Letter of Intent for Experiments at 50 GeV PS of the JPARC

Measurement of the $K_L^0 \to \pi^0 \nu \overline{\nu}$ Branching Ratio

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Abstract

The $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ decay is a uniquely pure and clean process. The precise measurement of the $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ decay branching ratio, which we are proposing here, will provide a clean determination of a basic parameter of the present particle physics, and will play an important role for a new-physics search and for a profound understand of the CP-violation. The 50 GeV Proton Synchrotron (PS) is the best place for such a measurement. It can deliver a K_L^0 beam whose intensity is much higher than that of the present 12 GeV PS at KEK by about three hundreds times. Since we are going to start a kind of pilot experiment using the present 12-GeV PS in KEK, the plan, which we are proposing as a high sensitivity experiment at the 50-GeV PS, is a natural extension of our program. After modest upgrades of the detectors, we will be able to get ready at the Time(0) for the experiment at the 50 GeV PS. The goal of the proposing experiment is to achieve a sensitivity of less than 3×10^{-13}, which corresponds to an observation of more than hundred $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ events for the Standard Model prediction and to a determination of η in less than 5% accuracy.

1 Physics Motivation

The $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ decay is a rare decay process of flavor-changing-neutral-current (FCNC) with CP violation. A direct term, which proceeds through a ΔS=1 transition as expressed by diagrams shown in Figures 1, dominates a mixing term which proceeds through a ΔS=2 transition where K_L^0 changes into K_S^0 via $K^0-\overline{K^0}$ mixing[1]. Then, the $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ decay will offer a pure information of the ΔS=1 process. The hadronic matrix element can be factorized as the well-known branching ratio of the $K \rightarrow \pi e\nu$ decay [2]. The remaining corrections which couple to the virtual top quark are calculable and small due to the large top-quark mass [3]. A long-distance interaction little contributes to the $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ decay, because neutrino is a weekly interacting particle[4]. Consequently an uncertainty in the theoretical calculation is estimated to be only a few % [5], and the $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ decay will offer a clean information of a basic parameter of the present elementary particle physics.

In the Standard Model the decay amplitude of $K_L^0 \rightarrow \pi^0\nu\overline{\nu}$ is proportional to the imaginary part of a product of CKM matrix elements, $Im(V_{td}V_{ts}^*)$, which corresponds to

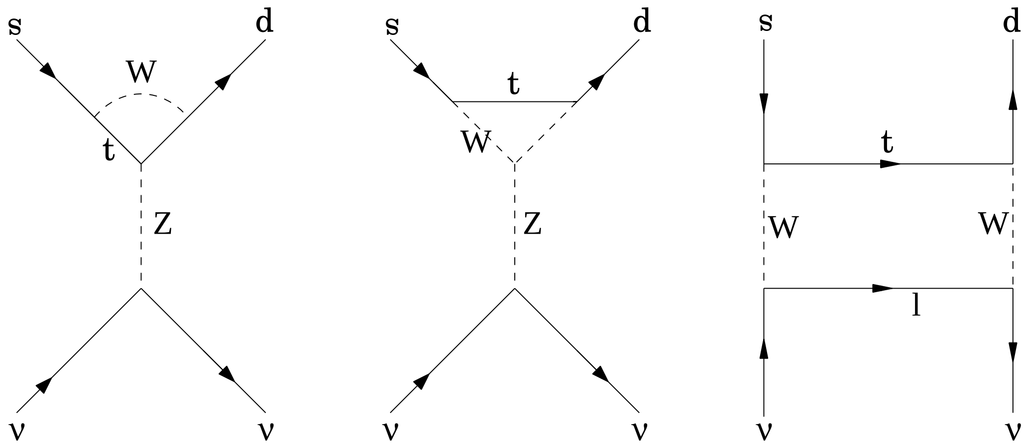

Figure 1: Diagrams for the $K_L^0 \to \pi^0 \nu \overline{\nu}$ Decay

the height of the unitarity triangle as shown in Figure 2[6]. The unitarity of the CKM matrix has been considered as one of the most critical check for extra-effects beyond the Standard Model. The pure and clean information obtained by the $K_L^0 \to \pi^0 \nu \overline{\nu}$ decay is crucial for the check as well as those by B-decays. Various models beyond the Standard model predict sizable effects to the $K_L^0 \to \pi^0 \nu \overline{\nu}$ decay [7]. It is very interesting that most model predicts different effects to the observable in K-decay from those in B-decay. For example, an additional contribution to the $K_L^0 \to \pi^0 \nu \overline{\nu}$ decay from the MSSM (Minimal Super-symmetric extension of the Standard Model) is expected to be 10-20% of the Standard Model value, while that to B-decay observable is small.

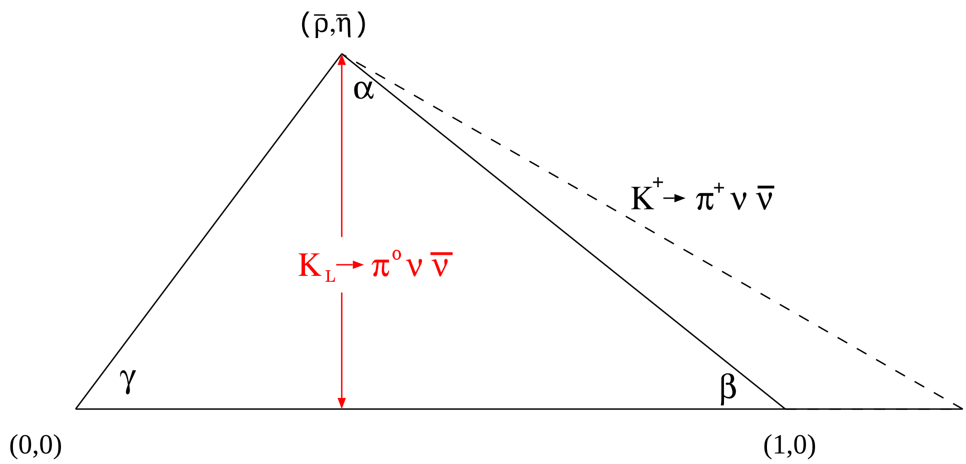

Figure 2: Unitarity triangle

Even in the K-decay observables, the additional effects move the Standard Model predictions in the different direction. For example, ϵ in $K^0 - \bar{K^0}$ mixing and the $K_L^0 \rightarrow \pi^0 \nu \overline{\nu}$ decay change their value in the opposite direction [8]. So, once we measure the $K_L^0 \rightarrow \pi^0 \nu \overline{\nu}$ branching ratio in an accuracy of a few %, it will provide a critical check of beyond-the-Standard-Model effects.

The super-weak model, which causes CP violation only in the mixing term (ΔS=2 transition), is almost ruled out by the recent experiments [9]. However, another explanation, the CKM matrix (the Standard Model), which accommodates with the experimental results, has basic problems, such as strong CP problem and lack of strength for baryogenisis. Problems of CP-violation are not yet solved. One of the best ways to understand profoundly the physics of CP-violation is to precisely measure the strength of CP-violation in all FCNC processes, ΔS=1,2 and ΔB=1,2. For ΔB=1,2, several B-factories, such as BELLE, BABAR, CDF, BTeV and LHC-b, can provide an answer of few % level. For ΔS=2 lattice calculations will soon solve the problem of large theoretical ambiguity for ϵ. While, the precise value of ΔS=1 can be only obtained from the measurement the $K_L^0 \rightarrow \pi^0 \nu \overline{\nu}$ decay.

Table 1 shows competence of K-decay approach with B-decay one for the determination of the basic parameters. An observation of 100 events for the branching ratio predicted by the Standard Model, which corresponds to the sensitivity of 3×10^{-13}, can provide a similar accuracy with B factories for the determination of ρ and η [10].

	$K \rightarrow \pi \nu \overline{\nu}$	B-Factory	LHC-b
$\sigma(\lvert V_{td} \rvert)$	$\pm$ 10 %	$\pm$ 5.5 %	$\pm$ 5.0 %
$\sigma(\overline{\rho})$	$\pm$ 0.16 %	$\pm$ 0.03 %	$\pm$ 0.01 %
$\sigma(\overline{\eta})$	$\pm$ 0.04 %	$\pm$ 0.04 %	$\pm$ 0.01 %
$\sigma(\sin 2\beta)$	$\pm$ 0.05 %	$\pm$ 0.06 %	$\pm$ 0.02 %
$\sigma(\text{Im } \lambda_t)$	$\pm$ 5 %	$\pm$ 14 %	$\pm$ 10 %

Table 1: Illustrative example of the determination of CKM parameters from $K \rightarrow \pi \nu \overline{\nu}$ and B-decays (from *hep-ph/9905437)*[10].

2 Experimental Method

2.1 General description of the method

It is quite challenging to measure the $K_L^0 \to \pi^0 \nu \overline{\nu}$ branching ratio in a sensitivity of 3×10^{-13}. All particles concerning with the decay are neutral particles and there is no clear kinematic signature because it is a three-body decay with undetectable two neutrinos. Moreover, it is a rare decay whose branching ratio is predicted to be around 3×10^{-11} The upper bound given by the present experiment is 5.9×10^{-7} [11]. An improvement by another six orders of magnitude is required to reach the sensitivity of 3×10^{-13}. In order to solve this large gap we plan a series of experiments: the first is an experiment at the present 12-GeV PS (Proton Synchrotron) in KEK and next at the 50-GeV PS in the Joint Project. The KEK experiment (E391a), which is now under construction [12], will reach a sensitivity of 3×10^{-10} after a few months run in 2004. Based on the knowledge from the E391a we would modify some parts of the detection apparatus and continue the experiment to achieve a sensitivity of better than 3×10^{-13} at the 50-GeV PS.

2.2 Event signature

In our method [12] $K_L^0 \to \pi^0 \nu \overline{\nu}$ decays will be observed by an in-flight decay of K_L^0 by a signal of $K_L^0 \to \pi^0(\pi^0 \to 2\gamma) + \textit{nothing}$. The energies and positions of the two gammas decayed from π^0 are measured and *nothing* is confirmed by no additional signal in the detectors which fully cover the fiducial decay region.

The incident K_L^0's are collimated to a pencil beam. The detection system consists of a crystal calorimeter and lead-scintillator sandwich calorimeters as shown in Figure 3. The crystal calorimeter measures the energies and positions of the two gammas from π^0. The vertex position along the beam axis is obtained assuming that the two gammas come from π^0 and then the transverse momentum of the π^0 with respect to the beam axis (P_T) is calculated. The $K_L^0 \to \pi^0 \nu \overline{\nu}$ event will be identified by an existence of the vertex in the fiducial decay region with a P_T between 120 MeV/c and the kinematic limit of 231 MeV/c. If any other emitting particles are detected in the crystal and lead-scintillator, the event will be discarded.

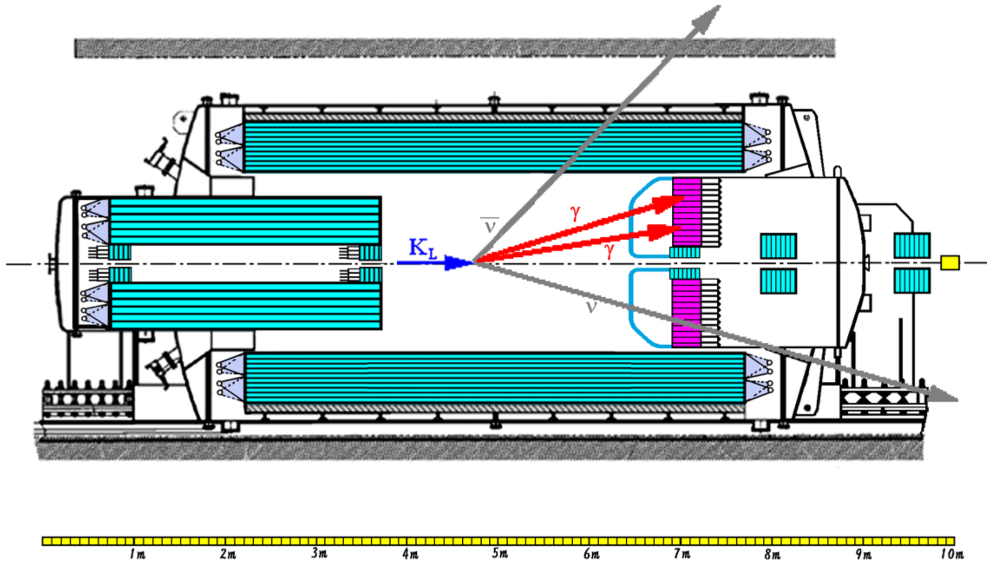

Figure 3: Experimental Setup at KEK 12-GeV PS

The detail of the detection method is described elsewhere [12].

2.3 Comparison with other plans

Two other experiments, KOPIO (E926-BNL) and KAMI (Fermilab), have been planned for the $K_L^0 \to \pi^0\nu\overline{\nu}$ decay. Among them KOPIO was scientifically approved and they claim to run in 2006. Unique features of our plan are that almost all detectors are placed in vacuum and that it has two chambers, and the downstream chamber contains the decay fiducial region. A wider acceptance for the $K_L^0 \to \pi^0\nu\overline{\nu}$ decay is another difference from KOPIO. Table 2. shows a comparison among various plans, where we re-estimated the goal of each plan after normalizing the primary proton beam as the full intensity of each accelerator, the running time as 3×10^7sec and the running efficiency as 50%. It is apparent that the combination of 50-GeV PS with our plan possibly reaches the best result.

Now, we would like to stress that the sensitivity of better than 3×10^{-13} is somehow ultimate. It corresponds to a determination of η in a few % accuracy in the SM scheme. The accuracy is comparable with an error of the branching ratio of the other K_L^0 decay ($K_L^0 \to \gamma\gamma$, $\pi^0\pi^0$ and $\pi^0\pi^0\pi^0$) modes which must be experimentally used for a normaliza-

	BNL	Fermilab		KEK	
	KOPIO	KTeV-99	KAMI-near	E391A	JHF
Proton energy	24 GeV	800 GeV	120 GeV	12 GeV	50 GeV
Protons/pulse	5×10^{13}	1×10^{13}	3×10^{13}	2×10^{12}	2×10^{14}
Cycle time	3.6 sec	80 sec	2.9 sec	2.5 sec	3.42 sec
Flat-Top	1.6 sec	40 sec	1.0 sec	0.5 sec	0.75 sec
Ext.angle	45°	4.8 mr	24 mr	4°	10°
Beam profile	4mr×125mr	0.22mr×0.22mr	0.6mr×0.6mr	4 mr$^\phi$	2.6 mr$^\phi$
Solid Angle	500 μstr	0.048 μstr	1 μstr	12.6 μstr	5.5 μstr
$Y_{K_L^0}$/p/str	4.8×10^{-3}	4.8×10^{2}	3.7	5.9×10^{-2}	0.96
Av.K_L^0 mom.	0.7 GeV/c	70 GeV/c	10 GeV/c	2 GeV/c	2 GeV/c
Decay region	3.5 m	38 m	34 m	2.7 m	2.7 m
Decay prob.	16 %	2.1 %	10 %	4.3 %	4.3 %
K_L^0/pulse	1.2×10^{8}	2.3×10^{7}	1.1×10^{8}	1.5×10^{6}	1.1×10^{9}
K_L^0-decay/pulse	1.9×10^{7}	4.8×10^{5}	1.1×10^{7}	6.5×10^{4}	4.7×10^{7}
Av.K_L^0-decay/sec	5.3×10^{6}	6×10^{3}	3.8×10^{6}	2.6×10^{4}	1.4×10^{7}
Inst.decay-rate	12 MHz	12 kHz	11 MHz	130 kHz	63 MHz
Acceptance	1.6 %	5 %	7.4 %	8 %	16 %
Run Time	3×10^{7} sec	6×10^{5} sec	3×10^{7} sec	1×10^{7} sec	3×10^{7} sec
Running Eff.	50 %	50 %	50 %	50 %	50 %
Sensitivity	7.8×10^{-13}	1.1×10^{-8}	2.3×10^{-13}	1.0×10^{-10}	3.0×10^{-14}
Events(3×10^{-11})	38 events		130 events		1000 events

Table 2: Experiments for the $K_L \to \pi^0 \nu \overline{\nu}$ decay [13]

tion of the number of incident K_L^0, an error of the top quark mass which links to the SM calculation, and the theoretical ambiguity for QCD correction. In other word, we have a chance to reach an ultimate goal at the 50-GeV PS, and to keep a position of the highest sensitivity for a long time.

2.4 Goal and modifications of E391a apparatus

As already mentioned, knowledge obtained from E391a are crucial not only for a detail design of the experiment but for a determination of the goal sensitivity. What we will learn from E391a ranges over a variety of subjects from technical ones to physics. After all the goal should be set to be between 3×10^{-13} and 3×10^{-14}, to meet the demand of physics and to show the significance of 50-GeV PS.

In any case modifications are necessary in some parts of the E391a apparatus, because the background rejection will be much more severe and counting rate of all detectors will increase in the experiment at 50-GeV PS. Now we would discuss about a basic plan for the modifications.

In E391a, we use many recycles from the previous experiments. Two big recycles are CsI crystals which were used in the KEK-PS E162, and 15-bit ADC used in the Tristan experiments. Beam line, barrel calorimeters, collar counters and vacuum vessel (together with support structure) are newly constructed. Most of recycles will not match to the experiment at 50-GeV PS. The crystals are too short in length to minimize the inefficiency due to punch through and too large in cross section to reduce fusion of two gammas into one cluster. ADC is too slow for the high rate expected at 50-GeV PS. On the other hand the newly built components have been designed to be used as it is or with a minor modification at 50-GeV PS. For example, the remote alignment system for the beam line, which is the most expensive part among the beam line components, can be used again without change, and then a neutral beam line at 50-GeV PS can be constructed only by changing the shape of tungsten blades. The main barrel will not be thick enough at 50-GeV PS, and the vacuum vessel is designed to be wide so that additional layers can be inserted on the outside of the present barrel.

There are several candidates for the new crystals, such as CsI, CeF_3, PWO and BaF_2. We have started an R&D by summarizing requirements. One of interesting features, which we found recently, is a possibility of the measurement of photon direction using crystals [14]. The measurement will considerably improve a rejection power against background. For the readout a kind of waveform digitizer will be used in the experiment at 50-GeV PS to avoid signal overlap in high rate environment. Unless we find unexpected big weak points or serious bugs in the E391a setup, these crystals and readout system would be changed for the experiment at 50-GeV PS.

3 Resources

One of the most important resources is man power. As shown in the collaborator list of this LOI, about 50 members are now working in E391a with an outlook for the experiment at 50-GeV PS. Since people in K-decay physics have been attracted to the $K_L^0 \to \pi^0 \nu \overline{\nu}$ decay, we foresee that many more researchers would join to the experiment at 50-GeV PS.

Although we already pointed out that major components of the secondary beam line and the detection apparatus can be used again, it is worth mentioning that the software tools which we are accumulating in E391a are also very important resources. Moreover, we would like to stress that many young members are now being trained in E391a. This is one of two main reasons why we request for the early start of the experiment at 50-GeV PS. The other reason for the urgency is of course a strong competition with KOPIO.

4 Cost and Budgetary Support

It is roughly estimated that two major upgrades, crystals and readout system, cost several M$, and that minor upgrades for the other parts, delivery and reassembling of the present system cost a few M$.

Right now funding of total $3.5M from the KAKENHI in Japan grant are approved for four years between 2002 and 2005. Half of it (in 2002 and 2003) will be spent for E391a and the remaining half will be possibly used for the experiment at 50-GeV PS in 2004 and 2005. For the rest we will start preparing the applications for funding not only from the next KAKENHI but also from various grants of the membership countries.

Finally it is worth to mention about the primary beam line, which is serious for users of slow extracted beam. We have heard that only one primary line can be constructed at Time(0) within the phase-1 budget of the Joint Project due to the shortage of construction money. We have also heard that what the construction group extensively studies is the primary line A not the line B where the K0 line is supposed to be. Although we still believe that our experiment, having significantly important physics, can compete with other plans to construct at first the primary line B, it is reasonable to look for the way living together with other plans. In any case we understand that the primary beam should be also taken into consideration by our group, too. In order to solve the problem we would like to start a design study of the primary line B. We are now looking for specialists to collaborate with the construction group of the Joint Project as well as the participation of young active members to the construction group. Most urgent issues to be studied are the beam optics and the treatment of production target and primary-beam dump. Along the design study, we will look for recycles of beam line elements internationally, especially from the institutes concerning with us.

5 Possible Scenarios

It is not realistic that the full intensity beam will come to our experimental area just after the commissioning, and that all requested budgetary supports will come before the preparation to match the Time (0) experiment. There are two possible scenarios for that.

One is to use the primary line A at the beginning. It is possible to draw a line, whose length including our experimental setup stays inside the experimental hall, from the common target for K1.1. However, the extraction angle of K0 is restricted to be 16° with respect to the primary line as shown in Figure 4. A preliminary calculation tells that it reduces the K_L^0/proton ratio by more than one order of magnitude. Assuming the average intensity of the primary beam in a few years from TIME (0) as 10% of the design value, the sensitivity goal is around the branching ratio predicted by the Standard Model. The value is worse than the goal described in KOPIO proposal. Therefore, this scenario strongly depends on their preparation as well as how much we can improve our detection system.

The other scenario is to construct the primary line B and to use the E391a detectors with minimum upgrade at the beginning. The detectors will be upgraded year by year while running. This scenario seems to be natural for the expected budget profile. The main factor is how we can construct the primary beam line B with low cost, in other word, how many recycles for beam line elements we can find.

In any case we have a strong intention to start our experiment at Time (0).

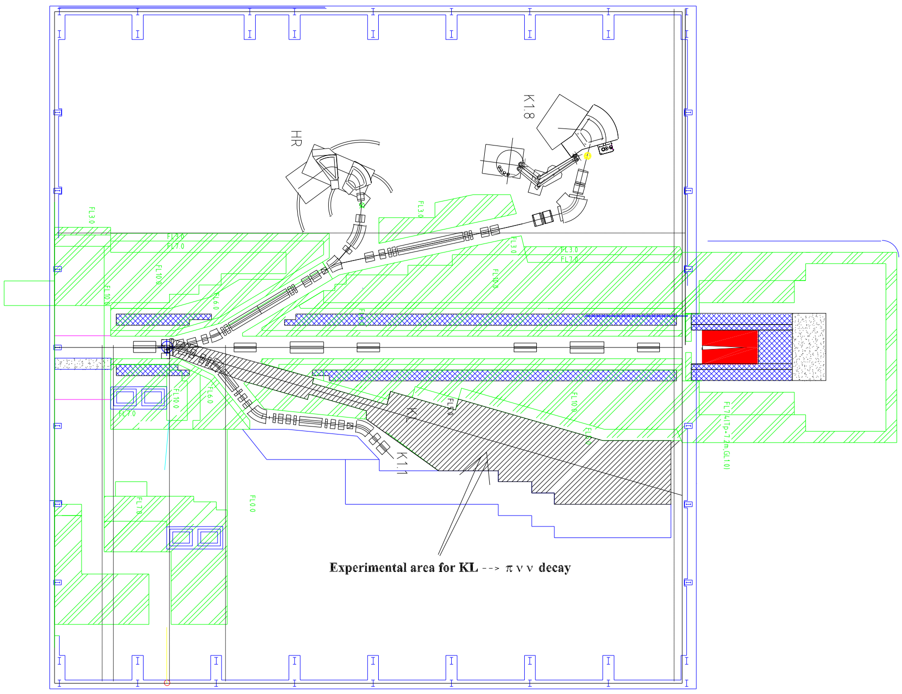

Figure 4: Possible layout of K-hall at the JHF. The hatched area is expressed as K0 beam line and experimental area for the $K_L^0 \to \pi^0 \nu \overline{\nu}$ decay measurement. Detector system will be located at 20 meters far from the T1 target

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