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SEARCH FOR THE VIOLATION OF TIME-REVERSAL INVARIANCE IN $K_{\mu 3}$ DECAYS

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ABSTRACT

We have measured the polarization of the μ^+ from the decays $K_L^0 \rightarrow \pi^- \mu^+ \nu$ and $K^+ \rightarrow \pi^0 \mu^+ \nu$. The transverse polarization forbidden by time reversal invariance is $(1.85 \pm 3.60) \times 10^{-3}$ based on our final data sample of thirty-four million events. This null result places constraints on certain models of CP-violation through the exchange of Higgs bosons.

Recently attention has again focused on the interaction responsible for the violation of charge-parity (CP) invariance. The successes of gauge theories in describing the weak, electromagnetic and strong interactions have led to the expectation that CP violation too can be explained naturally in this framework. As yet, however, our understanding of CP violation is incomplete and several experiments[1] are underway to learn more about the nature of this effect.

At Brookhaven, a Yale/BNL collaboration has made a sensitive search for a violation of time reversal (T) invariance through the measurement of muon polarization in the decay $K^+ \rightarrow \pi^0 \mu^+ \nu_\mu$. The T-(or CP-) violating correlation of interest is $P_n \propto \vec{S} \cdot (\vec{p}_\pi \times \vec{p}_\mu)$, that is, the component of muon polarization normal to the decay plane. A search for T violation in $K_{\mu 3}$ decays is a sensitive test of milliweak models of CP violation. For example, in a class of models due to Weinberg,[2] where CP violation is the result of an extended Higgs sector, milliweak effects are possible in $K_{\mu 3}$ decays ($P_n \sim$ few $\times 10^{-3}$). On the other hand, the six-

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quark model of Kobayashi and Maskawa yields essentially superweak results with no observable effect expected in $K_{\mu 3}$ decays.

The experiment was performed in a nearly monochromatic 4 GeV/c K^+ beam which passes through the cylindrically symmetric detector shown in Fig. 1. Positive muons from $K^+ \to \pi^0 \mu^+ \nu_\mu$ decays occurring in a 5 meter drift space are focused towards the beam line and degraded by the steel toroidal magnet, and finally brought to rest in the aluminum polarimeter. The trigger logic requires, in addition to the muon, the detection of a gamma ray (from the $\pi^0 \to 2\gamma$ decay) in a small lead glass array ($\sim$ 8 radiation lengths) located downstream of the polarimeter. The sense of the decay plane $\vec{p}_\pi \times \vec{p}_\mu$ is thus preserved in the Lorentz transformation to the laboratory (see lower inset, Fig. 1) so that the T-violating component of polarization in the laboratory is effectively $\vec{S}_\mu \cdot (\vec{p}_K \times \vec{p}_\mu)$, that is, normal to the plane defined by the laboratory momenta of the kaon and the muon.

The polarization of the muon is measured in the polarimeter, which consists of 32 aluminum wedges distributed azimuthally with scintillation counters mounted between the wedges (G) on the upstream (F) and downstream (I) face of each wedge (see super inset, Fig. 1). The muon decay is identified by the detection of the positron ($\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$) as a delayed pulse in one of the two G counters flanking the wedge in which the muon came to rest. Each G counter is associated with a clock which is gated on by the fast trigger. The detection of the positron stops the clock, thus recording the time and direction of the decay. Before the muon decays, its spin is processed with a period of 1.3 μsec by a 54 gauss axial magnet field. Because of the parity violating nature of the weak decay of the muon, the positron is emitted preferentially along the direction of the muon spin. Thus, the amplitude of the asymmetry, $A = \frac{R - L}{R + L}$, of positrons detected in G counters to the right (R) or left (L) of the muon stop position varies sinusoidally as a function of time. The geometry of the

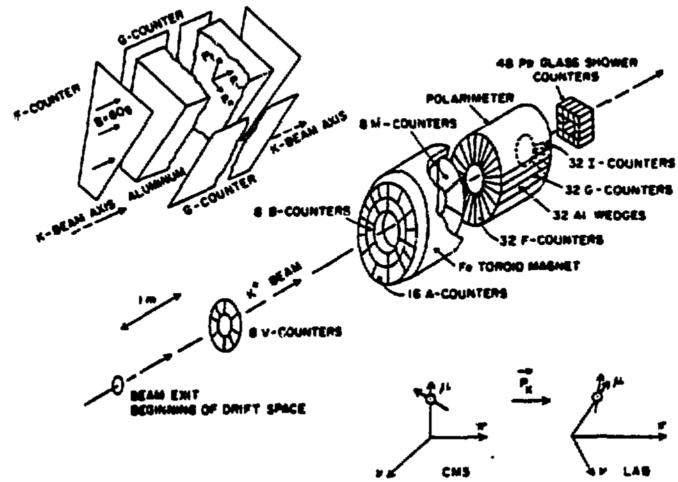

Figure 1. The central figure shows a schematic view of the basic experimental apparatus. The upper diagram represents an exploded view of the polarimeter element. The lower drawing presents a schematic view of the relationship between the momentum and spin vectors of the $K_{\mu 3}$ decay products in the c.m. and lab systems.

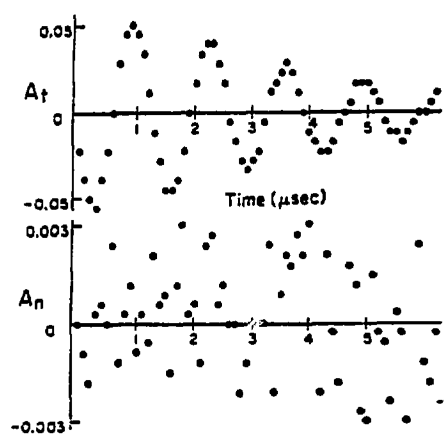

Figure 2. The upper graph shows, at the left, the variation of A_t as a function of time and the bottom graph shows similar data on A_n. Note the different ordinate scales. The best fits to those plots give $A_t = -0.06920 \pm 0.00043$ and $A_n = -0.00029 \pm 0.00046$.

polarimeter and the applied magnetic field allow a measurement of two components of the muon polarization: P_t, the T-conserving transverse polarization, and P_n, the T-violating component. The field direction is reversed before each beam pulse, allowing an independent determination of the P_t and P_n components.

The curves of Fig. 2 shows the on line results for the measured asymmetry A, plotted as a function of time. The upper curve shows the sinusoidal dependence of A_t, the asymmetry due to T-conserving polarization P_t. The lower curve (with an expanded vertical scale) shows the time dependence of the T-violating asymmetry A_n. The damping of the sinusoid in the A_t plot is due to random (background) clock stops. A least squares fit to the amplitude A_t yields a T-conserving polarization $P_t = 0.86$, which is consistent with Monte Carlo calculations and serves to calibrate the detector. For the T-violating data, the fit (using the frequency and phase from the A_t fit) implies a value for the T-violating polarization $P_n = (3.0 \pm 4.7) \times 10^{-3}$, consistent with zero. This is to be compared with the value of $P_n \sim 0.005$ generally expected from milliweak theories of CP violation.

The $K^+_{\mu 3}$ experiment is part of a program of investigation of the nature of CP violation by the Yale-BNL collaboration. Final results from the $K^+_{\mu 3}$ experiment, when combined with our previous results[4] for $K^0_{\mu 3}$ decays gives $P_n = (1.85 \pm 3.60) \times 10^{-3}$. This rules out large Higgs boson induced CP-violating effects in these decays.

REFERENCES

1. See J.W. Cronin, Science 212, 1221 (June 12, 1981) for an excellent review of the status of CP violation.
2. S. Weinberg, Phys. Rev. Lett. 37, 657 (1976); also A.R. Zhitnitskii, Yad. Fiz. 31, 1024 (1980) (Sov. J. Nucl. Phys. 31, 529 (1981).
3. L.B. Leipuner et al., IEEE Trans. Nuc. Sci. NS-28, 333 (1981).
4. W.M. Morse et al., Phys. Rev. D21, 1750 (1980).