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A New Measurement of CP Violation Parameter ϵ'/ϵ^*

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A NEW MEASUREMENT OF CP VIOLATION PARAMETER ϵ'/ϵ

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The E731 experiment at Fermilab has measured the CP violation parameter $\text{Re}(\epsilon'/\epsilon)$ in $K_{L,S} \rightarrow \pi\pi$ decay. Four decay modes were collected simultaneously to reduce systematic errors. The result is $\text{Re}(\epsilon'/\epsilon) = -0.0005 \pm 0.0014$ (stat.) ± 0.0006 (syst.), and gives no evidence for direct CP violation.

E731 is a collaboration of University of Chicago, Fermilab, Elmhurst College, Princeton University, and Saclay.

1. INTRODUCTION

The existence of direct CP violation can be tested by measuring the double ratio of branching ratios :

$$R_{00/\pm} = \frac{\Gamma(K_L \rightarrow \pi^0\pi^0)/\Gamma(K_S \rightarrow \pi^0\pi^0)}{\Gamma(K_L \rightarrow \pi^+\pi^-)/\Gamma(K_S \rightarrow \pi^+\pi^-)}$$

$$= 1 - 6\text{Re}(\epsilon'/\epsilon)$$

The standard model¹ predicts $\text{Re}(\epsilon'/\epsilon) = O(10^{-3})$ whereas the SuperWeak model² predicts 0.

2. EXPERIMENT

2.1. Technique

In order to reduce systematic errors, K_L and K_S decays were taken simultaneously using the same trigger and detector. The K_S beam was made by placing a regenerator in one of two parallel K_L beams. This technique reduced the effect of changes in chamber gas gain, calorimeter response, and accidental activity (which can be different between charged and neutral detectors) to high order.

The disadvantage of this technique is that we had to rely on Monte Carlo to find the detector acceptance as a function of decay vertex because of a large lifetime difference between K_L and K_S . In order to check the acceptance and detector performance, we took >100 times more K_{e3} and $K_L \rightarrow \pi^0\pi^0\pi^0$ events compared to the $K_L \rightarrow 2\pi$ events.

Kaons were produced by 800GeV protons incident at 5 mrad on a beryllium target. The regenerator was located 123m downstream of the target.

The new result is based on 20% of the full data set; in this sample, all four modes were recorded simultaneously.

2.2. Charged mode

$K_{L,S} \rightarrow \pi^+\pi^-$ events were triggered by requiring two charged particles and no muons. The position and momentum of the charged pions were measured by four drift chambers with a resolution of $100\mu\text{m}$, and a spectrometer magnet with p_T kick of $0.2\text{GeV}/c$. The good kaon mass resolution, $3.4\text{MeV}/c^2$, eliminated $K_L \rightarrow \pi^+\pi^-\pi^0$ events and largely reduced background from $K_L \rightarrow \pi e \nu$. The squared transverse

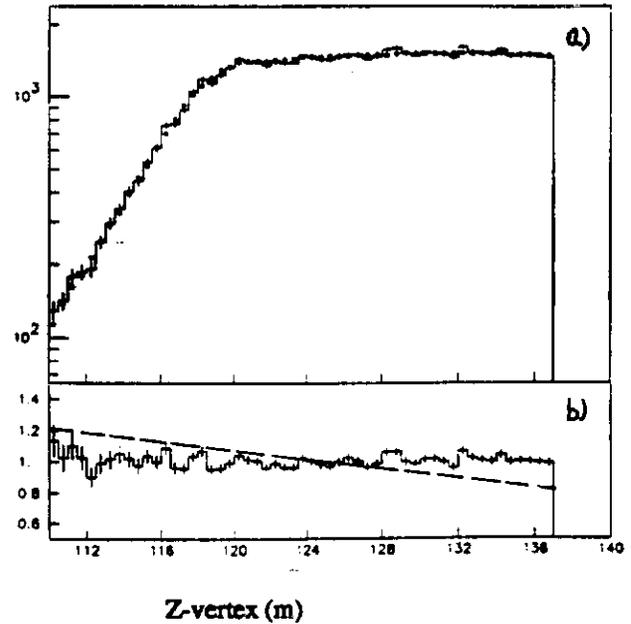


Fig.1. a) Distribution in decay vertex for $K_L \rightarrow \pi^+\pi^-$ events. The line (dot) is for data (Monte Carlo). b) Ratio of data to Monte Carlo. This ratio would follow the dashed line were there an acceptance error large enough to cause a 2% shift in the K_S to K_L ratio.

momentum of the $\pi^+\pi^-$ system with respect to the initial K_L direction, p_T^2 , was used to subtract non-coherent regeneration background in the K_S beam and K_{e3} background in the K_L beam. The background in the K_S and K_L samples were $(0.13 \pm 0.01)\%$ and $(0.31 \pm 0.06)\%$, respectively.

Figure 1 shows the K_L decay z-vertex distribution, and the ratio between data to Monte Carlo. The excellent agreement shows our good understanding of the acceptance.

2.3. Neutral mode

A leadglass calorimeter located 181m from the target was used to measure the energy and position of photons from $K_{LS} \rightarrow \pi^0\pi^0$ events. The neutral mode trigger required a total energy deposition $> 30\text{GeV}$ and four or six clusters found by a trigger processor³; a cluster is defined by a group of neighboring blocks, each of which had more than 1GeV deposited. The energy resolution of the glass was about $1.5(2.5)\% + 5\%/\sqrt{E}$ for electrons (photons), and the position resolution was about 3mm.

Figure 2 shows the invariant mass distribution for the K_L candidates. The background, caused by photons from $K_L \rightarrow 3\pi^0$ missing the leadglass, is reduced to 0.37%, by eleven planes of "photon vetoes" placed outside the solid

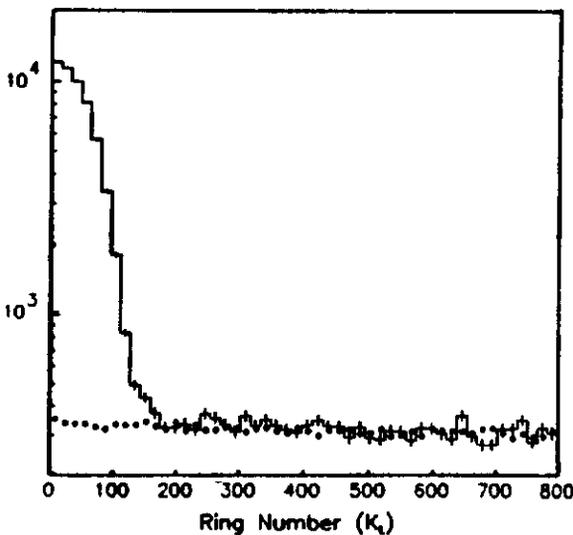


Fig.2. Invariant mass distribution for $K_L \rightarrow 2\pi^0$ events. The histogram is the data, and the dots are the Monte Carlo for the $K_L \rightarrow 3\pi^0$ background, absolutely normalized.

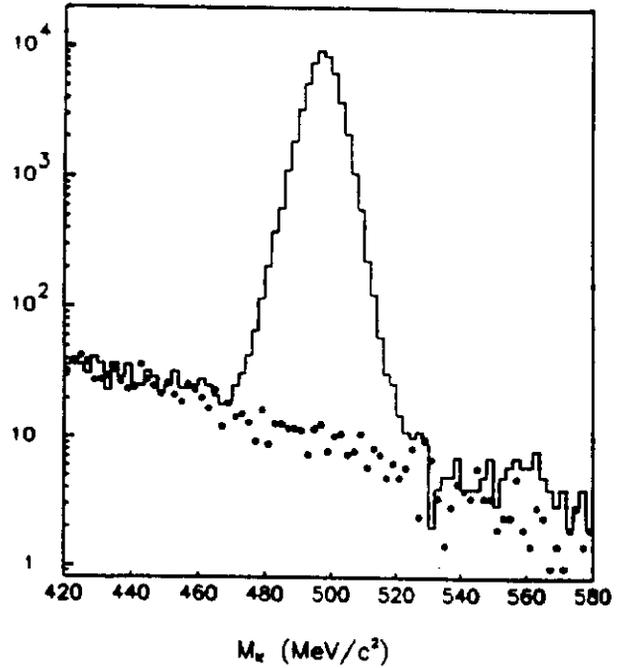


Fig.3. The 'ring plot' around the center of the vacuum beam for $2\pi^0$ events. The histogram is data, and the dots are the absolutely normalized background predicted by Monte Carlo.

angle of the leadglass array.

The major background in the neutral mode comes from noncoherent regeneration events at the regenerator, which are not as well resolved as in the charged mode because we do not have as good a measurement of P_T^2 . The background was subtracted by using a plot of the event density in concentric rings away from each beam. Fig.3 shows such a plot for the vacuum beam. The overlaid points are the absolutely normalized background predicted from a neutral mode Monte Carlo simulation where the P_T^2 shape is measured by the charged mode events. The background was $4.66 \pm 0.14\%$ for K_L and $2.58 \pm 0.07\%$ for K_S .

2.4. Monte Carlo simulation

A detailed Monte Carlo simulation of the beam and the detector properties was used for the acceptance correction. The Monte Carlo treats:

- simulated photon cluster shape by using electron data and EGS-simulation⁴,
- initial photon conversion in the lead-glass,
- different light attenuation lengths in the glass blocks which were measured by electron calibration,
-

shower leakage checked by data and EGS, e) inherent phototube resolution measured by a flasher system, f) internal and external radiation, g) detector configuration and apertures which are found by K_{e3} and μ tracks, h) drift chamber wire efficiencies and a few dead wires found by K_{e3} and μ tracks, j) dead time in the drift chamber electronics, and k) capability of overlaying accidental activity. The only things which did not come from the first principles are the K^0 and \bar{K}^0 momentum spectra and the beam shape; adjusting them had little effect on results. We did not even have a tunable parameter to adjust the leadglass resolution, but the simulation reproduced the non-linear and non-gaussian response of a lead glass block to photons (studied with $\pi^+\pi^-\pi^0$ decays).

3. EXTRACTION OF ϵ'/ϵ

We required that the reconstructed z-vertex to be between 120m and 137m from the target, and the reconstructed kaon momentum to be between 40GeV and 150GeV. The events were then divided into 10GeV momentum bins for the following corrections and extraction of the result.

First, corrections were made for the backgrounds and the residual K_S decays in the K_L beam. The overall correction to the double ratio was 2.5%.

The number of events was then corrected for the acceptance of the detector, which are listed in Table 1. Note that the difference between K_L and K_S acceptance is small. The overall correction due to the acceptance is 4.4%.

Table 1. Acceptance

	neutral	charged
vacuum beam	0.1885	0.5041
regenerated beam	0.1813	0.5064

The data was then fit for a functional form of the ratio of integrated decay rates. The decay rate for vacuum (regenerated) beam, $R_V (R_R)$, is given by:

$$R_V^{\pm} \propto |\eta_{\pm}|^2$$

$$R_R^{\pm} \propto |\rho e^{-i/2\tau_s + i\delta_{\text{int}}} + \eta_{\pm}|^2$$

where ρ is the regeneration amplitude, and η is the ratio of

amplitude of $K_L \rightarrow 2\pi$ to that of $K_S \rightarrow 2\pi$ decay. The ratio of the integrated number of regenerated to vacuum decays, $R_{\pm}(R_{00})$ for charged (neutral) mode, is simply a function of $|\rho/\eta|$. Note that since $|\rho| \approx 10 |\eta|$, the ratios are roughly

$$R_{\pm} = \int R_R^{\pm} dt / \int R_V^{\pm} dt \propto |\rho/\eta_{\pm}|^2 \quad \text{and}$$

$$R_{00} = \int R_R^{00} dt / \int R_V^{00} dt \propto |\rho/\eta_{00}|^2$$

thus

$$R_{00/\pm} \approx R_{\pm}/R_{00}$$

$\text{Re}(\epsilon'/\epsilon)$ was obtained by making a grand fit for both R_{\pm} and R_{00} with floating regeneration parameters. The result is:

$$\text{Re}(\epsilon'/\epsilon) = -0.0005 \pm 0.0014 \text{ (stat.)}$$

4. SYSTEMATIC ERRORS

The possible sources of systematic errors include uncertainty in the acceptance, energy scale and non-linearities in the lead-glass detector, backgrounds, and accidental activities. The total systematic error on the double ratio was 0.38%, where each uncertainty is discussed here in detail.

4.1. Acceptance

We have used the high statistics modes to estimate the possible systematic error.

For the neutral mode, we modified the $2\pi^0$ acceptance by the ratio of data to Monte Carlo obtained from 6 million $K_L \rightarrow 3\pi^0$ events; the shift in R_{00} was 0.08%.

For the charged mode, we used the same technique by using 10 million K_{e3} events. The shift in R_{\pm} was 0.05%. We also made fits in 2m z-vertex bins to nearly eliminate the dependence on acceptance, and found a consistent result. We varied apertures, beam shapes, cuts, and detector efficiencies, and assigned a systematic uncertainty of < 0.18% for each mode.

4.2. Energy scale/resolution/non-linearity

The energy scales of charged and neutral decays have to be identical, since the single ratio depends on the kaon energy; the K_L decay rate is $\propto E^{-1}$ due to the finite decay volume, and the K_S decay rate is $\propto E^{-1.2}$ due to regeneration.

The energy scale in charged mode is easily determined by using the K_S mass. The overall shift that we made for the measured field map of the spectrometer was < 0.4%.

Each lead glass block was calibrated by special runs using electron positron pairs. The electron momentum was measured by the same field map used for the charged mode. The calibration was also used to find the nonlinearity of the blocks. The calibration was good to 0.1% for electrons, but there remained a response difference between electrons and photons; the overall kaon energy was adjusted ($\approx 0.5\%$) by using the sharp edge in the K_S decay vertex at the regenerator. The residual uncertainty in the energy scale was 0.1%. The uncertainty in R_{00} was less (0.03%) because we chose the fiducial region to make approximately the same number of K_L decays leave at the downstream boundary as they enter at the upstream boundary when the energy scale was shifted.

There was however, an uncertainty in the energy resolution, and we estimated a 0.2% uncertainty in R_{00} .

4.3. Backgrounds

The background levels and their uncertainties were discussed before. The overall uncertainty in the double ratio due to the background subtraction is 0.18%.

4.4. Accidental effects

The accidental activity in the detector can cause good events to fail the analysis cuts. To first order, this effect is approximately the same between K_L and K_S since the both decays are taken simultaneously. However, there could be a residual systematic error caused by the combination of the difference in the accidental activity between the two beams, and the difference in the illuminations of K_L and K_S decays.

We have collected accidental events throughout the run with rate proportional to the instantaneous beam intensity; these events had a photon cluster 2.7% of the time and an average of 8.5 chamber hits in total. We overlaid the accidental events on Monte Carlo events to study the possible effect. The procedure reproduced a 3% loss in charged reconstruction efficiency for both beams over the intensity range of the data. There was, however, no asymmetry between K_L and K_S events within 0.07% for either mode; the possible bias on the $R_{00,\pm}$ from accidental activity is 0.10%.

5. OTHER CHECKS

We used the same data and analysis to fit for τ_S and Δm to check our procedure. Neutral and charged fits were consistent and the combined results were $\tau_S = (0.8902 \pm 0.0021) \times 10^{-10} \text{sec}$ and $\Delta m = (0.534 \pm 0.009) \times 10^{10} \text{hsec}^{-1}$, where the errors are statistical. The results are consistent with the accepted values⁵, giving increased confidence in our ϵ'/ϵ result.

6. THE RESULT AND CONCLUSIONS

Our final result is :

$$\text{Re}(\epsilon'/\epsilon) = -0.0005 \pm 0.0014(\text{stat.}) \pm 0.0006(\text{syst.}).$$

We conclude that :

- a) the result is consistent with zero, and does not confirm the recent evidence for direct CP violation⁶;
- b) the result is consistent with the superweak model² and also consistent with the standard model with a high top quark mass⁷.

The statistical error will be further reduced when we analyze the full data set.

REFERENCES

1. See for example, A.J.Buras, Rare Decay Symposium, Vancouver, Canada, Nov.30 - Dec. 3, 1988.
2. L.Wolfenstein, Phys. Rev. Lett. 13, 569 (1964).
3. H.Sanders *et al.*, IEEE Trans. Nucl. Sci. 36, 358 (1988).
4. W.R.Nelson, H.Hirayama and D.W.O.Rogers, SLAC-Report-265 (1985).
5. Particle Data Group, G.P.Yost *et al.*, Phys. Lett. B204, 1 (1988).
6. H.Burkhardt *et al.*, Phys. Lett. B206, 169 (1988) find $\text{Re}(\epsilon'/\epsilon) = 0.0033 \pm 0.0007(\text{stat.}) \pm 0.0008(\text{syst.})$.
7. A.Buras and J.M.Gerard, Phys. Lett. B203, 272(1988); C.S.Kim, J.L.Rosner, and C.P.Yuan, DTP-89-52, EFI 89-47, ANL-HEP-PR-119.