Status of KOTO Experiment at J-PARC

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Abstract. The KOTO experiment at the J-PARC laboratory seeks to obtain the first observation of the $K_L \to \pi^0 \nu \bar{\nu}$ decay. The branching ratio is calculated in the Standard Model to be 2.4×10^{-11}. This decay is a good probe to explore new physics beyond the Standard Model with its small theoretical uncertainty (∼2%). During 2012 - 2013, KOTO performed commissioning runs with most of the detectors, and we started the first physics run in May 2013. We accumulated 100 hours with the 24 kW beam power, and the analysis is on going. In this paper, the status of the KOTO experiment, including the data analysis and prospects, is reported.

1. Introduction

The very rare decay $K_L^0 \to \pi^0 \nu \bar{\nu}$ is a sensitive probe for direct CP violation in the quark sector. The decay is a Flavor Changing Neutral Current process and is induced through electroweak loop diagrams. The branching ratio for $K_L^0 \to \pi^0 \nu \bar{\nu}$ is predicted to be 2.4×10^{-11} in the Standard Model, and the theoretical uncertainty is estimated to be only a few percent. The decay is also sensitive to new physics scenarios beyond the Standard Model such as Supersymmetric theories.

A model-independent upper bound on the branching ratio, called the Grossman-Nir bound [1], is derived as $BR(K_L^0 \to \pi^0 \nu \bar{\nu}) < 4.4 \times BR(K^+ \to \pi^+ \nu \bar{\nu})$ from the isospin symmetry arguments. The measured $BR(K^+ \to \pi^+ \nu \bar{\nu})$ at $(1.7 \pm 1.1) \times 10^{-10}$ from the BNL E787 and E949 experiments [2] yields an upper limit on $BR(K_L^0 \to \pi^0 \nu \bar{\nu})$ of 1.2×10^{-9} (68 % C.L.).

The latest experimental results were obtained from the E391a experiment at KEK 12 GeV PS, and the upper limit on the branching ratio was 2.6×10^{-8} [3]. The goal of the KOTO (K0 at TOkai) experiment is to study $K_L^0 \to \pi^0 \nu \bar{\nu}$ at the Standard Model sensitivity [4].

2. Experiment

A schematic cross-sectional view of the KOTO detector is shown in Figure 1. The KOTO detector subsystems are categorized into two parts. One is the CsI calorimeter, which detects two photons from π^0 decay, and the other is a set of hermetic veto counters, which requires no energy deposition in the $K_L^0 \to \pi^0 \nu \bar{\nu}$ events. With two photon detection in the CsI calorimeter, the decay vertex can be reconstructed assuming the nominal π^0 mass using the very narrow K_L beam generated by the collimator system in the upstream [5].

The detector design follows the same concepts as those in the E391a experiment, and most part of counters used in the E391a are reused. We had major upgrades to the detector subsystems that are placed around the beam hole to suppress the halo-neutron background reported at the E391a experiment [3].

We finished the construction of the K_L beam line in 2009, and most of the detectors were installed by 2013.

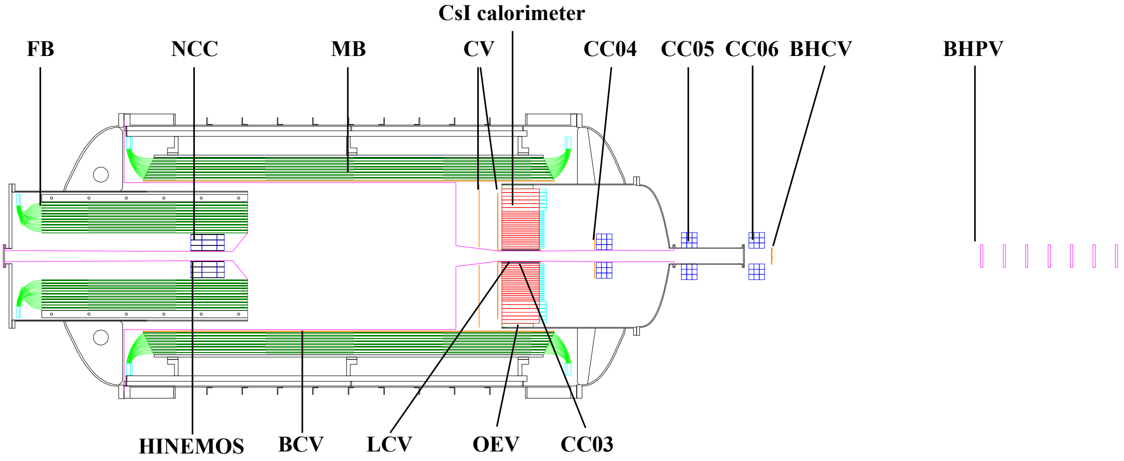

Figure 1. Schematic cross-sectional view of the KOTO experiment.

3. First physics run in 2013

In January 2013, we conducted engineering runs for studying the response of all detectors and confirming the K_L yield using $K_L \to 3\pi^0, 2\pi^0, 2\gamma$ decay modes [6]. We took 5-day data across March and April for tuning the detectors and DAQ for physics data taking. Finally, we started the first physics run in May; unfortunately the beam was terminated due to the hadron hall accident. We accumulated the data for 100 hours with the 24 kW beam power, and it is expected to be close to the sensitivity of the E391a experiment.

The performance of the detectors was checked by the $K_L \to 3\pi^0$ and $2\pi^0$ decays. Figure 2 shows the K_L invariant mass spectrum and the reconstructed vertex distribution using the events of 6 photons in the CsI calorimeter. These events are from $K_L \to 3\pi^0$ decay and are useful to check the performance of the calorimeter. The Monte Carlo simulation, considering the detector response and accidental hits which were accumulated by a beam-related trigger, reproduces the data well.

Figure 3 shows the K_L invariant mass spectrum using the events of 4 photons in the CsI calorimeter. The K_L mass peak from $K_L \to 2\pi^0$ and a large amount of continuum from $K_L \to 3\pi^0$ due to missing photons in the calorimeter are observed. Most of such missing photons are going to the veto detectors. Thus, after imposing extra-particle veto for all the hermetic detectors, $K_L \to 3\pi^0$ event is highly suppressed and the K_L mass peak from $K_L \to 2\pi^0$ be clear. The Monte Carlo simulation reproduces the data well. We concluded that the performance of the CsI calorimeter and the veto detectors were well understood.

The analysis of $K_L^0 \to \pi^0 \nu \bar{\nu}$ is on going with the signal region masked.

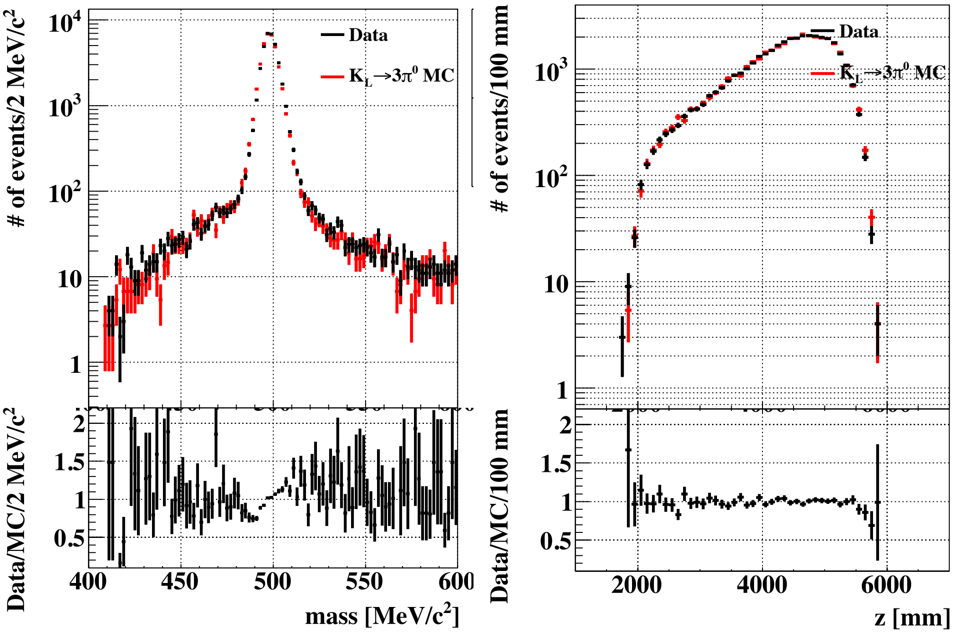

Figure 2. Left) K_L invariant-mass spectrum and Right) reconstructed vertex distribution using the events of 6 photons in the CsI calorimeter. Black and red colors indicate events of real data and of the Monte Carlo simulation, respectively; their ratio is shown in the bottom.

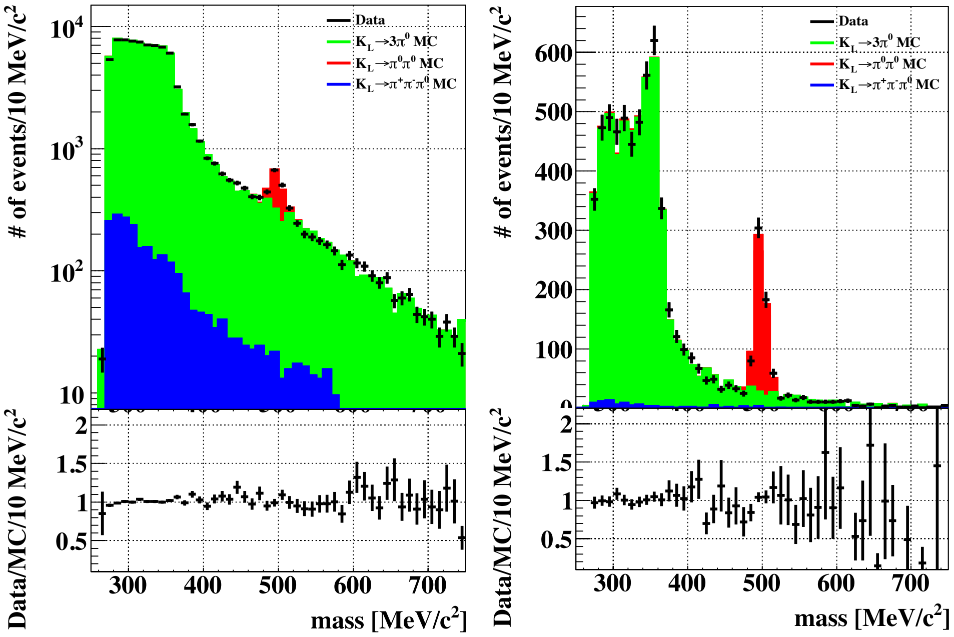

Figure 3. K_L invariant-mass spectrum using the event of 4 photons in the CsI calorimeter. Left) Reconstructed π^0 mass with the information from the CsI calorimeter only. Right) After imposing extra-particle veto for all the hermetic detectors. The ratio of the data and the Monte Carlo is shown in the bottom.

4. Detector upgrades

To reach the sensitivity of the Standard Model prediction, it is necessary to increase the photon detection efficiency in part of the veto detectors. Now, we are planning to :

- increase the number of modules of photon veto in beam (BHPV in Figure 1),
- replace the charge veto in beam to a new one (BHCV in Figure 1),
- add photon veto counters around the decay region (inside MB in Figure 1).

The current BHCV is composed of segmented scintillators, and the count rate is high due to the material. A new BHCV is designed as a gas chamber to reduce the amount of material. We prepared a prototype and checked the performance with the K_L beam during the engineering run; it was confirmed the gas chamber system will be fit to the highest beam intensity at J-PARC.

An new Inner Barrel detector (IB) is planning to be installed inside the Main Barrel (MB) for increasing the photon detection efficiency; the radiation length increases from 13.5 X_0 to 18.5 X_0 in total. Then the punch-through events are suppressed by 50. It is a sandwich calorimeter and consists of 25 layers of lead plates and scintillators read by wavelength shifting fiber.

The new detectors are being constructed, and will be installed at summer in 2015.

5. Summary

The KOTO experiment at J-PARC studies $K_L^0 \to \pi^0 \nu\bar{\nu}$. The first 100 hours of physics data in May 2013 is being validated and the analysis for $K_L^0 \to \pi^0 \nu\bar{\nu}$ is on going. The KOTO experiment will resume data taking in early 2015; and it is expected to reach the Grossman-Nir bound. We plan to install new detectors in the summer of 2015. These detectors are essential to go further in the $K_L^0 \to \pi^0 \nu\bar{\nu}$ sensitivity.

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