A MEASUREMENT OF $K^+_{e\nu\gamma}$ DECAY[1,2]

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Received 17 December 1974

The decay $K^+ \to e^+\nu\gamma$ has been observed. In a counter experiment at CERN, 56 events of this type have been identified by detection of a γ with an energy > 100 MeV and of an e^+ with an energy between 236 MeV and the maximum e^+ energy, 247 MeV. The angle between γ and e^+ was > 120°. Thus, the experiment was sensitive only to the structure decay (SD) term proportional to the squared sum of vector- and axialvector amplitudes, $|v_K + a_K|^2$, corresponding to the emission of right handed γ. We find

$\Gamma_+(SD)/\Gamma(K_{e2}) = 1.05^{+0.25}_{-0.30}$ and $\Gamma_-(SD)/\Gamma_+(SD) < 85$ (90% CL).

Γ_+ is in agreement with theoretical predictions.

We report on a measurement of the structure term in radiative K_{e2} decay, $K^+ \to e^+\nu\gamma$ ($K^+_{e\nu\gamma}$), which was performed concurrently with a measurement of the $K_{e2}/K_{\mu2}$ branching ratio [1].

There are two effects contributing to $K_{e\nu\gamma}$ decay: internal bremsstrahlung (IB), where a soft γ is emitted by the electron, and structure decay (SD), where a high energy γ is emitted from the interaction vertex. A measurement of SD therefore gives information on the states coupling the kaon to the leptons.

SD is described by vector- and axialvector amplitudes v_K and a_K; v_K can be calculated assuming saturation of the intermediate states by the K^* and K_A mesons. Various calculations agree with each other within 20%. We quote the result of ref. [6]:

$$v_K(q^2) = \frac{0.12}{m_K(1-q^2/m^2_{K^*})}, \quad q^2 = (p_e + p_\gamma)^\mu (p_e + p_\gamma)_\mu .$$

Estimates of the ratio $|a_K/v_K|$ yield results between 0.05 and 0.58.

IB and SD dominate in markedly different regions of the $K^+_{e\nu\gamma}$ Dalitz plot. IB produces low energy γ at small angles $\theta_{e\gamma}$ to the e^+. SD has two non-interfering terms for positive and negative γ-helicities, which will be denoted SD_+ and SD_-. Both produce a γ-spectrum with an average energy of 160 MeV, with different $e^+\gamma$ and $\nu\gamma$ angular correlations. For the SD_+ term, 98% of the γ-rays are emitted with angles $\theta_{e\gamma} > 90°$, and the $\nu\gamma$ angular correlation is nearly isotropic. For the SD_- term, the situation is reversed: The $e^+\gamma$ correlation is nearly isotropic, while $\theta_{\nu\gamma} > 90°$ for 98% of the decay events. Consequently, the electron spectrum of SD_+ is peaked at the maximum energy $E_{\max} = 247$ MeV, while that of SD_- is peaked at $\frac{1}{2}E_{\max}$. Interference terms between IB and SD are negligible. Details on form factors and kinematics can be found in refs. [2–9].

The $SD_+(SD_-)$ rate is proportional to $(v_K + a_K)^2 \times ((v_K - a_K)^2)$.

So far, only an upper limit for SD, $\Gamma(SD)/\Gamma(all) < 1.3 \times 10^{-5}$, has been reported [10].

In view of the small branching ratio, $K_{e\nu\gamma}$ decay can be studied only at e^+-energies above the endpoint of the K_{e3} spectrum at 228 MeV. In our experiment, we accepted $E_e \geqslant 236$ MeV, $\theta_{e\gamma} \geqslant 120°$ and $E_\gamma \geqslant 100$ MeV. In this kinematical region, IB is

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[1] A preliminary result has been reported at the IInd Intern. Aix-en-Provence Conf. on High Energy Physics, 1973.

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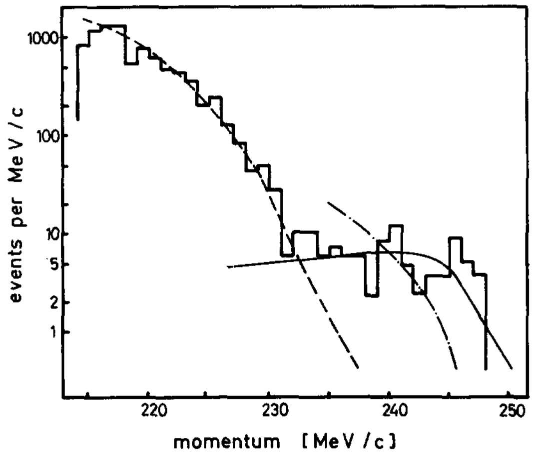

Fig. 1. e^+ momentum spectrum of $K_{e\nu\gamma}$ candidates. Smooth curves are calculated spectra, normalised to the observed spectrum above $p_e = 236$ MeV/c (a, b) or $p_e = 215$ MeV/c (c): a) SD_+ term in $K_{e\nu\gamma}$ decay, ——, b) SD_- term in $K_{e\nu\gamma}$ decay, —·—·—, c) K_{e3} decay, – – – –.

expected to be three orders of magnitude smaller than SD. Due to the different e^+-γ angles, the fraction of events within this region is two orders of magnitude larger for SD_+ than for SD_-.

The apparatus and the experimental method is described in ref. [1]. Only the part A_I of the hodoscope behind the magnet is used in the analysis of $K_{e\nu\gamma}$ events. Due to the geometrical arrangement of the γ-detector and the high momentum cut in the e^+ spectrum, about 75% of the $e^+\gamma$-coincidences from $K_{e\nu\gamma}$ decay have their e^+ detected in A_I.

Candidates for $K_{e\nu\gamma}$ decay are selected from the sample of electron triggers (mode 2, see ref. [1]) by application of the same criteria to the K^+ decay time and to the signal of the gas Cerenkov counter as for the K_{e2} candidates (criteria 1 and 3 in ref. [1]), and by the additional requirement, that the γ-detector shows a signal in coincidence with the gas Cerenkov counter.

The selection of electron candidates for K_{e2} decay is also described in ref. [1]. For K_{e2} candidates, the absence of a signal from any γ-counter phototube is demanded to suppress K_{e3} decay relative to K_{e2} decay. This causes a loss of (13 ± 4)% of all events due to accidental γ-counter signals, as evaluated from observed $K_{\mu 2}$ decays. (Note that this loss does not influence the $K_{e2}/K_{\mu 2}$ branching ratio).

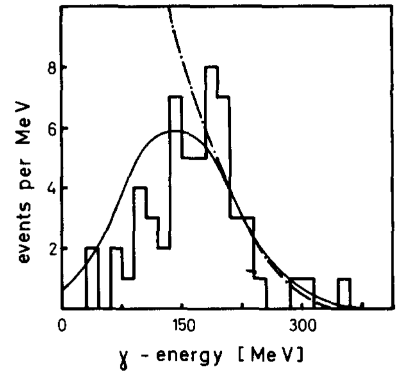

Fig. 2. γ energy spectrum of $K_{e\nu\gamma}$ candidates with $p_e \geqslant 236$ MeV/c. Smooth curves are calculated spectra, normalised to the observed spectrum above $E_\gamma = 150$ MeV: a) SD_+ term, ——, b) SD_- term, —·—·—.

After subtracting the background from random gas Cerenkov counter and γ-counter signals, we obtain the electron spectrum shown in fig. 1. The $K_{e\nu\gamma}$ decays are clearly visible above the upper edge of the K_{e3} spectrum. Fig. 1 also shows the shape of the K_{e3} spectrum, which was calculated taking into account bremsstrahlung in the target and surrounding counters, and the spectrometer resolution, as determined from observed $K_{\mu 2}$ decays ($p_\mu = 236$ MeV/c).

Above 236 MeV/c, the electron spectrum contains 56 events, which we ascribe to $K_{e\nu\gamma}$ decays. Background from K_{e2} decays with an accidental γ-counter signal and from K_{e3} decays with a high energy e^+ from either a Dalitz pair or a γ conversion is calculated to be less than one event.

The γ energy spectrum of the events with $p_e \geqslant 236$ MeV/c is shown in fig. 2. In both figures, the line shapes expected for the contributions from SD_+ and SD_- decay are also shown. From the comparison of observed and calculated line shapes, we find an upper limit of 7 events (68% CL) for a contribution from the SD_- term (14 events with 90% CL). The number of observed SD_+ events with its statistical error then is 56^{+8}_{-12}.

The fraction of $K_{e\nu\gamma}$ events with observed e^+ momentum $p_e \geqslant 236$ MeV/c is $r = 0.174$ for SD_+ and $r = 0.0008$ for SD_-, taking into account the spectrometer resolution and bremsstrahlung in the target.

The efficiency of the γ-counter for such $K_{e\nu\gamma}$ events is calculated from the observed efficiency for

γ from $K_{\pi 2}$ decays, which are identified by the π^+ momentum and range. The result is $\epsilon_\gamma = 0.72 \pm 0.12$ for the SD_+ term and $\epsilon_\gamma = 0.47 \pm 0.20$ for the SD_- term.

We determine the $K_{e\nu\gamma}$ branching ratio relative to K_{e2} decay. In that way, the e^+ detection efficiency drops out. The K_{e2} sample selected with the same e^+ criteria contains 260 events above 240 MeV/c. The fraction of events above this cutoff is calculated to be 0.70 ± 0.20 [1]. We also have to include the loss of $(13 \pm 4)\%$ due to random signals from the γ-counter.

With these numbers we find

$$\Gamma(K^+_{e\nu\gamma}, SD_+)/\Gamma(K_{e2}) = 1.05^{+0.25}_{-0.30}.$$

Using the $K_{e2}/K_{\mu 2}$ branching ratio $R = (2.37 \pm 0.17) \times 10^{-5}$ measured simultaneously in our apparatus [1], we obtain

$$\Gamma(K^+_{e\nu\gamma}, SD_+) = (1280^{+320}_{-380})\ \mathrm{sec}^{-1}.$$

For the SD_- term, we find an upper limit

$$\Gamma(SD_-)/\Gamma(SD_+) < 85\ (90\%\ \mathrm{CL}).$$

To compare our result with theoretical predictions, we use the SD_+ rate to calculate

$$m_K |v_K + a_K| \sin\vartheta_c = (3.3^{+0.4}_{-0.5}) \times 10^{-2},$$

where ϑ_c is the Cabibbo angle.

For the Cabibbo angle we may choose $\sin\vartheta_c = 0.212$ as derived from the K_{e3} decay rate, or $\sin\vartheta_c = 0.269$ as derived from the $K_{\mu 2}/\pi_{\mu 2}$ branching ratio [11]. From hyperon decays, one has $\sin\vartheta_c = 0.237$ [12]. This range of possible values of the Cabibbo angle gives a larger uncertainty for the amplitudes than the experimental uncertainty. We find

$$0.10 < m_K |v_K + a_K| < 0.18,$$

which is in agreement with the predictions

$$m_K |v_K(q^2 = 0.4/m_K^2)| = 0.14$$

and

$$0.05 < |a_K/v_K| < 0.6.$$

In principle, a_K/v_K could be determined from the ratio of the SD_- and SD_+ rates independently from the Cabibbo angle, if one only assumes the same Cabibbo angle for V and A currents. This would, however, require measurements at lower electron energies, which seems to be prohibited by abundant background from K_{e3} decay. From our limit on the SD_- rate, we find

$$|v_K - a_K|/|v_K + a_K| < 9\ (90\%\ \mathrm{CL}).$$

We thank Dr. D. Gromes for enlightening discussions on the theoretical aspects of $K_{e\nu\gamma}$ decay.

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