Background study for solar neutrino measurement in Super Kamiokande

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Outline

- Introduction of SK and SK-III.
- Motivation for the solar neutrino measurement.
- Origin of the background events and the efforts for reduction.
  - Water purification system.
  - Germanium Radioactivity measurements
  - Lantern-Mantle Experiments
- Summary
Super-Kamiokande is a 50,000 ton water Cherenkov detector with 13,000 PMTs located 1,000m (2,700m.w.e.) underground in Kamioka mine.
SK-III reconstruction completed!

- 2001 Accident, 2002 SK-II
- 12 Apr. 2006. PMT mount finished
- 11 Jul. 2006. Tank filled
- 3 Oct. 2006 Water purification is progressing.
Motivation for solar neutrino

- Energy Spectrum in SK-I,II

- SK-I $^8$B Solar $\nu$ Spectrum

10% up-turn?

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Lower the background and lower the energy threshold with small errors in order to observe the distortion of the $^8$B neutrino spectrum and measure the oscillation parameter precisely.

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Goal of SK–III in solar neutrino

- 70% reduction from SK–I in 4–5MeV region.
- Energy threshold 4.5MeV → 4.0MeV

Expected up–turn of the \(^8\)B solar neutrino spectrum
Low Energy Background Sources

- Water supply origin \(^{222}\text{Rn}(^{214}\text{Bi}, E_{\beta_{\text{max}}} = 3.26\text{MeV})\)
  - Residual radon dissolved in the purified water
  - Accumulated radioactive dusts/radon (emanated from SK components, Air?) in the bottom of the tank diffuses with the convection.

  Expected to be reduced!

- Internal origin
  - Radioisotopes in the SK components such as PMT, FRP case, ...

  Now we are studying.
SK-I water supply

Rn was stirred up by the convection of the water

SK-I final sample

Z-distribution

4.5–5.0 MeV
Water flow in SK-III tank (New system)

- The water inlet pipe was extended with holes to prevent the convection
Profile of the water temperature

Before

Z(m)

138℃  BEFORE

213℃  AFTER

Convection was clearly suppressed!
The effects of the radioisotopes (U/Th/K) in the SK-III detector should be understood to achieve further lowering BG.

Especially, the newly installed FRP PMT-enclosing cases designed to prevent shockwave propagation (in case of PMT breaking) seemed to contain many radioisotopes!
Radioactivity measurement

- We checked all the SK components with HP Ge detector in Kamioka.
- BG spectrum (370 cm$^3$)

- **Th**
  - 239keV $(6.90\pm3.29) \times 10^{-5}$ counts/sec
  - 583keV $(4.70\pm1.65) \times 10^{-5}$ counts/sec
  - 861keV $(1.81\pm1.44) \times 10^{-5}$ counts/sec
  - 2615keV $(4.21\pm0.99) \times 10^{-5}$ counts/sec

- **U**
  - 352keV $(6.90\pm3.29) \times 10^{-5}$ counts/sec
  - 609keV $(3.83\pm1.68) \times 10^{-5}$ counts/sec
  - 1764keV $(0.96\pm1.02) \times 10^{-5}$ counts/sec

- **K**
  - 1461keV $(11.7\pm2.01) \times 10^{-5}$ counts/sec
Detector Components of the SK-III

- FRP for PMT case
- Acyclic cover for PMT
- SUS for the Frame
- Glass for PMT
- PMT base with cable
- Dust with wiping paper
Summary of the Activity Measurement

- FRP (barrel) No production year dependence!
  - Th $15\text{Bq/kg} \times 7.4\text{kg/PMT} = 110\text{Bq/PMT}$
  - U $10\text{Bq/kg} \times 7.4\text{kg/PMT} = 70\text{Bq/PMT}$
  - K $16\text{Bq/kg} \times 7.4\text{kg/PMT} = 120\text{Bq/PMT}$

- PMT glass (After furnace repair)
  - Th $1.4\text{Bq/kg} \times 5.2\text{kg/PMT} = 7.8\text{Bq/PMT}$
  - U $5.1\text{Bq/kg} \times 5.2\text{kg/PMT} = 27\text{Bq/PMT}$
  - K $18\text{Bq/kg} \times 5.2\text{kg/PMT} = 94\text{Bq/PMT}$

- PMT glass (Before furnace repair)
  - Th $1.8\text{Bq/kg} \times 5.2\text{kg/PMT} = 9.4\text{Bq/PMT}$
  - U $8.3\text{Bq/kg} \times 5.2\text{kg/PMT} = 43\text{Bq/PMT}$
  - K $22\text{Bq/kg} \times 5.2\text{kg/PMT} = 110\text{Bq/PMT}$

- PMT Base
  - Th $0.47\text{Bq/kg} \times 0.9\text{kg/PMT} = 0.42\text{Bq/PMT}$
  - U $0.70\text{Bq/kg} \times 0.9\text{kg/PMT} = 0.63\text{Bq/PMT}$
  - K $0.54\text{Bq/kg} \times 0.9\text{kg/PMT} = 0.49\text{Bq/PMT}$

- SUS
  - Th $0.01\text{Bq/kg} \times 31\text{Kg/PMT} = 0.3\text{Bq/PMT}$

- Dust
  - Th $40\text{Bq/kg} \times 0.03\text{g/PMT} = 0.0012\text{Bq/PMT}$
  - U $30\text{Bq/kg} \times 0.03\text{g/PMT} = 0.0009\text{Bq/PMT}$
  - K $300\text{Bq/kg} \times 0.03\text{g/PMT} = 0.009\text{ Bq/PMT}$

- Acrylic resin, Tyvek, Black sheet below the limit of the sensitivity

10000 PMTs
= 1MBq source!

Normalized to 1PMT
Can SK detect the 2.6MeV gammas emitted behind PMTs?

We put source behind the PMTs!
The mantle contains $^{208}$Tl for brightening the lantern lights.

\[ ^{208}\text{Tl}\rightarrow^{208}\text{Pb} \]

- $2.615$ MeV (99.2%)
- $861$ keV (12.4%)
- $583$ keV (84.5%)
- $511$ keV (22.6%)

We put 300 pieces of Lantern mantle into a SUS container.

The source intensity is 59.5kBq (measured by Ge) and that corresponds to 500 FRP cases.
Source Position

Center of the tank

Hole to access behind PMTs

Z

X

Y

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The measurement was conducted on 23 Aug.

In that period, the water is in the early stage of purification and the transparency was only 75m. (In stable SK, >100m)

Energy calibration is not completed.

The analysis is not optimized and the following results are preliminary!
Reconstructed vertices

L-M
BG
This tail may invade the fiducial volume.
The tail (in this early analysis)

- 2m fiducial cut should be effective, but...
- Resolution will be better.
  - Water purification
  - Tuning the analysis
 Preliminary BG subtracted L-M spectrum.
Energy of surviving events seems to be mostly below 4MeV.

4.8MeV and 6MeV electron beams were irradiated near the L-M source positon.
Summary

- Backgrounds for low energy solar neutrino are being studied.
- Backgrounds originated from Rn might be reduced by upgrading water supplying system.
- We confirmed that radioisotopes (2.6MeV) are also background sources in the water Cherenkov detector by Lantern-Mantle experiment.
- 2m fiducial cut should be sufficient for reject the events emanated from the wall material, however, some events survives in fiducial volume at this stage. (Water transparency, energy resolution, position resolution will be improved!)
- We have got “controlled samples!”
- We can tune the analysis to reduce backgrounds by getting rid of Lantern-Mantle event from fiducial volume.
以下 隠しだま
Super-Kamiokande

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

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

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

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Typical low-energy event at SK-I

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

Sensitive to $\nu_e$, $\nu_\mu$, $\nu_\tau$

\[ \sigma(\nu_\mu(\tau)e^{-}) \approx 0.15 \times \sigma(\nu_e e^{-}) \]

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

$E_e = 9.1\text{MeV}$
$\cos \theta_{\text{zen}} = 0.95$

Resolutions (for 10MeV electron)

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

FULL Volume mean, with obsolete fitter
Super-Kamiokande [SK] is a 50000 ton water Cherenkov detector located 1000 meters underground in the Kamioka mine. One of the main tasks of SK is a precise measurement of B8 solar neutrinos.

The lower energy threshold of SK-I (before the accident) had been limited to around 5.0 MeV due to residual radon dissolved in the purified water. After reduction of this Rn contamination through improvements in the SK water purification system, we eventually succeeded in observing the solar neutrino energy spectrum as low as 4.5 MeV near the end of the SK-I data-taking period.

Now, we have reconstructed the SK-III detector with 11129 PMTs. In order to measure the solar neutrino oscillation parameters more precisely and to examine the distortion of the energy spectrum of the 8B solar neutrinos, lowering SK's analysis energy threshold down to about 4.0 MeV is highly desirable.

In order to achieve further lowering, we will need to understand the effects of the remaining radioisotopes in the SK-III detector. These include emanations from newly added detector components such as PMT-enclosing cases designed to prevent shock wave propagation. Therefore, we have measured the radioactivities of the SK detector components using HPGe and simulated their effects in the SK fiducial volume.

In this talk, we will present our current attempts to understand and further reduce these backgrounds and to lower the energy threshold to 4.0 MeV.
GRINGO cut (goodness stability cut)
- evaluation of the difference between the “goodness” of the reconstructed vertex and those at test vertices around the original one to reject noisy hit events

Patlik cut (pattern likelihood cut)
- Test of the pattern of the Cerenkov ring image to reject ex. Gamma–induced smeared pattern.

Gamma cut
- the reconstructed direction of each event is projected backwards and evaluate the distance from the reconstructed vertex to the ID wall (Energy dependent!)
By scaling the intensity of lantern-mantle (60kBq) to real FRP (100Bq x 11000 PMTs), the total background in 2m and 4m fiducial volume can be explained. But, there is some discrepancy for all volume.
Air purification system

- Remove radon by (cooled) activated charcoal

Flow rate: \(\sim 15 \text{m}^3/\text{h}\)

Compressor → Buffer Tank → Air Drier → Carbon Column \(4 \text{m}^3\) → Heat Exchanger → Carbon Column \(4 \text{m}^3\) → Air Filter \((0.1 \mu\text{m})\) → Cool Charcoal \((-40 \, ^\circ\text{C})\) → Air Filter \((0.01 \mu\text{m})\) → Water (2mBq) → SK dome

Mine air

\(\sim 60 \text{cm}\)
Radon concentration in
mine air: \(\sim 1000\text{Bq/m}^3\) (summer)
\(\sim 40\text{Bq/m}^3\) (winter)

purified air: \(2\sim 3\text{mBq/m}^3\)

air in SK tank: \(10\sim 20\text{mBq/m}^3\)

Seasonal variation is caused by different wind direction in mine tunnel.
Measured Spectrum of the FRP Case

- Th
  - $15 \text{ Bq/kg} = 110 \text{ Bq/PMT}$
- U
  - $10 \text{ Bq/kg} = 70 \text{ Bq/PMT}$
- K
  - $16 \text{ Bq/kg} = 120 \text{ Bq/PMT}$

2.6 MeV
Energy of surviving events seems to be mostly below 4MeV

4.8MeV and 6MeV electron beams were irradiated near the L-M source positon
BG Comparison between experiments

- DAMA NaI
- ZEPLIN before PSD cut
- Kamioka Ge
- Current XMASS (new improvement!)
- Heidelberg Moscow
- XMASS 800kg
- CDMS II After PID
- KamLAND (>0.8MeV)
- DM signal for LXe 100GeV 10^-6pb
- Super-K

Events/kg/keV/day vs. energy (keV)