Solar neutrino results from Super-Kamiokande

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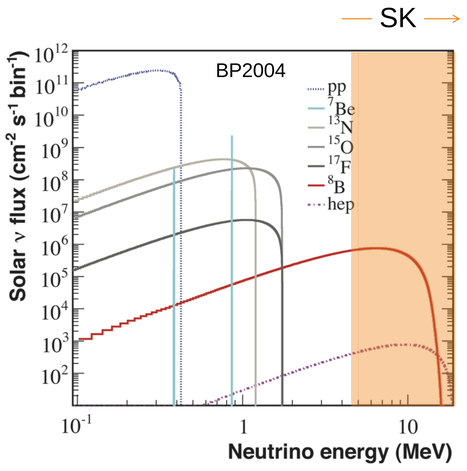
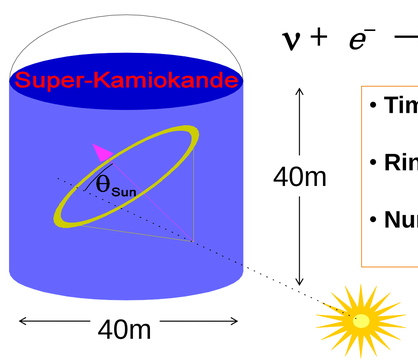
Preface: Super-Kamiokande currently continues data taking as the fourth phase of the experiment (SK-IV), but high quality ^{8}B solar neutrino data has been accumulated since August 2006 when SK resumed operations as the third phase of the experiment (SK-III). Here, new results of the solar neutrino measurement of SK-III and the prospects of SK-IV are presented. By adding SK-III data to SK-I & II, our measurements now favor only LMA solutions. SK-III data also improved the accuracy of the global analysis.

1.Solar neutrino measurement in SK

SK observes the ^{8}B(+*hep*) νs via electron scattering in 22.5kt(fiducial volume) water.





$\nu + e^- \rightarrow \nu + e^-$

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

- ✓ Precise solar neutrino flux
- ✓ Electron energy spectrum
- ✓ Time variation (ex. Day/Night)

Live times

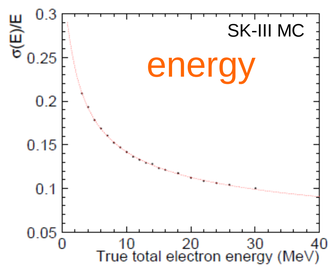
SK-III	548 days	6.5 - 20 MeV
	289 days	5.0 - 20 MeV
SK-I	1496 days	5.0 - 20 MeV
SK-II	791 days	7.0 - 20 MeV

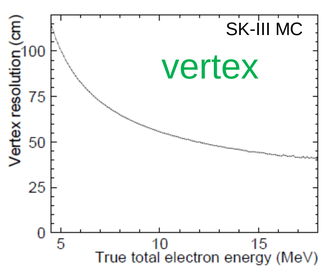
2. SK-III improvements

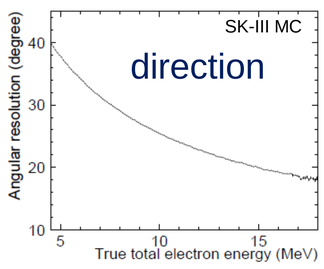
- Improved resolutions by calibration/software tunings

Resolutions (for 10MeV electrons)

SK-I energy: 14% vertex: 87cm direction: 26°
SK-III energy: 14% vertex: 55cm direction: 23°

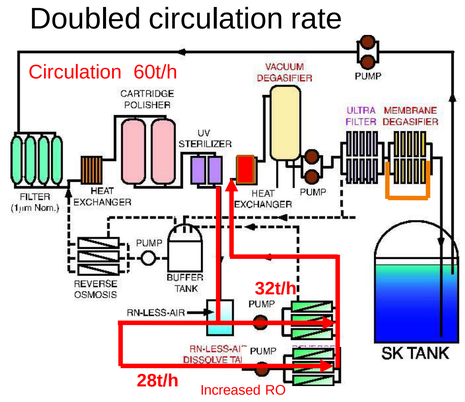




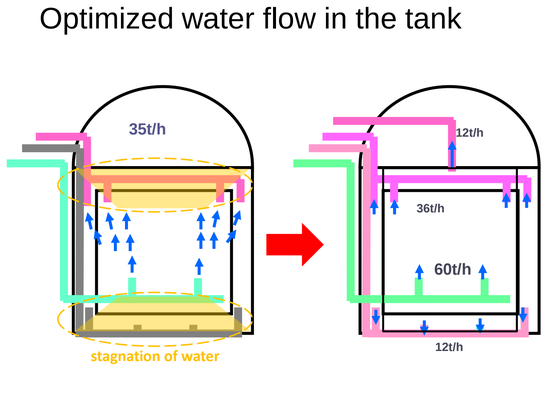


- Improved water quality

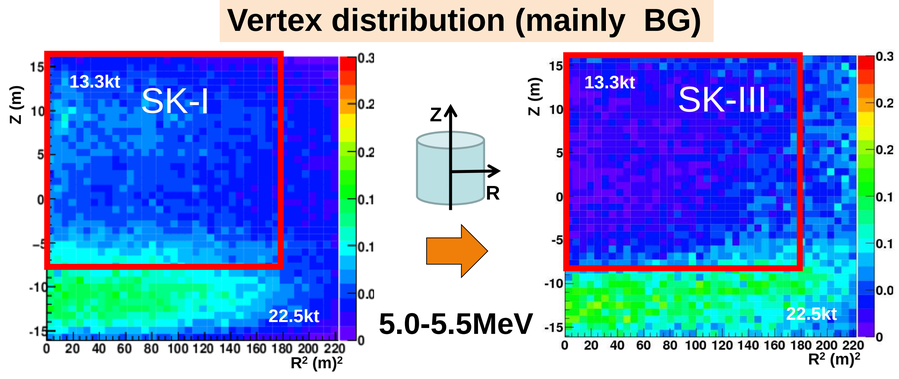
Doubled circulation rate



Optimized water flow in the tank

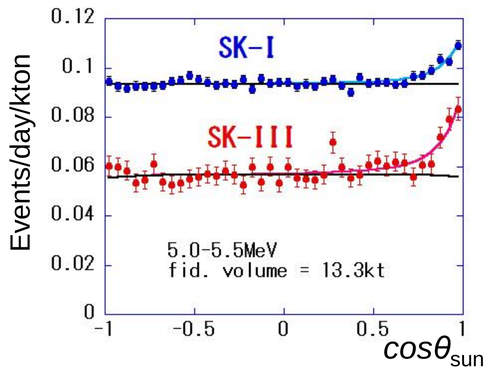


Vertex distribution (mainly BG)



Increased signal-to-noise ratio

Solar angle distribution



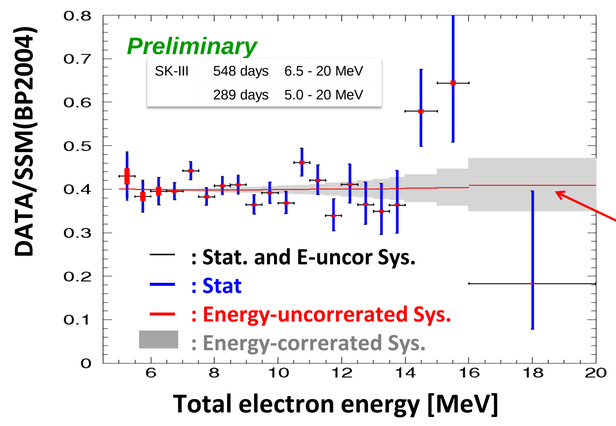
S:Better directional resolution
N:Lower Background

Reduced systematic errors

	SK-III	SK-I (PRD73,112001)
Energy scale	±1.4	±1.6
Energy resolution	±0.2	
^{8}B spectrum shape	±0.2	+1.1 / -1.0
Trigger efficiency	±0.5	+0.4 / -0.3
Vertex shift	±0.54	±1.3
Reduction	±0.65	+2.1 / -1.6
Small cluster hits cut	±0.5	
Spallation cut	±0.2	±0.2
External event cut	±0.25	±0.5
Background shape	±0.1	±0.1
Angular resolution	±0.67	±1.2
Signal extraction method	±0.7	
Cross section	±0.5	±0.5
Live time calculation	±0.1	±0.1
Total	**±2.1**	**+3.5 / -3.2%**

3. SK-III Flux & spectrum results

^{8}B Flux: 2.32±0.04(stat.)±0.05(syst.) (x10^6/cm^2/s)
SK-I: 2.38±0.02(stat.)±0.08(syst.)
SK-II: 2.41±0.05(stat.)+0.16/-0.15(syst.)



Day/Night flux ratio

$$A_{DN} = \frac{(\Phi_{Day} - \Phi_{Night})}{(\Phi_{Day} + \Phi_{Night})/2}$$

= -0.056±0.031(stat.)±0.013(syst.)
SK-I: -0.018±0.016(stat.)+0.013/-0.012(syst.)
SK-II: -0.036±0.035(stat.) ±0.037(syst.)

Solar best-fit (see below)
$\tan^2\theta$=0.42
Δm^2=6.2×10^{-5}eV
Φ_{B8} = 0.92× $\Phi_{B8,SSM}$
Φ_{hep} = 1.0 × $\Phi_{hep,SSM}$

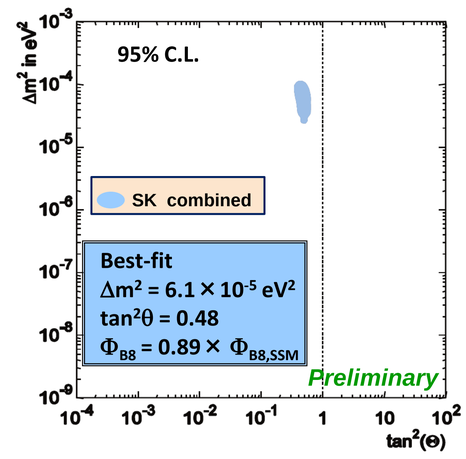
… consistent with no-distortion

4.Oscillation analysis

- 2 flavor analysis

SK-I & II & III with flux constraint

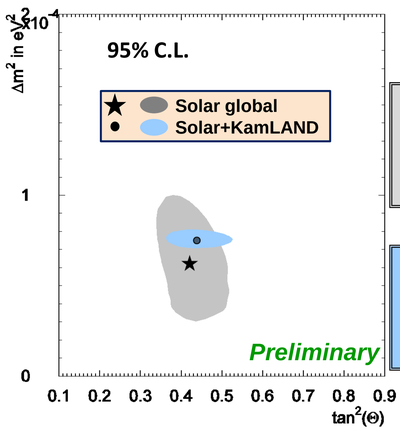
B8: SNO(NCD+LETA) NC flux
= (5.14±0.21) 10^{6}cm^{-2}s^{-1}
hep: SSM flux with uncertainty(16%)



SK favors only LMA solutions!!

Solar global *hep*: SSM flux with uncertainty(16%)

- SK-I &II & III
- SNO
  - CC flux (Phase-I & II & III)
  - NC flux (Phase-III & LETA combined)
  - Day/Night asymmetry (Phase-I & II)
- Radiochemical : Cl, Ga
  - Ga rate: 66.1±3.1 SNU (All Ga global) (PRC80, 015807(2009))
  - Cl rate: 2.56±0.23 (Astrophys. J. 496 (1998) 505)
- Borexino
  - ^{7}Be rate: 48±4 cpd/100tons (PRL101, 091302(2008)
- KamLAND : 2008
- ^{8}B spectrum : Winter(2006)

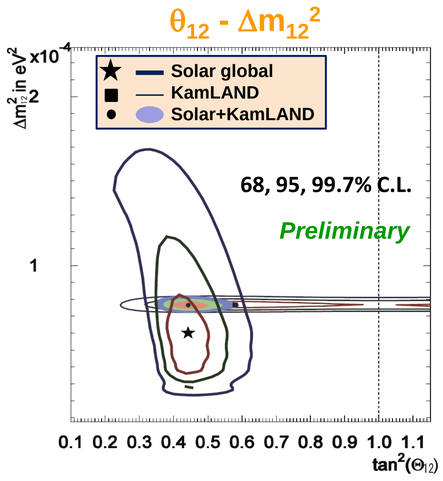


Solar global:
Best-fit
$\Delta m^2 = 6.2 \times 10^{-5}$ eV^2
$\tan^2\theta = 0.42$
$\Phi_{B8} = 0.92 \times \Phi_{B8,SSM}$

Solar global + KamLAND:
Best-fit
$\Delta m^2 = 7.6 \times 10^{-5}$ eV^2
$\tan^2\theta = 0.44$
$\Phi_{B8} = 0.89 \times \Phi_{B8,SSM}$

- 3 flavor analysis

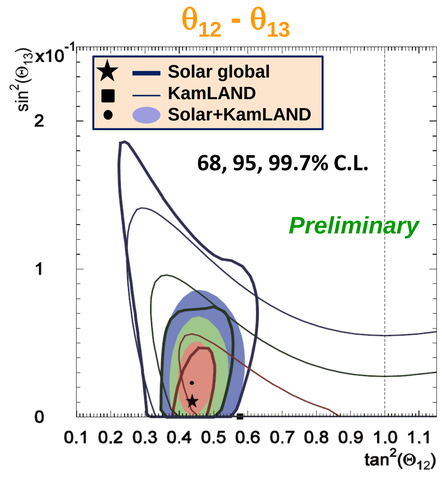
θ_{12} - Δm_{12}^2



Solar global:
Best-fit
$\Delta m_{12}^2 = 6.0 \times 10^{-5}$ eV^2
$\tan^2\theta_{12} = 0.44$
$\sin^2\theta_{13} = 0.010$
$\Phi_{B8} = 0.92 \times \Phi_{B8,SSM}$

Solar global + KamLAND:
Best-fit
$\Delta m_{12}^2 = 7.7 \times 10^{-5}$ eV^2
$\tan^2\theta_{12} = 0.44$
$\sin^2\theta_{13} = 0.025$
$\Phi_{B8} = 0.91 \times \Phi_{B8,SSM}$

θ_{12} - θ_{13}



Solar global:
$\sin^2\theta_{13} < 0.060$ @95%C.L.

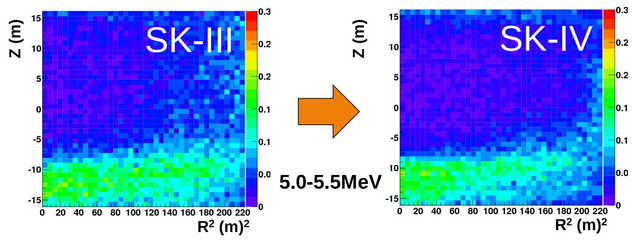
Solar global + KamLAND:
$\sin^2\theta_{13} = 0.025^{+0.018}_{-0.016}$ (<0.059 @95%C.L.)

5.SK-IV Prospects

Super-Kamiokande continues the solar neutrino observation for the possible distortion in the solar neutrino spectrum.

→ More precise measurement of the neutrino parameters

- ✓ Reduce background and systematic uncertainties
  Water temperature control system was installed for further stabilization of the water quality.
- ✓ Lower the energy threshold to 4MeV
  Completely new DAQ was installed. (→ **Jul 24 Y.Obayashi's talk**)



Expected "upturn" distortion

($\sin^2\theta_{12}$, Δm_{12}^2) = (0.30,7.9x10^{-5}) case