

# $\eta$ -meson decay into $\gamma\mu^+\mu^-$ in the vector dominance model

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(Submitted 20 February 1979)

*Pis'ma Zh. Eksp. Teor. Fiz.* **29**, No. 7, 439-442 (5 April 1979)

We obtained a value for  $B(\eta \rightarrow \gamma\mu^+\mu^-)$  of  $3.08 \times 10^{-14}$ – $3.13 \times 10^{-14}$  as a function of the relative contribution of vector mesons.

PACS numbers: 13.40.Hq, 13.20.Jf, 14.40.Ka

The decay  $\eta \rightarrow \gamma\mu^+\mu^-$  was reported recently.<sup>1</sup> Below we shall evaluate the probability of this decay and the effective mass distribution of the  $\mu^+\mu^-$ -pair within the framework of the vector dominance model (VDM). Subsequent measurements will permit us to verify this model and to refine our knowledge of the quark composition of the  $\mu$ -meson. If the experiment and VDM predictions disagree, this will signify the existence of new physical effects.

The decay probability of  $\eta \rightarrow \gamma\mu^+\mu^-$  is<sup>2</sup>

$$\frac{d\Gamma}{ds} = \frac{2\alpha}{3\pi} \Gamma_{\gamma\gamma} \frac{1}{s} \left(1 - \frac{s}{m_\eta^2}\right)^3 \left(1 + \frac{2\mu^2}{s}\right) \sqrt{1 - \frac{4\mu^2}{s}} |F(s)|^2. \quad (1)$$

Above,  $\Gamma_{\gamma\gamma}$  is the width of decay  $\eta \rightarrow \gamma\gamma$ ,  $\mu$ —mass of  $\mu$ -meson. The form factor  $F(s)$  describes the strong interaction for an off mass shell photon which satisfies the normalization condition  $F(0) = 1$ . In the standard vector dominance model (see, for example, Ref. 3):

$$F(s) = \frac{1}{g_{\eta\gamma\gamma}} \left( \frac{g_{\rho\eta\gamma}}{g_{\rho\gamma}} \frac{m_\rho^2}{m_\rho^2 - s - i\Gamma_\rho m_\rho} + \frac{g_{\omega\eta\gamma}}{g_{\omega\gamma}} \frac{m_\omega^2}{m_\omega^2 - s - i\Gamma_\omega m_\omega} + \frac{g_{\phi\eta\gamma}}{g_{\phi\gamma}} \frac{m_\phi^2}{m_\phi^2 - s - i\Gamma_\phi m_\phi} \right), \quad (2)$$

where

$$g_{\eta\gamma\gamma} = \frac{g_{\rho\eta\gamma}}{g_{\rho\gamma}} + \frac{g_{\omega\eta\gamma}}{g_{\omega\gamma}} + \frac{g_{\phi\eta\gamma}}{g_{\phi\gamma}}. \quad (3)$$

The constants  $g_{\eta\gamma\gamma}$  and  $g_{\nu\gamma\gamma}$  may be determined from the experimental data on the decay width  $\Gamma(v \rightarrow p + \gamma) = \frac{1}{3} \alpha g_{\nu p\gamma}^2 |\mathbf{k}|^3$  and  $\Gamma(v \rightarrow e^+ + e^-) = \frac{1}{3} \alpha^2 (g_{\nu\gamma}^2 / 4\pi)^{-1} m_\nu$ , respectively.

TABLE I.

$x$	$-0.29 (\theta_p = -10^\circ)$	$-0.202 (\theta_p = -23^\circ)$	$-0.258$
$R(\eta \rightarrow \gamma \mu^+ \mu^-)$	$8.24 \cdot 10^{-4}$	$8.1 \cdot 10^{-4}$	$8.18 \cdot 10^{-4}$
$B(\eta \rightarrow \gamma \mu^+ \mu^-)$	$3.13 \cdot 10^{-4}$	$3.08 \cdot 10^{-4}$	$3.11 \cdot 10^{-4}$

Since these widths<sup>4</sup> are known to have large errors, it appears more prudent, knowing the normalization condition, to express  $F(s)$  as follows:

$$F(s) = \frac{1-x}{1+y} \left( \frac{m_\rho^2}{m_\rho^2 - s - i\Gamma_\rho m_\rho} + y \frac{m_\omega^2}{m_\omega^2 - s - i\Gamma_\omega m_\omega} \right) + x \frac{m_\phi^2}{m_\phi^2 - s - i\Gamma_\phi m_\phi} \quad (4)$$

and to determine the values of parameters "x" and "y" which follow from the experiment or theoretical considerations. Of greatest importance to us is the fact that the parameter "x" is negative. The sign of "x" follows both from quark models<sup>1)</sup>

$$g_{\rho\eta\gamma} = \frac{1}{3} g_{\omega\eta\gamma} = \frac{2\mu_p}{\sqrt{3}} (\cos \theta_p - \sqrt{2} \sin \theta_p), \quad (5)$$

$$g_{\phi\eta\gamma} = \frac{4\mu_p}{3\sqrt{3}} (\sqrt{2} \cos \theta_p + \sin \theta_p),$$

$$1/g_{\rho\gamma} : 1/g_{\omega\gamma} : 1/g_{\phi\gamma} = 1 : \frac{1}{3} : -\frac{\sqrt{2}}{3}$$

and from Eq. (3) in which it is postulated by the requirement of a better agreement with the experimentally-measured constant  $g_{\eta\gamma\gamma}$ . If, however,  $g_{\phi\eta\gamma}/g_{\phi\gamma}$  has a positive sign in Eq. (3), it is impossible to attain satisfactory agreement with the width  $\Gamma_{\eta\gamma}$ <sup>4</sup> even if experimental errors are taken into consideration.

The parameter  $y = g_{\omega\eta\gamma} g_{\rho\gamma} / g_{\rho\eta\gamma} g_{\omega\gamma}$  is experimentally imprecisely known, but since  $B(\eta \rightarrow \gamma \mu^+ \mu^-) = \Gamma(\eta \rightarrow \gamma \mu^+ \mu^-) / \Gamma_{tot}$  is practically independent of this parameter, we shall use the theoretical value  $y = \frac{1}{3}$ . The table shows results of calculations of  $R(\eta \rightarrow \gamma \mu^+ \mu^-) = \Gamma(\eta \rightarrow \gamma \mu^+ \mu^-) / \Gamma_{\eta\gamma}$  and  $B(\eta \rightarrow \gamma \mu^+ \mu^-)$ . In the first two columns the values of "x" derive from Eq. (5), while the third column shows the experimental value with the sign of "x" taken into consideration.

To refine the results we allow for a correction to the final width for the  $\rho$ -meson contribution.<sup>6</sup> It turns out that the difference in  $R(\eta \rightarrow \gamma \mu^+ \mu^-)$  with and without the corrected final width is 1.2% of  $R$ . The relative accuracy of the calculation of

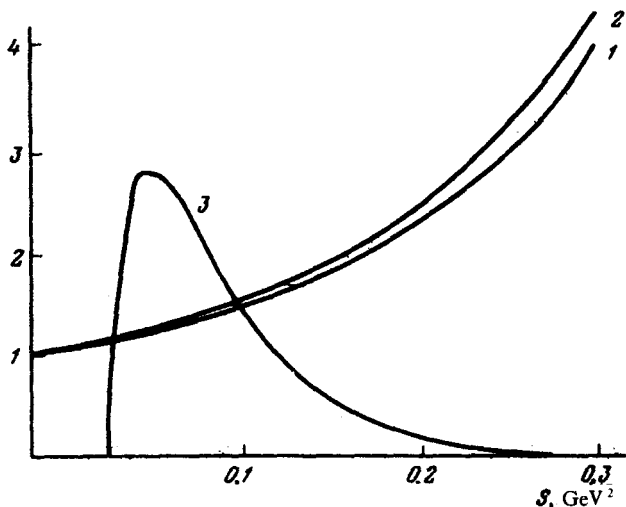


FIG. 1. Dependence of form factor  $F(s)$  and differential distribution  $d\Gamma/ds$  [Eq. (1)] on the invariant mass of the  $\mu^+\mu^-$  pair; curve 1— $F(s)$  at  $x = -0.2$ ; curve 2— $F(s)$  at  $x = -0.3$ ; curve 3— $(d\Gamma/ds) \times 10^9 (\text{GeV})^{-1}$  at  $x = -0.3$ .

$R(\eta \rightarrow \gamma\mu^+\mu^-)$  is not less than 1.5% and results from the error contained in  $\Gamma_\rho$ ,  $m_\rho$  and in the excitation curve of the  $\rho$ -meson.

The accuracy of  $B(\eta \rightarrow \gamma\mu^+\mu^-)$  deteriorates due to errors in  $B(\eta \rightarrow \gamma\gamma) = (0.38 \pm 0.01) \times 10^{-2}$  since  $B(\eta \rightarrow \gamma\mu^+\mu^-) = R(\eta \rightarrow \gamma\mu^+\mu^-)B(\eta \rightarrow \gamma\gamma)$ .

In the original experiment  $B(\eta \rightarrow \gamma\mu^+\mu^-) = 1.5 \times 10^{-4}$  with a 50% systematic error. In the second series of measurements<sup>7</sup> this value increased to  $2.42 \times 10^{-4}$  with a 25% error. Because of the considerable errors it is premature to draw conclusions concerning an agreement between VDM and experiment. It is probably more feasible to compare the differential distribution  $d\Gamma/ds$  instead of  $B(\eta \rightarrow \gamma\mu^+\mu^-)$ ; the curve below shows  $d\Gamma/ds$ .

In conclusion the authors thank M.V. Gritsuk, A.M. Zaitsev and L.G. Landsberg for discussions.

<sup>11</sup>We picked  $\phi = s\bar{s}$ ; for  $\phi = -s\bar{s}$  the sign of "x" remains unchanged.

<sup>12</sup>Yu.B. Bushnin *et al.* *Yadern. Fiz.* **28**, 1507 (1978) [*Sov. J. Nucl. Phys.* **28**, 775 (1978)].

<sup>13</sup>N.M. Kroll and W. Wada, *Phys. Rev.* **98**, 1355 (1955).

<sup>14</sup>R. Feinman, *Vzaimodeistvie fotonov s adronami* (Interaction Between Photons and Hadrons), M., Mir, 1975.

<sup>15</sup>Particle Data Group, *Phys. Lett.* **B75**, (1978).

<sup>16</sup>Nguyen Van Xieu, *Lektsii po teorii unitarnoi simmetrii elementarnykh chastits* (Seminars on the Theory of Unitary Symmetry of Elementary Particles), M., Atomizdat, 1967.

<sup>17</sup>G. Gounaris and J. Sakurai, *Phys. Rev. Lett.* **8**, 79 (1962).

<sup>18</sup>L.G. Landsberg, *Doklad na nauchnoi sessii OYaf AN SSSR* (Reported at the Scientific Session of the Department of Nuclear Physics of the USSR Academy of Sciences), 16–20 January 1979.