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

A. Bonnemaison, R. Cornat, L. Domine, O. Drapier, O. Ferreira, F. Gastaldi, M. Gonin, J. Imber, M. Licciardi, F. Magniette, T. Mueller, L. Vignoli, and O. Volcy

Ecole Polytechnique, IN2P3-CNRS, Laboratoire Leprince-Ringuet, Palaiseau, France

S. Cao and T. Kobayashi

High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki, Japan

M. Khabibullin, A. Khotjantsev, A. Kostin, Y. Kudenko, A. Mefodiev, O. Mineev, S. Suvorov, and N. Yershov

Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia

B. Quilain

Kavli Institute for the Physics and Mathematics of the Universe (WPI), The University of Tokyo Institutes for Advanced Study, University of Tokyo, Kashiwa, Chiba, Japan

T. Hayashino, A. Hiramoto, A.K. Ichikawa, K. Nakamura, T. Nakaya, K Yasutome, and K. Yoshida

Kyoto University, Department of Physics, Kyoto, Japan

Y. Azuma, J. Harada, T. Inoue, K. Kin, N. Kukita, S. Tanaka, Y. Seiya, K. Wakamatsu, and K. Yamamoto

Osaka City University, Department of Physics, Osaka, Japan

A. Blondel, F. Cadoux, Y. Karadzhov, Y. Favere, E. Noah, L. Nicola, S. Parsa, and M. Rayner

University of Geneva, Section de Physique, DPNC, Geneva, Switzerland

N. Chikuma, F. Hosomi, T. Koga, R. Tamura, and M. Yokoyama

University of Tokyo, Department of Physics, Tokyo, Japan

Y. Hayato

University of Tokyo, Institute for Cosmic Ray Research, Kamioka Observatory, Kamioka, Japan

Y. Asada, K. Matsushita, A. Minamino, K. Okamoto, and D. Yamaguchi

Yokoyama National University, Faculty of Engineering, Yokoyama, Japan

November 30, 2017

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.

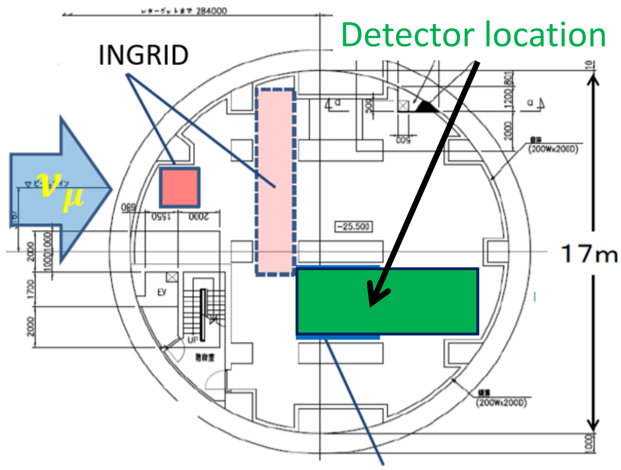

Figure 2: Candidate detector position in the B2 floor of the near detector hall.

2.2 Baby MIND

2.3 Side muon range detector

Two Side-MRD modules will be constructed by the end of January 2018. Each Side-MRD module is composed of iron plates and scintillator bars for tracking secondary particles from neutrino interactions. Support structure of the Side-MRD module mainly consists of 11 steel plates of which dimensions are $1800 \times 1610 \times 30$ mm^3, is sized as $2236 \times 1630 \times 975$ mm^3 as shown in Figure 5, and weights ~8.5 ton. 80 scintillator bars are installed in one Side-MRD module, and each scintillator bar is sized as $1800 \times 200 \times 7$ mm^3 including reflector part. Scintillation light is collected by wave length shifting fibers, Y-11 (S type) with a diameter of 1.0 mm produced by Kuraray. The fiber is glued by optical cement in a S-shape groove on the surface of the scintillator bar as shown in Figure 6. Two optical connectors are attached to either end of the fiber, and scintillation light is lead to two MPPCs, S13081-050CS(X1), produced at Hamamatsu Photonics. For each MPPC, 667 pixels of APD are aligned in a shape of square 1.3 mm on a side.

Construction of scintillator bars of the Side-MRD modules had been completed in Russia, and they were transported to Japan in July 2017. Construction of Side-MRD modules will be done from November 2017 to January 2018 at Yokohama National University, then they will be transported to J-PARC and will be installed to the B2 floor of the T2K near detector hall before staring the T2K beam in March 2018.

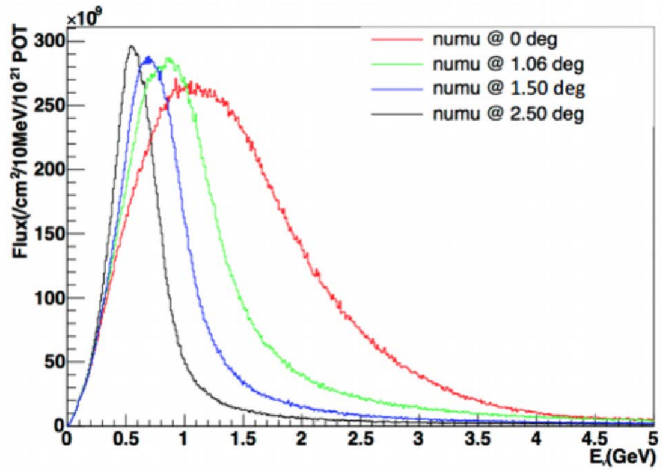

Figure 3: Neutrino energy spectrum at the candidate detector position(red). The spectrum at the ND280 site (black) is also shown.

3 Physics goals

4 Status of J-PARC T59 experiment

We had submitted a proposal of a test experiment to test a new detector with a water target, WAGASCI, at the T2K near detector hall to J-PARC PAC on April 2014, and the proposal was approved as J-PARC T59. There are several updates on the project after three years from then. Fist, the start time of neutrino beam measurement is changed from December 2015 to October 2017, and the requested neutrino beam is changed from 1×10^{21} POT of ν beam to 0.8×10^{21}POT of anti-ν beam. Second, the detector configuration is changed. In the original proposal, central neutrino detector are expected to be surrounded by newly developed muon-range detectors (MRDs), but we will use spare neutrino detectors of the T2K experiment instead of them during neutrino beam measurement from October to December 2017. Construction of the newly developed MRDs, Baby-MIND and Side-MRD, is in progress, and they will be installed to the both sides and the downstream of the central neutrino detector from January to March 2018. Then, we will resume neutrino beam measurements from March 2018 and will take the neutrino beam data until May 2018.

4.1 On-axis beam measurement with Prototype detector

Add INGRID water module measurement here.

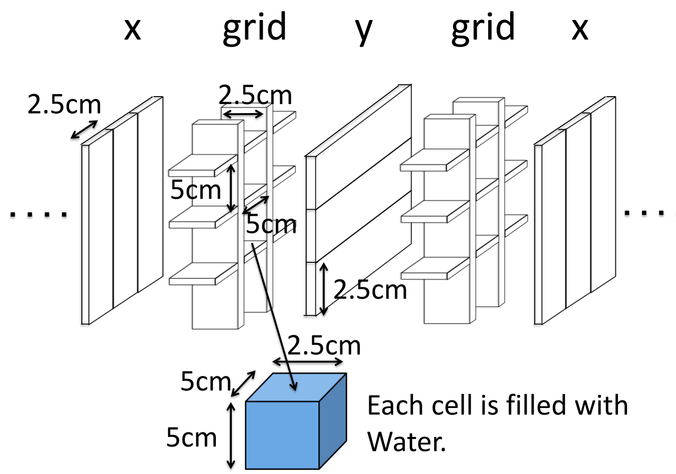

Figure 4: Schematic view of 3D grid-like structure of plastic scintillator bars inside the central detector.

4.2 Plans from October 2017 to May 2018

J-PARC MR will extract its proton beam to T2K neutrino beam-line from October to December 2017, and, from March to May 2018. T2K experiment will produce anti-neutrino beam and will accumulate $\sim 8 \times 10^{20}$ POT data during the above period.

J-PARC T59 will perform neutrino beam measurements on the B2 floor of the T2K near neutrino detector hall during the above period to test basic performances of the WAGASCI detector and new electronics. During the beam measurements from October to December 2017, one WAGASCI module will be placed between spare neutrino detectors of the T2K experiment, INGRID Proton module and INGRID standard module as shown in Fig. **??**. Detector location on the B2 floor of T2K near detector hall is shown in Fig. 8. Here, the INGRID Proton module is used as a charged particle VETO detector and, the INGRID standard module is used as a downstream muon detector. We had submitted a proposal to use these spare neutrino detectors for the T59 neutrino beam measurements to the T2K collaboration, and we got an approval from T2K.

During the beam measurements from March to May 2018, Baby-MIND and two side muon-range detector (Side-MRD) modules will be installed on the downstream and the both sides of the WAGASCI detector, as shown in Fig. 9, to increase angular acceptance for secondary charged particles from neutrino interactions. Add Baby-MIND commissioning items here!!!

Expected number of neutrino events in the WAGASCI detector during the above beam period is evaluated with Monte Carlo simulations. Neutrino beam flux at the detector

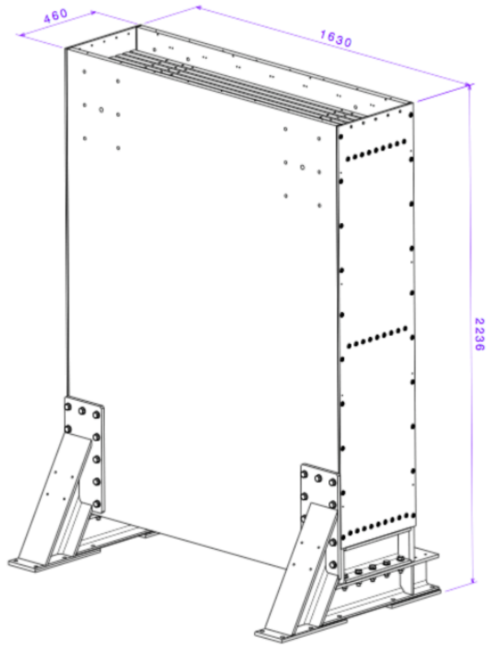

Figure 5: Support structure of the Side-MRD module.

location is simulated by T2K neutrino flux generator, JNUBEAM, neutrino interactions with target materials are simulated by a neutrino interaction simulator, NEUT, detector responses are simulated using GEANT4-based simulation. The neutrino flux at the detector location, 1.5 degrees away from the J-PARC neutrino beam axis, is shown in Figure 3, and its mean neutrino energy is around 0.68 GeV. An event display of the GEANT4-based detector simulation is shown in Figure 10.

To perform the detector performance test, the following event selections are applied to the data. First, track reconstructions are performed in the WAGASCI detector, and the reconstructed vertex is required to be inside a defined fiducial volume, $80 \times 80 \times 32$ cm^3 region at the center of the detector, to reduce contamination from external backgrounds. Second, at least one charged particle is required to reach to INGRID standard module or Side-MRD modules, and it makes more than two hits in these sub-detectors. With the event selection, expected numbers of the neutrino-candidate events during the beam period are summarized in Table 1. Using the data, we will test the detector performance with $\sim 3\%$ statistical uncertainties.

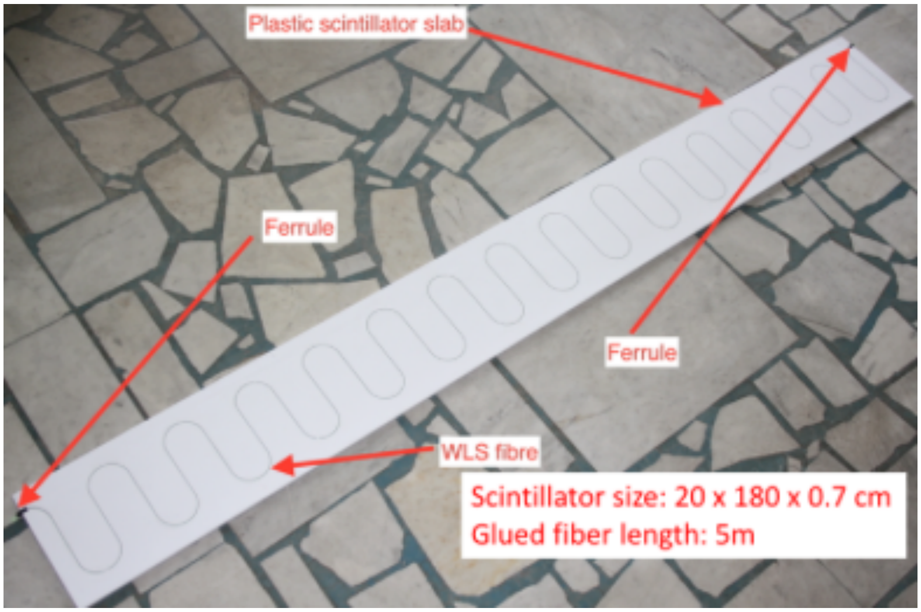

Figure 6: Scintillator bar of the Side-MRD modules.

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 11 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.12. 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.

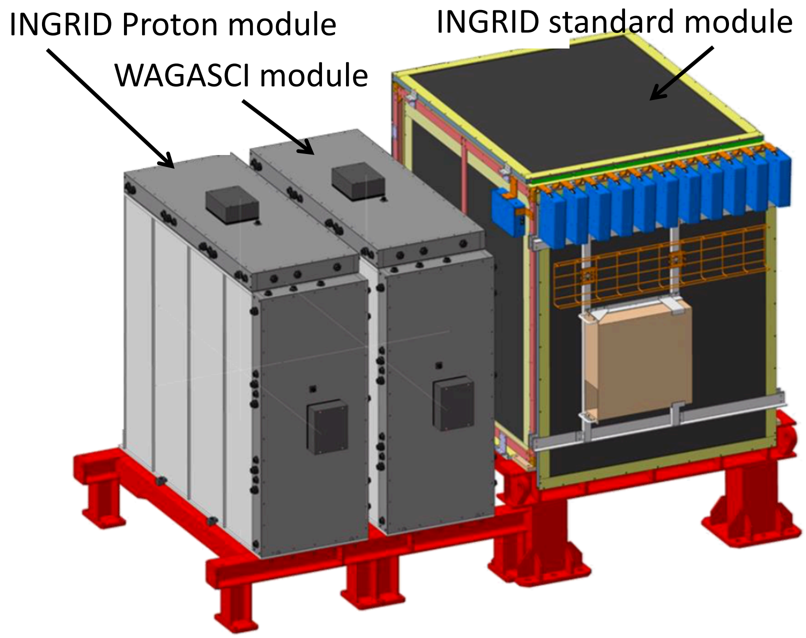

Figure 7: J-PARC T59 detector configuration from Oct. to Dec. 2017

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)

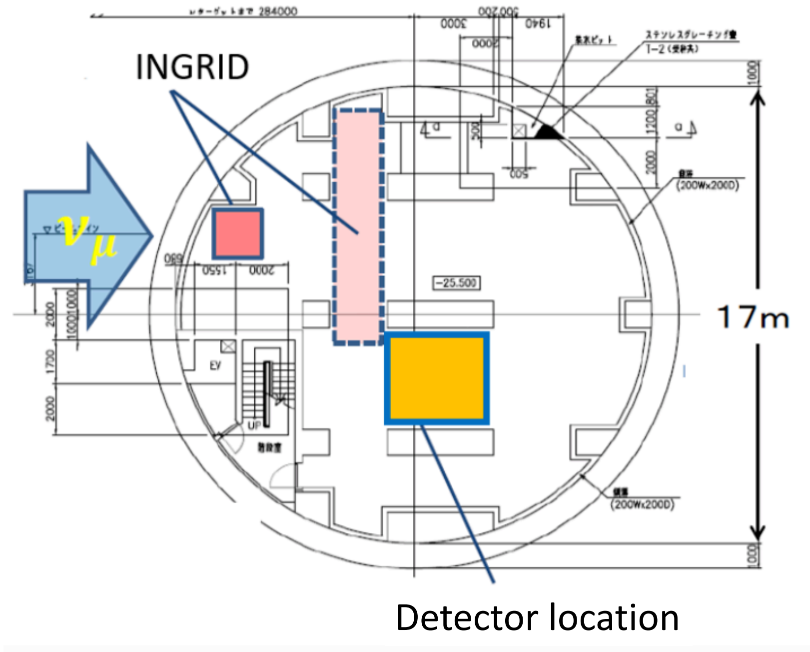

Figure 8: J-PARC T59 detector location from Oct. to Dec. 2017

- Electricity (∼10kW) for the electronics and water circulation system
- Beam timing signal and spill information
- Network connection

9 Conclusion

tmp.pdf

Figure 9: J-PARC T59 detector configuration with Baby-MIND and two Side-MRD modules from Mar. to May 2018. (Need to prepare the figure.)

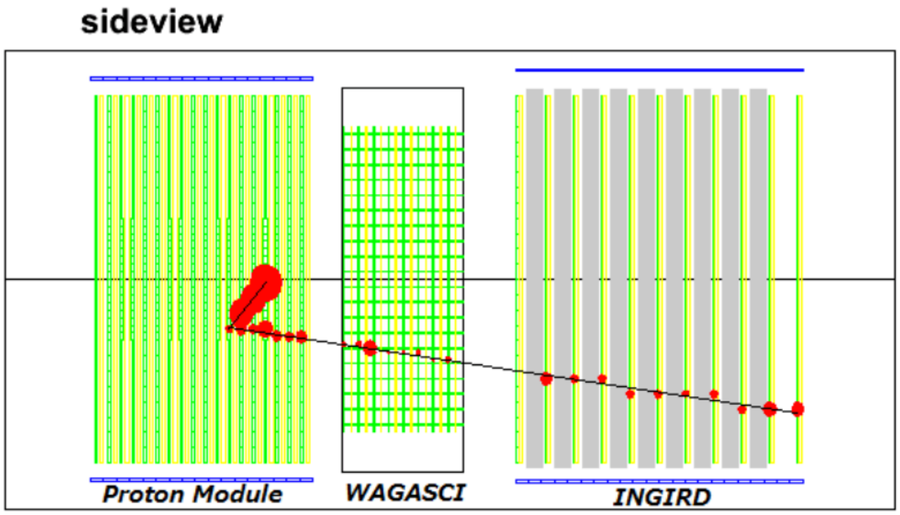

Figure 10: J-PARC T59 event display of a neutrino event in the GENAT4-based detector simulation.

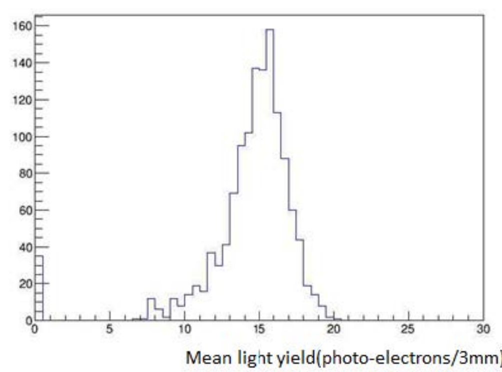

Figure 11: Light yield of channels for muons produced by the interaction of neutrinos in the hall wall.

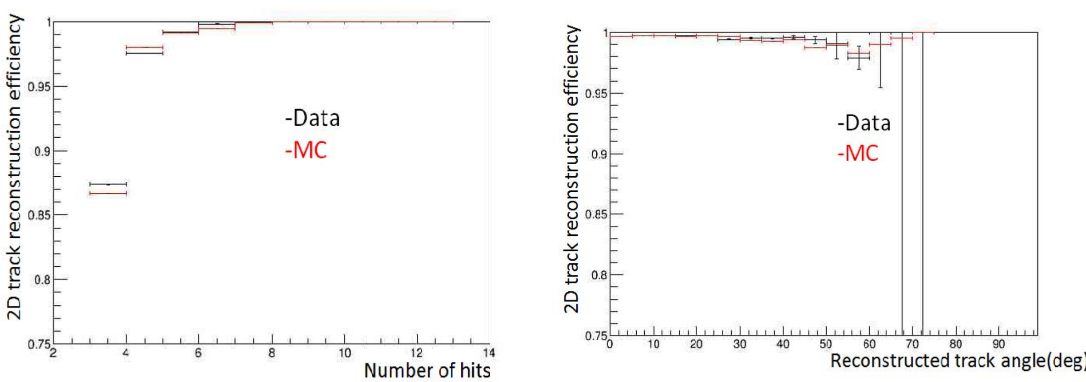

Figure 12: 2D track reconstruction efficiency as a function of number of hits (left) and track angle (right). Here the track angle is the one reconstructed by the INGRID module.