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

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Abstract. To suppress the $K_L \rightarrow \pi^+\pi^-\pi^0$ decay background, the Downstream Charged Veto(DCV) to detect charged pions was made. The DCV is composed of two plastic scintillator pipes read out by Multi Pixel Photon Counter(MPPC)s through WaveLength Shifting(WLS) fibers. As the result of the cosmic-ray test, the number of photoelectrons(p.e.) at the center of the DCV is about 60. Energy calibration was done with cosmic-rays.

1. Introduction

The KOTO experiment at J-PARC is searching for the $K_L \rightarrow \pi^0\nu\bar{\nu}$ 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 $K_L \rightarrow \pi^+\pi^-\pi^0$ was 0.05 ± 0.02. This number can reach about 2 at SM sensitivity. As shown in Fig. 1 from the result of the Monte Carlo(MC) simulation, π^+ and π^- coming through the beam pipe could interact with non-active materials such as G10 pipe, membrane, and Al pipe.

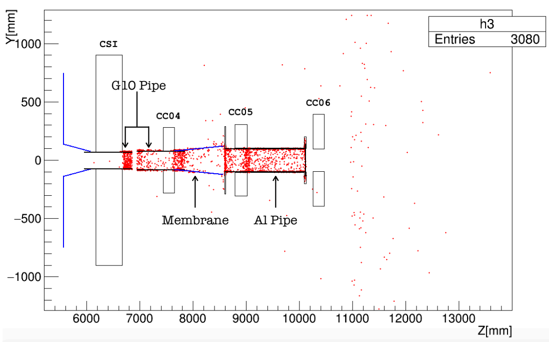


Figure 1. Interacting point with $\pi^+ and\ \pi^-$. Red dots indicate where the charged pions disappeared.

For reducing the $K_L \rightarrow \pi^+\pi^-\pi^0$ 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-thickness 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 which is put in the scintillator and made of aluminum material. The WLS fibers put in the grooved scintillator and go side by side into the light guide. Given the above design, the WLS fibers are naturally bent to converge into the light guide. Fig. 3 shows the light loss by the radius of curvature of the WLS fiber. We measured the light yield and the radius of curvature using the LED light(430 nm). The light loss increases rapidly in a radius of less than 20mm. The DCV consists of two square pipes with 4 sheets of scintillator combined. The DCV1 is located inside the membrane with the CC04, and the DCV2 is located inside the aluminum pipe with the CC05.

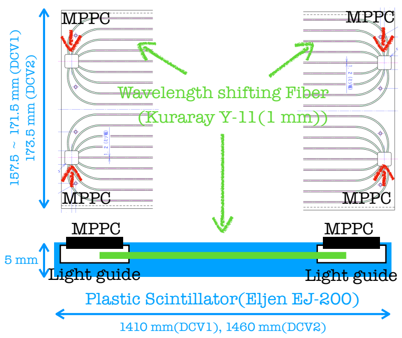


Figure 2. Scheme of the DCV.

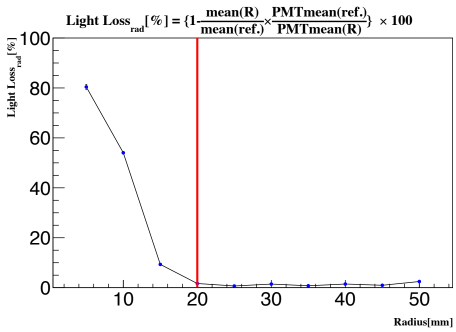


Figure 3. The light loss by the radius of curvature.

3. Fabrication Process

3.1. MPPC Gain Measurement and Fiber Test

We measured the MPPCs single-photon gain using the LED light(430 nm) and grouped the MPPCs into four similar gain sets at a given operating voltage. The type number of MPPC is S13360-6050PE from Hamamatsu. 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, and the MPPC was attached the other side. After the measurement of the light yield, we chose the WLS fiber from the highest value of the 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 is evacuation by a vacuum chamber. We extracted the outgas from the glued scintillators at less than 1 pa, over the 48 hours. Third, the scintillators were wrapped the 12 − μm-thickness aluminized film. Next is, the MPPCs were respectively put on the light guide and fixed by the aluminum plates. After the cosmic-ray test, the scintillators were combined as a square pipe.

3.3. Cosmic-ray test

We measured the number of p.e. using the cosmic-ray at the 8 points, as shown in Fig.4. At the center point, the average number of p.e. for 1 MeV is 60.2 for the DCV1 and 58.6 for the DCV2. As the result of fitting with 1^{st} exponential function, the attenuation length is 2469 ± 165.1 mm for the DCV1 and 2566 ± 166.0 mm for the DCV2.

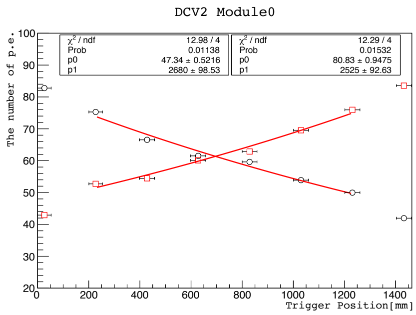


Figure 4. The number of p.e. at each cosmic-ray trigger point

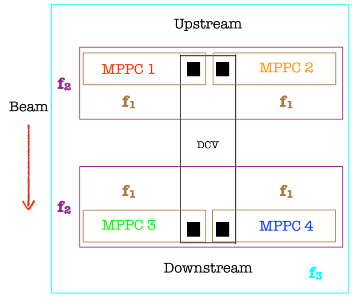
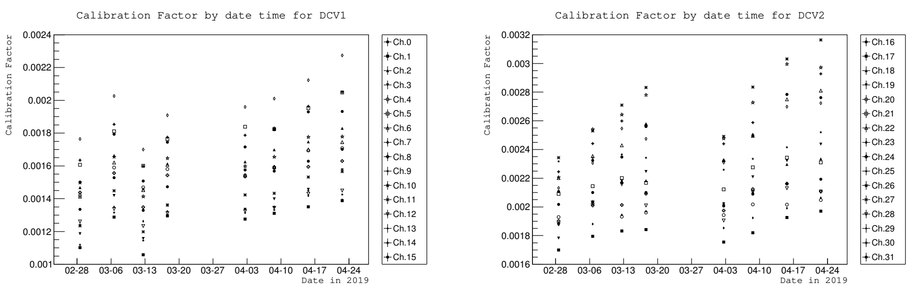


Figure 5. Calibration method for DCV with 4 MPPCs. There is 3 type of normalization factor(f_1 : for each MPPC, f_2 : for a pair of MPPC at upstream(downstream), f_4 : for all MPPCs).

4. Energy Calibration

After the installation of the DCV in the KL beamline, we took the cosmic-ray data for energy calibration. The CC04 and CC05 surrounding the DCV were used as the trigger counter. We assigned the flag number to the track of the cosmic-ray. Fig. 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 applied the 3 types of the normalization factors. During the beam time from Feb. to Apr. 2019, we received the cosmic-ray data. Fig. 6 shows how the calibration factor varies to cover the 8 periods. The calibration factors tend to increase over time.



(a) (b)

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

5. Conclusion

The fabrication and installation of a new charged particle detector, named the DCV to reduce the background events from the $K_L \to \pi^+\pi^-\pi^0$, was finished in Feb. 2019. From the cosmic-ray test, we got about 60 p.e. at the center of the DCV. The energy calibration was done for the 1 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