PROCEEDINGS OF SCIENCE

New measurements of neutrino-nucleus interactions in T2K

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T2K is a long-baseline neutrino experiment which uses a 600 MeV muon neutrino beam created at the J-PARC facility on the east coast of Japan and directed towards the Super-Kamiokande detector to measure neutrino oscillations. It includes a suite of detectors located 280 m from the target. Three recent neutrino-nucleus charged current cross section measurements made using the off-axis near detectors are presented. These are inclusive $\bar{\nu}_\mu$ and ν_μ cross section measurements on water; a ν_μ inclusive measurement on plastic with 4π muon selection; and a ν_μ cross section measurement on plastic with a final state containing no pions but at least one proton, which uses transverse variables to compare different models of nuclear effects.

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1. Introduction

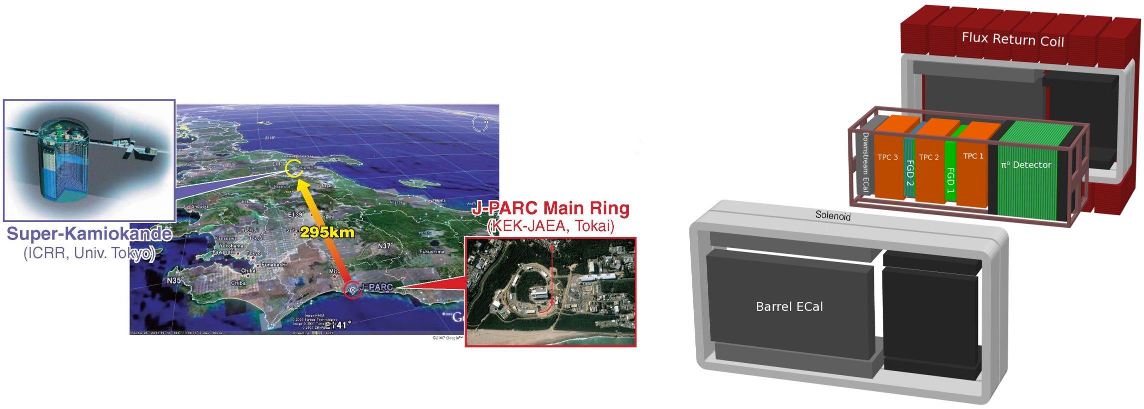

Figure 1: (Left) Overview of the T2K experiment. (Right) Exploded view of the ND280 near detector.

The T2K experiment [1] is a long baseline neutrino experiment whose primary purpose is to measure neutrino oscillations which result in the disappearance of muon neutrinos and the appearance of electron neutrinos at the Super-Kamiokande detector near the west coast of Japan. Neutrinos are produced in a beam at the J-PARC facility on the east coast of Japan which is 2.5 degrees off axis from the direct line to Super-Kamiokande, resulting in a beam of energy between ~ 400 MeV and ~ 1000 MeV, peaked at around 600 MeV.

The Super-Kamiokande detector [2] consists of a tank containing 50 kton (22.5 kton fiducial mass) of water under Mount Ikeno in Japan. Neutrinos interact with nuclei in the water producing electrons or muons travelling faster than the speed of light in water. The resulting Cherenkov light is observed by phototubes. Electrons and muons can be distinguished by the sharpness of the resulting rings.

The T2K neutrino energy is tuned to maximise muon neutrino disappearance at Super-Kamiokande. At this energy the dominant neutrino nucleus interaction is the Charge Current Quasi-Elastic (CCQE) process in which a neutrino interacts with a neutron to produce a proton and the energy of the incoming neutrino can be calculated from measurements of the angle and energy of the outgoing lepton. However a number of factors interfere with this simple interpretation. The interaction can also proceed via production of a delta resonance, or by scattering off of a quark within the nucleon. In addition the nucleon exists within a nucleus so various nuclear effects can alter the result. For example Fermi motion of the nucleon, or coherent scattering from a nucleon pair (2p-2h) have to be taken into account. In addition the products of the interaction can be altered by final state interactions before they leave the nucleus.

The T2K experiment includes a suite of detectors located 280 m from the target designed to both characterise the beam and also help to understand the effects described above. The ND280 off axis detector is shown in Figure 1. The central region consists of the PØD detector, which contains alternating layers of water and plastic, followed by a region containing three TPCs and two fine grained detectors (FGDs) which contain crossed planes of scintillator bars. The tracker region is surrounded by a lead/scintillator sandwich electromagnetic calorimeter. All these detectors are in a 0.2 T magnetic field provided by the solenoid thus allowing the TPCs to measure charge and momentum. Outside this is the flux-return coil which is also instrumented to provide muon detection and momentum-by-range measurements.

2. Charged Current $\bar{\nu}_\mu$ and ν_μ cross sections measured in the PØD

This measurement [3] is made using events where the incoming neutrino has interacted in the water target within the PØD detector. Measurements are made using similar quantities of neutrino and anti-neutrino data. This is an inclusive charged current measurement so the selection only requires outgoing muon tracks with no constraints applied to any other tracks which may be present in the event. The muon track has to pass into TPC 1 where its charge and momentum can be measured. The tracks are required to start in one of the 25 water filled layers of the PØD detector.

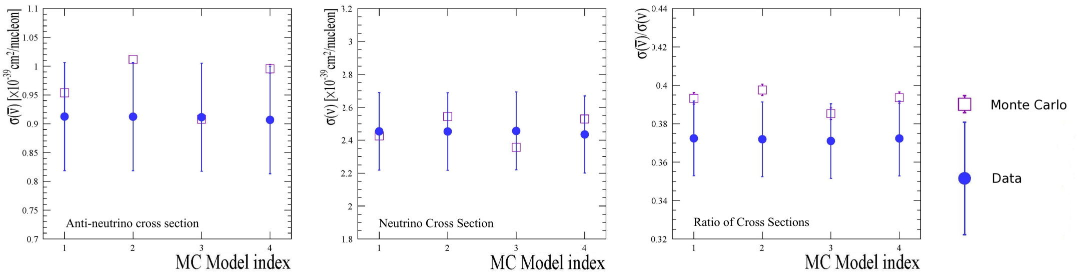

Figure 2: $\bar{\nu}_\mu$ and ν_μ charged current inclusive cross sections on water, and their ratio, compared to predictions from four variations of the NEUT Monte Carlo simulation.

The data is compared to four variations of the NEUT model in Figure 2, by taking (1) first the default configuration , and then adding (2) the relativistic Fermi gas [6], then (3) the random phase approximation [7] and finally (4) the 2p-2h contribution [7] . Here the figures in curved brackets correspond to the MC Model index label in in Figure 2.

3. Inclusive Charged Current ν_μ cross sections measured in FGD1.

This measurement is a flux-integrated double-differential measurement of neutrino interactions on plastic in FGD1, binned in terms of the angle and momentum of the outgoing muon. There is a 4π acceptance for the outgoing muon. A maximum likelihood fitting procedure is used to translate measured muon angle and momentum into true values. In addition control samples are used to measure background rates. The results are shown in Figure 3. The data are shown twice, for the two Monte Carlo programs, NEUT [4] and GENIE [5], used in the unfolding procedure. The light blue bands show the systematic error. In the forward direction the statistical and flux systematic errors contribute roughly equally and are the dominant source of error. In the samples where the muon travels in a direction that is at large angle with respect to the incoming neutrino there is also a significant contribution from the detector systematic error. Also shown are the Monte Carlo predictions. Both results for the data, and the Monte Carlo predictions are in good agreement.

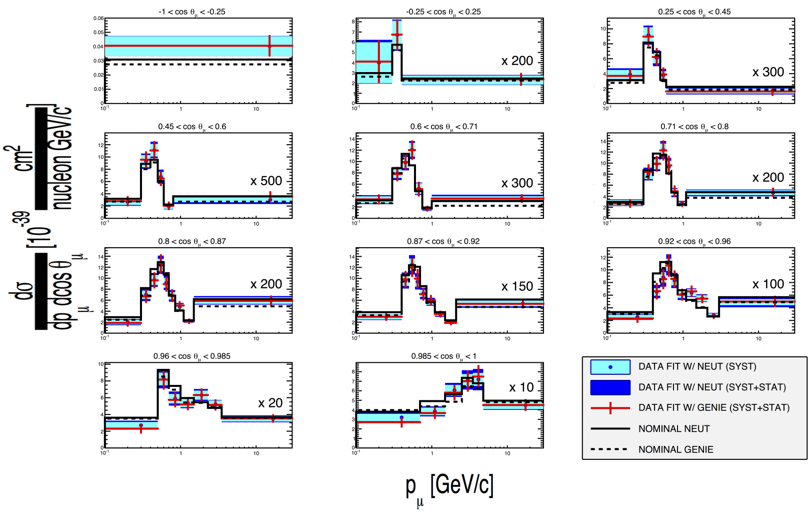

Figure 3: Cross sections for ν_μ charged current inclusive neutrino nucleus interactions observed in FGD1 in bins of muon momentum and angle. The last bin has been multiplied by the factor shown in the plots.

4. Charged Current 0π+Np in FGD1 With Transverse Variables

This study uses additional information available about the final state measured at ND280 to give a hint in deciding which processes are involved inside the nucleus. In the pure quasi-elastic process the transverse momentum of the outgoing lepton is balanced by that of the proton, so in a plane transverse to the incoming neutrino the momentum of the outgoing lepton is balanced by that of the outgoing proton. However when nuclear effects such as the 2p-2h process or final state interactions are included then this will no longer be the case. Three transverse variables (δp_t, $\delta\phi_T$ $\delta\alpha_T$) are constructed to search for these effects, as shown in figure 4, .

A sample of events is selected which has a vertex in FGD1 and no outgoing pion but one or more protons detected in the final state. A Michel electron tag and information from the ECal are used to veto pions. Control samples where pions are explicitly selected help to constrain the background measurement.

The results are shown in Figure 4 compared to a number of models [4][5][9][10]. There are marked differences between the measurements and some of the models so these measurements provide a powerful tool for distinguishing between the various predictions.

5. Summary

In summary T2K continues to make significant cross section measurements using greater statistics, improved calibration and new ideas to improve the understanding of neutrino nucleus interactions, and ultimately to reduce the systematic error on oscillation measurements.

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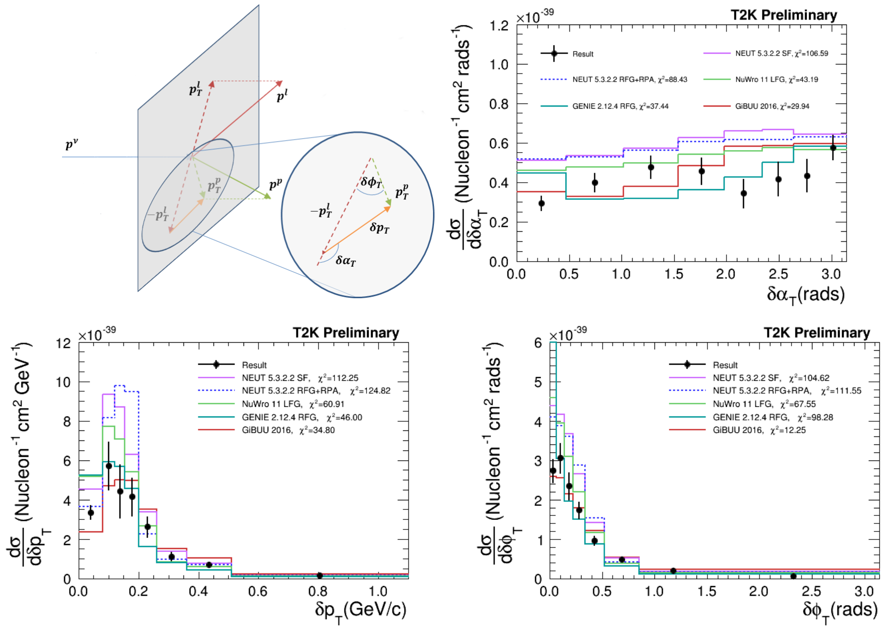

Figure 4: Transverse variables. Definition and measurement compared to a number of different models.

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