

RESULTS ON NUCLEON LIFE-TIME FROM THE KOLAR GOLD
FIELD EXPERIMENT

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1. Introduction

The KGF nucleon decay experiment has been in operation since October 1980 with a 140 ton calorimetric detector at a depth of 2.3 Km underground. The detector comprises 34 layers of proportional counters arranged in an orthogonal geometry with 12 mm thick iron plates in between successive layers. The proportional counters are made up of square (10 x 10 cm²) iron plates of wall thickness 2.3 mm. Each of the 1600 counters is instrumented to provide data on (i) ionisation, dE/dx and (ii) arrival time.

The visible energy of a particle is determined to an accuracy of ~20% from the ionisation and range of its track. The end point ionisation of a stopping track provides the direction of motion as well as the nature of the particle (μ/π , k, p). Decay of μ^+ is recorded with an overall efficiency of only 20% in view of the thickness of 13 g/cm² between successive layers.

2. Method and analysis

The great depth of the installation has resulted in suppression of the intensity of cosmic ray muons and their associated background to about 2 events/day. The neutrino background, at energies < 2 GeV is less (~70%) compared to the other detectors operating around the world in view of the location of the detector at ~3°N (Geomagnetic).

About 2600 events were recorded in a live time of

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3.6 years and 96% of them are due to atmospheric muons and are easily identified as such. From the remainder, only 40 events have a vertex inside the detector and are mostly due to the cosmic ray γ -collisions. For nucleon decay search, we consider only 19 events whose tracks are fully confined to the detector volume, from this sample of 40 events. The energy distribution of these events is shown in Fig 1 and compared with the predictions (solid curve) on the γ -induced events. It is clear that there is no clustering of events around the nucleon mass, implying that an event by event analysis is necessary to isolate decay signals, if any. These 19 events could be broadly classified as (i) single-prong (9) and (ii) multi-prong events (10) in which a large fraction are γ -induced.

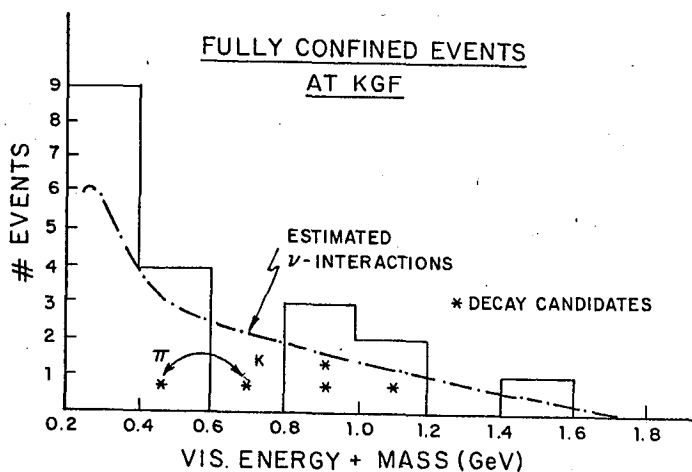


Fig 1: Energy spectrum of confined events. The solid curve is predicted for γ -induced events. The 4 candidate events are shown in the appropriate energy bins.

Candidates for nucleon decay

Four confined, multi-prong events were identified as plausible examples of nucleon decay on the basis of the total energy, momentum balance and track configurations.

(i) Event 587 is composed of showers of electromagnetic nature with total energy 980 ± 200 MeV and momentum imbalance < 250 MeV/c and is interpreted as $p \rightarrow e^+ + \pi^0$. The background from γ -interactions is estimated as < 0.5 events at 90% C.L.

(ii) Event 867 appears at first glance as a single track with a kink around the middle of its range of 167 g/cm^2 with an angle of 40° . A closer examination based on the end point ionisation indicates that it is a good candidate for $p \rightarrow \bar{\nu} k^+$ with $k^+ \rightarrow \mu^+ \bar{\nu} \mu$. The total energy of the kaon is $\sim 700 \text{ MeV}$ and of the decay muon $\sim 270 \text{ MeV}$. It could have been produced in a N.C interaction of neutrinos with a very low probability. A conservative estimate of $\bar{\nu}$ -background is 0.2 events at 90% C.L.

(iii) Event 877 has 3 clear tracks in a back-back configuration. A down moving track with large angle scatter is interpreted as a muon of energy 340 MeV. The two upmoving particles with a large opening angle have effective mass consistent with that of k_s^0 , if they are interpreted as pions. Thus the overall interpretation of the event is $p \rightarrow \mu^+ k_s^0$ with $k_s^0 \rightarrow \pi^+ \pi^-$; the total energy being $900 + 150 \text{ MeV}$. In this event the end point ionisation of 2 tracks (μ and π) clearly establishes their opposing directions of motion, a necessary condition for proton decay. The $\bar{\nu}$ -background for this event is < 0.2 events at 90% C.L.

(iv) Event 1766 is a semi-isotropic event with a total visible kinetic energy of 650 MeV and is unusual of a $\bar{\nu}$ -interaction. The event comprises a shower and well separated penetrating tracks apparently in the opposite hemisphere. It could be interpreted as $n \rightarrow \bar{\nu} \eta^0$, $e^+ p^-$ or $p \rightarrow e^+ k^0$ but the data are insufficient to pin down the preferred decay scheme.

A majority of the single prong events are due to low energy muons produced in elastic $\bar{\nu} \mu$, $\nu \mu$ collisions. However, Event 2099 has kinetic energy 340 MeV and if interpreted as due to a pion, the total energy of $480+50 \text{ MeV}$ is consistent with that to be expected in the decay $p \rightarrow \bar{\nu} + \pi^+$. This event is used to set a limit on the life time, τ , of the proton decaying through this specific mode.

3. Results and discussion

The 4 multi track candidate events discussed above form a special category and cannot be simply dismissed as $\bar{\nu}$ -interactions as can be seen from the estimated backgrounds. From the presently available fluxes and cross-section of cosmic ray neutrinos we expect to record only 15 ± 3 confined events from this source with half of them of multi-prong nature. Among them, events having back-back topology with opening angle $> 140^\circ$ are estimated to be $< 10\%$ i.e., less than 0.8 events during the entire operation of the detector. Energy cuts around

the nucleon mass will reduce this to about 0.3 events or less. We thus consider our data as compatible with nucleon decay even though the statistical significance needs to be improved.

For life time estimate, we consider only the fiducial weight of 60 - 70 tons in the interior of the detector. The partial lifetimes, τ/BR as well as 90% C.L. limits for several decay modes are listed in Table 1. In this calculation we include the detector efficiency as well the probability of hadron absorption inside the iron nucleus.

Table 1

Proton Years : 6.05×10^{31}
 Neutron Years : 6.98×10^{31}

<u>Decay mode</u>	<u>Events</u>	<u>τ/BR(Years)</u>	<u>90% C.L</u>
1. $p \rightarrow e^+ \pi^0$	1	3×10^{31}	7.7×10^{30}
2. $p \rightarrow \mu^+ k_s^0$ $\quad \quad \quad \rightarrow \pi^+ \pi^-$	1	2.1×10^{31}	5.4×10^{30}
3. $p \rightarrow \bar{\nu} k^+$	1	3.8×10^{31}	9.8×10^{30}
4. $p \rightarrow \bar{\nu} \pi^+$	1	4.2×10^{31}	1.1×10^{31}
5. $n \rightarrow \bar{\nu} \eta^0$	1 ^a	1.1×10^{31}	2.9×10^{30}
6. $n \rightarrow e^+ \pi^0$	1 ^a	3.5×10^{31}	8.9×10^{30}

 a: corresponds to the same event no. 1766

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