LUNA: from Sun to Novae and beyond

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

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

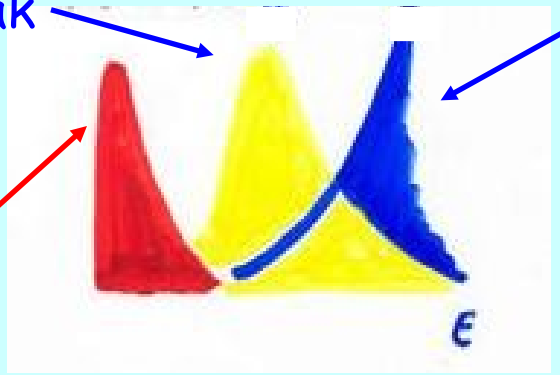
$$\sigma(E) = S(E)\, e^{-2\pi\eta}\, E^{-1}$$

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

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

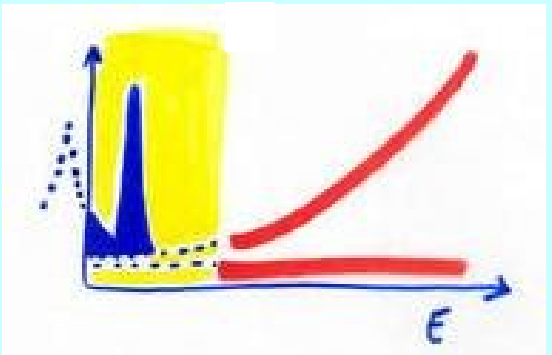
Gamow Peak

Maxwell Boltzmann

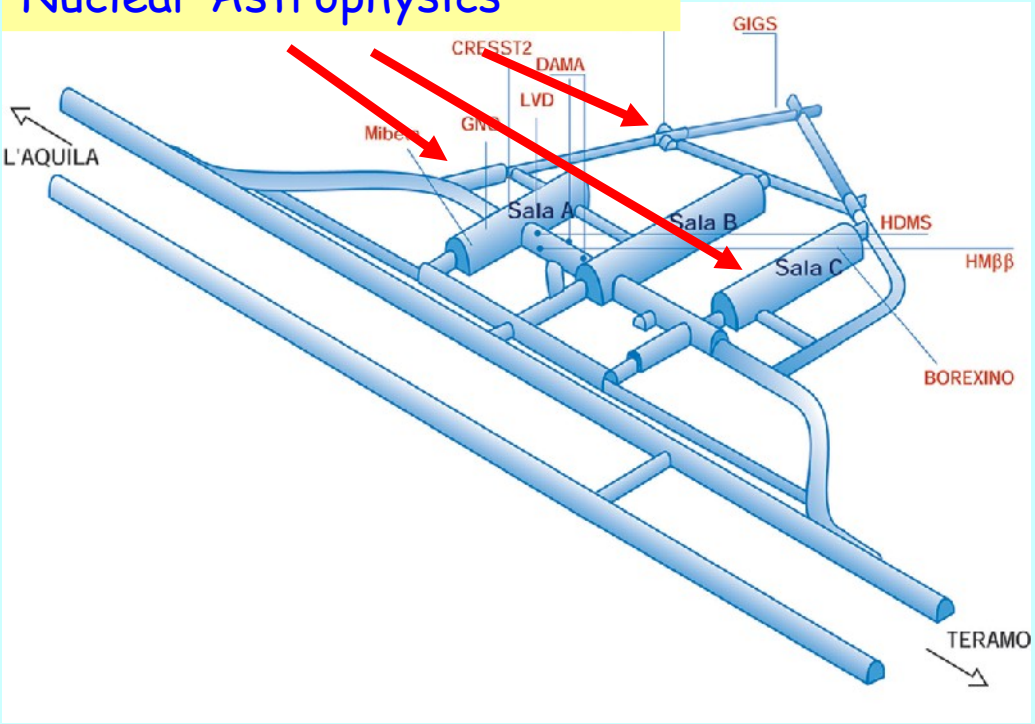


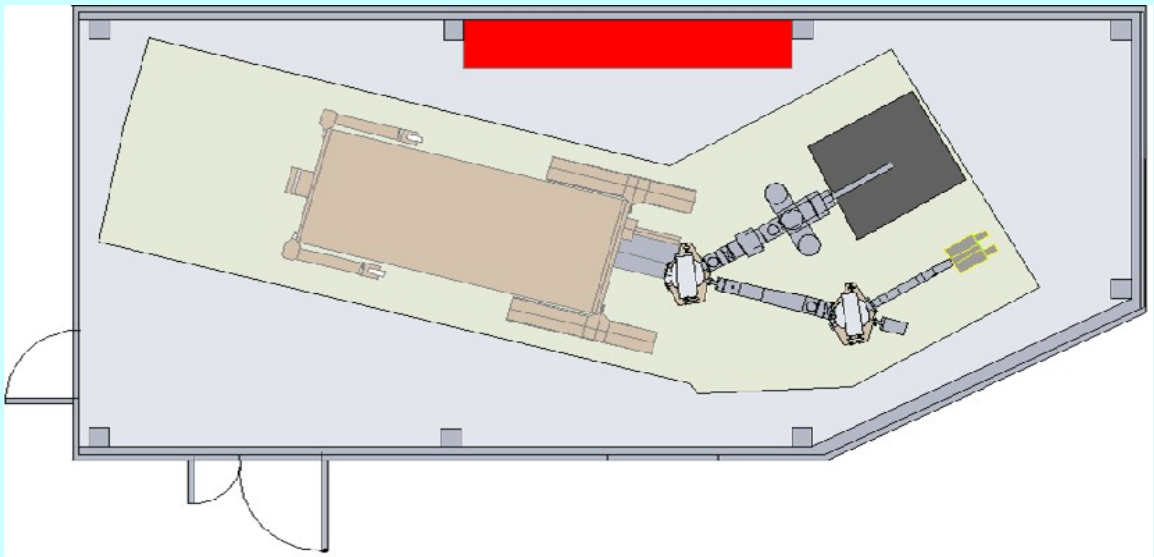
Extrap. ← Meas. →

S(E)



Laboratory for Underground Nuclear Astrophysics





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:

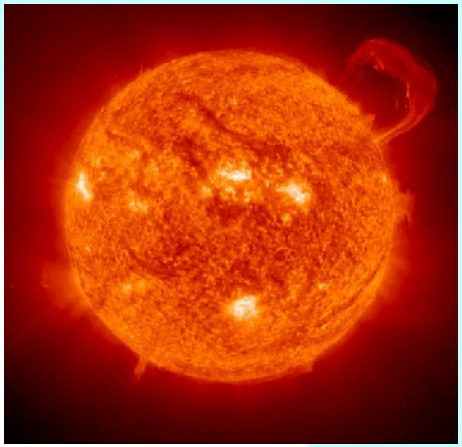
Hydrogen burning in the Sun @$15*10^6$ degrees:

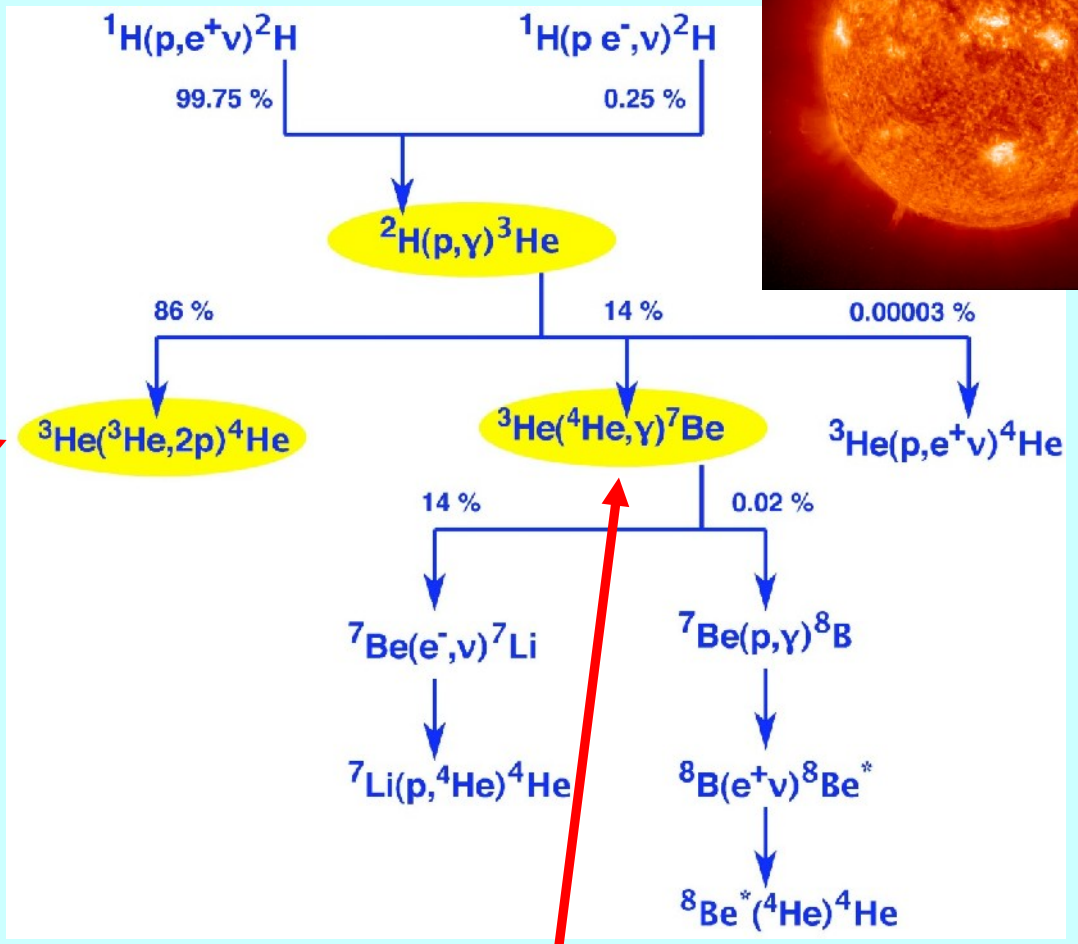
$6*10^{11}$ kg/s of H → He

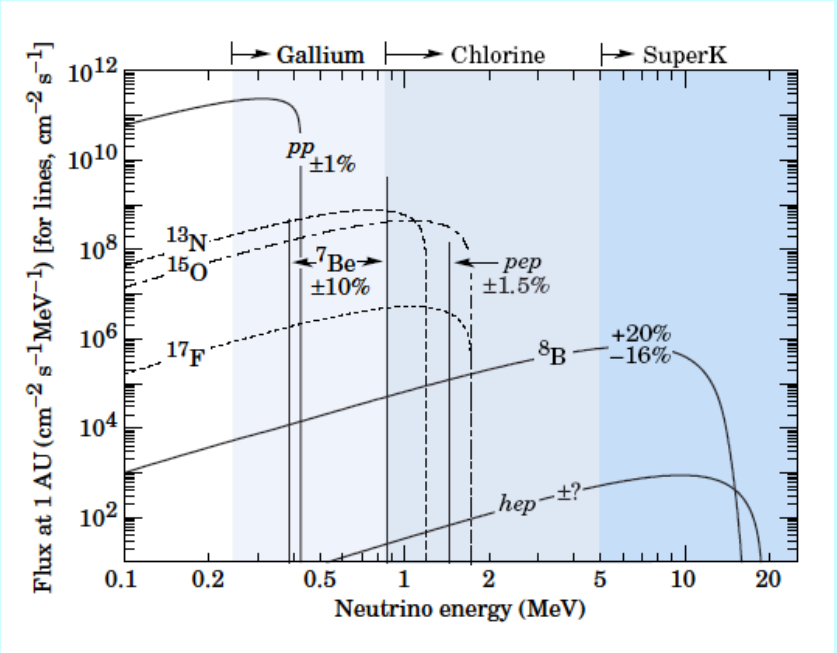
+0.7% M_H → E

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

Resonance?



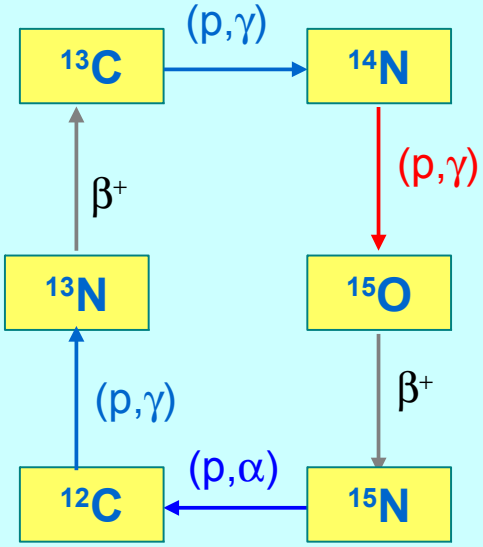


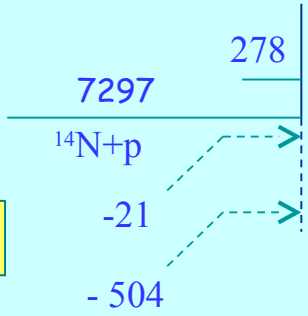


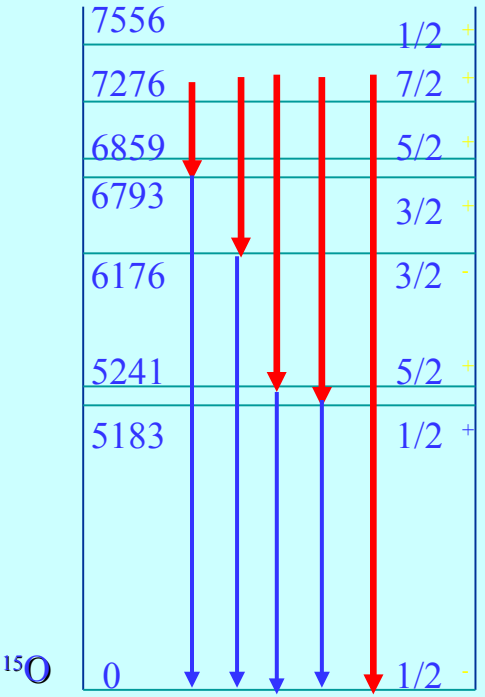
activation=prompt gamma

σ at low energy with 4% error

The CNO Cycle

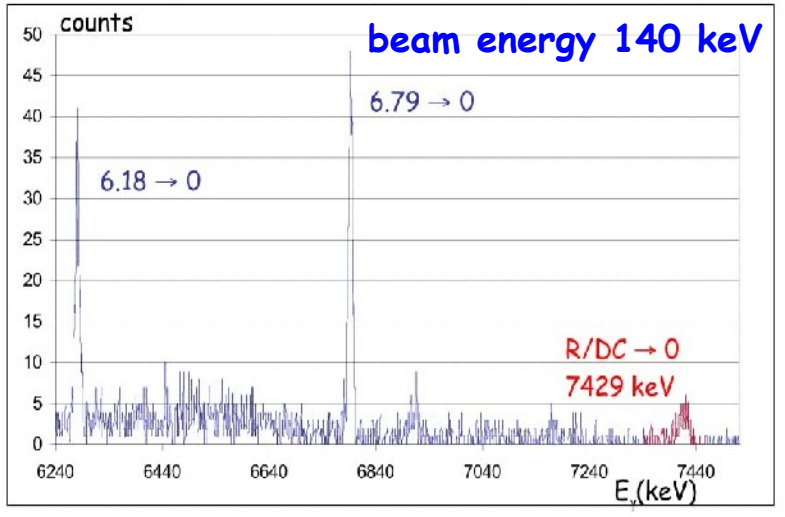




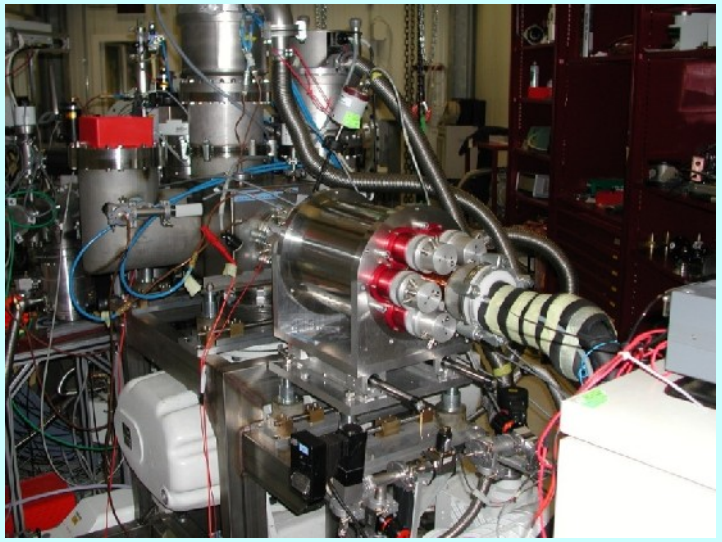


^{14}N(p,γ)^{15}O

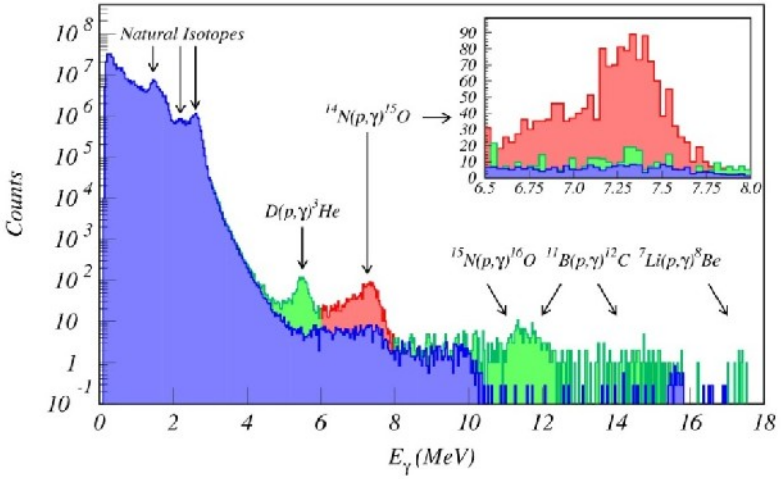
"High" energy: solid target + HpGe

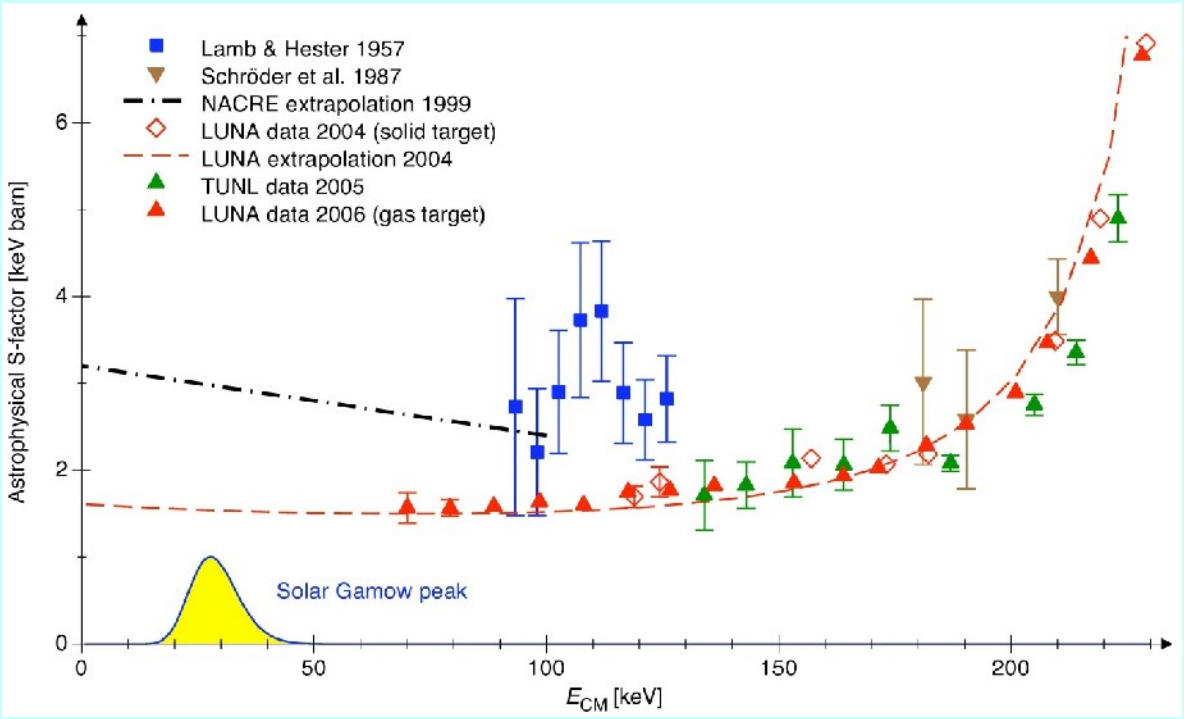


Low energy: gas target + BGO



beam energy 90 keV





$S_t(0)=1.57\pm0.13$ keV b
as suggested by indirect measurements

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

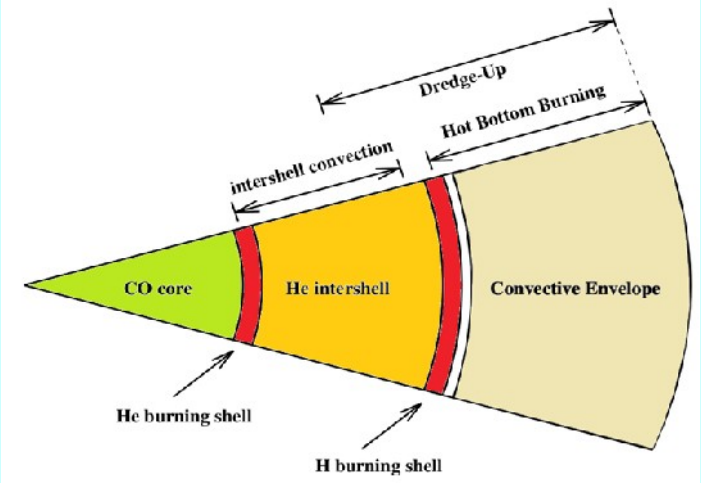
Solar composition problem:
Z/X ~0.024 → ~ 0.018
SSM predictions disagree
with Helioseismology results

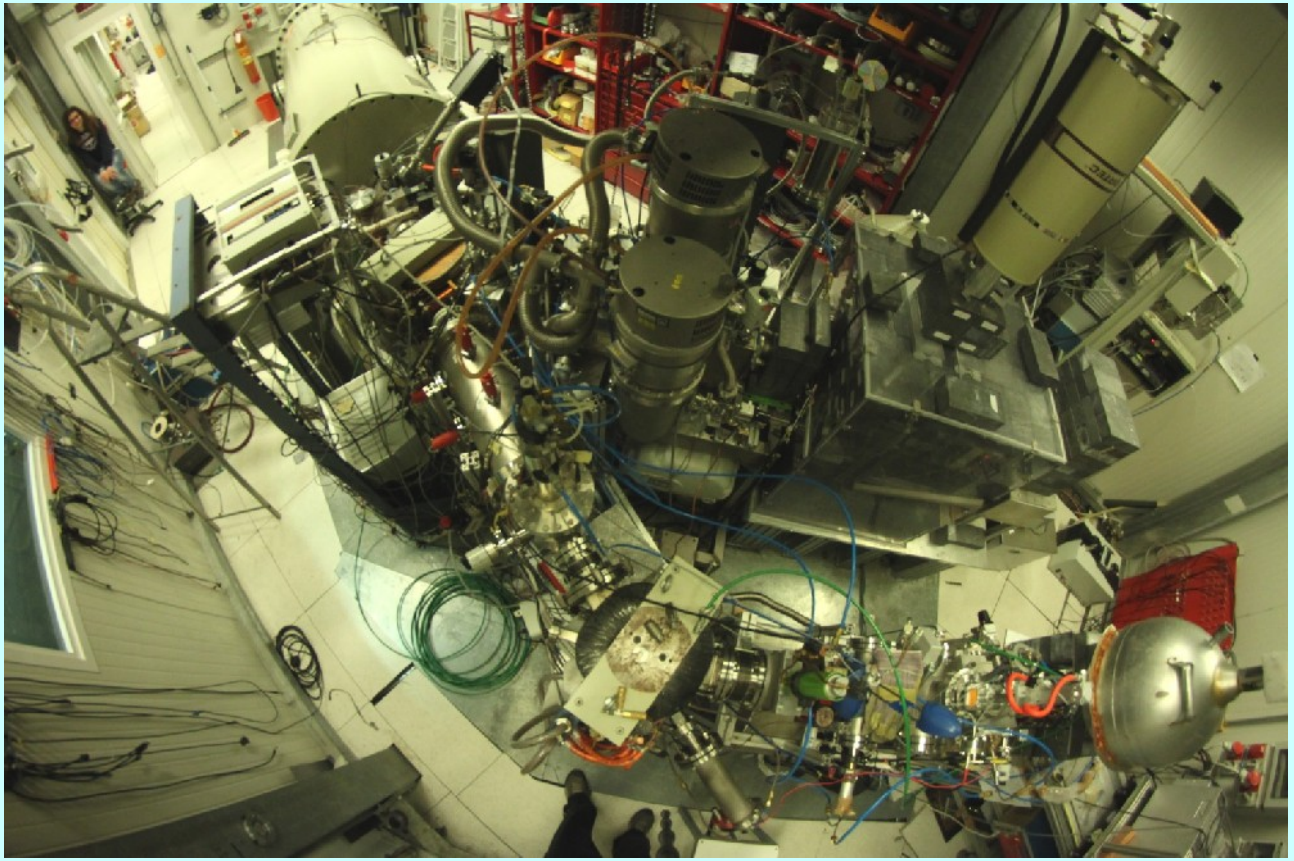
$\nu_{cno}=f(Z,S_{14})$, ~30% decrease from high to low metallicity

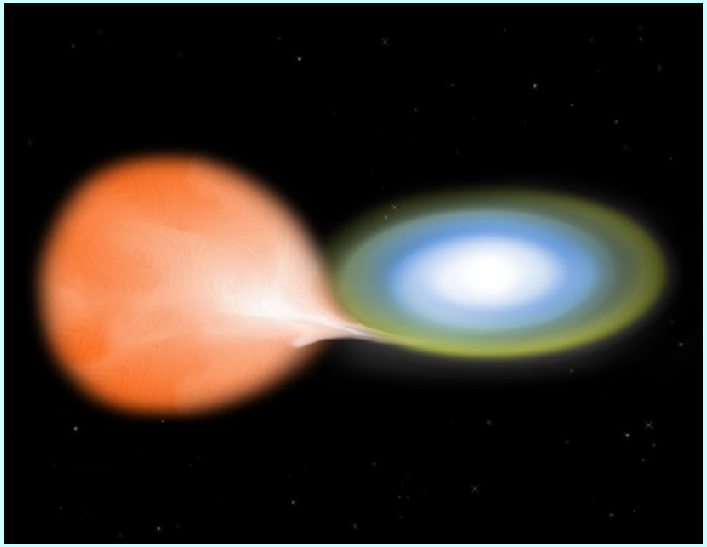
From a measurement of ν_{cno} from the Sun

Metallicity of the Sun core (C+N)
Photosphere and core metallicity equal?
Correlation with the high C+N of giant planets?

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







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

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

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

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

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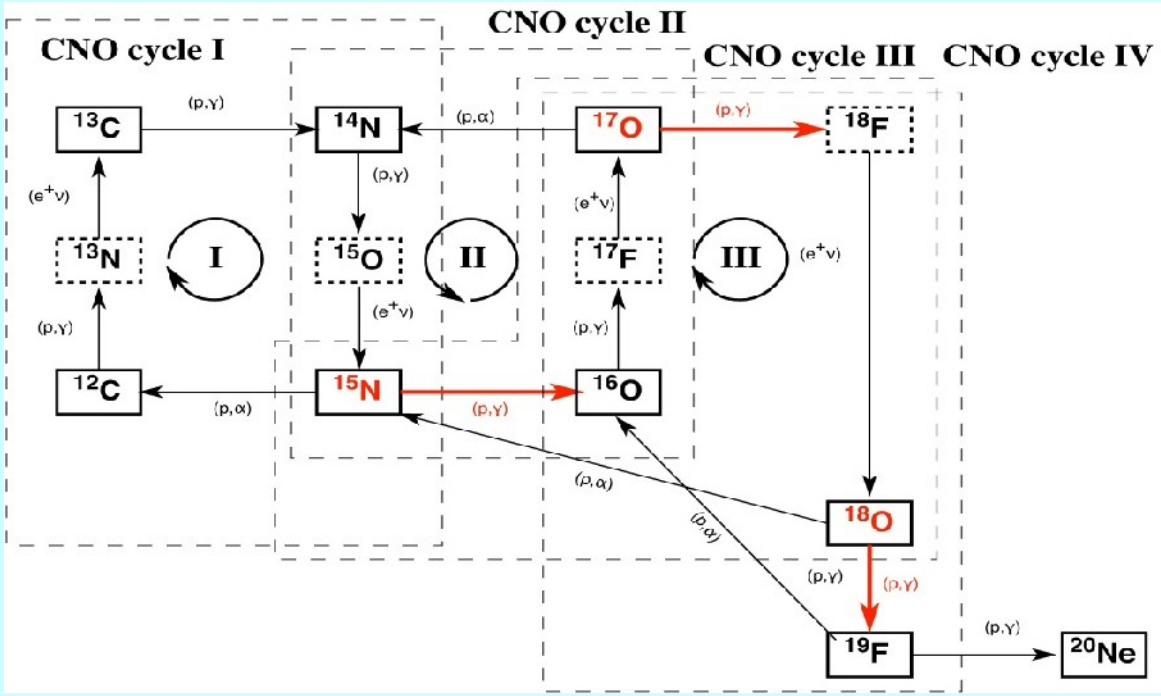
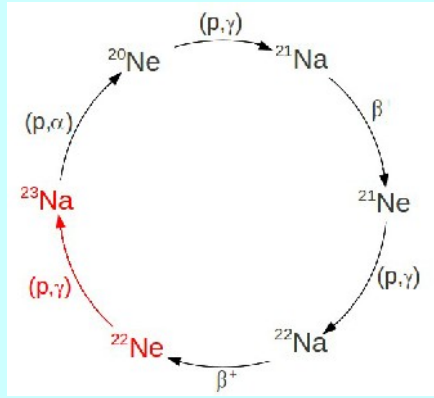


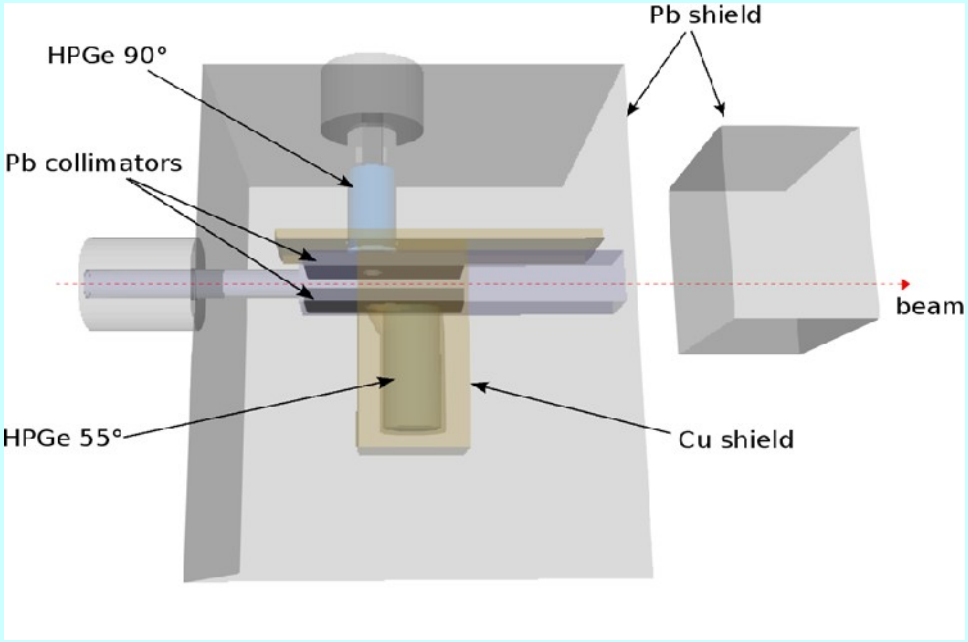
The Ne-Na Cycle

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

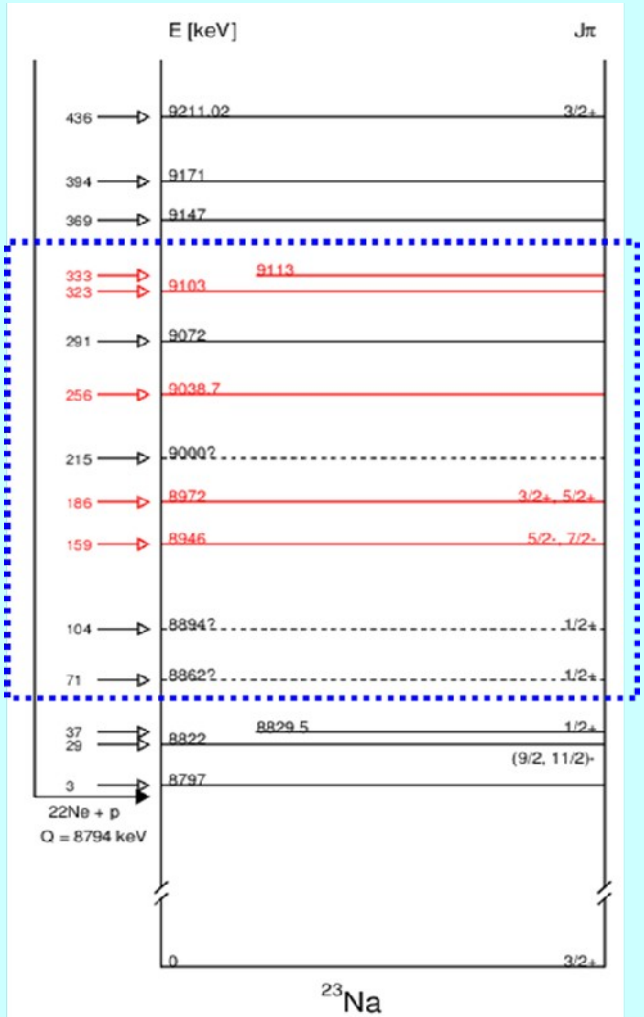
Only upper limits (μeV) on the strength of the 14 possible resonances below 400 keV (factor 2000 on the rate)

→ Ne, Na, Mg and Al yield in AGB and Novae (up to a factor 100)





The strength of 5 resonances measured in the first 3 months of the experiment with a neV sensitivity



What Next: 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

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

LUNA-MV accelerator financed by MIUR, to be installed in Hall C of LNGS (Opera space)

- ^{3}He (^{3}He,2p)^{4}He: σ down to 16 keV

  no resonance within the solar Gamow Peak

- $^{3}He(\alpha,\gamma)^{7}Be$: ^{7}Be ≈ prompt γ , 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

- $^{15}N(p,\gamma)^{16}O$: σ down to 70 keV, reduced by ~ 2

- $^{25}Mg(p,\gamma)^{26}Al$: first measurement of the 92 keV resonance,

  strength $\omega\gamma=(2.9\pm0.6)\times 10^{-10}$ eV

- $^{17}O(p,\gamma)^{18}F$: rate uncertainty @ Novae temperature reduced to 5%

  ⟶ uncertainty on ^{18}O, ^{18}F and ^{19}F less than 10% (from 40-50%)

- Future: Hydrogen and Helium burning (3.5 MV accelerator)

LUNA Collaboration

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