KEK_J-PARC-PAC2010-06

Proposal for Measuring Hadron Response at K1.1BR for K^{O}TO Experiment

Naoki Kawasaki, Eun-Joo Kim[1], Kwanbeom Kim[1], Gei-Youb Lim[2], Yosuke Maeda, Takahiko Masuda, Hajime Nanjo*, Daichi Naito, Tadashi Nomura[2], Miki Sasaki[3], Noboru Sasao[4], Kazufumi Sato[5], Kouji Shiomi, Tetsushi Shimogawa[6], Yasuhisa Tajima[3], Goh Takahashi, Taku Yamanaka[5], Hiroshi Yoshida[3], Hiroaki Watanabe[2]

Department of Physics, Kyoto University, Kyoto 606-8502, Japan
[1]*Chonbuk National University, Jeonju 561-756, Korea*
[2]*High Energy Accelerator Research Organization (KEK), Ibaraki 305-0801, Japan*
[3]*Department of Physics, Yamagata University, Yamagata 990-8560, Japan*
[4]*Research Core for Extreme Quantum World, Okayama University, Okayama 700-8530, Japan*
[5]*Department of Physics, Osaka University, Osaka 560-0043, Japan*
[6]*Department of Physics, Saga University, Saga 840-8502, Japan*

June 14, 2010

Abstract

We request 2-day beam time for measuring the hadron response of the detectors for K^{O}TO in 2010 at K1.1BR beam line.

1 Introduction

The K^{O}TO experiment[1] aims to discover a CP-violating decay mode, $K_L^0 \to \pi^0\nu\bar{\nu}$. The CP-violating parameter, η, in the CKM matrix can be determined from the branching ratio of the decay with a theoretical uncertainty of $1-2$ %. The branching ratio is expected to be 2.5×10^{-11} in the Standard Model (SM) prediction[2]. Due to the small uncertainty and the

*Contact person, nanjo@scphys.kyoto-u.ac.jp

small branching ratio, it is a sensitive probe for the SM and new physics beyond the SM[3].

The signatures of the decay distinct from other backgrounds are that only two gammas from a π^0 exist and the transverse momentum of the π^0 is large due to the missing neutrinos. A hermetic detector and a small-diameter beam are adopted for the detection. The hermetic detector ensures only two gammas and noting else, and the small-diameter beam enables the π^0 reconstruction constraining the decay vertex of the π^0.

In order to discover the extremely rare decay, we use the high-intensity proton beam at J-PARC, where we constructed a neutral beam line in 2009. The beam line was designed to realize a small-cross-section neutral beam with a solid angle of 7.8 μsr using two collimators and a sweeping magnet (Fig.1) [4, 5]. The length of the beam line is 20 m, where short-lived particles

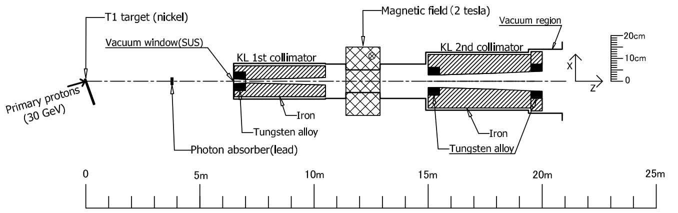

Figure 1: Schematic top view illustrating the neutral beam line at J-PARC.

are decayed. Only gammas, neutrons, and K_L's are remained at the beam-line exit. The gamma flux is reduced with a 7-cm-long lead absorber at the upstream of the beam line.

There are three important points for the performance of the beam line. The first point is the K_L yield, which determine the sensitivity of our experiment. Second, fluxes and energy spectrums of the gammas and neutrons in the beam core are important, because our detector should be hermetic and cover the beam core, where a operation of the detector with good detection efficiency is difficult. The last item is described in the next paragraph.

Most of the neutrons are collimated in the small solid angle defined by the collimators ("core neutrons"). Neutrons slightly exist also in the halo of the beam due to scattering at the lead absorber or on the collimators' surfaces ("halo neutrons"). The halo neutrons can interact with the K^{O}TO-detector components and produce π^0's or η's, which decay into 2 gammas. It is estimated to be one of the main background sources in the K^{O}TO experiment[6]. We designed the collimators in order to reduce the ratio of the halo-neutron and K_L fluxes to be 7×10^{-4}, which is one of the key performances to determine the sensitivity of this experiment. In addition, the core neutron measurement is important to understand the nature of the halo neutrons, because the halo neutrons are produced from the core neutrons.

In order to examine the nature of our beam line, we performed a test experiment, "beam survey", in JFY 2009 after the construction of the beam line. We tried to measure the following items:

- beam profile,
- K_L flux and spectrum,
- fluxes and spectrums for the core gammas and neutrons, and
- fluxes and spectrums for the halo neutrons.

The results will be reported elsewhere. For the last two items, we should understand the neutron response of detectors used in the beam survey, because it is directly related to the final result for the neutron measurement. For the core-gamma measurement, gamma flux should be discriminated from huge neutron flux, where the neutron response of the detector decide the performance. The charged-pion response is also doubted in the analysis of the halo-neutron measurement, where halo neutrons should be discriminated from a huge amount of particles from K_L decays. More detailed information will be presented in section 2.

We want to understand the hadron response in the early of the slow extraction in 2010 before the late slow extraction term, when we want to measure the beam property with improved detector design based on the better understanding of the hadron response.

The hadron response of such detectors are also important for the real experiment, because we used prototype detectors in the beam survey. With the better understanding of the hadron response, we want to finalize the detector design and examine the performance in the real beam using the prototype in this fiscal year before the construction in the next fiscal year.

2 Importance of Hadron Response for K^{O}TO

The detectors used in the beam survey and the importance of the hadron response for each measurement are described.

2.1 Core Neutron Measurement with Cerberus

The energy distribution of the core neutrons were measured with a hadron calorimeter, named "Cerberus", as shown in Fig. 2.1. It consisted of 6 modules, each was 40 cm square in cross-section and 20 cm in thickness. The front module (EM module) consisted of 25-layers of 4 mm-thick lead and 3.7 mm-thick scintillator plates sandwiched with each other. The radiation length and the nuclear interaction length of the front module were 18 X_0 and 0.7 λ_I, respectively. For the other 5 modules (hadron modules), 4 mm-thick

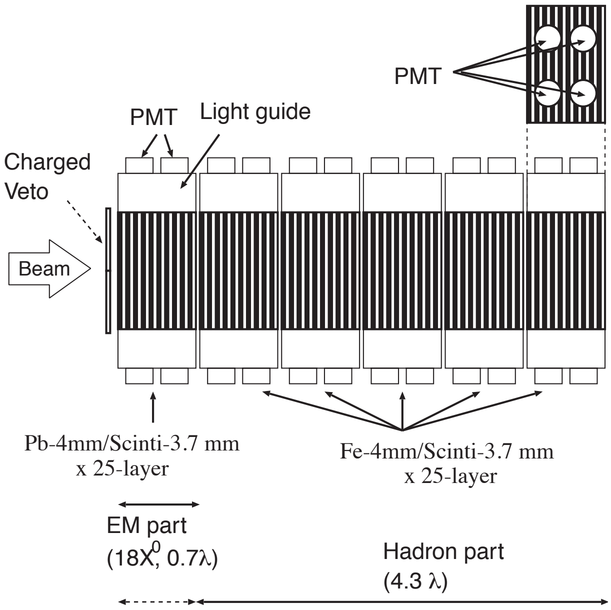

Figure 2: Schematic side view of the hadron calorimeter, Cerberus.

iron plates were used as a converter. The total nuclear interaction length of the Cerberus was 4.27 λ_I.

In order to discriminate neutrons from gammas, we defined a parameter "F/T", which is the ratio of the energy deposition in the EM module and the total modules. Neutrons can be selected by applying $F/T < 0.5$ with good purity. The energy reconstruction and the detection efficiency are needed for measuring the flux and the energy spectrum. We used the MC simulation for evaluating those. The response of the electromagnetic interaction was already validated using a positron beam. We want to validate the hadronic interaction in the MC simulation using protons.

2.2 Core Gamma Measuremnt with BHPV tagging

For the core gamma measurement, it is difficult to discriminate gammas from a huge amount of the neutrons with F/T of the Cerberus because the neutron rejection power is not enough. The neutron contamination was estimated to be 90 % with $F/T > 0.85$.

We used a BHPV (which is described in the next paragraph) module for the gamma tagging because its neutron rejection was more powerful. The EM module of Cerberus is used for the calorimeter as shown in Fig. 3. The contamination of the neutron was estimated to be 1 % by applying the BHPV hit.

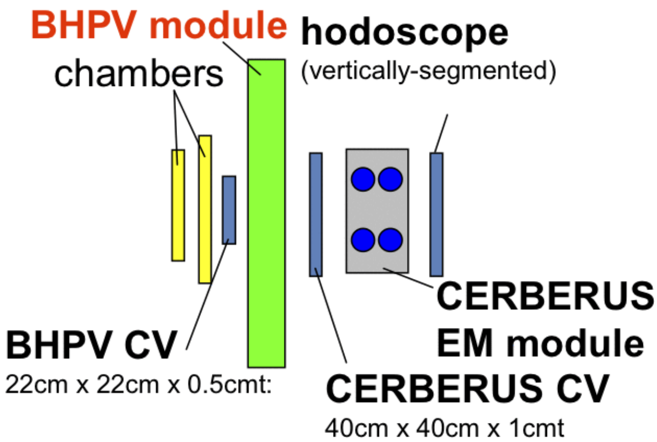

Figure 3: The setup of the core gamma measurement.

The BHPV is the Beam Hole Photon Veto detector in the K^OTO detector which covers the beam core region at the downstream as shown in Fig. 4. It consists of 25 modules along the beam axis. A single BHPV module is

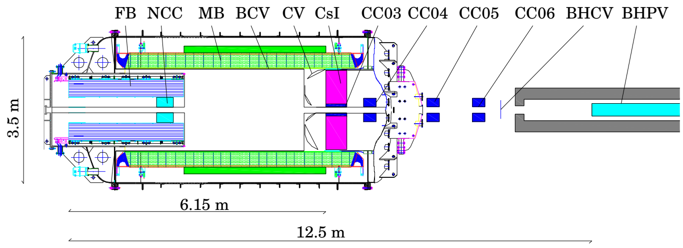

Figure 4: Schematic cross-sectional view of the K^OTO detector.

shown in Fig. 5 and it consists of:

- a lead gamma converter in front of the aerogel to convert a gamma to e^+ and e^-, of which thickness varies 0-3 mm among the 25 modules,
- a 5.6-cm-thick aerogel Cerenkov radiator with the refractive index of 1.05, which is sensitive to the e^+ and e^- from the gamma conversion, and is insensitive to particles from the interaction of neutrons in the lead,
- two flat mirrors to divide Cerenkov photons into two PMTs which reduces the PMTs'counting rate,
- a Wisnton cone to collect Cerenkov photons into the PMTs, and

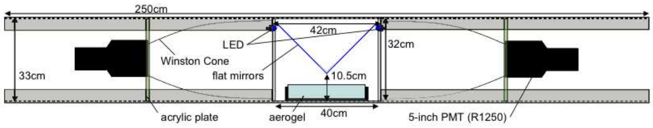

Figure 5: Schematic top view of the BHPV single module. A lead gamma converter in front of the aerogel is not shown here.

- two 5-inch PMTs to detect photons.

The neutron inefficiency of the BHPV is the key to reduce the neutron contamination in the core gamma measurement. We want to measure its proton response in order to validate it.

2.3 Halo Neutron Measurement with NCC Prototype

The NCC is one of the veto detectors for K^OTO, which surrounds the beam at the upstream as shown in Fig. 4. Its location is close to the beam and was designed to measure the flux and energy spectrum of the halo neutrons in the real experiment. It consists from 44 modules and the single modules is shown in Fig. 6. The single module consists of three 6.8cm$\times$6.8cm pure CsI crystals

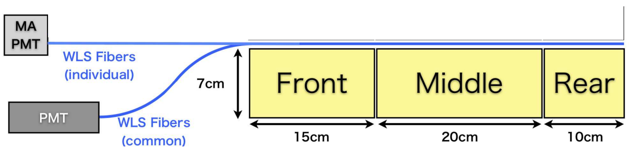

Figure 6: Schematic cross-sectional view of NCC single module.

aligned along the beam axis; a 15-cm-long front part, a 20-cm-long middle part, and a 10-cm-long rear part. The signal is read through wavelength-shifting (WLS) fibers on the CsI surface. The total number of the WLS fibers is 40 per module; 28 fibers are contacted commonly through three parts ("common readout") which are used for the main veto purpose, and 4 fibers are contacted individually for each part ("individual readout"). Such segmentation and the individual readout enables the neutron and gamma discrimination as shown in Fig. 7. For the neutron discrimination, the front and rear parts, and middle parts near the beam are used to veto gammas and charged particles.

In the beam survey, we prepared 3×3 NCC prototype modules with the same segmentation and readout scheme as shown in Fig. 8. We tried to measure the halo neutrons with it.

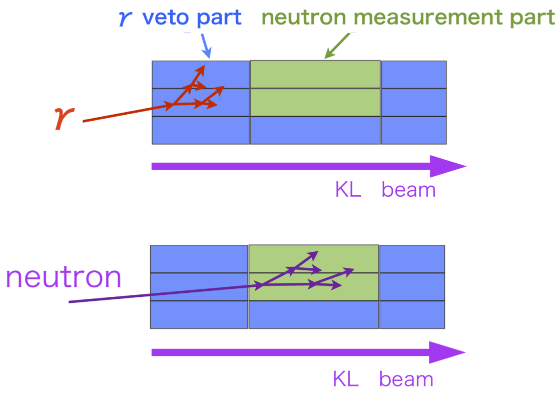

Figure 7: The neutron and gamma discrimination with NCC.

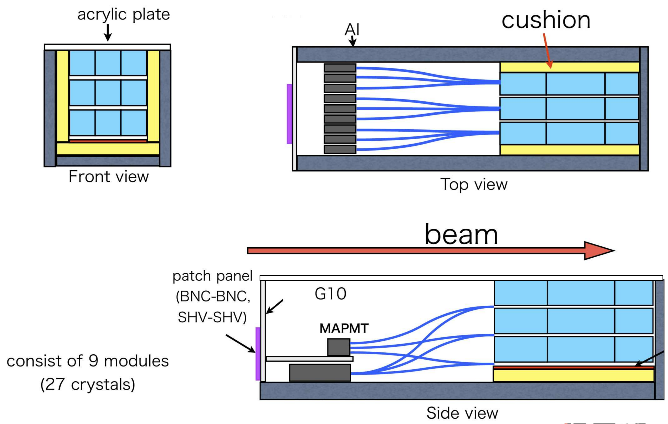

Figure 8: The NCC prototype modules used in the beam survey.

The detector response to the electromagnetic interaction was already examined using a positron beam. We want to test the detector response to hadronic interactions with protons and charged pions.

3 Measurement at K1.1BR

The K1.1BR beam line and the experimental area is shown in Fig. 9. For the measurement of BHPV, Cerberus, and NCC, we request a 2.5 m × 3 m space as show in Fig. 9, where the trigger counters, $T1$, $T2$, and $T3$, and the BHPV and Cerberus or NCC are placed as shown in Fig. 10. We will also prepare the most upstream TOF counter, $T0$. We will make a trigger from the coincidence of $T0$, $T1$ and $T2$. For the muon trigger, $T3$ is included for

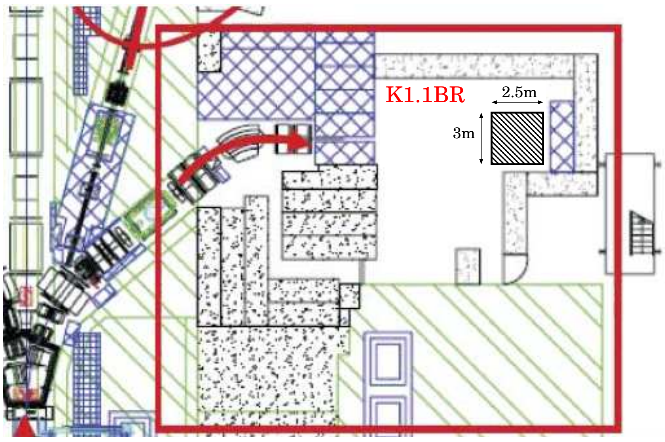

Figure 9: The K1.1BR beam line and the experimental area. Proposed space for our measurement is also shown.

the coincidence. We want to use 5 momentum points from 0.4 to 0.8 GeV/c without the DC separator. Expected particle yield right after the target is shown in Fig. 11[7], where the yields of the proton and charged pion are $10^6 - 10^7$ per spill for 1 kW beam power. A beam slit can be used to reduce the flux.

In our measurement, protons can be discriminated by using a time-of-flight (TOF) method. Charged pions with the smaller momentum can be discriminated also by using the TOF. Contamination of electrons and muons are expected to be small enough. We want to measure the proton and charged-pion response for the BHPV, Cerberus, and NCC at the 5 momentum points.

4 Plan

All the detectros, cables and DAQs are already prepared, which were used in the beam survey. We have to prepare support structures to keep the detectors at the beam height.

The measurement plan is as follows. The BHPV is also used for the purpose of the particle identification without the lead converter and with the arogel of which refractive index is 1.03 ("PID mode").

1. Beam tuning with the TOF in order to understand the beam flux and particle contents.
2. BHPV
   (a) Confirmation of the beam particle contents with the BHPV in the PID mode.

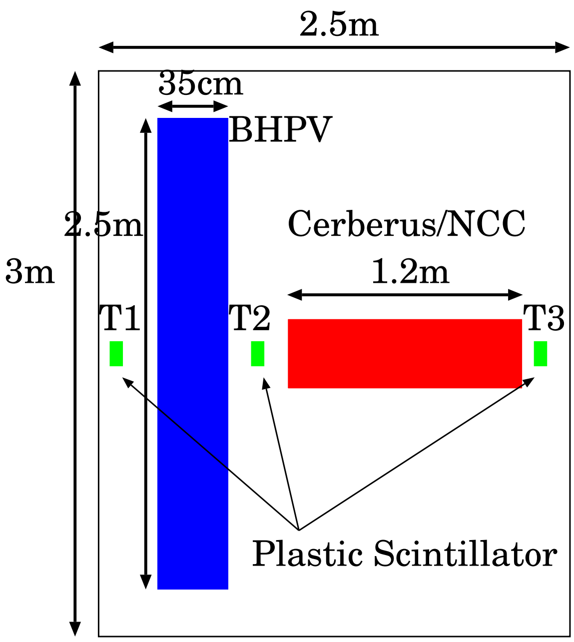

Figure 10: The floor plan for our measurement.

(b) Calibration by measuring the light yield of the aerogel for the charged particles without the lead converter.

(c) Test of BHPV responses to protons and charged pions with the lead converter.

3. Cerberus
   Test of the hadron interaction at 5 momentum points.

4. NCC
   Calibration with the muon trigger and test of the hadron interaction at 5 momentum points.

Two days are necessary for the setup and measurement. We want to do the measurement in the early of the slow extraction in 2010 in order to make a feedback to the later slow-extraction period in the view points of the beam survey and the real detector construction. In the beginning of the slow extraction in this autumn, the commissioning of K1.1BR will be done by TREK group. We have to consult them about the plan.

5 Summary

We would like to propose an experiment to measure the hadron response for K^{O}TO. We performed the beam survey to measure the properties of our

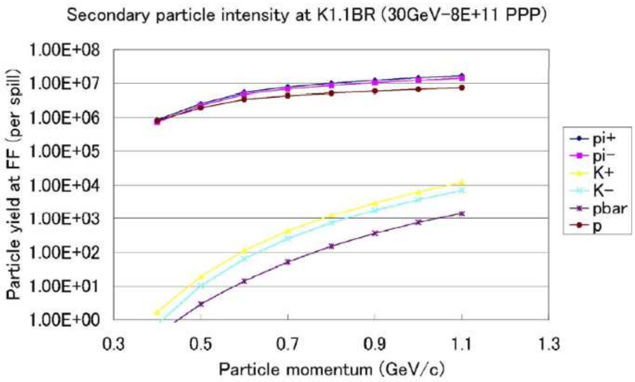

Figure 11: Particle yield at K1.1BR beam line [7].

beam line, which determine the sensitivity of K^{O}TO experiment. To get a reliable conclusion for the measurement, it is necessary to understand the hadron response of the detectors. Some detectors used in the beam survey were prototype detectors for the real experiment. It is important to ensure the detector performance in advance of the real detector construction. We want to measure the hadron response of such detectors in the early of the slow extraction in 2010 using protons and charged pions at K1.1BR beam line.

References

[1] J. Comfort *et. al.* (E14 collaboration) "Proposal for $K_L^0 \to \pi^0 \nu \bar{\nu}$ Experiment at J-Parc", http://j-parc.jp/NuclPart/Proposal_e.html.

[2] F. Mescia and C. Smith, "Improved estimates of rare K decay matrix elements from K_{l3} decays", Phys. Rev. D76, 034017 (2007).

[3] Andrzej J. Buras, Selma Uhlig, and Felix Schwab, "Waiting for precise measurements of $K^+ \to \pi^+ \nu \bar{\nu}$ and $K_L^0 \to \pi^0 \nu \bar{\nu}$", Rev. Mod. Phys. 80, 965 (2008), and references therein.

[4] T. Shimogawa, "Design of the neutral K_L^0 beamline for the J-PARC E14 KOTO experiment." in the Proceedings of TIPP09, to appear in Nucl. Instrum. Methods Phys. Res., Sect.A. (2010).

[5] T. Shimogawa, "Design Of The Neutral K(L) Beamline For The J-Parc E14 K0to Experiment," PoS **KAON09**, 020 (2009).

[6] H. Nanjo, "J-Parc E14 K0to Experiment For K(L) → Pi0 Nu Anti-Nu," PoS **KAON09**, 047 (2009).

[7] A.Badertscher*et. al.*, "Towards a Long Baseline Neutrino and Nucleon Decay Experiment with a next-generation 100 kton Liquid Argon TPC detector at Okinoshima and an intensity upgraded J-PARC Neutrino beam", http://j-parc.jp/NuclPart/Proposal_e.html.