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Design of the neutral K_L^0 beamline for the *KOTO* experiment

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ABSTRACT

The J-PARC E14 *KOTO* experiment aims at the first observation of the $K_L^0 \to \pi^0 \nu\overline{\nu}$ decay. This experiment requires a well-collimated neutral beam with the small amount of halo neutrons. Collimation lines and beamline components in the beamline have been optimized to suppress halo neutrons by utilizing the GEANT-3 Monte-Carlo simulation package. We have achieved the design with sharp cross-sectional profiles of the beam and the halo-to-core neutron flux ratio of 10^{-5} level.

1. Introduction

The decay $K_L^0 \to \pi^0 \nu\overline{\nu}$ is a flavor changing neutral current process and a probe for direct CP violation in the quark sector. This process is induced by electroweak loop diagrams and is a good testing ground of the Standard Model. This decay mode is also sensitive to possible new physics. The branching fraction for $K_L^0 \to \pi^0 \nu\overline{\nu}$ is predicted to be $(2.49 \pm 0.39) \times 10^{-11}$ in the Standard Model [1]. The current experimental limit is 6.7×10^{-8} at the 90% confidence level by the KEK-PS E391a experiment [2]. The J-PARC E14 *KOTO* experiment aims at the first observation of the $K_L^0 \to \pi^0 \nu\overline{\nu}$ decay with the major upgrade of the E391a detector.

For the observation the $K_L^0 \to \pi^0 \nu\overline{\nu}$ decay, there are two essential points. One is to use electromagnetic calorimeter with a "*hermetic*" photon detection system. Energies and positions of two photons from π^0 decay are measured by the CsI calorimeter at the downstream of the fiducial decay region. To ensure the existence of two photons and nothing else in the final state, the decay region should be hermetically covered by photon-veto counters with high efficiency (Fig. 1). The other is to have a well-collimated narrow neutral beam. In the experiment, the π^0 and its transverse momentum (P_T) are reconstructed by assuming that the decay vertex is on the beam-axis. Since the P_T is a key parameter to discriminate signal from background events, the uncertainty in the P_T should be kept small. Thus the beam size has to be compromised between a signal-to-background ratio and a total K_L^0 yield. In addition, there is a beam-related background due to the neutrons in the halo region of the beam (*halo neutrons*), which are mostly composed of the scattered neutron at the beamline materials. From our experience at the E391a experiment, the most serious backgrounds are π^0's and η^0's produced by halo neutrons, which directly interact with detector materials near the fiducial decay region. Therefore, the beamline for the *KOTO* experiment, named "KL beamline", is required to provide a well-collimated K_L^0 beam with small halo neutron to K_L^0 ratio less than 1.34×10^{-3}, which corresponds to a signal-to-background ratio more than 10. In this paper, we describe essential points of the K_L^0-beamline design for the *KOTO* experiment.

2. Design of the beamline

The beamline has been designed by the Monte-Carlo simulation based on the GEANT-3 program and the GFLUKA hadronic package [3], because GEANT-3 can reproduce beam profiles and energy spectra of the neutral beam in the E391a beam survey data fairly-well [4]. Fig. 2 shows a schematic view of the KL beamline. A proton beam with a kinetic energy of 30 GeV extracted from the J-PARC main ring hits the primary T1 target which consists of rotating disks made of Nickel. The design intensity is 2×10^{14} per spill coming every 3.75 s. The target is shared with other beamlines in the experimental hall. The KL beamline is extracted at 16° with respect to the primary proton beam. It consists of a photon absorber to reduce the amount of photons in the beam, the vacuum pipes, two stages of a long collimator and a magnet to sweep out charged particles. Total length of the KL beamline, 20 m, is long enough to decay out for short-lived particles such as K_S^0's and hyperons, which are potential candidates of background sources. And remaining beam at the experimental area is composed of neutrons, photons, and K_L^0's.

Halo neutrons are produced by multiple scattering of beam neutrons on the beamline materials including the collimators. The

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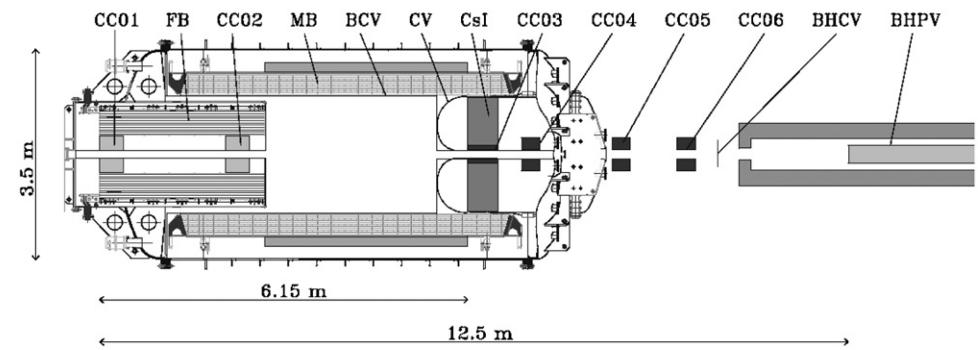

Fig. 1. Schematic cross-sectional view of the *KOTO* detector.

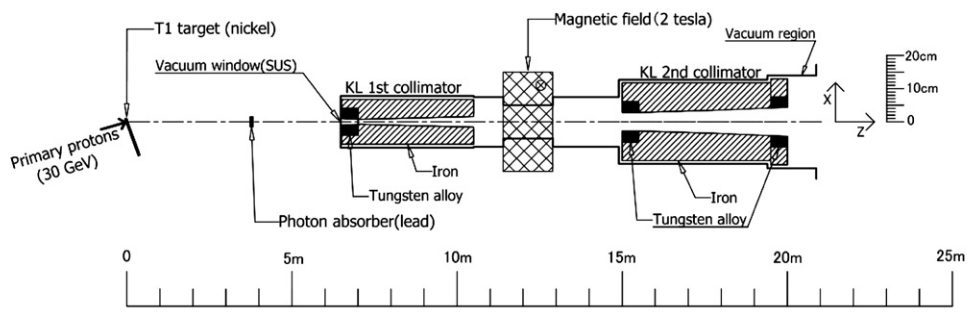

Fig. 2. Schematic plan view of the KL beamline. Two stages of collimator are placed far from the T1 target, the sweeping magnet is located between them, and photon absorber is located at beam center upstream of collimators. The *Z* axis is set to KL beam.

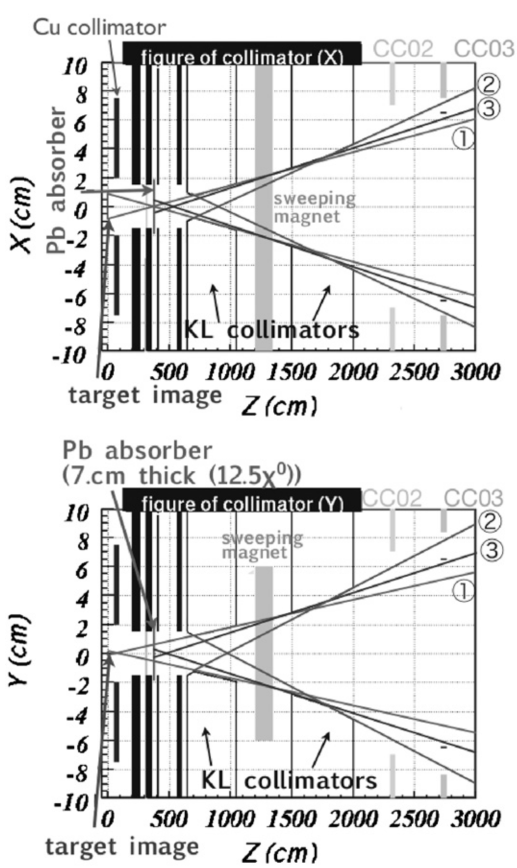

Fig. 3. Schematic view of the *KL* beamline in *X*–*Z* (top) and *Y*–*Z* (bottom) planes. Note that the scales in the horizontal and vertical axes are different. The number in these lines corresponds to the trimming line explained in the text. The black boxes in this figure are other beamline components.

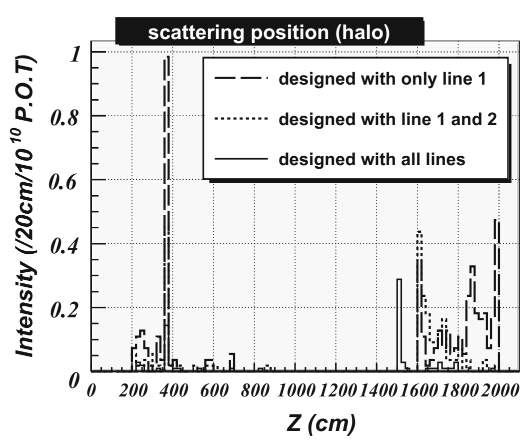

Fig. 4. Distribution of the scattering position of the halo neutrons in the *Z* direction. The dashed line represents the case of using only Line-1, dotted line represents the case of using Line-1 and 2, and solid line represents the case of all lines, respectively.

beamline components should be designed so as not to be an origin of the halo neutrons. The scattering of neutrons at the collimators is avoided by trimming the inner surface of the collimators. The schematic view of the final design is shown in Fig. 3. The aperture of the collimators is designed by considering three collimation lines.

- Line-1 defines the beam size and profiles. This line is drawn in the principle that the inner surface of the collimators should not be faced to the target.
- Line-2 is drawn to avoid scattering of neutrons at the rear edge of the second collimator.
- Line-3 is drawn to take the size of the lead absorber into account to determine the inner surface of second collimator.

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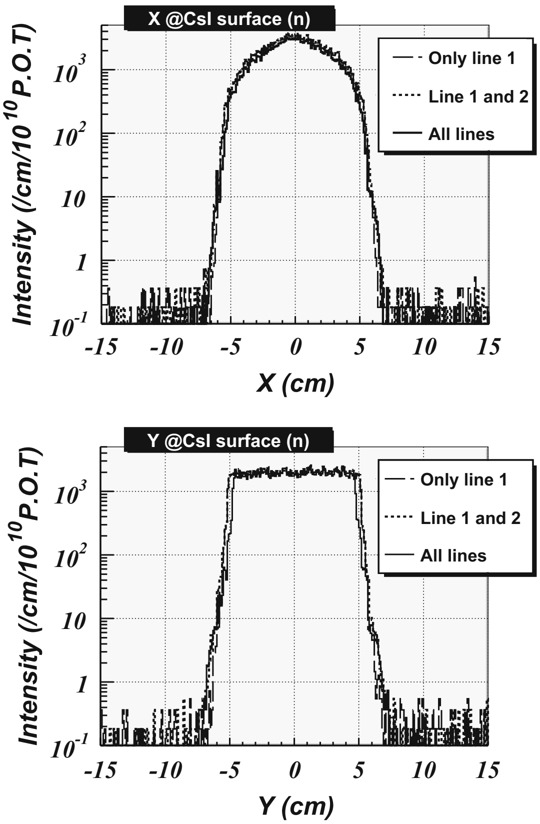

Fig. 5. Horizontal beam profiles (top) and vertical profiles (bottom) of neutrons at the Z position of the CsI calorimeter, where P.O.T. means protons on target.

The line-1 determines the beam size and the profiles. The total thickness of the collimators should be enough to stop the particles and shape the beam size. For this purpose, tungsten-alloy blocks are employed at the front edge of the first collimator and both edges of the second collimator.

Fig. 4 shows the Z distribution of the generating position of the halo neutrons. Most of the halo neutrons are scattered at the photon absorber and the rear edge of the second collimator. We suppress these neutrons by adopting line-2 and 3 to determine the inner surface of the second collimator. Line-2 was adjusted to avoid generating the halo neutrons, which are scattered at the rear edge of the collimator. A large amount of core neutrons hit the photon absorber and are scattered there. Line-3 was adjusted to avoid these scattered neutrons to the inner surface of the second collimator.

As a result, we obtained the neutron profiles with a very sharp edge at the CsI calorimeter, which is placed at 27 m as shown in Fig. 5. We have achieved that halo-to-core neutron ratio and halo neutron to K_L^0 ratio are suppressed to be 10^{-5} level and less than 10^{-4}, which meet the experimental requirement. Finally, performances of the KL beamline adopting all collimation lines are summarized in the Table 1.

Table 1
Flux of the particles expected in KL beamline.

	#. of particles per 1 spill
core neutron ($T > 0.1$ GeV)	$(3.76 \pm 0.04) \times 10^8$
core K_L^0 ($T > 0.1$ GeV)	$(1.46 \pm 0.08) \times 10^7$
halo neutron ($\|P\| \geq 0.78$ GeV/c)	$(1.02 \pm 0.04) \times 10^4$
ratio of halo to core neutron	$(2.70 \pm 0.11) \times 10^{-5}$
ratio of halo neutron to K_L^0	$(6.99 \pm 0.47) \times 10^{-4}$

T means the kinetic energy and P means the momentum.

3. Conclusion

The design of the KL beamline with a well-collimated beam and very low halo neutrons level has been completed by carefully optimizing collimation lines. The fabrication and construction of the KL beamline have been started in April 2009, and we are going to survey this beamline to confirm beamline performances.

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References

[1] F. Mescia, C. Smith, Phys. Rev. D 76 (2007) 034017.
[2] J.K. Ahn, et al., Phys. Rev. Lett. 100 (2008) 201802.
[3] CERN Application Software Group, GEANT-Detector Description and Simulation Tool, W5013, CERN, 1993.
[4] H. Watanabe, et al., Nucl. Instr. and Meth. A 545 (2005) 542.

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