UCRL-10246
Cy. 2

University of California

Ernest O. Lawrence Radiation Laboratory

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545

Berkeley, California

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

UCRL-10246

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

EXPERIMENTAL TESTS OF THE $\Delta I = \frac{1}{2}$ RULE, AND THE $\Delta S = \Delta Q$ RULE IN THREE-BODY DECAYS OF NEUTRAL K MESONS

Gideon Alexander, Silverio P. Almeida, and Frank S. Crawford, Jr.

May 28, 1962

EXPERIMENTAL TESTS OF THE $\Delta I = \frac{1}{2}$ RULE, AND THE $\Delta S = \Delta Q$ RULE IN THREE-BODY DECAYS OF NEUTRAL K MESONS*

Gideon Alexander,† Silverio P. Almeida, and Frank S. Crawford, Jr.

Lawrence Radiation Laboratory
University of California
Berkeley, California

May 28, 1962

The selection rule $\Delta I = \frac{1}{2}$ [1,2,3] is compatible with many observations on the nonleptonic (NL) decays of strange (S) particles.[4] Whether or not this rule applies also[5] to the S-changing leptonic (L) decays has not been established. The first results[6] were compatible with the rule, under the assumption $\Delta S = + \Delta Q$.[7]

The rule $\Delta S = + \Delta Q$ has recently had its first experimental test, in L decay of neutral K, and apparently failed.[8]

In the present experiment we check all three rules independently, by using K^0 produced in the Alvarez 72-inch hydrogen chamber through the reaction $\pi^- + p \rightarrow \Lambda + K^0$. We study those cases where the K subsequently decays into one of the modes $e^{\pm} \pi^{\mp} \nu$, $\mu^{\pm} \pi^{\mp} \nu$, or $\pi^+ \pi^- \pi^0$.

Three amplitudes $a(\frac{1}{2}, \frac{1}{2})$, $a(\frac{3}{2}, \frac{1}{2})$, and $a(\frac{3}{2}, \frac{3}{2})$ suffice to describe L decays of K^+ and K^0, where for instance $(\frac{3}{2}, \frac{1}{2})$ means $\Delta I = \frac{3}{2}$, $\Delta I_z = \frac{1}{2}$. Assuming CP invariance, and aside from a common factor, one has the decay rates

$$\Gamma(K^0 \rightarrow L^+) = \Gamma(\bar{K}^0 \rightarrow L^-) = |a|^2 = |-2a(\tfrac{1}{2}, \tfrac{1}{2}) + a(\tfrac{3}{2}, \tfrac{1}{2})|^2,$$

$$\Gamma(\bar{K}^0 \rightarrow L^+) = \Gamma(K^0 \rightarrow L^-) = |\bar{a}|^2 = |\sqrt{6}\, a(\tfrac{3}{2}, \tfrac{3}{2})|^2, \text{ and}$$

$$\Gamma(K^+ \rightarrow L^+ \pi^0 \nu) = \Gamma_+(L^+) = |\sqrt{2}\, a(\tfrac{1}{2}, \tfrac{1}{2}) + \sqrt{2}\, a(\tfrac{3}{2}, \tfrac{1}{2})|^2.$$

For the K_1^0 and K_2^0 rates we have

$$\Gamma_1(L^+) = \Gamma_1(L^-) = \frac{1}{2}|a + \bar{a}|^2, \text{ and}$$

$$\Gamma_2(L^+) = \Gamma_2(L^-) = \frac{1}{2}|a - \bar{a}|^2.$$

The rule $\Delta S = +\Delta Q$ is equivalent to $a(\frac{3}{2}, \frac{3}{2}) = 0$, and thus predicts

$$\Gamma_1 (L) = \Gamma_2 (L) . \tag{1}$$

The $\Delta I = \frac{1}{2}$ rule corresponds to setting both $a(\frac{3}{2}, \frac{3}{2}) = 0$ and $a(\frac{3}{2}, \frac{1}{2}) = 0$. Then, in addition to (1), one has

$$\Gamma_2(L^{\pm}) = 2\Gamma_+(L^+) , \tag{2}$$

where $\Gamma_2(L^{\pm}) = \Gamma_2(L^+) + \Gamma_2(L^-) = |a - \bar{a}|^2$.

Thus, if we sum over e and μ decay modes, $\Delta I = \frac{1}{2}$ predicts

$$\Gamma_2(L^{\pm}) = (16.5 \pm 1.18) \times 10^6 \text{ sec}^{-1}. \tag{3}$$

how to get no

(See footnote a, Table I.)

Let $N(\Lambda)$ be the number of visible decays $\Lambda \rightarrow p + \pi^-$ (whether or not the K^0 undergoes visible decay). Let t be the time (in 10^{-10} sec) after K^0 production, measured in the K^0 rest frame, and $\epsilon(t)$ be the probability for observing a three-body K^0 decay, given a Λ decay. Then the decay rate for L^+ or L^-, (L^+, L^-), is given by

$$dN(L^+, L^-) = \frac{1}{2} N(\Lambda)\, \epsilon(t)\, dt \left\{ \frac{1}{2} |a + \bar{a}|^2 \exp(-t/\tau_1) + \frac{1}{2} |a - \bar{a}|^2 \pm (|a|^2 - |\bar{a}|^2) \cos \Delta m t \exp(-t/2\tau_1) \right\} , \tag{4}$$

where Δm is the $K_1^0 - K_2^0$ mass difference, and τ_1 is the K_1^0 mean life.[11] We here omit a factor $\exp(-t/\tau_2)$, since in our experiment it differs from unity by at most about 1% according to the previously measured value of τ_2.[12] Adding both signs of charge in (4) we obtain for the total L rate,

$$dN(L^{\pm}) = \frac{1}{2} N(\Lambda)\, \epsilon(t)\, dt \left\{ \Gamma_1(L^{\pm}) \exp(-t/\tau_1) + \Gamma_2(L^{\pm}) \right\} , \tag{5}$$

which is independent of Δm.

In order to check prediction (3) of the $\Delta I = \frac{1}{2}$ rule we look only at L decays with $t > 4\tau_1$. Then the K_1^0 L decay rate is negligible (it turns out) and we can neglect the first term in (5). In the $\Delta S/\Delta Q$ experiment to check (1) we examine the entire time distribution (5) to find $\Gamma_1(L)/\Gamma_2(L)$. The normalisation $\frac{1}{2}N(\Lambda)$ thereby cancels.

Our experimental procedure is to first try to fit a normal decay $K_1^0 \to \pi^+ + \pi^-$, using the least-squares kinematic fitting programs PANG and KICK.[13] If that fails we try a one-constraint (1-C) fit[13] (the K momentum is well known) to each of the six three-body-decay hypotheses. (See Table II.)

The Λ and K production and decay must satisfy certain fiducial volume criteria, and the decays must occur at least 0.5 cm from the production point. These criteria reduce a sample of 5000 Λ decays to $N(\Lambda) = 2703$. In addition of K decay is by definition visible only for $0.2 < t < 20.0$. (See Fig. 1a.)

It is crucial, especially in finding the absolute decay rate Γ_2, that no three-body K decay (associated with a Λ) be missed. We second-scan all single-vee Λ-production-and-decay events along the KICK-predicted direction of the missing K, to find K decays missed on the first scan. We check that no three-body decays are lost through their having an acceptable fit to normal K_1 decay (by checking the distributions and correlations in t and χ^2 for normal K_1 decay). There are no events that "fit nothing." We are convinced that we have found all of the three-body decays associated with normal Λ decay.

It is essential, especially in finding Γ_1/Γ_2, to eliminate all fake three-body K decays. Any cutoffs must be applied independently of t. The most common fake is due to a single Coulomb scatter (through a few degrees) of one pion from normal $K_1 \to \pi^+ \pi^-$. These are eliminated by means of a missing mass (MM) calculation, with one or the other of the charged tracks taken as "missing," and assuming normal K_1 decay. Decays $\pi \to \mu\nu$ in flight are also thereby eliminated. The next most common fake (i.e., failing normal decay and sometimes fitting three-body decay) is due to $K_1 \to 2\pi^0$, where one π^0 undergoes Dalitz decay into $e^+ e^- \gamma$. These are eliminated by (a) application of a cutoff on the invariant mass, $M(e^+e^-) \geq 45$ MeV,[14] and (b)

the requirement that the 1-C three-body decay fit well. A further possible contaminant would result from a small angle scatter of K_1 or K_2 through < 10 deg, followed by normal K_1 decay. The recoil proton would be invisible, normal K_1 decay would fail, and three-body decay might pass. This possibility is eliminated by trying to fit each three-body candidate as a 1-C normal K_1 decay, using only the two charged decay tracks. None pass, whereas normals always pass.

No cutoffs are needed to eliminate fake K_2 decays (due to K_1) for $t > 4\tau_1$, and none is applied in the determination of Γ_2. In determining Γ_γ/Γ_2, one "certain" K_2 ($t = 11.3$) is cut off by MM, along with six probable K_1 (all with $t < 1.2$). Two K_1 Dalitz decays are eliminated by $M(e^+e^-)$.

We believe that the remaining contamination is negligible, and turn now to the data.

The complete sample of events is contained in Table II. Because some of the events fit several hypotheses well, and especially because of the small number of events, we limit ourselves to checking predictions (1) and (2) without regard to the decay mode and charge assignment.

We consider first the results of the $\Delta I = \frac{1}{2}$ experiment. From the 14 L decays with $3.44 < t < 20.0$ we find from (5), with $N(\Lambda) = 2703$ and $\epsilon(\text{avg}) = 0.67$ the result

$$\Gamma_2(L^*) = 9.31 \pm 2.49 \times 10^6 \text{ sec}^{-1}.\ ^{15} \qquad (6)$$

Our result (6) differs by 2.6 standard deviations (std dev) from the prediction (3). We calculate one chance in 53 for a statistical fluctuation at least this large,[16] and conclude that our data is incompatible with the $\Delta I = \frac{1}{2}$ rule for leptonic K decays.

Of the 14 K events used to obtain (6), two fit $K \to \pi^+\pi^-\gamma$ (and also L). (See Table II.) If these were indeed $\pi\pi\gamma$ our result (6) would be reduced by a factor 12/14 and would then be in even worse agreement with $\Delta I = \frac{1}{2}$.

We next consider the $\pi^+\pi^-\pi^0$ (+-0) mode. All 4 events have $t > 4\tau_1$, and are therefore due to K_2, as expected. (Our K_1 branching ratio into (+-0) is therefore < 1/1350.) Based on 4 events we find

$$\Gamma_2(+-0) = 2.66 \pm 1.34\times10^6 \text{ sec}^{-1}. \tag{7}$$

Provided that (a) the $\Delta I = \frac{1}{2}$ rule holds for $K \to 3\pi$, (b) the final 3π state in $K^+ \to 3\pi$ is the symmetrical $I = 1$ state, and (c) the final 3π state in $K^0 \to 3\pi$ is the symmetrical $I = 1$ state, and taking into account the phase space factors,[17] one expects[5]

$$\Gamma_2(+-0) = \frac{2}{3}[1.284\ \Gamma_+(++-) + 1.032\ \Gamma_+(+00)], \tag{8}$$

that is,

$$\Gamma_2(+-0) = 2.959 \pm 0.088\times10^6 \text{ sec}^{-1}. \tag{9}$$

(See footnote h, Table I.)

Our result (7) agrees with the prediction (9), but is based on only four counts.

We now compare our ratio $\Gamma_2(+-0)/\Gamma_2(L^\pm)$ with that of Luers, et al.[18], who find

$$\Gamma_2(+-0)/\Gamma_2(L^\pm) = 0.155 \pm 0.22. \tag{10}$$

Based on our 14 L decays (10) predicts that we should see 2.2 (+-0) decays. This is not in disagreement with the 4 ± 2 seen.

It is reasonable to combine our rate $\Gamma_2(L^\pm)$, given by (6), with the branching ratio (10) of Luers et al., omitting our four $\pi^+\pi^-\pi^0$ as (relatively) statistically insignificant, to obtain a combined experimental rate

$$\Gamma_2(+-0) = 1.44 \pm 0.43\times10^6 \text{ sec}^{-1}. \tag{11}$$

This result differs from the prediction (9) by 3.4 std dev.

We conclude that at least one of the assumptions (a), (b), and (c) [following Eq. (7)] is invalid.

It is known that (a) and (b) predict correctly the $K^+ \to (+00)/(++-)$ branching ratio (see Table I). We attempt to check (c) by calculating the total K_2 decay rate

using the experimental rate (11) and the prediction that follows from (a) and (c), namely[5]

$$\Gamma_2(000) = \frac{3}{2}(1.218)\ \Gamma_2(+-0), \tag{12}$$

where again phase space is included.[17] We thus obtain a total K_2 decay rate $\Gamma_2 = \Gamma_2(L^*)\left\{1 + [\Gamma_2(+-0)/\Gamma_2(L^*)]\left[1 + \frac{3}{2}(1.218)\right]\right\}$, i. e.,

$$\Gamma_2 = (13.38 \pm 3.62)\times 10^6\ \mathrm{sec}^{-1}, \tag{13}$$

that is,

$$\tau_2 = (\Gamma_2)^{-1} = (7.47\ ^{+2.77}_{-1.59}) \times 10^{-8}\ \mathrm{sec}. \tag{14}$$

We emphasize that (14) rests on experiment, except for the assumption (12). This result may be compared with the lifetime measured directly by attenuation with distance, of Bardon et al.,[12] who obtain

$$\tau_2 = (8.1\ ^{+3.3}_{-2.4}) \times 10^{-8}\ \mathrm{sec}.$$

The agreement with (14) is excellent, but the errors are too large to really verify (12), and thus to verify (c).

We now turn to the $\Delta S/\Delta Q$ experiment to check (1). A total of 22 L decays satisfy the criteria described. Their t distribution is given in Table II and in Fig. 1b. To make a quantitative comparison we construct a normalized likelihood function corresponding to Eq. (5). We find

$$\Gamma_1(L^*)/\Gamma_2(L^*) = 6.6\ ^{+6.0}_{-4.0}, \tag{15}$$

in poor agreement with prediction (1). The calculated chance that $\Gamma_1 = \Gamma_2$, and that our results are then due to a statistical fluctuation is 6.5%.[19, 20]

Our result (15) can be compared with the result of Ely et al.[8], who find

$$\Gamma_1(e^{\pm})/\Gamma_2(e^{\pm}) = 11.9\,^{+7.5}_{-5.6}\,. \tag{16}$$

We thus substantiate the result of Ely et al., that the rule $\Delta s = +\Delta Q$ is not valid.

Since Eq. (5) in invariant under the interchange of a and $\bar{a}$, our result (15) corresponds to[21]

$$\bar{a}/a \quad \underline{\text{or}} \quad a/\bar{a} = +0.44\,^{+0.12}_{-0.20}\,. \tag{17}$$

In order to resolve the ambiguity it is necessary to include the information as to the lepton's charge, and use Eq. (4). Only the events in the first one or two K_1 mean lives are useful, because of the uncertainty in Δm. Because of the small size of our sample, and the charge ambiguity sometimes present, we are not able to resolve the ambiguity. Corresponding to (16), Ely et al. obtain[21]

$$\bar{a}/a = +0.55\,^{+0.08}_{-0.12}\,. \tag{18}$$

We can now resolve the apparent discrepancy between our present result (6) for $\Gamma_2(L^{\pm})$ and that of Crawford et al.[6] In that experiment, it was necessary to assume a value for Γ_1/Γ_2 in order to obtain $\Gamma_2(L^{\pm})$, since, because of the small (10-in.) chamber, it was not possible to get rid of the K_1 decays by going to large t. From the t distribution, they obtained $\Gamma_1/\Gamma_2 = 3.5\,^{+3.9}_{-2.7}$, but in what followed assumed $\Gamma_1 = \Gamma_2$. They thus obtained $\Gamma_2(L^{\pm}) = 20.4\,^{+7.2}_{-5.6} \times 10^6\ \text{sec}^{-1}$. One of us has reanalized that experiment, using $\Gamma_1/\Gamma_2 = 9$ [a compromise between our result (15) and that of Ely et al., (16)]. The result is $\Gamma_2(L^{\pm}) = (8.5 \pm 2.8) \times 10^6\ \text{sec}^{-1}$, in excellent agreement with our present result (6). [Our result (6) does not, of course, depend on any assumption for Γ_1/Γ_2.]

All predictions and experimental results are summarized in Table I.

In terms of the three amplitudes for $(\Delta I, \Delta I_z)$ our results for L decays can be summarized as follows:

(i) $a(\frac{3}{2}, \frac{3}{2})$ and $a(\frac{3}{2}, \frac{1}{2})$ are not both zero [from the absolute rate $\Gamma_2(L^{\pm})$].

(ii) $a(\frac{3}{2}, \frac{3}{2})$ is not zero [from the ratio $\Gamma_2(L^{\pm})/\Gamma_1(L^{\pm})$].

(iii) $a(\frac{3}{2}, \frac{1}{2})$ can easily be zero. [The best fit is $a(\frac{3}{2}, \frac{1}{2})/a(\frac{1}{2}, \frac{1}{2}) = +0.2$.]

(iv) $a(\frac{1}{2}, \frac{1}{2})$ cannot be zero. [With $a(\frac{3}{2}, \frac{3}{2})$ alone we cannot fit both $\Gamma_2(L^{\pm})$ and $\Gamma_1(L^{\pm})/\Gamma_2(L^{\pm})$.]

In the case of the large discrepancy between prediction and experiment in the non-L decays $K \to 3\pi$, the assumption of $I = 1$ in the final state for $K_2 \to \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0$ is the assumption least checked, and probably most open to doubt.

It is a pleasure to thank Professor Luis Alvarez for his encouragement and advice throughout the course of this work. We are indebted to J. A. Anderson and L. J. Lloyd for extensive assistance in the data processing, and to Dr. P. G. Burke for helping in the computer programs necessary in the analysis.

FOOTNOTES AND REFERENCES

* Work done under the auspices of the U. S. Atomic Energy Commission.

† On leave of absence from the Israel Atomic Energy Commission Laboratories, Rehovoth.

1. M. Gell-Mann and A. Pais, in Proceedings of the Glasgow Conference, 1954 (Pergamon Press, London, 1955).
2. R. H. Dalitz, Proc. Phys. Soc. (London) 69, 527 (1956).
3. M. Gell-Mann and A. H. Rosenfeld, Ann. Rev. Nuclear Sci. 7, 407 (1957).
4. F. S. Crawford, Jr., M. Cresti, R. L. Douglass, M. L. Good, G. R. Kalbfleisch, M. L. Stevenson, and H. K. Ticho, Phys. Rev. Letters 2, (1959); J. L. Brown, H. C. Bryant, R. A. Burnstein, D. A. Glaser, R. Hartung, J. A. Dadyk, J. D. Van Putten, D. Sinclair, G. H. Trilling, and J. C. Van der Velde, Nuovo cimento 19, 1155 (1961); B. Cork, L. T. Kerth, W. A. Wenzel, J. W. Cronin, and R. L. Cool, Phys. Rev. 120, 1000 (1960). See also reference 3.
5. S. Okubo, R. E. Marshak, and E. C. G. Sudarshan, Phys. Rev. Letters 2, 12 (1959).
6. F. S. Crawford, Jr., M. Cresti, R. L. Douglass, M. L. Good, G. R. Kalbfleisch, M. L. Stevenson, and H. K. Ticho, Phys. Rev. Letters 2, 361 (1959).
7. R. P. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1959).
8. R. P. Ely, W. M. Powell, H. White, M. Baldo-Ceolin, E. Calimani, S. Ciampolillo, O. Fabbri, F. Farini, C. Filippi, H. Huzita, G. Miari, U. Camerimi, W. F. Fry, and S. Natali, Phys. Rev. Letters 8, 132 (1962).

9. G. Alexander, R. H. W. Johnston, and C. O'Ceallaigh, Nuovo cimento 6, 478 (1957); B. P. Roe, D. Sinclair, J. L. Brown, D. A. Glaser, J. A. Kadyk, and G. H. Trilling, Phys. Rev. Letters 7, 346 (1961).

10. R. W. Birge, D. H. Perkins, J. E. Peterson, D. H. Stork, and M. W. Whitehead, Nuovo cimento 4, 834 (1956).

11. We use $\tau_1 = (0.86 \pm 0.03) \times 10^{-10}$ sec., obtained in the present associated-production experiment, and to be published. We neglect the effect of K^0 and $\bar{K}^0$ hydrogen interactions in depleting K_2^0 and in regenerating K_1^0.

12. M. Bardon, K. Lande, L. M. Lederman, and W. Chinowsky, Ann. Phys. 5, 156 (1958).

13. A. H. Rosenfeld and J. N. Snyder, Rev. Sci. Instr. 33, 181 (1962).

14. N. P. Samois, R. Plano, A. Prodell, M. Schwartz, and J. Steinberger, Columbia University Physics Department Report NEVIS-97, Jan. 6, 1962 (unpublished).

15. We have included a correction factor of 0.987 for K_2^0 attenuation by decay.

16. To calculate the probability we use Eq. (3) to predict the number $\bar{n}$ of counts expected, and then calculate the Poisson probability to see the observed 14 counts, or less. We take into account the error in Eq. (3) through a (Gaussian) weighted distribution in $\bar{n}$.

17. We use the phase-space formula of Dalitz, reference 2, with $m(K^0) = 497.8$, $m(K^+) = 493.9$, $m(\pi^+) = 139.59$, and $m(\pi^0) = 135.0$ to find phase-space factors ϕ for K^+ or K^0 decaying into three pions (1, 2, 3), and find $\phi_+(++-) = 6.282 \times 10^3$, $\phi_+(+00) = 7.814 \times 10^3$, $\phi_0(+-0) = 8.067 \times 10^3$ and $\phi_0(000) = 9.825 \times 10^3$. The appropriate ratios of these factors are then used. The factors ϕ were not included in the predictions of reference 5.

18. D. Luers, I. S. Mittra, W. J. Willis, and S. S. Yamamoto, Phys. Rev. Letters 7, 255 (1961).

19. The quoted error in (15), and thus also in (17), was obtained by going to values where the likelihood function decreases by a factor $e^{\frac{1}{2}}$. The probability 6.5% for $\bar{a} = 0$ was obtained separately by using an especially simple likelihood function, namely a binomial distribution with respect to counts n_1 and n_2 earlier and later than $2\tau_1$, normalized to a total of 22 counts. For $\bar{a} = 0$, $n_1 = 2.96$ is "expected." Six counts are observed (see Table II). The chance for at least six is 6.5% The binomial distribution with the observed $n_1 = 6$ also gives the result (15), and the same calculated errors, as does the complete (multinomial) likelihood function. The quoted errors are thus essentially given by $n_1 = 6 \pm \sqrt{6}$.

20. If we remove from the sample the six possible decays into $\pi^+\pi^-\gamma$ (see Table II), we find $\Gamma_1/\Gamma_2 = 4.7^{+5.9}_{-3.6}$.

21. The (fractionally) smaller error in $\bar{a}/a$ as compared to Γ_1/Γ_2 is somewhat misleading, since it arises only by virtue of taking (essentially) square roots of counts, through the relation

$$\bar{a}/a = [(\Gamma_1/\Gamma_2)^{\frac{1}{2}} - 1] / [(\Gamma_1/\Gamma_2)^{\frac{1}{2}} + 1] .$$

Table I. Summary of predictions and experimental results.

	$\Gamma_+(L^+)$ (10^6 sec^{-1})	$\Gamma_2(L^\pm)$ (10^6 sec^{-1})	$\frac{\Gamma_1(L^\pm)}{\Gamma_2(L^\pm)}$	$\Gamma_+(++-)$ (10^6 sec^{-1})	$\Gamma_+(+00)$ (10^6 sec^{-1})	$\frac{\Gamma_+(+00)}{\Gamma_+(++-)}$	$\Gamma_2(+-0)$ (10^6 sec^{-1})
Other exp	8.25± 0.59[a]	$\left\{\begin{array}{l} 20.4^{+7.2}_{-5.6}{}^{b} \\ 8.5\pm 2.8^{c} \end{array}\right\}$	$11.9^{+7.5}_{-5.6}{}^{e}$	4.65±0.15[f]	1.39± 0.11[f]	0.298±0.025[f]	---
$\Delta S=+\Delta Q$	---	---	1	---	---	---	---
$\Delta I=\frac{1}{2}$	---	16.50± 1.18[d]	1	---	---	0.311[g]	2.96± 0.088[h]
This exp	---	9.31± 2.49	$6.6^{+6.0}_{-4.0}$	---	---	---	1.44± 0.43[i]

a. We take the K^+ lifetime to be $(1.224\pm 0.013)\times 10^{-8}$ sec as an average of the results of L. W. Alvarez, F. S. Crawford, M. L. Good, and M. L. Stevenson, in Proceedings of the Seventh Annual Rochester Conference on High Energy Nuclear Physics, 1957 (Interscience Publishers, Inc., New York, 1957); and V. Fitch and R. Motley, Phys. Rev. 101, 496 (1956) and 105, 265 (1957). We average the K^+ branching ratio results of Alexander et al., and of Roe et al., reference 9, to obtain $\mu^+\pi^0\nu = (5.07\pm 0.54)\%$ and $e^+\pi^0\nu = (5.01\pm 0.47)\%$, and add these to obtain the total L^+ fraction. We point out that although these two experiments are in good agreement with each other, they are in poor agreement with the earlier branching-ratio results of Birge et al., reference 10, who obtain a total L^+ fraction of (6.0± 1.6)% i.e., nearly a factor of two less than in the two later experiments.

b. Reference 6 as published, with assumption $\Gamma_1 = \Gamma_2$.

c. Reference 6 reanalized, with assumption $\Gamma_1 = 9\,\Gamma_2$. (See text.)

d. See Eq. (2) and footnote a.

e. Reference 8.

f. We average the K^+ branching-ratio results of references 9 and 10, and also S. Taylor, G. Harris, J. Orear, J. Lee, and P. Baumel, Phys. Rev. 114, 359 (1959).

g. The prediction is $\frac{1}{4}$ (1.244). (See reference 17.)

h. See Eq. (8), reference 17, and footnote f.

i. See the discussion preceding Eq. (11).

Table II. Summary of twenty-seven three-body decays. (The χ^2 probability is for the 1-constraint three-body decay. The χ^2 probability (prob) distribution for the "best interpretation" on each event agrees excellently with that expected for 1-constraint. For instance, 11/27 have prob <0.5, 2/27 have prob <0.1, 0/27 have prob<0.01.)

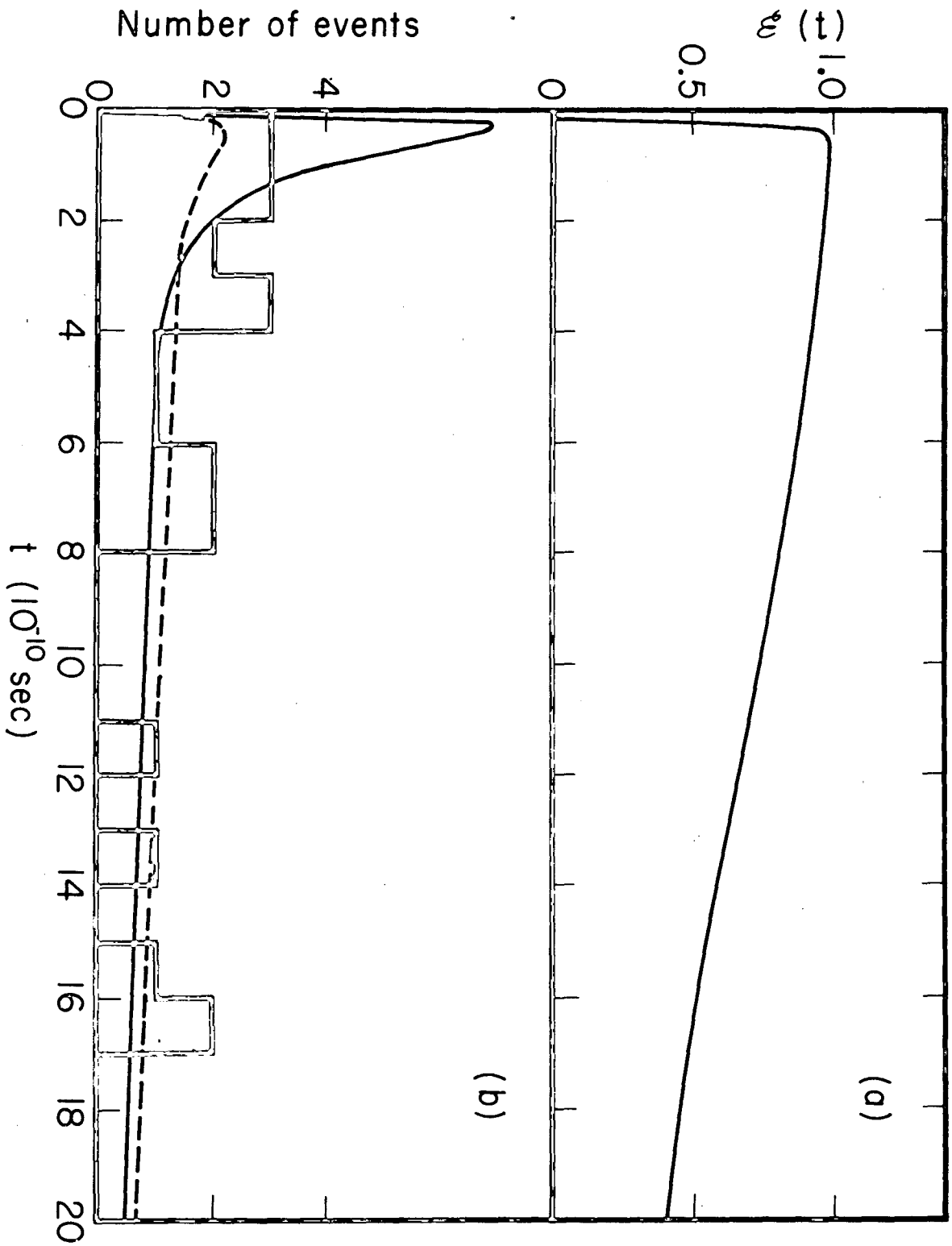
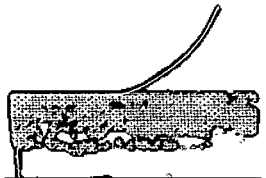
Serial No.	$P_{Lab}(K^0)$ (MeV/c)	ℓ (K^0) cm	t (K^0) 10^{-10} sec	χ^2 probabilities for decays $\pi^-e^+\nu$	$\pi^+e^-\nu$	$\pi^-\mu^+\nu$	$\pi^+\mu^-\nu$	$\pi^+\pi^-\pi^0$	$\pi^+\pi^-\gamma$
781 208	530.8 ± 9.6	1.14	0.36	0.56	0.16	0.17	0.61	0	0.56
766 317	649.3 ± 4.9	2.24	0.57	0.0025	0	0.018	0.002	0	0
704 248	423.2 ± 7.2	2.12	0.83	0.068	0	0.20	0.95	0	0
735 269	556.8 ± 7.6	3.55	1.06	0.20	0	0	0	0	0
713 256	243.7 ± 4.8	2.12	1.44	0	0	0.96	0	0	0
707 247	399.9 ± 4.1	3.54	1.47	0.95	0.15	0.28	0.68	0	0.05
692 228	521.9 ± 5.8	7.71	2.45	0.95	0.28	0.054	0.001	0	0
521 330	575.7 ± 12.0	9.17	2.64	0.61	0.015	0.99	0.42	0	0.70
564 309	468.3 ± 9.5	7.85	2.78	0.29	0.19	0.20	0.21	0	0.05
505 231	566.2 ± 8.0	11.84	3.47	0	0.0044	0.36	0	0	0
781 181	359.2 ± 4.6	8.38	3.87	0	0	0	0.23	0	0
773 547	452.8 ± 4.7	11.03	4.04	0.42	0.99	0.84	0.54	0	0
503 063	596.8 ± 7.0	20.95	5.82	0	0.17	0	0	0	0
853 275	486.0 ± 9.4	17.72	6.03	0	0	0	0	0.68	0
714 067	559.2 ± 8.8	21.80	6.46	0	0	0.15	0	0	0.44
722 026	481.7 ± 5.0	19.76	6.78	0.0024	0	0.59	0.27	0	0.05
559 553	633.8 ±10.9	26.02	6.81	0	0	0	0	0.084	0
522 599	597.1 ±13.6	24.59	6.83	0	0	0	0	0.61	0
565 027	442.1 ± 5.7	19.33	7.25	0.85	0.019	0.0017	0	0	0
819 009	602.1 ± 4.3	28.70	7.35	0.44	0.88	0.015	0.005	0	0
554 595	353.8 ± 3.1	22.76	10.69	0	0	0	0	0.25	0
568 280[a]	598.3 ±10.9	40.72	11.29	0	0.0014	0	0.76	0	0
525 293	291.2 ± 3.8	20.65	11.76	0	0	0.17	0.14	0	0
774 147	404.4 ± 5.0	32.42	13.29	0.77	0.024	0	0	0	0
532 310	621.1 ±14.1	56.93	15.20	0.014	0.47	0.022	0	0	0
756 453	273.9 ± 3.1	26.46	16.02	0	0.36	0.99	0.086	0	0
844 335	606.1 ±11.0	60.80	16.63	0	0.39	0.62	0	0	0

[a] This event is cutoff as a "Coulomb scatter" in the experiment to find $\Gamma_1(L^\pm)/\Gamma_2(L^\pm)$, but is accepted as a K_2 decay in the determination of $\Gamma_2(L^\pm)$ (see text).

FIGURE CAPTIONS

Fig. 1a. Geometrical efficiency $\epsilon(t)$ for detecting K decay. The decrease at short t is due to the cutoffs at 0.5 cm, and at 0.2×10^{-10} sec. At large t, $\epsilon(t)$ is the fraction of K's having potential time $T > t$.

Fig. 1b. Time distribution of leptonic decays. The smooth curves are predicted differential counting rates in counts per 10^{-10} sec normalized to 22 counts, for the cases $\Gamma_1 = \Gamma_2$ (dashed curve) and $\Gamma_1 = 9\,\Gamma_2$ (smooth curve). The best fit has $\Gamma_1 = 6.6\,\Gamma_2$, and is not plotted.


ℰ (t)
1.0
0.5
0
(a)
Number of events
4
2
0
(b)
0
2
4
6
8
10
12
14
16
18
20
t (10^{-10} sec)

MU-26893