# 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 a consequence of cosmic-ray test, the number of photoelectron(p.e.) at the center of DCV is about 60. Energy calibration was done with cosmic-rays tagged by surrounding detectors.

## 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 $\pi^0$ decay without any additional activity in a hermetic detector system surrounding the decay region. In order to detect this highly suppressed decay, expected at the $3 \times 10^{-11}$ level, it is important to reject background events related to other kaon decay modes. With the data collected in 2015, corresponding to $2.2 \times 10^{19}$ 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 that sensitivity, the number of $K_L \rightarrow \pi^+\pi^-\pi^0$ background events was $0.5 \pm 0.02$. This number can be reached approximately 2 at SM sensitivity. As the result of Monte Carlo(MC) simulation in Fig. 1, $\pi^+$ and $\pi^-$ coming through the beam pipe could interact with non-active materials such as G10 pipe, membrane and Al pipe.

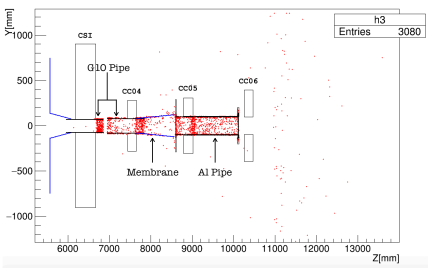



**Figure 1.** Interacting point with $\pi^+ and\ \pi^-$. Red dot is indicating the disappeared point of charged pions.

If these charged pions can be detected, the $K_L \rightarrow \pi^+\pi^-\pi^0$ background can be also rejected. Therefore, the DCV was designed to detect these charged pions.

## 2. Scheme of DCV

The scheme of DCV is shown in Fig. 2. Basically the DCV is consist of a plastic scintillator with a embedded WLS fiber. The plastic scintillator is EJ-200 from Eljen. The thickness of scintillator is 5 mm. The WLS fiber is 1 mm Y-11 from Kuraray. Due to very limited space for the DCV, a new scheme of light collection has been implemented. MPPCs are attached to the surface of the scintillator. The WLS fibers goes side by side into the light guide. Then, WLS fibers naturally bend. Light loss by bending radius increases rapidly in radius less than 20mm, as shown in Fig. 3. Totally the DCV consists of two square pipe(DCV1 and DCV2) with 4 sheets of scintillator combined. DCV1 is located inside the membrane with CC04, DCV2 is located inside the aluminum pipe with CC05.

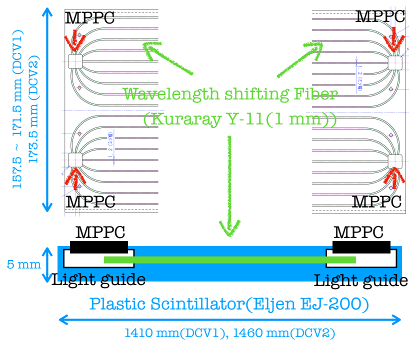



**Figure 2.** Scheme of DCV.

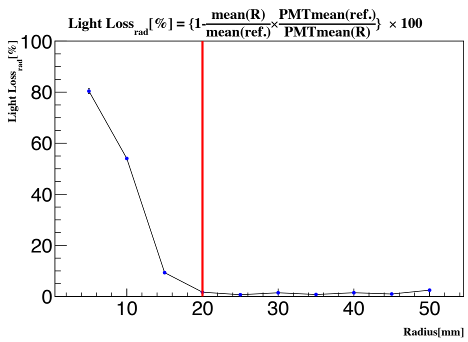



**Figure 3.** Light loss by bending radius.

## 3. Fabrication Process

### *3.1. MPPC Gain Measurement and Fiber Test*

We measured the MPPCs single photon gain using 430 nm LED and grouped the MPPCs into four similar gain sets at a given operating voltage. The type number of MPPC is S13360-6050PE from HAMAMATSU. Light yield of WLS fiber is also measured. 430 nm LED light was injected one side of flagged WLS fiber, MPPC was attached the other side. Then, we can choose the fiber from the highest value of light yield.

### *3.2. Making the scintillator pipe*

First, WLS fibers were glued to the plastic scintillator using BC-600 optical cement from Saint Gobain. The scintillators were dried for at least 48 hours. Second is evacuation by vacuum chamber. We extracted outgas from the glued scintillators at less than 1 pa, over the 48 hours. Third, the scintillators were wrapped the 12 $\mu$m aluminized film. Next is, MPPCs were respectively put on the light guide and fixed by the aluminum plates. After a cosmic-ray test, the scintillators were combined as square pipe.

### *3.3. Cosmic-ray test*

We measured the number of p.e. using 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 DCV1 and 58.6 for DCV2. As the result of fitting with 1$^{st}$ exponential function, attenuation length is $2469 \pm 165.1$ mm for DCV1 and $2566 \pm 166.0$ mm for DCV2.

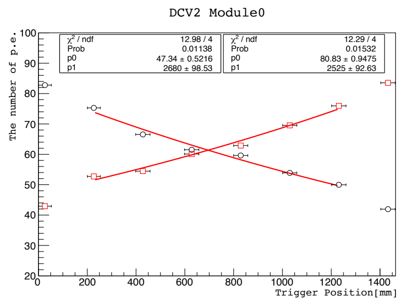



**Figure 4.** The number of p.e. at each cosmic-ray trigger point

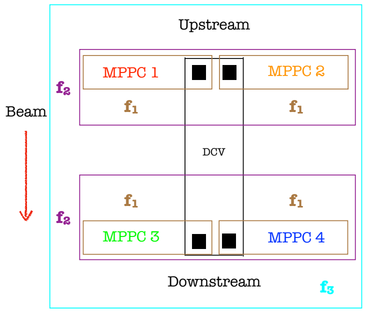
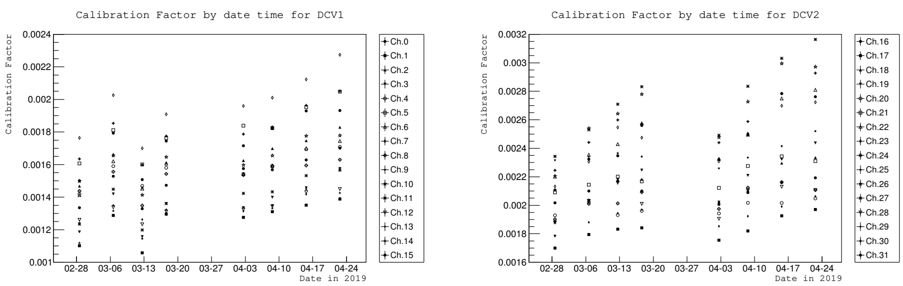



**Figure 5.** Calibration method for DCV with 4 MPPCs. There is 3 type of normalization factor($f_1$ : for each MPPC, $f_2$ : for a pair of MPPC at upstream(downstream), $f_4$ : for all MPPCs).

## 4. Energy Calibration

After installation of DCV in the beam line, we got the cosmic-ray data for energy calibration. CC04 and CC05 surrounding DCV were used as trigger counter. We assigned the flag number to the track of cosmic-ray. The Fig. 5 shows the diagram of the calibration method for DCV with 4 MPPCs. The energy response to cosmic-ray of each DCV module was applied 3 type of normalization factor. During the beam time from Feb. to Apr. 2019, we continually received the cosmic-ray data. Fig. 6 shows how the calibration factor varies cover the 8 periods. 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 DCV to detect charged pion from the $K_L \rightarrow \pi^+\pi^-\pi^0$ decay was finished in Feb. 2019. From the cosmic-ray test, we got about 60 p.e. at the center of DCV. Energy calibration was done for the 1 MeV scale. More study on stability of its performance during beam time is needed.

## Reference


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