**Introduction**

Neutral Current Quasi-Elastic (NCQE) on oxygen:

**Primary process:**

\[ \nu + ^{16}O \rightarrow \nu + ^{15}O + \gamma 's \]

De-excitation \( \gamma 's \) as a signature to detect NCQE

**Secondary process:**

\[ n + ^{16}O \rightarrow X + \gamma 's \]

Features:
1. De-excitation \( \gamma 's \) in 1-10 MeV
2. Accompanied by neutrons in many cases

Importance:
1. Main background to SRN (DSNB) detection
2. NC interaction study
3. Supernova detection with NCQE

**Super-Kamiokande**

- A large water-Cherenkov detector.
- PMT support structure divides it into an inner detector (ID) and an outer detector (OD).
- Fiducial volume at 20 kiloton.


- In SK-IV, new FEEs and DAQ system enabled a special trigger to record events with delayed neutron capture signal.
- An SHE trigger of [-5, 35] \( \mu s \) is issued when ID triggers above 7.5 (9.5) MeV without an OD trigger.
- A forced trigger AFT follows to record [35, 535] \( \mu s \) data, so as to record 93% of neutron capture 2.2 MeV \( \gamma \) signal on hydrogen.

**Simulation setup**

- Atmospheric neutrino flux: HHKM model [3]
- Generator: NEUT with Ankowski’s NCQE model [4]
- Detector Simulation: SKDetSim (GEANT3 based)

**Data reduction**

- Energy window: 8-30 MeV
- Pre-selection: remove non-physical events
- Spallation cut: remove events close to a muon (mainly 9Li)
- Further reduction: solar + FV + \( \mu / \pi \) + etc...
- Cherenkov angle: remove electron-like events
- Neutron tagging: selecting events with single neutron only

**Neutron tagging candidates**

The final sample consists of 89 events and is validated by a neutron capture time fitting.

The expected number of events is:
- NCQE: 58.0
- Single pion: 23.1
- Multi pion: 2.4
- Non-NC w/ neutron: 1.3
- Accidental: 13.7

In total, 98.5 events expected against 89 events observed, within 1\( \sigma \) statistical uncertainty.

**Analysis and cross-section**

\[ \frac{\langle \sigma_{NCQE} \rangle}{\langle \sigma_{NC} \rangle} = \frac{10 \times (38.5 \text{ MeV})^{2} \times \alpha(E_{\gamma})}{10 \times (38.5 \text{ MeV})^{2} \times \alpha(E_{\gamma})} \]

\[ = 1.14 \times 10^{-30} \text{ cm}^{2} \]

\[ \frac{\langle \sigma_{NCQE} \rangle}{\langle \sigma_{NC} \rangle} = \frac{\langle \sigma_{NCQE} \rangle}{\langle \sigma_{NC} \rangle} \times \frac{\langle \sigma_{NCOE} \rangle}{\langle \sigma_{NC} \rangle} \]

\[ = \left( \frac{89 - 13.7 - 1.3 - (21.1 + 2.4 + 0.0)}{58.0} \right) \times 1.14 \times 10^{-30} \text{ cm}^{2} \]

\[ = 0.95 \pm 0.12 \text{ (stat.)} \pm 0.49 \text{ (sys.)} \times 10^{-30} \text{ cm}^{2}. \]

Null hypothesis of no NCQE observation is rejected by 4.0 \( \sigma \).

**References**


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