LUNA and the Sun

Erice09

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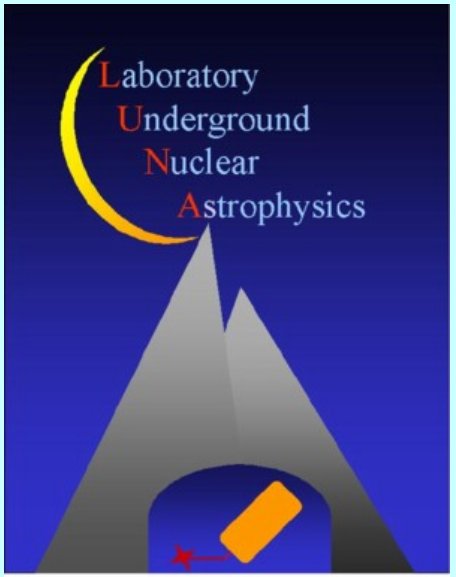
INFN-Padova



Men in pits or wells sometimes see the stars…. Aristotle

- Hydrogen burning in stars
- $\sigma(E_{star})$

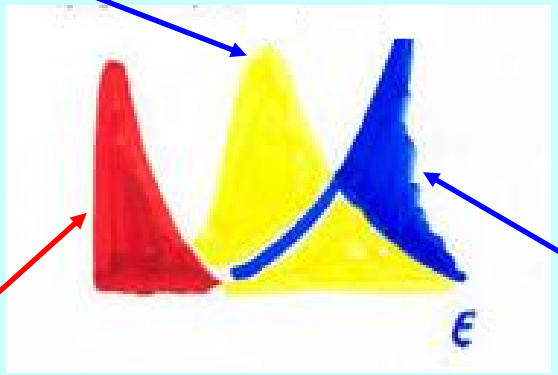
$$\text{Reaction Rate(star)} \div \int \Phi(E)\,\sigma(E)\,dE$$

$$\sigma(E) = S(E)\, e^{-2\pi\eta}\, E^{-1}$$

$$2\pi\eta = 31.29\, Z_1 Z_2 \sqrt{\mu/E}$$

$$\mu = m_1 m_2 / (m_1 + m_2)$$

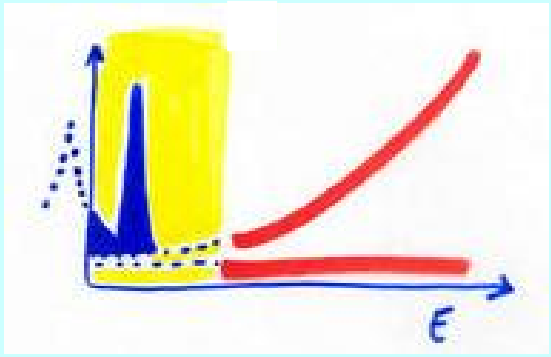
Gamow Peak



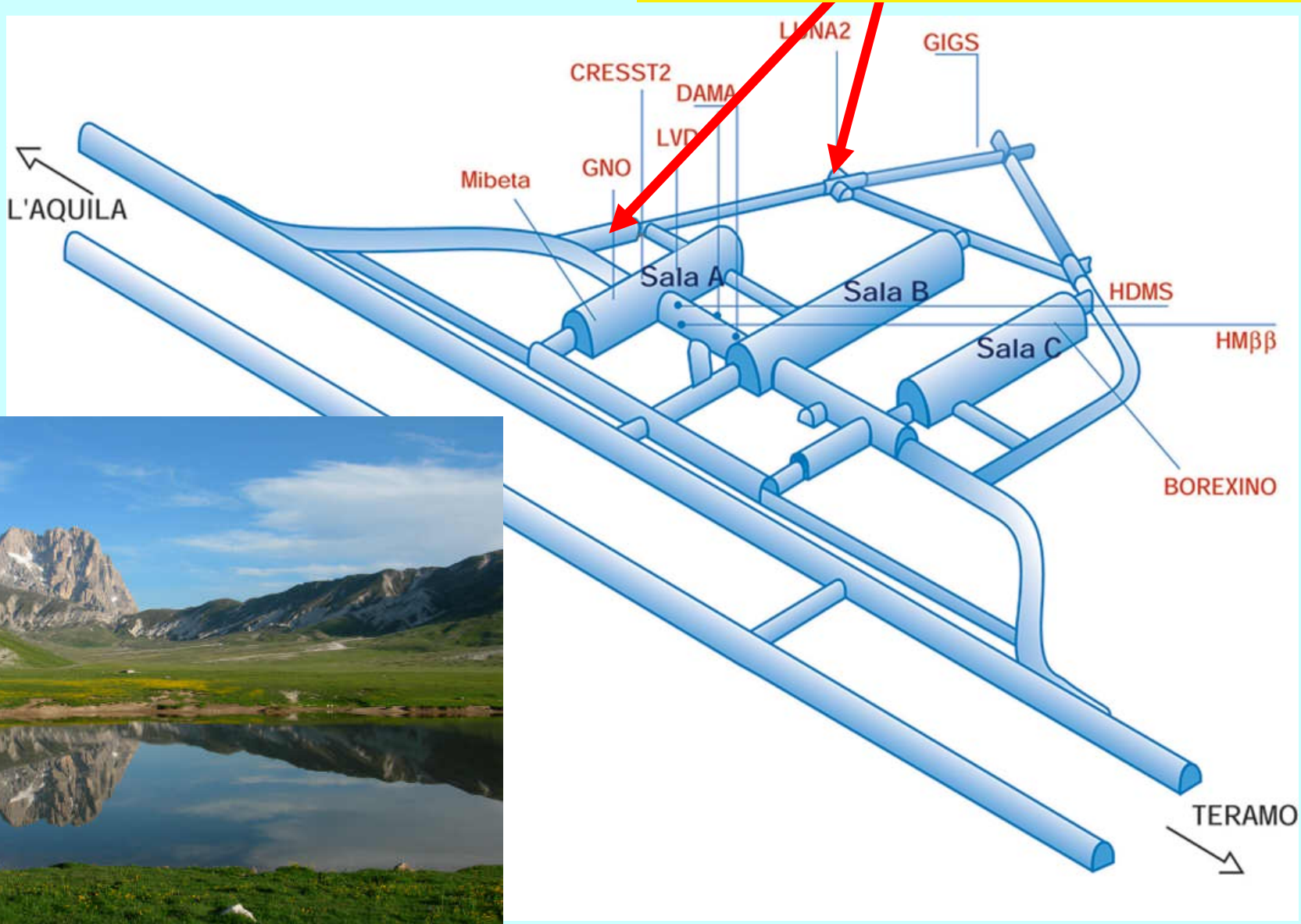
Maxwell Boltzmann

σ

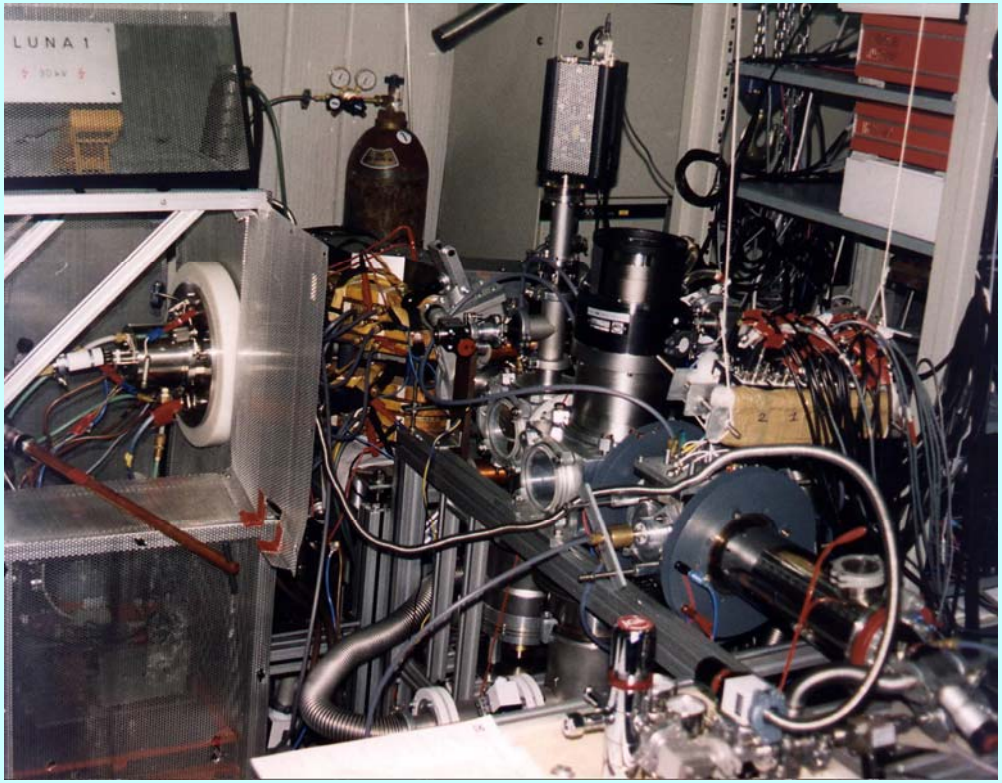
Extrap. ← Meas. →



Laboratory for Underground Nuclear Astrophysics

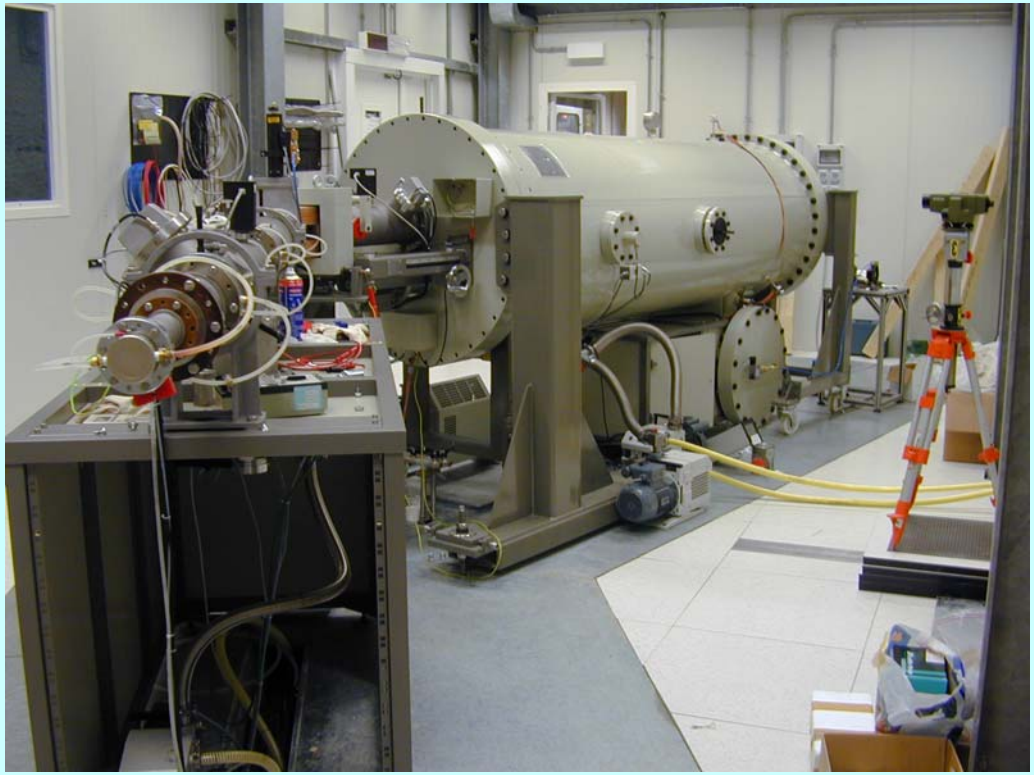


LUNA1 (50 kV)



Voltage Range :
1 - 50 kV
Output Current:
1 mA
Beam energy spread:
20 eV
Long term stability (8 h):
10^{-4}
Terminal Voltage ripple:
5 10^{-5}

LUNA2 (400 kV)



Voltage Range :50-400 kV
Output Current: 1 mA (@ 400 kV)
Absolute Energy error
±300 eV
Beam energy spread:
<100 eV
Long term stability (1 h) :
5 eV
Terminal Voltage ripple:
5 Vpp Ge detector

pp chain

$p + p \rightarrow d + e^+ + \nu_e$

$d + p \rightarrow {}^3He + \gamma$

84.7 %

13.8 %

$^3He + {}^3He \rightarrow \alpha + 2p$

$^3He + {}^4He \rightarrow {}^7Be + \gamma$

13.78 %

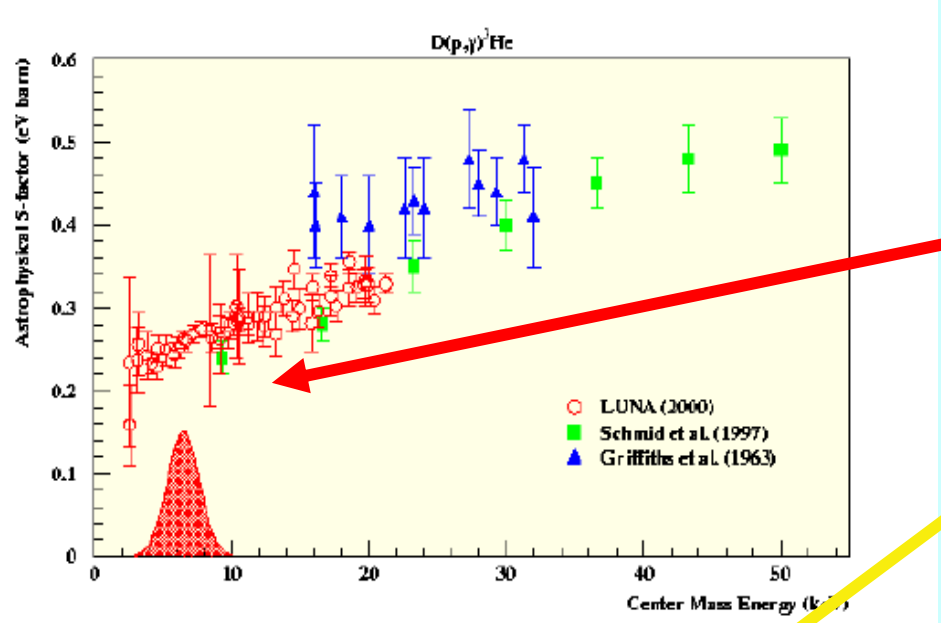
0.02%

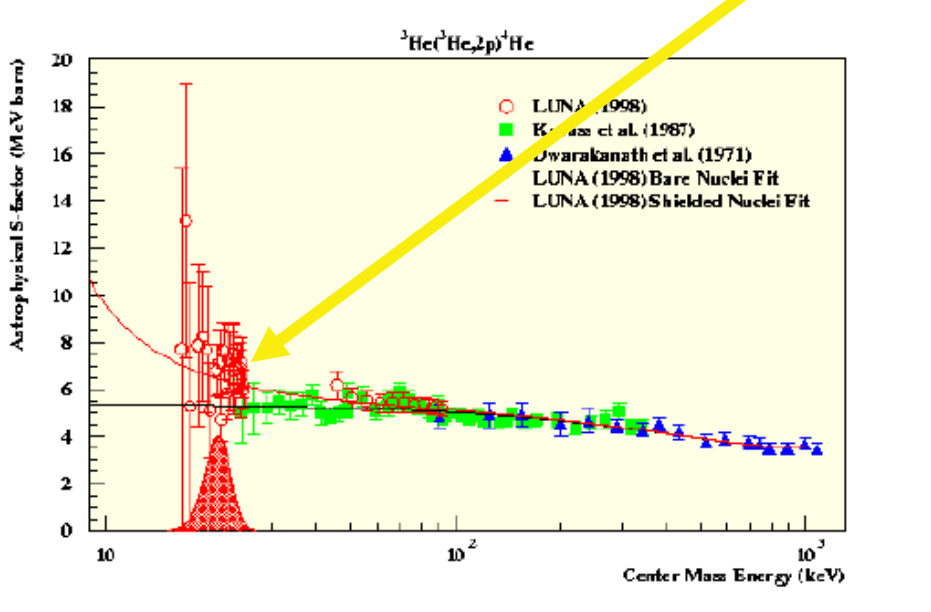
$^7Be + e^- \rightarrow {}^7Li + \gamma + \nu_e$

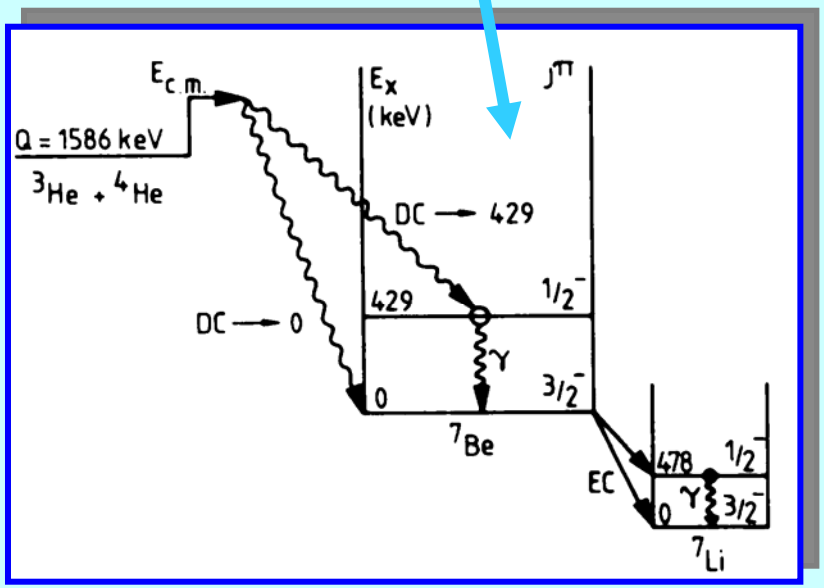
$^7Be + p \rightarrow {}^8B + \gamma$

$^7Li + p \rightarrow \alpha + \alpha$

$^8B \rightarrow 2\alpha + e^+ + \nu_e$







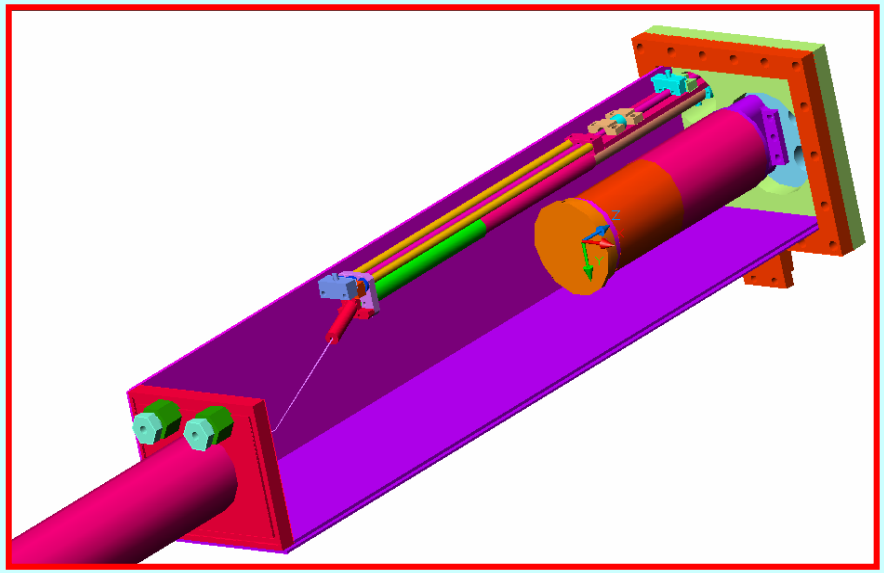
$^3He(\alpha,\gamma)^7Be$ Q=1.6 MeV

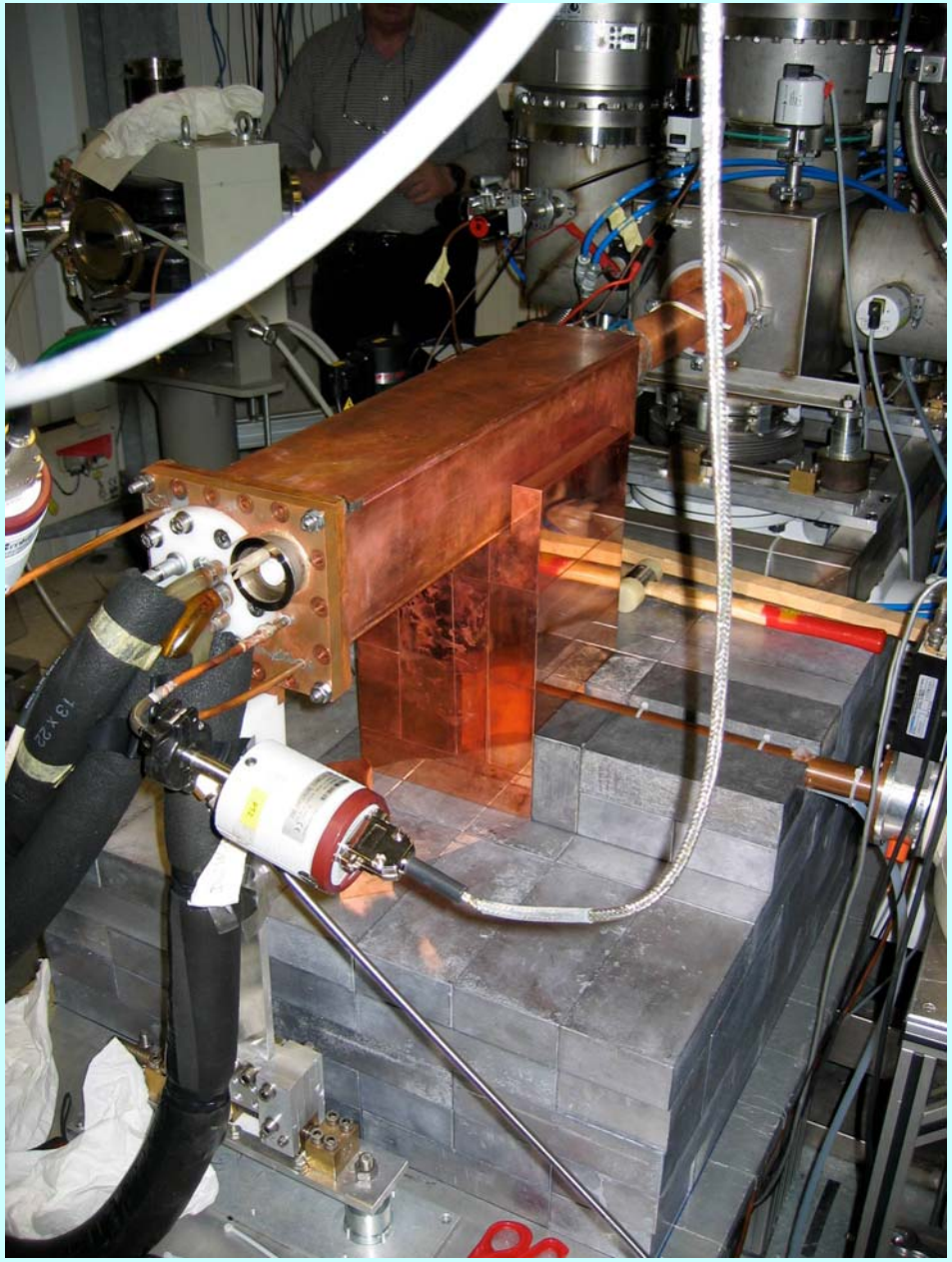
- Solar Neutrinos: ^7Be, ^8B

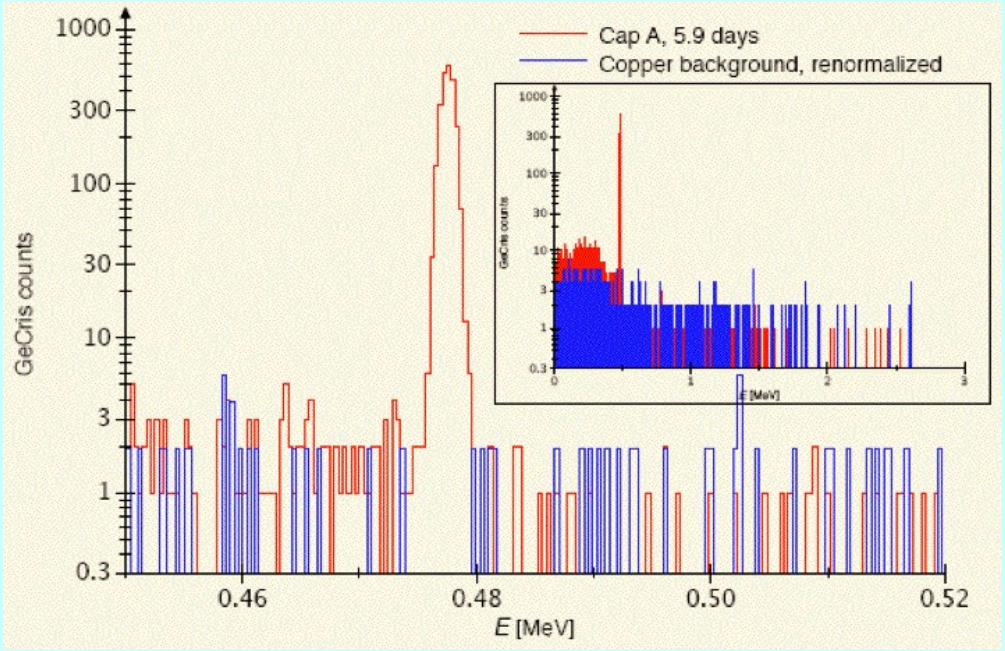
$$\Phi \sim S_{34}$$

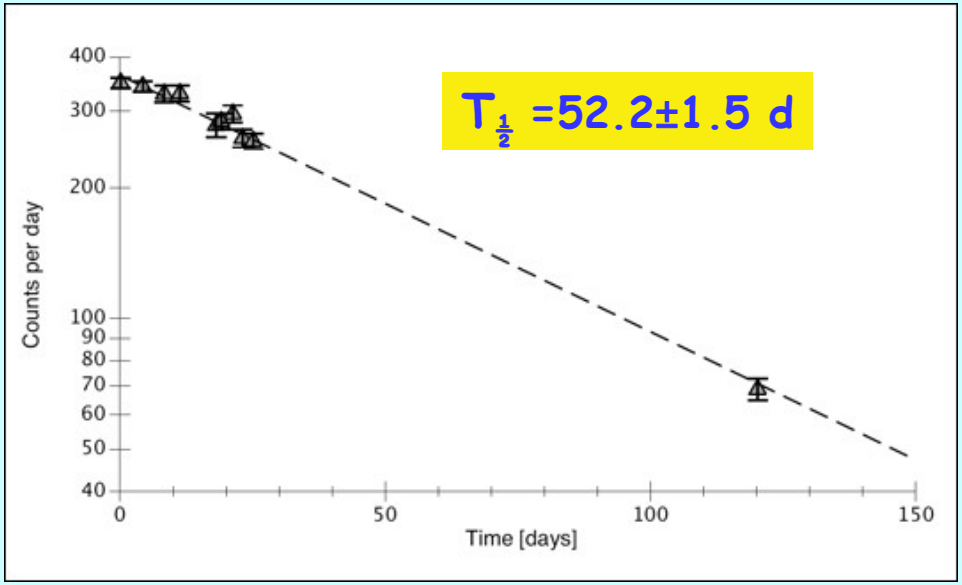
- BBN ^7Li

- Cross section from **prompt gamma** using ^4He beam on ^3He target
- from off-line **radioactive decay** of the ^7Be atoms collected in the beam catcher
- All with a final error < 5 %

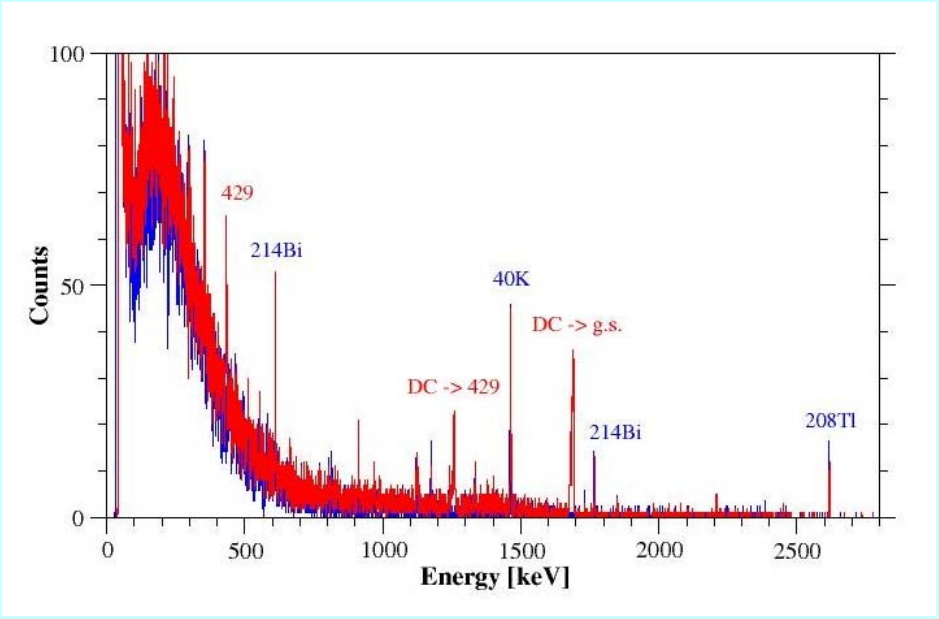


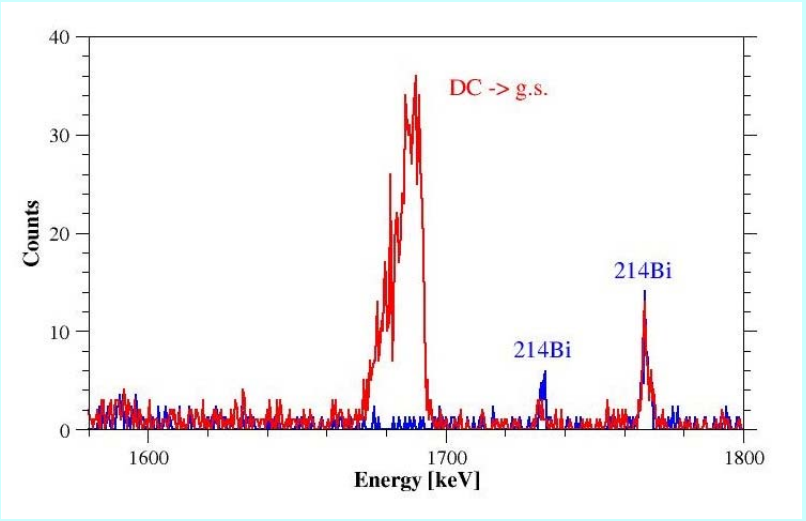


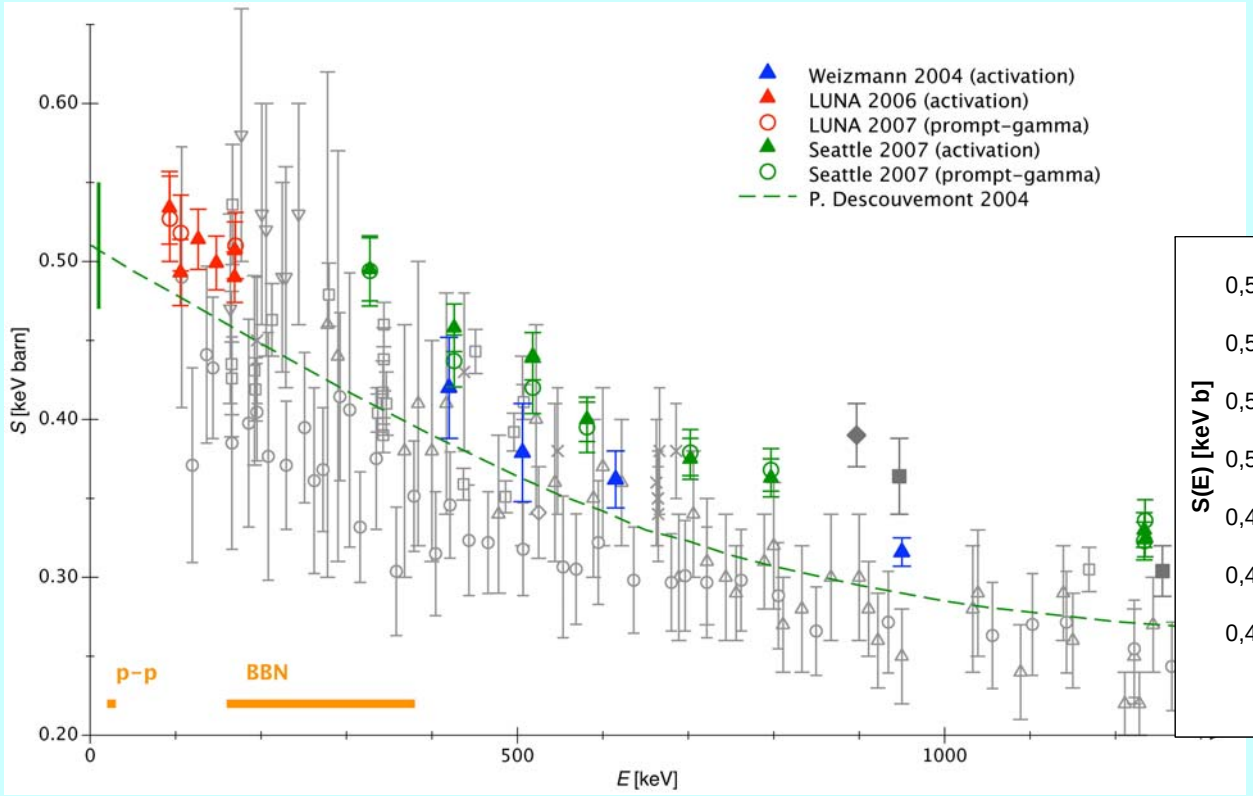


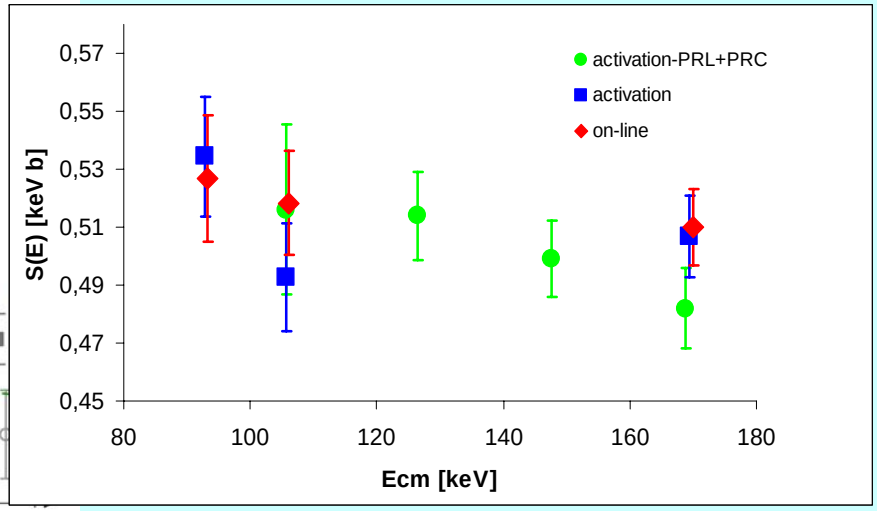


- ^{4}He beam @ 220 keV
- <I> ~ 240 μA
- Irradiation time: 24.4d









- σ down to 93 keV

  ^{7}Be ≈ prompt γ

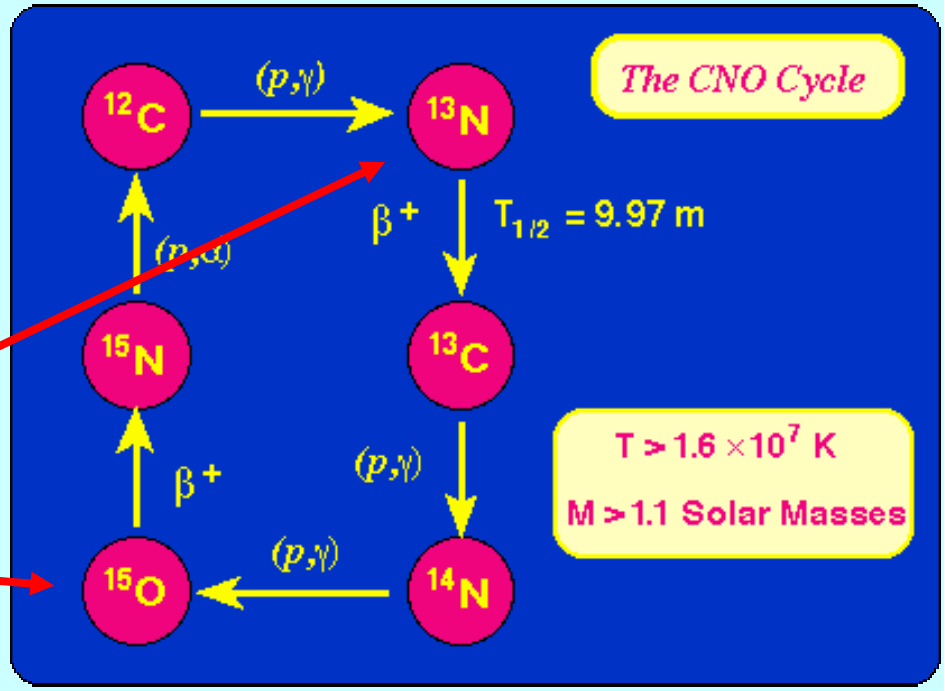
- $S_{34}(0) = 0.560 \pm 0.017$ keV barn

$\Delta\Phi(\nu_B)$ reduced from 12% to 10% (C. Pena-Garay)

$\Delta\Phi(\nu_{Be})$ reduced from 9.4% to 5.5% → Borexino-Kamland

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

Q=7.3 MeV



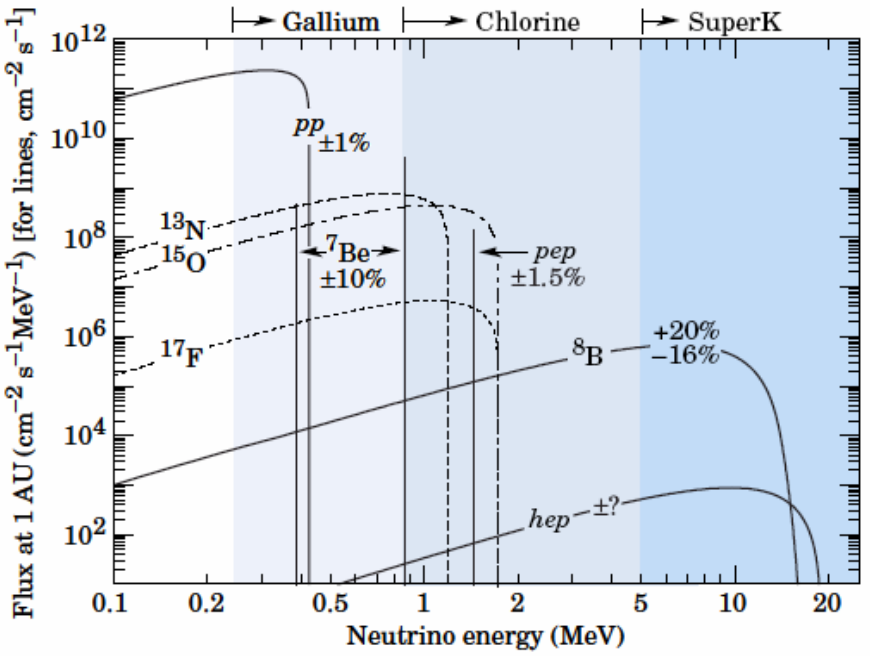
ν E<1.2 MeV

ν E<1.7 MeV

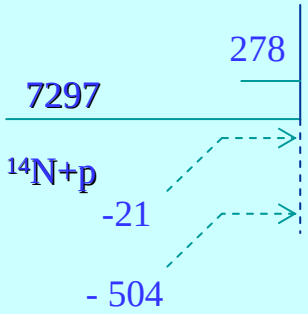
- ν_{cno} $\Phi_{cno} \sim S_{1,14}$
- Globular Cluster Age

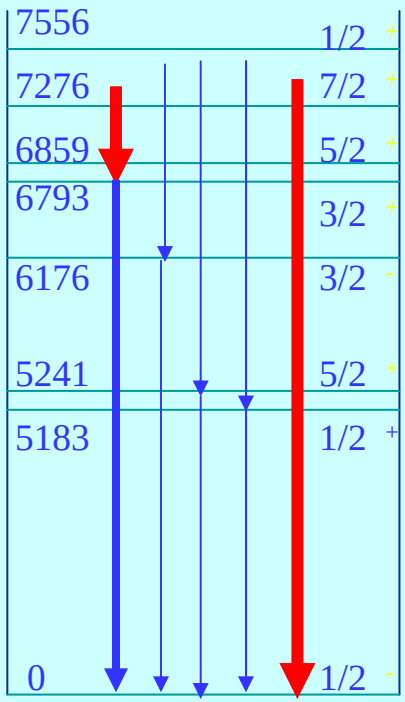
S(0)=$3.5_{-1.6}^{+0.4}$ keV b (Ad98)

S(0)=$3.2_{-0.8}^{+0.8}$ keV b (An99)



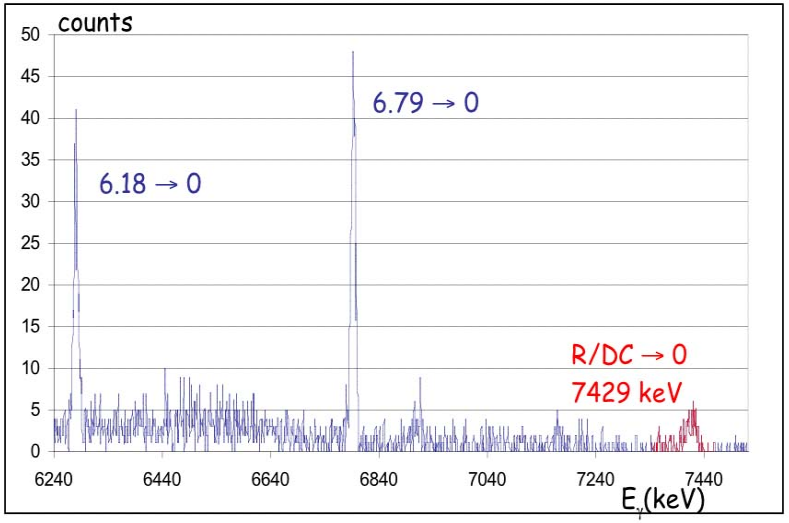
$^{14}N(p,\gamma)^{15}O$





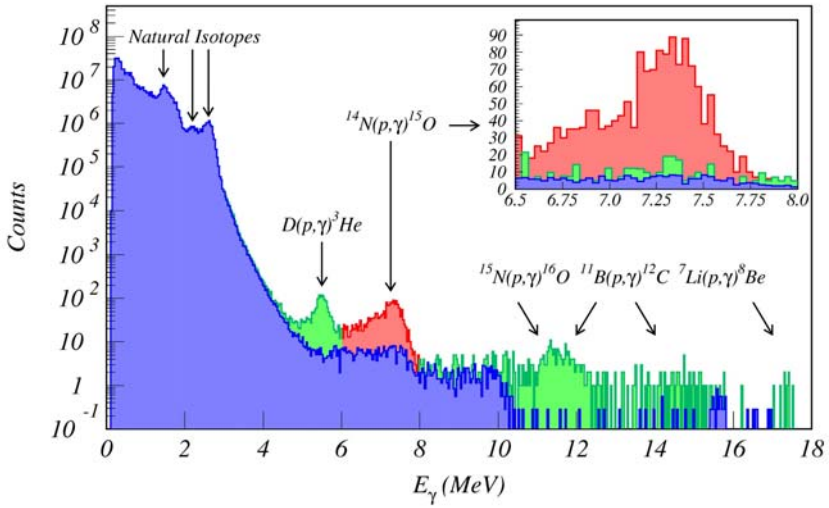
"High" energy: solid target + HpGe

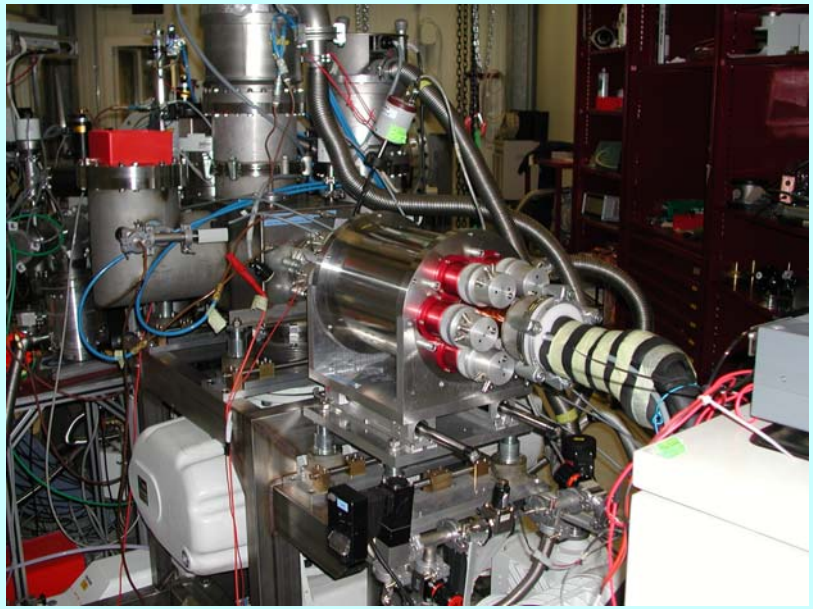
gamma spectrum of $^{14}N(p,\gamma)^{15}O$ at 140 keV beam energy

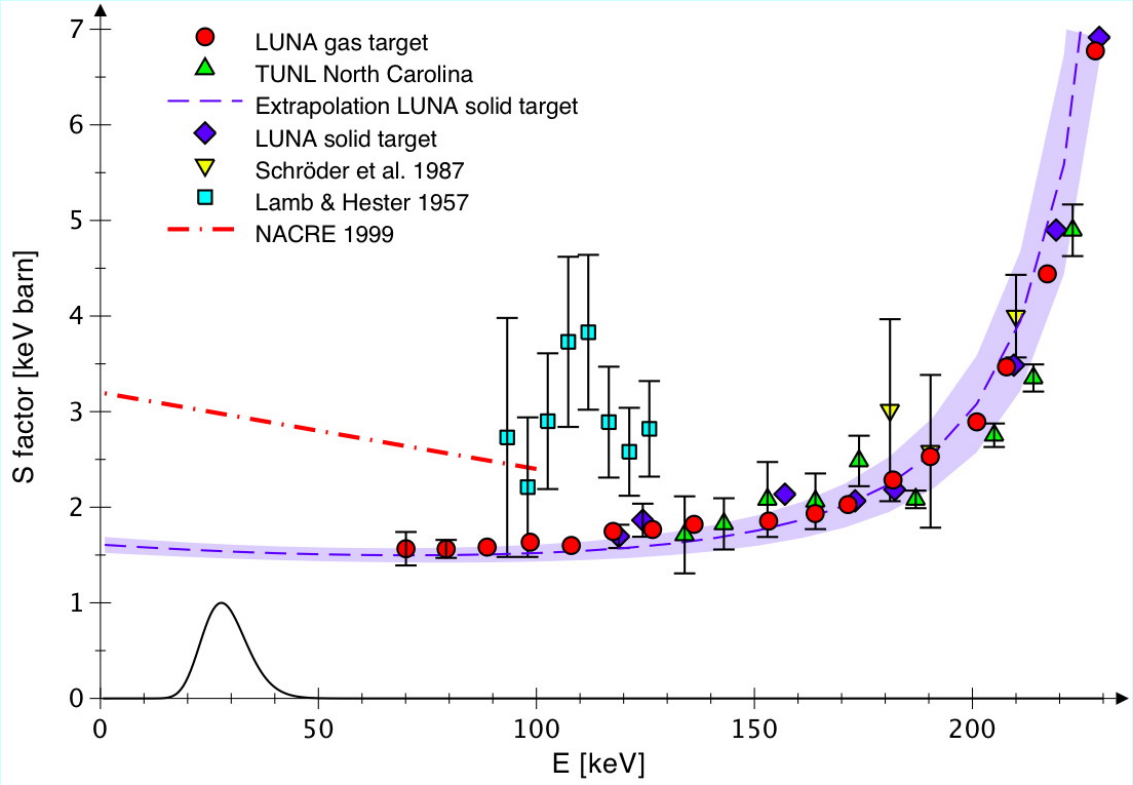


Low energy: gas target + BGO

beam energy 90 keV







$S_t(0)=1.61\pm0.18$ keV b

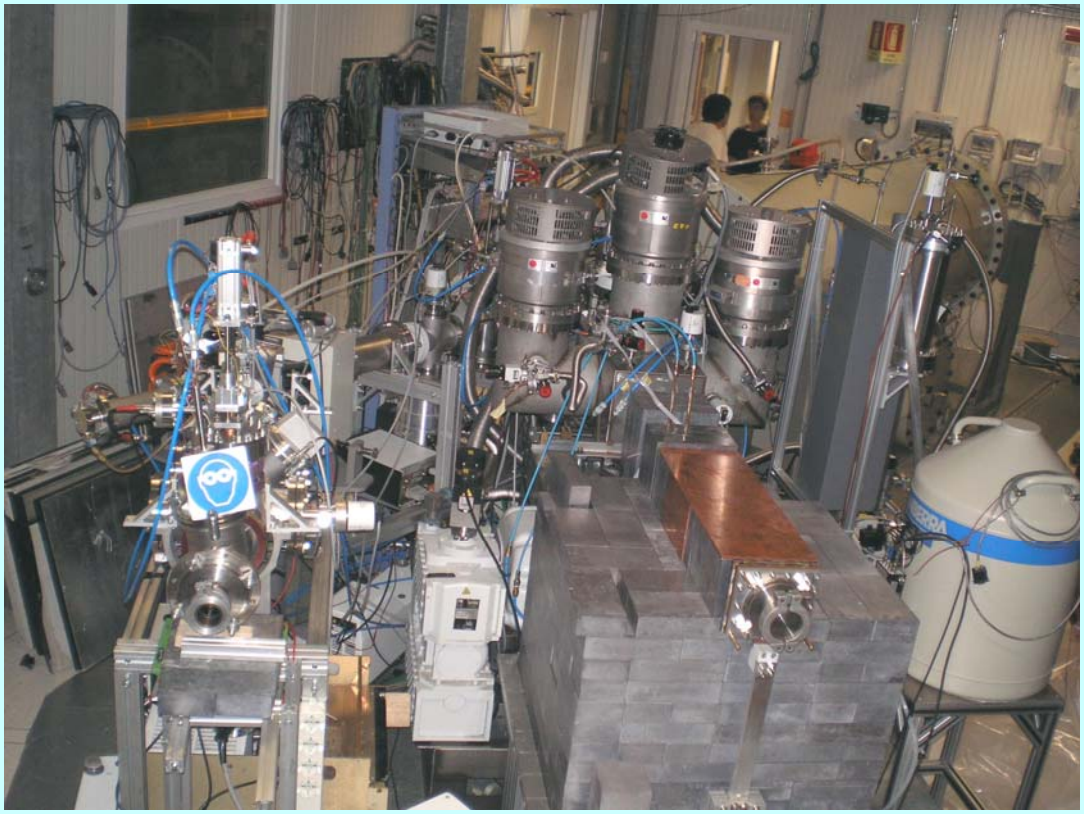
* $\frac{1}{2}\nu_{cno}$ from the Sun
* Globular cluster age
* C yield in AGB stars

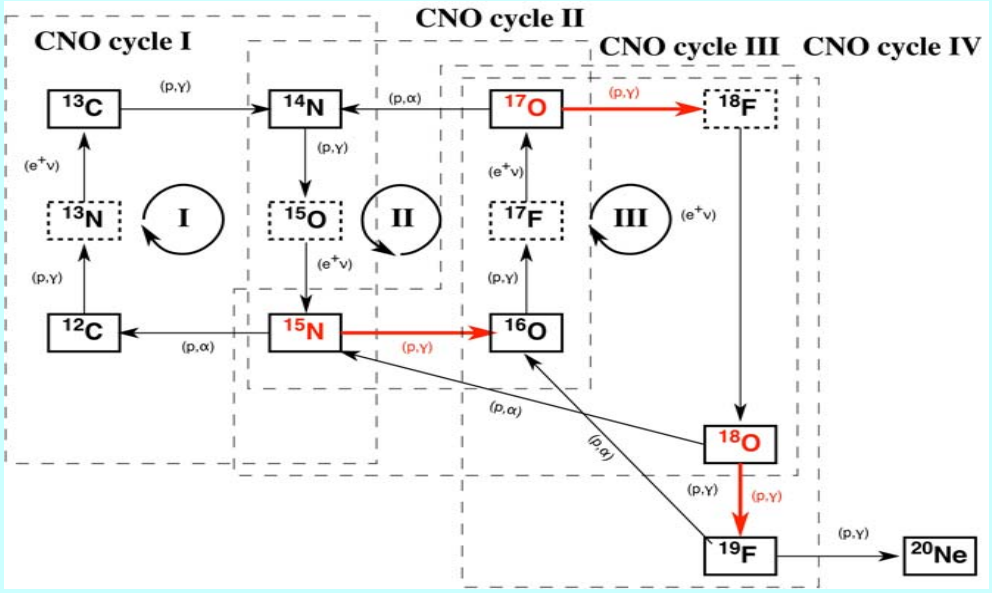
New study with a 'clover' detector of the capture to the ground state

$S_t(0)=1.57\pm0.13$ keV b

From a measurement of ν_{cno} from the Sun

→ solar core metallicity
homogeneous zero-age Sun





Rich program of Nuclear Astrophysics:

$^{25}Mg(p,\gamma)^{26}Al$ Q=6.3 MeV
(data taking completed)

$^{15}N(p,\gamma)^{16}O$ Q=12.13 MeV

$^{2}H(\alpha,\gamma)^{6}Li$ Q=1.47 MeV

$^{17}O(p,\gamma)^{18}F$ Q=5.6 MeV

$^{18}O(p,\gamma)^{19}F$ Q=8.0 MeV

$^{22}Ne(p,\gamma)^{23}Na$ Q=8.8 MeV

$^{23}Na(p,\gamma)^{24}Mg$ Q=11.7 MeV

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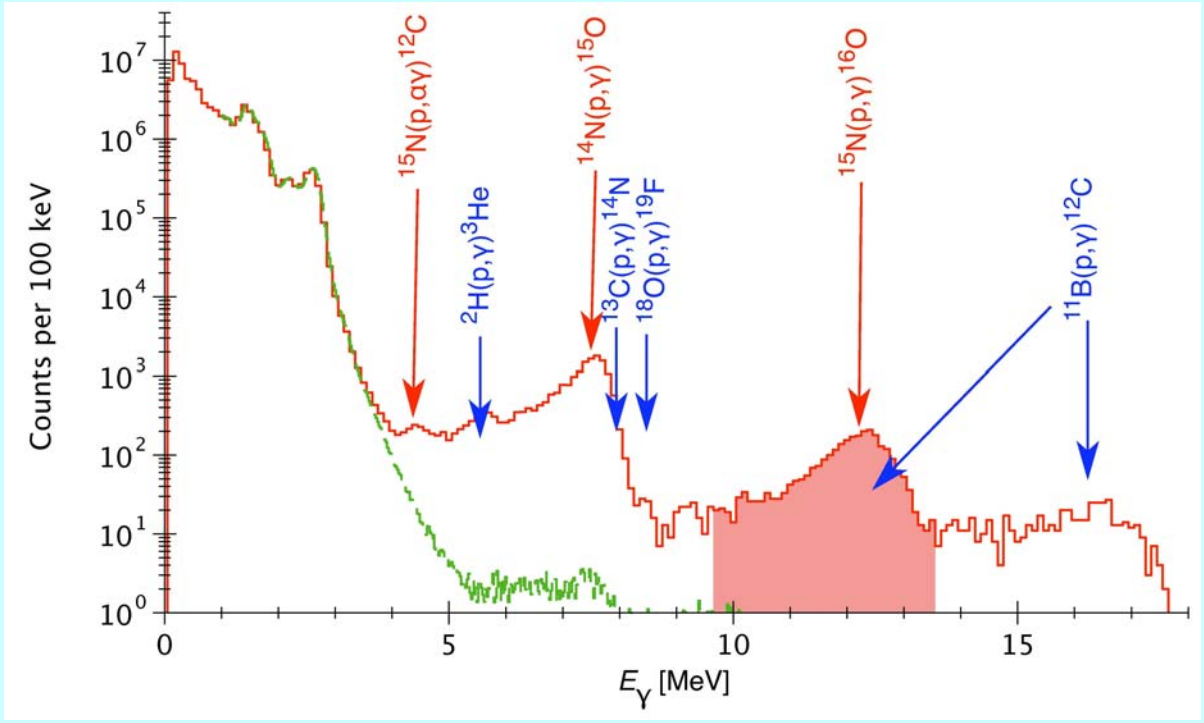
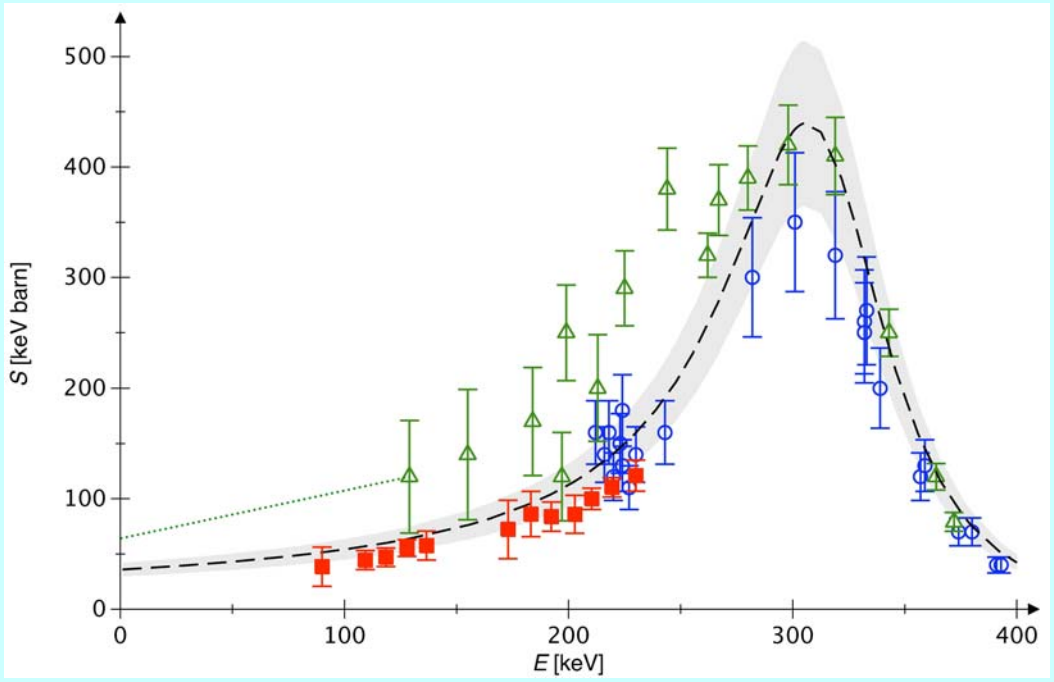


^{15}N(p,γ)^{16}O

beam energy 150 keV



- Hebbard 1960
- Rolfs Rodney 1974
- NACRE
- Mukhamedzhanov et al. 2008
- LUNA 2009

- ^3He $(^3He, 2p)^4He$: σ down to 16 keV

  no resonance within the solar Gamow Peak

- $^3He(\alpha,\gamma)^7Be$: $^7Be \approx$ prompt γ

  $\Delta\Phi(\nu_{Be})$ reduced from 9.4% to 5.5%

- $^{14}N(p,\gamma)^{15}O$: σ down to 70 keV (T=60 T_6)

  ν_{cno} reduced by ~ 2 with 8% error → **core metallicity**

  Globular cluster age increased by 0.7-1 Gy

  Higher C yield in AGB stars

- $^{15}N(p,\gamma)^{16}O$: σ down to 90 keV (Novae)

  ~ 2 reduction

New underground accelerators:
Gran Sasso, Dusel, Boulby Mine, Canfranc, Romania…

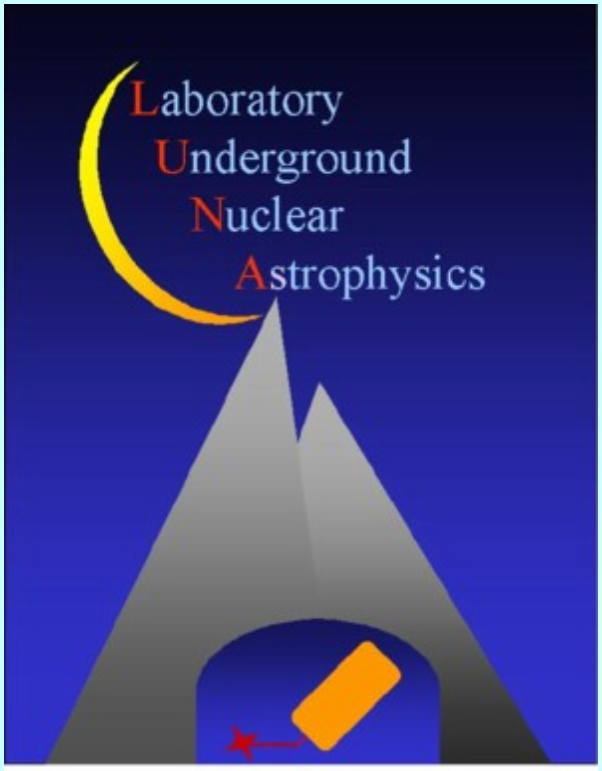
$^{12}C(\alpha,\gamma)^{16}O$

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

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

(α,γ) on ^{14}N, ^{15}N, ^{18}O……

LUNA



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D.Bemmerer,C.Broggini,A.Caciolli,P. Corvisiero,H.Costantini, Z.Elekes, M.Erhard,A.Formicola, Z. Fülöp, G.Gervino,A.Guglielmetti, C.Gustavino, G. Gyurky, G. Imbriani, M.Junker, A.Lemut, B.Limata, M.Marta,C.Mazzocchi,R.Menegazzo, P.Prati, V.Roca, C.Rolfs, C.RossiAlvarez,E.Somorjai, O.Straniero,F.Strieder, F.Terrasi,H.P.Trautvetter

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