Carlo Broggini, INFN-Pd

LUNA

Laboratory Underground Nuclear Astrophysics

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

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

Astrophysical Factor: $S(E)$

Gamow Factor: $e^{-2\pi\eta}$

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

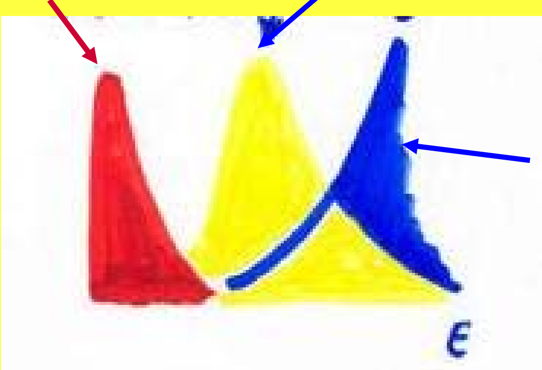
$$\mu = m_1 m_2 / (m_1 + m_2)$$

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

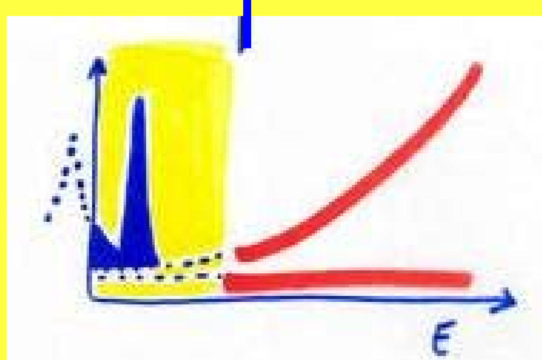
Maxwell Boltzmann

Gamow Peak

σ



Extrap. | ← Meas. →

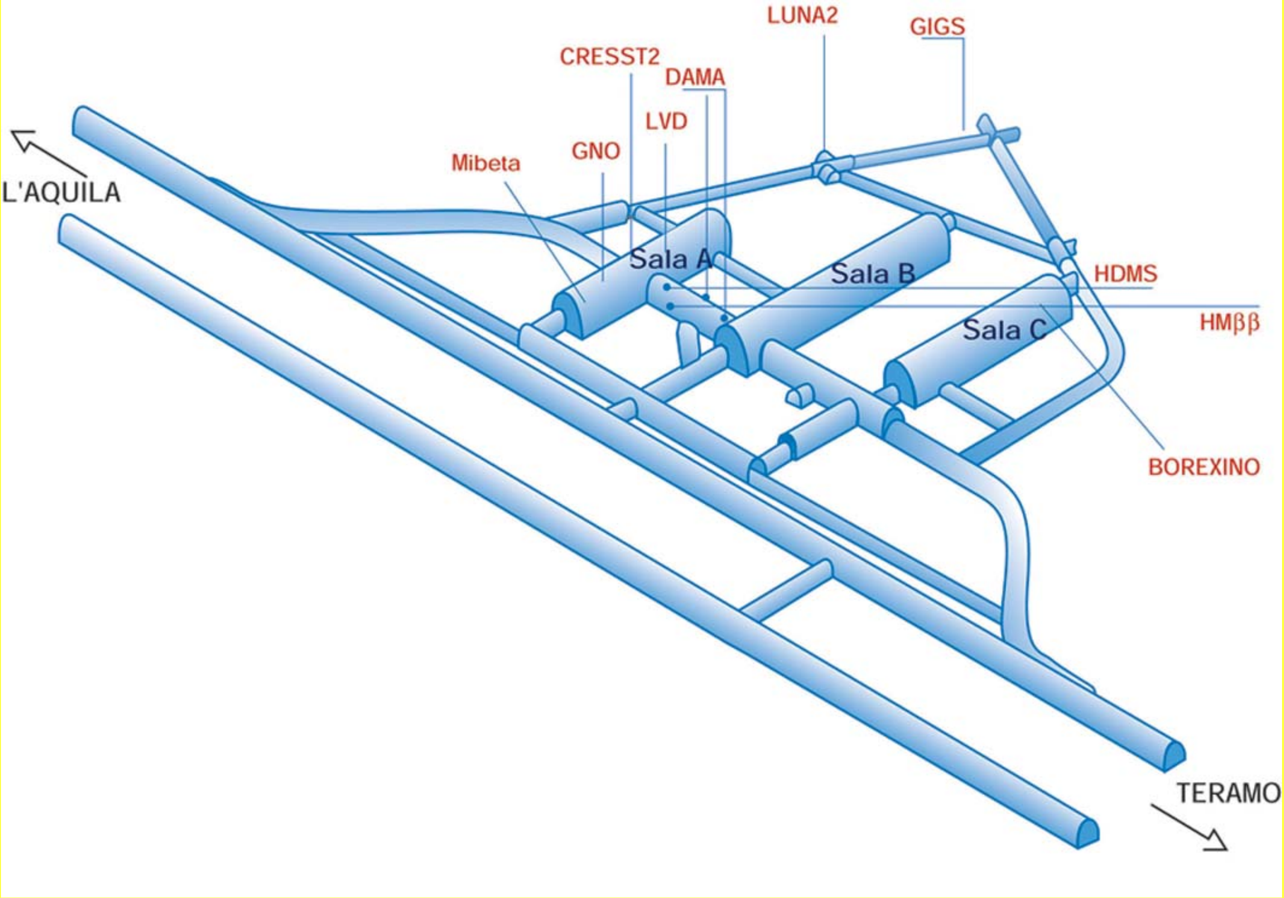


Laboratory for Underground Nuclear Astrophysics

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)



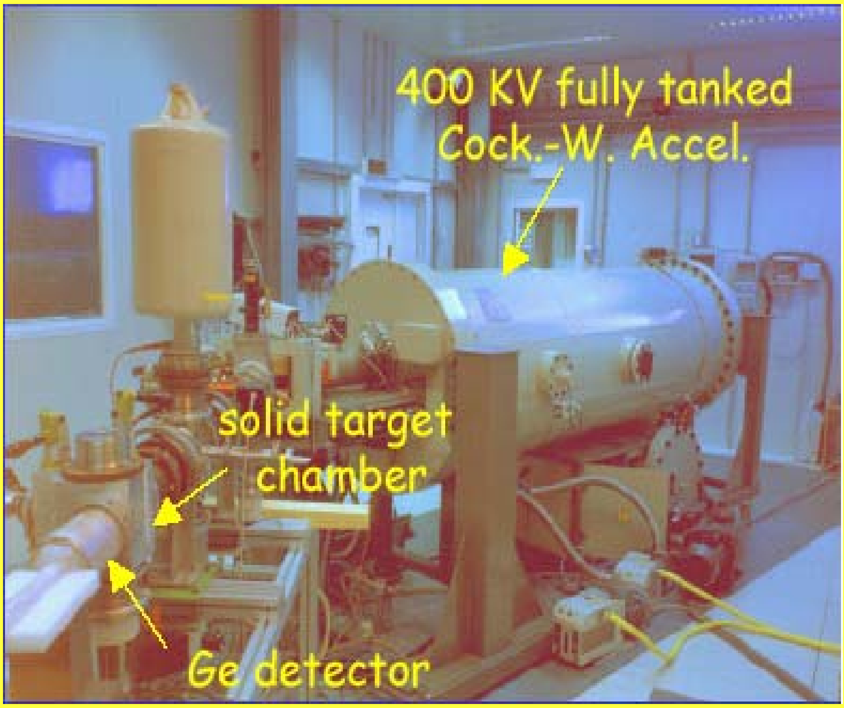
$$\Phi_{\mu} = 0.7 \; m^{-2} \, h^{-1}$$

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

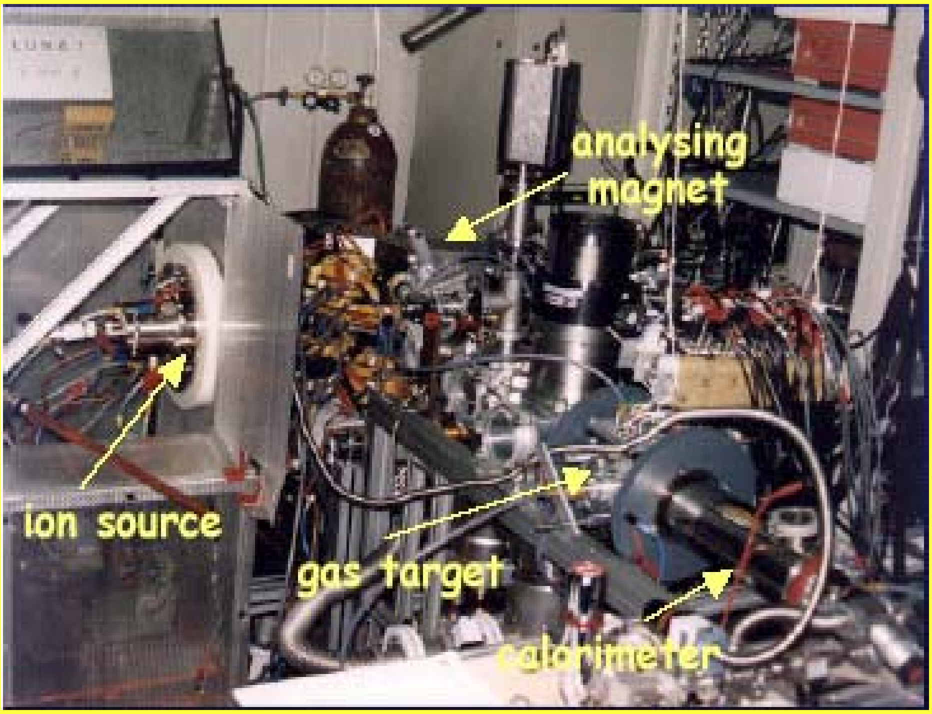
Accelerator facilities @ LNGS:

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

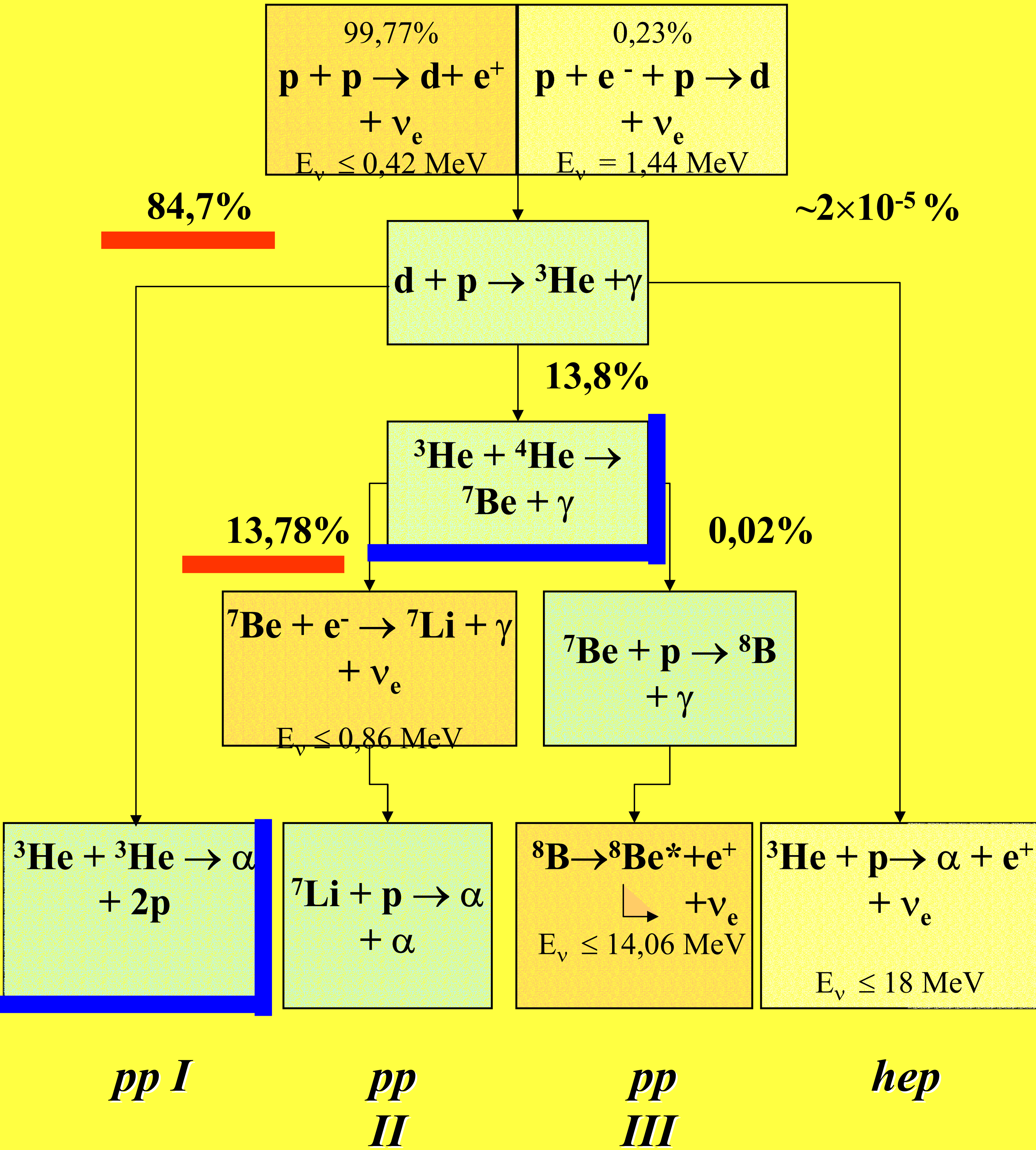


LUNA1 (50 kV)



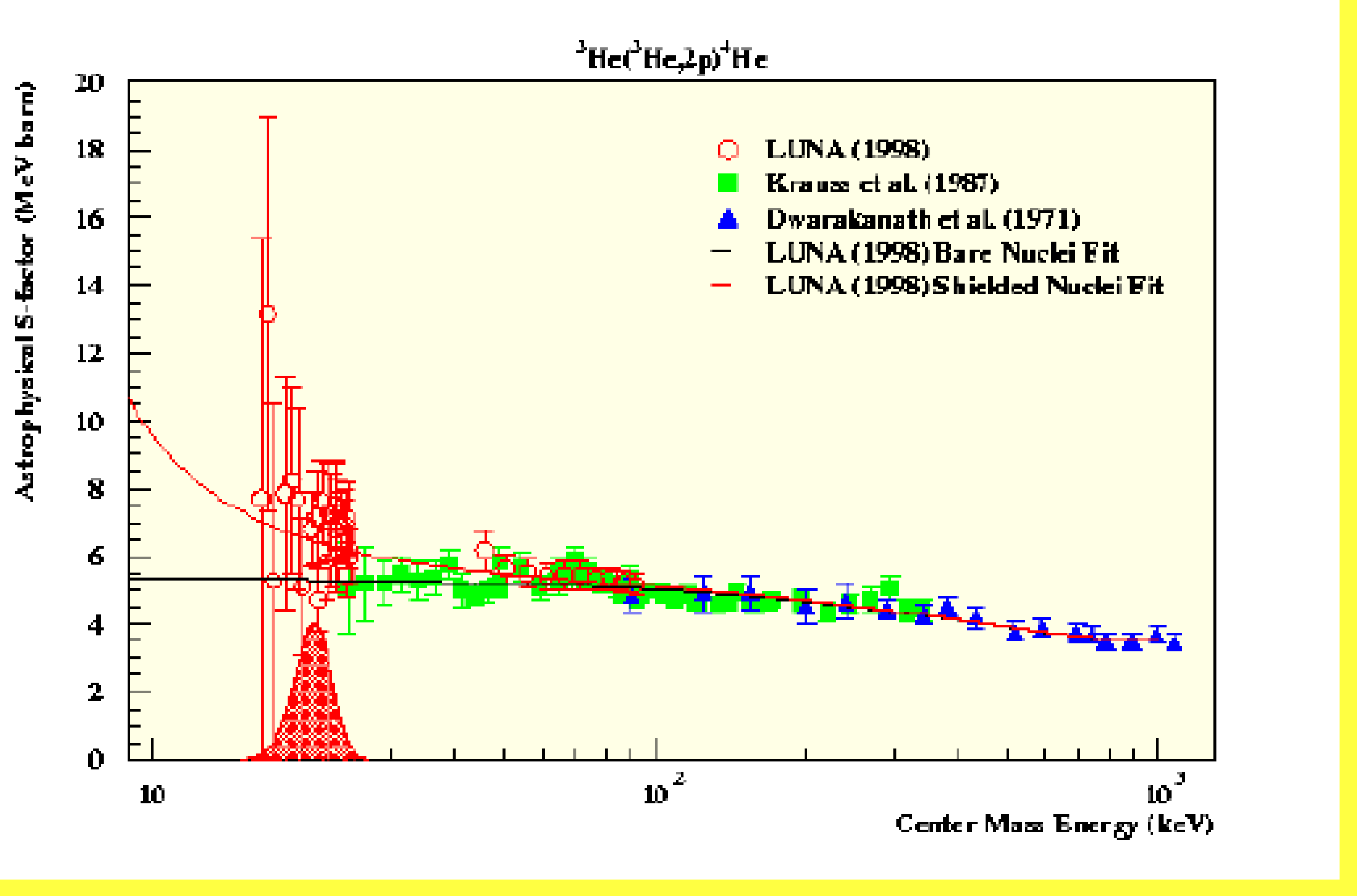
Voltage Range :
1 - 50 kV
Output Current:
1 mA
Beam energy spread:
20 eV
Long term stability (8 h):
10-4
Terminal Voltage ripple:
5 10-5

pp-chain



99,77%
$p + p \rightarrow d + e^+ + \nu_e$
$E_\nu \leq 0{,}42$ MeV
0,23%
$p + e^- + p \rightarrow d + \nu_e$
$E_\nu = 1{,}44$ MeV
84,7%
~2×10^{-5} %
$d + p \rightarrow {}^3He + \gamma$
13,8%
${}^3He + {}^4He \rightarrow {}^7Be + \gamma$
13,78%
0,02%
${}^7Be + e^- \rightarrow {}^7Li + \gamma + \nu_e$
$E_\nu \leq 0{,}86$ MeV
${}^7Be + p \rightarrow {}^8B + \gamma$
${}^3He + {}^3He \rightarrow \alpha + 2p$
${}^7Li + p \rightarrow \alpha + \alpha$
${}^8B \rightarrow {}^8Be^* + e^+ + \nu_e$
$E_\nu \leq 14{,}06$ MeV
${}^3He + p \rightarrow \alpha + e^+ + \nu_e$
$E_\nu \leq 18$ MeV
pp I
pp II
pp III
hep

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

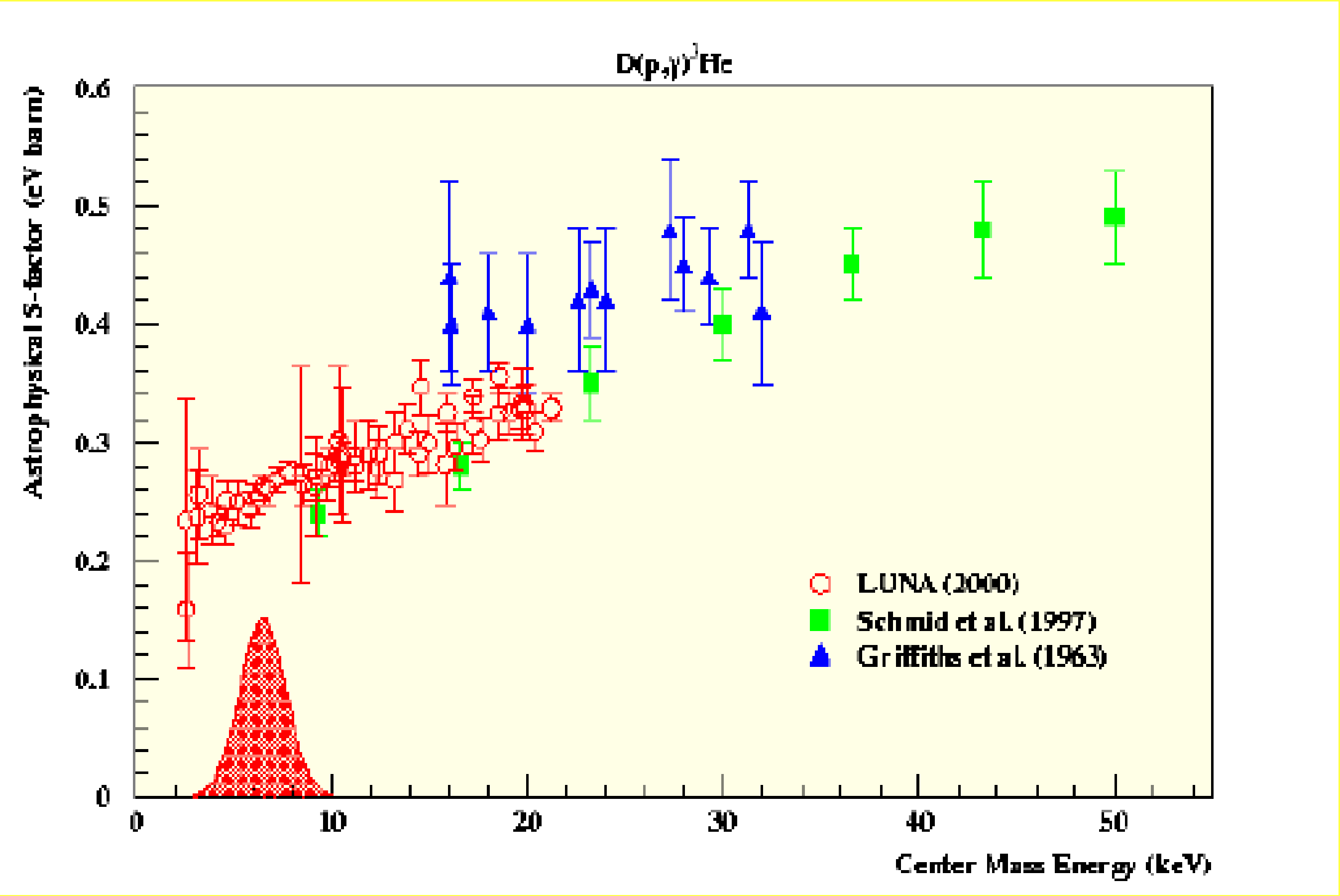


Q = 12.86 MeV

E_p^{max} = 10.7 MeV

σ = 7±2 pb (@24.5 keV)

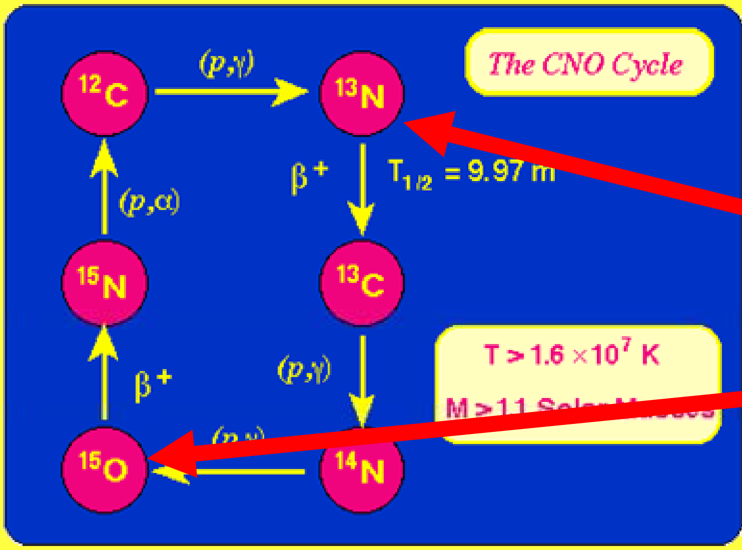
$D(p,\gamma)^3He$



Q=5.5 MeV

- Equilibrium abundance of D
- Proto-star life

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



Q=7.3 MeV

ν E<1.2 MeV

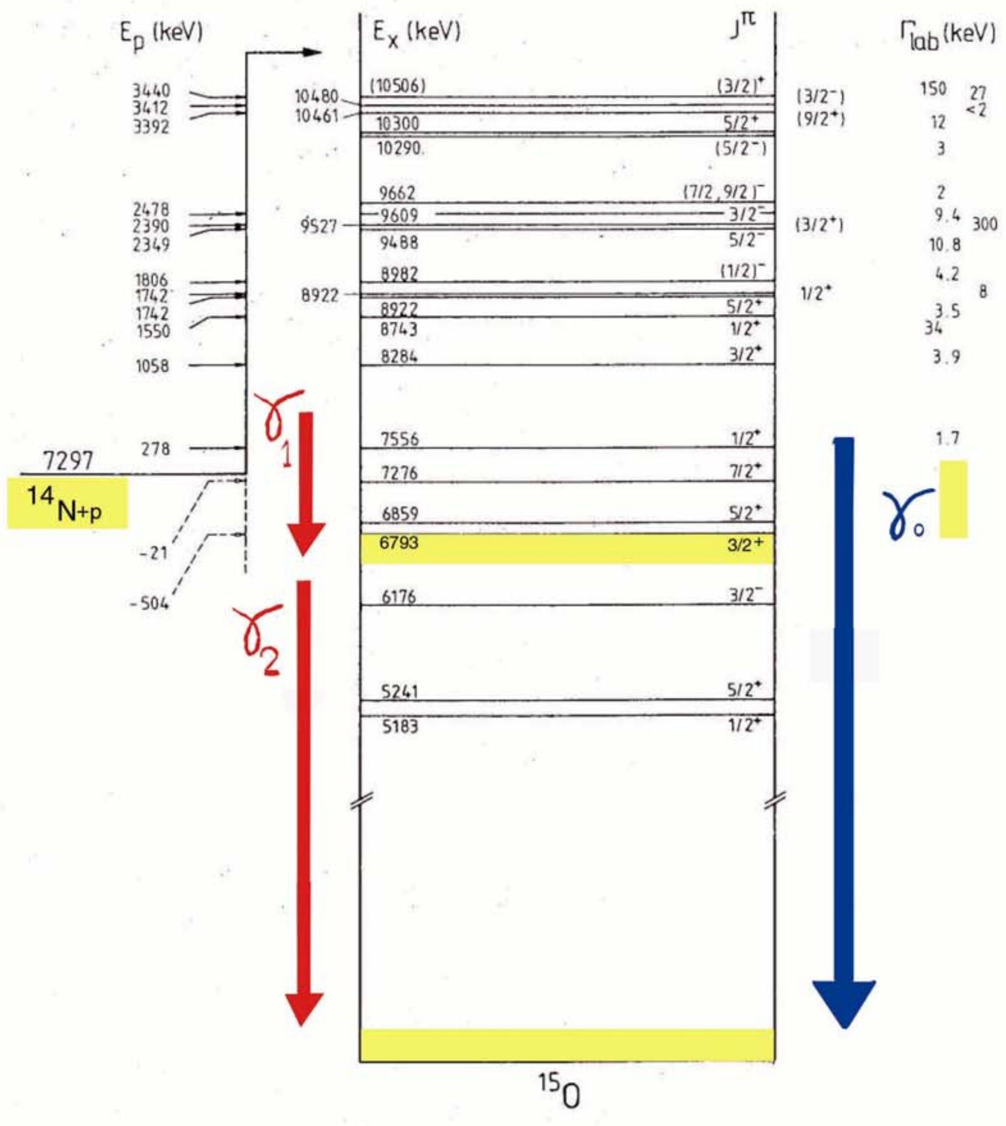
ν E<1.7 MeV

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

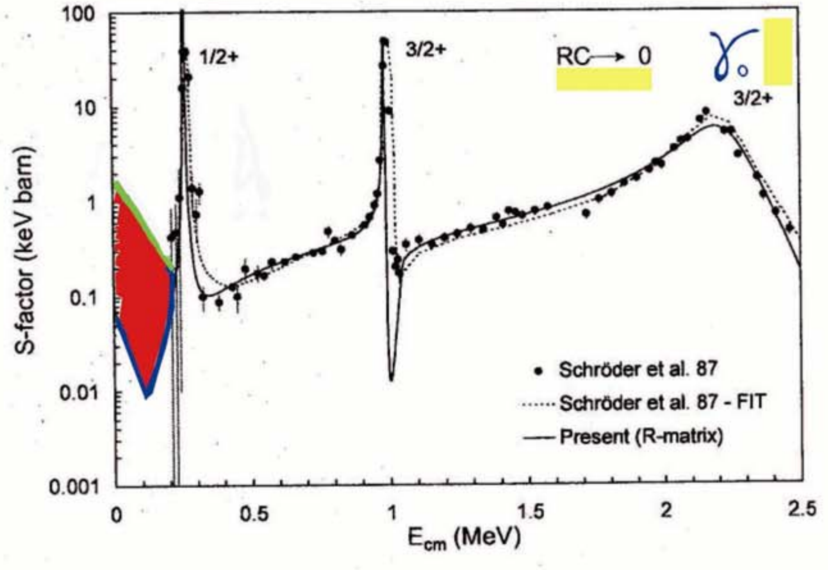
$S(0)=3.5_{-1.6}^{+0.4}$ keV b (Ad98)

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

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

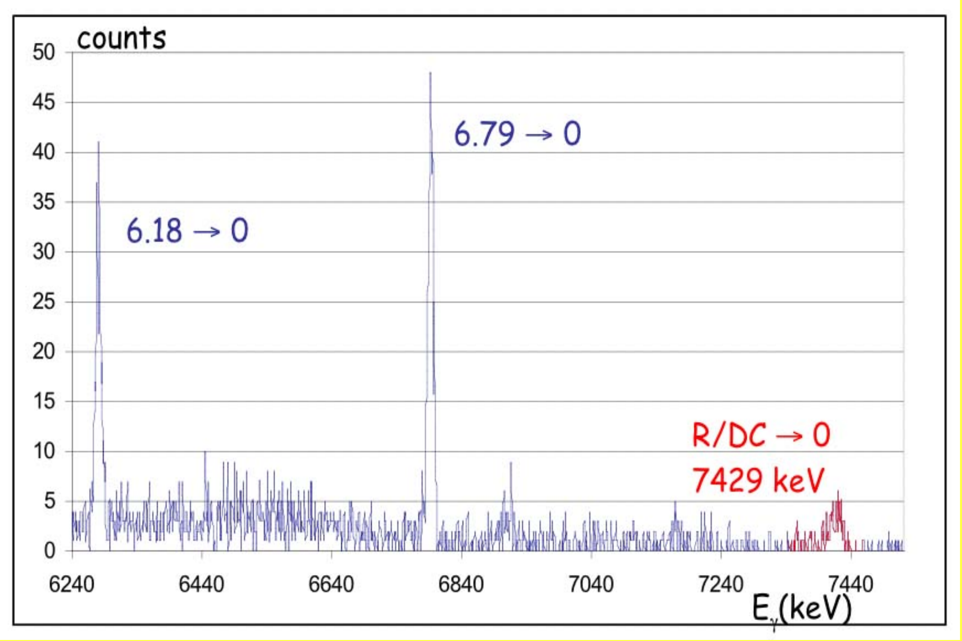


E_p (keV)
E_x (keV)
J^{π}
Γ_{lab} (keV)
3440
3412
3392
10480
10461
(10506) (3/2)+
10300 5/2+
10290. (5/2−)
(3/2−)
(9/2+)
150
27
<2
12
3
2478
2390
2349
9527
9662 (7/2, 9/2)−
9609 3/2−
9488 5/2−
(3/2+)
2
9.4
300
10.8
1806
1742
1742
1550
8922
8982 (1/2)−
8922 5/2+
8743 1/2+
1/2+
4.2
8
3.5
34
1058
8284 3/2+
3.9
278
7556 1/2+
1.7
7297
14N+p
7276 7/2+
6859 5/2+
6793 3/2+
−21
−504
6176 3/2−
5241 5/2+
5183 1/2+
γ1
γ2
γ0
15O

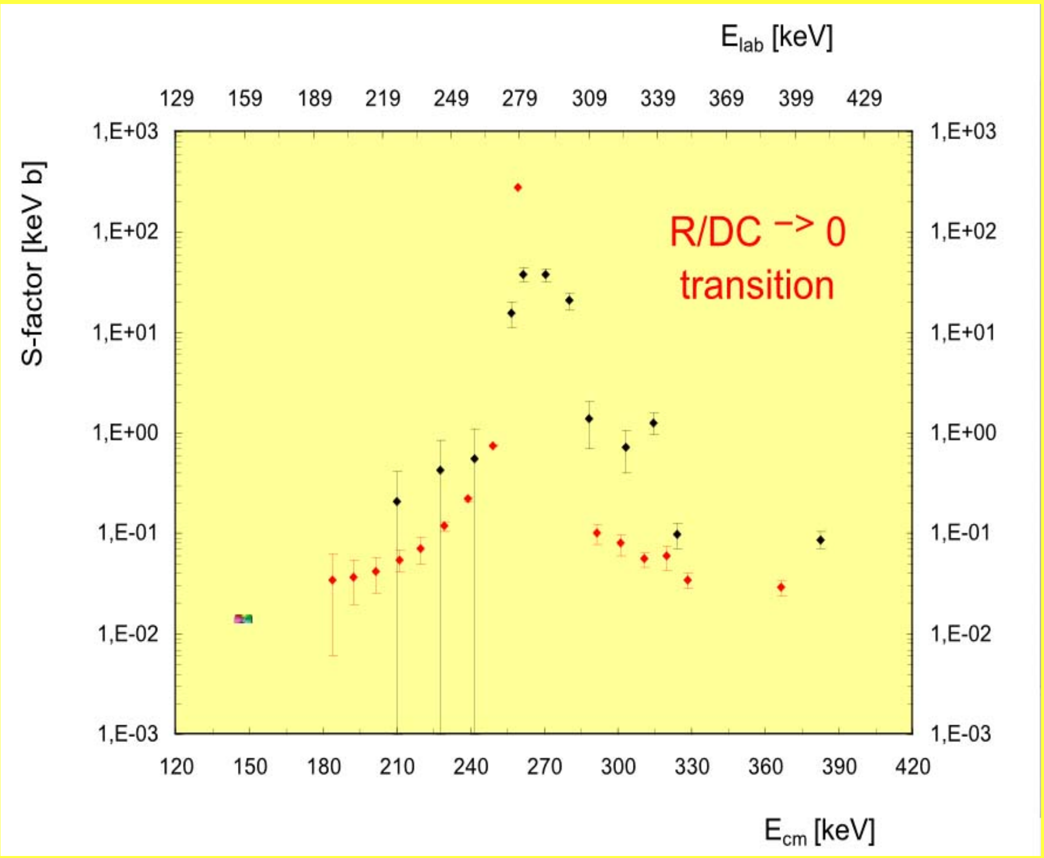


S-factor (keV barn)
100
10
1
0.1
0.01
0.001
1/2+
3/2+
RC→ 0
γ0
3/2+
• Schröder et al. 87
Schröder et al. 87 - FIT
Present (R-matrix)
0
0.5
1
1.5
2
2.5
E_{cm} (MeV)

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)

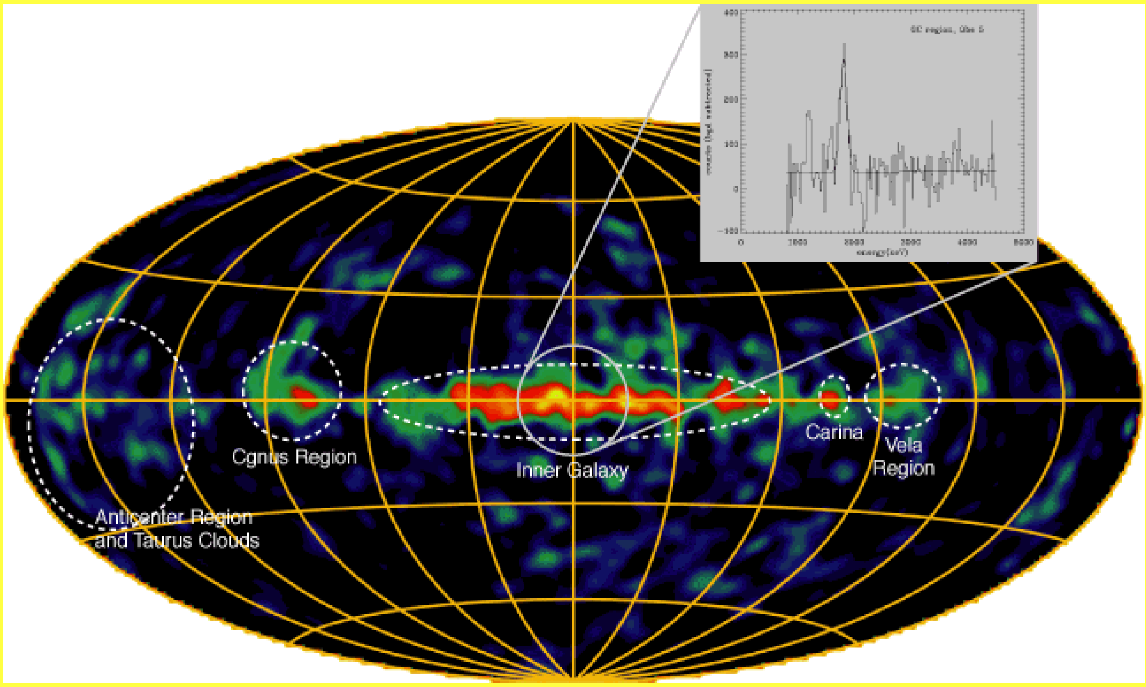
If $\Delta S_{34}/S_{34}$~3-5% and $\Delta\phi_B/\phi_B$~3%

➡ **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
- Present: $^{14}N(p,\gamma)^{15}O$
  ν_{cno}
  Globular cluster age
- Future: $^{3}He(\alpha,\gamma)^{7}Be$
  the Sun
  $^{25}Mg(p,\gamma)^{26}Al$
  Mg-Al cycle
  ^{26}Al sky