

Thin scintillation counter with a new readout method for the KOTO experiment

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Abstract. The KOTO experiment at J-PARC is dedicated to the search for the rare decay $K_L \rightarrow \pi^0 \nu \bar{\nu}$. While analyzing the data taken in 2018-2018, we found that some background events were caused by K^\pm decays in the beam. To reduce this background, we are developing a new charged particle detector. It uses a 0.2-mm-thick plastic scintillator. The scintillation light escaping from the surface of the scintillator without total reflection is collected by 12- μm -thick aluminized mylar and is read out by multiple PMTs on the side. Based on the performance evaluated with an electron beam, we expect to have 1/100 K^\pm background reduction.

1. J-PARC KOTO experiment

The KOTO experiment at J-PARC is dedicated to the search for the rare decay $K_L \rightarrow \pi^0 \nu \bar{\nu}$. This decay mode violates CP symmetry and is sensitive to new physics beyond the Standard Model(SM) because its branching ratio is predicted by SM to be 3.0×10^{-11} with a small theoretical uncertainty[1].

The signature of this decay is two photons from π^0 and nothing else. As shown in Figure 1 (a), we detect two photons with a CsI electromagnetic calorimeter. To ensure that there are no other detectable particles, hermetic veto detectors surround the decay region.

One of the main backgrounds is caused by K^\pm decays in the beam. When a K_L hits a collimator in the beam line, it can generate a K^\pm with a charge exchange interaction. If a K^\pm decays into $\pi^0 e^\pm \nu$ and the e^\pm hits an inefficient region in the detector, it will mimic the signal from $K_L \rightarrow \pi^0 \nu \bar{\nu}$ as shown in Figure 1 (b). In the analysis of the 2016-2018 data, K^\pm decays were the largest background[2].

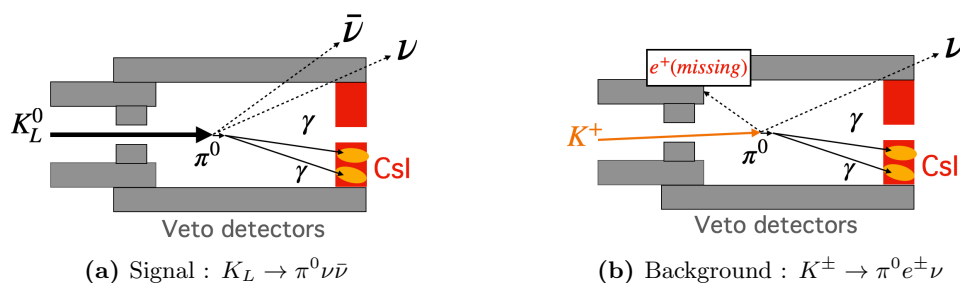


Figure 1: Schematics of (a) : signal($K_L \rightarrow \pi^0 \nu \bar{\nu}$), and (b) : K^\pm background($K^\pm \rightarrow \pi^0 e^\pm \nu$).

2. Method to reduce the K^\pm background

2.1. Upstream Charged Veto detector

To veto the K^\pm background events, a charged particle detector named Upstream Charged Veto(UCV) was installed upstream in the beam. This detector consisted of a plane of 0.5-mm-thick plastic scintillation fibers (Figure 2). The UCV had an 8% inefficiency and it suppressed the K^\pm background by a factor of 13 [3].

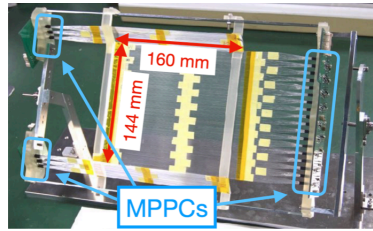


Figure 2: Photograph of current UCV

2.2. Limitations of current UCV

The current UCV has the following limitations.

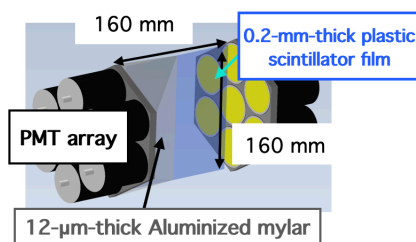
- (i) It increases the level of other backgrounds by scattering neutral particles.
- (ii) There is a possibility to veto signals due to the high counting rate of UCV itself. This problem is also caused by scattered neutral particles hitting other veto detectors.
- (iii) We need a further rejection of K^\pm background to reach the Standard Model sensitivity.

In order to solve these problems, we are developing a new version of UCV.

3. Development of New UCV

The purpose of this development is to make a thinner UCV with a higher efficiency.

As shown in Figure 3, the new UCV consists of a 0.2-mm-thick plastic scintillator film and 12- μm -thick Aluminized mylar.



(a) Design of new UCV



(b) Photograph of new UCV

Figure 3: Design and photograph of new UCV. A 0.2-mm-thick scintillator film is inserted inside an optical box made of a 12- μm -thick Aluminized mylar.

Normally, we collect scintillation light propagating inside a scintillator. However, with a 0.2-mm-thick plastic scintillator, we cannot get enough light yield due to a large attenuation of the light propagating inside the scintillator. We thus developed a new readout method. As shown in Figure 4, we collect the light escaping from the scintillator with reflectors and read them with PMTs on the side[4][5].

The goal of the new UCV is to reduce the thickness from 0.5 mm to 0.2 mm, and to have an inefficiency of 1% to suppress the K^\pm background by a factor of 100.

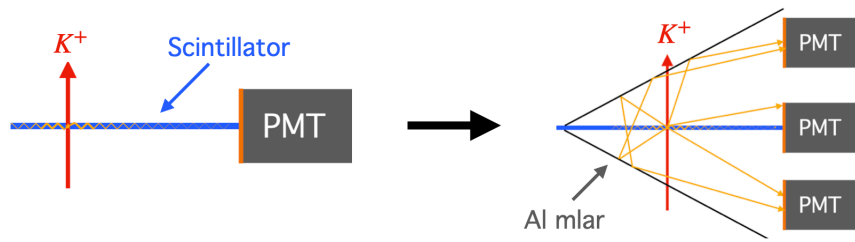


Figure 4: Idea of new light collection method.

4. Performance

We evaluated the performance of the new UCV with a 600 MeV/ c -electron beam at the Research Center for Electron Photon Science (ELPH) in Tohoku University.

Figure 5 shows the result of the performance. The total light yield is calculated by summing the light yield from each channel. As shown in Figure 5 (a), about 20 photoelectrons were obtained for a minimum ionizing particle. The inefficiency is calculated by the ratio of the number of events below the threshold to the total number of events. Figure 5 (b) shows that we achieved an inefficiency of less than 1% with a threshold of < 0.6 MIP. The UCV timing is defined by the average timing weighted by light yield. We obtained a timing resolution $\sigma \sim 1.2$ ns as shown in Figure 5 (c).

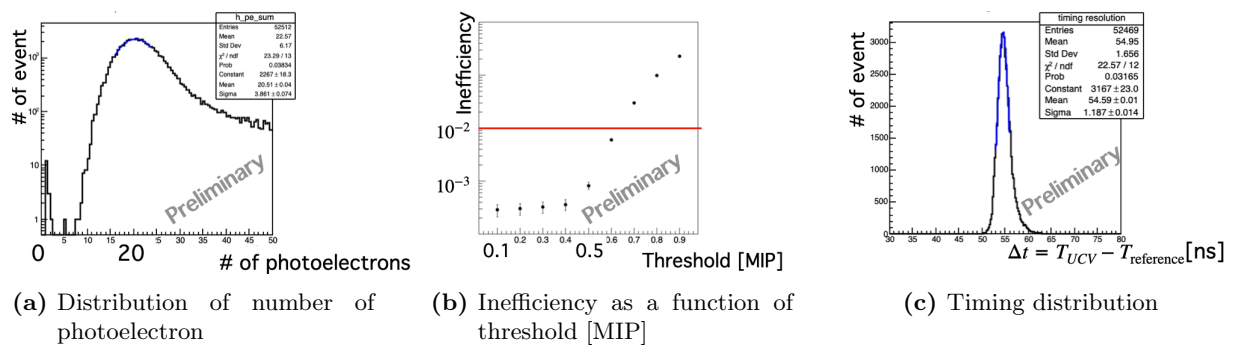


Figure 5: Result of performance tests with a 600 MeV/ c -momentum electron beam

5. Conclusion and Prospect

We are developing a new version of charged particle detector (UCV) to be placed in the beam, and we evaluated its performance with an electron beam. We confirmed that the new UCV meets our goal to reduce the K^\pm background and expect to have 1/100 K^\pm background reduction with a new readout method. This detector will be installed in the KOTO beam line in 2022 for the next run.

Acknowledgments

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References

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