Measurement of $K_L \to \pi^0 \nu\overline{\nu}$ at J-PARC: KOTO Step-2

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Understanding the origin of CP violation in physics beyond the Standard Model (BSM) is currently one of the most forefront issues in elementary particle physics. The very rare pure CP violating decay $K_L \to \pi^0 \nu\overline{\nu}$, the so called golden mode, provides one of the best probes for understanding the origin. Standard Model predicts the BR =$(3 \pm 0.3)\times 10^{-11}$. Therefore, precise measurement of the branching ratio is one of the better ways to search for new physics beyond Standard Model. Currently at J-PARC, KOTO Step-1 is a dedicated ongoing experiment to reach few times 10^{-11} single event sensitivity. KOTO Step-2 aims to collect ~100 signal events with a new beamline and detector.

The factor of 100 from Step-1 to Step-2 will come from a combination of increased kaon flux and detector acceptance [1]. For a higher K_L flux, the production angle of 5 degrees is considered while the current angle is 16 degrees. In addition, the gold target could increase from the current 60mm to 102mm in length. The neutral beam line for Step-2 follows the design principle of the current KOTO beam line. It consists of two 5m collimators, one sweeping magnet, and a photon absorber made of lead to reduce the photon yield in the beam. The hole of each collimator has a rectangular shape in cross-section, and their gradients along the beam direction were optimized to minimize the halo. The K_L momentum spectrum peaks at 3 GeV, and the K_L yield is 2.5 times larger than that in Step-1, about 1.1×10^7 per 2×10^{13} POT (Proton On Target).

The current Step-1 detector includes a 2m diameter pure CsI crystal calorimeter in fly-eye geometry in the forward region to measure the two photons from the π^0 decay while the cylindrical barrel surrounding the decay region acts as veto. There are numerous detectors upstream of the barrel and downstream of the CsI array to ensure veto hermiticity. For Step-2, the decay region will be expanded from 2m to about 13m, while the diameter of the calorimeter could increase to 3m. Upgrades of the J-PARC Hadron Eperimental Facility (HEF) to extend the current experimental hall is necessary for the changes.

One possible option to increase the detector acceptance is to detect and measure the photons in the barrel. Currently the barrel acts as veto, however there is no fundemental reason why its role could not be reversed. If the barrel could be used to measure photon, longitudinal segmentation along the beam direction is needed for energy and position measurements in addition for single rates consideration. The merit of the configuration renders an increase of a factor of 18 in acceptance. Further, if the photon direction (momentum) could be measured, the reconstructed π^0 mass will enhance S/N ratio likely for several backgrounds. Similarly argument could be made with respect to the forward calorimeter that the photon direction if measurable, will be beneficial to reject non π^0 backgrounds. Detailed studies and development efforts are needed. Moreover, with the increases of rates and the number of detector elements, timing improvements to to suppress accidentals is one of the key detector issues, so are the trigger sophistications and the data acquisition system.

For rare decay eperiment, the control and elimination of various backgrounds are paramount. With Step-1, KOTO accumulated much experience. Details could be found in published results. Overall, there seems there is no show stopper so far.

By ∼2025, Step-1 will reach SM single event sensitivity. From now to then, details on various concepts of Step-2 will be studied, and validated, and perhaps mature enough that Step-2 will be proposed and be built on time to continue the effort, i.e. a precision measurement of the $K_L \to \pi^0 \nu \overline{\nu}$ branching ratio with 100 observed events. Commensurating the mentioned expansions calls for the same in collaborations.

References

[1] Tadashi Nomura *2020 J. Phys.:Conf. Ser* ***1526*** *012027*.