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A measurement of the ν_μ charged-current cross section on water with zero pions in the final state at T2K

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The Tokai to Kamioka (T2K) experiment is a 295-km long-baseline neutrino experiment aimed towards the measurement of neutrino oscillation parameters θ_{13} and θ_{23}. Precise measurement of these parameters requires accurate knowledge of neutrino cross sections. We present a flux-averaged double differential measurement of the charged-current cross section on water with zero pions in the final state using the T2K off-axis near detector, ND280. A selection of ν_μ charged-current events occurring in the Pi-Zero subdetector (PØD) of ND280 is performed with 5.8×10^{20} protons on target. The charged, outgoing tracks are required to enter and be identified by the ND280 Tracker. The cross section is determined using an unfolding technique. By separating the dataset into time periods when the PØD water layers are filled with water and when they are empty, a subtraction method provides a distribution of ν_μ interactions on water only. Systematic uncertainties on the neutrino flux, interaction model, and detector simulation are propagated numerically within the unfolding framework.

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1. Neutrino interactions

At the T2K peak energy of approximately 0.6 GeV, the primary interaction mode is charged-current quasielastic (CCQE). In a CCQE interaction on free nucleon targets, a neutrino (antineutrino) interacts with neutron (proton) to produce its corresponding lepton and a proton (neutron). With nuclear targets, complications arise from both initial state nuclear effects and final state interactions (FSIs). These intranuclear effects can alter the outgoing particle kinematics and topologies. Pion absorption for example can make a non-CCQE interaction appear as a CCQE final state. Our detectors are not capable of detecting interactions within the nucleus and we are forced to classify events based on the detectable, post-FSI topology. A neutrino-nucleus interaction with a single muon and zero pions is a CCQE-like topology called "CC0π". Here, we present a double differential measurement in $(p_\mu, \cos\theta_\mu)$ of the CC0π cross section on water using the PØD and tracker of ND280.

2. Analysis strategy

The PØD contains a water-target region of alternating layers of water and hydrocarbon scintillator [1]. The water layers are passive but can be drained or filled during different data-taking periods. CC0π ν_μ interactions are selected for by searching for the μ^- signature. Only interactions consistent with the neutrino beam timing are considered. We require the μ^- candidate to originate in the PØD water-target fiducial volume and enter the tracker directly downstream of the PØD [2]. The tracker contains TPCs which provide accurate momentum reconstruction and allow us to select only negatively charged tracks. To enhance the CC0π signal, events with multiple reconstructed objects in the PØD are excluded as they often correspond to multi-pi interactions.

Two control samples (sidebands) are used to constrain the two largest background topologies in the signal selection. These are events with either a single pion, CC1π^+, or any other charged-current neutrino interaction, CCOther. Events with a μ^- candidate and extra tracks in the PØD are used for sideband selections. If, including the μ^- candidate, the PØD reconstructed exactly two tracks and a Michel electron from stopped muon decay the event is classified as CC1π^+. If, including the μ^- candidate, the PØD reconstructed more than two tracks the event is classified as CCOther. The ratio of the overall data sideband normalization to the overall MC sideband normalization is calculated and used to constrain the corresponding background in the CC0π MC selection.

The event selections described above are binned in the reconstructed double differential $(p_\mu, \cos\theta_\mu)$ phase space. Detector reconstructed variables are imperfect approximations to the muon's true initial state. To extract the true kinematics from the reconstructed, an unfolding technique is used [3]. The purpose of unfolding is to remove detector related imperfections to achieve a more accurate representation of how the muon emerged from the interaction.

To measure interactions on water, the PØD was designed to be drained and filled during different run periods. All things being equal except for the inclusion or exclusion of water, a subtraction of the true water-in and water-out distributions should give the number of interactions on water. The idea for a measurement on water is thus to first unfold the reconstructed distribution for water-in and water-out separately to get an approximation of their true distributions, then subtract the post-unfolding results to get the distribution that occurred on water. The number of interactions on water is given as,

$$N_i^O = \frac{U_{ij}^w N_j^w}{\varepsilon_i^w} - R\frac{U_{ij}^a N_j^a}{\varepsilon_i^a}, \tag{2.1}$$

where the indexes i and j indicate true and reconstructed bins respectively, w and a indicate water-in and water-out periods respectively, N is the number of purity-corrected, signal events measured in the data signal selection, ε the selection efficiency, and R the flux normalization factor between water-in and water-out periods. U_{ij} represents the unfolding matrix. From this, the differential cross section on water can be expressed as,

$$\frac{\mathrm{d}\sigma}{\mathrm{d}x} = \frac{N_i^O}{F^w N_n \Delta_i}, \tag{2.2}$$

where F^w is the integrated flux over the water-in period, N_n the number of neutrons, and Δ_i the area of bin i across variable x. F^w is calculated using flux simulations from FLUKA and constraints from the NA61/SHINE hadron production experiment at CERN [4]. As the water-in and water-out periods have different beam exposures, total flux for the water-out periods, F^a, is used to scale the flux normalization ratio, $R = F^w/F^a$.

3. Systematic uncertainties

Sources of systematic uncertainties affecting this measurement include uncertainties on the flux, interaction model, and detector simulation. Flux uncertainties are due in large part to uncertainties in the hadron production model but are affected by beamline uncertainties as well. A parameterization in neutrino energy and flavor is used to propagate flux uncertainties. Interaction model uncertainties affect the interaction cross section and FSI. Parameters that govern the cross section and FSI models are used to propagate interaction uncertainties. Detector simulation systematics affect the reconstructed kinematics of the μ^- candidate and selection efficiencies and purities. Uncertainties on the PØD simulation include the fiducial volume water mass, out-of-fiducial-volume contamination, and the PØD momentum resolution. Uncertainties on the tracker simulation include magnetic field distortions, TPC reconstruction efficiency, and the tracker momentum resolution. Detector systematics are typically applied to the MC reconstruction based on the MC truth information. All uncertainties are propagated by reweighting or varying events in the nominal simulation based on a perturbation of the underlying parameter. The tweaked MC is then used to recalculate elements in Eqs. (2.1) and (2.2) which give tweaked cross section results. Correlations between the water-in and water-out periods were taken into account in the subtraction. A set of such results, generated from a set of hypotheses on the MC, is used to construct the error envelope on the final result.

4. Results

The results shown in Fig. 1 use data from T2K Runs 2–4. The colored bars show the cumulative error contributions from various sources of uncertainty. Each error source listed in the legend is treated independently and their uncertainties are summed in quadrature. The black data points show the double differential result with full errors. MC predictions from NEUT v5.3.2 tuned to a relativistic Fermi gas model with Random Phase Approximation and the default GENIE v2.8.0 are shown as solid and dashed blue lines. This result shows good agreement with the measured CC0π cross section on carbon from an earlier tracker-based T2K analysis as shown in Fig. 2 [5].

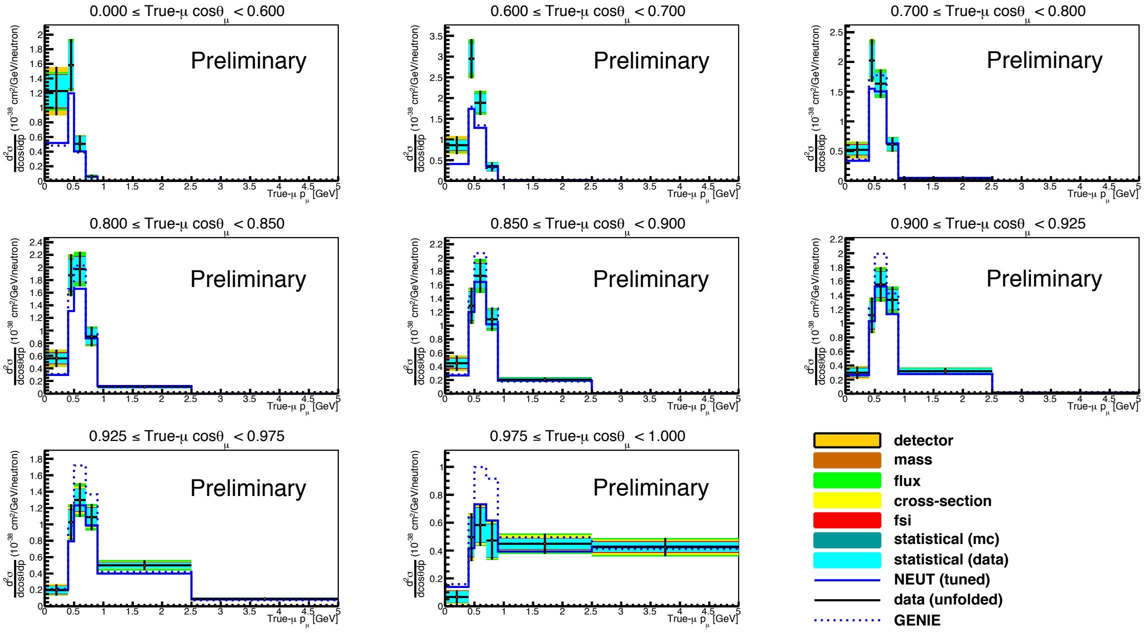

Figure 1: The double differential CC0π water cross section.

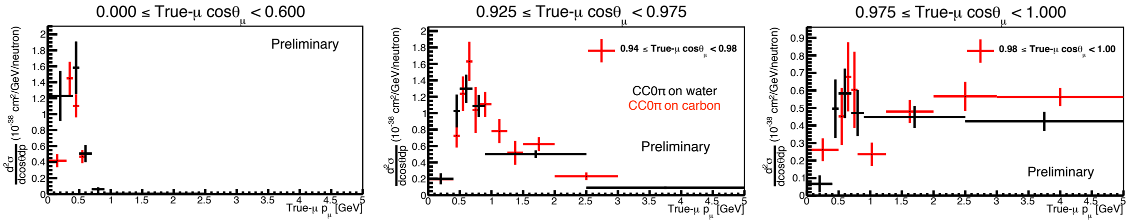

Figure 2: A comparison of this result to that obtained in analysis 1 of [5] which reports a CC0π measurement on carbon. Three angular slices are shown. Note that the binnings are not identical.

References

[1] S. Assylbekov *et. al.*, *The T2K ND280 off-axis pi–zero detector*, *Nucl. Instrum. Methods* **A686** (2012) 48

[2] K. Abe *et. al.*, *The T2K experiment*, *Nucl. Instrum. Methods* **A659** (2011) 106

[3] G. D'Agostini, *A multidimensional unfolding method based on Bayes' theorem*, *Nucl. Instrum. Methods* **A362** (1995) 487

[4] K. Abe *et. al.*, *T2K neutrino flux prediction*, *Phys. Rev.* **D87** (2013) 012001 `arXiv:1602.03652 [hep-ex]`

[5] K. Abe *et. al.*, *Measurement of double-differential muon neutrino charged-current interactions on C_8H_8 without pions in the final state using the T2K off-axis beam*, *Phys. Rev.* **D93** (2016) 112012 `arXiv:1602.03652 [hep-ex]`