Outline

- Solar neutrino
- Current status (Flux measurements)
- Super-Kamiokande
  - Flux independent results
  - Day / Night
  - Energy spectrum
  - Seasonal variation
- Oscillation analysis
- Future plans, experiments

This presentation is available at
http://www-sk.icrr.u-tokyo.ac.jp/~takeuchi/radon/
**Solar neutrino**

**Standard Solar Model (SSM)**

Sun burns through: \(4p \rightarrow ^4\text{He} + 2e^+ + 2\nu_e + 25\text{MeV}\)

- \(P + P \rightarrow ^2\text{H} + e^+\) (99.75%)
- \(P + e^- + P \rightarrow ^2\text{H} + e^-\) (99.85%)
- \(^3\text{He} + ^3\text{He} \rightarrow ^7\text{Be} + e^-\) (86%)
- \(^7\text{Be} + e^- \rightarrow ^7\text{Li} + 2\nu\) (99.75%)
- \(^8\text{B} \rightarrow ^8\text{Be}^* + e^+ + \nu\)

**pp-chain**

http://www.sns.ias.edu/~jnb/
### Solar neutrino experiments 1

**ν energy range**

\[ 7^\text{Be} \]

**pp**

\[ ^8\text{B} \]


**Homestake**:

\[ ν_e + ^{71}\text{Ga} \rightarrow e^- + ^{71}\text{Ge} \]

\[ E_{\text{th}} = 235\text{keV} \]

\[ 30 \sim 100 \text{ tons} \]

**Kamiokande**:

\[ ν_e + ^{37}\text{Cl} \rightarrow e^- + ^{37}\text{Ar} \]

\[ E_{\text{th}} = 817\text{keV} \]

**Homestake**:

\[ ν_e + ^{37}\text{Cl} \rightarrow e^- + ^{37}\text{Ar} \]

\[ E_{\text{th}} = 817\text{keV} \]

\[ 615\text{tons} \]

**Super-Kamiokande**:

\[ ν_e + ^{37}\text{Cl} \rightarrow e^- + ^{37}\text{Ar} \]

\[ E_{\text{th}} = 235\text{keV} \]

\[ 4,500\text{ tons} \]

**SAGE**:

\[ ν_e + ^{71}\text{Ga} \rightarrow e^- + ^{71}\text{Ge} \]

\[ E_{\text{th}} = 235\text{keV} \]

\[ 615\text{ tons} \]

**GALLEX**:

\[ ν_e + ^{71}\text{Ga} \rightarrow e^- + ^{71}\text{Ge} \]

\[ E_{\text{th}} = 235\text{keV} \]

\[ 4,500\text{ tons} \]

**GNO**:

\[ ν_e + ^{71}\text{Ga} \rightarrow e^- + ^{71}\text{Ge} \]

\[ E_{\text{th}} = 235\text{keV} \]

\[ 50,000\text{ tons} \]

**R=0.33 \pm 0.03** (GALLEX+GNO)

**1970-**

\[ ν_e + ^{37}\text{Cl} \rightarrow e^- + ^{37}\text{Ar} \]

\[ E_{\text{th}} = 817\text{keV} \]

**R=0.58 \pm 0.06** (SAGE)

**R=0.57 \pm 0.05** (GALLEX+GNO)


\[ ν_e + ^{37}\text{Cl} \rightarrow e^- + ^{37}\text{Ar} \]

\[ E_{\text{th}}(\text{analysis}) = 5.5-7.0\text{MeV} \]

\[ 4,500\text{ tons} \]

\[ 50,000\text{ tons} \]

\[ R=0.54 \pm 0.07 \text{ (Kam)} \]

\[ R=0.47 \pm 0.02 \text{ (SK)} \]

**1999-**

**SNO (D}_2\text{O)** to be explained later

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**Radio chemical experiments**: Cl, Ga

Homestake, SAGE, GNO/GALLEX

Integrated flux above a threshold

**CC**

**Water Cherenkov**:

Kamiokande, Super-Kamiokande, SNO

Directionality \((ν, e \leftrightarrow ν, e \text{ case})\)

Energy, Event time measurement

**CC+NC (SK)**, **CC/NC (SNO)**
## Solar neutrino experiments 2
(as of v2000)

### Target Data / SSM (BP98)

<table>
<thead>
<tr>
<th>Target</th>
<th>Data / SSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homestake</td>
<td>$^{37}\text{Cl}$ 0.33 ± 0.03</td>
</tr>
<tr>
<td>Kamiokande</td>
<td>$\text{e}^{-}$ (water) 0.54 ± 0.07</td>
</tr>
<tr>
<td>SAGE</td>
<td>$^{71}\text{Ga}$ 0.58 ± 0.06</td>
</tr>
<tr>
<td>GALLEX+GNO</td>
<td>$^{71}\text{Ga}$ 0.57 ± 0.05</td>
</tr>
<tr>
<td>SK</td>
<td>$\text{e}^{-}$ (water) 0.47 ± 0.02</td>
</tr>
</tbody>
</table>

### Experiments

- **$^{7}\text{Be}$**
- **$^{8}\text{B}$**
- **CNO**

### Theory vs. Experiments

- **Kam(SK) ↔ Cl**
- **Ga**

### Luminosity constraint

**Ga** vs. **Kam (SK)**

**Φ$_{7\text{Be}}$ = 0**

(without ν oscillation)
Hata and Langacker (Neutrino 98)

Astrophysical solution has difficulty to explain solar neutrino problem.

\[ \nu \text{ oscillation} \]
Oscillation parameters based on flux of Homestake, GNO, SAGE and SK

Including new GNO, SAGE and Super-Kamiokande 1117 Days

Allowed regions from Rates: M.C.G-G, C. Peña-Garay in preparation

<table>
<thead>
<tr>
<th>Observable</th>
<th>SMA</th>
<th>LMA</th>
<th>LOW</th>
<th>VAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta m^2/eV^2$</td>
<td>$5.6 \times 10^{-6}$</td>
<td>$1.9 \times 10^{-5}$</td>
<td>$9. \times 10^{-8}$</td>
<td>$8 \times 10^{-11}$</td>
</tr>
<tr>
<td>$\tan^2 \theta$</td>
<td>0.0014</td>
<td>0.2</td>
<td>0.57</td>
<td>0.51 (1.96)</td>
</tr>
<tr>
<td>Prob (%)</td>
<td>38 %</td>
<td>8 %</td>
<td>0.5 %</td>
<td>4 %</td>
</tr>
</tbody>
</table>
Goal of 2\textsuperscript{nd} generation solar neutrino experiments is to get flux independent evidence of $\nu$ oscillation.

SK, SNO, Borexino, ...

Borexino, SK, GNO, ...

SNO, SK, ...

Neutral current / charged current

**CC only:** $\nu_e + d \rightarrow p + p + e^-$

**NC:** $\nu_x + d \rightarrow \nu_x + p + n$

Edward T. Kearns
Super-Kamiokande

LINAC
Electronics hut
Control room
Water and air purification system

Atotsu entrance

41.4m
39.3m

50000 ton stainless steel tank

Inner Detector (ID)
11146 of 20 inch PMTs

Outer Detector (OD)
1867 of 8 inch PMTs

• photo coverage 40%
• outer detector 2.5m for all surfaces
• fid. vol. for $\nu_{\text{solar}}$ 22.5kt (2m from ID wall)
• for 10 MeV electron
  vertex resolution 87cm
  energy resolution 14%
  angular resolution 26°
A Typical low-energy event

- Timing information
- Ring pattern
- Number of hit PMTs

\[ E_e = 9.87 \text{MeV} \]
\[ \cos \theta_{\text{sun}} = 0.915 \]

Detect solar neutrinos by \( \nu + e \rightarrow \nu + e \) scattering

 spins

\begin{align*}
\text{• Timing information} & \quad \text{vertex position} \\
\text{• Ring pattern} & \quad \text{direction} \\
\text{• number of hit PMTs} & \quad \text{energy}
\end{align*}
What’s new

• Data update
  Run1742-7200 (SLE524d+LE825d) 1996/05/31-1999/04/03 (previous)
  Run1742-8656 (unified analysis 1117day) 1996/05/31-2000/04/24 (new)

• Lower trigger and analysis energy threshold
  Previous: 5.5-20MeV
  New: 5.0-20MeV
  (But, 5.0-5.5MeV data is not used for results yet)

• Improve analysis tools
  E<6.5MeV: Super-Low-Energy (SLE) analysis
  E>6.5MeV: Low-Energy (LE) analysis
  → whole energy range: unified analysis

• Re-tune M.C. simulation
  energy scale was shifted by 0.27 %
  (within estimated systematic error of 0.64%)

• Re-estimate systematic errors
Trigger threshold

• Low-Energy (LE) trigger (April 1996~)
  □ 29 PMT hits / 200nsec (10Hz)

• Super-Low-Energy (SLE) trigger (May 1997~)
  □ 24 PMT hits / 200nsec (120Hz)

  raw rate \( \sim \) 120Hz (most of them are close to the ID wall)

• SLE-version 2 trigger (September 1999~)
  □ 20 PMT hits / 200nsec (550Hz)

• SLE-version 3 trigger (July 2000~)
  □ 17 PMT hits / 200nsec (1650Hz)

Most of dead time = calibration

<table>
<thead>
<tr>
<th>Energy Threshold</th>
<th>Current Analysis Energy Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5 MeV</td>
<td>5.5 MeV &amp; 5.0 MeV</td>
</tr>
<tr>
<td>5.7 / 6.5 MeV</td>
<td>4.7 / 5.5 MeV</td>
</tr>
<tr>
<td>4.7 / 5.5 MeV</td>
<td>4.2 / 5.0 MeV</td>
</tr>
<tr>
<td>4.2 / 5.0 MeV</td>
<td>3.7 / 4.5 MeV</td>
</tr>
<tr>
<td>3.7 / 4.5 MeV</td>
<td></td>
</tr>
<tr>
<td>50%/100% trigger ef.</td>
<td>100%</td>
</tr>
</tbody>
</table>

raw rate \( \sim \) 120Hz (most of them are close to the ID wall)

on-line fid. vol. cut 20Hz

This talk: up to here (1117 days)
Data reduction

~2x10^9

Raw data

Total charge < 1000 p.e.

Vertex reconstruction

First reduction

Fiducial volume cut (22.5kton)
\( \Delta T \) to previous event < 50 \( \mu \)sec
Electrical noise cut
Goodness of fitting cut
Flasher cut

22.5kt, 5-20 MeV
2.4x10^7

Spallation event cut

Second reduction

GRINGO cut
Cluster fitting cut
Ring Pattern cut

Gamma cut

Eye scan

Final data sample

22.5kt, 5-20 MeV
192204 events

(solar neutrino MC)

Efficiency vs. Energy (MeV)

After SLE trigger
After 1st reduction
After spallation cut
After 2nd reduction
After gamma cut

(SK 1117 day data)

Number of events/day/22.5kt/0.5 MeV

After 1st reduction
After spallation cut
After 2nd reduction
After gamma cut

SSM(BP98) \( \times 0.4 \)
(efficiencies are considered)
May 31, 1996 - Apr. 24, 2000
1117 days

$^8$B flux

$^8$B FLUX = 2.40 $^{+0.03}_{-0.07}$ (stat.) $^{+0.08}_{-0.07}$ (syst.) \times 10^6 / cm^2 / s

\[
\text{Data} \over \text{SSM(BP98)} = 0.465 \pm 0.005 \text{(stat.)} \pm 0.015 \text{(syst.)}
\]
6.5-20MeV: Background – 63%
Signal – 20%

Analysis tools are improved
Day/Night Effect

Earth density: $\rho = 5\text{g/cm}^2$ (average), 13(at core)

Affect to oscillations for $\Delta m^2 = 10^{-6} - 10^{-4}$ eV$^2$

slight negative day/night effect
Day/Night analysis

SMA: \((7.9 \times 10^{-3}, 7.9 \times 10^{-6} \text{eV}^2)\)
LMA: \((0.7, 6.3 \times 10^{-5} \text{eV}^2)\)

Day: 545 days, 5.5-20 MeV
\[
\phi(\text{B}) = 2.35 \pm 0.04 \text{(stat.)} \pm 0.08 \text{(syst.)} \times 10^6 / \text{cm}^2 / \text{s}
\]

Night: 572 days, 5.5-20 MeV
\[
\phi(\text{B}) = 2.43 \pm 0.04 \text{(stat.)} \pm 0.08 \text{(syst.)} \times 10^6 / \text{cm}^2 / \text{s}
\]

\[
\frac{N-D}{(N+D)/2} = -0.034 \pm 0.022 \text{(stat.)} \pm 0.013 \text{(syst.)}
\]

(eccentricity is corrected)
Significance vs. time (day/night)

Errors: only statistical

Differential

Integral

1.6σ (only stat. err.)

1.3σ (including syst. err.)
Energy spectrum: First moment

Spectrum distortion highly depends on oscillation parameters

First moment: \( <T> = \frac{\sum <T>_i N_i}{\sum N_i} \)


---

**Observed first moment \(-1\sigma\) (stat.)**

Global fit (99\% C.L.)

Global fit (95\% C.L.)
Energy spectrum

5.5-20MeV:
χ² for flat = 13.7/17dof (including sys. err.)
C.L. = 69%
consistent with flat

NEW! (5.0-5.5MeV)
not used for oscillation analysis (sys. err. under study)
Significance vs. time (spectrum)

First moment: $<T> = \frac{\sum_i <T>_i \ N_i}{\sum_i N_i}$


$> 6.5$ MeV data (stat. error only)

Data: $8.14 \pm 0.02$ MeV
**Hep flux**

**Method 1:** fit $^8$B and Hep flux simultaneously

Hep flux $= 5.4 \pm 4.6 \times \text{SSM(BP98)}$

But, this result highly depends on possible distortion of the $^8$B spectrum in the lower energy region

**Method 2:** assume all signals coming from Hep in higher energy region (18-25MeV)

Hep flux $< 13 \times \text{SSM(BP98)}$ \qquad 90\%C.L.

(quote this number)

0 event observed (expected=0.2 events)
Time variation of the flux

Seasonal variation of the flux

Expected flux variation caused by the eccentricity of the earth

\( \chi^2 \) for eccentricity
4.1 (77%)

\( \chi^2 \) for flat
7.0 (42%)
(7d.o.f.)

Need more statistics
Definitions of $\chi^2$ 1

Day/Night

$$\chi^2 = \sum_{i = D,N1-N5} \left\{ \frac{\left( \frac{\text{Data}}{\text{SSM}} \right)_i - \left( \frac{\text{w/ oscil}}{\text{w/o oscil}} \right)_i \times \alpha}{\sigma_i} \right\}^2$$

$$\sigma_i = \sqrt{\sigma_{\text{stat},i}^2 + \sigma_{\text{syst},i}^2}$$

$\alpha$ : flux normalization factor (free)

Day spectrum + Night spectrum

$$\chi^2 = \sum_{D,N} \sum_{i = 1}^{18} \left\{ \frac{\left( \frac{\text{Data}}{\text{SSM}} \right)_i - \left( \frac{\text{w/ oscil}}{\text{w/o oscil}} \right)_i \times \alpha \times F_i(\epsilon)}{\sigma_i} \right\}^2 + \left( \frac{\epsilon}{\sigma_{\text{cor}}} \right)^2$$

$$\sigma_i = \sqrt{\sigma_{\text{stat},i}^2 + \sigma_{\text{uncorrelated},i}^2}$$

$\alpha$ : flux normalization factor (free)

$F_i(\epsilon)$ : response function

$\epsilon$ : shift factor of the correlated error

$\sigma_{\text{cor}}$ : correlated systematic error
Definitions of $\chi^2$ 2

Day/Night spectrum with flux constraint

$$\chi^2 = \sum_{D,N} \sum_{i=1}^{18} \left\{ \frac{(\text{Data}_{\text{SSM}})_i - (\text{w/ oscil w/o oscil})_i}{\sigma_i} \right\}^2 + \left( \frac{\varepsilon}{\sigma_{\text{cor}}} \right)^2$$

$$\sigma_i = \sqrt{\sigma_{\text{stat},i}^2 + \sigma_{\text{uncorrelated},i}^2}$$

$\alpha$: flux normalization factor

$F_i(\varepsilon)$: response function

$\varepsilon$: shift factor of the correlated error

$\sigma_{\text{cor}}$: correlated systematic error

$\sigma_{\alpha}$: flux error (theoretical)  BP98: $+19\% - 14\%$

Flux global

$$\chi^2 = \sum_{i,j = \text{Ga,Cl,SK}} \left\{ \frac{(\text{Data}_{\text{SSM}})_i - (\text{w/ oscil w/o oscil})_i}{\sigma_{i,j}} \right\}^2 \sigma_{i,j}^2$$

$$\sigma_{i,j}^2 = \sigma_{\text{th},i,j}^2 + \delta_{i,j} \sigma_{\text{exp},i} \sigma_{\text{exp},j}$$

$\sigma_{\text{exp}}$: experimental error

$\sigma_{\text{th}}$: theoretical error matrix

Day spectrum & night spectrum

SK 1117day 22.5kt ALL (Preliminary)
5.0-20MeV (only stat. error)

DAY

NIGHT
Oscillation analysis (SK vs. global, active)

Excluded by SK day spectrum & night spectrum at 95%C.L.
Allowed by global fit (Cl + Ga + SK flux) at 95%C.L.

SMA & VAC solutions are disfavored at 95% C.L.
by comparing global fit and SK d/n spectrum
Oscillation analysis (flux constraint, active)

Large mixing is favored by SK d/n spectrum with flux constraint (SK data only)
Oscillation analysis (dark side, active)

- Excluded by SK day spectrum & night spectrum at 95% C.L.
- Allowed by global fit (Cl + Ga + SK flux) at 95% C.L.
- Allowed by SK day spectrum & night spectrum & flux at 95% C.L.

SMA & VAC solutions are disfavored at 95% C.L. by comparing global fit and SK d/n spectrum
Oscillation analysis (SK vs. global, sterile)

- Excluded by SK day spectrum & night spectrum at 95% C.L.
- Allowed by global fit (Cl + Ga + SK flux) at 95% C.L.

2-flavor sterile solutions are disfavored at 95% C.L. by comparing global fit and SK d/n spectrum.
### Previous & this-time results

1. Previous result (6.5-20MeV, 825 day)
2. Apply eccentricity correction
3. Use new analysis tools (6.5-20MeV, 825 day)
4. Lower energy (5.5-20MeV, 825 day)
5. Add recent data (this time result, 5.5-20MeV, 1117 day)

### Flux

\[
\begin{array}{cccccc}
6.5:0-20MeV, & 7:6.0-20MeV, & 8:6.5-20MeV, \\
9:5.5-7.0MeV, & 10:7.0-10MeV, & 11:10-20MeV \\
\end{array}
\]

### D/N ratio

\[
\frac{(D-N)}{\left((D+N)/2\right)}
\]

No thing wrong
Previous & new analysis

- same run period
- same energy range

Day / Night

-0.044 △ 0.027 (new: ~800 days)
-0.057 △ 0.031 (old: ~800 days)

Energy spectrum

- difference in higher energy region is consistent with statistical fluctuation of BG events in solar direction.
- spallation BG is reduced by ~40% in higher energy region (additional dead time for signal is ~1%).
- eliminated BG events are studied carefully.

Consistent within error
Water transparency correction

Water transparency vs. time

Mean energy of decay e from $\mu$ vs. time

- Water transparency is corrected by using decay electrons from cosmic-ray stopped muons. (checked by LINAC, DT, and spallation events)
- Time variation of the energy scale is $< 0.5\%$ systematic error
Systematic error of Day/Night analysis

Relative energy scale difference between day and night.

Careful study using natural spallation events.

- **Time variation**
  - Nadir angle: 0.5%
  - Azimuthal angle: 0.5%

**Systematic errors (D/N ratio)**

- Energy scale: +1.2% -1.1%
- Non-flat back ground: ±0.4%
- Spallation dead time: ±0.1%
- Live time: ±0.1%
- Total syst. errors for (D/N): +1.3% -1.2%
\[ ^{16}\text{N calibration} \]

\[ \text{DT generator} \quad \text{D} + \text{T} \rightarrow \text{He} + n \quad n + ^{16}\text{O} \rightarrow p + ^{16}\text{N} \]

(14.2 MeV)

\[ E_n = 14.2 \text{ MeV} \]

\[ ^{16}\text{O}(n,p)^{16}\text{N} \]

\[ \sim 10^6 \text{ n/pulse} \]

\[ \sim 1\% \text{ of } n \text{ creates } ^{16}\text{N} \]

\[ ^{16}\text{N} \text{ decay is precisely known.} \]

\[ 66.2\% \quad 6.129\text{MeV}\gamma + 4.29\text{MeV}\beta, \]

\[ 28.0\% \quad 10.419 \text{ MeV } \beta, \text{ and etc.} \]

Data taken at various positions in the detector.

Uniform direction complementary to LINAC calibration.
**16N calibration data**

**Event time after fire**

\[ \tau_{1/2} = 7.13 \pm 0.03 \text{ sec} \]

**Energy spectrum**

Data and MC agree quite well

**Direction dependence of energy scale**

- **Azimuthal angle**
  - Variation: \(0.5\%\)

- **Zenith angle**
  - Variation: \(0.5\%\)
Vertex & direction distribution

Before gamma cut

After gamma cut (final data sample)

Gamma-cut removes non-flat background
Summary of SK 1117d results

- **1117 day results** (1996/05/31-2000/04/24)
  
  $^8\text{B} \text{ Flux} (5.5-20\text{MeV})$
  
  \[
  \text{Flux} = 2.40 \pm 0.03 \text{ (stat.)} ^{+0.08}_{-0.07} \text{ (syst.)} \ \text{(x10}^6/\text{cm}^2/\text{s)}
  \]
  
  \[
  \frac{\text{Data}}{\text{SSM}_{BP98}} = 0.465 \pm 0.005 \text{ (stat.)} ^{+0.015}_{-0.013} \text{ (syst.)}
  \]
  
  **Day / Night (5.5-20\text{MeV})**
  
  \[
  \frac{D-N}{(D+N)/2} = -0.034 \pm 0.022 \text{(stat.)} ^{+0.013}_{-0.012} \text{(syst.)}
  \]
  
  - **Sigma to 0 = 1.3** (including systematic error)
  
  **Spectrum**
  
  - $\chi^2$ for flat = 13.7 (17d.o.f.) C.L.=69%
  
  (5.5-20MeV, consider systematic error)

- **5.0-5.5MeV** $^8\text{B}$ flux is obtained

- **Systematic errors are precisely studied again**

- **Oscillation analysis**

  - SMA & VAC solutions are **disfavored** at 95% C.L. by comparing global fit and SK day & night spectrum
  
  - 2-flavor sterile solutions are **disfavored** at 95% C.L. by comparing global fit and SK day & night spectrum
  
  - Large mixing is **favored** by SK d/n spectrum with flux constraint (SK data only)
1) increase statistics

2) lower threshold down to 4.5 MeV

3) reduce background in the low-energy region and also even in the high-energy region
SK: flux in lower energy regions

- Signal = 1275 $^{+143}_{-127}$ (stat.) events
- $\frac{\text{Data}}{\text{SSM}_{\text{BP98}}} = 0.447^{+0.050}_{-0.045}$ (stat.)

(syst. error for flux is under study)

- Signal has been seen
- Need to reduce BG

5.0-5.5 MeV data is not used for results yet (BG is still high)
Hybrid detector @Homestake

**$\Phi(^7\text{Be})=0$ case:** $^8\text{B} = 365\text{events/year}$

**SSM case:** $^8\text{B} = 300\text{events/year}$, $^7\text{Be} = 55\text{events/year}$

3σ difference @3years (assume 60% atoms are counted)
LOW solution

4~6SNU difference between winter and summer

~10 years data might detect

G.L. Fogli et al  PRD61(2000)073009

http://www.lngs.infn.it/site/exppro/gno/Gno_home.htm
SNO
Sudbury Neutrino Observatory
http://www.sno.phy.queensu.ca

1000 tons of D_2O
7000 tons of H_2O
2,039 m underground
9,500 8-inch PMTs
64% coverage
~2MeV trig. threshold

CC: \( \nu_e + d \rightarrow p + p + e^- \) (Q=-1.44MeV) \ (~9ev/day)
CC: \( 1 - (1/3)\cos\theta \)

NC: \( \nu_x + d \rightarrow p + n + \nu_x \) (Q=-2.2MeV) \ (~3ev/day)
1. \( n + d \rightarrow t + \gamma \) 24%eff.
2. \( ^{35}\text{Cl}(n, \gamma)^{36}\text{Cl} \) 83%
3. \( ^{3}\text{He}-\text{counter} \) 45%

ES: \( \nu_x + e^- \rightarrow \nu_x + e^- \) \ (~1ev/day)

ES: consistency check
CC/NC: fraction of solar \( \nu_e \)'s oscillation evidence but cannot determine the parameters

SNO has started on 1st of May, 1999.
Calibration Phase1 (Nov. 1999~)
SNO: event display

http://www.sno.phy.queensu.ca/event/event.html

http://nu2000.sno.laurentian.ca/A.McDonald/Slide15.jpg
Data agree well with solar neutrino MC above ~7MeV
SNO: preliminary results 2

![Graph 1: Low NHT Threshold, Large Fiducial Volume](image1)

![Graph 2: SNO $\cos(\theta_{sun})$ distribution for H$_2$O (outward events)](image2)
SNO: some expectations

- Day/Night ratio (CC)
  \[ \frac{2(N-D)}{(N+D)_{CC}} \]
- First moment shift (CC)
  \[ \delta_{T_{CC}} \]
- NC/CC ratio
  \[ \frac{(NC_{DATA}/NC_{MC})}{(CC_{DATA}/CC_{MC})} \]

Allowed regions:
- LMA
- SMA
- LOW
- VAC_L
- VAC_S
- Sterile

No oscillation

Simulated data
- D/N: 3% (~SK 3y)
- F.M.: 1.3%
- NC/CC: 6.7%
Borexino

Detection of $^7$Be $\nu$ (edge 660 keV)

300 tons liq. scint. (fid. vol. 100 tons)
2,200 8-inch PMTs
$E_e > 250$ keV?
55 ev/day for SSM

$\nu_x + e^- \rightarrow \nu_x + e^-$

Expected operation in 2001
Borexino: Day/Night sensitivity

G.L. Fogli et al. PRD 61(2000)073009

LOW region \(\rightarrow\) 10\(^{-2}\)\% effect

Nighttime and Daytime rates in BOREXINO, normalized to SSM

\[
\begin{align*}
\delta m^2 \text{ (eV}^2) \quad &\quad \sin^2 2\theta / \cos 2\theta \\
10^{-8} \quad &\quad 10^{-7} \quad 10^{-6} \quad 10^{-5} \quad 10^{-4} \quad 10^{-3} \quad 10^{-2} \quad 10^{-1} \quad 10 \quad 100
\end{align*}
\]
KamLAND

Kamioka Liquid scintillator Anti-Neutrino Detector

long baseline reactor experiment
converted from KAMIOKANDE
hosted by Tohoku University

April 2001~

http://www.awa.tohoku.ac.jp/KamLAND

1,000 m$^3$ liq. scint.
1,300 17-inch PMTs
+600 20-inch PMTs
22+14% coverage
anti: 3,000m$^3$ water
reactor L~170km
700 events/kt/year

$\bar{\nu}_e + p \rightarrow e^+ + n \quad (E_{\text{th}} = 1.8\text{MeV})$
KamLAND: sensitivity

Allowed regions from Ga, Cl, and SK fluxes (95% C.L.)

Excluded by SK Day/Night spectra (95% C.L.)

KamLAND sensitivity (3 years, 90% C.L.)
Other experiments (next next generation?)

MOON

Precise measurements of pp and $^7\text{Be}$ ν flux and energy spectrum in real-time

LowNu: International workshop on Low Energy Solar Neutrinos

2nd LowNu workshop: December 4 and 5, 2000 @Univ. of Tokyo, Tokyo, Japan

http://www-sk.icrr.u-tokyo.ac.jp/lownu/

- LENS
- MOON
- GSO
- HERON
- CLEAN
- Xe
- ...