PROCEEDINGS OF SCIENCE

Status and future prospects for the KOTO experiment

Manabu Togawa[*]
Osaka University
E-mail: `togawa@champ.hep.sci.osaka-u.ac.jp`

The KOTO experiment at the J-PARC laboratory seeks to obtain the first observation of the $K_L^0 \to \pi^0 \nu \bar{\nu}$ decay, as a direct measurement of the CP-violating parameter in the Standard Model. The detector and the DAQ system have been built, and the experiment is ready to accumulate the first physics data in May-June 2013. In this paper, our expectation for the sensitivity at the first physics run and future prospects including detector upgrades are discussed.

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[*] Speaker.

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1. Introduction

The very rare decay $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$ is a sensitive probe for direct CP violation in the quark sector. The decay is a Flavor Changing Neutral Current process that is induced through electroweak loop diagrams. The branching ratio for $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$ 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.

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} [1]. The goal of the KOTO (K0 at TOkai) experiment is to search for $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$ at the standard model sensitivity [2].

2. Experimental design

A schematic cross-sectional view of the KOTO detector is shown in Figure 1. The KOTO detector is categorized into two sections. One is the CsI calorimeter, which detect two photons from π^0 decay, and the other is a set of hermetic veto detectors, which requires no energy deposition in the $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$ events.

The detector design follows the same concepts as those in the E391a experiment. In E391a, a limitation on the single event sensitivity was at 1.1×10^{-8} due to the so-called halo-neutron background [1]. The halo-neutrons surround the core of the neutral beam, and they hit the detector subsystems around the beam hole. Then, the halo neutrons can generate π^0 or η, which will be a source of the backgrounds. To suppress the halo-neutron background, we improved both the neutral beam and the detector.

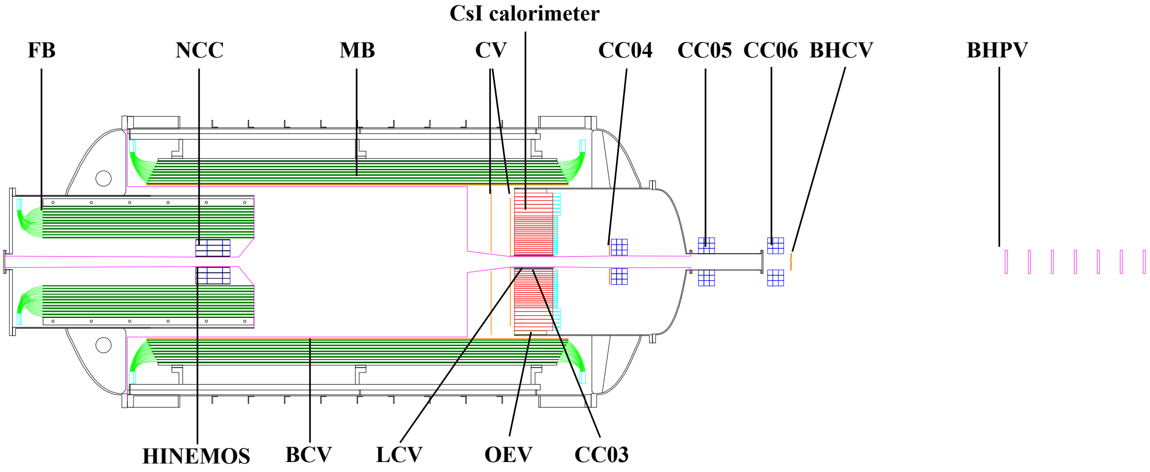

Figure 1: Schematic cross-sectional view of the KOTO experiment

2.1 The neutral beam

A plan view of the neutral beam line is shown in Figure 2. The 30 GeV proton beam is extracted from the J-PARC main ring and generates secondary particles by hitting the target made either of *Ni*, *Pt* or *Au*. The KOTO beam line selects neutral particles which are generated to the production angle of 16 degree. The remaining particles after the 20 m-long collimation with a sweeping magnet are K_L^0's, neutrons and photons.

The halo-neutrons are produced due to multiple scatterings of beam neutrons on the materials in the beam line apparatus. The beam line collimation is designed so that the scattered neutron should never be scattered again by the downstream materials. This scheme will reduce the halo component, and the ratio of halo to core neutrons is designed to be 10^{-5} [3]. We performed beam surveys in 2009, and obtained the expected beam profile [4]. The K_L yield with the *Pt* target was 2.6 times larger than that estimated in the proposal [5].

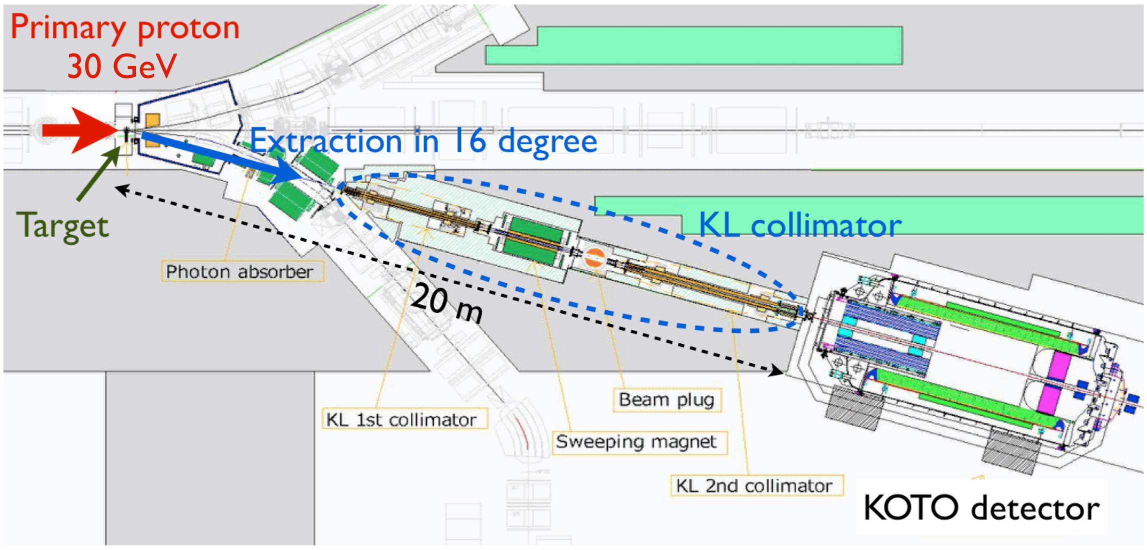

Figure 2: Plan view of the neutral beam line

2.2 Detector subsystems

In this paper we describe only the detector subsystems that are related to the halo-neutron background. A more general description of the KOTO apparatus can be found in [2, 6] .

To reduce the halo-neutron background, we had major upgrades to the detector subsystems that are placed around the beam hole. The Neutron Collar Counter (NCC), made of undoped CsI crystals, is placed upstream and its crystals are segmented along the beam direction to identify neutrons. NCC can veto the halo-neutron background by itself, and also has the capability of halo-neutron measurement. The Charged Veto counters (CV), made of 3 mm-thick plastic scintillators, is placed in front of the CsI calorimeter. The amount of material in CV is low, which will suppress the halo-neutron background while keeping a good efficiency for charged particles. We also upgraded the CsI calorimeter; the 27 X_0-long CsI crystals from the Fermilab KTeV experiment will improve the resolution of the reconstructed vertex of the π^0. These detector subsystems were installed, and are well functioning.

3. DAQ

The data flow of the KOTO DAQ is shown in Figure 3. The waveforms of the signals from the detector subsystems are recorded by a 125 or 500 MHz pipelined ADC.

The events are selected by three-level triggering. In the level 1 trigger, ADC values are summed up from all channels in each subsystem. We can judge an event by the energy deposition in the CsI calorimeter and also by the extra-energy deposition in the veto subsystems. In the level 2 trigger, we use the kinematic information on π^0 from the calorimeter. Here, we employ a Center-Of-Energy criteria (COE) defined as,

$$COE \equiv \frac{\sqrt{(\sum_i E_i x_i)^2 + (\sum_i E_i y_i)^2}}{\sum_i E_i}, \tag{3.1}$$

where E_i and (x_i, y_i) are the energy deposition and the position of i-th CsI crystal, respectively. The COE value from π^0 of $K_L^0 \to \pi^0 \nu\bar{\nu}$ must be large due to the energy taken by neutrinos. The level 3 trigger does an event reconstruction by the PC farm. We are currently preparing the clustering algorithm to reduce the data size.

With the current proton beam intensity, up to the 24 kW proton beam of J-PARC achieved in May 2013, the event reduction provided by the level 1 and level 2 triggers is sufficient to select $K_L^0 \to \pi^0 \nu\bar{\nu}$ data with high efficiency, but we are reaching the limitations of the system. In the near future we will need upgrades for the first 2 levels of triggers and to start implementing level 3 trigger in order to reduce the amount of data saved to disk.

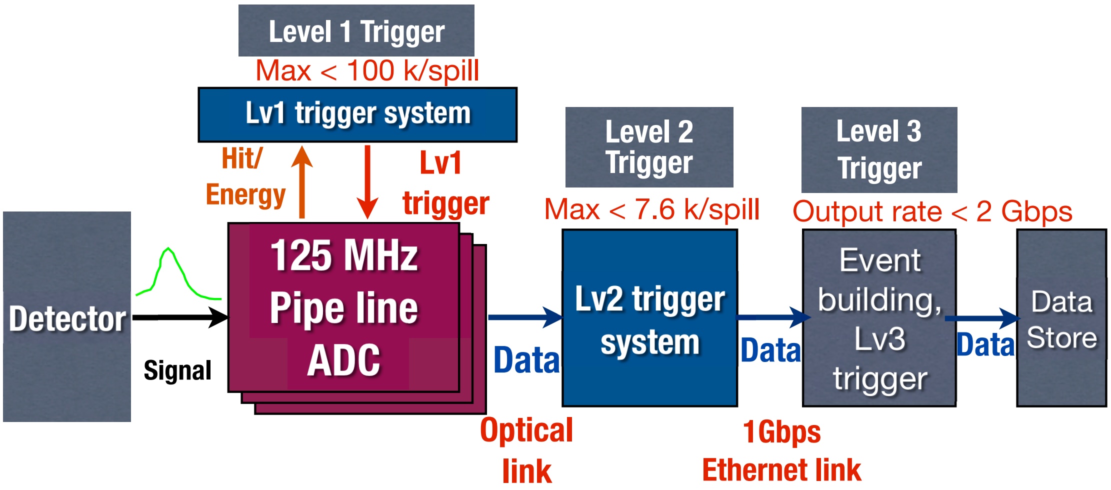

Figure 3: Data flow of the KOTO DAQ system

4. Expectation of the sensitivity at the first physics run and the prospects

After constructing the detector, engineering runs were performed in December 2012 and January 2013. The analysis is ongoing; preliminary results are presented in another talk at this conference [6]. We are currently checking the detector subsystems and Trigger/DAQ performance during a short physics run, with the 15 kW proton beam in early May.

The beam is scheduled to be back on May 13th, and we will start to accumulate the physics data [1]. To cross the so-called Grossman-Nir bound of 1.46×10^{-9}, we requested a physics run for 30 days with the 15 kW proton beam. The J-PARC main ring has already achieved the beam power of 20 kW or more.

The future prospects at the time of the KAON2013 conference were as follows. The proton beam power for slow extraction will be 50 kW in 2014 and 100 kW in 2015. If we assume we run for 4 months in every year, we will reach the single event sensitivity at the Standard-Model prediction by 2017.

5. Detector upgrade

After suppressing the halo-neutron background, the main background will be from $K_L^0 \to 2\pi^0$ by missing two out of four photons due to the photon detection inefficiency. According to simulation studies, the signal level is comparable to the background level at the standard model sensitivity with the current KOTO setup. The background events will be due to the detection inefficiency in the Main Barrel counters (MB). MB is the lead-scintillator sampling shower counters surrounding the decay region with the thickness of 14 X_0.

To reduce the background from $K_L^0 \to 2\pi^0$, we are planning to add shower counters with the same configuration, named Inner Barrel (IB), inside the MB. IB will have the thickness of 5 X_0 and will reduce the photon inefficiency caused by the penetration. With this upgrade, the signal to noise ratio is expected to improve by a factor of 1.8.

Currently, we are testing with a 30 cm-long prototype module and are establishing the way to stack and support the modules of the new detector. Also we are measuring the light yield of fibers and scintillators.

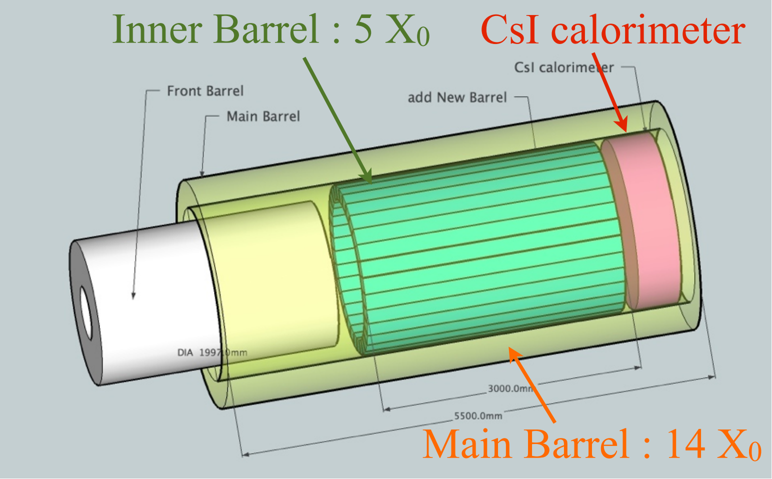

Figure 4: Schematic view of the upgrade with the Inner Barrel counters

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[1] The physics run started on May 17; the beam was stopped on May 23 due to an accident.

6. KOTO step2

The goal of the KOTO experiment is to achieve the search for $K_L^0 \to \pi^0 \nu \bar{\nu}$ with the standard model sensitivity (so-called KOTO-step 1). We are planning to proceed to the KOTO-step2 experiment to reach 100 events with the Standard-Model sensitivity [2]. At the step 2, we need to increase the K_L yield by,

- Higher intensity beam : 290 kW -> 435 kW ;
- Smaller extraction angle : 16 degree -> 5 degree ;
- Longer decay volume : 2 m -> 11 m.

A schematic view of the KOTO-step 2 is shown in Figure 5.

A possibility of the 5 degree extraction is being discussed with a future plan of Hadron Hall extension (Figure 6). The plan is to extend the Hadron Hall and to install 2 more targets to allow more experiments to be performed simultaneously. The location of KOTO step 2 is behind the beam dump with the neutral beam extracted from the 3rd target. The beam line will be placed inside the beam dump.

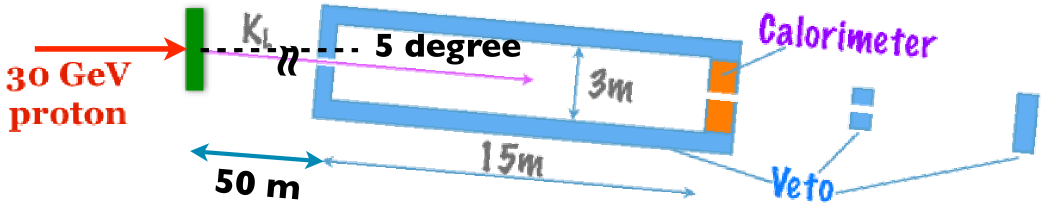

Figure 5: Schematic view of the beam line and the detector for KOTO step 2.

7. Summary

The KOTO experiment at J-PARC searches for $K_L^0 \to \pi^0 \nu \bar{\nu}$. The detector and DAQ system are ready to accumulate physics data. We are going to start the first physics run in May 2013 with a beam power around 20 kW. The aim is to reach the Grossman-Nir limit. The final sensitivity is expected to reach the standard model prediction with increased beam power and the detector upgrades. Furthermore, we are planning the KOTO-step 2 experiment with a sensitivity goal of order 10^{-13}. A long-range plan is shown in Figure 7.

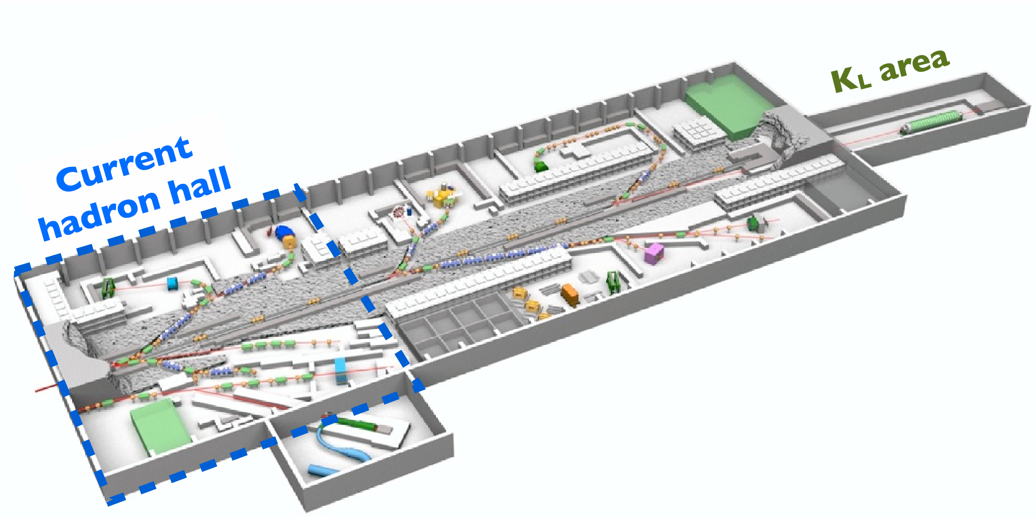

Figure 6: A plan of the Hadron Hall extension in future. The size of the current Hadron Hall is indicated with blue dotted line. KOTO step-2 will be located in the K_L area, behind the beam dump, at the rear of the hall.

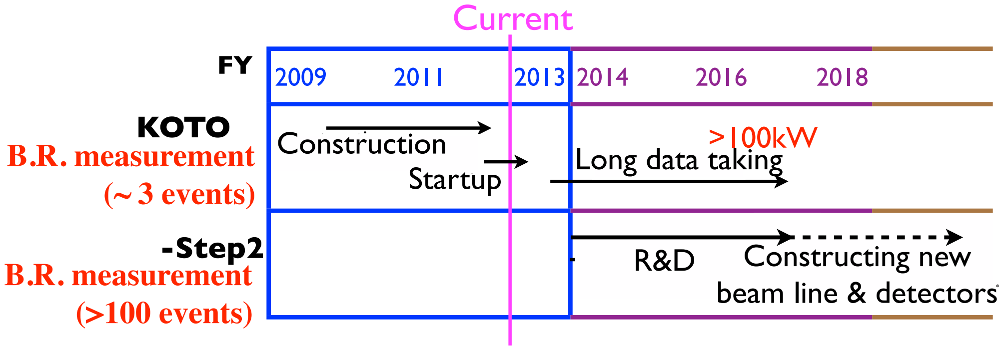

Figure 7: Plan for $K_L^0 \to \pi^0 \nu \bar{\nu}$ measurement at J-PARC.

References

[1] J. K. Ahn et al., Phys. Rev. **D81**, 072004 (2010).

[2] J. Comfort et al. for J-PARC E14 Collaboration, Proposal for $K_L^0 \to \pi^0 \nu \bar{\nu}$ Experiment at J-PARCÃĚh (Available at: http://j-parc.jp/researcher/Hadron/en/pac_0606/pdf/p14-Yamanaka.pdf) (2006).

[3] T. Shimogawa, Nucl. Instrum. Meth. **A623**, 585 (2010).

[4] G. Takahashi et al., Japanese Journal of Applied Physics **50**, 036701 (2011).

[5] K. Shiomi et al., Nucl. Instrum. Meth. **A664**, 264 (2012).

[6] T. Masuda, "KOTO Detector Status", Proceedings for this workshop.