Probability of decay $\phi \to 2\pi$

N. M. Budnev and S. I. Polityko
A. A. Zhdanov Irkutsk State University

(Submitted 26 January 1979)

Pis'ma Zh. Eksp. Teor. Fiz. **29**, No. 5, 305–308 (5 March 1979)

The probability of decay $\phi \to 2\pi$ is evaluated within the framework of the unitary model, $B(\phi \to 2\pi) = (2.063 \pm 0.41) \times 10^{-4}$.

PACS numbers: 13.25. + m, 14.40. – n

The enhanced luminosity of current accelerators using colliding e^+e^- beams provides the means of carrying out a number of precise experiments concerning the properties of vector mesons. One of these experiments involves the search for the decay $\phi \to 2\pi$. The low probability of this process is due to the fact that a strong transition $\phi \to 2\pi$ is forbidden by the conservation of G-parity and is only possible via electromagnetic processess. This paper deals with the feasibility of observing the $\phi \to 2\pi$ transition in terms of pion form factor interference in the region ($s^{1/2} \approx m_\phi$).

In recent experiments, conducted at the Institute of Nuclear Physics (Siberian Branch, USSR Academy of Sciences),[1] an upper limit was obtained for the relative decay probability

$$B(\phi \to 2\pi) \leqslant 6.6 \cdot 10^{-4}.$$

We note that processing of the statistics stored in the VEPP-2M[2] will permit a significant improvement in the accuracy of the above result (the luminosity integral[2] is an order of magnitude greater than the experimental statistics[1]).

The matrix element of the transition $\gamma \to \pi\pi$ in the region of ϕ-meson may be expressed as follows:

$$< \pi\pi | J_\mu | 0 > = i \left(F_\pi + e^{i\delta} \frac{1}{s - m_\phi^2 + i\Gamma_\phi m_\phi} M(\phi \to 2\pi) \right) (k_1 - k_2)_\mu . \qquad (1)$$

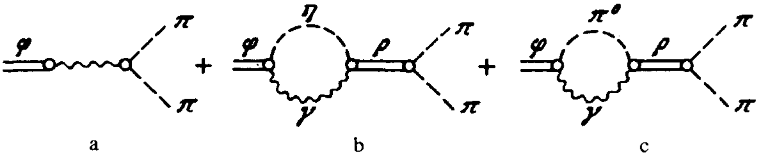

FIG. 1.

The decay amplitude $M(\phi \to 2\pi)$ was estimated earlier using the vector dominance model.[3] However, in view of improved experimental accuracy, a more refined consideration of the decay is in order.

The basic mechanism of the transition $\phi \to 2\pi$ is shown in Fig. 1(a).

The corresponding decay amplitude is

$$M = -i \frac{4\pi\alpha}{s} F_\pi(s) \frac{m_\phi^2}{g_\phi} \frac{\epsilon_\mu (k_1 - k_2)_\mu}{s - m_\phi^2 + i\Gamma_\phi m_\phi} . \tag{2}$$

When evaluating $B(\phi \to 2\pi)$, which follows from Ref. 2, we used direct experimental data instead of specific models in contrast to the approach in Ref. 3. Thus, the contribution of inelastic channels to the pion form factor in this region is already considerable and its experimental value is[1]

$$|F_\pi(m_\phi^2)|^2 = 2.6 \pm 0.2,$$

which is 1.5-fold higher than that derived from the vector dominance model. Taking the above into account, it follows from Eq. (2)

$$B(\phi \to 2\pi) = (1.98 \pm 0.38) \cdot 10^{-4}. \tag{3}$$

The most significant correction applicable to this result may be expected from the processes b and c in Fig. 1. We shall estimate it on the basis of the unitarity condition. Above all, the amplitudes of 1b and 1c are proportional to products of the coupling constants $g_{\phi\eta\gamma} g_{\rho\eta\gamma}$ and $g_{\phi\pi^0\gamma} g_{\rho\pi^0\gamma}$, respectively. The values of these constants are determined by the width of radiative decay of vector mesons

$$\Gamma(v \to p\gamma) = \frac{g_{vp\gamma}^2}{4\pi} \frac{m_v^2}{24} \left(1 - \frac{m_p^2}{m_v^2}\right)^3 . \tag{4}$$

Using the experimental values of widths,[4] we get

$$g_{\phi\eta\gamma}^2/4\pi = (0.41 \pm 0.05) \cdot 10^{-2}\ \text{GeV}^{-2}; \quad g_{\phi\pi^0\gamma}^2/4\pi = (1.37 \pm 0.49) \cdot 10^{-4}\ \text{GeV}^{-2};$$

$$g_{\rho\eta\gamma}^2/4\pi = (2.33 \pm 0.58) \cdot 10^{-2}\ \text{GeV}^{-2}; \quad g_{\rho\pi^0\gamma}^2/4\pi = (2.08 \pm 0.6) \cdot 10^{-3}\ \text{GeV}^{-2}. \tag{5}$$

Subsequently, contribution to the amplitude due to the decay in 1c is negligibly small in comparison with 1b. The amplitude of the latter is

$$M = +i\frac{4\pi a}{s}\;\frac{m}{g_\phi}\;\frac{g_{\rho\pi\pi}(m_\rho m_\phi)^{3/2}\epsilon_\mu g_{\mu\nu}\Pi_0(k_1-k_2)_\nu}{(s-m_\phi^2+i\Gamma_\phi m_\phi)(s-m_\rho^2+i\Gamma_\rho m_\rho)}, \tag{6}$$

where

$$\Pi_0 = \mathrm{Re}\Pi_0 - i\,\mathrm{Im}\Pi_0 = i\frac{2}{3}\;\frac{g_{\phi\eta\gamma}g_{\rho\eta\gamma}}{(m_\rho m_\phi)^{3/2}}\;\frac{1}{(2\pi)^4}\int\frac{d^4k(k^2q^2-(kq)^2)}{(k^2+i\epsilon)((q-k)^2-m_\eta^2+i\epsilon)}. \tag{7}$$

The imaginary part Π_0 may be easily calculated

$$\mathrm{Im}\Pi_0 = (\Gamma(\phi\to\eta\gamma)\Gamma(\rho-\eta\gamma))^{1/2}\frac{1}{s}\left(\frac{s-m_\eta^2}{m_\rho^2-m_\eta^2}\right)^{3/2}\left(\frac{s-m_\eta^2}{m_\phi^2-m_\eta^2}\right)^{3/2}. \tag{8}$$

The contribution to the relative decay probability of $\phi\to 2\pi$ associated with Eq. (8) is

$$B(\phi\to 2\pi) = (0.073\pm 0.38)\cdot 10^{-4}. \tag{9}$$

Unfortunately, calculation of the real part $\mathrm{Re}\Pi_0$ is impossible without a model. For example, if dispersion relationships are used to do this, additional information must be introduced to determine the coefficients of subtraction. However, it is unlikely that $\mathrm{Re}\Pi_0 \gg \mathrm{Im}\Pi_0$ and, therefore, allowing for the real part should not lead to a substantial change in the value of $B(\phi\to 2\pi)$.

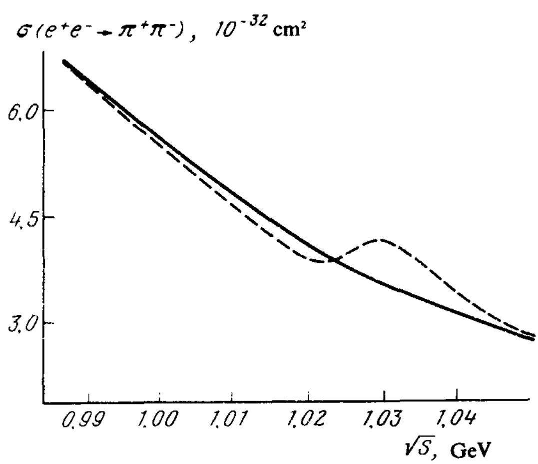

FIG. 2.

Thus, it may be stated that Eq. (9) constitutes the lower limit of $B(\phi \rightarrow 2\pi)$, while the most probable value is given in Eq. (3).

Interference of the $e^+e^- \rightarrow \phi \rightarrow 2\pi$ channel in the pion form factor is seen in Fig. 2. The solid line corresponds to an approximation to the experimental data for $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ over a broad region of $s^{1/2}$, without allowance for coupling with the ϕ-meson; the dotted line represents the cross section $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ allowing for the ϕ-meson coupling.

In conclusion, the authors thank V.M. Budnev for useful discussions and Yu. V. Parfenov for attention to this work.

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