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RADIAL EXCITATIONS AND THE ρ'

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Abstract

Using quark-model arguments for the photon-vector meson coupling we interpret the $\rho'(1600)$ meson as a radial $q\bar{q}$ excitation. The absence of $\pi\pi$ decays is explained by a selection rule for radial de-excitations, applicable also to the $P_{11}(1470)$ baryon state with similar dynamics. Our scheme parallels a recent consideration of scale invariance breaking.

Heavy vector mesons have long been predicted by Regge-type models [1] and by the quark model [2], in particular the ρ' with quantum numbers indentical to the ρ. In Regge-type models the ρ' should lie on the first daughter trajectory below the $\rho(770)$. Assuming linear and parallel trajectories, this would imply a ρ' mass near the $f(1270)$.

As noted by Harari [2], this prediction stands in contradiction to the naive quark model in which the requirement C=P relegates the ρ' to the second daughter trajectory. The ρ' would be either an orbitally excited 1^3D_1 $q\bar{q}$-state or a radially excited 2^3S_1 state (in spectroscopic $n^{2s+1}L_J$ notation, where n is the radial quantum number). A harmonic oscillator energy level formula [3]

$$E = \hbar\omega(2n + L + \tfrac{3}{2}) \quad (1)$$

would then predict equal masses for the 1^3D_1, 2^3S_1 and 1^3D_3 states:

$$M_{\rho'} \simeq M_g \simeq 1680 \text{ MeV}.$$

Recently the ρ' has been discovered, not in the long searched $\pi\pi$ channel, but in the $\rho^0\pi^+\pi^-$ channel of colliding e^+e^- beams [4] and photoproduction experiments [5,6]. The observed mass, near 1600 MeV, immediately lends support to the naive quark model rather than to Regge-type models with linear and parallel trajectories.

A clue as to whether the observed ρ' is a 1^3D_1 state or a 2^3S_1 state is offered by the non-relativistic quark model.. There the $q\bar{q}\gamma$-vertex is proportional to the $q\bar{q}$ bound state wave function at the origin [7], $\psi(0)$, which in turn is proportional to r^L; thus it vanishes for all $L \neq 0$. Therefore, as pointed out by Dalitz [8], the $2\,^3S_1$ state can couple to the photon, but $1\,^3D_1$ vector mesons are not expected to do so. Since all the observed ρ' mesons are indeed produced at photon vertices [4,5,6], and since in addition no trace of the ρ' is seen in the OPE reaction $\pi^+ p \rightarrow \rho^0 \pi^+ \pi^- \Delta^{++}$ [9], we would tentatively identify the ρ' with the radially excited $2\,^3S_1$ state.

The main puzzle with the ρ' is why it is so weakly coupled to the $\pi\pi$-system*). Indeed, no convincing evidence for the ρ' exists in the $\pi\pi$ decay channel, nor in the $\pi\pi$ production channel [9]. It is also excluded by the analysis in ref. 9 that the ρ' would be a kinematically enhanced tail of the $\rho(770)$.

At a mass of 1600 MeV the ρ' would be expected to decay into channels like $\pi\pi$, $\pi\omega$, πA_1, πA_2, $\rho\rho$ and $\rho\varepsilon$**). The sole observation of $\rho\varepsilon$ hints that some selection rule, characteristic of radial de-excitations, may be at work. Let us assume, as a zeroth order approximation, that very short lifetimes (the ρ' width is 300-600 MeV) cause the radial excitations to decay by

$$X'(n,L,S,J) \longrightarrow X(n-1,L,S,J) + \text{scalar meson (in relative s-wave)} \qquad (2)$$

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*) Note that elastic unitarity for $\pi\pi$ partial wave cross-sections (σ_L) alone gives $\sigma_1(\rho')/\sigma_1(\rho) = q^2_{\rho\rightarrow\pi\pi}/q^2_{\rho'\rightarrow\pi\pi} \simeq 0.2$.

**) By ε and κ we imply the s-wave $\pi\pi$- and $K\pi$-systems, respectively, regardless of whether they actually correspond to poles.

rather than by other modes. Explicitly, rule (2) predicts that the 2^3S_1 vector mesons would only have the decays**) $\rho' \to \rho\varepsilon$, $\omega' \to \omega\varepsilon$, $K^{*\prime} \to K^*\varepsilon$, $K^{*\prime} \to \rho\kappa$, and $\phi' \to K^*\kappa$.

The rule (2) should now apply also to other possible radial excitations. One candidate is [10] the Roper resonance $P_{11}(1470)$, in the first strongly inelastic πN-wave. To large extent the inelasticity is due to the $\pi N \to \pi\pi N$ channel [11,12,13]. Since the $\pi\pi$ s-wave (the "ε") is known to be strongly attractive at nearly all $\pi\pi$ energies [12], it obviously plays an important role in the formation of the $P_{11}(1470)$. Thus the situation strongly resembles that of the ρ', and the radial excitation $P_{11}(1470)$ obeys the rule (2).

It is interesting to note that corroborative evidence for a sudden inelasticity in the $\pi\pi$ p-wave, due to the onset of some other important channel (the $\rho\varepsilon$), seems to exist in the 17.2 GeV/c CERN-Munich $\pi^- p \to \pi^+\pi^- n$ data [14]. At a $\pi^+\pi^-$ mass of about 1500 MeV, both the mass spectrum and the $\langle Y_2^0 \rangle$ moment exhibit a shoulder (on the f meson) and a sudden drop.

Also the E(1420) meson has been advanced as a candidate of radial excitation. However, the very existence of the E is in doubt (its signal is weak in all experiments), and in any case its J^P are undetermined [12] .

Our scheme may be compared with the considerations by Friedman, Nath and Arnowitt |15|, who postulate, in analogy with PCAC in current algebra, that scale invariance breaking [16] relates the ε-meson field to the f-meson by $f_\sigma \phi_\sigma = \theta_M$. Here θ_M is the trace of the improved Belinfante stress tensor, and $f_\sigma^{-1} = b$ is the ε-hadron coupling strength. From this follows, for instance, that the vector currents are modified by ε-terms in the usual vector dominance form:

$$V^\mu(x) = g_\rho \rho^\mu(x)[\,1 + b\phi_\varepsilon(x)]^2\ . \qquad (3)$$

Using the $\rho^\mu(x)\phi_\varepsilon(x)$ term alone Friedman et al. [15] then calculate the annihilation cross-section $e^+e^- \to \rho^o \varepsilon \to 4\pi$. As expected, the cross-section rises rapidly in the 1500 MeV region (corresponding to an ε mass of about 700 MeV). Beyond 2E ≈ 1800 MeV, however, this cross-section decreases much too slowly, judging from the experimental data [4]. To correct the energy dependence one would obviously need to add a ρ' pole term.

If both the 2^3S_1-states and the 1^3D_1 states coexist, the nearness in mass would lead to mixing effects. Although the 2^3S_1-state alone is photoproduced, mixing could effect the transition $2^3S_1 \to 1^3D_1$ and give rise to the decay $\rho' \to \pi\pi$. Thus, from the present data one is lead to infer either that the 1^3D_1-state does not exist, or that mixing is strongly suppressed for some reason. Note that the spin-orbit coefficient is -3 for the 1^3D_1-state, 0 for the 2^3S_1, +2 for the 1^3D_3 (g-meson) [8] , so that the orbital ρ', if existing, may be lighter than the radial ρ'.

Assuming ideal octet-singlet mixing and the $M^2_{I=\frac{1}{2}} - M^2_{I=1} \approx 0.3\ \mathrm{GeV}^2$ rule, the masses of the radial ρ' partners are

$$M_{\omega'} \approx M_{\rho'} = 1600 \pm 200\ \mathrm{MeV}$$

$$M_{\phi'} \approx 1800 \pm 200\ \mathrm{MeV}$$

$$M_{K^*}' \approx 1700 \pm 200\ \mathrm{MeV}\ .$$

The cross-sections for the processes $\gamma p \to \omega' p$, $\phi' p$ can be estimated using the arguments of Kajantie and Trefil [17], taking $\sigma(\rho') = 2.4 \pm 0.6\ \mu b$ at 9.3 GeV/c [6] :

$$\sigma(\omega') \approx 0.27 \pm 0.07\ \mu b$$

$$\sigma(\phi') \approx 0.07\ \mu b.$$

At a higher energy the next radial excitation, 3^3S_1, is expected to appear. Its isovector member ρ'' would have a mass of about 2150 MeV.

In conclusion, our scheme for heavy vector mesons as radial $q\bar{q}$ excitations leads to strong predictions, testable when more data become available. The possible connection between the quark model, "bootstrap-like", and scale breaking arguments is interesting and merits further study.

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