

Nucleon Decay Search in Super-Kamiokande

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Abstract: Nucleon decay search is one of the key for opening door to Grand Unified Theories (GUTs). This report summarize the latest results of the nucleon decay searches in Super-Kamiokande.

1. Introduction

Strong

Weak

EM

(Electroweak)

GUTs: attempt to unify Strong and Electroweak interactions.

Lepton and baryon numbers are not conserved in GUTs.

Grand Unified Theories

Nucleon decay experiment is the direct probe for GUTs.

Super-Kamiokande is the most sensitive to Nucleon Decay in the world

- Large water Cherenkov detector.
- Contains 7×10^{33} protons in fiducial volume.
- High efficiency for $p \rightarrow e^+ \pi^0 / \mu^+ \pi^0$ due to two free protons (w/o interaction in nucleus).
- Well understand atmospheric ν background.
- Total exposure: 306 kiloton \cdot year

2. $p \rightarrow e^+ \pi^0 / \mu^+ \pi^0$: Favored by non-SUSY GUTs

All final particles detectable by SK!

Selection for $e^+ \pi^0$ ($\mu^+ \pi^0$):

- Fully contained, VTX in fiducial volume.
- 2 or 3 ring and all e-like (one μ -like), w/o (with) Michel electron.
- $85 < M_{\pi^0} < 185$ MeV (for 3-ring event).
- $800 < M_p < 1050$ MeV & $P_{\text{tot}} < 250$ MeV/c
 - $P_{\text{tot}} < 100$ MeV/c: Free proton enriched, almost background free.
 - $100 \leq P_{\text{tot}} < 250$ MeV/c: Bound proton enriched.
- No neutrons (only for SK4).

Two events found in $\mu^+ \pi^0$

Mode	P_{tot} (MeV/c)	Effi(%)	BKG	Obs	Limit(90CL)
$p \rightarrow e^+ \pi^0$	$P_{\text{tot}} < 100$	18.8 ± 1.1	0.07 ± 0.02	0	$> 1.7 \times 10^{34}$ yrs
	$100 \leq P_{\text{tot}} < 250$	19.9 ± 3.0	0.54 ± 0.16	0	
$p \rightarrow \mu^+ \pi^0$	$P_{\text{tot}} < 100$	17.9 ± 0.9	0.05 ± 0.02	0	$> 7.8 \times 10^{33}$ yrs
	$100 \leq P_{\text{tot}} < 250$	16.7 ± 2.8	0.82 ± 0.24	2	

3. $p \rightarrow \bar{\nu} K^+$ mode: Favored by SUSY GUTs

Features

- K^+ stops in water and two body decay ($K^+ \rightarrow \nu \mu^+, \pi^+ \pi^0$) \rightarrow monochromatic momentum.
- Remained nucleus emits 6 MeV γ ray.
- 3 methods are combined for sensitivity study;
 - excess in P_{μ} above background,
 - μ with prompt γ ,
 - monochromatic π^0 with PMT activities in backward of π^0 .

Method	Av. Eff(%)	BKG	OBS
$K^+ \rightarrow \mu^+ \nu$ with γ	7.9 ± 1.7	0.39 ± 0.10	0
$K^+ \rightarrow \pi^+ \pi^0$	8.2 ± 0.8	0.56 ± 0.16	0

No evidence has been observed.

Lifetime limit at 90%CL: $> 6.6 \times 10^{33}$ yrs

Nucleon lifetime limit summary (90%CL)

Mode	Limit (years)
$p \rightarrow e^+ \pi^0$	$> 1.7 \times 10^{34}$
$p \rightarrow \mu^+ \pi^0$	$> 7.8 \times 10^{33}$
$p \rightarrow \bar{\nu} K^+$	$> 6.6 \times 10^{33}$

Recent publications

- Di-nucleon decay search, $pp \rightarrow \pi^+ \pi^+, pn \rightarrow \pi^+ \pi^0, nn \rightarrow \pi^0 \pi^0$: PRD91,072009 (2015)
- Neutron-anti-neutron oscillation; PRD91, 072006(2015)
- $p \rightarrow \nu K^+$: PRD90, 072005 (2014)
- Tri-lepton decay, $p \rightarrow e^+ \nu \nu, \mu^+ \nu \nu$; PRL113,101801 (2014)
- $n \rightarrow \nu \pi^0, p \rightarrow \nu \pi^+$: PRL113,121802 (2014)
- $pp \rightarrow K^+ K^+$; PRL112,131803 (2014)

More papers coming soon!

5. Summary

A 306kton \cdot year data has been analyzed for $p \rightarrow e^+ \pi^0, \mu^+ \pi^0$, and νK^+ search. We found two candidates in $p \rightarrow \mu^+ \pi^0$ but still consistent with background. Several other modes have been studied intensively and so far we have not observed any evidences of nucleon decays.