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FULLY CONTAINED EVENTS IN THE MONT-BLANC NUCLEON DECAY DETECTOR

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ABSTRACT.

Four events have been recorded in the Mont-Blanc nucleon decay experiment with all tracks fully contained in the detector volume. Three of them can be easily interpreted as due to interactions of atmospheric neutrinos. On the contrary it has been evaluated that the fourth event is very unlikely to be due to a neutrino or neutron interaction. This event is compatible with a nucleon decay.

We report here the first results from the nucleon stability experiment, NUSEX, presently running in the Mont-Blanc laboratory at a depth of about 5000 m. w. e. of standard rock. The detector consists of a cube made up of 134 horizontal iron plates of 3.5×3.5 m^2 and one centimeter thickness, interspaced with planes of plastic streamer tubes(1) of 3.5 m length and 0.9×0.9 cm^2 internal cross section. They are made of extruded PVC with a high resistivity internal coating acting as cathode, and 100 μm anode wires which are supported every 50 cm by spacers. The gas mixture consists of 48% CO_2, 29% Ar and 23% N-pentane, and the operation voltage is 3.9 kV. Using the transparency of the cathode to electro-magnetic pulses, the X and Y coordinates of the streamers are read externally by means of longitudinal and transversal pick-up strip electrodes. The pulses from the strips, which are about 5 mV/50 Ω high and about 40 ns wide, are discriminated and shaped to 7 μs, in order to record also muon decay, and then fed into a shift register memory. All discriminators of one detector plane are OR-ed together providing the basic signal for triggering, with 100 ns time jitter. They are also sent to TDC's to identify μ-e decay. All information of accepted events is then transmitted by Camac controllers to a PDP 11/60 computer and stored on tape. Minimum trigger requirements are that four contiguous planes, or three double contiguous planes, or three contiguous planes plus any set of double contiguous planes, are fired. The trigger rate is of about one every ten minutes and is mainly due to radioactivity.

To summarise, our detector has a total mass of 150 tons, having 42 880 and 38 592 X and Y channels respectively, an average density of about 3.5 g cm^{-3}, and a radiation length of 4.5 cm.

In order to determine "a priori" the performance of our detector in the analysis of events and in the rejection of background, we have carried out tests at the CERN PS, with a module of reduced mass (one tenth), but with the same geometrical structure and granularity. Runs have been carried out with pion and electron beams with momenta ranging from 150 to 2000 MeV/c and with a neutrino beam produced by 10 GeV protons on a bare target which simulates closely the expected spectrum of atmospheric neutrinos. The results are reported elsewhere(2).

The detector has been operated in the Mont-Blanc laboratory for the equivalent of 40 ton x x year. We have observed 2870 muons crossing the apparatus, 23 muons stopping in it and 36 muon bundles. For the present analysis we consider only completely contained events. In this case the total energy can be estimated. Furthermore we can avoid in this way the confusion with events produced by incoming charged particles.

We have selected events with at least a total track length in iron >10 cm. Four fully contained events have been observed and are shown in Figs. 1 to 5. The most natural interpretation of the first three of these events is as interactions of atmospheric neutrinos with a rate in agreement with theoretical predictions(2). The fourth event, whose energy is around 1 GeV, shows features which do not allow it to be easily classed as a neutrino interaction: it has three prongs and momentum balance if one assumes the tracks to be either pions or muons.

In order to assess the probability that this event is also due to a neutrino interaction we have analysed the 400 neutrino events with at least 300 MeV visible energy collected in two runs at CERN, of equal integrated fluxes, with the neutrino beam at 90° and 45° with respect to the iron plates. We could envisage only three interpretations :

a) A neutrino interaction with vertex at A producing three charged particles ($AB = \mu$, $AC = \pi$, $AD = \pi$). In this case the visible energy is 1.0 ± 0.2 GeV and the total momentum is 0.4 ± 0.2 GeV/c, which are kinematically inconsistent, at the 2.0 s. d. level, with the neutrino hypothesis, Fermi motion included.

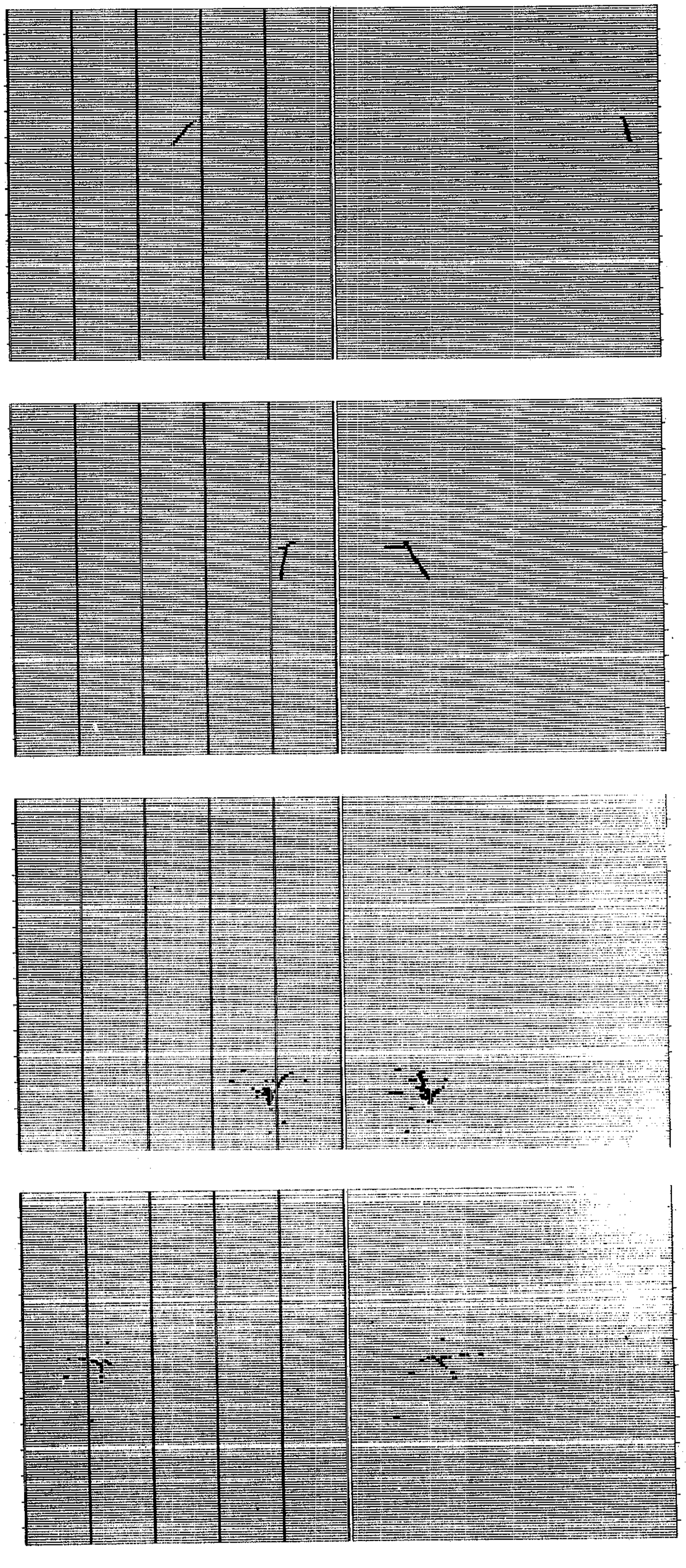

FIG. 1 - The two orthogonal projections of the detector showing the four contained events.

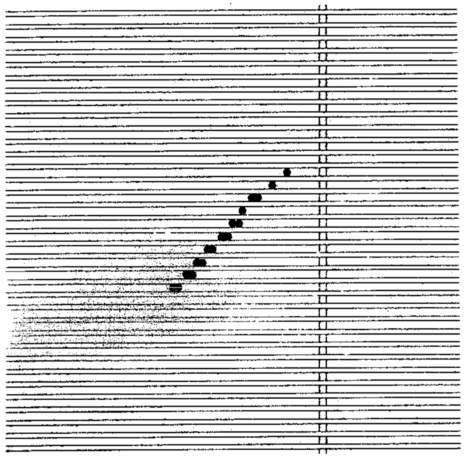

FIG. 2 - Single track, interpreted as single muon due to a quasi-elastic neutrino interaction - total energy 330 ± 15 MeV.

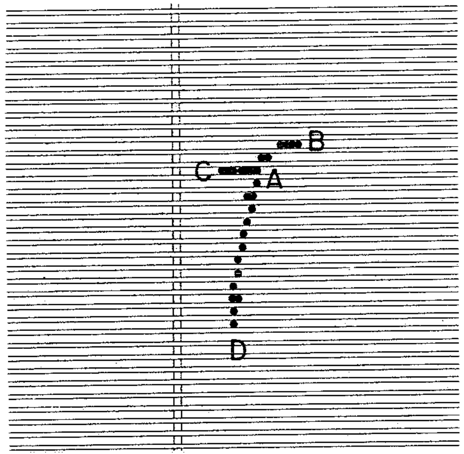

FIG. 3 - Three possible interpretations are possible: a) $\nu + N \rightarrow \mu + \pi$ or nucleon with vertex at A; b) π produced at D with interaction at A; c) μ^- produced at D with capture at A. Total energy 400 ± 100 MeV taking into account all possibilities.

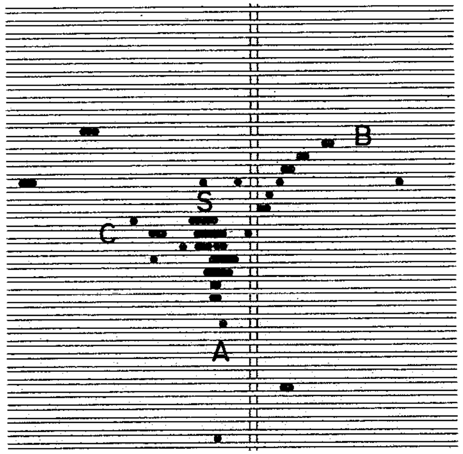

FIG. 4 - Clear example of up-going neutrino interactions with vertex at A. The event consists of two charged tracks AB and AC and an electromagnetic shower S. Two interpretations are possible:
a) $\nu_e + N \rightarrow e + (\pi/p) + (\pi/p)$;
b) $\nu_\mu + N \rightarrow \mu + \pi^o + (\pi/p)$.
Total energy 1.5 ± 0.4 GeV.

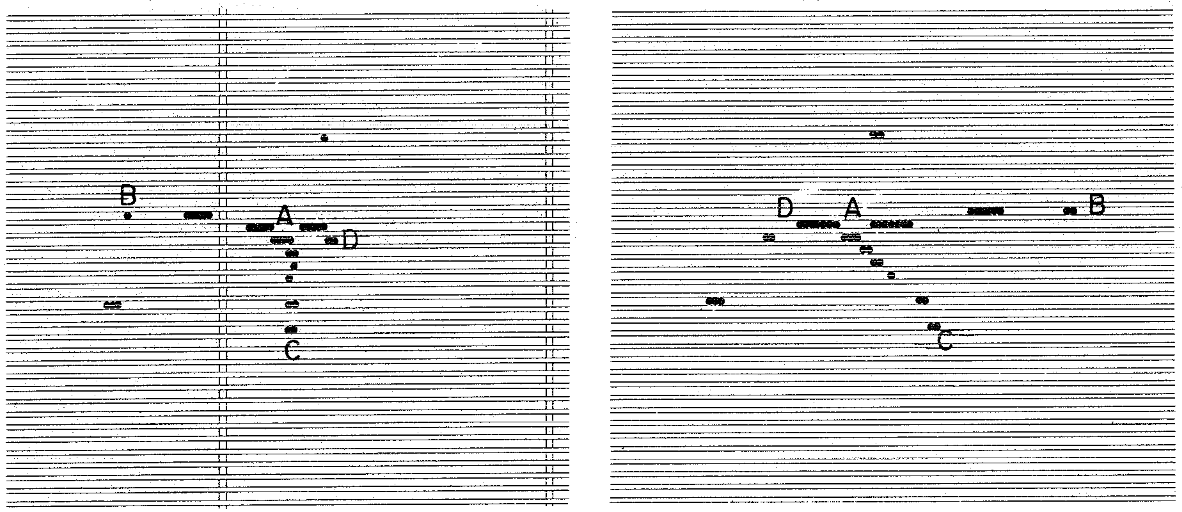

FIG. 5 - The two orthogonal views of the proton decay candidate. The hits beyond the tracks indicated in events 3 and 4 are considered to be due to soft photons or neutrons from nuclear breakup, and are certainly not accidental.

Furthermore, independent of any kinematic arguments, we note that the angle between the tracks AB and AD is $160^\circ \pm 7^\circ$. In the neutrino test runs in which we recorded only 23 three-prong events, only one has an angle between the muon candidate and any one of the two other tracks greater than 140°. We conclude that the probability that the event be neutrino induced is $< 1\%$ at 90% C. L.

b) A neutrino interaction at D producing two almost parallel charged particles (DB = μ, DAC = = π, scattering at A). In this case the visible energy is 1.2 ± 0.3 GeV and the total momentum 1.2 ± 0.3 GeV/c, which are kinematically consistent with a ν interaction, such as $\nu N \rightarrow \mu^- \pi^+$ plus a low energy nucleon. The angle however, between the two visible tracks is small ($< 10^\circ$). In the neutrino test run we observed 98 two-prong events, but none with an angle less than 15°. We conclude that the probability of such a neutrino hypothesis is $< 0.5\%$ at 90% C. L.

c) A single pion produced by a neutral current interaction. From our test runs with charged particles we find that only 7% of the pions with energy around 1 GeV could simulate a three-prong event. Taking into account the relative frequency, evaluated from our neutrino test run, that a neutrino produces a single pion neutral current event, we find that the overall probability of this hypothesis is negligable with respect to the previous two.

In conclusion we expect, at 90% C. L., < 0.04 neutrino events with this topology.

We have also calculated the probability that this event be simulated by a neutron produced by a muon interaction in the rock and interacting in the detector unaccompanied by the muon itself. The contribution by this process may be evaluated from two independent calculations(3,4) and is found to be definitely lower than the neutrino one (less than 0.01 events at the 90% confidence level).

This event can be interpreted as a nucleon decay, in various modes:

1) $P \rightarrow K^0 \mu^+$

In this case the $\pi\pi$ mass (tracks AC and AD) is 0.55 ± 0.08 GeV, the muon and kaon momenta 0.38 ± 0.15 and 0.3 ± 0.1 GeV/c, and the total energy 1.0 ± 0.2 GeV. Total momentum unbalance is 0.4 ± 0.2 GeV/c, in good agreement with proton decay, if Fermi momentum is taken into account.

2) $P \rightarrow K^*$, with $K^* \rightarrow K^0 \pi$

The three pion invariant mass is 0.96 ± 0.20 GeV, the K^* momentum is 0.4 ± 0.25 GeV/c.

3) $P \rightarrow 3\mu$

The total energy is 0.90 ± 0.15 GeV and a momentum unbalance of 0.3 ± 0.1 GeV/c.

Other decay modes containing a ρ are also possible, but would be strongly suppressed by pion absorption in the nucleus.

We would like to conclude that our nucleon decay candidate seems hard to be explained as a neutrino or neutron interaction. Our grain looks adequate to discriminate proton decay from the background, which, as for the Kolar Gold Fields Experiment$^{(5)}$, comes mainly from neutrino interactions when the detector is located very deep underground. A single event can however, represent only an indication for proton decay. After evaluating the efficiency of our apparatus, we calculate that one event corresponds to a mean nucleon lifetime/branching ratio between 0.8 and 1.6×10^{31} years depending on the decay mode.

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