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The primary nucleon spectrum at the knee and neutrino astrophysics experiments

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Abstract. It is shown in the work that to study diffuse cosmic neutrino fluxes and to search for cosmic ray neutrinos from different sky sources with a new generation of giant neutrino telescopes we need to know the spectrum and composition of primary nucleon flux, the behavior of pion and kaon production cross-sections at energies near the knee and at higher energies better than we do today.

1 Introduction.

The problem of an experimental study of diffuse and other kind of cosmic neutrinos has been discussed in literature for many years: see, for example, Greisen (1960), Markov (1960), Berezinsky and Zatsepin (1977). During the last decade the interest to the problem has been increased much because of creation of a new generation of giant neutrino telescopes and a big number of works on calculations of cosmic neutrino fluxes from different assumed sources has appeared. A summary of some recent publications on the theme is given, for example, in Manheim (1995), Cline and Stecker (2000).

The atmospheric neutrino fluxes make the main background for mentioned above experiments. Cosmic neutrino fluxes could be higher than atmospheric ones only at high energies. It could take place just beginning from energies $\sim 10^{13}-10^{15}$ ev. Primary nucleons with effective energies near the knee are responsible for such neutrinos. In this work we discuss the problem of accuracy of our knowledge of primary nucleon fluxes needed to interpret results of experiments on cosmic neutrinos in a proper way. We mention also some other sources of uncertainties in atmospheric neutrino calculations.

2 Atmospheric neutrino fluxes.

Pions, kaons and charmed particles are produced in the atmosphere in primary nucleon interactions with air nuclei :

$N+A^{air} \rightarrow \pi, K, D, \Lambda_c, ...$

The decays of these particles give the main contributions into atmospheric muon and electron neutrino and antineutrino fluxes ν_l,$(\overline{\nu}_l)$,

where l=μ, e.

The calculations of atmospheric neutrino fluxes were performed in Volkova (1980) and Volkova and Zatsepin (2001) with analytical decision of kinetical equations for cosmic ray particle propagation through the atmosphere. Neutrinos from decay of pions and kaons are called "conventional" and neutrinos from charmed particles decays are called "prompt".

At some energies the contribution of charmed particles to atmospheric neutrino fluxes becomes to be equal and at higher energies it exceeds that from pions and kaons. It takes place because of very short life-time of charmed particles compared to that of pions and kaons in spite of the fact that charmed particle production cross-sections are much lower than those for pion and kaon production and probabilities to decay with neutrino production for charmed particles is lower too. For muon neutrinos it takes place at $\sim$10 Tev and for electron neutrinos it takes place at $\sim$1 Tev for the vertical direction (Volkova and Zatsepin, 2001).

Uncertainties that are introduced into atmospheric neutrino flux calculations due to uncertainties of our modern knowledge of primary nucleon fluxes, inclusive cross-sections of pion and kaon generation in nucleon-air nuclei interactions and mechanism of charmed particle production at high energies are discussed lower in the work.

3 Comments on primary nucleon fluxes at high energies.

The mentioned above calculations of atmospheric neutrino fluxes were performed under the assumption that differential primary nucleon spectrum $P_N(E_N)$ was a pure powerful spectrum of energy:

$P_N(E_N)dE_N = AE_N^{-(\gamma+1)}dE_N$,

where A =Const and γ=Const : γ changed its value at $E_N \geq 3 * 10^6$ Gev.

The absolute values of atmospheric neutrino fluxes (and cosmic diffuse flux too) are proportional to A and to an integral that is a value averaged over the primary nucleon spectrum, thus introducing the dependence from the value of γ.

The direct data on primary proton fluxes measured in JACCEE (1997) and RUNJOB (2001) show that the accuracy of the data is very poor. Protons give the main contribution into primary nucleon flux. The data on helium fluxes differ from each other in their absolute values at least as much as twice.

Thus the upper mentioned data on primary nucleon fluxes show that uncertainties of our knowledge of these fluxes is worse than two times.

4 Remarks on Feynman's scaling.

It seems that Feynman's scaling takes place in nuclear interactions of nucleons with air nuclei. Really it was shown in accelerators' experiments for nucleons with energies of some tens of Gev . An analysis of data by Volkova et al. (1979) on cosmic ray muons up to energies $\sim$ some tens of Tev shows that scaling continues to take place up to energies of some tens of Tev. But we can't be sure that this continues to be correct up to those high energies that are of our interest here. For example, it was found in an experiment carried out at Mt. Chacaltaya by Aguirre et al. (2000) that the number of hadrons in the air shower does not agree with the simulated one. The authors make the conclusion that the Feynman's scaling law is violated more strongly than it is assumed in their simulation at 10^{16} ev.

5 On charmed particle production.

Calculations of atmospheric neutrino fluxes from charmed particle decays were performed by Volkova and Zatsepin (2001). They seem to have uncertainties in the main due to uncertainties in charm particle production cross-sections which were normalized to those measured on accelerators at energies lower than we need in our work: the used spectra of produced charmed particle seem to us to be close to reality.

6 Discussion.

In the figure atmospheric muon neutrino fluxes together with cosmic neutrino flux predictions (we use the results of referenced upper works) are given: the curve pp is for diffuse cosmic neutrino flux from pp-interactions in interstellar and intergalactic medium, rq is for neutrinos from radio-quiet AGN and rl is for neutrinos from radio-loud AGN (the curve marked as "max" is its upper limit and the curve marked as "min" is its lower limit); the curves π+K, $\theta = 0°$ and π+K, $\theta = 90°$ are for atmospheric conventional vertical and horizontal neutrino fluxes (neutrinos from decays of pions and kaons) and the curves π+K+prompt,$\theta = 0°$ and $\theta = 90°$ are corresponding fluxes when charmed particle production is taken into account.

It is seen from the figure that uncertainties in atmospheric neutrino fluxes (which we estimate to be some times by today) could not allow us to interpret the results of experiments on cosmic neutrinos in the wide energy interval. New giant planned experiments on primary nucleon flux measurements (for example, experiments of Auger Center or American Center for study of primary cosmic ray radiation) could improve the situation in future.

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