



## RECENT RESULTS FROM KTEV

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Recent results are presented for (1) the charge asymmetry in semielectronic kaon decay; (2) the charge radius of the neutral kaon; (3) the decay  $K_L^0 \rightarrow \pi^0 \pi^0 e^+ e^-$ ; (4) constraints on  $\rho_{CKM}$  from kaon decays; (5) lepton flavor violation. A few words about future kaon physics work at Fermilab are included.

## 1 Charge Asymmetry

The charge asymmetry in the decay  $K_L^0 \rightarrow \pi^\pm e^\mp \nu$ , defined by

$$\delta_L = \frac{N(K_L^0 \rightarrow \pi^- e^+ \nu) - N(K_L^0 \rightarrow \pi^+ e^- \bar{\nu})}{N(K_L^0 \rightarrow \pi^- e^+ \nu) + N(K_L^0 \rightarrow \pi^+ e^- \bar{\nu})} \quad (1)$$

equals  $2\Re(\varepsilon - Y - X_-)$ , where  $\varepsilon$  is the familiar indirect CP violation parameter,  $Y$  parameterizes CPT violation in  $\Delta S = \Delta Q$  amplitudes and  $X_-$  parameterizes CPT violation in  $\Delta S = -\Delta Q$  amplitudes<sup>1</sup>. A comparison of the real part of  $\varepsilon$  as measured in  $K \rightarrow \pi\pi$  decays with  $\delta_L$  can reveal new, CPT violating processes.

The PDG 2000 average for  $e^\pm$  and  $\mu^\pm$  is  $\delta_L = (3.27 \pm 0.12) \times 10^{-3}$ ; the best  $e^\pm$  result<sup>2</sup> is  $(3.41 \pm 0.18) \times 10^{-3}$ , obtained from a dataset of  $34 \times 10^6$  events. Here we present a result based on about  $300 \times 10^6$  events.

Building a detector with the same efficiencies for both charge combinations at the required level is approximately impossible. Instead, we begin by defining subsamples with nearly cancelling efficiencies. So for example we compare the number of  $e^+$  events measured when the spectrometer magnet was set to positive polarity to the number of  $e^-$  events with negative magnet polarity. Then,

$$R = \frac{N(K_L^0 \rightarrow \pi^- e^+ \nu; +mag)}{N(K_L^0 \rightarrow \pi^+ e^- \bar{\nu}; -mag)} = \frac{Br(\rightarrow e^+) \cdot Flux(+mag) \cdot \epsilon(e^+; +mag)}{Br(\rightarrow e^-) \cdot Flux(-mag) \cdot \epsilon(e^-; -mag)}, \quad (2)$$

Table 1: Summary of corrections for systematic effects in  $\delta_L$ , in units of  $10^{-8}$ , with sources for the corrections.

$\pi^+\pi^-$ different in calorimeter	Data	$-156 \pm 10$
$\pi^+\pi^-$ loss in trigger scintillator	Data	$54 \pm 10$
$\pi^+\pi^-$ loss in spectrometer	Simulation	$3 \pm 3$
$\pi^+\pi^-$ punchthrough differences	Data	$34 \pm 40$
$e^+e^-$ different in calorimeter	Data	$-19 \pm 18$
$\delta$ ray production differences	Simulation	$-8 \pm 4$
$e^+$ annihilation in spectrometer	Simulation	$11 \pm 1$
Backgrounds ( $K_{\pi 3}, K_{\mu 3}, \Lambda$ )	Data, Simulation	$1 \pm 1$
Target/adsorber interference	Simulation	$-2 \pm 1$
Collimator, regenerator scatters of $K_L^0$	Data	$-1 \pm 1$
Spectrometer polarity mismatch	Data	$-3 \pm 2$
Total		$-97 \pm 46$

and the ratios of dataset size  $\frac{Flux(+mag)}{Flux(-mag)}$  and detection efficiency  $\frac{\epsilon(e^+;+mag)}{\epsilon(e^-;-mag)}$  nearly cancel. Since the KTeV apparatus contains two beams, there are four values of  $R$ ; we take the fourth root of their product.

Clearly, the viability of the method lies in our ability to allow for small variations from perfect cancellation. Table 1 lists the corrections we have made; a detailed paper is being written<sup>3</sup>. Our preliminary result on the data taken in 1997 is

$$\delta_L = (3.320 \pm 0.058_{STAT} \pm 0.046_{SYS}) \times 10^{-3}. \quad (3)$$

With this result, the new world average is  $(3.320 \pm 0.063) \times 10^{-3}$ , which differs from  $(2\Re(\eta_{+-}) + \Re(\eta_{00}))/3$  by only  $(-2 \pm 35) \times 10^{-6}$ , consistent with CPT conservation.

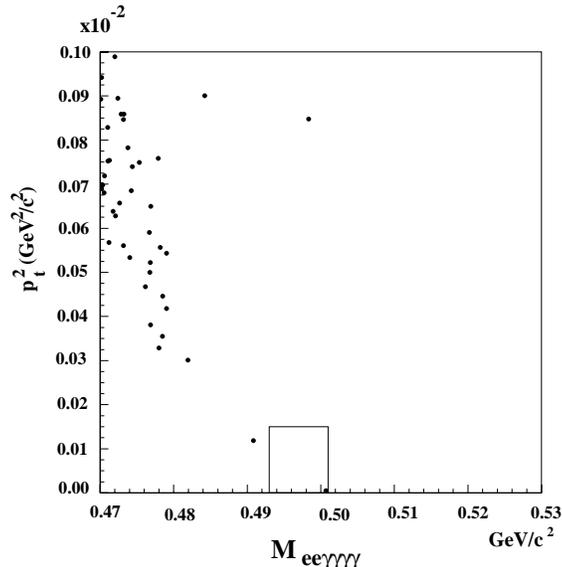
## 2 Charge Radius

There are three contributions to the process  $K_L^0 \rightarrow \pi^+\pi^-e^+e^-$ . The first is a direct emission amplitude (DE) where the  $K_L^0\pi\pi$  vertex emits a photon; the second is the bremsstrahlung amplitude (BR); and the third is the charge radius (CR) amplitude. This third term corresponds to a  $K_L^0 \rightarrow K_S^0\gamma^*$  transition immediately prior to a  $K_S^0\pi\pi$  vertex. The photon then materializes as an  $e^+e^-$  pair. Each of these amplitudes are multiplied by a coupling factor, and the factor multiplying the CR term is proportional to the charge radius,  $-\langle \sum q_i (\vec{r} - \vec{R})^2 \rangle m_K^2/3$ . We use our clean sample of 1811 events<sup>4</sup> to fit the charge radius amplitude's coupling constant using the data's phase space distribution while holding the coupling constants for the other amplitudes, the indirect CP violation parameters  $\eta_{+-}$  and  $\Phi_{+-}$  and the DE form factor fixed. Variations in these parameters are used to assign systematic uncertainties, as is the finite size of the Monte Carlo sample, potential biases in the event reweighting procedure used in the fitting process and background levels. We obtain a coupling constant of  $|g_{CR}| = (0.100 \pm 0.018_{STAT} \pm 0.013_{SYS})$ , corresponding to a charge radius of  $-\langle R^2 \rangle = (-0.047 \pm 0.008_{STAT} \pm 0.006_{SYS}) fm^2$ .

## 3 $K_L^0 \rightarrow \pi^0\pi^0e^+e^-$

The decay  $K_L^0 \rightarrow \pi^0\pi^0e^+e^-$  has no BE contributions to the amplitude and the DE is suppressed because Bose statistics and gauge invariance force the  $\pi\pi$  system to have  $l = 2$ . As a result, this process is dominated by the charge radius process studied above. Existing predictions<sup>5</sup> are in the range  $(0.8 \sim 2.0) \times 10^{-10}$ . The background is  $K_L^0 \rightarrow \pi^0\pi^0\pi^0$ , where one of the  $\pi^0$  decays

Figure 1:  $P_{\perp}^2$  vs. reconstructed mass in the data for the  $\pi^0\pi^0e^+e^-$  channel.



results in an  $e^+e^-$  pair, possibly due to the interaction of a photon with material in the detector. One of the photons must go unseen, and so the background is suppressed by requiring correctly reconstructed  $\pi^0$  masses and that the decay vertex found from the photons using a  $\pi^0$  mass constraint be consistent with the vertex found from the  $e^+e^-$  pair. Using a Monte Carlo sample three times the size of the data sample, we estimate the background to be  $0.4 \pm_{-0.3}^{+0.4}$  events.

Figure 1 shows the distribution of reconstructed momentum transverse to the  $K_L^0$  flight direction squared ( $P_{\perp}^2$ ) versus the reconstructed mass in the data. There is one event in the signal region, and our preliminary 90% C.L. limit, based on the 1997 data, is

$$Br(K_L^0 \rightarrow \pi^0\pi^0e^+e^-) < 5.4 \times 10^{-9}, \quad (4)$$

which is the first experimental result in this mode. A short letter is being prepared<sup>6</sup>.

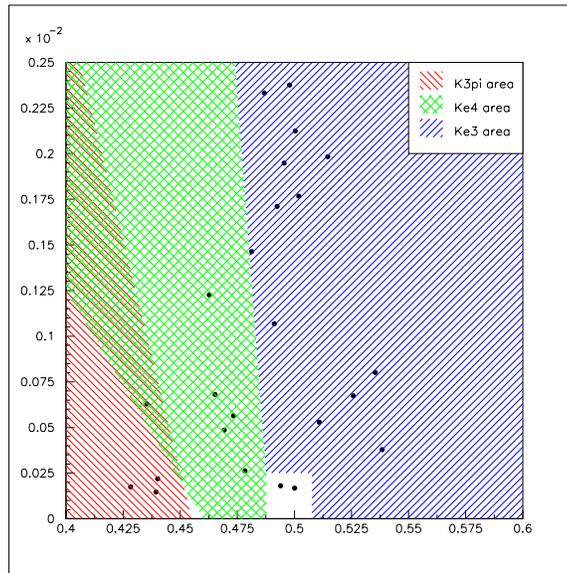
#### 4 Constraining $\rho_{CKM}$

The possibility of constraining or even measuring  $\rho_{CKM}$  with kaon decays has been studied for quite some time. The approach is to limit the short-distance contributions to  $K_L^0 \rightarrow \mu^+\mu^-$  by comparing the measured branching ratio for this process with known and large long-distance contributions which proceed through two photons. To understand these long-distance effect the decays  $K_L^0 \rightarrow \mu^+\mu^-e^+e^-$ ,  $K_L^0 \rightarrow e^+e^-e^+e^-$ ,  $K_L^0 \rightarrow e^+e^-\gamma$  and  $K_L^0 \rightarrow \mu^+\mu^-\gamma$  are of particular interest. At this time, the best limits on  $\rho_{CKM}$  are obtained using form factors from the  $K_L^0 \rightarrow \mu^+\mu^-\gamma$  channel, but these limits are much weaker than those existing from other global analyses. A more leisurely discussion is available in<sup>7</sup> and the references therein.

#### 5 Lepton Flavor Violation

At KTeV, we can search for the lepton flavor violating process  $K_L^0 \rightarrow \pi^0\mu^{\pm}e^{\mp}$ . Figure 2 shows the distribution of  $P_{\perp}^2$  versus the reconstructed mass in the 1997 data. The backgrounds are  $K_L^0 \rightarrow \pi^+\pi^-\pi^0$ ,  $K_L^0 \rightarrow \pi^0\pi^{\pm}e^{\mp}\nu$ , and  $K_L^0 \rightarrow \pi^{\pm}e^{\mp}\nu$  with other activity in the detector that appears as a  $\pi^0$ . The regions where these different backgrounds predominate are marked in Fig. 2; we estimate a background level of  $0.61 \pm 0.56$  events. There are two events in the signal

Figure 2:  $P_{\perp}^2$  vs. reconstructed mass in the data for the  $\pi^0\mu^{\pm}e^{\mp}$  channel.



region, and our preliminary 90% C.L. limit is

$$Br(K_L^0 \rightarrow \pi^0 \mu^{\pm} e^{\mp}) < 4.4 \times 10^{-10}. \quad (5)$$

## 6 More Data!

The data taken in 1999 will increase the KTeV data set by a factor of about 2.3. The kaon physics community in the U.S. is increasingly focused on the  $\pi\nu\bar{\nu}$  modes, which will permit placing theoretically clean constraints upon  $(\rho_{CKM}, \eta_{CKM})$ , and possibly the discovery of new physics if those constraints are incompatible with other results, such as the recent B factory results. Two collaborations proposed to study these modes using the Fermilab Main Injector; CKM proposed<sup>8</sup> to measure the  $K^+ \rightarrow \pi^+ \nu\bar{\nu}$  mode and KaMI proposed to measure  $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$ . After this conference, both programs were extensively reviewed. CKM won scientific approval from Fermilab, but KaMI unfortunately did not.

## References

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