

Limits on calculated atmospheric neutrino fluxes at high energies

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60-th October Anniversary pr. 7a, 117312 Moscow, Russia*

Abstract

Basing on modern data on cosmic ray muons, accelerator data and modern theoretical considerations an attempt is made to put lower and upper limits on fluxes of neutrinos produced in atmosphere in charm particle decays.

1 Introduction:

The dream to realize experiments with cosmic neutrinos can come true in not so far future because of creation of a number of huge neutrino telescopes and installations (for example, AMANDA, ANTARES, AUGER, BAIKAL, NESTOR, SuperKAMIOKANDE and so on). Therefore it is very important to know atmospheric neutrino fluxes well as they are the main background for the considered experiments: namely atmospheric neutrinos define how large the size and exposition should be for a lucky search for diffuse cosmic neutrinos and what the angular resolution of these installations should be for a lucky search for point sources of neutrinos in the sky.

Attempts have been made to calculate atmospheric neutrino fluxes taking charm particle production mechanism as it is described at high energies within the frames of this or that theoretical model in a number of recent works (for example, Zas, Halzen & Vazquez, 1993; Thunman, Indelman & Gondolo, 1996; Naumov, Sinigovskaya & Sinigovsky, 1998; Gurentsov, Volkova & Zatsepin, 1998). All these models endow charm particle production mechanism with the features that are in good agreement with the data obtained with accelerators but at higher energies unattainable today with accelerators their results differ from each other very much. As a result calculated in different works prompt atmospheric neutrino fluxes at energies of some tens of Tev can differ from each other two orders in magnitudes.

2 Prompt atmospheric neutrino fluxes:

We shall mainly deal with particles at the energies ≥ 1 Tev below. In this case the equations for cosmic ray particle propagation through the Earth's atmosphere can be solved analytically.

The differential energy spectrum of primary nucleons is a power spectrum of nucleon energy and the power index is $(\gamma+1)=2.7$ for nucleon energy

$$E_N \leq 3 \cdot 10^6 \text{ Gev and } (\gamma+1)=3 \text{ for } E_N \geq 3 \cdot 10^6 \text{ Gev.}$$

If we assume the spectra of charmed particles produced in nuclear interactions of nucleons with air nuclei to be proportional to $(1-u)^\delta$, where $u = \frac{E_\eta}{E_N}$ (E_η is the energy of a produced charmed particle) then the number of muon or electron neutrinos α_v^{charm} from decays of charmed particles produced in the atmosphere at an angle θ to the vertical per one nuclear interaction of a nucleon can be written:

$$\alpha_v^{charm}(E_v, \theta) = \sum_i W_{sl}^\eta * \int_{w_{min}}^{w_{max}} \int_0^1 b * \varphi^\eta(u) * (1-u)^\delta * \sigma_{NA}^{D\bar{D}, \Lambda_c \bar{D}}(E_\mu / u / w) / \sigma_{in}^{NA}(E_\mu / u / w) * w^\gamma * f(w) / (1 + E_\mu / w / E_\eta^{cr}(\theta)) dw du, \quad (1)$$

where summing up over i is summing up over all kinds of charmed particles;

W_{sl}^η is the probability that a charmed particle decays with neutrino production ;

$b=1.08$ and $\delta=5$ for D-mesons, $b=1.4$ and $\delta=0.4$ for Λ_c -baryons;

$w = E_v / E_\eta$; $w_{max}, w_{min}, f(w)$ are connected with the kinematics of a three-body decay

of a charmed particle; $\varphi^\eta(u) = u^{\gamma-1}$ for D-mesons and $\varphi^\eta(u) = u^\gamma$ for Λ_c -baryons;

$E_\eta^{cr}(\theta)$ is a charmed particle critical energy ;

$\sigma_{NA}^{D\bar{D}, \Lambda_c \bar{D}}$ and σ_{in}^{NA} are cross-sections for charmed particle pairs ($D\bar{D}$ -pair and $\Lambda_c \bar{D}$ -pair) production in nucleon-air nuclei interactions and for inelastic interactions of nucleons with air nuclei correspondingly.

From (1) it is easy to see which parameters and expressions are responsible for the fluxes under discussion. The values W_{sl}^η are taken from accelerator data (Particle Data Group, 1996). Variation in γ within the reasonable interval (± 0.1) exerts slight influence on the value α_v^{charm} ($\sim 10\%$). If one changes $\delta=3$ for 5 in D-mesons spectra this value is increased by two times in magnitude (D-mesons give the main contribution into fluxes of particles from charm decays).

In Fig. 1 and 2 the differential energy spectra (multiplied by neutrino energy cubed) are given for conventional neutrinos (generated in pion, kaon and muon decays) taken from (Volkova, 1980) and recalculated for $\gamma=1.7$ and prompt neutrinos (from charmed particle decays): data from experiments on accelerators E653 and E743 on total charm production cross sections in pp interactions at proton energy ~ 1 TeV which have good statistics and do not contradict each other within their statistical uncertainties (Shabelsky, 1998 and references therein) were used.

Prompt atmospheric muon fluxes calculated in (Thunman, Indelman & Gondolo, 1996) and these given in (Gurentsov, Volkova, Zatsepin, 1999) differ from each other ~ 40 times in their magnitudes at the energy ~ 100 TeV. This takes place in spite of the fact that cross-sections for charmed particle production at 10^3 TeV (effective energies of nucleons responsible for production in the atmosphere of muons considered) are used almost the same in these both works. Thus, as to the difference shown in the two works it can be accounted for by the difference in the charmed particle production spectra used in those works. To receive cosmic ray prompt muon flux ~ 30 times lower than in calculations with D-meson spectra with $\delta=5$ we should put $\delta=50$.

So we would have a very large change in the value δ (from 3-5 up to 50) at energy change from 1 up to 1000 Tev.

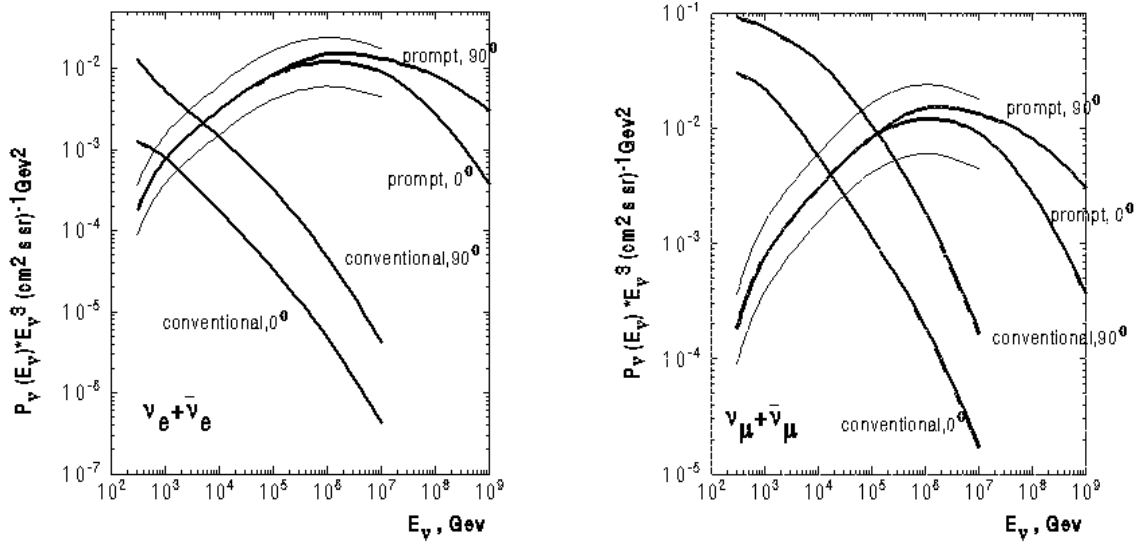


Figure 1 and 2: Differential energy spectra of atmospheric neutrinos and antineutrinos multiplied with neutrino energy cubed for vertical (0°), horizontal (90°), prompt and conventional fluxes (thin curves show prompt fluxes when normalization in the value of charm production cross-section is changed two times).

Spectra of charmed particles at high energies are usually calculated in different models based on QCD. These spectra depend heavily on the quark and gluon structure functions. Indeed two calculations of prompt cosmic ray muon fluxes made in (Zas, Halzen & Vazquez, 1993) within the framework of PQCD model but with different assumptions concerning behavior of gluon structure functions (for their soft and hard behavior but within the ambiguity in the existing data from modern experiments on accelerators) gave the difference in the results ~ 20 - 40 times in the magnitude at 100-1000 Tev.

We need to know these functions at very small values of Bjorken variable $x < 10^{-4}$ for the energies considered here . Really, let for the charm quark ($C\bar{C}$) production in pp-interaction through gluon-gluon (gg) fusion (this process is predominantly responsible for the charm production at high energies considered) in the parton model x_1 and x_2 are Bjorken's variables for gluons. Because of the nature of primary radiation spectra in cosmic rays the values of variables $x_F = x_1 - x_2$ in the interval ~ 0.1 -0.2 give the main contribution into charmed particle fluxes produced in the atmosphere. $x_1 * x_2 = M^2 / S$, where M^2 is square of produced charm quarks pair mass, S is square of energy in the rest system of interacting protons. Then for the projectile proton energy in the laboratory system ~ 50 -500 Tev the value x_2 is $\sim 10^{-4} - 10^{-5}$.

Cross-section for charm pair production in pp-interaction in the conventional NLO parton model can be written (Shabelsky, 1998 and references therein):

$$\sigma(pp \rightarrow C\bar{C}) \sim \int dx_1 dx_2 \sigma_{gg}(M^2) f_g(x_1) f_g(x_2), \quad (2)$$

where f_g are structure functions of gluons which are known from experiments on accelerators for discussed here values of x with accuracy near 30%.

The consideration of the behavior of charmed particle production spectra with projectile proton energy increase leads to the conclusion that $x d\sigma/dx$ can change its absolute value but does not change its shape.

The analysis of experimental data on cosmic ray muons shows (Volkova, Zatsepin & Kuz'michev, 1979) that in the fragmentation region the scaling is broken very weakly for spectra of pions produced in nucleon-air-nuclei interactions from energies of accelerators' experiments up to energies \sim some hundreds of Tev. Considerations in the framework of NLO-model show that this break should take place even in a lower measure for charmed particles.

3 Conclusion:

A reasonable assumption, that breaking down of Feynman's scaling in the fragmentation region for charm production is not larger than that occurs in the process of pion production together with the conclusion in the frame of NLO model that the behavior of charmed particle production spectra with projectile proton energy increase gives the change in the absolute value of $x d\sigma/dx$ but does not change its shape allow us to calculate charmed particle contribution to atmospheric neutrino flux with the accuracy of our knowledge of the charm particle generation process at accelerator energies. Thus the conclusion is that uncertainties in prompt neutrino flux calculations by today could be estimated to be less than $\sim 4-5$ times in magnitude.

Prompt neutrinos increase significantly the background for experiments with cosmic neutrinos. But an optimistic remark is that some features of these fluxes differ from those of cosmic neutrinos: for example, they should have different angular distributions as well as they should have different ratios of neutrinos of different flavors and conjugations.

References

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