New experiment at J-PARC to measure the muon neutrino cross section ratio between water and hydrocarbon

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Abstract. A new experiment, named WAGASCI can precisely measure the ratio of muon neutrino cross sections between water and hydrocarbon for charged-current interactions with a large angular acceptance at J-PARC. A new detector mainly consists of two water target modules and two hydrocarbon target modules. Each module is composed of scintillators aligned in a 3D grid-like structure having almost $4\pi$ solid angle acceptance. Each scintillator has a groove for a WLS fiber to be put on, and they are glued with the optical cement by using a semi-automated gluing system. WLS fibers are connected to Multi-Pixel Photon Counters (MPPCs), which are crosstalk suppression type. The detector is now under construction, and we will start taking the data in 2017.

1. Introduction
The T2K experiment\[^{[1]}\] is a long-baseline accelerator neutrino oscillation experiment that uses intense beams produced at J-PARC. In this experiment, neutrino oscillation parameters are determined by measuring the neutrino flux before oscillation at the near-detector, ND280 and after oscillation at the far-detector, Super-Kamiokande (SK). The target nucleus of ND280 is mainly hydrocarbon (partially water), while that of SK is water. Due to this difference of nuclear targets, uncertainties of neutrino-nucleus interactions do not cancel, which causes systematic errors of the oscillation analysis at T2K. Moreover, SK has a $4\pi$ solid angle acceptance, while ND280 can mainly measure forward scattering events. The difference in acceptance also contributes to systematic errors.

In order to suppress such systematic errors, we decide to construct a new detector to precisely measure the neutrino cross-section ratio between water and hydrocarbon with the (anti-)neutrino beam at J-PARC.

2. New neutrino detector
2.1 Configuration
A schematic view of the new detector\[^{[2]}\] is shown in Figure 1. It consists of a central detector and muon range detectors (MRDs). In the central detector, there are two water modules and hydrocarbon modules. Each module has 1-ton target mass and $1\times1\times0.5$ m$^3$ volume. As shown in Figure 2, each module is composed of 3D grid-like scintillators, and this characteristic structure achieves a $4\pi$ solid
angle acceptance. The thickness of each scintillator is 3 mm, then the central detector has a large target volume of about 80%.

![Figure 1](image1.png)

**Figure 1.** The new detector contains water modules (blue box), hydrocarbon modules (green box), and muon range detectors (MRDs). Each module is composed of 1280 scintillators. The MRD in the right side is omitted in this figure.

![Figure 2](image2.png)

**Figure 2.** 3D grid-like scintillators in the central detector. Each scintillator has a groove, and a wavelength shifting fiber is put on it and glued with the optical cement. The signal is read out by Multi-Pixel Photon Counters (MPPCs).

### 2.2. Measurement of neutrino cross section

Neutrino cross section $X$ is derived from the equation below,

$$ X = \frac{N_{\text{obs}} - N_{BG}}{\Phi \cdot T \cdot \varepsilon}, $$

where $N_{\text{obs}}$ is the number of observed events in the detector, $N_{BG}$ is the number of background events, $\Phi$ is the neutrino flux, $T$ is the number of nucleons in the target material, and $\varepsilon$ is the detection efficiency. The $N_{BG}$, $\Phi$, and $\varepsilon$ are estimated by Monte Carlo (MC) simulation. There is a 50 cm gap between the central detector and MRDs, and the direction of the charged particle can be derived from the difference in the hit timing. Therefore, background events from outside of the central detector are rejected by the information of TOF (Time Of Flight).

### 2.3 Expected number of events by the simulation

The number of signal/background events in the new detector are estimated by MC simulation. The number of events after the selection are summarized in Table 1. Charged-current (CC) neutrino interactions are signal events in SK. High statistics and low backgrounds are expected.

| Table 1. Summary of the number of events after the selection |
|-------------------------------------------------------------|
| **Event rate / $10^{21}$ POT** | **CC interactions** | **NC interactions** | **Backgrounds from outside** | **All events** |
|--------------------------------|---------------------|---------------------|-----------------------------|---------------|
| **Event rate / $10^{21}$ POT** | 29450               | 1060                | 1640                        | 32150         |
| **Fraction**                   | 91.6%               | 3.3%                | 5.1%                        | 100%          |
3. Construction status of the new detector
One of the water modules has been constructed in 2015 as a prototype, as shown in Figure 3. At first scintillators and WLS fibers are glued with the optical cement using a semi-automated gluing system. Glued scintillators are painted with black spray in order to suppress the crosstalk effect between scintillators. Then we align these scintillators in a 3D grid-like structure. Four scintillator layers are assembled into one sub-module, and 4 sub-modules are also assembled into one target module. The target module is installed into water tank in order to fill the gap of each scintillator with water. After the completion of the prototype construction, we have installed it into the T2K near-detector hall. We check the ADC distribution of 1280 MPPCs and we find that they work well. As shown in Figure 4, a cosmic-ray muon is successfully reconstructed. The neutrino beam measurement will be started in Autumn 2016.

The construction of MRDs and new read-out electronics is going on by LLR in France, INR in Russia, and Geneva University. A new water module and one hydrocarbon module will be constructed by Summer 2017. In Autumn 2017, we will start the neutrino beam measurement using these new components.

![Figure 3. Construction work for one water module. One module is composed of 16 scintillator layers. The right figure shows the water tank.](image)

![Figure 4. Event display of a reconstructed muon in the detector. Each red circle indicates a hit of a charged particle on the scintillator, and a black line is a reconstructed track of a particle.](image)

4. Summary
A new experiment to measure the neutrino cross section ratio between water and hydrocarbon is being prepared at J-PARC. The new detector has a 3D grid-like structure so that it has a 4π solid angle acceptance. The detector consists of two water/hydrocarbon modules, and each module has 1280 scintillators. One water module was constructed as a prototype, and we installed it into the T2K detector hall in May, 2016. We checked that all MPPCs work, and a cosmic-ray muon can be reconstructed well. Now, one water module, one hydrocarbon module, MRDs, and electronics are in preparation. The construction work will be finished by Summer 2017, and we will be ready for starting the neutrino beam measurement using them in Autumn 2017.

References
[1] K. Abe et al. “The T2K Experiment”, Nucl.Instrum.Meth. A659 (2011) 106-135
[2] K. Kin, “Measurement of neutrino interactions at an off-axis angle 1.6 degrees using the near-detector INGRID and development of a new neutrino near-detector for the T2K neutrino oscillation experiment”, Master’s thesis, Osaka City University (2015).