Measurement of neutron multiplicity in muon capture on ^{16}O in Super-Kamiokande

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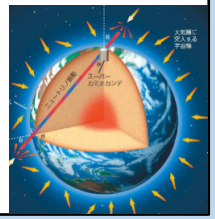
Abstruct

Neutron multiplicity in μ^- capture on ^{16}O was measured using cosmic ray muon in Super-Kamiokande. 26(8)% of the events ended with no neutron, 70(7)% one neutron, and 3.5(1.8)% two neutrons. This is the first direct measurement and will be used to improve reconstruction of neutrino energy and direction in future atmospheric neutrino study.

SK and Atmospheric Neutrino Studies

- Super-Kamiokande (SK) is a water Cherenkov detector, located 1000 m underground.
- Atmospheric neutrino, generated from cosmic rays in the atmosphere, is one of the main targets of SK.
- Oscillation probability depends on neutrino energy and flying distance.

→ Energy and direction resolutions are important.



Neutron in Neutrino Study

- Neutron multiplicity in the neutrino reaction can be used to correct neutrino energy.

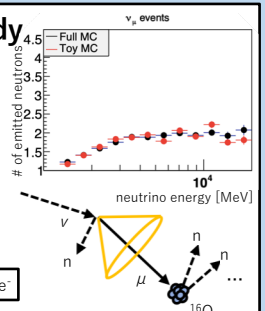
$$\nu_\mu + {}^{16}O \rightarrow \mu^- + F + n + n + \cdots$$

higher energy → more neutrons

- Neutrons produced in μ^- capture on ^{16}O yields systematic error here.

$$\mu^- + {}^{16}O \rightarrow N + \nu_\mu + n + n + \cdots$$

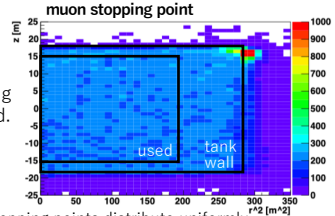
18.4% of μ^- is captured , not decay to e^-



Goal of this work : Measuring the neutron multiplicity in μ^- capture using cosmic ray muon.

Event Selection

- Events induced by cosmic muons which stopped in the detector tank (stopping muons) were accumulated.
- Livetime 33 days, in June - July 2020



Stopping points distribute uniformly.

- Selection

#	Cut	# of passed events
0	-	253911
1	Stopping point is >3m apart from tank wall	124623
2	No decay-electron	49834

Strict conditions are set for decay-e (efficiency ~65%) in order not to lose capture events.
(De-excitation γ from μ^- capture mimic decay-e.)

Neutron Tagging

- Free neutron in water is captured by proton. (TimeConst. = 202 μs)

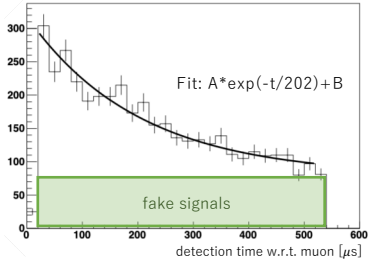
→ 2.2 MeV γ is generated.

↳ ≃ energy threshold in SK

- This signal is searched for using Neural Network. Signal efficiency = 27%
- Time uncorrelated components = fake signals

↓

mis-tagging rate = 0.0164(8) /event



Result of Multiplicity Measurement

- Observed neutron multiplicity

# of tagged neutron /event	0	1	2	3
# of events	47014	2750	70	0

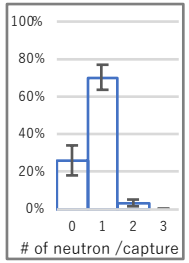
correct analytically considering :
・tagging efficiency ・mis-tagging
・# of capture events (calculated from μ^+/μ^- & capture prob.)

- Corrected neutron multiplicity

# of neutron /capture	0	1	2	3
# of events	2528	6808	339	0
statistic uncertainty	369	313	159	51
systematic uncertainty	678	563	69	
Total uncertainty	772	645	174	51

Systematic uncertainty mainly come from neutron tagging efficiency.

# of emitted neutrons /μ^- capture
$P(0) = 26 \pm 8\,\%$
$P(1) = 70 \pm 7\,\%$
$P(2) = 3.5 \pm 1.8\%$



- This is the first measurement of neutron multiplicity distribution in μ^- capture on ^{16}O.
- Averaged multiplicity (average of # of neutron /capture) was reported to be 0.77±0.18 (M. Plett and S. Sobottka (1971)), which was 0.77±0.08 in this work.

Future Plan

- Now we have dissolved Gd in SK (SK-Gd).
- Gd emits more energetic γ (8 MeV in total) after neutron capture.
  → Neutron tagging efficiency is estimated to be 50-60%.
- The efficiency should be measured more precisely.