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Cherenkov Radiation from the Three –Dimensional Cascade Shower for Electron Neutrino

N.TAKAHASHI[1], I.NAKAMURA[2], A.MISAKI[3]
[1]*Department of Advanced physics,Hirosaki University,Hirosaki,Japan*
[2]*Molecular Analysis and Life Science center,Saitama University ,Saitama,Japan*
[3]*Reserch Institute for Science and Technology,Waseda University,Tokyo,Japan*
misakiakeo@air.ocn.ne.jp

Abstract: In high energy neutrino astrophysics experiment, such as, NT-2000,AMANDA, ANTARES, we could get reliable information on electron neutrino events than that on muon neutrino due to muon, because the electron cascade showers due to the electron neutrino events are recognized as *Fully Contained Events,* while, the muon neutrino events are done as *Partially Contained Events* exclusively. We calculate the three-dimensional structure of the Cherenkov radiation from the one dimensional cascade shower, by using the exact Monte Carlo method which are expected to be available for the reliable analysis of the electron neutrino events as the first step of construction from the three-dimensional cascade showers.

Introduction

Following the terminology adopted by Super-Kamiokande, the neutrino events detected in high energy neutrino astrophysical experiments, such as, NT-2000 AMANDA, ANTARES and so on([1]) , are classified as, *Fully Contained Events, Partially Contained Events, Stopping Muon Events* and *Upward Through Going Muon Events Fully Contained Events* among these events are regarded as the most qualified ones from which we could derive more ambiguity-free interpretation to neutrino events.

From such the point of view, we should be more interested in the neutrino events initiated by electron neutrino in high energy neutrino astrophysics experiment. Because the electron neutrino events are recognized as Fully Contained Events even up to 10^{20}eV even for the presence of the LPM effect in the scale of 1cubic kilometer experiment, while we could not recognize muon neutrino as Fully Contsained Events beyond $5\text{x}10^{11}$eV. In the presence of the LPM effect, the distance for total absorption of the cascade shower with 10^{21} eV attain at about 2 kilometer ,which are not recognized as the Fully Contained Events([2]).

Three-dimensional treatment to cascade shower

Three-dimensional treatment to the cascade showers are absolutely necessary for the accurate determination for the primary energy of the cascade showers and their arrival direction for the incident electron neutrinos. However, here, first of all, we treat the cascade shower in one-dimensional way, although the emitted angle of the Cherenkov radiation is taken into account, because the one-dimensional treatment of the cascade shower is the basement on the three-dimensional treatment one in future.

Here, we treat the cascade shower within the framework of Approximation A ([3]), because, for the moment, it is enough for clarifying quantitative characteristics of the Cherenkov radiation from the electron showers

We treat rigorously Cherenkov radiation due to shower particles under the one-dimensional development of the shower by the exact Monte Carlo method. The lateral distribution of the Cherenkov light thus obtained should be compared the corresponding ones under the three-dimensional treatment of the cascade shower in future.

As for the three-dimensional treatment to the electron cascade showers in subsequent paper, we adopt the Shibata-Okamoto formalism [4]. They extend the procedure for the correlated angular-lateral distribution function due to the multiple scattering developed by Eyges [5] to the case with ionization loss.

The BH showers and LPM showers

We calculate the lateral distributions of the Cherenkov radiation from both the BH showers and the LPM showers by the exact Monte Carlo method in order to obtain the ambiguity free data on the fluctuation. We compare the quantities derived from the BH shower with that of the LPM shower and try to find the proper characteristics of the LPM showers for future gigantic experiment for extremely high energy neutrino astrophysics experiments. In order to obtain the lateral distribution of the Cherenkov radiation which is available for the analysis of the experimental data, we must follow shower particles down to 1 MeV. However, for the moment, it is impossible to carry out such Monte Carlo simulation. Therefore,we put higher threshold energy, say , 10^{15}eV for the primary energy 10^{21}eV to extract the characteristics of the lateral distribution of the Cherenkov radiation in the LPM shower, compared with that of the BH showers.

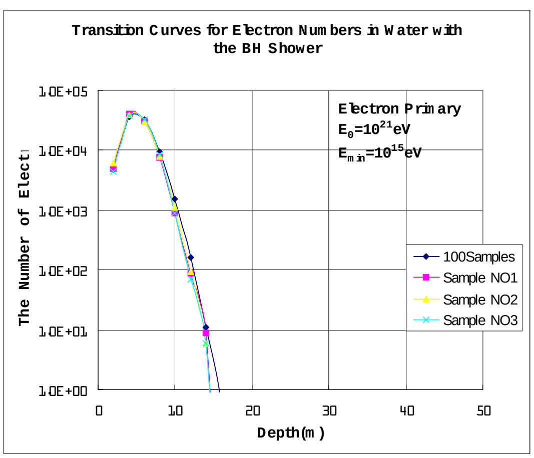

Figure 1

In Figure 1, we give the transition curves for electrons in the BH showers. Three individual showers are given together with the averaged one obtained by 100 showers. It is clear from the figure that the fluctuation is pretty small and even one sampled shower represents approximately the averaged one.

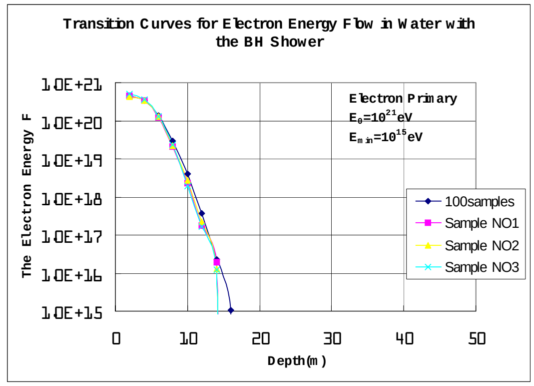

Figure 2

In Figure 2, the transition curves for electron energy flows are given in the corresponding showers. Fluctuation in the energy flow is also pretty small, too.

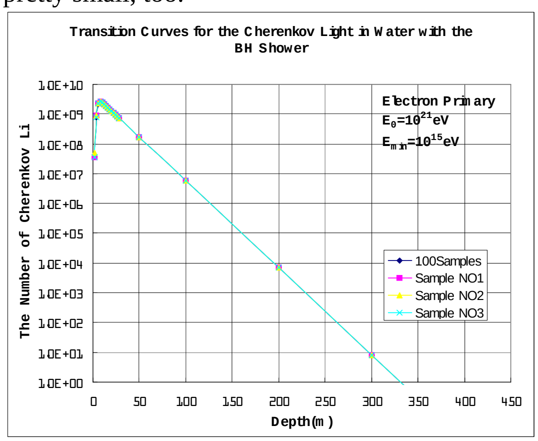

Figure 3

In the calculation of the Cherenkov light, we simulate the electron segments of the electrons as exactly as possible from which the Cherenkov light are generated. In Figure 3, we give the longitudinal development of the total Cherenkov light. Reflecting small fluctuation on the electron number in a cascade shower, the fluctuation in the Cherenkov light is rather small. In Figure 4, we give the lateral distribution of the Cherenkov light for different observation depths. Except 10m depth, the observation depths for the Cherenkov light are outside the extensions of the cascade showers concerned are far from them except 28 meter observation point . Therefore, their longitudinal extensions could be approximated as points for them.

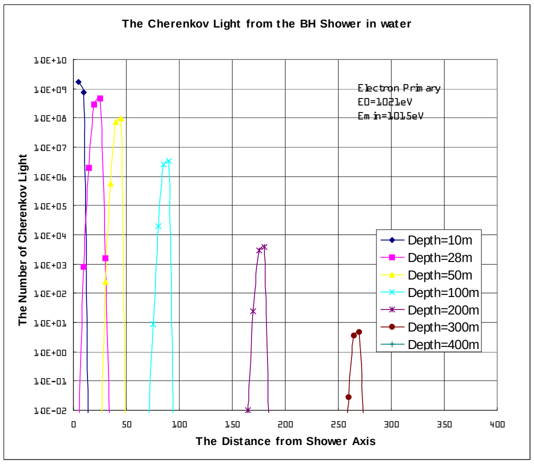

Figure 4

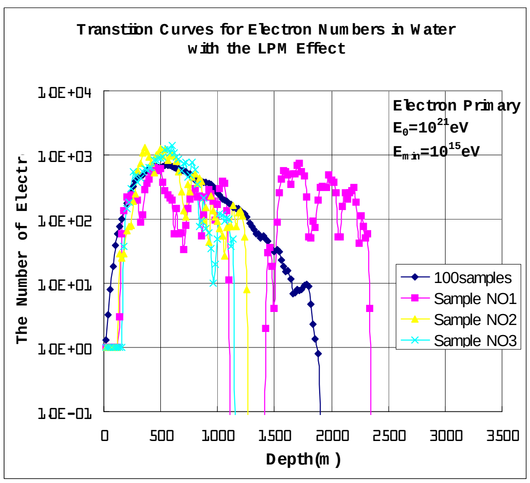

Figure 5

For the comparison with the BH showers, we discuss the situation around the LPM showers.

In Figure 5, we give the transition curves for electron numbers for three individual cascade showers together with the averaged ones from 100 sampled showers. It should be noticed from the figure that their fluctuation is too big, compared with that of the BH shower(see, Figure 1) and their extensions are too large. In Figure 6, we give the corresponding energy flow of the electrons. In Figure 7, we give the longitudinal development for the total Cherenkov light in the LPM showers. Their variety should be emphasized. In Figure 8, the lateral distributions for the Cherenkov light are given in shower to shower and they are largely different in shower to shower, reflecting the big difference in their shower developments. In Figure 9, we give the averaged lateral distributions for the Cherenkov light for the different observation depths. It is easily understand that from the comparison of Figure 4 with Figure 8 that the lateral distribution for the Cherenkov light due to LPM showers spread far widely than due to BH shower. Also, it is clear

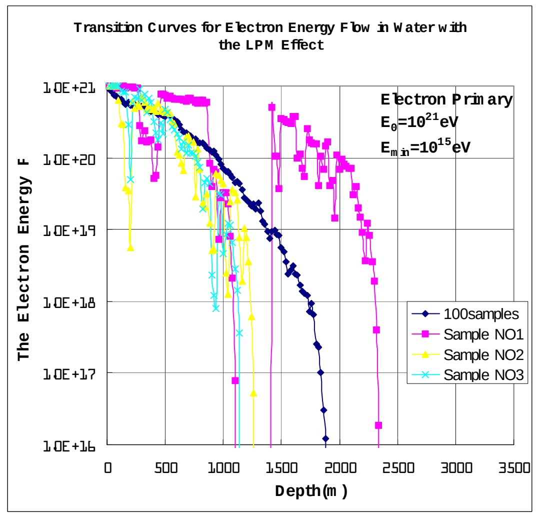

Figure 6

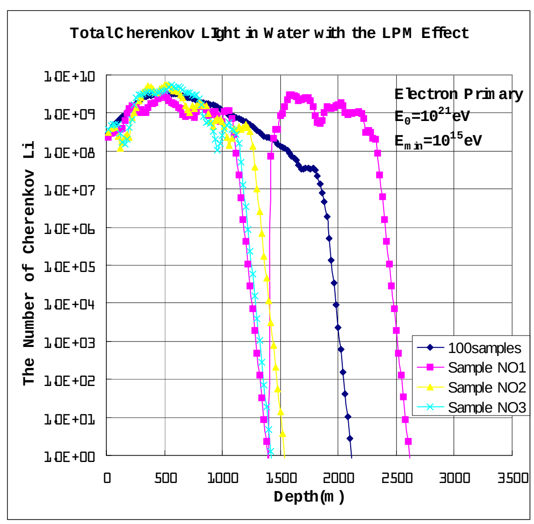

Figure 7

from the comparison of Figure 8 and Figure 9 that individual lateral distribution for Cherenkov light due to LPM shower is largely different the averaged one.

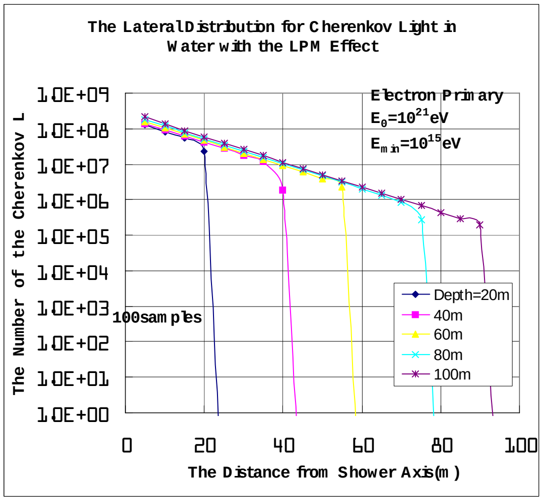

Figure 8

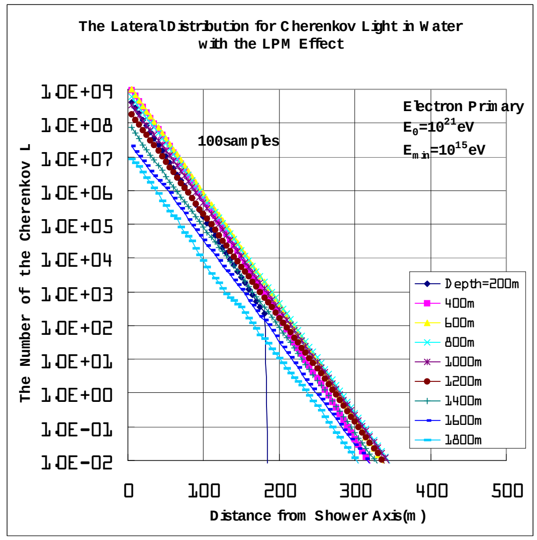

Figure 9

Conclusion

For the practical application of our results to the analysis of the real experiments in future, our calculations should be extended to lower shower particle energies, say, the threshold energy of the Cherenkov light. However, it should be emphasized that the essential feature of the multi-peak structure of the LPM shower never diminish, even if we take into account of the shower particles with far lower energies where the LPM effect is completely neglected ([6]). It should be noticed that we do not include the effect on the decrease of the Cherenkov light due to electron pair coming from the cancellation effect of their electromagnetic field ([7]). For the qualitative estimation of the Cherenkov light from the LPM shower, this effect should be included. Also, for the practical application of the LPM showers to the analysis of the experiment, the three-dimensional treatment to the LPM shower is necessary.

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