



# LUNA

☀ Nuclear Burning in Stars

☀  $\sigma(E_{\text{star}})$

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

Astrophysical  
Factor

Gamow  
Factor

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

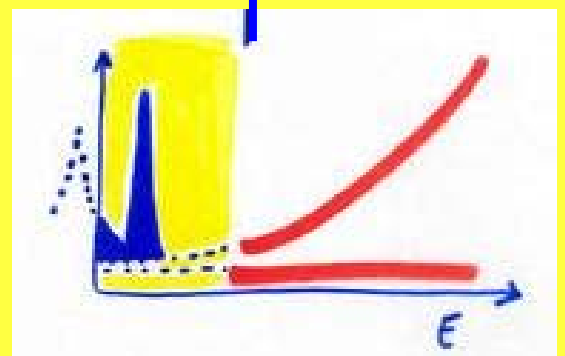
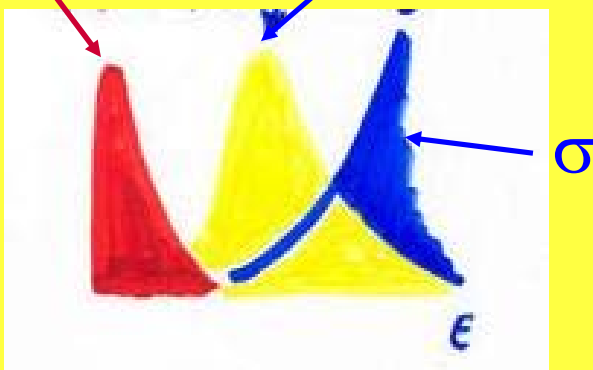
$$\mu = m_1 m_2 / (m_1 + m_2)$$

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

Maxwell  
Boltzmann

Gamow Peak

Extrap. ← Meas. →



# Laboratory for Underground Nuclear Astrophysics

## INFN - Laboratori Nazionali del Gran Sasso

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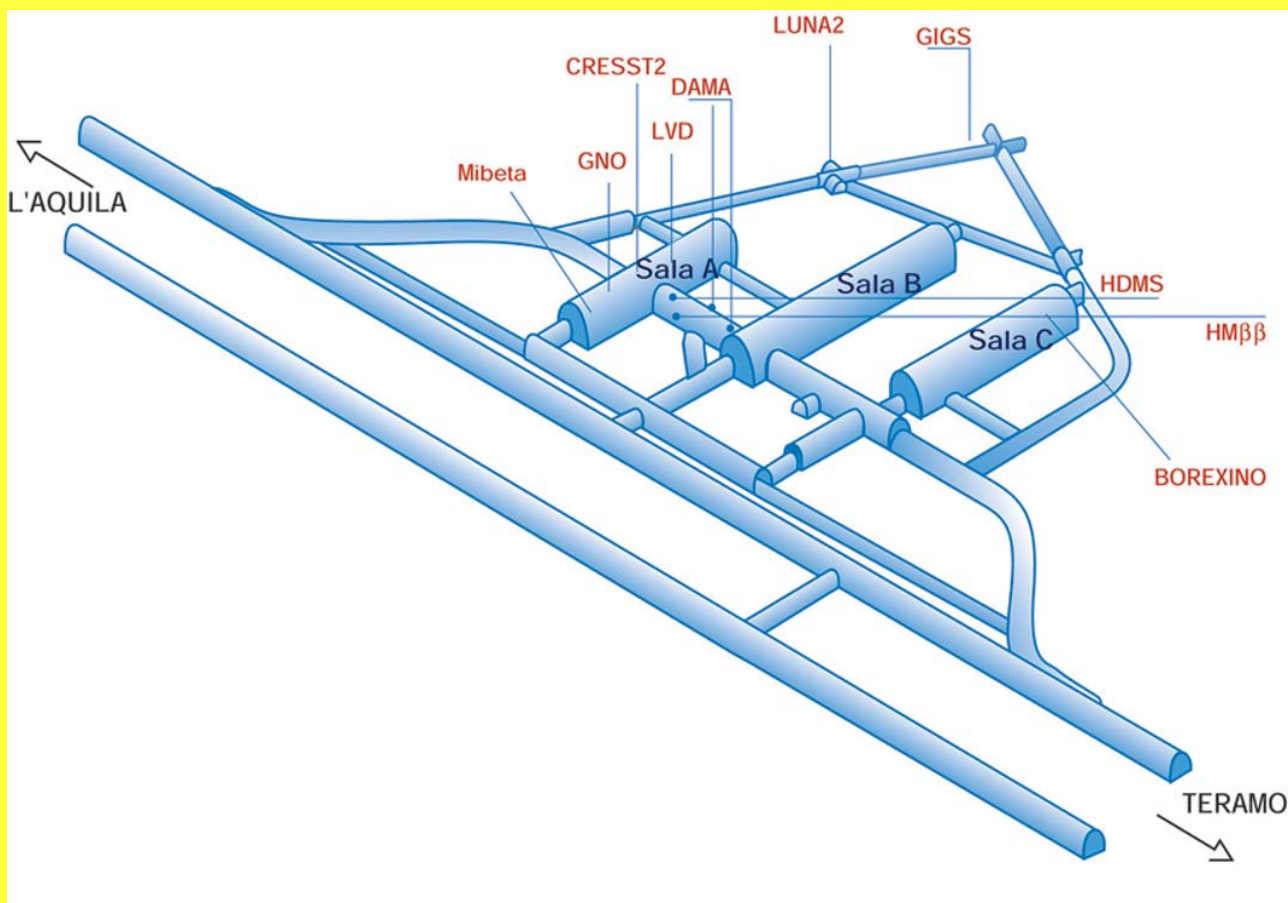
### • INFN Sezioni di :

Genova, LNGS, Milano, Napoli, Padova e Torino

• Inst. Physik mit Ionenstrahlen, Ruhr-Universität  
Bochum (GE)

• Centro de Fisica Nuclear da Universidade del  
Lisboa (Portugal)

• Atomki Debrecen (Hungary)



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

$$\Phi_n \approx 3 * 10^{-6} \text{ cm}^{-2} \text{ s}^{-1}$$

# Accelerator facilities @ LNGS:

## LUNA2 (400 kV)

Voltage Range :  
50 - 400 kV

Output Current: 1 mA 75% H  
(@ 400 kV)

25% H<sub>2</sub>

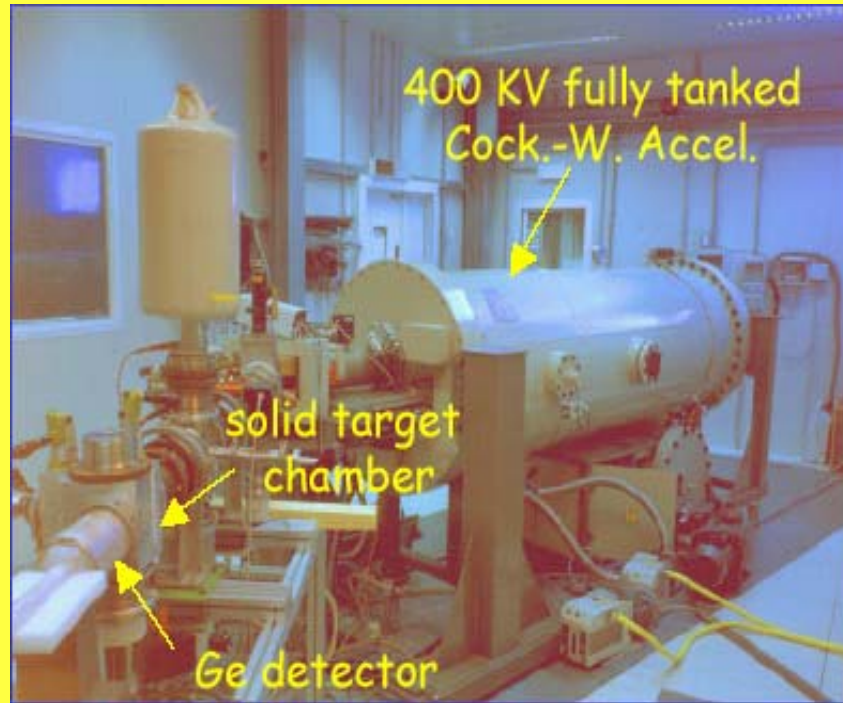
: 0.5 mA 4He

Absolute Energy error  
 $\pm 300$  eV

Beam energy spread:  
<100 eV

Long term stability (1 h) :  
5 eV

Terminal Voltage ripple:  
5 Vpp Ge detector



## LUNA1 ( 50 kV)

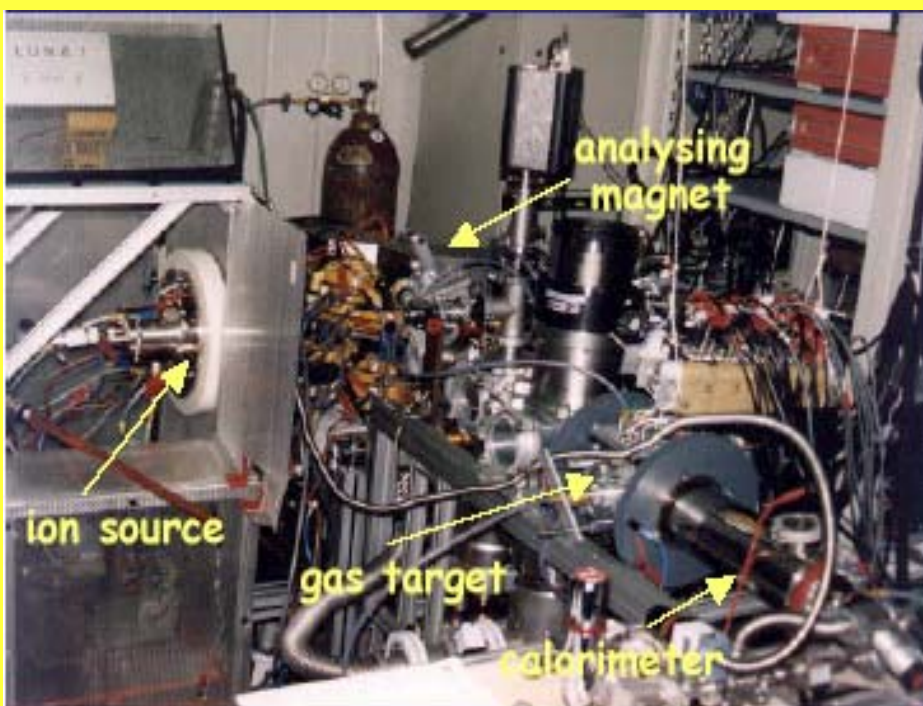
Voltage Range :  
1 - 50 kV

Output Current:  
1 mA

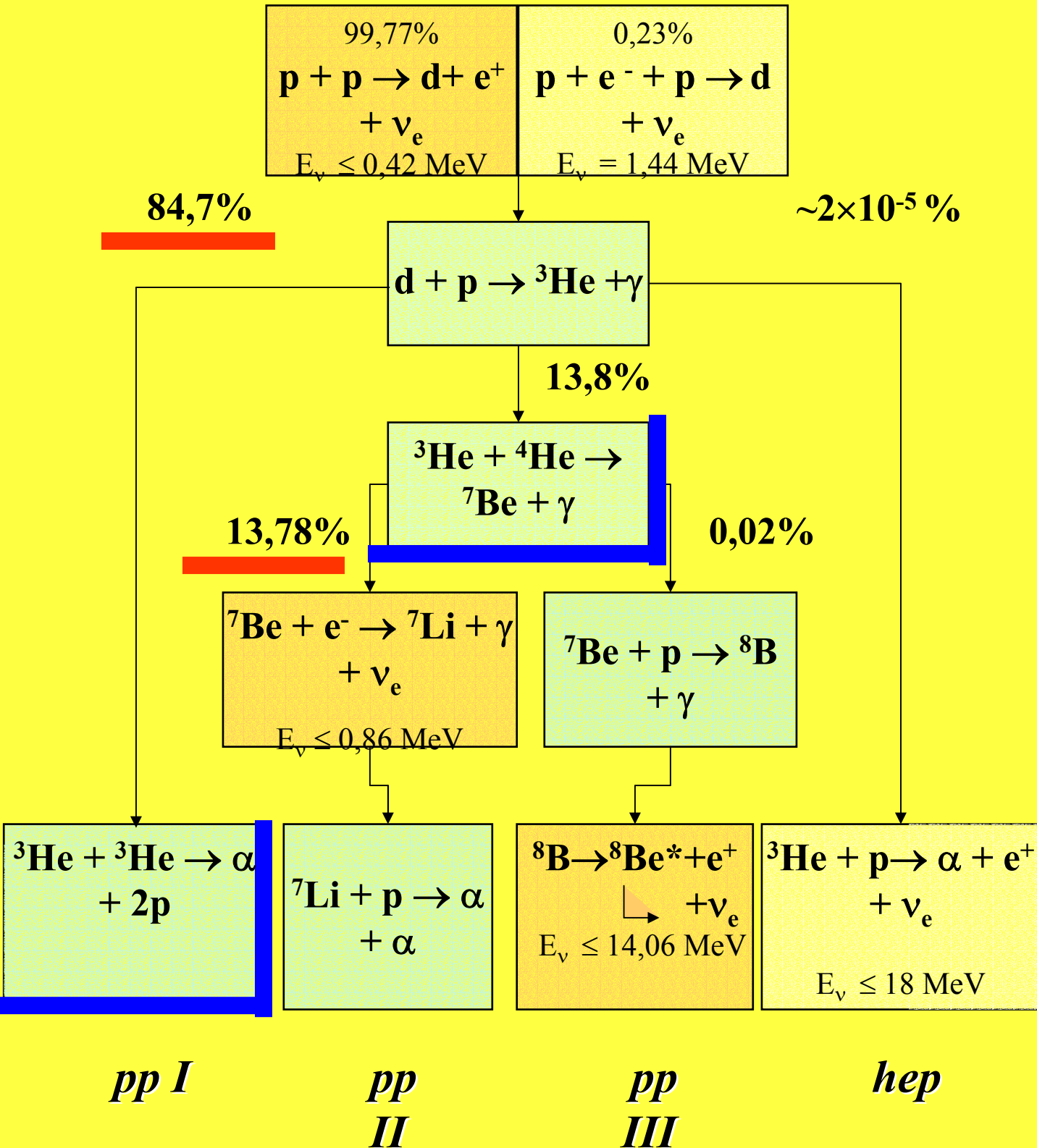
Beam energy spread:  
20 eV

Long term stability (8 h):  
10-4

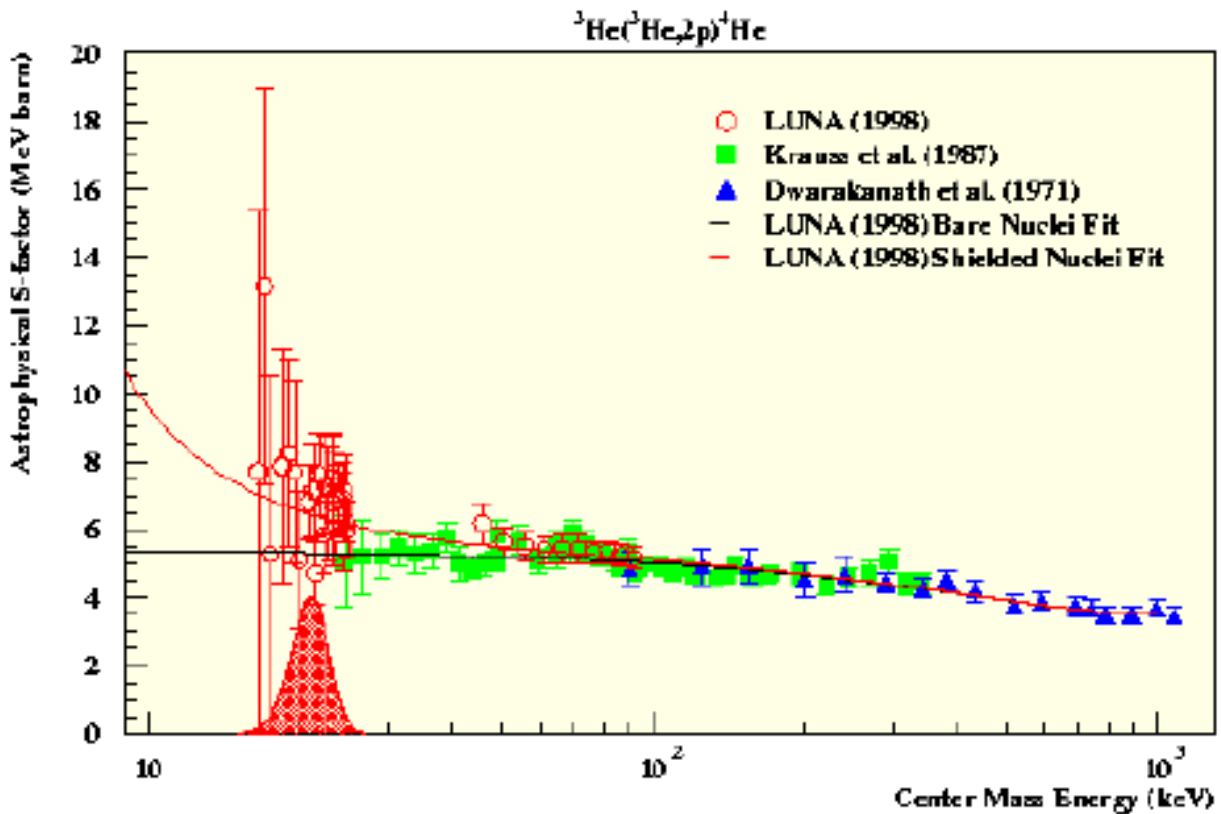
Terminal Voltage ripple:  
5 10<sup>-5</sup>



# pp-chain



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

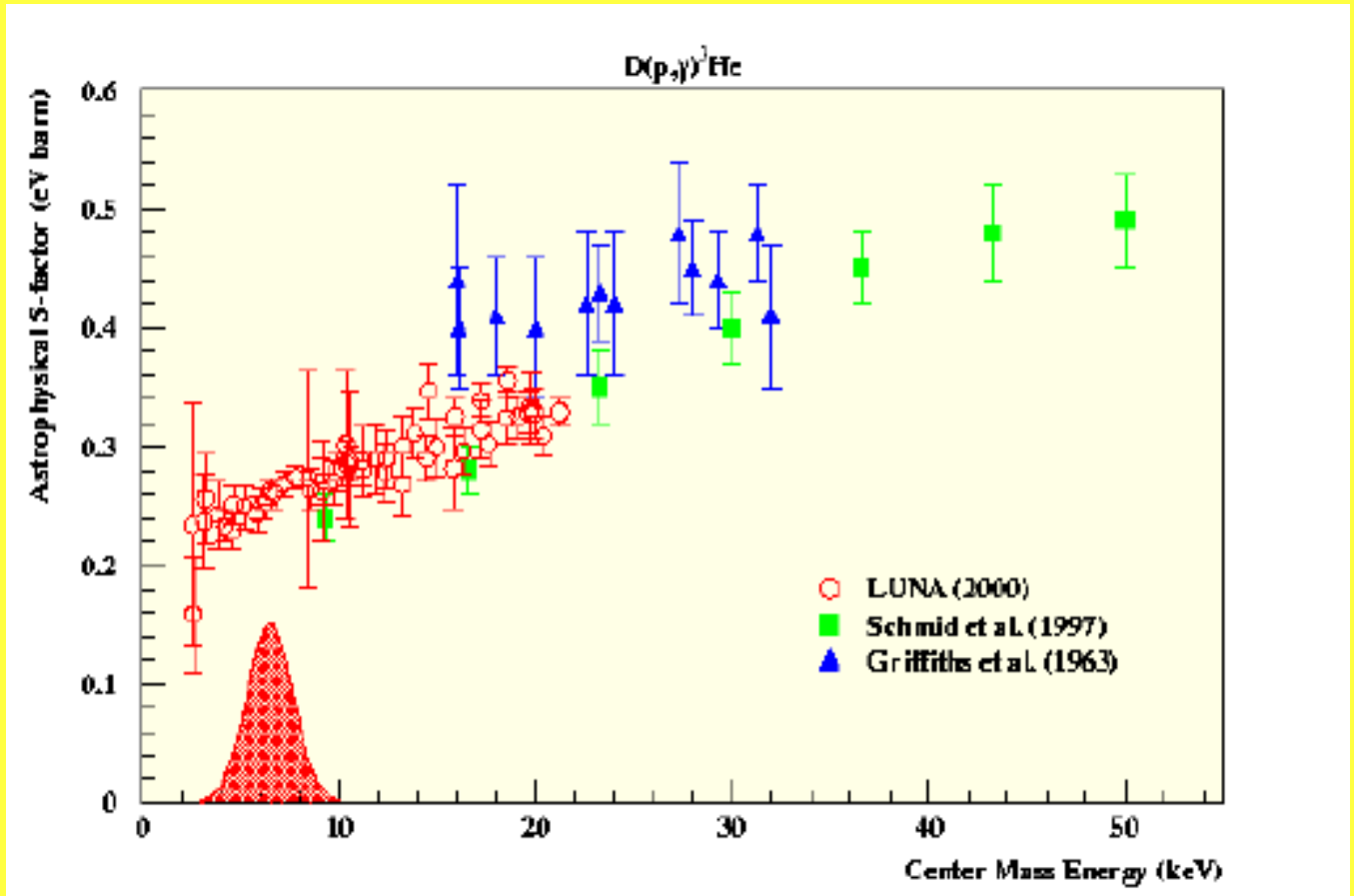


$$Q = 12.86 \text{ MeV}$$

$$E_p^{\text{max}} = 10.7 \text{ MeV}$$

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

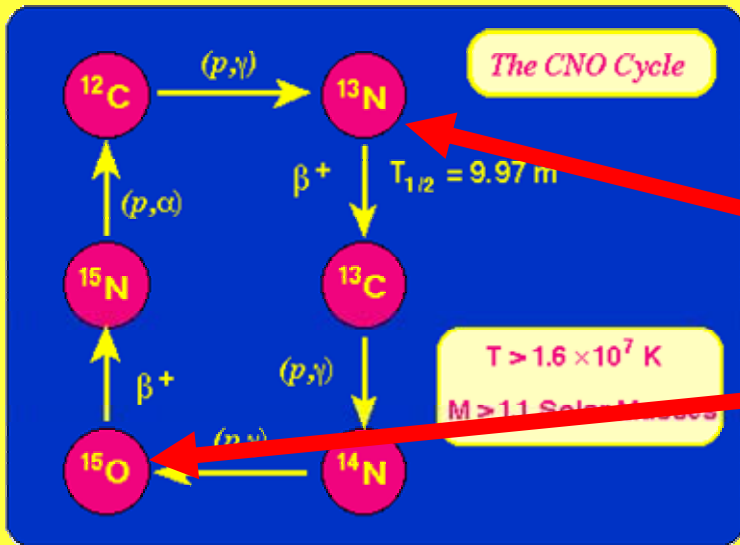
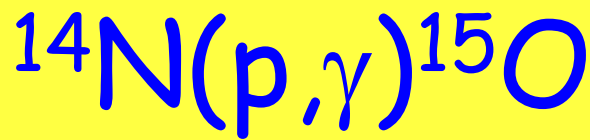
# $D(p,\gamma)^3\text{He}$



$Q=5.5 \text{ MeV}$

☀ Equilibrium abundance of D


☀ Proto-star life



$Q = 7.3 \text{ MeV}$

$\nu \quad E < 1.2 \text{ MeV}$

$\nu \quad E < 1.7 \text{ MeV}$

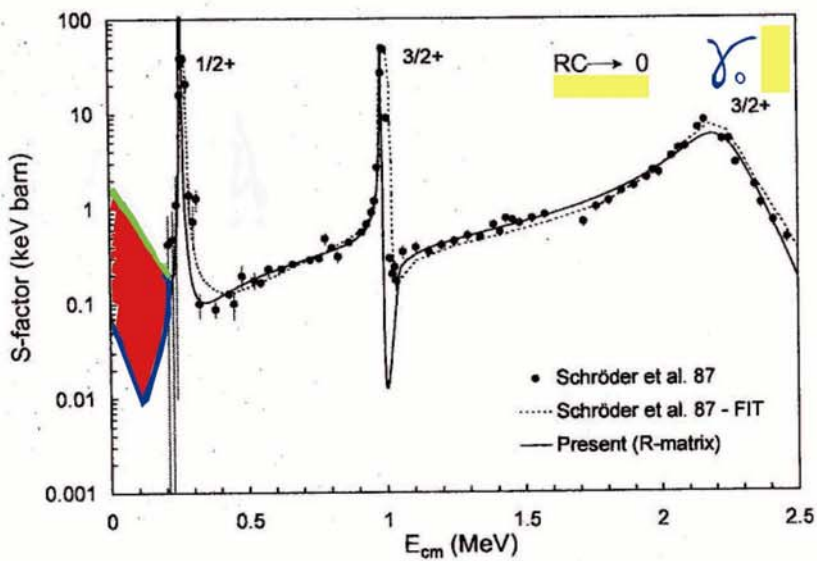
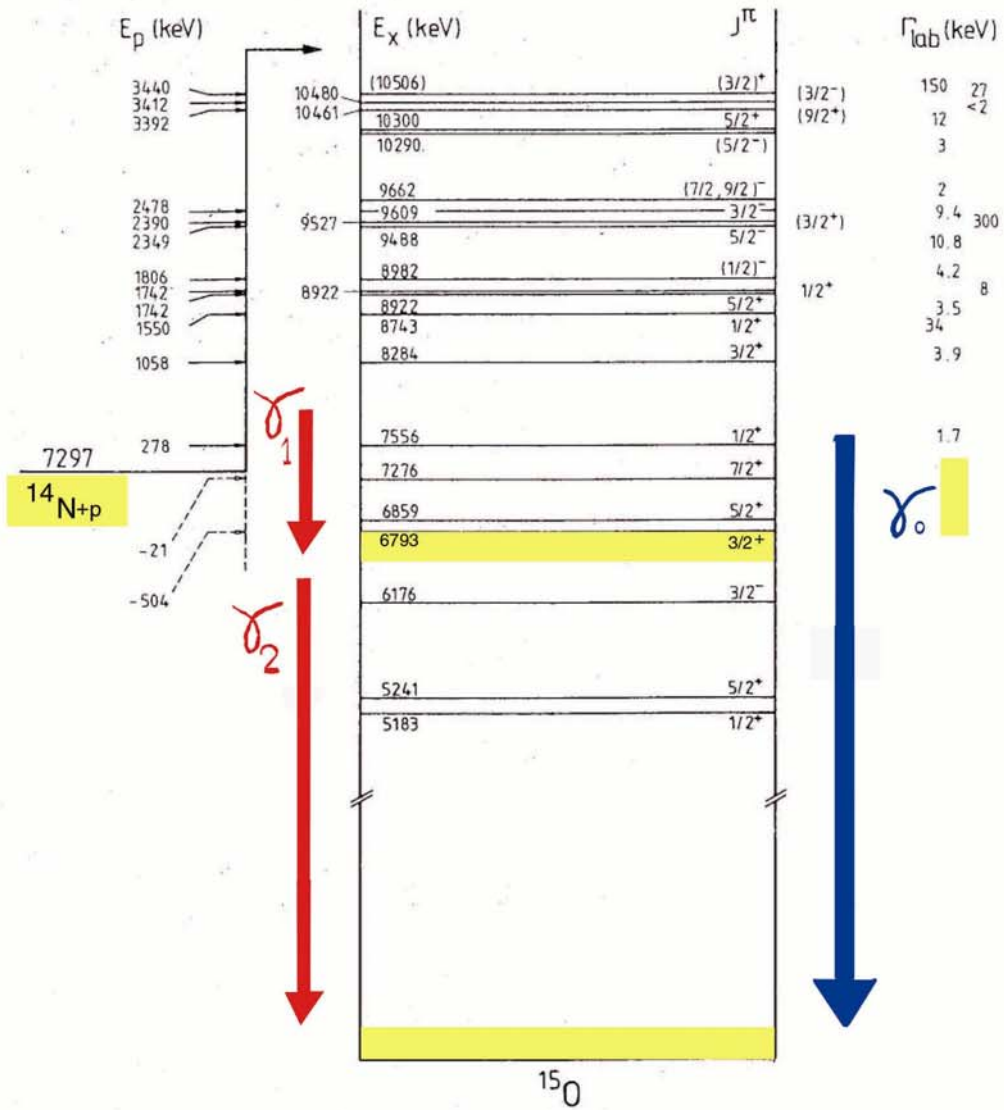

 $\nu_{\text{cno}} \quad \Phi_{\text{cno}} \sim S_{1,14}$


 Globular Cluster Age

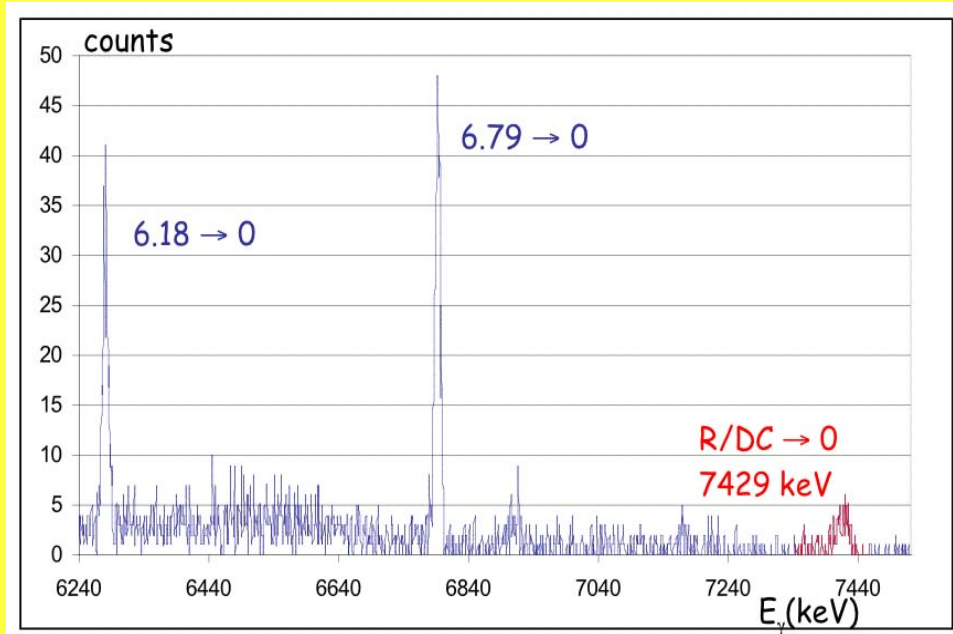
$S(0) = 3.5_{-1.6}^{+0.4} \text{ keV b (Ad98)}$

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

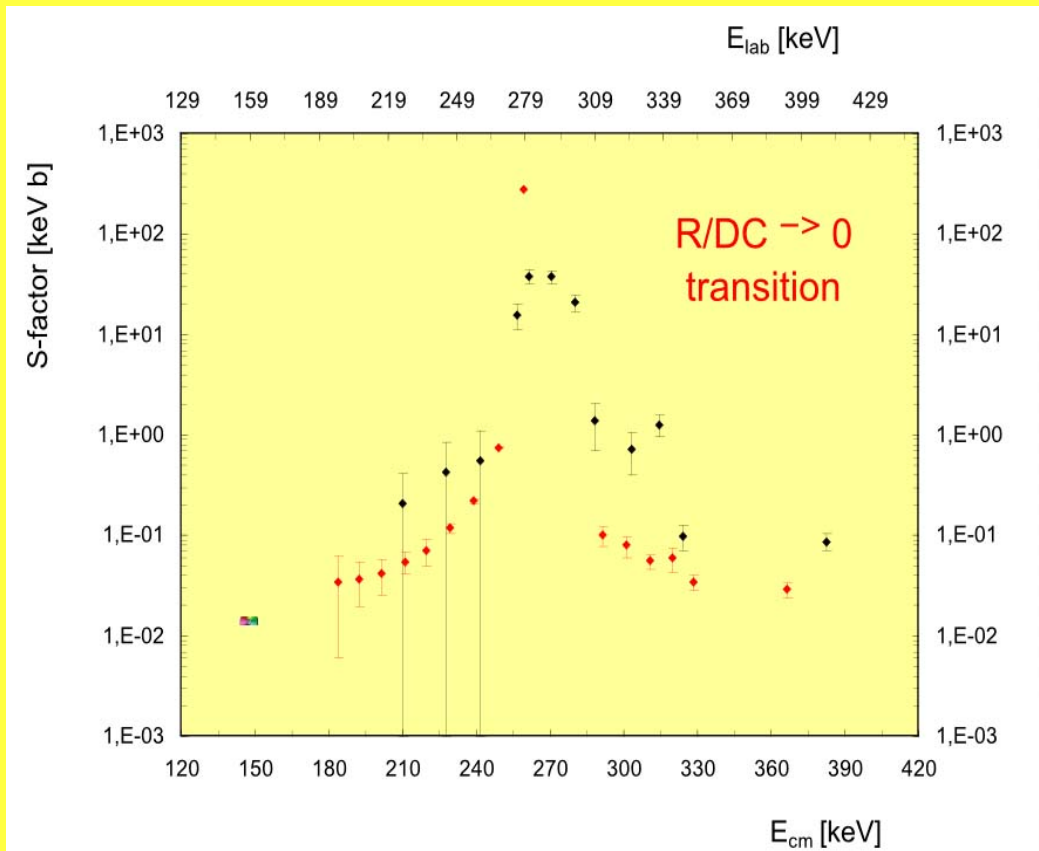
- "High" energy: solid target + HpGe
- Low energy: gas target + BGO



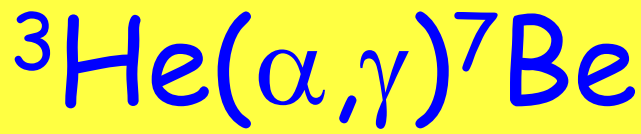
# preliminary results



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



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



$$Q=1.6 \text{ MeV}$$

☀ Solar neutrinos

➔ Sun core properties

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

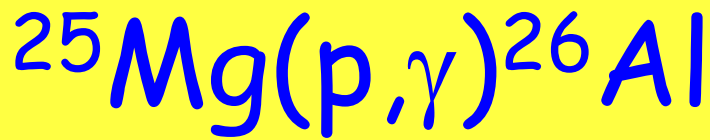
➔ Solar thermometer

$$S(0)=0.53\pm 0.05 \text{ keV b (Ad98)}$$

$$S(0)=0.54\pm 0.09 \text{ keV b (An99)}$$

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

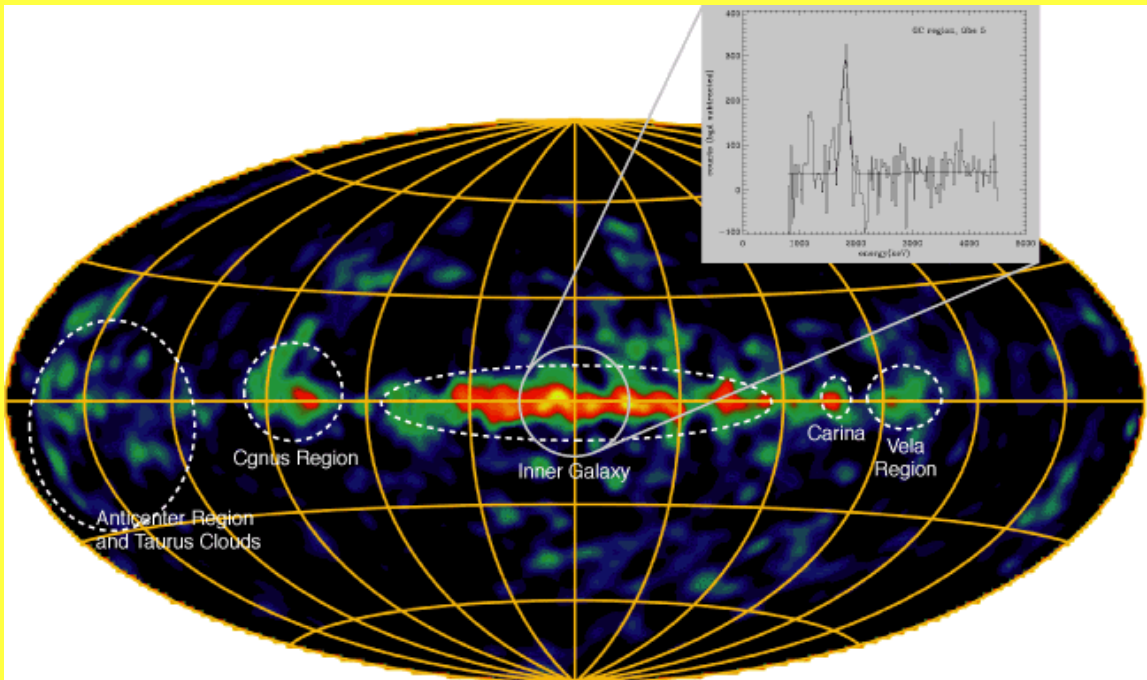
➔ Better than Helioseismology



$Q=6.3\text{ MeV}$

☀ Nucleosynthesis of  $24 < A < 27$

☀ Astronomical interest of the  $1.8\text{ MeV } \gamma$  from  $^{26}\text{Al}$  decay



(image taken by COMPTEL)

☀ LUNA has shown that it is possible to measure  $\sigma(E_{\text{star}})$

☀ Past:  ${}^3\text{He}({}^3\text{He}, 2p){}^4\text{He}$   
 $V$  from the Sun

$\text{D}(p, \gamma){}^3\text{He}$   
Proto-stars

☀ Present:  ${}^{14}\text{N}(p, \gamma){}^{15}\text{O}$   
 $V_{\text{cno}}$   
Globular cluster age

☀ Future:  ${}^3\text{He}(\alpha, \gamma){}^7\text{Be}$   
the Sun  
 ${}^{25}\text{Mg}(p, \gamma){}^{26}\text{Al}$   
Mg-Al cycle  
 ${}^{26}\text{Al}$  sky