The observation of gamma rays after neutral current interactions at Super-Kamiokande by using the T2K neutrino beam

The T2K Collaboration

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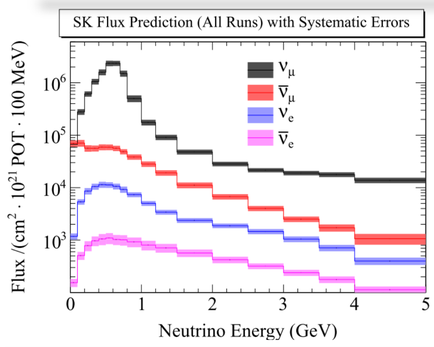
Abstract

We report the first measurement of the neutral current quasi-elastic (NCQE) cross section on oxygen by observing nuclear de-excitation gamma rays with the T2K neutrino beam. The interaction from atmospheric neutrino is one of the main background in supernova relic neutrino search. The de-excitation gamma rays can be observed in the Super-Kamiokande (Super-K) water Cherenkov detector. We selected candidate events by using the T2K beam timing, dramatically reducing the background of natural radioactivity. We observed 43 events in the 4~30 MeV reconstructed energy region. We measured the NCQE cross section of $1.35 \times 10^{-38}\mathrm{cm}^2$.

Motivation

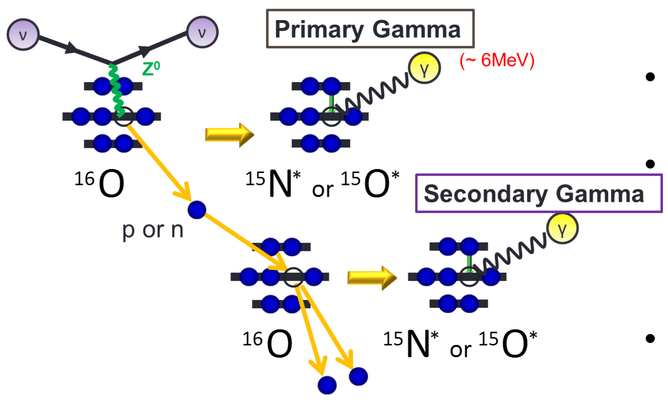
- No previous measurements of NCQE scattering on oxygen at hundreds of MeV with de-excitation gamma rays.
- Gamma rays produced by atmospheric neutrinos are one kind of the main backgrounds in supernova relic neutrino searches.
- NC samples can be used to search for sterile neutrino oscillations.
- Can use similar low-energy samples to look for low-mass dark matter.

T2K neutrino beam @Super-K



- Off-axis 2.5 degree
- Energy peak is at 630 MeV.
- NCQE interactions are the largest NC samples in T2K-SK data.

NCQE physics process



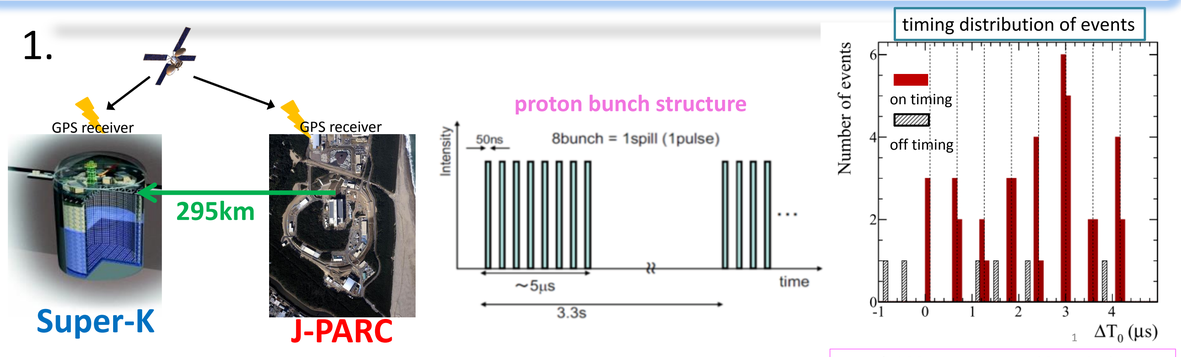
- After a neutral current interaction, a nucleon is kicked out from an oxygen atom.
- The de-excitation gamma rays are emitted from oxygen nucleus.
- When the kick-out nucleons interact with other oxygen nuclei in water, secondary gamma rays can also be produced.
- We can observe Cherenkov light from Compton electrons.

- Goal: De-excitation gamma rays of NCQE interaction.
- Backgrounds
  - ν beam-related: NC-other interactions, CC interactions
  - ν beam-unrelated: gamma rays from radioactive impurities of Super-K wall and PMTs, decay e from cosmic muon.

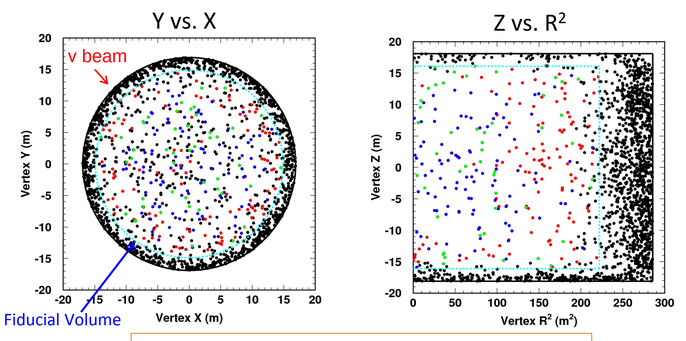
MC production

- Neutrino flux-- simulated with FLUKA & Geant3, constrained by monitoring and external experiments.
- NEUT--Use Ankowski model for NCQE scattering and photon production.
- Detector simulation-- Geant3, GCALOR to simulate Cherenkov photons and neutrons which produce secondary gammas.

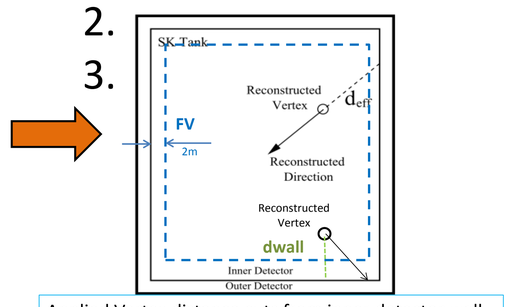
Data reduction



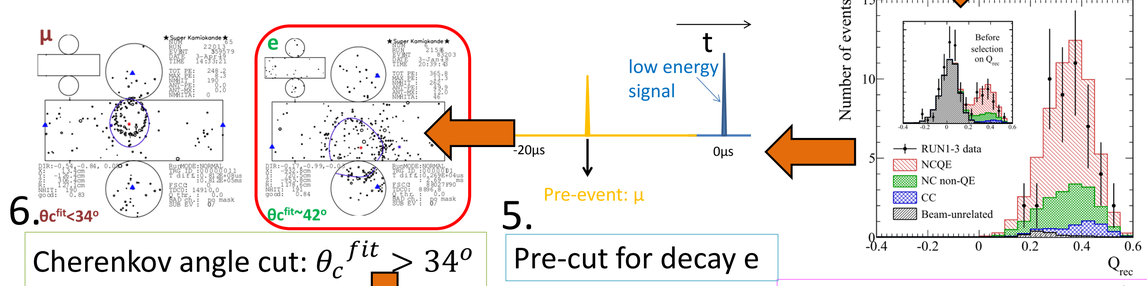
- ±100 ns cut around bunch times to reduce radioactive background.



Vertex distribution before (after) the following cuts
Black : Before FV cut Red : After dwall cut
Blue : After effwall cut Green : After Q_{rec} cut



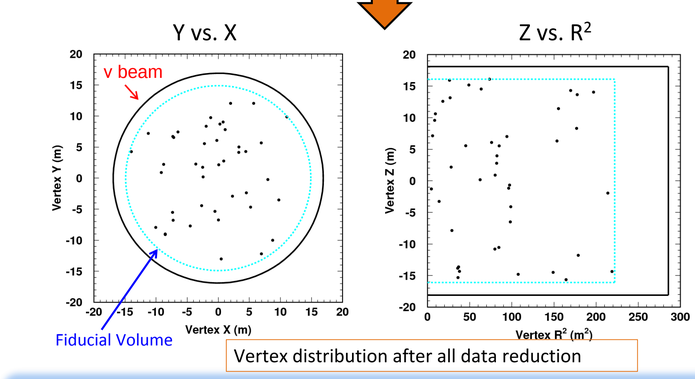
Applied Vertex distance cuts from inner detector wall.



Cherenkov angle cut: $\theta_c{}^{fit} > 34^o$

Pre-cut for decay e

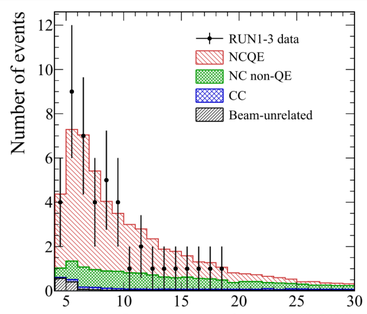
Fit quality cut: Quality cut criterium $Q_{rec} = g^2{}_t - g^2{}_p$
$g^2{}_t$: goodness of hit times $g^2{}_p$: goodness of hit pattern



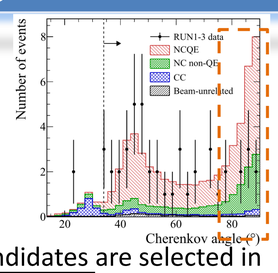
Vertex distribution after all data reduction

	Reductions
1	GPS timing
2	Fiducial Volume
3	dwall, effwall
4	Fit Quality
5	Decay e
6	Cherenkov angle cut

Observed Event Candidates



Expected number of events		
NCQE	39.1	70.3%
NC others	13.1	23.6
CC	2.2	3.9
Beam unrelated	1.2	2.2
Total	55.7	



- After all the reductions, 43 event candidates are selected in reconstruction energy (E_{rec}) region of 4~30MeV.
- Simulation predicts 55.7 events.
- Discrepancies between MC and data at large Cherenkov angle.

Systematic Errors and σ_{NCQE} measurement result

Fraction of sample	Signal NCQE ~70%	NC-nonQE ~24%	CC ~4%	Beam unrel. ~2%
Flux	11%	10%	12%	-
Cross-section	--	18%	24%	-
Primary γ Production	10%	3%	6%	-
Secondary γ Production	13%	13%	7.6%	-
Detector response	2.2%	2.2%	2.2%	-
Oscillation Parameters	-	-	10%	-
Total	20%	25%	30%	0.8%

No previous experimental data about secondary gamma production. We compared different MC models to get these systematic error values.

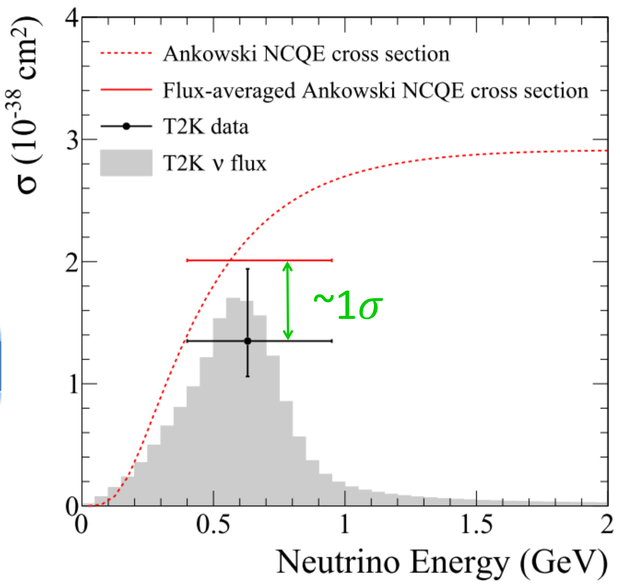
- NCQE cross section as below

observed data event # in Run1~3

$$< \sigma^{obs}_{\nu,NCQE} >= \frac{N^{obs} - N^{exp}_{bkg}}{N^{exp} - N^{exp}_{bkg}} < \sigma^{theory}_{\nu,NCQE} >$$

$2.01 \times 10^{-38}\mathrm{cm}^2$

$$< \sigma^{obs}{}_{\nu,NCQE} > = 1.35 \times 10^{-38}\mathrm{cm}^2$$
$$68\%\mathrm{C.I.}\ (1.06, 1.94) \times 10^{-38}\mathrm{cm}^2$$



Summary

- T2K has already reached 6.57x10^{20} protons on target (POT) now, and we have analyzed about half accumulated data to search for NCQE event candidates.
- After data reduction, 43 event samples are selected as γ ray candidates, which is lower than MC simulation prediction (55.7).
- There are discrepancies between MC and data in the Cherenkov angle distribution. Analysis is now in progress.
- Observed NCQE cross section: $< \sigma^{obs}{}_{\nu,NCQE} > = 1.35 \times 10^{-38}\mathrm{cm}^2$ with a 68% confidence interval of (1.06, 1.94)$\times 10^{-38}$ cm^2.