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KTeV

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Representing the KTeV Collaboration

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Status of the KTeV Experiment at Fermilab

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The KTeV experiment is a fixed target experiment at Fermilab. Its primary goal is the search for direct CP violation in the decay of neutral kaons. Its current status and some preliminary results will be discussed.

1. Introduction

The primary goal of the KTeV experiment is the search for direct CP violation in the neutral kaon system. It is believed that CP is violated through two different processes. The first process has been observed and has been termed indirect CP violation. It is the result of mixing in the mass matrix through $K^0 - \bar{K}^0$ mixing. The second process, called direct CP violation, occurs in the decay amplitude.

The KTeV experiment is a fixed target experiment at Fermilab. It is, in fact, two different experiments. The first is E799-II, which searches for CP violation through the rare decay processes $K_L^0 \rightarrow \pi^0 \bar{l}l$ ($l = e, \mu, \nu$). These processes are expected to have a large CP violating amplitude, in contrast to $K_L^0 \rightarrow \pi\pi$, where the direct CP violating amplitude is $\ll 10^{-2}$ of the indirect CP violating amplitude. Table 1 shows the current theoretical predictions and experimental upper limits on the branching ratios, along with the expected sensitivity for E799-II. In addition, E799-II will also search for and/or measure other rare or forbidden decays. The other experiment is E832, which endeavors to measure the direct component of $K_L^0 \rightarrow \pi\pi$, parameterized as ϵ' .

E832 measures the double ratio of the four $K_{L,S} \rightarrow \pi\pi$ decay rates to determine $\text{Re}(\epsilon'/\epsilon)$ through the expression:

$$\frac{\Gamma(K_L^0 \rightarrow \pi^+\pi^-)/\Gamma(K_S^0 \rightarrow \pi^+\pi^-)}{\Gamma(K_L^0 \rightarrow \pi^0\pi^0)/\Gamma(K_S^0 \rightarrow \pi^0\pi^0)} \approx 1 + 6\text{Re}(\epsilon'/\epsilon). \quad (1)$$

Current experimental measurements of $\text{Re}(\epsilon'/\epsilon)$

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are:

$$\text{Re}(\epsilon'/\epsilon) = \begin{cases} (23 \pm 3.5 \pm 6.0) \times 10^{-4} & \text{NA31 [1]} \\ (7.4 \pm 5.2 \pm 2.9) \times 10^{-4} & \text{E731 [2]}, \end{cases}$$

while the theoretical predictions cover the range $(-50 \rightarrow +43) \times 10^{-4}$ [3]. KTeV's goal is to measure $\text{Re}(\epsilon'/\epsilon)$ to a precision of $\sim 1 \times 10^{-4}$.

In September of 1997, the Fermilab fixed target program completed a successful 15 month run. During that run, each of the two experiments had two running periods. E832 ran first, for seven weeks, accumulating roughly four times the statistical sample of the previous generation of the experiment, E731. E799-II ran next for eight weeks, almost quadrupling the number of kaons observed in E799-I. Taking both E832 running periods into account, approximately 16 times the statistical sample of E731 was accumulated. E799-II had a slightly shorter second run of 6 weeks, and almost doubled the statistical sample gathered in its first run. Most of what will be discussed in these proceedings will be based on data collected during the first running period of each experiment.

2. The KTeV Detector

To reduce detector performance dependence effects, E832 measures all four $K_{L,S} \rightarrow \pi\pi$ decay rates simultaneously. The charged mode decays are measured with a charged spectrometer, consisting of four drift chambers and an analysis magnet (two chambers on each side of the magnet). The neutral mode decays are measured with an electromagnetic calorimeter. A series of photon veto scintillation counters are used to de-

Table 1
Branching Ratios for the direct CP violating modes $K_L^0 \rightarrow \pi^0 \bar{l} l$.

Decay mode	Theory	Experimental limit	E799-II's goal in 1997
$K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$	$(2.8 \pm 1.7) \times 10^{-11}$ [4]	$< 5.8 \times 10^{-5}$ [5]	$< 1.8 \times 10^{-7}$
$K_L^0 \rightarrow \pi^0 e^+ e^-$	$10^{-11} - 10^{-12}$ [6]	$< 4.3 \times 10^{-9}$ [7]	$< 2.5 \times 10^{-10}$
$K_L^0 \rightarrow \pi^0 \mu^+ \mu^-$	6.3×10^{-12} [8]	$< 5.1 \times 10^{-9}$ [9]	$< 1.6 \times 10^{-10}$

The upper limits are presented at the 90% C.L.

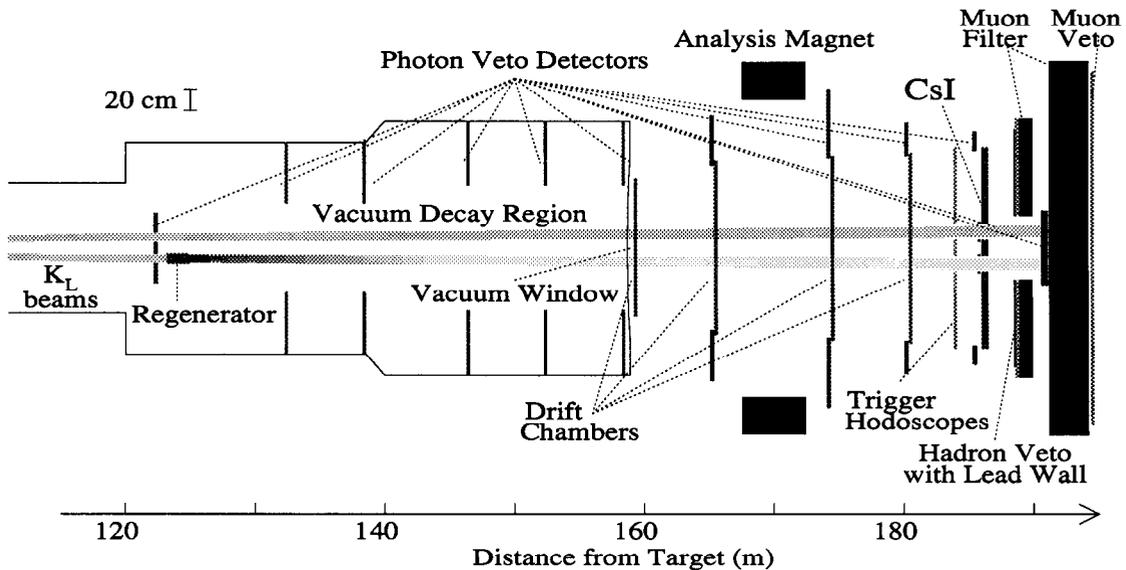


Figure 1. The KTeV spectrometer.

fect photons escaping the fiducial volume (see figure 1).

To simultaneously create both K_L^0 s and K_S^0 s, two parallel neutral kaon beams are created. The KTeV detector is located almost 30 K_S^0 lifetimes downstream from the target so that two parallel K_L^0 beams arrive at the detector. At 124 meters from the production target, one of the beams passes through a regenerator producing K_S^0 s. To reduce acceptance biases, the regenerator moves between the two beams, once per minute. Both the K_L^0 s and K_S^0 s decay inside the vacuum vessel.

For E799-II, the regenerator and the photon veto detector upstream of it are removed. To improve the π/e rejection, a necessity for rare kaon decay measurements, eight planes of transition

radiation detectors are placed directly after the most downstream drift chamber. They provide an additional 200:1 π/e rejection to the roughly 500:1 rejection of the calorimeter.

3. E832

3.1. Measurement Technique

To achieve the design precision on the measurement of $\text{Re}(\epsilon'/\epsilon)$ to 1×10^{-4} , both the statistical and systematic errors must be reduced relative to the E731 measurement.

To reduce the statistical error, several improvements were made to the experiment: the experiment ran with a more intense beam, the detector was upgraded to enable running at higher inten-

sity and trigger rates, the data acquisition live time was increased, and the the experiment took data for a longer period of time.

There are four dominant contributions to the systematic error: background events, uncertainty in the energy scale, acceptance, and accidental activity. Several detector and beam improvements will reduce background events: a new beamline design that was significantly cleaner than before, a fully active regenerator that will better separate events from interactions in the regenerator, a hermetic photon veto system, and a high resolution CsI calorimeter. The energy scale of the calorimeter will be calibrated to high precision using electrons from a large $K_L^0 \rightarrow \pi^0 \nu$ sample. The detector acceptance for charged mode and neutral mode decays will be studied using the large samples of $K_L^0 \rightarrow \pi^0 \nu$ and $K_S^0 \rightarrow 3\pi^0$ decays, respectively. Accidental activity, that is, activity not associated with the event, was reduced because of the improved beam design, the fully active regenerator, and improved timing resolution. It is expected that the combined systematic error on $\text{Re}(\epsilon'/\epsilon)$ will be less than 1×10^{-4} .

3.2. Status

Figure 2 shows the online invariant-mass plots for the four $K_{L,S} \rightarrow \pi\pi$ decays using statistics accumulated over the first running period. Offline analysis will remove approximately 30% of the events and reduce the backgrounds by an order of magnitude. A more thorough calibration of the detector will improve the mass resolution by $\sim 10\%$.

Combining both runs and after applying offline cuts, E832 will have accumulated $\sim 4 \times 10^6$ vacuum $\pi^0\pi^0$ decays (this is the mode that statistically limits the measurement). This will give a statistical error on $\text{Re}(\epsilon'/\epsilon)$ of $\sim 1.3 \times 10^{-4}$.

4. E799-II

In addition to the two running periods described in section 1, E799-II took data for one day, in a special configuration, optimized to search for $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$.

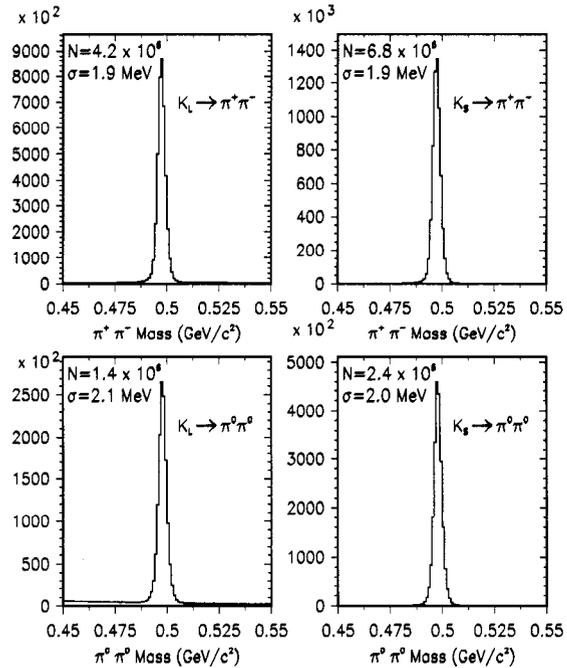


Figure 2. Invariant mass distributions for the four decay modes contributing to the measurement of $\text{Re}(\epsilon'/\epsilon)$. The decays from the beam going through the regenerator are in the histograms in the right column, while the decays from the vacuum beam are in the histograms in the left column.

4.1. Search for $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$

The branching ratio of $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ is directly proportional to the scale of CP violation in the Standard Model. The current status of the measurement is given in table 1.

The signature for the decay is a single π^0 with large transverse momentum, P_T , relative to the direction of the decaying K_L^0 . The detector configuration was optimized to search for a single π^0 during a special one day run. A single beam, $4 \times 4 \text{ cm}^2$ in size was used. In addition, the regenerator and transition radiation detectors were removed.

Figure 3 is the P_T distribution of the recon-

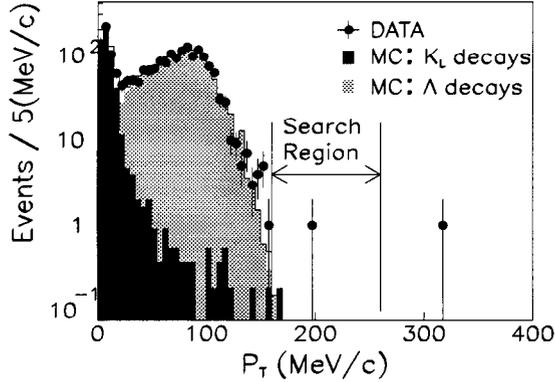


Figure 3. The π^0 transverse momentum distribution in the search for $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$, after all cuts except for the P_T cut have been applied. The data are overlaid on the simulation of the two dominant background modes. The events with a peak at zero come from the $K_L^0 \rightarrow \gamma\gamma$ decay.

structed π^0 s. The signal region requires the π^0 to have a P_T between 160 and 260 MeV/c, in order to be above the kinematic limit of π^0 s from the decay $\Lambda \rightarrow \pi^0 n$ and within the upper kinematic limit of the decay. There are two events with P_T greater than 160 MeV/c. One is in the signal region and the other is above it. Preliminary analysis of the data shows that the source of the events is most likely an interaction of a beam neutron with the detector, $n+n(p) \rightarrow n+2\pi^0+X$, where a photon from each π^0 is lost and the remaining two photons form a π^0 at the wrong z position and large P_T .

The analysis has not yet been completed, however, there is a preliminary result for the branching ratio. Using the decay $K_L^0 \rightarrow \pi^0 \pi^0$ as the normalization mode, the single event sensitivity for $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ is $(4.4 \pm 0.1) \times 10^{-7}$, where the event in the signal region is treated as background and the error quoted is entirely due to statistics. This gives an upper limit on the branching ratio of 1.8×10^{-6} at the 90% confidence level. This result is ~ 30 times more sensitive than the previous result.

4.2. $K_L^0 \rightarrow \pi^+ \pi^- e^+ e^-$

In addition to searches for direct CP violation at KTeV, there are searches for rare kaon decay modes. One such decay mode is $K_L^0 \rightarrow \pi^+ \pi^- \gamma^* \rightarrow \pi^+ \pi^- e^+ e^-$. The interest in this mode arises from the fact that the emitted γ^* s have a net circular polarization. This polarization arises from the interference of CP conserving and CP violating amplitudes. One amplitude is due to the inner bremsstrahlung of the CP violating $K_L^0 \rightarrow \pi^+ \pi^-$ decay. The other amplitude is from the CP conserving direct emission process. In the final state, the two amplitudes interfere with each other, causing the γ^* to be emitted with a net circular polarization. The net polarization can be determined by measuring an asymmetry in the angle between the electron and pion planes in the center of mass. The asymmetry is expected to be sensitive to indirect CP violation, however any deviation from the theoretical expectation could be a sign of new physics. The most recent experimental upper limit on the branching ratio is 4.6×10^{-7} , at the 90% confidence level [10], while the theoretical prediction is $\sim 3 \times 10^{-7}$ [11].

There are several signatures to the decay $K_L^0 \rightarrow \pi^+ \pi^- e^+ e^-$: four tracks originating at a common vertex, opposite signed π s and e s, the resultant momentum vector of the decay products should have a small component relative to a line connecting the target and the decay vertex, and the event must pass a kinematic cut designed to remove the dominant background mode $K_L^0 \rightarrow \pi^+ \pi^- \pi^0 \rightarrow \pi^+ \pi^- e^+ e^- \gamma$.

Figure 4 shows the $\pi^+ \pi^- e^+ e^-$ invariant mass distribution for approximately one sixth of the full E799-II data set. The $K_L^0 \rightarrow \pi^+ \pi^- e^+ e^-$ signal is clearly visible at the kaon mass. The events at lower invariant mass are from the background mode $K_L^0 \rightarrow \pi^+ \pi^- e^- e^+ \gamma$ decay, where the photon was missed.

A preliminary analysis of one day's worth of data yields 36.1 ± 6.4 signal events. This determines the branching ratio to be $(2.6 \pm 0.5) \times 10^{-7}$, where the statistical and systematic errors have been combined.

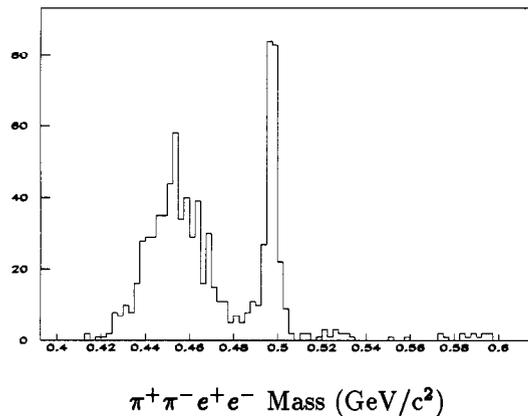


Figure 4. The reconstructed $\pi^+\pi^-e^+e^-$ invariant mass for approximately one sixth of the total data sample collected.

5. Summary

The KTeV experiment collected a very high quality data set at the design beam intensity. Over the next few years, the Fermilab kaon program will produce a multitude of significant results. Although the data collected thus far for E832 will not be enough to reach the design sensitivity on $\text{Re}(\epsilon'/\epsilon)$, another run is scheduled for 1999. It is expected that the data sample collected during this past run, will be doubled, thus lowering the statistical error on $\text{Re}(\epsilon'/\epsilon)$ to 0.9×10^{-4} .

The rare kaon program has also collected a large data set. Some of the decays modes under study have 100 times more events than previous measurements, so that definitive measurements of many rare processes will be made.

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