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The T2K off-axis near detector: recent physics results

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Abstract

The T2K near detector complex, ND280, is located at the J-PARC accelerator facility in Tokai, Japan, 280 meters downstream from the target. This proceeding will summarize recent physics results from ND280.

Keywords: long baseline experiment, neutrino cross sections, neutrino oscillations

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1. Introduction: the T2K experiment

The T2K experiment is a long baseline experiment probing neutrino oscillation parameters *via* ν_e appeareance and ν_μ disappeareance [1]. The neutrino flux is generated by the J-PARC super beam and sent towards Super-Kamiokande (SK), the 50 kton water Cherenkov far detector located 295 km away and 2.5° off the beam axis. The near detector complex is located 280 m from the beam target and contains the on-axis INGRID detector which measures the beam intensity and direction, while the off-axis ND280 detector is used to constrain the event rates on SK.

ND280 is a complex of detectors which are used to constrain the off-axis flux and neutrino interaction model. Charged current (CC) interactions are measured in the tracker, which is made of two fine grained detectors (FGDs) placed between three time projection chambers (TPCs). The FGDs provide target mass and good vertex and tracking resolution, alongside a full carbon target mass for the FGD1 and a half-carbon half-water target mass for the FGD2. Particle identification is achieved from their energy loss in the TPCs. Upstream of the tracker is the π^0 detector which is designed to measure neutral current interactions in carbon and water. Both the tracker and the π^0 detector are surrounded with electromagnetic calorimeters (ECals) and side muon range detectors (SMRDs) to reject more background by tagging photons and cosmic muons respectively. All detectors but SMRDs are located inside the old UA1 magnet to recontruct the particles momenta from their curvatures in the magnetic field.

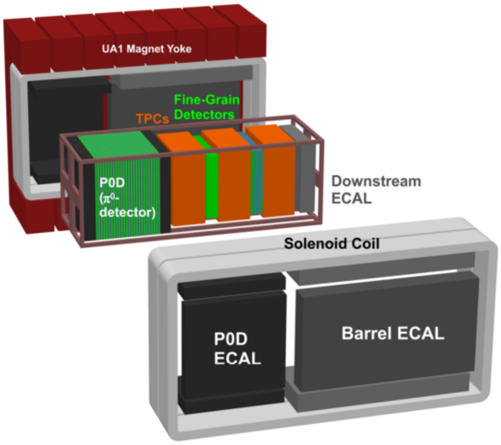

Figure 1: ND280, the T2K off-axis near detector.

2. Oscillation measurements

2.1. Constraints on neutrino oscillation fits

The event rate in the far detector is constrained by fitting the flux and neutrino interaction model in ND280. The MUMON, INGRID and the NA61 experiment data are input for the flux model [2], while the cross section model is estimated with the Monte-Carlo (MC)

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generator NEUT v5.1.4.1 [3] tuned with external data from MiniBooNE [4]. A CC inclusive sample is selected in FGD1 and split into quasi elastic charged current (CCQE) and non-quasielastic charged current (CC-nQE) subsamples. CCQE events allow a good understanding of the neutrino energy inferred from the final-state lepton kinematics. Since in the far detector the CCQE sample is dominant at those energies, restricting the oscillation analysis to this sample will enhance the appearence/disappearence signal. The present selection of CCQE events requires one track only passing through the FGD1 and TPC2 and no Michel electron to reject π production. This sample is refered to as CC-0π from the absence of detectable pion and has an efficiency of 47.8% and a purity of 72.4%. The complementary CC-nQE sample gives indication on the background (mainly the misidentification of pions as muons) and relevant cross sections. This sample is divided into a positively charged pion production CC-1π subsample, which has an efficiency of 28.4% and a purity of 49.2%; and the selection of all the other CC events in the CC-other subsample which has an efficiency of 29.7% and a purity of 73.3%. Constraints on cross-section systematics can be applied for different interaction topologies from this division into subsamples. The CC-0π, CC-1π and CC-other selections are binned in momentum and angle, and then fit using the flux, cross-section model and detector uncertainties to constrain the interaction rate in SK as shown on Figure 2.

2.2. Sterile neutrino search

A precise characterisation of the ν_e content of the T2K beam has been done in order to constrain this intrinsic background tp the oscillation appearance signal $\nu_\mu \rightarrow \nu_e$. It has been estimated to be 1.2% of the total T2K neutrino flux [5] which corresponds to 1 event in SK for 5.9×10^{20} p.o.t. A ν_e sample of 68% purity selected in ND280 has also been used to study the possibility of oscillation to a fourth neutrino state with a mass in the eV range. It was notably motivated by oscillation anomalies reported by several experiments as reviewed in [6]. The ND280 fit gave a p-value for the no-oscillation hypothesis of 6.07%, not rejecting the null hypothesis but only showing weak evidence against it.

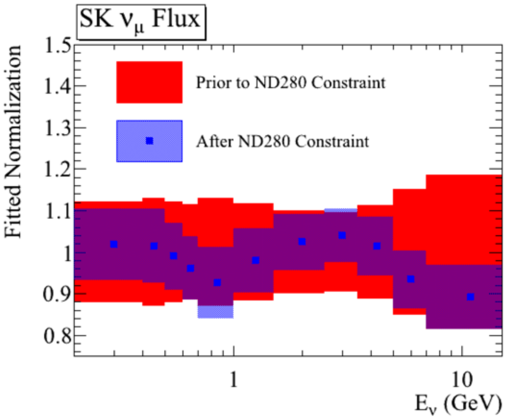

Figure 2: The fitted SK ν_μ flux normalization parameters and comparison of the error band with(without) ND280 constraint in blue(red).

3. Cross-section measurements

3.1. ν_μ charged current inclusive

ν_μ CC events are selected with a vertex inside FGD1 and at least one track required to be forward going, negatively charged and with a energy loss in the TPC2 compatible with the one of a muon. The resulting selection has an efficiency of 50% and a purity of 87% [7]. The flux-averaged double-differential cross section as a function of the muon kinematics shown in Figure 3 was obtained by using a model-independent Bayesian unfolding method. The integrated flux-averaged cross section is:
$\langle\sigma_{CC}\rangle_\phi = (6.93 \pm 0.13(stat) \pm 0.85(syst)) \times 10^{-39} cm^{-2}$ per nucleon. It is compatible with the predictions of 7.36×10^{-39} and 6.54×10^{-39} in the MC generators NEUT and GENIE [8] respectively.

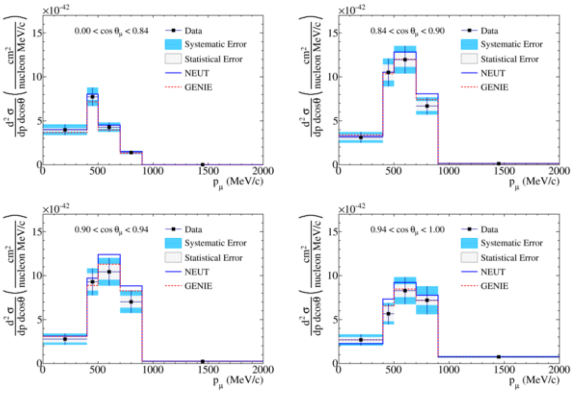

Figure 3: Unfolded flux averaged and differential ν_μ CC inclusive cross section with a comparison with NEUT and GENIE MC predictions. Figures (a-d) show the μ momentum distribution in each bin of $\cos\theta_\mu$.

3.2. ν_μ charged current quasi-elastic

The CCQE selection described on section 2.1 was used to determine the CCQE cross-section with a model dependent fit of the NEUT MC distribution in (p_μ, θ_μ). E_ν was divided in 5 bins and the CCQE cross section shown in Figure 4 was extracted using a maximum likelihood method. The agreement of the data best fit with the NEUT cross-section model gave a p-value of 17%, showing reasonable agreement. The axial mass paramater has been determined with a fit directly to NEUT parameters. At first shape and normalisation were varied and $M^{sh.+norm.}_{A(CCQE)} = 1.14^{+0.27}_{-0.20}$ GeV was obtained. Then only the shape was varied which resulted in $M^{sh.}_{A(CCQE)} = 1.38^{+0.39}_{-0.27}$ GeV. With their still important error bars, those values are consistent with both MiniBooNE and NOMAD, which show disagreements between their respective fits of $M_{A(CCQE)}$.

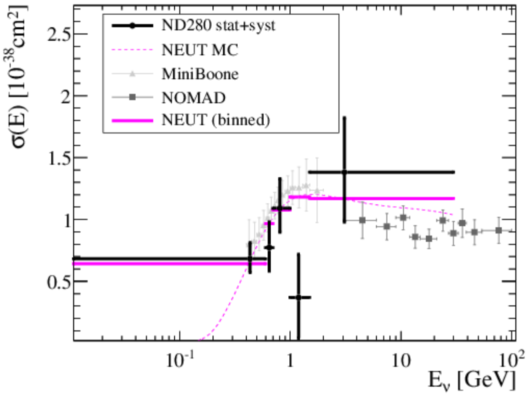

Figure 4: ν_μ CCQE best-fit cross section with a comparison with MiniBooNE and NOMAD measurement and the Monte-Carlo prediction of the NEUT generator.

3.3. ν_e charged current inclusive

From the ν_e content of the beam described in section 3.3, 315 events have been selected with interaction in FGD1. The requirements are an electron-like track from the energy loss in the TPC and ECals and no positron to prevent a contamination from pair production. The purity of the sample was estimated to be 65% and it was unfolded with the same model-independent unfolding method described in the section 3. Figure 5 shows the flux-averaged differential ν_e CC inclusive cross section as a function of the electron momentum. It also has been extracted as a function of the electron scattering angle and transfered momentum [9]. The integrated flux-averaged ν_e cross section is: $\langle\sigma_{CC}\rangle_\phi = (1.11 \pm 0.09(stat) \pm 0.18(syst)) \times 10^{-38} cm^{-2}$ per nucleon which is compatible with the predictions of 1.23×10^{-38} and 1.08×10^{-38} by NEUT and GENIE respectively. This is the first measurement of a ν_e cross section since Gargamelle (1978) and the first ever differential ν_e measurement.

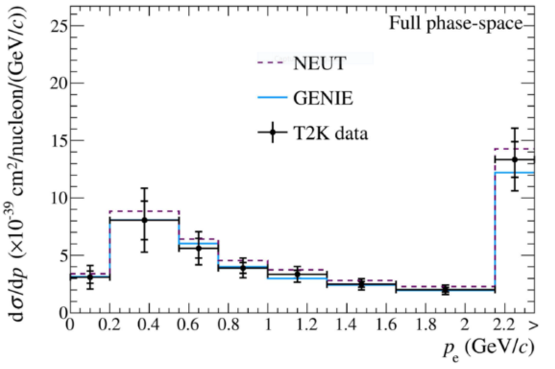

Figure 5: Unfolded ν_e CC inclusive cross section as a function of p_e with a comparison with NEUT and GENIE MC predictions. Inner(outer) error bars show the statistical(total) uncertainty. Last bin contains overflow bins and is normalised to the width shown.

4. Conclusion: future prospects

The ND280 detector is an essential feature of T2K as it permits the reduction of the systematic uncertainties on the ν_μ and ν_e event rates observed in the far detector. Its modularity allows the measurement of various neutrino cross sections, and numerous measurements are ongoing with different topologies and target nuclei. Reducing uncertainties on oscillation measurements is important in order to achieve the determination of δ_{CP} in long baseline experiments such as the proposed Hyper-Kamiokande [10], especially now that the mixing angle θ_{13} is known to be non-zero. This notably was one of the main motivations for T2K to run in antineutrino mode for the first time in June 2014.

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