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The Relation between the incident neutrino energy spectrum and fundamental parameters for the neutrino oscillation

N. Takahashi[a] and A. Misaki[b]
(a) Faculty of Science and Technology, Hirosaki University, Hirosaki 036-8561, Japan
(b) Advanced Research Institute for Science and Engineering, Waseda University, Tokyo 169-0092, Japan
Presenter: N. Takahashi (taka@cc.hirosaki-u.ac.jp), jap-takahashi-N-abs1-he22-poster

In the sense of the traditional cosmic ray physics, the effective detection for the existence of the neutrino oscillation is reduced to the effective recognition for the incident neutrino energy spectrum with the neutrino oscillation. We discuss the relation between the incident neutrino energy spectrum and fundamental parameters through the analysis of the neutrino events occurred outside detector obtained by the computer numerical experiment.

1. Introduction

Superkamiokande group (hereafter, simply SK) analyze the zenith angle distribution and L/E distribution to verify the existence of the neutrino oscillation [1]. From the view point of the traditional cosmic ray physics, the examination on the neutrino oscillation is reduced to confirmation of the atmospheric neutrino energy spectrum with neutrino oscillation probability. It is indispensable and inevitable to utilize the MONTE CARLO method for the analysis of the neutrino oscillation. Without the introduction of the Monte Carlo method, we could do nothing. Therefore, careful examination of the validity of the Monte Carlo Method really utilized for the analysis is absolutely requested. We have carried out the computer numerical experiment for confirmation of the existence of neutrino oscillation under the adoption of neutrino oscillation parameter utilized by SK. As the result, our results shows that SK have not found the existence of the neutrino oscillation between muon and tau yet [2,3]. In this article, we show the zenith angle distribution of *Upward Through-Going Muon Events* and *Upward Stopping Muon Events* and L/E distribution for those Events by our Monte Carlo method, the essence of which is described in the paper [4].

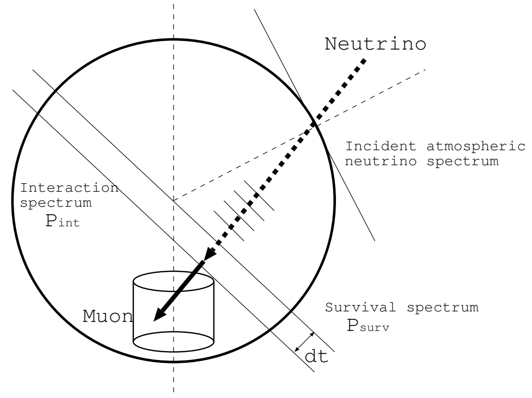

Figure 1. Schematic illustration of the experiment.

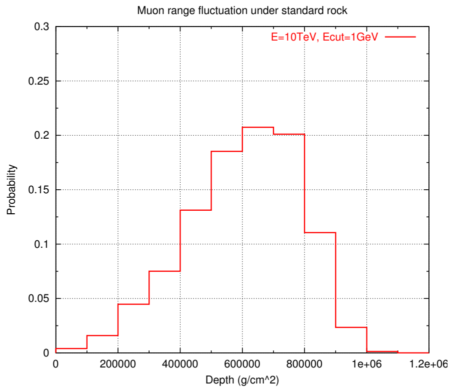

Figure 2. Range Energy Fluctuation of 10 TeV muons.

2. Monte Carlo Simulation Procedure

Our simulation (computer numerical experiment) should be called as Time Sequential Simulation, while SK simulation as Detector Simulation contrast to us. We start our simulation, which is schematically shown in Figure 1, with the atmospheric neutrino energy spectrum at the opposite side of the Earth to the detector. We utilize Honda's spectrum up to 10 TeV for incident neutrino [5], and therefore, the maximum energy of the muon emitted from the neutrino interaction, here, is 10 TeV. We calculated the range fluctuation of 10 TeV muon by the exact Monte Carlo Method, taking into account the physical processes concerned – bremsstrahlung, direct pair production, nuclear interaction and ionization - and show the results in Figure 2. It is clear from that the range of such a high energy muon is widely distributed and therefore, we should treat it in the stochastic manner. Also, we conclude from Figure 2 that it is sufficient to consider the neutrino events for *Upward Through-Going Muon Events* and *Upward Stopping Muon Events*, which are generated in the region within 10^6 g/cm^2 of the SK detector (less than 4 km), because neutrino interactions further than 4 km from the detector could not contribute physical events into the detector. Each individual produced from the neutrino event is pursued in a stochastic manner, taking into account the physical processes concerned. As the result, we determine which category each individual muon falls into : [a] stopping before it reaches detector, [b] stopping inside the detector, or [c] passing through the detector.

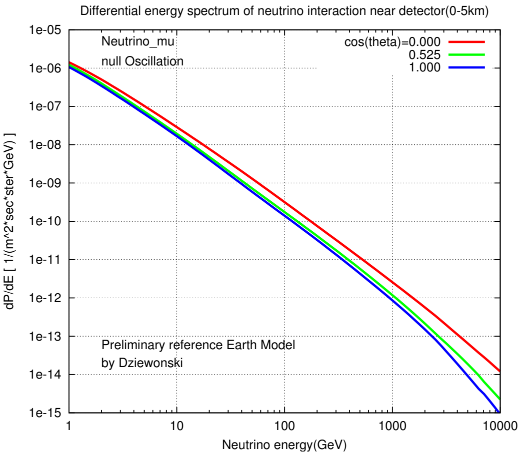

Figure 3. Interaction energy spectrum without neutrino oscillation.

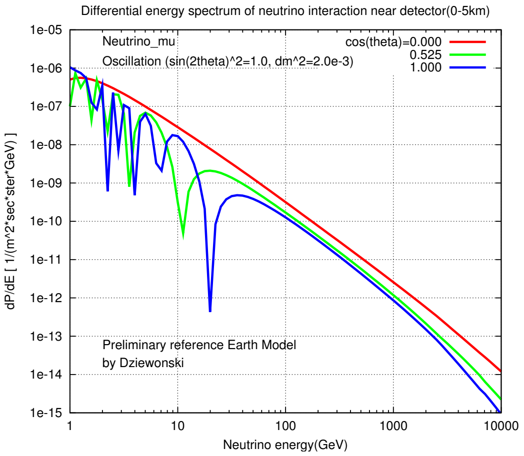

Figure 4. Interaction energy spectrum with neutrino oscillation.

In Figure 3 and 4, we give the interaction neutrino energy spectrum without, and with, neutrino oscillations. It is clear Figure 4 that effect of the neutrino oscillation for the SK parameters does not appear in the horizontal direction, $cos(\theta_\nu) = 0.0$, due to short path length for traversed neutrino while the effect clearly appears in the vertical case, $cos(\theta_\nu) = 1.0$. In our simulation, for a given zenith angle, $cos(\theta_\nu)$, we sample the energy of the incident neutrino from neutrino interaction energy spectrum which are given in Figure 3 and Figure 4. Whether the sampling procedure is carried out in correct way or not is of vital importance for precise simulation. As an example, the result for our sampling for $cos(\theta_\nu) = 0.525$ is given in Figure 5. The continuous curve represents the neutrino interaction energy spectrum with the SK neutrino oscillation parameters. The histogram shows the sampled result. The excellent agreement between them shows that our sampling is carried out in the correct way.

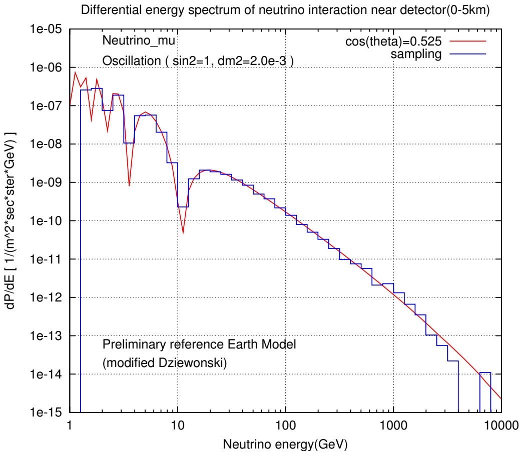

Figure 5. Sampled neutrino spectrum.

3. Results and Discussion

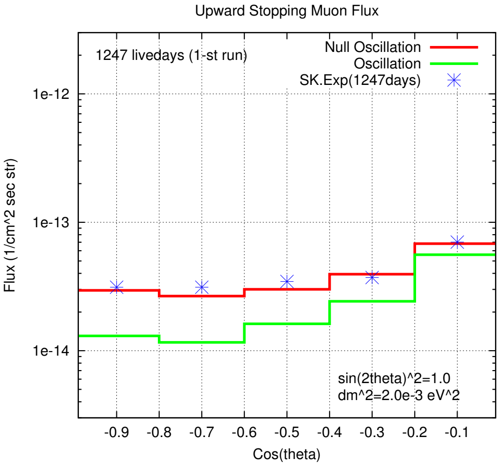

Figure 6. Zenith angle distribution of *Upward Stopping Muon Events*.

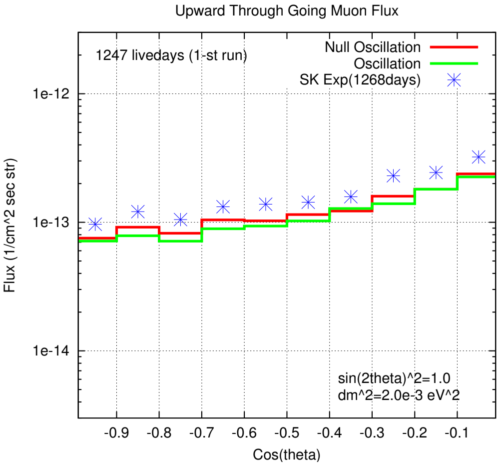

Figure 7. Zenith angle distribution of *Upward Through-Going Muon Events*.

In Figure 6, we give the zenith angle distribution for *Upward Stopping Muon Events* in the case of [with and without neutrino oscillation] together with SK experimental data. The agreement between SK experimental data and our numerical experimental results with null-oscillation seems to be nice. In Figure 7, we give corresponding results for *Upward Through-Going Muon Events*. It is easily understood from the figure that SK experimental result can coincide with our result without oscillation within the precision of 50%. Furthermore, it should be noticed from our numerical experiment that there is almost no difference between the zenith angle distribution without, and with, neutrino oscillation. Such small difference is, in some sense, natural. Because, from the definition of the *Upward Through-Going Muon Events*, the experimental condition imposed upon these events is to traverse the detector only and consequently, such a simple criterion makes it impossible the separation between them.

Compared Figure 6 with Figure 7, it is easily understood that the difference between [without and with] neutrino oscillation in *Upward Stopping Muon Events* is clearly larger than that in *Upward Through-Going Muon Events*, which reflects the difference in the quality of the experimental data between two different categories of the physical events. Namely, the quality of *Upward Stopping Muon Events* as experimental data is better than that of *Upward through-Going Muon Events*.

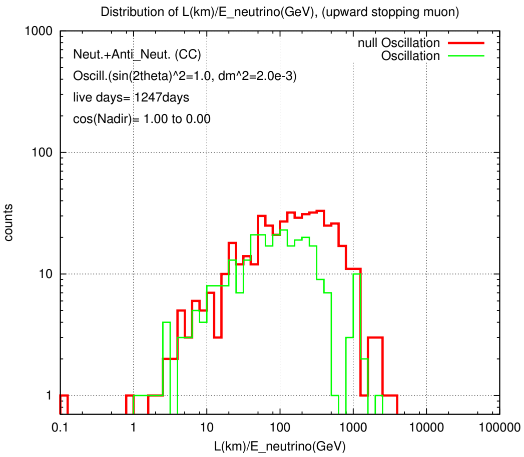

Figure 8. Distribution of L/E_ν for *Upward Stopping Muon Events*.

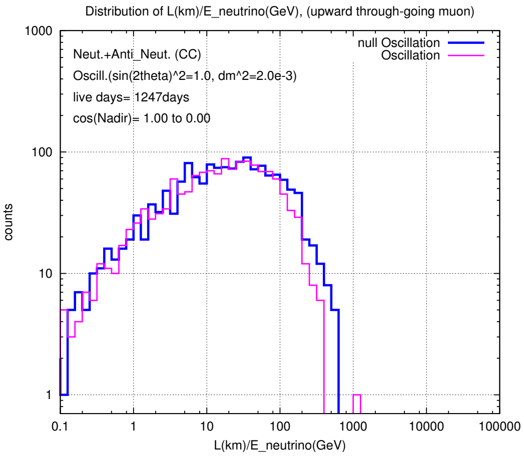

Figure 9. Distribution of L/E_ν for *Upward Through-Going Muon Events*.

In our Monte Carlo simulation, we could obtain the L/E distribution for *Upward Stopping Muon Events* and *Upward Through-Going Muon Events*, too. In Figure 8 , we give L/E distribution for [without, and with] neutrino oscillation for *Upward Stopping Muon Events*. In Figure 9, we give corresponding ones for *Upward Through-Going Muon Events*. Compared with [Figures 6 and 7] with [Figures 8 and 9], we could find similar tendencies between them, as they must be. In Figure 8, we could find gap around the region 560 Gev/km for the case of neutrino oscillation (green histogram), which correspond to $P(\nu_\mu \longrightarrow \nu_\mu) = 0$, where $P(\nu_\mu \longrightarrow \nu_\mu)$ denotes the probability for the existence of the neutrino oscillation. From the Figure 8, we could predict that the effect of the neutrino oscillation becomes clear in the region where L/E is larger than about 100, if the neutrino oscillation really exists. However, we could almost exclude the existence of the neutrino oscillation from Figure 7. Therefore, the existence of the gap in Figure 8 shows the fact that we surely sample neutrino events correctly as shown in Figure 5.

References

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