Search for Right-Handed Currents in the Decay $K^+ \to \mu^+ \nu$

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The longitudinal polarization of the muon emitted from the $K^+ \to \mu^+\nu$ decay was measured to search for the right-handed weak currents in the strangeness-changing process. The polarization was determined to be -0.970 ± 0.047, which is consistent with the $V-A$ hypothesis.

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In this paper we report on the search for the right-handed current effect in the $K^+ \to \mu^+\nu$ decay, by measuring the longitudinal polarization of the decay muon. The standard $SU(2) \otimes U(1)$ model of the electroweak interaction, which fully violates parity conservation, predicts that the muons from $\pi \to \mu\nu$ or $K \to \mu\nu$ should be 100% polarized. A certain class of models beyond the standard theory, such as $SU(2)_L \otimes SU(2)_R \otimes U(1)$, includes the existence of a right-handed weak current mediated by W_R.[1] In such models the left-handedness of the present world is provided if the spontaneous symmetry breaking gives W_R a larger mass than W_L, thereby suppressing the mixing of the right-handed currents. Although the ultimate confirmation of such models is to produce W_R at high energies, the W_R effect can still be looked for by use of low-energy phenomena.

Recently, Carr *et al.*[2] measured precisely the e^+ asymmetry in the decay $\mu^+ \to e^+\nu\bar{\nu}$, where the muon was produced by pion decay at rest (surface muon beam). They obtained $|P_\mu \xi\delta/\rho| > 0.9959$ within an accuracy of 0.005, where P_μ is the muon longitudinal polarization in the $\pi \to \mu\nu$ decay, and ξ, ρ, δ are the muon-decay Michel parameters. This experiment sets a severe limit on the right-handed current admixture, and it also suggests that $\mu \to e$ decay asymmetry can be used as an excellent muon polarization analyzer.

This result, however, does not preclude the possible observation of the right-handed current effect in strangeness-changing processes, since, in general, quark mixing angles can be different between the left- and right-handed sectors. There are three measurements on the muon polarization in $K_{\mu 2}$ decay. Coombes *et al.*[3] obtained $P_\mu = -0.96 \pm 0.12$, and Cutts *et al.* reported -0.94 ± 0.21[4] and -1.0 ± 0.1.[5] These measurements were made in 1957, 1965, and 1969, respectively, when the weak interaction was simply believed to be purely left handed.

Recently, Oka[6] has tried to solve the discrepancy between the Cabibbo model predictions and the experiments on the hyperon decay parameters,[7] by introducing the $SU(2)_L \otimes SU(2)_R \otimes U(1)$ model. In order to fit the experimental data, a large mixing of the right-handed currents was required, which implied P_μ in $K_{\mu 2}$ decay to be -0.85 ± 0.06. The fit is suggestive that P_μ may be significantly different from -1, a fact that cannot be rejected by the presently available data.

In order to search for the right-handed currents in $\Delta S = 1$ leptonic decay, we have measured the longitudinal polarization of muons from the $K_{\mu 2}$ decay with an improved accuracy. The experiment was made by the following steps: (1) stop K^+ in scintillation counters, (2) transport and focus the μ^+ from the $K_{\mu 2}$ decay with precise information on the μ^+ trajectory, (3) degrade the energy of the 236-MeV/c μ^+, while keeping the μ^+ depolarization as small as possible, (4) stop μ^+ in an aluminum plate without further depolarization, and (5) measure the polarization of the μ^+ by use of the muon-spin-rotation technique.

Figure 1 shows a plan view of the experimental apparatus. We utilized the experimental setup for the search for heavy neutrinos in $K_{\mu 2}$ decay[8] after suitable modifications for the present purpose. Muons from $K^+ \to \mu^+\nu$ decay were focused to a muon stopper through a magnetic spectrometer, to select the muons by their unique momentum (235.6 MeV/c). Four multiwire proportional counters (MWPC's) were placed at the entrance and the exit of the spectrometer to determine the

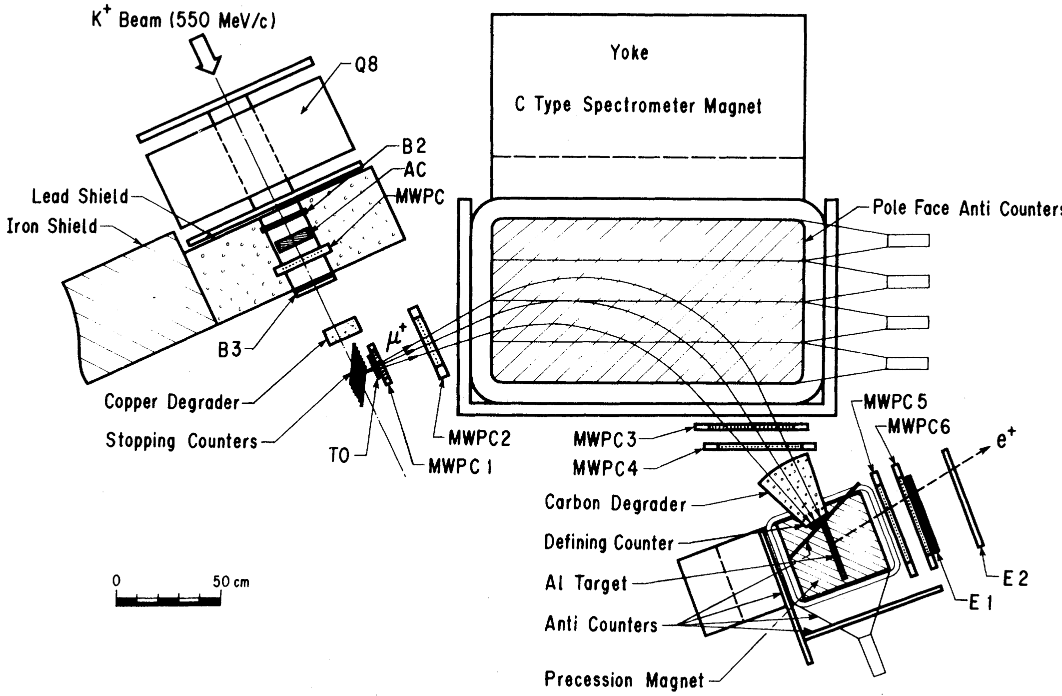

FIG. 1. Plan view of the muon polarization measurement apparatus.

muon trajectory precisely, which was required to specify the initial direction of the muon spin. After passing through MWPC4, the muons were degraded by a carbon degrader with 30 cm thickness, and then stopped in the muon stopper. The carbon was chosen as the lightest possible degrader in order to minimize the depolarization of the relativistic muons. Since the muon trajectory after the degrader has no useful information because of multiple scattering, it was not measured. The muon stopper was made of high-purity aluminum (99.99%) to avoid muon-spin relaxation before the muon decays.

The polarization of the muon was measured by an energy-integrated asymmetry of the positrons emitted in the decay $\mu^+ \rightarrow e^+ \nu\bar{\nu}$. Two counters (E1 and E2) were placed beside the muon stopper to trigger on the decay positron, and two MWPC's (MWPC5 and MWPC6) were placed before E1 to determine the decay position and the emission angle of the e^+. The efficiencies of the chambers were 82% for MWPC1, and 94% for the others. In order to minimize the systematic errors, a magnetic field of about 220 G was applied in the vertical direction to make the muon spin precess. The decay time was measured by counting the output of a 1-GHz pulser, whose error was calibrated to be less than 3×10^{-5}. The target area was surrounded by anti counters to reject particles which were not emitted from the target. Also, in order to reduce the multiple scattering of muons and positrons, the gaps between the poles of the spectrometer and precession magnets were filled with helium gas.

In order to estimate the asymmetry, we have integrated the decay spectrum over the positron energy instead of observing near the end-point energy. The reasons are these: (i) It will reduce the statistical error of the polarization, which was the largest error in our measurement. (ii) Since the event rate is quite small at the low-energy region, the systematic error due to fluctuation of the energy threshold of the positron counters (<0.1 MeV) will be minimized to below 0.01%. (iii) The decay asymmetry of positrons near the maximum energy is subject to radiative corrections, while the energy-integrated asymmetry is less dependent. The overall theoretical correction in the present experiment is estimated to be 0.3%.[9]

Figure 2 shows the asymmetry of positrons against the precession angle of muons. This was obtained by dividing the raw precession pattern by an exponential decay factor. The number of total analyzed events was 1.1×10^4. The precession angle θ is defined by

$$\theta = \omega t - \Delta,$$

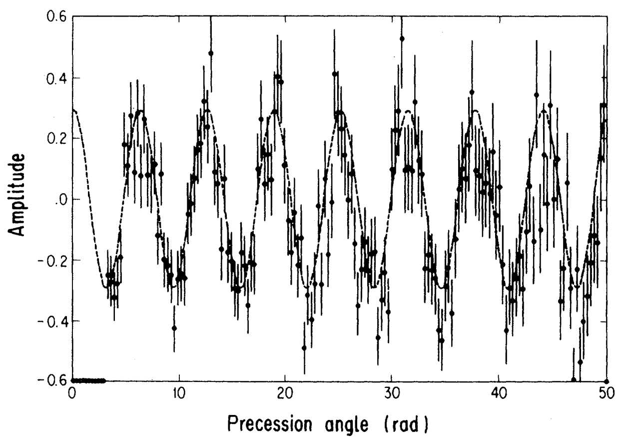

FIG. 2. Precession pattern of μ^+ emitted in $K_{\mu 2}$ decay.

where ω = angular velocity of precession, t = time elapsed until the μ^+ decay, and Δ = angle between the initial muon spin direction (namely, the direction of μ^+ before entering the degrader) and the direction of e^+ projected to a plane normal to the magnetic field. As we know the decay position and thus its magnetic field, ω was calculated for each event, and the precession pattern has become independent of the field distribution. The precession amplitude is attenuated compared with the $V-A$ value $\frac{1}{3}$, because we are observing a *projected angle,* which is a convolution of various μ-e angles.

In order to estimate the expected amplitude for the pure left-handed model, about 40 000 of Monte Carlo events were generated. After applying the same cuts and analyses to both the experimental data and the Monte Carlo data, we fitted the precession patterns with the following function:

$$f(\theta) = 1 + \alpha \cos(\beta\theta + \gamma),$$

where α, β, and γ are free parameters for fitting. The fit up to 50 rad yielded $\alpha = 0.292 \pm 0.013$ with the experimental data, and $\alpha_{\rm MC} = 0.304 \pm 0.006$ with the Monte Carlo data. Even the fit up to 25 rad showed $\alpha = 0.292 \pm 0.011$, and therefore, no depolarization effect was observed. After taking into account the following correction factors, $\alpha_{\rm MC}$ was reduced to $\alpha_{\rm MC}' = 0.301 \pm 0.006$: (i) depolarization of the 236-MeV/c μ^+ in the carbon degrader, 0.43%[10]; (ii) multiple scattering of μ^+ in the kaon stopping counters, 0.06%; (iii) background events which could not be rejected, 0.1%; (iv) radiative correction to positron asymmetry in muon decay; 0.3%.[9] To the present level of precision, the muon decay parameter $\xi\delta/\rho$ can safely be put equal to 1.00 from the experiment of Carr *et al.*[2] Furthermore, since Carr *et al.* found no initial depolarization in a pure Al target even in their transverse-field precession experiment, we can safely say that there is no depolarization in the Al stopper. Then, from these two α's, the μ^+ polarization is obtained as

$$P_\mu = -\alpha_{\rm exp}/\alpha_{\rm MC}' = -0.970 \pm 0.047.$$

Now, if we assume the $SU(2)_L \otimes SU(2)_R \otimes U(1)$ model, the longitudinal polarizations of μ^+ from $\pi_{\mu 2}$ and $K_{\mu 2}$ decays are given by

$$P_\pi = -(1 - a^2\lambda^2)/(1 + a^2\lambda^2),$$

$$P_K = -(1 - b^2\lambda^2)/(1 + b^2\lambda^2),$$

respectively,[6] where $\lambda = g_R^2 M_L^2 / g_L^2 M_R^2$, $a = \cos\theta_1^R / \cos\theta_1^L$, $b = \sin\theta_1^R \cos\theta_3^R / \sin\theta_1^L \cos\theta_3^L$. Here, $g_{L,R}$ are the coupling constants associated with the subgroups $SU(2)_{L,R}$, $M_{L,R}$ are the masses of the charged gauge bosons, and $\theta_{1,3}^{L,R}$ are mixing angles in the Kobayashi-Maskawa matrices for the left-hand and right-hand sectors. Then, with neglect of the neutrino mass, the experiment of Carr *et al.* on P_π yields $a^2\lambda^2 < 0.004$ (90% C.L.), while the present experiment gives $b^2\lambda^2 < 0.087$ (90% C.L.). The experiment is fully compatible with the standard $V-A$ hypothesis and places a new limit on the admixture of right-handed currents in strangeness-changing weak decays.

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