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FUTURE PROSPECTS OF $K_L \to \pi^0\nu\bar{\nu}$ EXPERIMENT AT FERMILAB

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We reviewed the current status of a proposed KAMI (Kaon at Main Injector) experiment at Fermilab to measure the direct CP-violating $K_L \to \pi^0\nu\bar{\nu}$ decay. Good progress and encouraging results have been made in the past two years for measuring the required photon veto inefficiencies for both CsI and lead-scintillator detectors in a test beam at INS-KEK Japan. New beam test with 150 GeV Main Injector protons has also been scheduled in January 2000 at Fermilab using the existing KTeV detector with two new beam calorimeters. Prospects of a feasible KAMI experiment in the future is discussed here.

Current status of the CP violation experiments has now just firmly established the effect of "direct" CP violation through the non-zero measurement [1] of ϵ'/ϵ in neutral kaon decays to 2π. This important result makes the test of Standard Model CP hypothesis, that a single phase in the CKM matrix is the sole source of CP-violation, much more interesting. Over-constraining the parameters of CKM Unitarity Triangle through both B and K decays will be the ultimate test to the Standard Model, which will either reveal any new physics or furhter constraint the type of new physics beyond the Standard Model in explaining the origin of CP-violation.

Within the Standard Model the decay $K_L \to \pi^0\nu\bar{\nu}$ violates CP-invariance in the decay process through the Z-penguin diagram, so called direct CP-violation. The contributions from indirect CP-violating and CP conserving effect are highly suppressed,[2] because the $K_L \to \pi^0\nu\bar{\nu}$ decay is a flavour changing neutral current process through direct CP-violation only. Furthermore, the decay $K_L \to \pi^0\nu\bar{\nu}$ is not affected by the long distance effects [3] and the theoretical ambiguity due to the QCD corrections is quite small. [4] Therefore, a discovery of the $K_L \to \pi^0\nu\bar{\nu}$ decay would be a clean measurement to the CP-violating CKM parameter, η. The current knowledge for the CKM parameters predicts $B(K_L \to \pi^0\nu\bar{\nu})$ to be $(2.8 \pm 1.7) \times 10^{-11}$. Because of the theoretical cleanness, an observation of the $K_L \to \pi^0\nu\bar{\nu}$ decay outside the predicted range in branching ratio would indicate exciting new physics.

The current experimental limit [5] from KTeV is $B(K_L \to \pi^0\nu\bar{\nu}) < 5.9\times10^{-7}$, using the π^0 Dalitz decay as the tagging method. There are 3 new initiatives for measuring $K_L \to \pi^0\nu\bar{\nu}$, KEK-391, BNL-926 (KOPIO) and KAMI. [6]

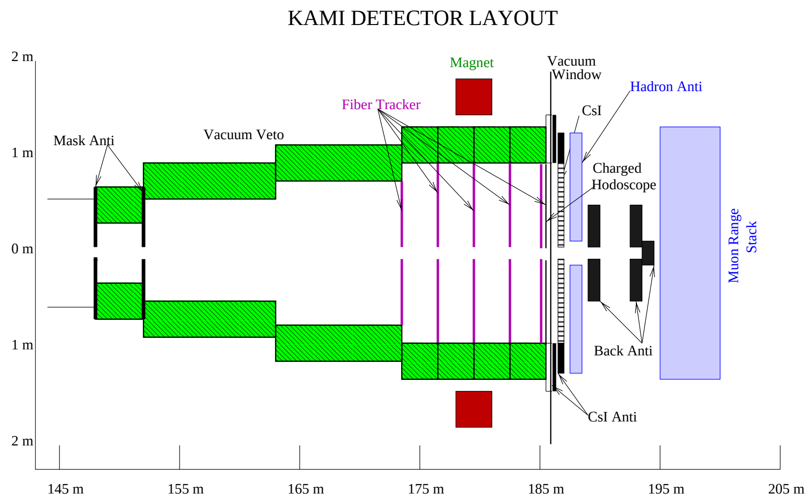

Figure 1: Plan view of the proposed KAMI aparatus for $K_L \to \pi^0 \nu \bar{\nu}$ detection.

The goal of KAMI experiment is to make a measurement of $K_L \to \pi^0 \nu \bar{\nu}$ using the decay $\pi^0 \to \gamma\gamma$. The signature of the $K_L \to \pi^0 \nu \bar{\nu}$ mode is then two γs with large, unbalanced transverse momentum (p_t). Due to the copious π^0s in the K_L decays, the detector has to be hermatic covered for γ detection.

A schematic of the planned apparatus is shown in Figure 1. A few key features and challenges in KAMI detector will be emphasized here:

1) In order to determine the p_t of the π^0, an intense single pencil or flat K_L beam would be produced by the high intensity source of 120 GeV protons (up to 10^{13} Hz) from Fermilab Main Injector. To reach the single event sensitivity well below 10^{-11}, at least 3 MHz K_L decays have to be produced which correspond to at least 30 MHz K_L flux.

2) A new high efficiency hermatic photon veto system and a precision photon detector (CsI) would be used to cover a 34-meter decay region. The KTeV 3100 blocks of pure CsI calorimeter is the ideal photon detector to have better than $1\%/\sqrt{E}$ energy resolution and 1 mm position resolution.

3) An efficient hadronic veto and muon identification with range stacks.

4) An efficient Beam hole photon veto in the presence of high n/K flux.

5) An analyzing magnet and scintillating fiber tracker in the vacuum decay region can provide measurements for charged particles and precision calibration of detector elements. This provides KAMI a diverse program for many other interesting physics, such as $K_L \to \pi^0 e^+ e^-$, $K_L \to \pi^0 \mu^+ \mu^-$, $K_L \to \pi^0 \mu^\pm e^\mp$ and

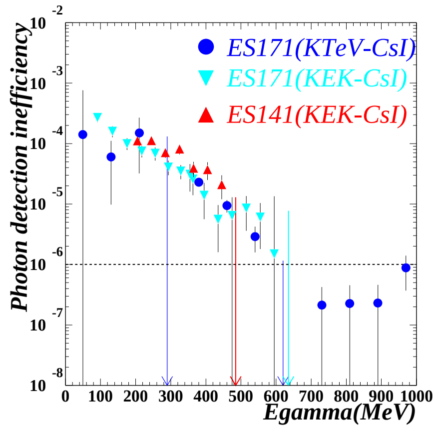

Figure 2: Photon detection inefficiency measurements for CsI with energy threshold of 10 MeV. The inefficiency falls below 10^{-6} (dotted line) for $E_\gamma > 600 MeV$.

$K_L \to \pi^+\pi^-e^+e^-$, in searching for new physics.

Because the $K_L \to 3\pi^0$ decay is so copious, the p_t cut must be above the kinematic cutoff ($\sim$ 150 MeV/c) to avoid being swamped with $\pi^0\pi^0\pi^0$ background. The p_t cut also removes background from Λ and Ξ decays. The longitudinal position of the decay vertex could then be determined by requiring that the invariant mass of the two observed photons equal the π^0 mass. The remaining background mainly comes from $K_L \to \pi^0\pi^0$, especially the asymmetric odd pairing γs from different π^0 decay. Stringent photon veto efficiency over a wide energy range is required to reduce such background. The fully reconstructed $K_L \to \pi^0\pi^0$ also serves as the normalization mode for $K_L \to \pi^0\nu\bar{\nu}$.

There are two options for KAMI experiment. The KAMI-far option will use the existing KTeV beam line geometry. Since target is 145 meter upstream of the decay region, the neutral kaon beam is then quite clean. The KAMI-near option requires new target/dump station very close to the detector to enhance the neutral kaon flux for the improvement of the sensitivity. Debunched proton beam from Main Injector with high duty factor in KAMI-near is required to reduce the accidental background or double decays.

A beam test at INS KEK-Tanashi, ES171, using a tagged photon beam and liquid scintillator neutron tagging detectors, was performed to measure the photon detection inefficiency due to the dominant contribution from photonuclear effect between 100 MeV to 1 GeV for E_γ.[7] Several calorimeter samples were examined with different energy thresholds (1 MeV, 5 MeV and 10 MeV):

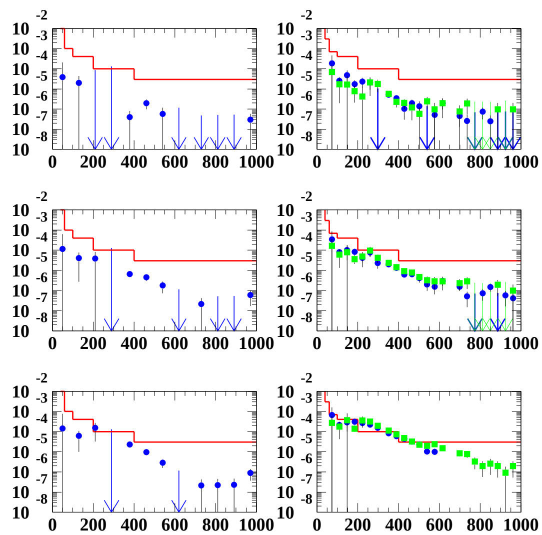

Figure 3: Photon veto inefficiency versus E_γ for CsI (left) and Pb/scintillator (right) calorimeters. The energy thresholds are 1 MeV, 5 MeV and 10 MeV respectively from top to bottom. Also shown for comparison are the KAMI requirements (solid line).

1) CsI crytals, 18 X_0 KEK-CsI (from ES147) and 27 X_0 KTeV-CsI;

2) Pb/scintillator sampling calorimeters, $1mm/3mm$ ($18X_0$), $1mm/5mm$ ($18X_0$) and $0.5mm/5mm$ ($21X_0$) Pb/scintillator sampling prototypes.

Three measurements were made for the two types of CsI crystals and the detection inefficiency for all three measurements with a 10 MeV energy threshold are all consistent, as shown in Fig. 2, confirms the earlier ES147 results. [8] This result shows that with $E_\gamma > 600$ MeV the inefficiency is well below 10^{-6}. This is truly a very encouraging result. The residual of the nuclear resonance absorption above 140 MeV (pion-production threshold) is clearly visible but small.

The inefficiency results for KTeV-CsI, $1mm$-Pb/$5mm$-scint. sampling and $0.5mm$-Pb/$5mm$-scint. sampling prototypes are shown in Fig. 3. The comparison with the KAMI requirement is also shown in this energy region. The plots on left-side are for KTeV-CsI and on the right-side are for the Pb-scintillator sampling calorimeters. The plots from top to bottom have the threshold of 1 MeV, 5 MeV and 10 MeV applied, respectively. From this figure it is quite clear that better than 10^{-6} inefficiency can be achieved with photon energy above 1 GeV with the veto threshold at 10 MeV or lower in both CsI and

Pb-scintillator. Below 100 MeV the inefficiency is dominated by the sampling effect due to the inactive lead. A GEANT monte-carlo study has shown that both $1mm$-Pb/$5mm$-scint. and $0.5mm$-Pb/$5mm$-scint. samplings can satisfy the KAMI requirement at low γ energies.

A new KAMI 150 GeV beam test is scheduled at the end of '99 fixed target run at Fermilab in mid-January 2000 for three weeks. A $6\lambda_I$ depleted Uranium hadron calorimeter and a $10X_0$ Pb/quartz-bar EM calorimeter are currently in construction for this beam test. We will measure the n/K neutral beam flux, ratio and energy spectra at several different targeting angles and several absorber configurations. Study of the beam hole photon detection efficiency in the presence of beam neutron/kaon environment will also be performed. The results of this beam test and the results of photon detection inefficiency from INS test will be used to optimize the beam/detector configuration for preparing a full technical proposal for $K_L \rightarrow \pi^0 \nu\bar{\nu}$ measurement at KAMI.

Although experimentally the $K_L \rightarrow \pi^0 \nu\bar{\nu}$ measurement is quite challenging, but it is not impossible especially with the very encouraging γ detection inefficiency results from INS test. The goal for $K_L \rightarrow \pi^0 \nu\bar{\nu}$ experiment is to collect more than 100 events with low backgrounds to make a 10% measurement in branching ratio (or a 5% measurement in η). Such accuracy together with 10% measurement from $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ and $sin(2\beta)$ from $B \rightarrow \psi K_S$ as well as another measurement from $B - \overline{B}$mixing can over-constraint the CKM Unitarity Triangle and provide useful information on CP-violation.

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