Frascati Physics Series Vol. VVVVVV (xxxx), pp. 000-000
XX Conference – Location, Date-start - Date-end, Year

KTEV RESULTS ON RARE KAON DECAYS

Elliott Cheu
University of Arizona

ABSTRACT

The KTeV experiment has carried out a broad program of studies of rare kaon decays. In this paper we present results on $K_L \to \pi^0 l\bar{l}$ decay modes. These decays offer a possible window for observing direct CP violation in a decay. We do not observe any signals in these decays and present 90% upper limits for each of the modes. Our analyses represent the most sensitive searches to date.

1 Introduction

The decays $K_L \to \pi^0 l\bar{l}$, where $l\bar{l}$ represents $\nu\bar{\nu}$, e^+e^- or $\mu^+\mu^-$, are interesting because they can be used to observe direct CP violation in a decay. In addition, mechanisms for new physics beyond the Standard Model suggest that the branching ratios for these decays can be significantly enhanced relative to their

Standard Model values. [1] Three components contribute to the $K_L \to \pi^0 l\bar{l}$ amplitude: direct CP violation, indirect CP violation (and an interference term), and a CP conserving term. Recent measurements of the decay $K_S \to \pi^0 e^+ e^-$ [2] and $K_S \to \pi^0 \mu^+ \mu^-$ [3] have helped to determine the indirect CP violating contributions to $K_L \to \pi^0 e^+ e^-$ and $K_L \to \pi^0 \mu^+ \mu^-$. The magnitude of the CP conserving contributions to $K_L \to \pi^0 l\bar{l}$ can be determined by measurements of the decay $K_L \to \pi^0 \gamma\gamma$. [4, 5] Therefore, measuring the branching ratio of any of the $K_L \to \pi^0 l\bar{l}$ decays allows one to extract the direct CP violating component. In the mode $K_L \to \pi^0 \mu^+ \mu^-$, the three amplitudes are predicted [7] to be roughly of the same size. In the electron final state, the CP conserving term is estimated to be small [8]. And, in the neutrino mode, the direct CP violating terms are expected to dominate, with the indirect and CP conserving amplitudes negligible. [9]

The KTeV experiment is a fixed target experiment located at Fermilab, and is shown in Figure 1. The detector contains a charged spectrometer with four drift chambers, two on either side of a large dipole magnet. At the downstream end of the detector is a two-meter square calorimeter consisting of 3100 pure CsI blocks. Just upstream of the CsI calorimeter is a transition radiation detector capable of e/π separation of 200:1 with a 90% efficiency. Following the calorimeter are 10 cm of lead and 5 meters of steel which act as a muon filter. Two planes of scintillator, used for muon detection, are located just downstream of the steel. Photon vetoes to detect the the presence of particles that would otherwise escape detection surround the spectrometer. The charged spectrometer achieves a hit resolution of better than 100 μm, while the CsI calorimeter obtains better than 1% energy resolution over the range of energies of interest.

The KTeV experiment took data during two runs in 1997 and 1999. Between the 1997 and 1999 runs, a number of upgrades were made to the detector to increase its reliability and to improve its live time. In addition, the transverse kick from the magnet was reduced from 205 MeV/c to 150 MeV/c, enabling a larger acceptance for high multiplicity decay modes. In the first period, nearly 3×10^{11} K_L decayed in the detector, while in 1999 a flux of 3.6×10^{11} K_L decays was recorded. This large kaon flux allows us to have an unprecedented sensitivity to a number of rare kaon decays with large multiplicity final states.

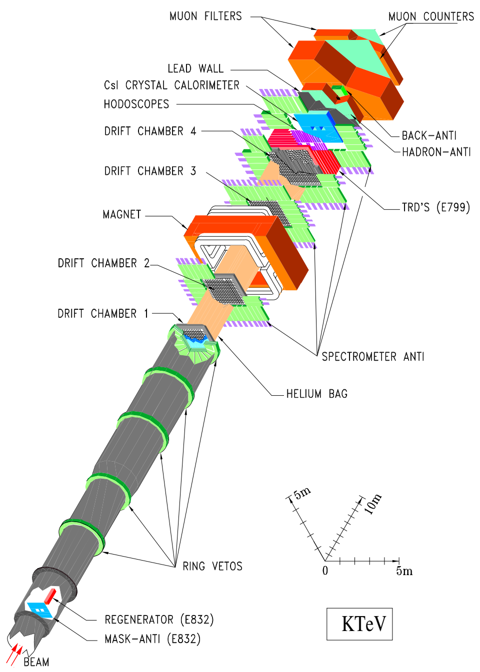

Figure 1: *The KTeV detector.*

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

In the decay $K_L \to \pi^0 \nu\bar{\nu}$ the final state consists of a single π^0 with nothing else detected in the experiment. In our experiment, the calorimeter cannot determine a photon's angle of incidence. So, we cannot reconstruct the mass of a π^0 from its daughter photons without first determining the decay vertex. To circumvent this problem, we use the Dalitz decay ($\pi^0 \to e^+e^-\gamma$) to reconstruct the π^0 vertex and mass. This requirement reduces our sensitivity by about two orders of magnitude because of the small Dalitz decay branching ratio.

Our analysis utilizes only the 1997 data set. We proceed by first selecting events with two electrons and a photon in the final state. Electrons are determined by using the ratio of the energy in the calorimeter to the momentum measured in the charged spectrometer (E/p). Events with a good π^0 mass are selected and the transverse momentum p_T of the π^0 is plotted. Because of the

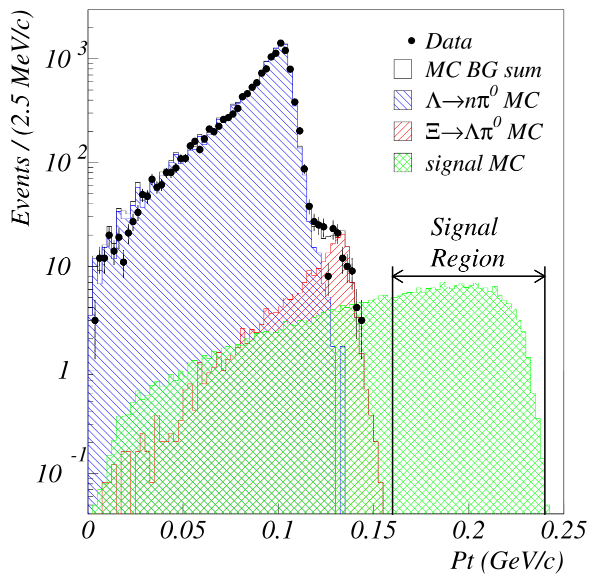

Figure 2: *The reconstructed transverse momentum for $K_L \to \pi^0\nu\bar{\nu}$ candidates. The solid histogram represents the sum of our Monte Carlo background estimate. No candidates are found in the signal region indicated in the figure.*

two missing neutrinos, the p_T for $K_L \to \pi^0\nu\bar{\nu}$ events should be relatively large.

Backgrounds to this measurement come from both kaon and hyperon decays. In particular, the largest sources of background result from $\Lambda \to n\pi^0$ and $\Xi \to \Lambda\pi^0$ where the neutron and the Λ daughters are not reconstructed.

As shown in Figure 2, we find no events in the signal region. We determine the kaon flux by reconstructing the decay $K_L \to e^+e^-\gamma$, and set an upper limit of $\mathrm{BR}(K_L \to \pi^0 e^+e^-) < 5.9 \times 10^{-7}$. [10] Note that this limit is significantly higher than the Standard Model prediction. Clearly, using the $\pi^0 \to \gamma\gamma$ decay rather than the $\pi^0 \to e^+e^-\gamma$ decay mode would significantly help to improve the limit. Two experiments KOPIO and E391A propose to use the $\pi^0 \to \gamma\gamma$ decay to reach the Standard Model prediction for $K_L \to \pi^0\nu\bar{\nu}$.

3 $K_L \to \pi^0 e^+ e^-$

As opposed to the $K_L \to \pi^0 \nu\bar{\nu}$ decay, all final state particles in the mode $K_L \to \pi^0 e^+ e^-$ can be reconstructed in our detector. Since the decay position can be determined from the e^+e^- vertex, we do not need to rely on the π^0 Dalitz decay, but instead use the $\pi^0 \to \gamma\gamma$ final state. Again, we look for events with two oppositely charged electrons. In this analysis the TRDs are also used to help improve the electron purity.

The most serious background in this analysis comes from the decay $K_L \to e^+e^-\gamma\gamma$. Since this decay is produced through inner and outer bremsstrahlung, there are strong kinematic constraints that can distinguish this decay from that of $K_L \to \pi^0 e^+ e^-$. In particular, we rely on $\cos\Theta_\pi$, where Θ_π is the angle between the momentum of the e^+e^- system and the γ in the $\gamma\gamma$ center-of-mass. This variable is uniform for signal events because of the π^0 spin but peaks near ± 1 for background events. We also cut on the variable Θ_{min} which is the smallest angle between the photon and the $e^\pm$ in the K_L center-of-mass. For signal events, this variable is uniformly distributed, while it is peaked at small angles for background because of radiation.

This analysis uses data collected in both 1997 and 1999. We expect 0.87 ± 0.15 events from background. We find two events in the signal region as shown in Figure 3. Using the decay $K_L \to \pi^0\pi^0$, $\pi^0 \to e^+e^-\gamma$, we determine $\mathrm{BR}(K_L \to \pi^0 e^+ e^-) < 2.8 \times 10^{-10}$. [11]

4 $K_L \to \pi^0 \mu^+ \mu^-$

Like the previous search, in the $K_L \to \pi^0 \mu^+ \mu^-$ decay, all of the final state particles can be reconstructed in the KTeV detector. We search for two oppositely charged muons, and two neutral clusters in the calorimeter. The two photons are required to have a mass consistent with a π^0.

The most serious background to this decay comes from $K_L \to \mu^+\mu^-\gamma\gamma$ decays, which has a branching ratio of $2.62 \pm 0.40 \pm 0.17) \times 10^{-9}$. Like the $K_L \to \pi^0 e^+ e^-$ search, we can utilize two kinematic variables $\cos\Theta_\pi$ and Θ_{min}. However, the Θ_{min} cut is less effective than in the $K_L \to \pi^0 e^+ e^-$ search because there is less bremsstrahlung radiation. So, while the branching ratio for the background decays is much smaller, there are fewer kinematic constraints in this decay.

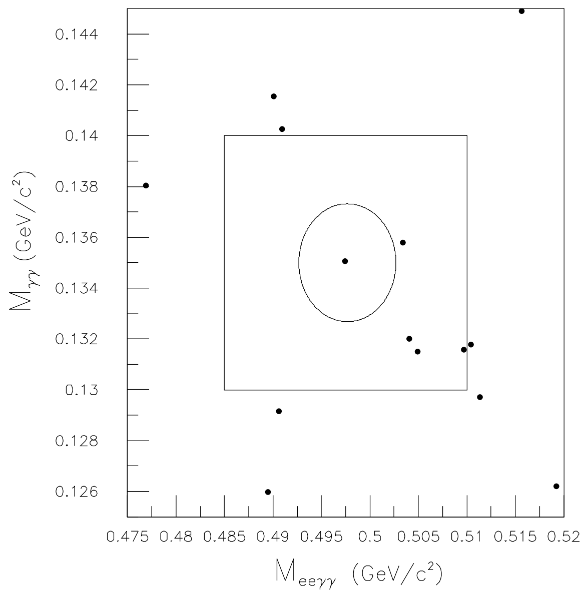

Figure 3: *Reconstructed $\gamma\gamma$ mass versus $e^+e^-\gamma\gamma$ mass for $K_L \to \pi^0 e^+ e^-$ candidates. The square region represents the area masked off while the selection criteria were determined. The ellipse represents the signal region. One candidate event is present in the signal region.*

As shown in Figure 4, we expect 0.99 ± 0.35 background events in our signal region. We find one event, and determine a 90% upper limit of $\mathrm{BR}(K_L \to \pi^0 \mu^+ \mu^-) < 3.8 \times 10^{-10}$ (90% C.L.). [12] This result is based upon our 1997 data. A combined result using both our 1997 and 1999 data should be forthcoming shortly. As of this time, there are no other planned experiments to measure this decay mode.

5 Summary and Conclusions

The KTeV experiment has made the best measurements to date on the decays $K_L \to \pi^0 \nu \bar{\nu}$, $K_L \to \pi^0 e^+ e^-$ and $K_L \to \pi^0 \mu^+ \mu^-$. These results are approaching the Standard Model limits, leaving little room for new physics. We expect

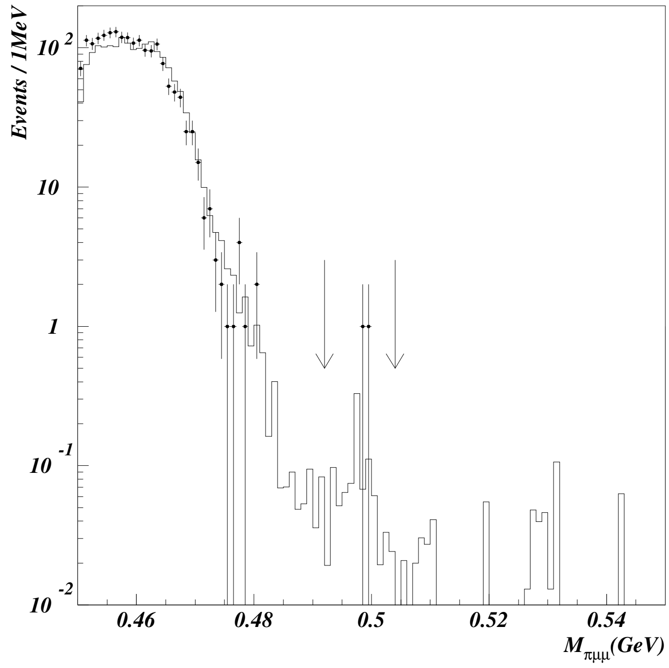

Figure 4: *The reconstructed $\mu^+\mu^-\gamma\gamma$ mass for $K_L \rightarrow \pi^0\mu^+\mu^-$ candidates. The solid histogram represents a Monte Carlo prediction of our estimated background. Two events were found in the signal region indicated by the arrows.*

to make further improvements to the $K_L \rightarrow \pi^0\mu^+\mu^-$ search, and future experiments have been designed to push the limits on $K_L \rightarrow \pi^0\nu\bar{\nu}$. Figure 5 shows the current status on the $K_L \rightarrow \pi^0 l\bar{l}$ decays.

References

1. A.J. Buras, G. Colangelo, G. Isidori, A Romanino, and L. Silvestrini, Nucl. Phys **B566** 3 (2000).
2. J.R. Batley *et al.*, Phys. Lett. **B576**, 43 (2003).
3. J.R. Batley *et al.*, CERN PH-EP Preprint 2004-025.
4. A. Lai *et al.*, Phys. Lett. **B536**, 229 (2002).

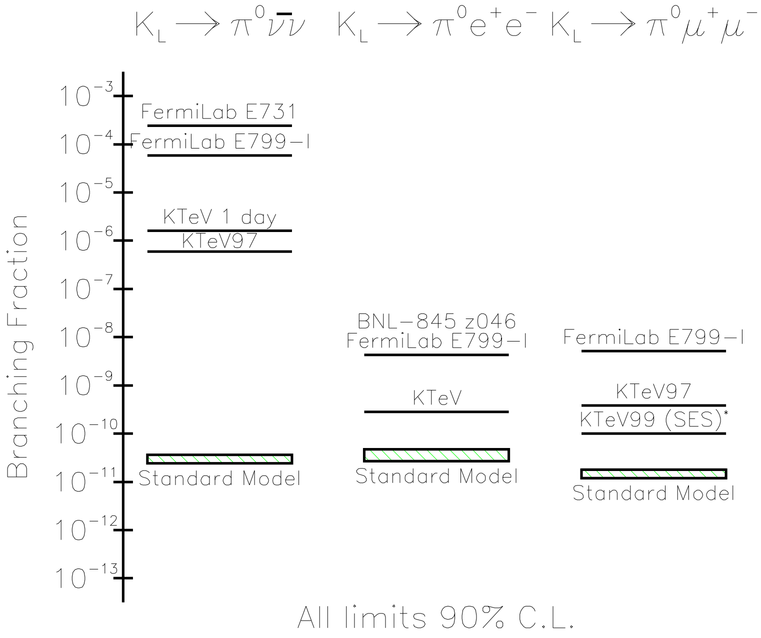

Figure 5: *Current status of $K_L \rightarrow \pi^0 l\bar{l}$ searches.*

5. A. Alavi-Harati *et al.*, Phys. Rev. Lett. **83**, 917 (1999).

6. A.J. Buras, F. Schwab, S. Uhlig, hep-ph/0405132.

7. G. Isidori, C. Smith, R. Unterdorfer, hep-ph/0404127.

8. G. D'Ambrosio, G. Ecker, G. Isidori and J. Portoles, J. High Energy Physics, **08**, 004 (1998).

9. L.S. Littenberg, Phys. Rev **D39** 3322 (1989).

10. A. Alavi-Harati *et al.*, Phys. Rev. **D61** 072006 (2000).

11. A. Alavi-Harati *et al.*, Phys. Rev. Lett. **93** 021805 (2004).

12. A. Alavi-Harati *et al.*, Phys. Rev. Lett. **84** 5279 (2000).