Development of new trigger system for KamLAND2-Zen

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Abstract.
KamLAND2-Zen is the future plan for the existing KamLAND-Zen experiment, which will search for neutrinoless double-beta decay. In this experiment, muon spallation products are expected to be the main background. Spallation backgrounds can be tagged by delayed coincidence with neutrons emitted in spallation. Therefore, it is important to detect neutrons with high efficiency. However, enhancement of light yield will increase after-pulses and fake triggers due to them resulting in DAQ deadtime and low detection efficiency of neutrons. To solve this problem, a new trigger scheme which uses simultaneous hit of neighboring PMTs was developed. According to a simulation performed with real PMT waveforms, this scheme is expected to improve neutron detection efficiency from 54% to 89%. Consequently 99% of $^{10}$C background events can be tagged.

1. Introduction
KamLAND2-Zen is the plan of the $0\nu\beta\beta$ decay search experiment using KamLAND2 detector, which is the upgrade of existing KamLAND detector. To reduce the two-neutrino double-beta($2\nu\beta\beta$) decay background, which is the most dominant one in KamLAND-Zen[1], the energy resolution of the detector will be improved by enhancement of photoelectron yield, aiming at the sensitivity of Majorana effective mass $(m_{\beta\beta}) \sim 20$ meV.

As the result of the reduction of $2\nu\beta\beta$ decay background, the spallation products are expected to be one of the main backgrounds in KamLAND2-Zen. They are generated in liquid scintillator by cosmic-ray muon. Especially, $\beta$ decay of $^{10}$C and $^{137}$Xe will become serious backgrounds since the energy spectrum of them overlaps with that of $0\nu\beta\beta$ decay. Since muon spallation is accompanied by emission of neutrons and these neutrons are captured by protons with a mean lifetime of 210 $\mu$s, the spallation backgrounds can be identified by the triple delayed coincidence of muon, neutron capture and spallation product, in principle. Therefore, it is important to detect neutrons efficiently for the backgrounds rejection.

After muon events, high rate after-pulses ($\sim 50$ MHz, typically) continue about 1 ms and issue many fake triggers. In such situation, front-end buffer cannot store all the data and it result in the DAQ deadtime.

Currently, we deal with this problem by introducing a deadtime-free electronics named “MoGURA[2]” in addition to the original DAQ system.

However, it has been recognized that the neutron detection efficiency is lower($\sim 54\%$) after high-energy muon events which is accompanied by the showering of the secondary particles.
In KamLAND2-Zen, it is anticipated that the enhancement of photoelectron yield will result in higher after-pulse rate and lead to inefficiencies for the triple delayed coincidence detection of the spallation products.

In this study, we developed a new trigger scheme which can reduce the fake triggers caused by after-pulses. This is achieved by issuing a global trigger based on simultaneous hits of neighboring PMTs. As the result of it, the efficiency of neutron detection and spallation product tagging will improve. We will describe the concept of the new trigger scheme and system. Then, we will show the estimation of the neutron detection efficiency with the simulation based on real PMT waveforms and the new trigger scheme.

2. New Trigger
To reduce the fake-trigger rate by the after-pulses, we developed a new trigger scheme which can find signal pulses by mitigating the after-pulse effects.

In the conventional KamLAND trigger system, the global trigger is issued based on the number of hits in a 120 ns time window (left part of Fig.1). This time window is determined by the variation of the hit-timing in the whole detector. In the new scheme, each neighboring PMTs are grouped and connected to the same board. The "board hit" is defined by simultaneous hit of PMTs in each boards and the global trigger is issued based on the number of board hit in the whole detector (called "local hit ratio") in a 20 ns time window (right part of Fig.1). Since the timing of the after-pulses is random, the fake trigger caused by after-pulses can be reduced by narrowing time windows. This scheme will be activated only after muon events.

To install this new trigger scheme, we are developing a new data acquisition system. Fig.2 shows the overview of the new system. SoC on front-end and back-end electronics achieve powerful signal processing and high-speed data transfer.

3. Evaluation of new trigger
The performance of the new trigger scheme is evaluated by a simulation performed with real PMT waveforms. We used a PMT which is a candidate for usage in KamLAND2-Zen (R12860-HQE, 20" Box and Line type PMT, HAMAMATSU). The setup for waveform measurement and an example of the acquired waveform are shown in Fig.3. The result for the local hit ratio simulation (Fig.4) states that the fake triggers converge within about 20 μs after muon
(a) Setup for waveform acquirement. LED and pico second LASER were used to imitate muon event and neutron event respectively.

(b) An example of waveform inputted to the simulation.

Figure 3: Data acquirement for the simulation

This value corresponds to 89±2% of the neutron detection efficiency. As the result of this improvement, 99% of spallation products will be tagged considering the multiplicity of neutrons generation.

Figure 4: The simulated local hit ratio. The green line corresponds to the optimized threshold for trigger. If the ratio of the local hit is larger than this value, a trigger will be issued and data will be acquired. After dT = 20 \mu s, triggers caused by after-pulses will not be issued.

4. Summary
KamLAND2-Zen is the future plan for KamLAND-Zen. Since the photoelectron yield will be enhanced, the after-pulse rate will become higher and the detection efficiency of neutrons for the spallation background rejection may become lower. In this work, we developed a new trigger system and scheme which will be used in KamLAND2-Zen to detect neutrons more efficiently. According to the simulation study performed with real PMT waveforms, this new trigger will achieve more than 89±2% of neutrons detection efficiency even after high-energy muon passage. Consequently, 99% of spallation backgrounds can be tagged.

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References
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