Observation of the decay $K^- \to \pi^- \pi^0 \pi^0 \gamma$

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(Submitted 27 September 1985)
Pis'ma Zh. Eksp. Teor. Fiz. **42**, No. 9, 390–392 (10 November 1985)

On the basis of an analysis of the events in the decay $K^- \to \pi^- \pi^0 \pi^0 \gamma$ (98% confidence level) it is determined that the relative probability for the decay $BR(K^- \to \pi^- \pi^0 \pi^0 \gamma)$ is $(7.4^{+5.5}_{-2.9}) \times 10^{-6}$ for γ-ray energy $E^*_\gamma > 10$ MeV in the rest frame of a K^- meson.

Among the radiative decays of charged K mesons, the decay $K \to 3\pi\gamma$ has been studied least extensively. Several events detected in the decay $K^+ \to \pi^+ \pi^+ \pi^- \gamma$ is the only experimental evidence of the existence of this decay.[1] Theoretical estimates of the probability of this decay, carried out under the assumption that the decay amplitude is dominated by the internal bremsstrahlung, are consistent with the experimental data.[2]

The radiative decay

$$K^- \to \pi^- \pi^0 \pi^0 \gamma \tag{1}$$

has so far not been studied experimentally. The relative probability for the decay $BR(K^- \to \pi^- \pi^0 \pi^0 \gamma) = \Gamma(K^- \to \pi^- \pi^0 \pi^0 \gamma)/\Gamma(K^- \to all)$ is estimated to be $\sim 10^{-5}$ for γ-ray energy $E^*_\gamma > 10$ MeV in the rest frame of a kaon.

In the present study we have concluded on the basis of an analysis of the events in the decay (1) (98% confidence level) that the relative probability of this decay is $BR(K^- \to \pi^- \pi^0 \pi^0 \gamma) = (7.4^{+5.5}_{-2.9}) \times 10^{-6}$, at $E^*_\gamma > 10$ MeV.

The measurements were carried out concomitantly with the study of the rare modes of the decay of the in-flight π^- and K^- mesons in the 70-GeV accelerator of the Institute of High Energy Physics (the ISTRA apparatus of the Institute of Nuclear Research was used). The energy of the unseparated K^--meson beam was 25 GeV. The photons produced in the decay (1) were detected with a full-absorption hodoscopic spectrometer which consisted of a 24×20 matrix of lead-glass counters.[3] The coordinates of the K^- and π^- mesons were recorded with the use of hodoscopic photomultipliers and proportional chambers that yielded information in analog form.[4,5] The ISTRA apparatus and its characteristics are described in greater detail in Ref. 3. To distinguish the events with γ rays $n_\gamma \geqslant 3$ and to partially suppress the dominant decay $K^- \to \pi^- \pi^0$, we modified the trigger to rapidly select several γ-ray showers in the Cherenkov spectrometer.

In selecting the candidate events corresponding to the decay (1) we have stipulated that (1) the spectrometer must have five γ-ray showers with an energy $E_\gamma > 1$ GeV, (2) the total energy release in the spectrometer must be greater than 10 GeV, (3) only one track must be present in the hodoscopic photomultipliers and proportional chambers, (4) the minimum distance between the point at which the π^- track intersects the spectrometer plane and the nearest γ ray must be greater than 10 cm and (5) the

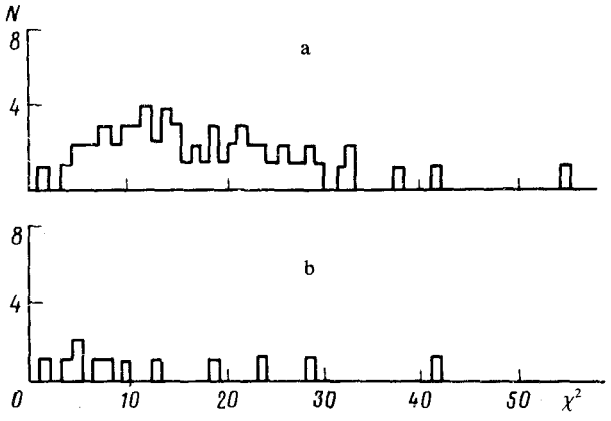

FIG. 1. χ^2 distribution of the events for the hypothesis $K^- \to \pi^- \pi^0 \pi^0 \gamma$. (a) After a preliminary selection; (b) after the introduction of additional selection criteria.

decay point must be situated in the decay gap.

The hypothesis $K^- \to \pi^- \pi^0 \pi^0 \gamma$ was tested for all events that were selected preliminarily. Figure 1a shows the χ^2 distribution for 65 events that satisfy this hypothesis. The accuracy of the data evaluation was tested by reconstructing the events in the decays $K^- \to \pi^- \pi^0$ and $K^- \to \pi^- \pi^0 \pi^0 (\tau')$, which were detected simultaneously with the process being studied.

Our analysis showed that the events in Fig. 1a are primarily the instrumental background produced as a result of superposition of the τ'-decay events spaced closely apart and a "random" particle or noise from the counters and electronic components of the spectrometer.

To reduce this background, we have introduced more stringent conditions for selecting the events, which have reduced the number of useful events by 25%: 1) The measured effective mass of the γ-ray pairs corresponding to the π^0 mesons, $M_{2\gamma}$, lies in the interval 105 MeV $< M_{2\gamma} <$ 165 MeV, 2) the effective mass of the π^- meson–γ-ray pair (corresponding to the bremsstrahlung in the decay), $M_{\pi\gamma}$, lies in the interval 155 MeV $< M_{\pi\gamma} <$ 200 MeV, and 3) the energy of a bremsstrahlung γ ray, E^*_γ, is lower than 45 MeV. Figure 1b shows the χ^2 distribution of the remaining 12 events.

The preliminarily selected events (300 events) were used to estimate the background level. These events were first tested to determine whether they are compatible with the hypothesis $K^- \to \pi^- \pi^0 \pi^0$ by looking at all possible ways to combine four of the five γ rays into two π^0 mesons. The characteristics of the unconnected fifth γ ray were used as a random-background model for the events whose χ^2 distribution was no greater than 14 (97% confidence level). This background was then "admixed" into the model of the τ' decay and the resulting events were subjected to the same routine of analysis and selection as that used in constructing the experimental distributions shown in Figs. 1a and 1b. After an appropriate normalization to the number of detected events, we found that the contribution of the instrumental background to the region with a χ^2 distribution less than 10.5 [90% confidence level for the decay (1)] corresponds to 2 events, whereas we have observed 7 events in this region.

The rare radiative decay (1) is thus observed at the 98% confidence level.

The relative probability for the decay (1) can be calculated by normalization to the number of events in the τ' decay. The acceptance of the apparatus, the efficiency of the programs for reconstruction of the events and for the kinematic analysis, and the criteria used for selecting the useful events were taken into account in determining the efficiency at which the events were detected. The ratio of the partial widths was found to be $\Gamma(K^-\to\pi^-\pi^0\pi^0\gamma)/\Gamma(K^-\to\pi^-\pi^0\pi^0) = (4.3^{+3.2}_{-1.7})\times 10^{-4}$. Using the experimental value of $\Gamma(K^-\to\pi^-\pi^0\pi^0)$ (Ref. 6), we find

$$BR(K^-\to\pi^-\pi^0\pi^0\gamma) = (7.4^{+5.5}_{-2.9})\times 10^{-6}.$$

We wish to thank the management of the Institute of Nuclear Research of the Academy of Sciences of the USSR and the management of the Institute of High Energy Physics for support of the experimental program carried out at the ISTRA facility.

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Translated by S. J. Amoretty