

The Energy Determination for the High Energy Muon in the Large Volume Detector for High Energy Astrophysics

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Abstract: This paper is a preliminary study for seeking the reliable method in future by which we could determine the direction of the high energy muon accurately. As the high energy muons are inevitably accompanied by the aggregation of d electron showers, we need detailed knowledge on the three-dimensional cascade showers for the reliable determination for the direction of the high energy neutrino events.

Introduction

There are two fundamental parameters which play essential roles in the analysis of high energy neutrino astrophysics experiment, such as, NT200+, AMANDA, ANTARES, NESTOR and ICE CUBE, the scale of which may exceeds over 1kilometer in future. One is the energy of the neutrino event concerned and the other is its direction. For the moment, electron neutrino events and muon neutrino events are the usual candidates to be carefully examined. Both electron neutrino events and muon neutrino events have advantages and disadvantages in their analysis. Electron neutrino events are regarded as *Fully Contained Events* up to 10^{20} eV even in the presence of the LPM effect [1] but it is rather difficult to determine their direction without detailed understanding the three-dimensional structure of the electron showers. On the other hand, the muon neutrino events are regarded as the *Partially Contained Events* exclusively at 5×10^9 eV even in 1 cubic kilometer detectors due to their longer paths of high energy muons, but one claim to determine their direction reliably, utilizing their long path. However, it is not so easy task to determine the direction of muon neutrino events reliably, even if one could utilize their longer paths,

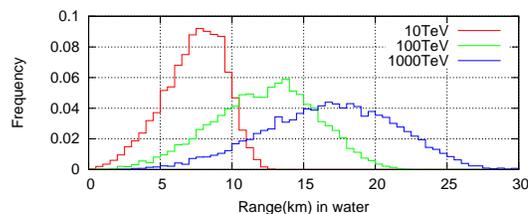


Figure 1: Range fluctuation of muon with 1TeV to 1000TeV

because of their complicated stochastic structure due to accompanied electron shower. In the present paper, we examine the uncertainty in the behavior of higher energy muons which are produced by the muon neutrino events

Range Straggling of High Energy Muon

The behaviors of high energy muons are influenced by the fluctuation effect in their energy loss which come from bremsstrahlung, direct electron pair production and nuclear interaction due to the muon.

In Figures 1, we give the range fluctuation of muons with different primary energies. As seen in

the figure, we find stronger fluctuation in the track lengths of muons as increase of their primary energy. It should be noticed that the muons which have shorter range smaller than their average range may be influenced by catastrophic energy loss due to either bremsstrahlung or nuclear interaction.

As track lengths of the muons are proportional to total Cherenkov light due to muons themselves. However, total energies of the original muons are determined from the measurement of the summation of the Cherenkov light due to muons themselves and total Cherenkov light from accompanied electron showers which muons concerned produce. It is, however, impossible to separate the Cherenkov light due to muons themselves from the corresponding ones due to all electron showers produced by muons concerned. Therefore, it seems rather difficult to determine the direction of the high energy muon reliably, if we have not enough information for the three-dimensional structure on the electron shower.

Track lengths due to muon and those due to all electron showers which are produced by muons concerned

High energy muons travel through the detector, being surrounded with "electron cloud" (electron showers due to muon). As the energy of the muon due to muon neutrino event increases, a number of electron showers due to direct electron pair production, bremsstrahlung and nuclear interaction are twining around the muon which are also origin of the Cherenkov light. As the Cherenkov light generated due to muon is proportional to the total track lengths above the threshold energy for the Cherenkov light from both the original muon and electron showers due to the muon concerned.

In Figure 2, the transition curves for the integral of the track length of the muons are given up to 2.5 km. We understand almost muons with 10 TeV or more could survive up to 2.5 km. In Figure 3, the transition curves for the differential electron track lengths are given. The decrease of the track length for 1 TeV muons above 1000 meters denotes that pretty number of the muons concerned "die" so that they could not produce electron showers any more. Higher differential track lengths corre-

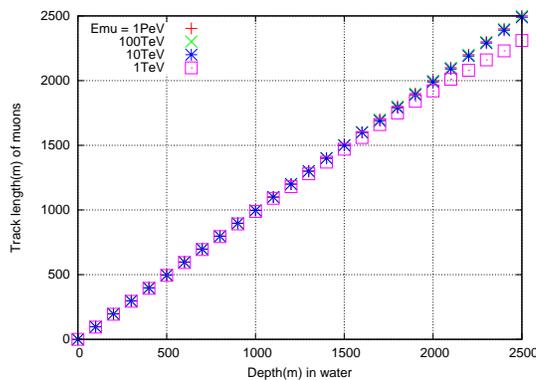


Figure 2: The transition curves for the integral of the track lengths from muon. Sampling number is 100.

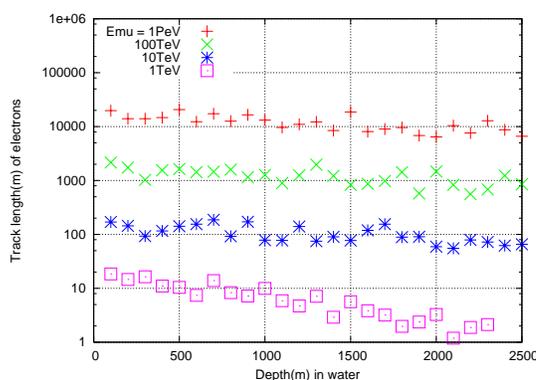


Figure 3: The transition curve for the differentials of the track lengths from electron showers. Sampling number is 100.

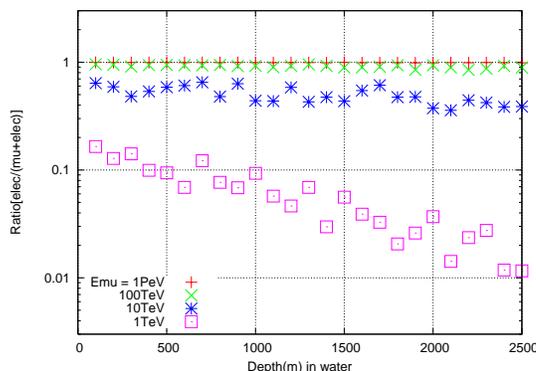


Figure 4: The transition curves for ratio of the track length due to electron shower to the total track length from electron showers and muon. Sampling number is 100.

spond to the occurrence of electron showers due to bremsstrahlung or nuclear interaction. "normal" differential track lengths correspond to the occurrence of electron showers due to direct pair production.

In Figure 4, Ratio of track length due to electron showers to total track length both muons and electron showers are given. We could understand muons with 1 TeV radiate Cherenkov light through the muon, while muons with 10 TeV radiate 80 % of total Cherenkov light through electron showers and muons with 100 TeV or more radiate the Cherenkov light exclusively through electron showers, where the contribution from muons concerned are practically negligible.

Examples of behavior of individual muons with different primary energies

In Figure 5, we give an example of individual behavior of muon with 1 TeV where and with what reason the muon concerned loses its energy. In this energy region, the muon loses its energy essentially through direct electron pair creation.

In Figure 6, individual behavior of the muon with 10 TeV is given. We could see non-negligible energy loss is caused by the bremsstrahlung. In Figure 7, one example with 100 TeV is given which indicate catastrophic energy loss, ending shorter range. For comparison with Figure 7, we give another example with 100TeV(Figure 8), which has longer range, losing energy in moderate way. In Figure 9, one example with 1000TeV run far longer than the average range (17 km) which lose its energy gradually.

Conclusion

Muon events with energies larger than 500GeV essentially are recognized as *Partially Contained Events*. It is absolutely impossible to infer their primary energies by measuring their Cherenkov light. Only we can estimate their energy statistically after accumulation of large amount of experimental data.

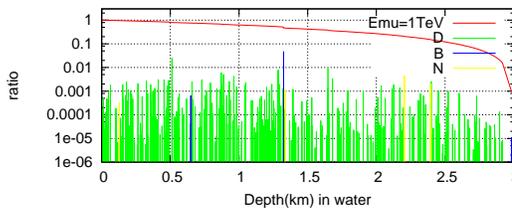


Figure 5: Individual behavior of a muon with 1TeV. The numerical value for energy losses and their causes (Direct electron pair, Bremsstrahlung and Nuclear interaction)

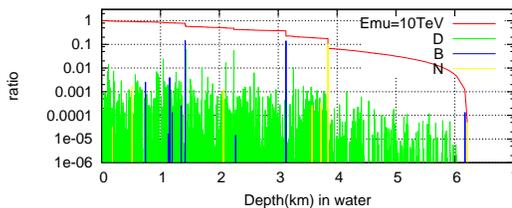


Figure 6: Individual behavior of a muon with 10TeV.

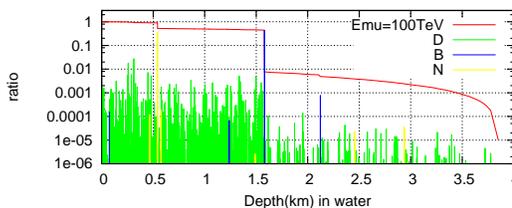


Figure 7: Individual behavior of a muon with 100TeV.

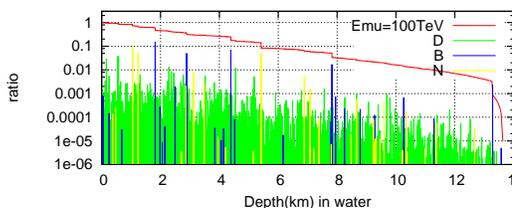


Figure 8: Individual behavior of a muon with 100TeV.

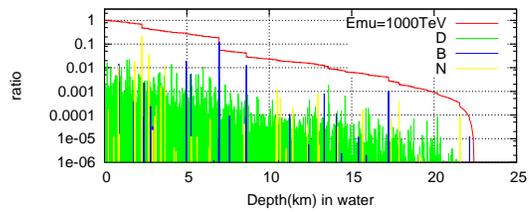


Figure 9: Individual behavior of a muon with 1000 TeV.

References

- [1] A. Misaki. *Fortschr. Phys.*, 38:413, 1990.