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Experimental Studies of the Radiative Decays of Vector Mesons

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Radiative decays of the low-lying vector mesons are very interesting for tests of the quark model, SU(3), Vector Dominance Model (see the review in [1]). We present below a brief review of the experimental situation with the decays $V \to P\gamma$ where V and P stand for a vector and pseudoscalar meson respectively and related to them so called conversion decays in which a real photon is replaced by a virtual one producing a lepton pair (electron or muon one).

The decay mode $\rho^{\pm} \to \pi^{\pm}\gamma$ has traditionally been studied using coherent $\rho^{\pm}$ production on nuclear targets (Primakoff effect). Actually observed in this case is the reaction $\pi^{\pm}A \to \pi^{\pm}\pi^{\circ}A$ and to obtain the radiation width one has to extract the contribution of the inverse process $\gamma\pi^{\pm} \to \rho^{\pm}$. The extraction procedure requires separation of the Coulomb and nuclear parts and is therefore model dependent. At high energies the extraction of radiative widths becomes less sensitive to the phenonemology of the nuclear models employed in the analysis. This is probably the reason accounting for the discrepancy between the first measurement performed with the π momentum of 22.7 GeV/c [2] and later experiments at much higher energy around 200 GeV [3-5].The experimental values of the widths obtained as well as the world average one [6] are shown in Table 1.

Table 1

$Mode$	$\Gamma(\pi\gamma), keV$	$Ref.$
$\rho^- \to \pi^-\gamma$	35 ± 10	[2]
$\rho^- \to \pi^-\gamma$	71 ± 7	[3]
$\rho^+ \to \pi^+\gamma$	59.8 ± 4.0	[4]
$\rho^- \to \pi^-\gamma$	$81 \pm 4 \pm 4$	[5]
$\rho^{\pm} \to \pi^{\pm}\gamma$	68 ± 7	[6]

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The radiative width of the neutral ρ° meson was studied in one experiment only which had been performed with the ND detector at the e^+e^- collider VEPP-2M at Novosibirsk [7]. The value of the width is obtained from the analysis of Dalitz plots of a three photon final state arising from the reaction $e^+e^- \to \pi^\circ\gamma$. Since both ρ and ω-mesons contribute, one has to take into account their interference. Although the contribution of the $\rho^\circ \to \pi^\circ\gamma$ decay is statistically significant, it is not possible to distinguish between the constructive and destructive $\rho - \omega$ interference using the experimental data only. One has to additionally consider other data. The quark model and isospin invariance predict the same values of partial widths for charged and neutral ρ. The value 824±16 keV obtained for the destructive $\rho - \omega$ interference is in obvious disagreeement with the above value 68±7 keV for the $\rho^\pm$. Another confirmation for the constructive case comes from the analysis of the ratio $B(\omega \to \pi^\circ\gamma)/B(\omega \to \pi^+\pi^-\pi^\circ)$. For destructive interference it is 0.157 ± 0.011 in disagreement with the value 0.089 ± 0.010 obtained from the reaction $\pi^-\rho \to \omega\eta$ [8] in which $\rho - \omega$ interference vanishes. For the constructive interference the value from e^+e^- data is 80.099 ± 0.007 consistent with the hadroproduction data. Thus the whole bulk of the data favors the constructive $\rho - \omega$ interference and one obtains

$$\Gamma(\rho^\circ \to \pi^\circ\gamma) = 121 \pm 31 \ keV$$

$$\Gamma(\omega \to \pi^\circ\gamma) = 746 \pm 51 \ keV$$

Although the value of $\Gamma(\rho^\circ \to \pi^\circ\gamma)$ is higher than that of $\Gamma(\rho^\pm \to \pi^\pm\gamma)$, their difference is statistically insignificant (less than 2 standard deviations) not contradicting their expected equality. Further improvement of the accuracy can be achieved at $DA\Phi NE$ and at VEPP-2M. In addition to the measurement of the radiative width of the ρ° one can think of an exotic way of observing both $\rho^\circ \to \pi^\circ\gamma$ and $\rho^\pm \to \pi^\pm\gamma$ decays studying $\phi \to \pi^+\pi^-\gamma$ and $\phi \to \pi^\circ\pi^\circ\gamma$ decays. The idea is to look for a $\phi \to \rho\pi$ decay followed by a $\rho \to \pi\gamma$ decay. Simple estimations show that the expected probability of such a decay is about $5 \cdot 10^{-5}$ which makes it observable at the level of luminosities expected at $DA\Phi NE$. The value of $\Gamma(\omega \to \pi^\circ\gamma)$ is consistent with the previous measurements (see [6]) and has much better accuracy. Note also that the value itself changed significantly because recent Novosibirsk measurements [9,10] of the ω-meson total width resulted in the new average value of 8.43 ± 0.10 MeV [6]. This value is much lower than a previous one 9.8 ± 0.3 MeV [11] and should be taken into account since the value of $\Gamma(\omega \to \pi^\circ\gamma)$ is a basis for theoretical predictions of the radiative widths.

The problem of $\rho - \omega$ interference is also very important when one studies ρ, ω decays into $\eta\gamma$. Until recently there were two measurements only: one is diffractive photoproduction of vector mesons from a complex-nucleus target using the tagged photon beam at Cornell [12] and another one is the ND measurement at VEPP-2M [7]. In both cases the authors could not find the unique solution from their data only and presented both solutions for the values of the radiative widths in keV shown in Table 2. However, the results for the constructive interference seem more preferable since they agree with the quark model satisfactorily explaining all radiative decays.

Table 2

Mode	*Constructive case*	*Destructive case*	*Ref.*
$\rho \to \eta\gamma$	50 ± 13	76 ± 15	[12]
	62 ± 17	111 ± 22	[7]
$\omega \to \eta\gamma$	$3.0 + 2.5 - 1.8$	29 ± 7	[12]
	6.1 ± 2.5	29.4 ± 4.7	[7]

These difficulties seem to be avoided in a recent experiment of the GAMS collaboration which studied decays of ω produced in the charge-exchange reaction $\pi^- p \to \omega n$ [13]. By choosing a region of sufficiently high momentum transfers the authors suppress the effects of $\rho - \omega$ interference and present a model-independent value $\Gamma(\omega \to \eta\gamma) = (7.0 \pm 1.8)$ keV or which solves the ambiguity above and supports the constructive interference.

Decays of the ϕ-meson into $\pi^\circ\gamma$ and $\eta\gamma$ were studied in several experiments. The first experiments on hadro- or photoproduction of the ϕ-mesons [14,15] were followed by more precise from Orsay [16,17] and Novosibirsk [18,19] e^+e^- colliders. The current accuracy of the branching ratios is determined by the dedicated high statistics experiment with at VEPP-2M [19].

One should also mention an only existing experiment on the decay $\phi \to \eta'\gamma$ performed by the ND group [20] who placed an upper limit

$$B(\phi \to \eta'\gamma) < 4.1 \cdot 10^{-4} \quad \text{at } 90\% \text{ CL} \tag{0.1}$$

The current experimental situation is summarized in Table 3 presenting the world average values of the branching ratios [6]. Note also a recent theoretical paper discussing possible relations between the discussed radiation widths and QCD anomalies [21].2

Table 3

Decay mode	*Branching ratio*
$\rho^\pm \to \pi^\pm\gamma$	$(4.5 \pm 0.5) \cdot 10^{-4}$
$\rho^\circ \to \pi^\circ\gamma$	$(7.9 \pm 2.0) \cdot 10^{-4}$
$\rho^\circ \to \eta\gamma$	$(3.8 \pm 0.7) \cdot 10^{-4}$
$\omega \to \pi^\circ\gamma$	0.085 ± 0.005
$\omega \to \eta\gamma$	$(8.3 \pm 2.1) \cdot 10^{-4}$
$\phi \to \pi^\circ\gamma$	$(1.31 \pm 0.13) \cdot 10^{-3}$
$\phi \to \eta\gamma$	0.0128 ± 0.0006
$\phi \to \eta'\gamma$	$< 4.1 \cdot 10^{-4}$

An obvious consequence of the radiative decays is the existence of conversion decays. A transition form factor F(q^2) arising in the vertex provides information on the meson structure (see the comprehensive review [22] discussing predictions for q^2 dependence in different theoretical models). In conversion decays one can study a range of q^2 from $4m_l^2$ up to $(m_V - m_P)^2$ where m_l, m_V and m_P are masses of lepton, vector and pseudoscalar respectively. Experimental information on such decays is rather scarce, the branching ratios of three such decays only have been measured, see Table 4, which agree with the estimations based on the experimental values of the corresponding radiative width [23] and lattice calculations [24].

Table 4

Decaymode	*Branching ratio*	*Ref.*
$\omega \to \pi^\circ e^+ e^-$	$(5.9 \pm 1.9) \cdot 10^-4$	[25]
$\omega \to \pi^\circ \mu^+ \mu^-$	$(9.6 \pm 2.3) \cdot 10^-5$	[26]
$\phi \to \eta e^+ e^-$	$(1.3 \pm 0.8) \cdot 10^-4$	[27]
$\phi \to \pi^\circ e^+ e^-$	$< 1.2 \cdot 10^-4$	[25]

The transition form factor was studied in [22] using 60 observed $\pi^\circ \mu^+ \mu^-$ events. In general, one can also obtain information on the transition form factors $F(q^2)$ from the reactions $e^+e^- \to \rho\pi, \omega\pi, \phi\pi$ and, under some additional assumptions, from the Dalitz decays like $\pi^\circ, \eta, \eta' \to e^+e^-\gamma, \mu^+\mu^-\gamma$ as well as from the two photon production of π°, η and η'. Each of the processes mentioned above gives $F(q^2)$ in some range of q^2. The available experimental information qualitatively does not contradict the predictions of Vector Dominance, but much higher statistics is needed for the consistent picture of vector to pseudoscalar transitions [6,22,28]. One can hope for substantial improvement of the situation after new series of experiments at VEPP-2M with the CMD-2 [29] and SND [30] detectors and $DA\Phi NE$.

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