An Evaluation of Scattered Angular Distributions of Low Energy Electrons to a Solar Neutrino Flux of the Kamiokande Observation

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Abstract

In solar neutrino observations, there seems much contradictions among the Homestake, the Kamiokande and the Sage experimental results. We used other scattering angle distribution for low energy electrons produced by ^{8}B solar neutrinos in a place of the EGS4 code which has been used in the Kamiokande analysis, and obtained a fewer solar neutrino flux than the Kamiokande one.

Key words: ^{8}B Solar neutrino; scattering angles of low-energy electrons; Kamiokande detector; EGS4 Code.

1 Introduction

The chlorine experimental results from the Homestake experiment has shown an average total solar neutrino flux over the period 1970 to 1989.3 is 2.3 $\pm$ 0.3 SNU[1)]. There is an apparent variation in the solar neutrino flux that anti-correlates with the 11 year solar activity cycle. The rate reached a maximum value of the 4.1 $\pm$ 0.9 SNU for 1977 and 4.2 $\pm$ 0.7 SNU for 1987~1988.3 at each of the solar minimum. At solar maximum the rate dropped to 0.4 $\pm$ 0.2 SNU in 1980~1981 and 0.9 $\pm$ 1.0 SNU during the ascending phase of 1988.3~1989.3[1)]. On the other hand, the Kamiokande II group has published[2)] recent measured flux of ^{8}B solar neutrinos from a data sample of 1040 days, consisting of subsamples of 450 days at electron energy threshold $E_e \geq 9.3$ MeV and 590 days at $E_e \geq 7.5$ MeV. The relative flux to calculations of the ^{8}B flux based on the standard solar model is 0.46 $\pm$0.05(stat) $\pm$0.06(syst) times of the prediction of Bahcall and Ulrich[3)]. The observation for the period of 1987.1~1988.4 ($E_e \geq 9.3$ MeV) and 1988.6~1991.4 ($E_e \geq 7.5$ MeV) has given no obvious sign of time variations[2)]. Also a radiochemical ^{71}Ga $-^{71}Ge$ of the Sage experiment indicate that the total flux is consistent with 0 SNU (<70 SNU in 68% CL, <135 SNU in 95% CL)[4)]. There seems much contradictions among them. Some theorists propose to settle the contradictions[5)] by neutrino mass differences or variations in the sun. But, we shall discuss unaccuracy of treatments for angular distribution of scattering of low energy electrons in the Kamiokande data.

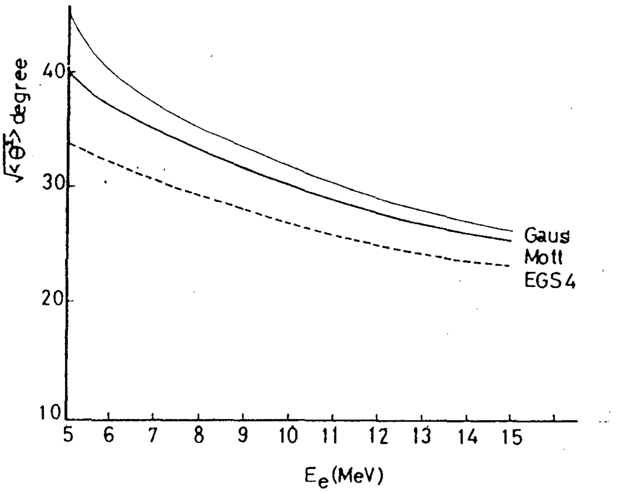

Figure 1: Comparisons of angular deviations calculated by us using Motto and Gauss formulae with one by Kamiokande group using the EGS code as a function of electron total energy.

Table 1: Results (significance probability) of Rayleigh test to the measured flux of ^{8}B solar neutrinos obtained by the recent Kamiokande II observations. The 450 run days[2] are in the time period of January 1987 through May 1988 and the 590 run days[2] in the period of June 1988 through April 1990. The 288 run days[7] are in the period of June 1988 through April 1989.

Total event number	Live time (days)	Electron energy threshold	significance probability (P-value)
1274	450	9.3 MeV	1.98×10^{-3}
3132	590	7.5 MeV	3.89×10^{-2}
1282	288	7.5 MeV	8.5×10^{-3}

2 Rayleigh test on the recent Kamiokande II results

To check whether the Kamiokande neutrino signal is statistically significant, we applied the following statistical tests to the data: Rayleigh test, Z_n-test, V-test, Watson's U_n-test, and Kuiper's test in the previous paper[6]. These tests have showed the similar results. As the Rayleigh test is perhaps the most familiar test, we shall check with the test for the most recent measured flux of the Kamiokande data sample of 1040 days. The data consist of subsamples of 450 days at electron energy threshold $E_e \geq 9.3$ MeV and 590 days at $E_e \geq 7.5$ MeV. The results in Table 1 indicates that the data of the 450 days run (1274 events with $E_e \geq 9.3$ MeV) deviate more from a uniform distribution than those of the 590 days run (3132 events with $E_e \geq 7.5$ MeV) in spite of its fewer number of the events. Also the higher statistics sample of 3232 events of the 590 days run do not give more significant results than the fewer samples of 1282 events of the 288 days run with the same energy threshold $E_e \geq 7.5$ MeV which has been published before[7]. This would imply that the result with $E_e \geq 7.5$ MeV on the significance of the solar neutrino flux is not limited by statistics but rather systematics.

3 An effect of scattering of low energy electron

The Kamiokande observation detects solar ^{8}B neutrinos via $\nu_e e^-$-$\nu_e e^-$ scattering process in water. The $\nu_e e^-$ scattering events have to be extracted from large isotropic backgrounds. In this method the exactness of used angular distribution of electrons due to multiple coulomb scattering in water is most important. The calculation of Kamiokande is based on the EGS4 code[8], which uses the Moliere approximation that the scattering nucleus is approximated as a point charge. In this approximation the frequencies of single large angle scattering events are increased with respect to the real case, and the root mean square scattering angle will diverge for low energies. In order to avoid the divergence, the EGS code contains a weighted function which becomes zero at a scattering angle of π, independent of the energies of incident electrons. This corresponds to an effective cut-off angle of θ_{cut}=$(2/3)\pi$. Instead, it would be reasonable to use a cut-off for a scattering angle of $\theta_{max} \simeq \lambda/d$ (d:nuclear radius, λ: wave length of the electron ($\lambda = h/p$)). The EGS

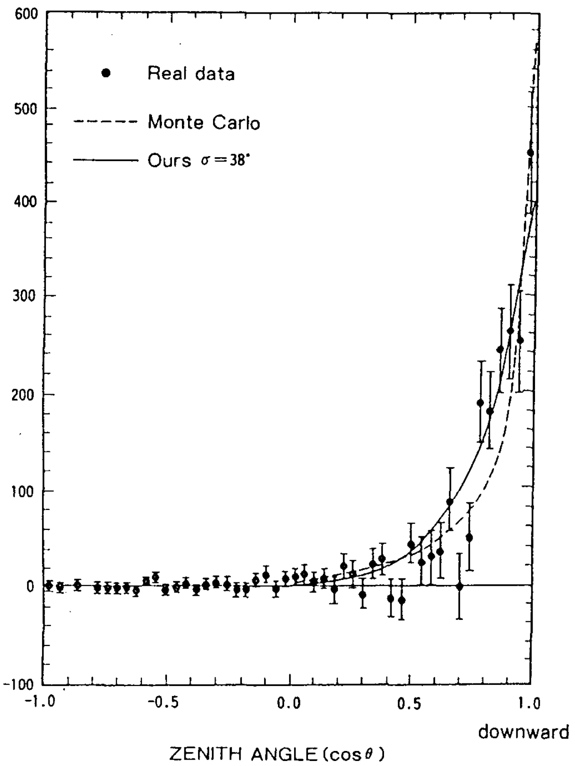

Figure 2: A comparison of our calculated zenith angle distribution with the Kamiokande measured distribution of the gamma rays from a Nickel block using a Califorium 252 neutron source and their fitted calculated distribution.
a real line: our distribution with an angular resolution of 38.0°.
a broken line: Kamiokande calculated one with the same angular resolution.

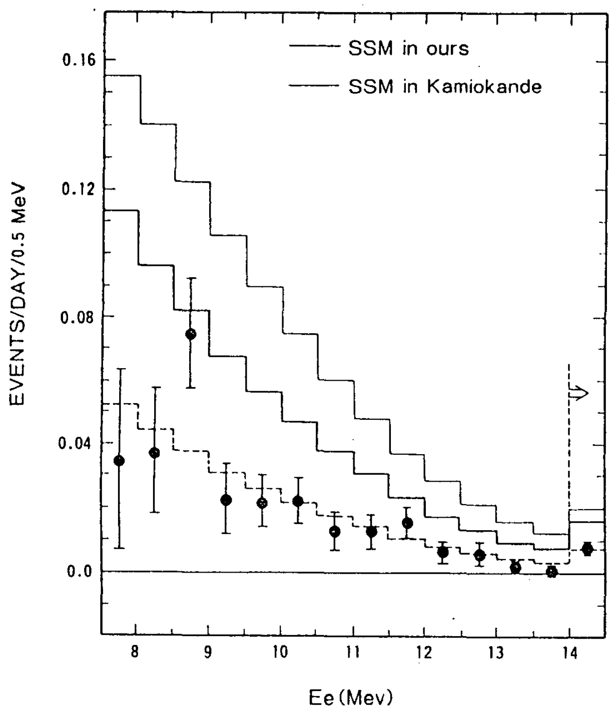

Figure 3: Comparisons of energy distributions of scattered electrons by ^8B solar neutrinos of the standard model to be measured by the Kamiokande II detector.

cut converted to energy ($\lambda/d = (2/3)\pi$) leads to 20∼30 Mev. Accordingly, if the electron energy E is larger than E_{cut} =20∼30 MeV, $\theta_{cut} > \theta_{max}$ holds, leading to an overestimation of the scattering angle. On the other hand, if the electron is smaller than E_{cut}, λ/d might exceed , which is unphysical. To avoid this, EGS introduces a cut-off angle of $\theta_{cut} = (2/3)\pi$, thus underestimating large angle scattering at low electron energies. This behavior is shown in Fig. 4 in our paper[6]. Now we can show comparisons of angular deviations, $\sqrt{\langle\theta^2\rangle}$, among our calculated ones for two cases and the EGS case as a function of electron total energy. Our two cases are given by using Mott formula and Gaussian formula and the EGS one is cited from the Kamiokande paper[9]. There seems considerable large differences among them.

For a calibration of the angular distribution, Kamiokande group used gamma rays from Ni(n,γ)Ni reaction[9]. The measured zenith angle distribution is shown in Fig. 2, compared with its Monte Carlo simulated result using the EGS code. According to their paper, the energy of the data sample is $N_{eff.hit} \geq 19$ ($E_e \geq 8.3$ MeV) and the measured angular resolution is 35.4°+1.5°−2.3°. Their Monte Carlo simulation using EGS code gives a broken line distribution with an angular resolution of 38° (according to our checking, it may give 34° for the angular resolution). A real line shown in the figure is our calculated distribution with the same angular resolution of 38.0° based upon Nakatsuka expression[10]. Numbers of events shown in the ordinate are not measured numbers in absolute values, the background level being normalized to zero. Accordingly, although significance probabilities of the goodness-of-fit of both the distributions to the measured one can not be obtained, we get a χ^2 value of the real distribution with 440.6 for a degree of freedom of 25

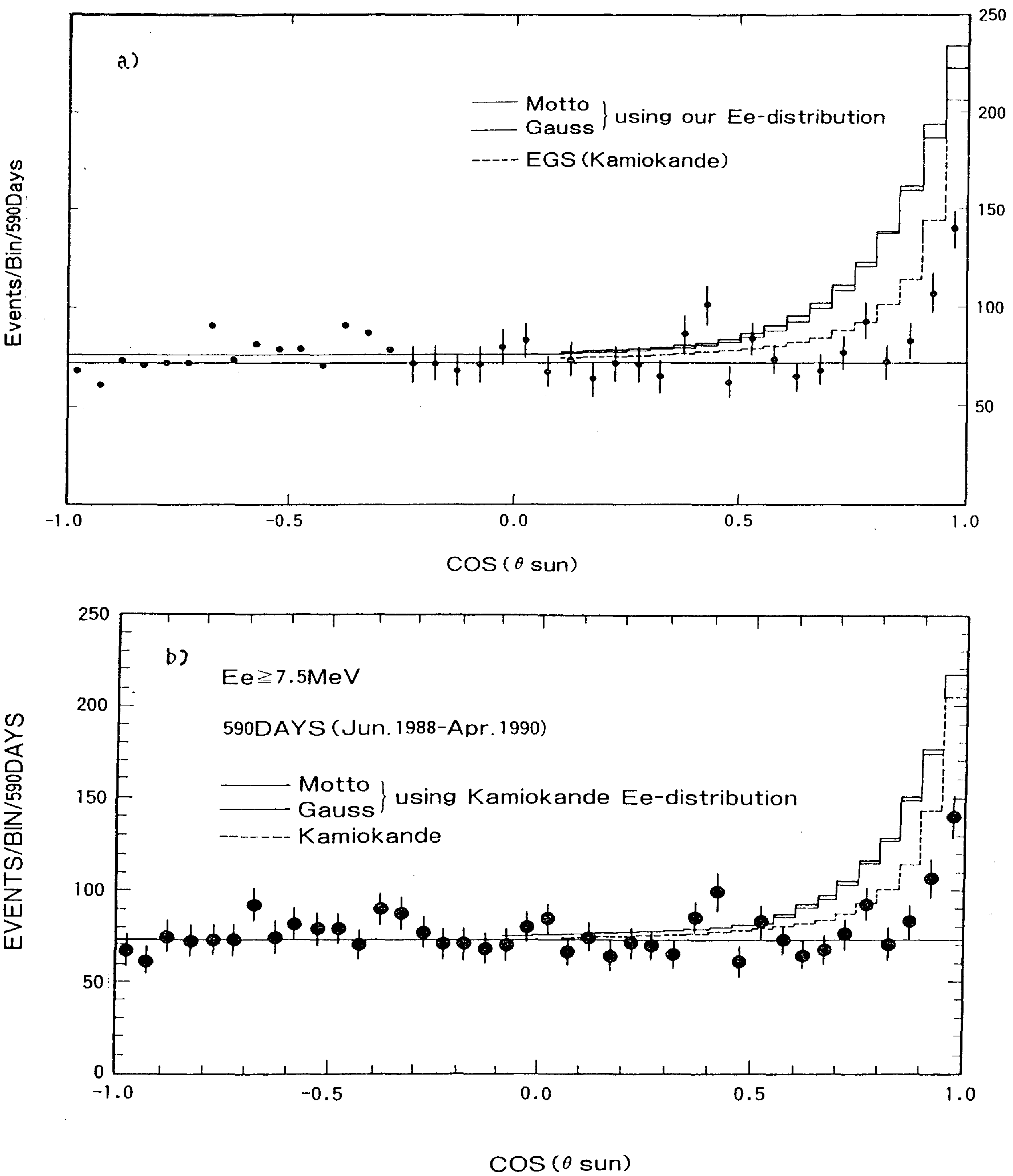

Figure 4: Comparisons of our angular distributions (histograms) in cos θ using Motto anf Gauss formulae based on the standard solar model with the Kamiokande same histogram and the measured data for $E_e \geq 7.5$ MeV.

a) a case using an electron energy distribution obtained by us,

b) a case using the Kamiokande electron energy distribution.

a dotted histogram: Motto formula,

a broken histogram: Gauss formula,

a real histogram: Kamiokande using EGS4.

Table 2: Comparisons of the respective relative flux value to each prediction of the standard solar model obtained from Kamiokande's and our calculations. The estimations are done by using an electron energy spectrum calculated by us (a) and the Kamiokande one (b).

	flux/SSM	bin no=13 f. d.= 12	bin no=19 f. d.= 18	bin no= 40 f. d. = 39
Kamio-kande	0.45	χ^2=10.7 s. p.=0.55	χ^2=12.0 s. p.=0.85	χ^2=21.4 s. p.=0.99
Motto (a)	0.27	χ^2=2.14 s. p.= 1.0	χ^2=3.60 s. p.= 1.0	χ^2=12.51 s. p.= 1.0
Gauss (a)	0.27	χ^2=15.67 s. p.= 0.21	χ^2=17.17 s. p.= 0.51	χ^2=26.09 s. p.=0.94
Motto (b)	0.32	χ^2=14.06 s. p.= 0.30	χ^2=15.50 s. p.= 0.63	χ^2=24.40 s. p.= 0.97
Gauss (b)	0.32	χ^2=15.36 s. p.= 0.22	χ^2=16.81 s. p. = 0.54	χ^2=25.73 s. p.= 0.95

and that of the broken distribution with 510.3 for the same degree of freedom. It indicates that the goodness-of-fit of our distribution is better than that of the EGS distribution.

4 Comparisons of the energy and angular distributions of scattered electron by ^{8}B between our and Kamiokande's calculations

Following to the Kamiokande procedures, we calculate differential total energy distribution of scattered electrons by ^{8}B solar neutrinos which is predicted by the SSM of Bahcall and Ulrich[3]. For the calculations, we used Fig. 3.1 of the Kamiokande paper[9] for the ^{8}B solar neutrino spectrum and Fig. 3.2 of the same paper for the scattered electron kinetic energy spectrum by ^{8}B solar neutrinos in order to have exact comparisons between calculated energy and angular distributions obtained by us and by Kamiokande's group. For comparing our calculated energy distribution of scattered electrons with the Kamiokande measured result, it must be taken into considerations of the trigger efficiency for electron energies and effects of the energy resolution of $22/\sqrt{E_e(\mathrm{MeV})}/10\%$ in the energy measurements. These are cited from their paper[11]. The energy distribution obtained by our calculation is shown by histogram in Fig. 3 together with the Kamiokande calculated and measured results. From the figure, it seems that our distribution is higher than the Kamiokande distribution with a factor of about 50%, keeping to have the almost same percentage value for all the region of electron energies, despite that it is obtained from the same scattered electron spectrum by ^{8}B solar neutrinos. Also, we calculated angular distributions (histogram) for $E_e \geq 7.5$ MeV using Motto and Gauss formulae based on the standard solar model and compared them with the Kamiokande's same distribution that are shown in Fig. 4. The figures (a) and (b) show comparisons of our angular distribution using the electron energy distributions in Fig. 3 obtained by us and by Kamiokande, respectively, with the measured Kamiokande data for $E_e \geq 7.5$ MeV which have been published in ref.(2). From the comparisons, we can get respective relative flux value to each prediction of the standard solar model for Kamiokande's and our calculations. The values for relative flux/SSM are given in Table 2 together with their significance probabilities which are obtained by using Brandt-Snedecor's formula in the maximum likehood estimation. From the comparisons, it may be concluded that the case of Motto formula for scattered electrons using our calculated electron energy spectrum can give the best significance probability.

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