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FUTURE KAON PROGRAM AT KEK/J-PARC

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ABSTRACT

The current program of kaon-decay experiments at the KEK 12 GeV Proton Synchrotron (KEK-PS) and the prospects for the future kaon program at the new 50 GeV PS of J-PARC, being constructed in Japan, are reviewed.

1 Overview

Experiments at KEK-PS started in 1977, and distinguished kaon experiments in search of $K^+ \to \pi^+ \nu\bar{\nu}$, heavy-neutrino emission in $K^+ \to \mu^+ \nu$, right-handed currents in $K^+ \to \mu^+ \nu$ and $K_L^0 \to \mu^\pm e^\mp$, respectively, were made in 1980's. After the Booster of BNL-AGS increased the proton intensity to be high, a measurement of $K_L^0 \to \pi^+ \pi^- e^+ e^-$ and a search for T-violating transverse muon polarization in $K^+ \to \pi^0 \mu^+ \nu$, which were suitable for low-energy kaons and complementary to the experiments in other laboratories, were performed

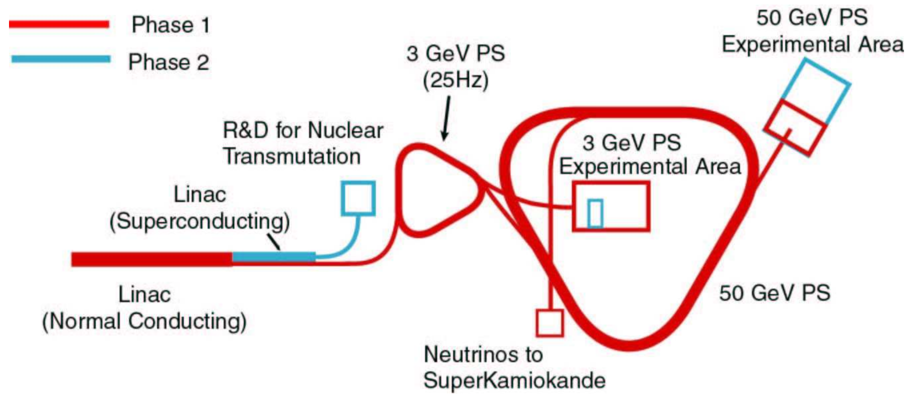

Figure 1: *J-PARC accelerators.*

at KEK-PS. Kaon physicists also participated in the E787/E949 experiments at BNL and the KTeV experiment at FNAL through the Japan-U.S. Cooperative Research Program.

To this day KEK-PS delivers fast-extracted beams to the K2K long-baseline neutrino experiment for 6 months per year and slow-extracted beams to the experiments in the East and North Counter Halls for 2 to 4 months per year [1]. A typical slow-extracted beam is $2.5 \cdot 10^{12}$ protons per 2.0-second spill in every 4.0 seconds. Experiment 391a [2], which is the first dedicated search for the $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ decay, has carried out the first physics run successfully from February to June 2004.

J-PARC, which stands for Japan Proton Accelerator Research Complex [3], is the joint project of Japan Atomic Energy Research Institute (JAERI) and KEK. The accelerators (fig.1) are under construction at the Tokai site of JAERI located at 50km northeast of KEK. The construction will be finished in 2008 and, with very intense proton beams from the new 50 GeV PS, great opportunities for various researches in nuclear and particle physics, including kaon experiments with much higher sensitivities than ever, would be opened.

The rest of this article is devoted to a report of the status of the E391a experiment and the future kaon experiments at J-PARC. The E246/E470 experiments on T-violation in $K^+ \to \pi^0\mu^+\nu$ and direct photon emission in $K^+ \to \pi^+\pi^0\gamma$ are reported elsewhere [4) 5)].

2 E391a Experiment for $K_L^0 \to \pi^0\nu\bar{\nu}$

Observation of the rare decay $K_L^0 \to \pi^0\nu\bar{\nu}$ is a new evidence for CP violation in kaon decays. The branching ratio is represented within the Standard Model (SM) as [6)]:

$$B(K_L^0 \to \pi^0\nu\bar{\nu}) = 2.12 \cdot 10^{-10} \times [\ \frac{\lambda}{0.224}\ ]^8 \times (\ \frac{Im\lambda_t}{\lambda^5} \cdot X(x_t)\ )^2 \tag{1}$$

where $X(x_t)$ is the Inami-Lim loop function [7)] with the QCD correction, x_t is the square of the ratio of the top to W masses, and

$$\lambda_t \equiv V_{ts}^* \cdot V_{td} = A^2\lambda^5 \cdot (1 - \rho - i\eta) \tag{2}$$

in the Wolfenstein parametrization A, λ, ρ, and η. The SM prediction is $(3.0 \pm 0.6) \cdot 10^{-11}$, in which theoretical uncertainties are only a few %. A model-independent bound called the Grossman-Nir limit [8)]:

$$B(K_L^0 \to \pi^0\nu\bar{\nu}) < 4.4 \times B(K^+ \to \pi^+\nu\bar{\nu}) < 1.4 \cdot 10^{-9} \tag{3}$$

can be extracted from its isospin-relation to the $K^+ \to \pi^+\nu\bar{\nu}$ decay [9)]. New physics beyond the SM could enhance the branching ratio by one order of magnitude: $(3.1 \pm 1.0) \cdot 10^{-10}$ [10)]. The current upper limit on the branching ratio $< 5.9 \cdot 10^{-7}$ was set by the KTEV collaboration [11)] using the Dalitz decay mode $\pi^0 \to e^+e^-\gamma$ of 1.2%.

The E391a experiment [1](fig.2) searches for the $K_L^0 \to \pi^0\nu\bar{\nu}$ decay with collimated "pencil" neutral beams. An endcap calorimeter with undoped CsI crystals detects two photons from $\pi^0 \to \gamma\gamma$ and measures their energy and position. The K_L^0-decay vertex position along the beam line is determined from the constraint of π^0 mass. Calorimeters that cover the decay region do hermetic photon detection and reject the background from $K_L^0 \to \pi^0\pi^0$. Charged particles are removed by their energy deposits in a plastic scintillator in front of each calorimeter.

[1]E391a is an international collaboration of KEK, Saga, Yamagata, RCNP, Osaka, NDA, JINR, Chicago, TNU, Pusan, and Kyoto.

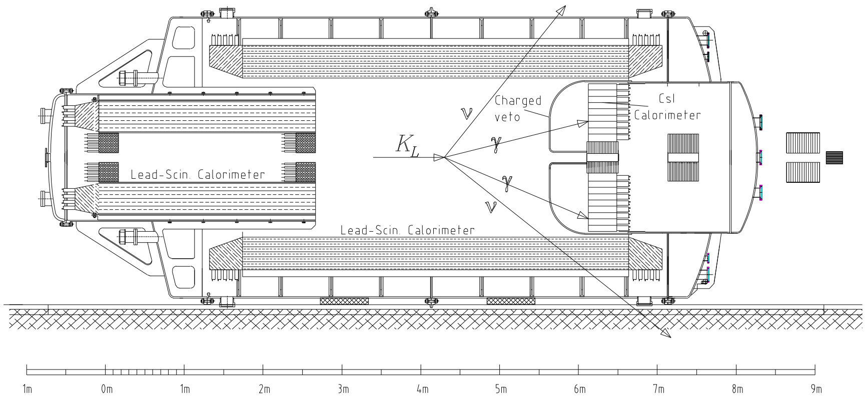

Figure 2: *Side-view of the E391a detector.*

Beam line survey and detector construction were performed from 2001 to 2003, and the first physics run was carried out in 2004. The beam line, which had been designed carefully, provided clean neutral beams; in the decay region a high vacuum of $1.21 \cdot 10^{-5}$ Pa was achieved. Fig.3 shows the $K_L^0 \to \pi^0\pi^0\pi^0$ decay reconstructed from the events with six clusters in the CsI calorimeter. These events were used online to monitor the beam line and detector during the data taking.

The goal of E391a is to achieve a sensitivity below the Grossman-Nir limit ($1.4 \cdot 10^{-9}$) and to reach the level predicted by new-physics ($3.1 \cdot 10^{-10}$). The analysis is in progress. They plan to continue the study at J-PARC.

3 Future Kaon Experiments at J-PARC

The J-PARC 50 GeV PS was designed to provide, in the slow extraction, $300 \cdot 10^{12}$ protons per 0.7-second spill in every 3.42 seconds to an experimental area named Hadron Experimental Hall. The beam energy at the initial operation phase (Phase-1) will be 30 GeV.

Call for Letters of Intent (LoI's) for nuclear and particle physics experiments at the J-PARC was issued in July 2002, and thirty LoI's [12] were

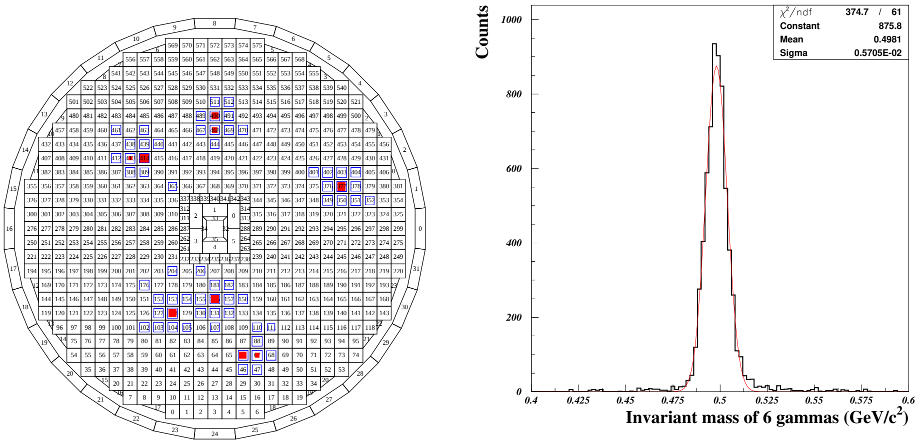

Figure 3: *Display of an event with six clusters in the E391a CsI calorimeter (left); invariant-mass distribution of the* $K_L^0 \rightarrow \pi^0\pi^0\pi^0$ *decay reconstructed from the six-cluster events (right).*

submitted. There were five LoI's for kaon experiments:

- measurement of the $K_L^0 \rightarrow \pi^0\nu\bar{\nu}$ branching ratio

with neutral beams and

- study of the $K^+ \rightarrow \pi^+\nu\bar{\nu}$ decay,
- search for T-violation in K^+ decay,
- study of the decay spectra of stopped kaons, and
- precise measurement of the $K^+ \rightarrow \pi^0 e^+\nu$ branching ratio

with K^+ beams of low momentum (0.6-0.8 GeV/c). These LoI's are regarded as a natural extension of the kaon program that has been worked out (E391a, BNL-E949 and E246/E470). In the beam-line layout plan of the Hadron Experimental Hall at Phase-1, reported in February 2004 [13], the hall has been designed so as to accommodate these experiments in the future. Call for full proposals is expected to be issued in the autumn of 2004; intensive discussions have been held in a series of workshops [14].

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