PROCEEDINGS OF SCIENCE

Towards the measurement of neutrino cross-section on H_2O and CH target at 1 GeV region by T2K-WAGASCI experiment

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The T2K experiment is searching for the CP phase, δ_{CP} violation in the lepton sector by a precise measurement of neutrino oscillations. We published the latest paper to show the CP violation at 95% confidence level. The reduction of statistical and systematic uncertainties is essential to achieve higher significance in this measurement. The T2K-WAGASCI detectors were newly introduced to T2K experiment as one of near detectors to reduce the systematic uncertainty related to the neutrino-nucleus interactions. They are located at 1.5-degree from the neutrino beam axis, a different off-axis from other T2K near detector ND280, and is therefore exposed to higher energy neutrino beam. This research has aimed for a precise measurement of neutrino interaction induced by neutrino beam generated from the high intensity proton beam at J-PARC which would lead to a better understanding of neutrino interaction models. In this report, the analysis status of the cross-section measurement on H_2O and CH targets at 1 GeV energy region with data set corresponding to 6.5×10^{20} protons on target will be shown including the potential impact on the T2K oscillation measurement.

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1. T2K experiment

The T2K experiment aims at measuring neutrino oscillations, notably δ_{CP}, using a proton beam accelerated by J-PARC main ring to generate intense numu beam oriented to Super Kamiokande (SK) which is located 295 km away from J-PARC at 2.5-degree off-axis. The beam line can produce either numu or numubar beam with about 1% of nue contamination and peak energy of about 0.6 GeV. The neutrino beam is measured by Near Detector (ND280) [1] at the same off-axis as SK, and it constrains the systematic uncertainties for the measurement of neutrino oscillations. We published the latest results to show the CP violation at 95% confidence level in [2]. The reduction of statistical and systematic uncertainties is essential to achieve a higher significance.

2. WAGASCI BabyMIND detectors

New near detectors called, WAGASCI-BabyMIND [3], were installed at 1.5-degree off-axis where they can measure at a little higher neutrino energy with respect to the near detector ND280 (Figure 1 on the left). The main target of ND280 is plastic and the acceptance is limited to forward direction, unlike SK. The motivation of the WAGASCI experiment is to reduce the systematic uncertainty on the neutrino cross-section with the same target and acceptance as SK. The experiment is divided into 4 sub-detectors. Two of which are referred to as neutrino target detectors, since they are hosting the targets for the neutrino interactions, and the other two as Muon Range Detectors (MRD). WAGASCI detector has a three-dimensional grid structure of scintillators and is filled with water (500 kg), which is acting as a neutrino interaction target. The Proton Module consists of fully-active tracking planes of scintillators acting as a plastic target. Both target detectors have separation power between proton and Minimum Ionising Particle (MIP) particles, while no way to separate pions from muons. Two Wall MRDs are located on both sides of these target detectors in order to identify muons and measure their momentum. The other muon range detector is Baby MIND installed downstream of the target detectors. It consists of 33 magnetised iron modules and 18 detector modules. This detector can identify the charge of muons. The subdetector specifications are summarised in Table 1.

Detector	Target	Acceptance	Light yield (p.e.)	Angle res.	PID
WAGASCI	H_2O : CH = 4 : 1	4π	18 / 24	2-3 degree	$\mu, \pi/p$
Proton Module	CH	forward	20 / 50	2-3 degree	$\mu, \pi/p$

Detector	Material	Light yield (p.e.)	Momentum Res.	PID
Wall MRD	iron and scintillators	18	10-15%	μ
Baby MIND	iron core magnet + scintillators	17 / 30	5-10%	μ

Table 1: Performances of target detectors (top) and muon range detectors (bottom) of WAGASCI-BabyMIND. Each mean of light yields is estimated for MIP. WAGASCI, Proton Module and Baby MIND have two kinds of scintillators, corresponding to two different light yields. Angle and momentum resolutions are estimated using muons having 1 GeV momentum by MC. The last column for both tables shows which particle should be identified. Target modules are expected to have performance to discriminate μ-like particle (μ, π) from proton like particle.

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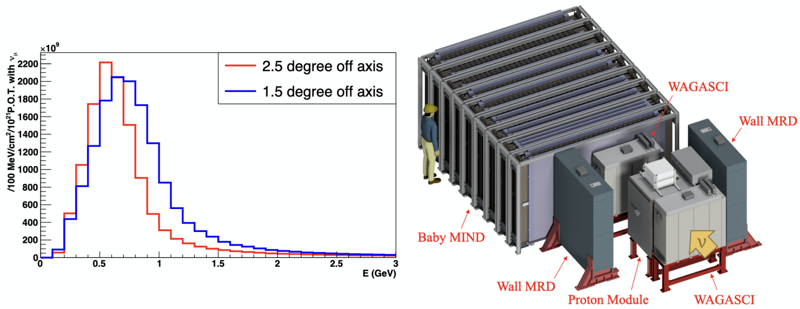

Figure 1: Neutrino fluxes at WAGASCI-BabyMIND location (1.5-degree off-axis) and SK / ND280 location (2.5-degree off-axis) on the left. 3D CAD image of WAGASCI detectors on the right.

The physics run with the full setup of WAGASCI-BabyMIND was conducted in several periods. The total beam exposure corresponds to 6.5×10^{20} protons on target with a numu beam. Figure 1 on the right shows detector configuration in the physics run.

3. MC simulation and track reconstruction

Monte Carlo simulation has been used to evaluate signal and background ratio and optimise the event selection criteria. JNUBEAM[4] is the software to simulate the neutrino production in the T2K neutrino beam line and predict the neutrino fluxes at detectors. Neutrino interactions are simulated by NEUT[5], which is the nominal neutrino interaction generator in this experiment. A GEANT4-based MC framework simulates the detector response with the neutrino flux and interactions, providing all hit information. Hits are classified into a hit collection called cluster based on a Cellular Automata algorithm. Pairs of clusters are chosen between detectors if they satisfy the matching conditions considering differences of the angle and distance between the extrapolated position from one detector and the hit position in the other detector. Finding all pairs of clusters creates 2D track candidates having hits across all sub-detectors. It tries to find 3D track candidates by checking the initial and final positions of each 2D track. If there is at least one 3D track candidate, the vertex position and track kinematics such as angle and momentum are reconstructed.

4. Event selection

This analysis aims at a measurement of the charged current numu neutrino interaction without charged pions in the final state, called numu CC0π. The interaction topology is the main sample used for the oscillation analysis in the T2K experiment. Selection criteria shown in Figure 2 is determined to optimise the signal purity and efficiency for the topology. The most important part of the criteria is the particle identification for a MIP-like particle (call it μ-like here). The largest contribution of CC0π is the charged current quasi elastic interactions and 2p2h (two-particle-two-hole) which scatters off two nucleons and leaves two empty states. Those interactions are supposed to have one μ-like particle while other interactions such as charged pion production via resonance and charged current deep inelastic scattering have two or more μ-like particles which could be also a pion. The muon confidence level (MUCL) based on the energy deposit in target detectors is introduced to discriminate μ-like particles from proton like particles. The longest track (1st track) is assumed to be μ-like track without computing MUCL. For other tracks, when the discriminative parameter is larger than 0.2, they are assumed to be μ-like track otherwise proton like track. This particle identification gives one μ-like track sample. When the μ-like track passes through BabyMIND, the charge of the track is reconstructed from the track curvature in the magnetic field. This analysis requires the μ-like particle to be negative because it focuses on numu interaction. If the reconstructed charge is negative, then the event is counted as a numu CC0π candidate.

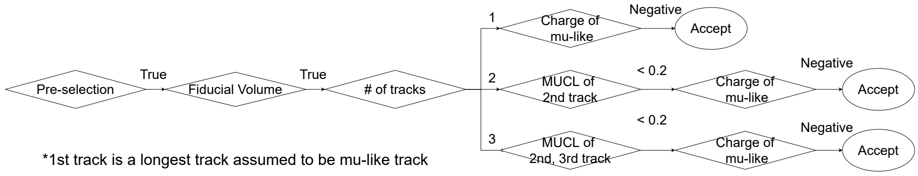

Figure 2: Event selection criteria for numu CC0π. Preselection includes timing clustering, 2D and 3D track reconstruction. MUCL refers to the MUon Confidence Level, which is the discriminative parameter to choose μ-like. When the reconstructed charge is negative, the event is counted as a signal candidate.

The main sources of backgrounds come from neutrino interactions with the pion production via resonance and secondary interactions of neutral particles produced in other modules or in walls at the experimental place. The signal efficiency and purity are studied based on the criteria above in order to check how it works. The efficiency is defined as the number of selected numu CC0π events to the number of numu CC0π interactions in the fiducial volume while the purity is the number of selected signal events to the number of selected events. Figure 3 shows the muon angle distribution for all selected events on H_2O target and CH target. All NC interactions are populated at -1 because there is no muon, and it is difficult to get proper kinematics of the μ-like particle when the hits come from several kinds of particles. It confirms dominant contribution comes from the signal (CC0π). Purity and Efficiency for both targets are estimated to be 62% purity at 28% efficiency and 67% purity at 40% efficiency respectively.

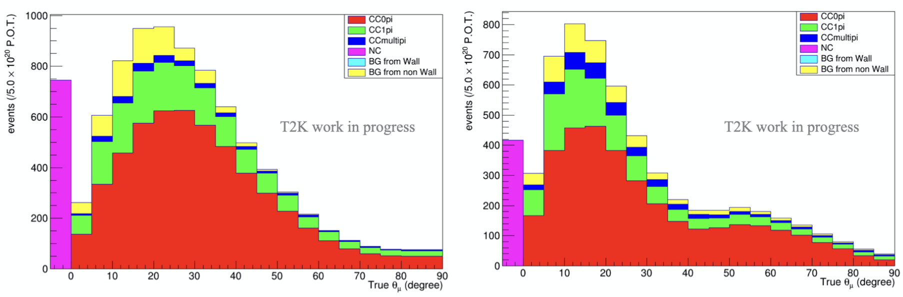

Figure 3: Event distribution for H_2O target (left) and CH target (right) normalised by 5.0×10^{20} protons on target. For NC interactions, true θ, p values are assigned to -1 in these histograms. Interactions of neutral particles in other modules are included in BG from non Wall.

5. Prospects

The final physics goal of measurement with WAGASCI-BabyMIND is to apply the result to the oscillation analysis in the T2K experiment. There are differences between the CC0π measurement by the near detector ND280 and the event prediction before data fit in [6]. Those differences are compensated by the tuning of neutrino interaction models against ND280 data which have introduced relatively large systematic uncertainties. A combined analysis with ND280 measurement will give additional information to be used for the cross-section modelling. Subtraction of one flux from another provides a relatively sharp neutrino energy spectrum as shown in Figure 4. The subtracted flux in red shows the case neutrino flux at 2.5-degree off-axis is subtracted from the one at 1.5-degree off-axis. It would be possible to investigate the energy dependency of neutrino interaction by using these subtracted fluxes in the calculation of flux integrated cross-section extraction. This approach could help to understand the neutrino interaction model more precisely as well as the stand-alone cross-section measurements, leading to the improvement of oscillation analysis to search for CP violation in the lepton sector.

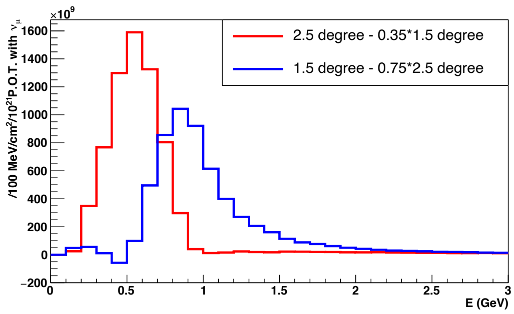

Figure 4: Subtracted fluxes using neutrino fluxes at both locations at 1.5-degree off-axis and 2.5-degree off-axis. Both coefficients, which are 0.35 and 0.75, are chosen to make each subtracted flux sharper.

References

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