PROCEEDINGS OF SCIENCE

In-beam charged particle detector using 0.2-mm thick plastic scintillator for the J-PARC KOTO experiment

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The KOTO experiment at J-PARC is dedicated to searching for the rare decay $K_L \to \pi^0 \nu\bar{\nu}$. This decay violates CP symmetry and is sensitive to new physics beyond the Standard Model (SM) because its branching ratio is predicted to be 3×10^{-11} with a small theoretical uncertainty in SM. One of main backgrounds is caused by a small contamination of charged kaons in the neutral beam. We installed a new charged particle detector in the beam to reject the background events by detecting charged kaons directly. This detector consists of a 0.2-mm-thick plastic scintillator film and 12-μm-thick aluminized mylar. The scintillation photons escaping from the scintillator surface are reflected by the mylar and are detected with multiple photomultiplier tubes on the sides. With the data taken in 2024, we conclude that the new detector has the light yield of 18.5 photoelectrons and the inefficiency of 5×10^{-4} at the 0.4 MIP threshold. As a result, we can eliminate the charged kaon background.

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1. Introduction

The KOTO experiment at J-PARC is dedicated to searching for the rare decay $K_L \to \pi^0 \nu\bar{\nu}$. This decay violates CP symmetry directly and is sensitive to new physics beyond the Standard Model (SM) because its branching ratio in SM is 3×10^{-11} with less than 2% theoretical uncertainty [1].

The signature of this decay is only two photons from the pion decay. As shown in Fig.1, we detect two photons with a CsI electromagnetic calorimeter, while we ensure that there are no other detectable particles with hermetic veto detectors surrounding the decay region.

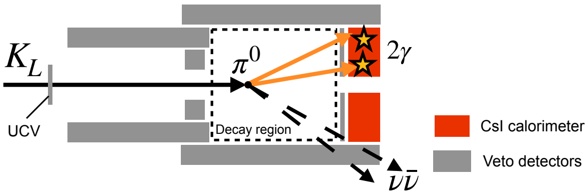


Figure 1: The schematics of KOTO detector with $K_L \to \pi^0 \nu\bar{\nu}$.

One of the main backgrounds is caused by the decay of $K^\pm$ contaminating in the neutral beam. If a $K^\pm$ decays into $\pi^0 e^\pm \nu$ in the decay region and $e^\pm$ is not detected due to an inefficient region in veto detectors, it will become background ($K^\pm$ background). To reduce this background, a charged particle detector, which is called Upstream Charged Veto (UCV), was installed in the beam in 2021. The $K^\pm$ background is reduced by directly detecting $K^\pm$ with UCV.

UCV consists of 0.5-mm-thick scintillating fibers with Multi-Pixel Photon Counters (MPPCs) for the signal readout. In the analysis of the data taken in 2021, UCV had the inefficiency of 7.8% against a Minimum Ionizing Particle (MIP) and suppressed the $K^\pm$ background by a factor of 13 [2].

2. Upgrade of UCV

In 2023, we upgraded UCV to NewUCV in order to make UCV more sensitive to MIPs and more insensitive to neutral particles with less material budget. As shown in Fig.2, NewUCV consists of a 0.2-mm-thick plastic scintillator film and 12-μm-thick aluminized mylars.

Normally, we collect scintillation photons propagating inside a scintillator to detect a signal. However, with a 0.2-mm-thick scintillator, we cannot get enough light yield due to a large attenuation. As shown in Fig.2, we collect scintillation photons escaping from the scintillator surface. The photons are reflected by the aluminized mylar and are detected with fourteen photomultiplier tubes on the side. We aimed at the inefficiency of 1% against a MIP, which corresponds to the reduction of the $K^\pm$ background by a factor of 100.

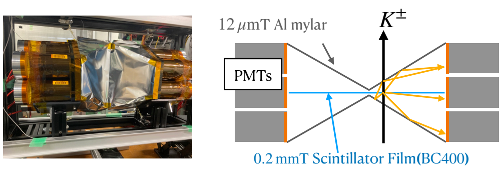


Figure 2: Photograph of the NewUCV (left) and the idea of the light collection method (right). A 0.2-mm-thick scintillator is inserted inside an optical box made of 12-μm-thick aluminized mylar.

3. Performance evaluation of NewUCV

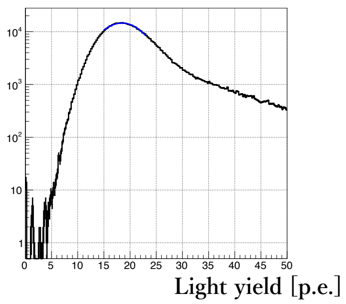
3.1 Evaluation method

Performance of NewUCV was evaluated using data collected in a special run in 2024. In our beam line, there is a sweeping magnet to remove charged particles and a beam plug made of brass to stop the beam if necessary. During the special run, we turned off the magnet to enhance the flux of charged particles, and closed the beam plug to reduce the flux of neutral particles. With this configuration, we increased the fraction of charged particles including charged pions and muons.

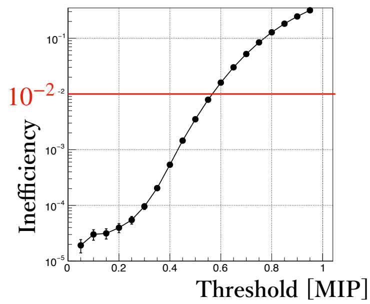
In addition to this setup, we used two movable trigger counters. These are placed upstream and downstream of NewUCV, respectively. In physics run, these counters are located away from the beam. In the special run, we moved them to the beam region and required the coincidence hits. As a result, we took a data effectively in which MIPs pass through NewUCV.

3.2 Result of performance evaluation

The light yield of NewUCV was calculated by summing the light yield from each channel. As shown in Fig.3 (a), we obtained 18.5 photoelectrons per a MIP. We also confirmed the uniformity by changing tagging position. The inefficiency was calculated by the ratio of the number of events below the threshold to the total number of events. Figure 3 (b) shows that we achieved 1% inefficiency with a threshold less than 0.55 MIP. In particular, inefficiency was 5×10^{-4} at the 0.4 MIP threshold. As a result, we can expect to eliminate $K^{\pm}$ background with this detector.



(a) Distribution of number of photoelectron.



(b) Inefficiency as a function of threshold [MIP]. Red line corresponds to the inefficiency of 1%.

Figure 3: Result of performance evaluation with 2024 data.

4. Conclusion

We installed NewUCV and evaluated the performance using the data taken in 2024. As a result, we conclude light yield is 18.5 photoelectrons per a minimum ionizing particle and inefficiency is 5×10^{-4} at the 0.4 MIP threshold. With this detector, we can eliminate $K^{\pm}$ background.

References

[1] Buras, Andrzej J., Eur. Phys. J. C 83, 66 (2023)

[2] R Shiraishi J. Phys. Conf. Ser. 2446 012051(2023)