Solar Neutrino Results from Super-Kamiokande

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- Super-Kamiokande-I detector
- Solar neutrino results from SK-I
- Accident & reconstruction
- Prospects for SK-II
- Summary
Super-Kamiokande-I

- April 1996 to July 2001
- Fiducial volume 22.5 kt
- Photo coverage 40%

- \( \nu + e^- \rightarrow \nu + e^- \)
- Resolution (10 MeV e)
  - Energy: 14%
  - Vertex: 87 cm
  - Direction: 26°

- ~60% of PMTs destroyed on November 12, 2001

- 50 kton stainless steel tank
- Inner Detector (ID): 11146 of 20 inch PMTs
- Outer Detector (OD): 1867 of 8 inch PMTs

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SK-I: Solar neutrino flux

- Live time: 1496 days
- Analysis energy range: 5.0~20 MeV
- Fiducial volume: 22.5 kt

- Signal (at 1 AU) = 22404 ±226(stat.) ±784-717(sys.) events
- Expected = 48173 events
- Data/SSM\textsubscript{BP2001} = 0.465 ±0.005(stat.) ±0.016-0.015(sys.)
- Flux = 2.35 ±0.02(stat.) ±0.08(sys.) \times 10^6/cm^2/s

(preliminary)
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SK-I: Time variation1 (1.5 month)

Data/SSM

SK-I 1496day 5.0-20MeV 22.5kt
without eccentricity correction, stat. err. only
(Preliminary)

χ² for eccentricity 34.8
χ² for flat 40.1
(41d.o.f., with sys. err.)

Expected eccentricity of earth’s orbit

sunspot

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SK-I: Time variation2 (10day)

(preliminary)

χ² for eccentricity = 209.5 (184-1 d.o.f.) (with sys. err.)
χ² for flat = 216.5

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SK-I: Seasonal variation (preliminary)

Data/SSM

SK-I 1496day 5.0-20MeV 22.5kt (Preliminary)

Expected eccentricity of earth’s orbit

χ^2 for eccentricity = 4.7  C.L. = 69%
χ^2 for flat = 10.3  C.L. = 17%
(7 d.o.f., with sys. err.)

Δχ^2 = 5.6
2.4sigma difference

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SK-I: Day / Night variation

(preliminary)
SK-I: Energy spectrum

\( \chi^2 \) for flat = 17.4
19-1 d.o.f. 50\%C.L.

(considering correlated error)
SK-I: Angular distributions

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SK-I: $\bar{\nu}_e$ from Sun

(preliminary)

Before subtraction
After subtraction

$^8$B $\nu$ spectrum

Visible energy (MeV)

Monochromatic spectrum

Neutrino energy (MeV)

90% CL

Preliminary

$\bar{\nu}_e$ flux (cm$^{-2}$/sec)

$\bar{\nu}_e$/SSM(%)

90% CL

Preliminary

$\bar{\nu}_e$ flux (cm$^{-2}$/sec)

$\bar{\nu}_e$/SSM(%)

• Apply statistical subtraction of spallation events
• Assume all the remaining events in $\cos\theta_{\text{sun}} < 0.5$ are solar antineutrinos

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SK-I: hep neutrino

- Expected hep $\nu$ events in 18-21MeV = 1.06 events
- (Expected $^8$B $\nu$ events in 18-21MeV = 1.72 events)
- Observed signal = 4.9+-2.7 events
- Assuming all signals are hep $\nu$, then hep $\nu$ flux limit (90%UL) = $7.9 \times 10^3$/cm$^2$/s
SK-I: Zenith spectrum

• Test spectral distortion & day/night variation
• 7 zenith angle x 6 energy + 2 energy = 44bin

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SK-I: Oscillation analysis

SK-I zenith spectrum (no flux constraint)

Rate global

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SK-I: Oscillation analysis

All SK-I information + flux constraint by SSM

SK likes large mixing
Combined fit

PLB539 (2002) 179-187

- Best fit:
  - \( \tan^2 \theta = 0.38 \)
  - \( \Delta m^2 = 6.9 \times 10^{-5} \text{ eV}^2 \)
  - \(^8\text{B flux} = 1.06 \text{ SSM}_{\text{BP2001}} \)
  - hep = 3.9 \text{ SSM}_{\text{BP2001}}
  - \( \chi^2_{\text{min}} = 43.5 \)

- Quasi-VAC (1.5, 6.68 \times 10^{-10}) \( \chi^2 = 53.5 \)
- LOW (0.66, 7.2 \times 10^{-8}) \( \chi^2 = 52.5 \)
- SMA (0.0012, 6.6 \times 10^{-6}) \( \chi^2 = 58.9 \)
Cause of the accident is:

- A PMT at the bottom imploded.
- Shock wave from the first implosion broke surrounding PMTs, then chain reaction started.

View from the inspection hole on the top of the detector. Most of 20inch PMT’s below water surface are broken.
PMT vessel for SK-II

- To prevent the chain reaction, all 20inch PMTs are put into the vessel.
- PMT vessels were tested at -30m water depth.
- Radon diffusion from PMT would be stopped.
Reconstruction plan

- Implosion test in the detector (~Feb. 2002)
- Drain water, clean up, remove existing 20inch ID PMTs (Mar. ~ May, 2002)
- Mount about 5200 20inch ID PMTs and full 8inch OD PMTs (May ~ Sep. 2002)
- Water filling started on Oct. 3, 2002 at 35ton/hour.
- Close top inspection hole, then start physics run (early Dec. 2002)

- We are making efforts to reconstruct ID part fully by summer 2006 (before JHF-SK start).
Rebuilding of Super-Kamiokande

SK-I: Photo coverage 40%  SK-II: Photo coverage 19%

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SK-II: prospects

- No serious effect for Supernova burst search, atmospheric neutrino, proton decay, and K2K. (except for $p \rightarrow \nu K$ mode)

- For low-energy data sample:
  - Energy resolution: $\sim 1.4$ times large
  - Energy threshold: $5\text{MeV} \Rightarrow 7\text{MeV}(?)$ because of BG increase (c.f. Kamiokande-III had 7MeV threshold under similar photo coverage and 100 times much radon in water)
  - Need to remake most of analysis tools

- About solar neutrino analysis:
  - Continue to measure time variation, seasonal variation, and day/night asymmetry of $^8\text{B}$ flux in higher energy region.

- Some amount of radon BG would be reduced.
SK-I: Radon BG

Vertical water flow stirs up radon on the detector bottom (emanated from PMT)

Event excess at bottom: ~40% (5.0-5.5MeV, 22.5kt, 30ton/hour)

Y. Takeuchi et al., PLB452(1999)418

(5.0-6.5MeV, R<700cm, before gamma-cut)

Water system on (70ton/hour)

Water system stop

~5mBq/m³ (only excess)

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SK-II: improvement of Rn reduction

1. Cover PMT
2. Use horizontal water outlet

Radon BG would be reduced at SK-II.
Summary

- SK-I precisely measured $^8$B flux, spectrum, and time variations.
- We are still investigating data quality to obtain SK-I final results.
- Reconstruction of SK is almost finished.
- SK-II will be started in Dec. 2002.
- Radon in fid. vol. would be reduced at SK-II.
- Solar neutrino observation would be done in higher energy region in SK-II.