Twenty years of LUNA

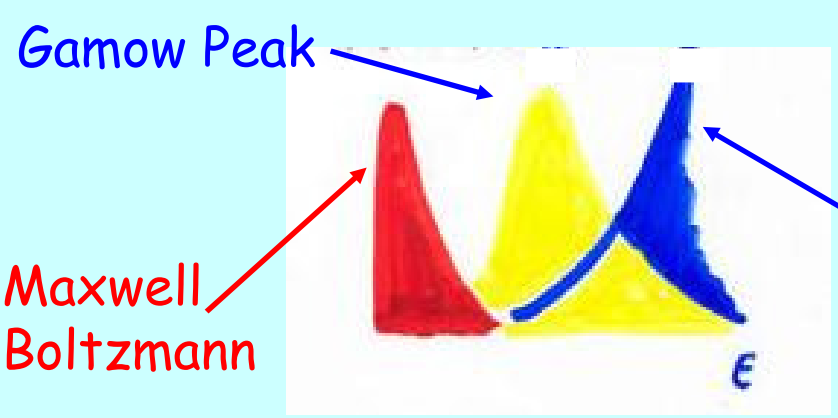
Carlo Broggini, INFN-Padova

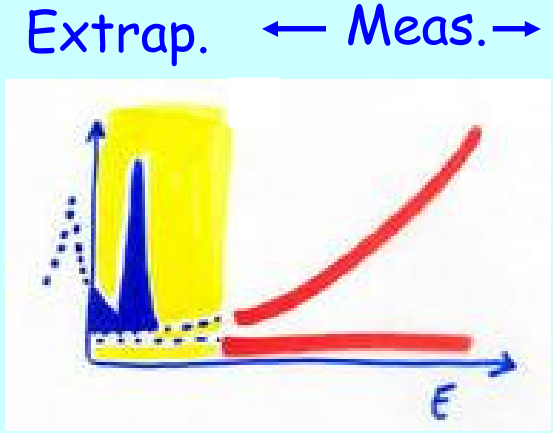
- Stellar Energy+Nucleosynthesis
- Hydrogen Burning
- $\sigma(E_{star})$ with $E_{star} << E_{Coulomb}$

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

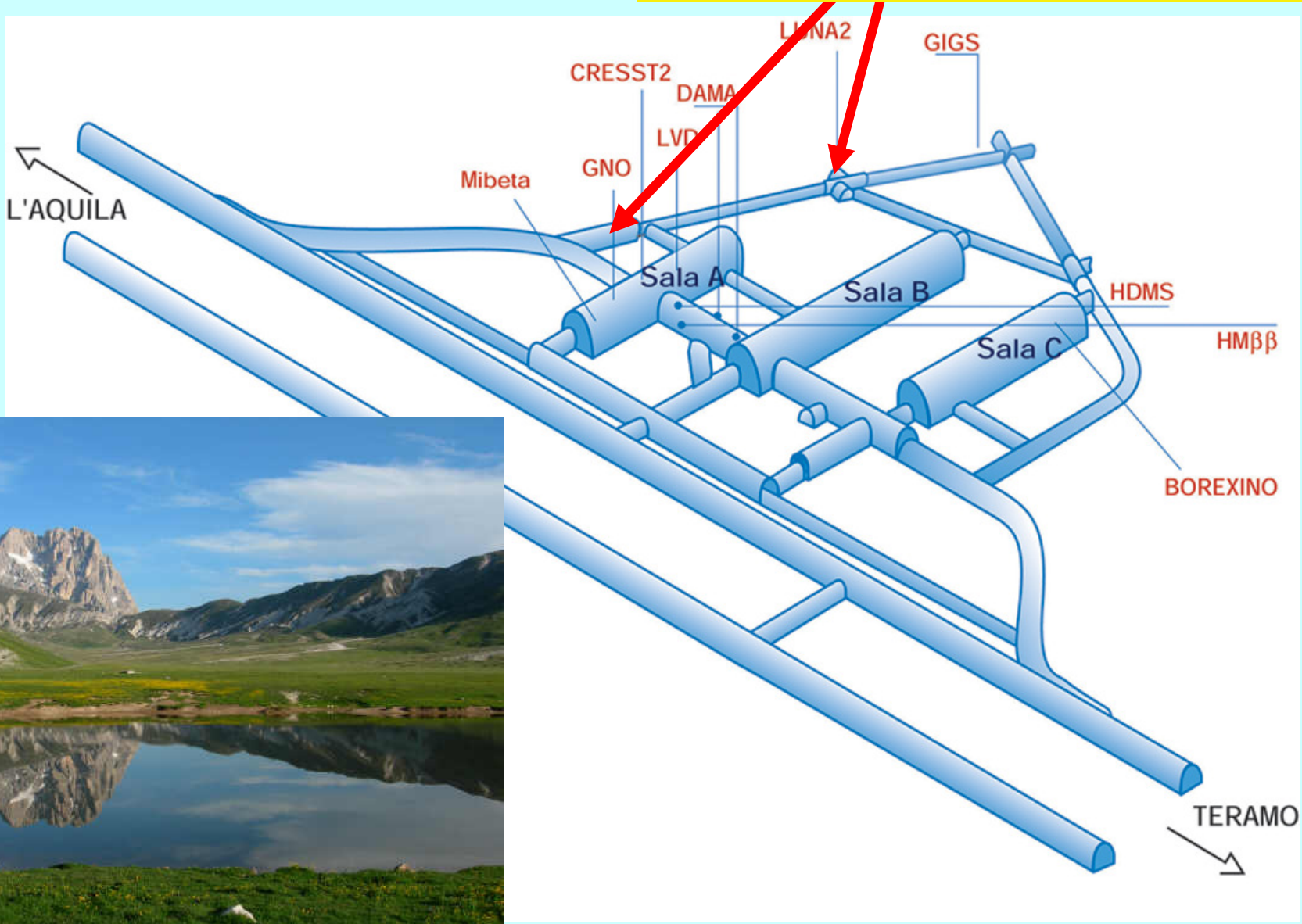
$$2\pi\eta = 31.29\, Z_1 Z_2 \sqrt{\mu/E} \qquad \mu = m_1 m_2 / (m_1+m_2)$$

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

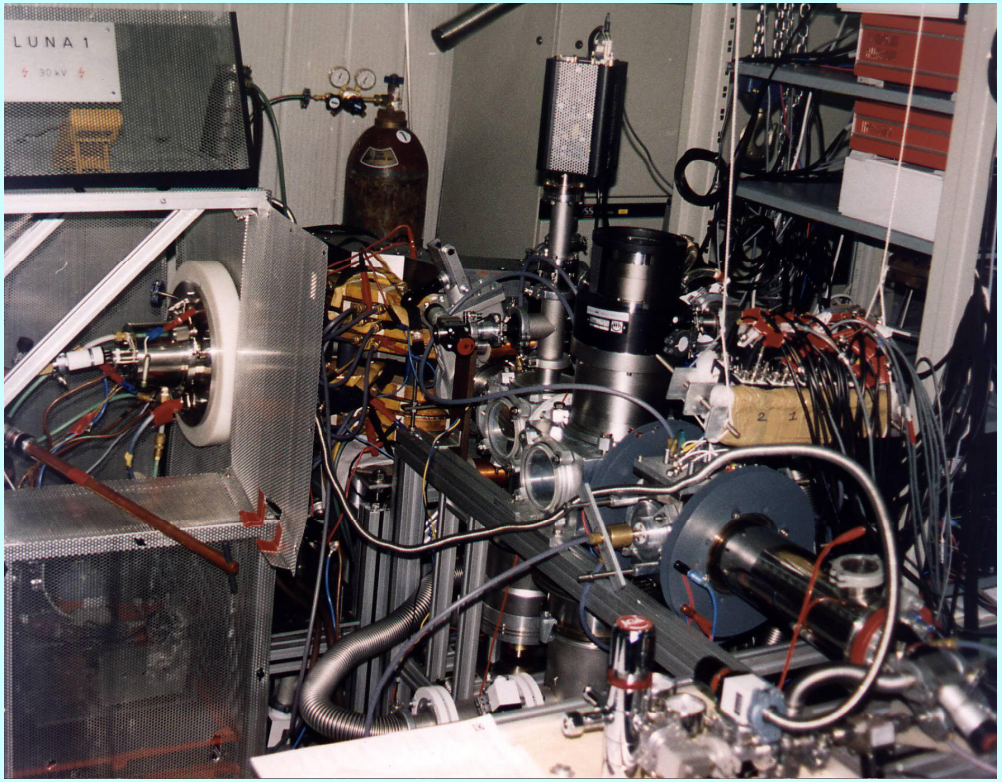




Laboratory for Underground Nuclear Astrophysics

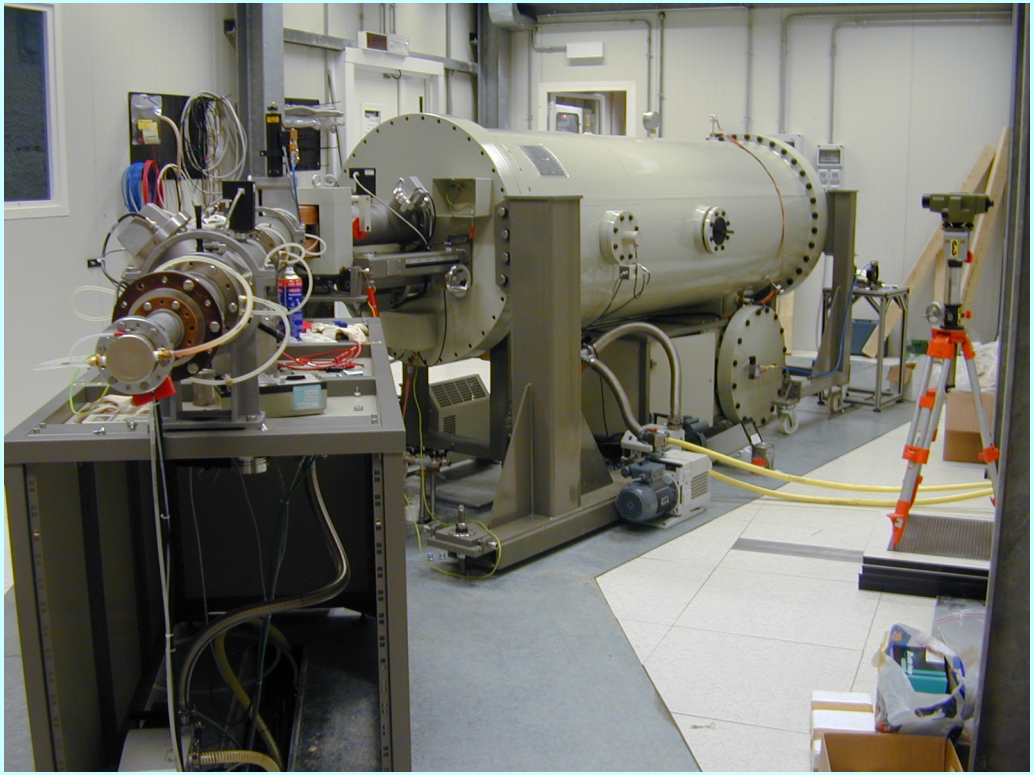


LUNA1 (50 kV)



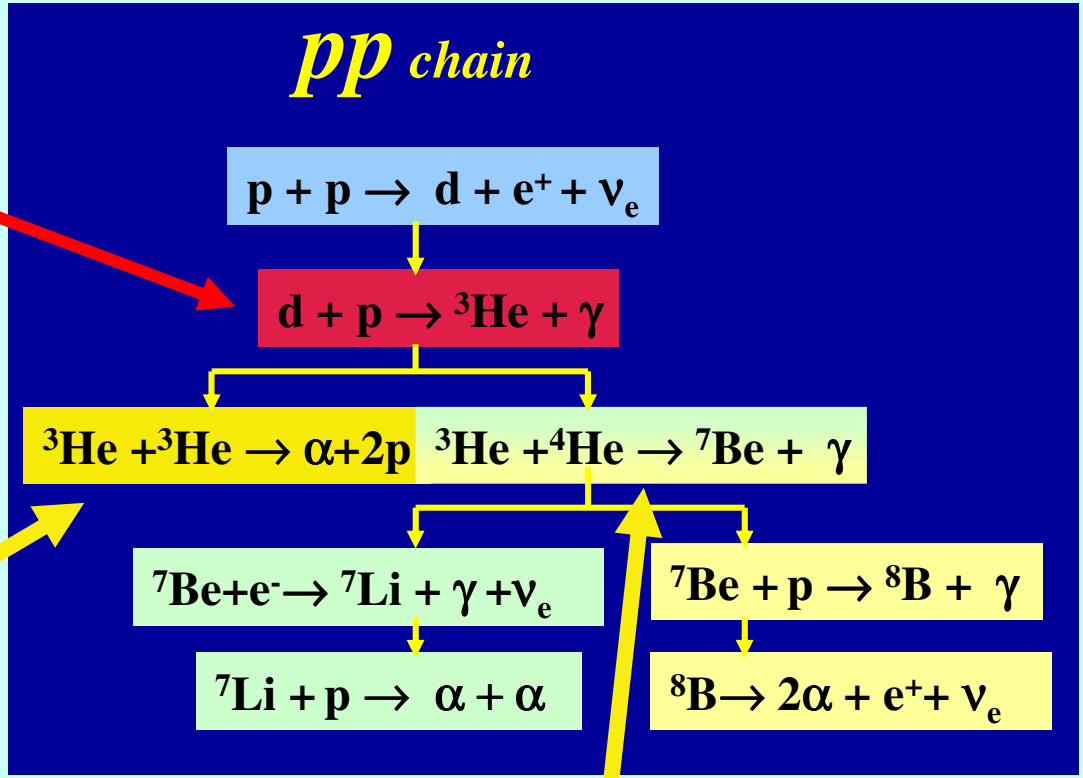
Voltage Range :
1 - 50 kV
Output Current:
1 mA
Beam energy spread:
20 eV
Long term stability (8 h):
10^{-4}
Terminal Voltage ripple:
$5\ 10^{-5}$

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

Proto-stars and BBN



In search of the resonance

7Be solar neutrino flux

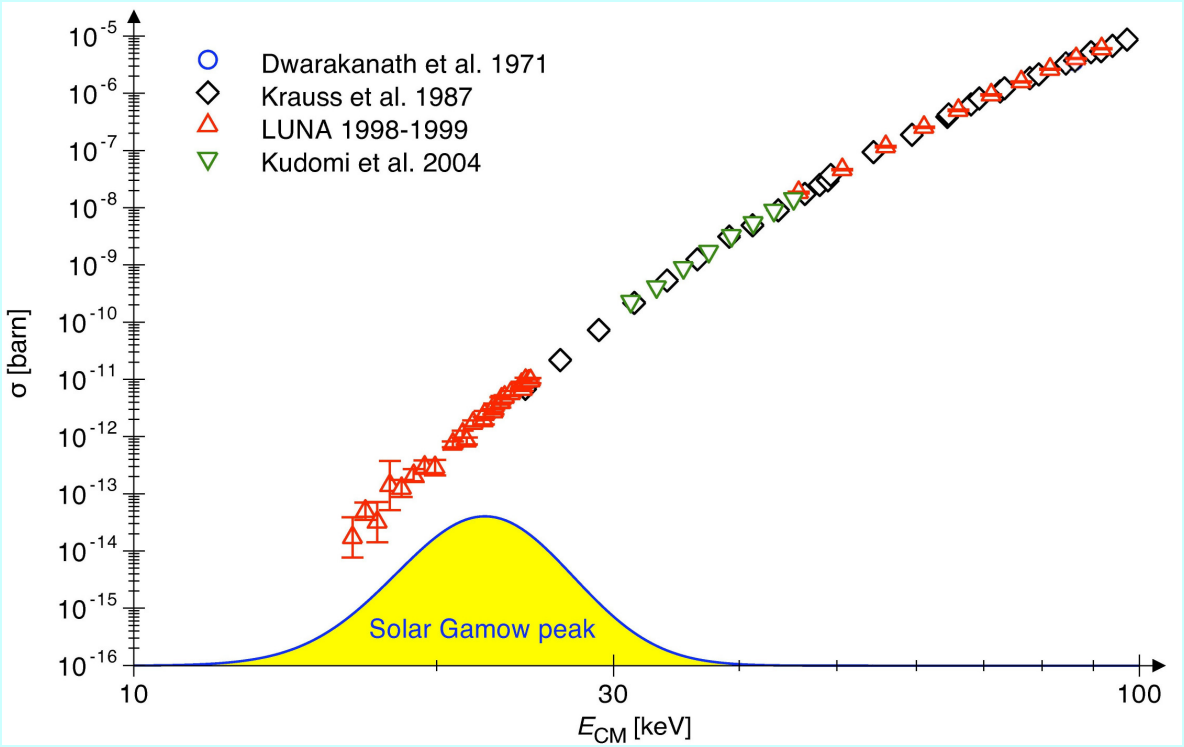
$^3He\ (^3He,2p)^4He$

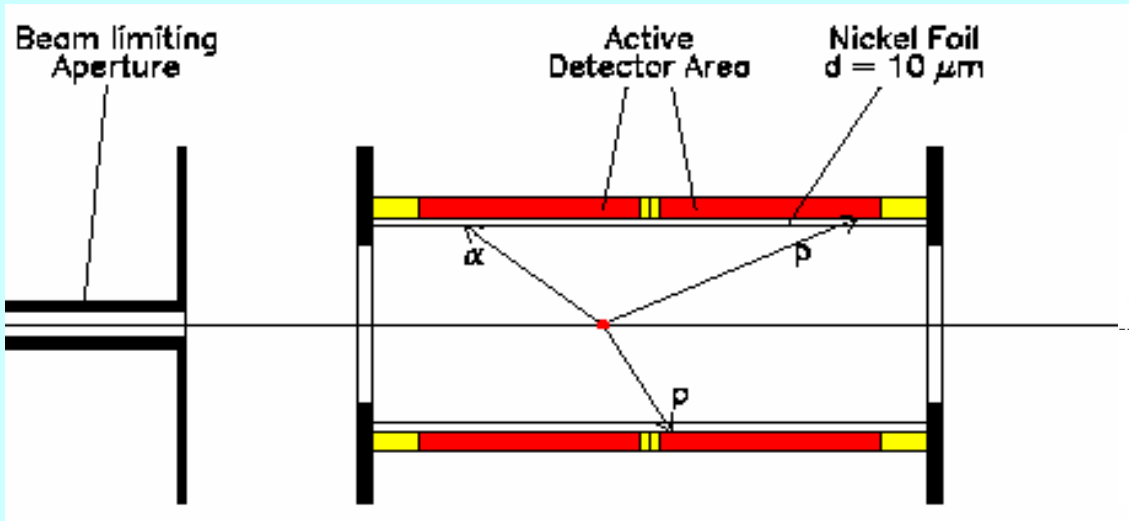
Q = 12.86 MeV

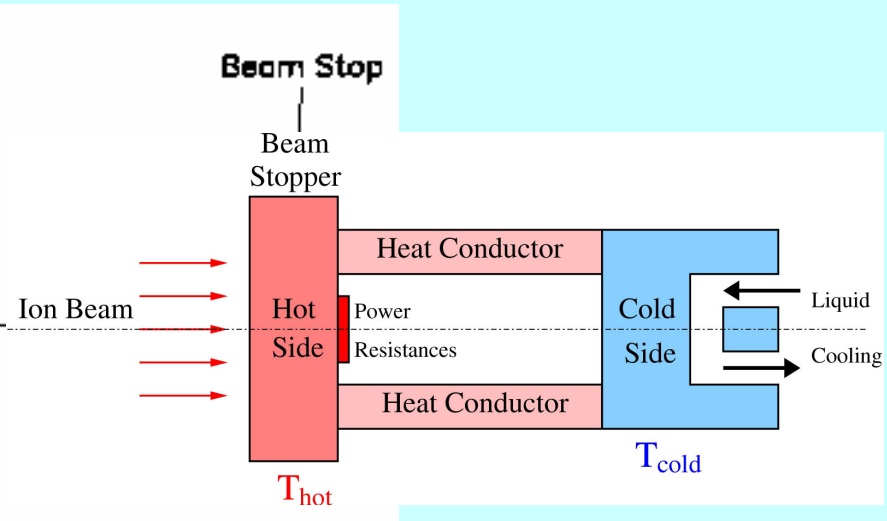
E_p^{max}= 10.7 MeV

Suppression of ^7Be and ^8B ν?

σ_{min} = 0.02 pb





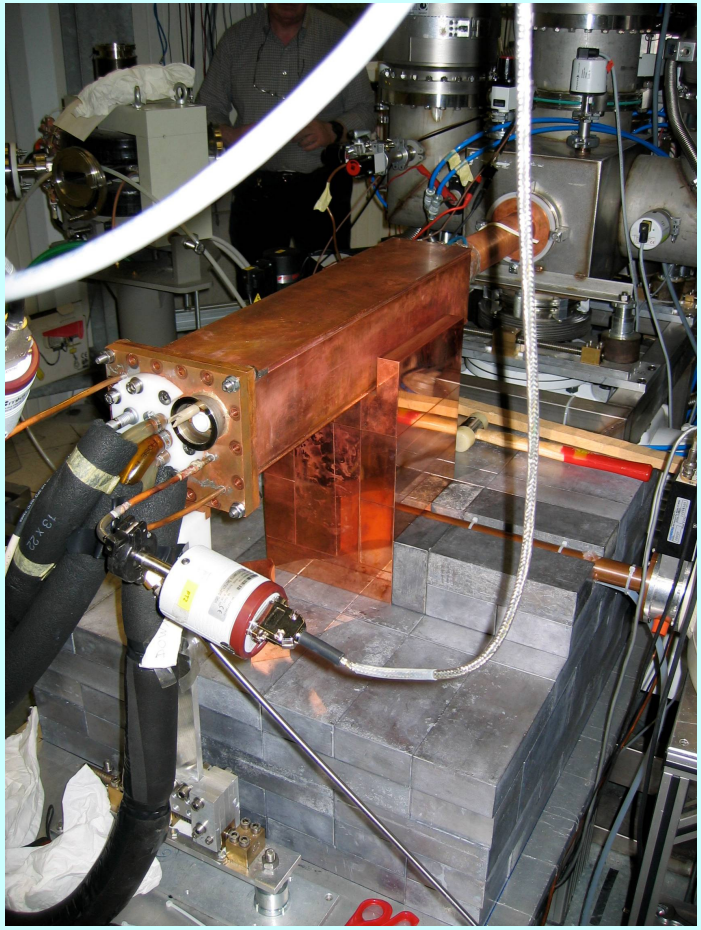


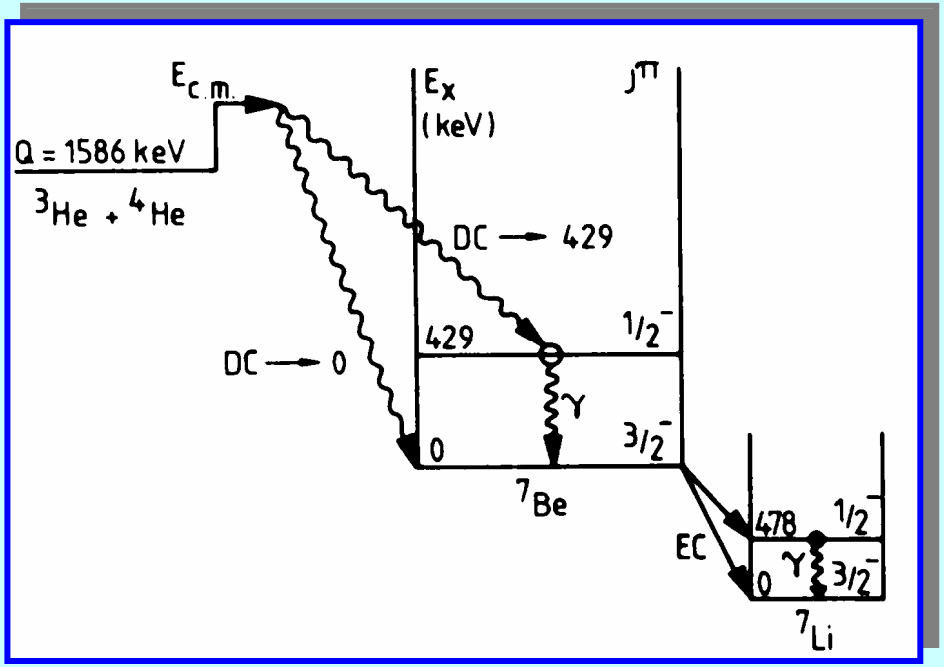
$^3He(\alpha,\gamma)^7Be$ Q=1.6 MeV

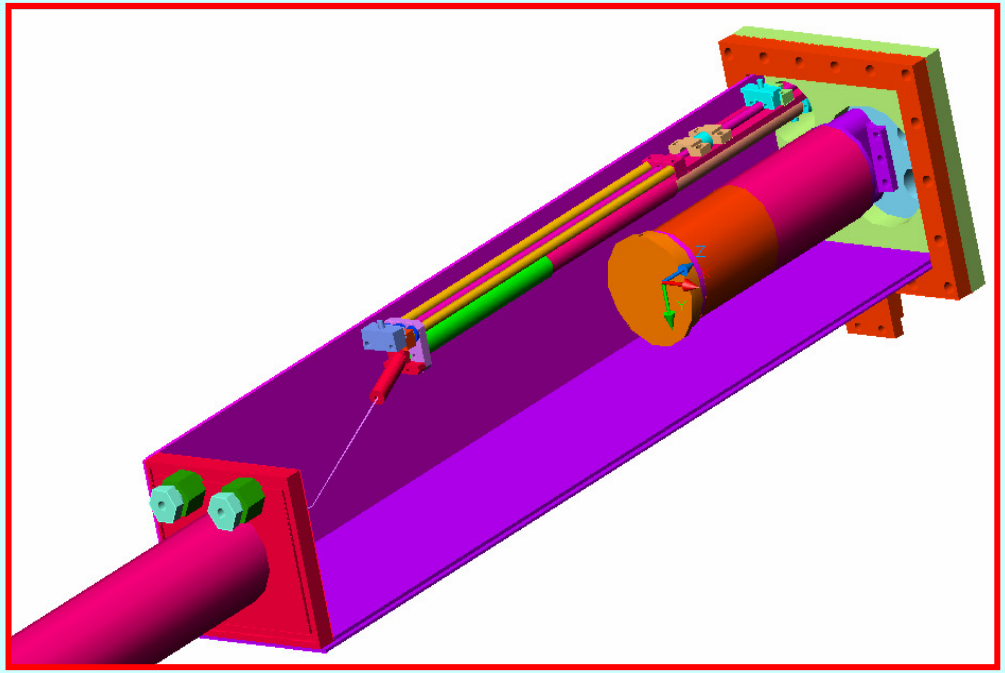
- Solar Neutrinos: ^7Be, ^8B

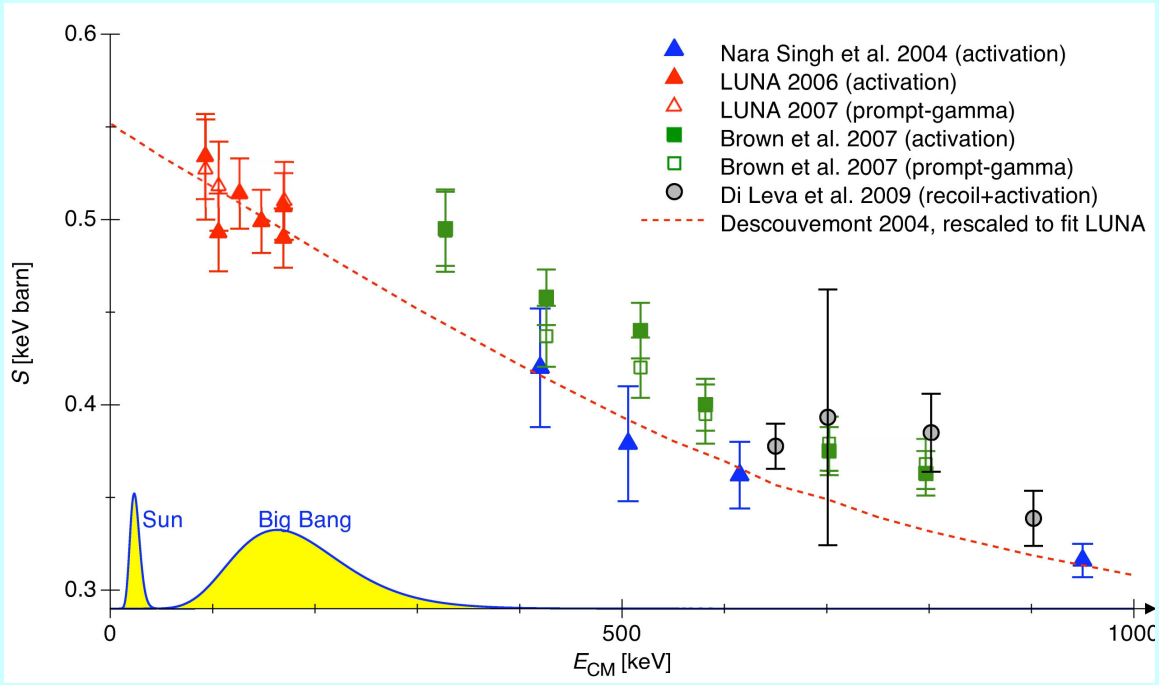
$$\Phi \sim S_{34}$$

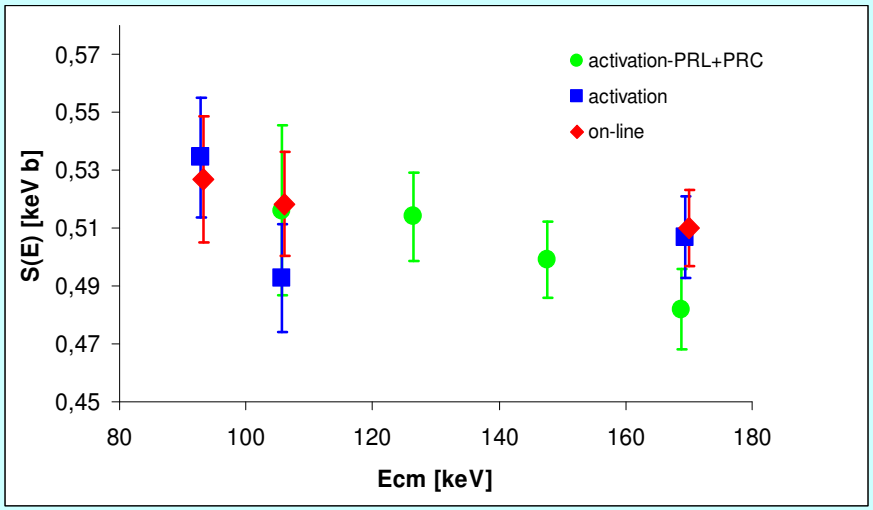
- BBN ^7Li











- σ down to 93 keV

  ^{7}Be ≈ prompt γ

- $S_{34}(0) = 0.567 \pm 0.018$ keV barn

$\Delta\Phi(\nu_B)$ reduced to 11%

$\Delta\Phi(\nu_{Be})$ reduced to 6% (dominant error source: opacity)

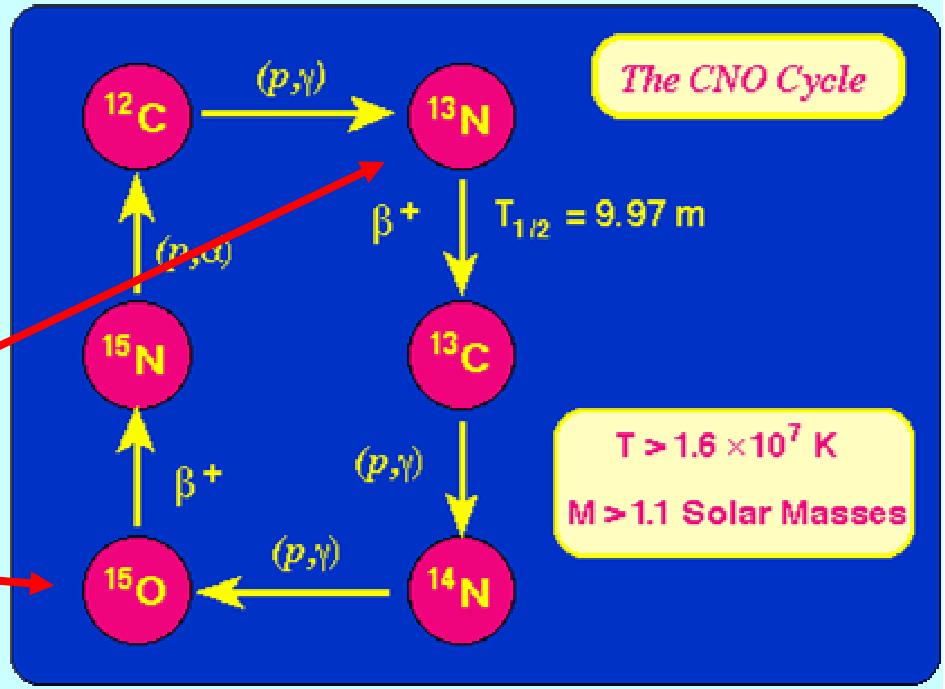
→ Borexino

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

Q=7.3 MeV

ν E<1.20 MeV

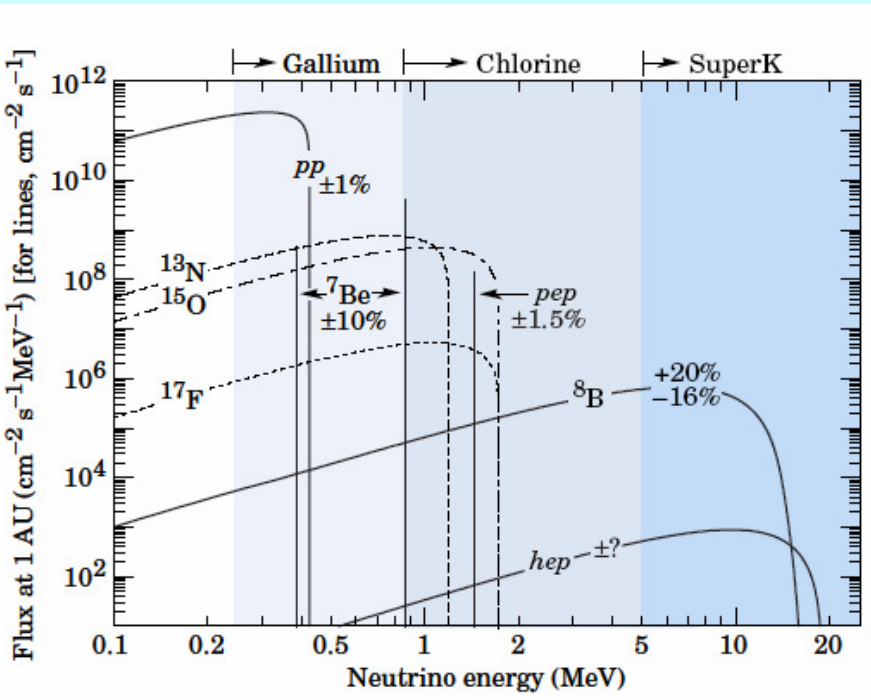
ν E<1.73 MeV



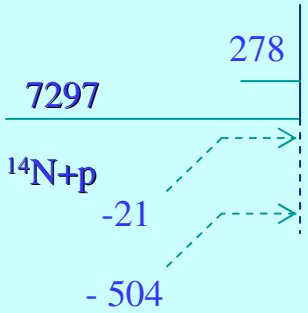
- $\nu_{cno}\ \Phi \sim S_{1,14}$
- **Globular Cluster Age**

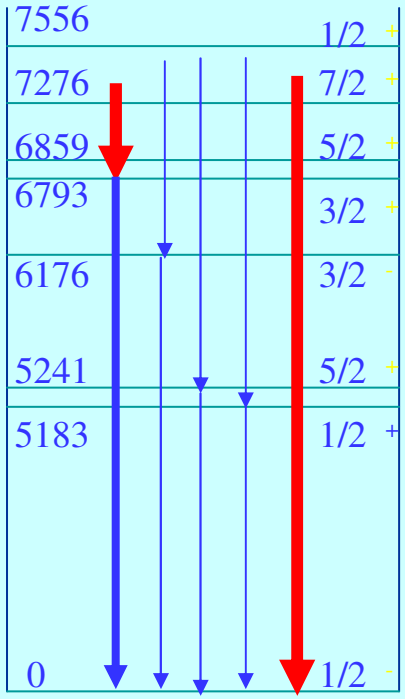
$S(0)=3.5_{-1.6}^{+0.4}$ keV b (Ad98)

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



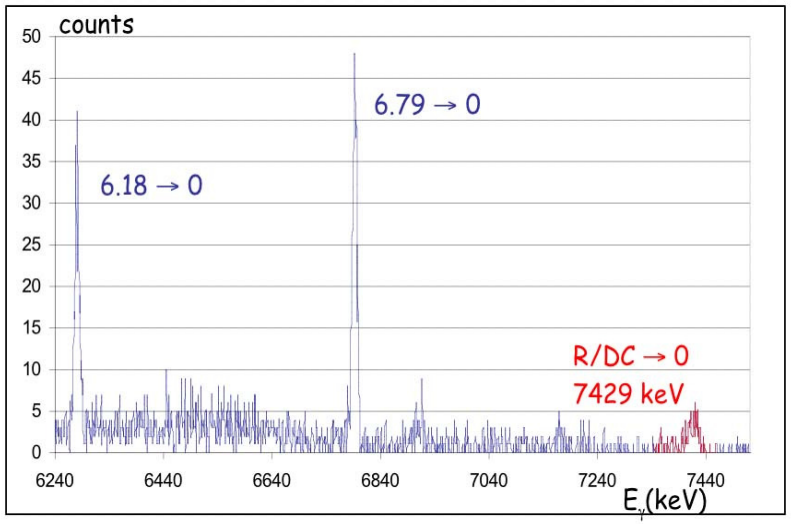
$^{14}N(p,\gamma)^{15}O$





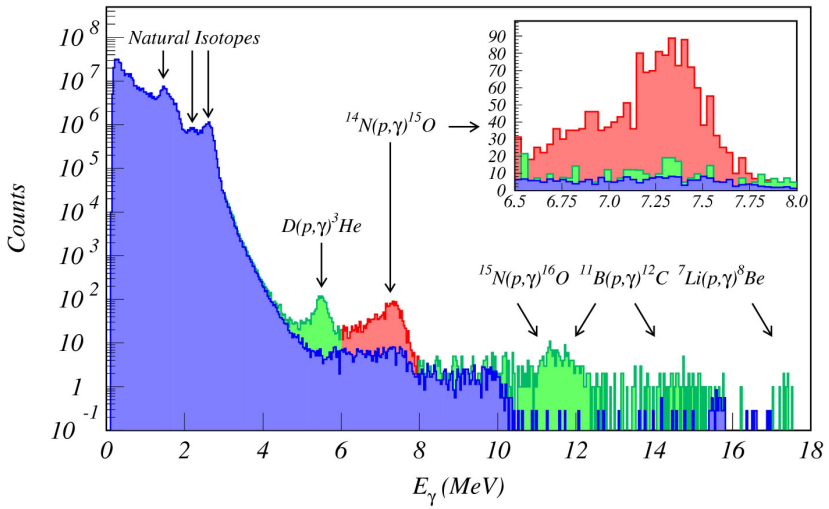
"High" energy: solid target + HpGe

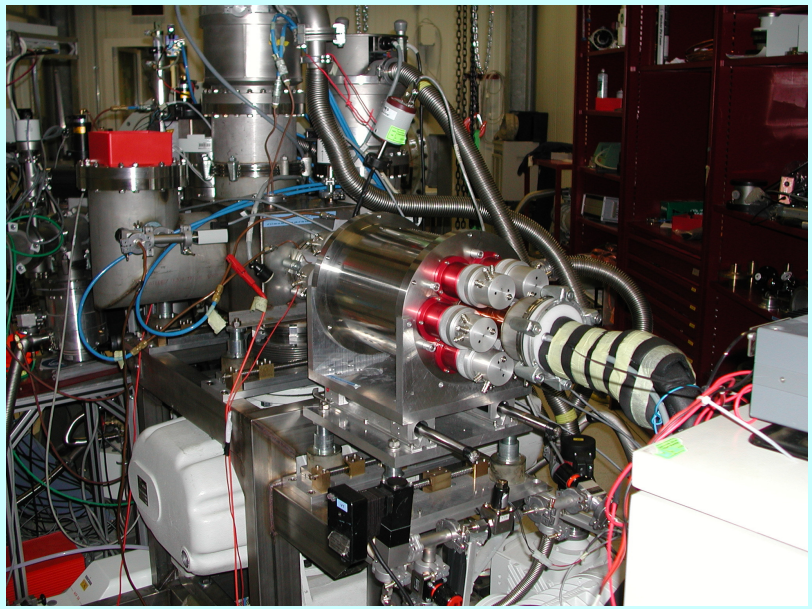
gamma spectrum of $^{14}N(p,\gamma)^{15}O$ at 140 keV beam energy

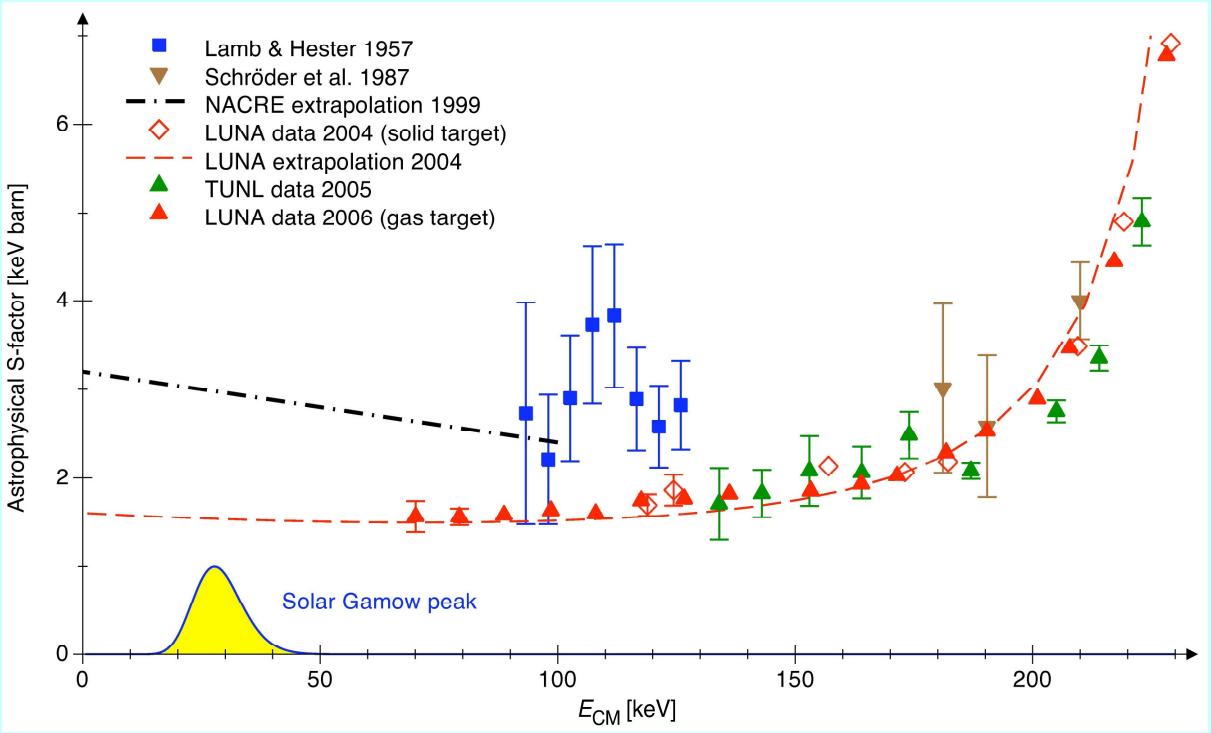


Low energy: gas target + BGO

beam energy 90 keV







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

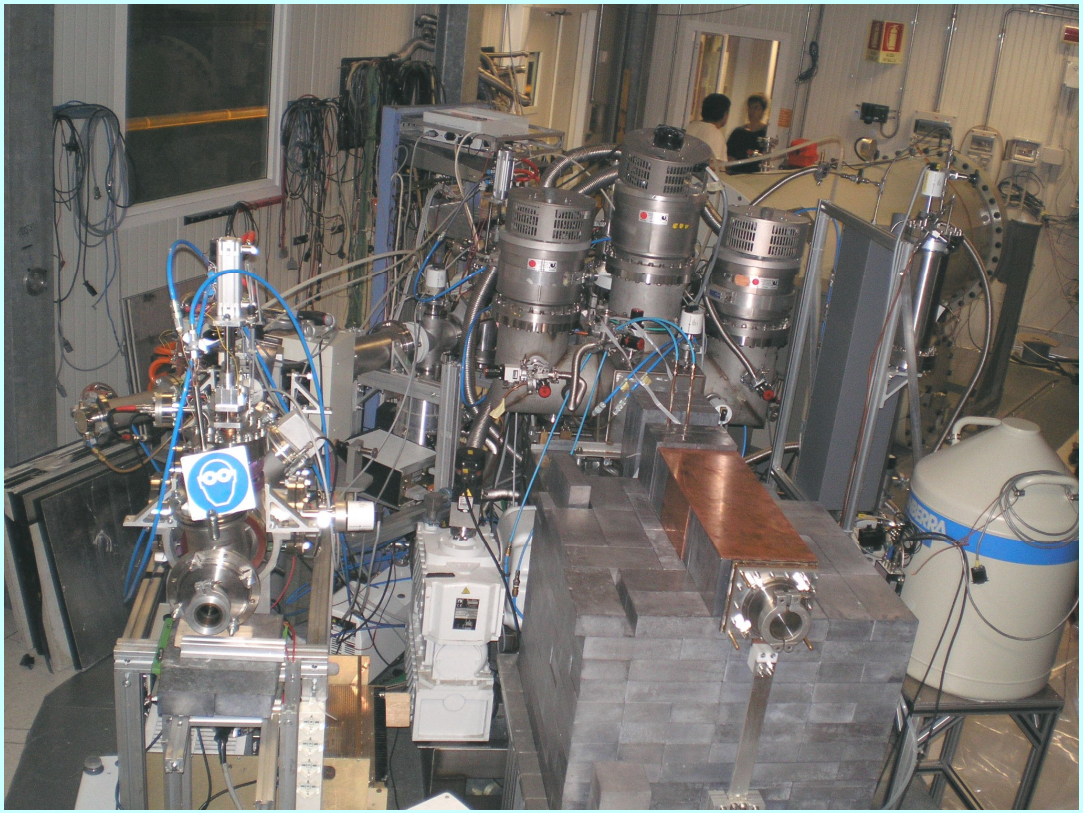
* $\frac{1}{2}\nu_{cno}$ from the Sun
* Globular cluster age
* C yield in AGB stars

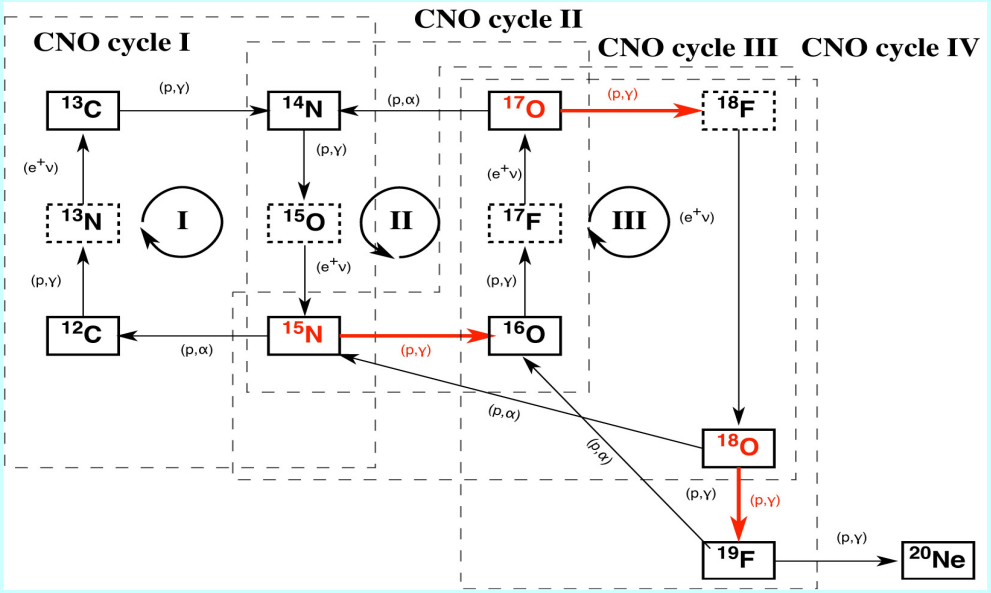
New study with a 'clover' detector of the capture to the ground state

→ $S_t(0)=1.57\pm0.13$ keV b

From a measurement of ν_{cno} from the Sun

→ Metallicity of the Sun core (C+N)
Photosphere and core metallicity equal?





Rich program of Nuclear Astrophysics:

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

$^{15}N(p,\gamma)^{16}O$ 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

. . . . . .

- ^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 to 6%

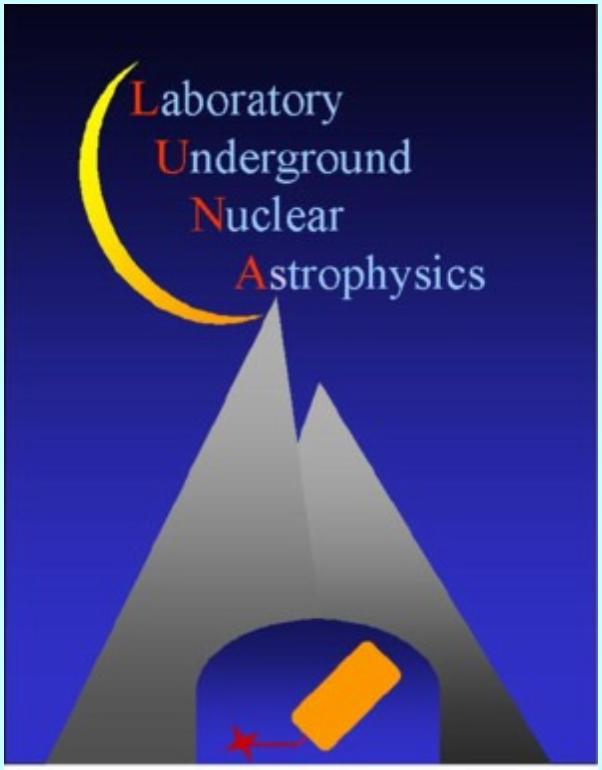
- $^{14}N(p,\gamma)^{15}O$: σ down to 70 keV

  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

LUNA



INFN - Laboratori Nazionali del Gran Sasso

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

- INFN : Genova, LNGS, Milano, Napoli, Padova, Torino
- Inst.Physik mit Ionenstrahlen, Ruhr-Universität Bochum
- Forschungszentrum Dresden-Rossendorf
- Atomki Debrecen