Observation of the $\eta' \to \mu^+\mu^-\gamma$ decay

V. A. Viktorov, S. V. Golovkin, M. V. Grutsuk, [1)] R. I. Dzhelyadin, A. M. Zaĭtsev, D. B. Kakauridze, V. A. Kachanov, A. S. Konstantinov, V. F. Konstantinov, V. P. Kubarovskiĭ, A. V. Kulik, L. G. Landsberg, V. M. Leont'ev, V. A. Mukhin, V. F. Obraztsov, T. I. Petrunina, N. S. Pokrovskiĭ, and Yu. D. Prokoshkin

Institute of High Energy Physics

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The mass spectrum of $\mu^+\mu^-\gamma$ systems produced in the $\pi^-\rho$ interactions at momenta of 25 and 33 GeV/c was investigated. A wide-aperture magnetic spectrometer and a hodoscopic γ-ray detector were used for the recording of muon pairs and γ quanta. A sharp peak corresponding to the $\eta' \to \mu^+\mu^-\gamma$ decay not observed earlier was detected in the mass spectrum. The relative probability of this decay (8×10^{-5}) and the spectrum of muon pairs are in agreement with the model of the form factor of the η' meson, which is based on vector dominance.

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In this paper, which is a continuation of a series of investigations of rare electromagnetic decays of light mesons,[1,2] we conducted a search for the decay

$$\eta' \to \mu^+\mu^-\gamma. \tag{1}$$

A description of the "Lepton-G" apparatus, which was used in these experiments, and of the measurement and evaluation procedure was given in the preceding papers.[1,2] The main components of the apparatus were a wide-aperture magnetic spectrometer for the detection of muon pairs and a hodoscopic multichannel γ-ray spectrometer for recording of γ quanta.

The source of η' (958) mesons was the charge-exchange reaction

$$\pi^- p \to \eta' n. \tag{2}$$

The experiments were performed in a beam of negative pions at momenta of 25 and 33 GeV/c. The total flux of π^- mesons through the apparatus was 3×10^{11}.

In the first stage of analysis of the experimental data we reconstructed the tracks of charged particles in the spark chamber and in the proportional chamber and selected events with two hard ($E_\mu > 4$ GeV) muons produced in the target. It was also required that there should be no additional tracks emerging from the vertex of the interaction in the front part of the spectrometer. Then we searched in the γ-ray spectrometer for single showers that satisfied the selection criteria for showers from γ quanta with an energy $E_\gamma > 1.5$ GeV. To suppress the background due to hadronic showers, the distance between the center of mass of the shower and the coordinate of each of the two charged particle at the entrance to the γ-ray spectrometer had to be greater than 24 mm.

We selected events corresponding to the exclusive process $\pi^- p \to \mu^+\mu^-\gamma n$ and

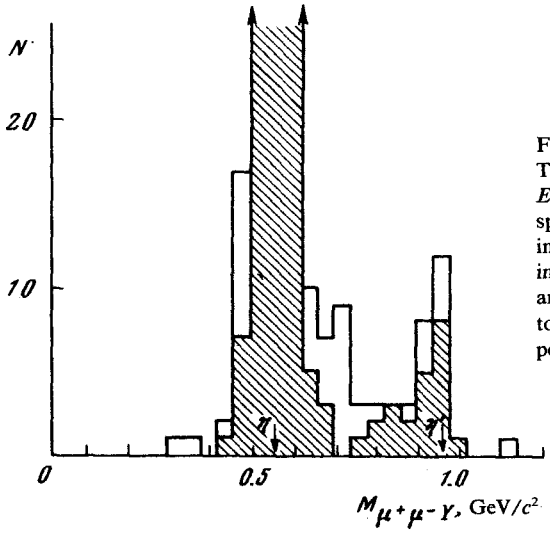

FIG. 1. The mass spectrum of $\mu^+\mu^-\gamma$ systems. The cross-hatched histogram corresponds to $E_\gamma > 5$ GeV and the unshaded histogram corresponds to $E_\gamma > 3$ GeV. N is the number of events in the mass interval of 40 MeV/c^2. The arrows indicate the table values of the masses of the η and η' mesons. The left-hand peak corresponds to the $\eta \to \mu^+\mu^-\gamma$ decay[1] and the right-hand peak corresponds to decay (1).

investigated the spectrum of the effective masses of the $\mu^+\mu^-\gamma^-$ systems in this reaction.

The background conditions in the mass region $M_{\mu^+\mu^-\gamma} > M_\eta$ improved substantially with increasing energy threshold of the γ quantum. Such a cutoff further suppressed the recording of hadronic showers and at the same time affected the detection efficiency for the decay (1) slightly within certain threshold limits. The maximum energy of the γ quanta ($E_\gamma < 16$ GeV) was also cut off in order to reduce the background from the fast π^0 mesons (for example, from the $\omega \to \pi^0\mu^+\mu^-$ decay[2]) for which the showers from the two γ quanta were not resolved in the detector.

The final spectrum of the effective masses of the $\mu^+\mu^-\gamma$ systems is shown in Fig. 1. In addition to the peak corresponding to the $\eta \to \mu^+\mu^-\gamma$ decay,[1] a sharp peak in the mass spectrum can be observed in the mass region of the η' meson, which contains 25 events ($E_\gamma > 3$ GeV) and 2 to 4 events at the nonresonance-background level. The mass of the peak is $M_{\mu^+\mu^-\gamma} = 0.95 \pm 0.01$ GeV/c^2, in good agreement with the table value of the masses of the η' meson, and its width correspond to our instrumental resolution. Thus, we detected experimentally in this work the decay of the η' meson into a muon pair and a γ quantum (1).

To determine the relative probability of this decay $BR(\eta' \to \mu^+\mu^-\gamma) = \Gamma(\eta' \to \mu^+\mu^-\gamma)/\Gamma(\eta' \to \text{all})$, we normalized it to the number of events of the reaction $\pi^- p \to \rho(\omega)n$, $\rho(\omega) \to \mu^+\mu^-$, which was observed in the same experiment[1]; the efficiencies of all the processes were calculated by the Monte-Carlo method. The detection efficiency of the reaction $\pi^- \rho \to \text{n}'n$, $\eta' \to \mu^+\mu^-\gamma$ is almost independent of the form factor in the matrix element of the decay (1). The cross sections of the reaction (2) for our energies were taken from the data of Ref. 3. As a result, we obtained the relative probability of the decay

$$BR(\eta' \to \mu^+\mu^-\gamma) = 8 \times 10^{-5} \qquad (3)$$

with a systematic error of 50%.

To theoretically estimate this probability, we used the Dalitz formula[4] for decay (1) with a simple form factor $F^2(M^2_{\mu^+\mu^-}) = [(1 - M^2_{\mu^+\mu^-}/M^2_\rho)^2 + (\Gamma_\rho/M_\rho)^2]^{-1}$ which was selected in accordance with vector dominance. Such an estimate gives a $BR(\eta' \to \mu^+\mu^-\gamma)_{\text{theor}} = 8.2 \times 10^{-5}$.[2)] The mass region of the ρ meson ($M_{\mu^+\mu^-} > 0.7$ GeV) is expected to have 15% of all the events, in qualitative agreement with the fraction of events observed by us in this range $30 \pm 10\%$.

Thus, we have detected the $\eta' \to \mu^+\mu^-\gamma$ decay in this work. The relative probability of this decay and the spectrum of the muon pairs are in agreement with the form-factor model of the η' meson, which is based on vector dominance.

[1)]ITÉF, Moscow.

[2)]$BR(\eta' \to \mu^+\mu^-\gamma) = 3.4 \times 10^{-5}$ when the form factor is not taken into account. The large role of the form factor is attributed to the fact that for decay (1) the ρ pole is located in the physical region.

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