Proposal of New Test Experiment

Measurement of neutrino-induced neutron and γ-ray background for BGO-based detectors at J-PARC

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Abstract

We propose a new test experiment to measure neutral particles, such as neutrons and γ rays, induced by the T2K neutrino beam in the J-PARC B2 hall, for bismuth-germanium-oxide (BGO)-based detectors for a future plan to measure the neutrino-oxygen neutral-current interacting events. In this experiment, we aim to evaluate the number of events of accidental coincidence in the BGO crystals by detecting recoil nuclei signals mainly in the BGO-based detector.

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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]. The Super-Kamiokande group estimated the NCQE background for the DSNB search using the model which is originated from the T2K result. The T2K group determined the ν-^{16}O NCQE cross-section to be $\left[1.70 \pm 0.17_{\text{(stat.)}}{}^{+0.51}_{-0.38}{}_{\text{(syst.)}}\right] \times 10^{-38}$ cm^2/oxygen for neutrino mode and $\left[0.98 \pm 0.16_{\text{(stat.)}}{}^{+0.26}_{-0.19}{}_{\text{(syst.)}}\right] \times 10^{-38}$ cm^2/oxygen for antineutrino mode [2]. However, there is an issue that water Cherenkov detectors have less sensitivity to low-energy (< 4 MeV) gamma-ray as a prompt signal. So, another approach to detect NCQE events is needed to reduce the model uncertainty.

We have a future plan to measure ν-^{16}O NCQE events, which has the potential of full reconstruction with oxygen recoil, γ-ray, and neutron, using a bismuth-germanium-oxide (BGO)-based detector, as shown in Fig. 1. BGO: $Bi_4Ge_3O_{12}$ 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 [3]. Therefore, this result inspired the new experiment.

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

2 Proposed measurement

We aim to measure neutron and γ-ray background events induced by the T2K neutrino beam using the BGO-based detectors. This section briefly describes the setup, equipment, calibration, and analysis strategy.

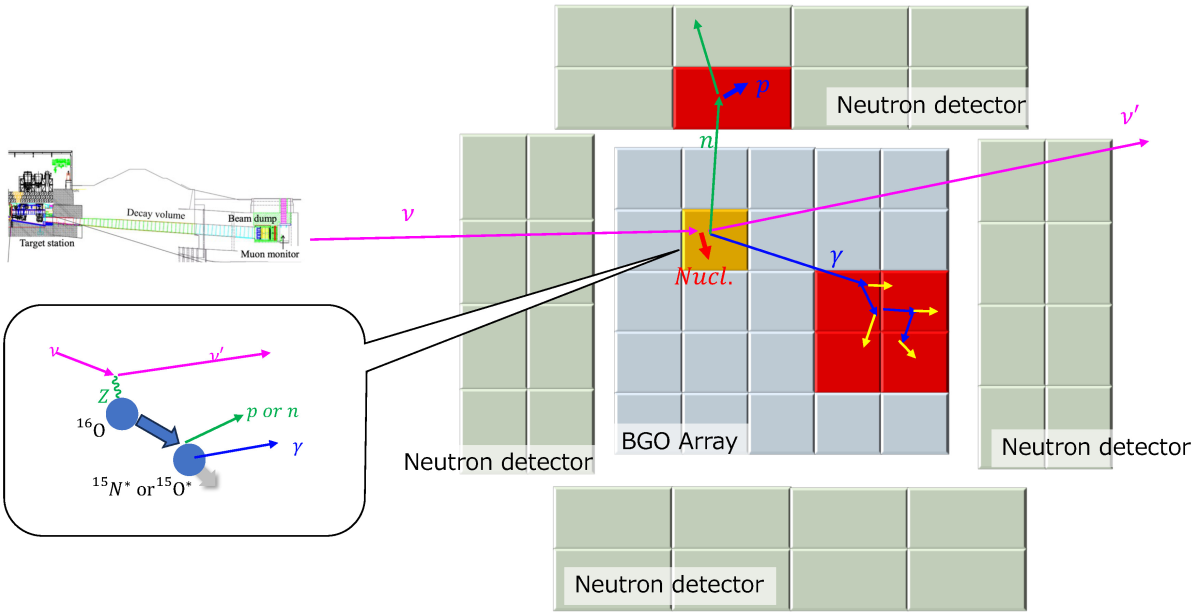

Fig. 1: Illustration of a future experiment to detect neutrino-oxygen neutral-current quasielastic scattering events using the BGO-based detector.

2.1 Setup

Figure 2 shows the schematic view of the setup and front data acquisition (DAQ) electronics. The detectors will be located in the B2 hall and will be moved to 1st floor in the neutrino monitoring building at J-PARC.

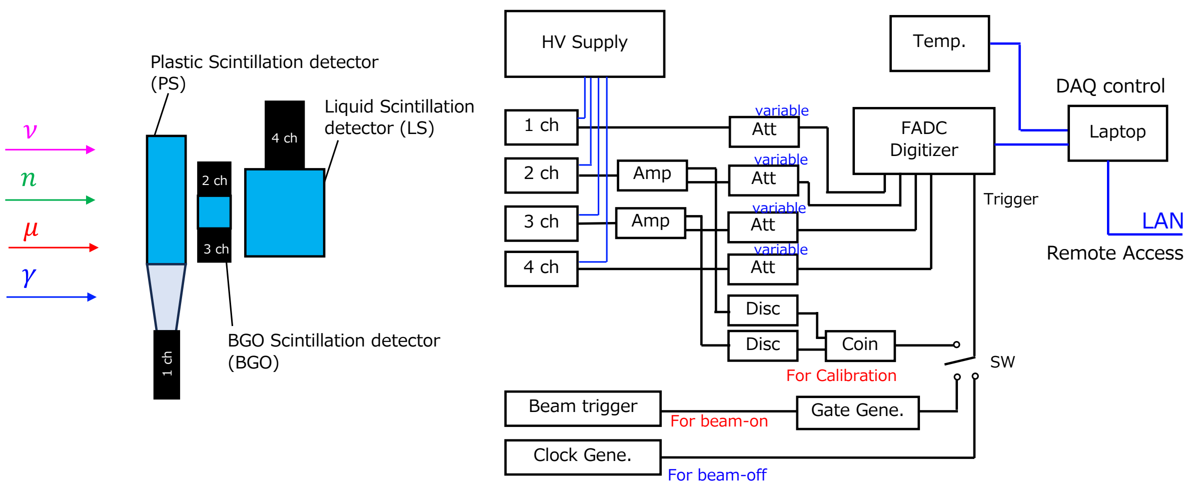

Fig. 2: Schematic view of setup and front-end DAQ electronics.

2.2 Equipment

A plastic scintillation (PS) detector, a BGO detector and a liquid scintillation (LS) detector are configured in the experiment. The plastic scintillator (size of 20 cm × 20 cm × 1 cm) was connected optically to a 2-inch phototube (PMT) as 1 ch through an acrylic light guide. The BGO (size of 5 cm in depth and 5 cm in diameter) was connected optically to 2-inch PMTs on the both sides of the BGO crystal, 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 as 4 ch. The analog signal for PMTs can be varied by the variable attenuators within 0 to 12 dB, to observe high-energy events.

A trigger can be switched to a beam timing signal (for beam on), output signal from a clock generator (for beam off), and coincidence signal with both two signals of PMTs which are connected to the BGO crystal (for calibration).

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. Fig. 3 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.

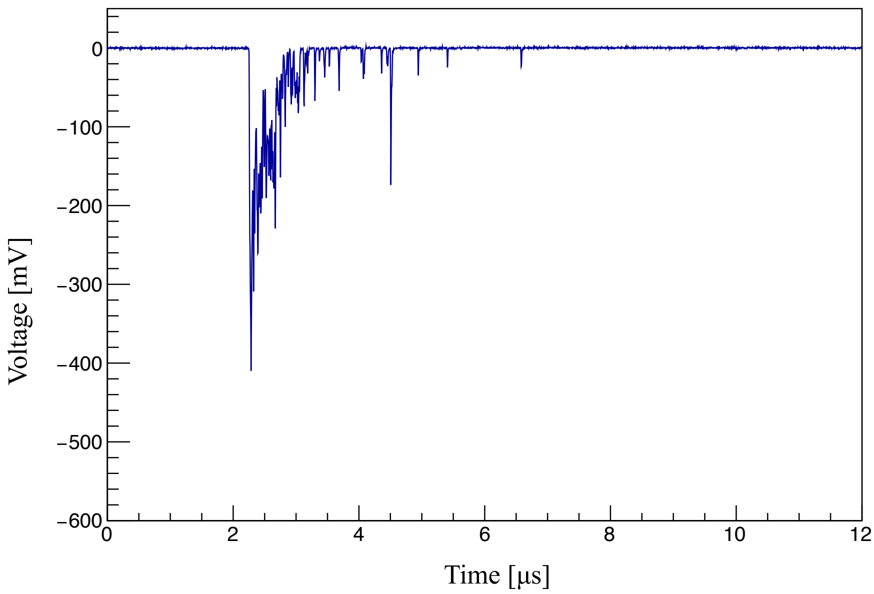

Fig. 3: Typical waveform of the BGO detector signal.

2.3 Calibration

We would perform the energy calibration of the BGO detector in the experimental site using γ-ray checking sources. The light yields of BGO have temperature dependence, so the temperature in the experimental site should be monitored. In order to start rapidly after the detector configuration at the experimental site, we have already performed the energy calibration of the BGO detector at Tokyo University of Science, as shown in Fig. 4, using ^{137}Cs, ^{57}Co, ^{133}Ba, and ^{241}Am of checking sources and ^{40}K of environmental radioactivity. The relation between an energy and a peak charge is good linearity and the energy resolution was in good agreement with a function of the energy given as, $a/\sqrt{E} + b/E$.

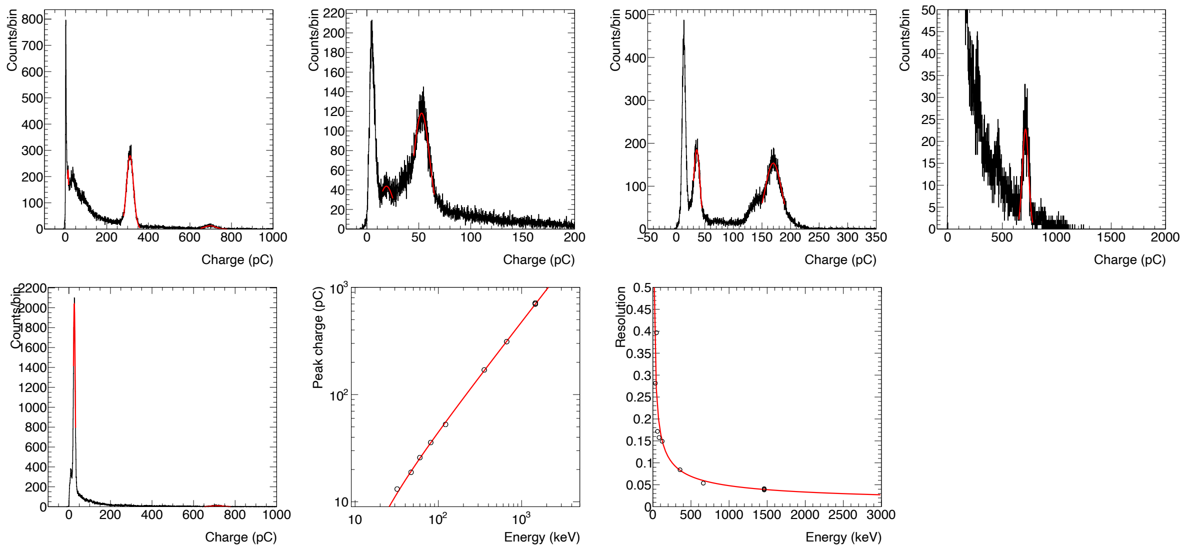

Fig. 4: Energy calibration results at the laboratory in Tokyo University of Science.

2.4 Analysis strategy

We have an analysis strategy to obtain neutron or γ-ray events regarding the neutrino beam by subtracting beam-on and beam-off distribution. A record time window will be 12 μs. The beam spill has eight beam bunches with 60 ns width and 540 ns interval, and the usual neutrino beam has spill per 2.5 s (0.4 Hz). So, the waveform data is included in one spill. 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 neutral particles, we can select an event with no hit of the PS detector and a hit of the BGO detector. Then, we can select the neutron scattering events, with no hit of the PS detector, a hit of the BGO detector, and a neutron-like event selected by pulse-shape discrimination[1] in the LS detector. On the other hand, neutrino-induced muon events can be selected by three hit signals. The muon hit timing would be useful to calibrate the timing of three detectors.

3 Beam time requirement

In March 2017, the J-PARC E61 group measured neutrino-induced neutrons by using a ^{3}He detector at B2 hall and 1st floor in the neutrino monitoring building [5]. As a result, the neutron signals were observed significantly to be 63 counts per 6 days corresponding to 42.6×10^{18} POT. The neutron flux induced by the neutrino beam has not been evaluated yet, but they found the neutrino flux at the B2 hall is lower than the 1st floor significantly.

In our experiment, the detection efficiency and the detector size are different because we will use the BGO detector. But we can estimate roughly expected number of events in an assumption of the result of the report. Therefore, we require one month of data taking in order to observe the events significantly (a few hundred events or more).

4 Schedule

We plan to measure from 20th November to 21st December in 2023. 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; it is okay to use either the neutrino or anti-neutrino beam for this experiment.

[1] Technical note for pulse-shape discrimination based on the LS detector details in Appendix of Ref. [4].

Table 1: Summary of measured emission rate and ratio for the AmBe source.

Date	
30th Oct. – 2nd Nov., 2023	Preparation: Setup configuration at B2 hall and Calibration
6th Nov. – 20th Nov., 2023	Data taking (Beam off)
20th Nov. – 5th Dec., 2023	Data taking (Beam on)
6th Dec. – 12th Dec., 2023	Move detectors if the number of observed events is enough. Calibration and Data taking (Beam off) If not enough, not move detectors.
13th Nov. – 21st Dec., 2023	Data taking (Beam on)
21st Dec., 2023	Finish and Withdrawal

- Experimental space of the B2 hall and 1st floor in the neutrino monitoring 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 neutrino-induced neutron and γ-ray background for BGO-based detectors at J-PARC, 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 one month to take data at B2 hall and 1st floor in the neutrino monitoring 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

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[3] 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.

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