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EXPERIMENTAL STUDY OF ATMOSPHERIC NEUTRINO FLUX IN THE NUSEX EXPERIMENT

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Experimental Study of Atmospheric Neutrino Flux in the NUSEX Experiment.

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Abstract. – The fully contained events detected in the NUSEX nucleon stability experiment have been analysed to search for possible anomalies in the fluxes of atmospheric neutrinos. The measured flux of muon neutrinos is in very good agreement with predictions and no anomaly has been found in the ratio between the rate of electron and muon neutrino events.

The fluxes of atmospheric neutrinos in the locations of the major nucleon decay detectors have been calculated recently by Gaisser *et al.* [1]. Experimental results on the interaction rates and energy distribution have been found to be in reasonable agreement with theoretical predictions [2-7]. Little information was however available experimentally on the ratio between the interaction rates of electron and muon neutrinos. In a recent paper [8] by the Kamiokande collaboration the separate contributions due to neutrinos of the two flavours have been investigated in detail. While the event rate due to electron neutrinos agreed with that predicted in ref. [1], the muon neutrino rate has been found to be consistently lower, namely $(59 \pm 7)\%$ than predicted. This result is considered by the Kamiokande collaboration to be in some indirect agreement with a possible lack of events clearly identified as «muonic» by detection of the decay electron reported in the IMB experiment [2]. No disagreement with the expected ratio of electron and muon neutrino interactions is on the contrary found by the Frejus collaboration [9].

Due to the fundamental role that a possible lack of muon neutrinos of atmospheric origin would play on the validity of new and unconventional theories, like those on the existence of neutrino oscillations [10], we present here the results obtained on electron and muon neutrino events observed and measured in the NUSEX nucleon stability experiment from June 1982 to June 1988. Our detection technique is totally different (and complementary) to the Cherenkov approach of the IMB and Kamioka experiments. It is similar in concept and granularity to the larger Frejus calorimeter which is located at about the same geomagnetic latitude and at only slightly lower depth. Our geometry (the plates are horizontal) and the trigger are however different. The NUSEX detector is the only one whose performance has been tested directly with artificially produced charged particle and neutrino beams. This allows to test our capability to discriminate among the various neutrino interactions, and expecially to determine unambiguosly the flavour of the incident neutrino.

The detector is essentially a cube of 3.5 metre side and 150 tons of active mass, and has been running since the middle of 1982 in a laboratory in the Mont Blanc tunnel at a depth of 5000 $hg\,cm^{-2}$ of standard rock, and at 42.7° geomagnetic latitude. It consists in a digital tracking calorimeter made by 134 horizontal iron plates of one cm thickness, interleaved with plastic streamer tubes 3.5 m long and of $(9 \times 9)\,mm^2$ cross-section.

Coordinates on each plane are read bidimensionally by means of X- and Y-strips parallel and orthogonal to the tubes, respectively. A trigger is generated when at least 4 contiguous planes, 3 contiguous planes plus at least two contiguous planes, or at least three separated pairs of contiguous planes are hit. Details on the structure of our detector, on its location, on the trigger and read-out and on the analysis of the events are reported elsewhere [11].

In order to decrease the background of spurious events without a substantial loss of the signal, the present analysis has been further restricted to events where at least five planes are fired. In order to eliminate any charged particle entering into the set-up and to better separate the various types of neutrino interactions, we have limited the present analysis to fully contained events, where all tracks stop in the detector. A track is defined to stop if the potential path at the end would cross at least two further active tubes. Before starting our underground experiment, we have tested directly its capability to distinguish between the various types of events and therefore to discriminate between neutrino interactions of different flavours. We have constructed a test module of the same structure of the nucleon decay detector, but nine times less massive. It has been exposed at CERN to various Cherenkov separated beams of negative particles with momenta ranging from 0.150 to 2.0 GeV/c and with angles between the beam direction and the normal to iron plates ranging from 0° to 40° [12]. In order to simulate the response of the detector to atmospheric

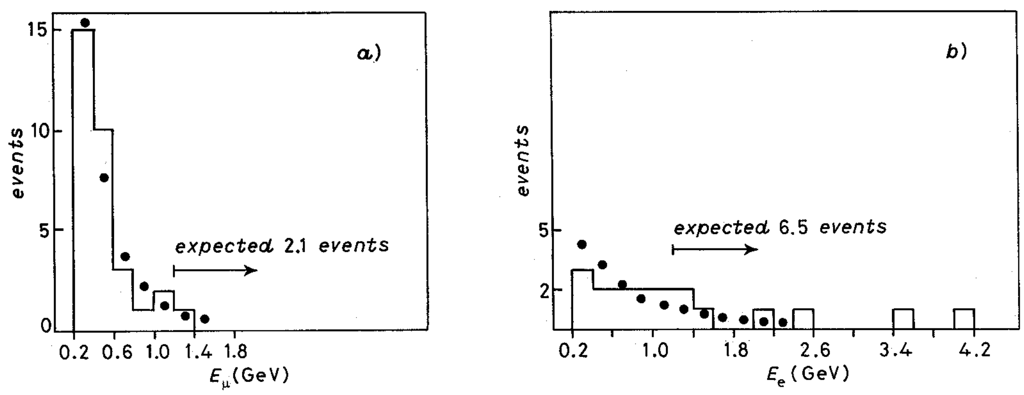

Fig. 1. – Energy spectra of the lepton candidate. The dots indicate the Monte Carlo prediction, averaged over neutrino and antineutrino fluxes and normalized to the observed number of events. *a*) μ-like, *b*) e-like.

neutrinos as well as possible, the test module was also exposed to a neutrino beam obtained at CERN with 10 GeV protons incident on a bare target. The corresponding energy spectrum is very similar to the atmospheric neutrino one in the region of interest [12]. Two exposures have been carried out at 0° and 45°, totalling $1.8 \cdot 10^{18}$ and $1.5 \cdot 10^{18}$ protons on target, respectively, and about 400 neutrino events have been detected and measured.

The statistics of atmospheric neutrinos reported here refers to measurements from June 1982 to June 1988, corresponding to 740 ton × year of total mass exposure. We have applied an energy cut to the lepton energy by selecting only interactions where the electron or muon energy was above 200 MeV. A sample of 50 events survived all cuts; the lepton energy distributions are shown in fig. 1.

Neutrino interactions in the NUSEX detector have been simulated with a Monte Carlo procedure [13] from the fluxes calculated by Gaisser *et al.* [1] for the location of our experiment, taking into account our trigger and detection efficiency and the probability of survival to the above-mentioned cuts. The neutrino cross-sections used are those quoted in [12], which have been found to agree with the results obtained with the test at CERN. The detection efficiency for charged-current electron and muon neutrino interactions, namely the probability for them to be detected and survive the cuts, are shown in fig. 2. We

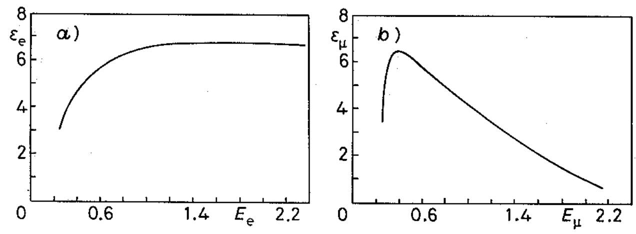

Fig. 2. – Neutrino detection efficiency as a function of the lepton energy: *a*) electron; *b*) muon.

expect 57.3 events satisfying our cuts with an absolute error of 25% due to uncertainties on fluxes and cross-sections. This number is fully consistent with the measured figure of 50 events. The Monte-Carlo–simulated lepton energy spectra (fig. 1) and zenith angle distribution (fig. 3) are also in good agreement with our experimental distribution. The average measured muon and electron energies ((503 ± 50) and (1270 ± 270) MeV) agree well with the predicted ones (542 and 1250). These predictions are only slightly affected by our uncertainties on the cross-sections, and the consequent error is negligible (an order of magnitude less than the statistical ones).

The flavour of the lepton in our neutrino interaction can be determined by inspecting the distribution of hits in the planes crossed by the lepton track and the gaps between contiguous planes. The test carried out at CERN shows that our detector can separate

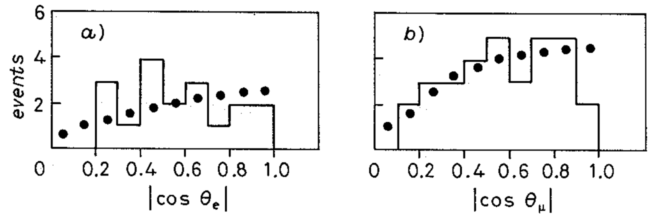

Fig. 3. – Distribution of the zenith angle of the neutrino in our experiment. The dots indicate our Monte Carlo prediction. In order to avoid ambiguities in the versus of the track, the absolute value of the cosinus is plotted. *a*) e-like, *b*) μ-like.

efficiently muonlike events from the electronlike ones. A 500 MeV/c pion, for instance, has a probability of less than 5% to simulate an electron. All our events can in fact be classified unambiguously in electronlike and muonlike interactions. Only one event presents some uncertainty since a shower indicating the presence of an electron is accompanied by a short track of much lower energy, which is most likely a pion, but which we cannot exclude to be a muon. This event has been classified as an electron-neutrino interaction, because the electronlike candidate has an energy greater than the muonlike one.

Our total sample consists of 32 muonlike and 18 electronlike neutrino interactions. Neutral current events cannot be distinguished unambiguously from the charged ones. Our Monte Carlo predictions are of 36.8 muonlike and 20.5 electronlike events, where these figures contain the predicted contribution of neutral-current interactions (2.0 and 1.7 events, respectively). We do not see therefore any lack of muonlike events with a ratio observed/predicted of $0.87 + 0.15$. We do not believe, however, that this comparison is significant, since it is strongly affected by the uncertainty in the cross-sections and in the total calculated neutrino flux. By means of a maximum-likelihood procedure we obtain for the ratio of electron to muon neutrino interactions surviving our cuts $R = 0.52^{+0.17}_{-0.15}$. This result has to be compared with the Monte Carlo estimate of 0.54. The error on this figure is negligible when compared to the statistical one, since uncertainties on fluxes and cross-sections tend to cancel out when the ratio between ν_e and ν_μ is considered. For comparison with other experiments the most significant figure is in our opinion the ratio R_{exp}/R_{MC} which has been evaluated with a maximum-likelihood procedure and found to be for our experiment $0.96^{+0.32}_{-0.28}$ (< 1.6 90% c.l.). We cannot therefore support any evidence in favour of a suppression of the muon neutrino flux with respect to the electron neutrino one.

* * *

The NUSEX collaboration dedicates this paper to the memory of M. ROLLIER: we deeply miss his help and advice, and his friendship.

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