

Proposal of New Test Experiment

BISCOTTEE Phase-0: Measurement of accelerated neutrino-induced neutron background at the J-PARC

H. Ito*

Depart. of Phys., Kobe Univ., Hyogo 657-8501, Japan

M. Ishitsuka

Depart. of Phys., Tokyo Univ. of Scie., Chiba 278-8510, Japan

A. Minamino

Depart. of Phys., Yokohama National Univ., Kanagawa 240-8501, Japan

Y. Koshio

Depart. of Phys., Okayama Univ., Okayama 700-8530, Japan

T. Yano

Kamioka Observatory, ICRP, Univ. of Tokyo, Gifu 506-1205, Japan

February 27, 2026

Abstract

This proposal is a test experiment to start a new physics experiment program, BISCOTTEE, for measurement of neutrino-nucleus (mainly oxygen) neutral-current quasielastic scattering (NCQE) interaction in short-baseline accelerated neutrino experiments. It is important to understand and to reduce the accidental neutron background for the precision measurement of NCQE events. In 2024 February and June, we have measured the neutrino-induced neutron background flux as the T101 experiment for neutrino mode and at the most north area on the B2 floor in the Neutrino Monitoring (NM) building, J-PARC. The finite neutron events were observed and the neutron flux was preliminary determined to be $(1.45^{+0.22}_{-0.24}) \times 10^{-12} \text{ cm}^2 \text{ s}^{-1} \text{ POT}^{-1}$ at 29.725×10^{19} POT data taking, where note that it is only statistical error. In this proposed test experiment, in order to determine the best place with the minimum of the neutron background flux, we request beamtime to take data of the neutron flux for both mode of neutrino/anti-neutrino and at some places on the B2 floor in the NM building.

*Corresponding author: itoh.hiroshi@crystal.kobe-u.ac.jp (H. Ito)

1 Introduction

In a search for diffuse supernovae neutrino background (DSNB) based on massive water Cherenkov detectors, one of the sources that limit the sensitivity is the model uncertainty of atmospheric neutrino-oxygen nucleus (ν - ^{16}O) neutral-current quasielastic (NCQE) interaction [1, 2], which is the following neutron channel: $\nu + ^{16}\text{O} \rightarrow \nu + n + ^{15}\text{O}^*$; $^{15}\text{O}^* \rightarrow ^{15}\text{O} + \gamma$. This NCQE background event is estimated by following models: the HKKM [3, 4] as the atmospheric neutrino flux, NEUT 5.4.0.1 [5, 6] for the neutrino interaction, and the model of Ankowski et al. as the nuclear de-excitation γ rays from the NCQE interaction below the energy of 16 MeV [7].

In the current DSNB search, the total systematic uncertainty for the estimation of the number of events in the NCQE reaction is estimated to be 68% below 15.49 MeV and 82% above 15.49 MeV, combined with the following systematic uncertainties: the cross section ($\sim 30\%$), the atmospheric neutrino flux ($\sim 5\%$ for neutrino / $\sim 7\%$ for antineutrino), the neutron multiplicity ($\sim 40\%$), and the spectral shape ($30 \sim 60\%$) in $7.5 \sim 29.5$ MeV.

On the other hand, the T2K collaboration determined the accelerated ν - ^{16}O NCQE cross section to be $1.70 \times 10^{-38} \text{ cm}^2/\text{oxygen}$ with $\pm 10\%$ (stat.) and $^{+30\%}_{-22\%}$ (syst.) for neutrino mode and $0.98 \times 10^{-38} \text{ cm}^2/\text{oxygen}$ with $\pm 16\%$ (stat.) and $^{+27\%}_{-19\%}$ (syst.) for antineutrino mode [8]. This result is based on the Super-kamiokande as the far detector. To reduce the uncertainty of the NCQE model, more statistics are required. On the short baseline, high-statistics NCQE measurements are expected to be achieved using relatively compact detectors.

We have a future plan to measure ν - ^{16}O NCQE events, *BISCOTTEE: Bismuth-germanate crystal based neutrino(neutron)-nucleus scattering experiment*, which has the potential of full reconstruction with oxygen recoil, γ -ray, and neutron, using a bismuth-germanate (BGO)-based detector, as shown in Fig. 1. BGO: $\text{Bi}_4\text{Ge}_3\text{O}_{12}$ has a good chemical stability, density of 7.14 g/cm^3 and is one of popular scintillators for high energy particle physics field. We measured recently a quenching factor of oxygen recoil energy as a function of the recoil energy [9]. Based on these results, we conclude that the above detection to measure the NCQE events is possible using the BGO.

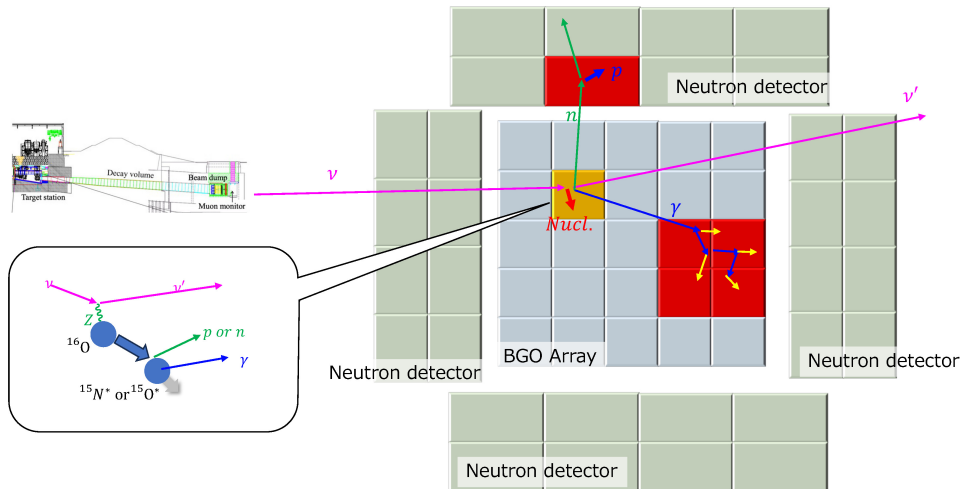


Fig. 1: Illustration of a future experiment to detect neutrino-oxygen neutral-current quasielastic scattering events using the BGO-based detector.

A main background for the new experiment is expected to be neutrons, which are induced by the accelerated neutrinos, scattering with a nucleus in the BGO crystals. We propose to measure the accelerated neutrino-induced neutron background in order to design the detector.

In 2024 February and June, we have conducted to measure the neutrino-induced neutron background flux as the T101 experiment [10] for neutrino mode and at the most north area on the B2 floor in the NM building, J-PARC. The beam power have been 650–800 kW with "neutrino mode". The setup was configured as a plastic scintillator (PS), BGO detectors (BGO), and a liquid scintillator (LS) along the beam axis. We have conducted 29.725×10^{19} POT data taking, and we found 88 events of the neutrino-induced neutron-like (proton recoil) using the LS with neutron identification by the pulse shape discrimination (PSD).

Figure 2 (a), (b), and (c) (bottom) shows observed energy distribution for the LS detector and simulation for setup 1, 2, and 3, respectively. These common setups are arranged along the beam axis in the order of PS, BGO, and LS. In setup 1, these detectors are placed on the table top simply. In setup 2, these detectors are fixed to the aluminum frame to strengthen the configuration, and the location of these detectors is a little different from that of setup 1. In setup 3, a small size BGO detector ($3 \times 3 \times 3 \text{ cm}^3$) is added between PS and BGO. The neutron spectrum is assumed that the function of $A \exp(-E_n/\lambda)$, where A is amplitude, E_n is neutron kinetic energy with unit of MeV, and λ is energy constant term. The simulation spectrum have been fit to data with two free parameters (A and λ), then the flux is calculate to be $A\lambda$ because of the integration from 0 to infinity for exponential function. Figure 2 (a), (b), and (c) (top) shows χ^2 distribution for setup 1, 2, and 3, respectively. The values of A and λ are strongly correlated.

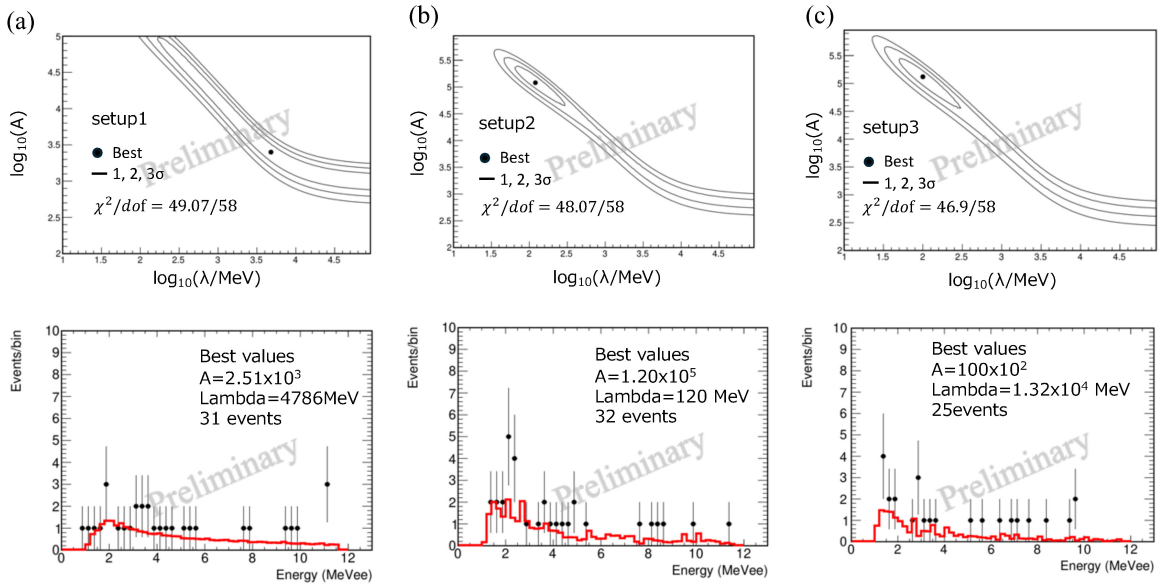


Fig. 2: The observed energy distribution in liquid scintillator with simulation spectrum (bottom) and χ^2 distribution in the fitting (top). (a), (b), and (c) are for setup 1, 2, and 3, respectively.

Figure 3 (left) shows the comparison of these three (χ^2 distribution) results. We found the trend for A - λ correlation for three setups. Then, three data have been combined, and the best fit values are $A = 1.0 \times 10^5$ and $\lambda = 145 \text{ MeV}$, with $\chi^2/\text{ndf} = 148.1/178$, as shown in Fig. 3

(right). The neutron flux was preliminary determined to be $(1.45^{+0.22}_{-0.24}) \times 10^{-12} \text{ cm}^2 \text{ s}^{-1} \text{ POT}^{-1}$, where note that it is only statistical error.

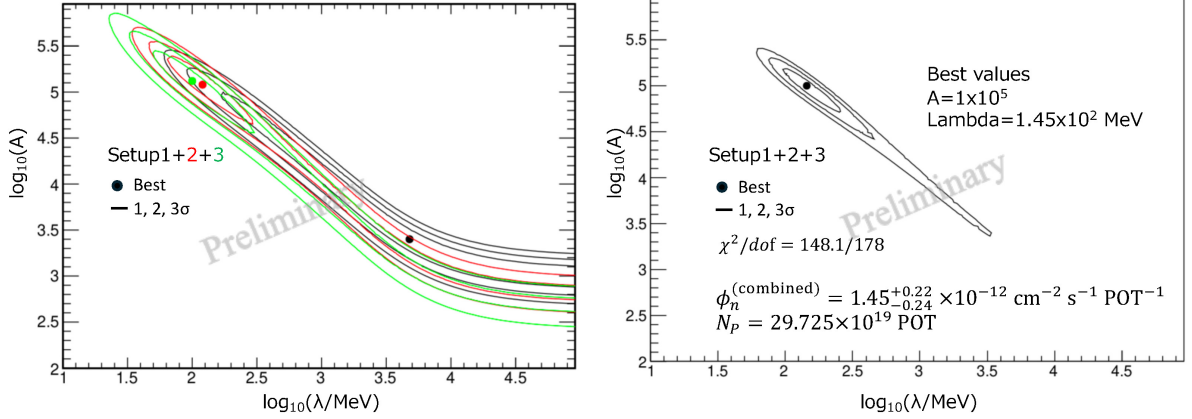


Fig. 3: The observed energy distribution in liquid scintillator with simulation spectrum (bottom) and χ^2 distribution in the fitting (top). (a), (b), and (c) are for setup 1, 2, and 3, respectively.

We have an opportunity to observe ν -BGO CC interacting events in the T101 setup. The expected number of the CC events is 1.4 ± 0.3 using 192 g BGO crystal at the beam time of 6.8×10^{19} POT. We calculate the detection efficiency to be $11.8 \pm 2.2\%$ including the muon acceptance. One event of the CC candidate is observed at this time and it is consistent with the expectation [11].

2 Proposed measurement

We aim to measure neutron background events, like the T101 experiment, for both mode of neutrino/anti-neutrino and at the other place on the B2 floor in the neutrino monitoring (NM) building. In addition, we would test to detect the neutrino CC events in the same setup. This section briefly describes the setup, equipment, calibration, and analysis strategy.

2.1 Setup

Figure 4 shows the schematic view of the detector setup, front-end electronics and data acquisition system (DAQ). The detectors will be located on several areas of the B2 floor in the NM building at the J-PARC. The system in this test experiment is compact in a similar size to the T101 experiment, as shown in Fig. 5.

2.2 Equipment

Two plastic scintillation detectors (PS-1 and PS-2), a BGO detector (BGO), and a liquid scintillation detector (LS) are configured in the experiment. One of the plastic scintillator (size of $20 \text{ cm} \times 20 \text{ cm} \times 1 \text{ cm}$) is connected to a 2-inch photo-multiplier tube (PMT) through an acrylic light guide, which is labeled as channel 1 (1 ch) as shown in Fig. 4. Second plastic scintillator (size of $10 \text{ cm} \times 10 \text{ cm} \times 1 \text{ cm}$) is connected to a 1/2-inch PMT through an acrylic light guide, which is labeled as 4 ch. The BGO (size of 5 cm in depth and 5 cm in diameter)

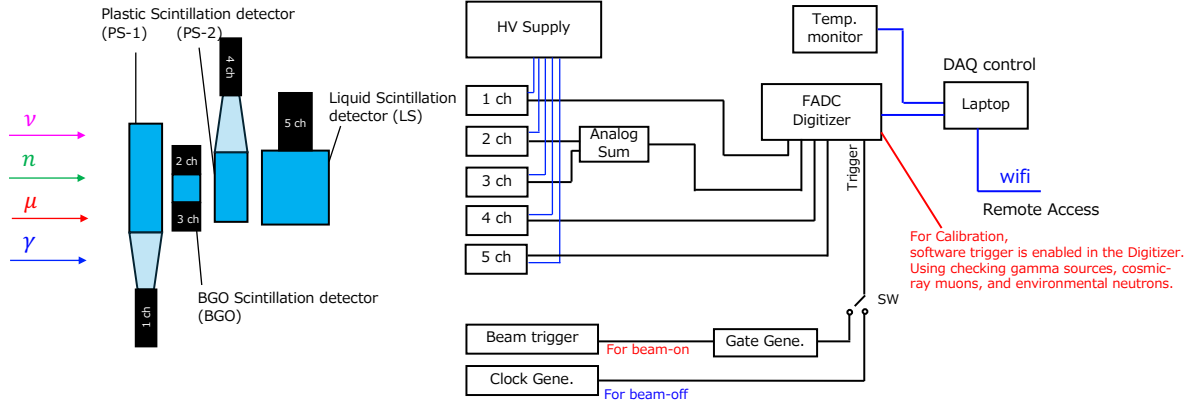


Fig. 4: Schematic view of setup and front-end DAQ electronics.



Fig. 5: Photograph of setup in the T101 experiment.

is connected to two 2-inch PMTs on the both sides of the BGO crystal, where the PMTs are labeled as 2 and 3 ch. The liquid scintillator (size of 7.62 cm in depth and 7.62 cm in diameter) was connected optically to a 3-inch PMT, which is labeled as 5 ch.

These PMT analog waveform signals are recorded by a flash ADC digitizer (CAEN, DT5720) with a 250 MHz sampling rate when the trigger signal occurs. A trigger can be switched to a beam timing signal (for beam on) and output signal from a clock generator (for beam off) as the external input. For the calibration, we use the internal self-trigger of one or some pulses coincidence in the digitizer. Data taking window will be 100 μ s. Figure 6 (left) shows a typical signal waveform of the BGO detector. Then, the waveform data is stored in the laptop for the DAQ control, where we can operate the laptop by remote access. Eight bunches of the neutrino beam can be observed on the on-time region in the T101 experiment, as shown in Fig. 6 (right). In the on-time, almost all events are muons from the wall. The amount of the accidental event rate is determined in the off-time region. Then, we can evaluate the net event

rate by subtracting the events of off-time from those of on-time.

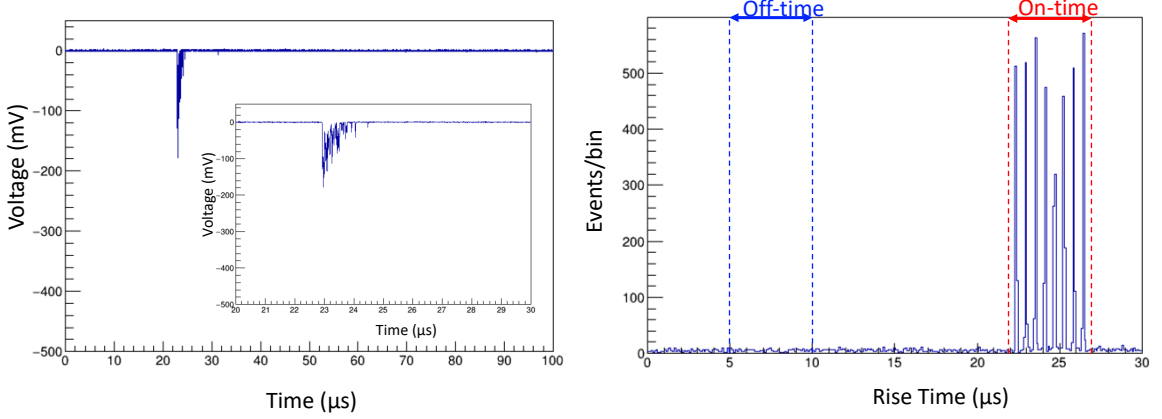


Fig. 6: Typical waveform of the BGO detector signal (left). Distribution of rise time in BGO detector (right).

2.3 Calibration

We would perform the energy calibration of the BGO, LS, PS-1, and PS-2 detectors and the signal timing tuning in the experimental site using γ -ray checking sources, cosmic-ray muons, and environmental neutrons at the beam-off period at J-PARC.

For BGO, the light yields have temperature dependence, so the temperature in the experimental site should be monitored. Especially, it is important to calibrate the lower energy region (tens to hundreds keV) for the measurement of the recoil nucleus with consideration of the quenching effect of the light yield. We have already performed the energy calibration of the BGO detector at our laboratories in Tokyo University of Science and Kobe University. However, at also onsite, using ^{137}Cs , ^{60}Co , ^{133}Ba , and ^{109}Cd of checking sources and ^{40}K of environmental radioactivity, we would measure photoelectron-absorption peaks to evaluate energy coefficient, and the energy resolution would be determined.

For LS, PS-1, and PS-2, electron with the Compton scattering for γ rays would be used in the energy calibration. Comparing the Compton edge of data and simulation with energy smearing, the best of both energy resolution and coefficient have been determined. Using Co-60 source, which emit 1.17 MeV and 1.33 MeV γ rays, one γ -ray event (e.g. 1.17 MeV) tagged by BGO, other γ ray (e.g. 1.33 MeV) enter to LS or PS. It is possible to compare with mono energy injection to the detector more purely. We have already established the method and performed the calibration of the LS detector at our laboratories.

For PSD of LS calibration, we will use environmental neutrons. At the beam-off period, LS is surround by lead blocks to shield γ rays to enhance the S/N for neutron events. We have already performed the PSD of LS at our laboratories.

For the timing calibration of these detectors, we use cosmic-ray muons. The setup is rotated by 90 degrees to enhance the cosmic-ray muon events rate.

2.4 Analysis strategy

We have an analysis strategy to obtain neutron events regarding the neutrino beam by subtracting beam-on and beam-off distribution. A record time window will be $100\ \mu\text{s}$. The beam spill has eight beam bunches with 60 ns width and 540 ns interval, and the usual neutrino beam has spill per 1.28 s. So, one spill data is recorded as one waveform. The decay time constant of BGO scintillation light is typically 300 ns, but we will synchronize each bunch's timing by the rise time.

For neutron events, we can select an event with no hit of the PS-1 or PS-2 and a hit of the BGO or LS. Then, we can select the neutron scattering events, with no hit of the PS-1 or PS-2, a hit of BGO, and a neutron-like event selected by PSD ¹ in LS.

On the other hand, neutrino-induced muon events can be selected by all hit signals. The muon hit timing would be also useful to calibrate the timing of detectors. In addition, neutrino charged-current (CC) interacting muon events can be selected by hits of BGO, PS-2, and LS without PS-1. It indicates that the muon is produced in the BGO and has passed on PS-2 and LS.

3 Beam time requirement

In the T101 experiment, the neutron flux is determined to be $(1.45^{+0.22}_{-0.24}) \times 10^{-12}\ \text{cm}^2\ \text{s}^{-1}\text{POT}^{-1}$ and 88 neutron events using a 3-inch size liquid scintillator at $29 \times 10^{19}\ \text{POT}$ on February and June, 2024.

To observe the hundred neutron events or more, $40 \times 10^{19}\ \text{POT}$ is needed. On the other hand, on the T101 setup, we observed one event of the CC candidate in parallel measurement. So, using 734 g BGO crystal, taking data of the requested beamtime, we estimate to detect 31 ± 7 of the CC events. Therefore, we require beamtime of $40 \times 10^{19}\ \text{POT}$ data taking to observe the events significantly (hundred or more neutron events and 30 CC events).

In assumption of average of $1.2 \times 10^{19}\ \text{POT/day}$ ² for the beam power of 900 kW, 8 bunches, and 1.28 s cycle spill, it is taking periods of 33 live days for the request data taking.

4 Schedule

We plan to measure from April 2026, if assigned our project. The schedule is summarized in Table. [1](#).

5 Requests

Our requests for the above experiment are as follows.

- T2K beam timing signal and spill information; we prefer a period of "anti-neutrino" mode. Even during "neutrino" mode, valuable data can be obtained by collecting it at different locations of the T101.

¹Technical note for pulse-shape discrimination based on LS details in Appendix of Ref. [\[12\]](#).

²The assumption value of POT/day is based on actual one by the T2K shift monitor on January 2026.

Table 1: Summary of schedule to take data

Date	
14 days	Preparation, Setup configuration at B2 hall Calibration (w. checking sources)
2 days	Data taking (Beam off, vertical axis direction, for muon) Data taking (Beam off, horizontal axis direction)
6 days	Data taking (Beam on)
1 day (Beam Maintenance)	Calibration (w. checking sources) Data taking (Beam off)
6 days	Data taking (Beam on)
1 day (Beam Maintenance)	Calibration (w. checking sources) Data taking (Beam off)
6 days	Data taking (Beam on)
1 day (Beam Maintenance)	Calibration (w. checking sources) Data taking (Beam off)
6 days	Data taking (Beam on)
1 day (Beam Maintenance)	Calibration (w. checking sources) Data taking (Beam off)
6 days	Data taking (Beam on)
1 day (Beam Maintenance)	Calibration (w. checking sources) Data taking (Beam off)
3 days	Data taking (Beam on)
2 days	Calibration (w. checking sources) Data taking (Beam off) Finish and Withdrawal

- Experimental space (around 1 m $\times$ 2 m) of the B2 hall in the NM building at J-PARC.
- Electricity to provide our devices.
- Network connection.
- γ -ray sources for the detector calibration.
- A table and chairs.

6 Summary

We proposed a new test experiment, "measurement of accelerated neutrino-induced neutron background at the J-PARC", as BISCOTTEE phase-0 for a future experimental program to measure neutrino-oxygen neutral-current scattering interaction. A main background is the neutrino-induced neutrons and γ rays, and we should evaluate in order to design the detector. We require a beamtime of two term of neutrino beamtime to take data at B2 hall in the NM building at J-PARC. In order to start rapidly after the carrying the detector configurations in the experimental site, we have done to prepare detectors, DAQ, setup, and calibration.

References

- [1] K. Abe, et al., Diffuse supernova neutrino background search at Super-Kamiokande, Phys. Rev. D 104 (12) (2021) 122002. [arXiv:2109.11174](#), [doi:10.1103/PhysRevD.104.122002](#).
- [2] M. Harada, et al., Search for Astrophysical Electron Antineutrinos in Super-Kamiokande with 0.01% Gadolinium-loaded Water, ApJL 951 (2) (2023) L27. [arXiv:2305.05135](#), [doi:10.3847/2041-8213/acdc9e](#).
- [3] M. Honda, et al., Improvement of low energy atmospheric neutrino flux calculation using the JAM nuclear interaction model, Phys. Rev. D 83, 123001 (2011).
- [4] M. Honda, et al., Calculation of atmospheric neutrino flux using the interaction model calibrated with atmospheric muon data, Phys. Rev. D 75, 043006 (2007).
- [5] Y. Hayato, A NEUTRINO INTERACTION SIMULATION PROGRAM LIBRARY NEUT, Acta. Physica Polonica B, 40, 9, 2477 (2009).
- [6] Y. Hayato, L. Pickering, The NEUT neutrino interaction simulation program library, Eur. Phys. J. Spec. Top. (2021) 230: 4469–4481.
- [7] A. M. Ankowski, et al., Analysis of γ -Ray Production in Neutral-Current Neutrino-Oxygen Interactions at Energies above 200 MeV, Phys. Rev. Lett. 108, 052505.
- [8] K. Abe, et al., Measurement of neutrino and antineutrino neutral-current quasielasticlike interactions on oxygen by detecting nuclear deexcitation γ rays, Phys. Rev. D 100 (2019) 112009. [doi:10.1103/PhysRevD.100.112009](#).
- [9] Y. Ommura, et al., A method to measure the quenching factor for recoil energy of oxygen in bismuth germanium oxide scintillators, Journal of Instrumentation 18 (04) (2023) T04006. [doi:10.1088/1748-0221/18/04/T04006](#).
- [10] H. Ito, et al., Measurement of neutrino-induced neutron and γ -ray background for BGO-based detectors at J-PARC, the J-PARC T101 proposal (2023).
- [11] H. Ito, A New Experiment to Measure the ν -oxygen NCQE Scattering with the BGO-based Detector in a Short-baseline Neutrino Facility, JPS Conf. Proc.(J-PARC Symposium 2024); Accepted.
- [12] H. Ito, et al., Analyzing the neutron and γ -ray emission properties of an americium-beryllium tagged neutron source, Nucl. Instr. Meth. A 1057 (2023) 168701. [doi:https://doi.org/10.1016/j.nima.2023.168701](#).