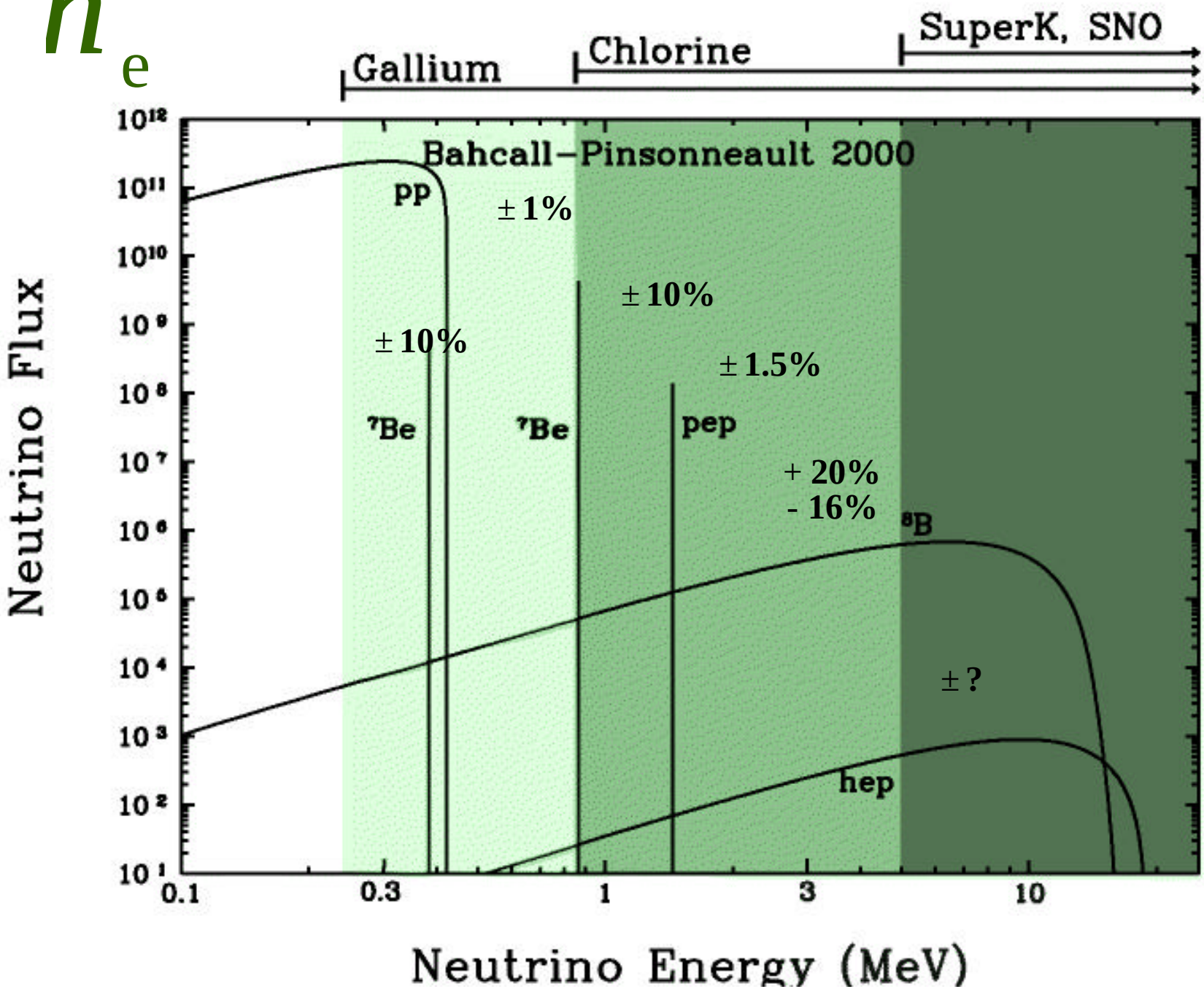
The Standard Solar Model and Experiments

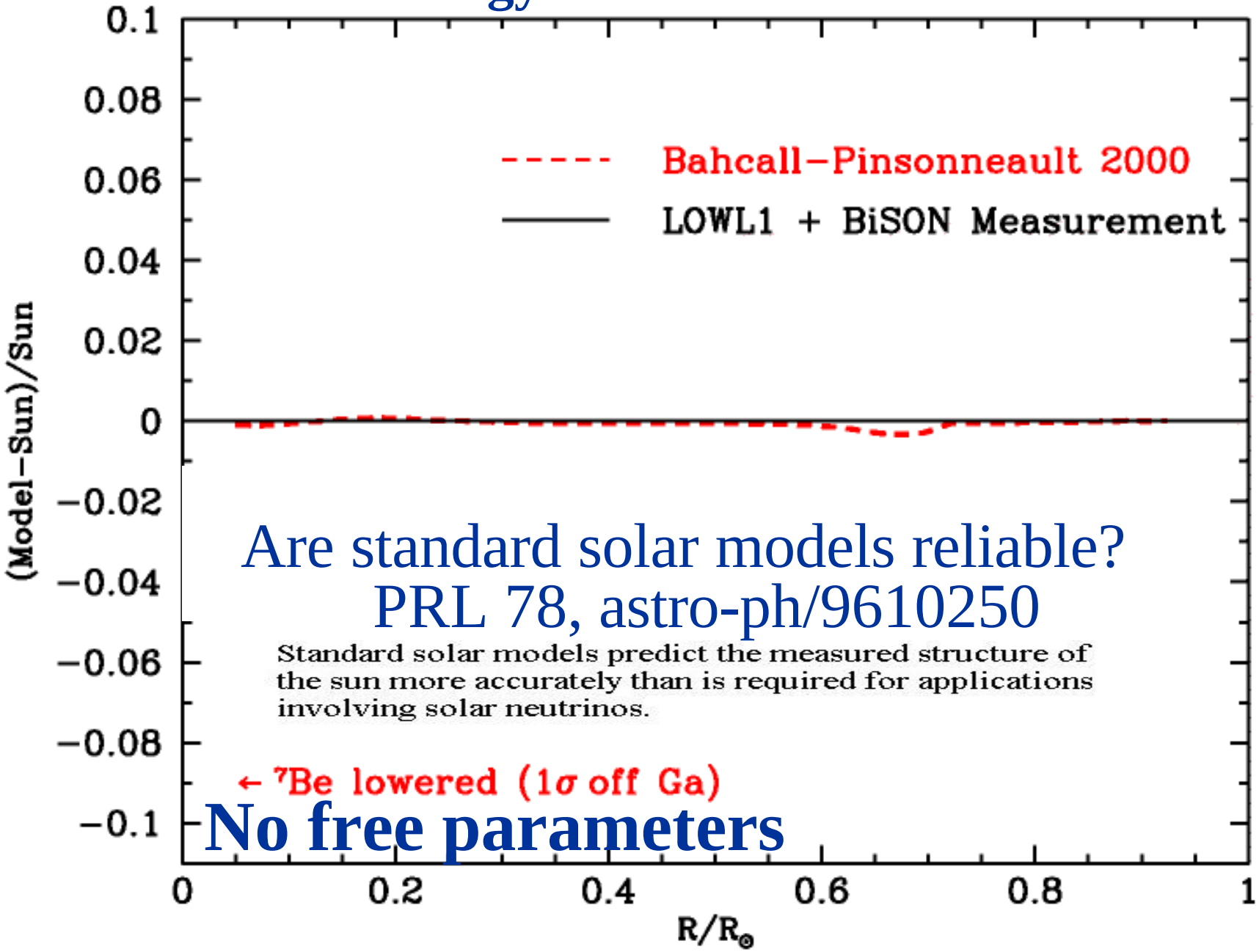
- Predictions versus experiments
- Uncertainties in predictions
- Challenges and open questions

BP00: astro-ph/0010346

n_e


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

Helioseismology confirms solar model to 0.0007



Are standard solar models reliable?
PRL 78, astro-ph/9610250

Standard solar models predict the measured structure of the sun more accurately than is required for applications involving solar neutrinos.

No free parameters

Highlights: 2001-2002

- **2001: First direct ? confirmation**

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

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

Agree to 0.3s

- **2002: SNO NC**

$$^{8}B(SNO\ NC) = 5.09 \pm 0.64$$ **(undistorted spectrum)**

Agree to 0.03s

Precision measurements of

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

g **Rays : 0.507 ± 0.016 (1963 - 1988)**

6 measurements

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

3 measurements

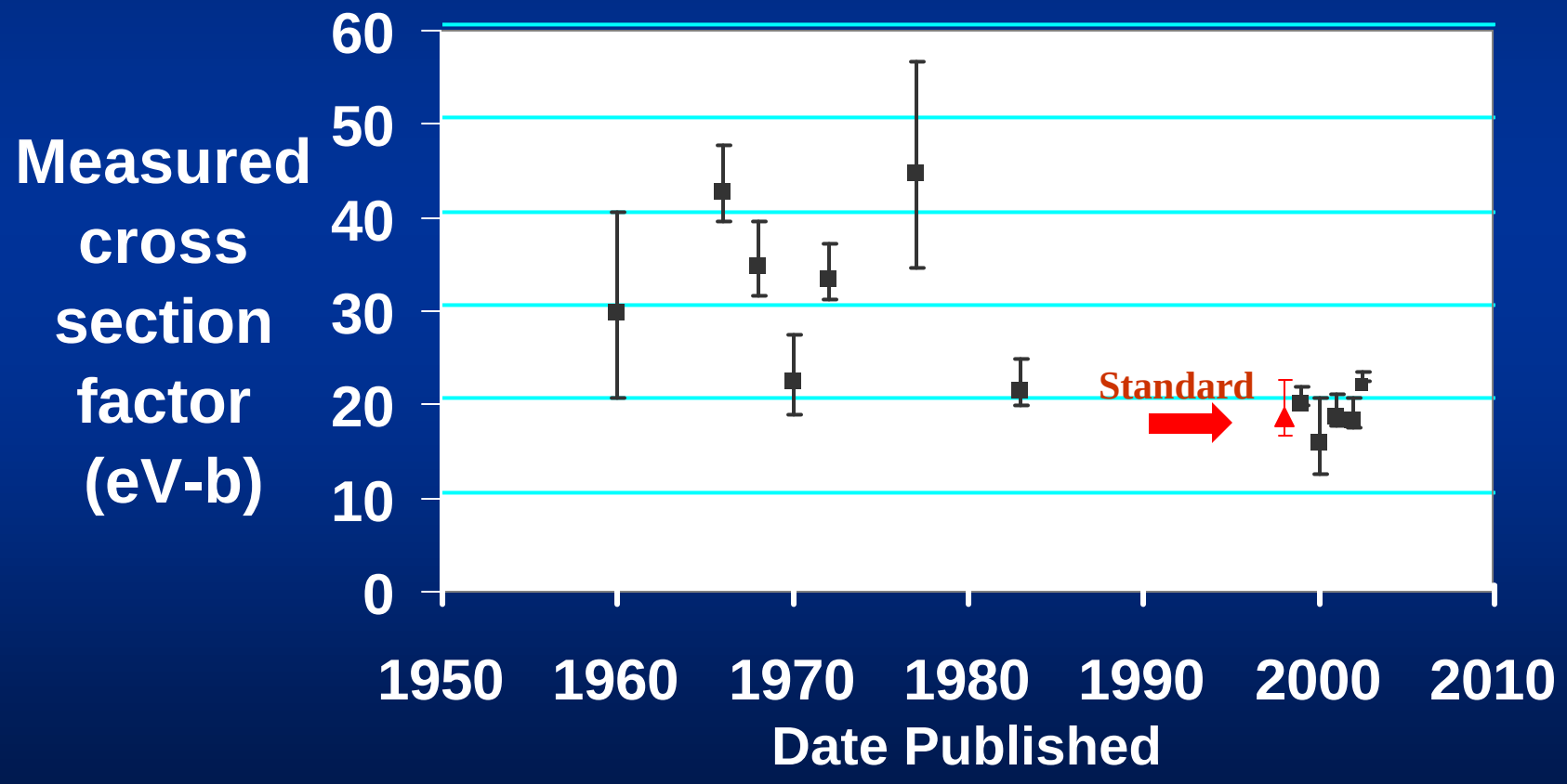
Average : 0.53 ± 0.05 kev b

Modern precision measurement:

urgently required: ± 3%!

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

$f(^{8}B) \propto$ 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:

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

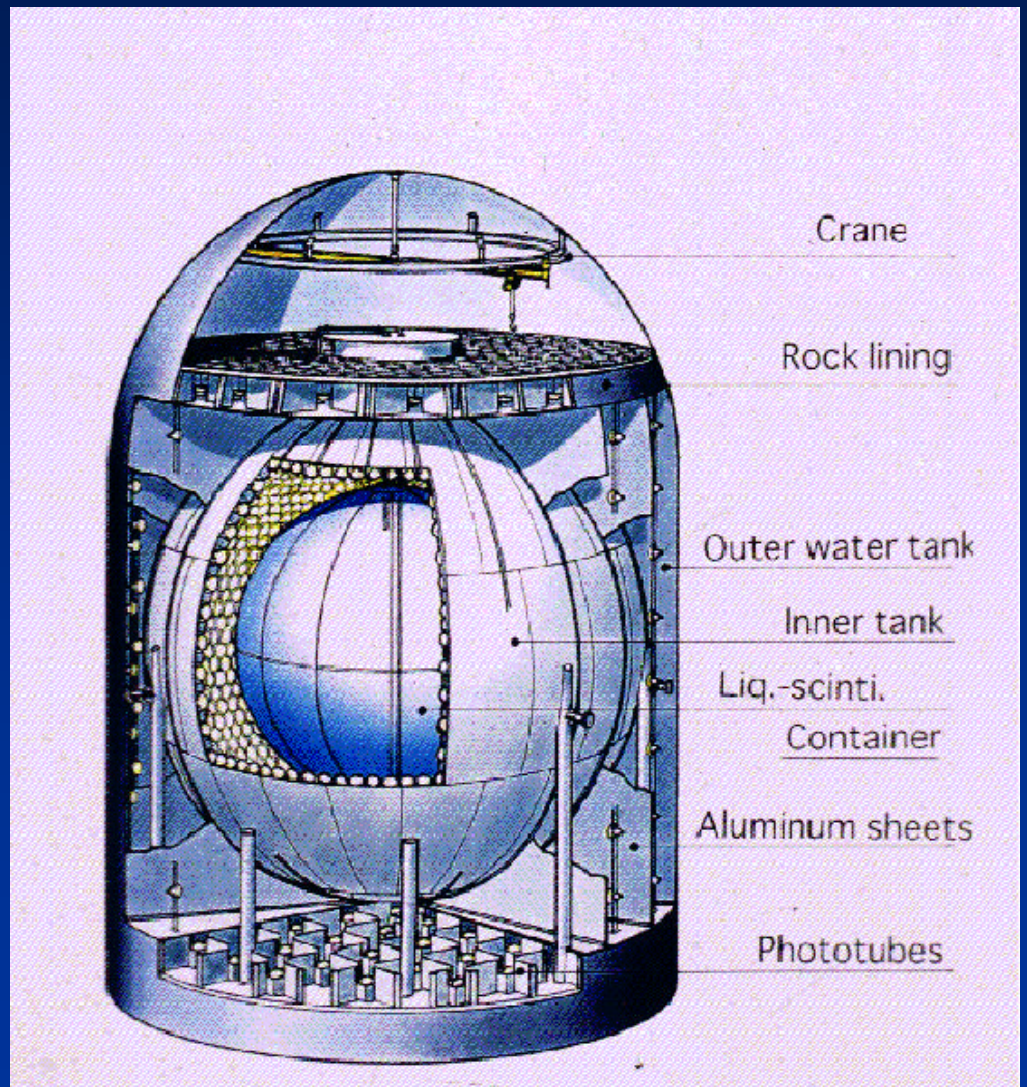
pp fusion formula: summarizes competition between different fusion chains.

- CNO neutrinos represent 1.5% of luminosity

· $?E({}^7Be) = 1.2\ keV$

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?

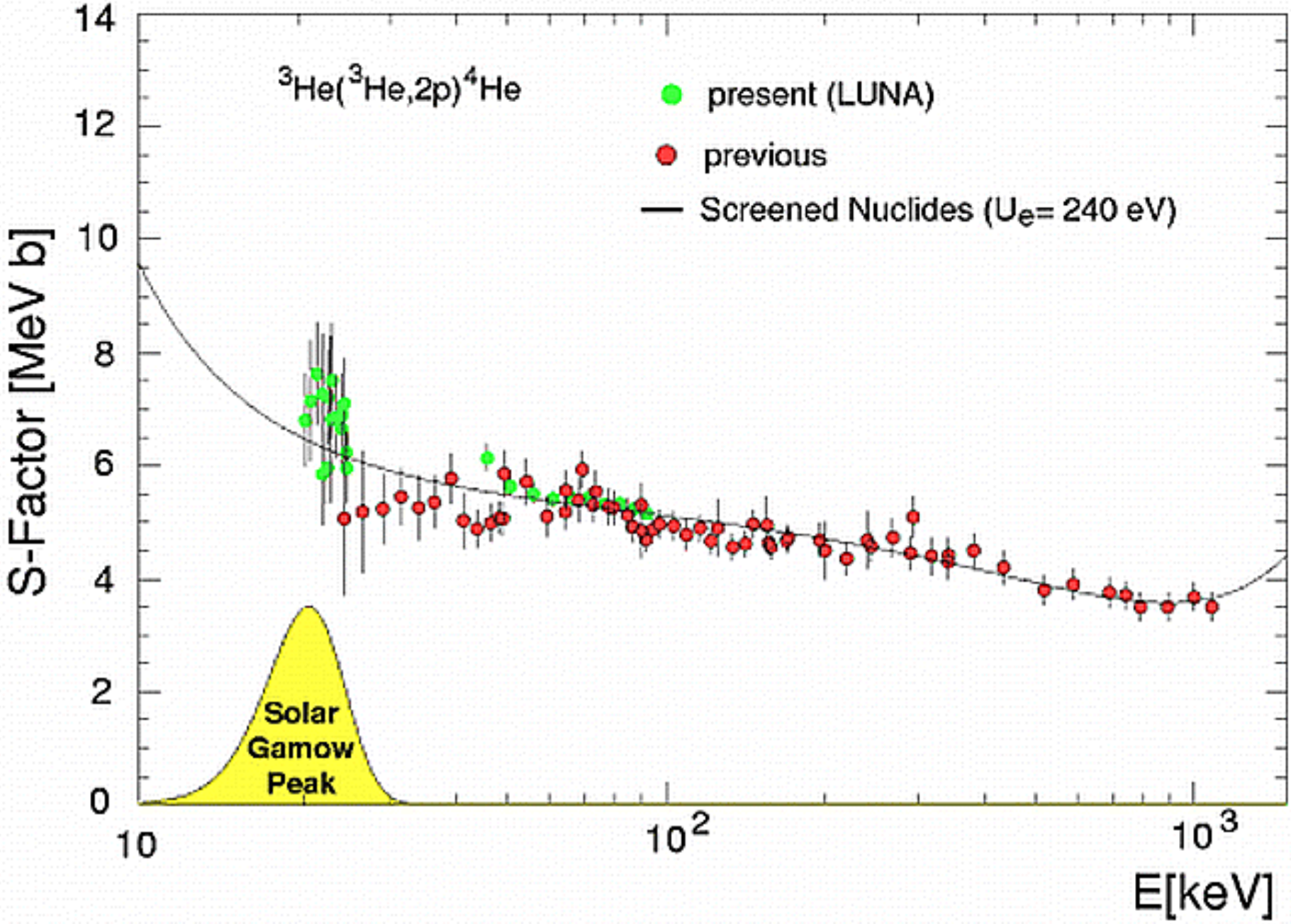
Theoretical error = 1%

$$4p \;!\; {}^{4}He + 2e^{+} + 2\div_{e} + ø\ 25\ MeV$$

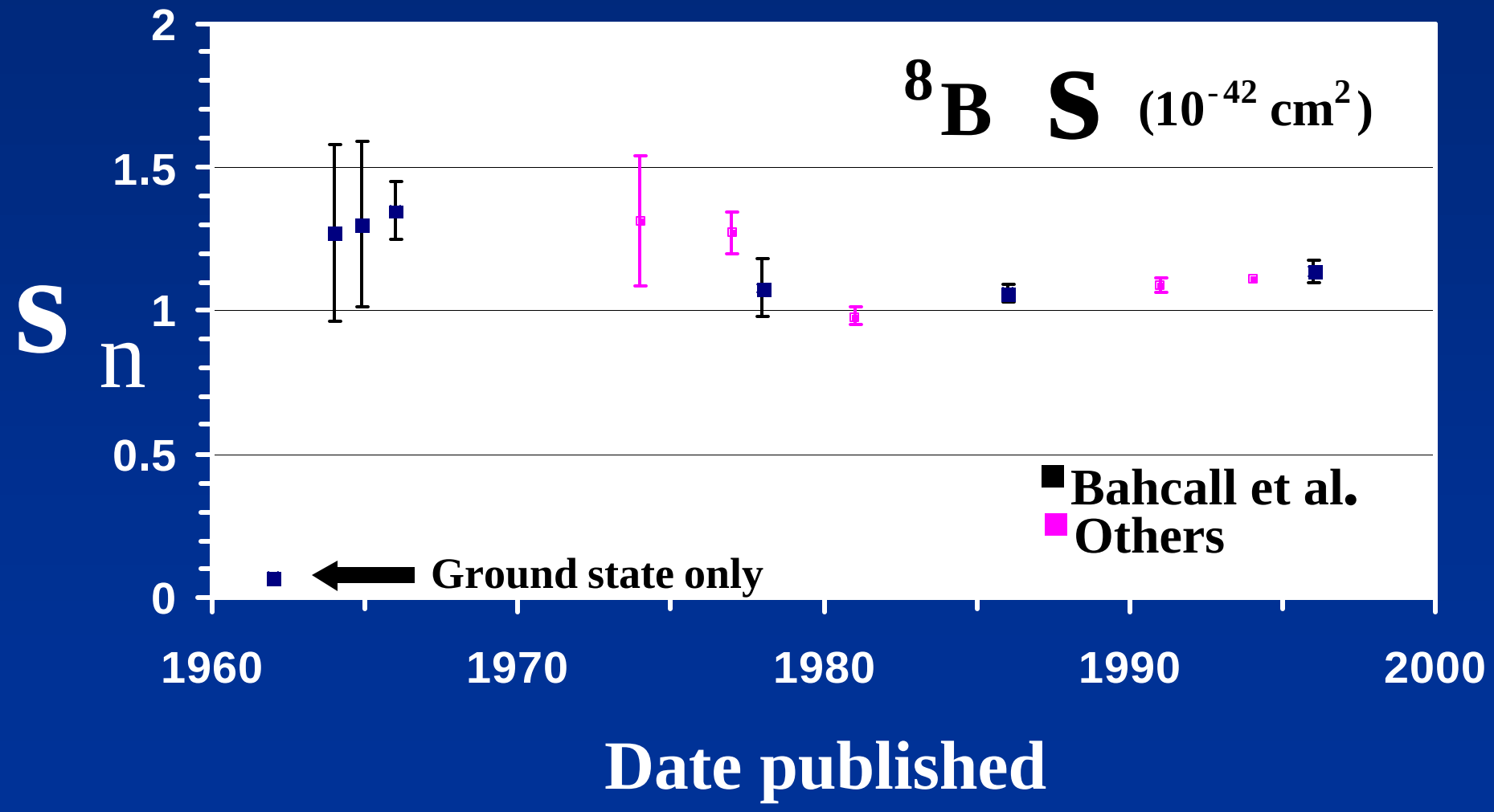
CNO cycle: 0 pp neutrinos

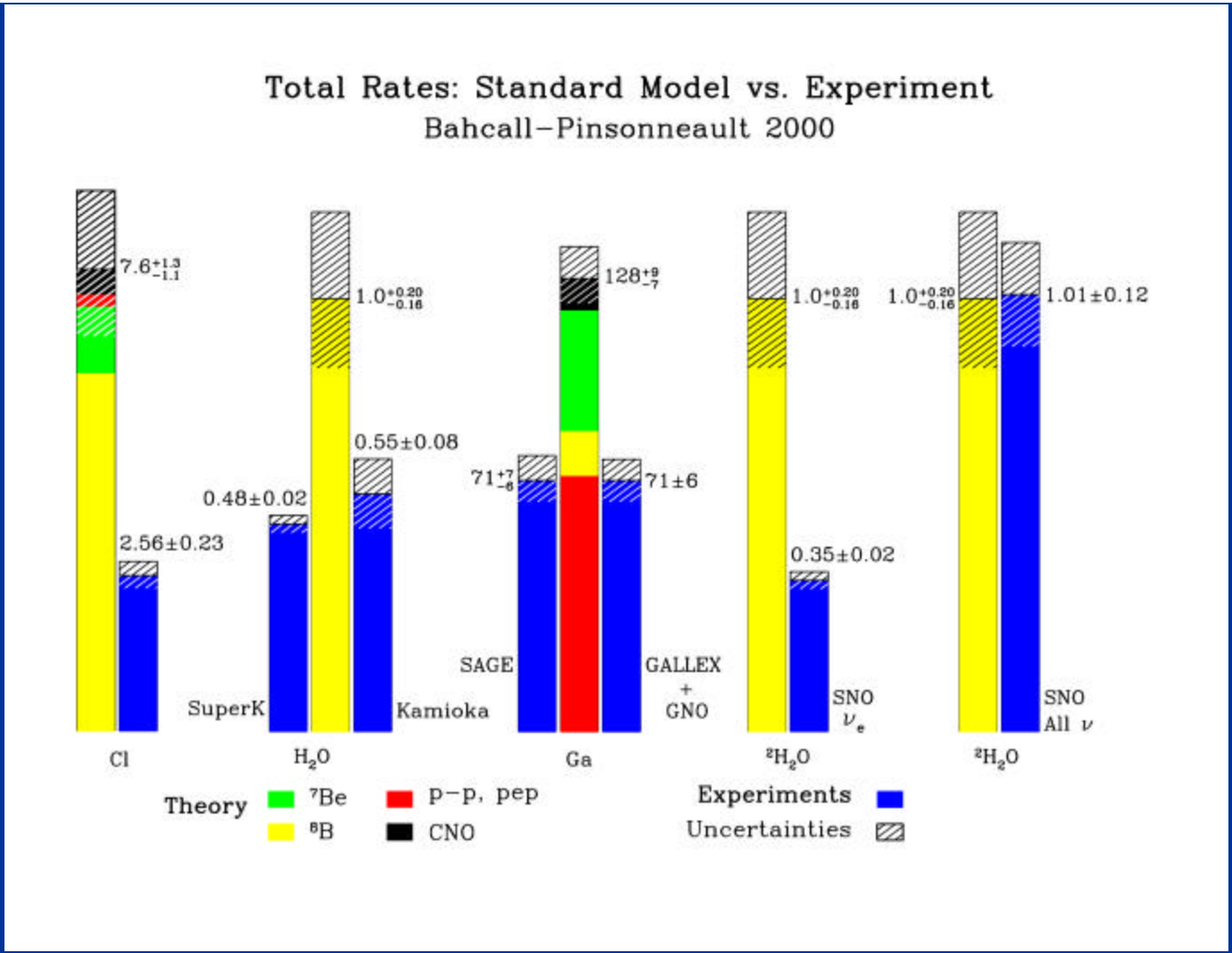
Big ^{7}Be flux : 0.5 max pp flux

Luminosity determines pp flux: 0 –1.0 max flux


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

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





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

A solar neutrino "opportunity"; not a problem.