VECTOR MESON DECAYS AND THE ROLE OF σ-MESON *

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ABSTRACT

The understanding of scalar mesons is one of the key problems of strong interaction physics. The low-mass pion-pion data provide indications on the existence of a low-mass scalar σ meson, however the mass and the decay width of σ meson candidate is not well known. In this work, we calculate the coupling constant of σ meson to vector meson ρ and to photon by utilizing the experimental branching ratio of $\rho^0\to\pi^+\pi^-\gamma$ radiative decay as a function of mass and decay width of σ-meson. We then calculate the decay rate of $\rho^0\to\pi^0\pi^0\gamma$ radiative decay using this coupling constant. Measurement of this branching ratio thus may be used to determine σ meson parameters more precisely.

The radiative decay processes of the type $V\to PP\gamma$, where V denotes vector meson and P denotes pseudoscalar meson, have been a subject of continuous interest both theoretically and experimentally [1-4]. There are two mechanisms that can contribute to these radiative decays. The first one is the internal bremsstrahlung where one of the charged pions from the decay $V\to P^+P^-$ emits a photon, and the second one is the structural radiation which is caused by the internal transformation of the V-meson quark structure. Since the bremsstrahlung is well described by quantum electrodynamics, different methods have been used to estimate the contribution of the structural radiation. Measurement of these decays provide us with important source of information on the structure and the properties of the intermediate states involved in these decays.

In this work, we investigate the decays $\rho^0\to\pi^+\pi^-\gamma$ and $\rho^0\to\pi^0\pi^0\gamma$ in the framework of a phenomenological approach. We consider vector meson as well as σ meson intermediate states. Experimentally, the branching ratio for $\rho^0\to\pi^+\pi^-\gamma$ is known [5]. Using the experimental values of this decay rate, we estimate the coupling constant $g_{\rho\sigma\gamma}$. We then use this coupling constant to calculate the decay rate of $\rho^0\to\pi^0\pi^0\gamma$ decay [6, 7] . Since this coupling constant is obtained for different sets of σ meson parameters, measurement of this decay rate may provide us with insight about σ meson and also about the mechanisms of this decay.

Our calculation is based on the Feynman diagrams in Fig. 1. The included vertices are:

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(1) $$L^{\text{int.}}_{\sigma\pi\pi} = \frac{1}{2} g_{\sigma\pi\pi} M_\sigma \vec{\pi}.\vec{\pi}\,\sigma$$

(2) $$L^{\text{int.}}_{\rho\pi\pi} = g_{\rho\pi\pi} \vec{\rho}_\mu .(\partial^\mu \vec{\pi} \times \vec{\pi})$$

(3) $$L^{\text{int.}}_{\omega\rho\pi} = g_{\omega\rho\pi} \varepsilon^{\mu\nu\alpha\beta} \partial_\mu w_\nu \partial_\alpha \vec{\rho}_\beta .\vec{\pi}$$

(4) $$L^{\text{int.}}_{V\pi\gamma} = \frac{e}{M_V} g_{V\pi\gamma} \varepsilon^{\mu\nu\alpha\beta} \partial_\mu \vec{V}_\nu .\vec{\pi}\, \partial_\alpha A_\beta$$

(5) $$L^{\text{int.}}_{V\sigma\gamma} = \frac{e}{M_V} g_{V\sigma\gamma} \left[\partial^\alpha V^\beta \partial_\alpha A_\beta - \partial^\alpha V^\beta \partial_\beta A_\alpha\right]\sigma$$

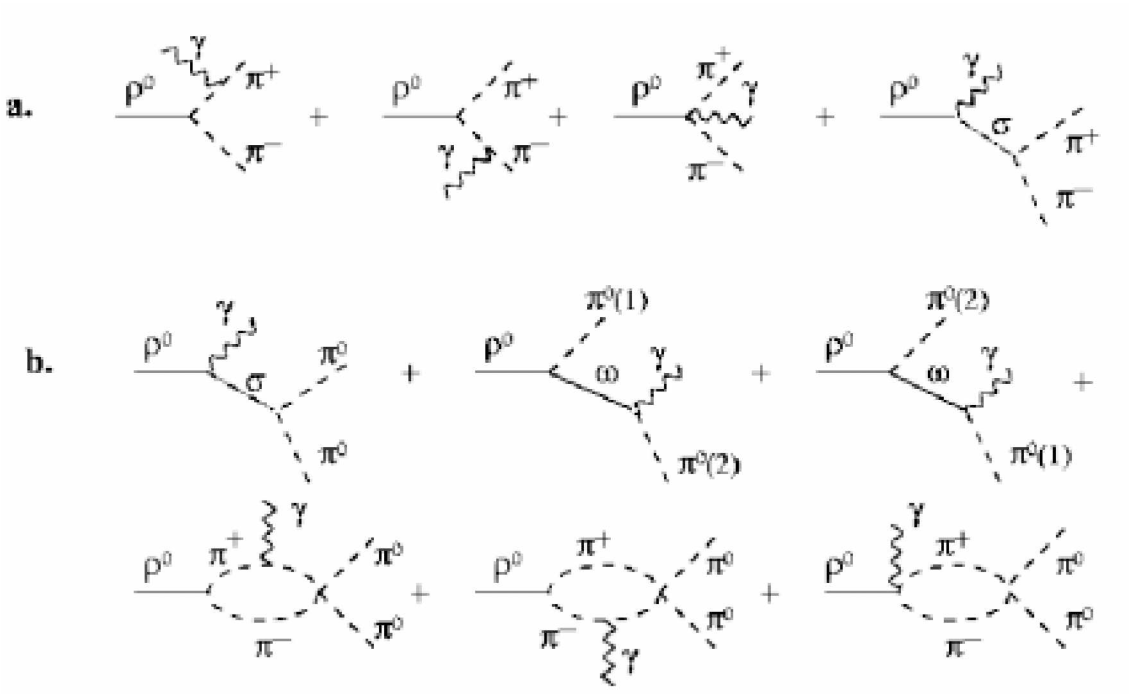

Figure 1: Feynman Diagrams for the decays; (a) $\rho^0 \rightarrow \pi^+\pi^-\gamma$, (b) $\rho^0 \rightarrow \pi^0\pi^0\gamma$.

In terms of the invariant amplitude $M(E_\gamma, E_1)$, the differential decay probability for an unpolarized vector meson at rest is then given as

(6) $$\frac{d\Gamma}{dE_\gamma dE_1} = \frac{1}{(2\pi)^3} \frac{1}{8M_V} |\mathrm{M}|^2$$

where E_γ and E_1 are the photon and pion energies respectively. The decay width $\Gamma(V \rightarrow PP\gamma)$ is then obtained by integration

(7) $$\Gamma = \left(\frac{1}{S}\right) \int_{E_{\gamma,\min.}}^{E_{\gamma,\max.}} dE_\gamma \int_{E_{1,\min.}}^{E_{1,\max.}} dE_1 \frac{d\Gamma}{dE_\gamma dE_1}$$

where $E_{\gamma,\max.} = (M_V^2 - 4M_\pi^2)/2M_V$ and the factor S is 2 for $\pi^0\pi^0$ pair in the final state and 1 for $\pi^+\pi^-$. The maximum and minimum values for pion energy E_1 are given by

$$\frac{1}{2(2E_\gamma M_V - M_V^2)}\left[-2E_\gamma^2 M_V + 3E_\gamma M_V^2 - M_V^3 \pm E_\gamma\sqrt{(-2E_\gamma M_V + M_V^2)(-2E_\gamma M_V + M_V^2 - 4M_\pi^2)}\right]$$

We first consider the $\rho^0 \to \pi^+\pi^-\gamma$ decay. We calculate the decay rate for this decay from the respective Feynman diagrams. Then using the experimental value of this decay rate we arrive at a quadratic equation for the coupling constant $g_{\rho\sigma\gamma}$ for a given set of σ-meson parameters M_σ and Γ_σ

We then calculate the decay rate of $\Gamma(\rho^0 \to \pi^0\pi^0\gamma)$ using the estimated coupling constant as a function of σ-meson parameters M_σ *and* Γ_σ within the framework of our phenomenological approach. Since the quadratic equation for the coupling constant has two solutions, one positive and one negative, there are two values for this decay rate for a given set of σ meson parameters. We present our results in Table 1.

Table 1: The coupling constant $g_{\rho\sigma\gamma}$ and the decay rate $\Gamma(\rho^0 \to \pi^0\pi^0\gamma)$ for different set of σ meson parameters.

M_σ (MeV)	Γ_σ (MeV)	$g_{\rho\sigma\gamma}$	$\Gamma(\rho^0 \to \pi^0\pi^0\gamma)$(KeV)
500	600	7.64	270.3
500	600	-6.00	232.5
500	800	8.45	255.1
500	800	-6.96	244.3
600	800	10.49	264.3
600	800	-7.70	242.6

We also show the calculated photon spectra for the decay $\rho^0 \to \pi^+\pi^-\gamma$ in Fig. 2. In this figure, the shape of diffferentia1 spectrum with respect to photon energy is in good agreement with the experimental result [8]. For the decay $\rho^0 \to \pi^0\pi^0\gamma$, the photon spectra is shown in Fig. 3 which will be tested in future experiments. In these figures we choose the set from the Table 1 that $M_\sigma = 500\,MeV$, $\Gamma_\sigma = 800\,MeV$, $g_{\rho\sigma\gamma} = 8.45$. It is seen that σ-term makes a significant contribution which becomes increasingly important in the region of high photon energies.

We therefore stress that measurement of the decay rate $\Gamma((\rho^0 \to \pi^0\pi^0\gamma)$ may serve as test for the sign of the coupling constant of σ meson and also may clarify the nature of σ meson by limiting the range of its parameters M_σ and Γ_σ. We moreover note that the coupling constant $g_{\rho\sigma\gamma}$ plays a crutial role in analysing photoproduction reactions within the framework of meson-exchange mechanism such as the photoproduction of vector mesons on nucleons near threshold [9].

We are presently extending this work to $\omega\rightarrow\pi^0\pi^0\gamma$ and $\omega\rightarrow\pi^+\pi^-\gamma$ decays to estimate the coupling constant $g_{\omega\sigma\gamma}$.

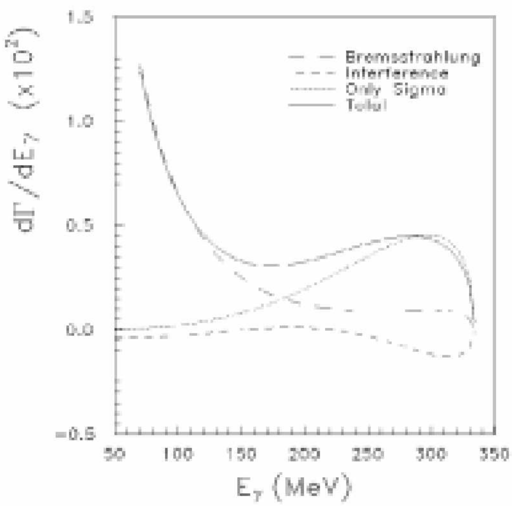

Figure 2: The photon spectra for the decay width of $\rho^0\rightarrow\pi^+\pi^-\gamma$. The contributions of different terms are indicated.

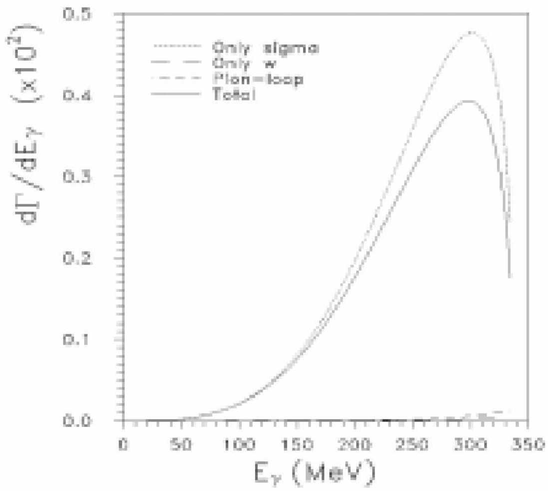

Figure 3: The photon spectra for the decay width of $\rho^0\rightarrow\pi^0\pi^0\gamma$. The contributions different terms are indicated.

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