Investigation of the transition electromagnetic form factor in the $\omega \to \pi^0 \mu^+ \mu^-$ decay

V. A. Viktorov, S. V. Golovkin, R. I. Dzhelyadin, A. M. Zaĭtsev, A. S. Konstantinov, V. F. Konstantinov, V. P. Kubarovskiĭ, L. G. Landsberg, V. A. Mukhin, V. F. Obraztsov, T. I. Petrunina, and Yu. D. Prokoshkin
Institute of High Energy Physics

(Submitted 28 December 1980)

Pis'ma Zh. Eksp. Teor. Fiz. **33**, No. 4, 239–243 (20 February 1981)

Sixty events of the rare electromagnetic decay $\omega \to \pi^0 \mu^+ \mu^-$ were recorded. The relative probability of this decay $BR \times (\omega \to \pi^0 \mu^+ \mu^-) = (9.6 \pm 2.3) \times 10^{-5}$ is determined. The spectrum of the effective masses of muon pairs was measured and the electromagnetic transition form factor of the $\omega\pi^0$ vertex was determined $F_\omega(m^2_{\mu\mu}; m^2_{\pi^0}) = (1 - m^2_{\mu\mu}/\Lambda^2)^{-1}$, where $\Lambda = 0.65 \pm 0.03$ GeV/c^2. A comparison with the vector-dominance model is made.

PACS numbers: 13.20. – v, 13.40.Fn, 14.40.Ka

We present in this paper new experimental data for the decay of an ω meson into π^0 meson and a muon pair

$$\omega \to \pi^0 \mu^+ \mu^- , \tag{1}$$

which was observed previously.[1] The main purpose of further study of the process (1) is to measure the transition form factor which determines the structure of the $\omega\pi^0$ vertex.

The source of ω mesons was the binary reaction

$$\pi^- p \to \omega n, \tag{2}$$

which has been thoroughly investigated in our energy range[2] and which provides favorable background conditions for the experiment.[1] The measurements were performed using a composite "Lepton-G" spectrometer in a pion beam with a momentum of 25 and 33 GeV/c, which was extracted from the 70-GeV accelerator of the Institute of High Energy Physics. The description of the experimental setup, the measurement procedure and analysis of the data were reported in the preceding papers.[1,3–6] 5×10^{11} π^- mesons were transmitted through the target of the device during the experiment; this corresponded to the production of 10^7 ω mesons in the reaction (1).

The events of the decay (1) were identified by analyzing the exclusive reaction

$$\pi^- p \to \underset{\hookrightarrow 2\gamma}{\pi^0} \mu^+ \mu^- n. \tag{3}$$

The particles were identified in the final state by using the same method as that used previously.[1] Figure 1 shows the distribution of the events (3) according to the effective mass of the $\pi^0\mu^+\mu^-$ systems. To reduce the background, we selected the events with $m^2_{\mu\mu} < 0.4$ GeV^2/c^4 in the kinematic region in which the form factor was studied subsequently.

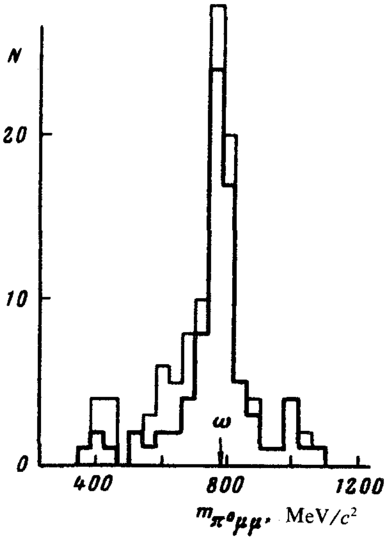

FIG. 1. Mass spectrum of $\pi^0\mu^+\mu^-$ systems for the events with $m^2_{\mu\mu} < 0.4$ GeV^2/c^4. The peak corresponds to the decay (1). The arrow indicates the table value of the mass of an ω meson. N represents the number of events in the internal 40 MeV/c^2. The inner and outer histograms correspond to energy thresholds of γ-ray quanta equal to 1 and 1.4 GeV, respectively.

A sharp peak corresponding to the decay (1) can be seen in the mass spectrum. The peak contains 60 ± 9 events of the decay (1) after subtraction of the 11% nonresonance background and the 3% background from the processes $\omega \to \pi^0\pi^+\pi^-$, $\pi^\pm \to \mu^\pm$ (the pions decay in flight in front of the γ-ray spectrometer and in the experimental setup's absorber[2,3]) and $\rho^0 \to \pi^0\mu^+\mu^-$. This enabled us to determine the relative probability of the decay $BR\,[(\omega \to \pi^0\mu^+\mu^-) = \Gamma(\omega \to \pi^0\mu^+\mu^-)/\Gamma(\omega \to 211)]$:

$$BR(\omega \to \pi^0\mu^+\mu^-) = (9{,}6 \pm 2{,}3)\cdot 10^{-5} \tag{4}$$

(both the statistical and systematic measurement errors are taken into account below).

To determine the transition electromagnetic form factor of the $\omega\pi^0$ vertex, we have investigated the mass spectrum of muon pairs $m_{\mu\mu}$ in the decay (1) in a similar manner as it was done previously for the decay $\eta \to \mu^+\mu^-\gamma$.[6] This spectrum is described by the equation[7,8]

$$\frac{d\Gamma(\omega \to \pi^0\mu^+\mu^-)}{d\,m^2_{\mu\mu}} = \frac{\alpha}{3\pi}\,\frac{\Gamma(\omega \to \pi^0\gamma)}{m^2_{\mu\mu}}\left(1 + \frac{2m^2_\mu}{m^2_{\mu\mu}}\right)\left(1 - \frac{4m^2_\mu}{m^2_{\mu\mu}}\right)^{1/2}$$

$$\times\left[\left(1 + \frac{m^2_{\mu\mu}}{m^2_\omega - m^2_{\pi^0}}\right)^2 - \frac{4m^2_\omega m^2_{\mu\mu}}{(m^2_\omega - m^2_{\pi^0})^2}\right]^{3/2} \left|F_\omega(m^2_{\mu\mu};\, m^2_{\pi^0})\right|^2 \tag{5}$$

The transition form factor of the $\omega\pi^0$ vertex

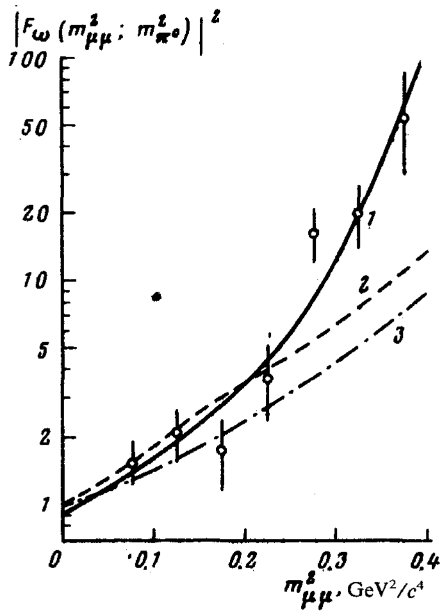

FIG. 2. Transition form factor for the $\omega\pi^0$ vertex. The points denote the experimental values $|F_\omega(m^2_{\mu\mu};\ m^2_{\pi^0})|^2$. Curve 1 represents the result of fitting of the experimental data using the pole dependence $|F_\omega|^2 = K\left(1 - \frac{m^2_{\mu\mu}}{\Lambda^2}\right)^{-2}$. The coefficient K takes into account the uncertainty of absolute normalization of the experimental values. $\Lambda = 0.65$ GeV/c^2. Curve 2 represents the prediction of the model[9] with a modified ρ propagator; curve 3 was calculated using the vector-dominance model.

$F_\omega(m^2_{\mu\mu};\ m^2_{\pi^0}) = F_\omega(q^2_1 = m^2_{\mu\mu};\ q^2_2 = m^2_{\pi^0})$, which was normalized: $F_\omega(0;\ m^2_{\pi^0}) = 1$, is generally parametrized in a polar approximation

$$F_\omega(m^2_{\mu\mu};\ m^2_{\pi^0}) = \left(1 - \frac{m^2_{\mu\mu}}{\Lambda^2}\right)^{-1} \tag{6}$$

Figure 2 is a plot of the values of $|E_\omega|^2$ determined by us. These values were determined as a ratio of the measured mass spectrum of muon pairs to the spectrum that was calculated by using the Monte-Carlo method according to Eq. (5) with $|F_\omega| = 1$, with allowance for the efficiency of the apparatus. The calculated spectrum was normalized to the total number of ω mesons produced in the reaction (2) in the device's target.

We used the polar formula (6) to fit the experimental values of the form factor (Fig. 2). The characteristic mass is

$$\Lambda = 0.65 \pm 0{,}03 \text{ GeV}/c^2\ . \tag{7}$$

The slope of the form factor at zero time of this pulse, $q_1 = 0$, is $dF_\omega/dq^2_1 = \Lambda^{-2} = 2.4 \pm 0.2$ GeV^{-2}$\cdot c^4$.

The transition form factor in the vector-dominance model depends on the contribution of one ρ pole. In this case $\Lambda_{VDM} = m_\rho$. This value differs from the measured value by four standard deviations. The form factor increases in the region of large masses $m_{\mu\mu}$ much faster than it was predicted by the vector-dominance model (Fig. 2).

The transition $\omega\pi^0$ form factor was analyzed in Ref. 9 by using the dispersion method with allowance for the intermediate $\pi\pi$ states ($\gamma^* \to \pi\pi \to \pi^0\omega$). As follows from the unitarity relation, the contribution from the amplitude of the reaction $\pi\pi \to \pi^0\omega$ must be taken into account in the expression for the form factor. This amplitude was parametrized, in accordance with the vector dominance, by introducing the ρ pole in the s, t, and u channels, which resulted in a slight modification of the ρ-meson propagator in the transition form factor. The results of the calculations based on this model are shown in Fig. 2. The plotted curve is slightly closer to the experimental points than the predictions of the ordinary ρ dominance; however, the discrepancy between the theory and the experiment remains noticeable.

We thank A. I. Vaĭnshteĭn, M. I. Vysotskiĭ, V. I. Zakharov, I. Yu. Kobzarev, and M. A. Shifman for a discussion of the results of the experiment.

[1]V. A. Viktorov *et al.*, Yad. Fiz. **29**, 1513 (1979) [Sov. J. Nucl. Phys. **29**, 777 (1979)]; Phys. Lett. **84B**, 143 (1979).
[2]V. D. Apel' *et al.*, Yad. Fiz. **31**, 167 (1980) [Sov. J. Nucl. Phys. **31**, 89 (1980)]; Lett. Nuovo Cim. **25**, 493 (1980).
[3]Yu. B. Bushnin *et al.*, Preprint IFVÉ 80-57, Serpukhov, 1980.
[4]Yu. B. Bushnin *et al.*, Yad. Fiz. **28**, 1507 (1978) [Sov. J. Nucl. Phys. **28**, 775 (1978)]; Phys. Lett. **79B**, 147 (1978).
[5]V. A. Viktorov *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **30**, 387 (1979), [JETP Lett. **30**, 359 (1979)]; Phys. Lett. **88B**, 379 (1979).
[6]V. A. Viktorov *et al.*, Yad. Fiz. **32**, 998, 1002, 1005 (1980) [Sov. J. Nucl. Phys. **32**, (1980)]; Phys. Lett. **94B**, 548 (1980).
[7]C. H. Lai and G. Ougg, Preprint FN-296, Fermilab, USA, 1976.
[8]V. F. Obraztsov, Preprint IFVÉ 79-115, Serpukhov, 1979.
[9]G. Kopp, Phys. Rev. **D10**, 932 (1974).

Translated by S. J. Amoretty
Edited by Robert T. Beyer