A MEASUREMENT OF THE FORM FACTORS

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ABSTRACT

The decay process $K_L^0 \rightarrow \pi\mu\nu$ has been studied in a wire chamber experiment using the three-degree K_L^0 beam at SLAC. A sample of 26,500 $K\mu_3$ events have been identified to obtain information on the form factors $f_{\pm}$ associated with the V-A hypothesis for this decay. Expressing the energy dependence of the form factors as $f_{\pm} = f_{\pm}(0)(1 + \lambda_{\pm} q^2/m_{\pi}^2)$, where $q^2 = (p_K - p_{\pi})^2$, the experiment yields the value $\lambda_{+} = 0.08 \pm 0.01$ and reveals a strong coupling between λ_{-} and $\zeta(0) = f_{-}(0)/f_{+}(0)$.

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Leptonic decays of the K meson have excited great experimental and theoretical interest for several years. By studying the features of $K\mu_3$ and Ke_3 decays, one can shed light on such questions as the V-A theory of weak interactions, the $\Delta I = 1/2$ rule, and μ -e universality. The matrix element for these decays depends on form factors which describe the strong interaction at the K- π vertex. Much of the experimental effort has been focused on the determination of the values of these form factors and the nature of their variation in $q^2 = (p_K - p_\pi)^2$. The $K\mu_3$ decay is particularly suited to such a determination, but a variety of experiments⁽¹⁾ has yielded inconclusive results.

We report here on a Dalitz plot analysis of 26,500 $K_L^0 \rightarrow \pi\mu\nu$ decays obtained in a wire chamber experiment performed in the 3° beam at the Stanford Linear Accelerator Center. This represents an order of magnitude increase in statistics over a previous experiment studying the $K\mu_3$ Dalitz plot.⁽²⁾ A schematic of the apparatus is shown in Fig. 1. K_L^0 decays occurred in a 1 meter decay volume bounded by an anti-coincidence counter upstream and a time of flight counter downstream. The directions of charged decay products were measured in a set of 1 meter x 1 meter magnetostrictive wire chambers. Tracks were subsequently momentum analyzed in a 10.5 kilogauss-meter magnet and a second set of 2 meter x 1 meter wire chambers. The spark chamber trigger consisted of a count in the time of flight counter in coincidence with counts from two charged particles in an array of trigger counters downstream from the rear chamber package and in anti-coincidence with the counter defining the upstream edge of the decay volume. This trigger produced an average Dalitz plot efficiency of 33% with a maximum of 56% and a minimum of 20% in any 20 MeV by 20 MeV bin averaged over the beam momentum spectrum. Electron identification was provided by shower counters consisting of lead-scintillator sandwiches; muons were identified by their ability to penetrate 19" of lead and an additional 5" of steel. Information from the lepton identifiers was recorded on

magnetic tape for each event, but was not used in the spark chamber trigger. The experiment was on line to an IBM 1800 computer.

The initial geometrical reconstruction yielded a sample of 300,000 events in all decay modes in which two particles of opposite charge were observed to traverse the wire chamber spectrometer. Candidates for $K\mu_3$ decays were selected by requiring that only one member of the pair trigger the muon counters, that the muon counter firing agree with the prediction from the reconstructed trajectory, that the shower counters struck by both members of the pair exhibit pulse heights below a pre-determined value, and that the pair originate from a vertex within the decay volume. The principal backgrounds remaining after these requirements come from pions leaking through the lead-steel absorber and from $\pi \rightarrow \mu\nu$ decays in flight. Estimates of these two effects yield contaminations of 5.5% and 2.4% due to the 3π mode.

The final sample of 26,500 $K\mu_3$ decays was obtained by imposing a cut on the transverse momentum of each charged track requiring it to be less than the maximum of 216 MeV/c allowed for this decay. In addition, the total transverse momentum of the charged pair was required to be consistent with the decay of a K_L^0 into a $\mu\mu$ system with the observed invariant mass.

As a check of the overall selection procedure, $(p'_0)^2$, the square of the longitudinal K_L^0 momentum in the longitudinal rest frame of the charged pair has been calculated for the entire data sample. The resulting distribution is shown in Fig. 2. The peak at negative $(p'_0)^2$ is due to Ke_3 and $K\mu_3$ decays; the peak just above zero is due to the $K_L^0 \rightarrow \pi^+\pi^-\pi^0$ decay mode. The cross-hatched histogram represents the data which survived the $K\mu_3$ selection criteria. The dotted curve shows the prediction of a Monte Carlo calculation. We point out that approximately one-half of the possible $K_{3\pi}$ decays that could feed through to this sample were eliminated because the photon from the

π^0 decay was detected by the shower counters. However, the 7.7% $K_{3\pi}$ contamination remains in this data sample and we are forced to make further cuts on the data to reduce this percentage. Although a restriction requiring $(p'_0)^2$ to be less than -7×10^3 MeV/c would eliminate this $K_{3\pi}$ contamination such a cut also eliminates approximately 50% of the events in the region of the Dalitz plot where $T_\pi + T_\mu < 100$ MeV. This is the region which is most critical to the determination of the form factors and therefore most critical to preserve.

Due to the high average momentum of the K_L^0 beam, the time of flight information was not used. This resulted in the well-known o-c fit ambiguity for the beam momentum for a given event, and therefore, each event is doubly plotted. This ambiguity and the experimental efficiency have been folded into the theoretical predictions by means of a Monte Carlo calculation. The incident beam momentum distribution has been determined in this experiment from a measurement of $K_2^0 - K_1^0$ regeneration from copper, and has been discussed elsewhere⁽³⁾. The kaon momentum of accepted events ranges from 3 to 12 GeV/c with an average of 5 GeV/c.

We have further cut these data by requiring that the two solutions for the decay lie in the same 20 MeV x 20 MeV bin in the Dalitz plot. This requirement reduces our sample size to 16,454 events but further suppresses the $K_{3\pi}$ contamination to the 4.0% level. Thus we need make no restriction on $(p'_0)^2$ which preferentially suppresses part of the Dalitz plot. The Dalitz plot for this "unambiguous" sample is shown in Fig. 3a. Fig. 3b shows the projection on the T_π and T_μ axes and the results of our fit to these data.

Assumptions of parity conservation at the $K-\pi$ vertex and the dominance of the V-A form of the weak interaction at the $\ell-\nu$ vertex (where $\ell = e$ or μ) leads to a matrix element for $K_{\ell 3}$ decays of the following form:

$$M \sim [(p_K + p_\pi)_\mu \bar{\mu}_\ell \gamma_\mu (1 + \gamma_5) \mu_\nu] f_+(q^2) + [m_\ell \bar{\mu}_\ell (1 + \gamma_5) \mu_\nu] f_-(q^2)$$

where f_+ and f_- , the strong interaction form factors, are functions of $q^2 = (p_K - p_\pi)^2$. Since the term involving $f_-(q^2)$ in $|M|^2$ will be proportional to the square of the lepton mass, it is evident that only $K_{\mu 3}$ decays are capable of probing this form factor. The first order expansion of the form factors given by

$$f_{\pm}(q^2) = f_{\pm}(0) [1 + \lambda_{\pm} q^2 / M_{\pi}^2]$$

$$\zeta(0) = \frac{f_-(0)}{f_+(0)}$$

has been used in fitting the Dalitz plot. Fig. 4 presents the χ^2 contours for λ_+ and $\zeta(0)$ in the plane $\lambda_- = 0$. We obtain

$$\begin{array}{lcl} \lambda_+ = 0.090 \pm 0.002 &) & \\ \text{and} &) & \text{for } \lambda_- = 0. \\ \zeta(0) = -0.680^{+0.12}_{-0.20} &) & \end{array}$$

The errors are statistical only. Table 1 shows the trend of the fit as λ_- is varied. A strong coupling between λ_- and $\zeta(0)$ is seen; the χ^2 function⁽⁴⁾ is relatively flat so that λ_- is not well determined. The minimum χ^2 occurs at $\lambda_- = -0.15$ and $\zeta(0) = -2.56$ even though this value cannot be considered as serious because of the flat χ^2 . Choosing λ_- equal to λ_+ , we find $\zeta(0) = -0.26$.

In conclusion, λ_+ is well determined. We find

$$\lambda_+ = 0.08 \pm 0.01$$

$\zeta(0)$ and λ_- are strongly coupled as shown in Table I. Electromagnetic corrections have not been applied to the data since at this statistical level they are of the order of magnitude of the statistical error.⁽⁵⁾

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REFERENCES

1. For a review of this subject, see C. Rubbia, CERN Topical Conference on Weak Interactions, 235 (1969).
2. P. Basile, et al., 14th Int. Conf. on High Energy Physics, Vienna (1968), contributed paper no. 175.
3. C. D. Buchanan, et al., UCLA Report #1046 - JHU Report #K1 (to be published), (1970).
4. We use $\chi^2 = (N_{\text{exp}} - N_{\text{MC}})^2 / N_{\text{MC}}$ where N_{exp} and N_{MC} refer to the number of data events and number of normalized Monte Carlo events in each bin of the Dalitz plot. Typically the number of Monte Carlo events generated were four times the number of experimental events in the Dalitz plot so that the expected statistical error in the Monte Carlo is small.
5. E. Ginsberg, Phys. Rev. 142, Vol. 1, #1, 224(1970).

FIGURE CAPTIONS

- Fig. 1. Schematic diagram of the wire spark chamber spectrometer used for the study of K_L^0 decays.
- Fig. 2. $(p'_0)^2$ plot for all decays and for the sample labeled $K\mu_3$ (cross-hatched area). Monte Carlo generated $K\mu_3$ decays are shown as a dashed line.
- Fig. 3. (a) $K^0 \rightarrow \pi\mu\nu$ Dalitz plot for the unambiguous events.
(b) Projections of the Dalitz plot on the T_μ and T_π axes. The best fit to the total Dalitz plot is shown as a dashed curve.
- Fig. 4. χ^2 contours for the data, showing the contours and fitted values in the $\lambda_- = 0$ plane. This figure illustrates statistical errors only.

TABLE I

λ_- , $\zeta(0)$, λ_+ , and χ^2 for the unambiguous sample of 16,454 events
(128 degrees of freedom)

λ_-	$\zeta(0)$	λ_+	χ^2
-0.30	-0.12	0.07	238
-0.25	-0.08	0.07	238
-0.20	-0.96	0.06	234
-0.15	-2.56	0.07	231
-0.10	-1.48	0.08	233
-0.05	-0.68	0.08	234
-0.00	-0.68	0.09	236
+0.05	-0.28	0.08	237
+0.10	-0.24	0.08	237

Fig. 1 JHU-7016 and JHU-7018

Fig. 2 JHU-7016

Fig. 3b JHU-7016

Fig. 4 JHU-7016