Recent results of solar neutrino measurement in Super-Kamiokande

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abstract

The results of solar neutrino data from the first phase of Super-Kamiokande are presented. Super-Kamiokande can measure not only the solar neutrino flux but also its energy spectrum and its time variations such as day vs. night and seasonal differences. This information can severely restrict parameters of solar neutrino oscillation. From the combination of several experiments' results with those of Super-K, the Large Mixing Angle solution is uniquely allowed at the 98.1% confidence level; this global solar neutrino oscillation analysis is presented. The current status of the second phase of Super-Kamiokande is also presented.

1. Introduction

The origin of the energy in the sun is the following nuclear fusion reaction which generates two neutrinos,

$$4p \rightarrow \alpha + 2e^{+} + 2\nu_{e} \quad (1)$$

The observed solar neutrino flux in all the experiments has significantly been smaller than the expected.[1] From the recent solar neutrino data, especially together with Super-Kamiokande and SNO, it comes from neutrino oscillation in solar neutrinos. In order to determine the neutrino oscillation parameter, mixing angle and delta mass square, it it important to measure not only solar neutrino flux but also energy spectrum and flux time variations, because those are independent of the uncertainties in the solar models.

Super-Kamiokande is a 50000 tons of imaging water Cherenkov detector, and it is located 1000m underground (2700m of water equivalent), to shield against cosmic ray muons, in the Kamioka mine in Gifu Prefecture, Japan. Cherenkov lights generated by charged particles scattered by neutrinos in water are detected by 11146 20-inch photomultiplier tubes. The detector can measure the energy spectrum of solar neutrinos very precisely because of the well calibrated energy of recoil electrons.[2] And it can also measure the time dependence of the solar neutrino flux, (day/night or seasonal differences). The experiment started normal

pp. 1225–1228

data taking from April 1st in 1996. In this paper, the results of 1496 days of solar neutrino data, which is from May in 1996 to July in 2001, are reported.

2. Results of solar neutrinos in Super-Kamiokande

We have obtained 1496 days of solar neutrino data in the first phase of Super-Kamiokande. The observed solar neutrino flux in Super-Kamiokande, whose energy threshold is 5.0MeV, is

$$2.35 \pm 0.02(stat.) \pm 0.08(sys.) \quad [\times 10^6/cm^2/sec]. \tag{2}$$

Comparing the result to standard solar model(BP2000)[3],

$$\frac{Data}{SSM} = 0.465 \pm 0.005(stat.)^{+0.016}_{-0.015}(sys.), \tag{3}$$

and the observed flux is significantly smaller than predicted flux. And comparing with SNO charged current results, the flux of $\nu_{\mu,\tau}$ by neutrino flavor oscillation from ν_e should be $3.45^{+0.65}_{-0.62}$. [4] Fig 1. shows the time variation of the solar neutrino flux, the observed variation is consistent with the expected line. No significant time variation of the solar neutrino flux can be seen except for expected yearly variation by the eccentricity.

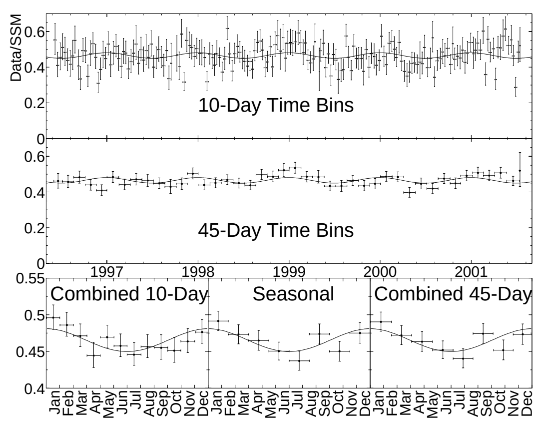

Fig. 1. Time variation of the solar neutrino flux in each time binning

The day-night flux differences are also observed, and the result is,

$$\frac{\phi_{day} - \phi_{night}}{(\phi_{day} + \phi_{night})/2} = -0.021 \pm 0.020(stat.)^{+0.013}_{-0.012}(sys.), \tag{4}$$

Fig 2. shows the solar neutrino flux in the daytime and the night-time bins. The MSW effect[5] through the earth, which is ν_e regeneration, could cause flux difference between daytime and night-time. The flux ratio depends on distances

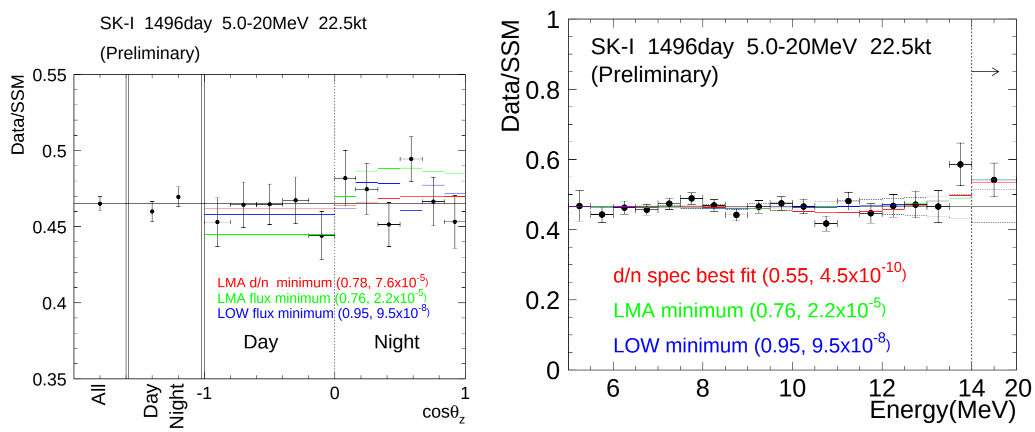

Fig. 2. Flux diveded by daytime and six night time bins (left). Energy spectrum of solar neutrino events normalized by the predicted energy spectrum (right). The expected flux assuming some neutrino oscillation parameters are also shown.

through the earth and the different electron density. For example, Fig 2. also shows the expected solar neutrino flux in each bin assuming typical MSW parameters. The plot is consistent with the flat, but also consistent with some MSW solar neutrino oscillation parameters, e.g. LMA solution. It can be used for the neutrino oscillation analysis as described in the next section precisely.

Fig 2. shows the observed spectrum of solar neutrino events normalized by the predicted energy spectrum. We cannot see any distortion. In this figure, the spectrum assuming the several couples of neutrino oscillation parameters are also shown. It is also be used for solar neutrino oscillation analysis.

3. Solar neutrino oscillation analysis

For the neutrino oscillation analysis, we divide the Super-Kamiokande solar neutrino data to day and six night bins in each six energy regions, called Zenith spectrum. The left figure of Fig 3. shows the exclude region from Zenith spectrum without flux constraint, which is overlaied with the allowed region obtained by the only flux results in all the solar neutrino experiment (green area). It can exclude some neutrino oscillation solution, "SMA", "LOW" and vacuum solution at 95% C.L., which are allowed from flux only results. And when we add the flux constraint, the remaining allowed region is only large mixing angle as shown in the center figure of Fig 3. (blue area). From these analysis, Super-Kamiokande results conclude that only the large mixing angle region can be allowed at 95% C.L..

And when we consider all the solar neutrino experimental data, the remaining allowed region is only "LMA" region. The right figure of Fig 3. shows the region with 95%C.L., and the confidence level of solutions other than LMA

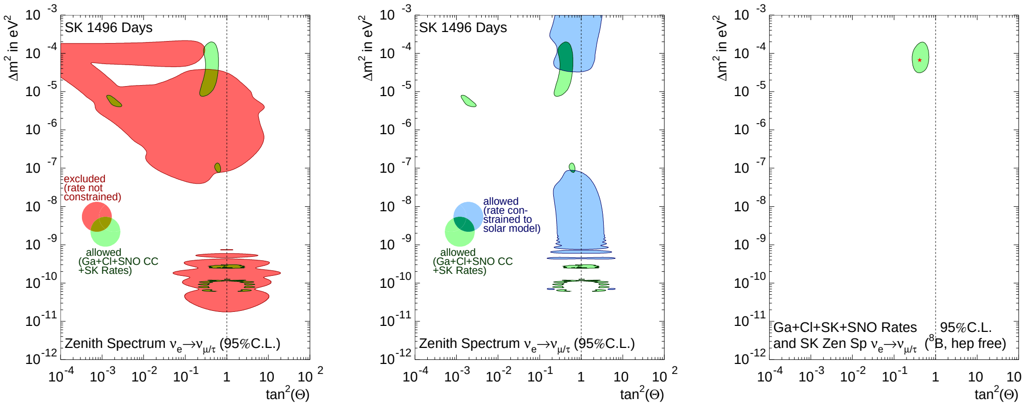

Fig. 3. The excluded region of neutrino oscillation parameter obtained from Zenith spectrum in Super-Kamiokande, which is overlaied with the allowed region obtained by the only flux results in all the solar neutrino. The left figure shows flux free and the center figure flux constrainted analysis.

are more than 98.1%.

4. Summary

Super-Kamiokande has measured precisely solar neutrino flux, recoil electron spectrum and time variations of the flux. No significant time variation and energy distortion appear from the 1496 days of data. The solar neutrino oscillation analysis has been done using those data. The result from the Super-Kamiokande Zenith spectrum data favor Large neutrino mixing at 95% C.L. And only LMA solutions remain at 98.1%C.L. combined with flux results from all solar neutrino experiments.

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