Status of the $Re(\epsilon'/\epsilon)$ and δ_{Ke3} Analyses in KTEV

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1. Introduction

The KTeV experiment at Fermilab was designed primarily to measure the direct CP violating parameter $Re(\epsilon'/\epsilon)$ with much better precision than previous measurements at Fermilab[1] and CERN[2]. The measured quantity is the double ratio of decay rates,

$$\mathcal{R} \equiv \frac{\Gamma(K_L \to \pi^+\pi^-)/\Gamma(K_S \to \pi^+\pi^-)}{\Gamma(K_L \to \pi^0\pi^0)/\Gamma(K_S \to \pi^0\pi^0)} \tag{1}$$

where $\mathcal{R} \simeq 1 + 6Re(\epsilon'/\epsilon)$. The CP-violating $K_L \to 2\pi$ decays can be explained by the parameter $\epsilon \sim 2 \times 10^{-3}$, which describes the tiny CP-violating asymmetry in the $K^0 \leftrightarrow \overline{K^0}$ mixing. If the double ratio $\mathcal{R}$ differs from unity, i.e., $Re(\epsilon'/\epsilon) \neq 0$, this would be a clear indication of direct CP-violation in the decay amplitude. In short,

$$\mathcal{R} \neq 1 \implies A(K^0 \to 2\pi) \neq A(\overline{K^0} \to 2\pi) \tag{2}$$

which would demonstrate that a particle and its anti-particle partner can decay differently.

The experimental challenge is to measure the double ratio $\mathcal{R}$ based on millions of decays, and then to control the systematic uncertainties to much better than a percent. The key is to collect K_L and K_S decays at the same time so that common charged or neutral mode systematic uncertainties will cancel in the K_L/K_S single ratios.

2. Results and Status of $Re(\epsilon'/\epsilon)$

New results have been published by both the Fermilab KTEV experiment[3], and CERN NA48[4],

$$Re(\epsilon'/\epsilon) = [28.0 \pm 3.0(stat) \pm 2.8(syst)] \times 10^{-4} \quad \text{(FNAL 99)} \tag{3}$$

$$Re(\epsilon'/\epsilon) = [18.5 \pm 4.5(stat) \pm 5.8(syst)] \times 10^{-4} \quad \text{(CERN 99)} \tag{4}$$

clearly establishing that $Re(\epsilon'/\epsilon)$ is non-zero. The KTEV result above is based on roughly 1/8 of the total data sample, where the "total" sample includes data sets collected in 1996, 1997 and 1999. A result based on all of the 1997 data ($\times 3$ increase in statistics) is expected in the spring of 2001. Great attention to systematic uncertainties will continue as we now enter the era of *precision* $Re(\epsilon'/\epsilon)$ measurements.

At this time the charged mode $K_{L,S} \to \pi^+\pi^-$ analysis has been completed, and the value of its acceptance-corrected single ratio[1] is consistent with the published result to better than one standard deviation. The largest systematic uncertainty in [3] was due to a 2.5σ discrepancy between data and Monte Carlo [MC] in the $K_L \to \pi^+\pi^-$ decay vertex distribution, and resulted in an uncertainty of 1.6×10^{-4} in $Re(\epsilon'/\epsilon)$. In the remaining 3/4 of the 1997 data set there is no such discrepancy; a fit to the ratio of data/MC vs. decay vertex gives a "z-slope" of $(0.0 \pm 0.4) \times 10^{-4}$/meter. The meaning of this z-slope is that our MC predicts the relative number of $K_{L,S} \to \pi^+\pi^-$ decays along the 40 meter decay region with a precision of $40\ m \times (0.4 \times 10^{-4}/m) < 0.2\%$. The different z-slopes in the two data periods could be due to

[1] the acceptance-corrected single ratio is proportional to $|\eta_{+-}|^2$

some improvements in the calibration and simulation, or it could be due to a fluctuation in the data; the $K_{L,S} \to \pi^+\pi^-$ data from the published result are being re-processed to resolve this issue.

At the conference I had shown a data/MC comparison for $K \to \pi e \nu$ decays which indicated a 2σ discrepancy. This was later found to be due to a missing kinematic cut which had let in some background; after applying this cut the data and MC decay vertex distributions agree very well, with a data/MC z-slope of $(0.2 \pm 0.2) \times 10^{-4}$/meter.

The neutral mode analysis has recently been completed and final systematic uncertainties are under evaluation. The data/MC comparison of the decay vertex distribution is still very good for both $K_L \to 2\pi^0$ and for $K_L \to 3\pi^0$ decays.

3. $K_L \to \pi e \nu$ Charge Asymmetry

The calibration of the CsI electromagnetic calorimeter was based on tracking electrons and positrons from $K_L \to \pi e \nu$ decays. This enormous sample of 3×10^8 fully reconstructed $K_L \to \pi e \nu$ decays is nearly ten times larger than what has been used previously to measure the charge asymmetry, and may be the largest *signal* sample ever analyzed in a particle physics experiment. The charge asymmetry is defined as

$$\delta_{Ke3} \equiv \frac{N(K_L \to \pi^- e^+ \nu) - N(K_L \to \pi^+ e^- \nu)}{sum} \quad (5)$$

$$= 2Re(\epsilon - \Delta - Y - X_-) \quad (6)$$

where $\epsilon \simeq 0.0022$ is the indirect CP violation parameter that describes the $K^0 \leftrightarrow \overline{K^0}$ mixing asymmetry, and the other parameters describe CPT violation in mixing (Δ), in the decay amplitude with $\Delta S = \Delta Q$ (Y) and in the decay amplitude with $\Delta S \neq \Delta Q$ (X_-).

The PDG2000 average of the charge asymmetry for $K_L \to \pi e \nu$ and for $K_L \to \pi \mu \nu$ is $(0.327 \pm 0.012)\%$, and is based mainly on CERN experiments in the early 1970s. Using the PDG2000 magnitude and phase of η_{+-} for ϵ gives $2Re(\epsilon) = (0.331 \pm 0.004)\%$. The experimental results for δ_{Ke3} and ϵ give excellent agreement with eq. 5-6 without invoking the CPT violating terms. Note that the experimental error on $|\eta_{+-}|$ is 1.2%, which is six times larger than the $Re(\epsilon'/\epsilon)$ correction of 0.2%.[2] The corresponding experimental error on the charge asymmetry is 3.6%. Our analysis of 300 million $K_L \to \pi e \nu$ decays will reduce the charge asymmetry uncertainty by roughly a factor of two.

The KTEV experiment used two parallel K_L beams, and a regenerator alternated between the two beams each minute to produce K_S for the $Re(\epsilon'/\epsilon)$ measurement. This also had the effect of alternating the source of $K_L \to \pi e \nu$ decays since regenerator beam $K_L \to \pi e \nu$ are ignored in the charge asymmetry analysis. The magnet polarity was also reversed roughly once per day. To reduce systematic uncertainties, δ_{Ke3} is obtained from the four-fold geometric mean of the four possible configurations involving magnet polarity and K_L beam position. This means that each "N" factor in eq. 5 is replaced by $(N_{+R}N_{+L}N_{-R}N_{-L})^{1/4}$, where the sign refers to magnet polarity and R, L refer to the right and left K_L beam positions.

Note that a Monte Carlo correction is *not* required, but corrections are needed to account for differences in the detection efficiency between π^{+-} and and e^{+-}. These corrections are based on additional data sampes collected in-situ, such as $K_L \to \pi^+\pi^-\pi^0$ decays to help understand charged pions. The largest correction is 0.016% in δ_{Ke3}, and is due to the pion cut that requires $E/p < 0.9$, where E is the energy deposited in the CsI calorimeter and p is the momentum measured in the magnetic spectrometer (note that $E/p \simeq 1$ for e^{+-}). A preliminary KTEV result on δ_{Ke3} is expected to be presented at the winter conferences in 2001.

REFERENCES

1. L.K.Gibbons *et al.* (E731 Collaboration), Phys. Rev. Lett. **70**, 1203 (1993).
2. G.Barr *et al.* (NA31 Collaboration), Phys. Lett. B **B317**, 233 (1993)
3. A.Alavi *et al.* (KTEV Collaboration), Phys. Rev. Lett. **83**, 22 (1999).
4. V.Fanti *et al.* (NA48 Collaboration), Phys. Lett. B **B465**, 335 (1999)

[2] Recall that $\eta_{+-} \simeq \epsilon + \epsilon'$