Proc. 2nd Int. Symp. Science at J-PARC — Unlocking the Mysteries of Life, Matter and the Universe —
JPS Conf. Proc. **8**, 023003 (2015)
http://dx.doi.org/10.7566/JPSCP.8.023003

Water/CH Neutrino Cross Section Measurement at J-PARC (WAGASCI Experiment)

T. Koga[1], N. Chikuma[1], F. Hosomi[1], M. Yokoyama[1], A. Bonnemaison[2], O. Drapier[2], O. Ferreira[2], M. Gonin[2], Th. A. Mueller[2], B. Quilain[2], I. Aizenberg[3], A. Izmaylov[3], I. Karpikov[3], M. Khabibullin[3], A. Khotjantsev[3], Y. Kudenko[3], S. Martynenko[3], A. Mefodiev[3], O. Mineev[3], T. Ovsjannikova[3], S. Suvorov[3], N. Yershov[3], T. Hayashino[4], A. K. Ichikawa[4], A. Minamino[4], K. Nakamura[4], T. Nakaya[4], K. Yoshida[4], Y. Seiya[5], K. Wakamatsu[5], K. Yamamoto[5], Y. Hayato[6]

[1] *Department of Physics, University of Tokyo, Bunkyo-ku, Tokyo, Japan*
[2] *IN2P3-CNRS, Ecole Polytechnique, Palaiseau, France*
[3] *Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia*
[4] *Department of Physics,Kyoto University, Kyoto, Japan*
[5] *Department of Physics, Osaka City University,Osaka,Japan*
[6] *Kamioka Observatory, Institute for Cosmic Ray Research, University of Tokyo, Kamioka, Japan*

E-mail: taichiro@hep.phys.s.u-tokyo.ac.jp

(Received September 15, 2014)

A good understanding of neutrino interactions on the nucleus is indispensable for a precise study of neutrino oscillation. In order to reduce the uncertainty in the neutrino interaction, we propose a new experiment at the J-PARC neutrino beamline to measure the ratio of charged current neutrino cross sections between water and plastic targets with an accuracy of a few percent. This new experiment, named WAGASCI, is described in this paper.

KEYWORDS: neutrino interaction

1. Introduction

For a precise study of neutrino oscillation, a good understanding of neutrino interactions on a nucleus is indispensable. In the T2K long-baseline neutrino oscillation experiment, the main neutrino-interaction targets of its near detector consist of plastic scintillators while its far detector, Super-Kamiokande, consists of water. The difference of the target materials induces a systematic uncertainty on the neutrino cross section that is one of the major systematic error in the neutrino oscillation analysis. The total systematic errors of the ν_e appearance measurement is 8.8%, of which 7.5% comes from the uncertainty of the neutrino interactions [1] because neutrino cross section with a water target has not been measured with a high precision so far. In addition, the near detector can measure mainly forward scattering events while far detector has 4π acceptance. The difference of the acceptance also contributes to the systematic errors.

In order to reduce these uncertainties, we propose a new experiment at the J-PARC neutrino beamline to measure the ratio of charged current neutrino cross sections between water and plastic (CH) targets with a large angular acceptance. The name of the project is WAGASCI (WAter Grid And SCIntillator detector) experiment. Our goals are as follows:

(1) Measure H_2O to CH charged current cross section ratio with an accuracy of a few percent.

(2) Measure charged current cross sections on H_2O and CH individually, with a large angular acceptance.

The absolute cross section measurements suffer from the uncertainty of the neutrino flux which is more than ten percent [2] [3]. However, by taking the ratio of the cross section, these uncertainties can be canceled and a high precision is achieved [4].

2. WAGASCI Experiment

2.1 Experimental configuration

The WAGASCI detector will be located in the B2 floor of the T2K near detector hall at J-PARC. To create the neutrino beam, 30 GeV protons are extracted from the synchrotron ring to strike a graphite target. Emitted pions are focused by three magnetic horns. The pions decay in a 96 m decay volume and produce neutrinos. The off-axis angle is 1.6 degrees at the candidate site, to be similar to the T2K off-axis angle, 2.5 degrees. Figure 1 shows the expected neutrino flux per 10^{21} protons on target (POT) at the candidate site. The peak of the spectrum is around 600MeV and it is similar to that at the T2K near detector.

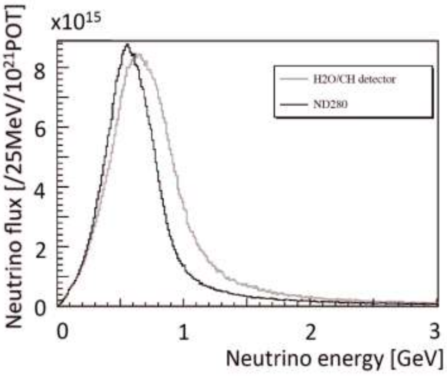

Fig. 1. Expected neutrino flux at the candidate site of WAGASCI(gray line) and at the T2K near detector(black line)

2.2 Detector design

Figure 2 shows a schematic view of the new detector. A central detector contains the neutrino target materials, water and hydrocarbon, and plastic scintillator bars. When the neutrinos interact with the target, charged particles are generated. Neutrino interactions are identified by detecting tracks of the charged particles through the plastic scintillator bars. Muons are identified and their momenta are measured by muon range detectors (MRDs) around the central detector. Background events from outside of the central detector are rejected by the time of flight (TOF) between the central detector and the MRDs.

The dimension of the central detector is $100\times100\times200$ cm^3. The total water and hydrocarbon target masses are 1 ton each. This water to hydrocarbon mass ratio is designed to minimize the statistical error of the cross section ratio measurement. Two water targets and two hydrocarbon targets are arranged alternately along with the beam axis to make the neutrino energy spectrum and the muon acceptance as identical as possible between the water targets and the hydrocarbon targets. This design reduces the uncertainties due to the flux and the neutrino cross sections for the measurement of the cross section ratio. Inside the central detector, plastic scintillator bars are aligned in a 3D grid like structure as shown in Fig. 3. The spaces between scintillators are filled with the neutrino target materials, water or hydrocarbon cubes. This structure enables us to reconstruct high angle tracks and obtain large acceptance. The scintillators are arranged at intervals of 2.5 cm to detect short range tracks and identify the neutrino interaction modes. The thickness of the plastic scintillators is thin, 3 mm, to reduce the fraction of non-water materials. The fraction of the water mass is 62% for this configuration. Each strip is read out by a wavelength shifting fiber and a semiconductor photo detector, Multi-pixel Photon Counter(MPPC).

The MRDs are placed on the left side, right side and downstream of the central detector. They are composed of a sandwich structure of iron plates and plastic scintillators. The design of the side MRDs and the downstream MRD is a little different because the momentum of the high scattering angle muons are relatively low, compared with that of the low angle muons. Ten 3-cm thick iron planes compose the side MRDs to stop ninety percent of the muons which penetrate into the side MRDs. Twenty iron planes compose the downstream MRD. The thickness of the first ten iron planes is 3 cm, while that of the last ten iron planes is 6 cm. This is designed to stop the muons with the momentum up to 1GeV.

The main background is considered to be the particles generated in the neutrino interactions with the MRDs and the wall of the detector hall. In order to reject such background coming from outside of the central detector, the time of flight information is used. The current design has a 50 cm space between the central detector and the MRDs and three layers of 1 cm thick scintillators are placed around the central detector, the MRDs and the upstream of the detector to achieve high timing resolution.

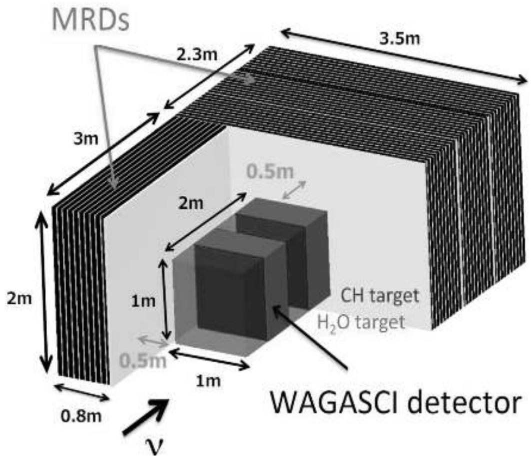

Fig. 2. Schematic view of the new detector

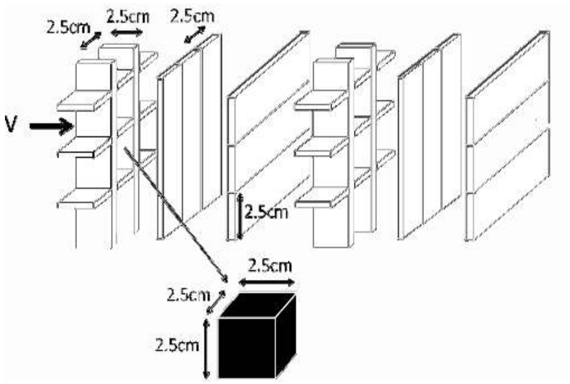

Fig. 3. Shematic view of the 3D grid-like structure of the plastic scintillator bars inside the central detector. The spaces between scintillators are filled with the neutrino target materials, water or hydrocarbon cubes (black one).

Table I. Summary of the detector parameters

Central detector		Size	100×100×200 cm^3
		Size of the each target part	100×100×50 cm^3
		Target masses (H_2O, CH)	1 ton each
		Size of scintillators in the target region	100×2.5×0.3 cm^3
		Size of scintillators for TOF	120×5×1 cm^3
		Number of channels	10,240
MRD	Side	Size	80×200×300 cm^3
		Thickness of iron plates	3 cm (10 planes)
	Downstream	Size	400×200×230 cm^3
		Thickness of iron plates	3 cm (10 planes) / 6 cm (10 planes)
	Total	Size of scintillators	200×20×0.7 cm^3
		Number of channels	1,460

2.3 Expected performance

The performance of the detector is evaluated with a Monte Carlo simulation. In this paper, we make the assumption that in two years 10^{21}POT will be delivered. For the charged current cross section measurement, including its ratio and the differencial cross section, we select the events which have a track penetrating more than one layer (five layers) of iron plates for side (downstream) MRDs. Table II shows the expected number of the selected events from the water targets. We expect to observe 39580 charged current interactions with a purity of 91.1%. In Fig. 4, black(gray) shows the efficiency of muons from the water (hydrocarbon) targets as a function of the scattering angle of muons. The large angular acceptance is expected and the efficiency from water targets and hydrocarbon targets are very similar. This enables to cancel the uncertainties of the neutrino flux and neutrino interactions between the water targets and the hydrocarbon targets for the cross section ratio measurement. After the requirement of the TOF, the dominant background is expected to be interactions of neutral particles coming from outside of the central detector. In this paper, the neutrino interactions with the wall of the hall are assumed as background sources. As shown in Fig. 5, the requirement of the MRDs penetration rejects such background events.

Table II. Expected number of selected events from 1ton water target

	Charged current interaction	Neutral current interaction	Background from outside	All
Events /10^{21} POT	39580	2560	1300	43440
Fraction	91.1%	5.9%	3.0%	100%

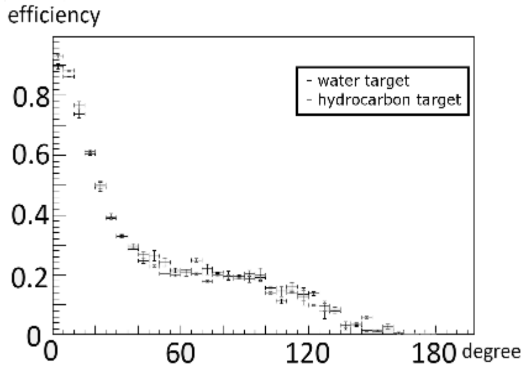

Fig. 4. Efficiency of the muons from water target(black) and hydrocarbon target(gray). The horizontal axis is the scattering angle of muons.

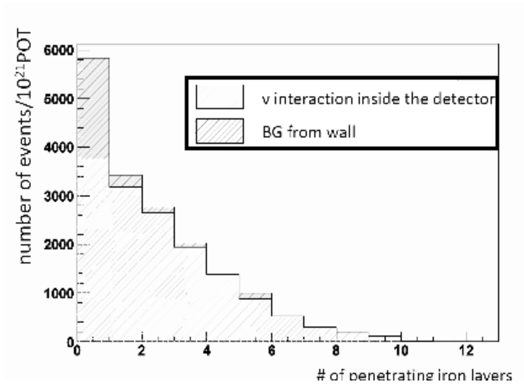

Fig. 5. The number of penetrated iron planes in side MRDs. The blank histgram shows the events from inside the central detector and the hatched histgram shows background events from wall of the B2 floor.

3. R&D of Detector Components

3.1 Semiconductor Photo Sencer, MPPC

The photo sensors of the WAGASCI are required to have low noise and high photo detection efficiency(PDE) because the low light yield is expected with the 3 mm thick scintillators in the central detector. We have tested new low noise MPPCs developed by Hamamatsu Photonics. Figure 6 shows the dark noise rate of the new MPPC and old MPPC, which is the same type as those used in T2K, for comparison. In this figure, ΔV is the operation voltage minus the breakdown voltage and the comparison is done under the new (old) MPPC's ΔV=3.0 (1.0) V. The dark noise rate of the new MPPC is about 1×10^4 Hz, an order of magnitude smaller than that of the old MPPC. Figure 7 shows the relative PDE of the MPPCs. The relative PDE is defined as the ratio of the measured PDE to the PDE of the old MPPC with ΔV = 1.0 V. The new MPPC can be operated with about ten times lower noise rate and 1.3 times higher PDE compared with the old MPPC as shown in Table III.

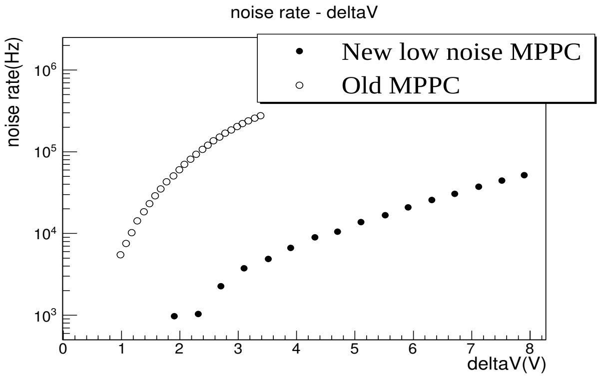

Fig. 6. Dark noise rate of MPPCs as a function of ΔV. Black (white) circles show the data of new low noise (old) MPPC and the threshold is set to 1.5 p.e.

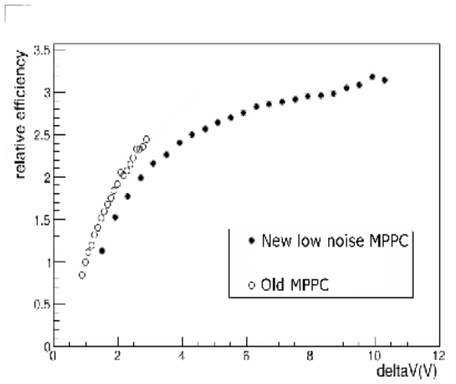

Fig. 7. Relative photo detection efficiency of MPPCs as a function of ΔV. Black(white) circles show the data of new low noise (old) MPPC.

Table III. Summary of the performance of the new and old MPPCs

	ΔV	dark noise rate	relative efficiency
Old MPPC	1.5V	3.6×10^4Hz	1.5
New MPPC	3.0V	5.0×10^3Hz	2.0

3.2 Scintillators

We have measured the light yield of 2.5 mm thick scintillators by using Tohoku University 500MeV positron beamline. Figure 8 shows the tested sample, produced by Fermi laboratory. It is machined to the shape of the 3D-grid structure. The old MPPC is used for this measurement with ΔV = 1.4V. Figure 9 shows the position dependence of the mean light yield per MIP. The light yield decreases as the position becomes more distant from the wave length shifting fiber. At the edge of the scintillator, the mean light yield is 6 p.e. and the detection efficiency is 90 %, which is too low for us. To increase the light yield,, we plan to test the scintillator again by using the new MPPC and the thicker, 3 mm thick scintillator.

We also have tested a sample of the scintillator for the MRDs by using a radiation source. The dimension of the scintillator is $200\times20\times0.7$ cm^3 and a wave length shifting fiber is glued in an S-shape groove. The light yield is more than 17 p.e. per MIP and the detection efficiency is above 99.5 %. The timing resolution is about 1.8 ns at the center of the scintillator. These performances are sufficient for us.

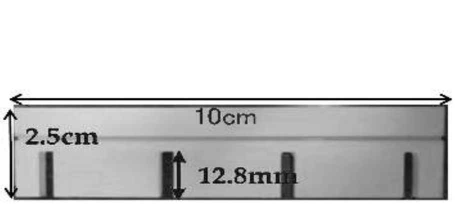

Fig. 8. The sample of the scintillator used for the beamtest. The size is $2.5\times25\times100$ mm^3 and it is machined to the shape for 3D-grid structure. A wave length shifting fiber is put in the 1.2 mm groove just above the center of the scintillator. The surface is painted with TiO_2 reflector.

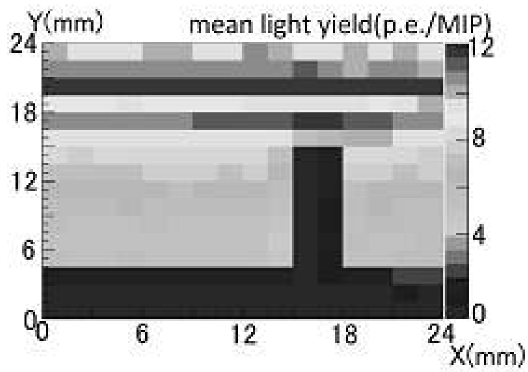

Fig. 9. The position dependence of the mean light yield per MIP of the scintillator.

3.3 Mechanical design of WAGASCI

Figure 10 shows the preliminary design of the mechanical structure. Each scintillator is fixed by an aluminum frame and the frame is outside of the target region to reduce the background. Four layers of the scintillators compose one module and are connected to MPPCs by wavelength shifting fibers through O rings. A prototype of the 3D-grid scintillator was made by plastic and the mechanical stability was checked.

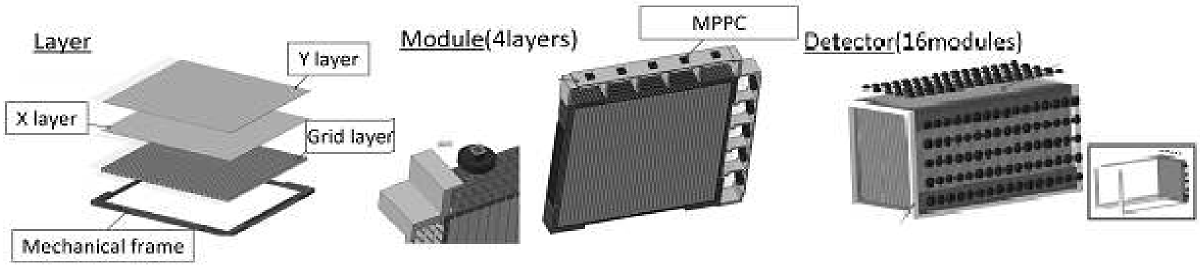

Fig. 10. Mechanical structure of WAGASCI

4. Expected Timeline and Prospects

The current schedule assumes that the design of the WAGASCI will be determined in October 2014. After that, a procurement and a delivery of the detector components will start. The construction of the WAGASCI will start in June 2015 and the WAGASCI detector will be installed and commissioned in the winter of 2015. We plan to accumulate physics data corresponding to 1×10^{21} POT in two years of running. The proposal of the WAGASCI was submitted by the J-PARC PAC in June 2014.

5. Conclusion

The WAGASCI experiment measures the H_2O to CH charged current cross section ratio with an accuracy of a few percent with a large angular acceptance, by using 600MeV J-PARC neutrino beam. It will help to reduce the uncertainty of the neutrino oscillation measurement, such as T2K experiment. The design of the detector and R&D of the detector components are ongoing. We expect to install the WAGASCI detector in the winter of 2015.

References

[1] K. Abe *et al.* [T2K Collaboration]: Phys.Rev.Lett.**112** (2014), 061802.
[2] K. Abe *et al.* [T2K Collaboration]: Phys.Rev.D**89** (2013), 092003.
[3] Y. Nakajima *et al.* [SciBooNE Collaboration]: Phys.Rev.D**83** (2011), 012005.
[4] K. Abe *et al.* [T2K Collaboration]: arXiv:1407.4256 [hep-ex], to be published in Phys.Rev.D.