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Simulation calculations around the discrimination of electron neutrinos from muon neutrinos in the Superkamiokande

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Abstract. Superkamiokande people asserts that electron neutrinos could discriminate almost from muon neutrinos without no ambiguity in the analysis for neutrino oscillation. We have made simulation calculations on the Cherenkov lights from cascade showers originated in electron neutrinos and from muon neutrinos for the virtual detector with the same size as Superkamiokande, and examined the discrimination between electron neutrinos and muon neutrinos.
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1 Introduction

Through examination on the Superkamioknade's papers (Fukuda et al. 1994; Fukuda et al. 1998), we have understood that they are never interested in the concept of the stochastic fluctuation in their discussions. They analyze physical events in terms of the average values. All the interactions due to elementary particles are, however, of stochastic natures and they have distributions around their average value. Such stochastic characters of physical events should be considered in the analysis of physical events, particularly in the case of rare events, such as neutrino events from cosmic ray.

The present paper is our first paper in which stochastic character of physical events is examined elaborately related to the Superkamiokande. We simulate the total structure of the Superkamiokande in our imaginary laboratory, that is, in the computer. We have simulated the Cherenkov lights from electron primary cascade showers (electron neutrinos) and the muons (muon neutrinos) for the virtual detector with the same size and the same arrangement of PMT (photo multiplier tube) as the Superkamiokande detector.

2 Method of Simulation

We use GEANT3 (CERN, 1993) software system for the purpose of our simulation instead of GEANT4, the revised edition of GEANT3. Because GEANT3 is essentially free from bug, while we are afraid a little that GEANT4 may have bugs that may cause troubles in our calculation.

We pursue the electrons in cascade showers down to 0.764MeV and muons down to 158.23MeV, respectively, which are the thresholds for emitting Cherenkov light in water.

3 Results

3-1 What do you mean 1.33 GeV?

Superkamiokande people mentions to numeral 1.33GeV. They classify events whose energies are less than 1.33GeV as Sub-GeV events, while they classify events whose energies are greater than 1.33GeV as Multi-GeV events (Fukuda et al. 1994; Fukuda et al. 1998). What is the meaning of 1.33GeV? We simulated Cherenkov lights from electrons and muons with energies 1.32, 1.33 and 1.34GeV, and superimposed the total detected photon number distributions as shown in Figures 1 and 2. We can easily find from these figures that the distributions overlap each other and it is

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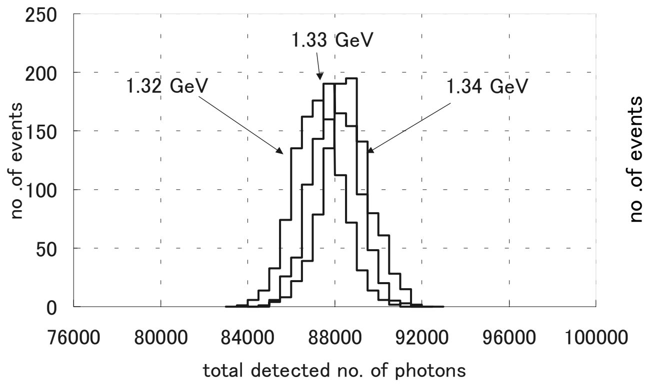

Fig.1 Total number distributions of detected Cherenkov lights emitted from cascade showers produced by electrons with energy 1.32, 1.33 and 1.34 GeV. Sampling numbers are 1000, respectively.

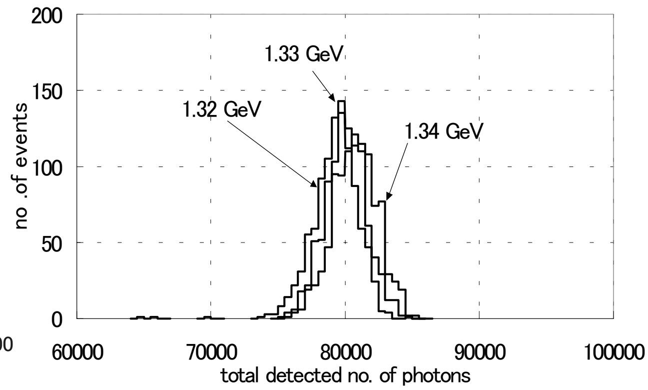

Fig.2 Total number distributions of detected Cherenkov lights emitted from muons with energy 1.32, 1.33 and 1.34 GeV. Sampling numbers are 1000, respectively.

separately in these energies, 1.32, 1.33 and 1.34GeV. Then what energy resolutions do electrons and muons have? We give the separated Cherenkov lights distributions with 1.26, 1.33 and 1.40GeV for electrons, in Figure 3, and with 1.23, 1.33 and 1.43GeV for muons, in Figure 4. The width of Cherenkov light number distribution does not come from experimental error, but comes from stochastic nature of the interactions of electrons or muons and of the mechanism emitting the Cherenkov light. We could say that numeral 1.33 (GeV) is meaningless from Figures 3 and 4, and we should say at most that the boundary energy is 1.3GeV to discriminate Multi-GeV events from Sub-GeV ones. Of course, such boundary energy has no physical meaning, it has nothing more than conventional meaning.

In Figures 5 and 6, we give the separated Cherenkov lights distributions around 5GeV, namely, with 4.85, 5.00 and 5.15GeV for electrons in Figure 5, and with 4.80, 5.00 and 5.20GeV for muons in Figure 6.

Through Figures from 1 to 6, we calculate the Cherenkov light for fixed incident energies, say 1.32GeV, 1.33GeV or so. Now we calculate for the case of distributed incident energy, and pick up events with condition being Cherenkov light number within a fixed interval and compose the incident energy distribution. In Figures 7 and 8,

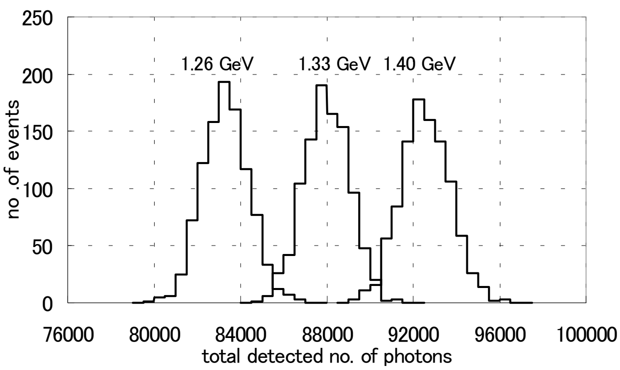

Fig.3 Total number distributions of detected Cherenkov lights emitted from cascade showers produced by electrons with energy 1.26, 1.33 and 1.40 GeV. Sampling numbers are 1000, respectively.

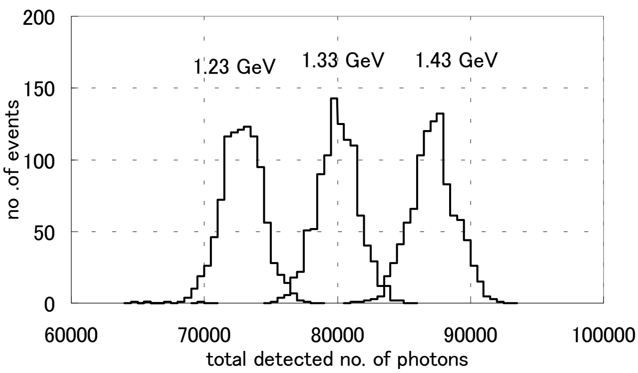

Fig.4 Total number distributions of detected Cherenkov lights emitted from muons with energy 1.23, 1.33 and 1.43 GeV. Sampling numbers are 1000, respectively.

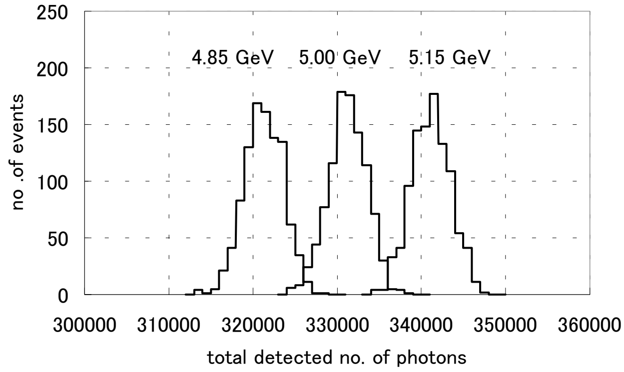

Fig.5 Total number distributions of detected Cherenkov lights emitted from cascade showers produced by electrons with energy 4.85, 5.00 and 5.15 GeV. Sampling numbers are 1000, respectively.

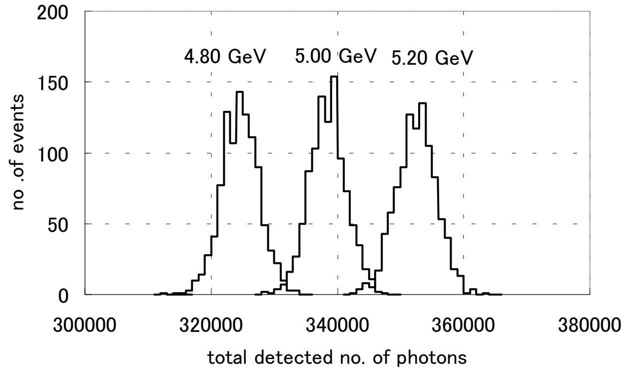

Fig.6 Total number distributions of detected Cherenkov lights emitted from muons with energy 4.80, 5.00 and 5.20 GeV. Sampling numbers are 1000, respectively.

incident energy of electrons or muons distribute from 0.9 to 1.1Gev uniformly, and events picked up have Cherenkov light number within the range from <y>-2SD to <y>+2SD, where <y> is mean number and SD is standard deviation of Cherenkov light for electrons or for muons at 1GeV (about <y> and SD see Figs.9 and 10 also). Figure 7 shows incident energy distribution of thus picked up electrons and Figure 8 shows that of muons. It is understood from these figures that the uncertainty of incident energy determination of muon is a little greater than that of electrons that are coming from stochastic fluctuations.

3-2 Could we discriminate electron neutrino from muon neutrino well on the viewpoint of total Cherenkov light?

We simulate the Cherenkov light from both electrons and muons assuming that particles are incident vertically on to bottom of the detector. Averaged total Cherenkov lights both from muons and electrons are given in Figure 9, with energies ranging from 200MeV to 1000GeV. It is easily understood from the figure that we could not discriminate electrons from muons in energy region from 1 to 10GeV. It should be noted furthermore that the total Cherenkov light number

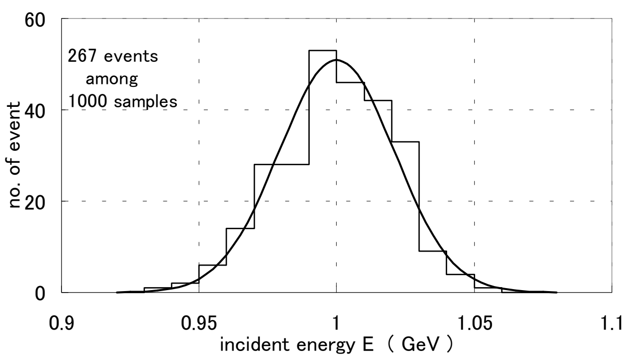

Fig.7 Distribution of the incident electron energies with conditions that total number of detected Cherenkov lights are within the range from <y> -2SD to <y>+2SD at 1 GeV (solid line, <y> = 66071, SD = 886). Solid curve shows normal distribution fitting with mean = 1.000 GeV and standard deviation = 0.021 GeV.

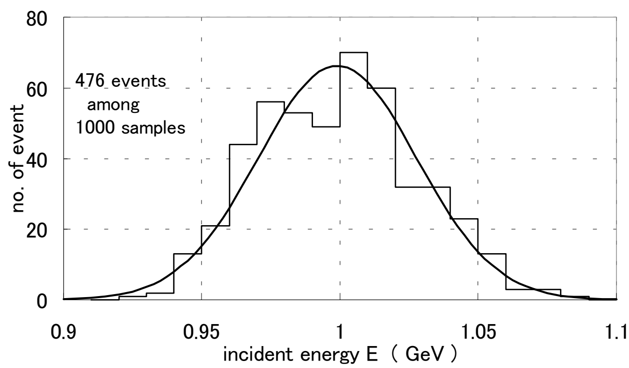

Fig.8 Distribution of the incident muon energies with conditions that total number of detected Cherenkov lights are within the range from <y> -2SD to <y>+2SD at 1 GeV (solid line, <y> = 56135, SD = 1567). Solid curve shows normal distribution fitting with mean = 0.999 GeV and standard deviation = 0.029 GeV.

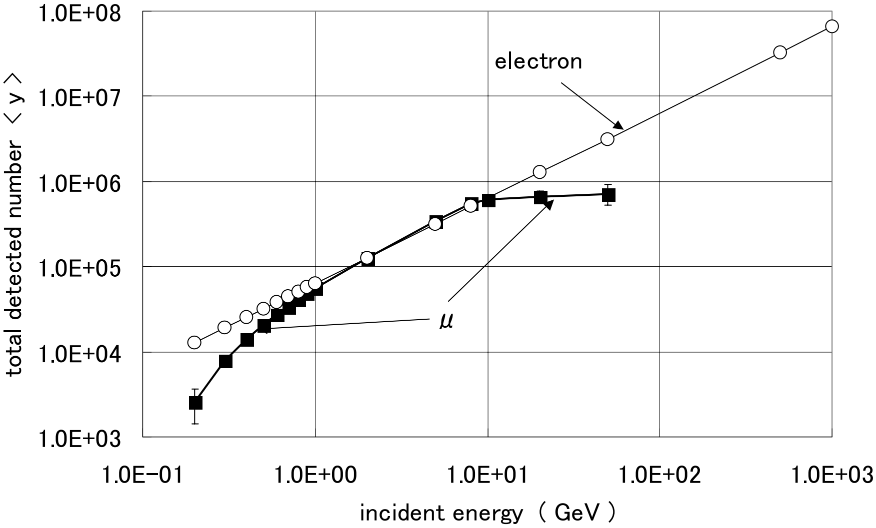

Fig.9 Averages of total detected Cherenkov light numbers, <y>, emitted from cascade electrons produced by incident electrons (white circles) and from muons (black squares) in the form of incident energy dependence. Error bars attached to muon plots show standard deviations.

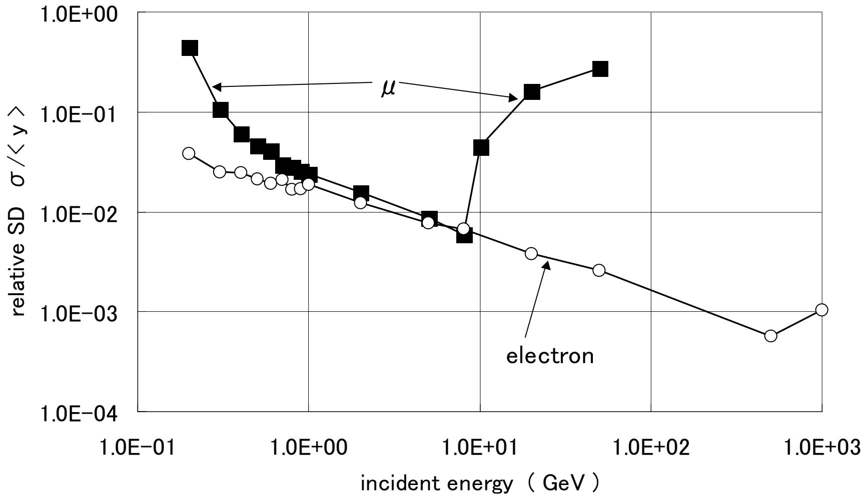

Fig.10 Relative standard deviations of total detected Cherenkov light numbers, SD/<y>, emitted from cascade showers produced by incident electrons (white circles) and from muons (black squares) in the form of incident energy dependence.

saturates above 8GeV because muons with energy greater than 8GeV pass through the detector. Namely, the maximum energy for muons is 8GeV or so if we interested primarily in fully contained events. It is possible that we expect fully contained events for electrons up to 1000GeV from Figure 9, however this theoretical maximum energy is strongly restricted due to the saturation of electronic circuit and PMT. The maximum energy is several ten of GeV for the electron fully contained event at most. In other words, we should say that the energy region covered with the Superkamiokande for fully contained event is rather small, say; 200MeV to several GeV, and more accurate studies on atmospheric neutrino interaction are expected in this energy region.

We give information on stochastic fluctuations in total Cherenkov light, in Figure 10, in the form of relative standard deviation energy dependence for both electrons and muons. It is easily understood that we could not discriminate electrons from muons from the viewpoint of the stochastic fluctuation. Judging from Figures 9 and 10, it is not so easy to discriminate definitely electron neutrinos from muon neutrinos not only from the average value but also from stochastic fluctuation of the Cherenkov light number. For the establishment of the definite discrimination of electron neutrinos from muon neutrinos, we need extensive examinations on various physical quantities related to stochastic natures of electrons and muons.

References.

Fukuda,Y et al., *Phys.Lett.B335* (1994) 237-245

Fukuda ,Y et al., *Phys.Lett.B436* (1998) 33-41