Low-energy neutrino observation at Super-Kamiokande-III

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Outline

■ SK detector

■ Update of the supernova neutrino observation in SK-I & SK-II
  ■ Supernova burst neutrino
  ■ Supernova relic neutrino

■ Solar neutrino observation in SK-III
  ■ Expected sensitivity
  ■ Current status

NEW
Super-Kamiokande Collaboration


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4 Brookhaven National Laboratory, USA
5 University of California, Irvine, USA
6 California State University, Dominguez Hills, USA
7 Chonnam National University, Korea
8 Duke University, USA
9 George Mason University, USA
10 Gifu University, Japan
11 University of Hawaii, USA
12 Indiana University, USA
13 KEK, Japan
14 Kobe University, Japan
15 Kyoto University, Japan
16 Los Alamos National Laboratory, USA
17 Louisiana State University, USA
18 University of Maryland, College Park, USA
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20 University of Minnesota, Duluth, USA
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22 Nagoya University, Japan
23 SUNY, Stony Brook, USA
24 Niigata University, Japan
25 Okayama University, Japan
26 Osaka University, Japan
27 Seoul National University, Korea
28 Shizuoka University, Japan
29 Shizuoka University of Welfare, Japan
30 Sungkyunkwan University, Korea
31 RCNS, Tohoku University, Japan
32 Tokai University, Japan
33 Tokyo Institute for Technology, Japan
34 University of Tokyo, Japan
35 Warsaw University, Poland
36 University of Washington, USA

~130 collaborators
33 institutions
5 countries
(as of Sep. 2007)

Tsinghua Univ., China
(June, 2005~)
Super-Kamiokande

SK-I (1996~2001)
- 50000 ton water
- ~11200 of 20inch PMTs
- Fid. vol. 22.5kt
- Photo coverage 40%
- Stopped by the accident in Nov. 2001

SK-II (2002~2005)
- ~5200 of 20inch PMTs
- Photo coverage 19%

SK-III (Jul. 2006~)
- 40% coverage
- OD Segmentation

50000 ton stainless steel tank

Inner Detector (ID)
11129 of 20 inch PMTs (SK-III)

Outer Detector (OD)
1885 of 8 inch PMTs (SK-III)
**Typical low-energy event**

Super-Kamiokande

Run 1742 Event 102496
16-05-11:07:13:23
Inner: 103 hits, 123 pE
Outer: -1 hit, 0 pE (in-time)
Trigger ID: 0x03
E = 9.066 GeV, θsun = 0.77, Cosθsun = 0.943
Solar Neutrino

\[ \nu + e^- \rightarrow \nu + e^- \]  
(for solar neutrinos)

Sensitive to \( \nu_e, \nu_\mu, \nu_\tau \)

\[ \sigma(\nu_\mu(\tau)e^-) = \sim 0.15 \times \sigma(\nu_e e^-) \]

- Timing information ➔ vertex position
- Ring pattern ➔ direction
- Number of hit PMTs ➔ energy

**Resolutions (for 10MeV electron in SK-I)**

**Energy:** 14%  **Vertex:** 87cm  **Direction:** 26°

\[ E_e = 9.1 \text{MeV} \]

\[ \cos \theta_{\text{sun}} = 0.95 \]
Supernova neutrinos
Supernova burst neutrino

- Live time: 2589.2 days in SK-I and SK-II
- $R_{\text{mean}} > 10\text{m}$ (average distance among vertices)
  - To reject spallation events, flasher events, etc.
- 3 searches are done in SK-I and SK-II
  - Distant search
    - 2 events / 20sec., $E > 17\text{MeV}$
  - Low-energy threshold search
    - 3ev/0.5sec, 4ev/2sec, or 8ev/10sec.
    - $E > 6.5\text{MeV}$ (SK-I) or 7MeV (SK-II)
  - Neutronization burst search
    - 2ev/1msec, 2ev/10msec, or 2ev/100msec.
    - $\nu_e$-e scattering with direction cut
- No significant burst was found
Supernova burst neutrino

- ~10% probability at Andromeda was achieved in the distant search

- Upper limit: (90%CL)
  0.32 SN/year in 100 kpc
Supernova relic neutrino

Previous analysis in SK-I: PRL90(2003)061101

Reaction in SK:

\[ \bar{\nu}_e + p \rightarrow e^+ + n \]

SRN measurement will enable us to investigate the history of past supernova. For example, the flux of SRN would show the star formation rate and supernova rate in galaxies.
SRN observation in SK-I & II

- The latest analysis tools are applied to both SK-I and -II

| Expected number of SRN event | SK-I: 5.7 event /1496days | SK-II: 2.9 event /791days |

**SK-I new spectrum fit**

**SK-II spectrum fit**

Visible energy [MeV]
New flux limits (90% C.L.):
SK-I : $< 1.25 \text{ cm}^2/\text{sec}$
SK-II : $< 3.68 \text{ cm}^2/\text{sec}$

Combined limit : $< 1.08 \text{ cm}^2/\text{sec}$

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Solar neutrinos
Solar neutrino measurements in SK

- High statistics \(\sim 15\) events/day with \(E_e > 5\text{MeV}\), \(^8\text{B}(+\text{hep})\)
- Time variations (Day/Night, Seasonal, 5 days each, etc.)
- Energy spectrum (Sensitive to \(\nu\) oscillation parameters)
- Precise energy calibration by electron LINAC and \(^{16}\text{N}\)
- Flux independent analysis (Time variation, Energy spectrum)

**Expected Day/Night asymmetry**

**Expected spectrum distortion**

(SK-III in LMA)

<table>
<thead>
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<th>(\tan^2(\theta))</th>
<th>(\Delta m^2 (\text{eV}^2))</th>
</tr>
</thead>
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<tr>
<td>0.55</td>
<td>(6.3 \times 10^{-5})</td>
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<tr>
<td>0.38</td>
<td>(4.8 \times 10^{-5})</td>
</tr>
<tr>
<td>0.38</td>
<td>(7.2 \times 10^{-5})</td>
</tr>
<tr>
<td>0.38</td>
<td>(10.0 \times 10^{-5})</td>
</tr>
<tr>
<td>0.28</td>
<td>(7.2 \times 10^{-5})</td>
</tr>
</tbody>
</table>

Data/SSM \(~10\%\) (not latest)
Future prospects in SK-III

**ν_e survival probability**
(at best-fit parameter)

Vacuum osc. dominant

matter dominant

We would like to see a spectrum distortion

Solar ν final data sample

- SK-I BG
- AIM in SK-III
- Expected Solar neutrino

~70% reduction below 5.5MeV
and lower threshold to 4MeV

Vacuum oscillation dominates

Matter oscillation dominates

Expected spectrum distortion
with 5 years SK-III data

BG is 70% reduced as SK-1 below 5.5MeV
Energy correlated systematic error is half as SK-1
5 years
SK-III solar $\nu$ analysis

- **Dataset:** (the first SK-III SLE data)
  - Jan. 24, 2007 ~ May 21, 2007
  - Live time 97 days
  - Super Low Energy (SLE) trigger mode
  - Trigger efficiency: $\sim100\%@5.0\text{MeV}$

- **Analysis:**
  - Applied preliminary SK-III analysis tools, then compared the first SK-III SLE data with SK-I final results.
  - These tools are still under improvement.
  - The efficiency for the $^8\text{B}$ solar neutrino signal of the final data sample was adjusted to the SK-I analysis. (not optimized yet)
Agreement of SK-III and SK-I looks quite good!
Angular distributions

Signal event rates look consistent

SK-III has already reached to the similar signal to noise ratio as SK-I in 5.0-20MeV in 22.5kt
There are more events near SK-III barrel & bottom.

SK-III has lower event rates in the central-top region.

(Both SK-I & SK-III rates in R>~10m are reduced by the same external event cut)
Angular distributions

Central-top region

- SK-III BG rate is smaller than SK-I in 5.0-5.5MeV in the central top region
- Signal rate looks consistent.
Radon injection in SK-III


- Inject purified water with known amount of Rn into a position in the SK detector through a long ¼-inch tube
- Event reconstruction works well below 5MeV region
- Detection efficiency for Rn will be obtained.
- Water movement in the detector can be studied.

- ~20Bq Rn, in central-top region
- Rn run – BG run
- Energy ~ 4.0-5.0MeV
- After ambient BG cut
Summary

- The upper limits for the supernova neutrinos are updated. (90% C.L., SK-I + SK-II)
  - Burst limit: $<0.32$ SN/year in 100kpc
  - SRN flux limit: $< 1.08$ /cm$^2$/sec (preliminary)

- The first SK-III SLE data were obtained.
  - Live time=97days, 22.5kt, 5.0-20MeV
- The S/N in 22.5kt looked similar as SK-I.
- More events from barrel & bottom in SK-III.
- In the central region, SK-III BG rate is smaller than SK-I in 5.0-5.5MeV.