ENERGY SPECTRA OF HIGH ENERGY ATMOSPHERIC NEUTRINOS

K. Mitsui
Institute for Cosmic Ray Research, University of Tokyo, Tokyo 188, Japan

Y. Minorikawa
Department of Physics, Kinki University, Osaka 577, Japan

1. Introduction

One of the important object of DUMAND is the measurement of high energy neutrinos. And also in the underground laboratories, such as Gran Sasso, neutrino physics will become more and more important subject. In such a case atmospheric neutrinos behave sometimes as guest and sometimes become an obstacle. In this paper focussing on high energy neutrinos ($\gtrsim$ 1 TeV), we carried out a new calculation of atmospheric neutrino intensities taking into account EMC effects observed in P-A collisions by accelerator, recent measurement of primary cosmic ray spectrum and results of cosmic ray muon spectrum and charge ratio. Another features of the present calculation are a) taking into account kinematics of three body decays of kaons and charm particles in diffusion equations and b) taking into account energy dependence of kaon production.

2. Methods of the calculation

Energy moment Z_{hc}^{A} in which particle h collide with nucleus A and produce particle c is given as following;

$$Z_{hc}^{A} = \pi \int_0^1 X^{\gamma-1} f_{hA}(X,p_t)\, dp_t^2\, dX,$$

where $$f_{hA} = \frac{1}{\sigma_{hA}} E \frac{d^3\sigma_A}{dp^3} = f_{hp} \frac{\sigma_{hp}}{\sigma_h^{\circ}} \zeta_h^c A^{\alpha(x)}.$$

On the other hand in nucleus-nucleus collisions, we take A-A collision as sum of "nucleon"-A collision. Where "nucleon" is considered that a part of nucleon is quark-gluon(Q-G) state. So Z_{pc}^{A} is modified taking into account the primary cosmic ray composition as follows;

$$Z'^{A}_{pc} = \delta_p Z_{pc}^{A} + (1-\delta_p)[(1-\beta) Z_{pc}^{A} + \beta Z_{p\tilde{c}}^{A}],$$

where δ_p is the proton excess at the top of the atmosphere and the value is 0.79. β is the rate of Q-G state and 0.237 estimated from cosmic ray muon charge ratio. More details of the above formulas and the values of Z'^{A}_{hc} can be found in Minorikawa and Mitsui[1].

Next we consider prompt neutrino production. Prompt neutrinos are produced through decays of charm particles, such as $pp \to D\bar{D}X$ or $\Lambda_c^+\bar{D}X$. Inclusive distribution of D-meson is very similar to the distribution of mesons produced by h-A collision and the distribution of Λ_c^+ baryon is similar to that of proton without diffractive part. From the above points, energy moments of charm particles are presented as following;

$$Z'^{A}_{pD} = (Z'^{A}_{p\pi^+} + Z'^{A}_{p\pi^-}) \beta_D ,$$

$$Z'^{A}_{p\Lambda_c^+} = Z'^{A}_{pp} \beta_{\Lambda_c^+} ,$$

where $\beta_c = \sigma_c \langle n_c \rangle A^{\alpha} / \sigma_{pp}^{tot} \langle n_\pi \rangle A^{\alpha}$. As a cross section, decay mode and branching ratio of charm particles, we take those presented by Castagnoli et al[2] and the collision mean free path of charm particle with nucleon was taken 200 g/cm^2 for D-meson and 100 g/cm^2 for Λ_c^+ baryon at the energy of 1 TeV. For neutrino intensities produced by three body decays of kaon and charm particles we can calculate using diffusion equation taking into account kinematics by Hagedorn[3] and given as follows;

$$n_\nu(E_\nu, x, \theta^*) = \frac{\pi^2}{R_3} \int_{M_1}^{M_2} \frac{F(M)}{2M} dM \int_{E_1}^{E_2} \frac{B_i \sec\theta^*}{E_i \, \rho(x) \, p_i} P(E_i) n_i(E_i, x, \theta^*) dE_i ,$$

where B_i is decay constant and $B_{k^\pm} = 850$, $B_{k_L^\circ} = 201.8$, $B_{D^\circ} = 9.04\times10^7$, $B_{D^\pm} = 4.33\times10^7$ and $B_{\Lambda_c^+} = 2.12\times10^8$ in GeV. Focussing on the neutrino from the decay $D \to K\mu\nu$, we present as following;

$$R_3 = \frac{\pi^2}{4 m_D^2} \int_{M_1'}^{M_2'} dM^2 \frac{m_D^2 - M^2}{M^2} \sqrt{[M^2 - (m_k + m_\mu)^2][M^2 - (m_k - m_\mu)^2]} ,$$

where $M_1' = (m_k - m_\mu)^2$, $M_2' = m_D^2$, $M_1 = m_k + m_\mu$, $M_2 = m_D$,

$$F(M) = \sqrt{[M^2 - (m_k + m_\mu)^2][M^2 - (m_k - m_\mu)^2]} ,$$

$$E_1 = \frac{E_\nu}{1 - r_c^2} + \frac{m_D^2 - M^2}{4 E_\nu} , \quad E_2 = \frac{2 E_\nu}{1 - r_c^2} , \text{ and } r_c = M/m_D .$$

Primary spectrum was taken as $1.87 E_0^{-2.7}$ ($E_0 \leq 5 \times 10^6$ GeV/nucleon) and

$191\ E_0^{-3.0}$ ($E_0 > 5 \times 10^6$ GeV/nucleon) in unit of $(\mathrm{cm}^2 \mathrm{sec\ sr\ GeV})^{-1}$.

3. Results

Calculated differential neutrino spectra are presented in Fig.1 as solid lines. The calculations performed in the early, Volkova[4] and Inazawa and Kobayakawa[5], are shown in the figure, however latter intensity was raised by a factor π for kinematical correction.
By integrating differential neutrino spectrum from 0° to 360° for azimuthal angle and from 0° to 90° for zenith angle, downward going integral neutrino intensities were estimated and presented in Fig.2.

4. Discussion

Rate of the intensity of electron neutrino to that of muon neutrino is 5.5% at 1 TeV and 2.6% over 10^6GeV. And also rate of the intensity of neutrino to that of anti-neutrino is 2.2 for muon neutrino and 1.7 for electron neutrino, independently of energy. The integral intensity of the prompt neutrino exceeds the conventional one at about 10 TeV for electron neutrino, and in the energy region of several hundreds TeV for muon neutrino. Because the above energy region will be covered by DUMAND, it seems to be able to detect the prompt effects.

This calculation was performed using the computer FACOM M180-II AD of the Institute for Nuclear Study, University of Tokyo.

References

1) Minorikawa Y and Mitsui K Lett. Nuovo Cimento 41 333 (1984)
2) Castagnoli C et al Nuovo Cimento 82A 78 (1984)
3) Hagedorn R Relativistic Kinematics (Benjamin Inc., New York, 1963)
4) Volkova L V Soviet J. Nucl. Phys. 31 784 (1980)
5) Inazawa H and Kobayakawa K Prog. Theor. Phys. 69 1195 (1983)

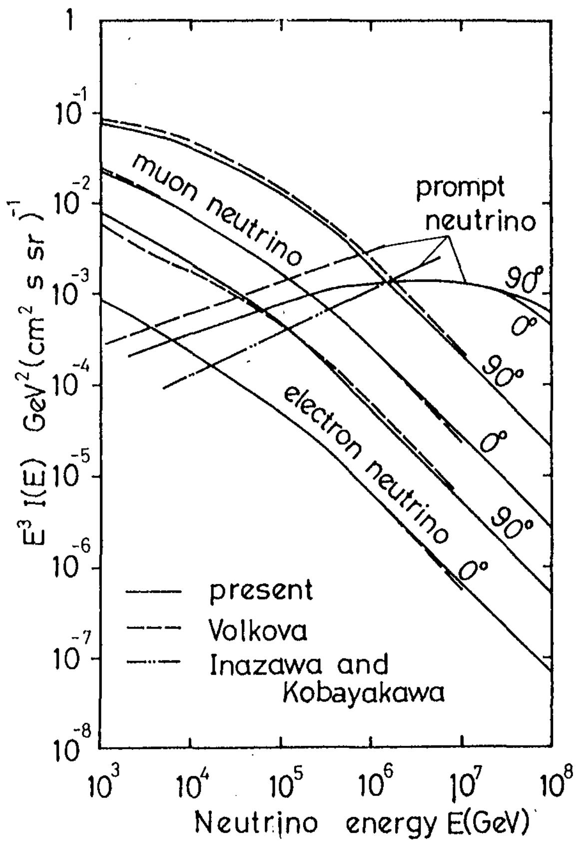

Fig. 1 :

Differential neutrino spectrum.
0° and 90° mean zenith angle.

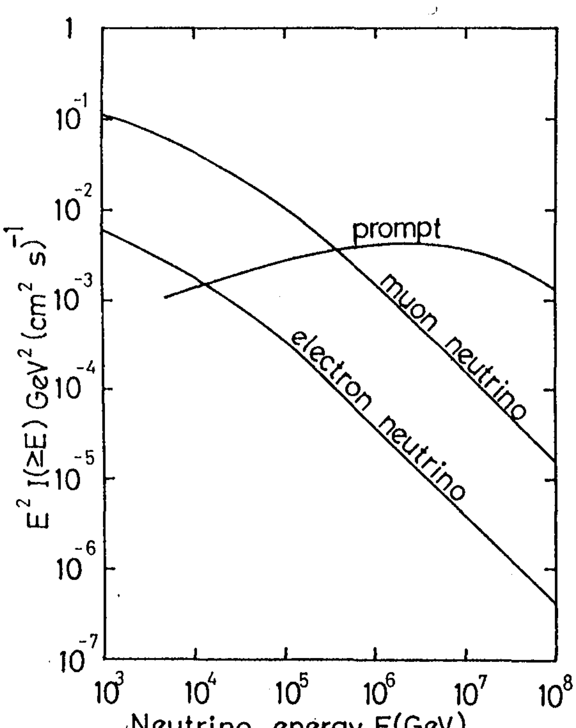

Fig. 2 :

Neutrino intensity I(≥E) obtained by integrating the differential spectrum from 0° to 360° for azimuthal angle and from 0° to 90° for zenith angle.