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ABSTRACT

In a very low momentum K^0_L beam, a sample of $K^0_L \rightarrow \pi^{\pm} e^{\mp} \nu$ decays has been identified in the 25-inch hydrogen bubble chamber by means of bubble density. Based on 531 events, the energy-dependence parameter for the K^0_{e3} vector form factor was determined $\lambda = +0.01 \pm .015$, which is consistent with no energy dependence.

A portion of the data from a low-momentum K^0_L experiment has been carefully analyzed to identify the common decay modes, and to determine the energy dependence of the form factor of the K^0_{e3} decays.[1] Although this form factor is predicted by the $|\Delta I| = 1/2$ rule to be the same as for K^+_{e3} decays, some of the more recent experimental results have cast doubt on the validity of the rule. While the energy dependence for the K^+_{e3} decay form factor is rather well known, that of the K^0_{e3} is generally characterized by much larger experimental uncertainties, and with one exception, the K^0_{e3} experimental results appear to indicate a larger energy dependence than seems to occur in K^+_{e3} decay.[2] The present experiment yields, with relatively high precision, the result that the K^0_{e3} form factor is consistent with no energy dependence, and is in good agreement with the result from K^+_{e3} decays.

In this experiment, the decays were observed in the Lawrence Radiation Laboratory's 25-inch hydrogen bubble chamber exposed to a K^0_L beam having a broad momentum spectrum extending from approximately 100 to 500 MeV/c and peaking at about 280 MeV/c. The K^0 particles were produced by K^+ charge-exchange on a dense target located 22 in. from the center of the chamber; in this way we obtained a reasonably high rate of K^0_L decays associated with only a few background tracks in each picture. Other details on the experimental technique, as well as a preliminary analysis of $K^0_L p$ interactions have been reported previously.[3]

Although the K^0_L momentum is not well known, the direction is well determined from the known position of the small target and the observed decay point. If the identity of the decay secondaries is known, the decay may then be completely reconstructed except for a two-fold quadratic ambiguity.

The correct decay mode could be identified by means of bubble density in a large fraction of the cases, since the K^0_L momentum, and therefore the secondary momenta, were quite low. The average electron momentum from K^0_{e3} decays was about 140 MeV/c. The tracks were identified by comparison of the observed bubble density with that predicted for π, μ, and e from the measured momentum, using the appropriate conical projection of the track on each view. These decisions were made by physicists and by experienced scanners working closely with and checked by the physicists. For many events, an unambiguous identification could be made solely from a visual estimate of the bubble density. In more difficult cases, usually when the secondary momentum was high, a gap-counting technique was also used. These two techniques were found to agree well on events where the identification could be made with certainty. Most of the more difficult judgments were made more than once by different people, whose independent conclusions nearly always were the same. Using these methods, it appears that reliable identifications of electrons can be made on tracks having momenta up to at least 200 MeV/c. Each event in the sample was resolved either uniquely, or to the minimum number of ambiguities consistent with the estimated uncertainties of judgment. Before any selection criteria were imposed, 801 events were consistent with the K^0_{e3} decay mode, 593 of which had identified electron secondaries.

To reduce the ambiguities still further, we used the following selection criteria. First, the electron momentum was required to be less than 200 MeV/c. Next, two geometrical selections were made: the dip angle of all tracks was required to be within ±80 deg of the chamber midplane, and the opening angle of the V^0 to be between 10 and 154 deg. The latter criterion decreased the data by less than 10%, but eliminated any possible scanning biases arising from similarity between K^0_{e3} decays and electron pairs or π-μ decays in flight.[4] These restrictions reduced the sample to 531 events used for determination of λ, plus only 5% events ambiguous with other decay modes.

In order to test the energy dependence of the K^0_{e3} form factor, we parameterized it in a conventional way, which assumes a small energy dependence:

$$f_+ (q^2) = f_+ (0) (1 + \lambda q^2/m_\pi^2),$$

where $f_+(q^2)$ is the form factor and q^2 is the square of the 4-momentum transfer between the K and π mesons. To find λ, we simulated several sets of K^0_{e3} decays by using FAKE,[5] a Monte Carlo program. Each set was generated with a different value of λ and according to the hypothesis of pure vector interaction. The K^0_L momentum spectrum was generated in the FAKE program from a Gaussian distribution having a 220-MeV/c full width at half maximum and peaking at 280 MeV/c. For the purposes of this analysis this representation was found to be a good approximation to the actual spectrum.

As is well known, two valid solutions generally are obtained from solving the zero-constraint fit which corresponds to two distinct values of K^0_L momentum. There are different ways to handle this problem, but as long as both real and simulated events are treated identically, no bias should result in the determination of λ, and only different degrees of sensitivity to λ will result. In practice this is found to be the case. The method chosen was to select the solution having the greater normalized weight factor, which was equal to the product of two factors: (a) the relative likelihood for obtaining the observed K^0_L momentum as deduced from the K^0_L spectrum, and (b) the relative probability in the Dalitz plot.[6] By subjecting the samples of real and simulated events to exactly the same selection criteria as described above, and by comparing between samples the distribution of events in the Dalitz plot, we obtained the best fit for λ:

$$\lambda = +0.01 \pm .015.$$

The functional dependence on λ of the chi-squared probability of fitting is shown in Fig. 1.

It should be noted that in this analysis, events occurring in all regions of the Dalitz plot were used in fitting for λ. No portion of the Dalitz plot was removed from the sample. The c.m. electron spectrum shown in Fig. 2a indicates no need for any additional correction for variation of electron detection efficiency other than that provided by the selection criteria. Figure 2b gives the c.m. pion energy distribution for the real events, compared with the Monte Carlo prediction for $\lambda = 0.01$. The resolution in determining the c.m. pion energy appears to be less than 10 MeV; this estimate was inferred from the observation that events appear to be lost from the upper end of the pion spectrum only in the last bin, which is 8.5 MeV wide.

A search for other possible systematic effects has revealed none larger than about half the quoted statistical error, and corrections for these have been made. This includes the effects of finite measurement errors, and of K^0_L particles that scatter before entering the fiducial volume. A fraction of the K^0_L particles scatter in a region close to the target before entering the fiducial volume, and this effect has been included in the Monte Carlo analysis. The number and distribution of these scatters is well known from fitting the K^0_Lp interactions, but if neglected would amount to a shift in λ of only $\Delta\lambda = 0.01$. Due to finite measurement errors, a small fraction (predicted to be 12% by FAKE) of the K^0_{e3} events from unscattered K^0_L will fail to have any kinematic solution; a larger fraction of the events from scattered K^0_L will fail. Both of these effects have been included in the Monte Carlo analysis which predicts the fraction of all K^0_{e3} events that fail to be 20%. This prediction agrees well with the observed fraction of failures among the real events.

We have also checked the effect of the 5% of events that are ambiguous with K^0_{e3}, by fitting for λ separately under the assumptions that (a) all ambiguous events are K^0_{e3} and are included in the fit, or (b) none of the ambiguous events are K^0_{e3} and are excluded from the fit. In each case, no significant shift was found from the previously determined value of $\lambda = 0.01$.

Finally, the c.m. neutrino spectrum was compared with that predicted by pure vector interaction and these were found to be in very good agreement. Note that this spectrum is deduced directly without ambiguity from the invariant (π, e) mass.

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FOOTNOTES AND REFERENCES

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

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1. J. A. Kadyk, J. H. Chan, D. Drijard, Y. Oren, B. M. Sheldon, and G. H. Trilling, Bull. Am. Phys. Soc. 12, 568 (1967). This subsample of the data represents about 20% of the total data at hand; the remainder is not yet analyzed.

2. Good summaries may be found in an article by G. H. Trilling, in Proceedings of the International Conference on Weak Interactions, Argonne National Laboratory, Oct. 25-27, 1965, ANL-7130; and in Proceedings of the XIIIth International Conference on High-Energy Physics (University of California Press, Berkeley, 1967), p. 44. In regard to the result published by G. Kalmus and A. Kernan in the latter Proceedings, a corrected value of $\lambda (K^{+}_{e3}) = 0.028^{+.013}_{-.014}$ is given in UCRL-17351, January 1967 [to be published in Phys. Rev. Letters 19 (1967)].

3. J. A. Kadyk, Y. Oren, G. Goldhaber, S. Goldhaber, G. H. Trilling, Phys. Rev. Letters 17, 599 (1966).

4. Although the number of electron pairs of π-μ decays that would pass the bubble-density criteria for K^0_{e3} events is quite negligible even without these cuts, some scanning bias is conceivable, and the cuts are made to guard against that possibility. Since the average scanning efficiency was found to be 88% for K^0_{e3} decays, no appreciable biases are expected.

5. Gerald R. Lynch, Lawrence Radiation Laboratory Report UCRL-10335, July 10, 1962 (unpublished).

6. The a priori probability calculated from the transformation Jacobian between the c. m. and lab. systems was found to be of negligible importance in helping to choose the correct solution, and was not used in our analysis. The value of λ assumed for the purpose of calculating the Dalitz-plot weight had only a very small influence on the fitted value of λ, and was set equal to zero in the final fitting.

FIGURE LEGENDS

Fig. 1. χ^2 vs λ, from fitting the Dalitz plot distribution. There are ten degrees of freedom. λ is determined to be $+0.01 \pm .015$.

Fig. 2. Distributions in the c.m. system of the (a) electron energy spectrum, and (b) pion energy spectrum, using the selection criteria described in the text. The dashed curves are the Monte Carlo predictions for $\lambda = 0.01$, using the same criteria, and normalized to the same number of events, 531.

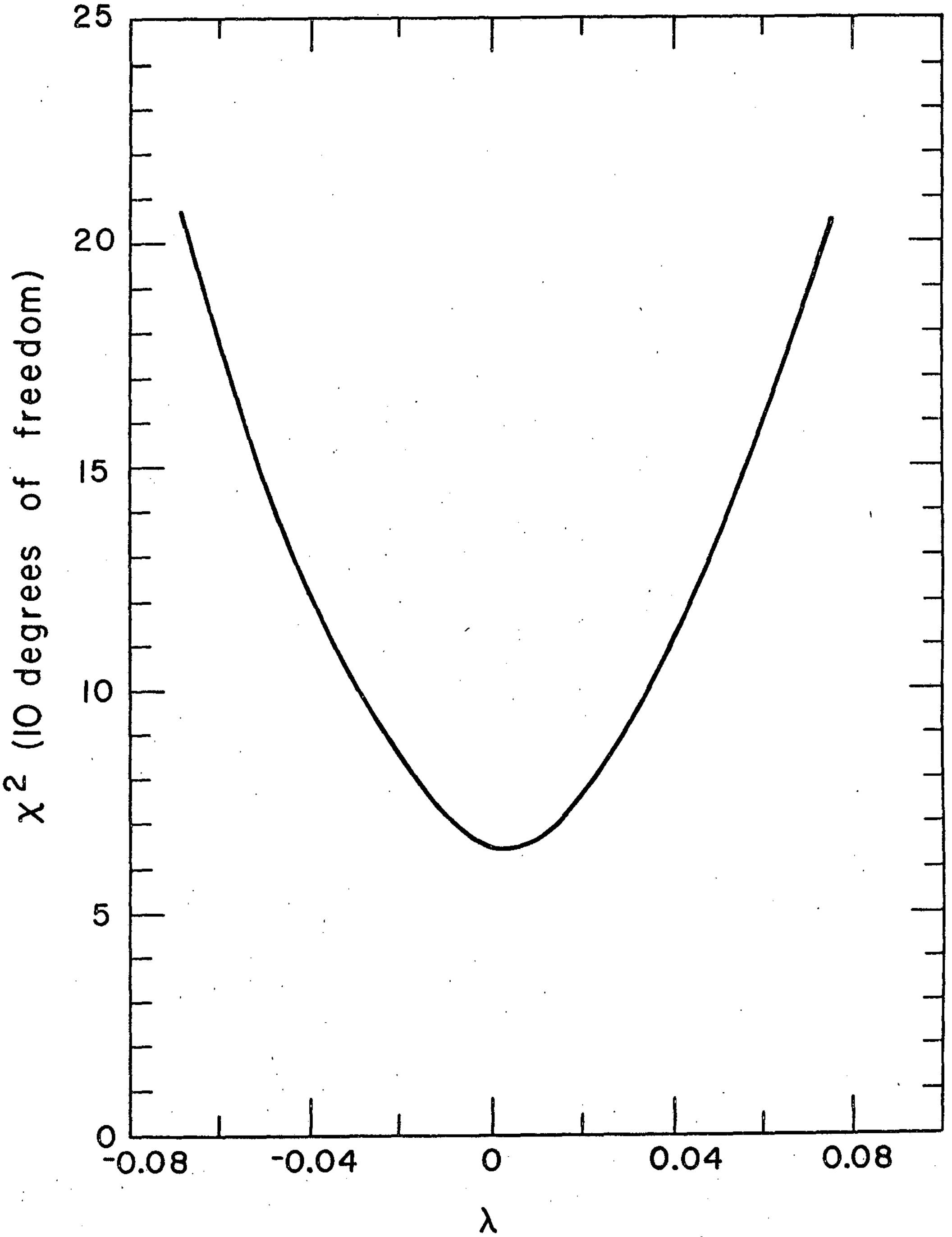
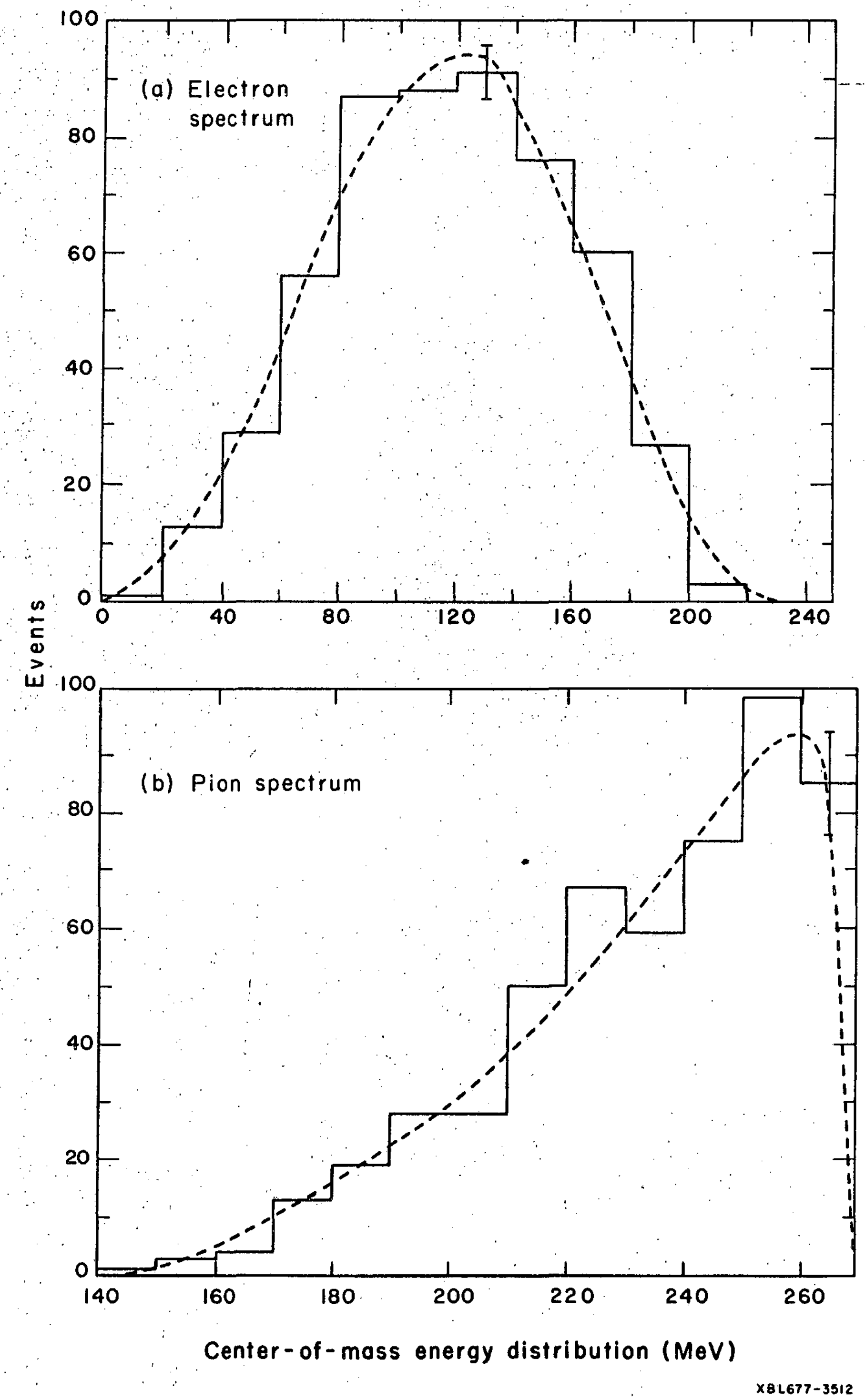

25
20
15
10
5
0
-0.08
-0.04
0
0.04
0.08
χ^2 (10 degrees of freedom)
λ
XBL677-3536A

Fig. 1



100
80
60
40
20
0
(a) Electron spectrum
0
40
80
120
160
200
240
Events
100
80
60
40
20
0
(b) Pion spectrum
140
160
180
200
220
240
260
Center-of-mass energy distribution (MeV)
XBL677-3512

Fig. 2