An experiment for the $K_L^0 \to \pi^0 \nu \bar{\nu}$ decay, KEK-E391a

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ABSTRACT

The rare K decay $K_L^0 \to \pi^0 \nu \bar{\nu}$ is considered as one of ideal processes in the flavor physics to make a critical test for the standard model and a search for new physics beyond it. The E391a experiment at the KEK 12-GeV proton synchrotron is the first dedicated experiment for the $K_L^0 \to \pi^0 \nu \bar{\nu}$ decay. The experiment started a data taking in February 2004 aiming at an improvement of sensitivity from the present experimental limit by three orders of magnitude and is planned as a pilot experiment that the study would be extended to a higher sensitivity experiment at the 50-GeV PS in J-PARC. Here, we would like to make a brief report on the physics interest, principles of experimental method, the current data analysis and future plans.

1. Introduction

One of promising ways to make a critical check of the standard model and to find out a signature of new physics beyond the standard model in the flavor physics is to examine accurately the unitarity triangle of the CKM matrix. Recent extensive results from the B-factories are stimulating such an effort. Among various scenarios, it is said that a comparison of the unitarity triangles deduced from different processes, K- and B-decays, is attractive and promising [1]. A measurement of the $K_L^0 \to \pi^0 \nu \bar{\nu}$ decay is crucial for such a study, because the decay is the most pure and clean process among various K-decays from a theoretical view point [2]. It provides a definite value of a basic parameter of η in the standard model. One of the examples to indicate the important role of the $K_L^0 \to \pi^0 \nu \bar{\nu}$ decay is a recent speculation pointed out by Buras et al.[3], based on $B \to \pi\pi$ and $B \to K\pi$ results given by the B-factories. In order to prove it, information of the $K_L^0 \to \pi^0 \nu \bar{\nu}$ decay is crucial. Another charm point of the decay is the fact that it is a last frontier in K-decay. No dedicated measurement has ever tried, and E391a [4] is the first dedicated experiment. There are several reasons why it remains. The decay is rare as the predicted branching ratio to be order of 10^{-11}, all concerning particles are neutral particles which are relatively hard to be detected than charged tracks, and there is no definite kinematical constraint to identify the decay because it is a three-body decay including two neutrinos. Key factor for the measurement of the $K_L^0 \to \pi^0 \nu \bar{\nu}$ decay is a tight background-rejection to identify the decay as well as a high sensitivity to reach the predicted branching ratio.

2. Our detection method

There are two plans to detect the $K_L^0 \to \pi^0 \nu \bar{\nu}$ decay. One is KOPIO at BNL-AGS [5]. They would measure kinematical variables as many as possible, such as momentum

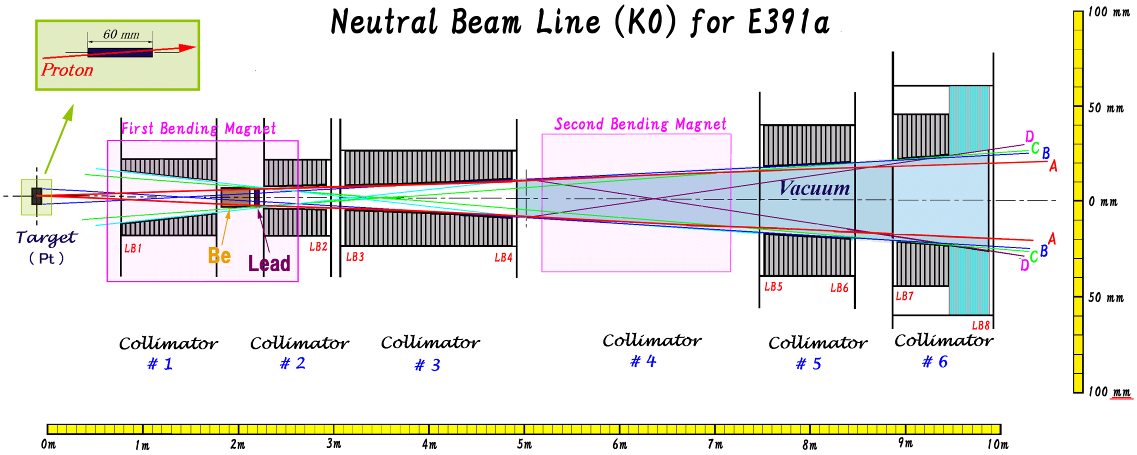

Figure 1: K0 beam line.

of K_L^0 and direction of each γ, to obtain a kinematical constraint. The other is E391a, in which we simply observe 2γ for π^0 with confirming no additional signals by a hermetic detection system covering the fiducial region. However, in terms of background-rejection two plans are only different in the last one order of magnitude. The difference only appears at the level of 10^{-10}. This is the reason why we define that E391a, the goal sensitivity of which is 3×10^{-10}, is a pilot experiment for both plans and why several members of KOPIO group are joining to E391a. While E391a takes the simple method, as nicknamed Meditation, we took special cares of following several points.

1. We prepared a tightly-collimated thin-beam (pencil beam) as shown in Fig.1. Then, we obtained an important variable of transverse momentum of π^0 with respect to the beam axis (P_T) and applied a high P_T selection to reject the low P_T events expected from major K_L^0 decays, hyperon decays and other processes.

2. Two chambers tightly covered with calorimeters were prepared in order to define the fiducial region redundantly.

3. Most of detectors were placed in the atmosphere of vacuum, and the vacuum region was separated with a thin membrane to make a differential pumping. By using this configuration we prepared an answer to both serious requirements for ultra high vacuum along the beam line and thin dead material in front the detectors, which are somewhat contradictory each other.

The detection system is shown in Fig.2.

Moreover, we designed the detection system to have a large acceptance for the $K_L^0 \to \pi^0\nu\bar{\nu}$ decay, which is crucial to achieve a high sensitivity. Then, we are taking a step-by step approach to reach the final goal of the sensitivity of 10^{-13}, as shown in Fig.3.

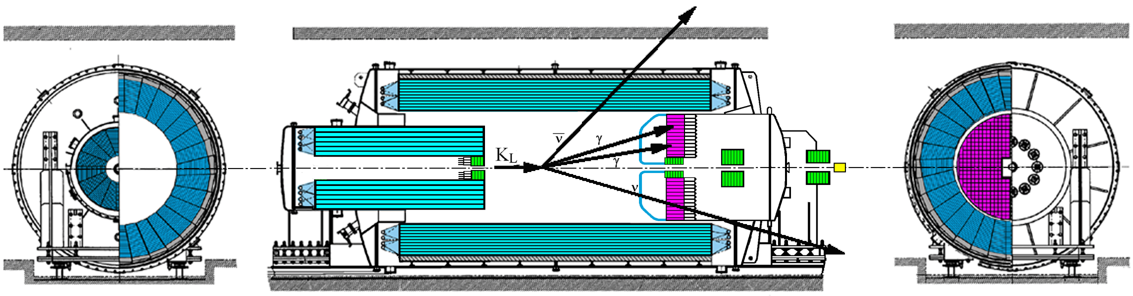

Figure 2: E391a detection system.

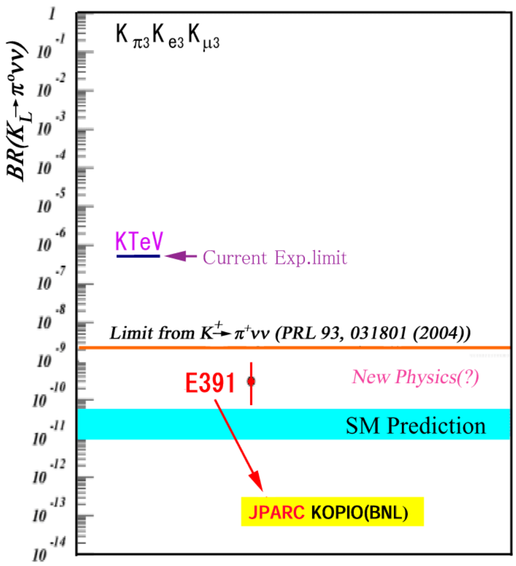

Figure 3: Current and future of experiments for the $K_L^0 \to \pi^0\nu\bar{\nu}$ decay. A pair of current limits are given from the direct measurement [6] and the indirect deduction [7] from the experimental data of the $K^+ \to \pi^+\nu\bar{\nu}$ decay.

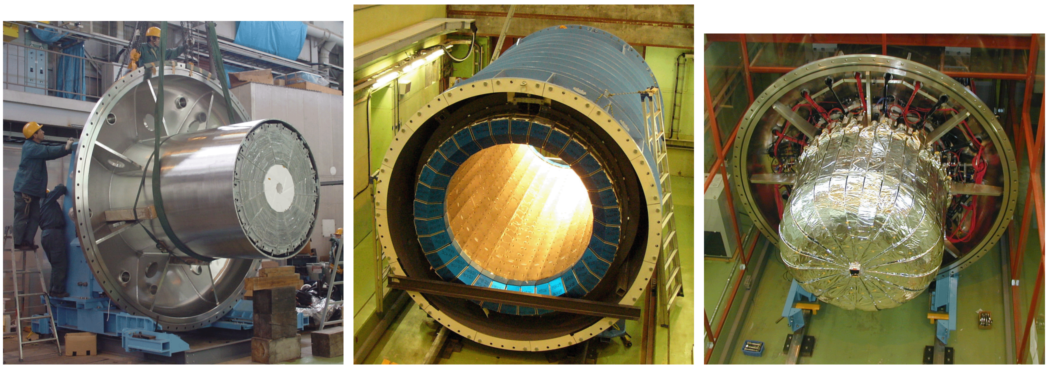

Figure 4: Three components of the detection system.

3. Detector construction

After the plan was conditionally approved in December 1996, a new pencil K_L^0 line was constructed at the East Counter Hall of the 12GeV-proton synchrotron in KEK. Several beam surveys were done until the full approval by showing a good performance of the beam line in July 2001. We constructed the detection system year-by-year as shown in Fig.4.

Several new techniques have been developed on the way of construction, such as new plastic scintillator which can be used for large size calorimeter, a new PMT having high quantum efficiency, special measurements of detection inefficiencies for various detectors, the pencil beam line and the differential pumping. Then, on 18 February 2004 we started data taking for about 100 days.

4. Preliminary data

Figs.5 show the effective-mass distributions for (a) $3\pi^0$ and (b) $2\pi^0$ samples, which were collected in a run period of one day. Clean peaks of $K_L^0 \to \pi^0\pi^0\pi^0$ and $K_L^0 \to \pi^0\pi^0$ are observed. We can simply estimate the final single-event-sensitivity for the $K_L^0 \to \pi^0\nu\bar{\nu}$ decay from both yields, based on their branching ratios, relative acceptances with $K_L^0 \to \pi^0\nu\bar{\nu}$ and run time. It is 4×10^{-10}, which is near to our goal of 3×10^{-10}.

The bump at the low mass region as seen in Fig. 4(b) can be well reproduced by 4γ events from $K_L^0 \to \pi^0\pi^0\pi^0$, in which 2 γ out of 6 γ from $K_L^0 \to \pi^0\pi^0\pi^0$ are missed in the detection. A similar background will appear in the case of the $K_L^0 \to \pi^0\nu\bar{\nu}$ decay from $K_L^0 \to \pi^0\pi^0$, when we missed 2γ out of 4γ from $K_L^0 \to \pi^0\pi^0$. In the next step of analysis we have to tighten the veto by lowering the detection threshold (raising detection efficiency) for additional γ so as to eliminate such a background. However, unfortunately it might decrease the acceptance for the $K_L^0 \to \pi^0\nu\bar{\nu}$ decay. We need a kind of optimization of the veto threshold for between background rejection and acceptance loss. The low-mass

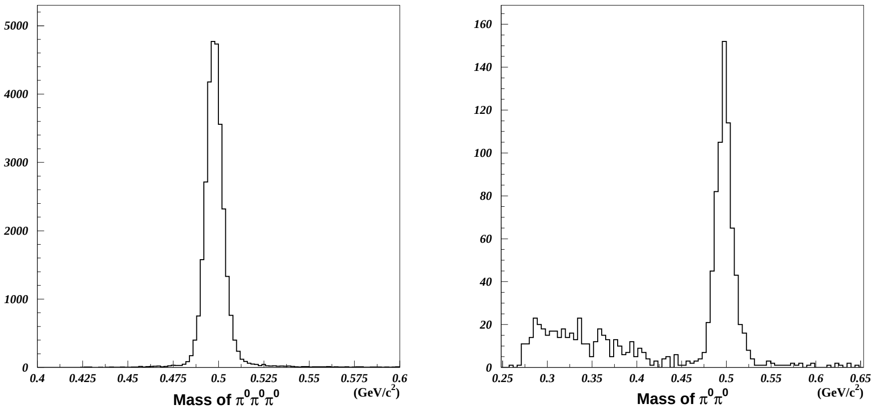

Figure 5: Effective mass distributions for (a) $3\pi^0$ and (b) 2piz.

bump appearing in Fig.5(b) provides us a nice play ground for further analysis.

5. Future plans

We are requesting a similar amount of beam time, Run-2, in 2005. It increases data sample and we can hear a reply of Nature about signal and background more clearly. Moreover, it is possible to take a redundant approach, that is a re-challenge after analyzing the first data and making a small upgrade or a minor change of setup. Such a dialog with Nature is very valuable for deeper understanding of the experiment.

As a long range plan most of E391a people wants to extend the experiment to J-PARC [8], which is now constructing at Tokai site of JAERI (Japan Atomic Energy Research Institute, locating 50 Km north-east of KEK). The beam power provided by the 50 GeV proton synchrotron in J-PARC is more intense than that by the present KEK 12-GeV PS by a factor of 300, and than that of AGS in BNL, which is providing a highest beam in the world at present, by a factor of 10. The beam power, which is a product of energy and intensity of primary protons, is roughly proportional to the K_L^0 yields. We have a chance to improve the sensitivity by another three orders of magnitude and to reach 10^{-13} for the $K_L^0 \to \pi^0\nu\bar{\nu}$ decay, which corresponds to more than 100 SM-predicting events. Some of CKM parameters can be more precisely determined by hundreds $K_L^0 \to \pi^0\nu\bar{\nu}$ events than observables given B-factories including LHC-b.

J-PARC will start a research program in 2008. We are making a full proposal to catch up the schedule for the first experiment at J-PARC.

6. References

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