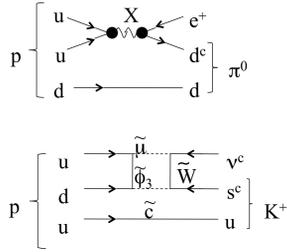


Introduction:

GUTs and Baryon number violating phenomena

- Grand Unified Theories (GUTs) of elementary particle are motivated to unify gauge forces of the Standard model (SU(3)×SU(2)×U(1)).
- One of the attractive features of GUTs is that it can naturally explain quantization of electric charges, and lepton/quark charge ratio.
- Another important prediction is that **nucleon decays via Baryon number violating processes.**
- Some class of GUTs predicts neutron can spontaneously convert to anti-neutron.

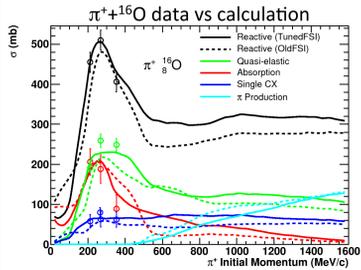


Nucleon decay, $n\bar{n}$ oscillation are direct evidence of GUTs.

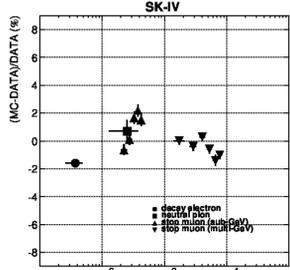
MC simulation of signals

Detailed Monte Carlo simulation of nucleon decays/ $n\bar{n}$ oscillation events are developed to understand the expected signals.

Kinematics of the nucleons in oxygen (Fermi motion, binding energy, nucleon-nucleon correlation, etc.) are considered.



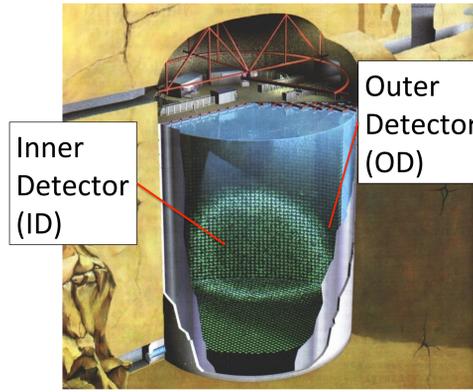
An important item is Meson interaction in nuclear/water. Interactions of mesons ($\pi/\eta/\omega/K$) are taken into account.



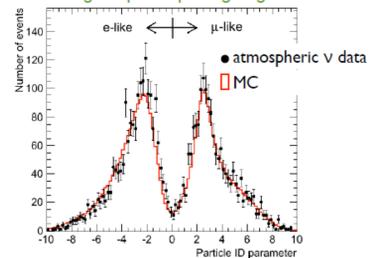
Reconstituted Energy of control samples (MC vs Data)

Full MC simulation of Super-Kamiokande detector has been developed with various calibration data. This is used for both signal/atm.v events.

Super-Kamiokande

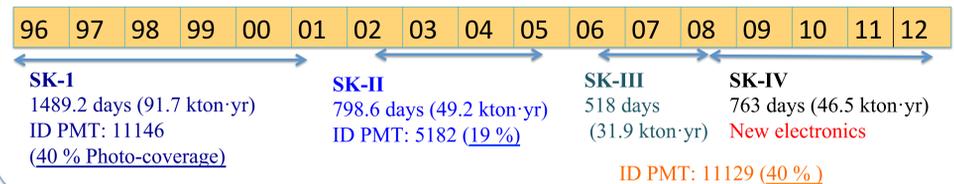


- Water Cherenkov detector
- Deep underground (1000m, 2700 m.w.e), Kamioka-mine, Japan.
- Cylindrical shape, 50kton water (22.5 kton fid.vol)
- Optically separated Inner Detector/Outer Detector
- ID : 20inch PMTs, OD: 8inch PMTs



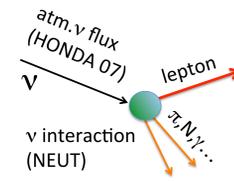
Good Particle ID: ~99% e/ μ
High momentum resolution: ~3% for 1GeV electron

History of detector



Background: Atmospheric neutrino events

Hadron production by atmospheric neutrino interactions can be mimic events for nucleon decays/ $n\bar{n}$ oscillation.



Atm.v MC events are developed based on calculated atm.n flux (HONDA07) and neutrino interaction model (NEUT). MC is normalized with sideband events, and $\nu_\mu \rightarrow \nu_\tau$ oscillation is taken into account.

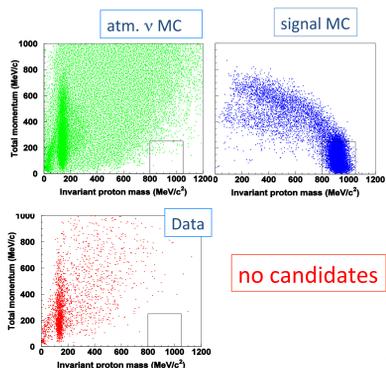
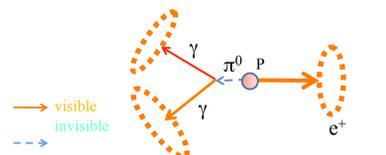
Results



SK-I+II+III+IV, 219.7kton yr

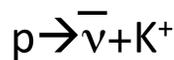
- EM showers of electron & γ 's from π^0
- Invariant Mass & total momentum are consistent with protons in H_2O .

- Selection
- All visible particle contained in ID
 - 2 or 3 Cherenkov rings, all rings are e-like
 - no decay-electrons
 - 85 MeV < M_{π^0} < 185 MeV (for 3-ring event)
 - 800 MeV < M_p < 1050 MeV & P_{tot} < 250 MeV/c

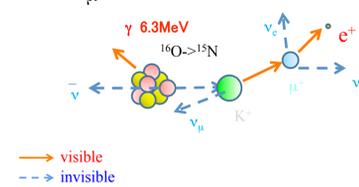
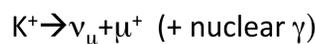


$\tau/B > 1.3 \times 10^{34}$ yrs (90% C.L.)

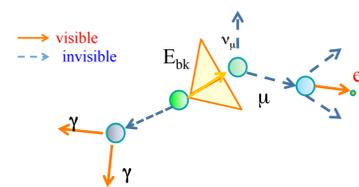
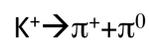
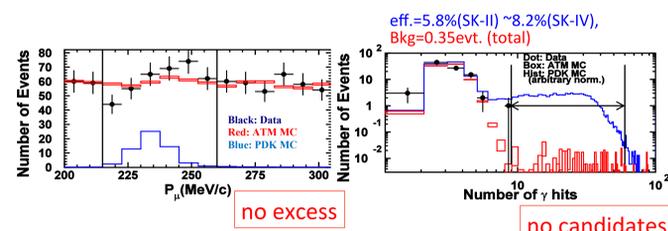
(syt. errors are taken into account by Bayesian statistics)



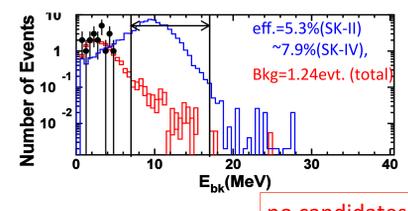
SK-I+II+III+IV, 219.7 kton yr



- Monochromatic μ^+ (236MeV/c) from K^+ decay
- Some fraction (~36%) will be accompanied by prompt signal of γ from nuclear de-excitation.



- Monochromatic π^0 (205MeV/c) from K^+ decay
- Weak Cherenkov light from π^+ in backward region



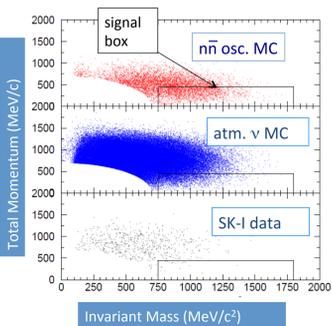
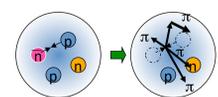
Combined lifetime limit: $\tau/B > 4.0 \times 10^{33}$ yrs (90% C.L.)

neutron-antineutron oscillation

SK-I 91.7ktyr

- Anti-neutron oscillated from neutron immediately pair-annihilates with a surrounding nucleon.
- Pions ($\langle n_\pi \rangle \sim 4$) of several 100MeV/c's are emitted isotropic inside the nuclei.

Branching ratio of anti-n + nucleon derived from bubble Chamber anti-p + d data

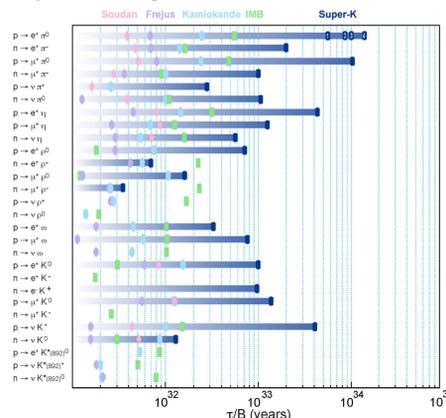


Detection efficiency 12.0%
Estimated B.G. events 24.0 events
Candidates 24 events
No excess

$T_{bound} = \frac{1}{\Gamma_{limit}} = 1.97 \times 10^{32}$ yrs (90% CL)
 $\rightarrow \tau_{free} > 2.49 \times 10^8$ sec
(Assuming suppression factor $R = 1.0 \times 10^{23} \text{sec}^{-1}$)

Other nucleon decay mode (N → l+m) results

N → l+m modes are widely searched for. No positive signature was found so far.



Summary

We have searched for Baryon number violating phenomena in Super-Kamiokande with up to 220 kt·yr data. No indications have been found yet, and most stringent limits are given. Many of GUTs are now at a range of Super-K searches.

