UCRL-11553

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Ernest O. Lawrence Radiation Laboratory

ANALYSIS OF THE DECAY $K^+ \rightarrow \pi^0 + e^+ + \nu$

Berkeley, California

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Proceedings of the International Conference on
High Energy Physics - Dubna, USSR, 1964.

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AEC Contract No. W-7405-eng-48

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George E. Kalmus and Anne Kernan
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George E. Kalmus and Anne Kernan
Lawrence Radiation Laboratory
University of California
Berkeley, California

Ugo Camerini
University of Wisconsin
Madison, Wisconsin

Cyril Henderson
University College London
London, England

(Presented by Ugo Camerini)

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We have studied the decay

$$K^+ \to \pi^0 + e^+ + \nu, \quad \pi^0 \to 2\gamma \to 2e^\pm \qquad (1)$$

using stopping K^+ mesons in the Berkeley 30-inch heavy liquid bubble chamber. The chamber filling was freon, C_3F_8, having a density 1.22 gm cm^{-3} and radiation length 28 cm. A total of 250 000 pictures containing 2.9×10^6 stopped K^+'s was taken.

The film was scanned for Ke_3 decays that satisfied the following criteria:

1. The positron from the K^+ decay went through a maximum radius vector (Fig. 1), without change of ionization.
2. Two electron-positron pairs pointed back to the K^+ decay point on all three stereo views.
3. Neither of these pairs was tangential to the positron near the origin.
4. The K^+ ionization was consistent with a decay at rest, and there were no kinks or changes of ionization along the incoming K^+ track within 1 cm of the origin.

Condition 1 ensured that the charged secondary was unambiguously identified as a positron. Condition 3 eliminated events in which one of the pairs was due to a bremsstrahlung from the decay positron. This criterion may eliminate some genuine events. We have calculated the magnitude of this effect and find it small compared to the statistical error. Condition 4 largely eliminated a background contamination of τ' and $K\mu_3$ decays for which the $\pi^+\mu^+$ chain or μ^+, respectively, were less than 1 cm.

All the tracks from the decay were measured by means of the Behr-Mittner method for calculating the momenta and errors.[1] A two-constraint fit for the Ke_3 hypothesis was made for each event. A total of 242 events, from 15% of the film, fitted the hypothesis.

A positron-detection efficiency $D_e(E_e)$ as a function of positron energy was calculated by means of a Monte Carlo method similar to that described in reference 2. This efficiency varied from 100% at $E_e = 0$ to 30% at $E_e = E_{e\,max}$. The π^0 detection efficiency $D_\pi(E_\pi)$ was also estimated by means of a Monte Carlo program. The maximum variation in π^0 detection efficiency was 20% over the spectrum. Each event was weighted by $1/[D_e(E_e) \cdot D_\pi(E_\pi)]$. All the distributions shown contain this weighting factor.

We ignored the correlation between $D_e(E_e)$ and $D_\pi(E_\pi)$; this is expected to be significant at high positron momenta. The importance of this correlation is evidenced by the fact that our weighted experimental distributions in electron variables are not identical with the corresponding distributions in neutrino variables. In Ke_3 decay these distributions are identical, in the approximation that $M_e = 0$. Because of this, we have plotted in Figs. 3 and 5 the sum of the positron and neutrino distributions. The reason for doing this is that, due to the shape of the Dalitz plot in E_e and E_ν, (Fig. 2), these summed distributions are almost independent of biases or inaccuracies in the weighting procedure.

The most general form of the matrix element for Ke_3 decay is

$$M \propto \sum_j \bar{u}_\nu O_j u_e A_j ,$$

where the O_j's are the Dirac matrices corresponding to the three possible types of coupling scalar, vector, and tensor, and $\bar{u}_\nu O_j u_e$ is the lepton current. The strong-interaction currents A_j are of the form:

Scalar	$A_j \propto f_s$
Vector	$A_j \propto f_+(P_k + P_\pi) - f_-(P_k - P_\pi)$
Tensor	$A_j \propto f_t P_k P_\pi$.

The P's are 4-momenta, and the f's are dimensionless form factors that depend on the pion energy alone.

The distribution in $\cos\alpha$(the angle between the direction of the neutrino or positron momentum in the dilepton center-of-mass system and the direction of the pion) is independent of the energy dependence of the form factors and provides a sensitive test of the nature of the interaction.[3] In Fig. 3 the sum of the experimental distributions in $\cos\alpha_{e\pi}$ and $\cos\alpha_{\nu\pi}$ is compared with the distributions predicted for pure vector, scalar, and tensor. The distribution is shown for only $0 \leq \cos\alpha \leq 1$, since the distribution from $0 > \cos\alpha \geq -1$ is a mirror image of the former ($\cos\alpha_{e\pi} = -\cos\alpha_{\nu\pi}$). Vector is very strongly favored in agreement with the V-A theory of weak interactions. A(V, S) or (V, T) mixture is also possible but less likely than pure vector.

If the coupling in Ke_3 decay is pure vector, the distribution in pion kinetic energy is given by

$$N(T_\pi)\, dT_\pi \propto f_+^2 P_\pi^3\, dT_\pi , \qquad (2)$$

and hence can be used to investigate the energy dependence of the form factor f_+. The term containing f_- is negligible in Ke_3 decay. It is generally believed that f_+

is a slowly varying function of the 4-momentum transfer $q^2 = M_k^2 + M_\pi^2 - 2M_k^2 E_\pi$ and it may, therefore, be expanded in a power series in q^2. We have fitted the π^0 energy spectrum, Fig. 4, to Eq. (2) with $\propto f_+ 1 + \lambda q^2/M_\pi^2$ and with the experimental error distribution folded in. The χ^2 probability for the fit is 5%. The poor fit is due to an excess of events at low pion momenta and may arise from a tail in the π^0 momentum error distribution. The value of λ, which minimizes χ^2, is $\lambda = 0.02 {}^{+0.04}_{-0.03}$. Since only the high-momentum end of the spectrum is sensitive to the possible energy dependence of the form factor, the value of λ is almost independent of the low-energy tail.

Figure 5 shows the combined electron- and neutrino-momentum spectrum. The distribution in $\cos\psi_{e\pi}$ where $\psi_{e\pi}$ is angle between e^+ and π^0, is shown in Fig. 6. Both distributions are in excellent agreement with the hypothesis of a pure vector interaction with constant form factor.

Our results are in good agreement with the previous study of K_{e3}^+ decay.[4] However, in contrast to this previous experiment, our events are kinematically over-determined and hence have been completely reconstructed.

FOOTNOTES AND REFERENCES

† This work was performed under the auspices of the U. S. Atomic Energy Commission.

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FIGURE CAPTIONS

Fig. 1. $Ke_3 \rightarrow \pi^0 + e^+ + \nu$
$\quad\quad \hookrightarrow 2\gamma \rightarrow 2e^{\pm}$.

The maximum radius vector R_{max} is marked on the positorn track.

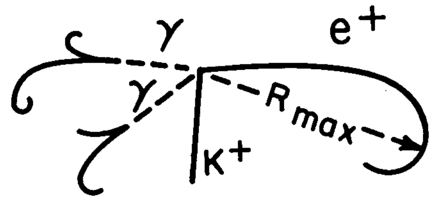
Fig. 2. The boundaries of the Dalitz plot of E_e, E_ν for Ke_3 decay.

Fig. 3. The sum of the weighted distributions in $\cos\alpha_{\pi e}$ and $\cos\alpha_{\pi\nu}$. The smooth curves are the distributions predicted for a pure vector, scalar, and tensor interaction. The distribution is symmetrical about $\cos\alpha_{\pi L} = 0$.

Fig. 4. Weighted pion-kinetic-energy spectrum. The smooth curve is a best fit of our data to Eq. (2), with the error spread in pion energy folded in.

Fig. 5. Sum of the weighted positron- and neutrino-momentum distributions. The curves show the distributions for a pure vector, scalar, and tensor interaction, assuming a constant form factor.

Fig. 6. Distribution of $\cos\psi_{e\pi}$ ($\psi_{e\pi}$ is angle between e^+ and π^0) for the weighted events. The curves show the distributions for pure vector, scalar, and tensor interactions, assuming a constant form factor.



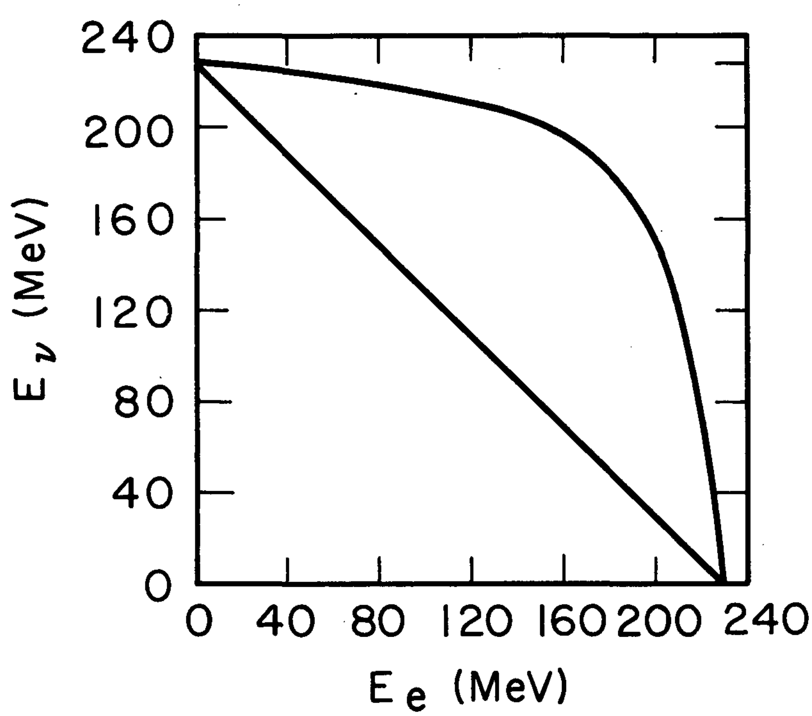


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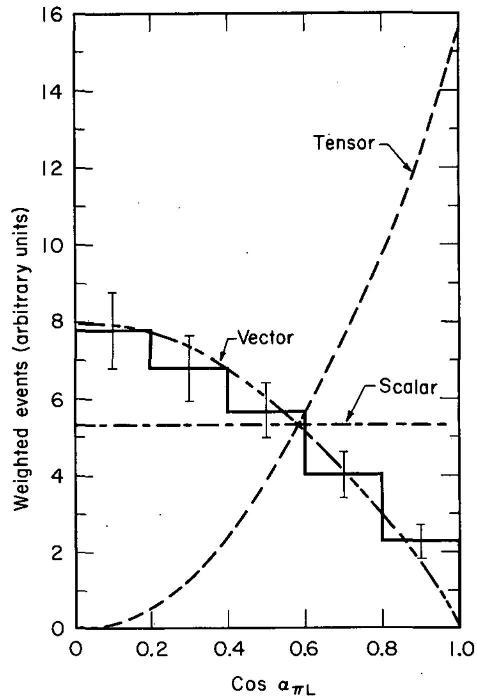
Fig. 1

Fig. 2



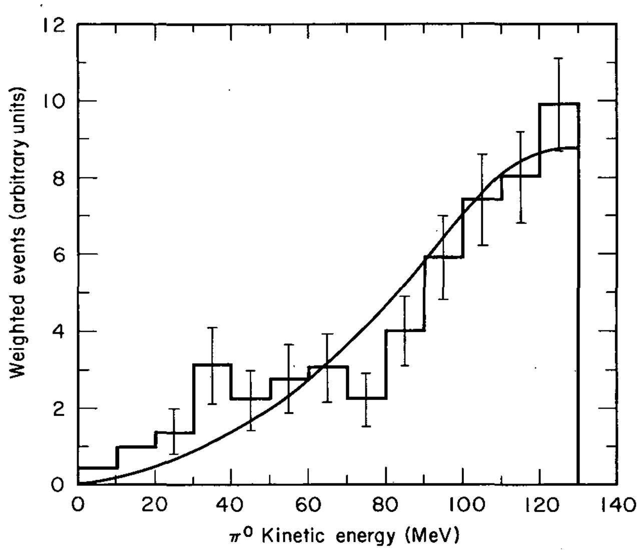


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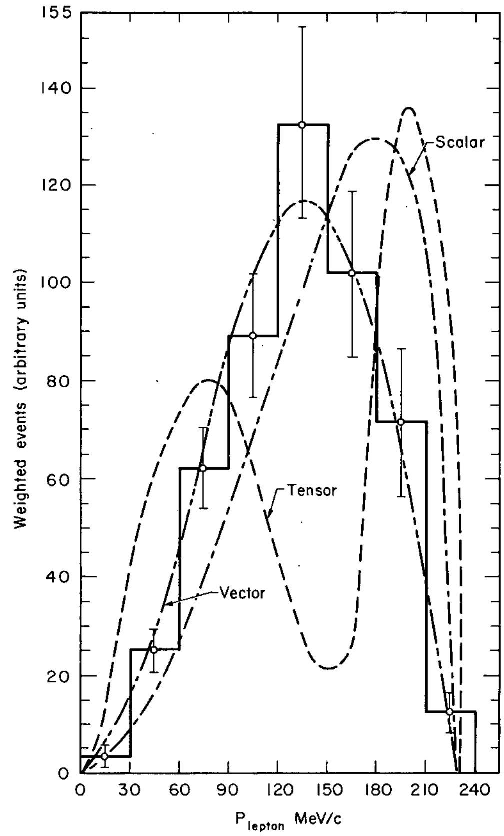
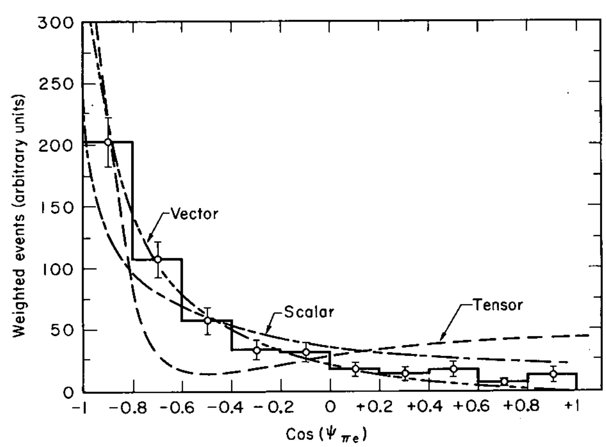
Fig. 3

Fig. 4



155
140
120
100
80
60
40
20
0
Weighted events (arbitrary units)
0 30 60 90 120 150 180 210 240
P_{lepton} MeV/c
Scalar
Tensor
Vector



300
250
200
150
100
50
0
Weighted events (arbitrary units)
-1 -0.8 -0.6 -0.4 -0.2 0 +0.2 +0.4 +0.6 +0.8 +1
Cos ($\psi_{\pi e}$)
Vector
Scalar
Tensor
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Fig. 5

Fig. 6