INFN
Laboratori Nazionali del Gran Sasso

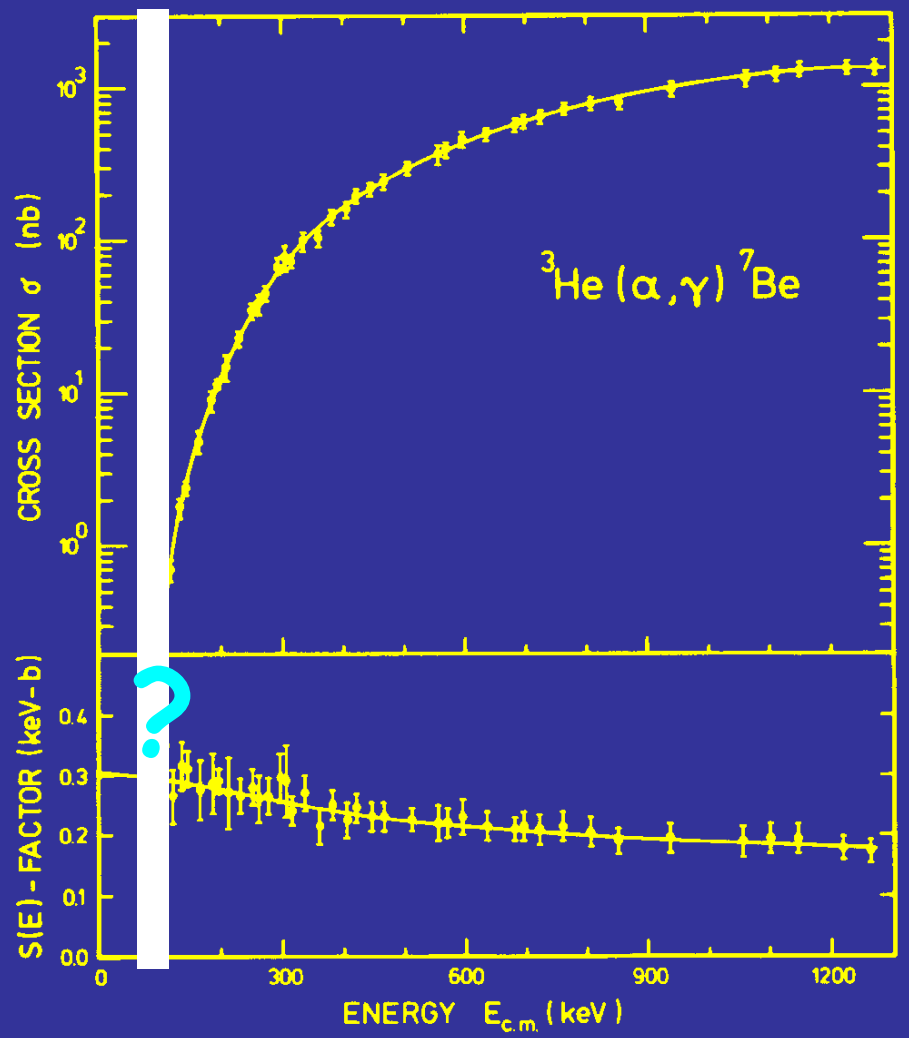
PHYSUN 2010
THE PHYSICS OF THE SUN
AND THE SOLAR NEUTRINOS

Best values and uncertainties of the nuclear reaction cross sections important to solar burning

(SOLAR FUSION II)

A. Formicola for LUNA collaboration

Reaction rate in the laboratory



$$R_{lab} = \sigma \cdot \varepsilon \cdot I_p \cdot \rho \cdot N_{av}/A$$

pb < σ < nb

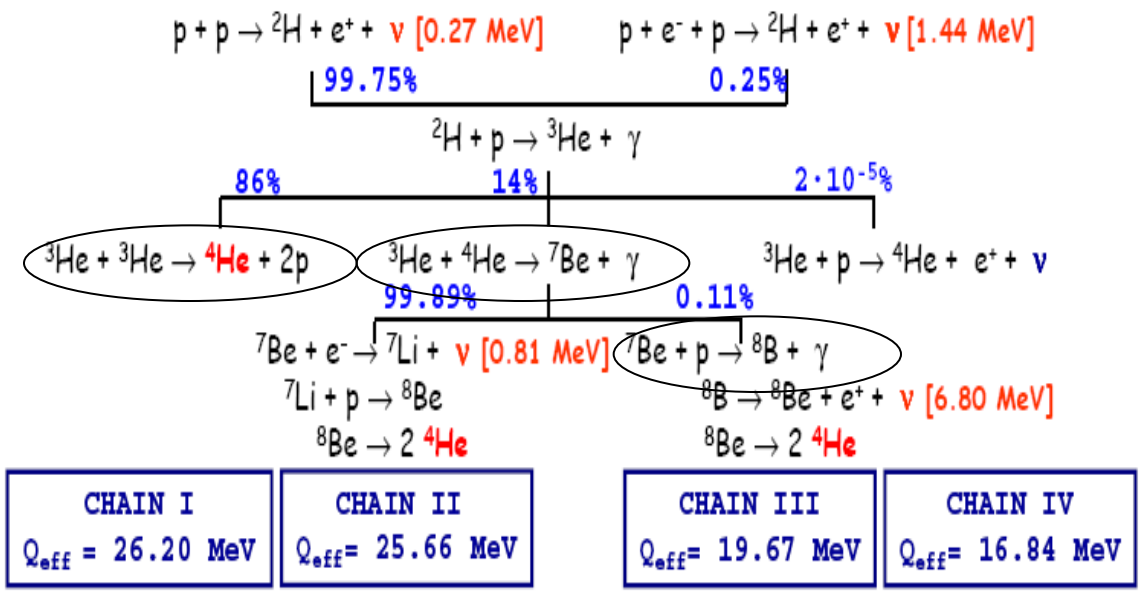
ε ~ 10 %
I_P ~ mA
ρ ~ μg/cm²

event/month < R_{lab} < event/day

$$\sigma(E) = S(E)/E \exp(-2\eta\pi)$$

Extrapolation is needed !!

pp chain



$S_{pp}(0)=(4.01\pm0.04)10^{-22}$ keVb

$S_{hep}(0)=(8.6\pm2.6)10^{-20}$ keVb

$\Phi(^8B) \propto (1+\delta S_{11})^{-2.73} (1+\delta S_{33})^{-0.43} (1+\delta S_{34})^{0.85} \times (1+\delta S_{17})^{1.0} (1+\delta S_{e7})^{-1.0} (1+\delta S_{1\,14})^{-0.02}$

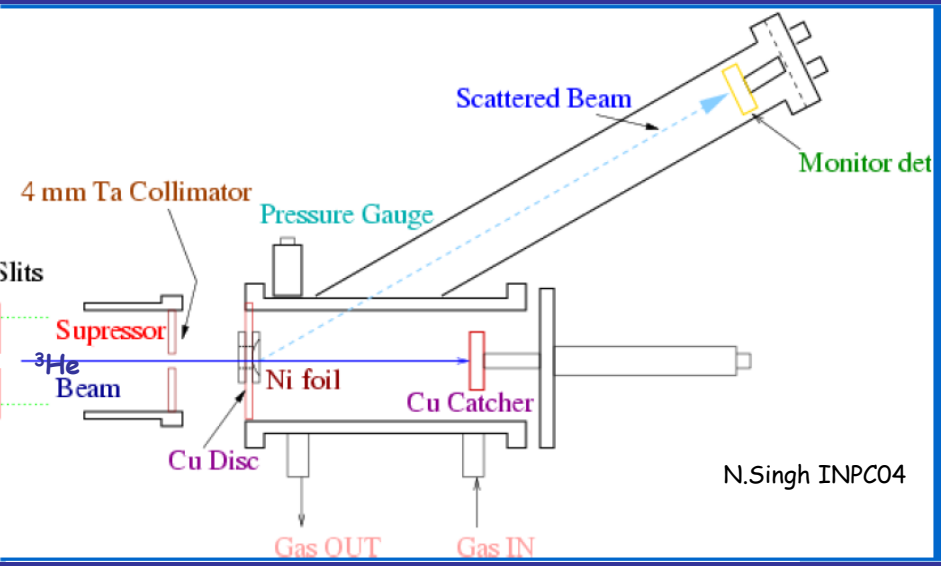
where fractional uncertainty $\delta S_{11} \equiv \Delta S_{11}/S_{11}(0)$

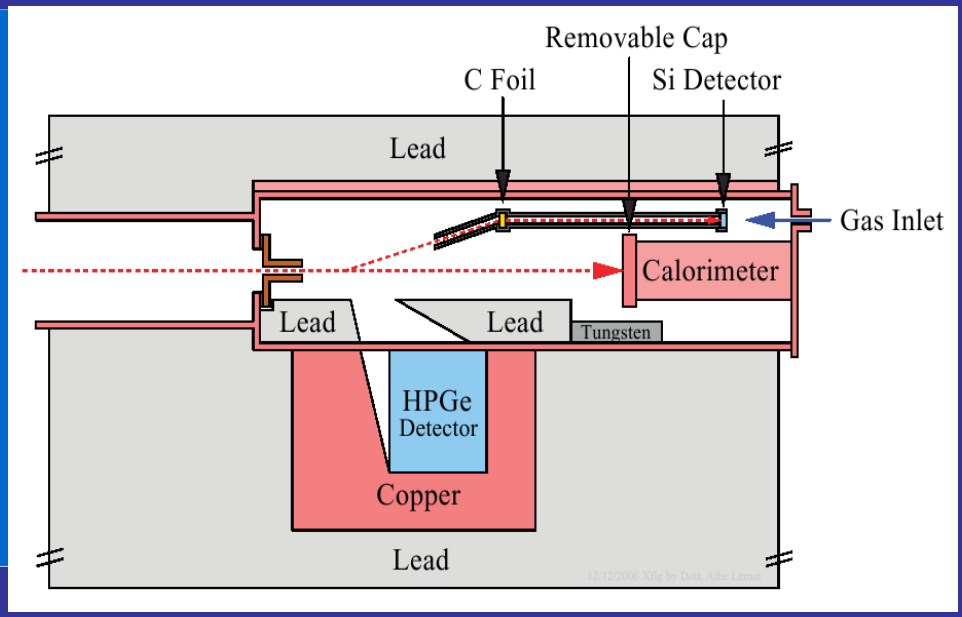
(Pena-Garay and Serenelli 2008, arXiv: 0811.2424)

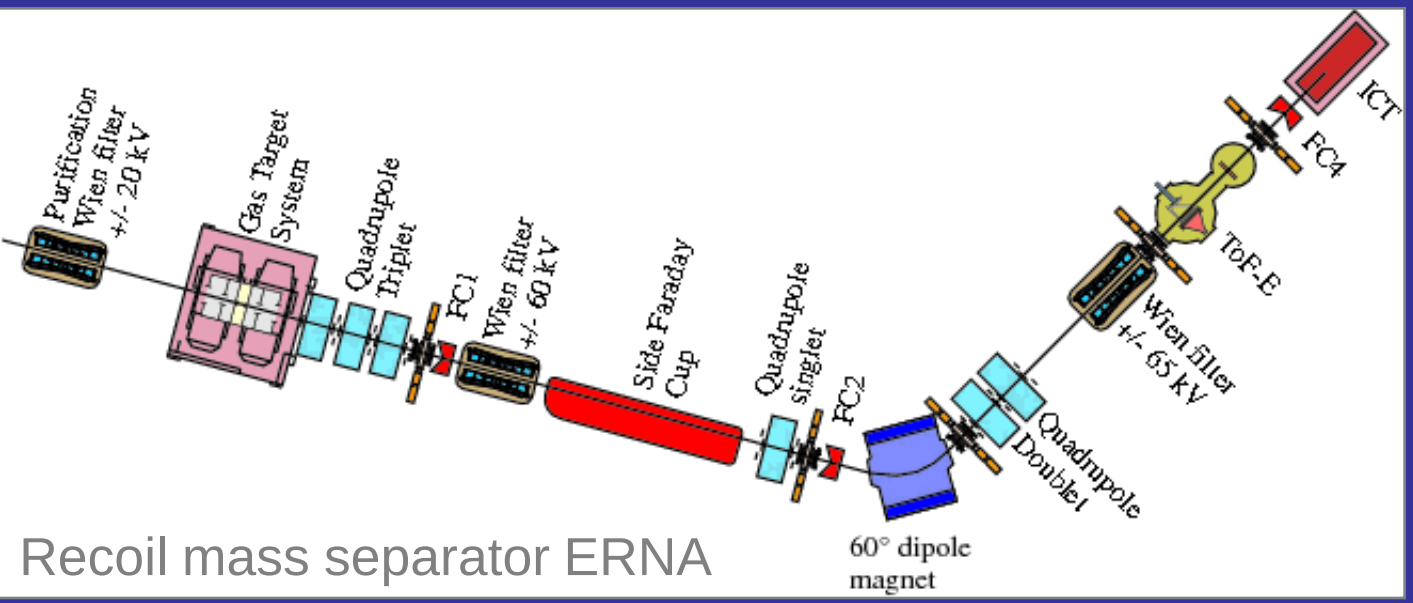
Weizmann Istitute Singh at al.
E_{cm}=0.45 – 0.95 MeV
Gas pressures: 52-20 torr

$^3He(a,\gamma)^7Be(e,\nu)\ ^7Li^*(\gamma)^7Li$

LUNA E_{cm}= 0.09 – 0.17 MeV







Recoil mass separator ERNA

The purpose is to provide current best values and uncertainties for S(0).

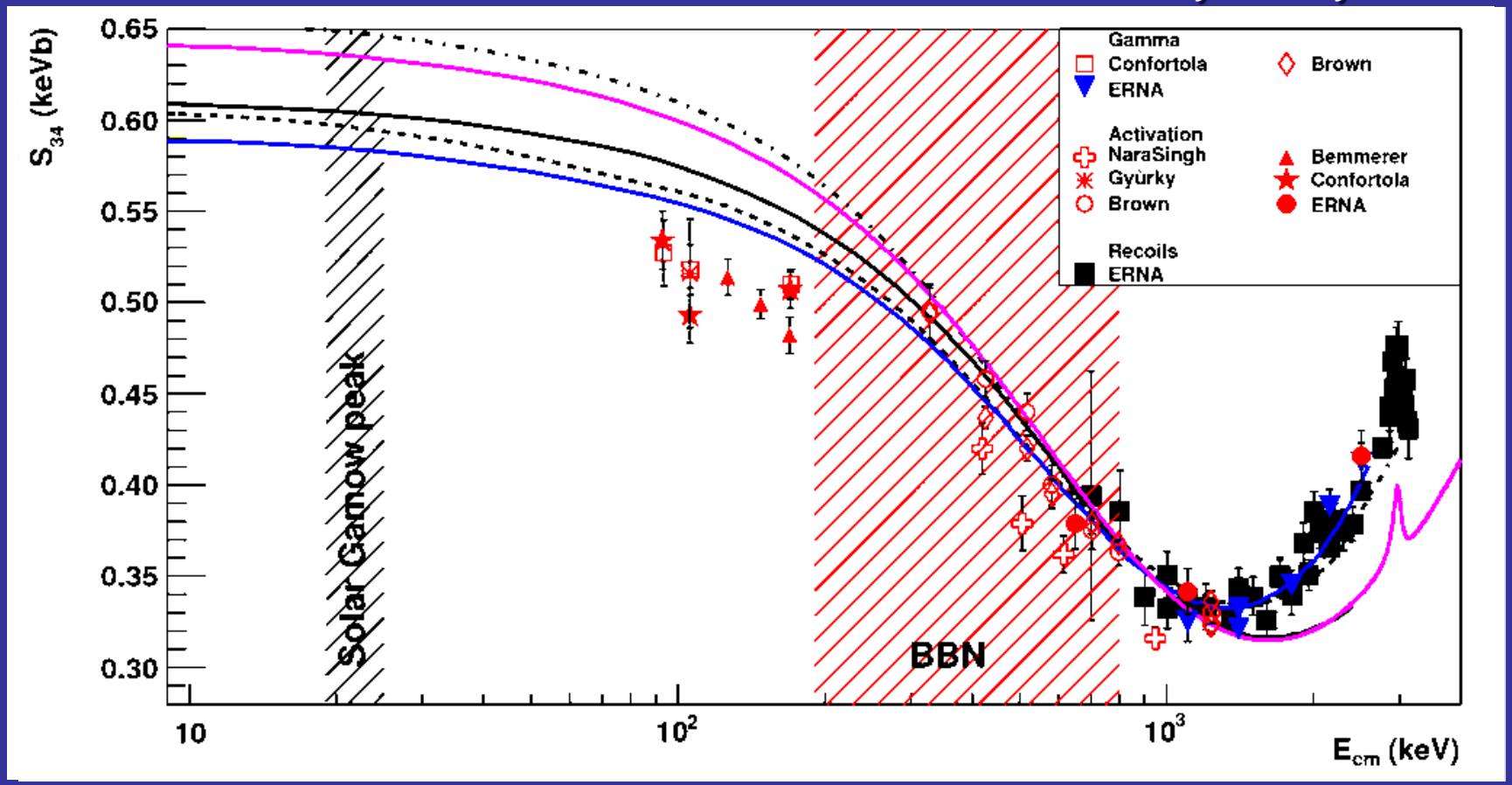
Extrapolation to solar energies

Potential models (global scaling parameter): Tombrello & Parker, Descouvemont (R-matrix based), Mohr

Microscopic models (no global scaling parameter): Csótó & Langanke, Kajino et al., Nollett, etc...

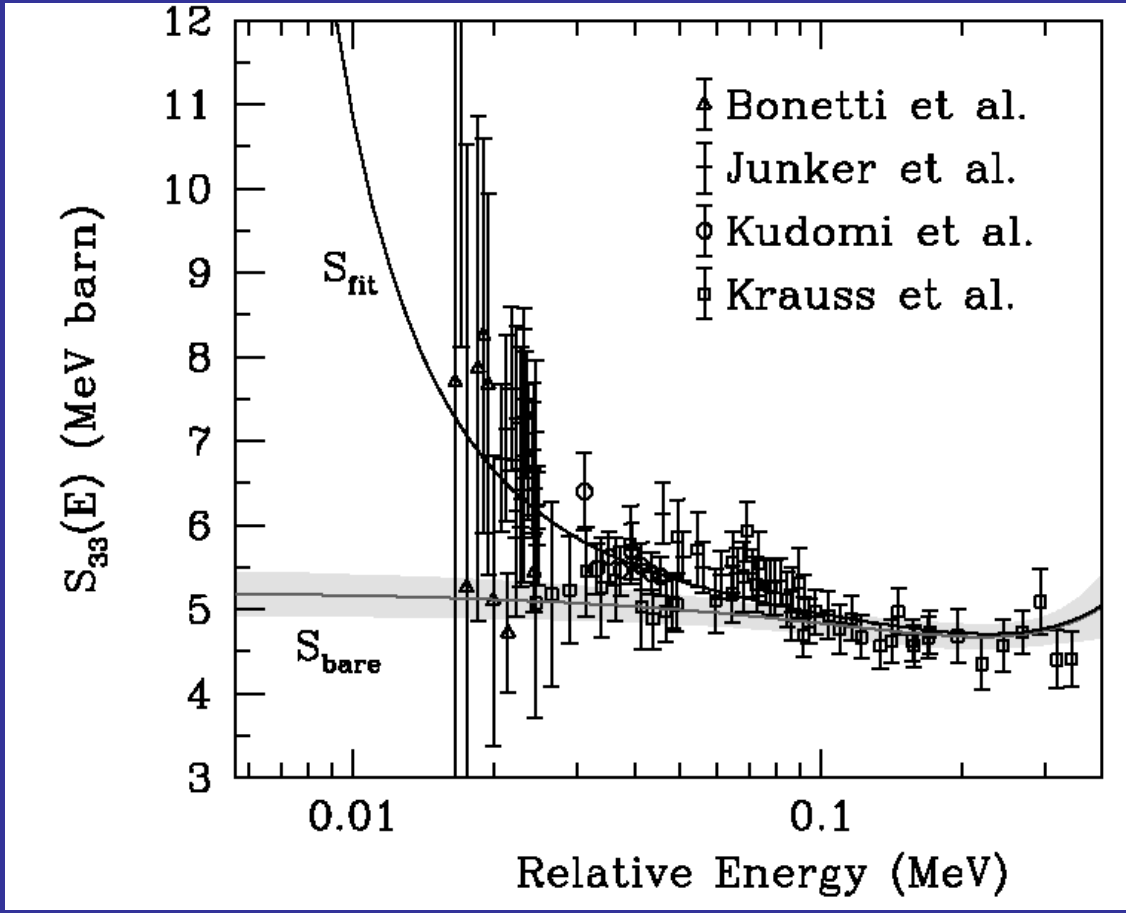
Usually claimed to be valid up to E_{cm}~2.0MeV

By Courtesy of A. Di Leva



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

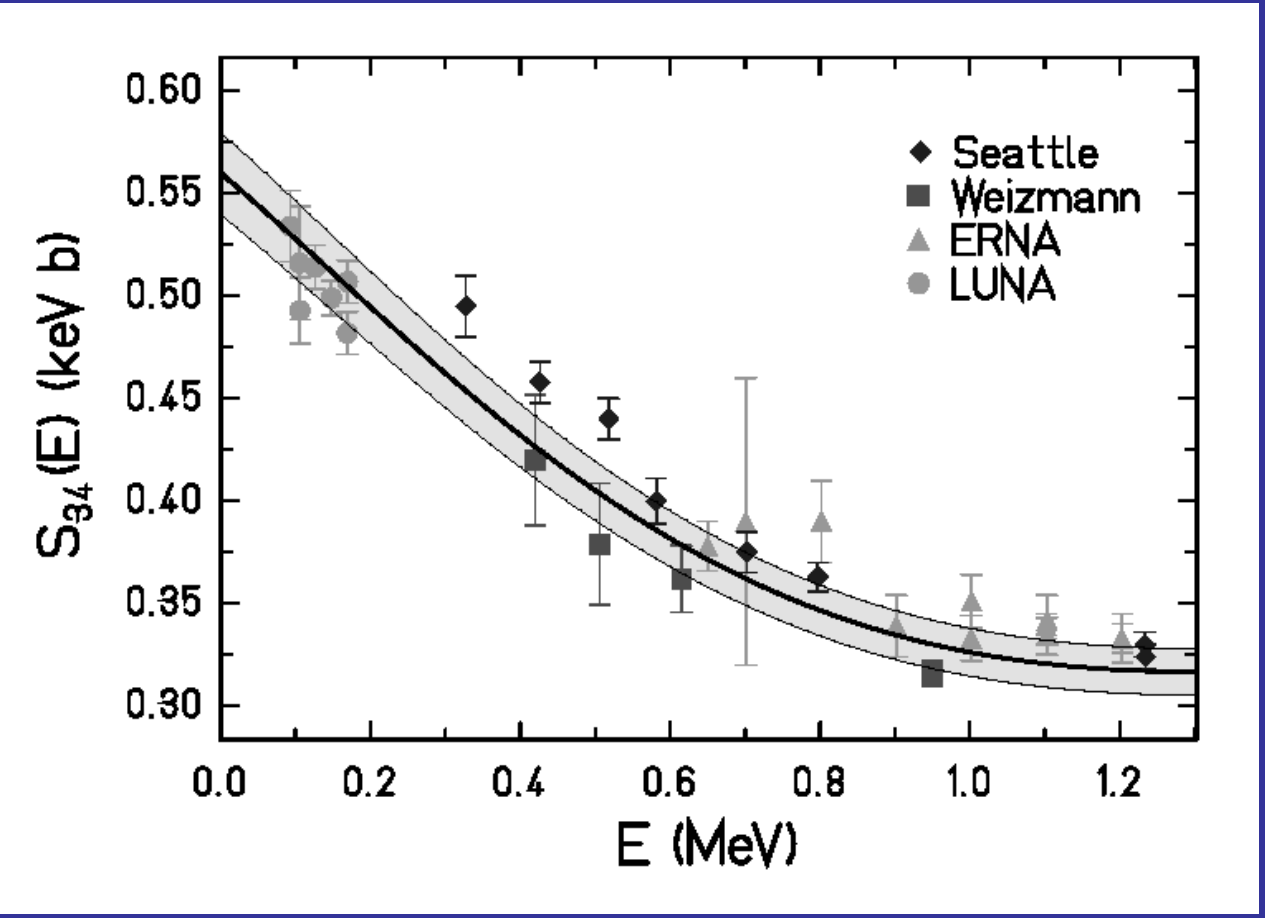
$S_{33}(E)$ remains of significant importance as it controls the pp/ ppII+ppIII branching ratio and thus the ratio of the pp/ pep to ^7Be/ ^8B neutrino fluxes.



There is no need for a theoretical model to guide an extrapolation, apart for a screening potential.

S_{33} = 5.21 0.27 MeVb

$^3He(^4He,\gamma)^7Be$



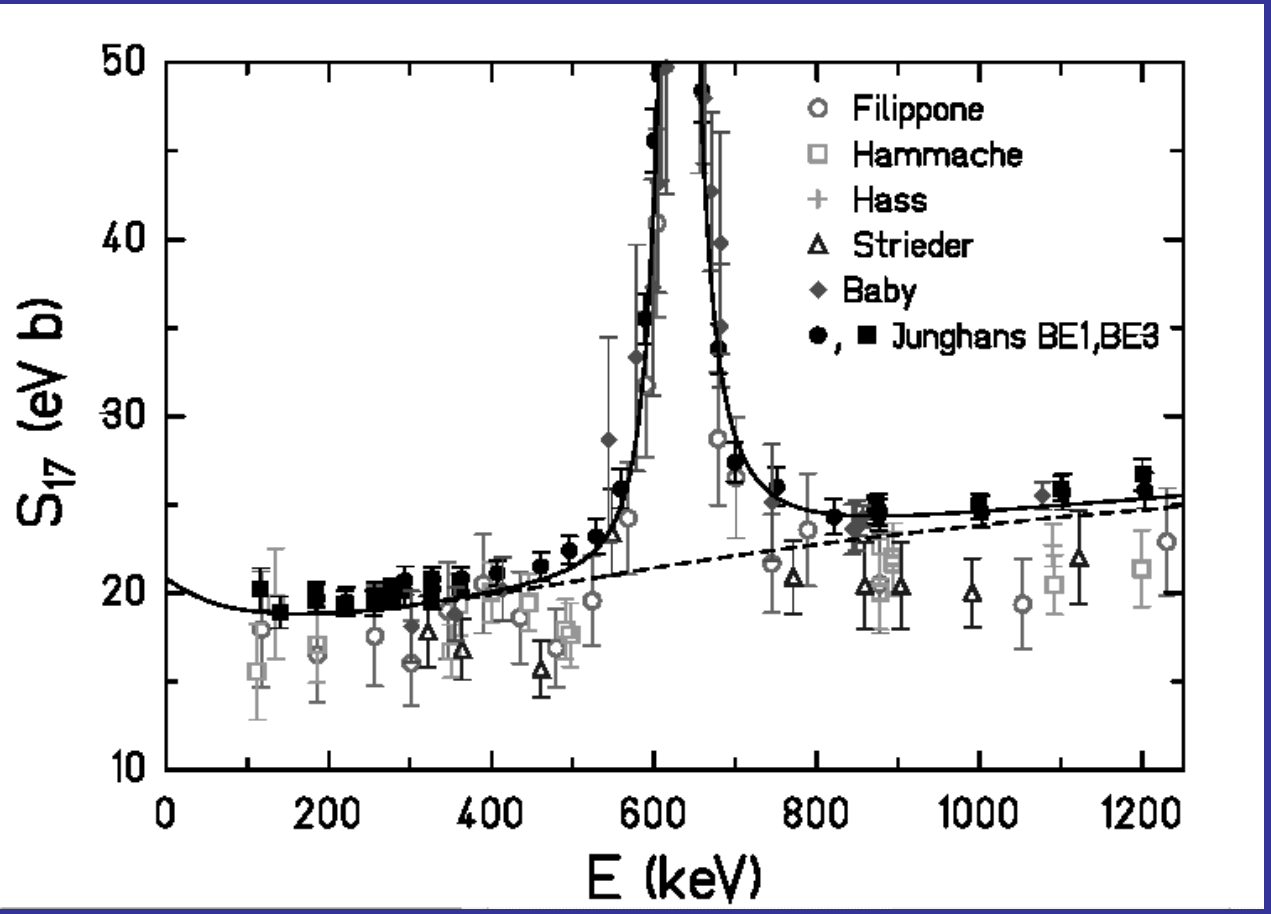
The analysis is based on activation data plus ERNA recoil data.

Energy range for fitting E< 1 MeV

The best fit curve was obtained by fitting each data set separately with the scaled theory. Then fitted the four S_{34} values to determine the mean

$S_{34}(0)$= 0.56 0.02 (expt) 0.02(theor) keV b

$^{7}Be(p,\gamma)^{8}B$

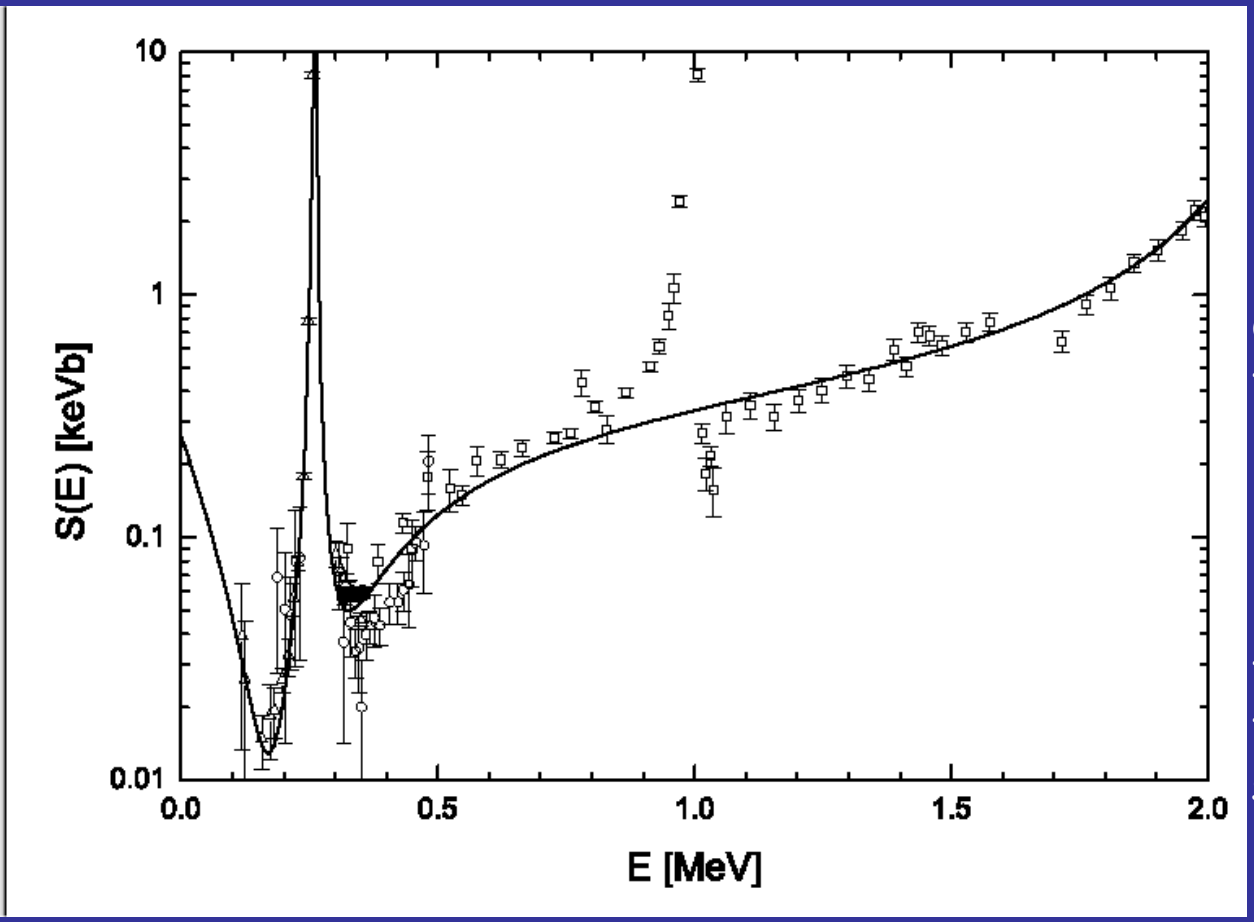


All data sets exhibit a similar S_{17} (E) energy dependence indicating that they differ mainly in absolute normaziation.

To estimate theoretical uncertainty different nuclear model were performed.

$S_{17}(0)$= 20.8 ± 0.7 (expt) ± 1.4(theor) eV b

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



Further work on $^{14}N(p,g)^{15}O$ is needed.

- A better understanding of the reaction mechanism to the 6.79 MeV state at high energies.

- Additional experimental and theoretical work on the transition to the 6.17 MeV state is needed

$S_{14}(0) = 1.66 \pm 0.12$ keV b

Conclusion

New underground facilities are under discussion

- ELENA proposed at Boulby salt mine in the UK
- CUNA proposed at Canfranc laboratory
- DIANA proposed at DUSEL, in Homestake gold mine South Dakota
- LUNA III proposed at LNGS

These facilities would be capable of mapping cross section
over broad energy ranges.

"Solar Fusion II is dedicated to John Bachall,
his appreciation for laboratory nuclear astrophysics and its importance
to solar neutrinos paved the way for many advanced in our field"

Solar fusion cross sections II: the pp chain and CNO cycles
arXiv:1004.2318