Nucleon Decay and Atmospheric Neutrinos in the Mont Blanc Experiment

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Abstract

In NUSEX experiment, during 2.8 years of operation, 31 fully contained events have been collected; 3 among them are nucleon decay candidates, while the others have been attributed to υ interactions. Limits on nucleon lifetime and determinations of υ interaction rates are presented.

The Detector.

NUSEX detector is a digital tracking calorimeter, planned to study the stability of nucleon.

It has been running since June 1st, 1982 in a cave aside the Mont Blanc Tunnel, covered by a minimum overburden of ≈ 5000 hg cm^{-2} S. R., with a live time of 2.5 years, that is about 86% of solar operation time.

The detector is a sandwich of 136 iron plates 1cm x 3.5 x 3.5m^2, interleaved by layers of plastic streamer tubes of the resistive cathode type.

Each plane of tubes is formed by an array of 320 tubes, 3.5m long and 1 cm^2 cross-section, aligned with the tunnel axis.

Tubes are made of extruded PVC; a high resistivity varnish covers the cathode walls; anodes are $\emptyset 100$ μm wires, and tubes are operated at 3.9 kV with an Ar-CO$_2$-Penthane (1+2+1) gas mixture.

Position of each hit in the detector is recorded through two sets of Al strips (each set has a 1 cm pitch),mounted externally to the tubes, which are respectively parallel (320 strips) and orthogonal (288 strips) to the wires.

Total mass is 150 tons; a detailed description of the detector will be shortly published[1].

Data are collected via CAMAC serial readout by a PDP 11/60 computer on magnetic tape.

Minimum trigger patterns are: either 4 contiguous planes hit or 3+2 contiguous planes hit or 2+2+2 contiguous planes hit, plus any combination of higher plane multiplicity.

Data set for each event consists of the coordinates of each tube fired together with time of firing relative to trigger start, recorded by 100 ns TDC's.

Time information allows identification of μ decays (μ stopping inside the detector) in 17% of the cases.

A trigger to detect magnetic monopoles has also been implemented and is described in [1].

Data concerning nucleon decay and atmospheric neutrinos.

An extimate of rate and topologies of υ interactions in our detector has been obtained through an exposure of a test module to a $\upsilon_\mu(\bar{\upsilon}_\mu)$ beam in CERN, designed to simulate atmospheric υ spectra in the energy region around 1 Gev[4].

Data thus collected have been used to compute backgrounds to nucleon decay that will be quoted further, considering also the presence of υ_e's in atmospheric υ flux.

Data from NUSEX experiment have been selected according to the foollowing characteristics:

1-. Vertex of the event must be inside the volume of the detector;
2-. Tracks coming from vertex must stop inside volume of the detector;
3-. No incoming visible track pointing to the vertex is required.

We guarantee thus to collect only events due to υ interactions in the detector, and possibly due to nucleon decay.

31 events satisfy the above quoted features; they are uniformly distributed in the detector volume and cannot be ascribed to neutron interactions ($\Phi_n < 10^{-6}$ cm^{-2} s^{-1} sr^{-1}); the first 10 among them have already been discussed in detail elsewhere [2,3].

Neutrino rates.

Trigger requirements put an effective threshold both for μ and e at 250 MeV total energy. At this energy trigger efficiency is 40% and rapidly falls below that value.

Supposing that all 31 events are υ interactions, we can identify 21 events

as v_μ interactions, 9 as v_e interactions, while 1 is ambiguous ($v_\mu - v_e$).
Correcting for detection efficiency (trigger x containment efficiency)
event by event, we get the total v interaction rate in our detector, above
the threshold of $E_{visible}$ = 200 MeV:

$$R_v = 152 \pm 20 \, v/(Kton \times yr)$$

and the ratio of v_e and v_μ interactions:

$$R(v_e/v_\mu) = 0.28 \pm 0.09 \pm 0.02$$

where the first term in the error is due to statistics and the second to v_e
v_μ ambiguity. A plot of visible energy distribution of data uncorrected for
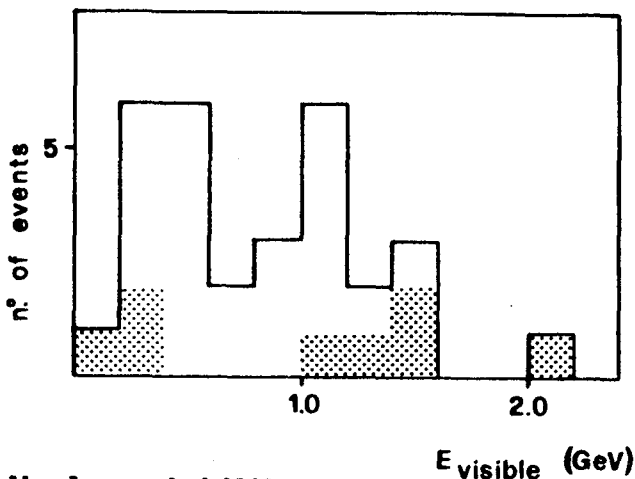detection efficiency is reported in fig. 1.

Fig. 1. Visible energy
distribution of events, not
corrected for detection
efficiencies.
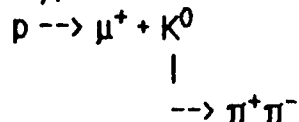Shaded areas are v_e events.
White areas are v_μ events.
1 v_e event of 3.7 GeV is out of
scale.

Nucleon stability.

At present we have 3 events that can be considered nucleon decay
candidates.

Event n. 1, that has been widely discussed elsewhere[2], is a proton decay
candidate, fitting well the hypothesis:

$$p \longrightarrow \mu^+ + K^0$$
$$\mid$$
$$\longrightarrow \pi^+ \pi^-$$

with E = 1.0 ± 0.2 GeV, P = 0.4 ± 0.2 GeV/c, p_μ = 0.38 ± 0.15 GeV/c, $M_{\pi\pi}$ =
0.55 ± 0.08 GeV/c^2, p_K = 0.3 ± 0.1 GeV/c. Errors on total energy and
momentum are mainly due to candidate μ track going almost parallel to
iron plates. Other decay modes also fitted[2] are p $\longrightarrow$ v + K* and p $\longrightarrow$ 3μ.

Background computed from test run is 2 events in 403 v interactions
(corresponding to ≈35 years of data taking with NUSEX), leading to the
expected background rate:

$$B = 0.1 \pm 0.07$$

Second candidate is event n. 22, which is a $\geq$ 2 back to back showers event; best fit is given by a 3 showers hypothesis with:

$E_1 = 370 \pm 110$ MeV $\quad \theta_{12} = 160°$ $\quad\quad$; $\quad\quad E_2 = 550 \pm 140$ MeV $\quad \theta_{13} = 140°$

$E_3 = 140 \pm 80$ MeV $\quad \theta_{23} = 50°$ $\quad\quad$; $\quad E_{tot} = 1060 \pm 200$ MeV; $P = 250$ MeV

consistent with a $\quad p \dashrightarrow e^+ + \pi^0$ decay mode. Expected background from analysis of $\mu\pi$ events in υ test run and electrons of 1.5 GeV from e beam test simulating the topology of our event gives a rate:

$$B = 0.25 \pm 0.07$$

Event n. 30 is a candidate for $n \dashrightarrow \mu^+\pi^-$ decay; kinematical fit is very good, both for total energy (.85 GeV) and for missing momentum (.35 GeV/c). However in this channel from our test we expect 0.6 background events.

Among other channels we have events compatible with nucleon decay only in $p \dashrightarrow \upsilon + \pi^+$; 7 events have been collected, but the expected background from quasi-elastic υ_μ is 6. Limit reported in Table 1 has been computed by background subtraction.

Table 1

Decay mode	N. of candidates	Background	Lifetime/branching ratio (yr x 10^{31}) 90% C. L.
$p \dashrightarrow e^+ \pi^0$	≤ 1	0.25	> 0.6
$n \dashrightarrow e^+ \pi^-$	0		> 0.8
$\underline{N \dashrightarrow e\ \pi}$			$\underline{> 1.0}$
$p \dashrightarrow \mu^+ \pi^0$	0		> 0.7
$n \dashrightarrow \mu^+ \pi^-$	1	0.6	> 0.3
$\underline{N \dashrightarrow \mu\ \pi}$			$\underline{> 0.8}$
$p \dashrightarrow \bar{\upsilon} \pi^+$	≤ 7	6	> 0.2
$n \dashrightarrow \bar{\upsilon} \pi^0$	0		> 1.1
$p \dashrightarrow \bar{\upsilon} K^+$	0		> 0.8
$n \dashrightarrow \bar{\upsilon} K^0$	0		> 0.9
$p \dashrightarrow \mu^+ K^0$	1	0.1	> 0.7

References

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3-. G. Battistoni et al. Phys. Lett. **133B** (1983) 454

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