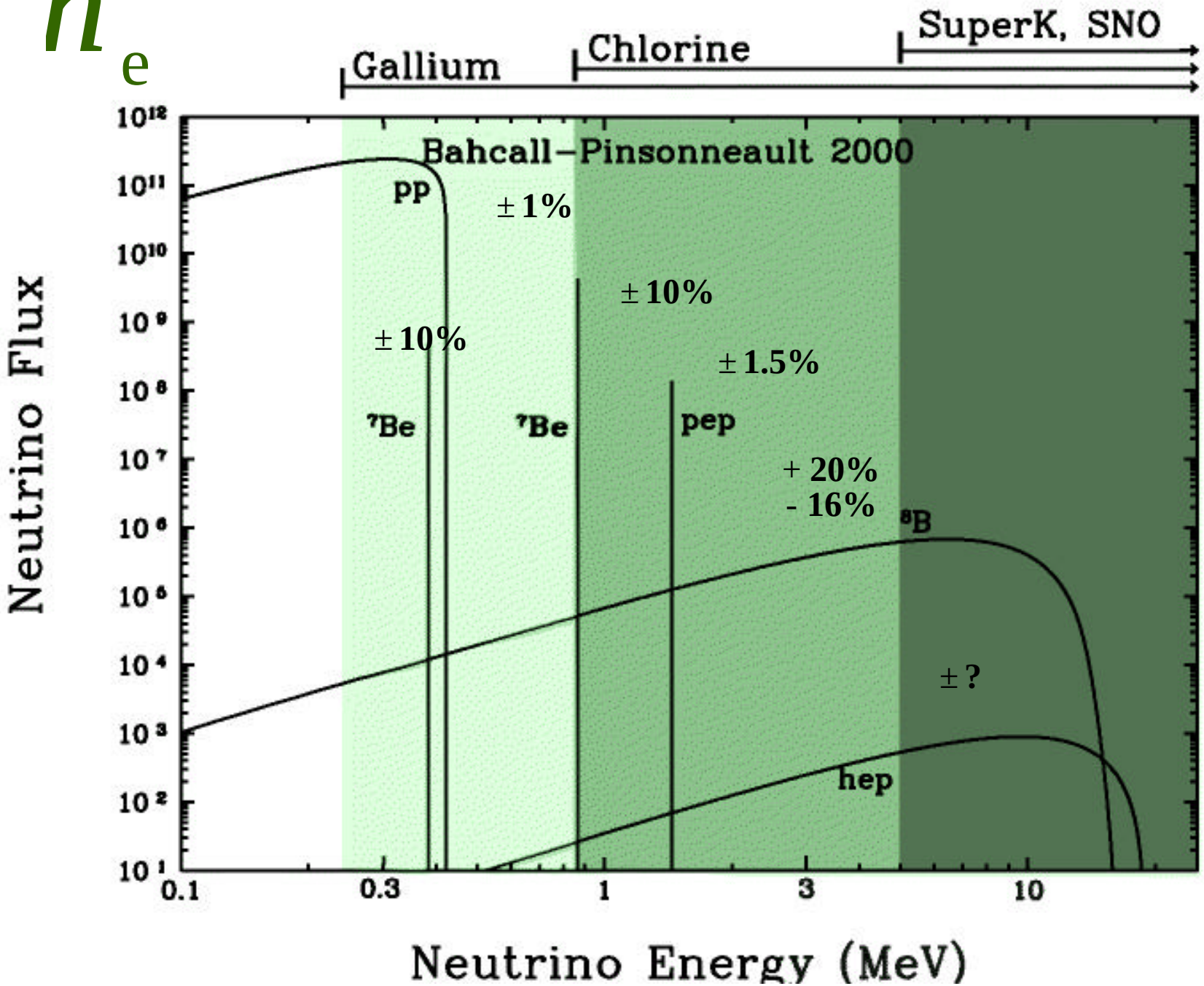
The Standard Solar Model and Experiments

- Predictions versus experiments
- Uncertainties in predictions
- Challenges and open questions

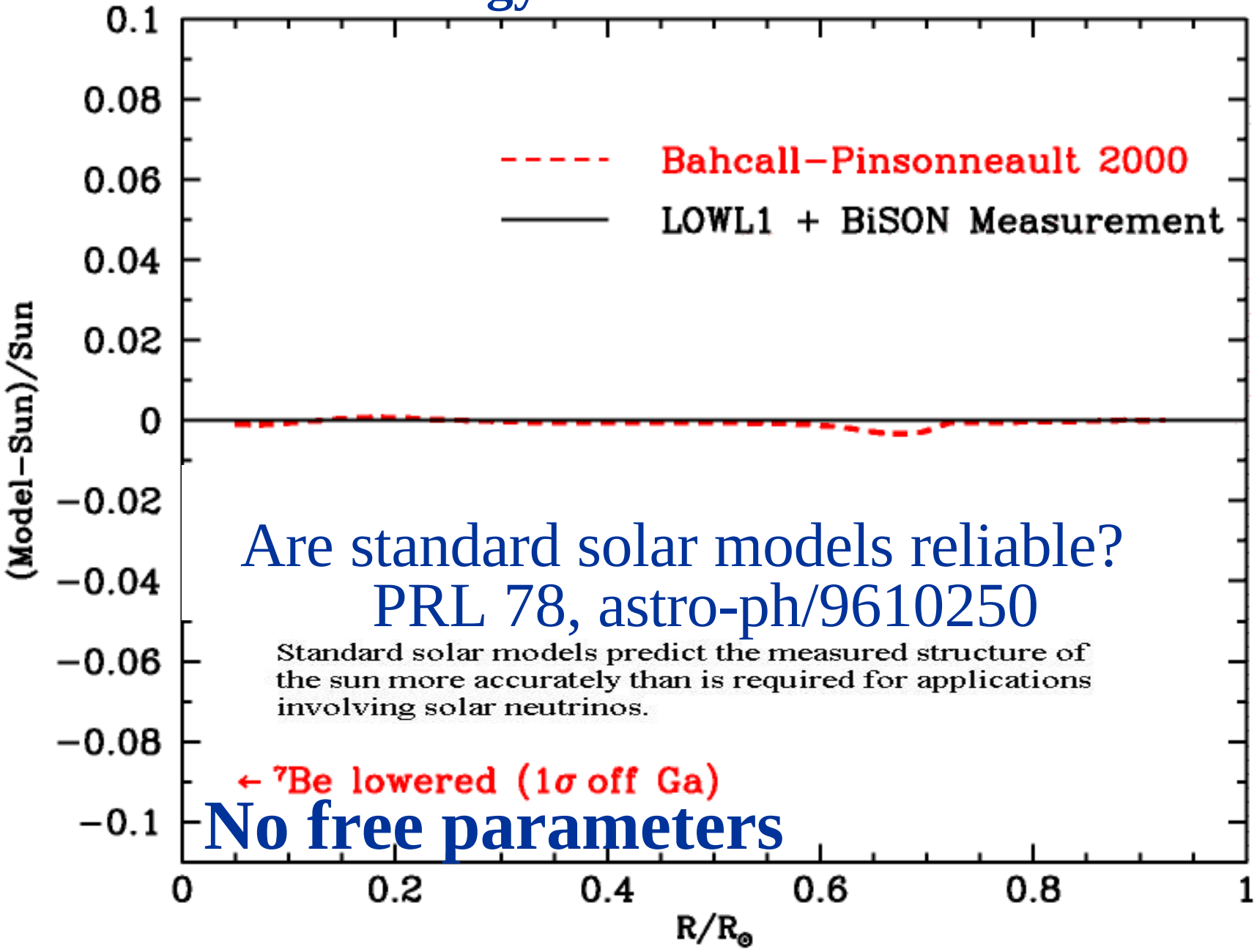
BP00: astro-ph/0010346

http://www.sns.ias.edu/~jnb

n_e


Gallium
Chlorine
SuperK, SNO
Bahcall–Pinsonneault 2000
pp
±1%
±10%
⁷Be
±10%
⁷Be
±1.5%
pep
+ 20%
- 16%
⁸B
±?
hep
Neutrino Flux
Neutrino Energy (MeV)
0.1
0.3
1
3
10

Helioseismology confirms solar model to 0.0007



Highlights: 2001-2002

- **2001: First direct n confirmation**

$^{8}\mathrm{B(BP00)} = 5.05^{+1.0}_{-0.8}$ **(unit : 10^{6} cm^{2}s^{-1})**

$^{8}\mathrm{B(SNO+SK)} = 5.44 \pm 0.99$

Agree to 0.3 s

- **2002: SNO NC**

^{8}B(SNO NC) = 5.09 ± 0.64 (undistorted spectrum)

Agree to 0.03 s

Precision measurements of

$^{3}He(a,g)^{7}Be$

γ Rays: 0.507 ± 0.016 (1963 - 1988)

6 measurements

^{7}Be activity: 0.572 ± 0.026 (1982 - 1984)

3 measurements

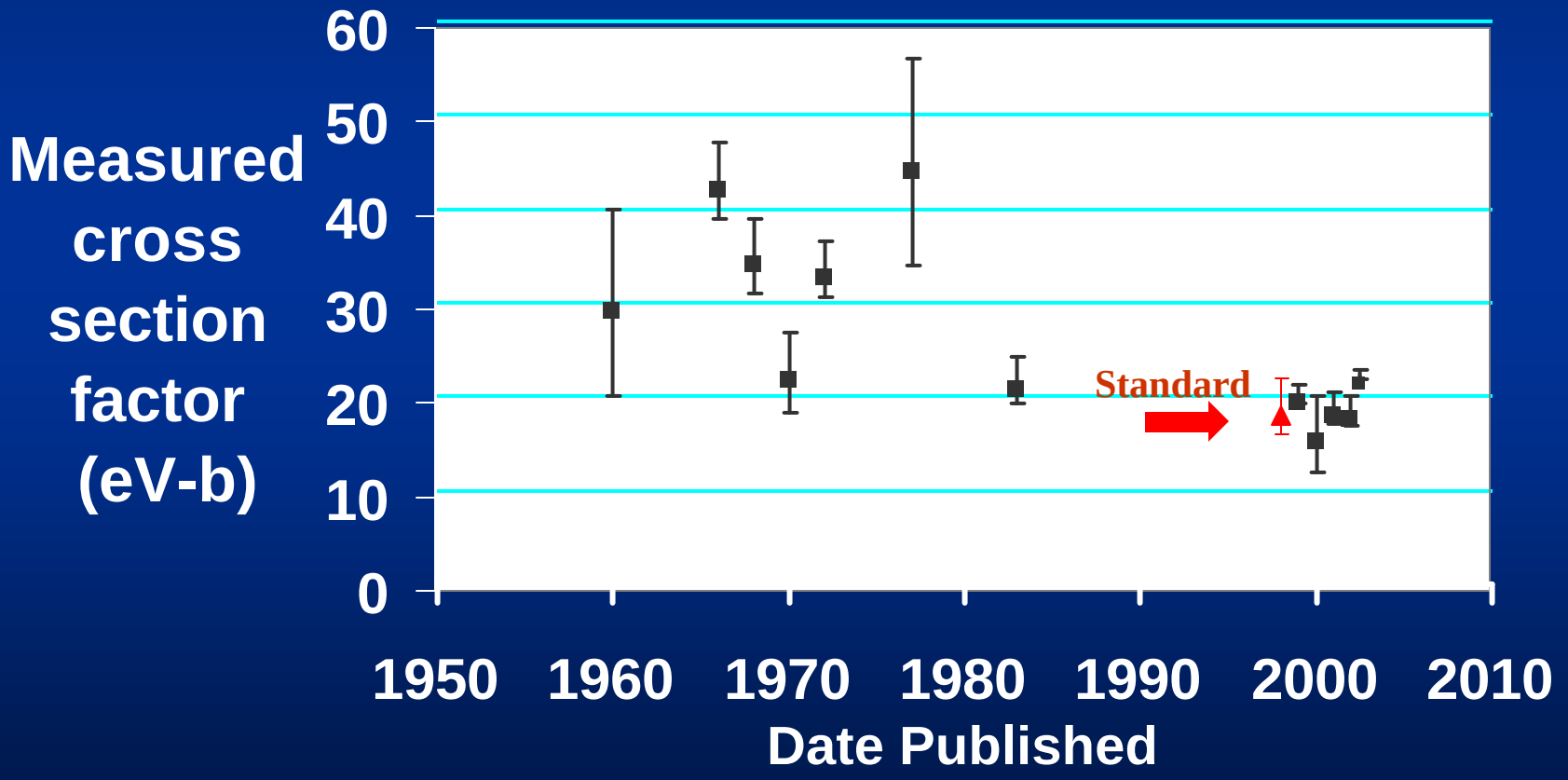
Average: 0.53 ± 0.05 kev b

Modern precision measurement:

urgently required: $\pm$ 3%!

Cross section: $^{7}\mathrm{Be}(p,g)^{8}\mathrm{B}$

$f(^{8}\mathrm{B}) \propto$ Cross Section Factor



BP00 %Uncertainties

astro-ph/0209080

Source	^{8}B	^{7}Be
p-p	0.04	0.02
$^{3}He + ^{3}He$	0.02	0.02
$^{3}He + ^{4}He$	0.08	0.08
$p + ^{7}Be$	$^{+0.14}_{-0.07}$	0.00
Composition	0.08	0.03
Opacity	0.05	0.03
Diffusion	0.04	0.02
Luminosity	0.03	0.01

Why do low energy solar neutrino experiments?

- **Test (refine) neutrino oscillation solutions**
  - **Same behavior at high energies**
  - **Different behavior at low energies**
  - **Could be wrong!**
- **Test solar fusion theory**
  - **SSM: 99.99% of solar neutrinos < 5 MeV**
  - **Low energy fluxes predicted more precisely**
- **Redundancy, redundancy, redundancy**

SSM: Fundamental Low-Energy tests

- **Stellar evolution theory predicts:**

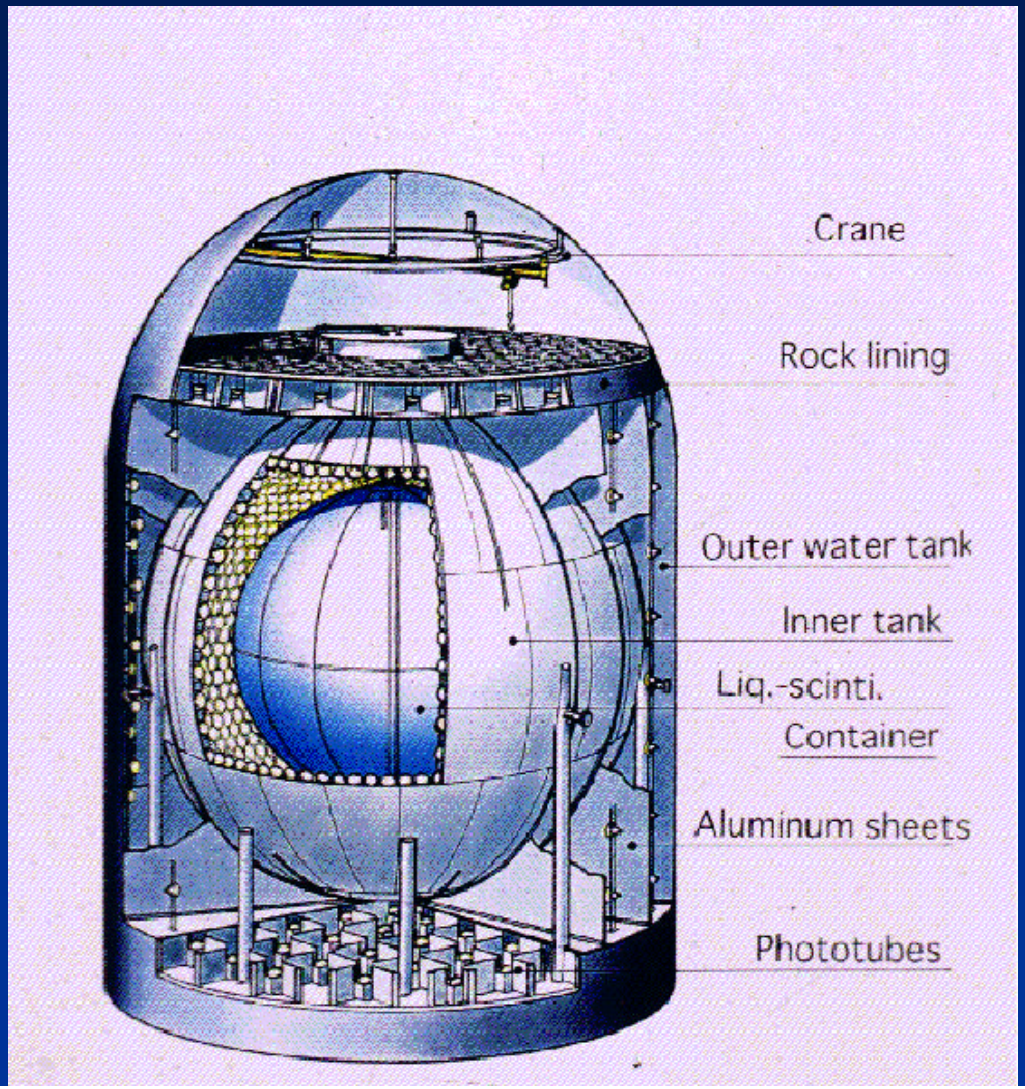
$$\frac{<{}^3\mathrm{He} + {}^4\mathrm{He}>}{<{}^3\mathrm{He} + {}^3\mathrm{He}>} = \frac{2\,j({}^7\mathrm{Be})}{j(pp) - f({}^7\mathrm{Be})} = 0.174$$

pp fusion formula: summarizes competition between different fusion chains.

- **CNO neutrinos represent 1.5% of luminosity**
- $\Delta E({}^7\mathrm{Be}) = 1.2\,\mathrm{keV}$

KamLAND (Japan)

$\bar{n}_e + p \rightarrow e^+ + n$ reactor anti-neutrinos



$0.49^{+0.20}_{-0.17}$ (1s)

hep-ph/0204314

Sterile neutrinos

$^8B_{total}$: ± 10%

$^8B_{sterile}$: ± 12%

hep-ph/0204194

CPT Test

£ 10^{-20} GeV

hep-ph/0201211

Does the solar luminosity determine the pp flux?

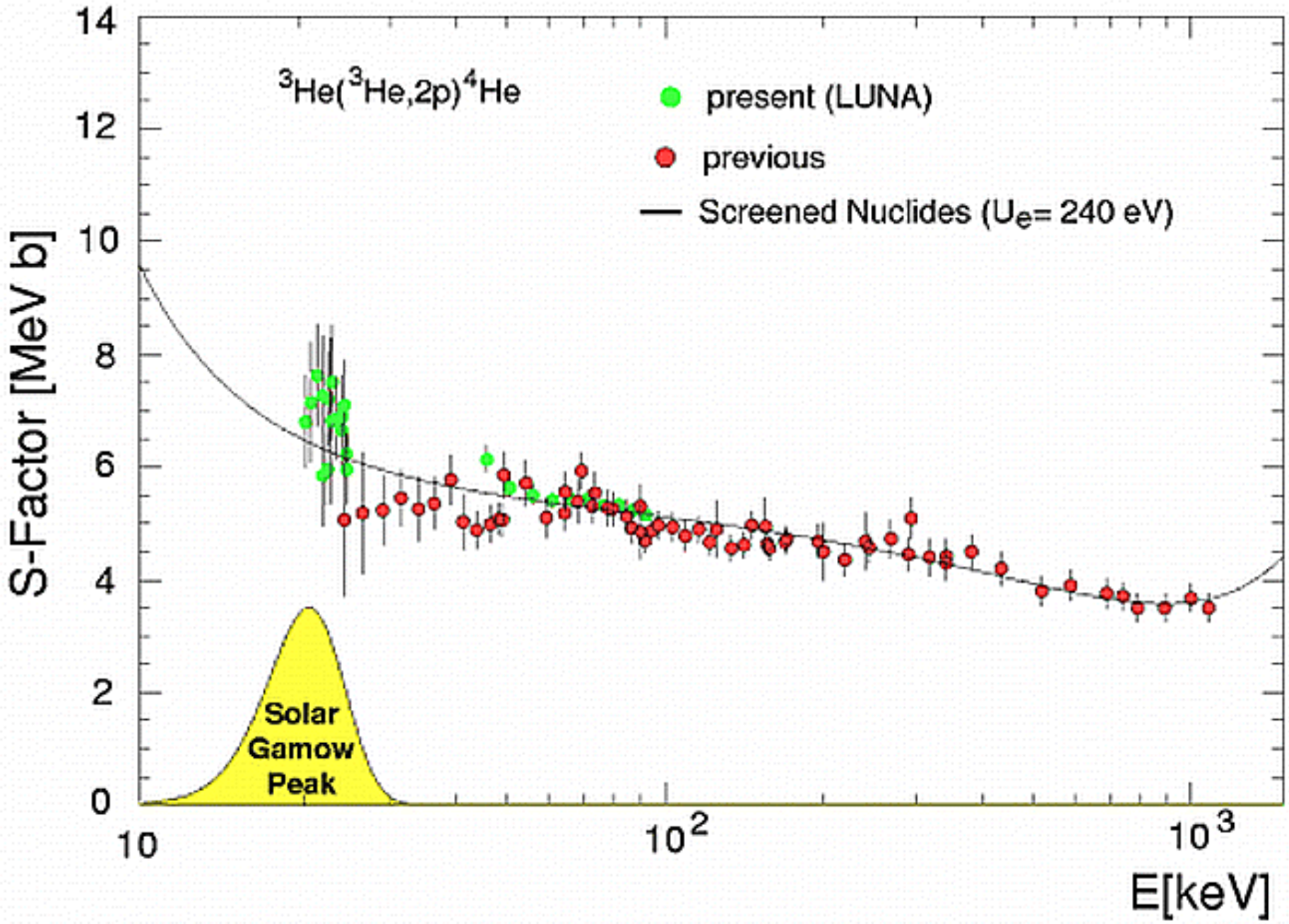
Theoretical error = 1%

$$4\,p \rightarrow {}^{4}\mathbf{He} + 2e^{+} + 2n_{e} + 25\,\mathbf{MeV}$$

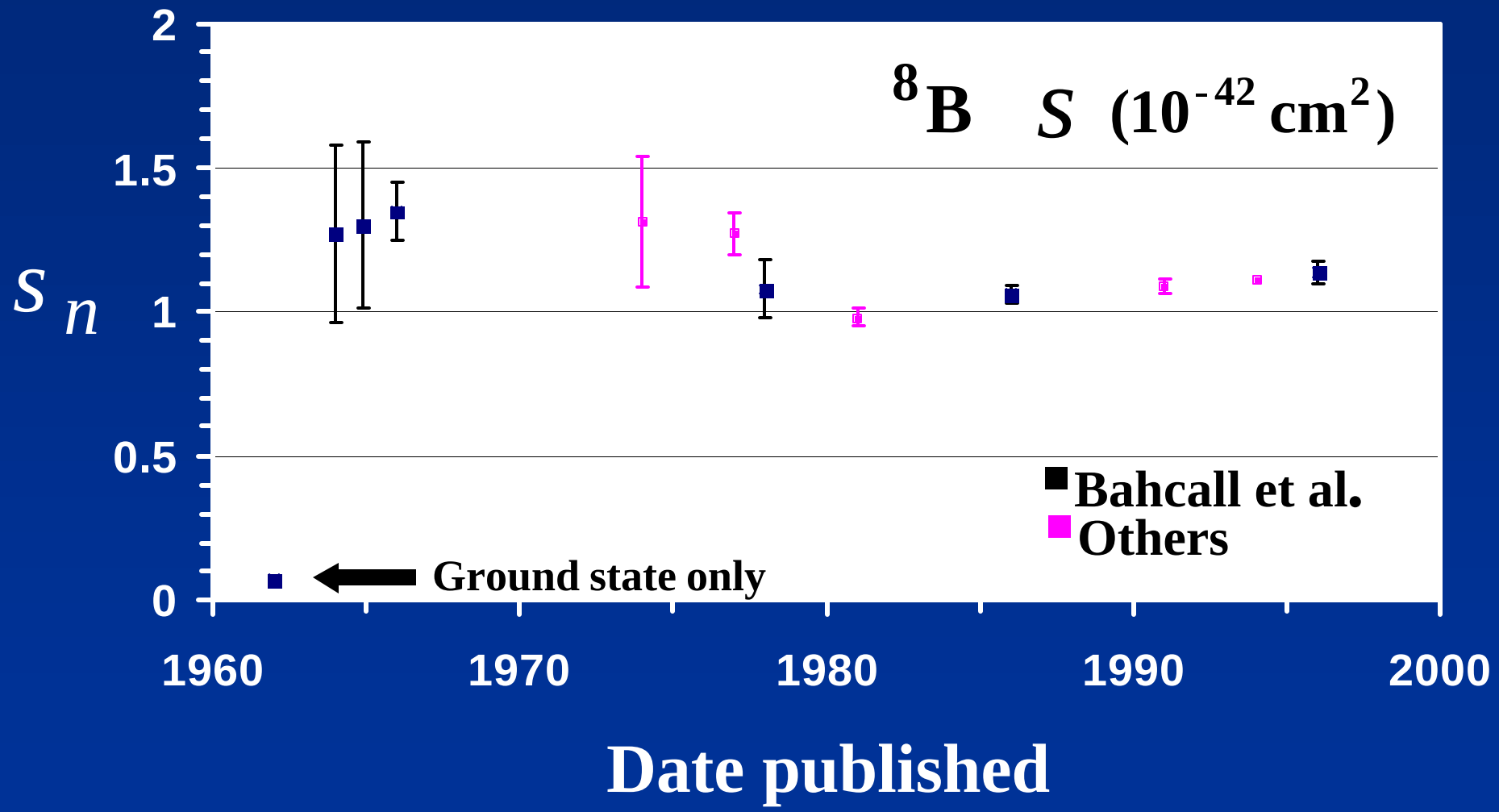
CNO cycle: 0 pp neutrinos

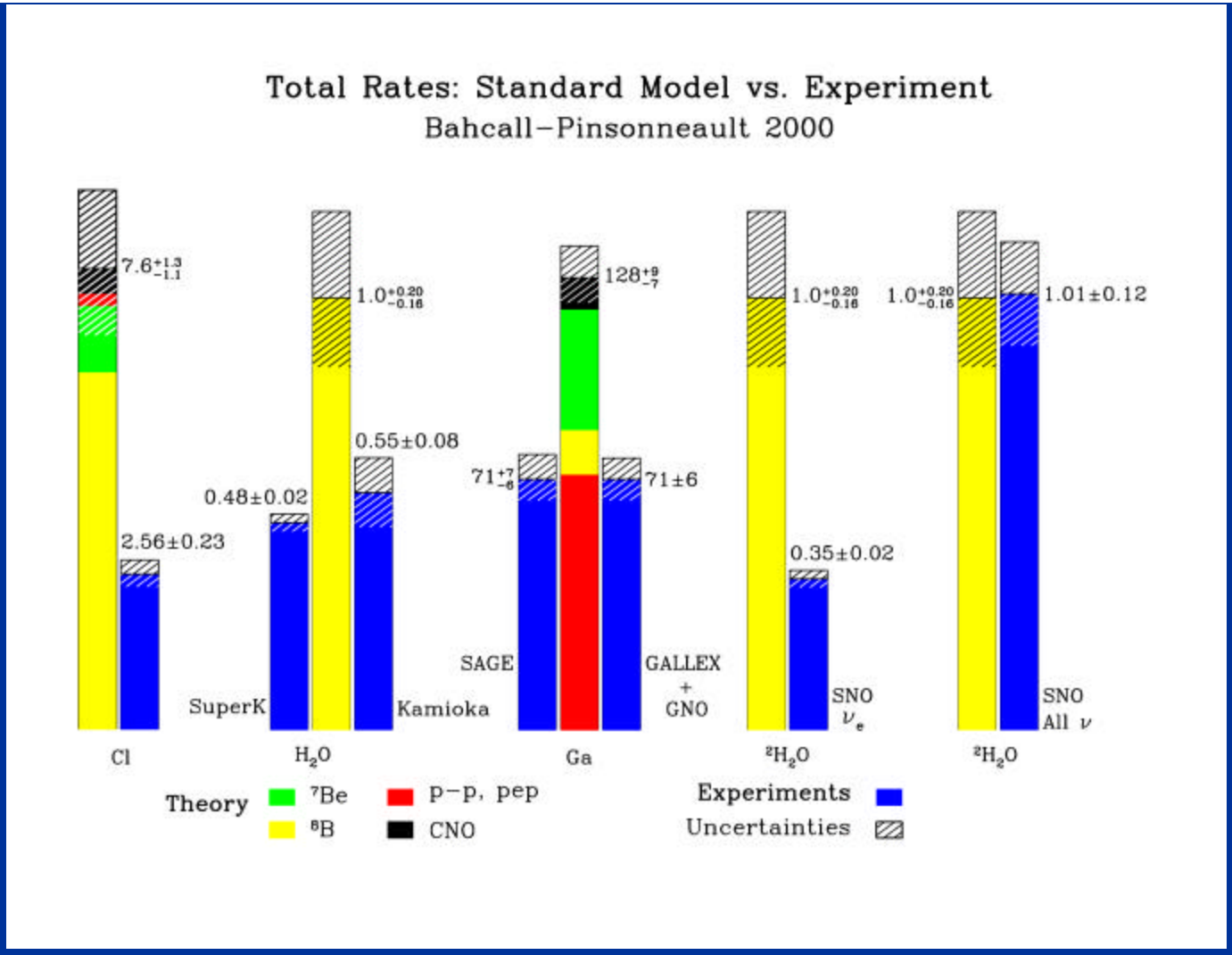
Big ^{7}Be flux : 0.5 max pp flux

Luminosity determines pp flux: 0 –1.0 max flux


^{3}He(^{3}He,2p)^{4}He
present (LUNA)
previous
Screened Nuclides (U_e= 240 eV)
S-Factor [MeV b]
E[keV]
Solar Gamow Peak
14
12
10
8
6
4
2
0
10
10^2
10^3

$^{37}Cl(n_e, e)^{37}Ar$ vs. date published





7 Experiments; 34 years; 0.01% of the flux.

A solar neutrino “opportunity”; not a problem.