A new charged particle detector for the KOTO experiment at J-PARC

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Abstract. A new detector called the Downstream Charged Veto(DCV) to suppress the $K_L \to \pi^+\pi^-\pi^0$ decay background for the J-PARC KOTO experiment was made. To detect charged pions from the $K_L \to \pi^+\pi^-\pi^0$ decay, the DCV is installed in vacuum downstream of the electromagnetic calorimeter. The DCV is composed of two plastic scintillator pipes read out by Multi Pixel Photon Counter(MPPC)s through WaveLength Shifting(WLS) fibers. Based on the cosmic-ray test, the number of photoelectrons(p.e.) at the center of the DCV is about 60. After the installation of the DCV, energy calibration was done with cosmic-rays.

1. Introduction

The KOTO experiment at J-PARC is searching for the $K_L \to \pi^0\nu\bar{\nu}$ decay, which is one of the most sensitive probes to new physics beyond the standard model(SM). Its signature is a pair of photons from a π^0 decay without any additional activity in a hermetic detector system surrounding the decay region. To detect this highly suppressed decay, expected at the 3×10^{-11} level, it is important to reject background events related to other kaon decay modes. With the data collected in 2015, corresponding to 2.2×10^{19} protons on target, a single event sensitivity of $(1.30 \pm 0.01_{stat} \pm 0.14_{syst}) \times 10^{-9}$ was achieved and no candidate events were observed [1]. In this sensitivity, the number of estimated background events of the $K_L \to \pi^+\pi^-\pi^0$ was 0.05 ± 0.02. This number can reach about 2 at the SM sensitivity. According to a Monte Carlo(MC) simulation, as shown in Fig. 1, π^+ and π^- coming through the beam hole in the CsI calorimeter and the beam pipe downstream of it could interact with non-active materials such as the Al beam pipe and a G10 pipe inside.

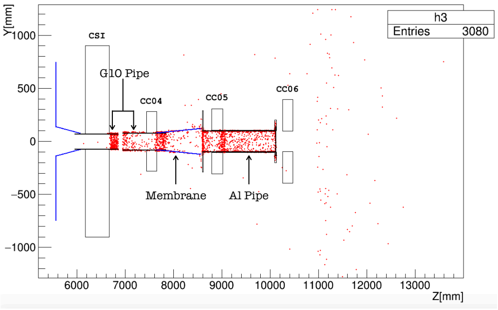


Figure 1. Interacting point with π^+ and π^-. Red dots indicate where the charged pions disappeared. The membrane is thin files to separate the high-vacuum region and the low-vacuum region. The G10 pipe support the membrane.

For reducing the $K_L \to \pi^+\pi^-\pi^0$ background events, the charged pions interacting with non-active materials should be detected. This is the motivation to develop and install the DCV.

2. Scheme of the DCV

The scheme of the DCV is shown in Fig. 2. One module of the DCV consists of a 5-mm-thick plastic scintillator(EJ200, Eljen Technology) with 18 embedded WLS fibers(Y-11(200M), Kuraray). The diameter of WLS fiber is 1 mm. Due to very limited space for the DCV, we evaluated the new scheme of the light collection. In the new scheme of the light collection, the 4 MPPCs are directly attached to the surface of the scintillator through the light guide made of aluminum which is placed in the scintillator. The WLS fibers in the grooved scintillator are routed into the light guide. In this design, the WLS fibers are naturally bent to converge into the light guide. Figure 3 shows the light loss due to the curvature of the WLS fiber. We measured the light yield using LED light(430 nm). The light loss increases rapidly if the radius is less than 20 mm. The DCV consists of two square pipes with 4 sheets of scintillators combined. The DCV1 is located inside the membrane with the CC04, and the DCV2 is located inside the aluminum beam pipe. The G10 pipe at the CsI was shortened from 900 mm to 550 mm, and the G10 pipe at the CC04 was removed.

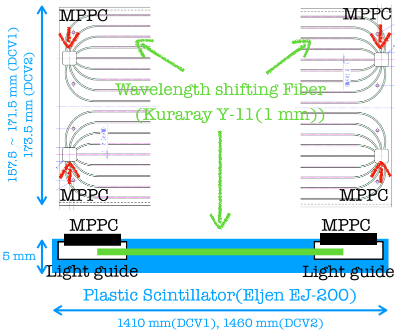


Figure 2. Scheme of the DCV.

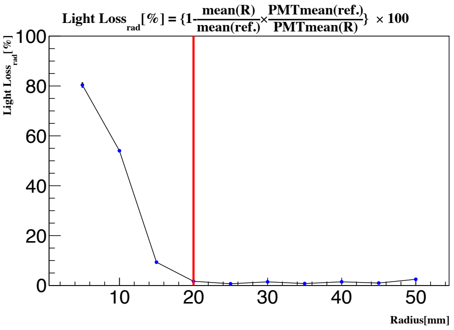


Figure 3. The light loss due to the curvature of the WLS fiber. The radius is a parameter of curvature.

3. Fabrication Process

3.1. MPPC Gain Measurement and Fiber Test

We measured the MPPC(S13360-6050PE, Hamamatsu)s single-photon gain using the LED light(430 nm), and we grouped the MPPCs into four similar gain sets at a given operating voltage. We also measured the light yield of the WLS fibers. The LED light(430 nm) was injected on one side of the flagged WLS fiber that we assigned before, and the MPPC was attached on the other side. After the measurement of the light yield, we chose the WLS fiber with a high light yield.

3.2. Making the scintillator pipe

First, the WLS fibers were glued to the plastic scintillator using the optical cement(BC-600, Saint-Gobain). The scintillators were dried for at least 48 hours. Second, the scintillators were placed in a vacuum chamber. We extracted the outgas from the glued scintillators at less than 1 Pa, over 48 hours. Third, the scintillators were wrapped by a 12-μm-thick aluminized film. Next, the MPPCs were respectively attached on the light guide and fixed by aluminum plates. After the cosmic-ray test, the scintillators were assembled to a square pipe.

3.3. *Cosmic-ray test*

We measured the number of p.e. using cosmic-rays at 8 points, as shown in Fig. 4. At the center, the average number of p.e. for 1 MeV was 60.2 for the DCV1 and 58.6 for the DCV2. By fitting the data with an exponential function, the attenuation length was found to be 2469 ± 165.1 mm for the DCV1 and 2566 ± 166.0 mm for the DCV2.

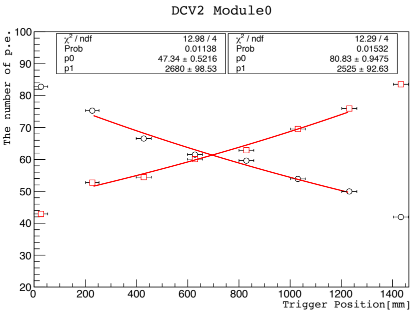


Figure 4. The number of p.e. at each cosmic-ray trigger point

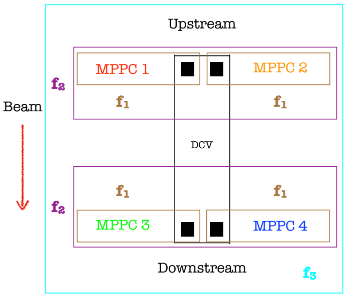
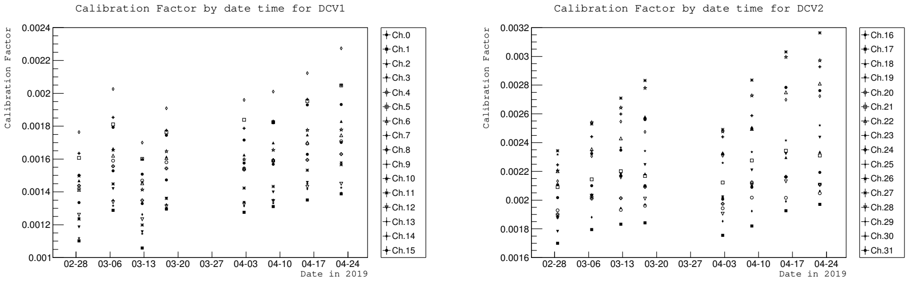


Figure 5. Calibration method for the DCV with 4 MPPCs. There are 3 types of normalization factors(f_1 : for each MPPC, f_2 : for a pair of MPPC at upstream(downstream), f_4 : for all MPPCs).

4. Energy Calibration

After the installation of the DCV in the KL beamline, we took the cosmic-ray data for an energy calibration. The CC04 and CC05 surrounding the DCV were used as the trigger counter. Figure 5 shows the diagram of the calibration method for the DCV with 4 MPPCs. The energy response to the cosmic-ray of each module of the DCV was used to derive the 3 types of normalization factors. During the beam time from Feb. to Apr. 2019, we collected the cosmic-ray data. Figure 6 shows how the calibration factor varies during the period. The calibration factors tend to increase over time.



(a) (b)

Figure 6. Calibration Factor over time for DCV1(a) and DCV2(b).

5. Conclusion

We fabricated and installed of a new charged particle detector named the DCV to reduce the background events from the $K_L \to \pi^+\pi^-\pi^0$. Based on a cosmic-ray test, the light yield is about 60 p.e. for 1 MeV at the center of the DCV. The energy calibration was done for the MeV scale. More study on the stability of its performance during the beam time is needed.

Acknowledge

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Reference

[1] J.K. Ahn *et al.* (KOTO Collaboration) 2019, *Phys. Rev. Lett.* **122** 021802