Measurement of the ν_μ CCQE Cross Section with the ND280 Detector at T2K

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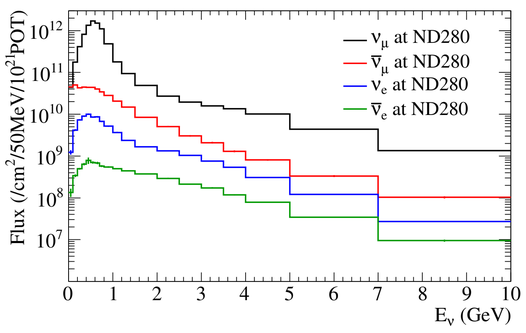
Abstract

The first measurement of the ν_μ Charged Current Quasi-Elastic (CCQE) cross section on Carbon by the T2K experiment is presented. The cross section is extracted in bins of E_ν from a fit of the NEUT neutrino generator model to the observed $p_\mu - \cos(\theta_\mu)$ distribution in the off-axis near detector (ND280).

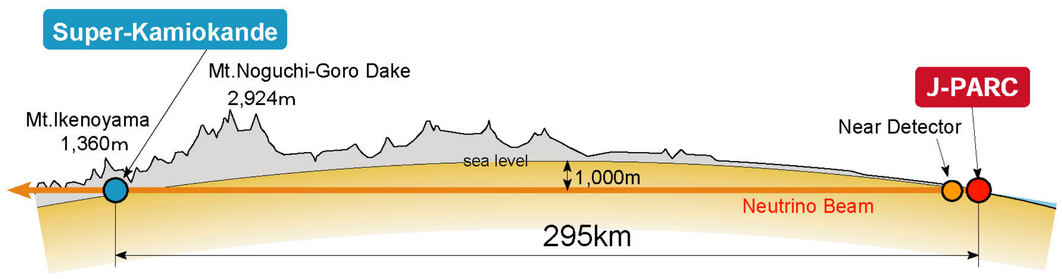
1. T2K Experiment



Predicted flux at the ND280

The goals of the T2K experiment [1] are to:

- discover ν_e appearance in a ν_μ beam,
- make precise measurements of ν_μ disappearance,
- study neutrino-nucleus interactions at $E_\nu \sim 1$ GeV.

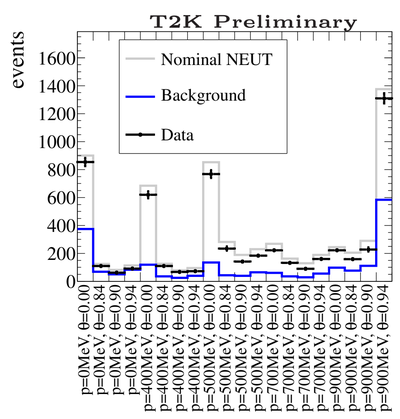


- A high intensity proton beam at J-PARC produces a narrow-band ν_μ beam with a peak energy of 0.6 GeV at the far detector,
- The Far detector is Super-Kamiokande, a 50kton water Cherenkov detector, located 2.5° degrees off-axis and 295km from the production point.
- Detectors in the ND280 complex at 280m are used to directly measure the neutrino beam properties and neutrino-nucleus interaction cross sections.

3. The NEUT Model

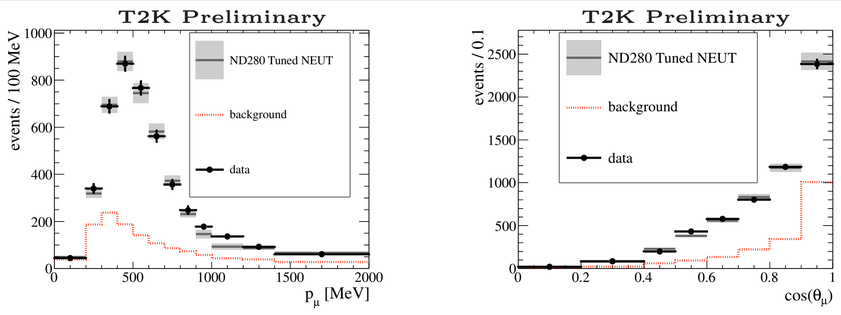
- CCQE with the Smith-Moniz implementation of Fermi Gas Model
- FSI cascade model
- No additional contribution from multi-nucleon effects

5. Analysis Method



Simulated template histograms were fit to the observed $p_\mu - \cos(\theta_\mu)$ distribution. The CCQE cross section was extracted by weighting 5 template histograms in bins of E_ν. Systematic uncertainties were accounted for by varying bin contents with nuisance parameters. A maximum likelihood fit was used to find the best fit parameters.

6. Kinematic Distributions

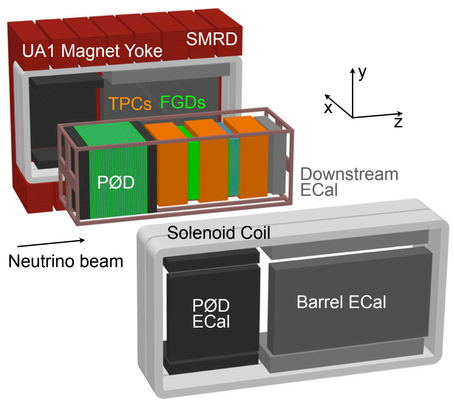


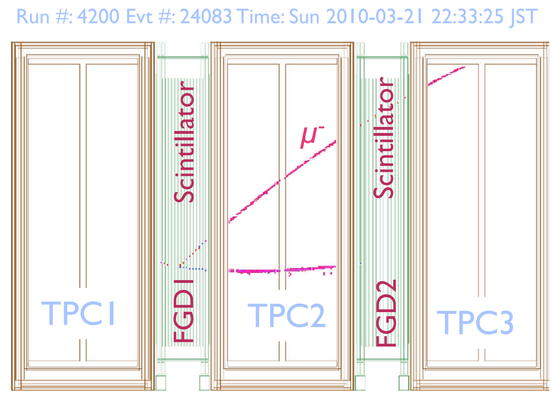
(a) p_μ (b) $\cos(\theta_\mu)$

(c) E^ν_{QE} (d) Q^2_{QE}

E^ν_{QE} and Q^2_{QE} are calculated from the reconstructed μ, assuming QE kinematics.

2. ND280 Detector





This analysis used the Tracker region of the off-axis near detector.

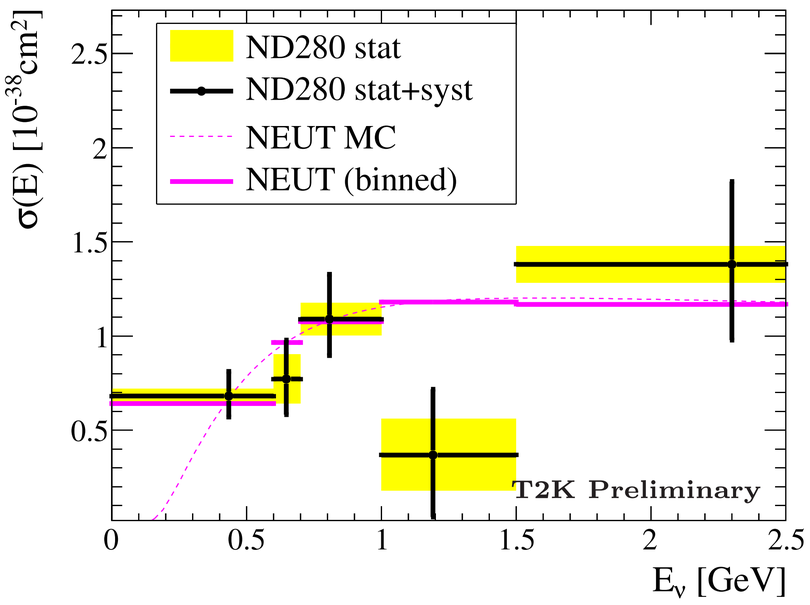
- The Fine Grained Detector (FGD1) consists of layers of 10×10 mm plastic scintillator bars readout with Multi-Pixel Photon Counters (MPPCs). It provided target mass and vertex reconstruction.
- The Time Projection Chambers (TPCs) provided PID based on dE/dx in the Argon based gas and momentum measurement from track curvature in the magnetic field.

4. Event Selection

- 1 good-quality track starting within the FGD fiducial volume with a muon-like TPC PID.
- No additional tracks in the TPC (as most protons from CCQE interactions stop in the FGD).
- Michel electron veto (to remove π backgrounds).

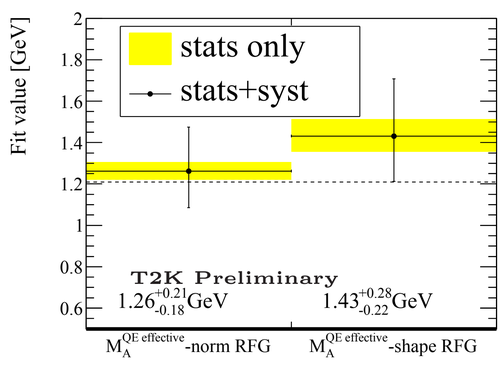
This event selection achieved an efficiency of 40% and purity 72% for CCQE events (as defined at generator level, before FSI). The analysis uses T2K Runs 1, 2 and 3 which corresponds to 2.7×10^{20} POT.

7. CCQE Cross Section Result



A χ^2 test comparing the fitted result with the nominal NEUT model, with $M_A^{\mathrm{QE}} = 1.2$ GeV, gives a p-value of 17% indicating good agreement between the data and the cross section model.

8. M_A^{QE} Fit



- Previous experiments have observed a discrepancy in the fitted values of M_A^{QE} between Deuterium and heavier nuclei.
- A large effective M_A^{QE} is believed to account for nuclear effects not included in the model.
- Both fit results are consistent with the value used in NEUT, $M_A^{\mathrm{QE}} = 1.2$ GeV.

References

[1] The T2K Experiment, K. Abe et al. (T2K Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A 659, 106 (2011).