The Analysis of Fully Contained Events and Partially Contained Event in the Virtual Super-Kamiokande and Neutrino Oscillation Problems

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Abstract

We have constructed a virtual Super-Kamiokande in the computer and have obtained both virtual electron events and muon events for [Fully Contained Events] and [Partially Contained Events] . We have constructed zenith angle distributions for both electron events and muon events. We compare our data from the numerical computer experiment with real data from Super-Kamiokande and discuss possibility of neutrino oscillation.

1. Introduction

Among similar experiments on neutrino oscillation, experimental results by Super-Kamiokande (SK, hereafter) has special status, confirming the discovery of neutrino oscillation between muon and neutrino [1]. It is said that [a] SK has succeeded in completing discrimination procedure between electron (neutrino) and muon (neutrino) by the beam of the KEK 12 Gev proton synchrotron [2], [b] they have applied this discrimination procedure for the analysis of [Fully Contained events] and [Partially Contained Events], finding significant muon deficit through the analysis of zenith angle distribution of muon like event which lead the set of parameters for neutrino oscillation of $\sin^2(2\theta) = 1.0$ and $\Delta m^2 = 3.2 \times 10^{-3} eV^2$,[c] the analysis of [Upward Through Going Muon Events]and [Stopping Muon Events] leads neutrino oscillation with same parameters .

As SK is the monopolistic experiment, the results obtained by SK should be carefully examined by any other means. The most meaningful examination to

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SK is to reproduce the SK's results to be examined. In this meaning, we have constructed the virtual SK apparatus in the computer and have produced virtual physical events concerned both inside and outside the virtual SK. Namely, we have performed numerical computer experiment for reproducing physical events concerned to examine the validity of the Sk assertion.

We have followed logics essentially adopted by SK. At first, we have developed the discrimination procedure between electron (neutrino) and muon (neutrino). The second, we have analyzed , neutrino events produced in the SK, namely, both [Fully Contained Events] and [Partially Contained Events]. The third, we have analyzed neutrino events produced outside the SK, namely, both [Upward Through Going Muon Events] and [Upward Stopping Muon Events].

We have examined the estimator for particle (electron or muon) identification adopted by SK by making numerical computer experiment. As the result of it, we have clarified that the SK estimator for particle identification never guarantee to separate electron from muon so well due to lack in the sense of fluctuation and have proposed alternative approach to reasonable discrimination between neutrinos [3].

Also, we have analyzed [Upward Through Going Muon Events] and [Stopping Muon Events] and have clarified that we could not assert the existence of neutrino oscillation between muon neutrino and tau neutrino [4]

2. Algorithm for analysis of [Fully Contained Events] and [Partially Contained Events]

In present paper, we have carried out the numerical computer experiments as exactly as possible, following the SK procedure. We have constructed the virtual SK detector in the computer, the scale and configuration of PMTs of which are as same as real SK. The algorithm for analysis is as follows:

2.1. The construction of the Neutrino Interaction Probability

Let us θ, zenith angle of the neutrino concerned which is produced in the atmosphere opposite to the Earth from the detector. The neutrino with different zenith angle arrive at the plane AB (in Figure1) after it traverses through different regions with different density, ρ_i . The survival probability for the neutrino with both energy of E at the plane AB and with zenith angle θ , is given as,

$$P_{sur}(E_\nu, t, cos(\theta)) = \left(1 - \frac{dt}{\lambda_1(E_\nu, t_1, \rho_1)}\right) \times \left(1 - \frac{dt}{\lambda_2(E_\nu, t_2, \rho_2)}\right) \times \cdots$$

$$\cdots \times \left(1 - \frac{dt}{\lambda_n(E_\nu, t_n, \rho_n)}\right) \tag{1}$$

, where

$$\frac{1}{\lambda_i(E_\nu, t_i, \rho_i)} = \frac{1}{\lambda_{i,dis}(E_\nu, t_i, \rho_i)} + \frac{1}{\lambda_{i,qel}(E_\nu, t_i, \rho_i)}$$

and $\lambda_{i,dis}(E_\nu, t_i, \rho_i)$ and $\lambda_{i,qel}(E_\nu, t_i, \rho_i)$ denote mean free paths of neutrino for deep inelastic scattering and corresponding one for quasi-elastic scattering, respectively.

Here, we could define, $N_{int}(E_\nu, t, cos(\theta))dT$ the interaction energy spectrum of muon in the interval dT in the following :

$$N_{int}(E_\nu, t, cos(\theta))dT = N_{sp}(E_\nu, cos(\theta)) \times P_{int}(E_\nu, t, cos(\theta))dT \tag{2}$$

Here, $P_{int}(E_\nu, t, cos(\theta))$ denotes the neutrino interaction interaction probability which is given in the following.

$$P_{int}(E_\nu, t, cos(\theta))dT = \left(1 - \frac{dt}{\lambda_1(E_\nu, t_1, \rho_1)}\right) \times \left(1 - \frac{dt}{\lambda_2(E_\nu, t_2, \rho_2)}\right) \times \cdots$$

$$\cdots \times \left(1 - \frac{dt}{\lambda_{n-1}(E_\nu, t_{n-1}, \rho_{n-1})}\right) \times \frac{dT}{\lambda_n(E_\nu, t_n, \rho_n)} \tag{3}$$

Further, $N_{sp}(E_\nu, cos(\theta))$ denotes the atmospheric neutrino energy spectrum at the opposite surface of the Earth from the detector.

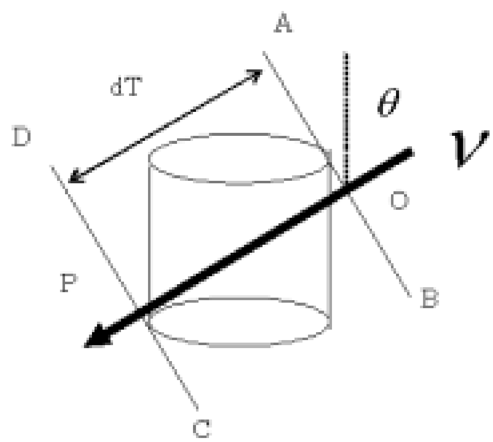

Fig. 1. Virtual SK.

2.2. *The determination of the interaction point of the neutrino concerned and the energy of the emitted particle. The determination of Fully Contained Events and Partially Contained Events*

Let us consider the following situation. The neutrino with zenith angle arrive at the plane AB in Figure 1 without interaction from the opposite surface of the Earth, the survival probability of which is given in (1). In other word, the neutrino concerned has the interaction probability in dT in Figure 1, which is given in (3). The interaction point distributes uniformly over dT. Therefore, we could decide whether the interaction point exist inside the detector or not and could decide the interaction pint accurately inside detector.

We could simulate, E_ν, the neutrino energy concerned by using the interaction energy spectrum (2) and ξ, the uniform random number between 0.0 and 1.0 in the following.

$$\xi = \frac{\int_{E_{min}}^{E_\nu} N_{int}(E_\nu, t, cos(\theta))dE}{\int_{E_{min}}^{E_{max}} N_{int}(E_\nu, t, cos(\theta))dE} \tag{4}$$

Further, we could decide the cause of the neutrino interaction, the deep inelastic scattering or quasi elastic scattering, by using the relation between the total mean free path of the neutrino and corresponding one for deep inelastic scattering (quasi elastic scattering) and the uniform random number.

Next, we simulate the energy of emitted electron or muon due to the neutrino interaction by using the following relation.

$$\xi = \frac{\int_{E_{min}}^{E_{e(\mu)}} D_{e(\mu)}(E_\nu, E_{e(\mu)})dE}{\int_{E_{min}}^{E_{max}} D_{e(\mu)}(E_\nu, E_{e(\mu)})dE} \tag{5}$$

,where $D_{e(\mu)}(E_\nu, E_{e(\mu)})$ denotes the emitted energy spectrum of electron or muon due to the deep inelastic scattering or quasi elastic scattering. Once the cause of the neutrino interaction , the energy of the emitted particle and the interaction point inside the detector , zenith and azimuthal angle are decided by using each probability function, the event concerned are pursued by the Monte Carlo method including the GEANT 3-21. Finally, the event concerned is decided whether it belongs to either [Fully Contained Events] and [Partially Contained Events].

3. Results

The following physical quantities are given. [a] The detailed zenith angle distribution of electron events in the cases of Fully Contained Event and Partially Contained Event. [b] Corresponding quantities of muon event to [a]. [c] The energy spectrum of electron events and muon events for each zenith angle in the cases of Fully Contained Events and Partially Contained Event.

4. References

1. Kameda J. et al. 2001, ICRC2001,5,1057
2. Kasuga,S. et al. 1996, Phys.Lett.B, 374,238
3. Anokhina et al. 2002,18th ECRS,HE44P
4. Takahashi Y et al. 2003, 58th Phys.Soc.Japan,31aSJ13