ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

N. N. Achasov, V. N. Ivanchenko

ON A SEARCH FOR FOUR-QUARK STATES IN RADIATIVE DECAYS OF Φ-MESON

PREPRINT 87-129

НОВОСИБИРСК

On a Search for Four-Quark States
in Radiative Decays of Φ-Meson

N.N. Achasov[*)], *V.N. Ivanchenko*

Institute of Nuclear Physics
630090, Novosibirsk, USSR

ABSTRACT

It is shown that if the $a_0(980)$- and $f_0(975)$-mesons are the four-quark $(q^2\bar{q}^2)$ states then they must be produced intensively enough in the decays $\Phi\to\pi^0\eta\gamma$ and $\Phi\to\pi\pi\gamma$ respectively, $Br(\Phi\to\gamma a_0\to\pi^0\eta\gamma)=2.0\cdot10^{-4}$ and $Br(\Phi\to\gamma f_0\to\pi\pi\gamma)=2.6\cdot10^{-4}$. In the case of their two-quark $(q\bar{q})$ nature the decay intensity is an order of magnitude less at least. That is why the experimental study of the $\Phi\to\pi^0\eta\gamma$ and $\Phi\to\pi\pi\gamma$ decays allows essential advance in the solution of the question about the four-quark nature of the $a_0(980)$ and $f_0(975)$-resonances.

[*)]Institute for Mathematics, USSR, 630090, Novosibirsk 90.

1. INTRODUCTION

It is common knowledge that $\Phi(1020)$-meson studies have made an outstanding contribution to the present particle physics notions such as the SU(3)-symmetry, the quark model, the Okubo-Zweig-Iizuka (OZI) rule and so on. The Φ-meson investigations were carried for a quarter of the century but up to now the interest in this resonance is far from being exhausted. Only relatively not long ago the rare decays $\Phi\to\pi^+\pi^-$ [1, 2] and $\Phi\to\eta e^+e^-$ [2] were discovered with the branching ratios of an order 10^{-4}. The modernization of the VEPP-2M [3] and the starting of the new detectors CMD [4] and SND [5] will give the possibility to study in detail the Φ-meson decays with branching ratios of an order 10^{-4} and under favourable circumstances 10^{-5}.

The aim of the given paper is to show that planned perestroika will allow to obtain the worth-while information on the nature of the $a_0(980)$- (former $\delta(980)$) and $f_0(975)$- (former $S(975)$)-mesons studying the decays $\Phi\to\pi^0\eta\gamma$ and $\Phi\to\pi\pi\gamma$ respectively.

There are rather serious arguments for the four-quark $(q^2\bar{q}^2)$ nature of $a_0(980)$- and $f_0(975)$-mesons [6—11] with a symbolic structure

$$a_0=s\bar{s}\,\frac{u\bar{u}-d\bar{d}}{\sqrt{2}},\qquad f_0=s\bar{s}\,\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}. \tag{1}$$

It is natural from qualitative point of view that if these mesons are the quark-antiquark $(q\bar{q})$ states

$$a_0 = \frac{u\bar{u} - d\bar{d}}{\sqrt{2}}, \qquad f_0 = \frac{u\bar{u} + d\bar{d}}{\sqrt{2}}, \tag{2}$$

then the $\Phi \to \gamma a_0$ and $\Phi \to \gamma f_0$ decays must proceed considerably less intensively than in the $q\bar{q}$-case for the OZI-rule. The fact is the Φ-meson consists of the strange ($s\bar{s}$) quarks almost entirely while the final a_0 and f_0 states do not contain the strange quarks.

Below in Section 2 the model of the $\Phi \to \gamma a_0$ and $\Phi \to \gamma f_0$ decays is constructed which is rather reasonable as we believe. In Section 3 it is shown that their branching ratios are expected to be about $2 \cdot 10^{-4}$ in the $q^2\bar{q}^2$-case and at least an order of magnitude smaller in the $q\bar{q}$-case*). In Section 4 the experimental verification perspectives of obtained results are discussed. Here the unresonant backgrounds for the decays $\Phi \to \pi^0\eta\gamma$ and $\Phi \to \pi\pi\gamma$ are estimated and it is shown that the $\pi^0\eta$ and $\pi\pi$ mass spectra have the clearly expressed resonance character caused by the a_0- and f_0-mesons respectively.

2. MODEL OF $\Phi \to \gamma a_0(980)$ AND $\Phi \to \gamma f_0(975)$ DECAYS

We intend to describe the $\Phi \to \gamma a_0$ and $\Phi \to \gamma f_0$ decays with the help of the diagrams plotted in Fig. 1. The diagram of Fig. 1,*c* ensures the gauge invariance of the imaginary part of the decay amplitude. A more detailed and refined motivation of the necessity to

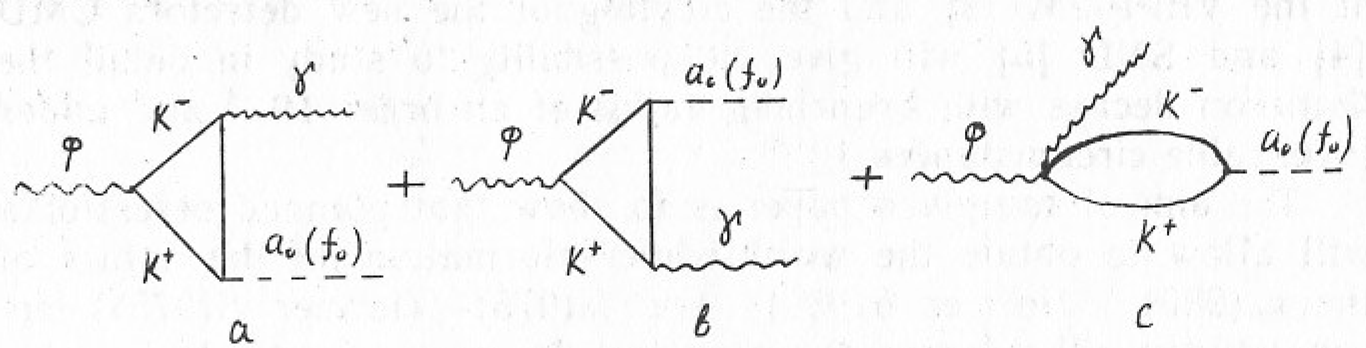

Fig. 1. Model of decays $\Phi \to \gamma a_0$ and $\Phi \to \gamma f_0$.

---

*) When we call the decays with the branching ratios of an order of 10^{-4} intensive enough, it should be minded, that the Φ-meson decays into the γ-quantum with a ω-energy and a heavy state, close to the Φ-meson in mass, are suppressed by the factor ω^3 due to the gauge invariance independent of the final products are in the *s*- or *p*-wave. It will be recalled that for the $\Phi \to \gamma\eta'(958)$ decay allowed by the OZI-rule theory expects $Br(\Phi \to \gamma\eta') = (0.5 \div 1.0) \cdot 10^{-4}$.

take into account this diagram one can connect with the correct construction of the vector meson dominance model [12].

How good is the suggested model? The model seems to describe the imaginary part of the $\Phi \to \gamma a_0$ and $\Phi \to \gamma f_0$ decay amplitudes practically exactly. It is simply not clear what intermediate states other than K^+K^- could give a visible contribution. Note that the imaginary part of the Fig. 1,*c* diagram arises only if the invariant mass of the $\pi^0\eta$ ($\pi\pi$) system, into which the a_0 (f_0) decays, is more than $2m_{K^+}$.

The sum of the Fig. 1 diagrams converges and gives the finite real part. But as in the case of $\gamma\gamma$-scattering it is determined in addition according to the gauge invariance condition that the amplitude vanishes when the γ-quantum energy vanishes. Of course, this property takes place for the imaginary part of the sum of the Fig. 1 diagrams from the very beginning.

Generally speaking, the more heavy intermediate states $K^*\bar{K} + \bar{K}^*K$, $K^*\bar{K}^*$ and so on could change the real part of the decay amplitude. Besides that taking into account the K^+K^- intermediate state with help of the Fig. 1 diagrams is approximate because in the dispersion integral language we describe the integrand with the help the $K^+K^- \to \gamma a_0$ (f_0) amplitudes in the Born approximation in the whole energy region that is justified near the K^+K^- channel threshold only. Therefore the decay amplitude real part calculated here must be regarded as a guide. But at the same time we have grounds to hope that the approximation is good enough if a_0 and f_0 have the $q^2\bar{q}^2$ structure. This hope is supported in particular by the circumstance that in the $q^2\bar{q}^2$-case the a_0 production by the $\gamma\gamma$ collision is described well by the $\gamma\gamma \to K^+K^- \to a_0$ model [11] connected with one under consideration here through the analytical continuation in the frame of the vector meson dominance model.

Let us introduce the amplitudes

$$M(\Phi \to \gamma R;\ m) = g_R(m) \cdot (\vec{e}(\Phi) \cdot \vec{e}(\gamma)), \qquad R = a_0,\ f_0, \tag{3}$$

$\vec{e}(\Phi)$ and $\vec{e}(\gamma)$ are the Φ-meson and γ-quantum polarization vectors in the Φ-meson rest frame.

$$\Gamma(\Phi \to \gamma R;\ m) = \frac{1}{3}\,\frac{|g_R(m)|^2}{4\pi}\,\frac{1}{2m_\Phi}\left(1 - \frac{m^2}{m_\Phi^2}\right), \tag{4}$$

m is the invariant mass of the ab state into which the R-meson decays, $m=m_{ab}$, a and b are the pseudoscalar mesons. Using this amplitudes one can find the width

$$\Gamma(\Phi\to\gamma R\to ab\gamma)=\frac{2}{\pi}\int\limits_{m_a+m_b}^{m_\Phi} m\,dm\,\frac{m\Gamma(R\to ab;\,m)\,\Gamma(\Phi\to\gamma R;\,m)}{|D_R(m)|^2}, \qquad (5)$$

$1/D_R(m)$ is the R-resonance propagator, see (9) — (11) below. $\Gamma(R\to ab;\ m)$ is the width of the R-meson decay into the ab state with the invariant mass m, see (10).

The calculation of the Fig. 1 diagrams gives for $m<2m_{K^+}$

$$g_R(m)=\frac{e}{2(2\pi)^2}\,g_{\Phi K^+K^-}\,g_{RK^+K^-}\left\{1+\frac{1-\rho^2(m)}{\rho^2(m_\Phi)-\rho^2(m)}\left[2|\rho(m)|\,\mathrm{arctg}\,\frac{1}{|\rho(m)|}-\right.\right.$$

$$-\rho(m_\Phi)\cdot\lambda(m_\Phi)+i\pi\rho(m_\Phi)-(1-\rho^2(m_\Phi))\times$$

$$\left.\left.\times\left(\frac{(\pi+i\lambda(m_\Phi))^2}{4}-\left(\mathrm{arctg}\,\frac{1}{|\rho(m)|}\right)^2\right)\right]\right\} \qquad (6)$$

here

$$\rho(m)=\sqrt{1-\frac{4m^2_{K^+}}{m^2}},\quad \lambda(m)=\ln\frac{1+\rho(m)}{1-\rho(m)},\quad \frac{e^2}{4\pi}=\alpha=\frac{1}{137},$$

$$\Gamma(\Phi\to K^+K^-)=\frac{1}{3}\,\frac{g^2_{\Phi K^+K^-}}{16\pi}\,m_\Phi\rho^3(m_\Phi). \qquad (7)$$

For $2m_{K^+}\leqslant m$

$$g_R(m)=\frac{e}{2(2\pi)^2}\,g_{\Phi K^+K^-}\,g_{RK^+K^-}\left\{1+\frac{1-\rho^2(m)}{\rho^2(m_\Phi)-\rho^2(m)}\left[\rho(m)\cdot(\lambda(m)-i\pi)-\right.\right.$$

$$\left.\left.-\rho(m_\Phi)\cdot(\lambda(m_\Phi)-i\pi)-\frac{1-\rho^2(m_\Phi)}{4}\left((\pi+i\lambda(m_\Phi))^2-(\pi+i\lambda(m))^2\right)\right]\right\}. \qquad (8)$$

3. NUMBERS AND OTHER DETAILS IN $q^2\bar{q}^2$ AND $q\bar{q}$-MODELS

In the table we present the branching ratios of decays $\Phi\to\gamma a_0\to\pi^0\eta\gamma$, $\Phi\to\gamma f_0\to\pi\pi\gamma$ and $\Phi\to\gamma(a_0+f_0)\to\gamma K\bar{K}$ for the $q^2\bar{q}^2$- and $q\bar{q}$-schemes.

We used

$$D_R(m)=m_R^2-m^2+\mathrm{Re}\,\Pi_R(m_R)-\Pi_R(m), \qquad (9)$$

where the term $\mathrm{Re}\Pi_R(m_R)-\Pi_R(m)$ takes into account the finite-width corrections [9]

$$\Pi_R(m)=\sum_{ab}\Pi_R^{ab}(m),$$

$$\mathrm{Im}\,\Pi_R^{ab}(m)=m\Gamma(R\to ab;\,m)=\frac{g^2_{Rab}}{16\pi}\,\rho_{ab}(m), \qquad (10)$$

$$\rho_{ab}(m)=\sqrt{\left(1-\frac{m_+^2}{m^2}\right)\left(1-\frac{m_-^2}{m^2}\right)},\qquad m_\pm=m_a\pm m_b.$$

The final particle identity is taken into account in the determination of g_{Raa}.

Let $m_a>m_b$, then for $m\geqslant m_+$

$$\Pi_R^{ab}(m)=\frac{g^2_{Rab}}{16\pi}\left[\frac{m_+m_-}{\pi m^2}\ln\frac{m_b}{m_a}+\right.$$

$$\left.+\rho_{ab}(m)\left(i+\frac{1}{\pi}\ln\frac{\sqrt{m^2-m_-^2}-\sqrt{m^2-m_+^2}}{\sqrt{m^2-m_-^2}+\sqrt{m^2-m_+^2}}\right)\right]. \qquad (11)$$

For $m<m_+$, the analytic continuation determines $\Pi_R^{ab}(m)$ [13].

We considered the finite-width corrections due to the $\pi^0\eta$-, $K\bar{K}$-, $\pi^0\eta'$-channels for the a_0-meson and the $\pi\pi$-, $K\bar{K}$-, $\eta\eta$-, $\eta\eta'$-, $\eta'\eta'$-channels for the f_0-meson.

In the $q^2\bar{q}^2$-model the a_0- and f_0-mesons are coupled to the $K\bar{K}$-channels strongly (in the Zwieg superallowed way) [6, 7, 9, 11, 13]. We put in [7, 9, 11, 13]

$$\frac{g^2_{a_0K^+K^-}}{4\pi}=\frac{g^2_{f_0K^+K^-}}{4\pi}=2.3\ \mathrm{GeV}^2. \qquad (12)$$

Besides that, in the $q^2\bar{q}^2$-model the following equations [6, 7] are valid:

$$g_{a_0\pi\eta}=\sqrt{2}\,g_{a_0K^+K^-}\,\sin(\theta_p+\theta_q)=0.85\,g_{a_0K^+K^-},$$

$$g_{a_0\pi\eta'}=\sqrt{2}\,g_{a_0K^+K^-}\,\cos(\theta_p+\theta_q)=-1.13\,g_{a_0K^+K^-},$$

$$g_{f_0K^+K^-}=-g_{a_0K^+K^-},\quad g_{f_0\eta\eta}=-g_{f_0\eta'\eta'}, \qquad (13)$$

$$g_{f_0\eta\eta}=g_{f_0K^+K^-}\,\sin 2(\theta_p+\theta_q)=0.96\,g_{f_0K^+K^-},$$

$$g_{f_0\eta\eta'}=-\sqrt{2}\,g_{f_0K^+K^-}\,\cos 2(\theta_p+\theta_q)=-0.40\,g_{f_0K^+K^-}.$$

It follows from (10), (12) and (13) that $\Gamma(a_0\to\pi^0\eta;\ 0.983)=$ $=275$ MeV. It will be recalled that in the four-quark interpretation

Table

Decay	Quark structure of the a_0- or f_0-mesons	Branching
$\Phi\to\gamma a_0\to\pi^0\eta\gamma$	$s\bar{s}\frac{u\bar{u}-d\bar{d}}{\sqrt{2}}$	$2.0\cdot10^{-4}$
	$\frac{u\bar{u}-d\bar{d}}{\sqrt{2}}$	$2.4\cdot10^{-5}$
$\Phi\to\rho^0\pi^0\to\pi^0\eta\gamma$		$0.8\cdot10^{-5}$
$\Phi\to\gamma f_0\to\pi\pi\gamma$	$s\bar{s}\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$	$2.5\cdot10^{-4}$
	$\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$	$4.5\cdot10^{-5}$
	$s\bar{s}$	$5.4\cdot10^{-5}$
$\Phi\to\rho\pi\to\pi\pi\gamma$		$3.0\cdot10^{-5}$
$\Phi\to\gamma(a_0+f_0)\to\gamma K^+K^-$	$s\bar{s}\frac{u\bar{u}-d\bar{d}}{\sqrt{2}}$, $s\bar{s}\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$	$2.6\cdot10^{-6}$
	$\frac{u\bar{u}-d\bar{d}}{\sqrt{2}}$, $\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$	$2.0\cdot10^{-7}$
$\Phi\to\gamma(a_0+f_0)\to\gamma K^0\bar{K}^0$	$s\bar{s}\frac{u\bar{u}-d\bar{d}}{\sqrt{2}}$, $s\bar{s}\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$	$1.3\cdot10^{-8}$
	$\frac{u\bar{u}-d\bar{d}}{\sqrt{2}}$, $\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$	$2.0\cdot10^{-9}$

the narrow structure with the 54 MeV width, observed in the $\pi^0\eta$-channel, arises against a background of the broad resonance due to the $K\bar{K}$-channel opening whose threshold is situated near the resonance mass [7, 9, 11, 13].

The calculations were carried out for $R=g^2_{f_0K^+K^-}/g^2_{f_0\pi\pi}=8$. The processes $\pi\pi\to\pi\pi$ and $\pi\pi\to K\bar{K}$ permit the wide enough range of $R=4\div10$ [9, 13], but it does not influence our result. For example, if $R=5$ then $\mathrm{Br}(\Phi\to\gamma f_0\to\pi\pi\gamma)$ increases by 23%.

In the $q\bar{q}$-model (2) we used according to the quark counting rule for the a_0-meson

$$g_{a_0\pi\eta}=2g_{a_0K^+K^-}\cos(\theta_p+\theta_q)=1.6\,g_{a_0K^+K^-}\,,$$
$$g_{a_0\pi\eta'}=2\,g_{a_0K^+K^-}\sin(\theta_p+\theta_q)=1.2\,g_{a_0K^+K^-}\,. \qquad (14)$$

For the f_0-meson

$$g_{f_0K^+K^-}=g_{a_0K^+K^-}\,,\quad g_{f_0\pi^+\pi^-}=2g_{f_0K^+K^-}\,,$$
$$g_{f_0\eta\eta}=\sqrt{2}\,g_{f_0K^+K^-}\cos^2(\theta_p+\theta_q)=0.91\,g_{f_0K^+K^-}\,,$$
$$g_{f_0\eta\eta'}=g_{f_0K^+K^-}\sin2(\theta_p+\theta_q)=0.96\,g_{f_0K^+K^-}\,. \qquad (15)$$
$$g_{f_0\eta'\eta'}=\sqrt{2}\,g_{f_0K^+K^-}\sin^2(\theta_p+\theta_q)=0.51\,g_{f_0K^+K^-}\,.$$

Besides that, we put in

$$g^2_{a_0\pi\eta}/4\pi=0.33\ \mathrm{GeV}^2,\qquad \Gamma(a_0\to\pi\eta;\,0.983)=54\ \mathrm{MeV}\,. \qquad (16)$$

In (13) — (15) it is used $\theta_p=-18°$ which seems to be most grounded at present, $\theta_q=54°.74$. It will be mentioned that the naive $q\bar{q}$-model (2), (14) and (15) not only is unable to explain the primary coupling of f_0 to the $K\bar{K}$-channel, $R\gg1$, but also predicts, as it follows from (10), (14), (15) and (16), $\Gamma(f_0\to\pi\pi;0.975)=190$ MeV in disagreement with the experiment. That is why we considered one more version of the $q\bar{q}$-model with

$$f_0=s\bar{s}\,, \qquad (17)$$

which explains the suppression of the f_0-meson coupling to the $\pi\pi$-channel but, of course, is doubtful for almost exact degeneracy of the a_0- and f_0-meson masses.

From (2) and (17) by the quark coupling rule it is obtained instead of (15)

$$g_{f_0K^+K^-}=\sqrt{2}\,g_{a_0K^+K^-}\,,$$
$$g_{f_0\eta\eta}=\sqrt{2}\,g_{f_0K^+K^-}\sin^2(\theta_p+\theta_q)=0.51\,g_{f_0K^+K^-}\,,$$
$$g_{f_0\eta\eta'}=-g_{f_0K^+K^-}\sin2(\theta_p+\theta_q)=-0.96\,g_{f_0K^+K^-}\,, \qquad (18)$$
$$g_{f_0\eta'\eta'}=\sqrt{2}\,g_{f_0K^+K^-}\cos^2(\theta_p+\theta_q)=0.91\,g_{f_0K^+K^-}\,.$$

The equations (14) and (16) take place as before. Besides, we used $R=4$ which correspond to $\Gamma(f\to\pi\pi;0.975)=24$ MeV as it follows from (10), (16) and (18).

It is of interest that both versions of the $q\bar{q}$-model gives practically the same results for the f_0-meson, see table.

It goes without saying that in both cases $\mathrm{Br}(\Phi\to\gamma a_0\to\pi^0\eta\gamma)$ is the same and overestimated for sure because the $K^*\bar{K}+\bar{K}^*K$, $K^*\bar{K}^*$

and so on heavier intermediate state contribution to the real part of the $\Phi\to\gamma a_0$ decay amplitude must compensate the K^+K^--state one to realize the OZI veto. The last observation is also true for the real part of the $\Phi\to\gamma f_0$ decay amplitude in the $q\bar{q}$-model (2) in its naive understanding, that is without taking into account the transitions between the quark and gluon freedom degree which are possible in the isoscalar scalar channel.

At the calculation of the $\Phi\to\gamma(a_0+f_0)\to\gamma K\bar{K}$ decay amplitudes the equation (5) was modified with due regard for the a_0 and f_0-meson interference. According to our model (Fig. 1) the a_0- and f_0-mesons interfere destructively in the $\Phi\to\gamma(a_0+f_0)\to\gamma K^0\bar{K}^0$ decay owing to the isotopic invariance, $g_{a_0K^+K^-}=-g_{a_0K^0\bar{K}^0}$, $g_{f_0K^+K^-}=g_{f_0K^0\bar{K}^0}$, which leads to its extremely small branching ratio, see table.

4. CONCLUSION. EXPERIMENTAL PERSPECTIVES

The backgrounds of the decays $\Phi\to\pi^0\eta\gamma$ and $\Phi\to\pi\pi\gamma$, unresonant in $\pi^0\eta$ and $\pi\pi$ invariant masses, are determined by the processes $\Phi\to\rho^0\pi^0\to\pi^0\eta\gamma$ and $\Phi\to\rho\pi\to\pi\pi\gamma$ (Fig. 2), which we calculated using the standard characteristics of the vector mesons [14], the quark model and the vector meson dominance model. As it is seen from the table, the intensity of the background processes is about an order of magnitude smaller than that of resonance ones in four-quark case. Moreover, in this case the mass spectra of the resonance and background processes do not intersect practically (Figs 3, 4). That is why there is no visible interference between the resonance and background amplitudes and on the whole the $\pi^0\eta$ and $\pi\pi$ mass spectra have the pronounced resonance character. It is important to note that the resonance shape of the spectra is due to $\mathrm{Im}g_R(m)$, which, as was mentioned above, are calculated practically exactly and contribute 20—25% of branching ratios (Figs 3, 4).

In the $q\bar{q}$-model it does not seem possible to extract the a_0- and f_0-resonance contribution from the background in the decays $\Phi\to\pi^0\eta\gamma$ and $\Phi\to\pi\pi\gamma$.

Unfortunately, even if the experimental possibility is very good, one can not use the $\Phi\to\gamma K^+K^-$ decay to study the a_0 and f_0 nature because the bremsstrahlung determines this decay completely. Its intensity is more than two orders of magnitude larger than the resonance decay one in the $q^2\bar{q}^2$-case. And nevertheless, the absence of

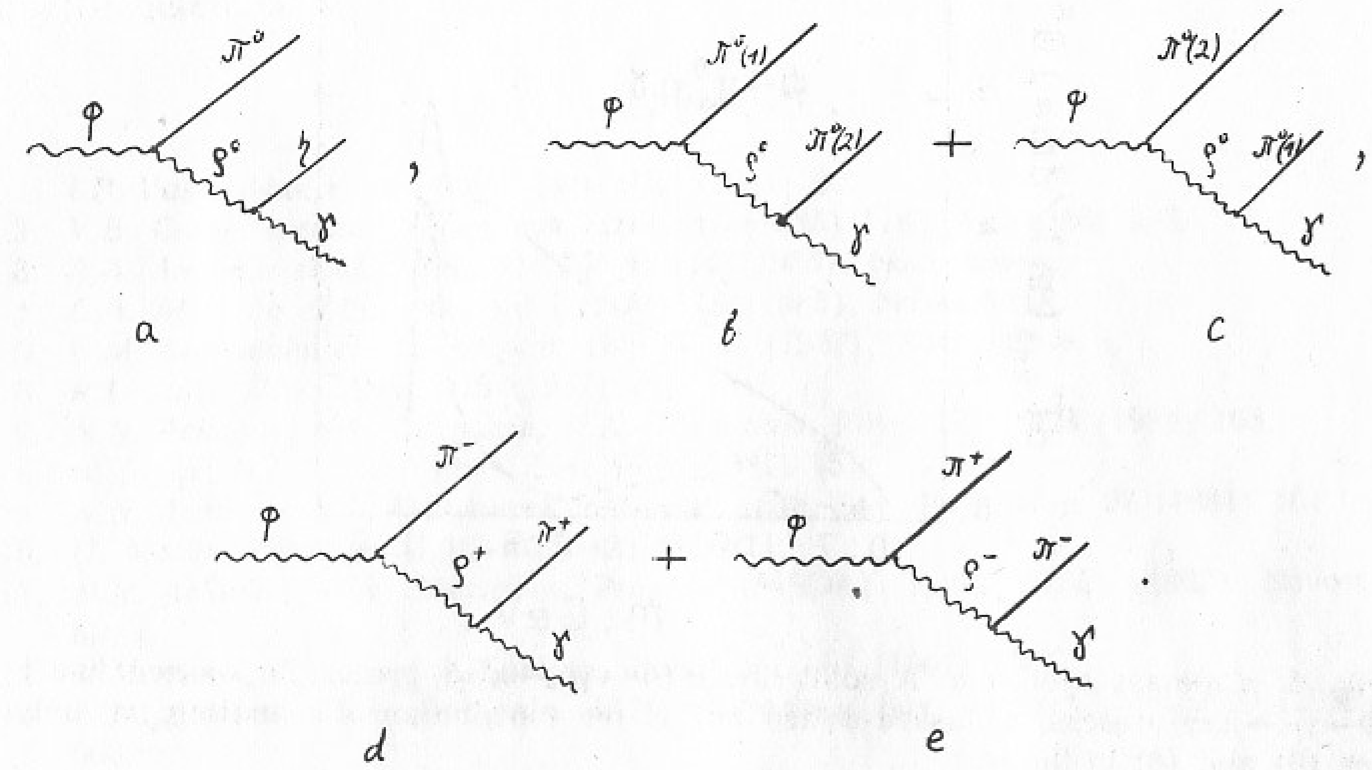

Fig. 2. Backgrounds unresonant in $\pi^0\eta$ and $\pi\pi$ invariant masses.

the decay $\Phi\to\gamma K^0\bar{K}^0$ (its extremely small value) is the sign in favour of our model.

It will be noted that the bremsstrahlung does not prevent from studying the $\Phi\to\pi^+\pi^-\gamma$ decay because the decay $\Phi\to\pi^+\pi^-$ is small, $\mathrm{Br}(\Phi\to\pi^+\pi^-)\simeq10^{-4}$ [14] and, in consequence, the bremsstrahlung is two orders of magnitude less intensive than the resonance decay in the $q^2\bar{q}^2$-model.

Let us sum up. From the experimental point of view the study of the $\Phi\to\pi^0\eta\gamma$ and $\Phi\to\pi\pi\gamma$ decays with a branching ratio of an order 10^{-4} will be the practical problem in the near future. From the theoretical point of view this problem is rather tempting because the search of the a_0- and f_0-resonances in the $\Phi\to\gamma a_0$ and $\Phi\to\gamma f_0$ decays is if not the experimentum crucis in the true sense of the word, then, at any rate, permits to advance essentially in the solution of the question about the four-quark nature of the $a_0(980)$- and $f_0(975)$-mesons. Particularly, the most important consequence of the four-quark interpretation, namely the strong coupling of the $a_0(980)$-meson to the $K\bar{K}$ and $\pi^0\eta$-channels (see (12) and (13)), the «broad» $a_0(980)$-meson [6, 7, 9, 11, 13], can be finally checked practically conclusively.

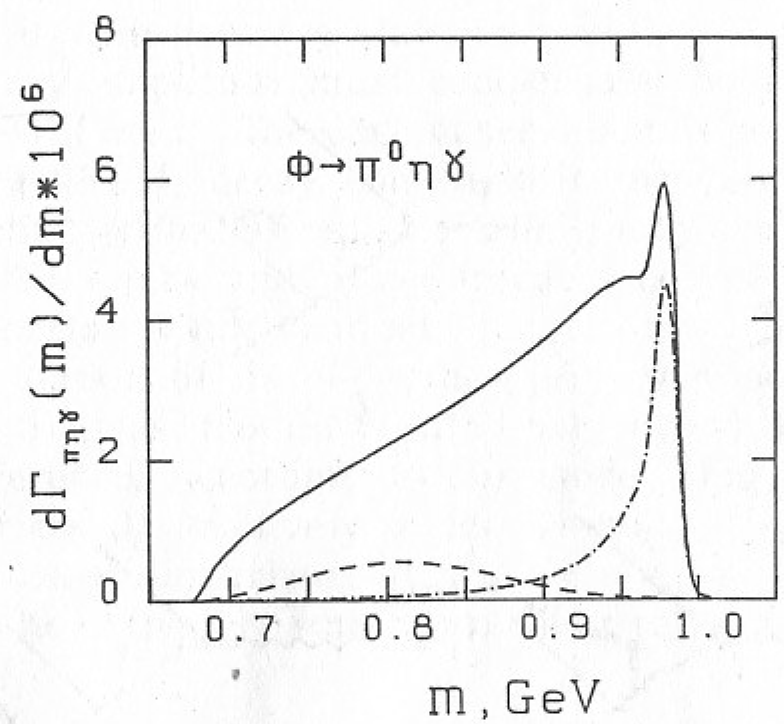

Fig. 3. $\pi^0\eta$-mass spectrum. A solid line is $\Phi\to\gamma a_0\to\pi^0\eta\gamma$ process, a dashed line is $\Phi\to\gamma f_0\to\pi\pi\gamma$ process, a dashed-dotted line is the contribution due to $\mathrm{Im}g_{a_0}(m)$ only, see (6) and (8) in the text.

$$\int_{m_\pi+m_\eta}^{m_\Phi} \frac{d\Gamma_{\pi\eta\gamma}(m)}{dm}\,dm=\Gamma(\Phi\to\pi^0\eta\gamma).$$

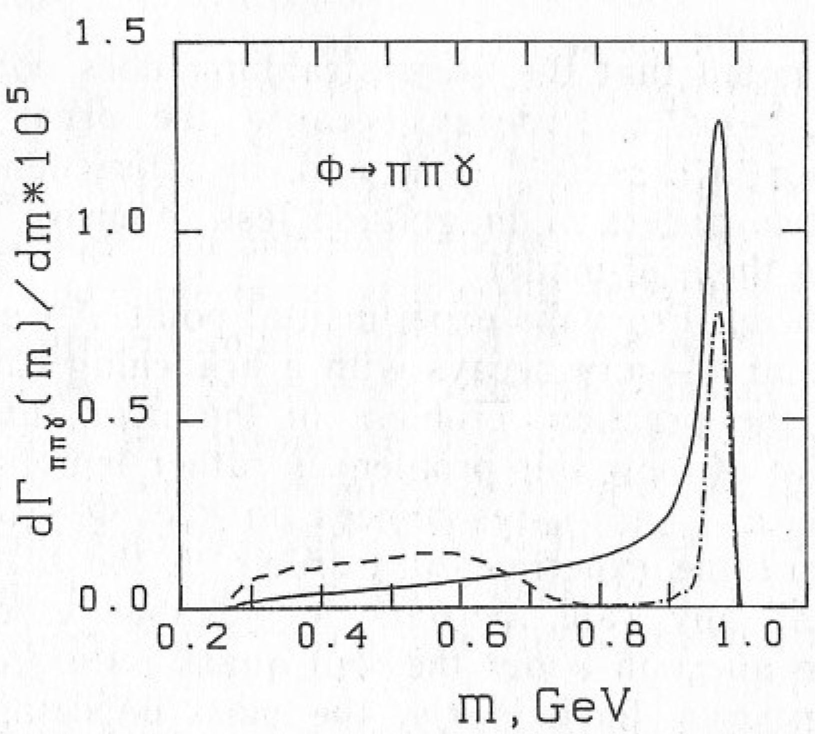

Fig. 4. $\pi\pi$-mass spectrum. A solid line is $\Phi\to\gamma f_0\to\pi\pi\gamma$ process, a dashed line is $\Phi\to\rho\pi\to\pi\pi\gamma$ process, a dashed-dotted line is the contribution due to $\mathrm{Im}g_{f_0}(m)$ only, see (6) and (8) in the text.

$$\int_{2m_\pi}^{m_\Phi} \frac{d\Gamma_{\pi\pi\gamma}(m)}{dm}\,dm=\Gamma(\Phi\to\pi\pi\gamma)=\Gamma(\Phi\to\pi^+\pi^-\gamma)+\Gamma(\Phi\to\pi^0\pi^0\gamma)=1.5\,\Gamma(\Phi\to\pi^+\pi^-\gamma).$$

We are grateful to S.I. Serednyakov and S.I. Eidelman for the useful discussions.

REFERENCES

1. *I.B. Vasserman et al.*, Phys. Lett. 99B (1981) 62.
2. *V.B. Golubev et al.*, Yadernaya Fizika 41 (1985) 1183; 44 (1986) 633.
3. *A.A. Anashin et al.*, Preprint INP 84-114 (1984), Novosibirsk.
4. *G.A. Aksenov et al.*, Preprint INP 85-118 (1985), Novosibirsk.
5. *V.M. Aulchenko et al.*, Preprint INP 87-36 (1987), Novosibirsk.
6. *R.L. Jaffe*, Phys. Rev. D15 (1977) 267, 281.
7. *N.N. Achasov, S.A. Devyanin, G.N. Shestakov*, Phys. Lett. 96B (1980) 168.
8. *N. Isgur, H.J. Lipkin*, Phys. Lett. 99B (1981) 151.
9. *N.N. Achasov, S.A. Devyanin, G.N. Shestakov*, Sov. Phys. Usp. 27 (1984) 161.
10. *U. Mallik*, Preprint SLAC-PUB-4238 (1987).
11. *N.N. Achasov, G.N. Shestakov*, Preprint IMSOAN Tph-25 (155) (1987), Novosibirsk.
12. *N.M. Kroll, T.D. Lee, B. Zumino*, Phys. Rev. 157 (1967) 1367.
13. *N.N. Achasov, S.A. Devyanin, G.N. Shestakov*, Sov. J. Nucl. Phys. 32 (1980) 566.
14. Particle Data Group, Phys. Lett. 170B (1986) 21.

N.N. Achasov, V.N. Ivanchenko

On a Search for Four-Quark States in Radiative Decays of Ф-Meson

Н.Н. Ачасов, В.Н. Иванченко

К поиску четырехкварковых состояний в радиационных распадах Ф-мезона

Ответственный за выпуск С.Г.Попов

Работа поступила 17 сентября 1987 г.
Подписано в печать 21.09. 1987 г. МН 08395
Формат бумаги 60×90 1/16 Объем 1,4 печ.л., 1,1 уч.-изд.л.
Тираж 210 экз. Бесплатно. Заказ № 129

Набрано в автоматизированной системе на базе фотонаборного автомата ФА1000 и ЭВМ «Электроника» и отпечатано на ротапринте Института ядерной физики СО АН СССР,
Новосибирск, 630090, пр. академика Лаврентьева, 11.