
Water cooling [l/h]	600 demin + 1400 normal
Compressed air	4 l/min @ 8bar
Crane	2T
Exhaust	40m^3/h

Safety Senors

6	x O_2
2	x SF_6
6	x Smoke CR
30 m	x Smoke AR
5	x TVCC



Accelerator: ready at HVE



HIGH VOLTAGE ENGINEERING EUROPA B.V.

Amsterdamseweg 63, 3812 RR Amersfoort, P.O. Box 99, 3800 AB Amersfoort, The Netherlands
Phone: +31-33-4619741. Fax +31-33-4615291. Trade register Amersfoort nr. 31014544
E-mail: info@highvolteng.com – Web: www.highvolteng.com

March19, 2018

FACTORY ASSEMBLY PROTOCOL

3.5 MV Singletron accelerator system

End-User/Consignee: Laboratory Nazionale del Gran Sasso, Assergi, Italy

Contract number: CIG No. 62076380EF and CUP No. 154G14000140005
CIG No. 62076380EF Amdt. No. 1

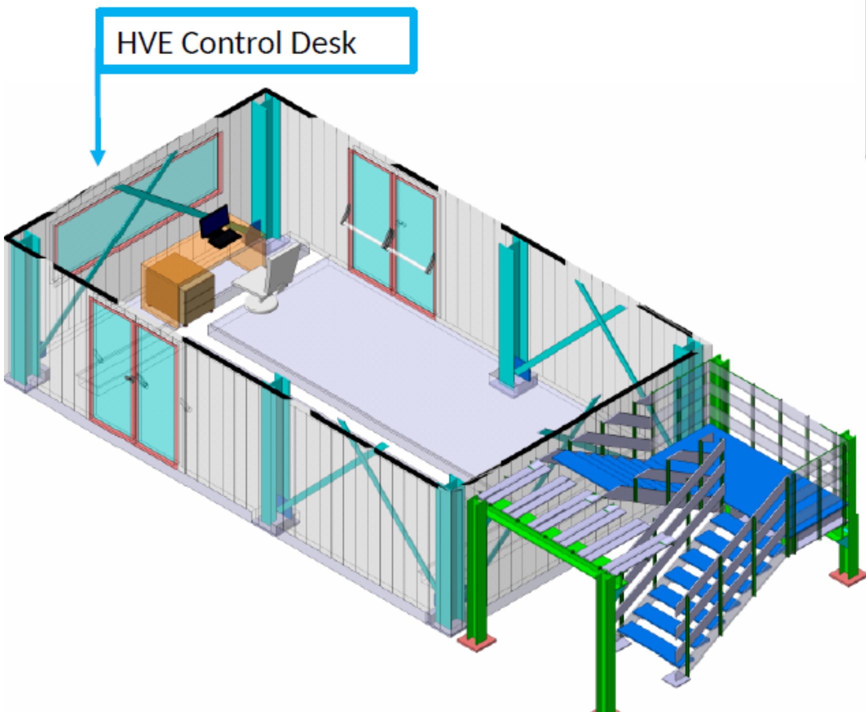
HVEE ref.: B9051

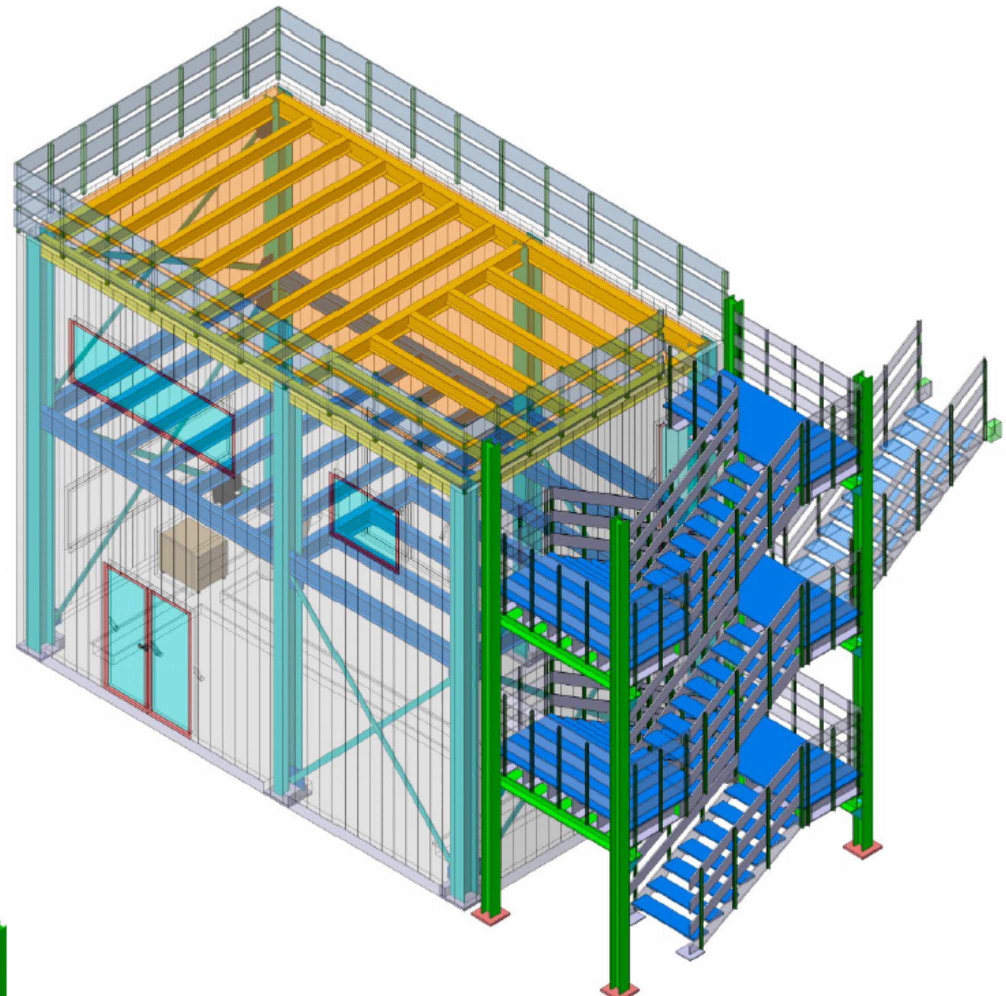
We herewith confirm that the 3.5 MV Singletron accelerator system for Laboratory Nazionale del Gran Sasso Assergi, Italy is fully assembled at HVE Amersfoort, The Netherlands.

Accelarator ready at HVE (March 2018)
1st acceptance test : May 28 – June 8, 2018
Accelerator room @ LNGS: conclusion by Sept. 2018
According to the contract signed by INFN, the site in Hall B must be ready at latest at January 2019.
Review of LUNA-MV project on March 23th 2018 by INFN committee (A Arcones, A Nobles, L. Patrizi, E. Santonocito, M. Taiuti)

LUNA-MV: control room

Dimensions: 9 x 5,40 x 7,20 m^3
Concrete platform at ground floor: 0,2 m
Distance CR ↔ AR: 2,5 m
Stair from OPERA Decommissioning





To be built between
Sept. & Oct. 2018
→ *some authorizations still pending*

LNGS, March 23th 2018: 1-day review of LUNA-MV

Review Committee Report:

Concerning the Luna-MV Review Of March 23rd, 2018

LNGS

A. Arcones, A. Noble, L. Patrizii, D. Santonocito, M. Taiuti

Contents

LNGS, March 23th 2018: 1-day review of LUNA-MV

3). Summary of Findings and Recommendations

iv. The scientific proposal outlines a series of experiments that are recognized world wide as being of high scientific merit.

v. The committee appreciated the proposal and endorses the choice of the key reactions to be studied in the following five years by the collaboration.

vi. The experimental program appears to be feasible from a budget and technological point of view, and the collaboration is very experienced, having operated the LUNA-400 accelerator for nearly two decades.

vii. The collaboration has well developed and well considered plans for the commissioning of both the accelerator and the neutron production monitors and interlocks.

The LUNA collaboration

- F. Amodio, G.F. Ciani*, L. Csedreki, L. Di Paolo, A. Formicola, M. Junker| INFN LNGS /*GSSI, Italy
- D. Bemmerer, K. Stoeckel , M. Takacs, | HZDR Dresden, Germany
- C. Broggini, A. Caciolli, R. Depalo, P. Marigo, R. Menegazzo, D. Piatti | Università di Padova and INFN Padova, Italy
- C. Gustavino | INFN Roma1, Italy
- Z. Elekes, Zs. Fülöp, Gy. Gyurky, T. Szucs | MTA-ATOMKI Debrecen, Hungary
- M. Lugaro | Monarch University Budapest, Hungary
- O. Straniero | INAF Osservatorio Astronomico di Collurania, Teramo, Italy
- F. Cavanna, P. Corvisiero, F. Ferraro, P. Prati, S. Zavatarelli | Università di Genova and INFN Genova, Italy
- A. Guglielmetti| Università di Milano and INFN Milano, Italy
- J. Balibrea, A. Best, A. Di Leva, G. Imbriani| Università di Napoli and INFN Napoli, Italy
- G. Gervino | Università di Torino and INFN Torino, Italy
- M. Aliotta, C. Bruno, T. Chillery, T. Davinson | University of Edinburgh, United Kingdom
- F. Barile, G. D'Erasmo, E.M. Fiore, V. Mossa, F. Pantaleo, V. Paticchio, R. Perrino, L. Schiavulli| Università di Bari and INFN Bari, Italy
- R. Perrino | INFN Lecce, Italy

Genova : FTE

Prati P. 70% + Corvisiero P. (100% ass. senior)

Zavatarelli S. 60%

Cavanna F. 80%

Ferraro F. 20 %

Genova : leadership misura $^{2}H(p,\gamma)^{3}He$, responsabilita' simulazioni

LUNA-MV: sviluppo bersagli e misura corrente