ENERGY SPECTRA AND ANGULAR CORRELATIONS OF K^0_{e3} *DECAY PARTICLES*

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The energy spectra and electron and π-meson emission-angle distributions based on 394 K^0_{e3} decay events are presented for those cases when the π-meson energy lies between 231 and 270 MeV or 244 and 270 MeV. The distributions can be satisfactorily described only by the vector interaction theory. With a certainty of more than 99.9% the scalar and tensor theories can be rejected as the only type of interaction. Their possible contribution to the interaction is 10—12%. No dependence of the form factor g_V on electron energy has been detected experimentally.

IN this paper we give the final results of a study of the spectra and angular correlations of particles in the decay $K^0_2 \to \pi^\pm + e^\mp + \nu$, detected by the magnetic cloud chamber method in the neutral particle beam from the proton synchrotron of the Joint Institute for Nuclear Research.

In comparison with the data contained in the previous communication [1] on this subject, upon conclusion of the analysis we added to the material on the K^0_{e3} decays, 194 events identified by checking the kinematic correspondence to the K^0_{e3} decay of V^0 events having one or both charged particles with momentum $p < 100$ MeV/c. By addition of these K^0_{e3} decays to the 200 K^0_{e3} decays identified previously by measuring the relative track density of particles with momenta $p < 80$ MeV/c, the number of K^0_{e3} decays of the first set[2] has been increased to 394 events. This made possible the construction of energy spectra of the electrons and angular correlations between electron and pion for the case when the pions are confined to a narrow energy interval, and consequently carry out a more reliable and stringent test of the form of the decay interaction. The experimental setup and conditions for selecting K^0_{e3} decays in the laboratory system have been described in detail in [1].

The total admixture to K^0_{e3} decays of the first set due to the $K^0_{\mu 3}$ decays and $K^0_2 \to \pi^+ + \pi^0$ decays amounts to 3–4%. In addition, among the decays identified by measurements of track density are contained 7–8 Dalitz pairs from the decay $K^0_{3\pi^0}$, for which only one electron could be identified.[3] The experimental distributions are corrected only for the contribution of the Dalitz pairs. The correction was carried out by subtracting from the experimental distributions the corresponding distributions for the experimentally identified 29 Dalitz pairs, when each pair was assumed to be a K^0_{e3} decay.

The theoretical (computed) distributions are obtained with the selection conditions and the identification of the K^0_{e3} decays in the laboratory system taken into account, by programming the V^0 events on an electronic computer on the assumption that the form factors for the strong interaction do not depend on the pion energy.

In Tables I and II and in Fig. 1 we show the experimental and theoretical spectra of the pions and electrons and the angular correlation for these particles. The dashed line in Fig. 1 corresponds to the theoretical distribution for the V-covariant for the decay interaction. The experimental errors given in the table and the figure include only the statistical deviations. The theoretical distributions are constructed on the basis of 672 trials.

Tables I and II and Fig. 1 show that only the vector interaction covariant is in good agreement with experiment. The value of the g_V form factor for the five pion energy intervals, determined as

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2)The second set consists of 160 K^0_{e3} decays identified by the energy loss of the decay particles in passing through a lead plate [1].

3)The identification of Dalitz pairs is described in [2].

Table I. Distribution for true configurations. First set

Pion spectrum					Electron spectrum			Distribution cos $\gamma_{e,\pi}$		
	N, %					N, %			N, %	
		Calculation								
$\Delta\left(\frac{E}{E_{max}}\right)$	Experiment	V	S	T	$\Delta\left(\frac{E}{E_{max}}\right)$	Experiment	Calculation for V	$\Delta \cos\gamma_{e,\pi}$	Experiment	Calculation V
0.0÷0.2	2.9±0.8	0,8±0.4	6.2±1.0	0,6±0.4	0.0÷0.2	20.4±2.3	19.1±2.1	1.0÷0.6	5.2±1.2	2.0 ±0.5
0.2÷0.4	6.3±1.3	3.4±0.8	16,6±1.7	5,0±0.9	0,2÷0,4	50.1±3,7	46.2±3.4	0,6÷0.2	9.0±1.5	6,4 ±9.7
0.4÷0,6	9,5±1.5	9.3±1,2	26.0±2.1	23,9±2,0	0.4÷0.6	24.5±2.5	25,8±2,6	0,2÷—0.2	14.1±1.9	14.4±1,5
0.6÷0.8	27,9±2.7	29,4±2,4	36,6±2,5	42,3±2,7	0,6÷0.8	4,7±1.2	7,7±1,6	—0.2÷—0,6	25,5±2.6	24,6±1.9
0,8÷1.0	54,6±3.7	57.1±2.7	14.6±1.6	28,2±2,2	0,8÷1,0	0,3±0.3	1.2±0,7	—0,6÷—1,0	46.1±3.5	52,6±2.8

Table II. Total distributions. First set

Pion spectrum					Electron spectrum			Distribution cos $\gamma_{e,\pi}$		
	N, %					N, %			N, %	
		Calculation								
$\Delta\left(\frac{E}{E_{max}}\right)$	Experiment	V	S	T	$\Delta\left(\frac{E}{E_{max}}\right)$	Experiment	Calculation for V	$\Delta \cos\gamma_{e,\pi}$	Experiment	Calculation V
0.0÷0.2	4,5±1.0	4.0±0.8	3.6±0.8	0.4±0.3	0,0÷0.2	18.1±2.2	16.2±1.6	1,0÷1.6	6.8±1.3	3.6±0.7
0,2÷0.4	11.2±1.8	7.2±1,1	7.9±1,2	4.9±0.9	0.2÷0.4	44.5±3.4	40.1±2.7	0.6÷0.2	9.6±1,6	8.4±1.1
0.4÷0,6	15.3±2.0	14.8±1.6	27.7±2.1	23.7±2.0	0.4÷0,6	23.0±2.4	26.5±2,0	0.2÷—0.2	17.4±2.1	14.4±1,5
0,6÷0.8	27.0±2.6	28.7±2.4	35.7±2.4	38.3±2.5	0.6÷0.8	11.3±1.8	13.1±1.4	—0.2÷—0.6	25.7±2,6	26.0±2.0
0.8÷1,0	42.0±3.1	45.3±2.8	25.1±2,0	32.8±2,3	0.8÷1.0	3.1±0.9	4.1±0.8	—0,6÷—1.0	40.3±3.3	47,6±2.7

the result of division of the number of events in each of these intervals for the experimental and computed spectra (normalized to 100%, are given below:

140—166	166—192	192—218	218—244	244—270
3.6±2.1	1,8±0.7	1,02±0.20	0,95±0,12	0,96±0.08
1.9±0.6	1,4±0,3	1.01±0,10	0.97±0,06	0.96±0.04

In determining the quantity g_V it was assumed that the decay interaction is CP invariant. If the obtained dependence of the g_V form factor on the pion energy is expressed in the form

$$g_V = 1 + \lambda q^2 / E_\pi^2,$$

where q^2 is the square of the 4-momentum, transferred to the lepton pair, then we obtain for the coefficient λ the following values

$$\lambda = \left(3.0 \begin{array}{l} +5.5 \\ -4.0 \end{array}\right) \cdot 10^{-2}.$$

As seen from the above data, the form factor g_V depends weakly on the pion energy. The character of this dependence—a slow decrease of the form factor with increasing pion energy—is in agreement with an approximate theoretical estimate, carried out in [3] on the assumption that the πK-interaction phase shifts are mainly determined by the πK resonance with mass M = 891 MeV. An analogous character for the dependence of the g_V form factor on the pion energy was obtained in the study of K^0_{e3} decays [4,5].

In the existing papers on the study of three particle leptonic decays of K^+ mesons[4)] a weak

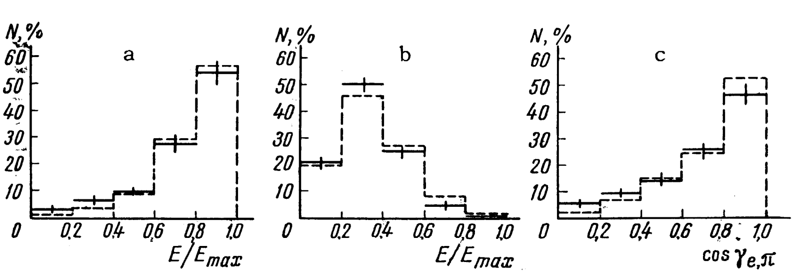

FIG. 1. The distributions for true configurations, first set: a) pion spectrum, b) electron spectrum, c) the angular correlation cos $\gamma_{e\pi}$.

4)See, for example, the review [6].

dependence of the form factor g_V on the pion energy was also obtained; however, in these papers both positive and negative values were obtained for the coefficient λ. Therefore at the contemporary precision of measurement of the particle energy spectra and angular correlations in the K_{e3} decays it is, apparently, not yet possible to consider as well established that the g_V form factor decreases with increasing pion energy.

In order to test whether it is possible to achieve agreement between the computed (theoretical) distributions for the S- and T-covariants for the interaction with the experimental data by introducing a dependence of the form factors g_S and g_T on the pion energy we modified in our first paper[1] the computed distributions pertaining to the first set of K^0_{e3} as follows. For the theoretical spectra, corresponding to true configurations, values of the form factors g_S and g_T in three energy intervals were found, which reconciled the theoretical pion spectra with the spectra obtained experimentally. Then, using the thus-obtained energy dependence of the form factors, the spectra of electrons in the angular distributions of the particles were calculated anew. A comparison of the modified computed distributions with the corresponding experimental distributions makes it then possible to conclude that even if the dependence of the form factors on the pion energy in the scalar and tensor covariants were taken into account, these covariants could not be the only interaction covariants. As regards the scalar covariant, this result was new as compared with the then available papers [4,7,8] on the study of K decays.

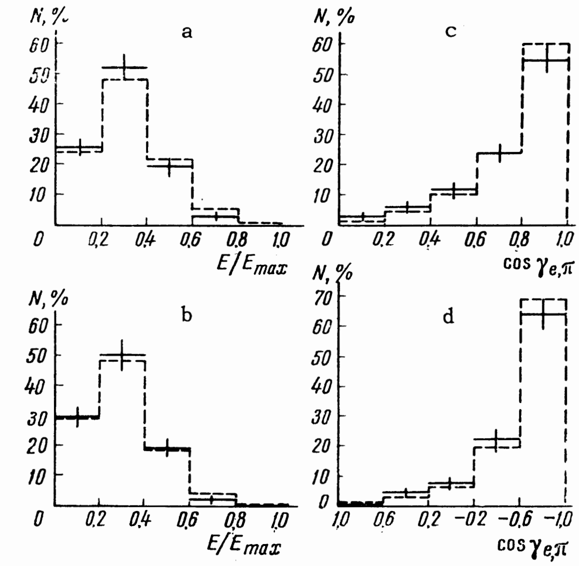

FIG. 2. The distribution for true configurations, first set: a), c)—electron spectra, b)—pion spectra, d)—the angular correlation cos $\gamma_{e,\pi}$.

As a result of the increased statistics on the K^0_{e3} decays, this conclusion is confirmed in the present paper by studying the energy spectra of

Table III. Distribution for true configurations, ΔE_π = 231–270 MeV. First set

Pion spectrum					Distribution cos $\gamma_{e,\pi}$				
$\Delta\left(\frac{E}{E_{max}}\right)$	N, %				$\Delta \cos \gamma_{e,\pi}$	N, %			
	Experiment	Calculation				Experiment	Calculation		
		V	S	T			V	S	T
0,0÷0.2	25,6±3,0	24.3±2.2	36.4±2,5	56,7±3.2	1,0÷0,6	2.9±1,0	1,2±0.5	12,8±1.5	25,7±2.1
0,2÷0,4	52.2±4,3	48.1±3.1	48.2±2.9	38.8±2.6	0,6÷0.2	6,1±1,5	4.4±0.9	14,5±1.6	24.1∓2.1
0,4÷0,6	19.4±2.6	21.8±2.1	12.0±1.4	2,4±0,6	0.2÷—0.2	11,8±2.0	10.2±1,4	19.0±1.8	21.9±2,0
0,6÷0,8	2.8±1.0	5.2±1.0	2.9±0.8	1,4±0.5	—0.2÷—0.6	24.0±2.9	23.8±2.1	25.7±2.1	19,0±1.8
0,8÷1,0	0.0	0,6±0.4	0,5±0,3	0,7±0,3	—0.6÷—1.0	55,2±4.4	60,4±3,6	28.0±2.2	9.3±1.3

Table IV. Distribution for true configurations, ΔE_π = 244–270 MeV. First set

Pion spectrum					Distribution cos $\gamma_{e,\pi}$				
$\Delta\left(\frac{E}{E_{max}}\right)$	N, %				$\Delta \cos \gamma_{e,\pi}$	N, %			
	Experiment	Calculation				Experiment	Calculation		
		V	S	T			V	S	T
0.0÷0.2	29.1±3.6	28,8±2,7	41.4±2.6	62.8±6.9	1.0÷0.6	0.9±0.6	1.2±0.5	9,3±1.2	15.9±3.5
0.2÷0.4	50.2±4.8	48,1±3,4	38.5±2.5	36.4±5.2	0.6÷0.2	4.8±1,5	2,8±0,9	9.7±1,3	18.2±3.7
0.4÷0.6	18.9±2.9	18.6±2.1	15.6±1.6	0.8±0.8	0.2÷—0.2	7.7±1.9	6.5±1,3	17,8±1.7	22,7±4.1
0.6÷0.8	1,8±0,9	3,9±1,0	4.2±0.8	0,0	—0.2÷—0.6	22.3±3.2	19.9±2,2	27.8±2.1	26,5±4.5
0.8÷1.0	0,0	0,6±0,4	0,3±0.2	0,0	—0.6÷—1.0	64,3±5.4	69.5±4.1	35,4±2,4	16,7±3,6

Table V

	Electron spectrum			Distribution $\cos\gamma_{e\pi}$		
	V	S	T	V	S	T
Value of χ^2	4.8	14.7	117.7	4.3	75.7	262.6
Expected value of χ^2	3.0	3	3	3	4	4
Probability $P(\chi^2)$	0.18	0,005	0,001	0.25	0.001	0.001

the electrons and the angular distributions of the pion and electron emission, when the pion energy is fixed in the interval ΔE = 231–270 MeV (288 K^0_{e3} events) and in the interval ΔE = 244–270 MeV (212 K^0_{e3}). The indicated distributions for the true configurations of the decay particles are shown in Tables III and IV and in Fig. 2. The dashed line in the figure shows the computed distributions for the vector interaction covariant. For the first pion energy interval the computed distributions were obtained on the basis of 500 trials, and for the second interval on the basis of 400 trials. As can be seen from a study of the tables and the figure, in both cases only the vector covariant is in good agreement with the experimental distributions.

The comparison of the agreement between the computed and experimental distributions for the first pion energy interval by the χ^2 test is shown in Table V. Analogous results are also obtained for the second pion energy interval.

It follows from these data that the scalar and tensor covariants are excluded as the only interaction covariants at better than 99.9% confidence level. These conclusions are independent of any assumptions on the dependence of the strong-interaction form factor on the pion energy. On this basis (when the interference between the scalar and tensor amplitudes is ignored[5)]), an estimate was made of the possible contributions of S- and T-covariants to the decay interaction by the method of minimizing the χ^2 distribution. It shows that the possible total contribution of both covariants does not exceed 10—12%. It should be noted here that owing to the existence of an admixture of $K^0_{\mu 3}$ decays this is really an overestimate. Within experimental errors it is in agreement with analogous data obtained in a study of K^+ decays.[9]

The good agreement of the experimental electron spectra and emission angles $\gamma_{e,\pi}$ with the computed distributions for the vector covariant of the interaction indicates that within the experimental errors the form factor g_V is independent of the electron energy. This result is an indication in favor of the locality of the weak interaction with respect to the leptonic current. In view of the fact that the mass of the scalar barolepton, which may be responsible for the nonlocality of the weak interaction in the leptonic current (if the latter exists at all), is, apparently, very large[6)], its appearance in the K_{e3} decay can be hardly expected to be noticed at the presently available accuracy of measurement of the spectra. An analogous conclusion is reached in the cited paper[9].

A study of the spectra and angular correlations of the particles in K_{e3} decays has been carried out in a number of papers[4,5,7-11]. The conclusions obtained in these papers on the decay interaction covariant are in agreement with each other. However, only in our paper has the distribution for fixed pion energy been considered for the first time, so that the conclusions reached are in no way dependent on assumptions about the dependence of the strong-interaction form factors on the pion energy.

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5) This interference term vanishes under CP invariance of the weak interaction.

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