Neutrino cross section measurements using a 3D grid-like neutrino detector, WAGASCI, in the J-PARC neutrino beamline

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1 Introduction

The understanding of neutrino-nucleus interactions in the 1 GeV energy region is critical for the success of accelerator-based neutrino oscillation experiments such as the T2K experiment. Complicated multi-body effects of nuclei render this understanding difficult. The T2K near detectors have been measuring these and significant progress has been achieved. However, the understanding is still limited. One of the big factors preventing from full understanding is the non-monochromatic neutrino beam spectrum. Measurements with different but some overlapping beam spectra would greatly benefit to resolve the contribution from different neutrino energies. We, the Wagasci collaboration, proposes to study the neutrino-nucleus interaction at the B2 floor of the neutrino monitor building, where different neutrino spectra can be obtained due to the different off-axis position. Our experimental setup contains 3D grid-structure plastic-scintillator detectors filled with water as the neturino interaction target (Wagasci modules), two side- and one downstream- muon range detectors(MRD's). The 3D grid-structure and side-MRD's allows a measuremen of wider-angle scattering than the T2K off-axis near detector (ND280). High water to scitillator material ratio enables the measurement of the neutrino interaction on water, which is higly desired for the T2K experiment because it's far detector, Super-Kamiokande, is composed of water. The MRD's consist of plastic scintillators and iron plates. The downstream-MRD, so called the Baby MIND detector, is also work as a magnet and provides the charge identification capability. The charge identification is essentially important to select antineutrino events in the antineutrino beam because contamination of the neutrino events is as high as 30%. Most of the detectors has been already constructed and commissioned as the J-PARC T59 experiment. Therefore, the collaboration will be ready to proceed to the physics data daking for the T2K beam time in January 2019. We will provide the cross sections of the charged current neutrino and antineutrino interactions on water with slightly higher neutrino energy than T2K ND280 with wide angler acceptance. When combined with ND280 measurements, our measurement would greatly improve the understanding of the neutrino interaction at around 1 GeV and contribute to reduce the most significant uncertainty of the T2K experiment.

2 Experimental Setup

Figure. 1 shows a schematic view of the entire set of detectors. A central detector, Wagasci modules, consists of 3D grid-structure plastic-scintillator detectors filled with water as the neturino interaction target. They are surrounded by two side- and one downstream- muon range detectors(MRD's) The MRD's are used to select muon tracks from the charged-current (CC) interactions and to reject short tracks caused by neutral particles that originate mainly from neutrino interactions in material surrounding the central detector, like the walls of the detector hall, neutrons and gammas, or neutral-current (NC) interactions. The muon momentum can be reconstructed from its range inside the detector. The MRD's consist of plastic scintillators and iron plates. In addition, eaco of the iron plates of the downstream-MRD, so called the Baby MIND detector, is wound by a coil and can be magnetized. It provide the charge selection capability.

For all detectors, scintillation light in the scintillator bar is collected and transported to a photodetector with a wavelength shifting fiber (WLS fiber). The light is read out by a photodetector, Multi-Pixel Photon Counter (MPPC), attached to one end of the WLS fiber. The signal from the MPPC is read out by the dedicated electronics developed for the test experiment to enable bunch separation in the beam spill. The readout electronics is triggered using the beam-timing signal from MR to synchronize to the beam. The beam-timing signal is branched from those for T2K, and will not cause any effect on the T2K data taking.

T2K adopted the off-axis beam method, in which the neutrino beam is intentionally directed 2.5 degrees away from SK producing a narrowband ν_μ beam. The off-axis near detector, ND280, is installed towards the SK direction in the B1 floor of the near detector hall of the J-PARC neutrino beam-line. We propose to install our detector in the B2 floor of the near detector hall, where the off-axis angle is similar but slightly different. The candidate detector position in the B2 floor is shown in Fig. 2. The expected neutrino tmp.pdf

Figure 1: Schematic view of entire sets of detectors.

energy spectrum at the candidate position is shown in Fig. 3.

2.1 Wagasci module

The dimension of the central detector is 100cm $\times$ 100cm in the x and y directions and 200cm along the beam direction. The total water and hydrocarbon masses serving as neutrino targets are $\sim$1 ton each. Inside the central detector, plastic scintillator bars are aligned as a 3D grid-like structure, shown in Fig. 4, and spaces in the structure are filled with the neutrino target materials, water and hydrocarbon. When neutrinos interact with hydrogen, oxygen or carbon, in water and hydrocarbon, charged particles are generated. Neutrino interactions are identified by detecting tracks of charged particles through plastic scintillation bars. Thanks to the 3 D grid-like structure of the scintillator bars, the central detector has 4π angular acceptance for charged particles. Furthermore, adopting a 2.5cm grid spacing, short tracks originated from protons and charged pions can be reconstructed with high efficiency. Thin plastic scintillator bars (thickness $\sim$ 0.3cm) will be used for the central detector to reduce the mass ratio of scintillator bars to neutrino target materials, because neutrino interactions in the scintillator bars are a background for the cross section measurements. Scintillator bars whose dimensions are 2.5cm x 0.3cm x 100cm will be used for the central detector. The total number of channels in the central detector is 12880.

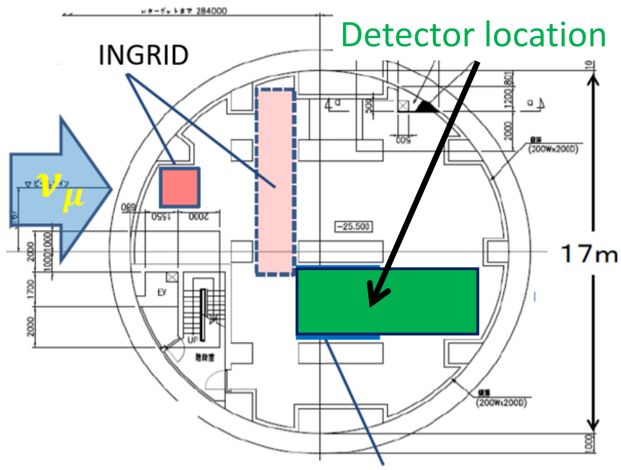

Figure 2: Candidate detector position in the B2 floor of the near detector hall.

2.2 Baby MIND

2.3 Side muon range detector

The dimension of the MRD in the side (downstream) region is ∼200(200)cm × ∼300(350)cm in a plane perpendicular to the muon direction and ∼75(230)cm along the muon direction. The MRD in the side (downstream) region consists of 12(30) 3 cm thick iron plates and 14(32) tracking scintillator planes. Muons generated at smaller angle to the beam axis have higher momentum, so the MRD in the downstream region is thicker along the muon direction. Each tracking scintillator layer of the MRD in the side (downstream) region has 25(28) scintillator bars whose dimensions are 20cm x 1cm x 200(200)cm and 20cm x 1cm x 300(350)cm, making a plane measuring 300(350)×200(200)cm^2 in the horizontal and vertical directions and 2 cm along the muon direction. The total number of channels in the MRD is 1246.

3 Physics goals

4 Status of J-PARC T59 experiment

We had submitted a proposal of a test experiment to develop a new detector with a water target at the T2K near detector hall to J-PARC PAC on April 2014, and the proposal was approved as J-PARC T59.

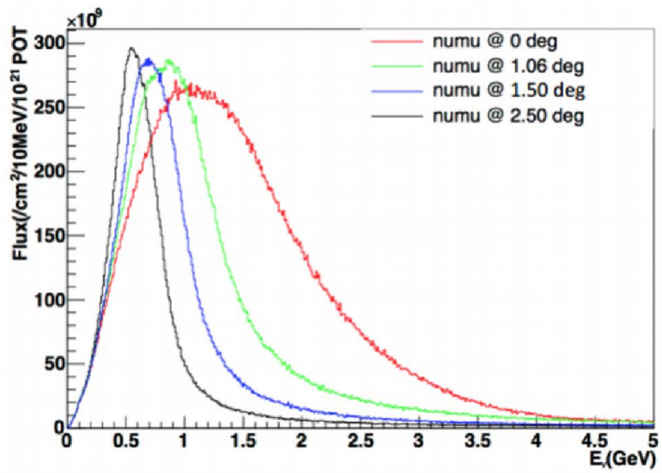

Figure 3: Neutrino energy spectrum at the candidate detector position(red). The spectrum at the ND280 site (black) is also shown.

5 Detector performance

5.1 Wagasci module

To demonstrate the performance of the Wagasci module and also to study the neutrino interaction, the first Wagasci module was installed at the on-axis position, in front of the T2K INGRID horizontal center module in 2016. The INGRID module is made of iron plates and segmented plastic scintillator bars. It's cross sectional size viewed from the beam direction is 1 m×1 m. The charged current interactions in the Wagasci module are selected by requiring a muon track candidate in the INGRIRD modules. Here, we describe the performance of the Wagasci module evaluated at this T2K on-axis measurement. Figure 5 shows the light yeild of channels for muons produced by the interaction of neutrinos in the hall wall. The light yield is sufficiently hgih to get good hit efficieincy. The tracking efficiency in 2-dimentional projected plane was evalualted by comparing the reconstructed track in the Wagasci module and the INGRID module and shown in Fig.6. Note that that the tracking efficinecy for high angle ($> 70\,\mathrm{deg}$) is not evaluated because of the acceptance of the INGRID module, not because of the limitation of the Wagasci module.

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Figure 4: Schematic view of 3D grid-like structure of plastic scintillator bars inside the central detector.

5.2 Baby MIND

5.3 Side muon range detector

6 MC studies

7 Schedule

8 Requests

8.1 Beam condition and beam time

The experiment can run parasitically with T2K, therefore we request no dedicated beam time nor beam condition. We request 1×10^{21} POT neutrino beam data and another 1×10^{21} POT antineutrino data.

8.2 Request of equipment

- Site in the B2 floor of the near detector hall (Fig. 2)
- Electricity ($\sim$10kW) for the electronics and water circulation system
- Beam timing signal and spill information
- Network connection

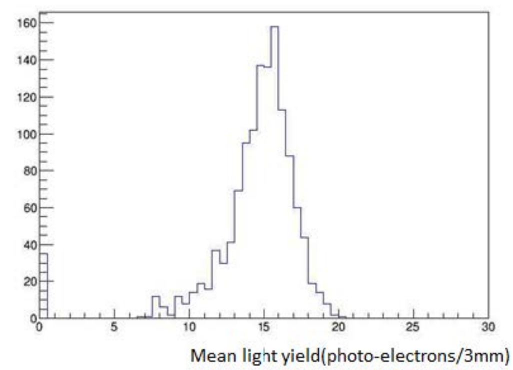

Figure 5: Light yield of channels for muons produced by the interaction of neutrinos in the hall wall.

9 Conclusion

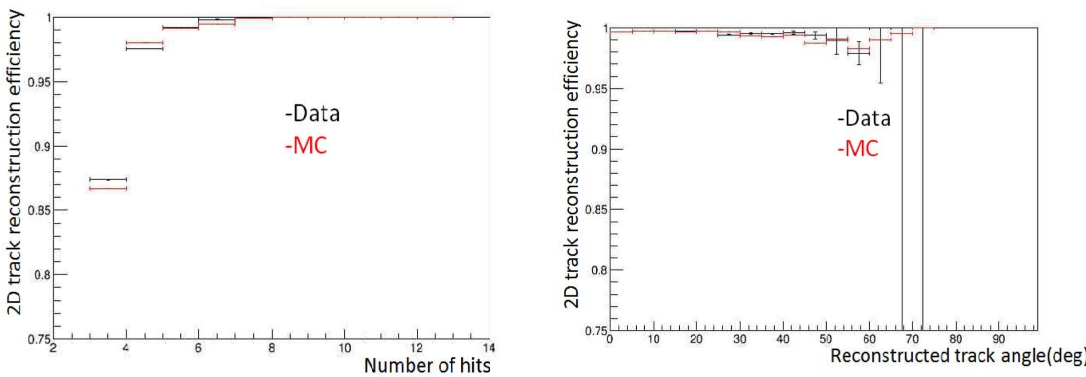

Figure 6: 2D track reconstruction efficiency as a function of number of hits (left) and track angle (right). Here the track angle is the one reconstructed by the INGRID module.