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The detection for extremely high energy neutrino and the interior structure of the Earth

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Abstract. By using either atmospheric neutrino energy spectrum or AGN from ($10^{12}eV$ to $10^{21}eV$), we try to understand the interior of the structure of the Earth. The Earth has internal structure with different densities. The mean free paths of extremely high energy neutrino depend on their energy and the densities of the medium they traverse. Neutrino oscillation, if they really exist, may offer powerful means to the understanding of the interior structure of the Earth, too.

1 Introduction

Up to now, much idea have been proposed to survey the internal structure of the Earth by using neutrino beam coming from either accelerator or cosmic rays (Volkova and Zatsepin (1974), De.Rujula,A (1983), Askar' yan,G.A (1984), Volkova,L.V (1985), Borisov,A.B. et al (1986), Tsarev,V.a and Chechin (1986), Kwiecinski.J et al (1999), Jain P. et al (1999)). In present paper, we examine the interior structure of the Earth by atmospheric neutrino and cosmic neutrino in wider range from $1GeV$ to $10^{11}GeV$ or so by more exact method. For the moment, we imagine our detector is located at the $1.5km$ from the surface of the Earth.

We get energy spectrum of muons (muon neutrinos)and electrons (electron neutrinos) inside the detector. These spectrum thus obtained surely reflect the interior structure of the Earth. Also, the neutrino oscillation, if really exists, may be very important means for surveying the interior structure of the Earth. We may examine the influence of the neutrino oscillation over muon and electron neutrino energy spectrum.

2 The method of the calculation

For our calculation, we adopt the rigorous procedure as much as possible , because we should decrease uncertainty as small as possible coming from the character of rare events of neutrino interaction.

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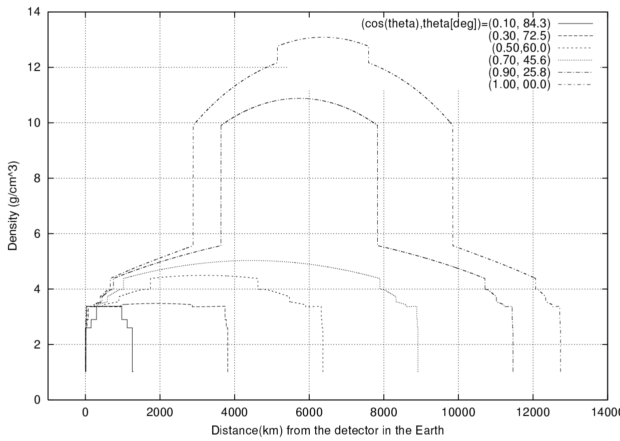

Fig. 1. Densities of the Earth for different nadir angles. The distance is measured from the point of the observation along the line of nadir to the detector underground.

We calculate neutrino interaction energy spectrum at arbitrary depth inside the Earth , starting from the incident neutrino energy spectrum at the opposite place of the Earth which we observe . We simulate the energy of the neutrino which produce the muon in charged current interaction and again simulate the energy of produced muon from the neutrino interaction concerned. The muon thus produced at some point inside the Earth is followed up to the detector by full Monte Carlo method, taking into account the processes of the bremsstrahlung, pair production and nuclear interaction. Then, we could get energy muon spectrum at the detector, energy spectrum of the muon at the occurrence point and corresponding parent neutrino energy spectrum, for different nadir angle.

We adopt the Preliminary Reference Earth Model for the Earth's density profile (Dzewonski A.M. and Anderson (1981)). In Fig.1, densities of the Earth are given for different nadir angles(zenith angle).

In Fig.2 and Fig.3, the relation between mean free paths

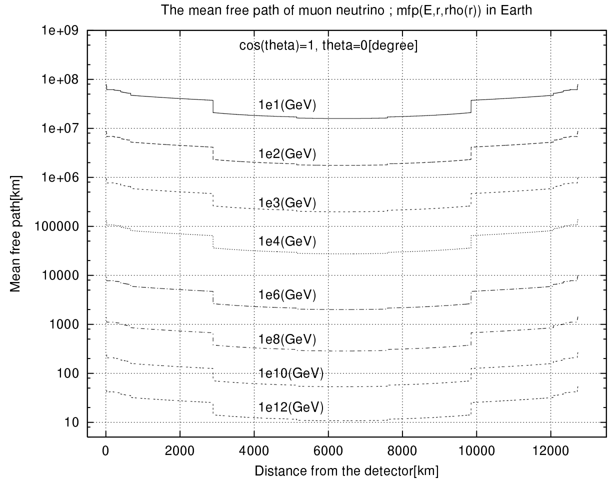

Fig. 2. Mean free paths of neutrino as the function of energy for nadir angle ($\cos\theta = 1.0$). The distance is measured from the point of observation to the detector bunderground.

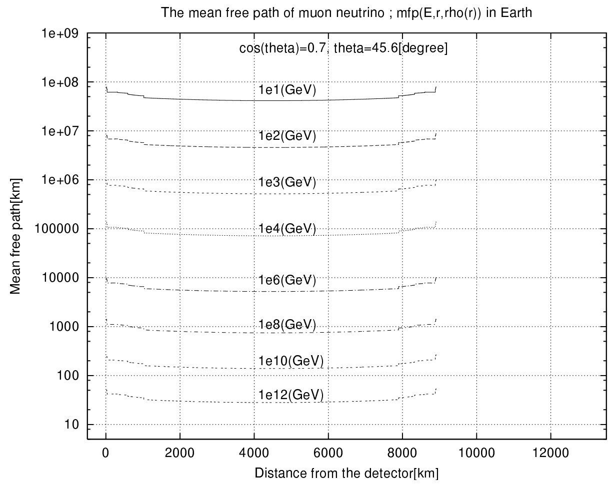

Fig. 3. Mean free path of the neutrino as the function of incident neutrino for nadir angle ($\cos\theta = 0.7$).

of neutrinos interaction and the distance from the detector are given for different incident neutrino energies for fixed nadir angle, which are calculated from expressions obtained by Gandhi R. et.al. (1996) and Reno M.H. (1999).

In Fig.4, we give the interaction probability for muon neutrino for $\cos\theta = 1.0$ and $10^6 GeV$ inside the Earth by both full Monte Carlo and numerical methods. We prepare bins with thickness $100km$ along the direction of the neutrino concerned ($10^6 GeV$ for $\cos\theta = 1.0$) we calculate the number of neutrino interaction within (t,$t + dt$) ($dt = 100km$) by full Monte Carlo method and numerical method. The agreement between them is perfect. Integral distribution in the figure denotes probability for the number of neutrino interaction up to the depth where we observe. Survival probability means that survival probability up to the depth t where we observe. There are two big gaps in the numbers of neutrino interaction in the figure at about $1000km$ and $3500km$. These correspond to two big change of the densities for $\cos\theta =$ 1.0 in Fig.1.

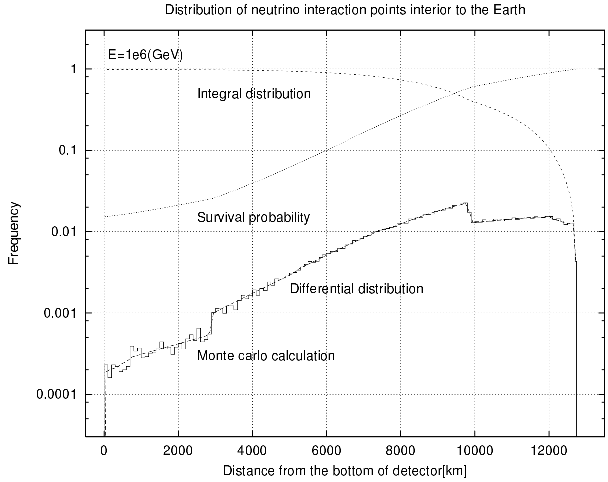

Fig. 4. Distribution of muon neutrino interaction points interior to the Earth.

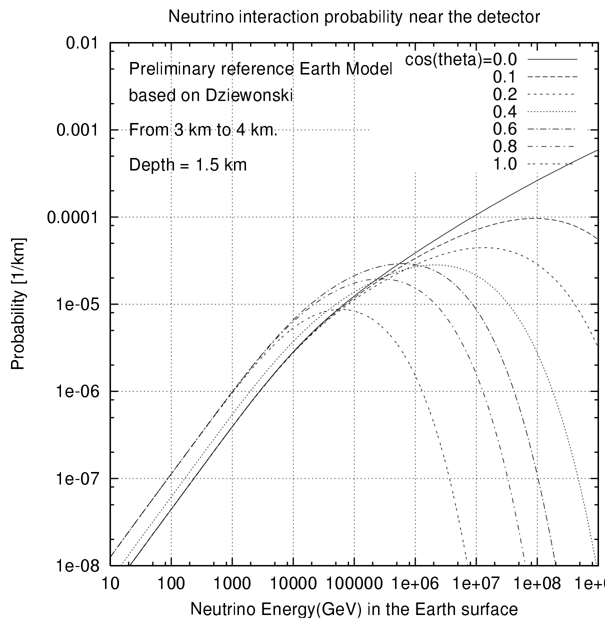

Fig. 5. Neutrino interaction probability near the detector. The Earth model is based on Dziewonski.

Although neutrino interaction may occurs anywhere in the Earth, the frequecy of which depend on both neutrino energy and density of the Earth there , only muon produced from neutrino interaction near the detector could arrive at the detector. Here, we neglect electron from electron neutrino interaction. Now, the detector is located at the $1.5km$ from the surface of the Earth. Neutrinos come from opposite direction to the detector with different nadir. We give the interaction probability for neutrino with definite energy and nadir near the detector.

We calculate the interaction probabilities for neutrinos produced in interval of $3km$ to $4km$ from the detector in given

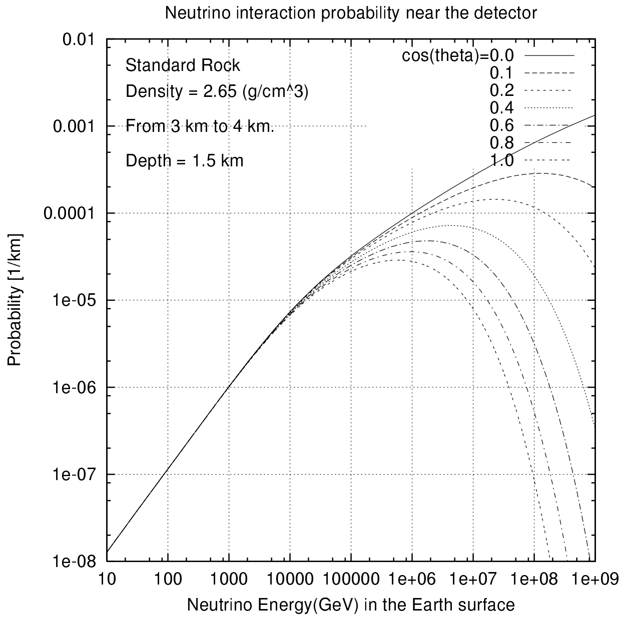

Fig. 6. Neutrino interaction probability near the detector. The Earth model is Standard Rock.

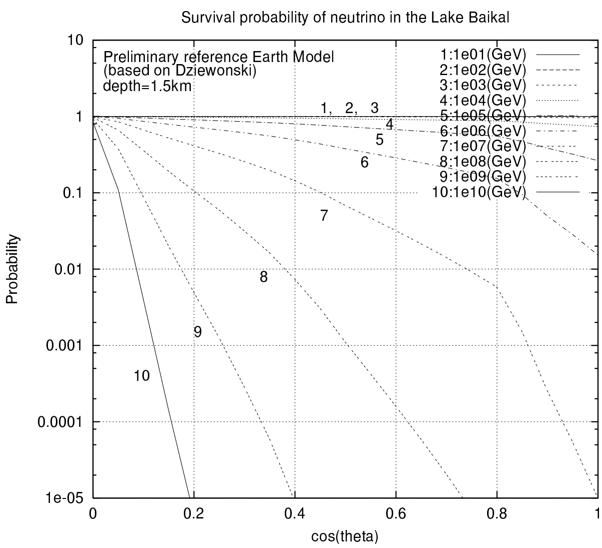

Fig. 7. Survival probability of neutrino in the Lake Baikal.

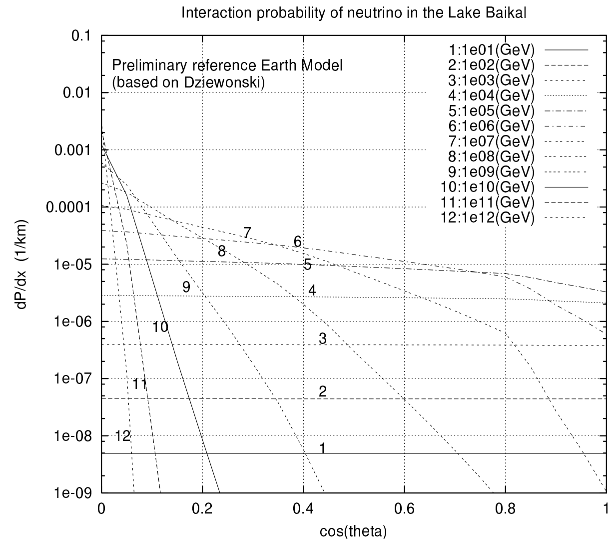

Fig. 8. Interaction probability of neutrino in the Lake Baikal.

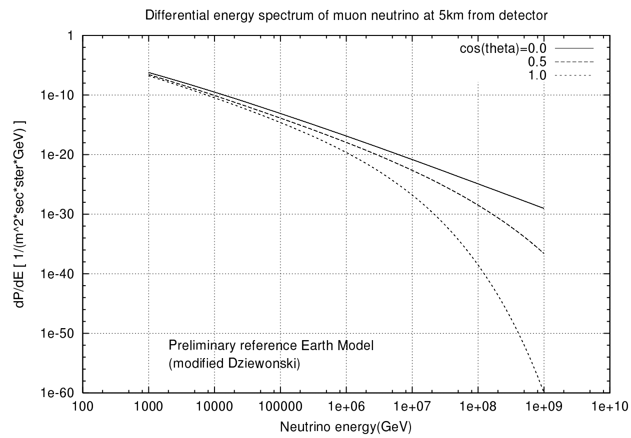

Fig. 9. The survival neutrino energy spectrum at the depth t

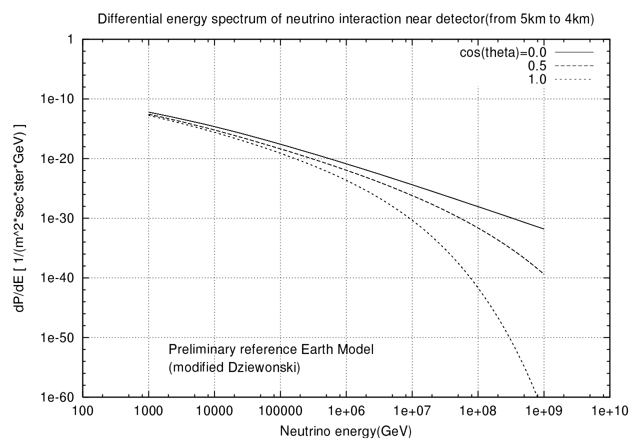

Fig. 10. The interaction neutrino energy spectrum at the depth $t+dt$

Fig.5. It is noticed that we expect smaller flux of the interaction from horizontal direction than that from vertical direction in lower energies. The medium traversed by muon from horizontal direction is occupied by water based on the Preliminary Reference Earth model. This is the reason why we get smaller flux. In Fig.6, we give same probability as in Fig.5, assuming that the density of the Earth is constant ($\rho = 2.65$). Comparison between Fig.5 and Fig.6 tells us that survival probability for neutrino interaction reflect the interior structure of the Earth. Also notice that there are always two different energies for neutrino which correspond to the same probability.

In Fig.7, the survival probabilities for neutrino for incident energies of neutrinos are given in the function of $\cos\theta$.

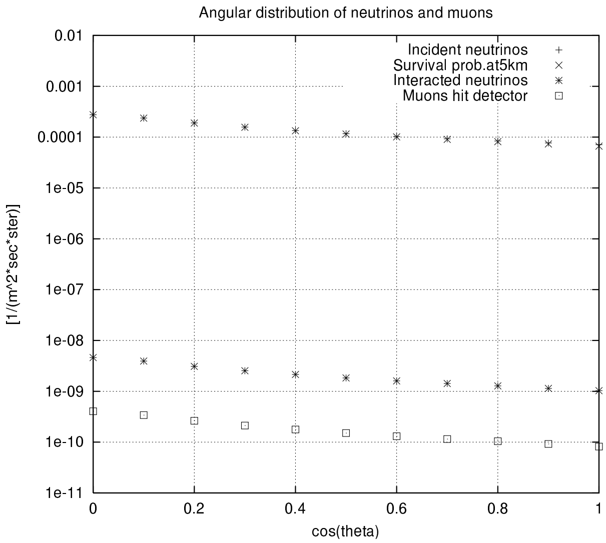

Fig. 11. Angular distribution of neutrinos and muons.

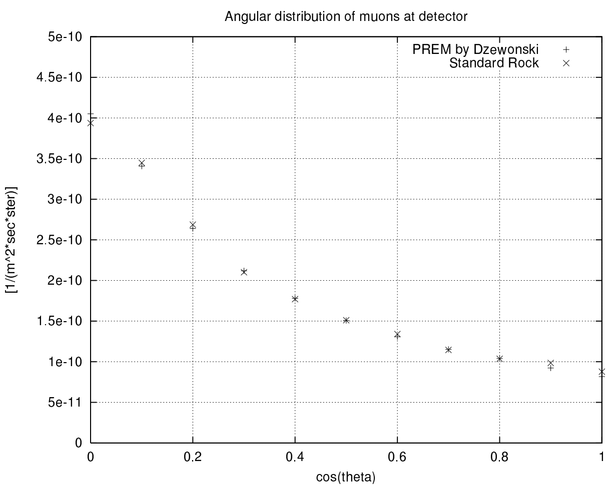

Fig. 12. Angular distribution of muons.

In Fig.8, interaction probability for neutrino for incident neutrino energies in the thickness of $1km$ in the lake Baikal are given as the function of $\cos\theta$.

In Fig.9 and Fig.10, the survival neutrino energy spectrum at $5km$ and the interaction neutrino energy spectrum at($4km$ to $5km$) are given, respectively, by using the incident energy spectrum of the surface of the Earth opposite to us (Naumov V.A. (2000)).

In Fig.11, we give the absolute flux of muon measured in the detector, the absolute flux of muon produced in the neutrino interaction and the absolute flux of energy of the neutrino which produce muons concerned, assuming atmospheric neutrino energy spectrum from 10^3GeV to 10^6GeV opposite side of the Earth to us (Naumov V.A. (2000)) and interior structure of the Earth (Deziewonski,1981).

In Fig.12, we compare the energy spectrum of the muons which arrive at the detector in Figure 11 with the corresponding ones, assuming that the density of the Earth is constant($\rho = 2.67$). We could not find the difference among them. It is ,thus, concluded that we could not understand the interior structure of the Earth if we utilize atmospheric neutrino "beam " from 10^3GeV to 10^6GeV which we now utilize. We could understand the interior of the structure of the Earth, if we could utilize more higher energy neutrino.

Once Minorikawa discussed density of the Earth over the neutrino oscillation(Minorikawa Y. (1989)). It is very interesting idea . We examine what kind of neutrino oscillation mode is really effective on elucidation the interior structure of the Earth.

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References

L.V.Volkova and G.T.Zatsepin, Izv. Akad. Nauk SSSR Ser.Fiz. 38 (1974) 1660
De. Rujula,A, Phys.Rep.99,342(1983)
Askar'yan,G.A, Sov.Phys.Uspekhi,27(1984)896
Volkova,L.V, Nuovo Cimento 8C,896(1985)
Borisov,A.B. et al, Sov.Jour.Nucl.Phys.,448(1986)442
Tsarev,V.a and Chechin, Sov.Jour.Part.Nucl.,17(1986)167
Kwiecinski.J, Martin Stasto, Phys.Rev.59(1999)093002
Jain P., Ralston, Frichter, Astopart.Phys.12(1999)192
Deziewonski,A,M, and Anderson, Phys.Earth Planet,Int 25(1981)297
Gandhi R., Quigg,Reno, M.H.Sarcevic, Astropart. Phys.5 (1996) 81
Reno M.H., private communication,(1999)
Naumov V.A., private communication,(2000)
Minorikawa Y., ICR-Report, 77-88-8,(1989) 18