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To interactions of low energy atmospheric neutrinos in a Gran Sasso detector

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Abstract

Estimations of the number of interactions and of the spectra of muons produced by atmospheric neutrinos at energies more than ~30 Mev in a deep underground detector (taking into account geomagnetic effects for Gran Sasso location) are given.

1 Introduction:

The calculations are made for one-dimensional variant for particle propagation through the atmosphere. It was declared (Bludman & Lee, 1988) that calculations with one-dimensional approximation of cosmic ray muon flux gave the results with the accuracy better than 20% at energies ≥ 200 Mev. Really primary nucleons with energies more than some Gev are in the main responsible for considered in this work atmospheric neutrinos. Neutrinos responsible for the interactions and muon fluxes of our interest here have effective energies ~ 300 Mev.

2 Atmospheric neutrino fluxes at Gran Sasso location:

The differential energy spectra of muon and electron atmospheric neutrinos (multiplied by neutrino energy squared) coming to the sea level in the up-going and horizontal directions for Gran Sasso location are given in Fig. 1 and 2.

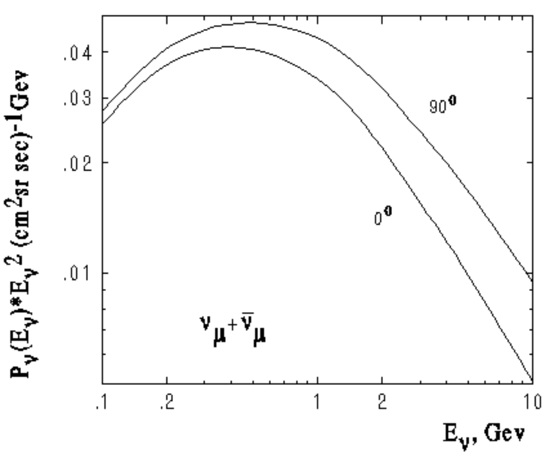


Fig. 1 Differential atmospheric muon neutrino spectrum multiplied by neutrino energy squared (0^o is for neutrinos going up and 90^o is for the horizontal direction)

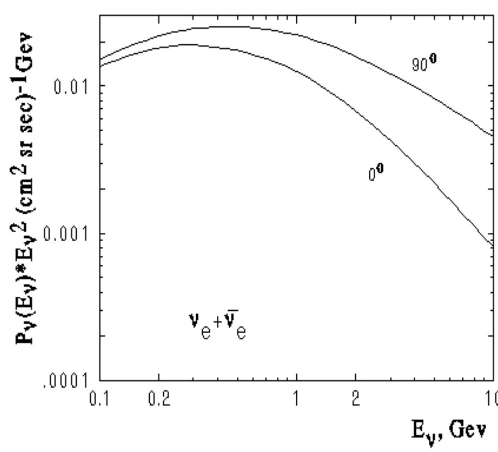
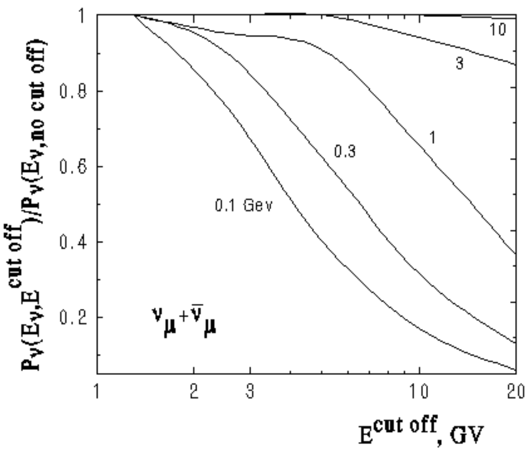


Fig. 2 The same as Fig. 1 but for electron neutrinos

The spectra of neutrinos given in (Volkova,1997) were used for the calculations together with data on the ratios of neutrino fluxes produced in the atmosphere at a given geomagnetic cut off $E^{cut-off}$ GV to that when no cut-off takes place (Fig. 3 and 4 for muon and electron neutrinos).



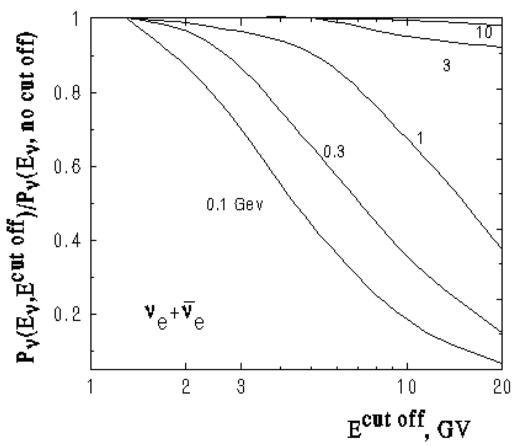


Fig.3 The ratio of differential muon neutrino flux for a given value of geomagnetic cut-off to that for no cut-off (different curves are for different neutrino energies)

Fig. 4 The same as in Fig. 3 but for electron neutrinos

3 Atmospheric neutrino interactions in a Gran Sasso detector:

Atmospheric muon and electron neutrinos and antineutrinos interact through charged currents (c. c) with nuclei of an installation:

$$\nu(\bar{\nu})+N\rightarrow\mu^{\mp}(e^{\mp})+N'$$
$$\nu(\bar{\nu})+N\rightarrow\mu^{\mp}(e^{\mp})+\pi+N' \qquad (1)$$
$$\nu(\bar{\nu})+N\rightarrow\mu^{\mp}(e^{\mp})+m\pi+N', \qquad m>1$$

and through neutral currents (n. c.) :

$$\nu(\bar{\nu})+N\rightarrow\nu(\bar{\nu})+N'$$
$$\nu(\bar{\nu})+N\rightarrow\nu(\bar{\nu})+\pi+N' \qquad (2)$$
$$\nu(\bar{\nu})+N\rightarrow\nu(\bar{\nu})+m\pi+N', \qquad m>1.$$

Cross-sections for neutrino-nucleon interactions for free and bound nucleons are taken from (Fukujita & Suzuki, 1994 and references therein) and (Los Alamos Meson Facility, 1995).

When estimating the ratios of the number of neutrinos to that of antineutrinos the result given in (Volkova, 1993) was used. In that work it was stressed that the data of MARS -10 program on proton-air nuclei interactions at energies ~2 Gev (based on accelerator experiments) showed the increase of the ratio of the number of positive pions to negative pions at production with the energy decrease.

Table l: the number of interactions per 1 g of matter (nucleons are packed into nuclei) per 1 ster per 1 sec in a detector in Gran Sasso produced by atmospheric neutrinos.

	$\nu_\mu + \bar{\nu}_\mu$	$\nu_e + \bar{\nu}_e$
up-going	$5.2 * 10^{-16}$	$2.5 * 10^{-16}$
90^o	$6.7 * 10^{-16}$	$5 * 10^{-16}$

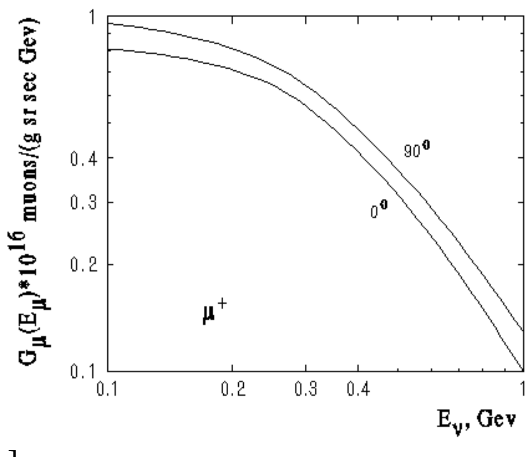
4 Produced muon spectra:

The spectra of muons produced in the processes (1) can be written:

$$G_\mu(E_\mu) d E_\mu = \int_{E_\mu}^{\infty} P_{\nu_\mu}(E_{\nu_\mu}) * N * \sigma_{\nu_\mu N} * \frac{dW(E_{\nu_\mu}, E_\mu)}{d E_\mu} d E_{\nu_\mu} \quad , \qquad (3)$$

where $P_{\nu_\mu}(E_{\nu_\mu})$ is the differential spectrum of muon neutrinos, $\sigma_{\nu_\mu N}$ is muon neutrino-nucleon interaction cross-section,N is the Avagadro's number, $\frac{dW(E_{\nu_\mu}, E_\mu)}{d E_\mu}$ is the probability that muon with an energy in the interval $E_\mu \div E_\mu + d E_\mu$ is produced in an interaction of neutrino with an energy E_{ν_μ}.

The spectra of muons produced by atmospheric muon neutrinos in an installation in Gran Sasso calculated in this work are given in Fig. 5 and 6 for positive and negative muons.



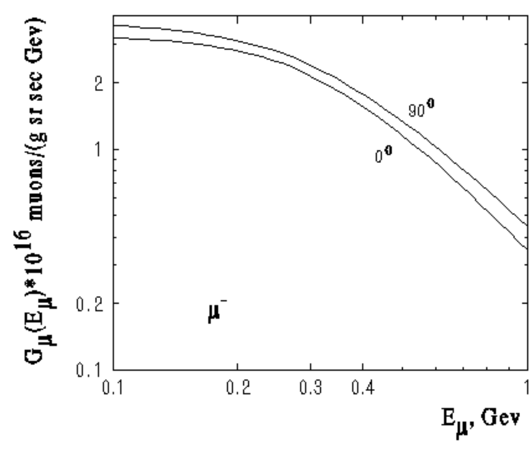


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Fig. 5 The differential positive muon flux (nucleons are bound in nuclei): 0^o is for up-going particles and 90^o is for muons coming in the horizontal direction

Fig. 6 The same as Fig. 5 but for ne- negative muons

5 Conclusion:

Calculations of atmospheric neutrino fluxes at low energies have been made in a number of works (see, for example, (Gaisser et al.,1983), (Dar, 1983), (Mitsui et al, 1986), (Barr, Gaisser & Stanev,1989), (Bugaev & Naumov, 1989), (Lee & Koh, 1990), (Honda et al., 1990), (Volkova, 1997). The results of these works differ sometimes much from each other. For example, neutrino fluxes in (Gaisser et al., v, 1983) and in (Bugaev & Naumov, 1989) differ twice at energies ~0.1-0.2 Gev. The main differences between these results are due to inclusive production spectra of pions created in nucleon-air nuclei interactions taken from accelerator data in the works. Unfortunately cosmic ray muon data at corresponding energies have big uncertainties and can not increase significantly the accuracy of calculated neutrino fluxes (Volkova, 1997).

The calculations made in all mentioned works were one-dimensional calculations. More exact three-dimensional calculations would be desirable : the accuracy of one-dimensional calculations is not better than ~20% at energies ~200 Mev (Lee & Bludman, 1990).

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