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# Four-dimensional calorimeter to discriminate gammas from neutrons for the KOTO experiment

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We study the rare decay $K_L \to \pi^0 \nu \bar{\nu}$ at the J-PARC KOTO experiment. The signature of the decay is two gammas from a $\pi^0$ decay and no other detectable particles. The two gammas are detected with a calorimeter. The calorimeter composed of undoped cesium iodide(CsI) crystals, and their energy, timing and two-dimensional position are measured. Small 2240 crystals (25 × 25 × 500 $\mathrm{mm}^3$) are used in the inner region close to the neutral beam while large 476 crystals (50 × 50 × 500 $\mathrm{mm}^3$) are used in the outer region. Each crystal is read out with a PMT attached on its rear side.

One of the main backgrounds to $K_L \to \pi^0 \nu \bar{\nu}$ is caused by the neutron in the beam halo. If the beam halo neutron produces a hadronic shower in the calorimeter, and another neutron from this shower interacts at a different position of the calorimeter, it can mimic the two electromagnetic showers.

We developed a new method to reduce this background by using the depth of the interaction position in the calorimeter. Gammas interact according to the radiation length, and make a shallow shower. On the other hand, neutrons interact according to the interaction length, and make a deep shower. We attached MPPCs on the front end of the crystals to obtain the depth of interaction .The timing difference between the MPPC signal from upstream and the PMT signal from downstream represents the depth of the interaction. Thus, we can obtain four-dimensional information on the showers from the calorimeter.

We attached 4080 MPPCs on the calorimeter in the autumn of 2018 and took the data during the beam time in 2019.The performance of the upgraded calorimeter was evaluated by using the data. With the time difference of the both-end readout, it was demonstrated that the neutron background is suppressed to be 1/40.

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