Measurement of the form factor for the decay $K^- \to \pi^0 e^- \tilde{\nu}$

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The q^2 dependence of the vector form factor f_+ has been studied in K_{e3}^- decay. The functional dependence is written in the form $f_+(q^2) = f_+(0)(1 + \lambda_+ q^2/m_\pi^2)$. For the parameter λ_+, the value $\lambda_+ = 0.029 \pm 0.004$ is found. Radiative corrections increase the value of λ_+ by 0.002. An experimental constraint on the branching ratio of the K_{e5}^- decay has been found for the first time: B.R. $(K_{e5}^-) < 3.5 \times 10^{-4}$.

Under the assumption that only a vector current contributes to K_{e3}^- decay, we write the matrix element as

$$M = \frac{G}{\sqrt{2}} \sin\theta\,(f_+(q^2)p_\alpha + f_-(q^2)q_\alpha)\varphi_\pi\varphi_K\,\bar{u}_\nu\gamma^\alpha(1+\gamma_5)u_e, \qquad (1)$$

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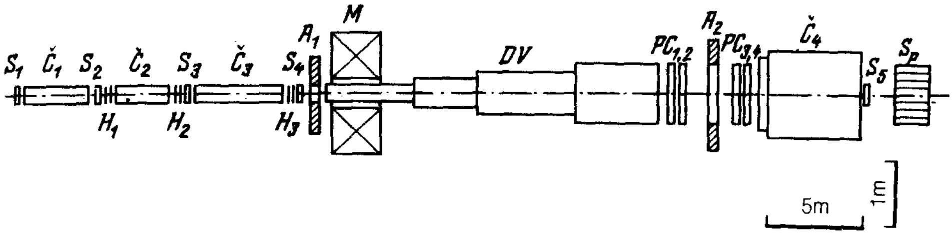

FIG. 1. Layout of the Istra experimental apparatus. S_{1-5}—Scintillation counters; $\check{C}_{1-4}$—gas-filled threshold Čerenkov counters; H_{1-3}—beam hodoscopic photomultipliers; PC_{1-4}—induced-charge proportional chambers; SP—hodoscopic Čerenkov spectrometer; A_{1-2}—anticoincidence counters; DV—decay volume; M—deflecting magnet for calibrating the spectrometer.

where $p = p_K + p_\pi$ and $q = p_K - p_\pi$ is the the 4-momentum transferred to the lepton pair. The form factors f_+ and f_- depend on only q^2 and are usually written in the linear approximation: $f_+(q^2) = f_+(0)\ \ (1 + \lambda_+ q^2/m_\pi^2)$. The term containing f_- makes a contribution proportional to the mass of an electron and can thus be ignored.

The most accurate value which has been found for λ_+ for the decays of K^+ mesons was found in the experiment of Ref. 1: $\lambda_+ = 0.027 \pm 0.008$.

The measurements which we are reporting in the present letter were carried out on the Istra apparatus of the Institute of Nuclear Research, Academy of Sciences of the USSR,[2] in a beam of negative particles with an energy of 25 GeV at the accelerator of the Institute of High-Energy Physics. The experimental apparatus (Fig. 1) has been described in other papers (e.g., Ref. 3). Figure 2 shows the geometric efficiency of the apparatus as a function of q^2.

In the experiment, 2.8×10^6 events of the type $K^- \to e^- + n(\gamma)$ were detected

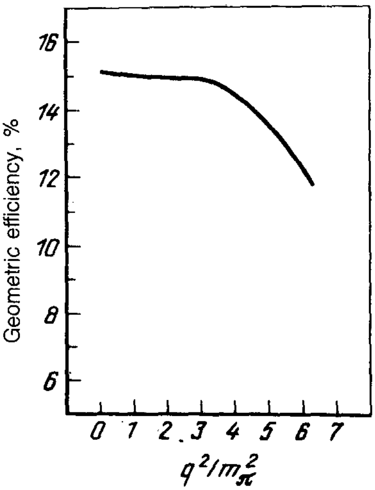

FIG. 2. Geometric efficiency of the apparatus.

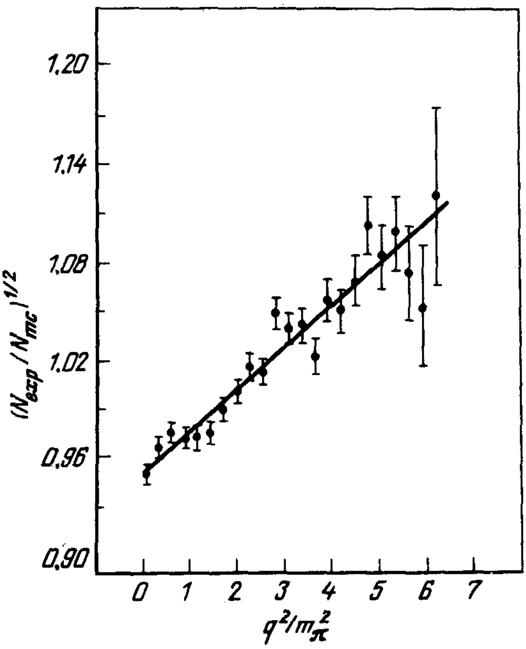

FIG. 3. The ratio $f_+(q^2)/f_+(0)$ according to data on K_{e3} decay. The result of a linear fit, which yields the value $\lambda_+ = 0.029$, is shown.

during the passage of 1.5×10^9 K mesons. After a geometric reconstruction of the recorded events, the following selection criteria were imposed in order to identify K^-_{e3} decays: a) A single track is detected in H and PC. b) Three electromagnetic showers with energies $E_\gamma > 1$ GeV are detected in Sp. c) The distance between the centers of the showers is at least 10 cm. d) The distance between the point at which the track from PC intersects the Sp plane and the center of the nearest shower is no greater than 5 cm. e) The distance from the beam axis to the center of the nearest shower is at least 5.5 cm.

In order to discriminate against the background, which was determined primarily by the decay $K^-\to\pi^-\pi^0$, we discarded events satisfying the hypothesis $K^-\to\pi^-\pi^0$ (a $5C$ fit) with $\chi^2 < 15.1$ (99% confidence level). From the remaining events we then selected those which satisfied the hypothesis K^-_{Le3} (a $3C$ fit) with $\chi^2 < 6.25$ (90% confidence level). After all these selection criteria, we were left with 62 000 events.

Since q^2 depends on E_π $[q^2 = (p_K - p_\pi)^2 = m_K^2 + m_\pi^2 - 2m_K E_\pi]$, the q^2 dependence of the vector form factor f_+ can be found by comparing the experimental pion energy spectrum with the corresponding distribution generated by the Monte Carlo method with the help of matrix element (1). With the large statistical base available, it was important to allow for possible sources of systematic errors from the outset. One possible source of systematic errors was a dependence of the electron detection efficiency on the coordinate of Čerenkov counter $\check{C}_4$. The following analysis procedure was accordingly adopted. The detection region of the Čerenkov counter was partitioned into 5×5-cm^2 regions, within which the efficiency varied only slightly. In the Monte Carlo simulation of the decay we obtained distributions of events separately for each such region. A maximum-likelihood fit was carried out in such a way that the best value of λ_+ for all regions simultaneously was found. The simulation incorporated all the cutoffs which are used in analyzing experimental data as well as the following factors: a) multiple scattering, b) the efficiencies of the detectors, c) errors in the determination of the coordinates and energies of the particles, and d) the geometric efficiency of the apparatus.

The validity of the simulation was checked by comparing a large number of different geometric and kinematic distributions with the experimental data. A good agreement was found in all cases.

The fitting procedure yielded $\lambda_+ = 0.029$ with $\chi^2 = 29$ for 21 degrees of freedom. The statistical error was 0.002. Radiation corrections to the pion energy spectrum, in accordance with Ref. 4, increase the value of λ_+ to $\lambda_+ = 0.031$.

The q^2 dependence of the form factor is shown clearly in Fig. 3. The number of experimentally observed events in the q^2 interval was divided by that predicted by (1) for a constant form factor ($\lambda_+ = 0$). The ratio is proportional to $f_+(q^2)^2$. The straight line corresponds to the value given above for the slope.

To check for the effect of a drift of the electron detection efficiency, we simulated events within each region, under the assumption of oscillations in the efficiency. The deviations in the value of λ_+ turned out to be on the order of the statistical error.

We also used the Monte Carlo method to estimate how the result would be affected by systematic errors of the detectors in the determination of the coordinates and energies. We studied systematic errors stemming from the following effects:

a) errors in the determination of the coordinates of the K^- hodoscopic photomultipliers;

b) errors in the determination of the coordinates of the e^- proportional chambers and the spectrometer;

c) a temporal drift in the accuracy at which the energies of the electrons and γ rays are determined (on the basis of data on the stability of the spectrometer characteristics).

These effects do not lead to the appearance of a systematic error in the determination of λ_+. An additional systematic error was studied on the basis of the dependence of λ_+ on the event selection conditions (on the basis of various cutoffs, partitionings, etc.). Using the procedure adopted by the Particle Data Group,[5] we determined the scaling factor for the error, which turned out to be 1.8. The final result (aside from radiation corrections) can thus be written as follows (the error has been increased by a factor of 1.8):

$$\lambda_+ = 0.029 \pm 0.004.$$

The events pertaining to decays $K^- \to e^- + n(\gamma)$, which were detected experimentally, were also analyzed in order to detect events from decays $K^- \to \pi^0\pi^0\pi^0 e^- \tilde{\nu}$, on whose probability no experimental limitation has so far been set. Theoretical estimates put the expected branching ratio of this decay at B.R.$(K_{e5}) \approx 10^{-11}$ (Ref. 6).

In the analysis, criteria a), c), d), and e), used to identify K_{e3}^- decays (see the discussion above), were applied to the three events in which spectrometer *Sp* detected seven electromagnetic showers with energies $E_\gamma > 1$ GeV. None of the events satisfied all of the criteria simultaneously. We thus find an upper limit $N(K_{e5}) < 2.3$ on the number of decays $K^- \to \pi^0\pi^0\pi^0 e^- \tilde{\nu}$ at a 90% confidence level. The numbers of K_{e5} and K_{e3} decays into the same number of decaying K mesons, N_K, are

$$N(K_{e5}) = N_K \, \text{B.R.}(K_{e5})\epsilon,$$
$$N(K_{e3}) = N_K \, \text{B.R.}(K_{e3})\epsilon',$$

where ϵ and ϵ' are the overall efficiencies of the detection and analysis of the processes, found by the simulation. After some simple manipulations and substitution of the known values $N(K_{e3}) = 177\,500$, B.R.$(K_{e3}) = 0.048$, and $\epsilon'/\epsilon = 6.3$, we find

$$\text{B.R.}(K_{e5}) < 3{,}5 \times 10^{-6}.$$

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