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Design of the neutral K_L^0 beamline for the J-PARC E14 K^OTO experiment

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High quality of neutral beamline is one of the key points in the J-PARC E14 K^OTO experiment, which aims at the first observation of the $K_L^0 \rightarrow \pi^0 \nu \overline{\nu}$ decay. This experiment requires a well-collimated neutral beam with very small neutron halo. This beamline is designed using the Monte-Calro simulation. We have achieved the beam with sharp x,y profile and the halo-to-core neutron flux ratio of less than 10^{-5}.

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1. Introduction

The decay $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ is the sensitive probe for direct CP violation in the quark sector via a Flavor Changing Neutral Current process. Since this process is induced by electroweak loop diagram, this is a good testing ground of the Standard Model and also this decay mode is sensitive to possible new physics. The branching fraction for $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ is predicted to be $(2.49\pm0.39)\times 10^{-11}$ in the Standard Model [1].

The current experimental limit is 6.7×10^{-8} at the 90% confidence level by KEK-PS E391a experiment [2]. The J-PARC E14 K^OTO experiment aims at the "first observation" of $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ decay with the major upgrade of the E391a.

For the successful observation the $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ decay, there are two essential points. One is to use good elecromagnetic calorimeter and *hermetic veto system*. Energy and position of 2 γ from π^0 decay in the final state is measured by main calorimeter(CsI) at the downstream of the decay region. To ensure 2 γ and nothing else, the decay region should be hermetically covered by γ veto counters with high efficiency (Fig. 1). The other is to have well-collimated "*pencil*" beam. In the experiment, π^0 will be reconstructed assuming that the decay vertex is right on the beam-axis. Since transverse momentum (P_T) of π^0 is a key parameter to identify signal from back grounds, the error of π^0 P_T should be kept small. So, the real π^0 vertex is required to be close to the assumed one, i.e. on the beam axis, and accordingly the beam size should be kept as small as possible. And also there is a problem of the existence of neutron in the halo of the neutral beam(*halo neutron*). It is mostly originated by the scattering of the neutron in the beam at the beamline materials. Halo neutron interacts with detector materials, which is located around the beam axis, and produce π^0 and η^0, which decay to 2 γ final state and make hits on CsI calorimeter. Our experience at the E391a, first dedicated measurement for $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ decay, show that the most serious back grounds was hadronically produced π^0 and η^0 by halo neutron away from the beam axis, which create the contamination in the signal box region due to the assumption at the "π^0" reconstruction.

The beamline for K^OTO experiment, called "KL beamline", is required to be well-collimated K_L^0 beam with small halo neutron/K_L^0 ratio. Such a beamline was designed by utilizing GEANT-3 Monte-Calro simulation program. In this paper, we describle the design of the "*pencil*" K_L^0 beamline for K^OTO.

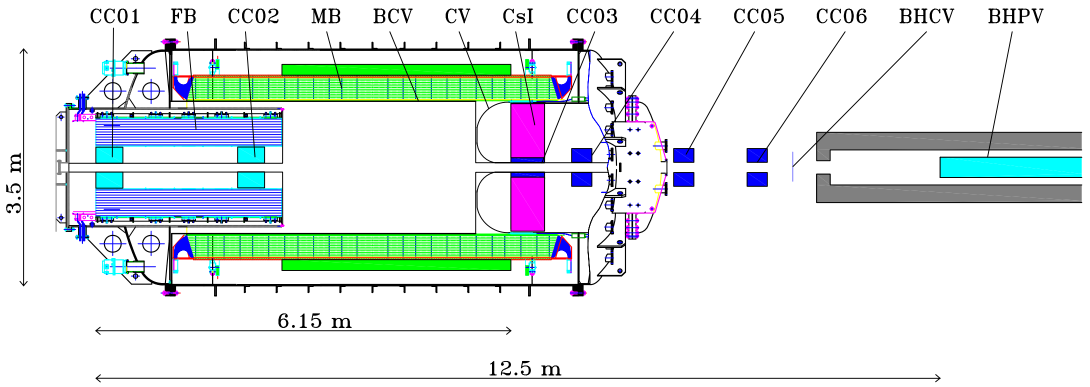

Figure 1: Schematic cross-section view of the K^OTO detector.

2. Neutral beamline design

Fig.2 shows the drawing of KL beamline. It has a length of 20m allowing short lived particles(K_s^0, hyperon, etc...) die out until they reach to the decay volume in the detector. We have the primary T1 target shared with other beamlines, lead absorber to reduce the γ in the beam, vacuum pipes, 2 stages of long collimator to collimate neutral beam and magnet to sweep out charged particles. T1 is a rotating disk type target made by Nickel. It is hit by 30GeV protons extracted from J-PARC main ring. The intensity of the primary protons is 2×10^{14} per spill. KL beamline makes an angle of 16° with respect to the primary proton beam. There are also some materials around the primary target region.

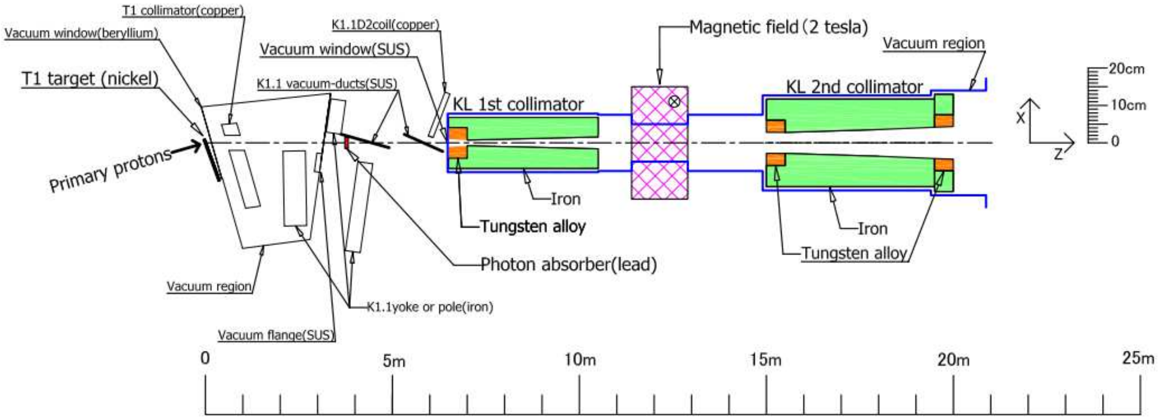

Figure 2: Schematic overview of the K^OTO beamline. 2 stage collimators are located far from T1 target. And sweeping magnet is located between them.

Halo neutron is produced by multiple scattering of beam neutrons on beamline materials including our collimators. The beamline must be designed to avoid its origin. Scattering of neutron at collimators is avoided by trimming inner surface of collimators. The schematic view of final design is shown in Fig.3. Beamline is designed considering 3 collimation lines. The each line in the Fig.3 is drawn as following purposes;.

1. Defining the basic profile. This line is drawn in the principle that the inner surface of collimators should not be faced to target.

2. This line is drawn to avoid scattering at rear edge of the 2^{nd} collimator.

3. This line is drawn to control the γ absorber image from inner surface of 2^{nd} collimator.

Line 1 defines beam size and beam profile. A certain thickness is needed to stop the particles and shape the beam spot. For this purpose, Tungsten is used at the front edge of the 1^{st} collimator and both edge of the 2^{nd} collimator.

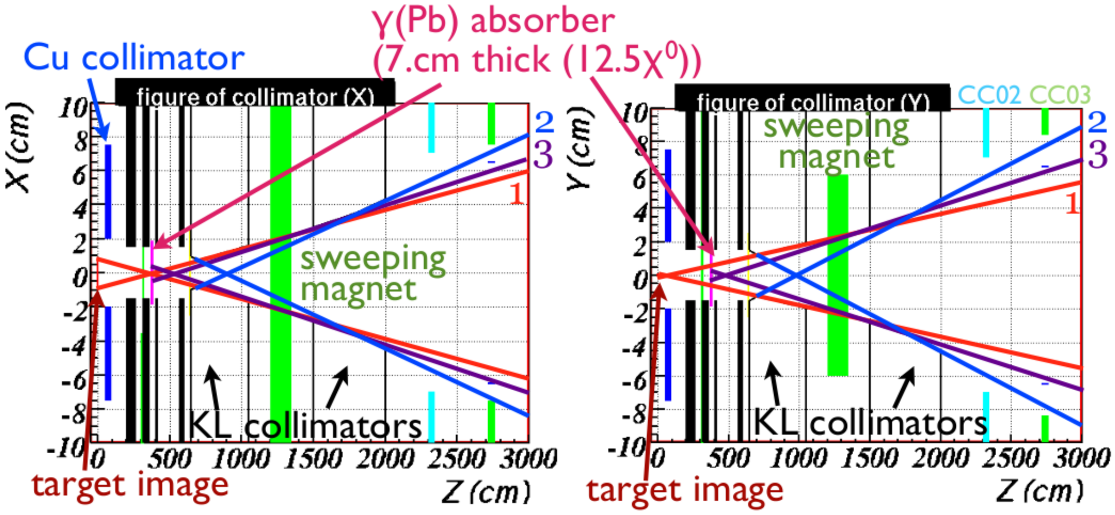

Figure 3: The schematic figure of KL beamline design in X-Z(top), Y-Z(bottom) plane. The line No. in these figures is corresponding to trimming line, which is explained in main text. It is also corresponding to itemized figure in main text. Note that the scale in horizontal and vertical axis is difference.

Fig.4 shows origin points of the halo neutron in the z coordinate. We can see most of the halo neutron is scattered at the γ absorber and rear edge of the 2^{nd} collimator. We tried to suppress those with adopting line 2 and 3 for the inner surface of the 2^{nd} collimator. Line 2 avoids halo neutron which is scattered at rear edge of collimator.

A large amount of core neutron hit the γ absorber and is scattered there. Line 3 avoids those scattered neutrons to hit the γ absorber hitting inner surface of the 2^{nd} collimator.

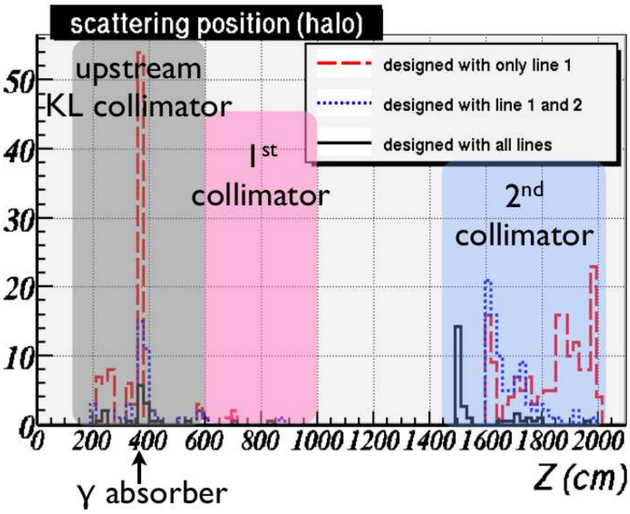

Figure 4: This figure shows scattering position of halo neutron in Z direction. Dashed red line is presents the case of using only line 1, dotted blue line is presents the case of using line 1 and 2 and solid black line presents the case of line 1-3. The collimator length was optimized with using all the lines.

As a result, we get neutron X,Y profile at CsI calorimeter shown in Fig.5. The beam profile has sharp edge and halo to core neutron ratio is suppressed to be 10^{-5} level. Finally, the performance

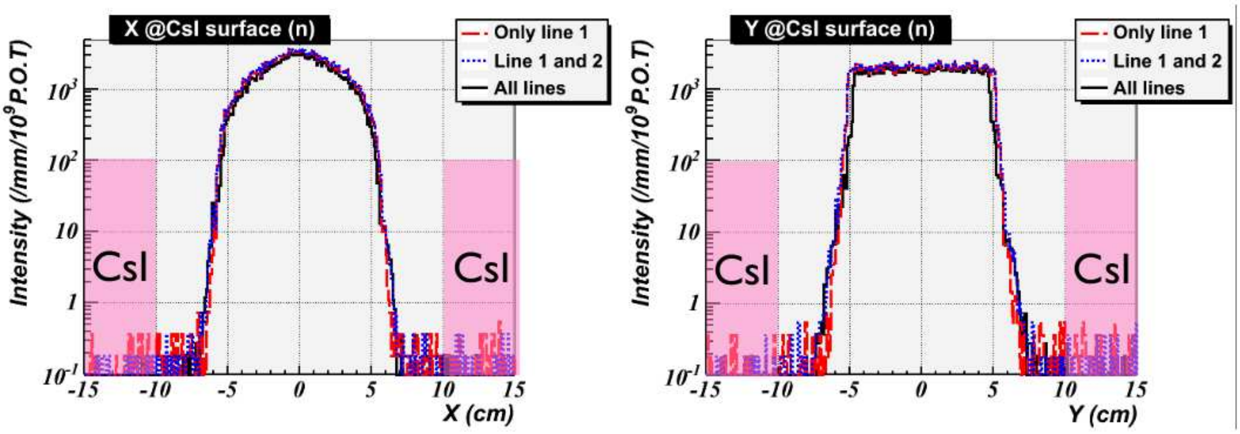

Figure 5: Top figure shows the X profile of the neutral beam at the CsI, and the bottom figure shows the Y profile. The meaning of the dashed red line, dotted blue line and solid black line is the same as plot of scattering position. We see that with using all the lines, we have less halo neutron and reasonable beam profile.

of design with 3 lines is shown in the Table.1.

Table 1: This table is shown the flux of particles in KL beamline.

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

3. Conclusion

The halo neutron is the most serious back ground sources in the J-PARC E14 K^OTO experiment. The neutral beamline for this experiment is designed with using Monte-Calro simulation to suppress the halo neutron. As a result, the KL beamline with well-collimated small sized beam and small halo neutron ratio was designed. Also we can understand that the remaining halo neutron is produced the scattering at the γ absorber and the front edge of the 2^{nd} collimator. The designing work is finished. The fablication and construction of beamline is started. In the autumn of 2009, we have the plan to make a survey this beamline with extracted beam.

References

[1] F.Mescia and C.Smith, PRD76, 034017(2007)

[2] J.K.Ahn *et al*. PRL 100, 201802(2008)