PROCEEDINGS OF SCIENCE

J-PARC E14 K$^{\rm O}$TO experiment for $K_L \to \pi^0 \nu \bar{\nu}$

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The K$^{\rm O}$TO experiment is the E14 at J-PARC, designed to discover $K_L \to \pi^0 \nu \bar{\nu}$ events based on the KEK-PS E391a experiment. The CP-violation parameter, η, can be determined from the branching ratio of $K_L \to \pi^0 \nu \bar{\nu}$ with $1-2$ % theoretical uncertainty and it is highly sensitive to the TeV-scale new physics beyond the Standard Model (SM). In order to achieve the SM sensitivity, an improvement of three orders of magnitude is needed for K$^{\rm O}$TO, compared to E391a. We aim to discover $K_L \to \pi^0 \nu \bar{\nu}$ events in 3 years from 2011, using high intensity beam at J-PARC to increase the number of K_L, constructing new beamline to suppress halo neutrons, and upgrading the E391a detector to suppress backgrounds based on the E391a experience.

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1. The K$^{\rm O}$TO experiment and $K_L \to \pi^0 \nu \bar{\nu}$

The K$^{\rm O}$TO experiment is the E14 [1] at J-PARC which is a high intensity proton accelerator complex at Tokai in Japan and the K$^{\rm O}$TO is an abbreviation of "K0 at Tokai". The collaboration is based on KEK-PS E391a [2] collaboration and aim to discover $K_L \to \pi^0 \nu \bar{\nu}$ events in three years from 2011 with a similar method used in the E391a experiment.

1.1 Motivation of $K_L \to \pi^0 \nu \bar{\nu}$ search

There are mainly two motivations for the search of $K_L \to \pi^0 \nu \bar{\nu}$. First, the process, $K_L \to \pi^0 \nu \bar{\nu}$, is a direct CP-violating process and the branching ratio is proportional to the square of the η which is one of the Wolfenstein parameters deciding the imaginary component in the CKM matrix. The CP-violating parameter, η, can be determined through the measurement of the branching ratio, where theoretical uncertainty is $1-2\%$ [3] in the Standard Model (SM) framework. Second, it is a rare flavor-changing neutral current and highly suppressed in the SM, where the branching ration was calculated to be $(2.49 \pm 0.39) \times 10^{-11}$ [4]. The branching ratio is very sensitive to the new physics beyond the SM and there are plenty rooms for such new physics [7] below the current limit, 1.46×10^{-9} [6] at 90% confidence level (CL). We have a chance to reach such TeV-scale new physics through $K_L \to \pi^0 \nu \bar{\nu}$.

1.2 Current situation for $K_L \to \pi^0 \nu \bar{\nu}$ search

The current theoretical limit, 1.46×10^{-9} [6] at 90% CL (Grossman-Nir bound [5]), was obtained indirectly with both the isospin symmetry and the measured branching ratio of $K^+ \to \pi^+ \nu \bar{\nu}$ at BNL E797/E949, which is $1.73^{+1.15}_{-1.05} \times 10^{-10}$ [6]. The direct limit was obtained by E391a, which is 6.7×10^{-8} [2] at 90% CL[1] with no events left after all the final cuts.

2. Concept of the K$^{\rm O}$TO experiment

The K$^{\rm O}$TO experiment adopts the same concept with the E391a experiment. The beamline and detector concepts are written as follows.

2.1 Beamline

The K_Ls are generated from proton hits on a target, where many other particles are produced at the same time. Short-lived particles are vanished within a long beamline to the detector. Charged particles are swept out by a magnet. Photons are reduced with a Pb absorber, keeping the loss of K_L small. A collimator is used to make a narrow K_L beam along the beam axis, the reason of which will be explained in the next subsection. Neutrons also exist in the narrow beam (core neutrons) and some neutrons are scattered on the collimator wall and become halo neutrons surrounding the core neutrons.

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[1] E391a will update the value through the analysis of the remaining data soon

2.2 Detector

The detection principle for $K_L \to \pi^0\nu\bar{\nu}$ is only two gammas from the π^0 decay and nothing. Therefore a calorimeter to detect the two gammas and hermetic veto detectors are essential.

For the hermetic veto, a veto detector in the core beam at the downstream (beam hole veto) is necessary, whereas the operation of the detector with high detection efficiency is difficult inside the huge flux of gammas and core neutrons. The narrow beam is required primarily to limit the size of the beam hole veto detector.

On the other hand, for the π^0 reconstruction, the opening angle of the two gammas detected in the gamma calorimeter is calculated with a relation, $M^2 = 2E_1E_2(1-\cos\theta)$, where M is the π^0 mass, the E_1 and E_2 are gamma energies, and the θ is the opening angle of the two gammas. The π^0 decay vertex is reconstructed with the opening angle together with the detected positions of the two gammas at the calorimeter, assuming the vertex is on the beam axis. The narrowly collimated beam assure this condition and then the reconstruction of the transverse momentum (p_T) of the π^0 with enough resolution, which is one of the most important discriminants of the signal from backgrounds. The narrow beam is required also from this second view point.

The gamma calorimeter and hermetic veto detectors, and narrowly collimated beam are the most important points for the detector concept.

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3. Strategy from the E391a to K$^{\mathrm{O}}$TO experiment

In order to achieve the SM sensitivity for $K_L \to \pi^0\nu\bar{\nu}$, an improvement of three orders of magnitude in the sensitivity is needed for K$^{\mathrm{O}}$TO, compared to E391a. The number of K_L have to be increased at first. For the backgrounds, the main background source was estimated to be the halo neutron in E391a [2]. Such halo neutrons interact with the detector components near the beam axis and produce π^0 or η mesons which decay into two gammas. Suppression of such halo neutrons is the second point. Finally, the detector upgrade is necessary to suppress halo-neutron backgrounds at the detector by reducing positions where halo neutrons hit or by making the detector sensitive to the π^0 or η productions. Detector efficiencies also should be increased to suppress $K_L \to 2\pi^0$ background.

4. High intensity beam to increase the number of K_L

The proton intensity becomes 97 times higher with J-PARC, whereas the K_L intensity becomes 29 times higher due to the larger extraction angle at K$^{\mathrm{O}}$TO. The momentum of the K_L becomes smaller as shown in Fig. 1 and the decay probability becomes twice. The improvement factor of 3800 is achieved with longer run time and larger acceptance as shown in Table. 1.

5. New beamline to suppress halo neutron

The new beamline was already designed and is now under construction at J-PARC. The schematic drawing of the beamline is shown in Fig. 2, where the total length is 21 m and the 1st collimator, the sweeping magnet, and the 2nd collimator are aliened in 16 ° direction from the primary proton direction. The target consists of five Ni disks with the total thickness of 53.9 mm as shown in

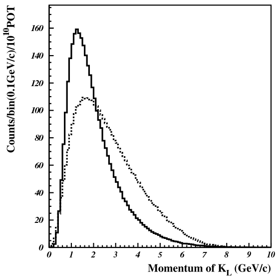

Figure 1: The momentum distributions for K$^{\mathrm{O}}$TO (solid line) obtained from the Geant4 simulation and for E391a (dashed line) used in the experiment [1].

Table 1: Comparison between the K$^{\mathrm{O}}$TO and E391a beam.

	K$^{\mathrm{O}}$TO	E391a (Run2)	Improvement factor
Proton energy	30 GeV	12 GeV	
Number of protons per spill	2×10^{14}	2.5×10^{12}	
Spill/cycle	0.7 sec / 3.3 sec	2 sec / 4sec	
Extraction angle	16 °	4 °	
Solid angle	9 μsr	12.6μsr	
K_L yield/spill	7.8×10^6	3.3×10^5	×29/sec
Run Time	12 months	1 month	×12
Decay Probability	4%	2%	×2.0
Acceptance	3.6%	0.67%	×5.4
			×3800 in total

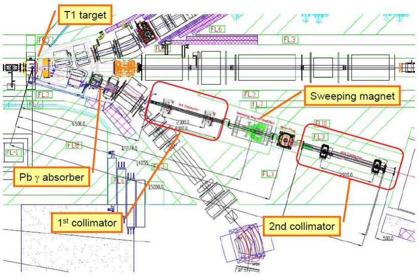

Figure 2: Schematic drawing of the beamline.

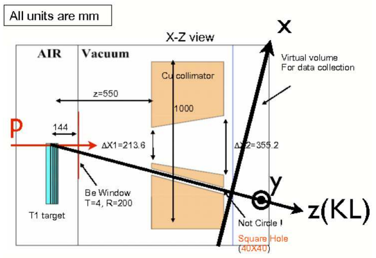

Figure 3: The target.

Fig. 3. So the shape of the beam image on the target is horizontally wide rectangular shape. To fit this and the square beam hole at the gamma calorimeter (CSI in Fig. 5), a rectangular beam hole is adopted for the collimators. The beam size is narrowly collimated with the solid angle of $\sim 9\ \mu$sr and the collimator is also designed to suppress halo neutrons, avoiding neutron scatterings on the collimator wall. The horizontal and vertical profiles at the gamma calorimeter are shown in Fig. 4. In this design, the number of halo neutrons is suppressed to 5 orders of magnitude compared to that of core neutrons, which is about 10 times better than E391a [8].

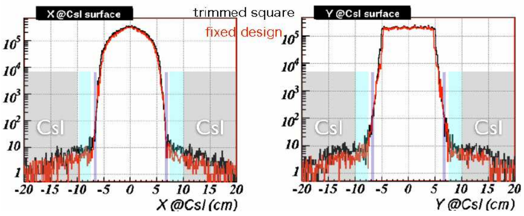

Figure 4: Horizontal (left) and vertical (right) profiles at the gamma calorimeter.

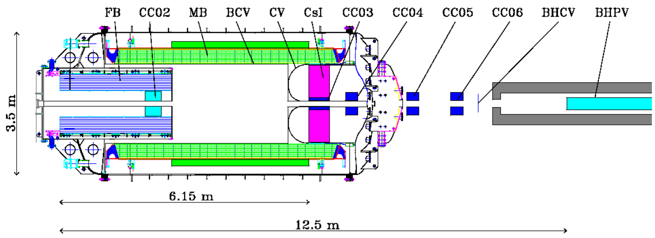

Figure 5: The K^OTO detector.

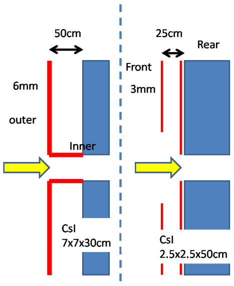

Figure 6: The CV at E391a (left) and at K^OTO (right).

6. Detector upgrade to reduce backgrounds

The K^OTO detector is shown in Fig. 5, where the FB is the same detector used in E391a, the thickness of MB is increased from the E391a MB, other detectors are replaced from those used in E391a. The background estimations for E391a Run2 analysis and for K^OTO are shown in Table. 2 [2] and Table. 3, respectively. The "CC02" background originates from π^0 production by halo neutrons hitting CC02. The "CV-π^0" and "CV-η"backgrounds originate from π^0 and η production by halo neutrons hitting CV, respectively. The halo neutron backgrounds in K^OTO are reduced both with the halo neutron suppression and with detector upgrades at CV and CC02 as follows.

6.1 CV upgrade

The K^OTO CV consists of two layers, removing the inner part as shown in Fig. 6, where η was produced and became backgrounds at E391a. The inner hole size of the front part is enlarged and its thickness is reduced from 6 mm to 3 mm, avoiding halo neutron interactions. Furthermore, it is moved to downstream by 25 cm far from the signal region, reducing the background contamination to the signal region. The detector is a plastic scintillator plane with wavelength shifting fibers (WLSFs) and MPPCs are used as photon sensors. Such prototype test is in progress.

6.2 CC02 upgrade, NCC

The position is moved to upstream by 30 cm from E391a case, far from the signal region. The detector was a Pb and plastic scintillator sampling detector in E391a, which is changed to a CsI full active detector, Neutron Collar Counter (NCC),increasing veto performance to π^0 production.

Table 2: Background estimation at E391a (Run2) [2].

K_L BG	$K\pi2$	0.11 ± 0.09
	CC02	0.16 ± 0.05
halo-n BG	CV-π^0	0.08 ± 0.04
	CV-η	0.06 ± 0.02

Table 3: Signal and background estimation at K$^{\mathrm{O}}$TO.

Signal	$K\pi\nu\nu$	2.7
K_L BG	$K\pi2$	1.7
	CC02	0.01
halo-n BG	CV-π^0	0.08
	CV-η	0.3

The detector is pure CsI crystals with wavelength shifting fibers which absorb UV light and emit blue light. With such WLSF readout, segmentation in z and radial directions can be achieved and it can measure the flux of halo neutrons with central crystals using surrounding crystals as veto in order to reduce gamma contamination. Its prototype test is in progress and enough light yield was already obtained.

6.3 CSI and MB upgrade

In E391a, $7 \times 7 \times 30$ cm crystals were mainly used, which is changed to 2240 crystals with a dimension of $2.5 \times 2.5 \times 50$ cm and 328 crystals with a dimension of $5 \times 5 \times 50$ cm in K$^{\mathrm{O}}$TO. They were used in the KTeV experiment and all the crystals were moved to Japan and are now tested. The thickness of MB is increased to 18.5 radiation length from 14. Those improve the photon veto performance to suppress $K_L \to 2\pi^0$ background.

7. Summary and prospects

The K$^{\mathrm{O}}$TO experiment is designed to discover $K_L \to \pi^0 \nu \bar{\nu}$ events based on the understanding of the background sources in E391a. The detector upgrade from E391a is designed and the prototypings and tests are in progress. The beamline construction and test experiment for beam survey will be done in this fiscal year and CsI calorimeter construction and engineering run with it will be done in 2010, the physics run will start from 2011 and we aim to discover $K_L \to \pi^0 \nu \bar{\nu}$ events in three years.

References

[1] "P14: Proposal for $K_L \to \pi^0 \nu \bar{\nu}$ Experiment at J-Parc", available from `http://j-parc.jp/NuclPart/Proposal_0606_e.html`.

[2] J. K. Ahn *et al.* [E391a Collaboration], Phys. Rev. Lett. **100**, 201802 (2008)

[3] A. J. Buras, F. Schwab and S. Uhlig, Rev. Mod. Phys. **80**, 965 (2008) [arXiv:hep-ph/0405132].

[4] F. Mescia and C. Smith, Phys. Rev. D **76**, 034017 (2007) [arXiv:0705.2025 [hep-ph]].

[5] Y.Grossman and Y.Nir, *Phys. Lett.* **B398**, 163 (1997).

[6] A. V. Artamonov *et al.* [BNL-E949 Collaboration], Phys. Rev. D **79**, 092004 (2009)

[7] FlaviAnet Kaon WG, http://www.lnf.infn.it/wg/vus/content/Krare.html

[8] H. Watanabe *et al.*, Nucl. Instrum. Methods Phys. Res. Sect. A **545**, 542 (2005).