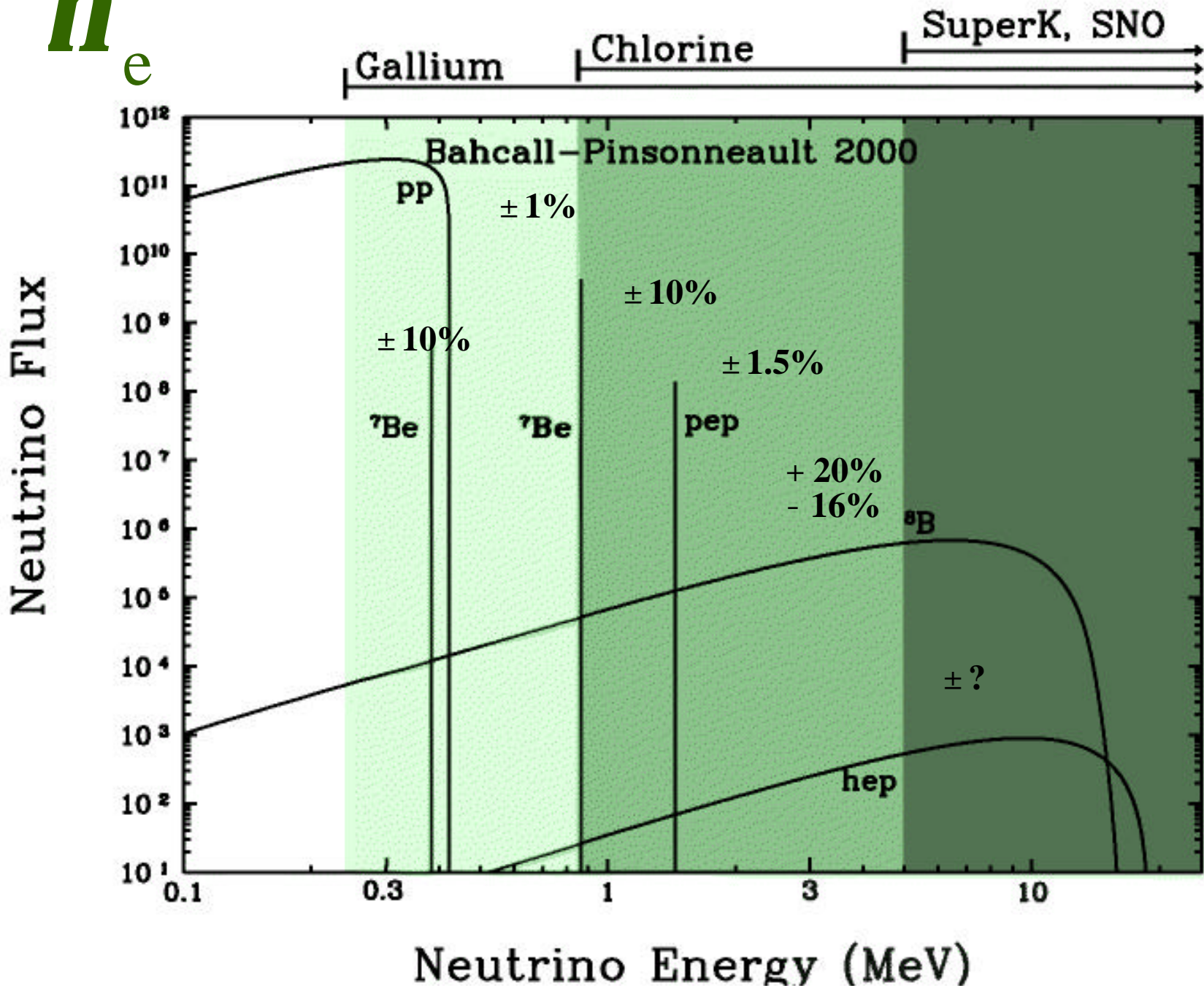


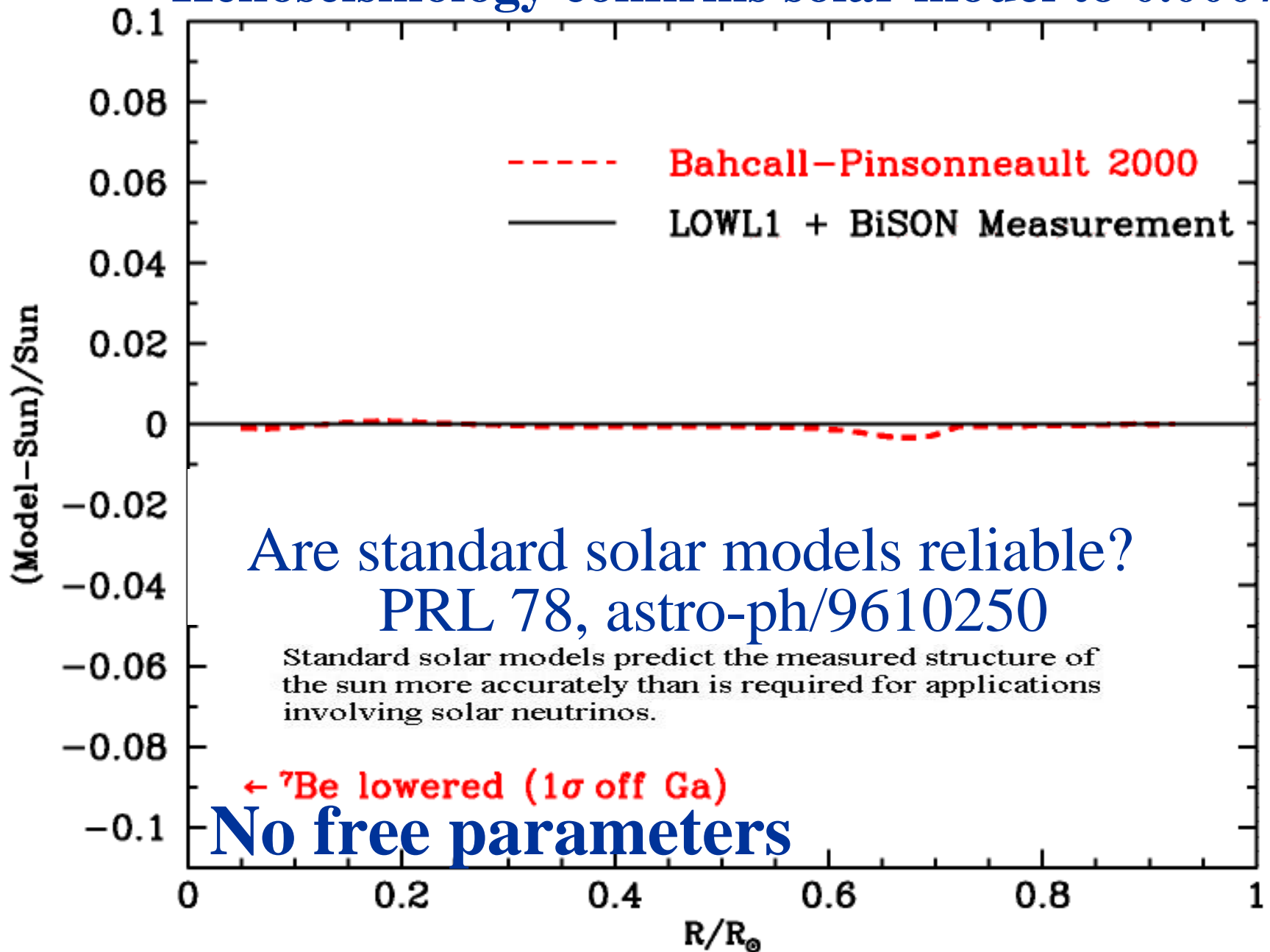
# **The Standard Solar Model and Experiments**

- Predictions versus experiments
- Uncertainties in predictions
- Open questions
- Why did it take so long?

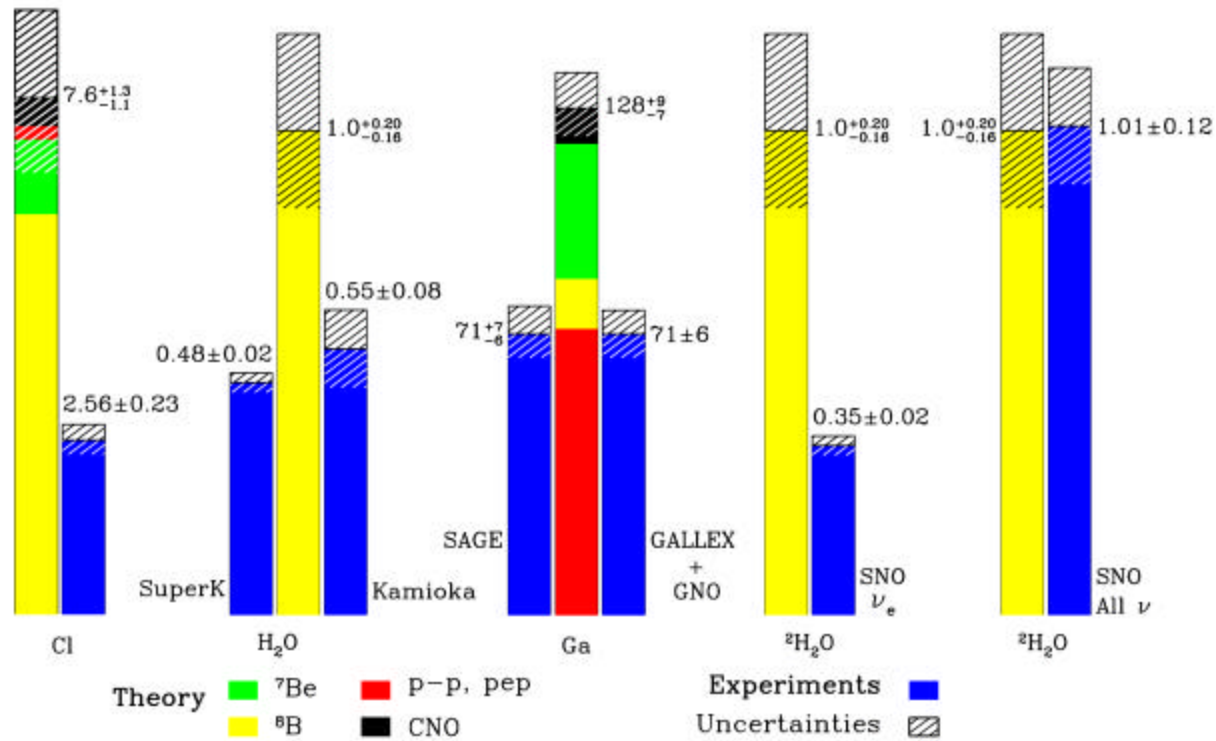
$n_e$



# Helioseismology confirms solar model to 0.0007



Total Rates: Standard Model vs. Experiment  
Bahcall-Pinsonneault 2000



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

**A solar neutrino “opportunity”; not a problem.**

$${}^8\text{B}n \text{ flux} \propto T^{24}$$

- **2001: First direct n confirmation**

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

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

**Agree to 0.3s**

- **2002: SNO NC**

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

**Agree to 0.03s**

# BP00 %Uncertainties

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

# Precision measurements of



**g Rays :  $0.507 \pm 0.016$  (1963 - 1988)**

**6 measurements**

**${}^7\text{Be}$  activity :  $0.572 \pm 0.026$  (1982 - 1984)**

**3 measurements**

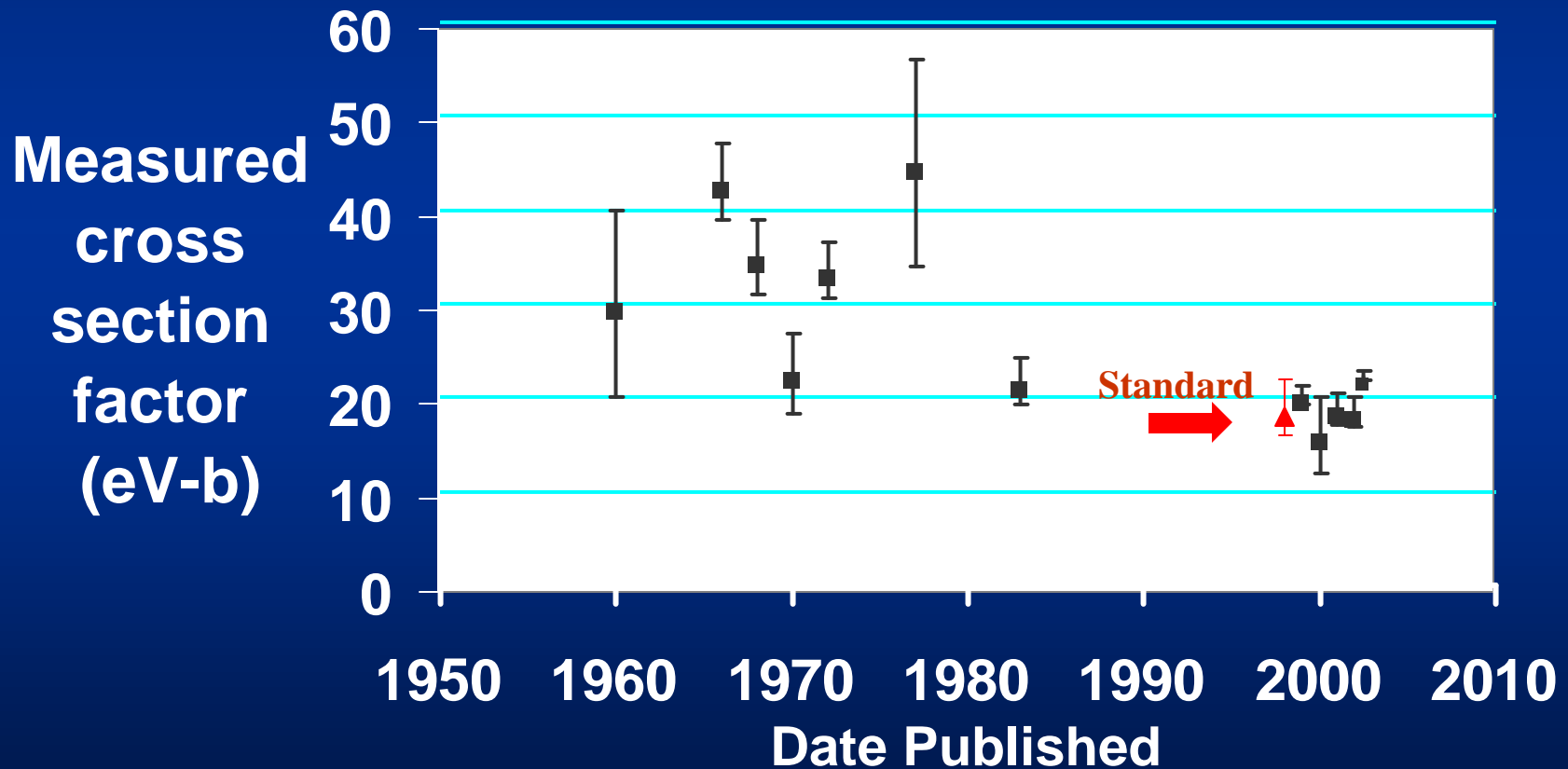
**Average :  $0.53 \pm 0.05$  keV b**

**Modern precision measurement:**

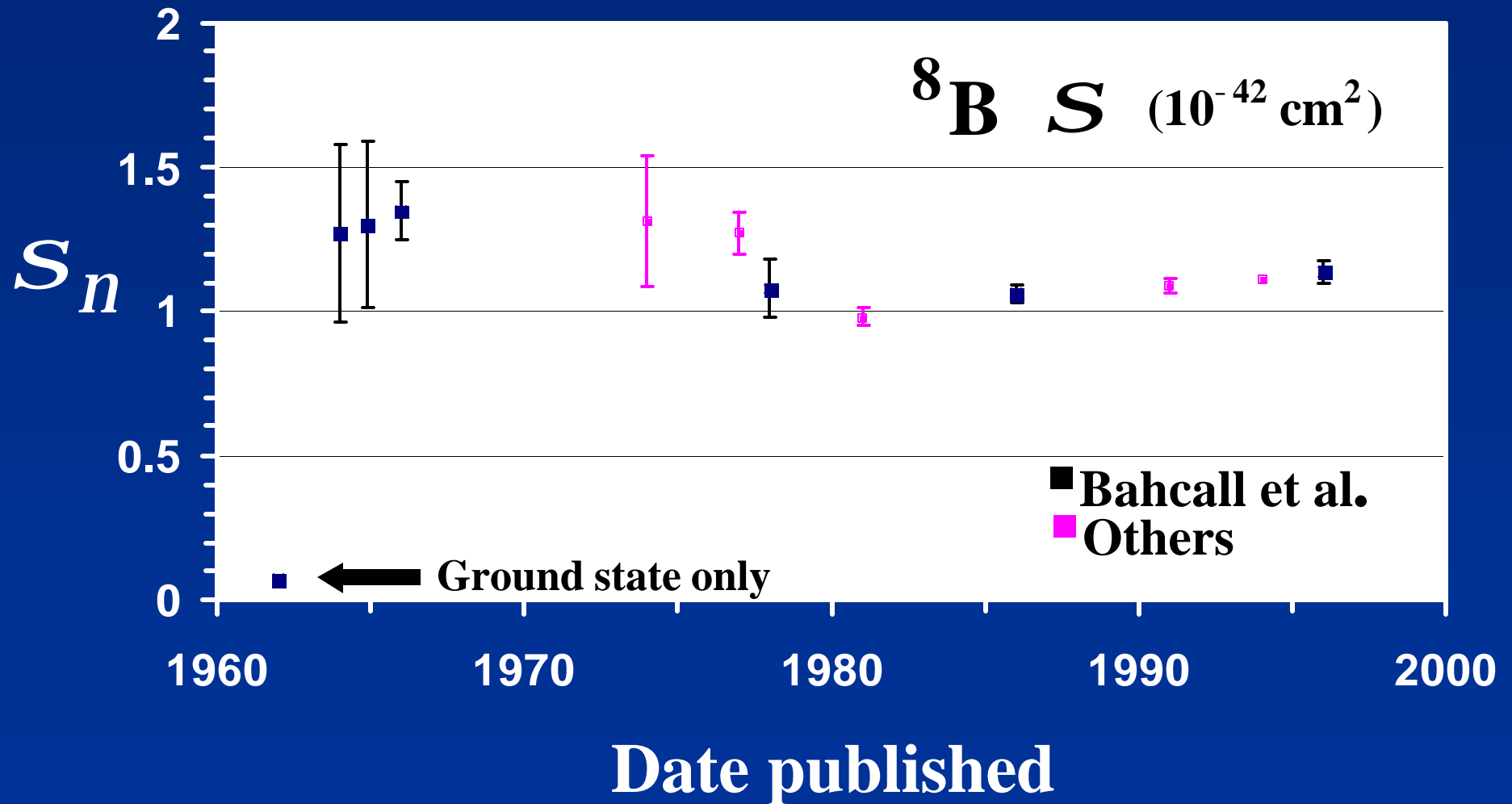
**urgently required:  $\pm 3\%$ !**

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

$j({}^8\text{B}) \propto \text{Cross Section Factor}$



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



# The Sterile Fraction ?

## Total £ 1.7 SSM

- SNO: Want flux; Measure rate.
- KamLAND: Know flux; Measure rate.
- KamLAND: infer  $\tan^2 \theta$ ,  $Dm^2$
- Determine:  $^8 B_{\text{total}} : \pm 10\%$   
 $^8 B_{\text{sterile}} : \pm 12\%$

With Carlos and Concha: [hep-ph/0204194](https://arxiv.org/abs/hep-ph/0204194)

## SSM: Additional fundamental tests

- 99.99% of predicted flux is below 5 MeV.

- Stellar evolution theory predicts:

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

**pp fusion formula: summarizes competition between different fusion chains.**

- CNO neutrinos represent 1.5% of luminosity.

## **Why did it take so long?**

- **Unfamiliar accelerator and beam**
- ${}^8\text{B}$  neutrino flux  $\propto (\text{Temperature})^{25}$
- **Large mixing angles (ironic)**

**“Most likely, the solar neutrino problem has nothing to do with particle physics. It is a great triumph that astrophysicists are able to predict the number of  $^8\text{B}$  neutrinos to within a factor of 2 or 3”....**

**H. Georgi and M. Luke, Nucl. Phys. B347, 1(1990)**

# **The Standard Solar Model and Experiments**

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

**BP00: astro-ph/0010346**

## **Ray Davis and Masatoshi Koshiro**

Ray and Toshi have made extraordinary contributions to science. Their contributions are all the more extraordinary because they are such extraordinary human beings.

Riccardo Giacconi energized, led, and inspired two decades of x-ray astronomy, resulting in a multitude of important discoveries.

**All three richly deserve the Nobel Prize.**