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Search for nucleon decay in Super-Kamiokande

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Abstract. Latest results on nucleon decay searches from Super-Kamiokande are presented. 1289days of Super-Kamiokande data have been analyzed. Among many possible decay modes, results on the search for $p \to \overline{\nu} K^+$ (which is predicted by some Super Symmetric Grand Unified Theories) and $p \to e^+\pi^0$ (which is predicted to be the dominant decay mode for gauge boson mediated decays) are reported. No evidence for nucleon decay for these modes has been observed. The 90% confidence level lower limits on the nucleon lifetime for $p \to \overline{\nu} K^+$ and $p \to e^+\pi^0$ decay modes are 1.6×10^{33} and 5.0×10^{33}yrs, respectively. These results give strong constraints on Grand Unification models.

1 Introduction

Recent discovery of neutrino oscilations2 (@) suggests the existence of new physics beyond the standard model of particle physics. One possibility is Grand Unified Theories(GUTs). The most impressive prediction of GUTs is baryon number violation. This means protons, which are completely stable in the standard model, decay to lighter leptons and mesons. In the past two decades several experiments searched for nucleon decays, but no evidence for it was observed. Observation of nucleon decay would be evidence for new physics. Many supersymmetric(SUSY) GUT models which allow the extrapolation of the running coupling constants to converge at the GUT scale favor decay modes via $p \to \overline{\nu} K^+$. In many GUT models, the gauge boson mediated decay, $p \to e^+\pi^0$, is predicted to occur with the partial lifetime typically longer than 10^{33}years. Searches for these two decay modes using Super-Kamiokande are presented.

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2 The Super-Kamiokande detector

Super-Kamiokande is a large ring imaging water Cherenkov detector which is located in Kamioka Observatory, ICRR, University of Tokyo, 1000m below the peak of a mountain. The detector is made of cylindrical stainless steel tank and is filled with 50kton of ultra-pure water. The sensitive volume of water is split into two parts. The inner detector is viewed by 11146 50cm diameter photomultiplier tubes (PMTs) and the outer detector is viewed by 1885 20cm diameter PMTs. The outer detector fully surrounds and is optically separated from the inner detector in order to identify incoming and outgoing particles. The fiducial volume is 22.5kton and the total livetime for physics analysis is now 1289days corresponding to a 79.3kton·year exposure. The photo-electron and timing information from each PMT are measured. The vertex position, total energy, the number of rings, particle type and momentum for each Cherenkov ring, and the number of decay electrons are automatically reconstructed. 70years statistics of atmospheric neutrino Monte Carlo(M.C.) sample is used for background estimation.

3 $p \to \overline{\nu} K^+$ mode

Since $\overline{\nu}$ cannot be detected, the main signal of nucleon decay in this mode is provided by K^+. The momentum of the K^+ produced by $p \to \overline{\nu} K^+$ is 340MeV/c. Because the interaction cross section of low momentum K^+ is small, almost all K^+ exit from the ^{16}O nucleus without interaction. Therefore we searched for the two dominant modes, $K^+ \to \mu^+\nu_\mu$ and $K^+ \to \pi^+\pi^0$. Two separate methods were used to search for $K^+ \to \mu^+\nu_\mu$ 4 (@)

3.1 $K^+ \to \mu^+\nu_\mu$ search

When a proton in ^{16}O decays, the remaining ^{15}N nucleus is left in either the ground state or excited states. From the latter case a prompt γ-ray is emitted. The most significant branch is the 6.32 MeV γ-ray from the p3/2-hole state. The

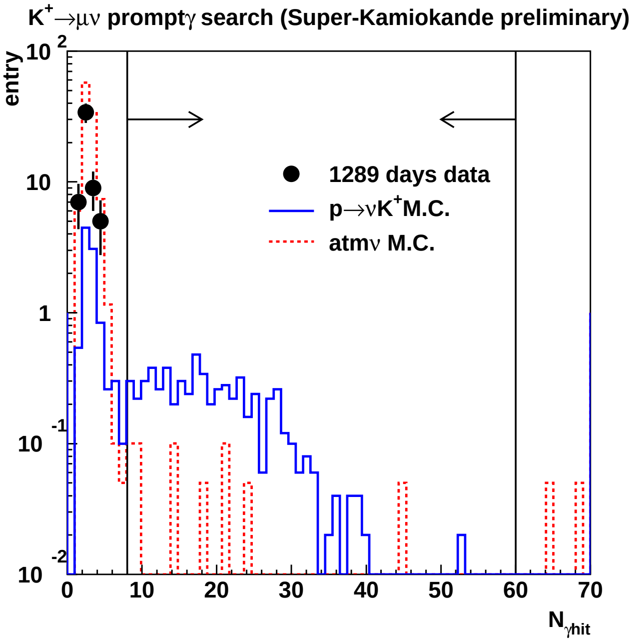

Fig. 1. $N_{\gamma hit}$ distribution for events that satisfy criteria (A1∼A5). The solid line shows the $p \rightarrow \overline{\nu} K^{+}$ M.C., the dashed line shows the atmospheric neutrino M.C. and the black points show data. The atmospheric neutrino M.C. is normalized by the livetime. The region pointed by arrows shows criterion (A6).

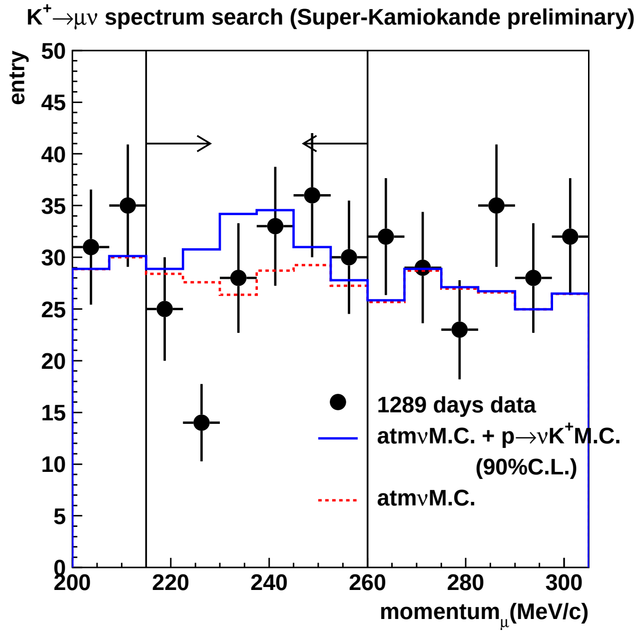

Fig. 2. reconstructed muon momentum distribution for events that satisfy criteria (A1,A3∼A5,A7). The solid line shows the estimated number of $p \rightarrow \overline{\nu} K^{+}$ signal at 90% C.L. + atmosperic neutrinos(dashed line). The black points shows data with statistical errors.

emission probablity is 41% 6 (@). Since the K^{+} is below the threshold of Cherenkov light emission and K^{+} lifetime is 12.6ns, we can separate the γ-ray signal from μ^{+} from K^{+} decay. As the γ-ray and μ^{+} can be detected, most neutrino induced backgrounds can be rejected. The selection criteria for this analysis is as follows: (A1) 1 μ-like(nonshower-type) ring (A2) $215<p_{\mu}<260$MeV/c (A3) 1 decay electron (A4) goodness of the fit requirement (A5) $0<t_{\mu}-t_{\gamma}<100$ns (A6) $7<N_{\gamma hit}<60$. Since 90% of the K^{+} stop before decaying to μ^{+}, the μ^{+} momentum is monochromatic at 236MeV/c. To detect this muon, we apply the criteria (A1,A2,A3). p_{μ} is the reconstructed muon momentum. Criterion (A4) is a requirement of goodness of the vertex reconstruction. This is for rejecting backgrounds caused by poor vertex reconstruction. Most of this type of backgrounds are proton-recoil events. t_{μ} is obtained using PMTs within 50 half opening angle towards the reconstructed muon direction. t_{γ} is determined so that the maximum number of hits in a 12ns window is observed using PMTs out of 50 half opening angle towards the reconstructed muon direction. t_{γ} is searched in the region of $t \leq t_{\mu 0}$. t_{μ_0} is where $dN_{\mu hit}/dt=0$. $N_{\gamma hit}$ is the number of hits in the 12ns window. By applying (A5,A6), backgrounds are reduced by about 1/500. Fig. 1 shows the results. From the atmospheric neutrino M.C. study, the expected number of backgrounds is estimated to be 0.5event. The detection efficiency is 8.8%. There is no event in the signal region. The obtained lower limit of the partial lifetime for this mode is 1.0×10^{33}years at 90% confidence level(C.L.).

We also searched for $p \rightarrow \overline{\nu} K^{+}, K^{+} \rightarrow \mu^{+}\nu_{\mu}$ without tagging the prompt γ-ray. The criteria are (A1∼A4) plus (A7) $N_{\gamma hit} \leq 7$. Fig. 2 shows the momentum distribution of events that satisfy the criteria (A1,A3,A4,A7). The estimated detection efficiency is 33%. The limit on the partial lifetime is set by fitting for the distribution with proton decay events above the atmospheric neutrino background. No excess was observed around 236MeV/c. The limit of this search is 4.4×10^{32}years (90% C.L.).

3.2 $K^{+} \rightarrow \pi^{+}\pi^{0}$ search

When searching for $p \rightarrow \overline{\nu} K^{+}, K^{+} \rightarrow \pi^{+}\pi^{0}$, the following criteria are required. (B1) 2 e-like (shower-type)rings (B2) 1 decay electron (B3) $85< m_{inv,\pi^0} <185$MeV/c^2 (B4) $175< p_{\pi^0} <250$MeV/c (B5) $40< Q_{back} <100$ photo electrons(PEs). m_{inv,π^0} and p_{π^0} are reconstructed π^{0} mass and momentum, respectively. Since the K^{+} decays to a π^{+} and a π^{0} at rest, these two particles go back-to-back. The π^{+} momentum is so close to the Cherenkov threshold that the Cherenkov ring is not detected in most cases. The π^{+} signal is searched for in the direction opposite the reconstructed π^{0} using criterion (B5). Q_{back} is the corrected PEs using PMTs within 40 half opening angle oppisite the π^{0} direction. Fig. 3 shows the results. 1 candidate event is found in the data sample. This, however, is consistent with the estimated background of 1.7events. With the detection efficiency of 6.8% the limit for this decay sequence is 5.9×10^{32}years at 90% C.L..

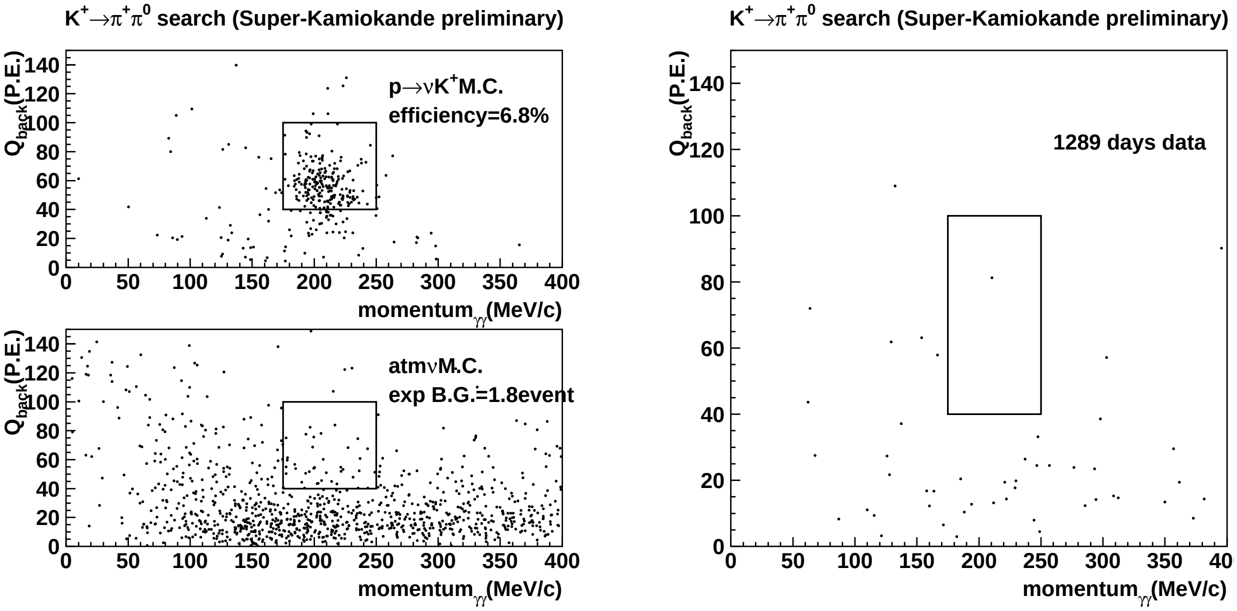

Fig. 3. The distribution of the reconstructed π^0 momentum versus the backward charge from the reconstructed π^0 direction for events that satisfy criteria (B1$\sim$B3). Each figure shows: (upper-left) $p \rightarrow \overline{\nu}K^+$M.C. (lower-left) atmospheric neutrino M.C. (right) data. The box shows criteria (B4,B5).

3.3 combined result for $p \rightarrow \overline{\nu}K^+$ mode

The nucleon decay search via $p \rightarrow \overline{\nu}K^+$ was carried out using three different event topologies. No evidence for nucleon decay was observed. The limit for $p \rightarrow \overline{\nu}K^+$ by combining the three searches is $\tau/B_{p\rightarrow\overline{\nu}K^+} > 1.6\times\ 10^{33}$years (90%C.L.)

4 $p \rightarrow e^+\pi^0$ mode

In this case, a proton decays to back-to-back e^+ and π^0. The e^+ makes an electromagnetic shower producing a single isolated ring. The π^0 almost immediately decays to two γ-rays which initiate showers creating two, usually overlapping, rings. This signature enables us to discriminate $p \rightarrow e^+\pi^0$events clearly from the atmospheric neutrino background. The selection criteria are as follows 8 (@): (C1) 2 or 3 e-like (shower-type) rings, (C2) if 3 rings, 85<m$_{inv,\pi^0}$<185MeV/c^2 (C3) no decay electrons (C4) 800<m$_{inv,tot}$<1050 MeV/c^2 (C5) p$_{tot}$<250MeV/c. m$_{inv,\pi^0}$ is the reconstructed π^0 mass. m$_{inv,tot}$ and p$_{tot}$ are the total invariant mass and total momentum, respectively. The proton invariant mass can be reconstructed in this mode. Criterion (C5) is determined by the Fermi monentum of ^{16}O. The results are shown in Fig.4. The expected background is 0.2 events. The efficiency to select $p \rightarrow e^+\pi^0$ events is 43%. In the data sample, we find no candidate events. The limit on the proton partial lifetime for this mode is $\tau/B_{p\rightarrow e^+\pi^0} > 5.0\times\ 10^{33}$ years (90% C.L.)

5 other modes

We have searched for nucleon decay signals for several decay modes. No evidence of nucleon decay has been observed. The partial life time limits for these modes are summarized in table 1.

6 Summary

Nucleon decay searches from Super-Kamiokande via $p \rightarrow \overline{\nu}K^+$ and $p \rightarrow e^+\pi^0$ are presented. No evidence for nucleon decay has been observed. Table 1 shows obtained lifetime limits including other modes. Fig. 5 compares the present limits with the limits from the other experiments. These results give strong constraints on GUT models.

Table 1. Summary of nucleon decay searches for several decay modes. These limits are calculated at 90% C.L..

mode	τ/B limit($\times10^{32}$years)
$p \rightarrow e^+\pi^0$	50
$p \rightarrow \mu^+\pi^0$	37
$p \rightarrow \overline{\nu}K^+$	16
$n \rightarrow \overline{\nu}K^0$	3.0
$p \rightarrow e^+K^0$	5.4
$p \rightarrow \mu^+K^0$	10

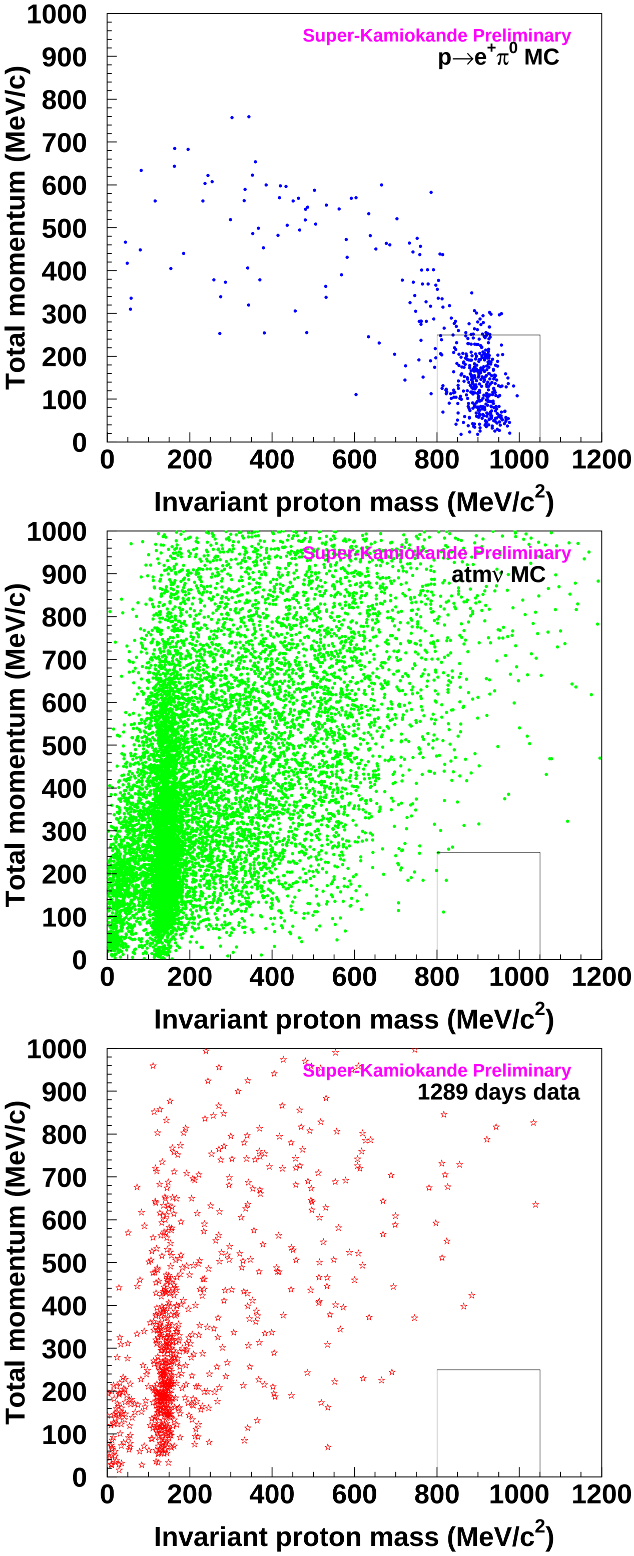

Fig. 4. Total invariant mass versus total momentum distribution for events that satisfy criteria (C1∼C3). Each figure shows: (top) $p \rightarrow e^+\pi^0$ M.C. (middle) atmospheric neutrino M.C. (bottom) data. Criteria (C4,C5) are indicated by the boxed region

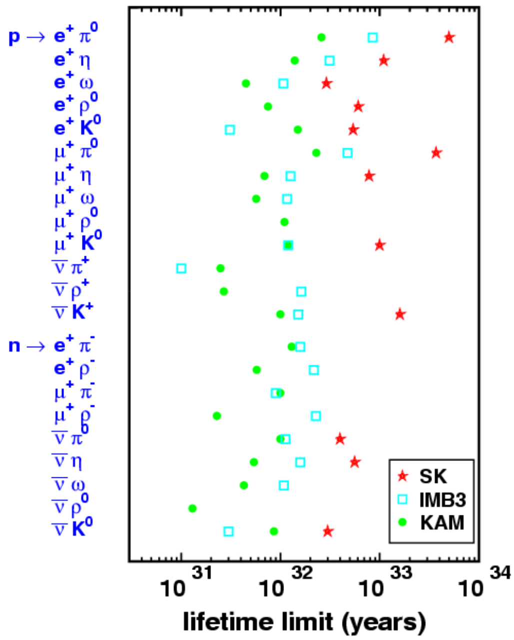

Fig. 5. Summary of the obtained lifetime limits for various nucleon decay modes from Super-Kamiokande , IMB3 and Kamiokande.

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