PROCEEDINGS OF SCIENCE

First physics run of the WAGASCI-Baby MIND detector with full setup

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WAGASCI-Baby MIND is a set of new detectors to measure the neutrino cross-sections with the T2K neutrino beam. It is composed of neutrino detectors made of water and scintillator surrounded by muon range detectors made of iron and scintillator. The downstream muon range detector is magnetized to discriminate the charge of the muons. It is located in the same building as ND280 detector but at a different off-axis angle from ND280. We have completed its commissioning run with a reduced setup in summer 2018. The next physics run with the full setup is scheduled to start in November. In this talk, we will present the results of the previous run and the strategy of the first full setup run.

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1. T2K experiment

The T2K experiment aims at measuring neutrino oscillations, notably δ_{CP}, using the proton beam accelerated by J-PARC main ring to generate intense ν_μ beam oriented to Super Kamiokande (SK) which is located 295 km away from J-PARC at 2.5-degree off-axis. The beamline can produce either ν or $\bar{\nu}$ beam with 1% of ν_e pollution and a peak energy of about 0.6 GeV. The neutrino beam is measured by Near Detector (ND280) which is located at the same off-axis as SK, and it constrains the systematic uncertainties for the measurement of neutrino oscillations.

2. WAGASCI-Baby MIND detectors

The WAGASCI experiment started in J-PARC in 2016 in order to measure the neutrino cross-section on water target with 4π acceptance. The main target of ND280 is plastic and the acceptance is limited to forward, 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. There are two kinds of neutrino target detectors surrounded by two kinds of muon range detectors. WAGASCI detector has three-dimensional grid structure of scintillators and is filled with water (500 kg), which is acting as a neutrino interaction target (figure 1). The Proton Module consists of fully-active tracking planes of scintillators acting as a plastic target. Two Wall MRDs are located aside these target detectors in order to identify muons and measure the momentum. The other muon range detector is Baby MIND, which consists of 33 magnetized iron modules and 18 detector modules. This detector can identify the charge of muons.

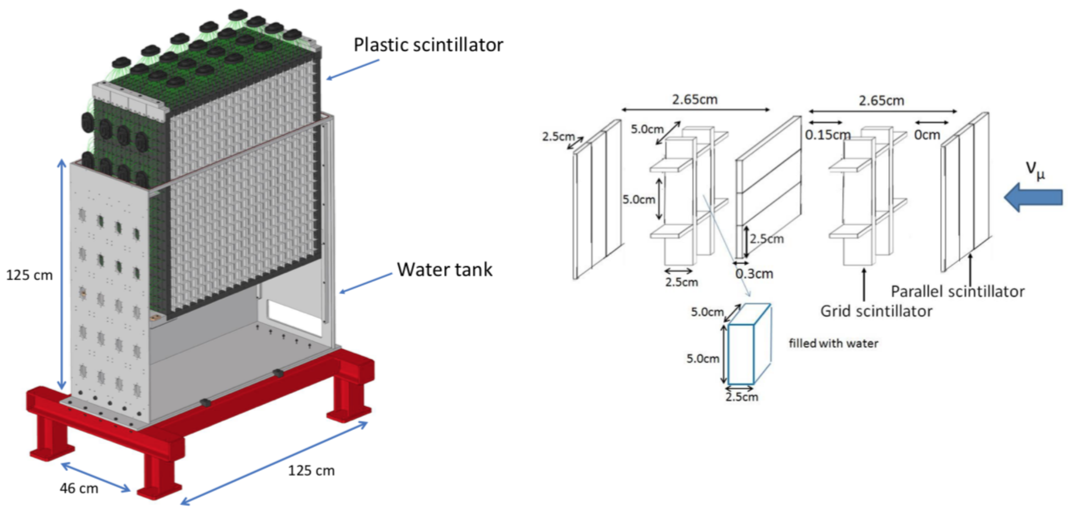

Figure 1: Schematic view of the WAGASCI detector (left) and its grid structure of scintillators (right)

3. Results of previous WAGASCI runs

The results of the first WAGASCI run are based on data collected from Oct. 2016 to Apr. 2017. The data sets include a beam exposure of 7.25×10^{20} protons on target (POT) in neutrino mode.

The WAGASCI detector was located on axis, where the mean energy of neutrino is 1.5 GeV. They extracted the neutrino cross-section on water, hydrocarbon and iron using CC inclusive sample (figure 2).

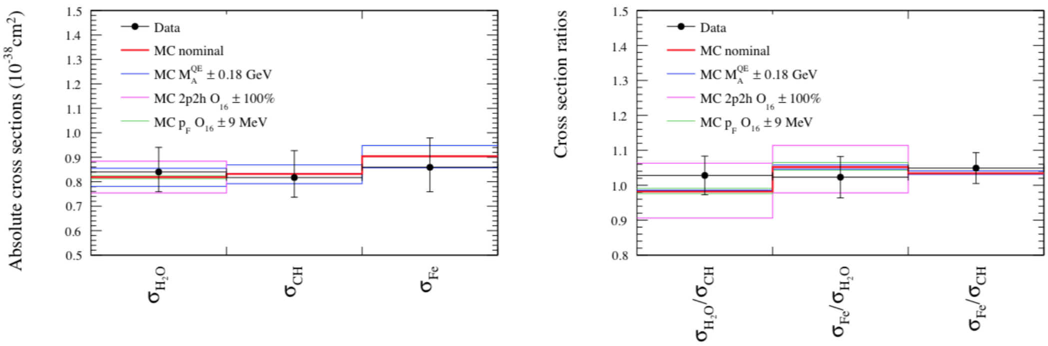

Figure 2: Results of the absolute cross-sections (left) and cross section ratios (right) measurements with total uncertainties and theoretical predictions by NEUT[1].

The results include 10-14% error for the absolute cross-section on water, hydrocarbon, iron, 5% for the cross-section ratios. All the measured cross-sections agree with the T2K neutrino interaction model, NEUT, within their errors. From Oct. 2017 to May. 2018, the second WAGASCI run was conducted. In this run the electronics and detector configuration are different. The data sets include a beam exposure of 8.5×10^{20} protons on target (POT) in antineutrino mode. The WAGASCI detector is located 1.5 degrees off-axis, where the mean energy of antineutrino is 1.06 GeV. Results are shown in figure 3.

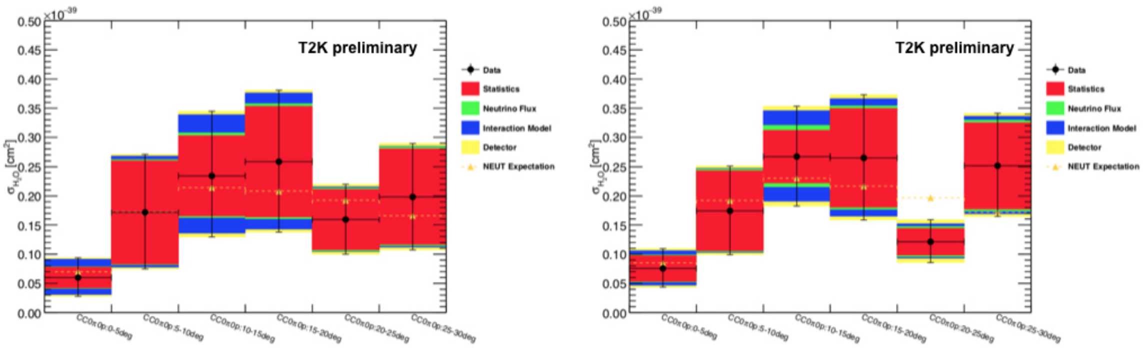

Figure 3: Measured values for the differential cross sections (T2K preliminary): $\bar{\nu}_\mu$ cross section (left) and $\nu_\mu + \bar{\nu}_\mu$ cross section (right) on water target. Each plot shows the cumulative quadratic sum of the uncertainties from statistics, neutrino flux, neutrino interaction model, and detector response.

One small non-magnetized muon range detector was used in this period. The ratio of neutrino contamination to antineutrino is about 30%, which remained as the main background. Error levels are almost the same as the previous run. We extracted the flux-integrated cross-sections on water and carbon, cross-section differential in outgoing muon scattering angle.

4. Strategy for precise measurement with full setup WAGASCI

The first physics run with the full setup of WAGASCI-Baby MIND is scheduled from Nov. 2019 to Feb. 2020. Figure 4 shows detector configuration in the next run. The asymmetric configuration shown here was determined based on MC, which is expected to increase the acceptance for largely scattering muons. The WAGASCI experiment collaborates with the NINJA experiment [2], which also aims to measure precisely neutrino interaction with nuclear emulsion.

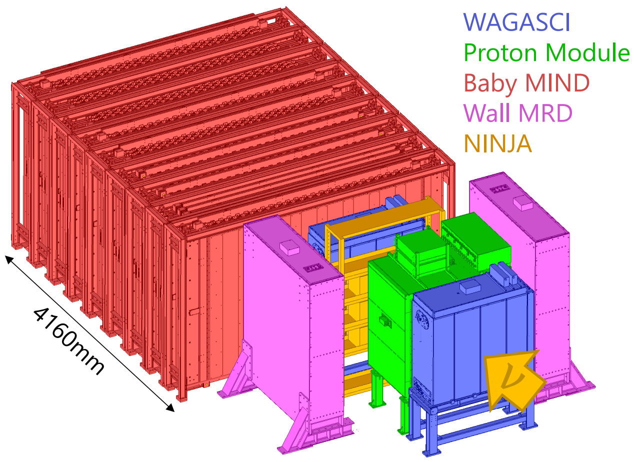

Figure 4: 3D CAD image of WAGASCI detectors

One of the main physics goals of this run is to understand precisely neutrino interactions and reduce the systematic uncertainties on neutrino interaction models for the T2K experiment. There are discrepancies between cross-section measurements by ND280 and the baseline model of neutrino interaction in NEUT[3]. Such discrepancies are basically compensated by the ND280 fit for the T2K oscillation analysis. The measurement of neutrino oscillation is affected by such uncertainties through the reconstruction of neutrino energy, notably due to the presence of a large high-energy tail in the survived numu spectrum in Super Kamiokande.

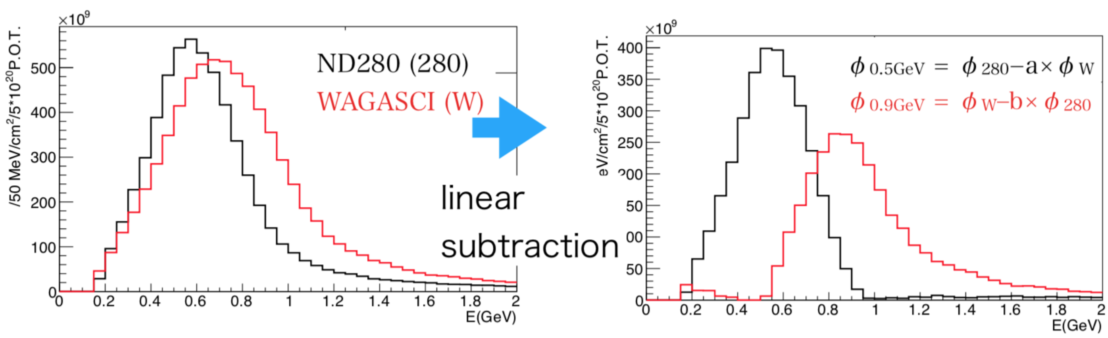

Figure 5: Simulated fluxes at ND280 and WAGASCI (left) and subtracted fluxes at two kinds of coefficients (right)

The WAGASCI experiment is aiming to measure the neutrino cross section precisely by combined analysis with ND280. The WAGASCI detectors are located at 1.5 degrees off-axis and ND280 at 2.5 degrees off-axis. Therefore two kinds of neutrino spectra are measured at different positions (figure 5). We can statistically remove the contamination from high-energy tail or low-energy tail by taking a linear subtraction of these spectra. Double differential cross-section for muon scattering angle and momentum on water and hydrocarbon can be extracted with the narrower-band flux. The expected number of events was calculated based on MC. The WAGASCI experiment will take enough data for measuring the differential cross-section using CC interaction sample with an uncertainty of 10%.

5. Conclusion

The T2K experiment is aiming to discover the CP violation in the lepton sector, which requires to decrease the systematic and statistic uncertainties. The WAGASCI experiment has been fighting to improve uncertainties on neutrino interaction models. The experiment reaches the final phase, where the full setup is available and the combined analysis between WAGASCI and ND280 will be performed.

References

[1] T2K Collaboration, K. Abe et al., "Measurement of the ν_μ charged-current cross sections on water, hydrocarbon, iron, and their ratios with the T2K on-axis detectors," arXiv:1904.09611 [physics.ins-det].

[2] T. Fukuda et.al., "First neutrino event detection with nuclear emulsion at J-PARC neutrino beamline", Prog. Theor. Exp. Phys. 063C02 (2017).

[3] T2K Collaboration, K. Abe et.al., "First measurement of the ν_μ charged-current cross section on a water target without pions in the final state", Phys.Rev.D 97, 012001.

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