Carlo Broggini, INFN-Pd

LUNA

- Nuclear Burning in Stars
- $\sigma(E_{star})$

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

Astrophysical Factor

Gamow Factor

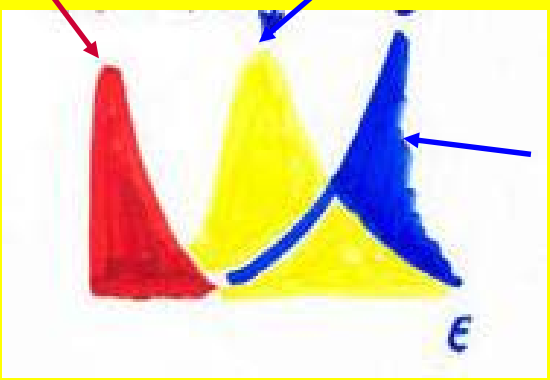
$$2\pi\eta = 31.29\, Z_1 Z_2 \sqrt{\mu/E_{cm}}$$

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

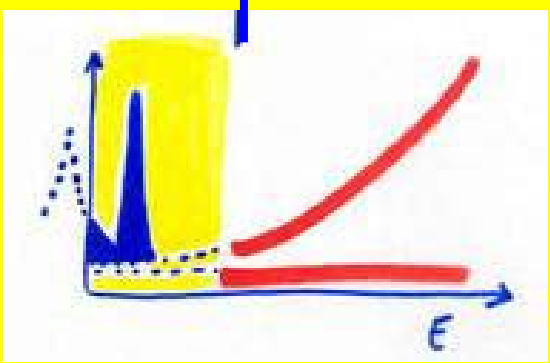
$$\text{Reaction Rate(star)} \div \int \Phi(E)\, \sigma(E)\, dE$$

Maxwell Boltzmann

Gamow Peak



Extrap. ← → Meas.

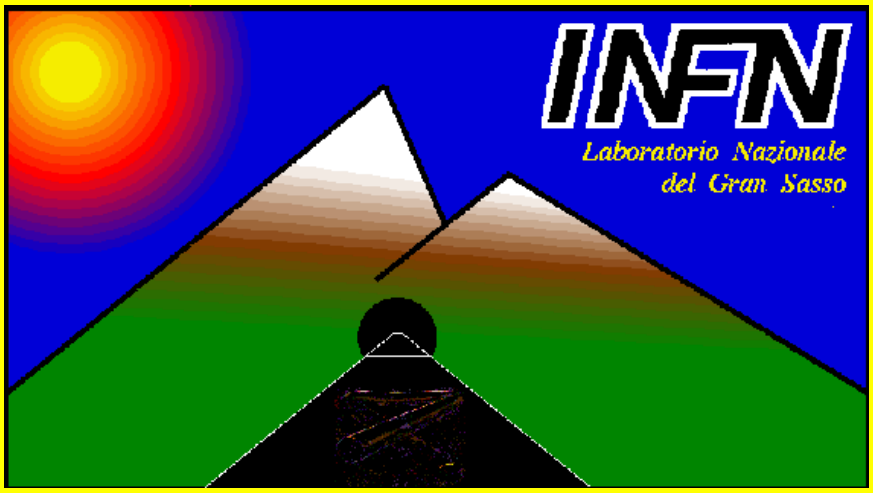


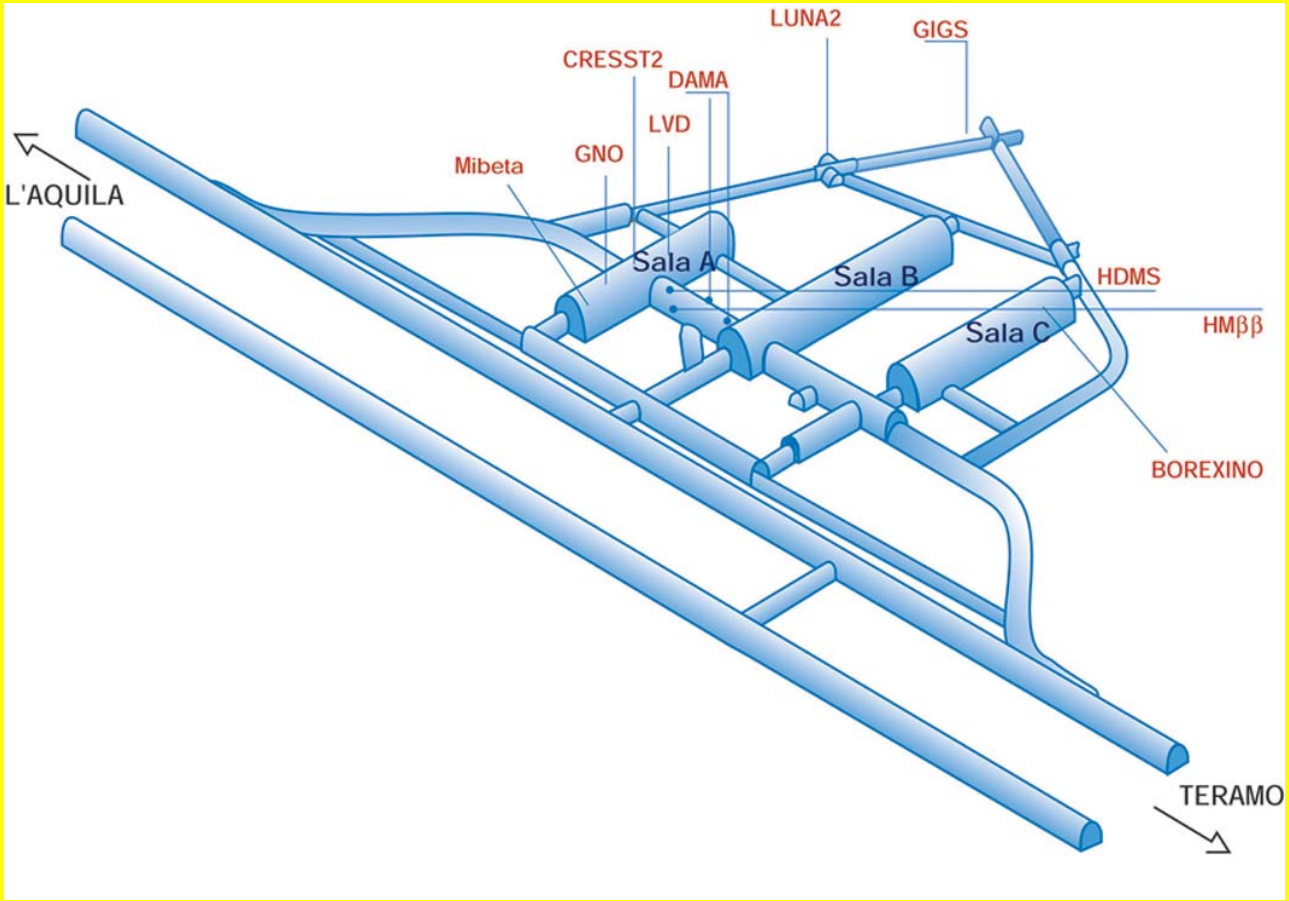
Laboratory for Underground Nuclear Astrophysics

INFN - Laboratori Nazionali del Gran Sasso

R.Bonetti, C.Broggini*,F.Confortola, P.Corvisiero, H.Costantini, J. Cruz, A.Formicola, Z. Fülöp, G.Gervino, A.Guglielmetti, C.Gustavino, G. Gyurky, G. Imbriani, A.P.Jesus, M.Junker, A.Lemut, R.Menegazzo, A.Ordine, P.Prati, V.Roca, D.Rogalla, C.Rolfs, M.Romano, C.RossiAlvarez, F.Schümann, O.Straniero, F.Strieder, E. Somorjai, F.Terrasi, H.P.Trautvetter, S.Zavatarelli

- INFN Sezioni di : Genova, LNGS, Milano, Napoli, Padova e Torino
- Inst.Physik mit Ionenstrahlen, Ruhr-Universität Bochum (GE)
- Centro de Fisica Nuclear da Universitade del Lisboa (Portugal)
- Atomki Debrecen (Hungary)





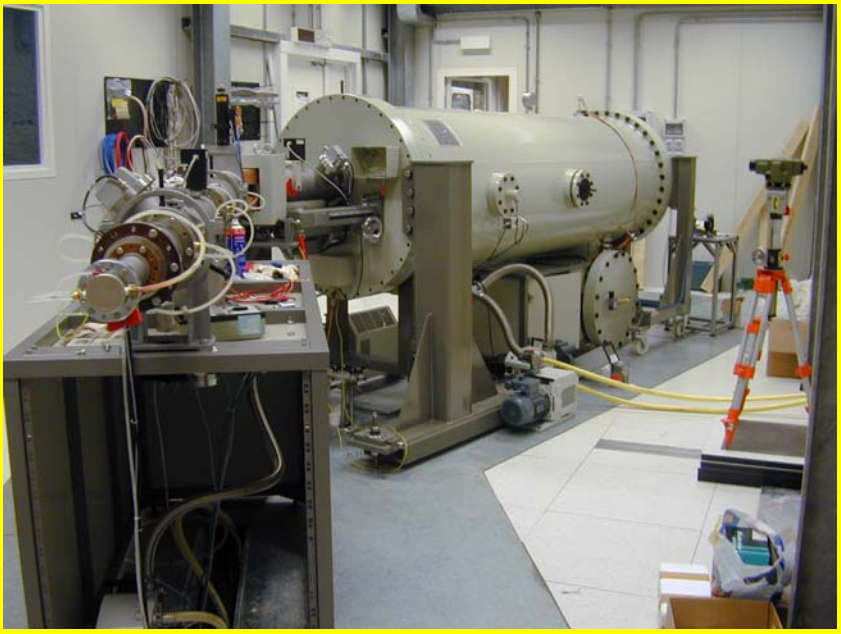
$$\Phi_{\mu} = 0.7\ m^{-2}\ h^{-1}$$

$$\Phi_{n} \approx 3*10^{-6}\ cm^{-2}\ s^{-1}$$

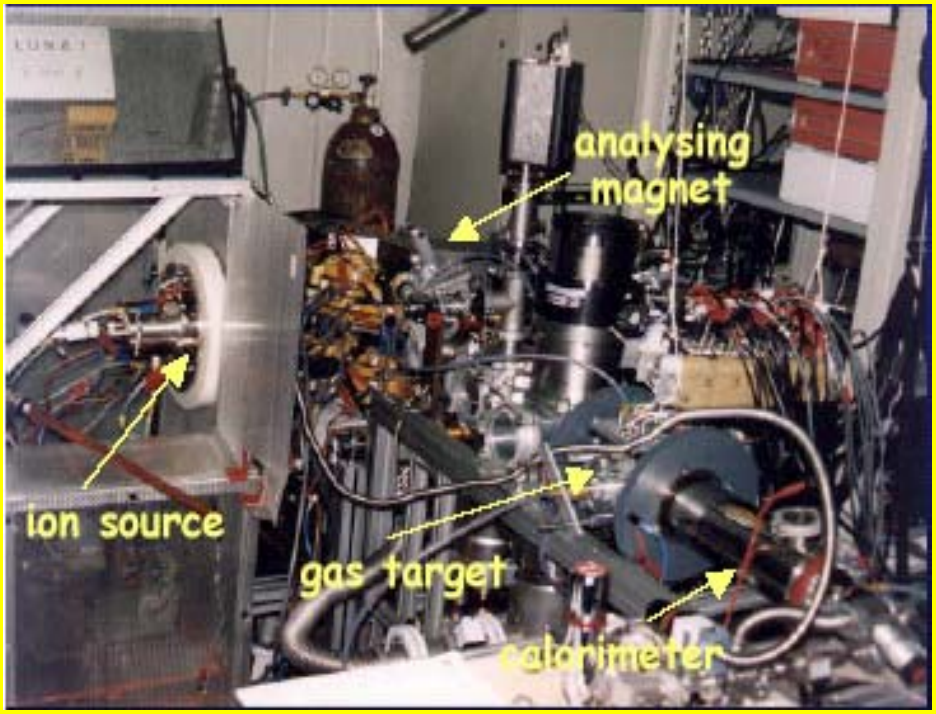
Acceleratori @ LNGS:

LUNA2 (400 kV)

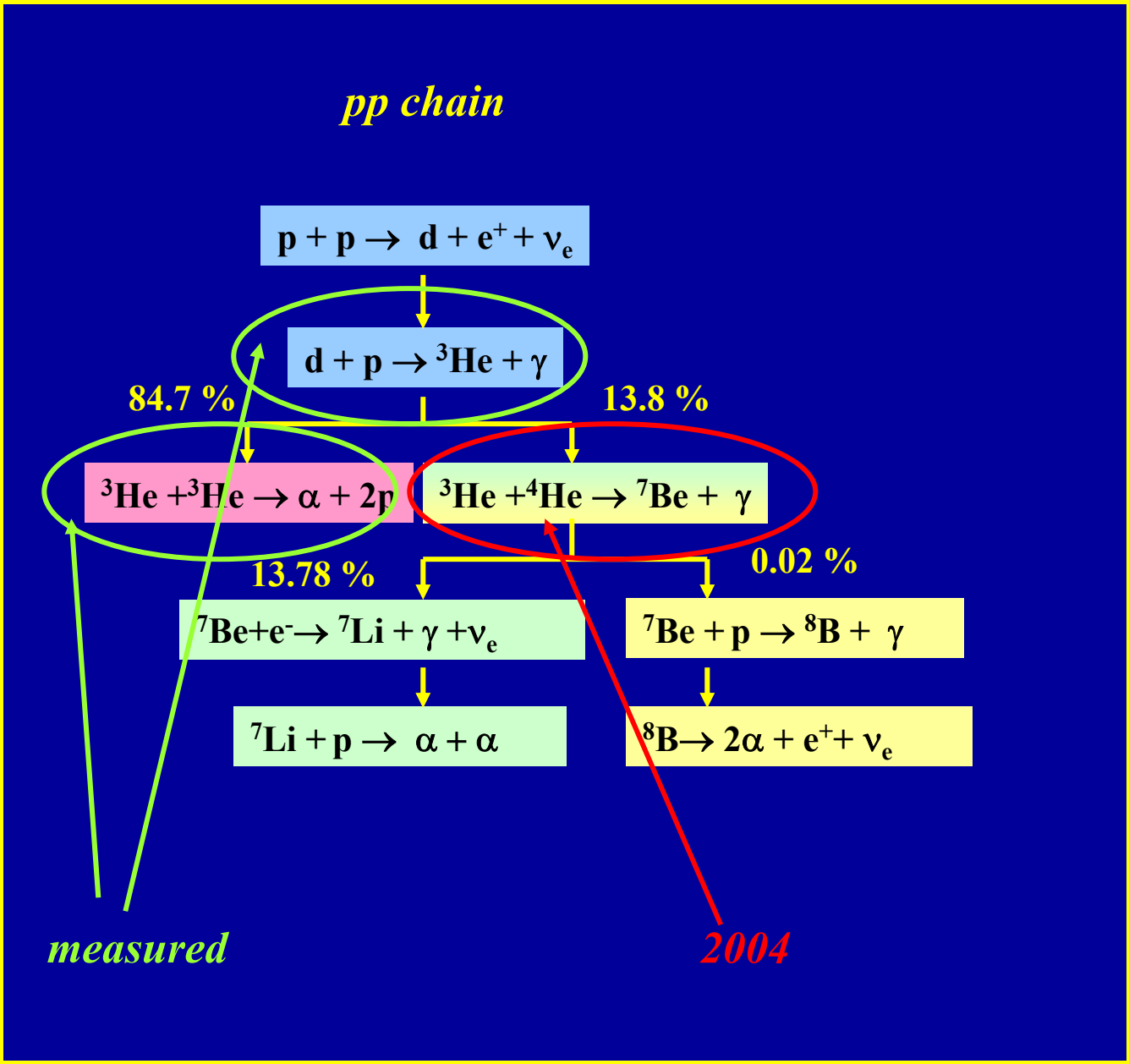
Voltage Range :
50 - 400 kV
Output Current: 1 mA 75% H
(@ 400 kV)
25% H2
: 0.5 mA 4He
Absolute Energy error
±300 eV
Beam energy spread:
<100 eV
Long term stability (1 h) :
5 eV
Terminal Voltage ripple:
5 Vpp Ge detector



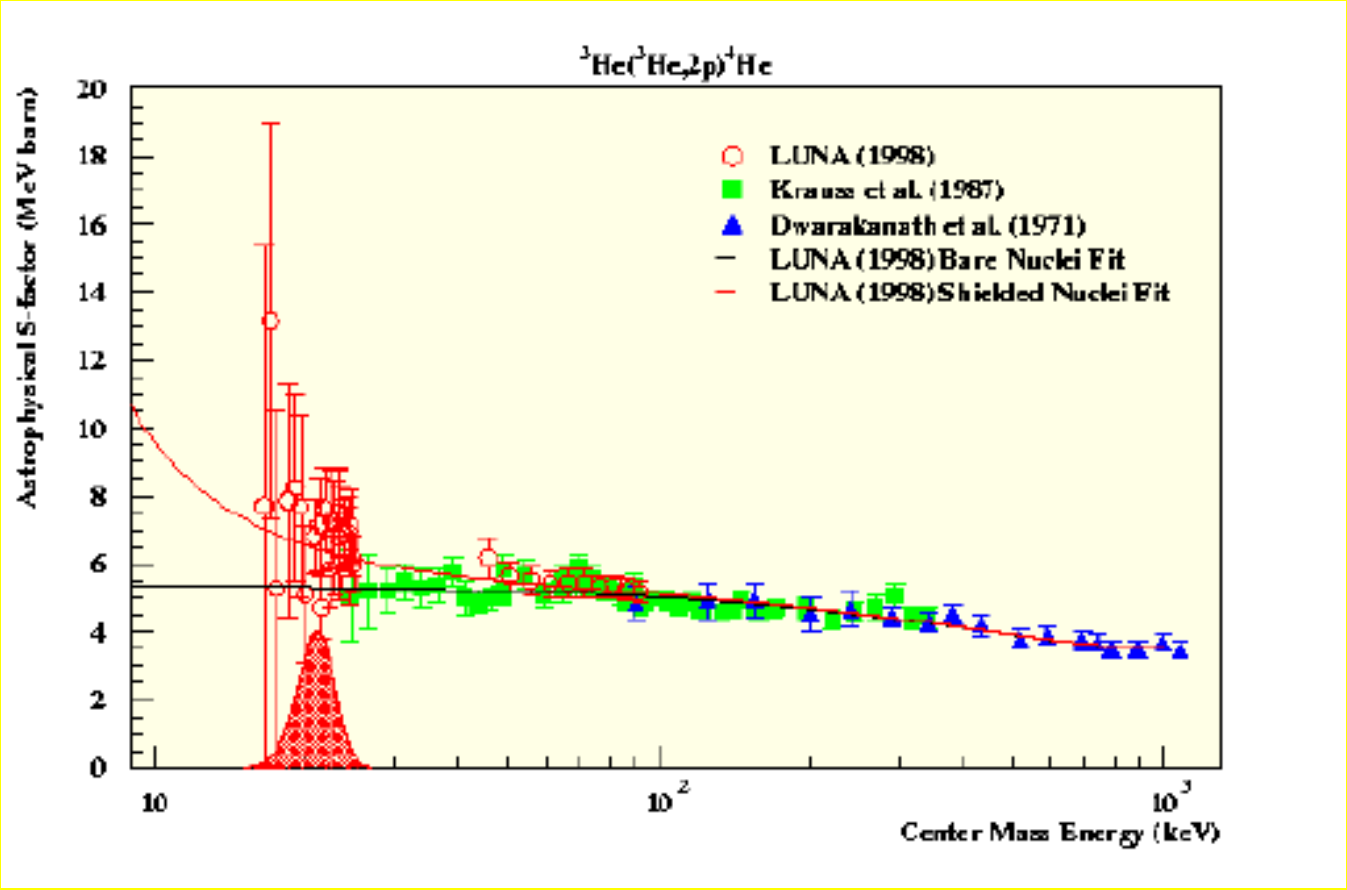
LUNA1 (50 kV)



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


pp chain
p + p → d + e+ + νe
d + p → 3He + γ
84.7 %
13.8 %
3He +3He → α + 2p
3He +4He → 7Be + γ
13.78 %
0.02 %
7Be+e- → 7Li + γ +νe
7Be + p → 8B + γ
7Li + p → α + α
8B → 2α + e+ + νe
measured
2004

$^3He\ (^3He,2p)^4He$

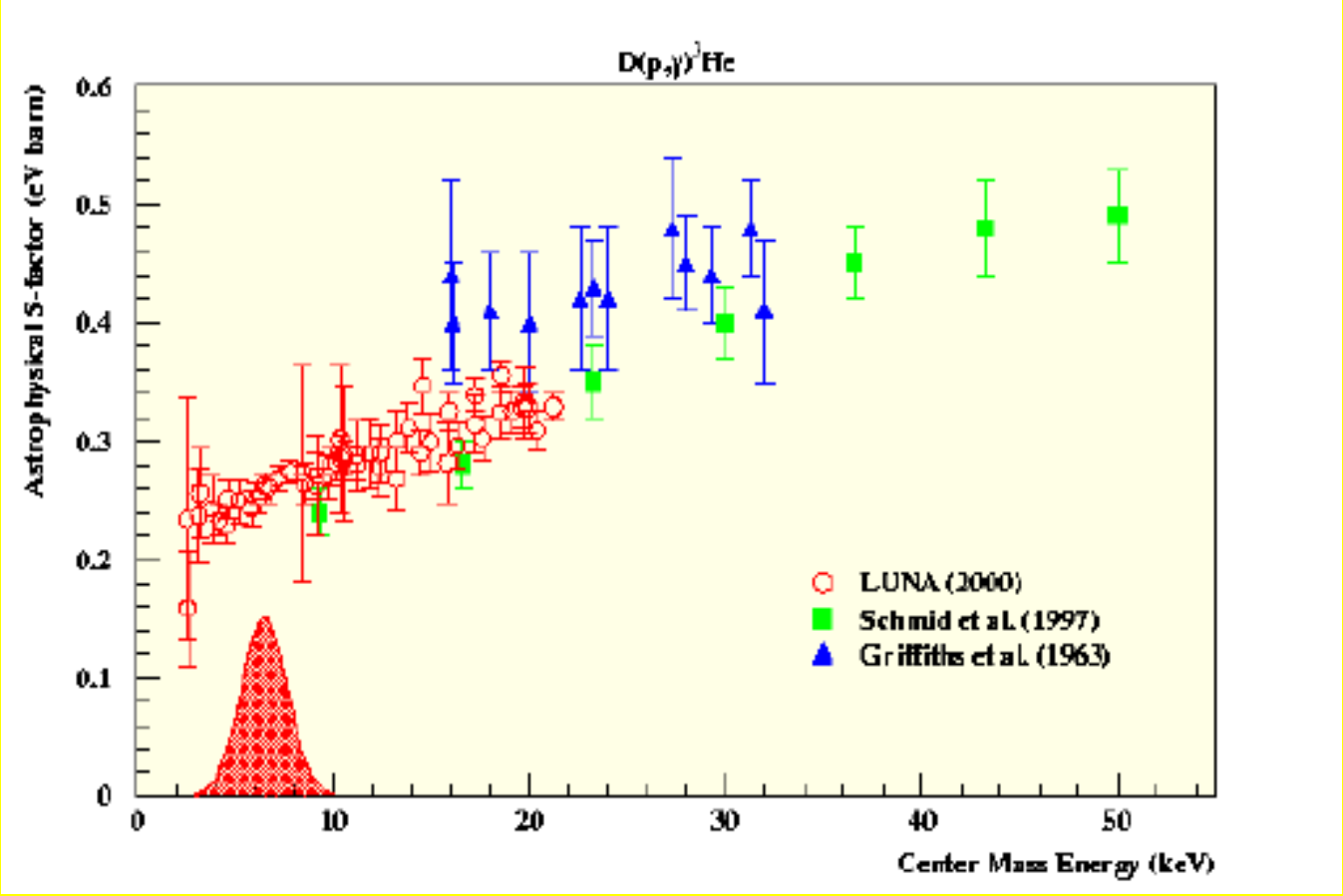


$Q = 12.86$ MeV

$E_p^{max} = 10.7$ MeV

$\sigma = 7 \pm 2$ pb (@24.5 keV)

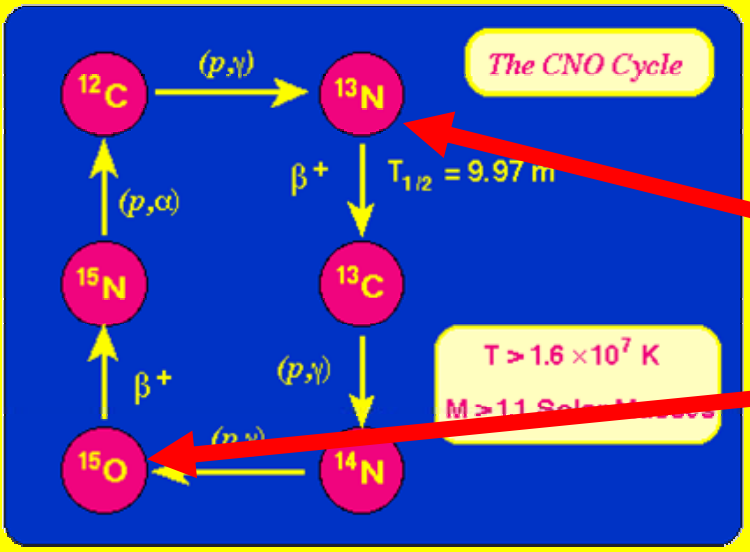
$D(p,\gamma)^3He$



Q=5.5 MeV

- Equilibrium abundance of D
- Proto-star life
- Big-bang nucleosynthesis

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



Q=7.3 MeV

ν E<1.2 MeV

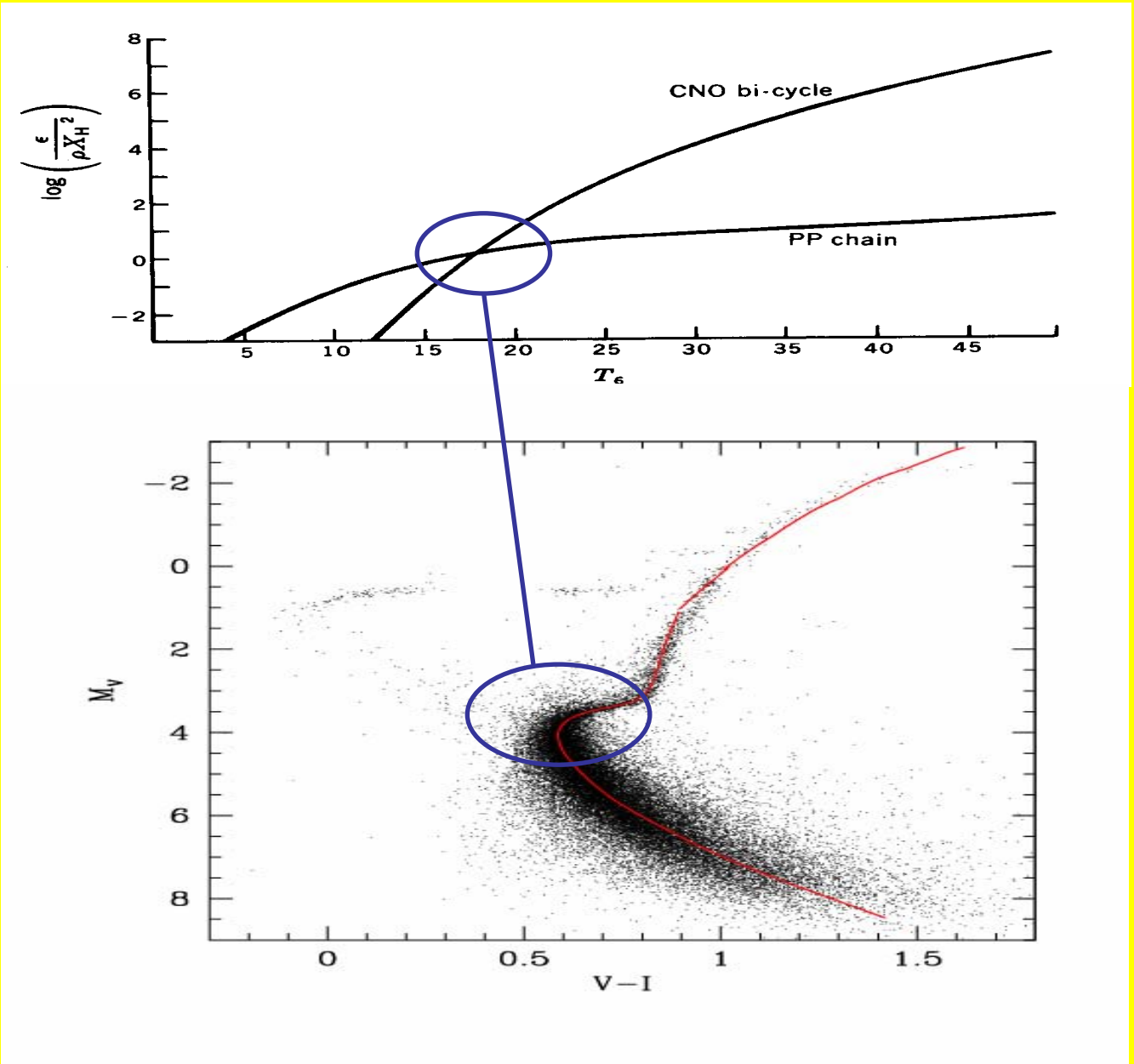
ν E<1.7 MeV

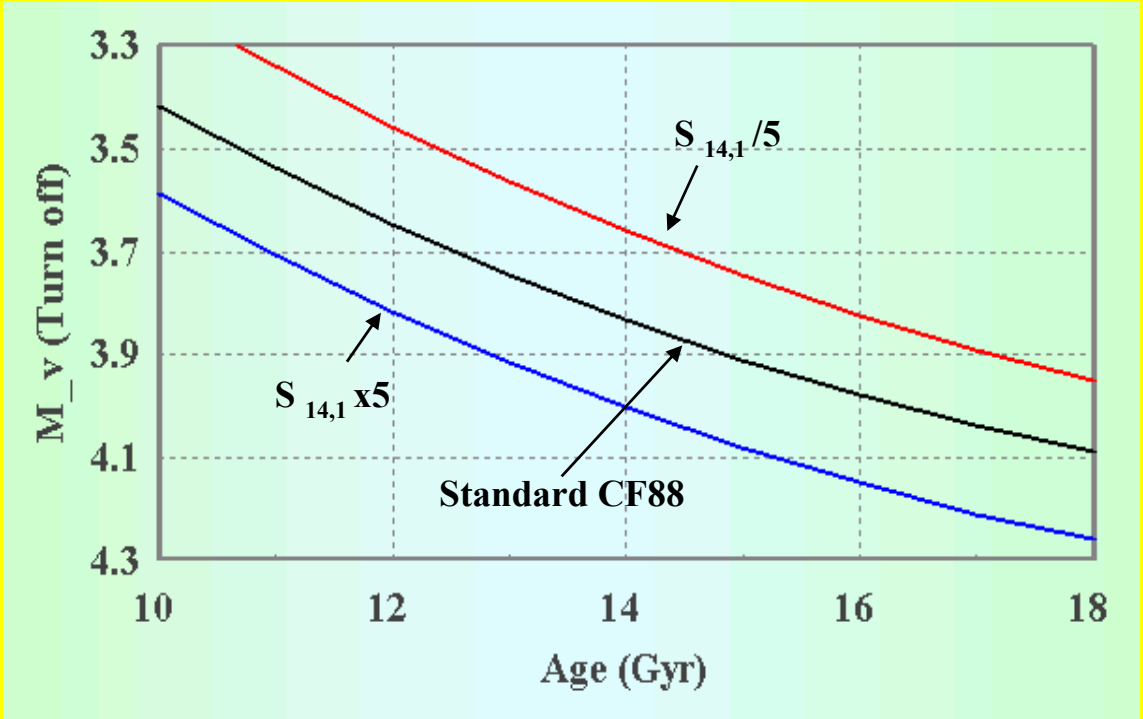
- ν_{cno} $\Phi_{cno} \sim S_{1,14}$
- Globular Cluster Age

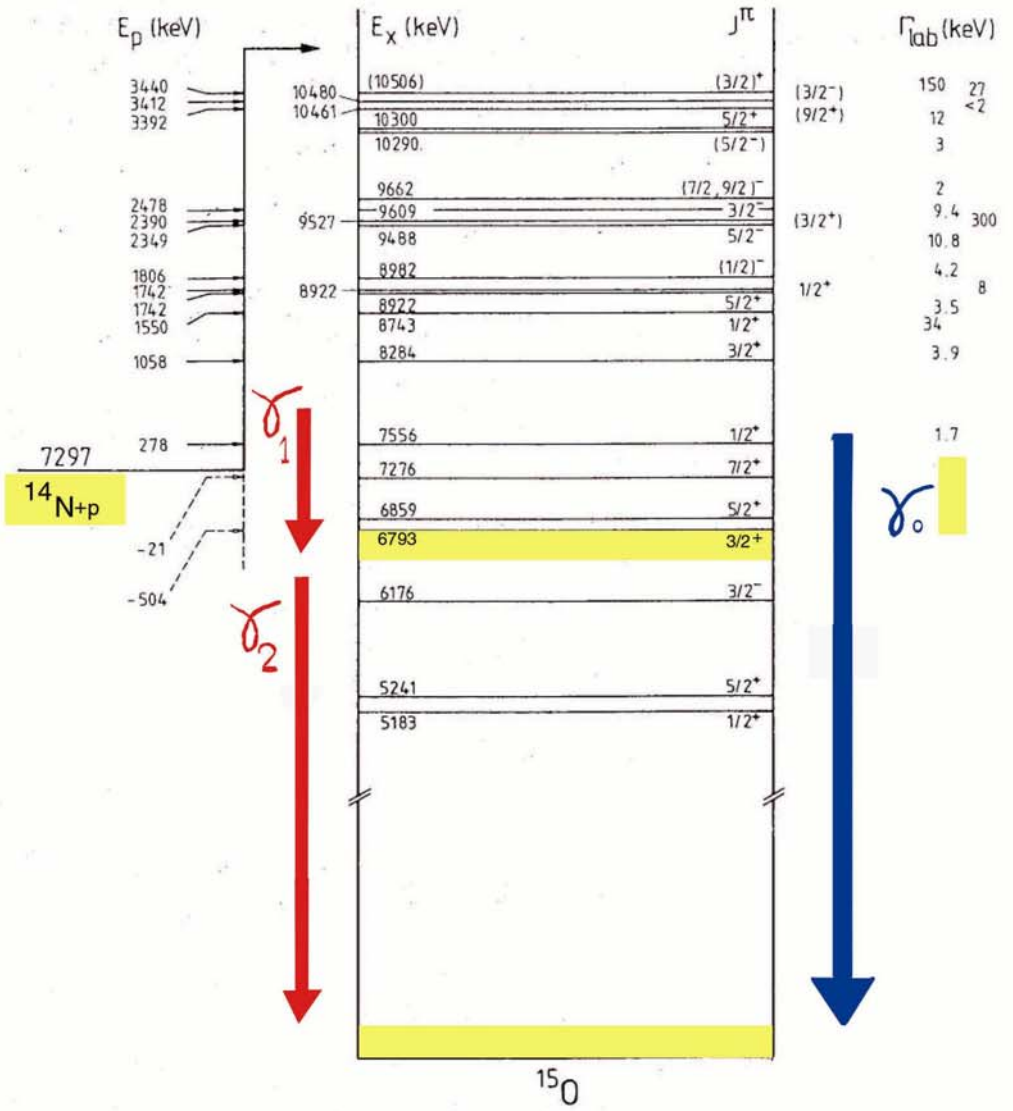
$S(0)=3.5_{-1.6}^{+0.4}$ keV b (Ad98)

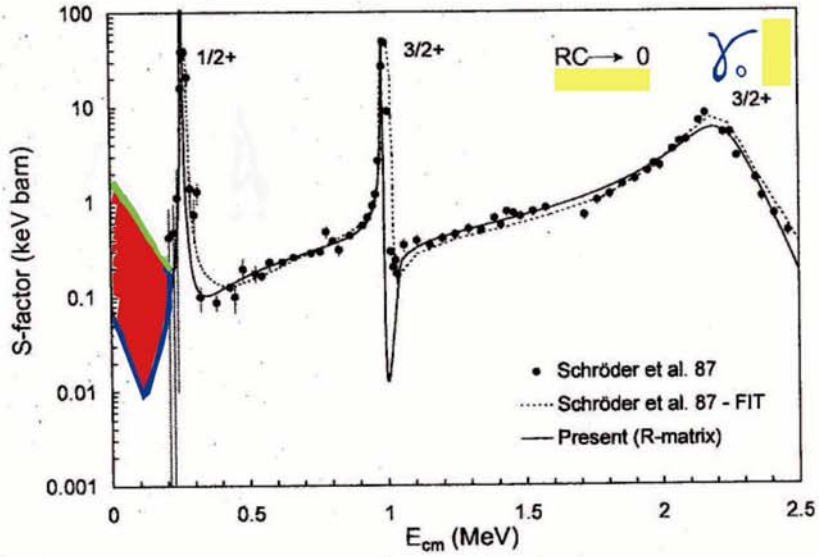
$S(0)=3.2_{-0.8}^{+0.8}$ keV b (An99)

- "High" energy: solid target + HpGe
- Low energy: gas target + BGO

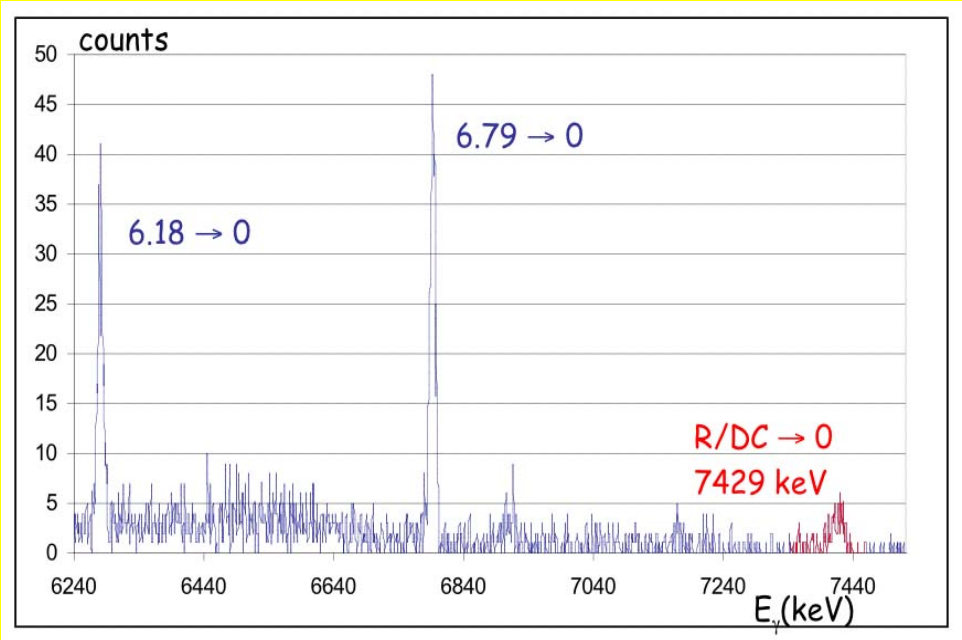

CNO bi-cycle
PP chain
$\log\left(\frac{\epsilon}{\rho X_H^2}\right)$
T_6
M_V
V−I


S 14,1 /5
S 14,1 x5
Standard CF88
M_v (Turn off)
Age (Gyr)

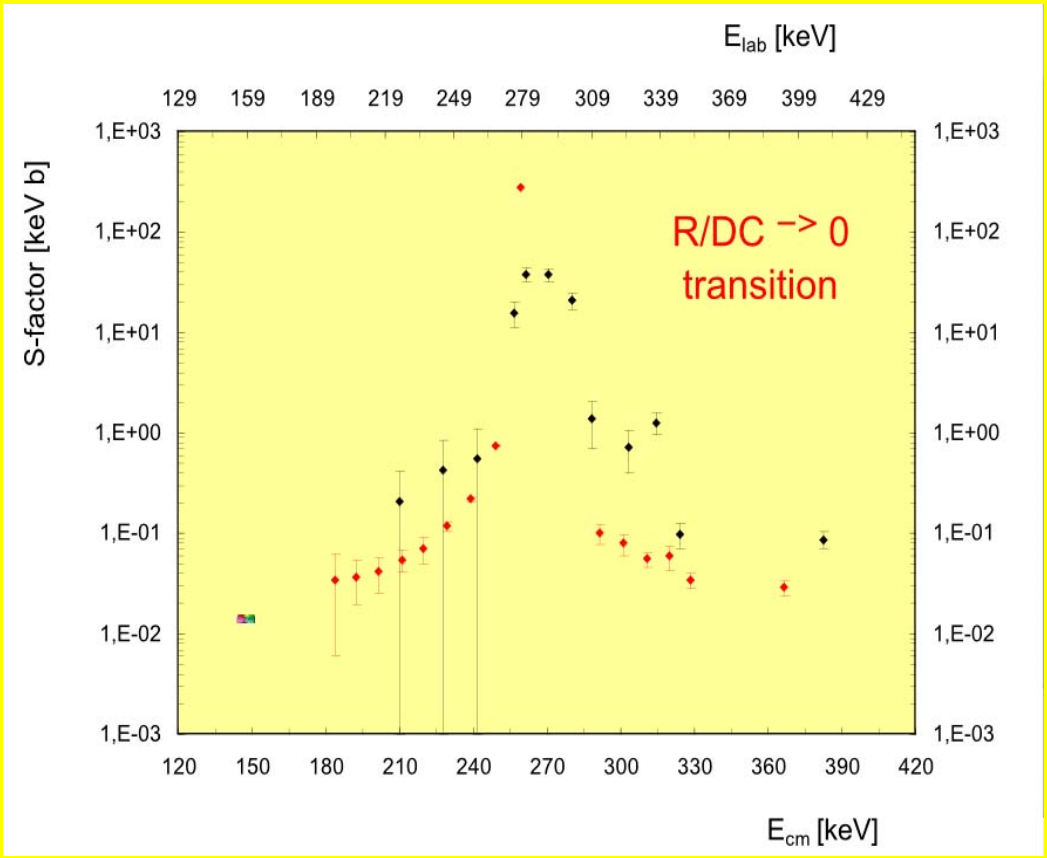

E_p (keV)
E_x (keV)
J^π
Γ_{lab} (keV)
3440
3412
3392
2478
2390
2349
1806
1742
1742
1550
1058
278
7297
^{14}N+p
-21
-504
10480
10461
9527
8922
(10506)
10300
10290.
9662
9609
9488
8982
8922
8743
8284
7556
7276
6859
6793
6176
5241
5183
(3/2)$^+$
5/2$^+$
(5/2$^-$)
(7/2, 9/2)$^-$
3/2$^-$
5/2$^-$
(1/2)$^-$
5/2$^+$
1/2$^+$
3/2$^+$
1/2$^+$
7/2$^+$
5/2$^+$
3/2$^+$
3/2$^-$
5/2$^+$
1/2$^+$
(3/2$^-$)
(9/2$^+$)
(3/2$^+$)
1/2$^+$
150
12
3
2
9.4
10.8
4.2
3.5
34
3.9
1.7
27
<2
300
8
γ_1
γ_2
γ_0
^{15}O


S-factor (keV barn)
E_{cm} (MeV)
100
10
1
0.1
0.01
0.001
0
0.5
1
1.5
2
2.5
1/2+
3/2+
RC → 0
γ_0
3/2+
Schröder et al. 87
Schröder et al. 87 - FIT
Present (R-matrix)

preliminary results



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



- preliminary S(E) factor (R/DC->0 transition) in $^{14}N(p,\gamma)^{15}O$
- results of Schroeder et al.

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

Q=1.6 MeV

- Solar neutrinos

  → Sun core properties

- $\Phi_B \sim S_{1,7} * S_{3,4}^{0.84} * T^{20}$

  → Solar thermometer

S(0)=0.53±0.05 keV b (Ad98)

S(0)=0.54±0.09 keV b (An99)

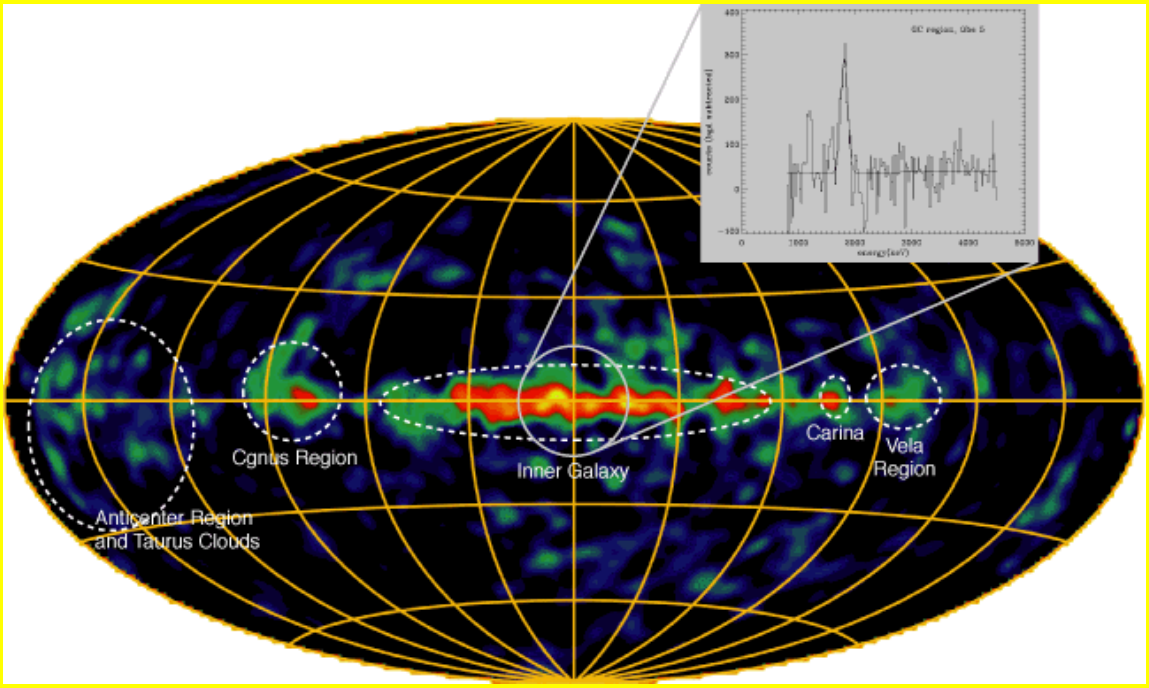
If $\Delta S_{34}/S_{34}$~3-5% and $\Delta\phi_B/\phi_B$~3%

→ Better than Helioseismology

$^{25}Mg(p,\gamma)^{26}Al$

Q=6.3 MeV

- Nucleosynthesis of 24<A<27
- Astronomical interest of the 1.8 MeV γ from ^{26}Al decay



(image taken by COMPTEL)

- **LUNA** has shown that it is possible to measure $\sigma(E_{star})$
- Past: $^{3}He\ (^{3}He,2p)^{4}He$

  ν from he Sun

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

  Proto-stars

  Big-bang
- Present: $^{14}N(p,\gamma)^{15}O$

  ν_{cno}

  Globular cluster age
- Near future: $^{3}He(\alpha,\gamma)^{7}Be$

  the Sun

  $^{25}Mg(p,\gamma)^{26}Al$

  Mg-Al cycle

  ^{26}Al sky