Solar Neutrinos: An Overview

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Physics in Collision June 26, 2003

Outline

- Introduction
- Current situation
- Low energy experiments (new)
- jnb, pena-garay: hep-ph/0305159

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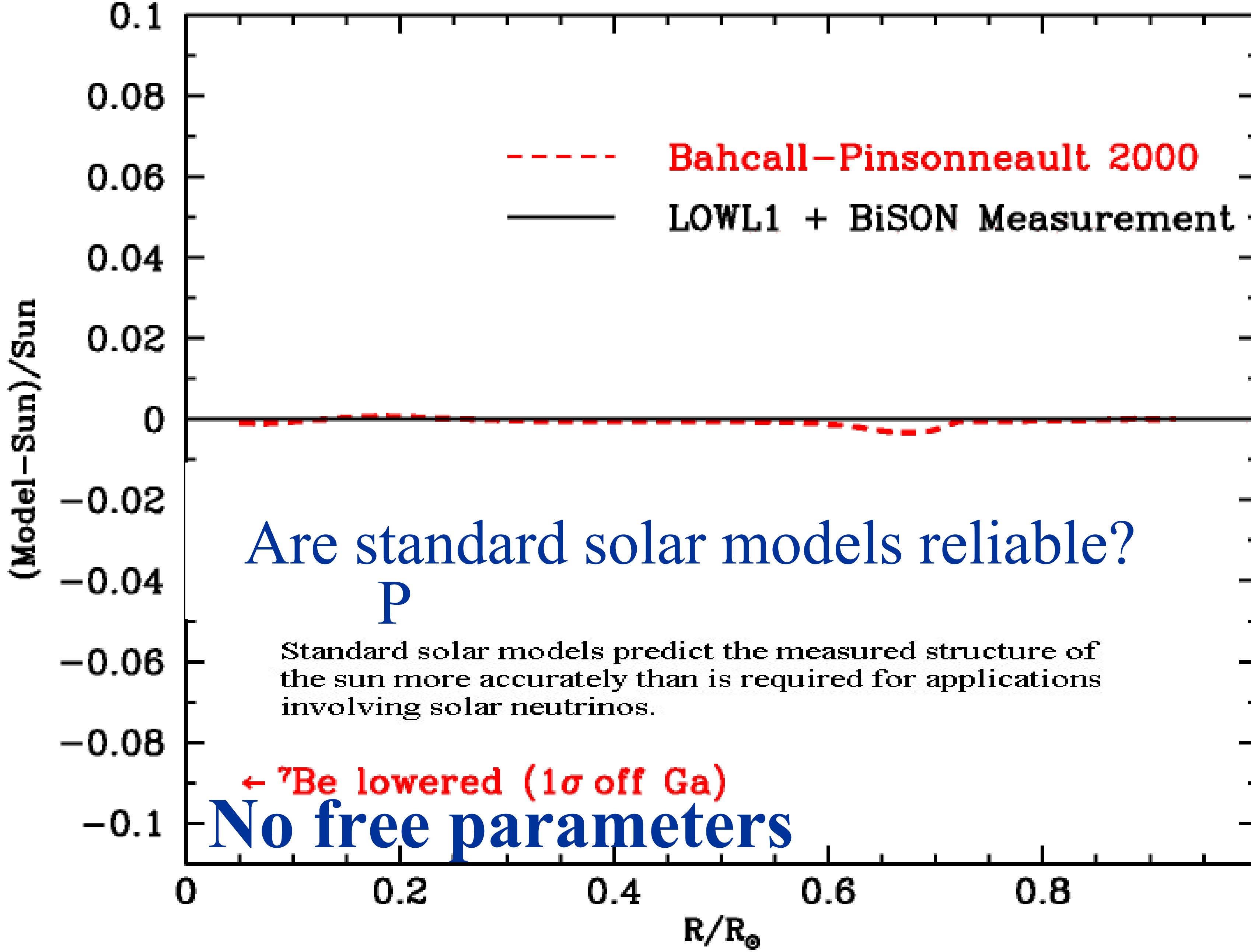
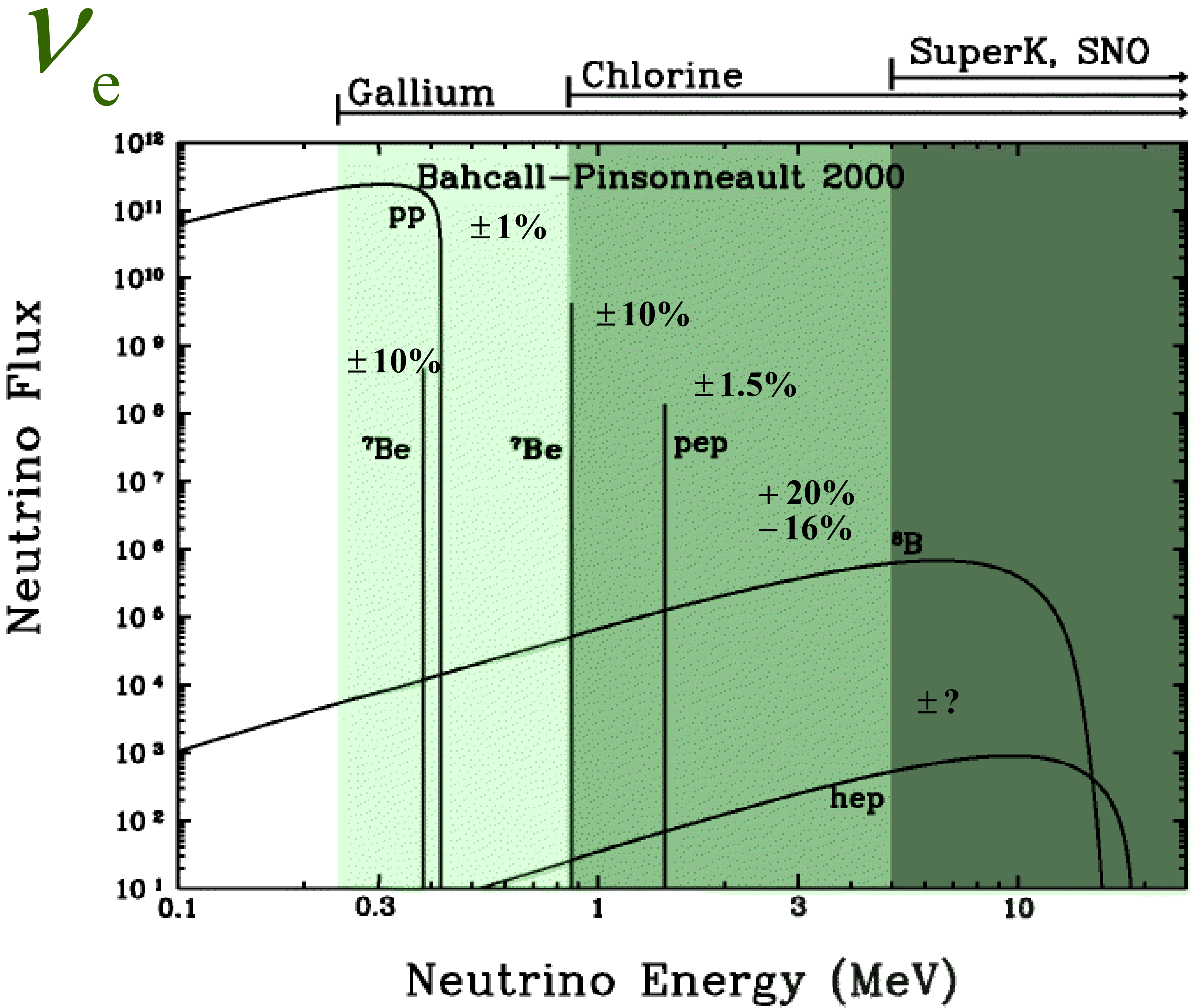


Are standard solar models reliable?

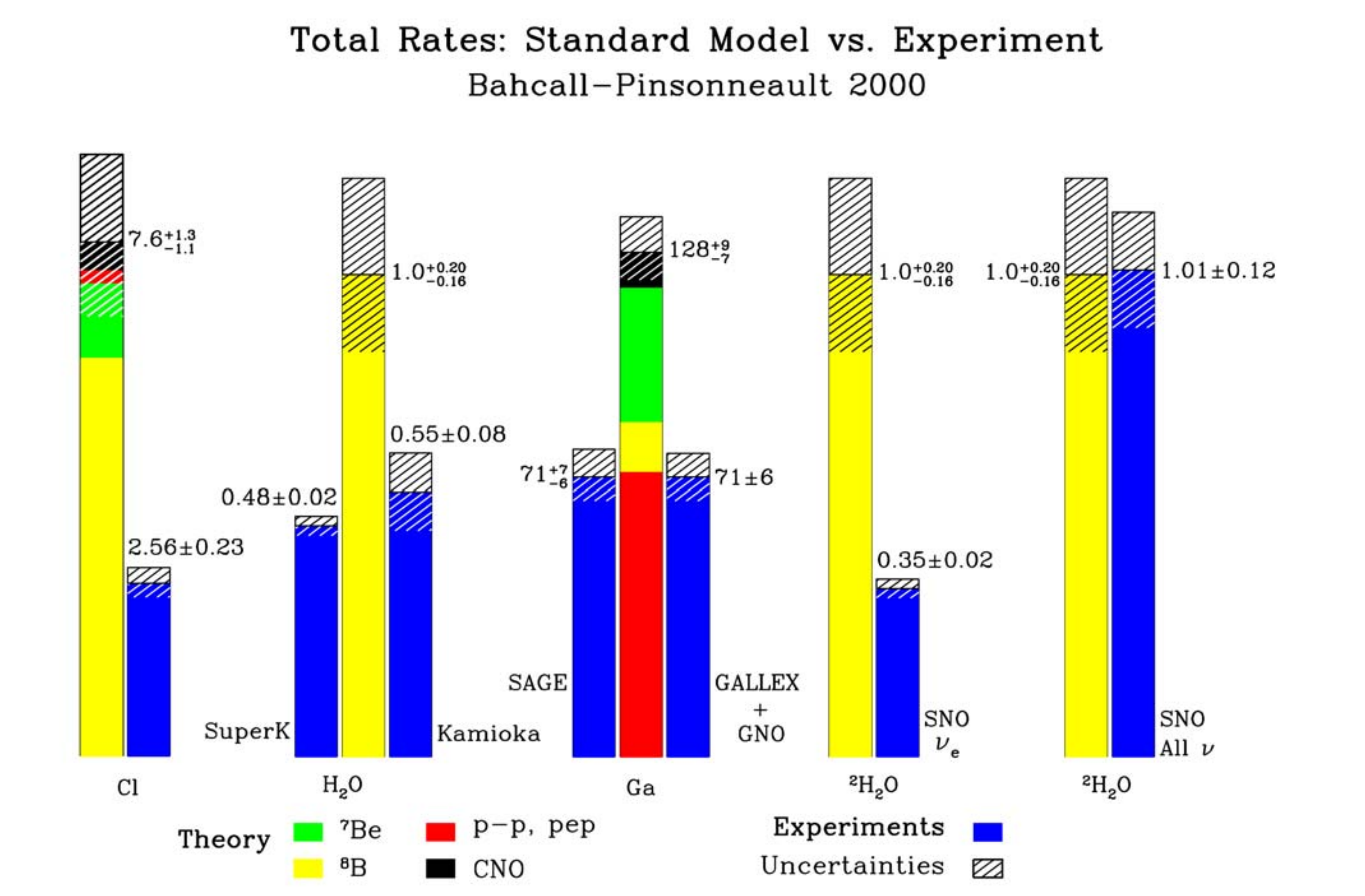
P

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

No free parameters



ν_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



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

A solar neutrino "opportunity"; not a problem.

^{8}B ν flux $\propto T^{25}$

- **2001: First direct ν confirmation**

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

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

Agree to 0.3σ

- **2002: SNO NC**

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

Agree to 0.03σ

Free fluxes: with luminosity constraint

$$\frac{L_{SUN}}{4\pi(A.U.)^2} = \sum_i \alpha_i \Phi_i$$

$$1 = 0.916\Phi_{pp} + 0.070\Phi_{Be} + 0.014\Phi_{CNO}$$

$$\Phi_{pp} = 1.01 \pm 0.02\,(1\sigma)$$

$$\Phi_{Be} = 0.97^{+0.28}_{-0.54}\ (1\sigma)$$

$$\Phi_{B} = 1.01 \pm 0.06\,(1\sigma)$$

Additional

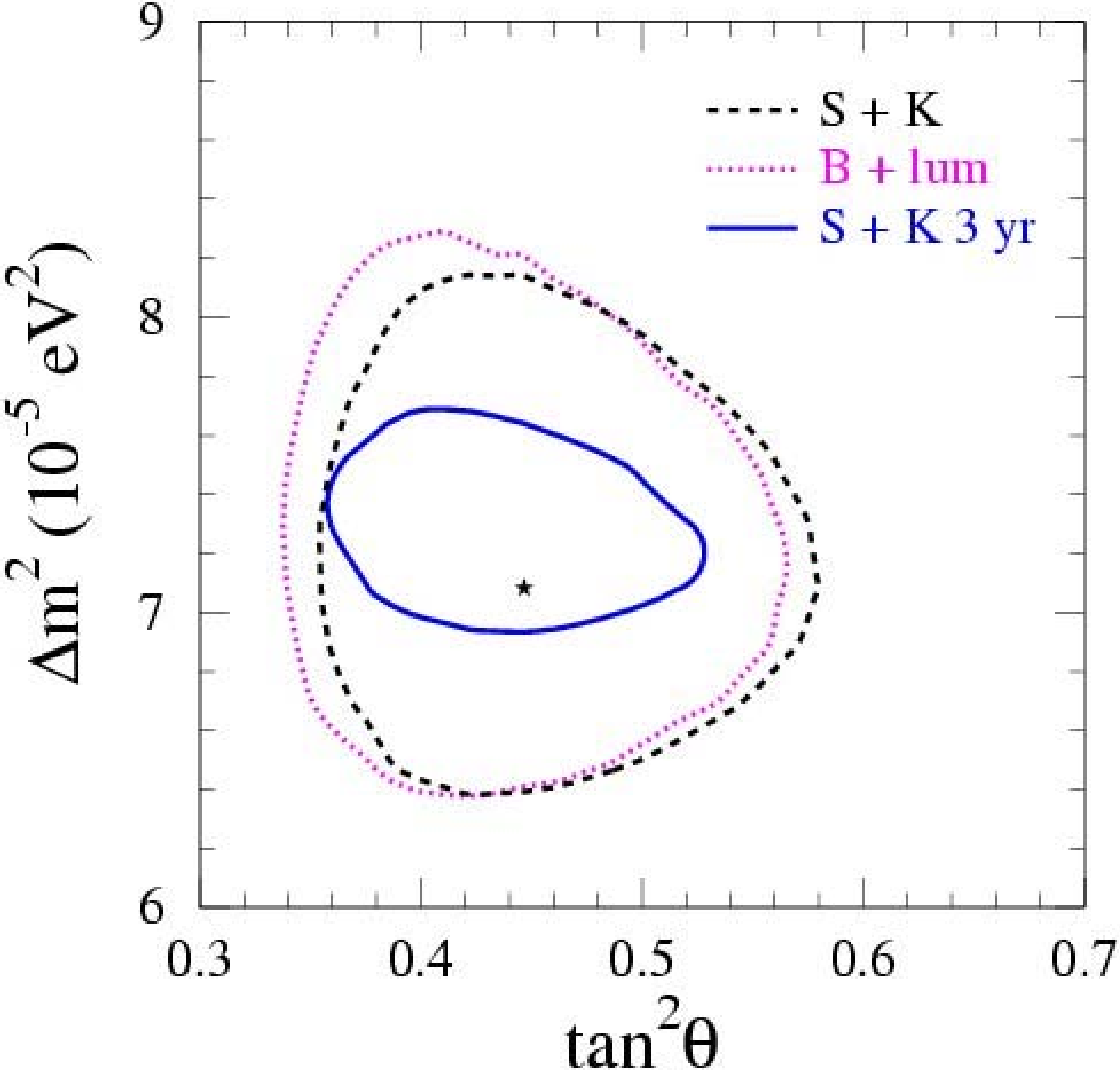
- No oscillation excluded at 7.9σ

- $^{8}B_{sterile} = 0.0^{+0.11}_{-0.00}$

- LMA only at 3.9σ

- $L(CNO)_{sun} \leq 2.8\%$ (1σ)

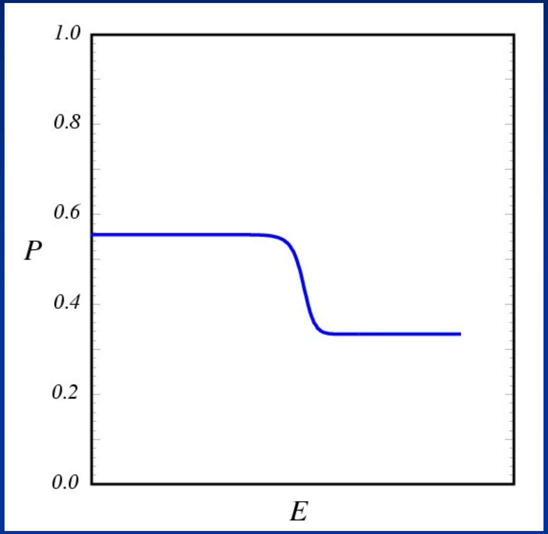
- $L_{\nu-measured} = 1.4^{+0.4}_{-0.2}\ L_{photon}$



9
8
7
6
0.3
0.4
0.5
0.6
0.7
S + K
B + lum
S + K 3 yr
Δm^2 (10^{-5} eV^2)
$\tan^2\theta$

Vacuum-Matter Transition

- $$\frac{\Delta m^2 \cos\Theta_{12}}{4E} \pm \frac{\sqrt{2}\, G_F n_e}{2}$$



- $E(\text{crit}) = 1.8\ \text{MeV}\ {}^8\text{B}\ [3.3\ \text{MeV}\ p - p]$

- High energy: matter; low energy:vacuum

A ^{7}Be solar ν experiment (± 5%)

$$\Phi(^{7}\mathrm{Be}) = 1 \pm 0.06$$

$$\Phi(\mathrm{pp}) = 1 \pm 0.005\ (0.5\%\,!)$$

Vacuum-matter

BOREXINO, KamLAND

A p - p solar ν experiment ($\pm$ 1%)

* Solar luminosity(ν) : $\pm$ 2%

* Ratio of terminations : ^{7}Be accuracy

* θ_{12} : factor of two improvement

* Sterile fraction : 25% improvement

Why do low energy solar neutrino experiments?

- SSM: 99.99% of solar neutrinos < 5 MeV
- Measure accurately the important fluxes
- Measure solar luminosity with neutrinos
- Observe matter-vacuum transition
- Test for new physics
- Measure precisely mixing angle

Solar Neutrinos: 1964-2003

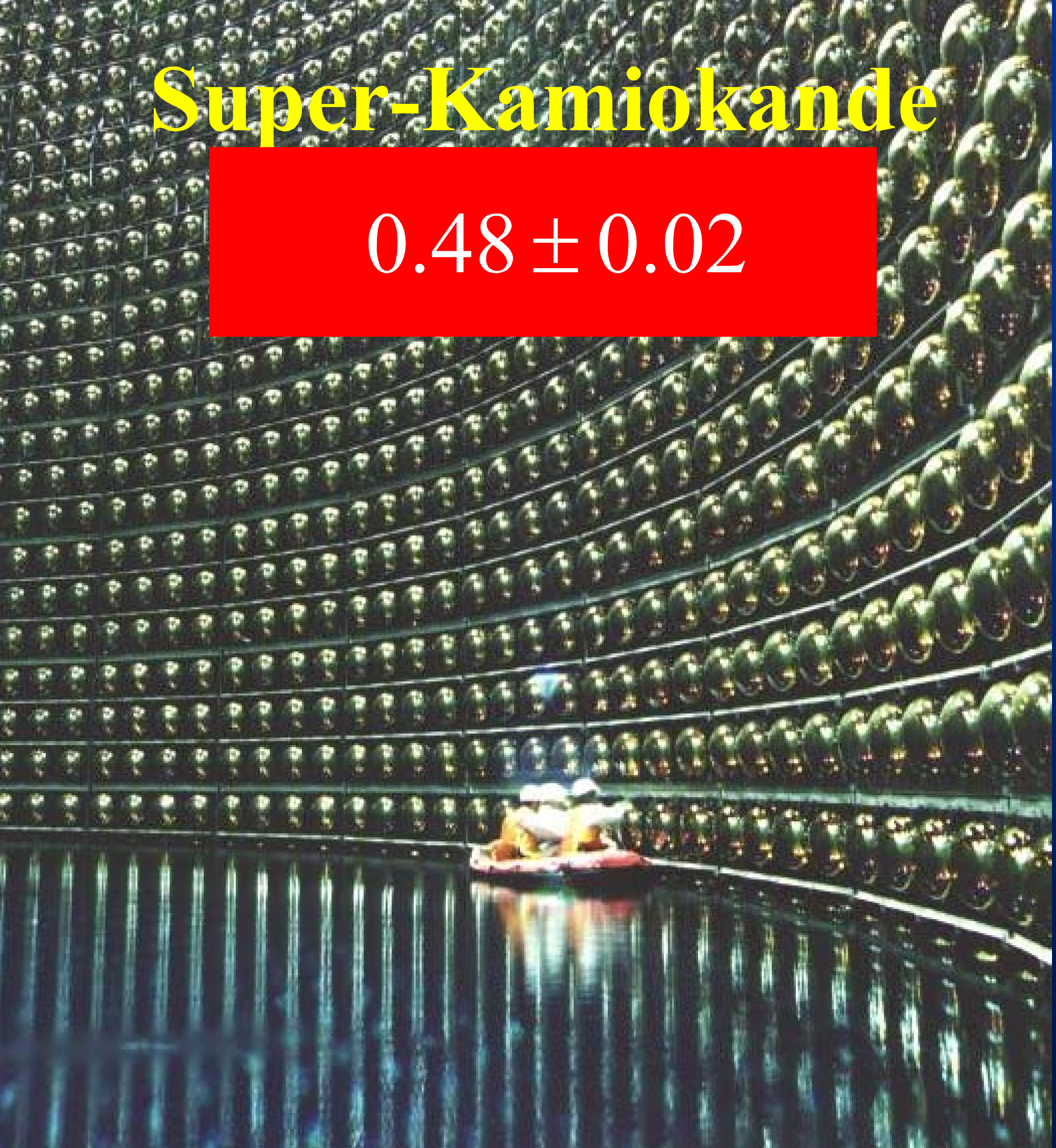
- Solar neutrinos detected
- Initiated neutrino astronomy
- New physics
- $\Phi(^{8}\mathrm{B}) = 1.01 \pm 0.06$
- $\Phi(\mathrm{pp}) = 1.01 \pm 0.02$

Why did it take so long?

- Unfamiliar accelerator and beam
- ^{8}B neutrino flux $\propto$ (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}B neutrinos to within a factor of 2 or 3"….

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



Super-Kamiokande

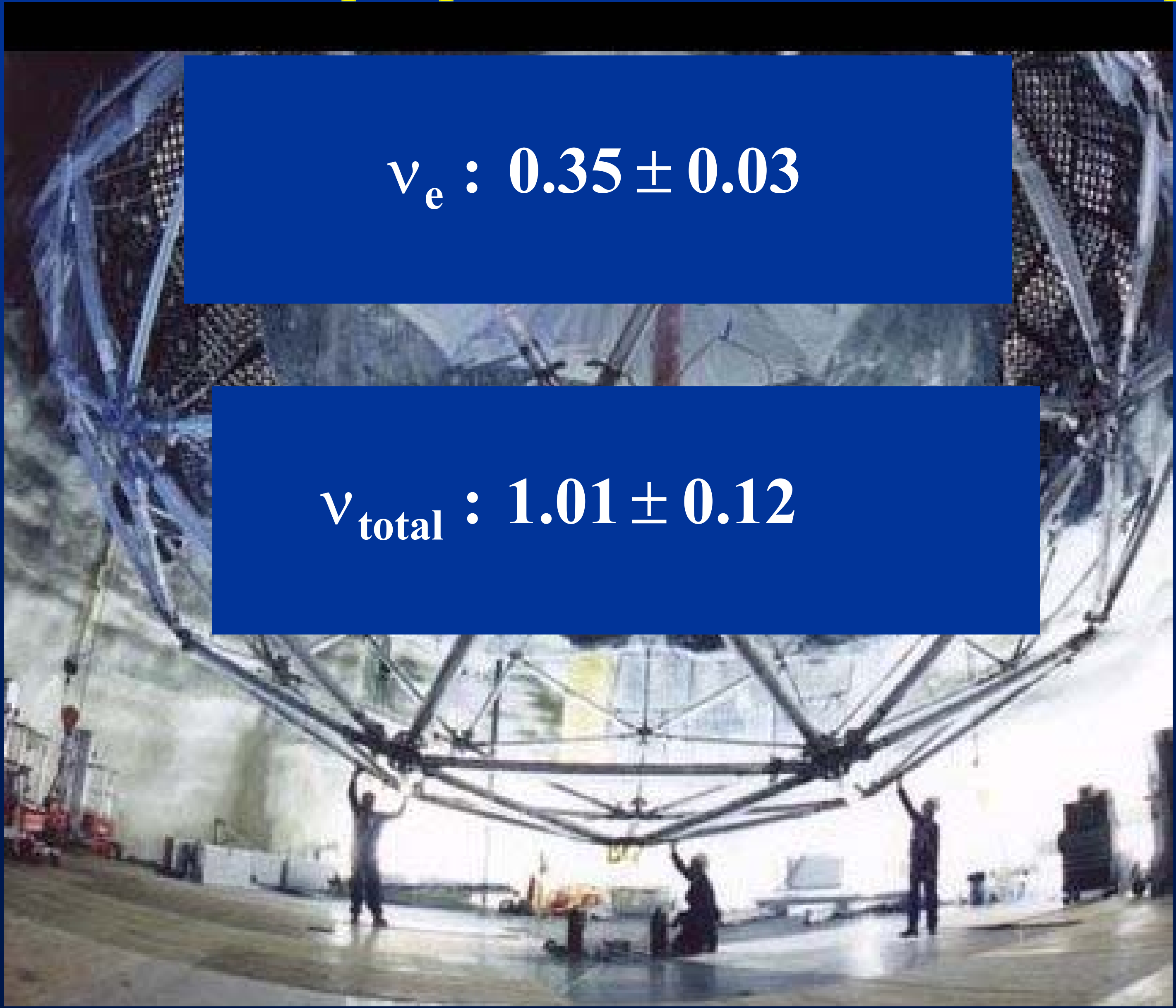
$\nu + e \rightarrow$

$\nu + e$

atmospheric and solar ν

SNO (Canada)

$\nu_e + {}^2\mathrm{H} \rightarrow e^- + p + p$ $\quad\quad$ $\nu + {}^2\mathrm{H} \rightarrow \nu + n + p$



ν_e : $\mathbf{0.35 \pm 0.03}$

ν_{total} : $\mathbf{1.01 \pm 0.12}$

Nuclear Burning

$$4p \rightarrow {}^{4}He + 2e^{+} + 2\nu_{e} + < 25\,MeV$$

Is this the way the sun

1964: Sole motivation

"… to see into the interior of a star and thus verify directly the hypothesis of nuclear energy generation in stars."

PRL 12, 300, 1964