Search for $\bar{\nu}_e$ from the Sun at Super-Kamiokande-I

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Abstract

We present the results of a search for low energy (reconstructed total positron energy = 5-20MeV) $\bar{\nu}_e$ from the Sun using 1496 days of data from Super-Kamiokande-I. We observe no significant excess of events and set an upper limit for the conversion probability to $\bar{\nu}_e$ for the ^{8}B solar neutrinos based on the standard solar model's (BPB2001) neutrino flux. We also set a flux limit for monochromatic $\bar{\nu}_e$ for E($\bar{\nu}_e$) = 10-17MeV.

1. Introduction

Spin Flavor Precession(SFP), magnetic moment solution for solar neutrino problem[5] was introduced as a one possibility to solve time variation of solar neutrino . Kamiokande already excluded this time variation and recent results of SK, SNO, KamLAND solved solar neutrino problem is due to neutrino mass oscillation[3] . But, search for $\bar{\nu}_e$ which is converted from ν_e is one of the most sensitive methods to investigate the unknown properties of neutrino. If the neutrino is Majorana, it has a large magnetic moment, and the Sun has a large magnetic field, ν_e changes to $\bar{\nu}_{\mu,\tau}$ by spin magnetic moment transition. Neutrino oscillation then yields $\bar{\nu}_{\mu,\tau} \rightarrow \bar{\nu}_e$. Solar $\bar{\nu}_e$ could also originate from neutrino decay[2]. This paper reports on the results of search for $\bar{\nu}_e$ from the Sun using Super-Kamiokande-I(SK-I) 1496 days data.

2. Data set and background estimation

Super-Kamiokande is a 22.5 kton fiducial volume water Cherenkov detector. The data used for the search were collected in 1496 live days between 31 May 1996 and 15 July 2001 in SK-I. Dominant backgrounds are ^{222}Rn in the water, external gamma rays and muon induced spallation products. To remove these background, first reduction, spallation cut, second reduction and gamma cut are applied [4] as shown in left figure of Fig.1. Predominant $\bar{\nu}_e$ interactions in SK is the inverse beta decay process, $\bar{\nu}_e + p \rightarrow n + e^+$. The cross section for this

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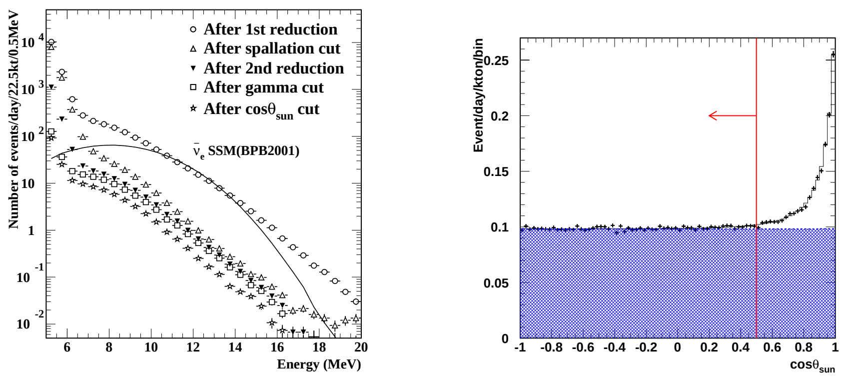

Fig. 1. Left figure: Energy spectrum after each reduction step. The solid curve shows the expected positron spectrum, after all cuts, assuming ^{8}B solar neutrinos convert to $\bar{\nu}_e$. The horizontal axis shows the reconstructed total e$^\pm$ energy. Right figure: Angular distribution before $\cos\theta_{\rm sun}$ cut for e$^\pm$ energy 5-20MeV.

process 2 order of magnitude greater than that for elastic scattering, and therefore SK has good sensitivity for the detection of solar $\bar{\nu}_e$. The positron energy is correlated with the $\bar{\nu}_e$ energy ($E_{e^+} \approx E_{\bar{\nu}_e} - 1.3$ MeV) and the positron angular distribution relative to the incident $\bar{\nu}_e$ direction is nearly flat with a small energy dependent slope[7]. So expected region for $\cos\theta_{\rm sun}$ distribution (θ_{sun} is the event direction with respect to the direction from the Sun) is shown as hatched region in right figure of Fig.1. Elastic scattering events from solar ν (blank region of right figure of Fig.1) are one of the backgrounds in this search, so we cut events with $\cos\theta_{\rm sun} \geq 0.5$. At SK, $\bar{\nu}_e$ events could not be identified because the delayed 2.2MeV gamma ray from $n + p \rightarrow d + \gamma$ is below the detector's threshold. So we applied two methods, statistical spallation subtraction and angular distribution analysis. After application of each reduction, dominant background for E$_e \geq$ 8MeV is spallation. Spallation cut removes events due to radio-isotopes(X) produced by cosmic ray muon interactions with water : μ+$^{16}O \rightarrow \mu$+X+... Short-lifetime spallation products and $\sim$ 90% of long-lifetime products such as $^{16}_{7}$N ($\tau_{1/2}$ = 7.1 sec) and $^{11}_{4}$Be ($\tau_{1/2}$ = 13.8 sec) are removed. But event by event removal of remaining $\sim$ 10% of these events is impractical because this introduces large dead time. However, we can estimate the contribution of these spallation events by using the time difference distribution between cosmic μ and observed, artificial random events. Left figure in Fig.2 shows this methods. Upper figure(A) shows μ time difference(Delta-T) distribution before observed events. In this distribution, the μs which are caused and not caused spallation products are included. To remove the μs which are not caused spallation products, we used similar distribution before artificial random events shown as central figure(B). Subtracting (B) with suitable normalization (ratio of number of μ events in the Delta-T = 100 - 200 sec) from (A), the number of μs which are caused for spallation products is

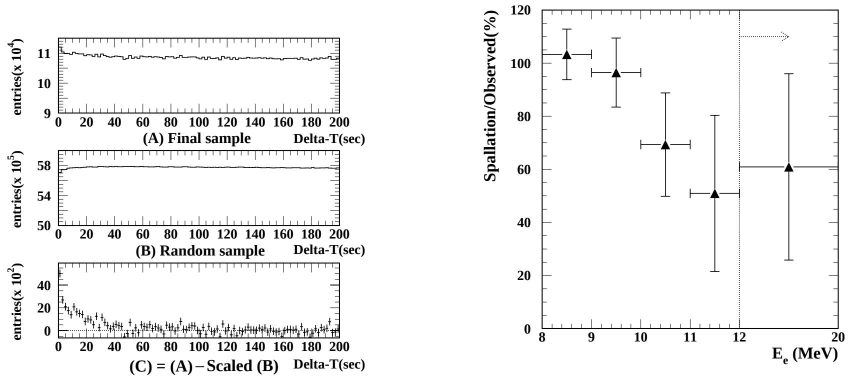

Fig. 2. Left figure: (A) μ delta-T distribution before observed events. (B) Before random events. (C) The delta-T distribution of events caused by spallation products obtained as (A) - scale factor $\times$ (B). Right figure: Spallation contamination in each energy bin.

calculated. Right figure of Fig.2 shows the spallation contamination in each energy bin. For 8-20MeV, this contamination ratio in lowenergy events is 93%$\pm$7%.

3. Analysis and results

The energy spectrum of the $\bar{\nu}_e$ is not known because the mechanism for $\bar{\nu}_e$ creation and these some parameters are not known. In order to deal with this ambiguity, we have chosen two spectrum models, ^{8}B neutrino spectrum[6] and monochromatic spectrum. For ^{8}B spectrum assuming analysis, we assumed all ^{8}B neutrinos convert to $\bar{\nu}_e$ and we used two methods. First method is spallation background subtraction. The result after application of statistical subtraction is shown by dashed lines in left figure of Fig.3. By combining the statistics for 8-20MeV, global upper limit of 0.8% of the SSM neutrino flux(BPB2001)[1] is obtained. Second method is angular distribution analysis. Positron angular distribution have sufficient slope and the event statistics are large. This $\cos\theta_{\rm sun}$ slope is distributed as $f(\cos\theta_{\rm sun}) = 0.5 \times (1 + \alpha \times \cos\theta_{\rm sun})$ and the fitting value of positron distribution of α is -0.076 at E = 5-6MeV, 0.107 at E = 12-20MeV and crosses 0 at $\sim$9MeV. The result from this angular distribution analysis is consistent with 0%, so we set the upper limit. This result is shown by dotted lines in left figure of Fig.3.

We also generalized our search by assuming a monochromatic energy $\bar{\nu}_e$ at each energies. We set the 1σ range by Gaussian fitting for spectrum after detector simulation and reduction processes. Comparing to observed data and expected data in this energy range, 90% C.L. upper limit is calculated. Right figure of Fig.3 shows the result for this analysis.

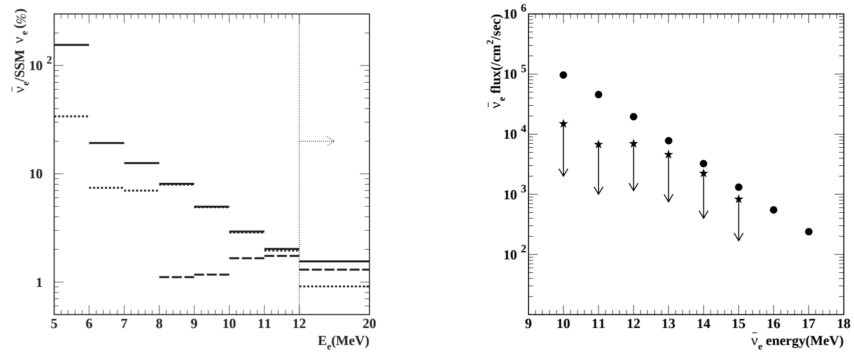

Fig. 3. Summary of $\bar{\nu}_e$ limits. Left figure: 90% C.L. upper limits of ^{8}B spectrum assuming analysis. The solid lines show the simple ratio limit. The dashed lines show the limit after statistical subtraction of the spallation background. The dotted lines show the result from the angular distribution analysis. Right figure: 90% C.L. upper limits of monochromatic spectrum analysis. The circles show the limits before application for background subtraction while the stars show the limits after subtraction. The two highest-energy bins have an insufficient number of events for statistical subtraction.

4. Summary

A search for $\bar{\nu}_e$ from the Sun was performed using 1496 days of Super-Kamiokande-I data. For the ^{8}B spectrum assuming analysis, the $\bar{\nu}_e$ upper limit was 0.8% of the SSM ν_e flux prediction for E_e = 8-20MeV. For the monochromatic energy spectrum analysis, the resulting upper limits are shown in right figure of Fig.3.

5. References

1. Bahcall J.N. *et al.*, Astrophys. J. **555** 990 (2001)
2. Berezhiani Z. *et al.*, JETP Lett. **55** 151 (1992); Acker A.*et al.*, Phys. Lett. B **285** 371 (1992); Raghavan R.S. *et al.*, Phys. Rev. D **38** 1317 (1988); Beacom J.F. and Bell N.F. Phys. Rev. D **65** (2002) 113009.
3. Fukuda S. *et al.*, Phys. Lett. B **539** 179 (2002); Ahmad Q.R. *et al.*, Phys. Rev. Lett. **87** 071301 (2001); Eguhi K. *et al.*, Phys. Rev. Lett. **90**, 021802 (2003)
4. Gando Y. *et al.*, Phys. Rev. Lett. **90** 171302 (2003)
5. Lim C.S. and Marciano W.J., Phys. Rev. D**37** 1368 (1988); Akhmedov E.Kh., Phys. Lett. B **213** 64 (1988); Sov. Phys. JETP **68** 690 (1989); Barranco J.*et al.*, Phys. Rev. D **65**, 113009 (2002)
6. Ortiz C.E.*et al.*, Phys. Rev. Lett. **85** 2909 (2000)
7. Vogel P. and Beacom J.F., Phys. Rev. D. **60** 053003 (1999)