CONF-8410222--3

BNL--35841

DE85 006687

A Measurement of ε'/ε

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Results are presented for a measurement at the Brookhaven AGS of the CP-violating parameter ε'/ε. The value determined, $\varepsilon'/\varepsilon = 0.0017 \pm 0.0082$, places important constraints on interesting models of CP violation.

I. INTRODUCTION

After twenty years of intense scrutiny CP violation is apparently still well described, if not explained, by the "superweak"[1] hypothesis, in which $|\Delta S| = 2$ (T-violating) transitions between the K^0, $\bar{K}^0$ states induce CP violating impurities in the K^0_L, K^0_S states. CP-violating effects observed in the $K^0 - \bar{K}^0$ system can be described in terms of one parameter, $|\varepsilon| \approx 2 \times 10^{-3}$, which defines the portion of the CP-even state K^0_1 found in the predominantly CP-odd K^0_L state: $K^0_L \propto K^0_2 + \varepsilon K^0_1$.

A precise measurement of the relative rates for the CP-violating decays $K^0_L \to \pi^+\pi^-$ and $K^0_S \to \pi^0\pi^0$ in principle provides a test for $|\Delta S| = 1$ CP-violating amplitudes which result in deviations from the "superweak" predictions: $\eta^{00} = \eta^{+-} = \varepsilon$, where η^{+-} and η^{00} are the ratios of K_L to K_S decay amplitudes into $\pi^+\pi^-$ and $\pi^0\pi^0$ final states. Gauge theory models of CP-violation are in general constructed to nearly mimic "superweak" predictions by having the dominant contribution to CP-violation arise from complex terms in the $K^0 - \bar{K}^0$ mixing amplitudes. However, there are usually additional contributions in the form of direct CP violating $|\Delta S| = 1$ decay amplitudes, parametrized by ε', which are not identical for the weak transitions into isospin I = 0 and 2 $\pi\pi$ final states. The effect of the direct amplitude is apparent from $\eta^{+-} \approx \varepsilon + \varepsilon'$ and $\eta^{00} \approx \varepsilon - 2\varepsilon'$, yielding $R = |\eta^{+-}|^2/|\eta^{00}|^2 = 1 + 6\varepsilon'/\varepsilon$.

II. THE EXPERIMENT

The Yale-BNL group has recently completed a measurement of R and thus ε'/ε at the Brookhaven AGS. The experiment is conceptually simple, involving a neutral beam (0°, 3.5 μsr) passing through the center of a detector consisting of multiwire proportional chambers (2560 wires) and scintillation counter arrays placed about a spectrometer magnet (24" gap, $\Delta p_t = 150$ MeV/c) and a large (208 element) lead glass array. The relative intensities for $K^0 \to \pi^+\pi^-$ and $K^0 \to \pi^0\pi^0$ decays were determined for two beam conditions: a K^0_L beam (no regenerator) and a predominantly K^0_S beam as afforded by a removable 80 cm carbon regenerator placed with the exit face 120 cm upstream of the beginning of the 120 cm fiducial decay volume. The detector was simultaneously sensitive to charged and neutral decays through different regions of solid angle.

The determination of R is obtained by taking the ratio of intensity ratios $R = R_L/R_S$ where $R_L = I(K_L \to \pi^+\pi^-)/I(K_L \to \pi^0\pi^0)$ and $R_S = I(K_S \to \pi^+\pi^-)/I(K_S \to \pi^0\pi^0)$ so that the detector efficiency and acceptance drops out to first order. The beam condition K_L or K_S, was changed several times per shift, to reduce possible biases associated with long term variations in the detector response.

Neutral event triggers were required to have one and only one gamma ray convert in a 1 mm thick lead sheet at the end of the decay volume and > 5 GeV of energy in the lead glass array as determined from a fast analog sum. The converted pair trajectories allowed, in combination with the narrow neutral beam ($\sigma_r = 0.5$ cm), a determination of the decay vertex ($\sigma_z = 13$ cm). Backgrounds for $K^0_L \to 2\pi^0$ due to $K^0_L \to 3\pi^0$ were largely suppressed by the detection of extra gamma rays outside the lead glass array by lead-scintillator veto counters and an additional small array of lead glass downstream of the hole in the main array.

Charged event triggers required two charged particles on opposite sides of the neutral beam as defined by scintillation counters in a 4 cm high horizontal gap in the gamma converter.

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Backgrounds due to $K_{\mu 3}$ decays were largely suppressed by vetos from a scintillation counter array behind a 60 cm steel wall following the lead glass array. K_{e3} backgrounds were largely eliminated (on-line) by the electron identification afforded by the lead glass array. Data acquisition was accomplished via our Brookhaven Fastbus system.[2]

Figure 1 shows the mass plot distributions for events finally included in the data sample. Charged events were required to fit, in addition to particle identification criteria, kinematics expected of a two body decay. Events were selected such that "χ_c^2" = $(\Delta\theta/0.75\ \mathrm{mr})^2 + (p_t/20\ \mathrm{MeV/c})^2 < 3$, where $\Delta\theta$ and p_t are the coplanarity and transverse momentum inbalance for the event. Neutral events were required to have the topology of a $2\pi^0$ event with "χ_n^2" = $(\bar{X}/2\mathrm{cm})^2 + (\bar{Y}/2\mathrm{cm})^2 + (\Delta Q_1/10\ \mathrm{MeV})^2 + (\Delta Q_2/10\ \mathrm{MeV})^2 < 10$, where $\bar{X}$ and $\bar{Y}$ are the first moments of energy in the lead glass array, and ΔQ_1, ΔQ_2 are the differences between the reconstructed and true π^0 mass for the two best gamma pair combinations. Charged and neutral events were required to have kaon energies 7 GeV < E_K < 14 GeV.

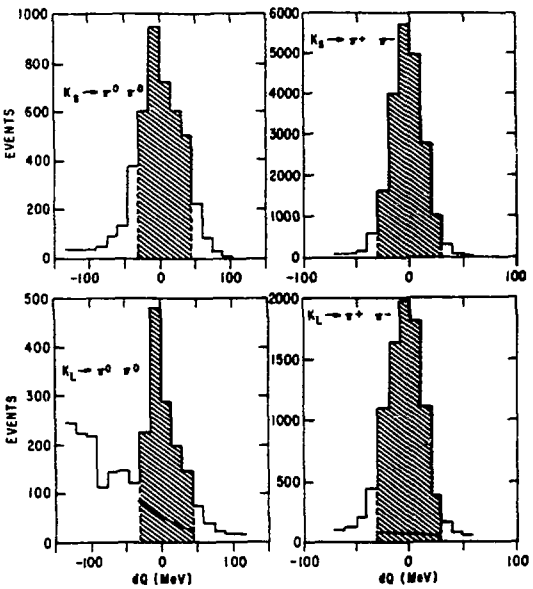

Figure 1. Mass distributions for the events surviving analysis.

The final event sample contains 1361 $K^0_L \to 2\pi^0$, 3537 $K^0_S \to 2\pi^0$, 8680 $K^0_L \to \pi^+\pi^-$ and 20963 $K^0_S \to \pi^+\pi^-$ events. A value for R was determined through a weighted mean of R_{ij} as determined in 7, 1 GeV energy bins and 6, 20 cm regions of decay space. This allowed the required cancellation of acceptance factors, despite the differences in energy and decay position distribution for the four event types, without explicit dependence on Monte Carlo results, which however agreed with the observed distributions. The background for $K^0_L \to 2\pi^0$, primarily due to $K^0_L \to 3\pi^0$ decays and neutron interactions with helium in the decay volume is found to be 17.5 ± 3.0% of the signal (− 30 MeV < ΔQ < + 45 MeV in Fig. 1) when averaged over the 42 data bins. Further corrections of the order of 2% are required for backgrounds in the other modes, for incoherent K_S production and K_L dilution of the nominal K_S decays. After these corrections we obtain R = 1.010 ± 0.043 (stat) ± 0.026 (sys), and compounding the errors we find ε'/ε = 0.0017 ± 0.0082 consistent with zero, with previous results[2,3], and with the recent value obtained at Fermilab[4] of ε'/ε = − 0.0046 ± 0.0058 (again, errors have been compounded). If we permit ourselves to combine these two most recent results we find ε'/ε = − 0.0025 ± 0.0047, a value which is not in agreement with the expectations of milliweak Higgs models ($\varepsilon'/\varepsilon \lesssim -0.02$) or the KM 6-quark model ($\varepsilon'/\varepsilon \gtrsim 0.01$) of CP violation.[5]

This work is supported in part by the U.S. Department of Energy under Contract Numbers DE-AC02-76ER03075 and DE-AC02-76CH00016

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