IOP Conf. Series: Journal of Physics: Conf. Series **800** (2017) 012044 doi:10.1088/1742-6596/800/1/012044

Beam-edge Photon Detector with Low Sensitivity to Neutrons for the KOTO Experiment

Satoshi Shinohara

Department of Physics, Faculty of Science, Kyoto University Kitashirakawa Oiwake-cho, Sakyo-ku, Kyoto, Japan

E-mail: shinohara@scphys.kyoto-u.ac.jp

Abstract. An acrylic Cherenkov counter named Beam Hole Guard Counter (BHGC) was developed as a photon-veto detector to cover the detection gap in the edge of the in-beam photon counter just outside of the beam core in the KOTO experiment. The KOTO experiment took physics data with the BHGC in 2015. We confirmed the stable operation and the expected performance of the BHGC. Therefore, the gap induced background can be rejected with the BHGC.

1. Introduction

The KOTO experiment at the J-PARC aims to observe the CP-violating rare decay $K_L \to \pi^0 \nu\bar{\nu}$. The branching ratio of this decay mode is suppressed in the Standard Model (SM) (3.0×10^{-11}) and its theoretical uncertainty is very small [1]. This decay mode is thus sensitive to new physics beyond the SM.

We identify the signal $K_L \to \pi^0 \nu\bar{\nu}$ decay by detecting a single π^0 reconstructed from two photons, and requiring that there are no observable particles other than the two photons. In order to ensure it, we need a hermetic veto system with high detection efficiency, as shown in Figure 1.

For the detection of particles escaping along the beam, an in-beam photon counter was installed in the downstream of the KOTO detectors, as shown Figure 2.

We found, however, that there is a detection gap in the edge of the in-beam photon counter due to shorter path length. This gap makes 1.9 background events from $K_L \to 2\pi^0$ decays at the SM level sensitivity. For reducing them we designed and made a new photon-veto detector named Beam Hole Guard Counter (BHGC) to cover the gap. Since the neutron rate is high around the beam core, the BHGC needs a high detection efficiency for photons and a low detection efficiency for neutrons.

2. Beam Hole Guard Counter (BHGC)

The BHGC consists of a lead plate to convert photons, and an acrylic plate which acts as Cherenkov radiator. The BHGC has two steps of thresholds to be insensitive to neutrons. The first step is Cherenkov threshold. Charged particles generated from neutrons tend to be slow and cannot make Cherenkov radiation when the velocity is below the Cherenkov threshold. The second step is total reflection condition threshold. The acrylic plate acts as a light guide to photomultiplier tubes (PMTs) attached at the both ends of the acrylic plate. If the speed of

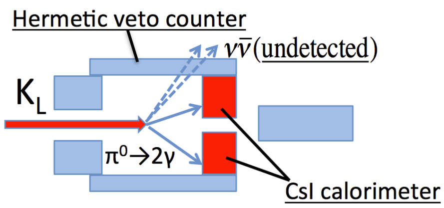

Figure 1. A schematic view of the KOTO detector system and a typical $K_L \to \pi^0\nu\bar{\nu}$.

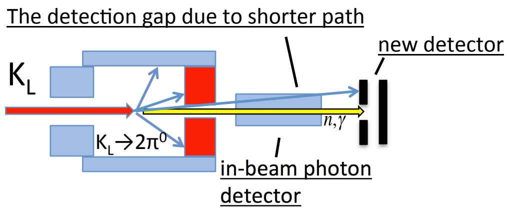

Figure 2. A typical case of $K_L \to 2\pi^0$ background.

the charged particles generated from neutrons exceed the Cherenkov threshold, the Cherenkov radiation is emitted, but the Cherenkov angle tends to be smaller. If the angle is smaller than the total reflection threshold in the acrylic plate, such photons cannot be transported to the edge of the acrylic plate (Figure 3).

3. Physics run with BHGC in 2015

3.1. Design of BHGC
The thickness of the lead plate and the position of the BHGC have been optimized. Based on studies with MC simulations, the lead plate thickness was decided to be 9.6 mm, and the module position was decided to be 130 mm away from the beam axis. With this design, 90% of the background events caused by 1 GeV photons going through the detection gap will be rejected.

After the design and construction, the BHGC has been installed in the KOTO detector system in March 2015 (Figure 4).

3.2. The performance of the BHGC
We checked and monitored the light yield in each BHGC module with high momentum charged particles. The charged particles were selected by closing beam plug located upstream of the KOTO detectors to stop neutrons and kaons, and by requiring a coincidence with an in-beam photon detector which detects only fast charged particles (β >0.98). As shown in Figure 5, the BHGC light yield was stable within a few percent. This means that there was no radiation damage.

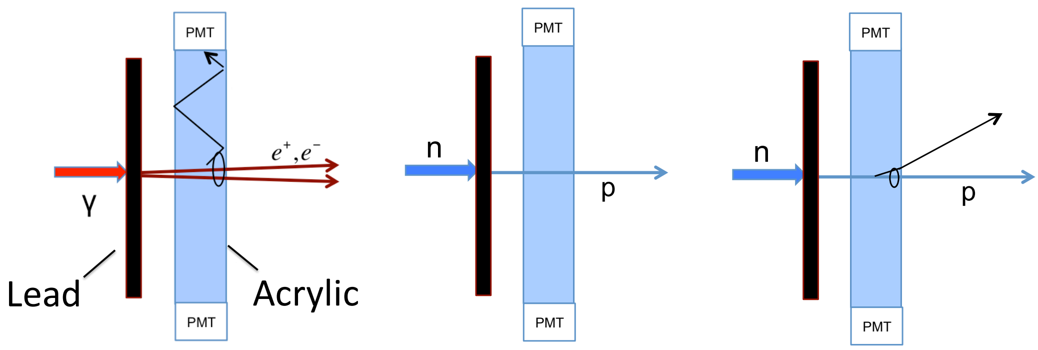

Figure 3. Principle of the BHGC. Left: γ hits BHGC. Middle and right: neutron hits on BHGC. A proton is generated and goes to an acrylic plate normally. Cherenkov threshold for $\beta > 0.67$ (middle), total reflection threshold for $\beta > 0.89$ (right).

The single counting rate agreed with the rate expected from beam photons or K_L decays or neutrons. This agreement shows that the BHGC has low sensitivity to neutrons. We also confirmed that the BHGC response was well reproduced with MC simulations by selecting photon from K_L decays. We finally compared reconstructed π^0 transverse momentum P_t and longitudinal position Z with a MC simulation. The signal (blind) region has been set in terms of those variables, as shown in Figure 6. A MC simulation had one $K_L \to 2\pi^0$ decay event inside the blind region without BHGC veto for the Single Event Sensitivity (S.E.S) of 1.8×10^{-10}. We confirmed that the BHGC rejected this one event inside the blind region.

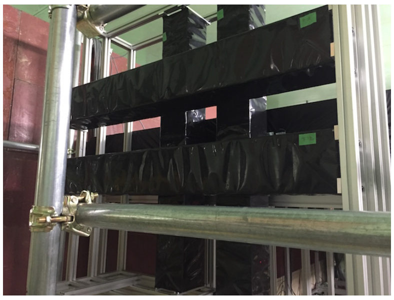

Figure 4. BHGC viewed from downstream.

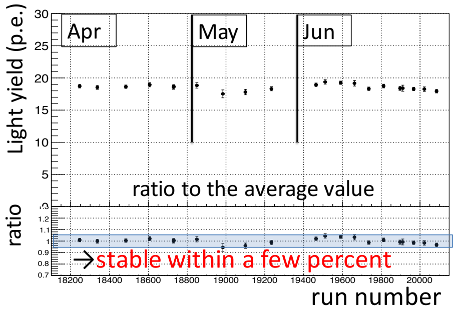

Figure 5. BHGC light yield stability as a function of the run. Top: number pf photoelectrons (p.e.). Bottom: ratio to the average value.

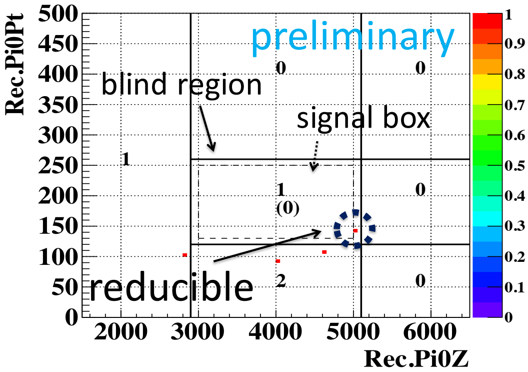

Figure 6. $K_L \to 2\pi^0$ backgrounds in a plane of the reconstructed π^0 P_t and Z position, estimated by a MC simulation.

4. Summary

The BHGC is an acrylic Cherenkov counter developed to cover the detection gap near the beam. Based on the stable operation and the expected performance, 90% of the background events caused by 1 GeV photons passing through the detection gap can be rejected with the BHGC.

5. References

[1] Buras A J, Buttazzo D, Girrbach-Noe J and Knegjens R 2015 *J. High Energy Phys.* **1511** 033.