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A New Limit on $K_L \to \pi^0 e^+ e^-$

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Based upon the analysis of the complete data set of Fermilab experiment E-731, we report a new limit on the branching ratio of $K_L \to \pi^0 e^+ e^-$ which is $< 7.5 \times 10^{-9}$ (90% confidence).

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The decay $K_L \to \pi^0 e^+ e^-$ has raised considerable interest theoretically [1] and experimentally [2,3,4] for its ability to elucidate direct CP violation. Within the Standard Model, this decay mode is likely to have a ratio of direct CP violation to that from mixing ('ε/ε') of order one, unlike the one measured[5] through the $K \to 2\pi$ decay modes. Earlier, we reported[2] a limit, $B(K_L \to \pi^0 e^+ e^-) < 4.2 \times 10^{-8}$, based on a special data set collected in Fermilab experiment E-731. Here we update the limit using the entire data sample.

The apparatus and event reconstruction are described elsewhere [2,6]. The momenta of the e^+ and e^- and the decay vertex of $K_L \to \pi^0 e^+ e^-$ candidates were determined by the drift chamber spectrometer. The energies and positions of all the final state particles were measured by an 804 block lead glass calorimeter. Each of the showers (clusters) observed in the lead glass was required to be consistent with an isolated photon or e^+ or e^- (the 'shape' cut). The e^+ and e^- were identified by matching the reconstructed tracks with the calorimeter clusters, and requiring $0.85 < E/P < 1.15$, where E is the cluster energy deposited in the lead glass and P is the track momentum. We further required that the invariant mass of the e^+ and e^- (M_{ee}) be greater than 100 MeV/c^2. From a study of $K_L \to \pi^+ \pi^- \pi^0$ decays, the π^0 mass resolution was determined to be about 4 MeV/c^2. The $\gamma\gamma$ mass was required to be within 10 MeV/c^2 of the nominal π^0 value. By then constraining the $\gamma\gamma$ mass to the nominal value, the expected kaon mass ($M_{\pi ee}$) resolution is about 4.5 MeV/c^2. The square of the transverse momentum (P_t^2) of the $\pi^0 e^+ e^-$ system with respect to the line connecting the decay vertex and the production target has an expected resolution of about 50 MeV^2/c^2.

The candidates from the entire data set are displayed in a two dimensional $M_{\pi ee}$ vs. P_t^2 plot as shown in Fig. 1. A candidate is defined to have $P_t^2 < 200$ MeV^2/c^2, $489 < M_{\pi ee} < 507$ MeV/c^2 and $M_{ee} > 100$ MeV/c^2; these cuts would include about 90% of the signal. No candidate is found in the signal region.

The 'shape' and M_{ee} cuts were not applied for our previous result [2]. The 'shape'

requirement suppressed background events from K_{e3} decay with an accidental π^0 (or radiative K_{e3} decay with a single accidental photon) when the pion showered in the calorimeter and satisfied the E/P cut. The M_{ee} cut retained 95% of the signal while rejecting events with π^0s decayed to γe^+e^- where the π^0 came from a neutral kaon decay. The sparsely distributed events outside the box in Fig. 1 are consistent [4] with the residual K_{e3} plus accidental π^0 background.

The limit is obtained with data from two types of triggers. The 'four-cluster' trigger required four electromagnetic showers and 30 GeV or more energy deposited in the lead glass calorimeter. The 'two-track' trigger required two tracks in the tracking spectrometer. For kaon energy between 30 and 160 GeV and assuming a uniform three-body phase space distribution, the acceptance is 9.0 % for a fiducial decay volume of 18 meters for the 'four-cluster' trigger and is 10% for a fiducial decay volume of 17 meters for the 'two-track' trigger. The 'two-track' data, unlike those collected in the special data set [2], were not prescaled.

The upper limit is obtained by normalizing to samples of more than 10^5 $K_L \rightarrow \pi^0\pi^0$ and $K_L \rightarrow \pi^+\pi^-$ decays observed simultaneously. The limits obtained from the 'two-track' and 'four cluster' data are $< 3.6 \times 10^{-8}$ and $< 9.5 \times 10^{-9}$ (90% confidence) respectively. The combined result, $B(K_L \rightarrow \pi^0e^+e^-) < 7.5 \times 10^{-9}$ (90 % confidence) is an improvement of about factor of six from our previous result. This limit is also consistent with the recent result obtained by a Brookhaven experiment [7] and helps to limit the possible contribution from direct CP violation.

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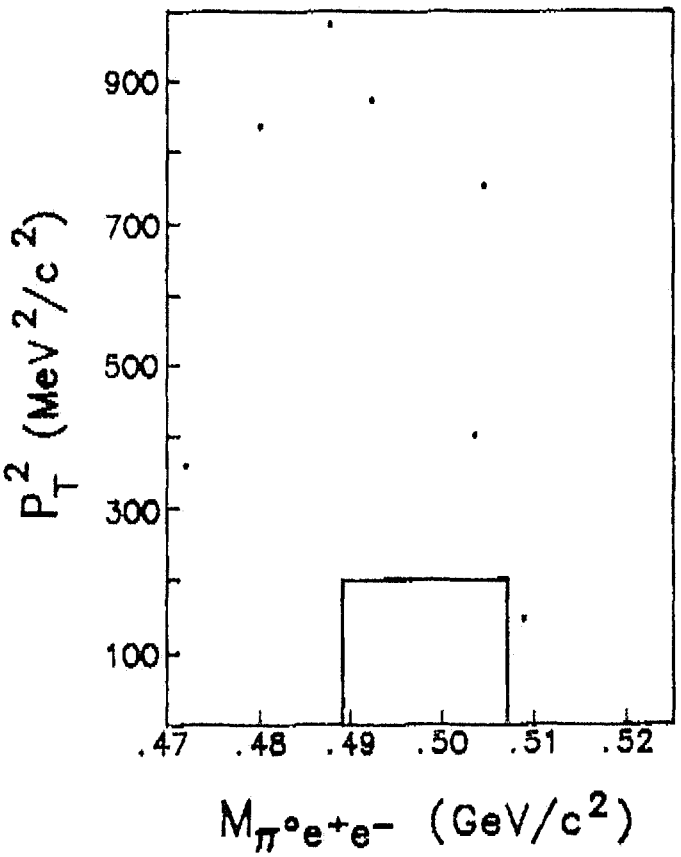
FIGURE CAPTIONS

Figure 1. Reconstructed kaon mass vs. the square of the transverse momentum for $K_L \rightarrow \pi^0 e^+ e^-$. The box represents the signal region.


900
700
500
300
100
P_T^2 (MeV^2/c^2)
.47
.48
.49
.50
.51
.52
$M_{\pi^0 e^+ e^-}$ (GeV/c^2)