Nuclear astrophysics

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‘An application of nuclear physics’

Nuclear astrophysics: **aims**

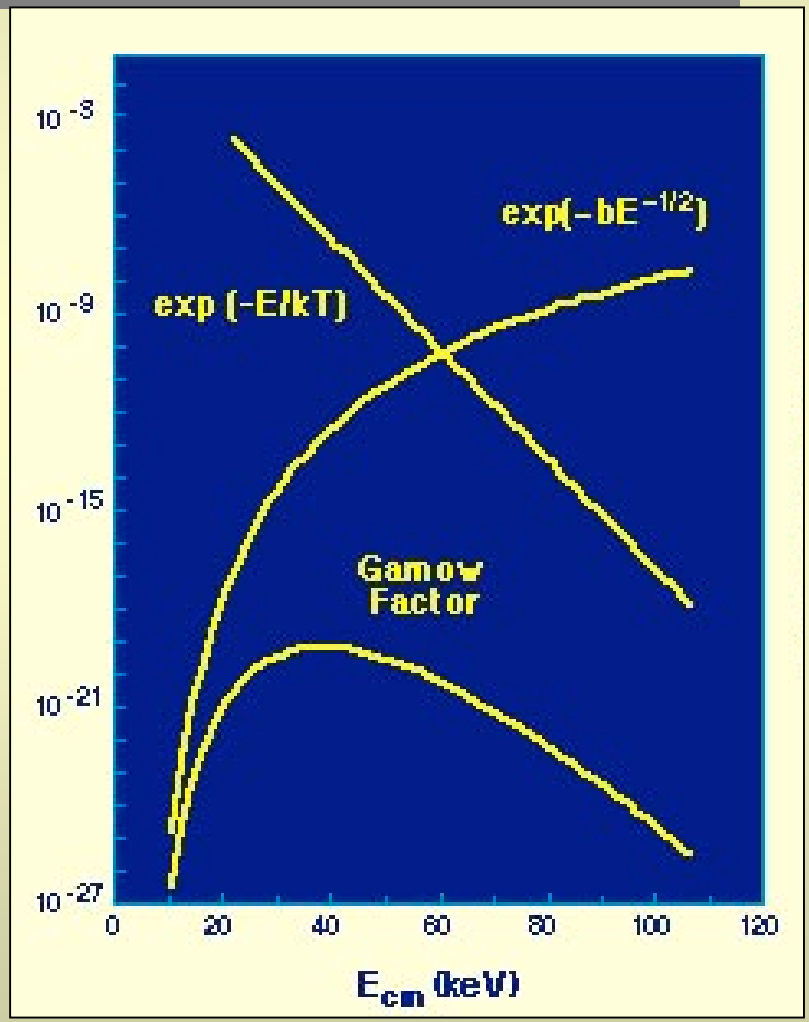
- Understanding astrophysical observations
- Origin, composition and evolution of matter

- 'Applied' nuclear physics:
  - Astrophysical motivation
  - Important results for nuclear physics, new phenomena

Temperature - reaction rate

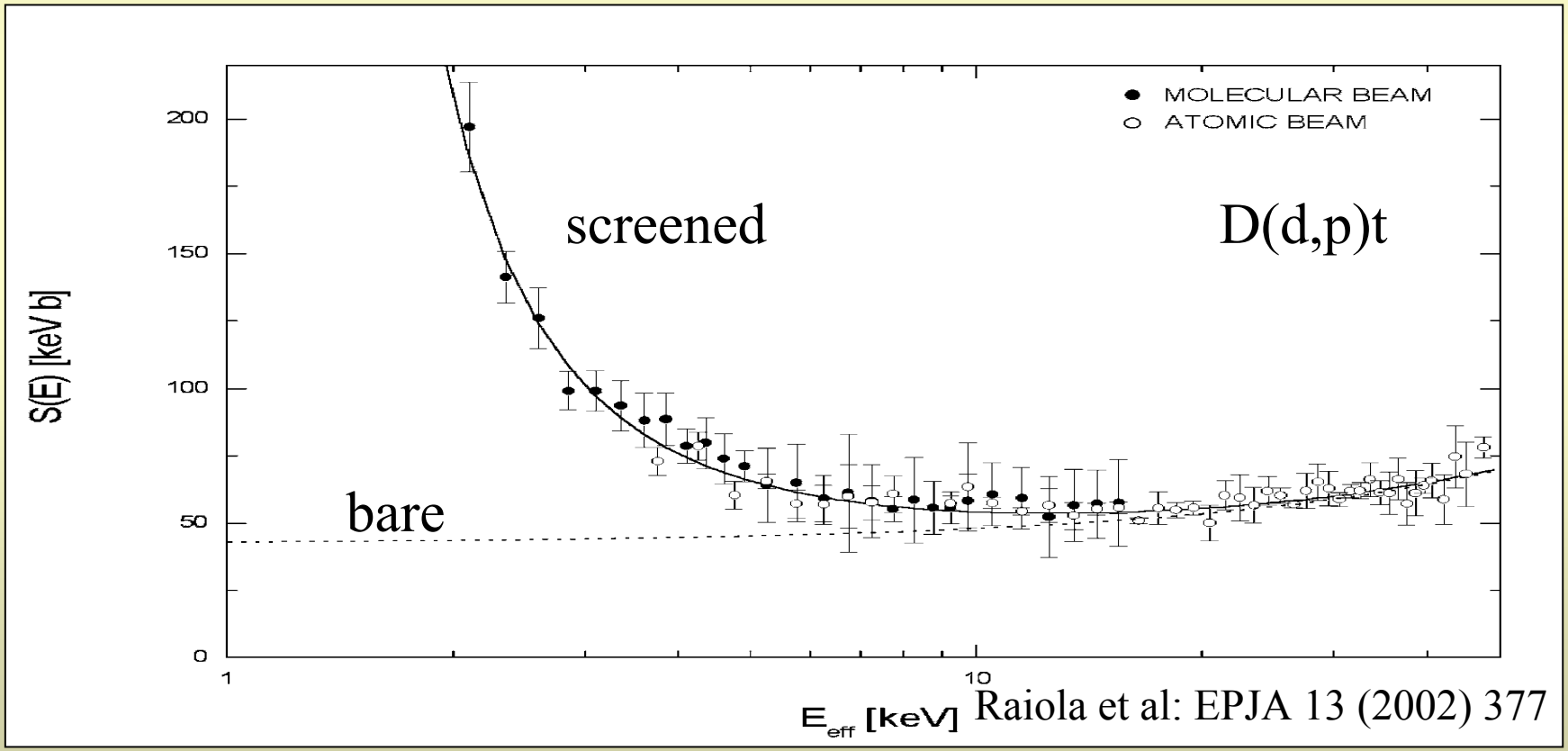
- **Nonexplosive scenario:**
  - Low energy
  - Small cross sections
  - Extrapolation needed (S-factor)
    ? indirect methods
- **Explosive scenario:**
  - Higher energies
  - High cross sections
  - Exotic nuclei (low intensities)
    Ŕ RIB

Charged particle reaction cross sections are difficult to measure at astrophysical energies



Electron screening effects at low energies

'Interplay between atomic and nuclear physics'

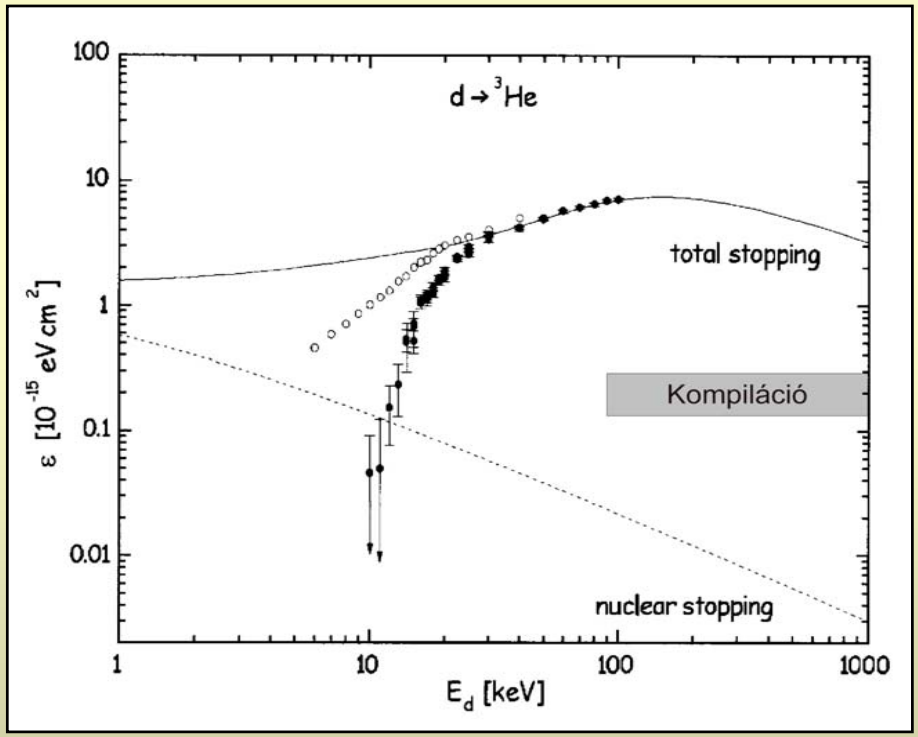


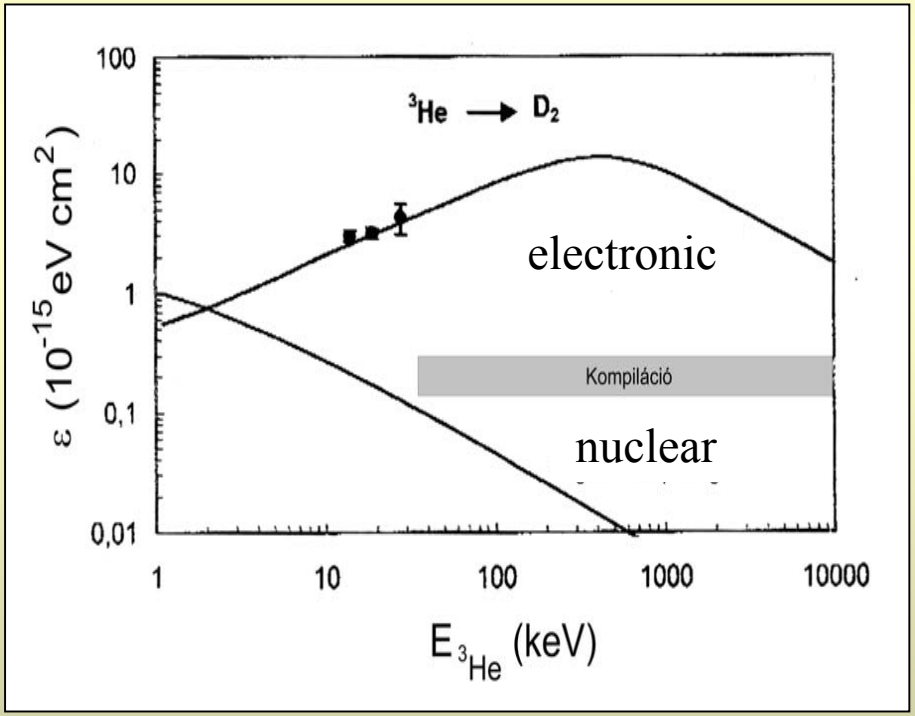
Raiola et al: EPJA 13 (2002) 377

More pronounced effect is observed for metallic environments!!

Stopping power anomalies at low energies

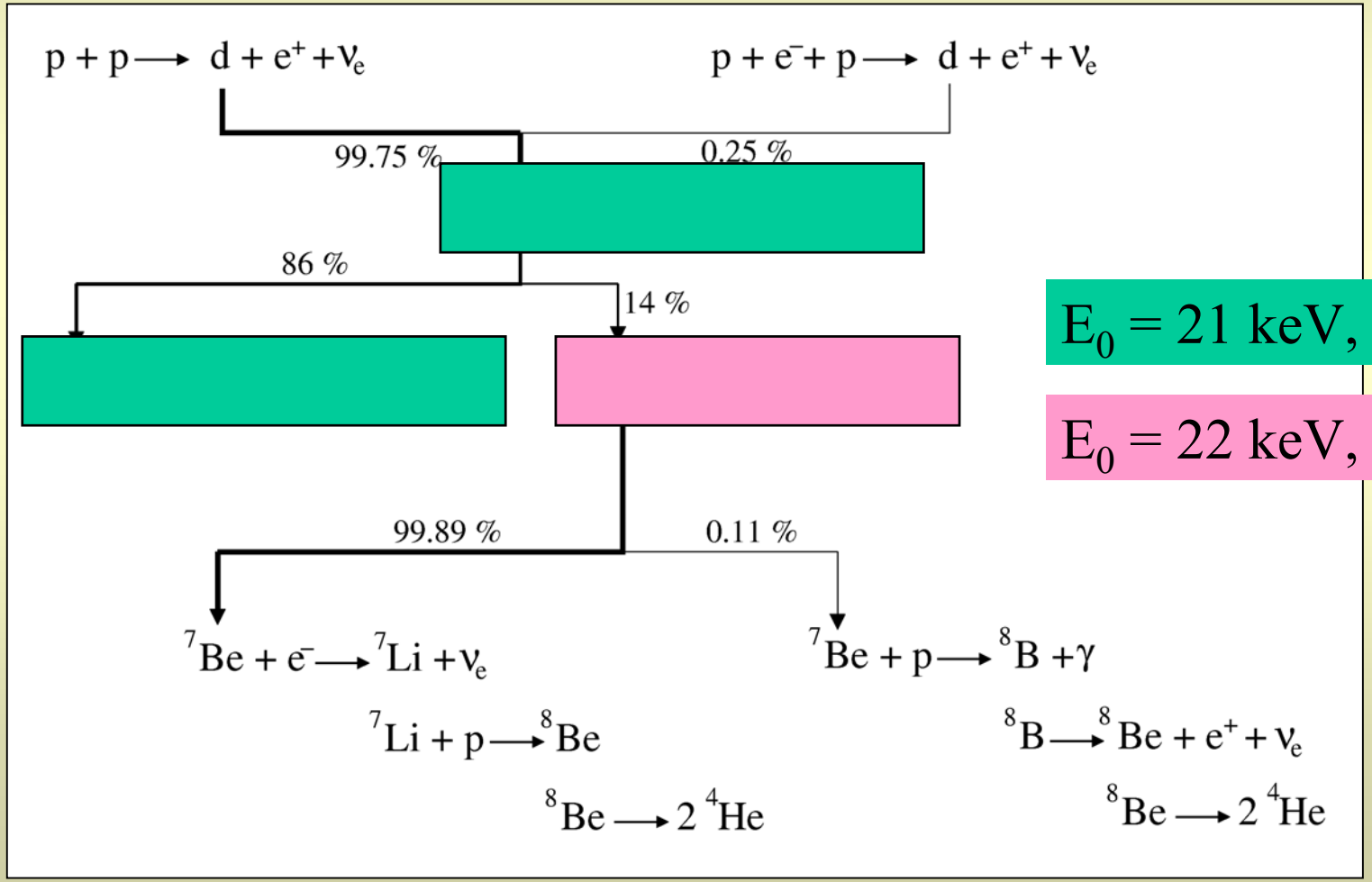
'Interplay between atomic and nuclear physics'





Formicola et al: EPJA 8 (2000) 443

Data needs for the pp-chain



$E_0 = 21$ keV, $s = 7 \cdot 10^{-13}$ barn

$E_0 = 22$ keV, $s = 9 \cdot 10^{-18}$ barn

Two approaches to stellar energies

Extrapolations:

- Measure level gamma widths
- Measure asymptotic normalization constants (ANCs)
- Measure cross sections at high energies
- R-matrix fit for each transition

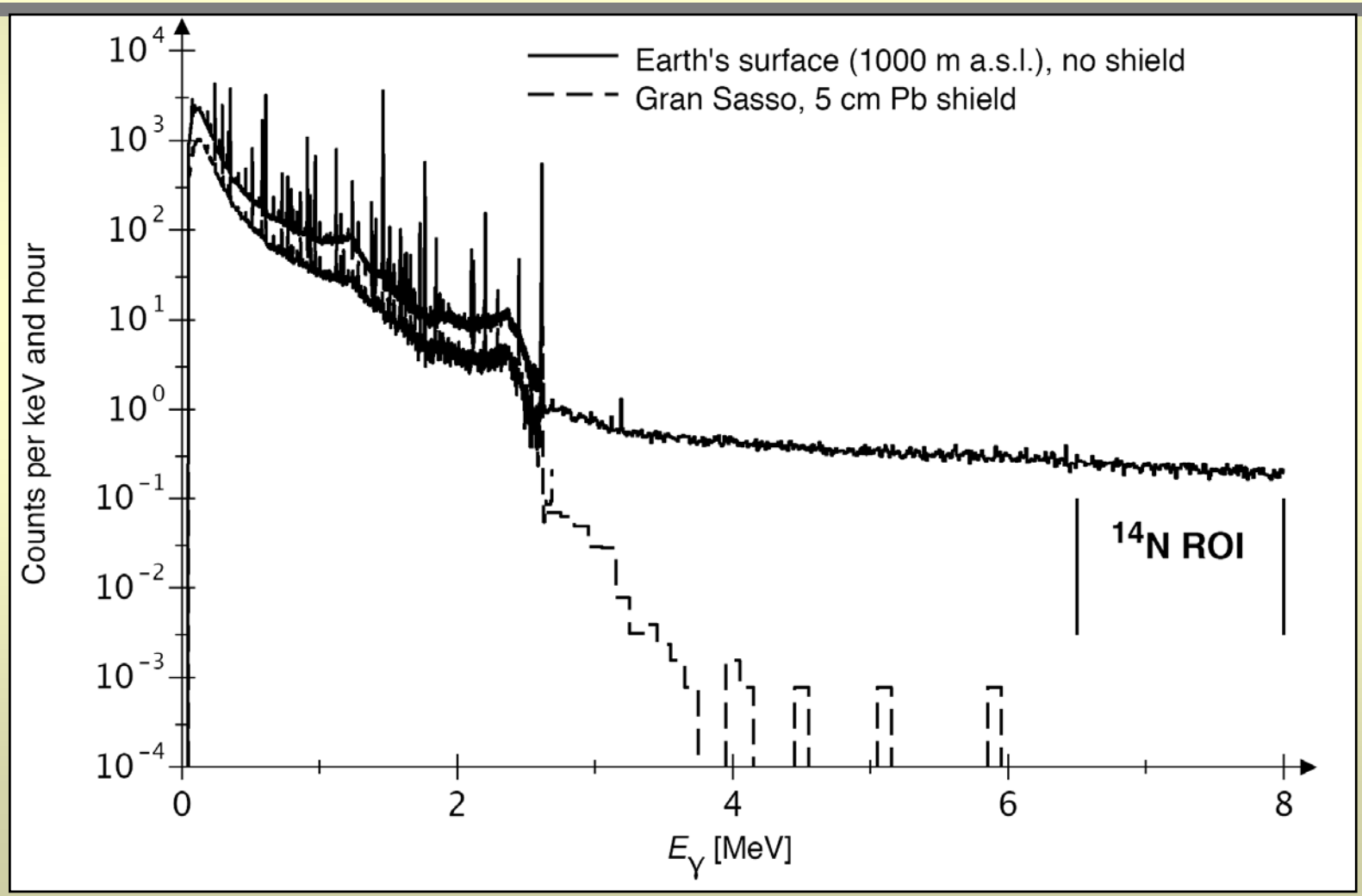
Extrapolations for each transition are summed to give the total extrapolated cross section at astrophysical energies

Direct Measurement:

- Low laboratory background
- Low ion beam induced background
- High beam intensity
- High detection efficiency

Direct data for the total cross section at astrophysical energies

HPGe detector underground



A unique approach: LUNA

Neutrino detection: shield+detector
Nuclear physics: shield+detector+source

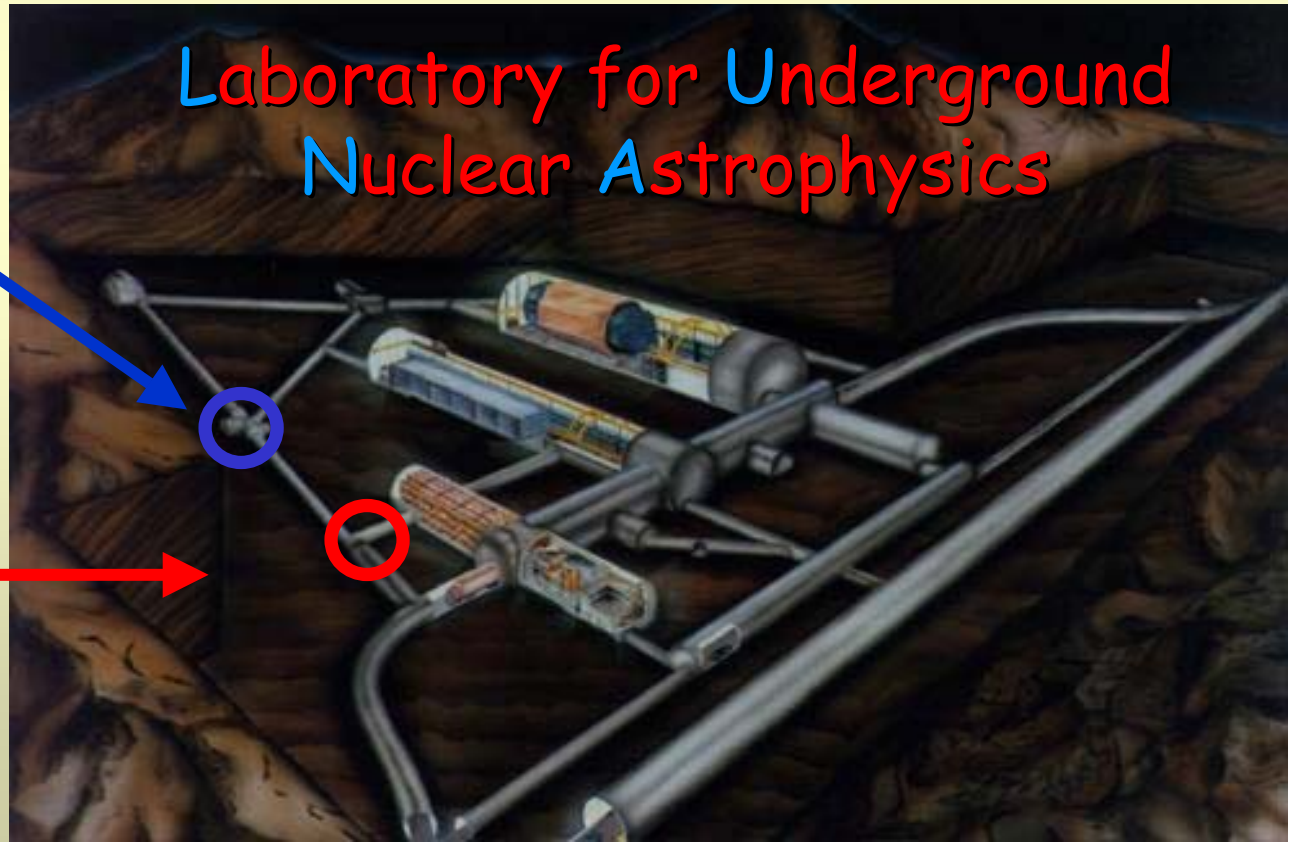
50 kV :
(1992-2001)

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

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

400 kV:
(2000→…)

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



Accelerator underground?

Ultra-low cross sections ? ultra long experiments

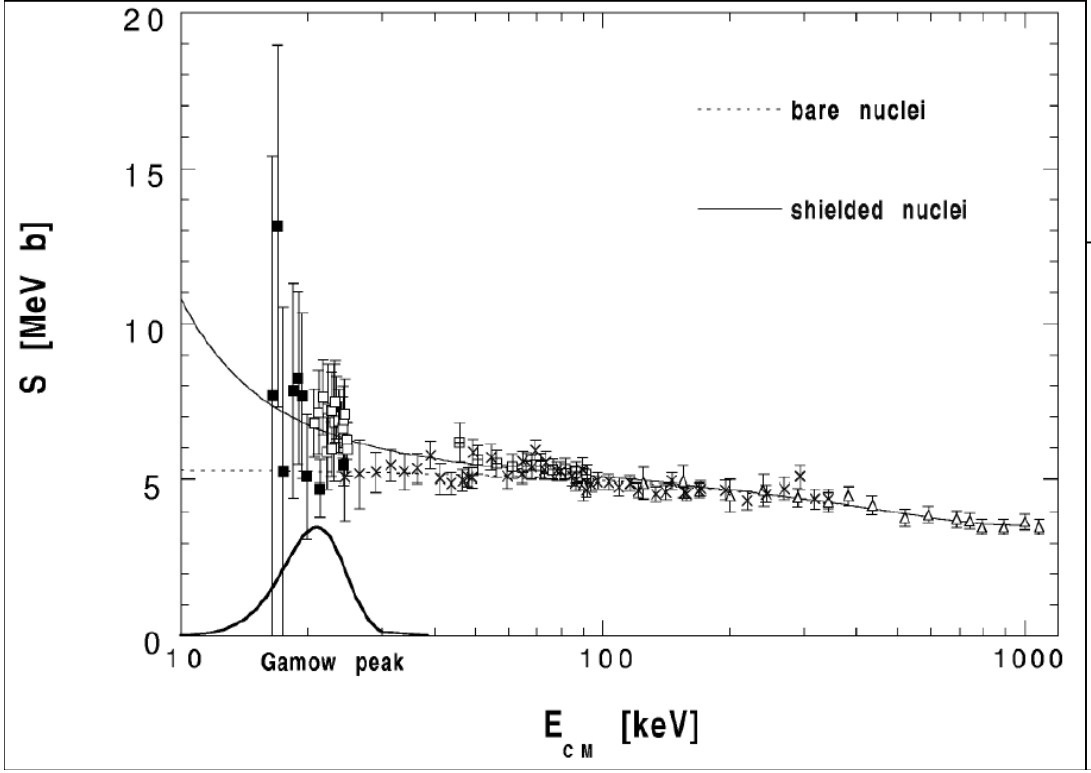
- Accessibility, automatization, monitoring
- Safety issues
- Target/beam stability (beam intensity: ~500μA)
- Background considerations
  - Limited beam/target combinations (no neutron production is allowed)
  - Beam induced background vs laboratory background
  - Target purity, scattered beam, apertures

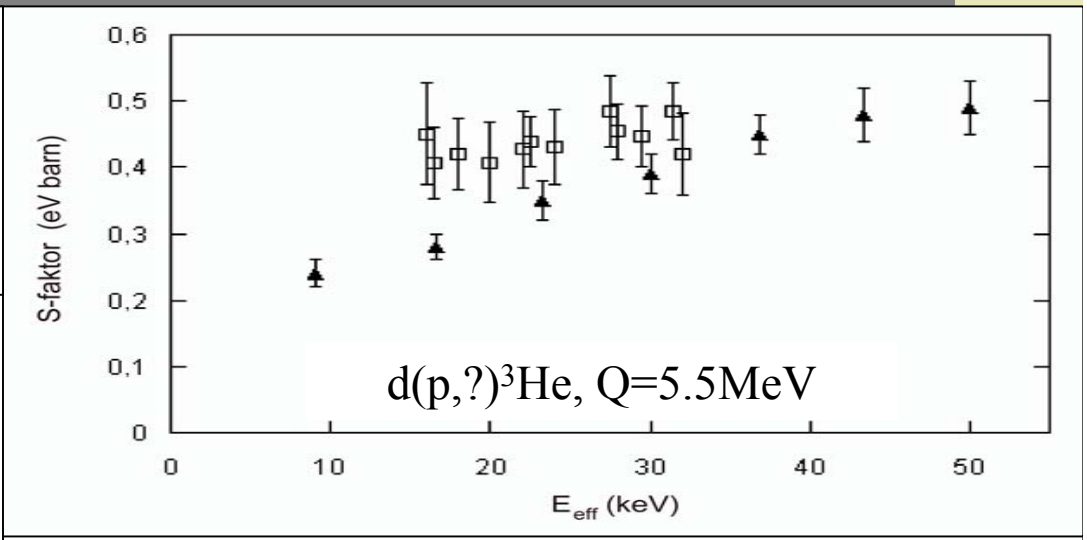
First successes at the 50kV machine

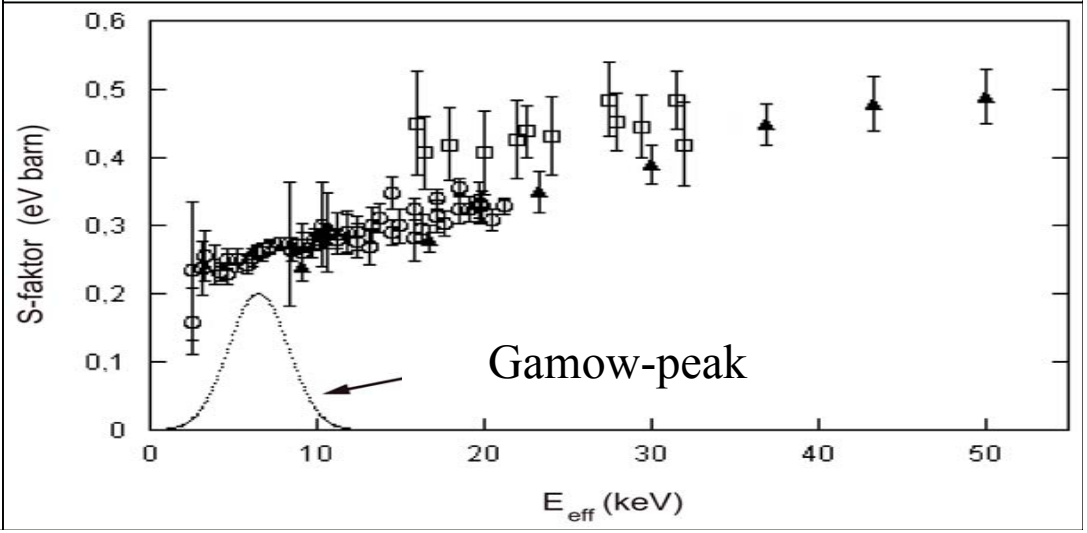
VOLUME 82, NUMBER 26 PHYSICAL REVIEW LETTERS 28 JUNE 1999

First Measurement of the $^3He(^3He, 2p)^4He$ Cross Section down to the Lower Edge of the Solar Gamow Peak

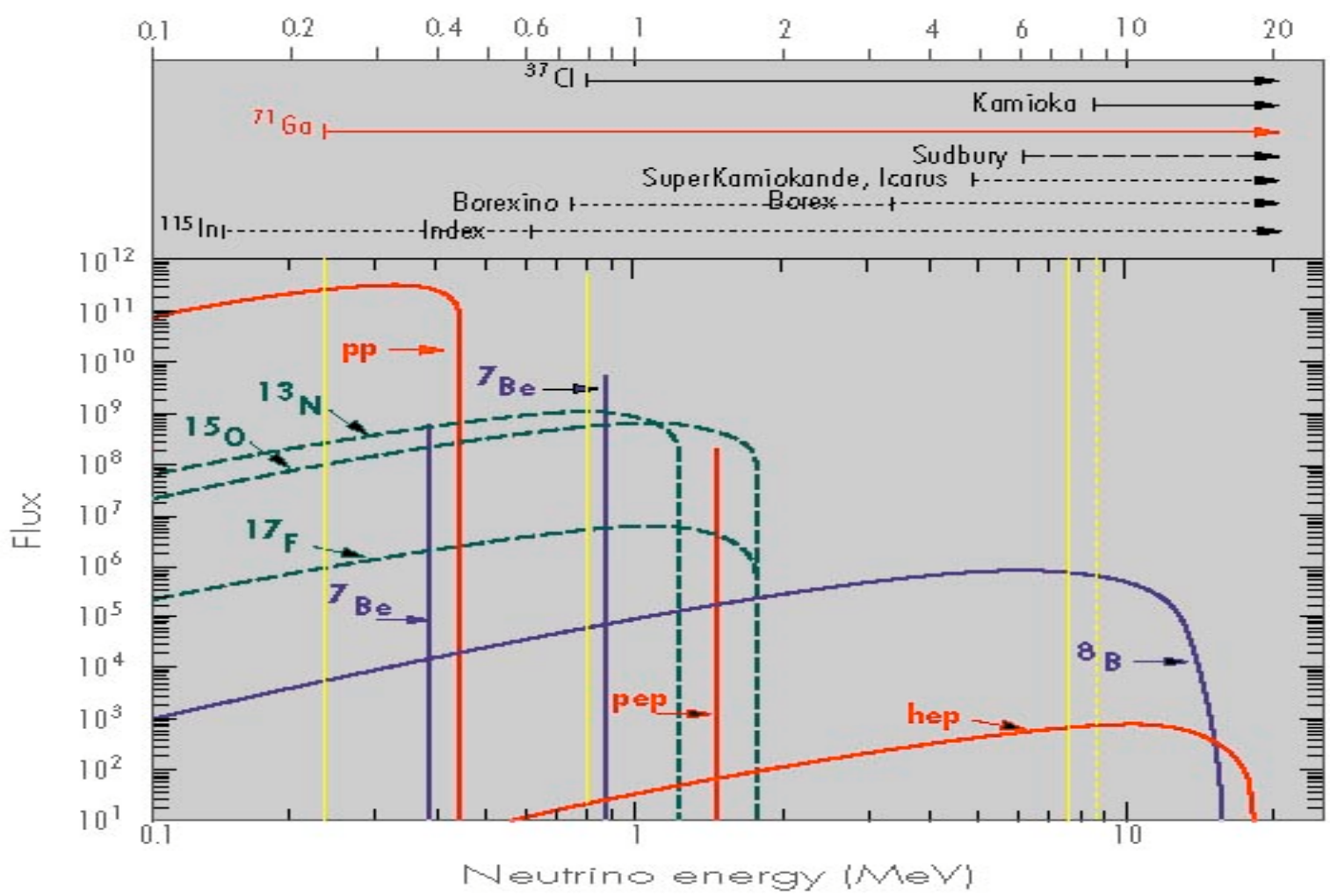
R. Bonetti,[1] C. Broggini,[2,*] L. Campajola,[3] P. Corvisiero,[4] A. D'Alessandro,[5] M. Dessalvi,[4] A. D'Onofrio,[6] A. Fubini,[7] G. Gervino,[8] L. Gialanella,[9] U. Greife,[9] A. Guglielmetti,[1] C. Gustavino,[5] G. Imbriani,[3] M. Junker,[5] P. Prati,[4] V. Roca,[3] C. Rolfs,[9] M. Romano,[3] F. Schuemann,[9] F. Strieder,[9] F. Terrasi,[3] H. P. Trautvetter,[9] and S. Zavatarelli[4]
(LUNA Collaboration)



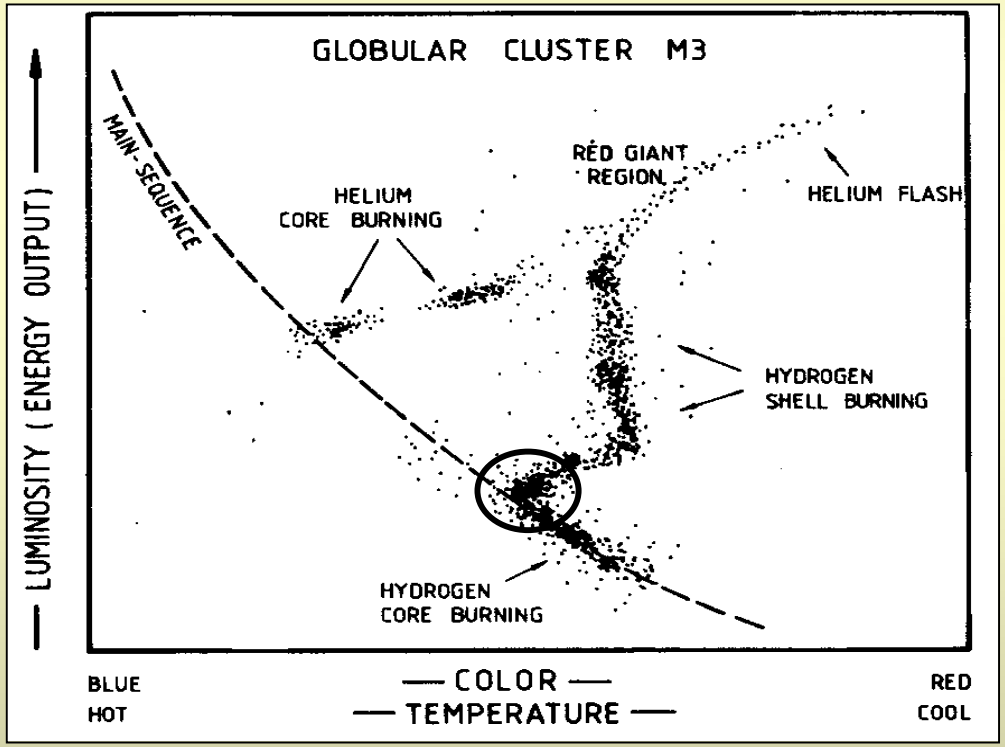


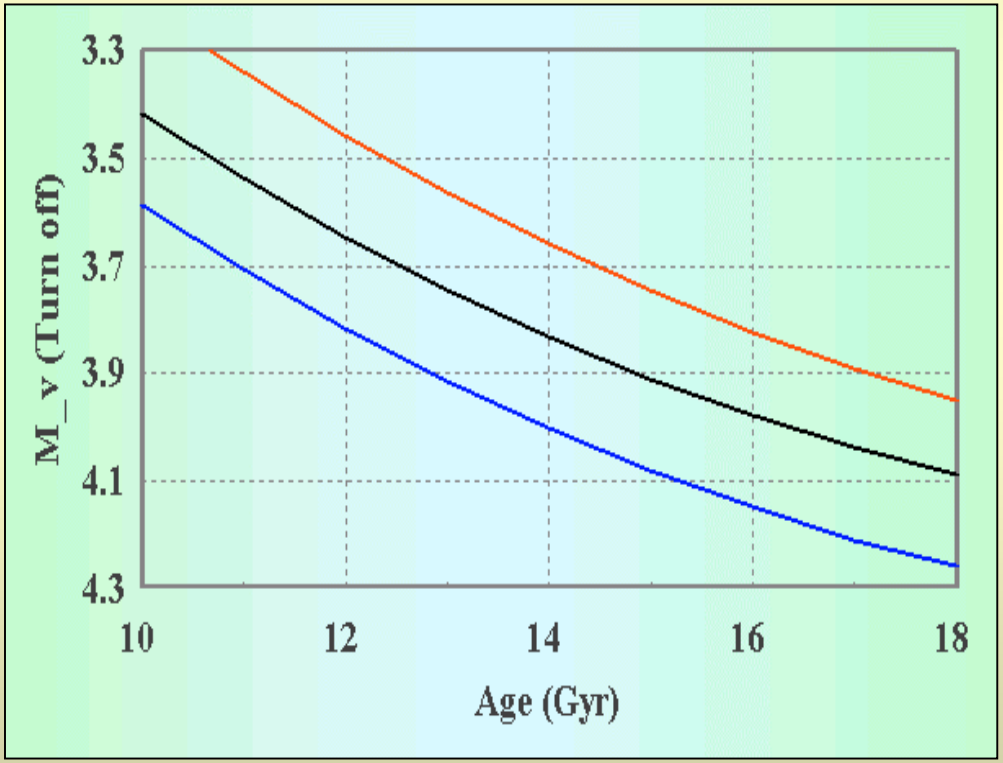


CNO as a source of neutrinos

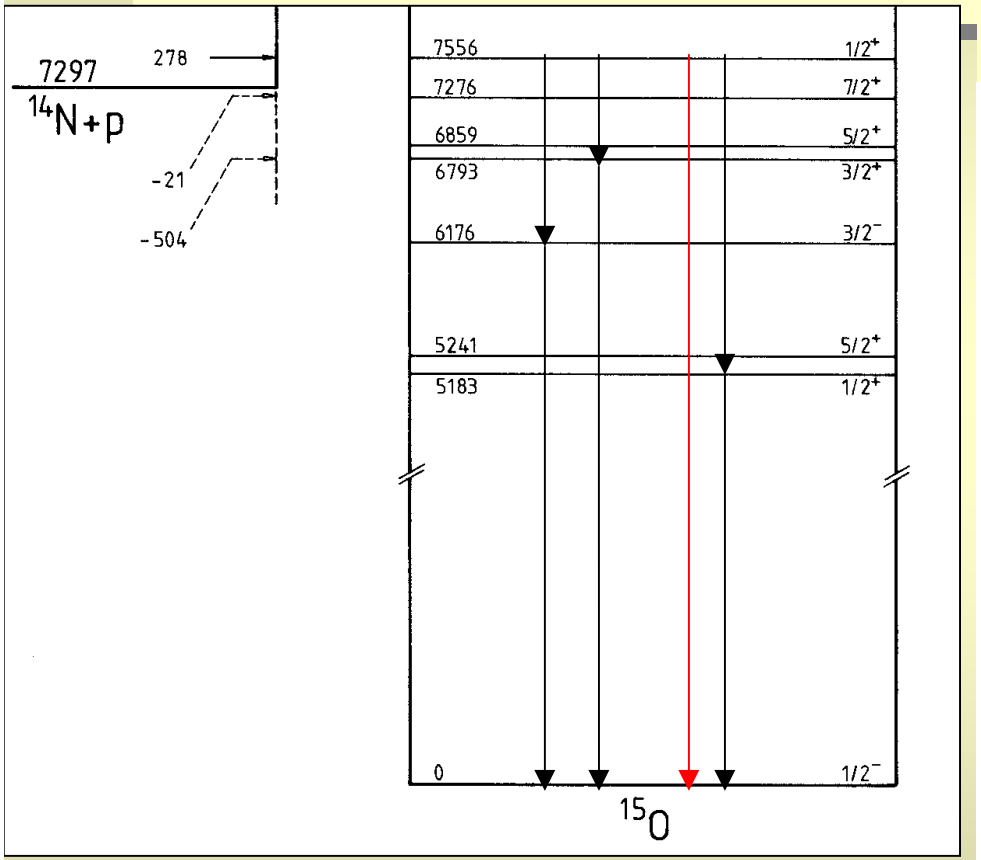


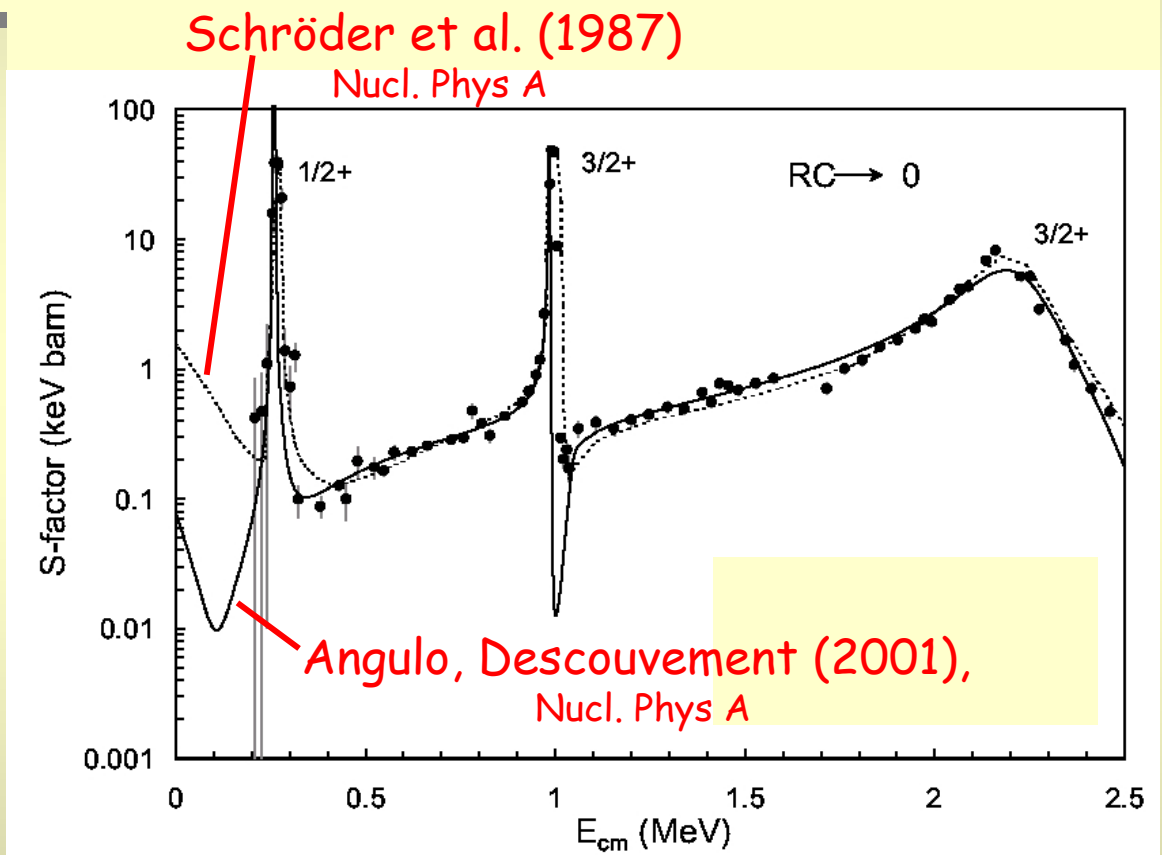
$^{14}N(p,?)^{15}O$: Age of globular clusters





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



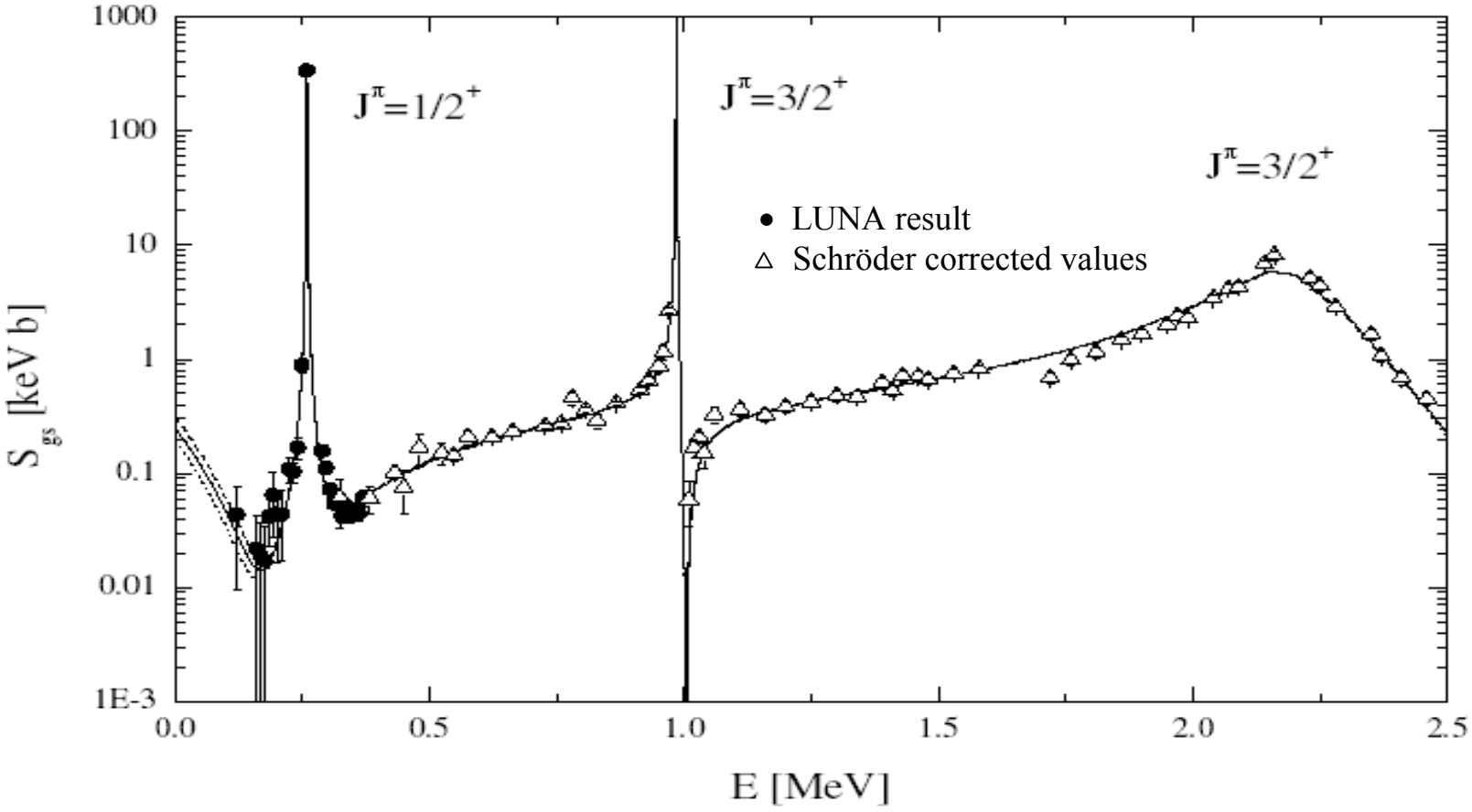


R/DC → 0

S(0) = 1.55 ± 0.34 keV-b (Schröder)

S(0) = 0.08 ±0.06 keV-b (Angulo)

LUNA Experiment: lower energies ? better extrapolation



$S_0^{gs} = 0.25 \pm 0.06$ keV b

Schröder('87) [*kev-b*]	Angulo ('01) [*kev-b*]
3.2 ± 0.5	1.8 ± 0.2

$S_0^{tot} = 1.7 \pm 0.1$ keV b

Phys. Lett. B591 (2004) 61.
Astron. Astrophys. 420 (2004) 625.

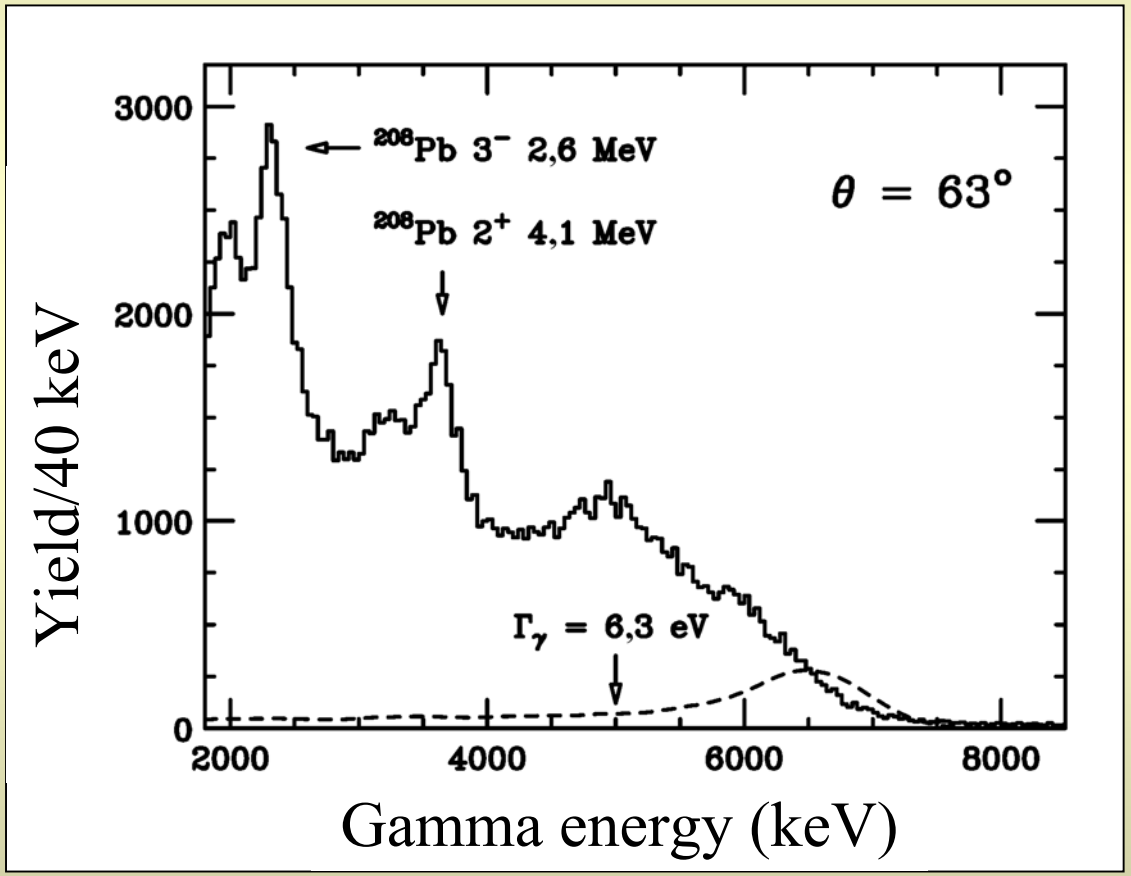
- Age of globular clusters is longer: +0.7-1 Gyr
- CNO neutrino flux is smaller (50%)

Science: Contradiction between the age of globular clusters and the universe?

? more precise observations are needed!! (GAIA)

Coulomb excitation of ^{15}O

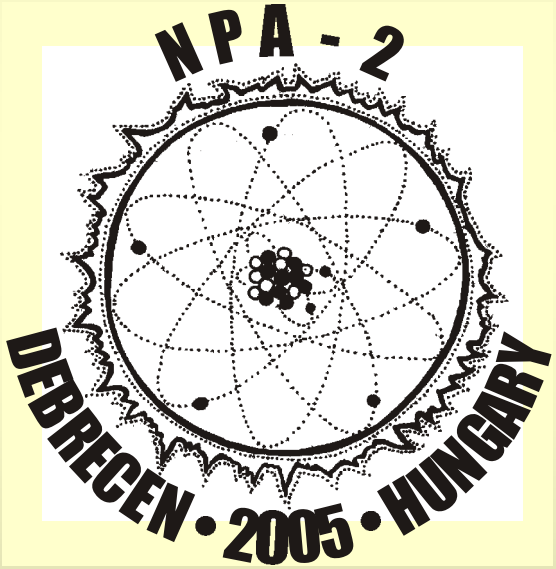
- ^{15}O RIB at 50 MeV/A (RIKEN)
- Pb target + NaI array
- Upper limit for the $3/2^+$ subthreshold state: $G_? = 0.95$ eV
- Previous data: $\Gamma_? = 6.3$ eV can be excluded (also by DSAM)



Yamada et al: PLB 579 (2004) 265

Nuclear Physics in Astrophysics

- New conference series organized under the umbrella of ‘Nuclear Physics Board’ of EPS
- Emphasis on nuclear physics problems motivated by astrophysics
- 2002 and 2005, ATOMKI, Debrecen, Hungary



Summary/outlook

- Accelerator based nuclear astrophysics is a promising application of nuclear physics
- A large variety of nuclear experiments is needed from low to high energy, from stable to radioactive beams, from structure to reactions.

- NuPECC recommendation: new accelerator underground (higher energy, heavy ions)
- New RIB facilities are designed keeping in mind astrophysical studies