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A study of the excited radial vector meson ρ

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We study the strong and radiative decays of the radial excitation of the ρ meson, with quantum numbers $n\,^{2S+1}L_J = 2\,^3S_1$, $I = 1$, and denoted as ρ_E, by making use of an effective model. We test different masses: 1.45 GeV, corresponding to well known assignment $\rho_E \equiv \rho(1450)$ state; 1.25 GeV for the assignment $\rho_E \equiv \rho(1250)$ (a resonance whose existence has not yet been confirmed), and 1.35 GeV, which lies just in the middle between them in order to study the dependence of the results on the mass. The decay widths for different decay processes and two branching ratios of the radially excited meson ρ_E were determined and compared to the experimental data reported in the Particle Data Group.

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1. Introduction

Quarks interact strongly via gluons and form color neutral hadrons. According to the quark model, the bound state of a quark (q) and an antiquark $(\bar{q})$ is a conventional meson. Mesons can be further classified into multiplets according to their quantum numbers.

The ground-state vector meson $\rho(770)$ is very well known, but its radial and orbital excitations are not yet fully clarified. Here, we focus on the radial excitation of $\rho(770)$. This state, called ρ_E, has quantum numbers $I = 1, J^{PC} = 1^{--}$ (I stands for the isospin, J for the total spin, P for the parity, and C for the charge conjugation). Usually, the meson ρ_E is assigned to $\rho(1450)$ [1]. However, the mass values for $\rho(1450)$ listed in the PDG vary in a wide range [2]. In addition, there is evidence that another ρ state, called $\rho(1250)$, exists [3, 4, 5, 6, 7, 8, 9], but confirmation is still needed (this state is omitted from the PDG summary). Moreover, it is not clarified if these two resonances would coincide or represent two different ρ states (and, in the latter case, which one would be the radially excited $u\bar{d}$ state).

In Ref. [10] a Quantum Field Theoretical (QFT) model was used to describe the strong and radiative decays of both radial and orbital excited quark-antiquark vector mesons (see sec. 2 for details). In that model, the radially excited meson ρ_E was identified with $\rho(1450)$. In this work, we test how the results of that model change when we change the mass of ρ_E. In practice we calculate the decays of the excited state ρ_E upon settings its mass to 1.45 GeV (corresponding to the standard case, $\rho(1450)$, just as in Ref. [10]), but also to 1.25 GeV (corresponding to the not yet confirmed $\rho(1250)$), and also to 1.35 GeV (just in the middle to test the dependence). In this way, we aim to test if $\rho(1250)$, instead of $\rho(1450)$, could be the radial excitation of the ground-state $\rho(770)$.

2. The effective Lagrangian

We make use of an effective QFT Lagrangian in which we couple the matrices P, V_μ, and $V_{E,\mu}$ that describe standard $\bar{q}q$ mesonic nonets. In particular, P stands for pseudoscalar mesons $\{\pi, K, \eta(547), \eta'(958)\}$, V_μ for the ground-state vector mesons $\{\rho(770), K^*892, \phi(1020), \omega(782)\}$, and $V_{E,\mu}$ for the radially excited vector mesons $\{\rho_E \equiv \rho(1450), K^*(1410), \phi(1680), \omega(1420)\}$. The Lagrangian reads:

$$\mathscr{L} = ig_{EPP} Tr\left([\partial^\mu P, V_{E,\mu}]P\right) + g_{EVP} Tr\left(\tilde{V}_E^{\mu\nu}\{V_{\mu\nu}, P\}\right). \tag{2.1}$$

The first term describes decays of V_E into two pseudoscalar mesons (PP) and the second into a pseudoscalar and a ground-state vector meson (VP). In our model we have two coupling constants: $g_{EPP} = 3.66 \pm 0.4$ and $g_{EVP} = 18.4 \pm 3.8$, determined in Ref. [10] by using experimental data from PDG [2]. The bracket $[.,.]$ refers to the usual commutator and $\{.,.\}$ to the anticommutator. Finally, $V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu$ and $\tilde{V}_E^{\mu\nu} = \frac{1}{2}\varepsilon^{\mu\nu\alpha\beta}(\partial_\alpha V_{E,\beta} - \partial_\beta V_{E,\alpha})$. This approach allows us to study the decays of resonances which predominantly correspond to radially excited vector mesons. Here, we consider different masses for the excited state ρ_E. For the results of the remaining members of the nonet of radially excited vector mesons as well as for orbitally excited vector mesons, see Ref. [10].

The tree-level decay widths of the resonance ρ_E can be derived from QFT by making use of a standard calculation, and read: $\Gamma_{\rho_E \to PP} = s_{EPP} \frac{|\vec{k}|^3}{6\pi m_\rho^2}\left(\frac{g_{EPP}}{2}\lambda_{EPP}\right)^2$, $\Gamma_{\rho_E \to VP} = s_{EVP} \frac{|\vec{k}|^3}{12\pi}\left(\frac{g_{EVP}}{2}\lambda_{EVP}\right)^2$

for strong decay channels and $\Gamma_{\rho_E \to \gamma P} = \frac{|\vec{k}|^3}{12\pi}\left(\frac{g_{EVP}}{2}\frac{e_0}{g_\rho}\lambda_{E\gamma P}\right)^2$ for radiative decay channel, where $\vec{k}$ is the three-momentum of one decay product, s_{EPP} and s_{EVP} are the symmetry factors, λ_{EPP}, λ_{EVP} and $\lambda_{E\gamma P}$ refer to amplitude coefficients (see Ref [10]), g_ρ is a constant related to the process $\rho(770) \to \pi\pi$, and e_0 is the proton electric charge.

3. Decays of ρ_E

In this section we present the results for the decay of the excited radial vector meson ρ_E. We examine how the decay widths depend on the mass of the decaying resonance ρ_E and then we compare the theoretical values to the experimental data. In table 1 we report the results for three types of decays (into PP, VP and γP) by testing the assignments $\rho_E \equiv \{\rho(1250), \rho(1350), \rho(1450)\}$. Moreover, (+) means that decay channel was observed in experiments and (-) means that it was not. The decay $\rho_E \to \omega\pi$ shows that, if we use the presently known experimental value listed under $\rho(1450)$ in the PDG, the agreement of theory with data is spoiled.

Table 1: Values of decay widths for strong and radiative decays of the excited radial vector meson ρ_E with different masses.

Decay channel	Decay width [MeV]			
	Theory			Experiment
	$\rho(1250)$	$\rho(1350)$	$\rho(1450)$	
$\rho_E \to \bar{K}K$	3.2 ± 0.7	4.8 ± 1.0	6.6 ± 1.4	$< 6.7 \pm 1.0$
$\rho_E \to \pi\pi$	25.7 ± 5.6	28.1 ± 6.1	30.8 ± 6.7	$\approx 27 \pm 4$
$\rho_E \to \omega\pi$	26.5 ± 11.0	45.5 ± 18.9	74.7 ± 31.0	$\approx 84 \pm 13$
$\rho_E \to K^*(892)K$	≈ 0	≈ 0	6.7 ± 2.8	$+$
$\rho_E \to \rho(770)\eta$	≈ 0	0.75 ± 0.31	9.3 ± 3.9	$< 16.0 \pm 2.4$
$\rho_E \to \rho(770)\eta'$	≈ 0	≈ 0	≈ 0	$-$
$\rho_E \to \gamma\pi$	0.044 ± 0.026	0.056 ± 0.033	0.072 ± 0.042	$-$
$\rho_E \to \gamma\eta$	0.12 ± 0.07	0.17 ± 0.10	0.23 ± 0.14	$\sim 0.2 - 1.5$
$\rho_E \to \gamma\eta'$	0.013 ± 0.008	0.029 ± 0.017	0.056 ± 0.033	$-$

The PDG provides also informations on experimental data about ratios of decay widths for various decay channels. The first quantity that we check is the $\pi\pi$ to $\omega\pi$ ratio. In the PDG we find:

$$\left.\frac{\Gamma_{\rho(1450)\to\pi\pi}}{\Gamma_{\rho(1450)\to\omega\pi}}\right|_{\text{exp}} \sim 0.32 \quad \text{by CLEGG94 [11].} \tag{3.1}$$

The corresponding theoretical values are: 0.41 ± 0.20 for $\rho_E \equiv \rho(1450)$ (in a good agreement with CLEGG 94); 0.97 ± 0.45 for $\rho_E \equiv \rho(1250)$; 0.62 ± 0.29 for $\rho_E \equiv \rho(1350)$ (the last two values are also in qualitative agreement with the experiment).
For the $KK/\omega\pi$ ratio the PDG reports:

$$\left.\frac{\Gamma_{\rho(1450)\to KK}}{\Gamma_{\rho(1450)\to\omega\pi}}\right|_{\text{exp}} < 0.08 \quad \text{DONNACHIE91 [12],} \tag{3.2}$$

which is compatible with our results for the assignment $\rho_E \equiv \rho(1450)$: 0.088 ± 0.043. However, the experimental value is not compatible for the other two masses: 0.121 ± 0.057 for $\rho_E \equiv \rho(1250)$ and 0.105 ± 0.049 for $\rho_E \equiv \rho(1350)$. Both values are too large of at least a factor 5. The results show that $\rho(1450)$ is predominantly the radial excitation of the $\rho(770)$ meson.

4. Conclusions

In this work we described the strong and the radiative decays of the excited radial vector meson ρ_E upon using different masses. To this end a relativistic QFT model based on flavor symmetry was employed. This model has been previously used for both radially and orbitally excited vector mesons [10]. We have shown that the results for the resonance $\rho(1450)$ is in good agreement with available experiments and with the assignment of being (predominantly) the radial excitation of the $\rho(770)$ meson. A lighter mass, such as a hypothetical $\rho(1250)$ meson, would be problematic (if we keep using the decay rates presently listed under $\rho(1450)$). An interesting future study along this direction is the evaluation of the effects of the quantum mesonic fluctuations on the radially excited vector meson.

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