The LUNA experiment : studying stars by going underground

Alessandra Guglielmetti
Universita' degli Studi di Milano and
INFN, Milano, ITALY

Laboratory
Underground
Nuclear
Astrophysics

Outline:

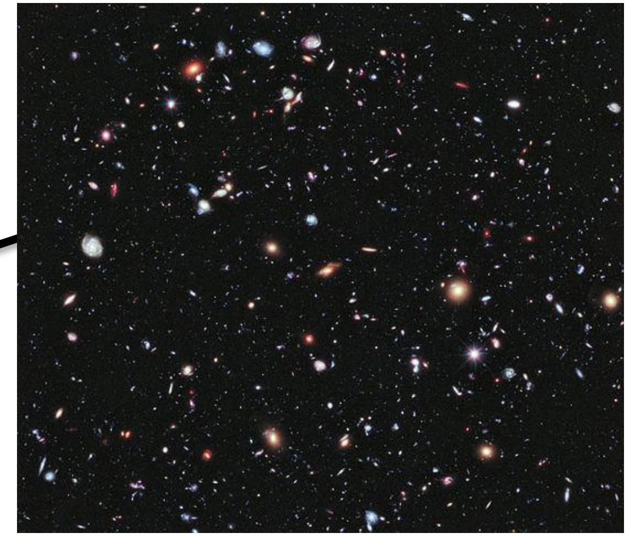
-Nuclear Fusion reactions in stars: why measuring their cross section?

-Why going underground to perform these experiments?

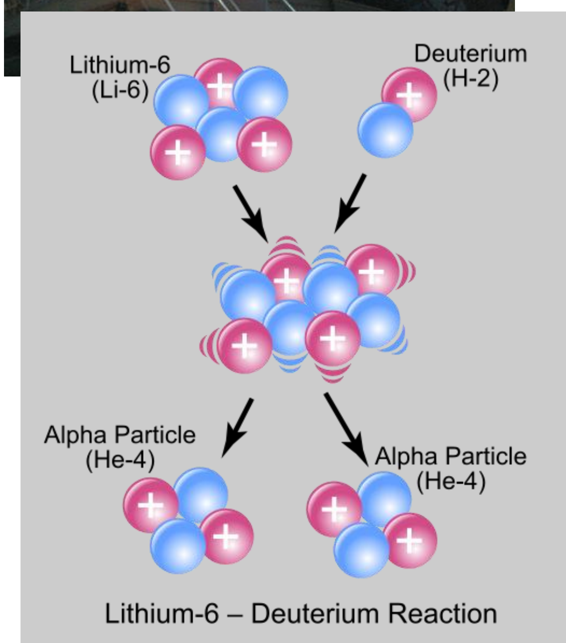
-The Luna Experiment: most important results

- On-going measurements and future perspective: the LUNA-MV project

Nuclear Astrophysics



Nuclear astrophysics

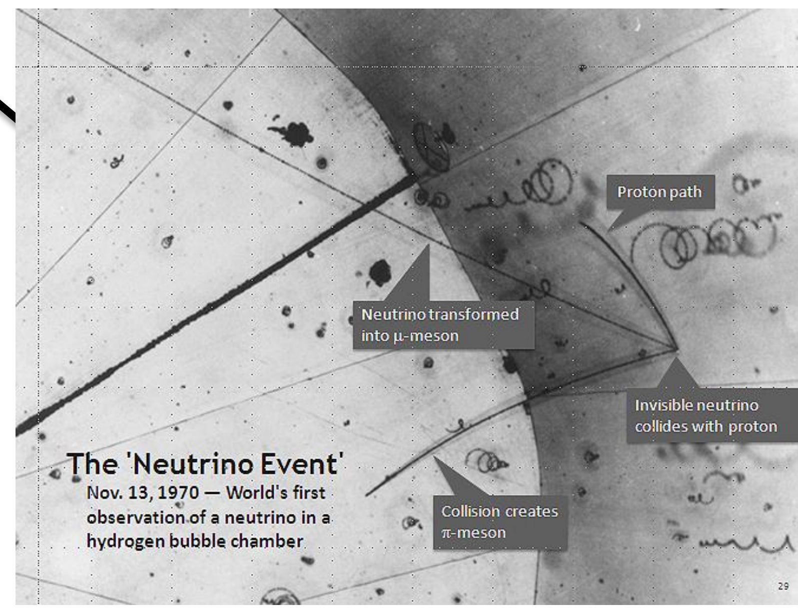


$$\frac{dP}{dM_r} = -\frac{GM_r}{4\pi r^4}$$

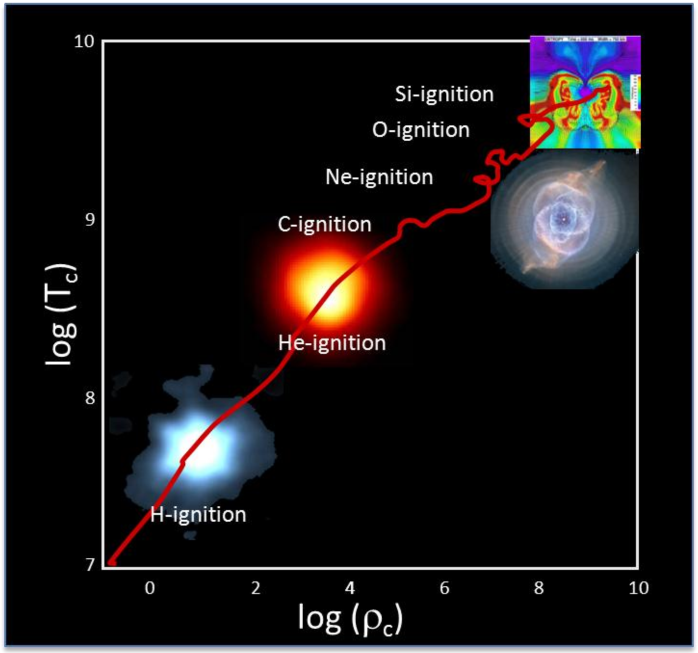
$$\frac{dT}{dM_r} = \nabla \frac{GM_r T}{4\pi r^2 P}$$

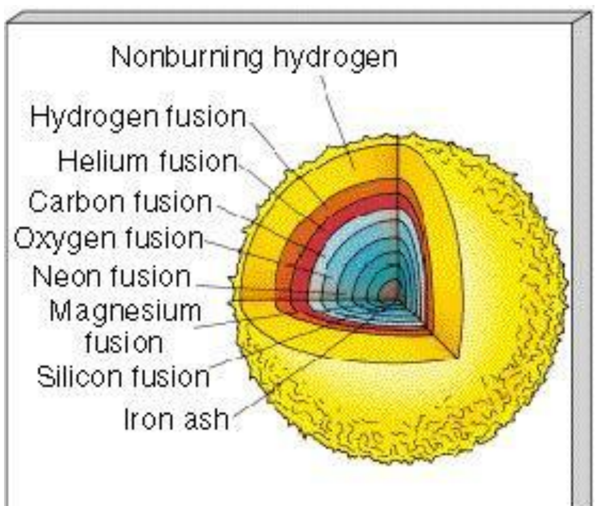
$$\frac{dr}{dM_r} = -\frac{1}{4\pi r^2 \rho}$$

$$\frac{dL_r}{dM_r} = \varepsilon_g + \varepsilon_\nu + \varepsilon_n$$



Why studying nuclear fusion reaction cross sections?





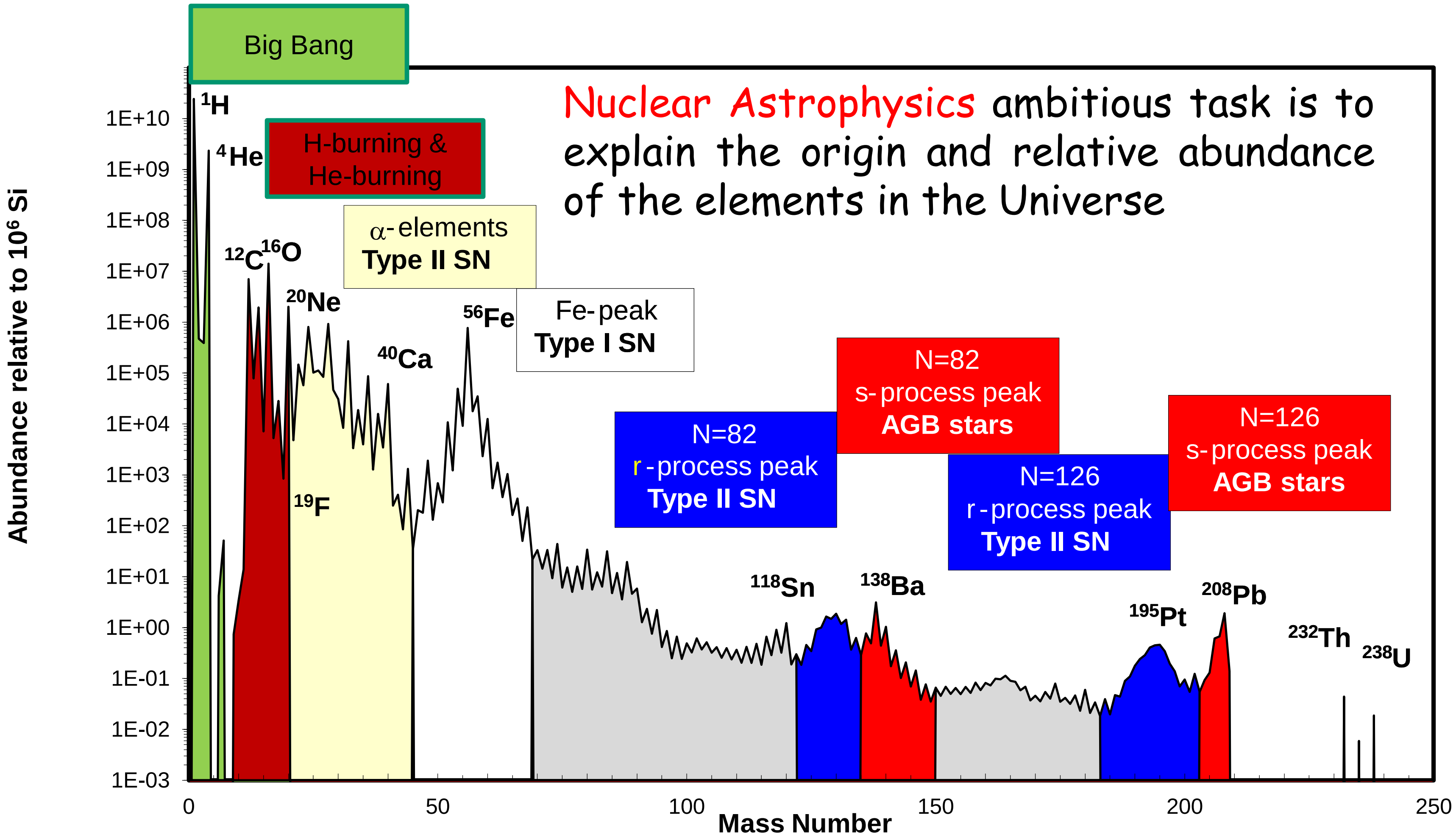
-Stars are powered by nuclear reactions

-Among the key parameters (chemical composition, opacity, etc.) to model stars, reactions cross sections play an important role

- They determine the origin of elements in the cosmos, stellar evolution and dynamic

- Many reactions ask for high precision data.

Element abundances in the solar system



The periodic table of the elements

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111	112	113	114	115	116	117	118

Lathanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

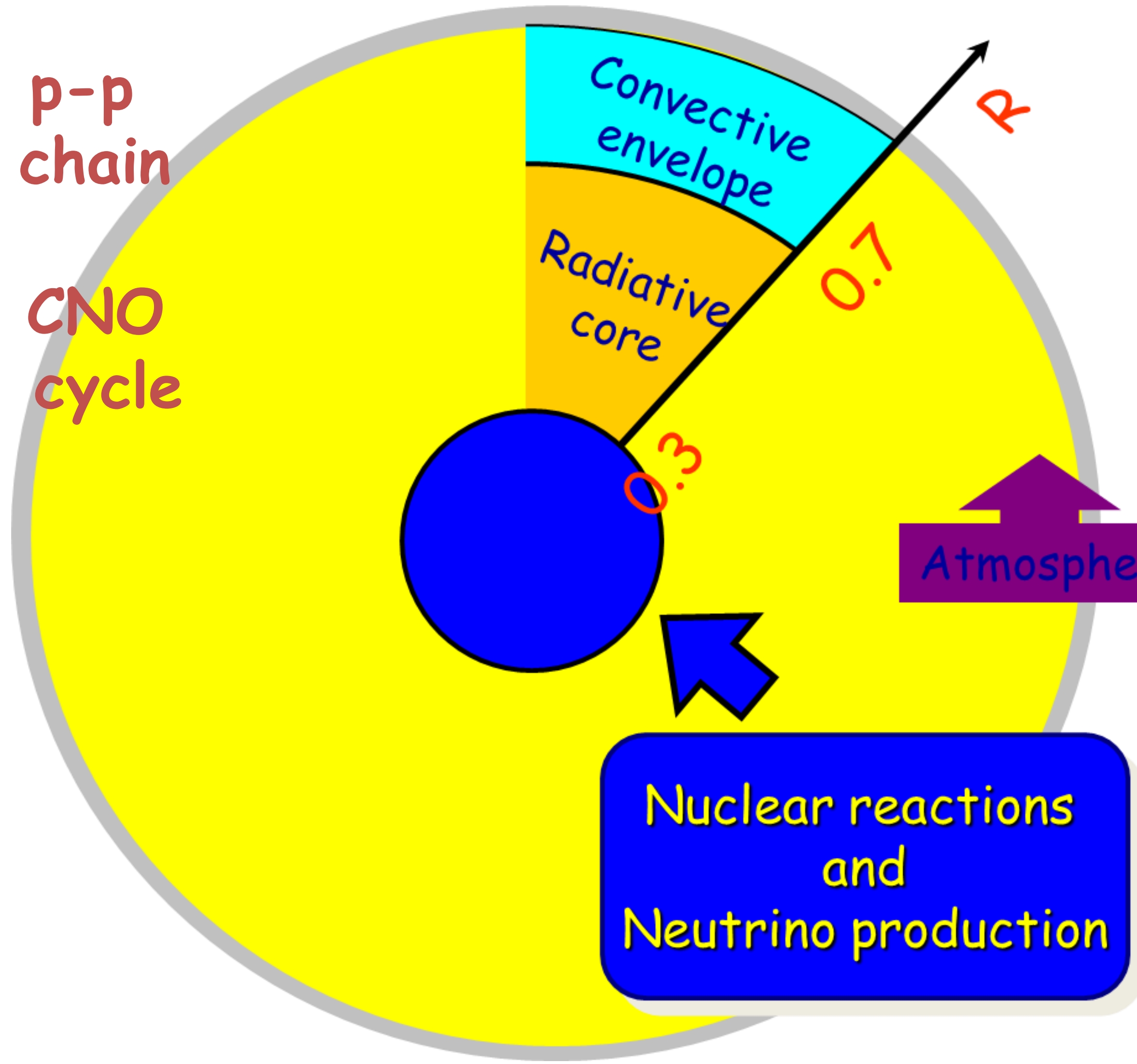
Neutrino production in stars

$$p + p \rightarrow {}^{2}H + e^{+} + \nu$$
$$p + e^{-} + p \rightarrow {}^{2}H + e^{+} + \nu$$
$$^{3}He + p \rightarrow {}^{4}He + e^{+} + \nu$$
$$^{7}Be + e^{-} \rightarrow {}^{7}Li + \nu$$
$$^{8}B \rightarrow {}^{8}Be + e^{+} + \nu$$

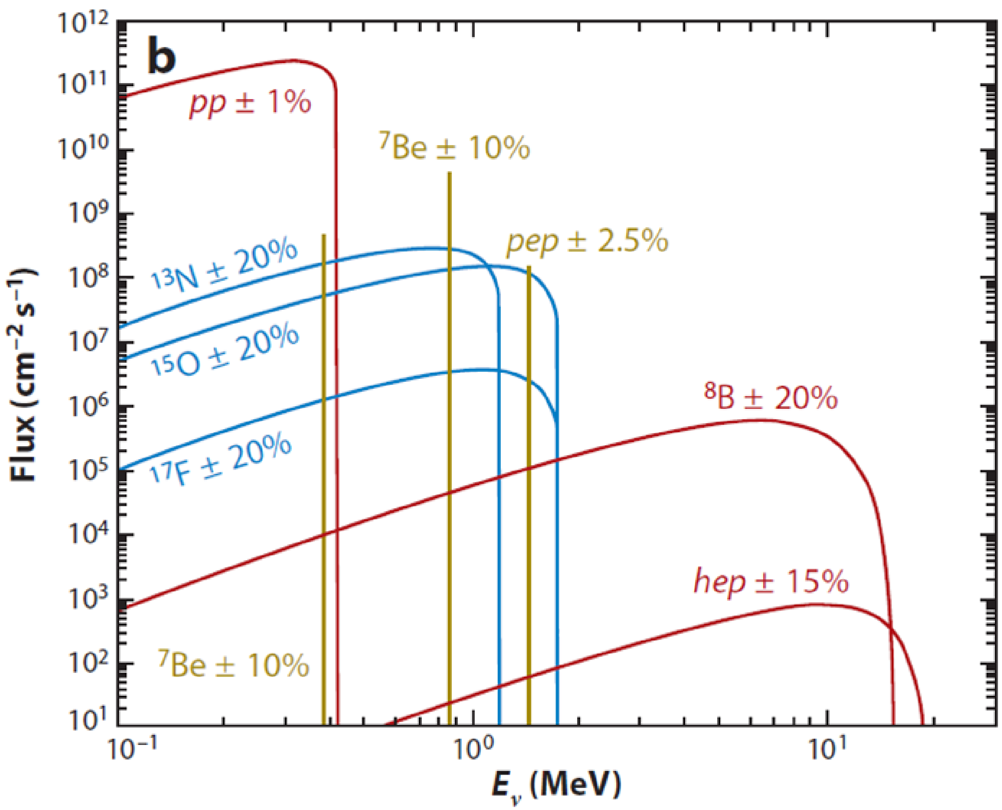
p-p chain

$$^{13}N \rightarrow {}^{13}C + e^{+} + \nu$$
$$^{15}O \rightarrow {}^{15}N + e^{+} + \nu$$
$$^{17}F \rightarrow {}^{17}O + e^{+} + \nu$$

CNO cycle



Neutrino flux experiments



Homestake > 0.8 MeV
Gallex/Sage > 0.2 MeV
Superkamiokande/SNO > 5 MeV
Borexino > 0.7 MeV
....

Solar neutrino puzzle: solved!
Neutrino flux from the Sun can be used to study:

- Solar interior composition
- Neutrino properties

ONLY if the cross sections of the involved reactions are known with enough accuracy

Big Bang nucleosynthesis

Production of the lightest elements (D, ^3He, ^4He, ^7Li, ^6Li) in the first minutes after the Big Bang

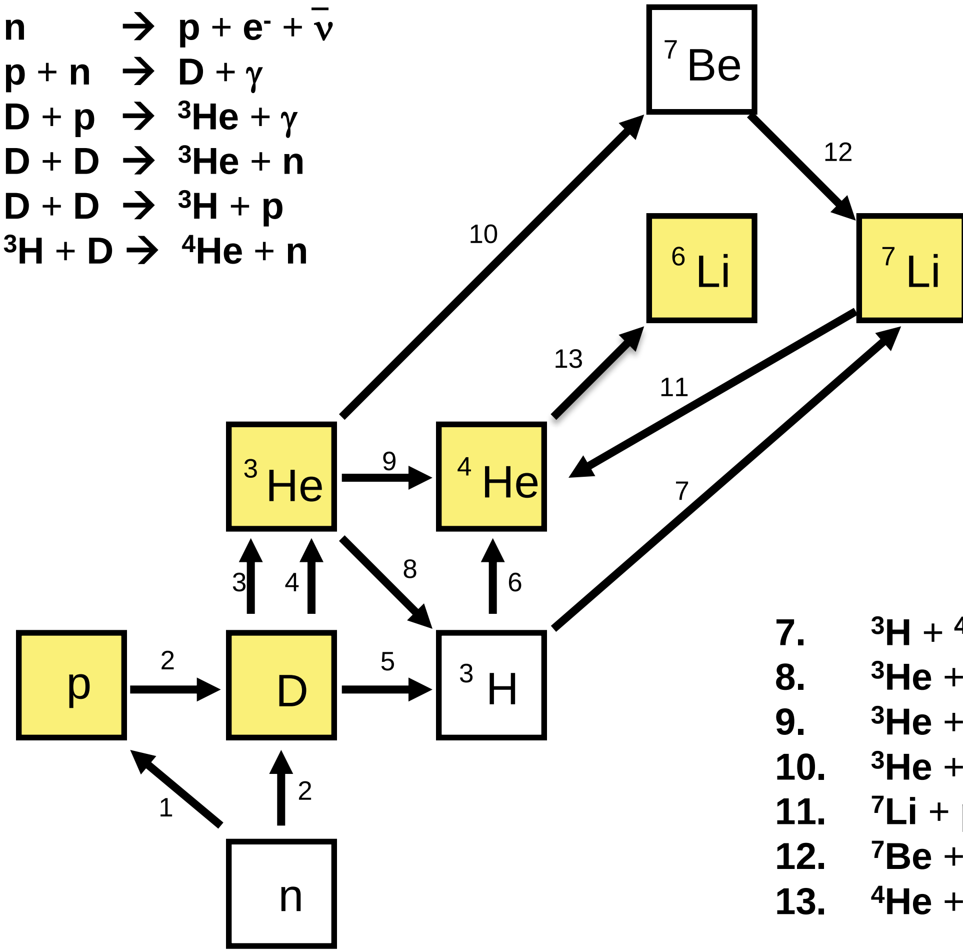
The general concordance between predicted and observed abundances (spanning more than 9 orders of magnitude) gives a direct probe of the Universal baryon density

CMB anysotropy measurements (WMAP satellite) gives an independent measurement of the Universal baryon density

The concordance of the two measurements has to be understood in terms of uncertainties in the BBN predictions

BBN reaction network

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



7. ^{3}H + ^{4}H → ^{7}Li + γ
8. ^{3}He + n → ^{3}H + p
9. ^{3}He + D → ^{4}He + p
10. ^{3}He + ^{4}He → ^{7}Be + γ
11. ^{7}Li + p → ^{4}He + ^{4}He
12. ^{7}Be + n → ^{7}Li + p
13. ^{4}He + D → ^{6}Li + γ

Apart from ^{4}He, uncertainties are dominated by systematic errors in the nuclear cross sections

LUNA program: astrophysical motivation

Solar neutrinos: $^{3}He(^{3}He,2p)^{4}He$, $^{3}He(^{4}He,\gamma)^{7}Be$, $^{14}N(p,\gamma)^{15}O$

Age of globular cluster: $^{14}N(p,\gamma)^{15}O$

Light nuclei nucleosynthesis ($^{17}/^{18}O$ abundances, ^{19}F production, ^{26}Mg excess,...): $^{15}N(p,\gamma)^{16}O$, $^{17}N(p,\gamma)^{18}O$, $^{25}Mg(p,\gamma)^{26}Al$

Big Bang Nucleosynthesis: $^{2}H(\alpha,\gamma)^{6}Li$, $^{3}He(^{4}He,\gamma)^{7}Be$, $^{2}H(p,\gamma)^{3}He$

Next:

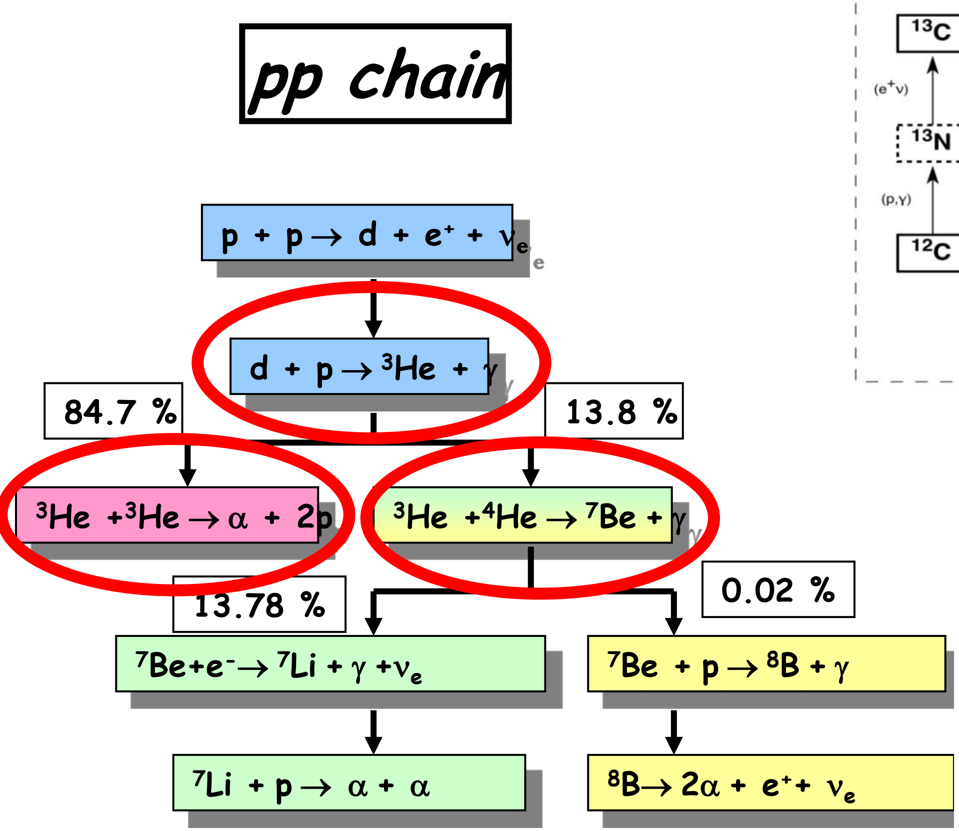
Light nuclei nucleosynthesis: $^{17}O(p,\alpha)^{14}N$, $^{22}Ne(p,\gamma)^{23}Na$, $^{23}Na(p,\gamma)^{24}Mg$, $^{18}O(p,\gamma)^{19}F$, $^{18}O(p,\alpha)^{15}N$

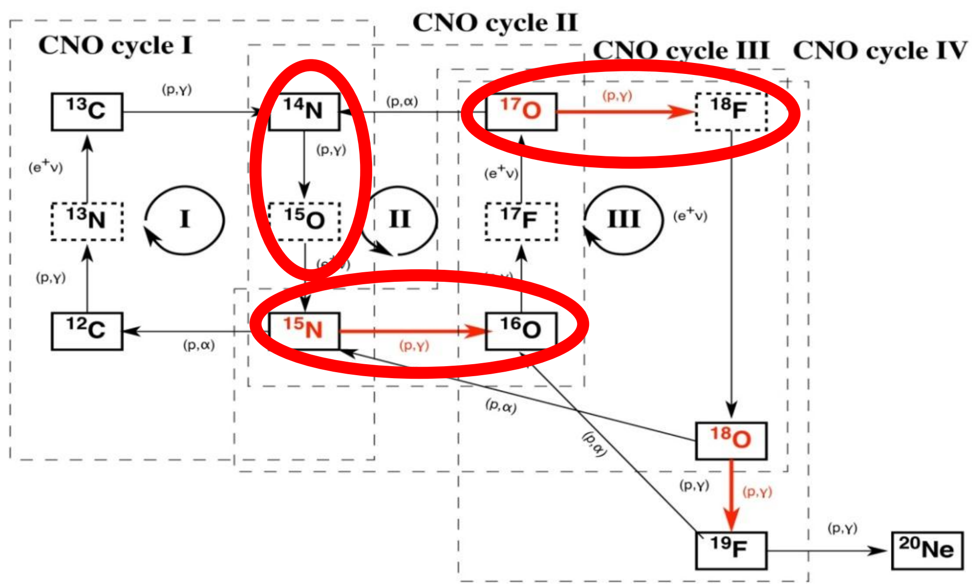
He burning and stellar evolution: $^{12}C(\alpha,\gamma)^{16}O$

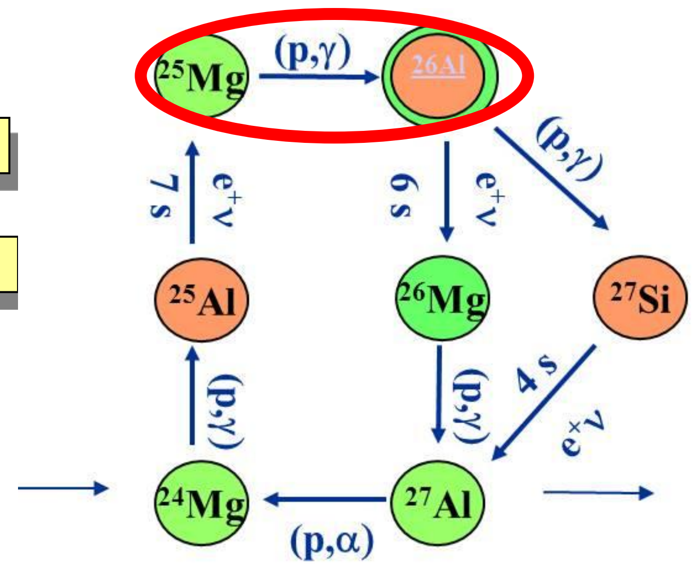
s process nucleosynthesis: $^{13}C(\alpha,n)^{16}O$, $^{22}Ne(\alpha,n)^{25}Mg$

Hydrogen burning

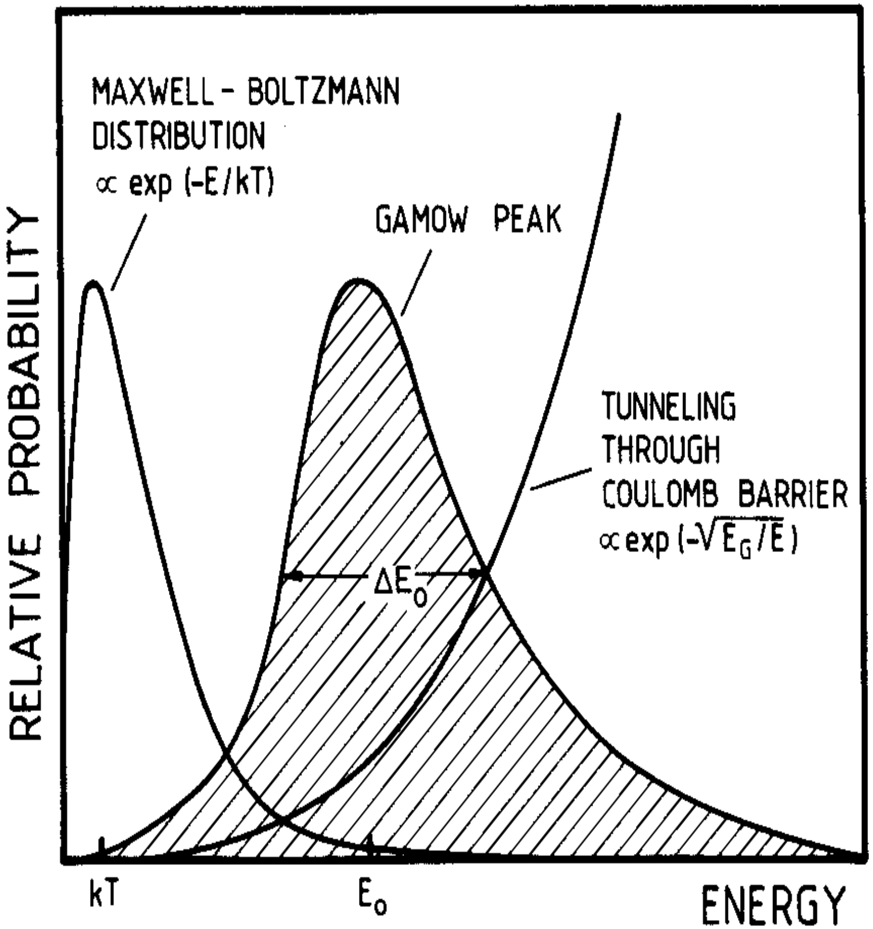
$$4p \rightarrow {}^4He + 2e^+ + 2\nu_e + 26.73\ MeV$$







Nuclear reactions in stars



Sun:

$T = 1.5\ 10^7$ K

$kT = 1$ keV $\ll E_C$ (0.5-2 MeV)

Reaction	E_0
$^3He(^3He,2p)^4He$	21 keV
$d(p,\gamma)^3He$	6 keV
$^{14}N(p,\gamma)^{15}O$	27 keV
$^3He(^4He,\gamma)^7Be$	22 keV

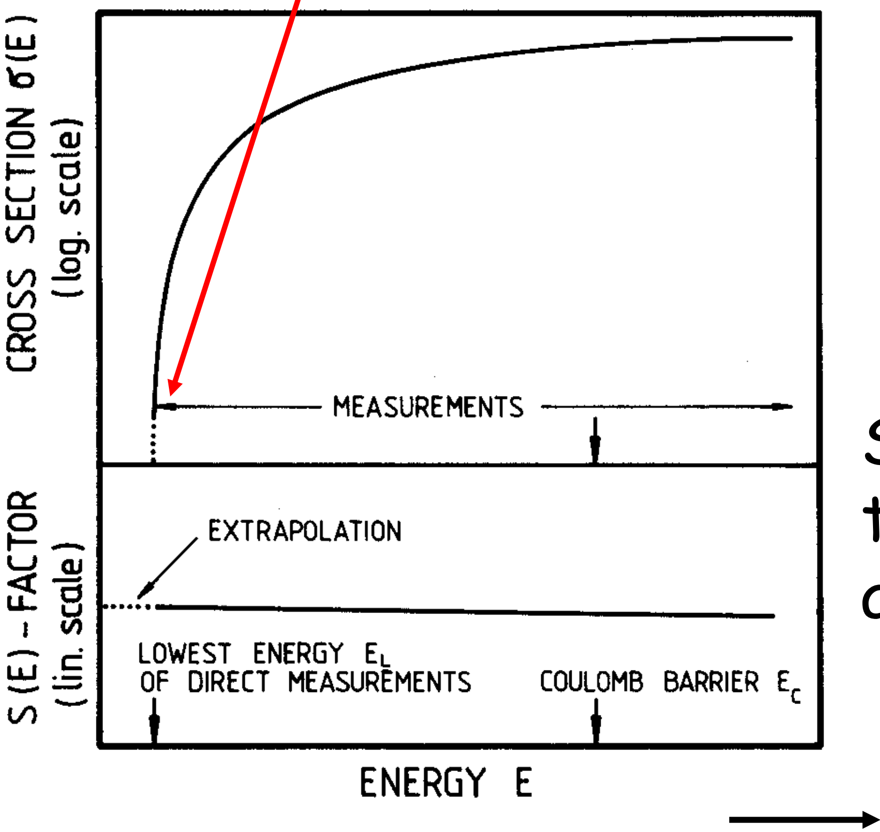
Cross section and astrophysical S factor

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

Gamow factor E_G

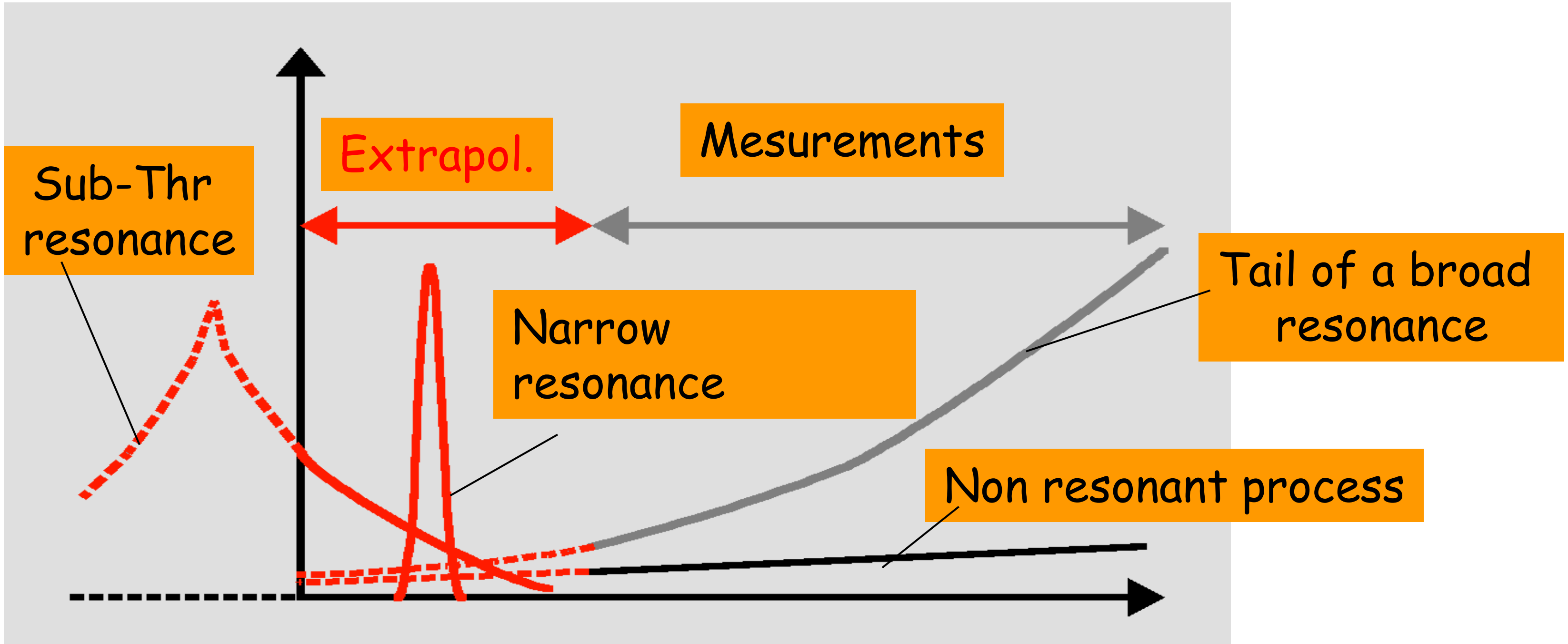
Astrophysical factor

Gamow energy region



Cross section of the order of pb!

S factor can be extrapolated to zero energy but if resonances are present?



Danger in extrapolations!

Sun

Luminosity = $2 \cdot 10^{39}$ MeV/s

Q-value (H burning) = 26.73 MeV

Reaction rate = 10^{38} s^{-1}

Laboratory

$R_{lab} = N_p N_t \sigma \varepsilon$

N_p = number of projectile ions ≈ 10^{14} pps (100 μA $q=1^+$)

N_t = number of target atoms ≈ 10^{19} at/cm^2

σ = cross section = 10^{-15} barn

ε= efficiency ≈ 100% for charged particles
1% for gamma rays

R_{lab} ≈ 0.3-30 counts/year

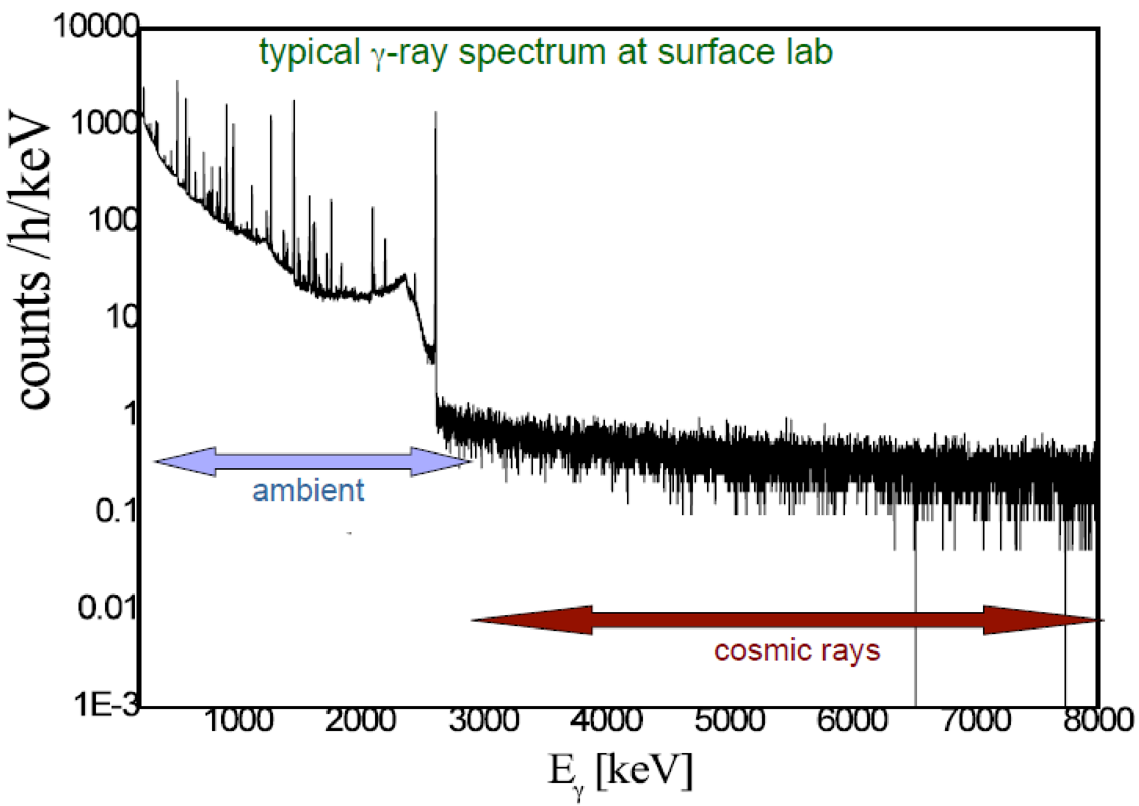
$R_{lab} > B_{beam\ induced} + B_{env} + B_{cosmic}$

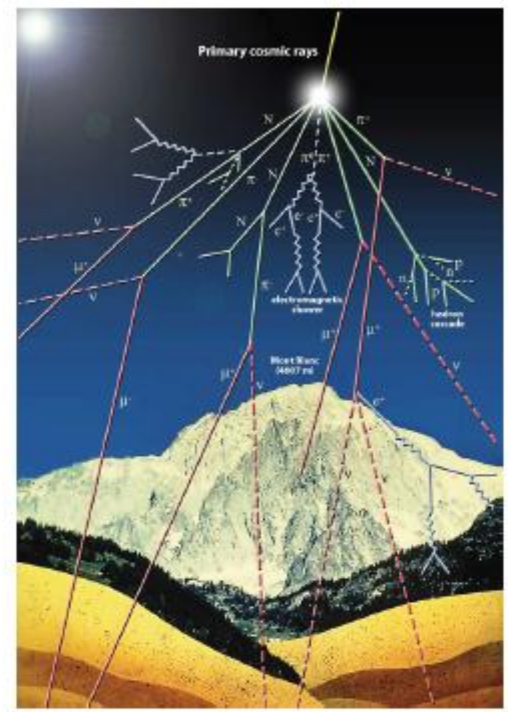
$B_{beam\ induced}$: reactions with impurities in the target

reactions on beam collimators/apertures

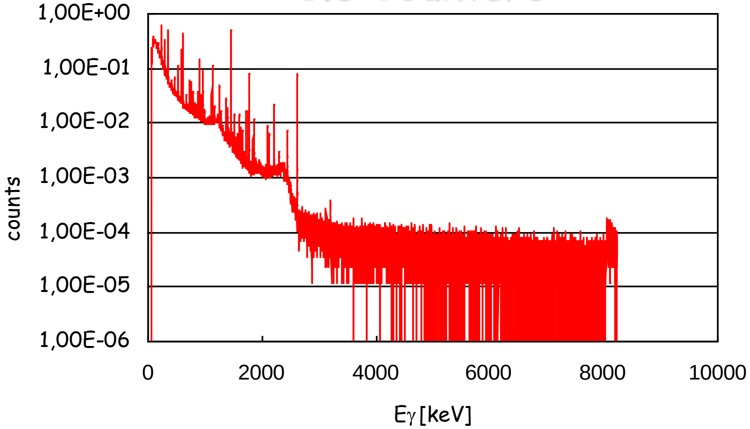
B_{env} : natural radioactivity mainly from U and Th chains

B_{cosmic} : mainly muons





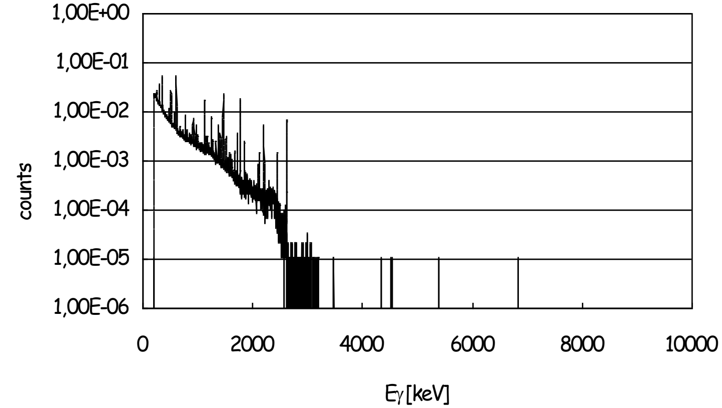
3MeV < E_γ < 8MeV:
0.5 Counts/s



HpGe

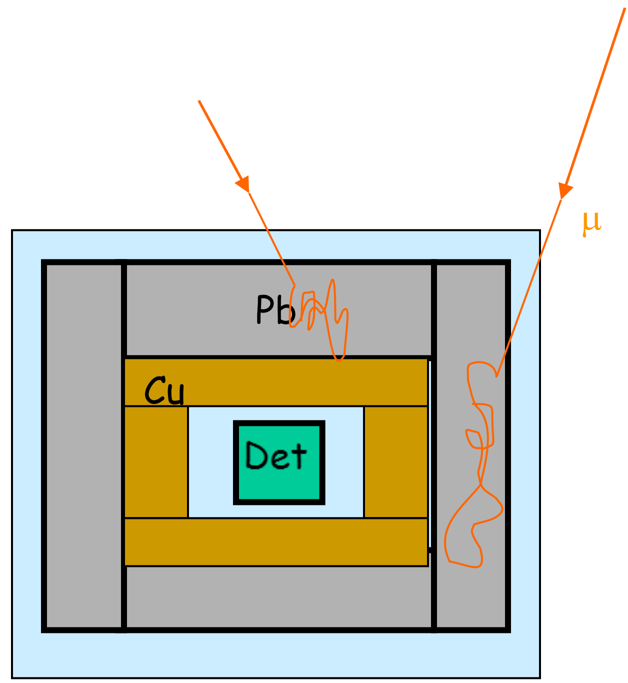
GOING UNDERGROUND →

3MeV < E_γ < 8MeV
0.0002 Counts/s

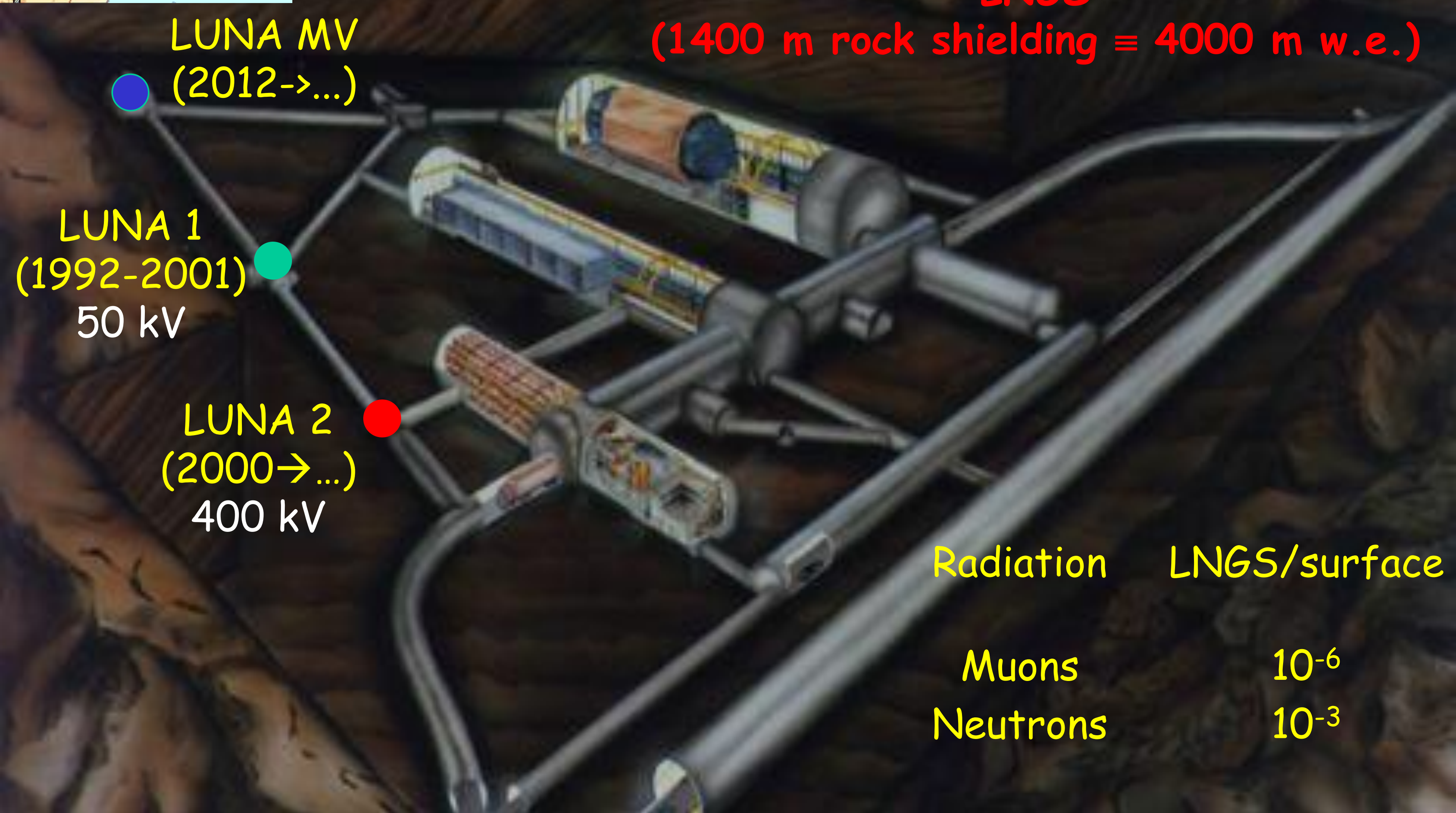


E_γ<3MeV→passive shielding for environmental background radiation

underground passive shielding is more effective since μ flux,that create secondary γ's in the shield, is suppressed



Laboratory for Underground Nuclear Astrophysics



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

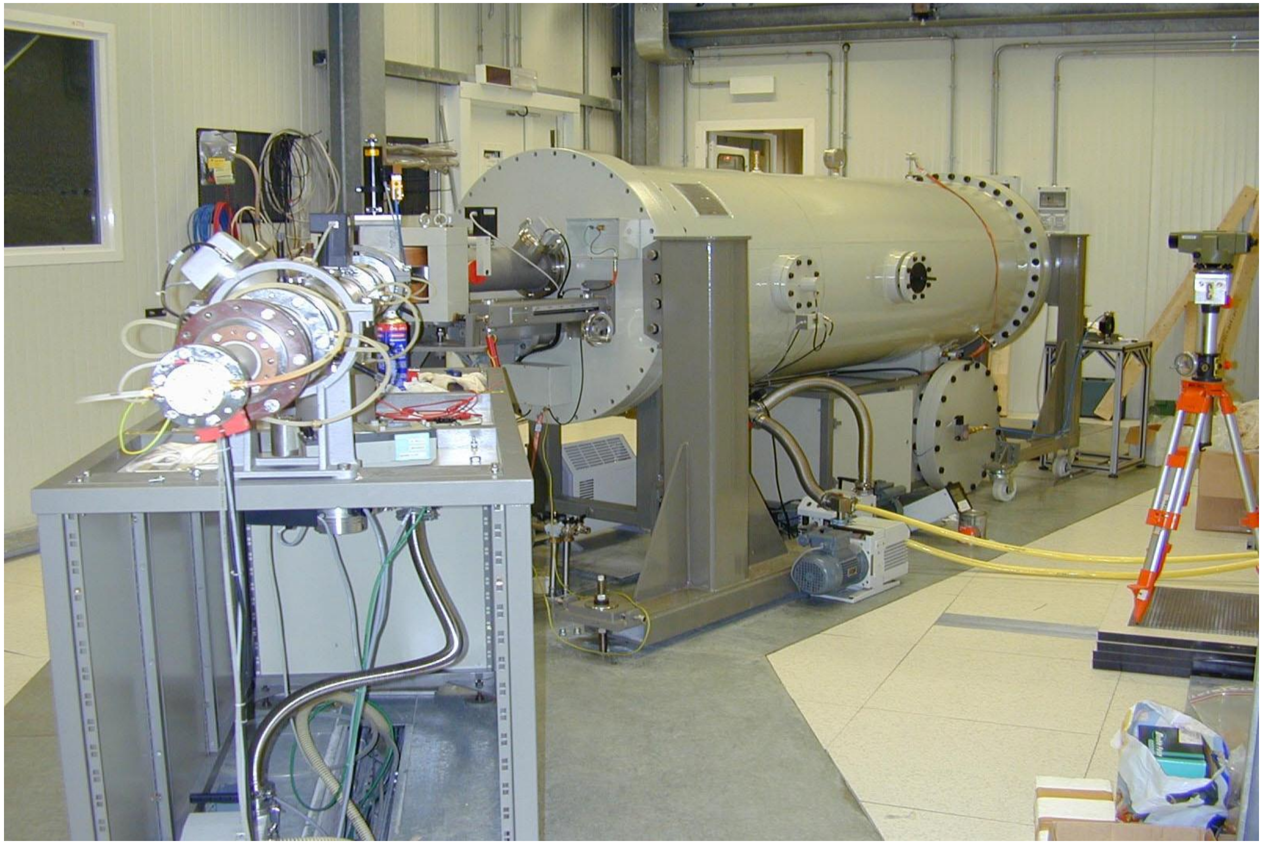
LUNA MV
(2012->...)

LUNA 1
(1992-2001)
50 kV

LUNA 2
(2000→...)
400 kV

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

Laboratory for Underground Nuclear Astrophysics

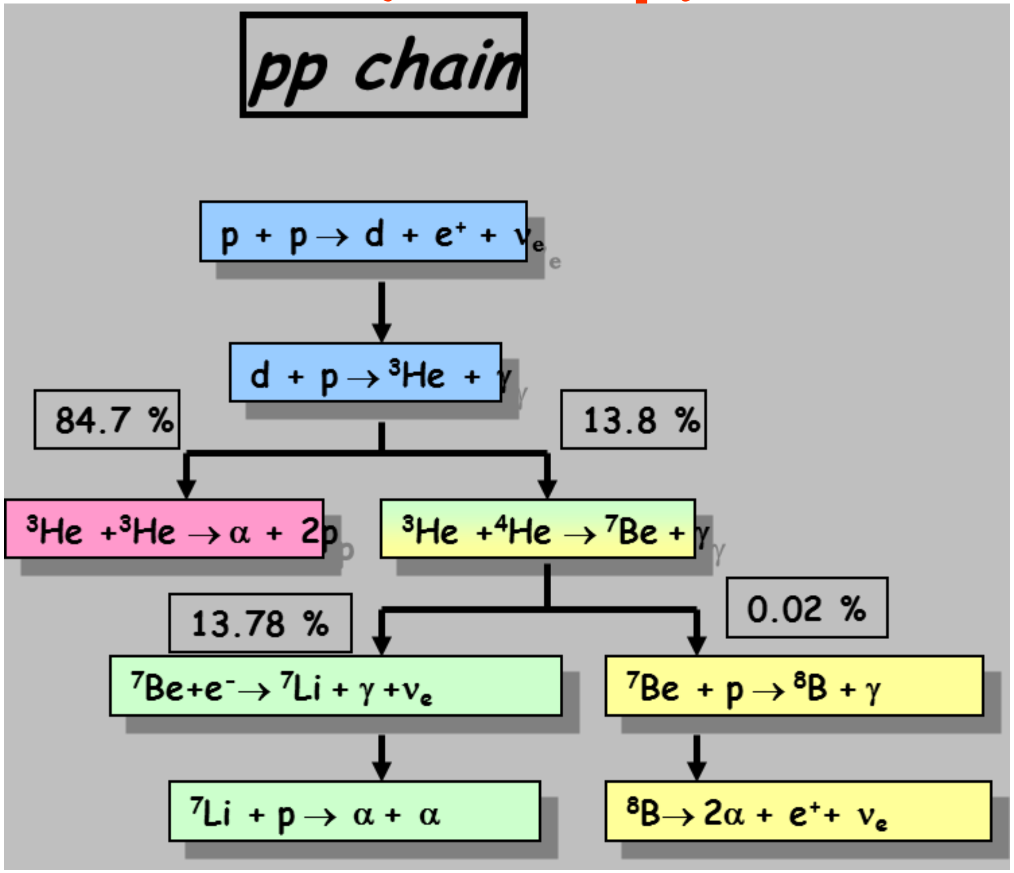


400 kV Accelerator : $E_{beam} \approx 50 - 400$ keV

$I_{max} \approx 500\ \mu A$ protons $I_{max} \approx 250\ \mu A$ alphas

Energy spread ≈ 70 eV Long term stability ≈ 5eV/h

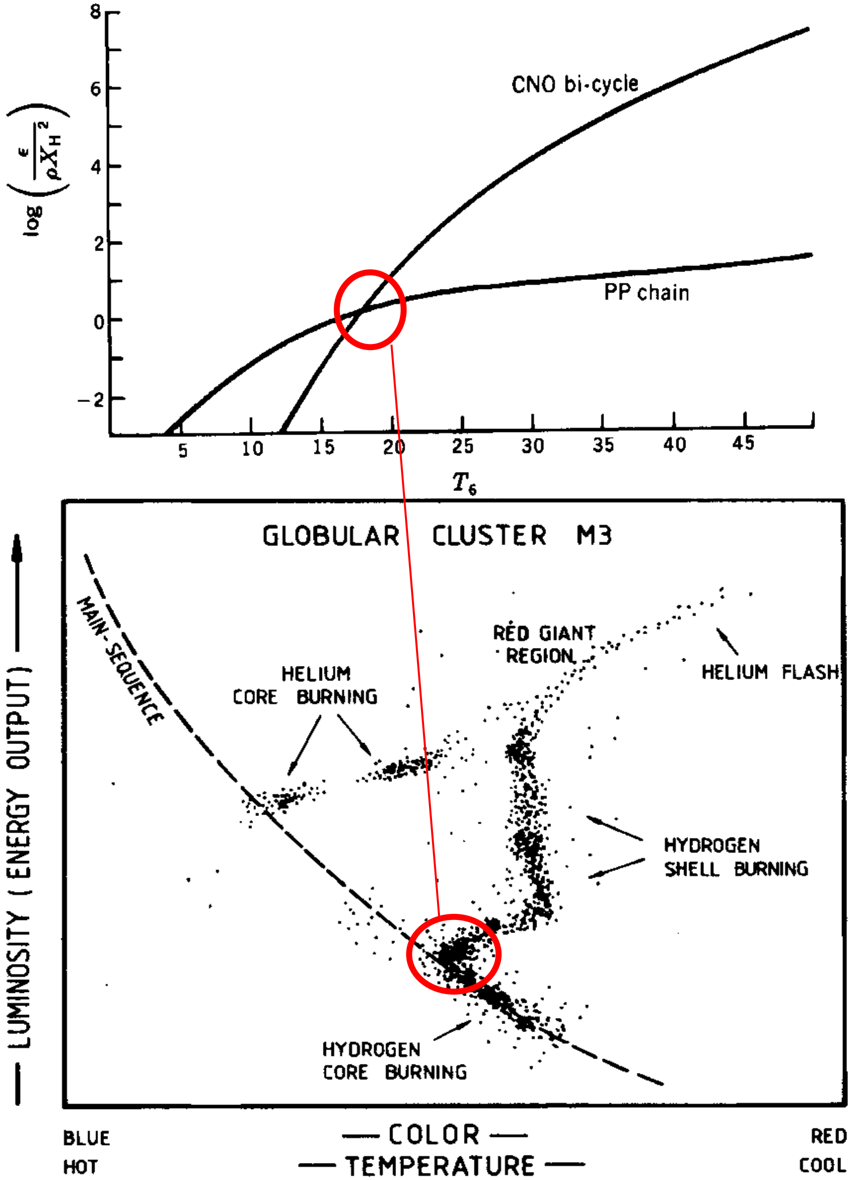
$^{3}He(^{3}He,2p)^{4}He$

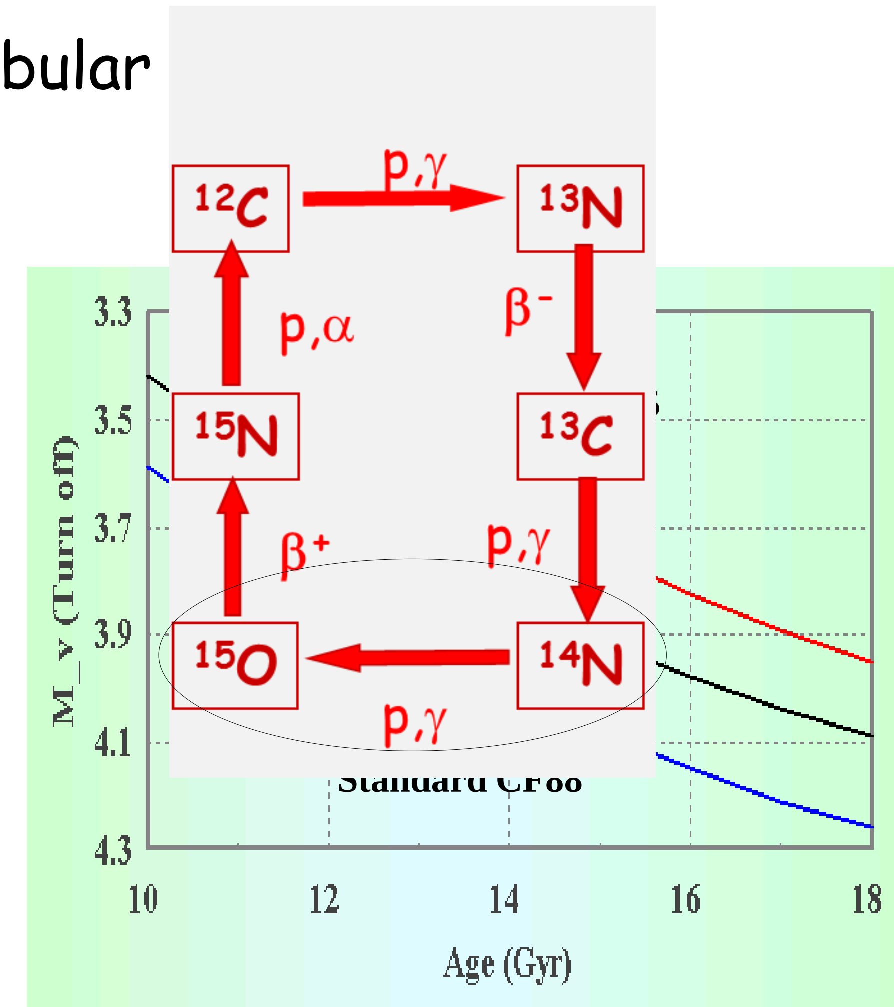


- Fundamental reaction of the p-p cycle
- Measured down to the lower edge of the solar Gamow peak
- No resonances → no nuclear explanation for the solar neutrino puzzle

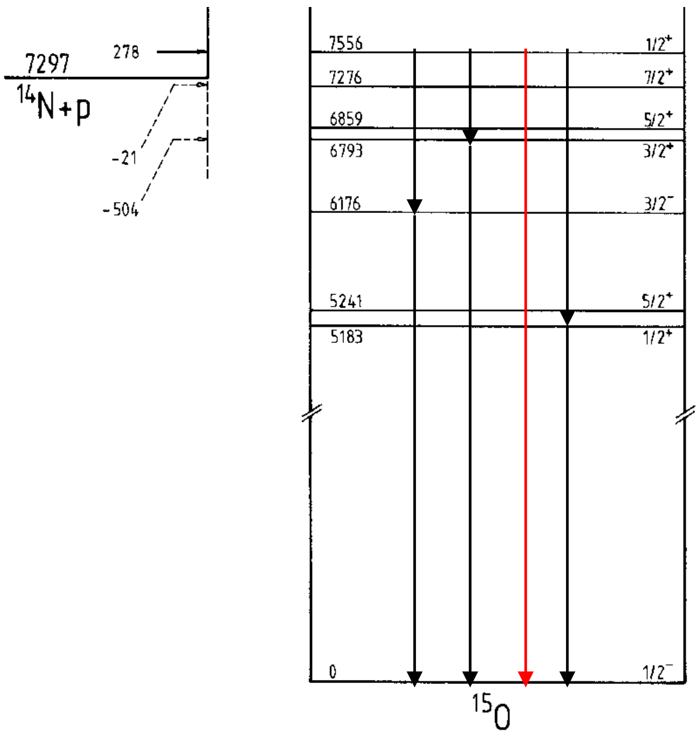
$^{14}N(p,\gamma)^{15}O$ cross section influences

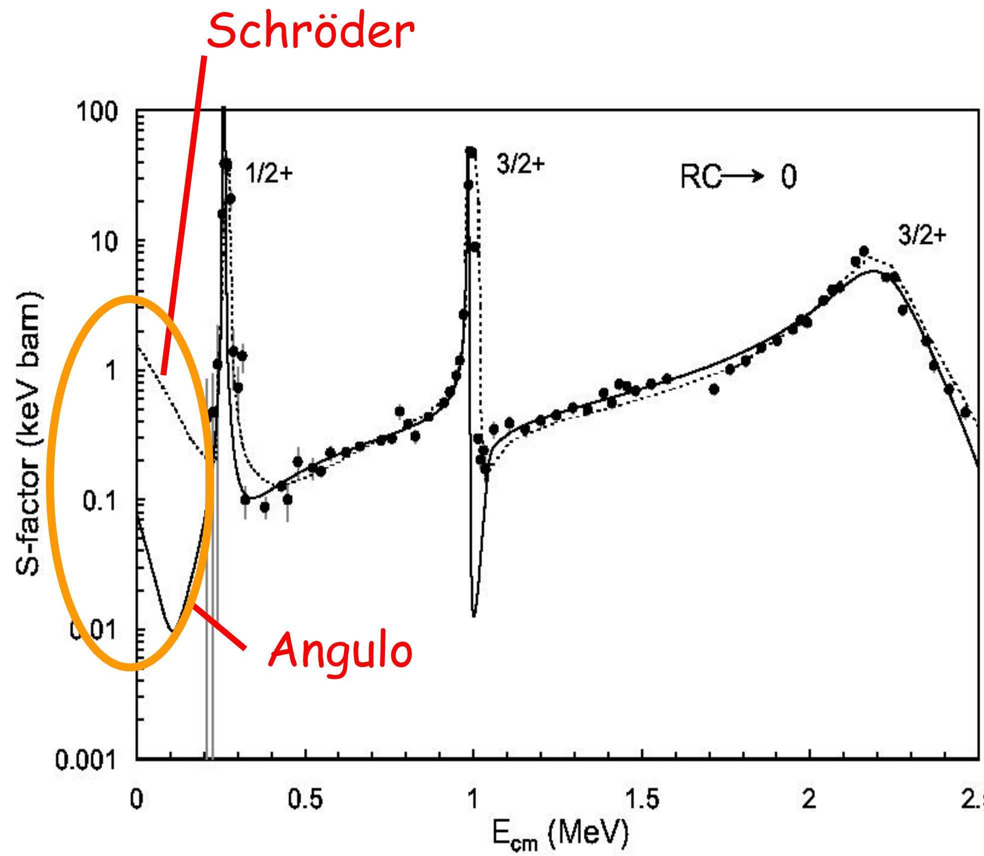
- CNO neutrino flux→Solar metallicity
- Globular





$^{14}N(p,\gamma)^{15}O$: the bottleneck of the CNO cycle

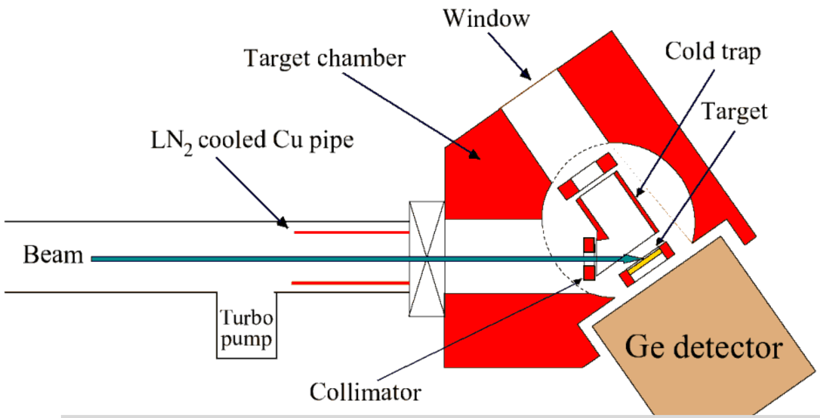




factor 20 !

Transition (MeV)	Schröder et al. (Nucl.Phys.A 1987)	Angulo et al. (Nucl.Phys.A 2001)
RC / 0	1.55 ± 0.34	0.08 ± 0.06
S(0) [kev-b]	3.20 ± 0.54	1.77 ± 0.20

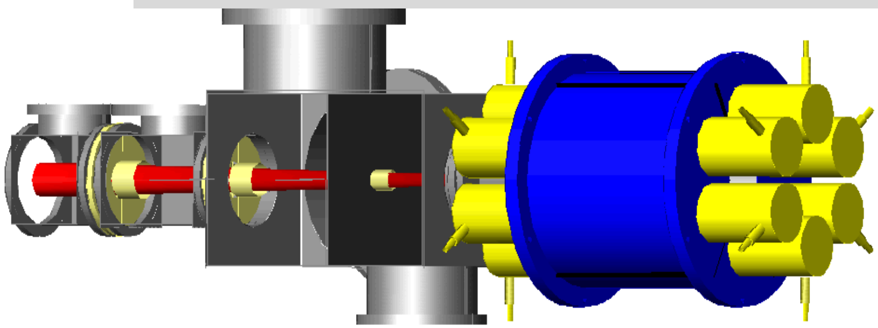
High resolution measurement



Solid target + HPGe detector

- single γ transitions
- Energy range 119-367 keV
- summing had to be considered

CNO neutrino flux decreases of a factor ≈ 2
Globular Cluster age increases of 0.7 – 1 Gyr: new upper limit on the Age of the Universe T<14 Gy



- high efficiency
- total cross section
- Energy range 70-230 keV

$S_0(\text{LUNA}) = 1.61 \pm 0.08$ keV b

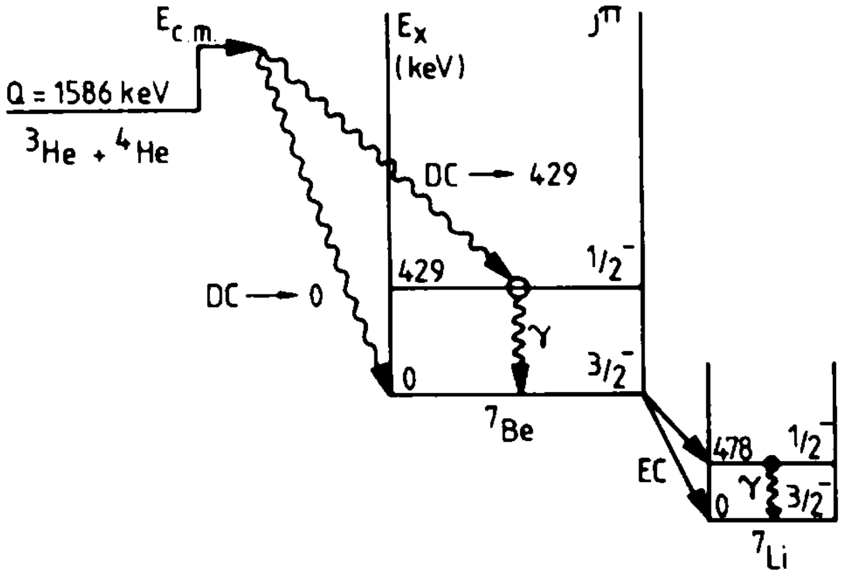
$^3He(^4He,\gamma)^7Be$

John Bahcall e M. H. Pinsonneault, astro-ph/0402114v1, 2004:

The rate of the reaction ^{3}**He(**^{4}**He,**γ**)**^{7}**Be** is the largest nuclear physics contributor to the uncertainties in the solar model predictions of the neutrino fluxes in the p-p chain. In the past 15 years, no one has remeasured this rate; it should be the **highest priority for nuclear astrophysicists**."

$$\Phi(^8B) \sim (1+\delta S_{11})^{-2.73}\,(1+\delta S_{33})^{-0.43}\,(1+\delta S_{34})^{0.85}\,(1+\delta S_{17})^{1.0}\,(1+\delta S_{e7})^{-1.0}\,(1+\delta S_{1,14})^{-0.02}$$

where fractional uncertainty $\delta S_{11} \equiv \Delta S_{11}/S_{11}(0)$



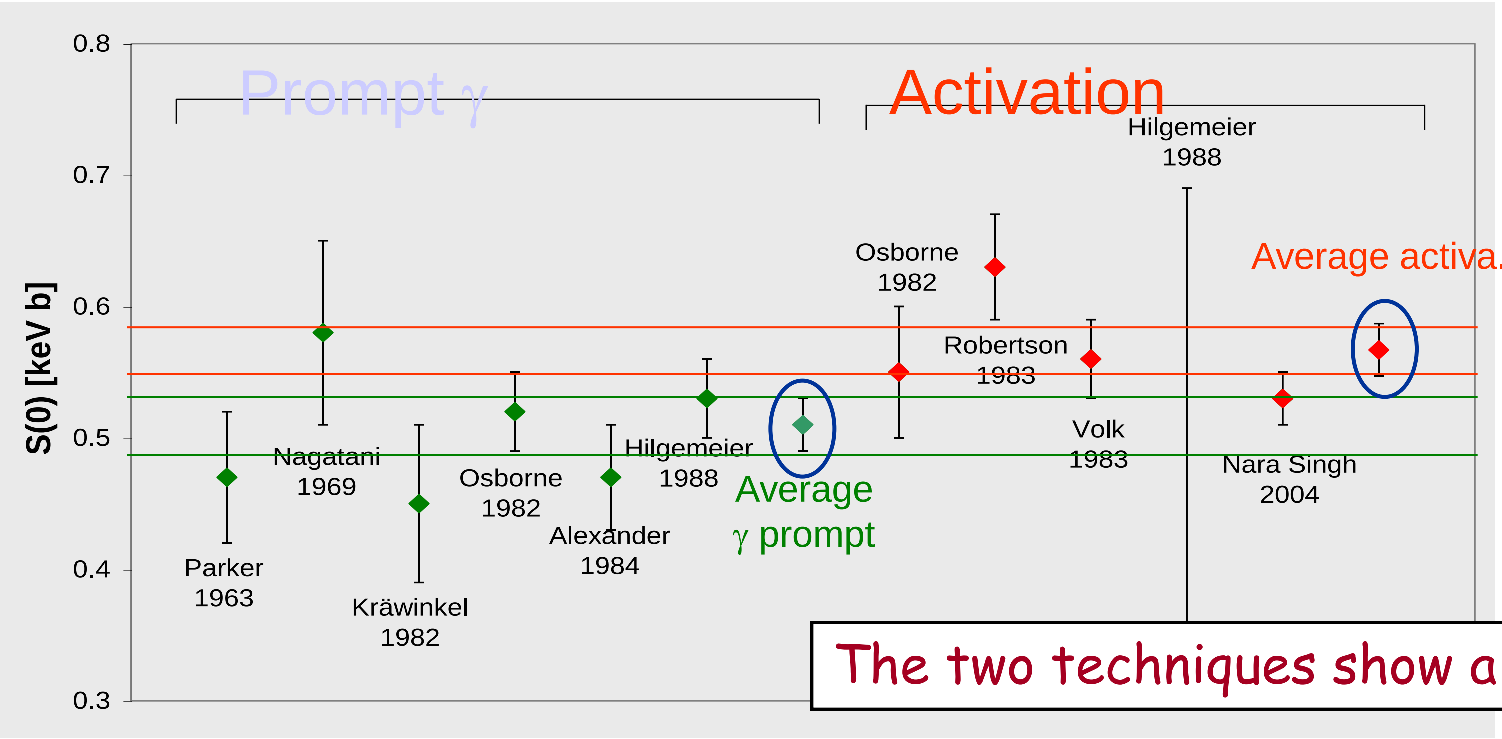
$^3He(\alpha,\gamma)^7Be(e,\nu)\ ^7Li^*(\gamma)^7Li$

E_γ = 478 keV

E_γ =1586 keV + E_{cm} (DC → 0);

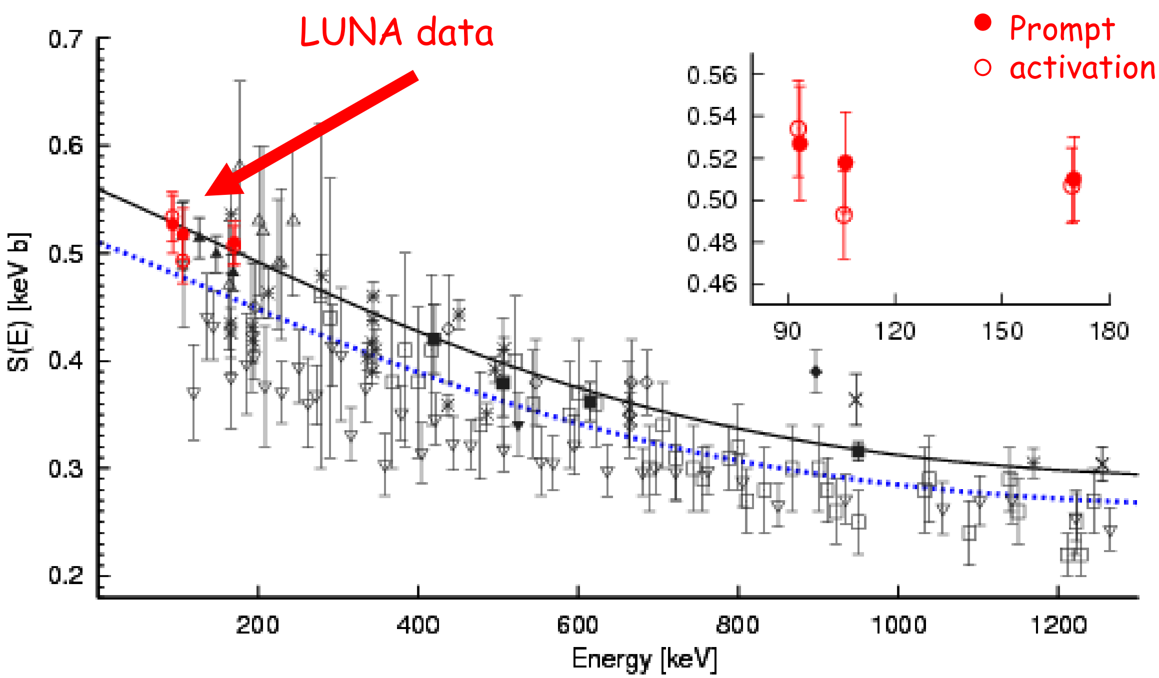
E_γ = 1157 keV + E_{cm} (DC → 429)

E_γ = 429 keV



The two techniques show a 9% discrepancy

LUNA measurements



Two techniques and reduced (4%) systematic uncertainties

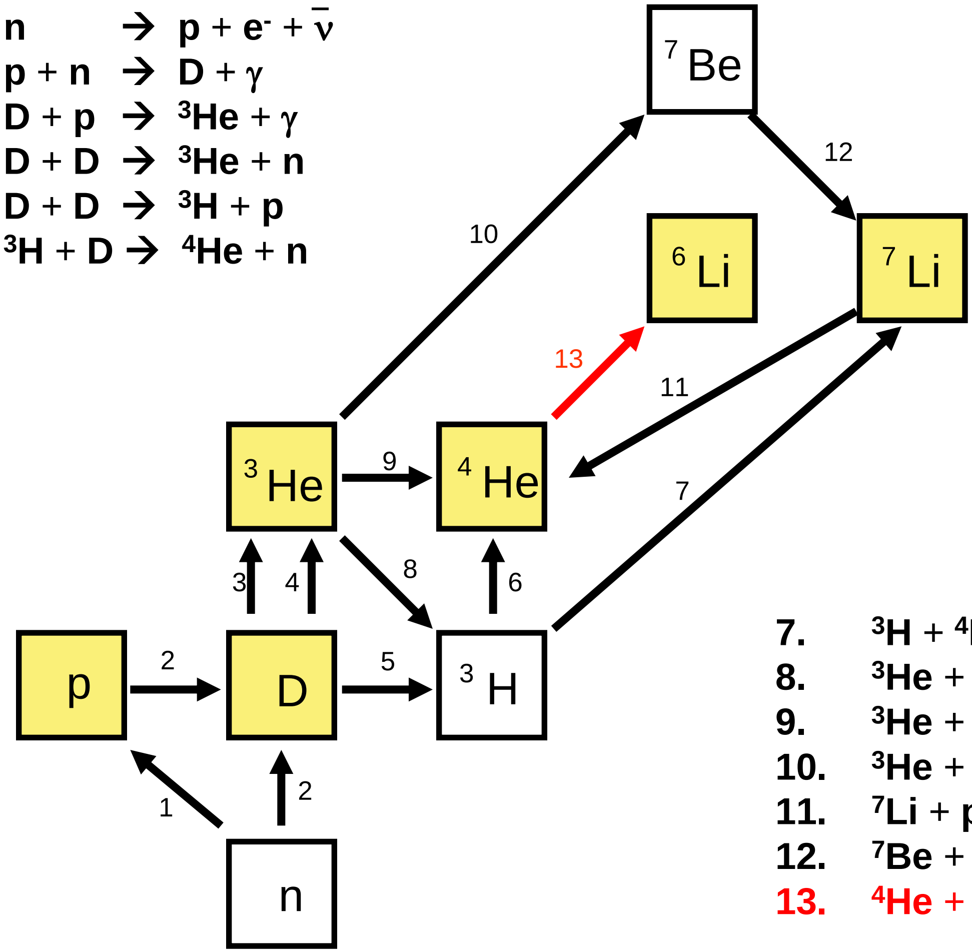
S_{34} (LUNA) =0.567±0.018±0.004 keV b

in Solar fusion cross sections II: arXiv:1004.2318v3
based on LUNA and successive measurements:
S_{34}= 0.56 ± 0.02 (exp) ± 0.02 (model) keV b

Uncertainty due to S_{34} on neutrinos flux:
$\Phi(^{8}B)$ 7.5% → 4.3%
$\Phi(^{7}Be)$ 8% → 4.5%

BBN reaction network

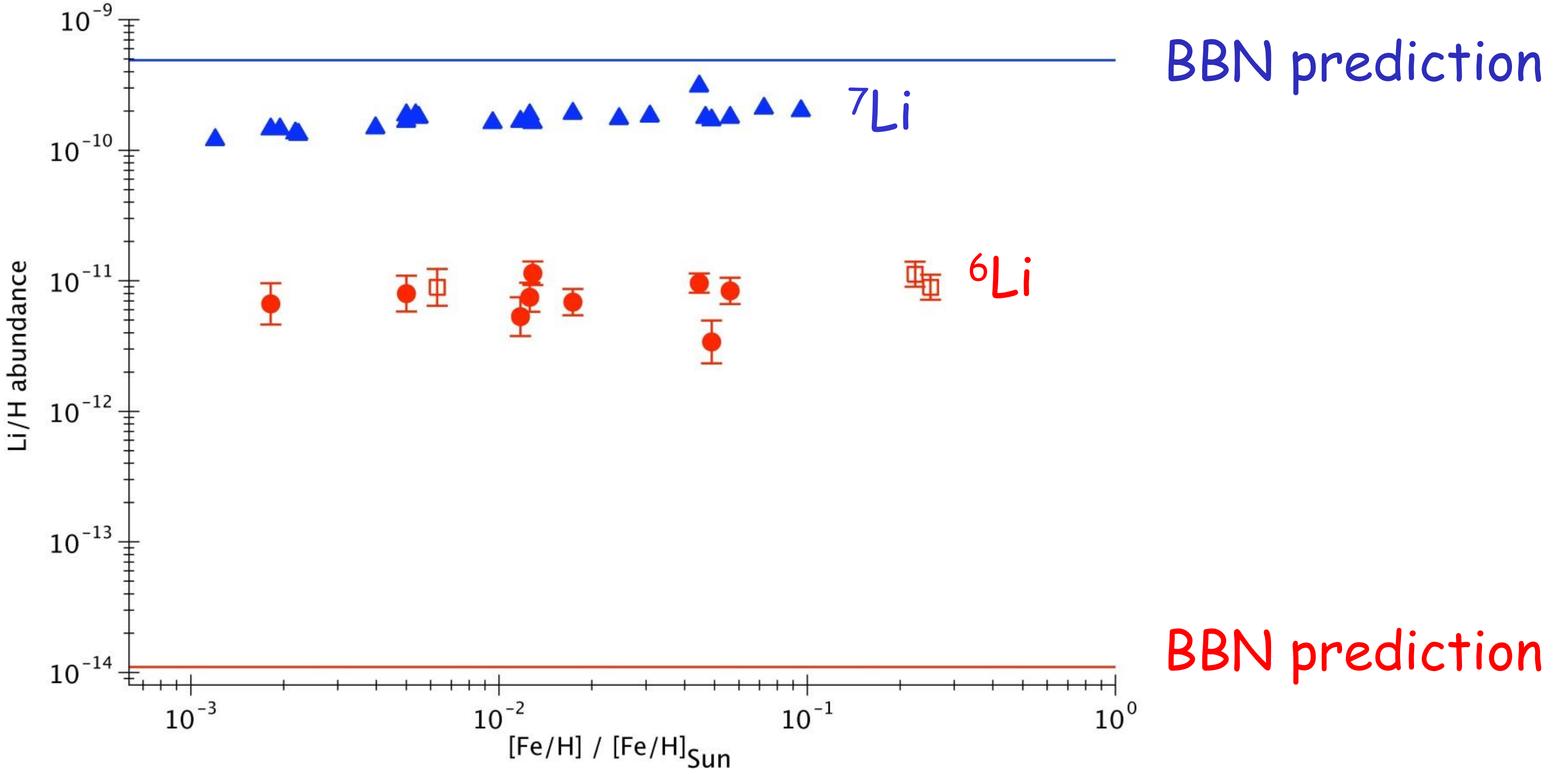
1. n → $p + e^- + \bar{\nu}$
2. p + n → D + γ
3. D + p → ^{3}He + γ
4. D + D → ^{3}He + n
5. D + D → ^{3}H + p
6. ^{3}H + D → ^{4}He + n



7. ^{3}H + ^{4}H → ^{7}Li + γ
8. ^{3}He + n → ^{3}H + p
9. ^{3}He + D → ^{4}He + p
10. ^{3}He + ^{4}He → ^{7}Be + γ
11. ^{7}Li + p → ^{4}He + ^{4}He
12. ^{7}Be + n → ^{7}Li + p
13. ^{4}He + D → ^{6}Li + γ

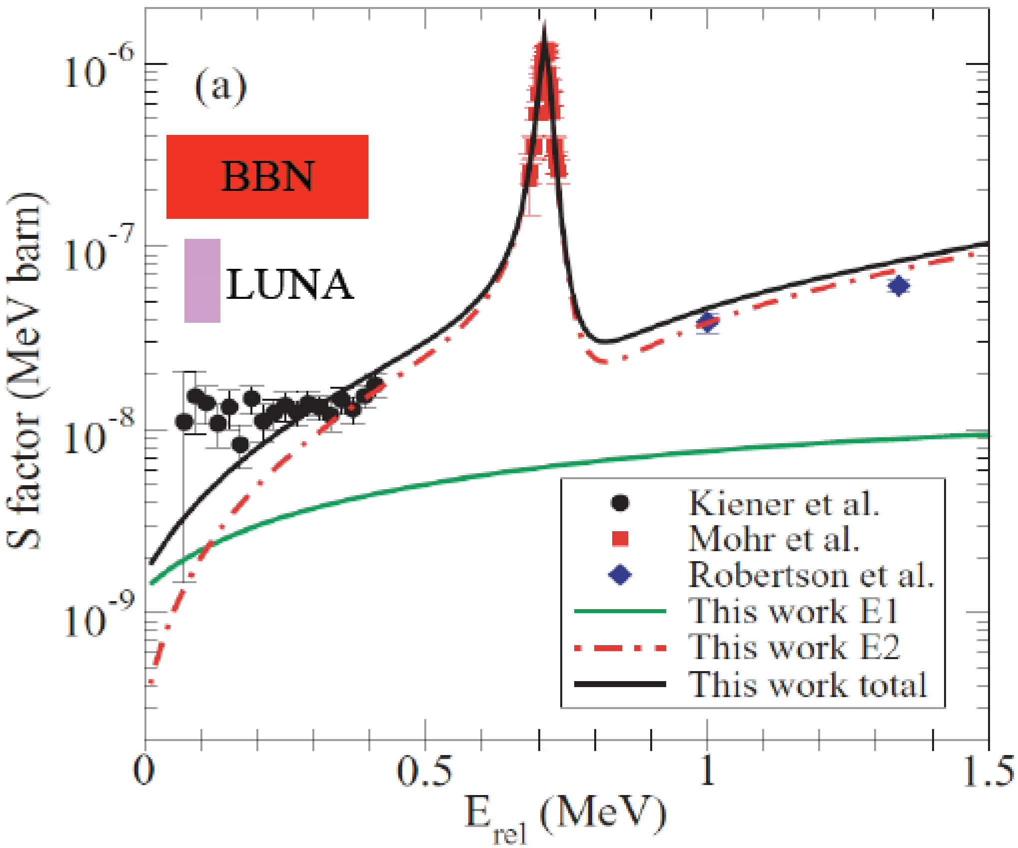
The ^{6}Li case

Constant amount in stars of different metallicity (→age)
2-3 orders of magnitude higher than predicted with the BBN network (NACRE)
(Asplund 2006, now debated since convective motions on the stellar surface can give an asymmetry in the absorption line mimicking the presence of ^{6}Li)



The primordial abundance is determined by:
^{2}H(α,γ)^{6}Li producing almost all the ^{6}Li
^{6}Li(p,α)^{3}He destroying ^{6}Li → well known

Available data



Direct measurements:
- Robertson et al.
E > 1 MeV
- Mohr et al.
around the 0.7 MeV resonance

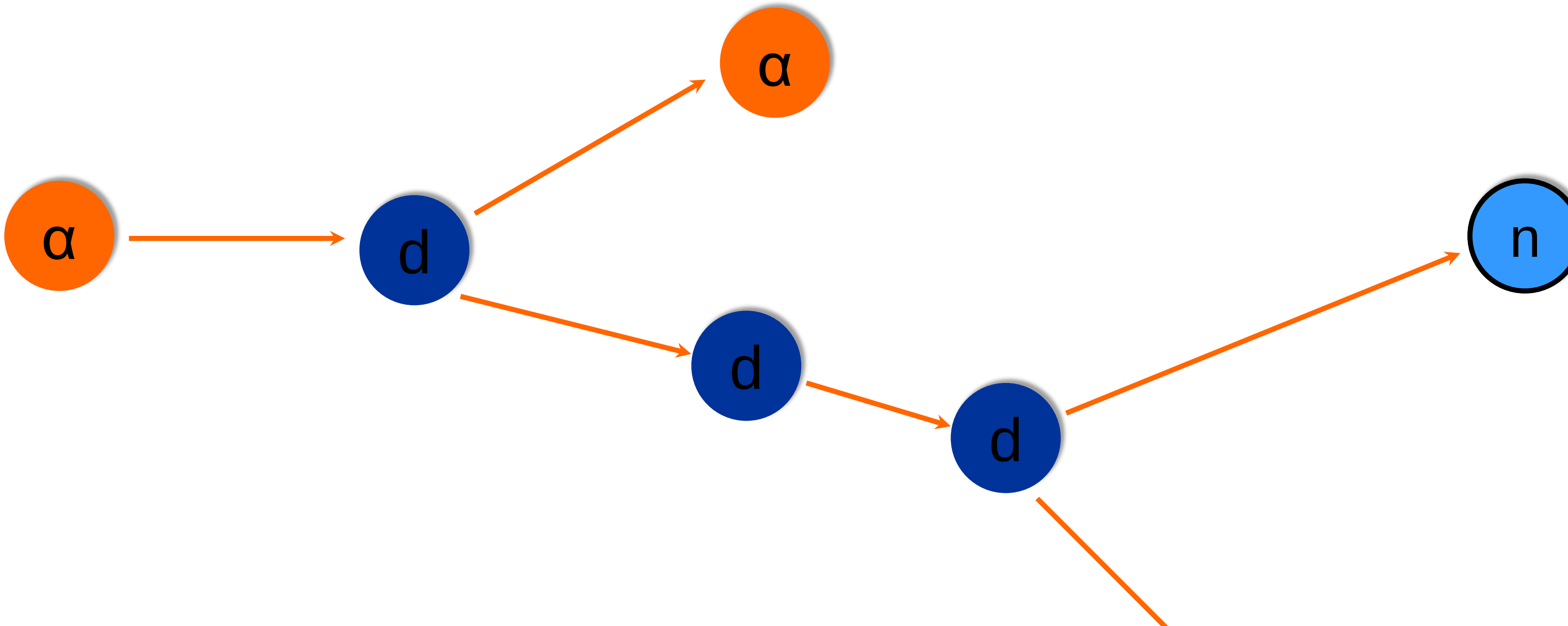
Indirect measurements:
- Hammache et al.
upper limits with high energy Coulomb break-up

At LUNA direct measurements at the energies of astrophysical interest

[F. Hammache et al.,
Phys. Rev. C 82, 065803 (2010)]

The beam-induced background

- neutron background generated by d(α,α)d Rutherford scattering followed by $d(d,n)^3He$ reactions



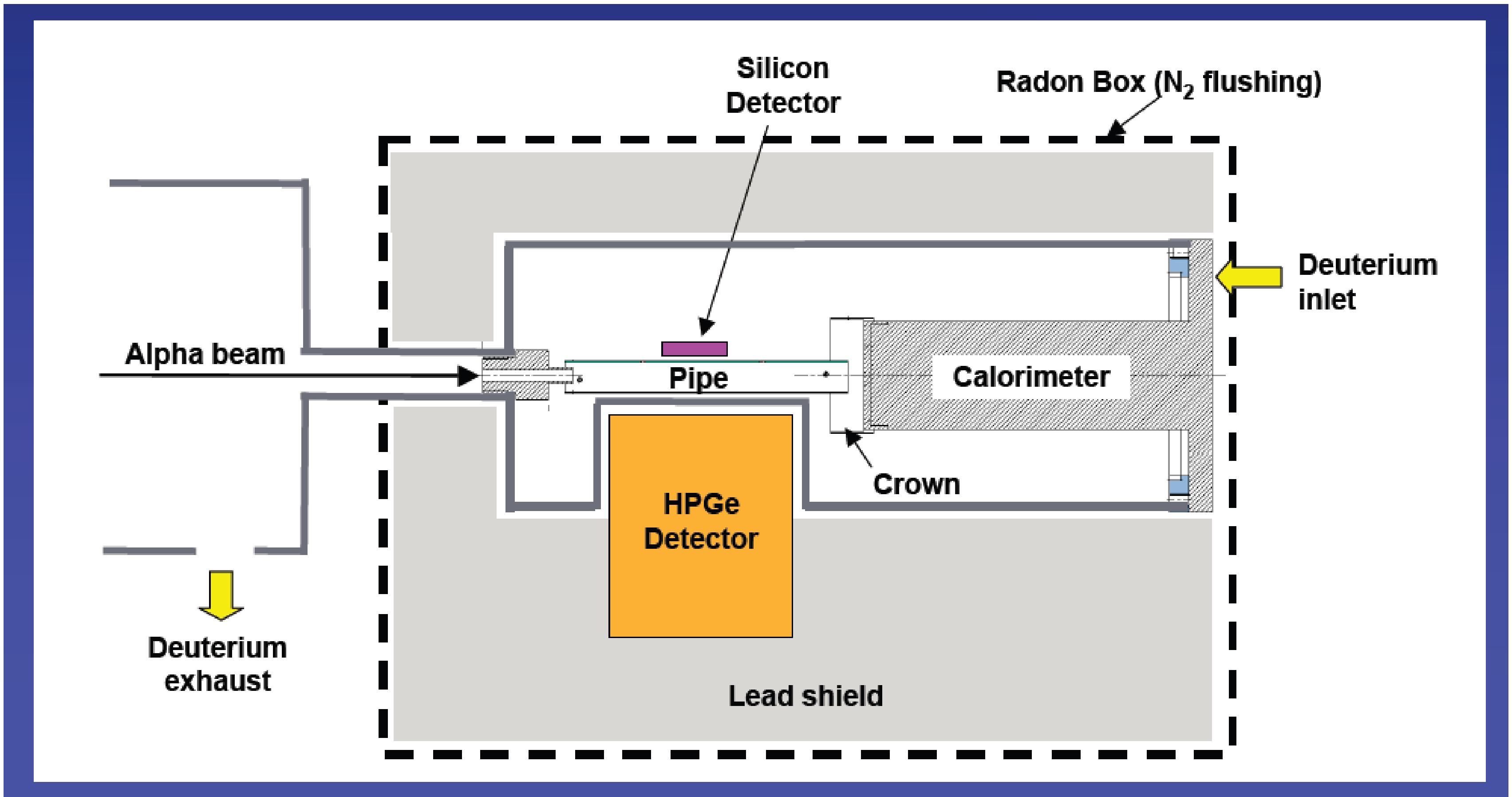
-> (n,n'γ) reactions on surrounding materials (Pb, Ge, Cu)

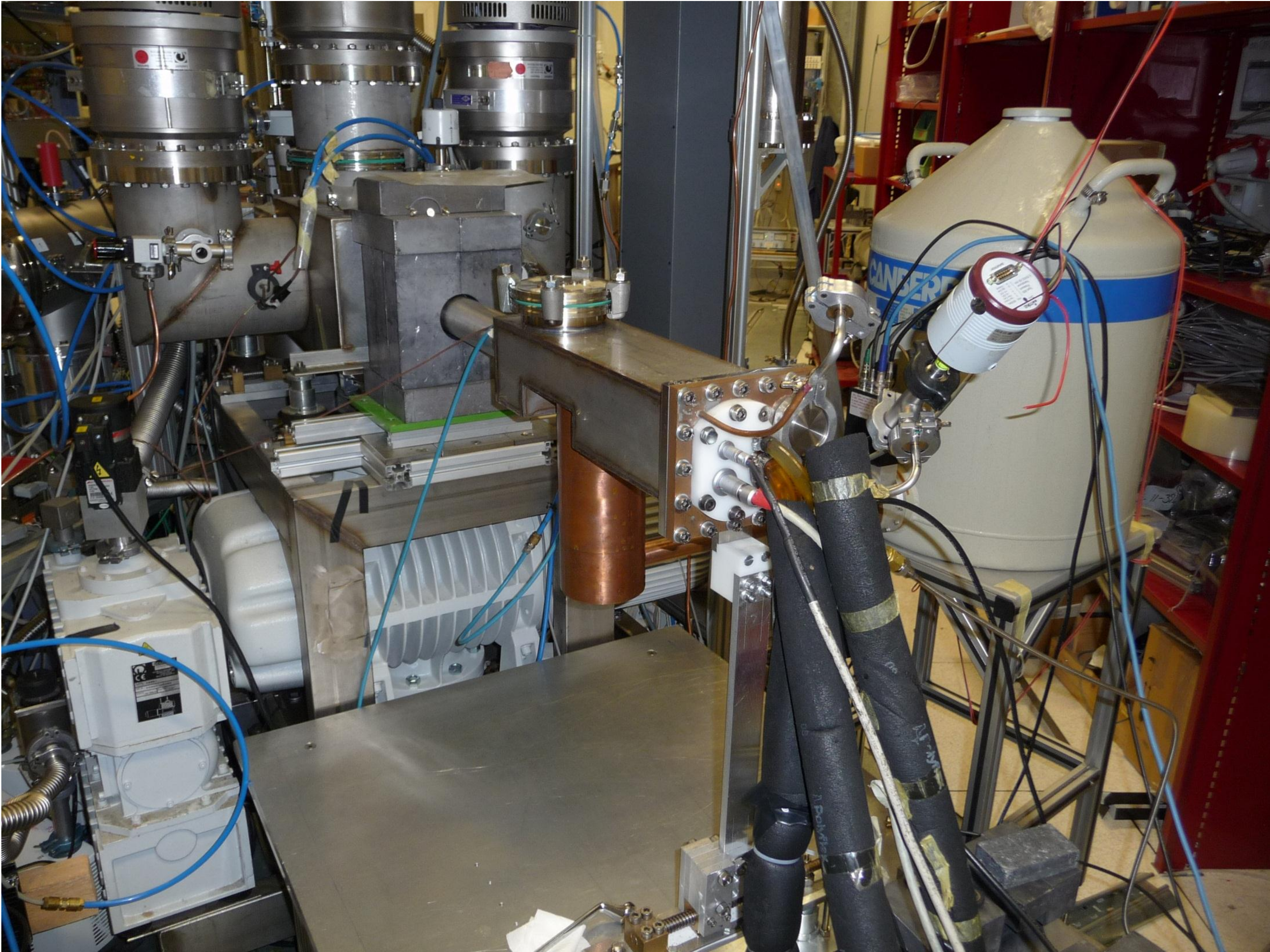
-> much higher γ-ray background in the RoI for the $d(\alpha,\gamma)^6Li$ DC transition (~1.6 MeV)

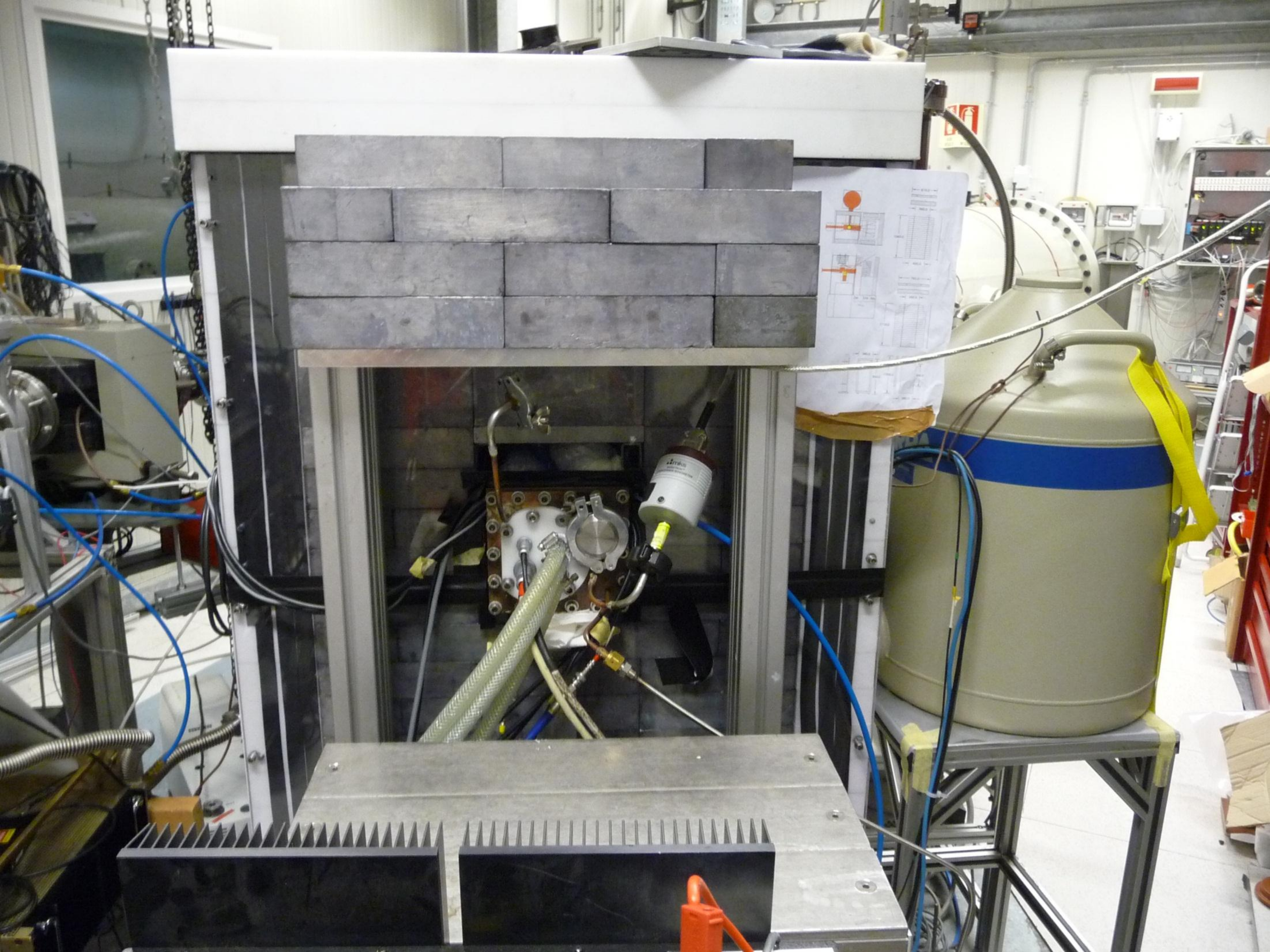
Experimental set-up

Reduced gas volume: pipe to minimize the path of scattered ^{2}H and hence diminish the d(d,n)^{3}He reaction yield

HPGe detector in close geometry: larger detection efficiency and improved signal-to-noise ratio





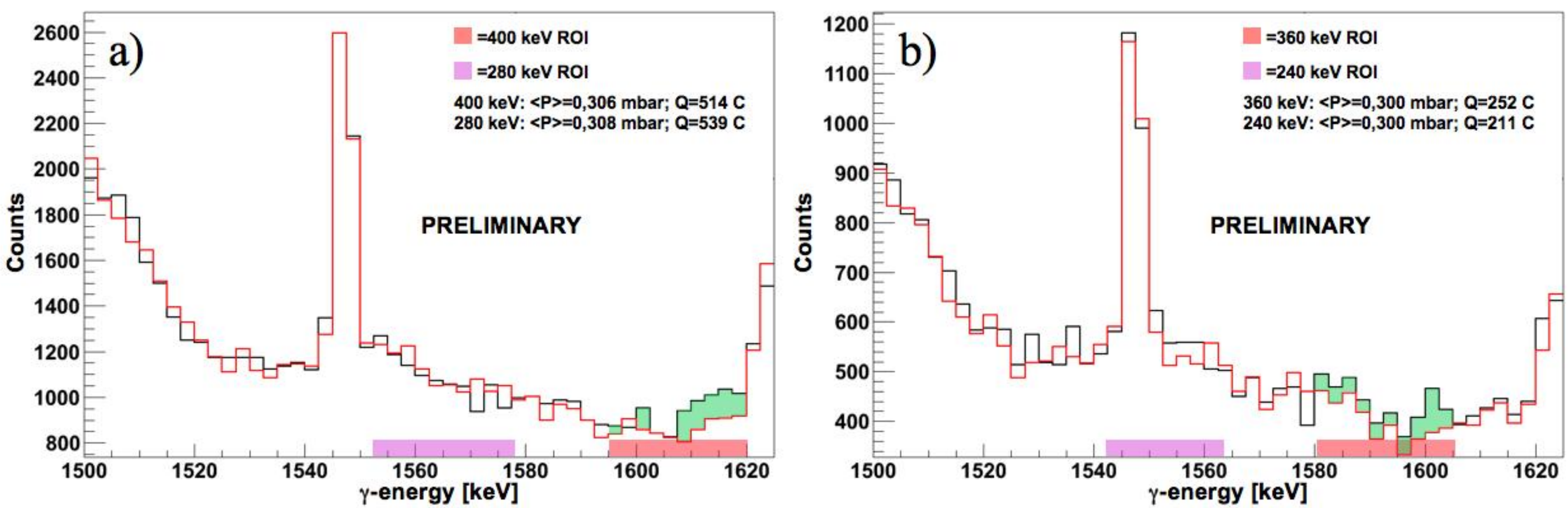


$^2H(\alpha,\gamma)^6Li$ analysis

Two measurement campaigns:
a) 400 keV and 280 keV
b) 360 keV and 240 keV
at 400 keV the expected S/N ratio is about 1/12

Signal: $E_\gamma = Q + E_{CM} - \Delta E_{rec} \pm \Delta E_{Doppler}$
400
Back

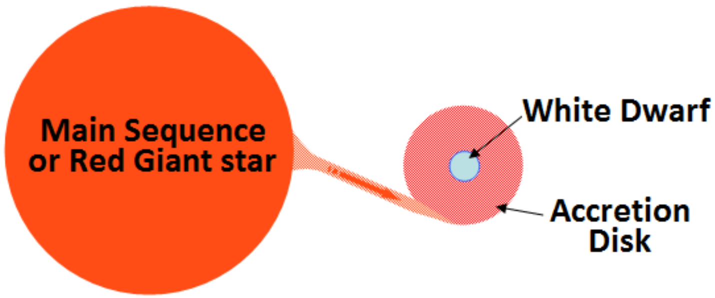
A counting excess is clearly visible both at 400 and 360 keV!
Possible systematics still to be evaluated



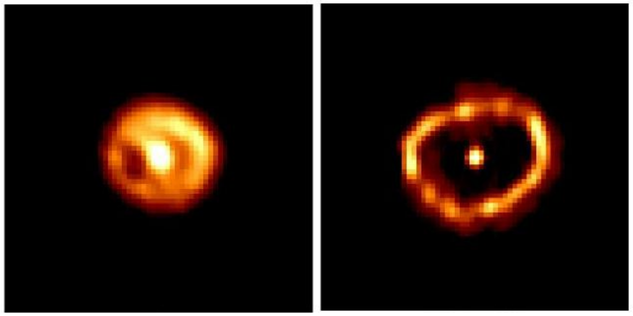
$^{17}O(p,\gamma)^{18}F$ measurement

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

- Red giants
- Massive stars
- AGB
- Novae



1. production of light nuclei ($^{17}O/^{18}O$ abundances....);
2. observation of ^{18}F γ-ray signal (annihilation 511 keV).

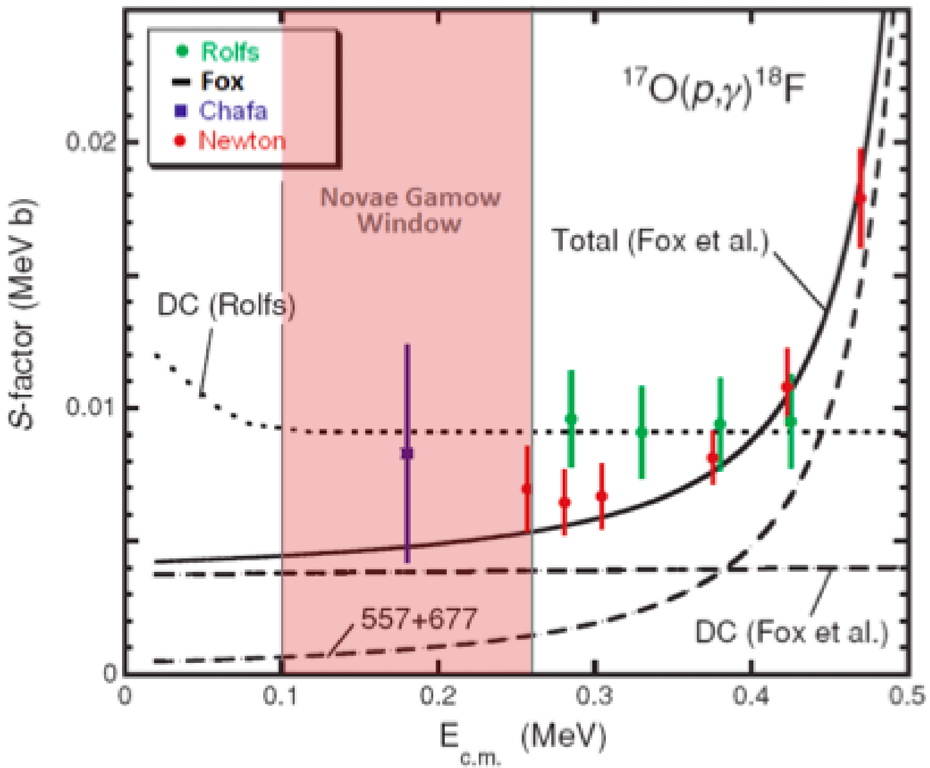


(Cygni 1992)

Classical novae **T=0.1-0.4 GK => E_{Gamow} = 100 - 260 keV**
Resonant Contribution: $^{17}O(p,\gamma)^{18}F$ resonance at **E_p = 183 keV and non resonant contribution**

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

State of the art before the LUNA measurement (1):



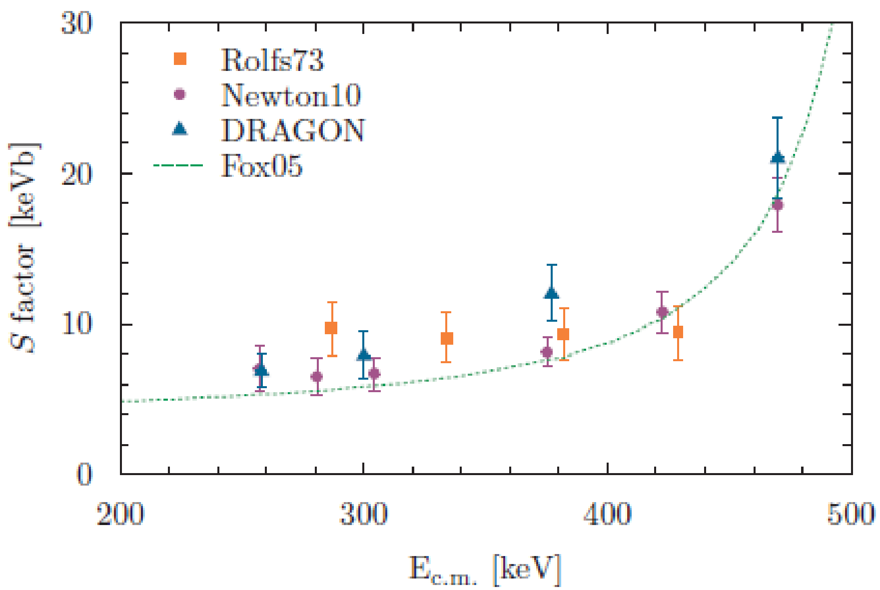
Rolfs et al., 1973, prompt γ
S_{DC} measured at 4 energies in the range E_{cm} = 290-430 keV
$S_{DC} \approx 9$ keV b for E_{cm}= 100-500 keV

Fox et al., 2005, prompt γ
discovered 193 keV resonance
$\omega\gamma = (1.2 \pm 0.2)\ 10^{-6}$ eV
calculation of DC
$S_{DC} = 3.74 + 0.676E - 0.249E^2$
determination of high energy resonance influence on S total

Chafa et al., 2007, activation
$\omega\gamma = (2.2 \pm 0.4)\ 10^{-6}$ eV
measured $S_{DC} = (8.3 \pm 4.0)$ keV b
$S_{DC} = 6.2 + 1.61E - 0.169E^2$
larger than Fox by more than 50%

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

Status of the art before the LUNA measurement (2):

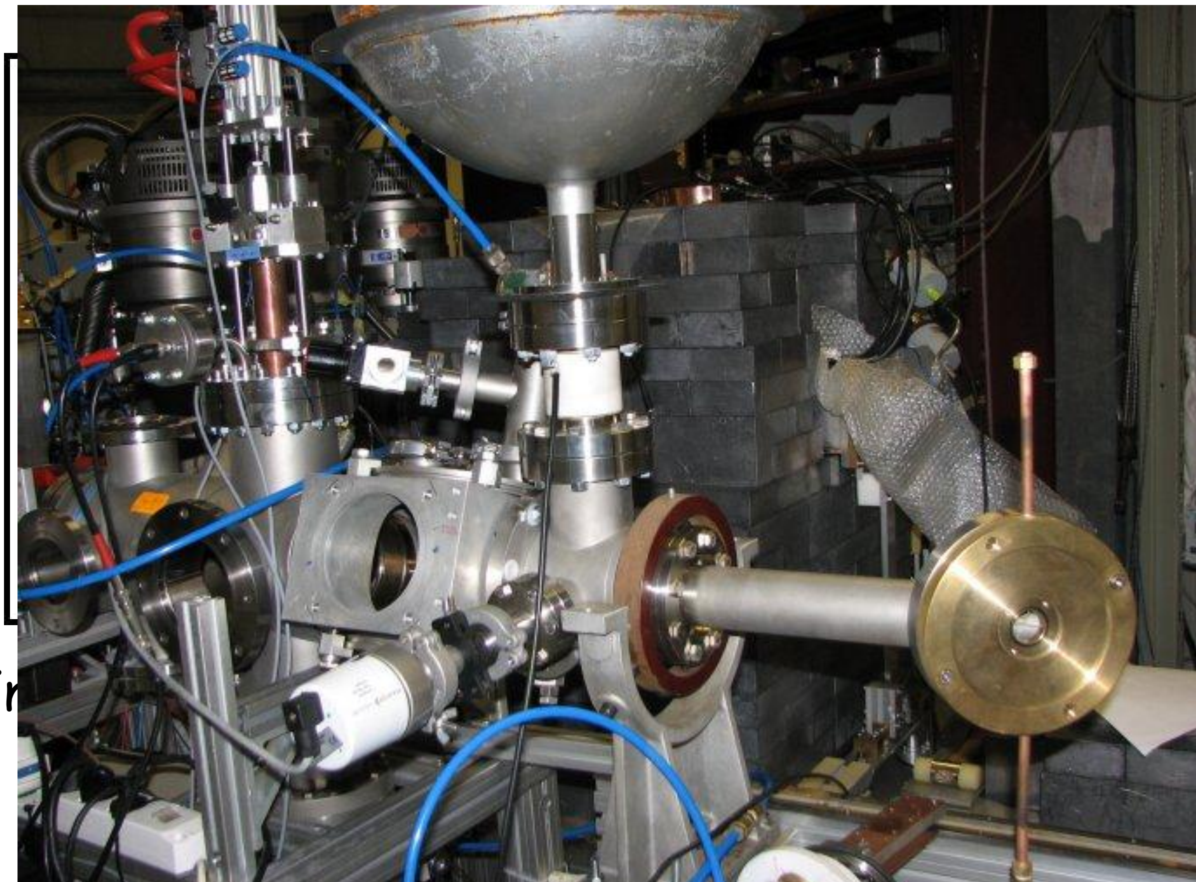


Newton et al., 2010, prompt γ
S_{DC} measured at 6 energies in the range E_{cm} = 260-470 keV
Calculated $S_{DC}(E)$ = 4.6 keV b (±23%)

Hager et al.(DRAGON), 2012, recoil separator
E_{cm} = 250-500 keV
S_{DC} higher than Newton and Fox. No flat dependence. Re-evaluate resonant contributions

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

183 keV resonance and direct capture component for E=200-370 keV measured with prompt gammas and activation →Gamow window for Novae region explored with the highest precision to-date



get

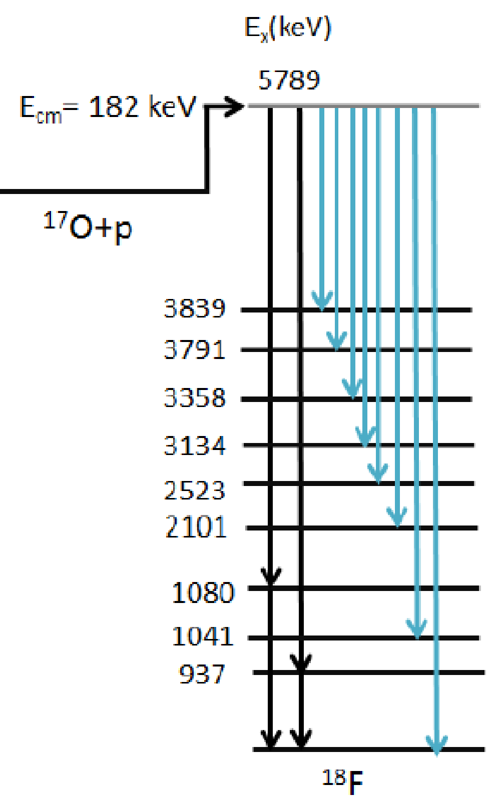
etector

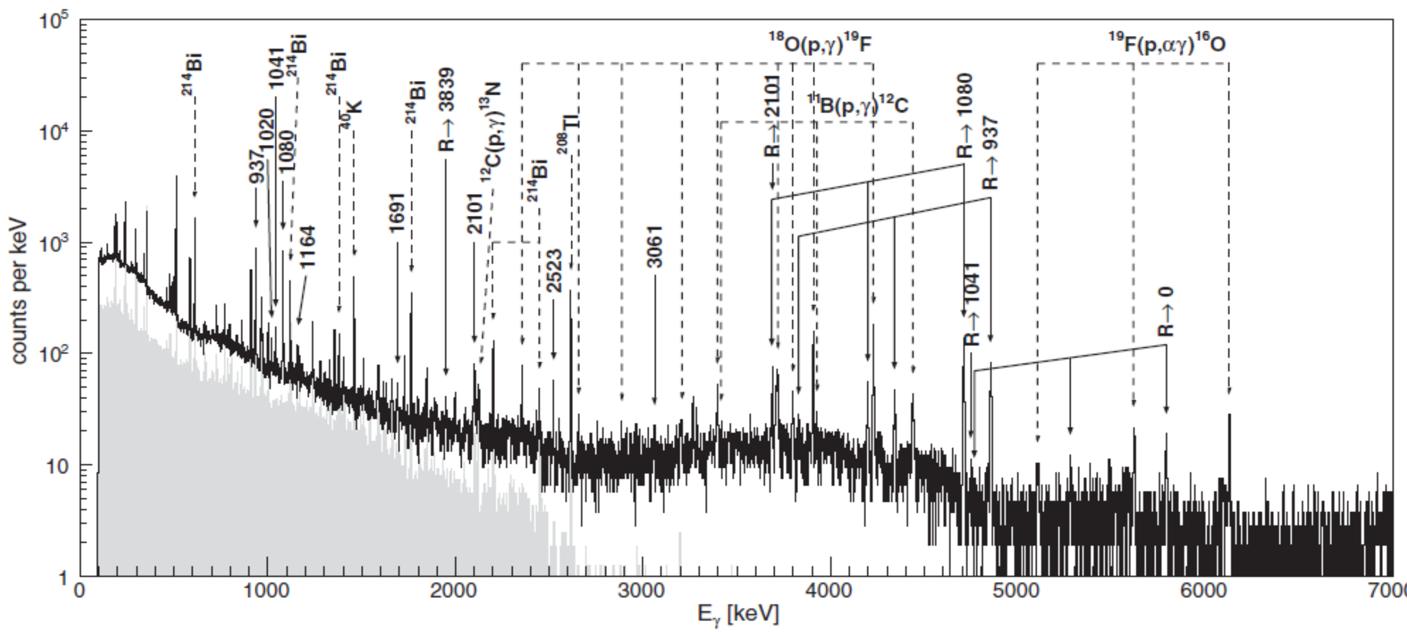
Er (anodization process)

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

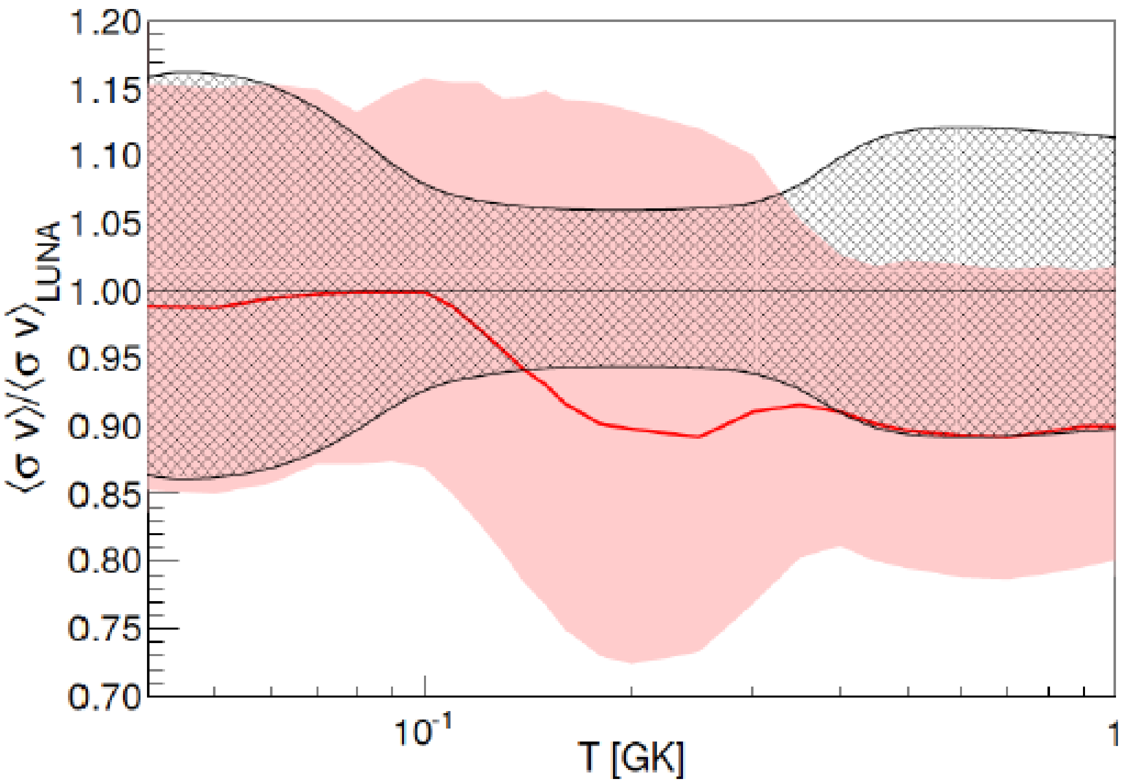
183 keV resonance: $\omega\gamma$=1.67±0.12 μeV (weighted average of prompt and activation)

Several new transitions identified and branching ratios determined





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



The best fit includes the contribution from the E=557 and E=667 broad resonances from literature and a constant direct capture component

Improvement of a factor of 4 in the reaction rate uncertainty!

D. Scott et al., Phys Rev Lett 109 (2012) 202501

LUNA 400 kV program

status	reaction	Q-value (MeV)
completed	$^{17}O(p,\gamma)^{18}F$	5.6
just started	$^{17}O(p,\alpha)^{14}N$	1.2
→	$^{18}O(p,\gamma)^{19}F$	8.0
→	$^{18}O(p,\alpha)^{15}N$	4.0
→	$^{23}Na(p,\gamma)^{24}Mg$	11.7
just started	$^{22}Ne(p,\gamma)^{23}Na$	8.8
completed	$D(\alpha,\gamma)^{6}Li$	1.47

Still three reactions to be measured→ to be completed by 2015

LUNA MV Project

April 2007: a Letter of Intent (LoI) was presented to the LNGS Scientific Committee (SC) containing key reactions of the He burning and neutron sources for the s-process:

$^{12}C(\alpha,\gamma)^{16}O$

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

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

(α,γ) reactions on $^{14,15}N$ and ^{18}O

These reactions are relevant at higher temperatures (larger energies) than reactions belonging to the hydrogen-burning studied so far at LUNA

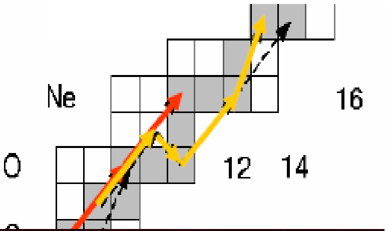
↓

Higher energy machine→ 3.5 MV single ended positive ion accelerator

$^{12}C(\alpha,\gamma)^{16}O$ – Holy Grail of Nuclear Astrophysics

Stellar Helium burning in Red Giant Stars

the He burning is ignited on the ^{4}He and ^{14}N ashes of the preceding hydrogen burning phase (pp and CNO)



- **Carbon**

we are made of !

- **Oxygen**

which we breath !

relevant questions:

Energy production and time scale of Helium burning:

$^{4}He(2\alpha,\gamma)^{12}C(\alpha,\gamma)^{16}O(\alpha,\gamma)^{20}Ne$

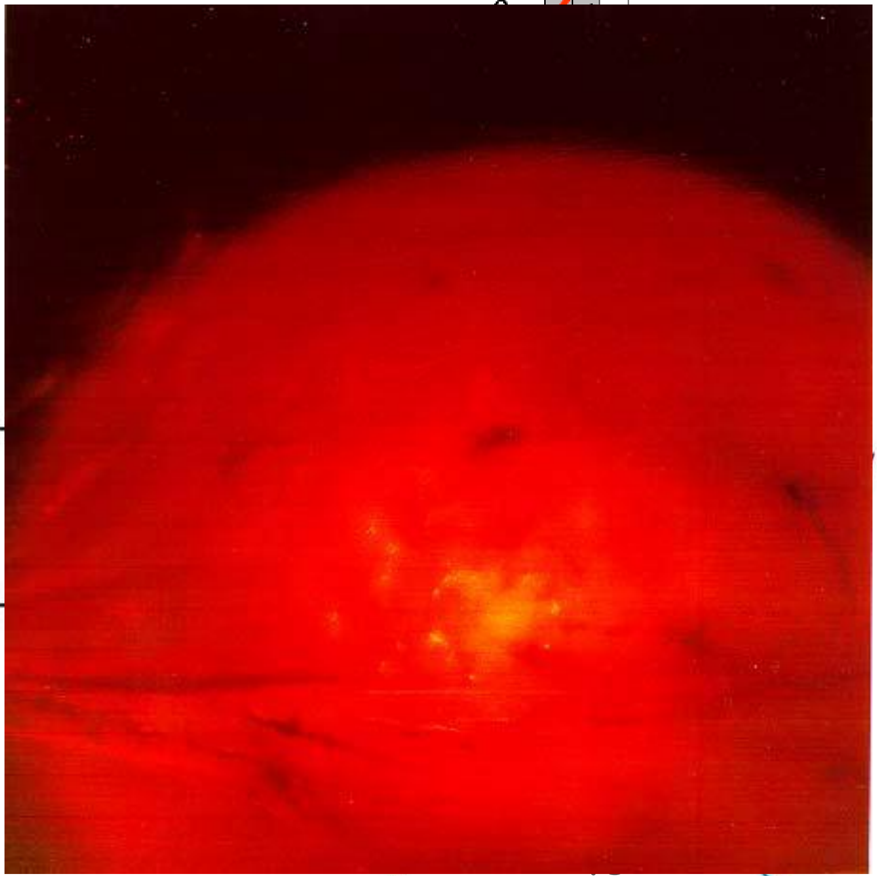
Consequences

- late stellar evolution
- composition of C/O White dwarfs
- Supernova type I explosion
- Supernova type II nucleosynthesis

Neutron sources for s process:

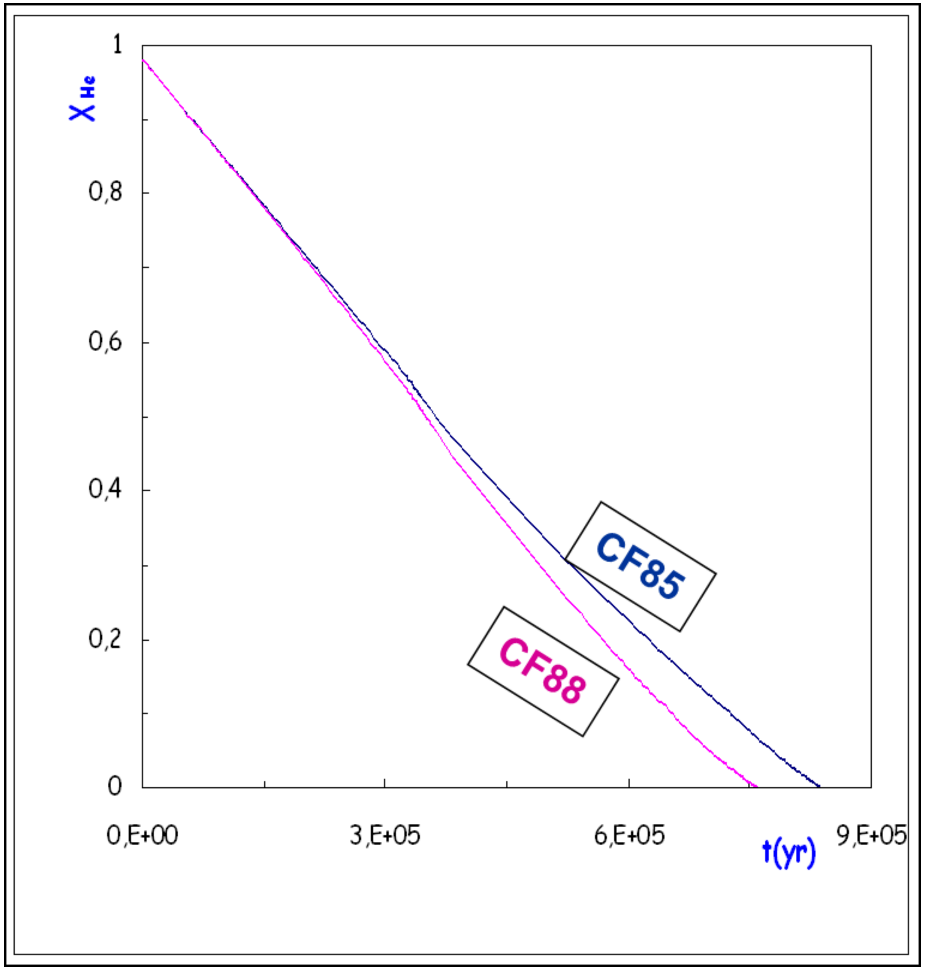
$^{14}N(\alpha,\gamma)^{18}F(\beta+\nu)^{18}O(\alpha,\gamma)^{22}Ne(\alpha,n)$

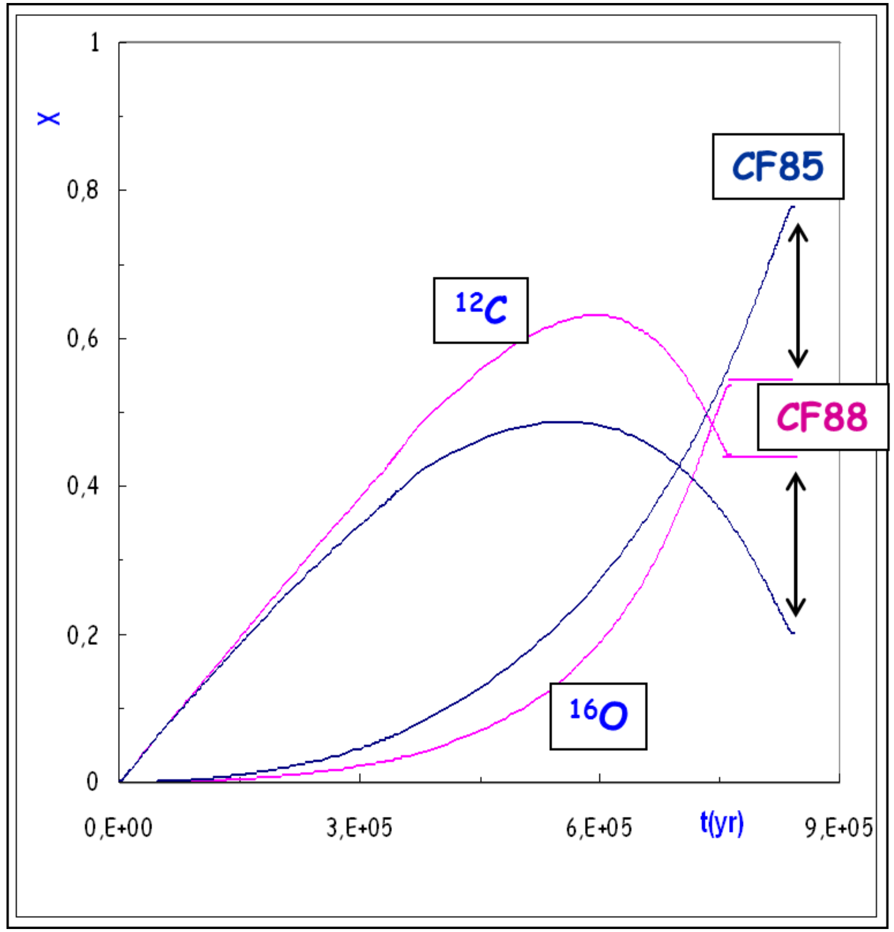
$^{22}Ne(\alpha,\gamma)$



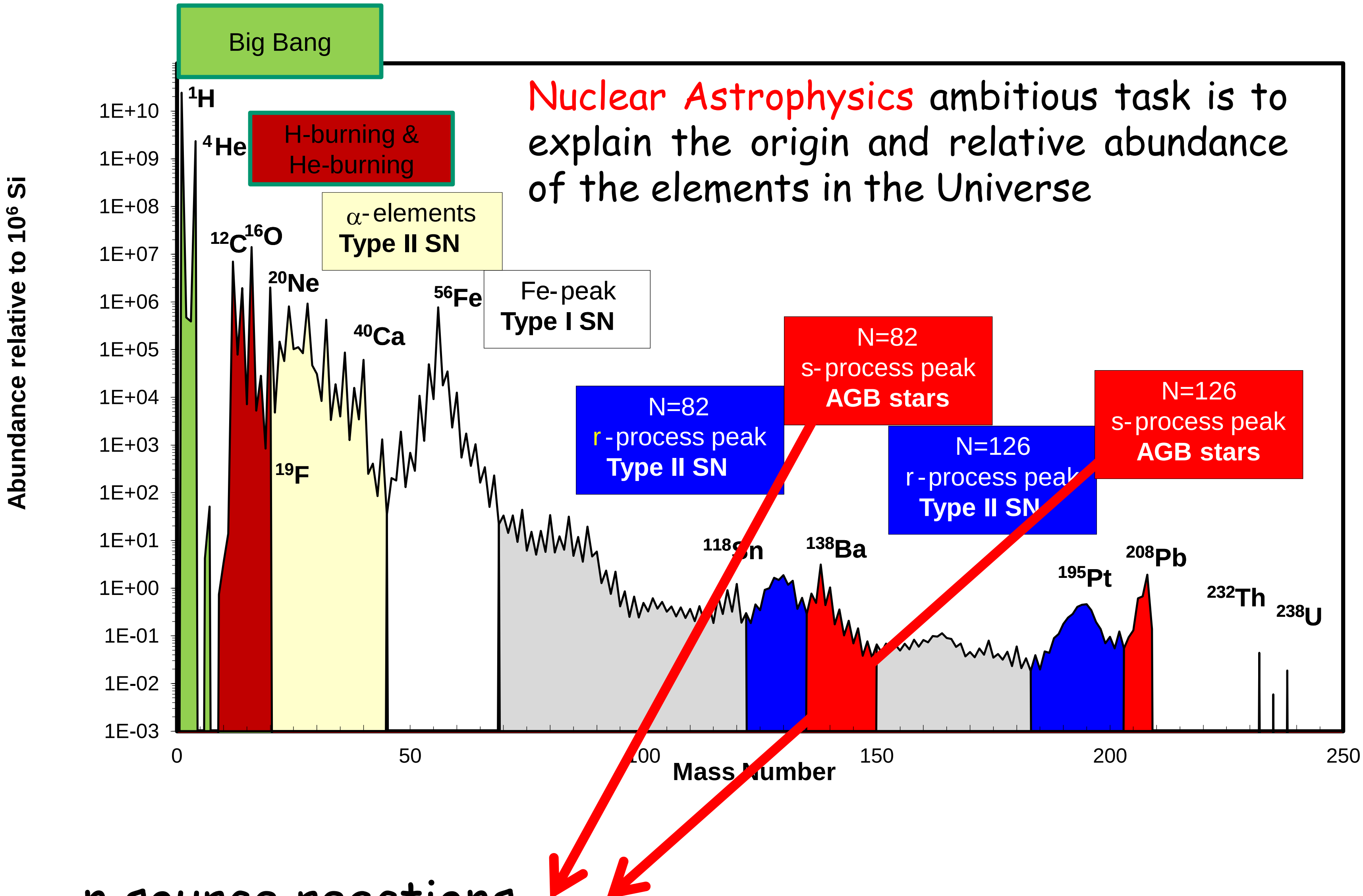
$^{12}C/^{16}O$ ratio at the end of Helium burning

example: Stellar model for a 20 M_{solar} Star
S factor(CF85) = 2 × S factor(CF88)





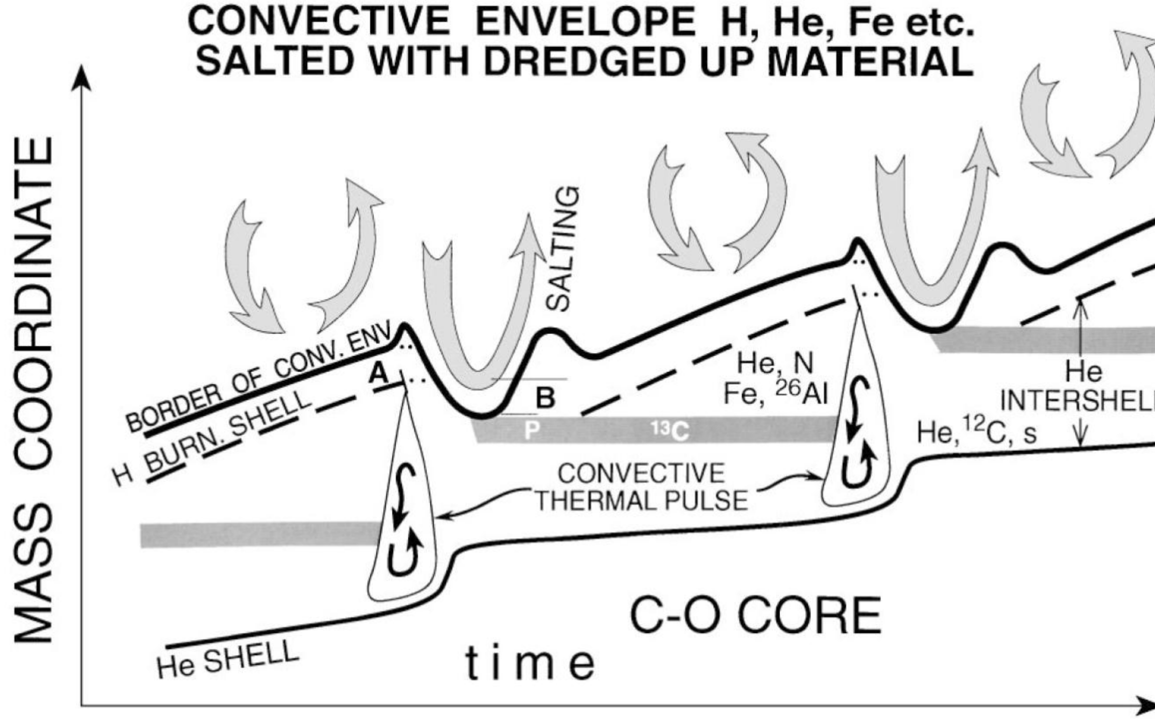
Element abundances in the solar system

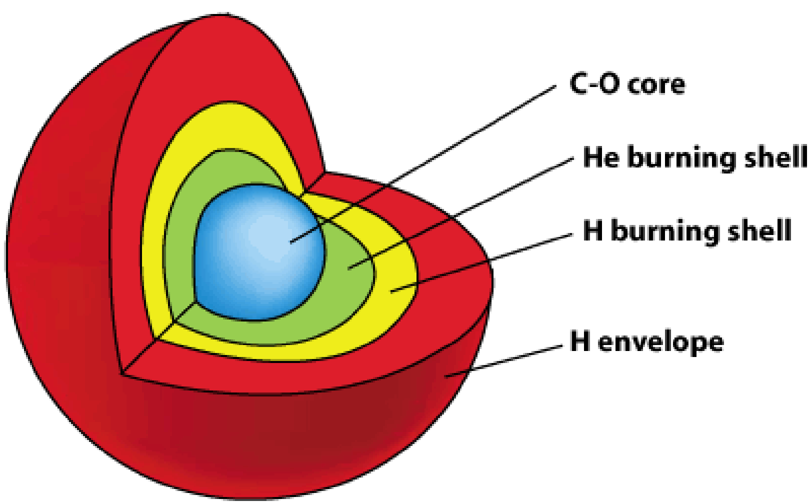


Nuclear Astrophysics ambitious task is to explain the origin and relative abundance of the elements in the Universe

n source reactions

s-process nucleosynthesis during AGB

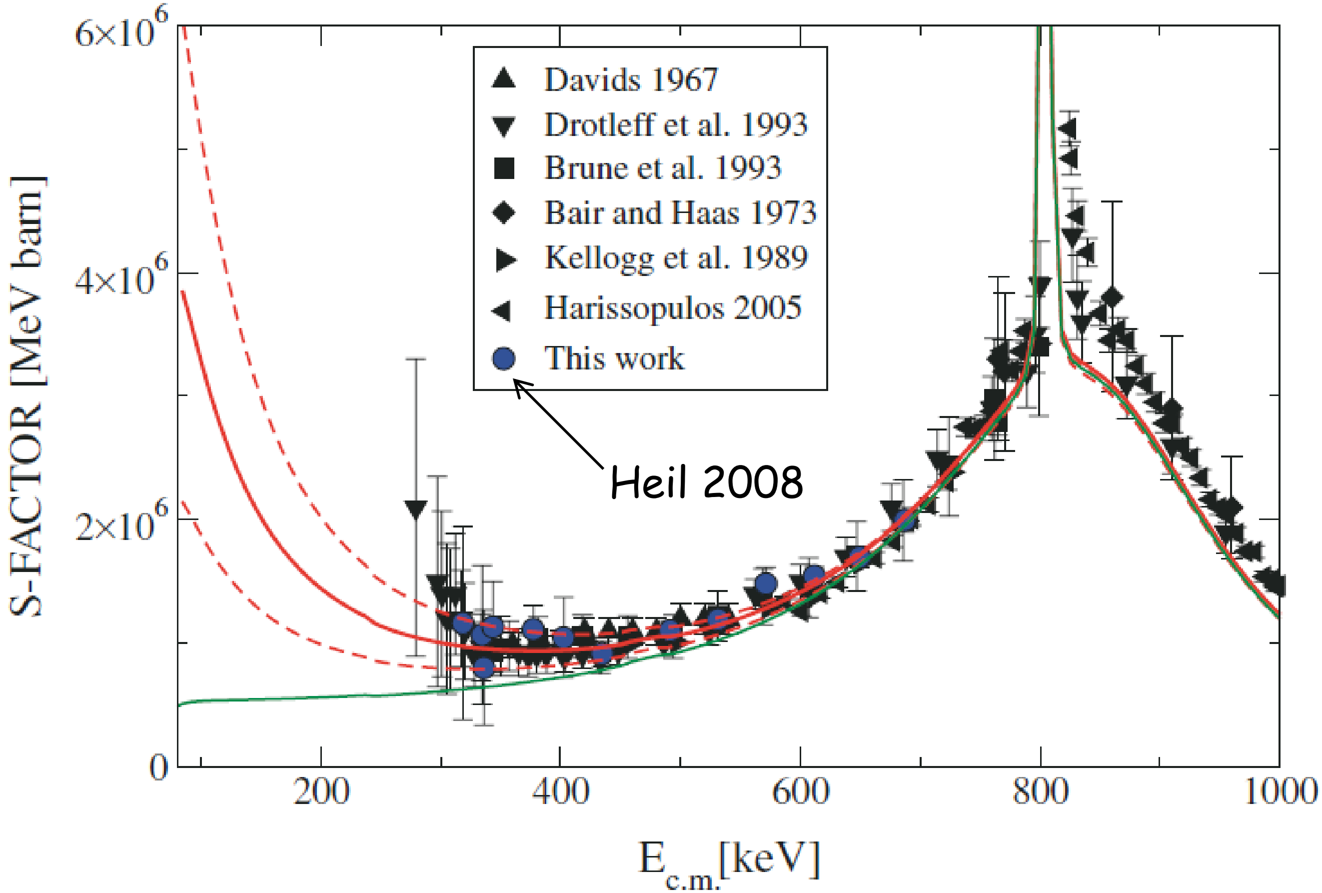




$^{13}C(\alpha,n)^{16}O$	$^{22}Ne(\alpha,n)^{25}Mg$
max flux 10^7 n cm^{-3}	max flux 10^9 n cm^{-3}
10^3 years	few years

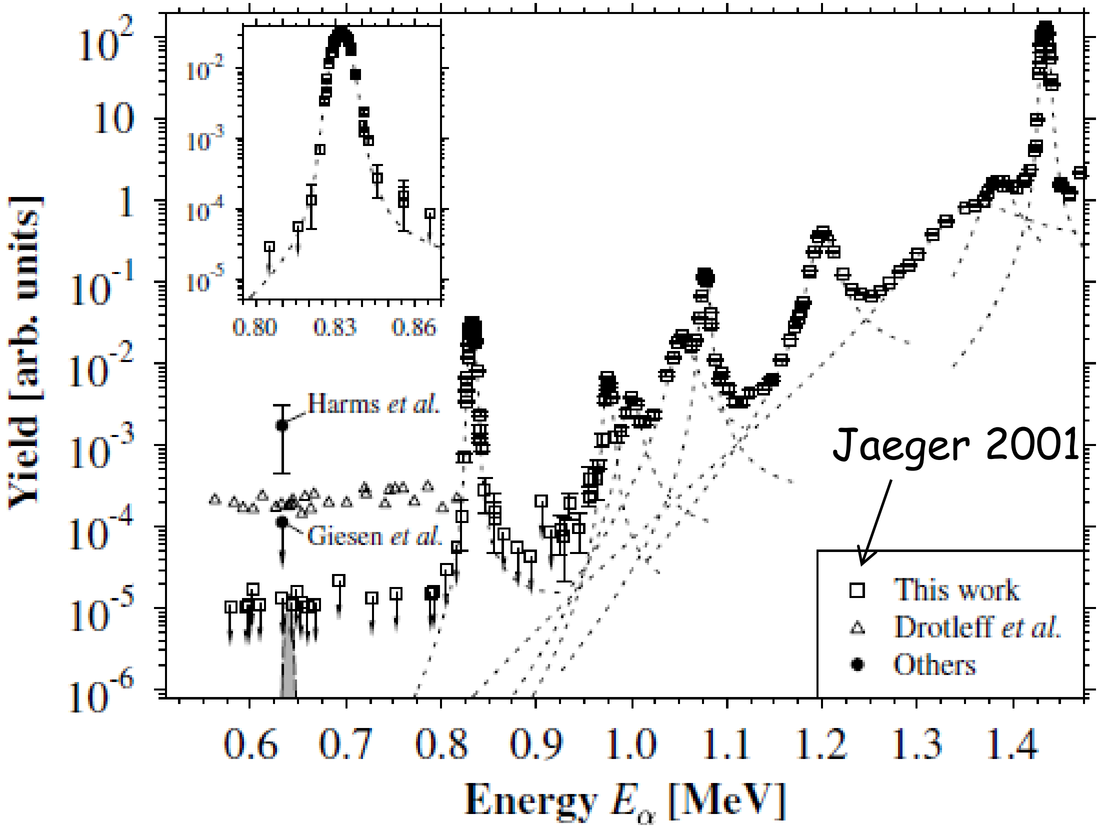
During the AGB phase, alternatively H and He-shells switch on and off several times. Then, the convective **H-envelope** can penetrate the **He-burning inter-shell**, dredging-up the produced elements during the s-process.

$^{13}C(\alpha,n)^{16}O$ experimental status of the art



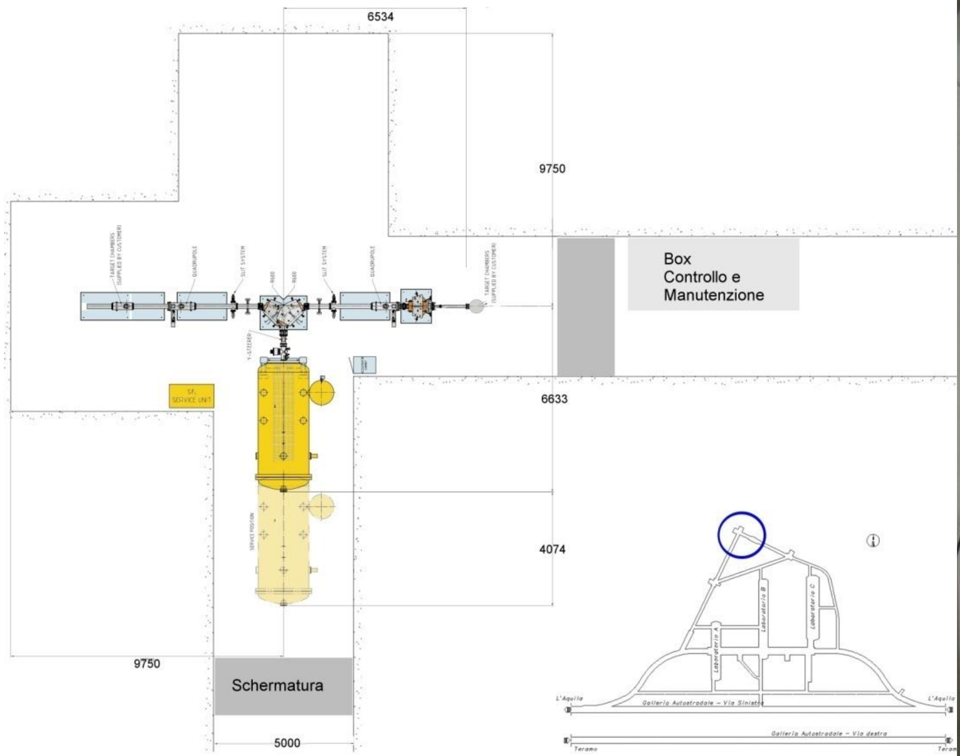
Big uncertainties in the R-matrix extrapolations. Presence of subthreshold resonances

$^{22}Ne(\alpha,n)^{16}O$ experimental status of the art



Unmeasured resonance at E=635 keV→ big uncertainties in the reaction rate.

Location at the "B node" of a 3.5 MV single-ended positive ion accelerator



- In a very low background environment such as LNGS, it is mandatory not to increase the neutron flux above its average value

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

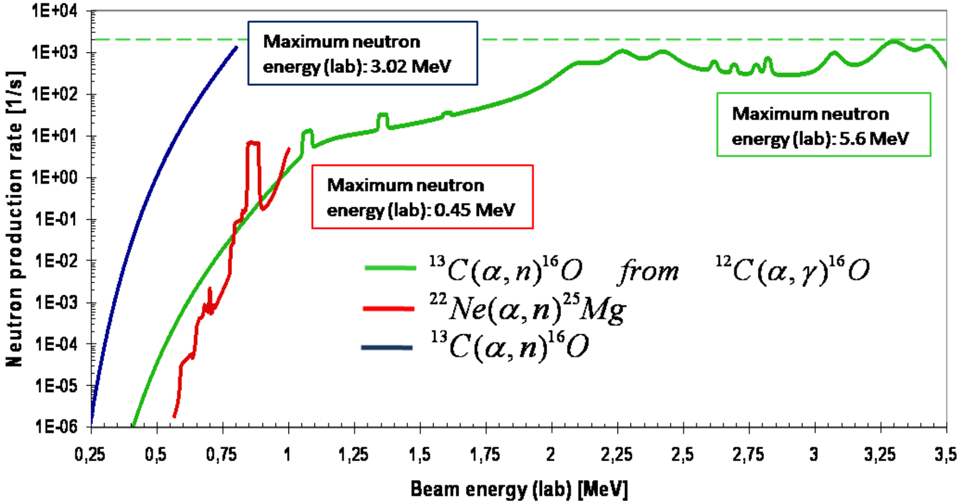
α beam intensity: 200 μA
Target: ^{13}C, 2 10^{17}at/cm^2 (99% ^{13}C enriched)
Beam energy(lab) ≤ 0.8 MeV

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

α beam intensity: 200 μA
Target: ^{22}Ne, 1 10^{18}at/cm^2
Beam energy(lab) ≤ 1.0 MeV

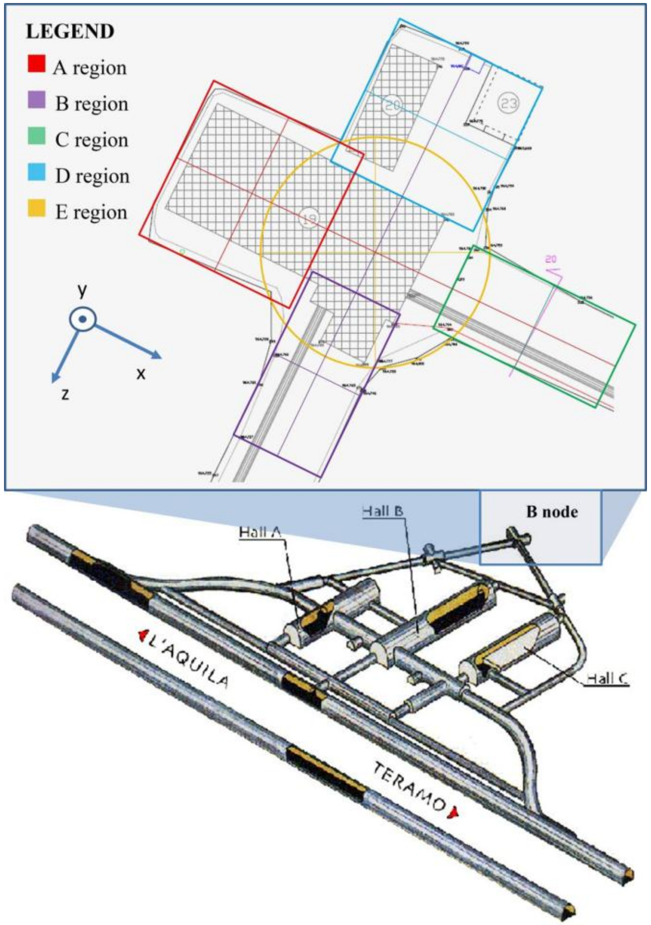
$^{13}C(\alpha,n)^{16}O$ from $^{12}C(\alpha,\gamma)^{16}O$

α beam intensity: 200 μA
Target: ^{13}C, 1 10^{18}at/cm^2 ($^{13}C/^{12}C = 10^{-5}$)
Beam energy(lab) ≤ 3.5 MeV

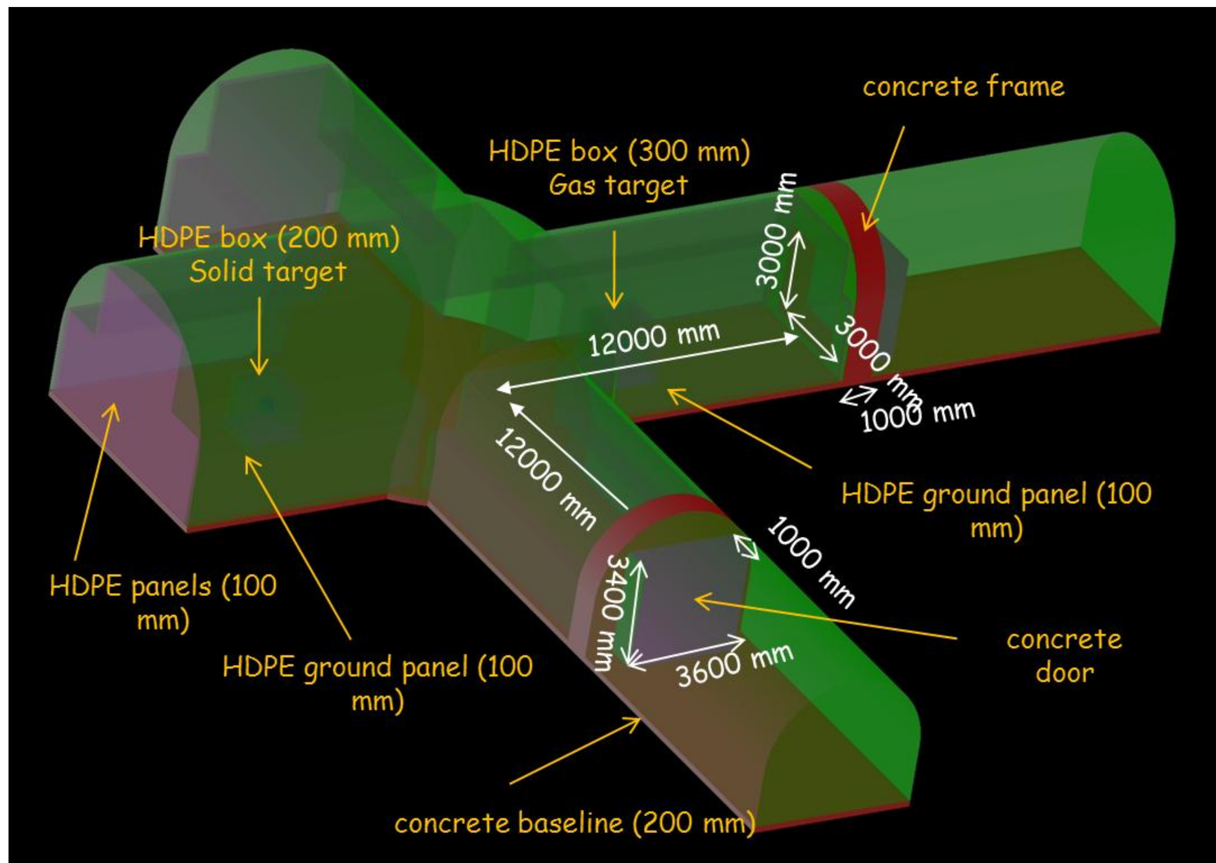


- Maximum neutron production rate : 2000 n/s
- Maximum neutron energy (lab) : 5.6 MeV

Geant4 simulations for neutron fluxes just outside the experimental hall and on the internal rock walls



Just-outside the wall the n-flux is less than 1% of the LNGS natural flux!



"Progetto Premiale LUNA -MV"

Special Project financed from the Italian Research Ministry with 2.805 Millions of Euros in 2012

Schedule:
2012-2013 Hall preparation- Tender for the accelerator- Shielding
2014 Beam lines R&D- Infrastructures
2015 Accelerator installation - Beam lines construction- Detectors installation
2016 Calibration of the apparatus and first tests of beam on target

New collaborations are highly welcome!

Workshop at LNGS: Starting-up the LUNA-MV collaboration

6-8th February, 2013
luna-mv.lngs.infn.it

The LUNA-MV project aims at measuring the astrophysical key reactions
$^{3}He(^{4}He,\gamma)^{7}Be$
$^{12}C(\alpha,\gamma)^{16}O$
$^{13}C(\alpha,n)^{16}O$
$^{22}Ne(\alpha,n)^{25}Mg$
using a MV machine placed in the Gran Sasso underground laboratory.

Goal of the workshop is to define the scientific priorities as well as the structure and the task sharing of the new collaboration. A possible timeline of the project will also be discussed.

LOCAL ORGANIZING COMMITTEE:
A. Guglielmetti (chair)
A. Formicola (scientific secretary)
M. Junker
P. Prati
F. Chiarizia (secretary)

INTERNATIONAL PROGRAMME COMMITTEE
C. Broggini - INFN Padova, Italy
M. Busso - Perugia University, Italy
H. Costantini - Aix-Marseille Universite-CPPM, France
Z. Fulop - ATOMKI Debrecen, Hungary
L. Gialanella - Seconda Università di Napoli, Italy
M. Hass - The Weizmann Institute, Israel
C. Iliadis - University of North Carolina, USA
A. Lefebvre - CSNSM CNRS/IN2P3, France

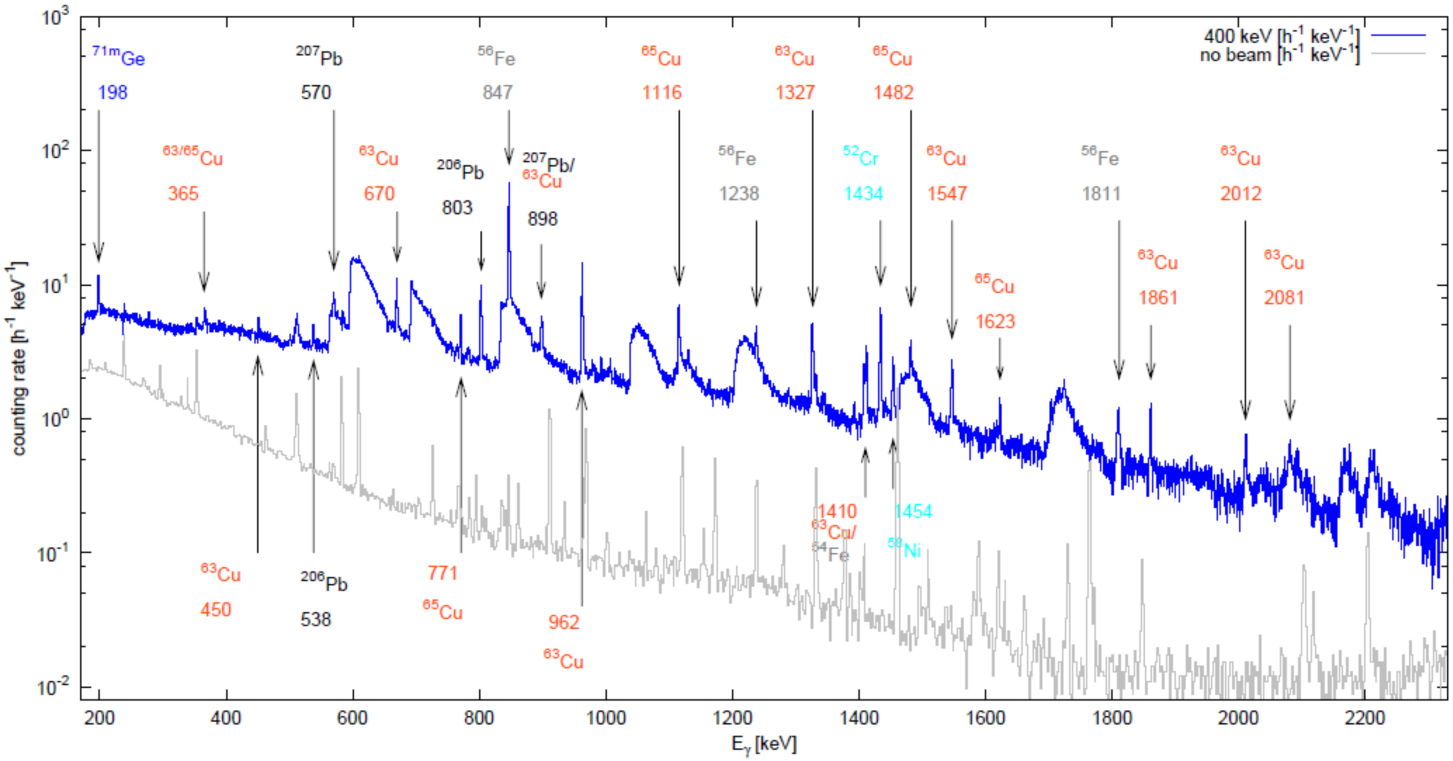
THE LUNA COLLABORATION

Laboratori Nazionali del Gran Sasso
A.Formicola, M.Junker
Helmoltz-Zentrum Dresden-Rossendorf, Germany
M. Anders, D. Bemmerer, Z.Elekes
INFN, Padova, Italy
C. Broggini, A. Caciolli, R.Menegazzo, C. Rossi Alvarez
INFN, Roma 1, Italy
C. Gustavino
Institute of Nuclear Research (ATOMKI), Debrecen, Hungary
Zs.Fülöp, Gy. Gyurky, E.Somorjai, T. Szucs
Osservatorio Astronomico di Collurania, Teramo, and INFN, Napoli, Italy
O. Straniero
Ruhr-Universität Bochum, Bochum, Germany
C.Rolfs, F.Strieder, H.P.Trautvetter
Seconda Università di Napoli, Caserta, and INFN, Napoli, Italy
F.Terrasi
Università di Genova and INFN, Genova, Italy
P.Corvisiero, P.Prati
Università di Milano and INFN, Milano, Italy
M.Campeggio, A.Guglielmetti, D. Trezzi
Università di Napoli ''Federico II'', and INFN, Napoli, Italy
A.di Leva, G.Imbriani, V.Roca
Università di Torino and INFN, Torino, Italy
G.Gervino
University of Edinburgh
M. Aliotta and D. Scott

$^2H(\alpha,\gamma)^6Li$ analysis

Two measurement campaigns:
a) 400 keV and 280 keV
b) 360 keV and 240 keV

at 400 keV the expected S/N ratio is about 1/12.



$^2H(\alpha,\gamma)^6Li$ analysis

Signal: $E_\gamma = Q + E_{CM} - \Delta E_{rec} \pm \Delta E_{Doppler}$

400 (360) keV and 280 (240) keV ROIs not overlapping

Background almost independent on beam energy