RAPID COMMUNICATIONS

PHYSICAL REVIEW D VOLUME 41, NUMBER 11 1 JUNE 1990

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

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(Received 12 March 1990)

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).

The decay $K_L \to \pi^0 e^+ e^-$ has raised considerable interest theoretically[1] and experimentally[2-4] 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, which had its primary goal to determine ϵ'/ϵ from $K \to 2\pi$ modes. 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

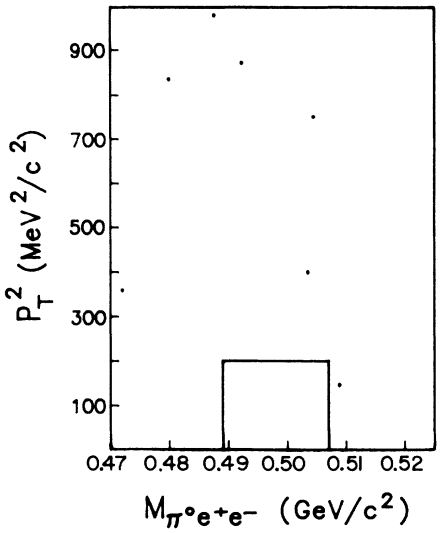

FIG. 1. Reconstructed kaon mass vs the square of the transverse momentum for $K_L \to \pi^0 e^+ e^-$. The box represents the signal region.

cut. The M_{ee} cut retained 95% of the signal while rejecting events with π^0's decayed to $\gamma e^+ e^-$ 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 m for the "four-cluster" trigger and is 10% for a fiducial decay volume of 17 m 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 $< 3.6\times10^{-8}$ and $< 9.5\times10^{-9}$ (90% confidence), respectively. The combined result $B(K_L \rightarrow \pi^0 e^+ e^-) < 7.5\times10^{-9}$ (90% confidence) is an improvement of about factor of 6 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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[5] J. R. Patterson *et al.*, Phys. Rev. Lett. **64**, 1491 (1990); H. Burkhardt *et al.*, Phys. Lett. B **206**, 169 (1988).

[6] For a complete description of the detector, see J. R. Patterson, Ph.D. thesis, University of Chicago, 1990.

[7] The result from the BNL-Vassar-Yale experiment (AGS-845) is $B(K_L \rightarrow \pi^0 e^+ e^-) < 5.5\times10^{-9}$ (90% C.L.). See M. Schmidt *et al.*, in Proceedings of the Meeting of the APS Division of Particles and Fields, Houston, Texas, 1990 (unpublished); K. E. Ohl *et al.*, Yale University report (unpublished).