LUNA experiment – status and perspectives

Carlo Broggini
INFN-Padova

Laboratory
Underground
Nuclear
Astrophysics

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

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

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

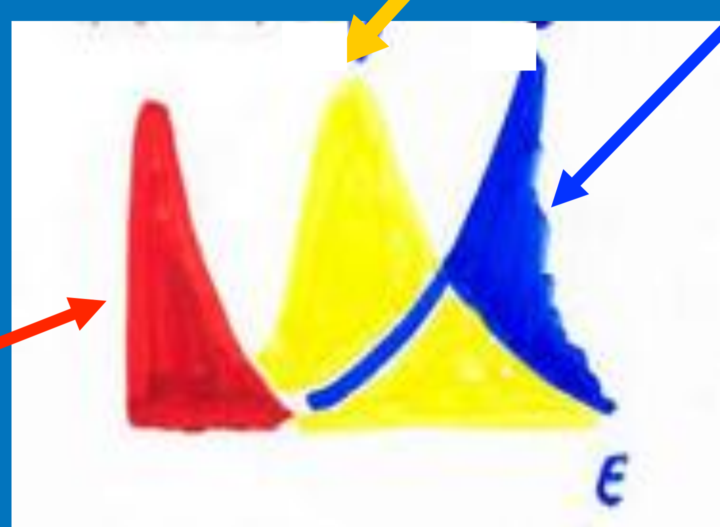
$$2\pi\eta = 31.29\, Z_1 Z_2 \sqrt{\mu/E} \qquad \mu = m_1 m_2/(m_1+m_2),\ E \text{ in keV}$$

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

Gamow Peak

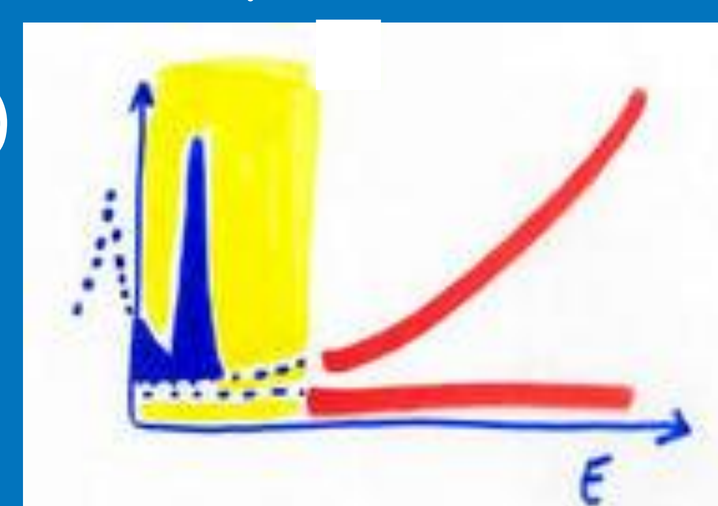
σ

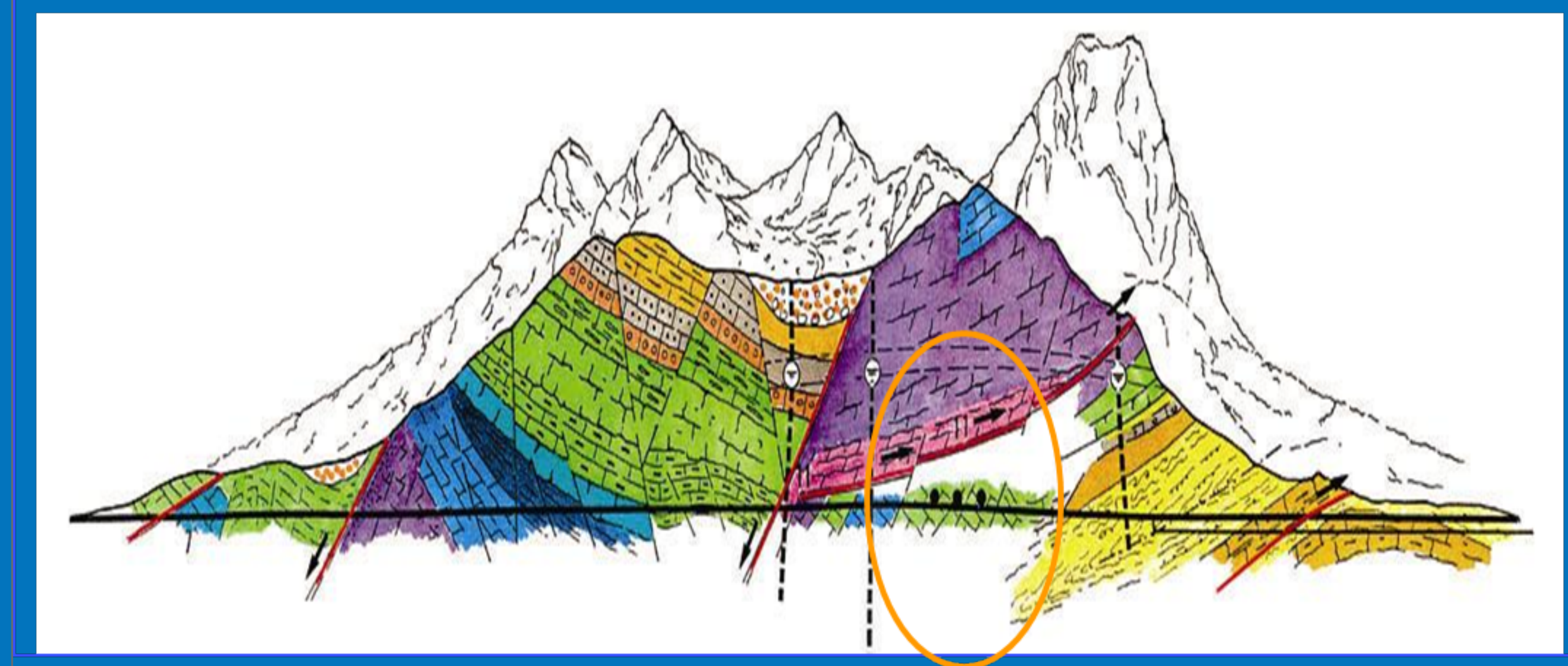
Maxwell Boltzmann



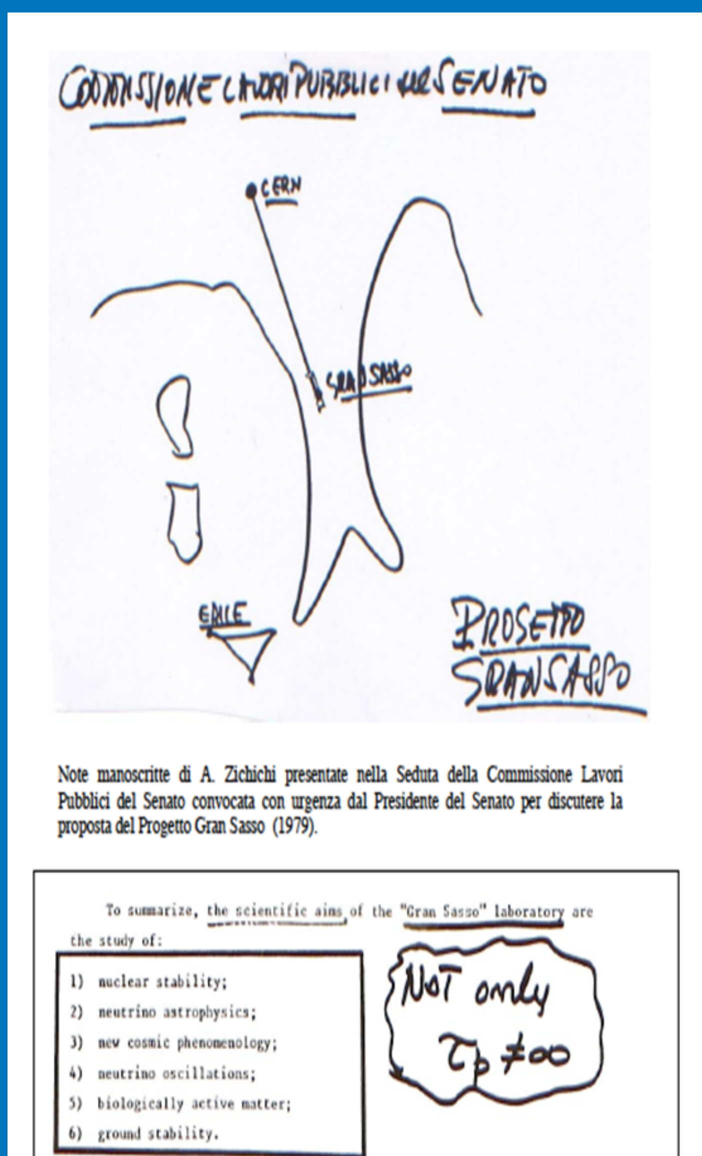
Extrap. ← Meas. →

S(E)





1979 proposed by A. Zichichi , 1989 MACRO experiment ON



Note manoscritte di A. Zichichi presentate nella Seduta della Commissione Lavori Pubblici del Senato convocata con urgenza dal Presidente del Senato per discutere la proposta del Progetto Gran Sasso (1979).

To summarize, the scientific aims of the "Gran Sasso" laboratory are the study of:

1) nuclear stability;
2) neutrino astrophysics;
3) new cosmic phenomenology;
4) neutrino oscillations;
5) biologically active matter;
6) ground stability.

NOT only $\tau_p \neq \infty$

1400 m of dolomite rock, $CaMg(CO_3)_2$, (~3800 m w.e.)
Surf.: 17 800 m^2, Vol.: 180 000 m^3, Ventilation: 1 vol / 3.5 hours
(Rn in air 20-80 Bq m^{-3})

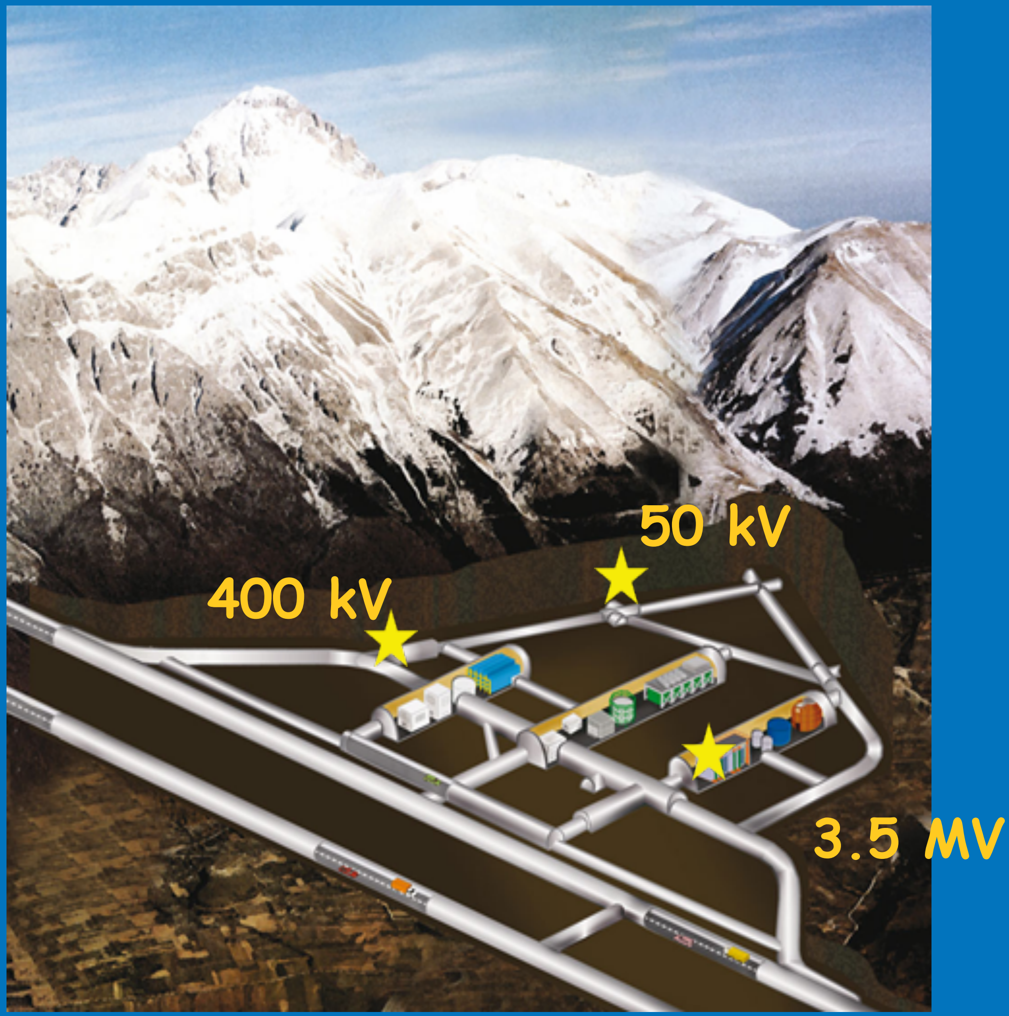
Muon flux: 1.1 $m^{-2}h^{-1}$, 6 orders of magnitude reduction

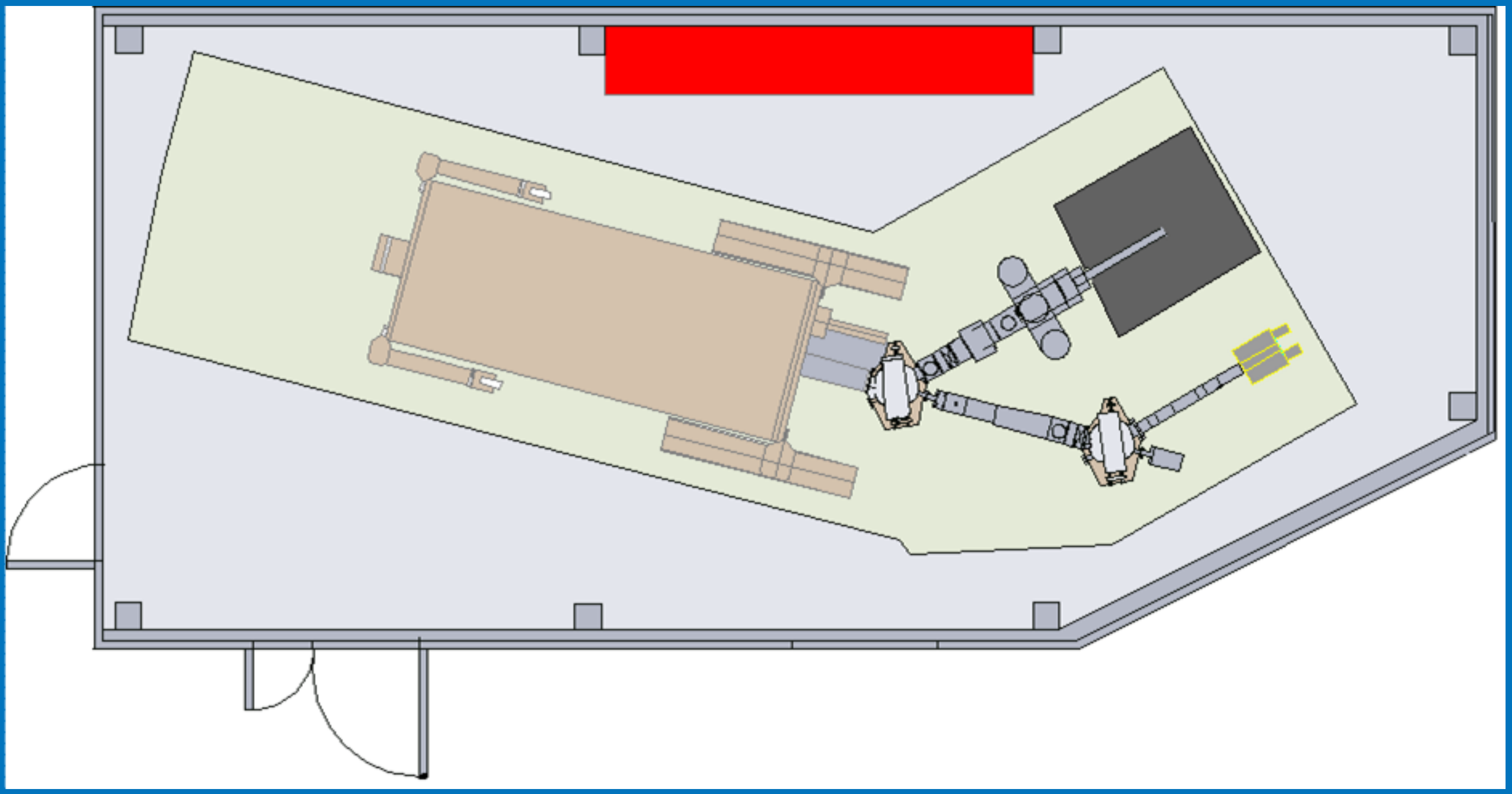
Neutron flux, mainly from (α,n): 2.92 10^{-6} $cm^{-2}s^{-1}$ (0-1 keV), 0.86 10^{-6} $cm^{-2}s^{-1}$ (> 1 keV), 3 orders of magnitude reduction

Gamma rays: only 1 order of magnitude reduction, but with thick shield about 5 orders of magnitude in the region of natural radioactivity and 4-5 orders above 3.2 MeV without any shield

Alpha particles: factor ~15 below 3 MeV (shielded Si detector)

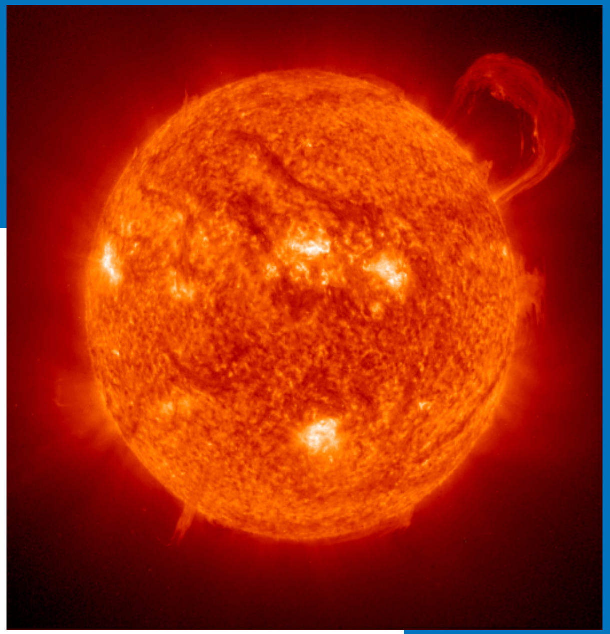
Laboratory for Underground Nuclear Astrophysics: LUNA





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

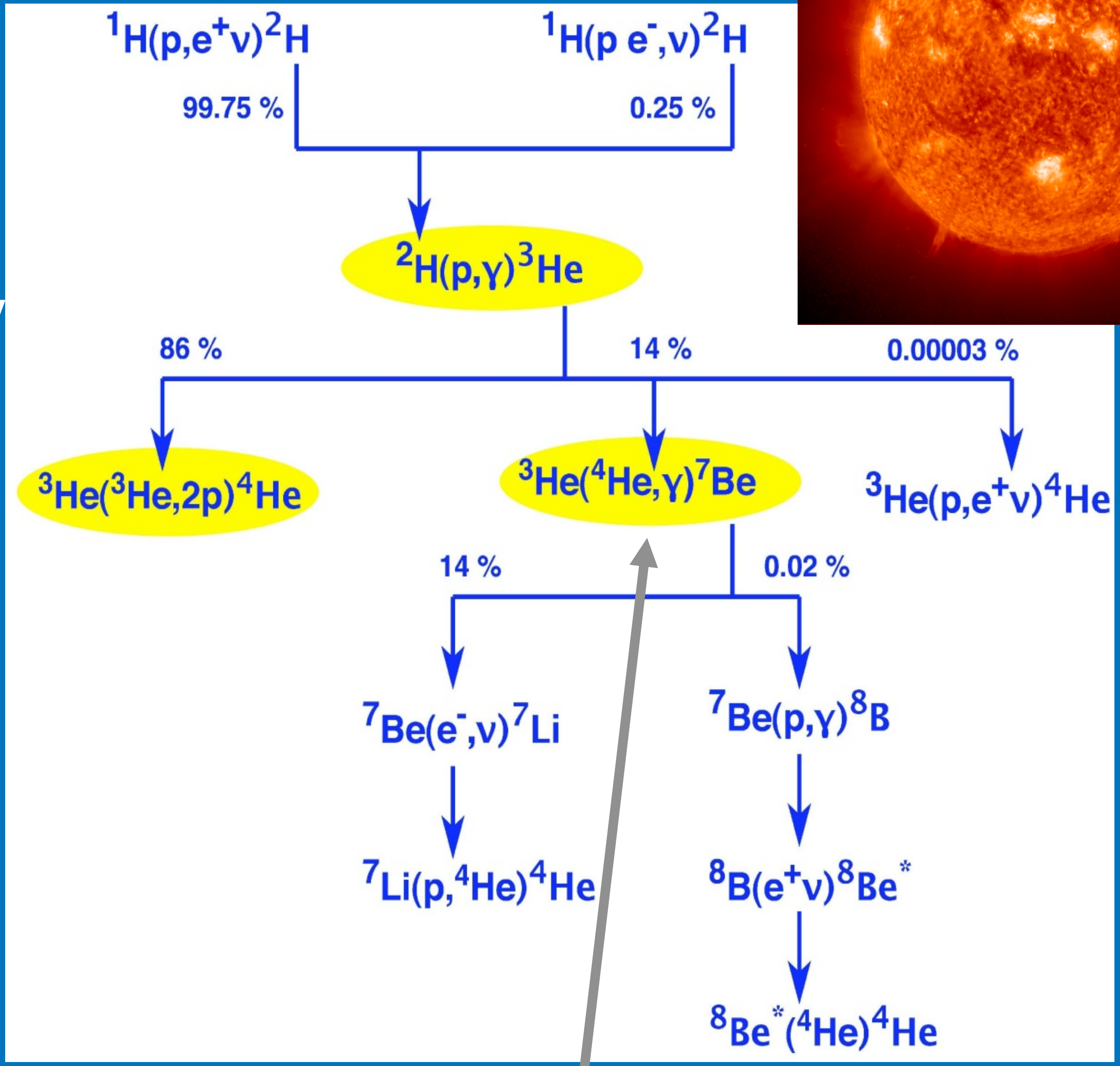
Hydrogen burning in the Sun @$15*10^6$ degrees:

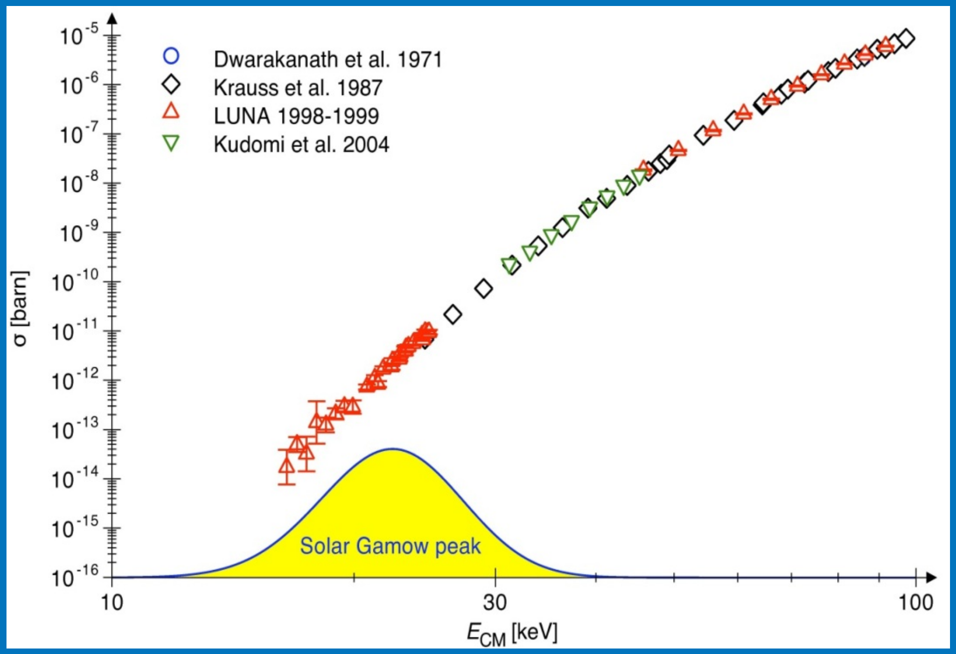


$6*10^{11}$ kg/s H $\longrightarrow$ He
+0.7% $M_H \longrightarrow$ E

$4H \rightarrow He + 2e^+ + 2\nu_e + 26.7$ MeV

^{3}He burning in the p-p chain



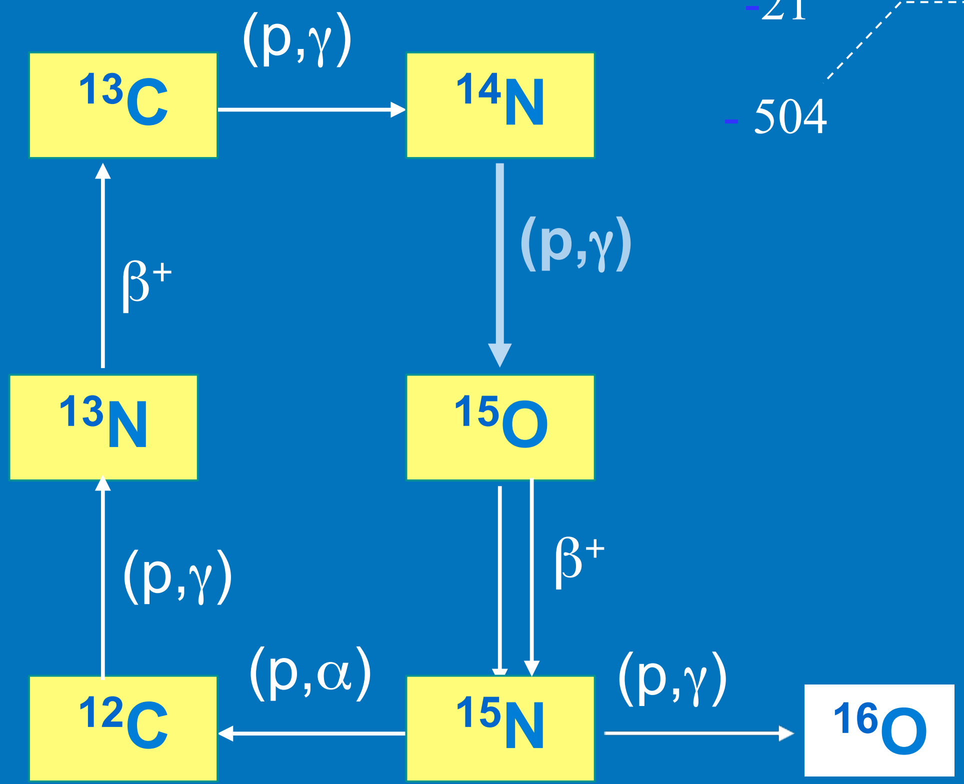


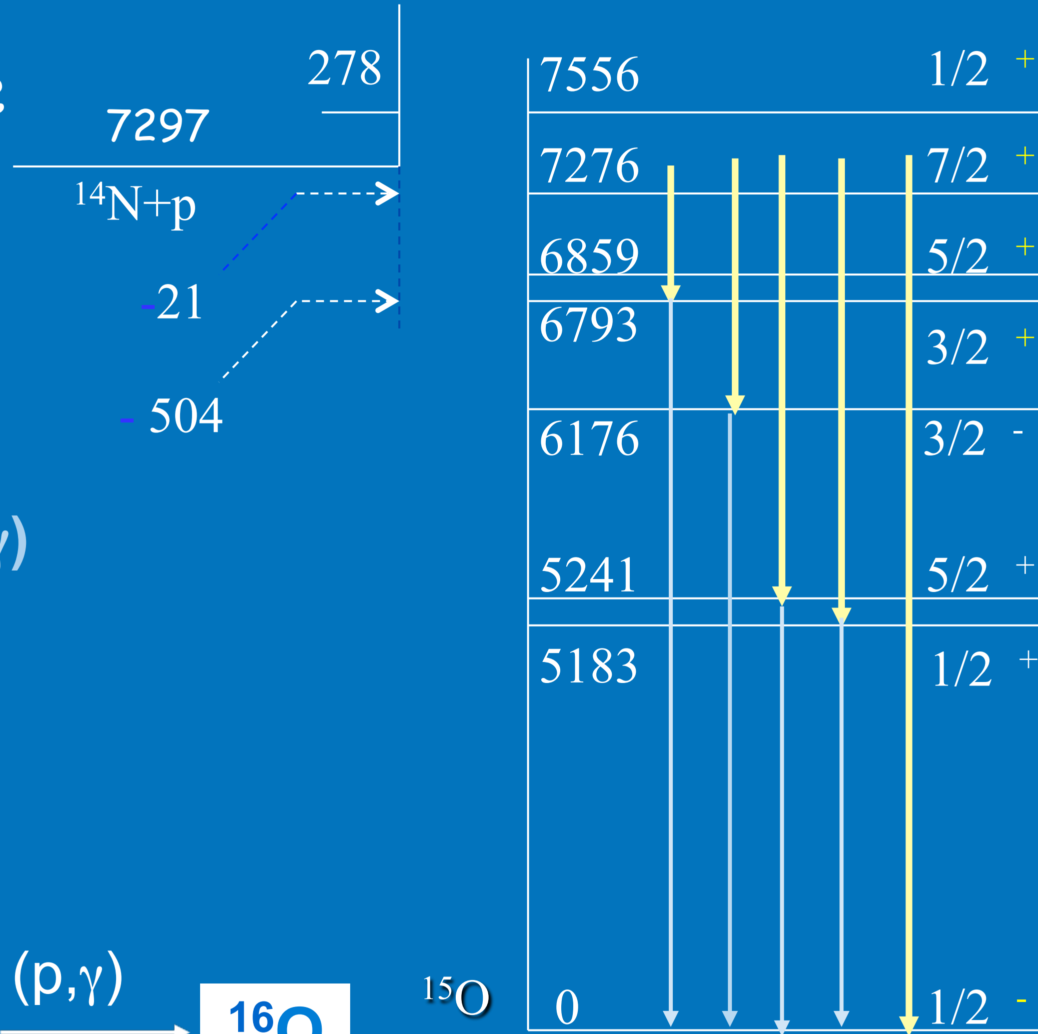
No ghost resonance @ solar Gamow peak

Activation=prompt gamma
no monopole contribution to σ
σ at low energy with 4% error

The CNO Cycle

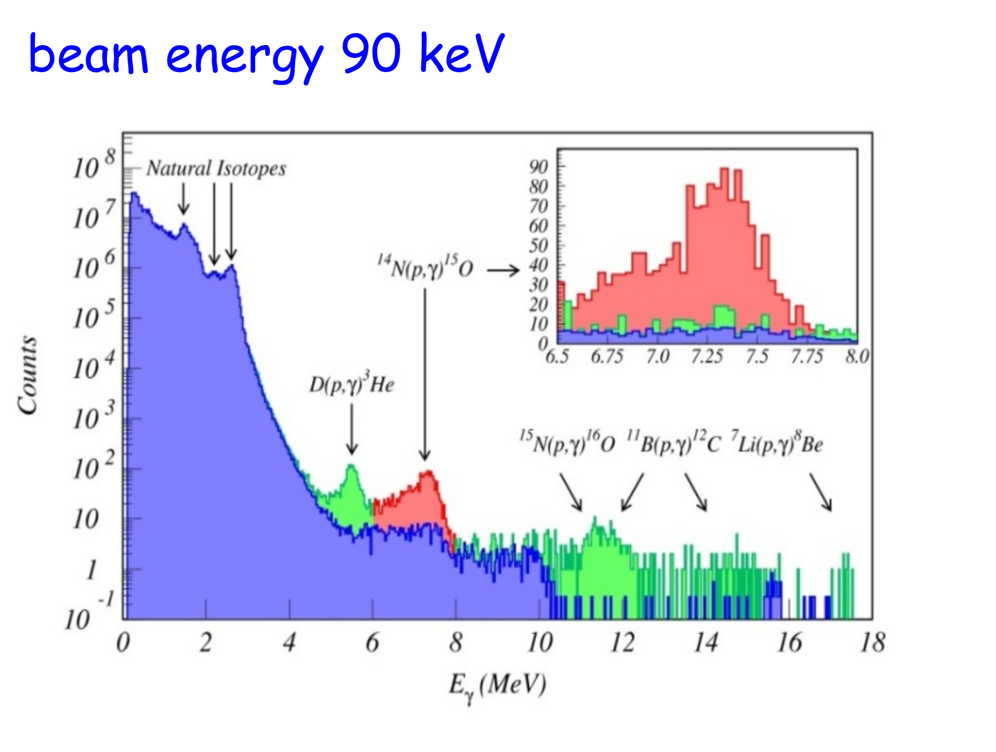
$^{14}N(p,\gamma)^{15}O$

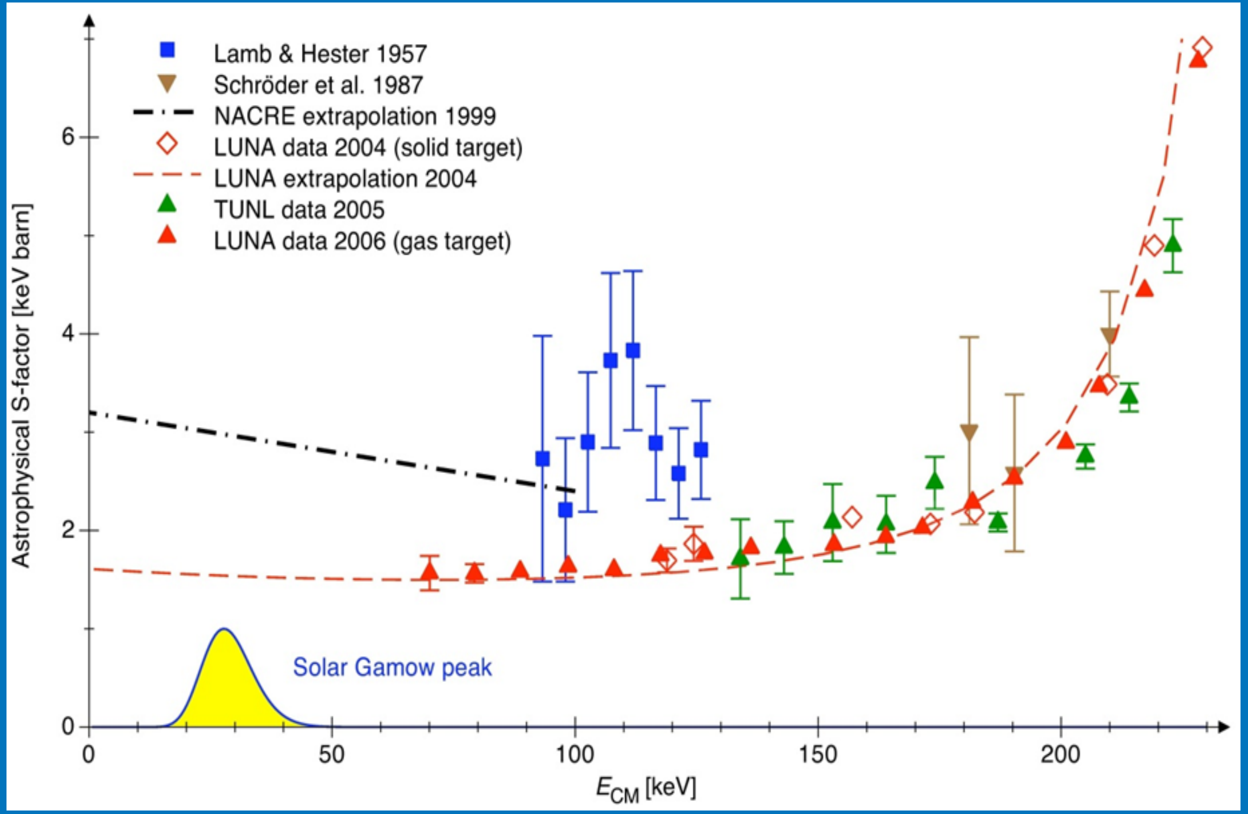




1) “High” energy: solid target + HpGe

2) Low energy: gas target + BGO



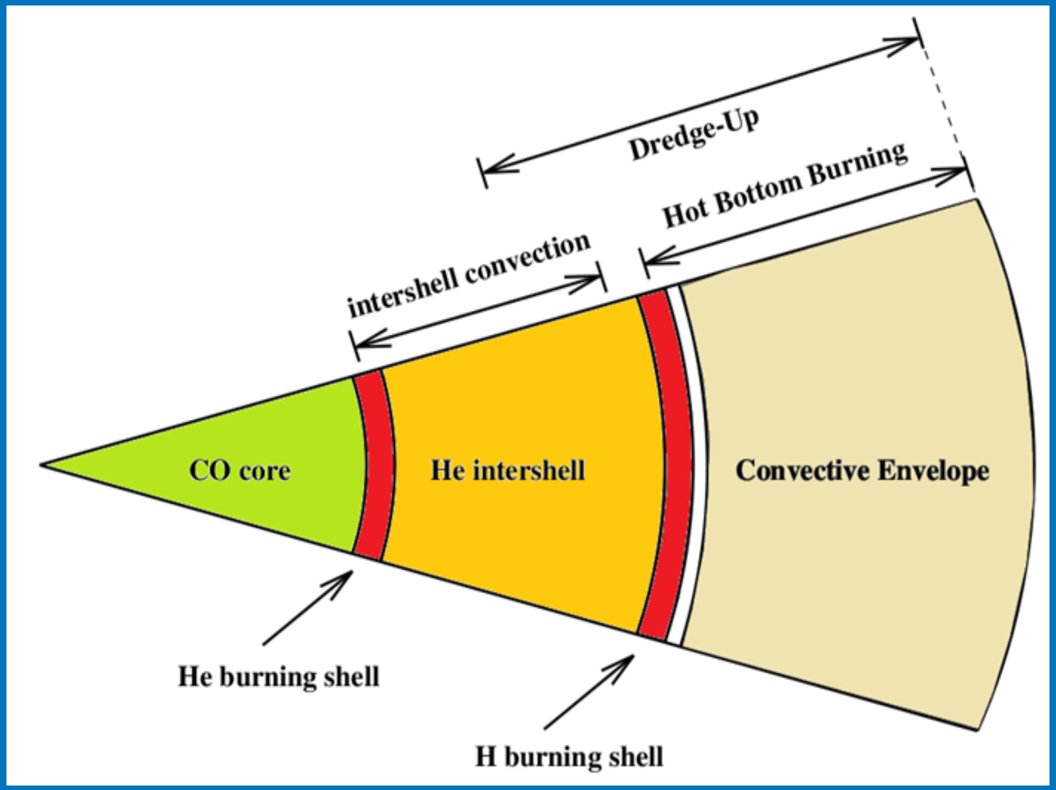


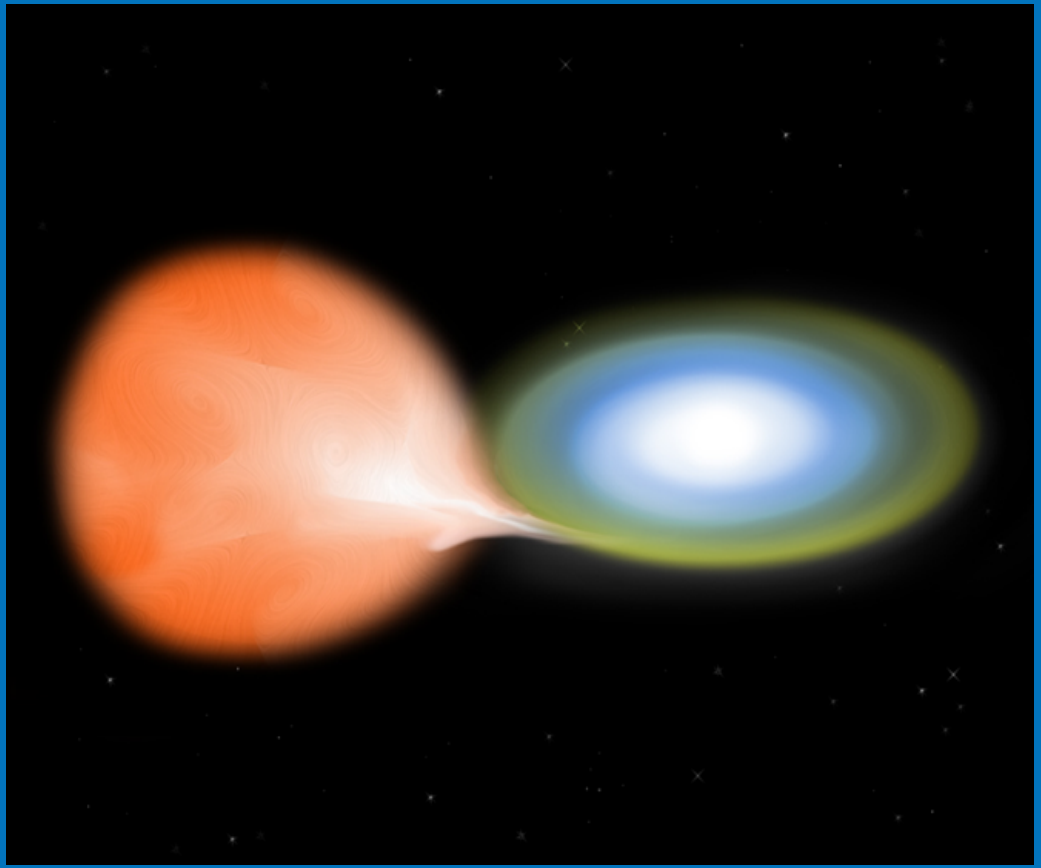
$S_t(0)=1.57\pm0.13$ keV b
as reported by indirect measurements
(Mukhamedzhanov et al. 2003)

* $\frac{1}{2}\nu_{cno}$ from the Sun
* Globular Cluster age +1Gy
* more C at the surface of AGB stars

$\nu_{cno} = F(S_{1,14}, Z_{core})$
probe of the metallicity Z of the Sun core

LUNA beyond the Sun: isotope production in the hydrogen burning shell of AGB stars (~30-100 T_6), Nova nucleosynthesis (~100-400 T_6) and BBN





Nova Cigni 1992

Isotopic abundances: how and where

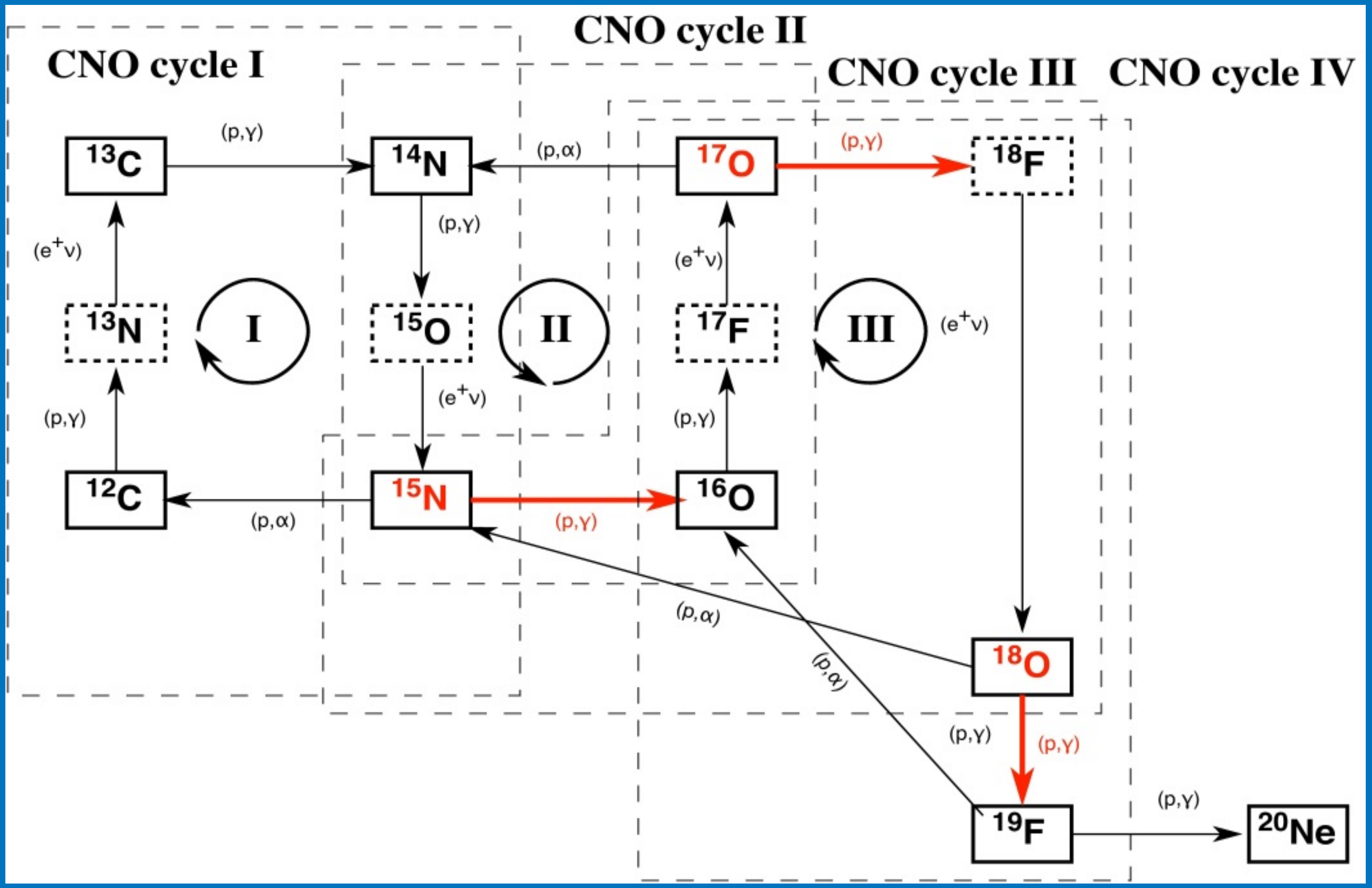
$^{15}N(p,\gamma)^{16}O$ Q=12.13 MeV

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

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

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

$^{17}O(p,\alpha)^{14}N$ Q=1.2 MeV



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

$^{18}O(p,\alpha)^{15}N$ Q=4.0 MeV

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

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

- First measurement of the 92 keV resonance in ^{25}Mg(p, **g**)^{26}Al, ωγ=(2.9±0.6)x 10^{-10}eV. Production of $^{26}Al^{gs}$ in H-burning regions is less efficient than previously obtained (Sky Map @ 1.8 MeV)

- Uncertainty on ^{16}O, ^{17}O, ^{18}O and ^{19}F at Nova temperature less than 10% (from 40-50%)

- First measurement of ^{2}H(α,**g**)^{6}Li at the BBN energies: ^{6}Li/^{7}Li =(1.5±0.3)*10^{-5}, no nuclear solution to the primordial ^{6}Li problem

A bridge towards LUNA-MV with the 400 kV accelerator (2015-2018):

^{2}H(p,γ)^{3}He – ^{2}H production in BBN

^{22}Ne(a,γ)^{26}Mg – competes with ^{22}Ne(a,n)^{25}Mg neutron source

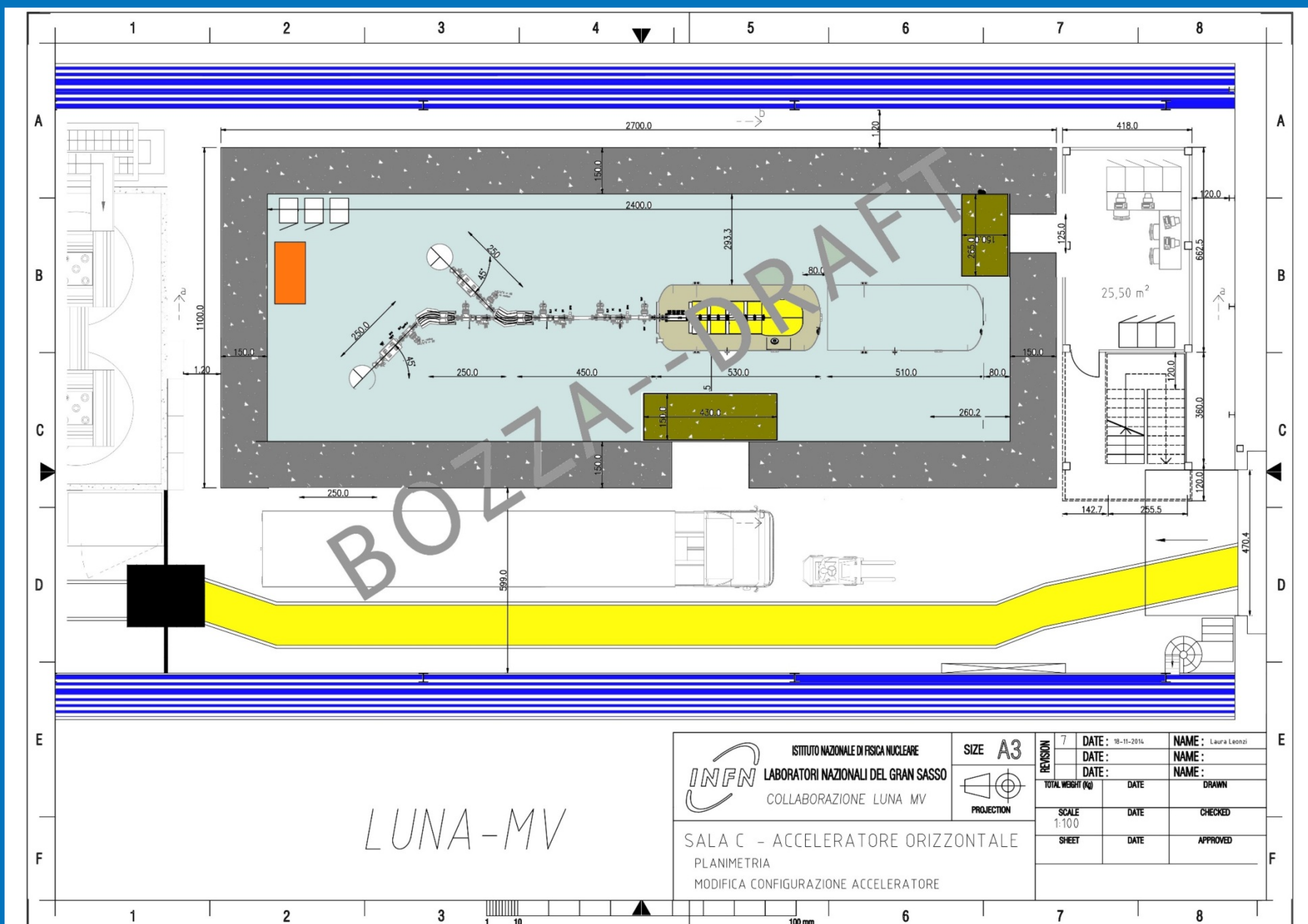
^{6}Li(p,γ)^{7}Be – low energy resonance?

^{13}C(a,n)^{16}O – neutron source for the S-process

^{12}C(p,γ)^{13}N and **^{13}C(p,γ)^{14}N** – ^{12}C/^{13}C in the deepest layers of H-rich envelopes of any star

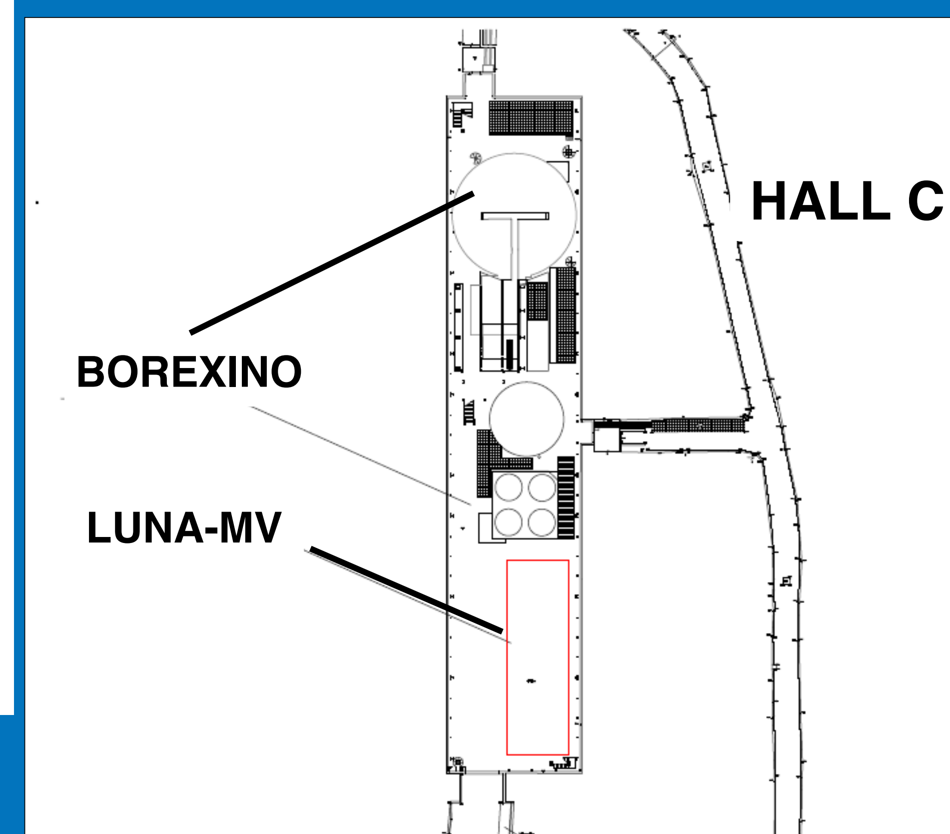
A new accelerator, LUNA-MV, will be installed in Hall C of LNGS (Opera space) and tested by July 2018. New LUNA hall: 27x11x5 m^3

Intense H^+, $^4He^+$, $^{12}C^+$ e $^{12}C^{++}$ beams in the energy range: 0.3 MeV-3.5 (7) MeV



Laboratory for Underground Nuclear Astrophysics

LUNA MV



3.5 MV accelerator mainly devoted to:

Helium-Burning (in stars: ~100 T_6, ~10^5 gr/cm^3)

$^{12}C(\alpha,\gamma)^{16}O$ the most important reaction of nuclear astrophysics: production of the elements heavier than A=16, star evolution from He burning to the explosive phase (core collapse and thermonuclear SN) and ratio C/O

Sources of the neutrons responsible for the S-process: 50% of the elements beyond Iron

$^{13}C(\alpha,n)^{16}O$: isotopes with A≥90 during AGB phase of low mass stars

$^{22}Ne(\alpha,n)^{25}Mg$: isotopes with A<90 during He and C burning in massive stars

Carbon-Burning (~500 T_6, ~$3\cdot10^6$ gr/cm^3)

$^{12}C(^{12}C,\alpha)^{20}Ne$, $^{12}C(^{12}C,p)^{23}Na$

+ (α,γ) on ^3He, ^{14}N, ^{15}N, ^{18}O……

- $^3He(^3He,2p)^4He$: σ down to 16 keV
  no resonance within the solar Gamow Peak

- $^3He(\alpha,g)^7Be$: $^7Be \approx$ prompt g cross section measured with 4% error

- $^{14}N(p,\gamma)^{15}O$: σ down to 70 keV
  ν_{cno} reduced by ~ 2 with 8% error ⟶ Sun core metallicity
  Globular cluster age increased by 0.7-1 Gy
  More carbon at the surface of AGB stars

- $^{25}Mg(p,\gamma)^{26}Al$: first measurement of the 92 keV resonance,
  strength $\omega\gamma=(2.9\pm0.6)\times 10^{-10}$ eV

- Uncertainty on ^{16}O, ^{17}O, ^{18}O and ^{19}F from Novae less than 10%

- $^2H(\alpha,g)^6Li$: no nuclear solution to the ^6Li problem

- Future: Helium and Carbon burning with the new 3.5 MV accelerator

The LUNA collaboration

- A. Best, A. Boeltzig*, A. Formicola, S. Gazzana, I. Kochanek, M. Junker, L. Leonzi I INFN LNGS /*GSSI, Italy
- D. Bemmerer, M. Takacs, T. Szucs I HZDR Dresden, Germany
- C. Broggini, A. Caciolli, R. Depalo, R. Menegazzo, D. Piatti I Università di Padova and INFN Padova, Italy
- C. Gustavino I INFN Roma1, Italy
- Z. Elekes, Zs. Fülöp, Gy. GyurkyI MTA-ATOMKI Debrecen, Hungary
- O. Straniero I INAF Osservatorio Astronomico di Collurania, Teramo, Italy
- F. Cavanna, P. Corvisiero, F. Ferraro, P. Prati, S. Zavatarelli I Università di Genova and INFN Genova, Italy
- A. Guglielmetti, D. Trezzi I Università di Milano and INFN Milano, Italy
- A. Di Leva, G. Imbriani, I Università di Napoli and INFN Napoli, Italy
- G. Gervino I Università di Torino and INFN Torino, Italy
- M. Aliotta, C. Bruno, T. Davinson I University of Edinburgh, United Kingdom
- G.F. Ciani*, G. D’Erasmo, E.M. Fiore, V. Mossa, F. Pantaleo, V. Paticchio, R. Perrino, L. Schiavulli, A. ValentiniI Università di Bari and INFN Bari, Italy