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# A phenomenological note on the missing $\rho_2$ meson

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The $\rho_2$ meson is the missing isovector member of the meson nonet with the quantum numbers $J^{PC} = 2^{--}$. It belongs to the class of $\rho$-mesons such as the vector meson $\rho(770)$, the excited vector $\rho(1700)$ and the tensor $\rho_3(1690)$. Yet, despite the rich experimental and theoretical studies for other $\rho$-meson states, no resonance that could be assigned to the $\rho_2$ meson has been measured. In this note, we present the results for the mass and dominant decay channels of the $\rho_2$ meson within the extended Linear Sigma Model.

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## 1. Introduction

PDG contains various mesons denoted with the letter $\rho$ [1] . These are the isovector resonances with quantum number of isospin ($I = 1$), of parity ($P = -1$), and of charge conjugation ($C = -1$). For instance, the vector mesons $\rho(770)$ with quantum number $J^{PC} = 1^{--}$ [2], the excited vector mesons $\rho(1450)$, $\rho(1700)$ [3–5], and the tensor meson $\rho_3(1690)$ with quantum number $J^{PC} = 3^{--}$ [6]. Despite the prediction of the $\rho_2$ in the Relativistic Quark model [7], it is still missing experimentally. We only have the following data which were observed from different experimental groups and listed as "further states" in PDG [1]: $\rho_2(1940)$ and $\rho_2(2225)$ with the total decay widths $\Gamma^{\text{tot}}_{\rho_2(1940)} \simeq 155 \pm 40$ MeV and $\Gamma^{\text{tot}}_{\rho_2(2225)} \simeq 335^{+100}_{-50}$ MeV accordingly. Axial tensor mesons are studied in recent LQCD simulations [8], where the authors consider the mass of $\rho_2$ is about 1.7 GeV as the $\rho_3(1690)$. We present the results about the missing $\rho_2$ [9] within a chiral effective model which is so-called the extended Linear Sigma Model (eLSM) [2].

## 2. Effective Model and Results

The physical resonances such as the pseudoscalar mesons $\{\pi, K, \eta, \eta'(958)\}$, the vector mesons $\{\rho(770), \overline{K}^\star(892), \omega(782), \phi(1020)\}$, and the tensor mesons $\{a_2(1320), \overline{K}_2^\star(1430), f_2(1270), f_2'(1525)\}$ together with their chiral partners construct chiral nonets. Table 1 describes the transformation of the chiral fields under different symmetries for (pseudo) scalars (P) S, (axial-) vector ($A_1^\mu$) $V^\mu$ and (axial-) tensor ($A_2^{\mu\nu}$) $T^{\mu\nu}$ nonets.

| Nonet | Parity ($P$) | Charge conjugation ($C$) | $U_R(3) \times U_L(3)$ |
|---|---|---|---|
| $\Phi(t,\vec{x}) := S(t,\vec{x}) + iP(t,\vec{x})$ | $\Phi^\dagger(t,-\vec{x})$ | $\Phi^t(t,\vec{x})$ | $U_L \Phi U_R^\dagger$ |
| $R^\mu(t,\vec{x}) := V^\mu(t,\vec{x}) - A_1^\mu(t,\vec{x})$ | $L_\mu(t,-\vec{x})$ | $-(L^\mu(t,\vec{x}))^t$ | $U_R R^\mu U_R^\dagger$ |
| $L^\mu(t,\vec{x}) := V^\mu(t,\vec{x}) + A_1^\mu(t,\vec{x})$ | $R_\mu(t,-\vec{x})$ | $-(R^\mu(t,\vec{x}))^t$ | $U_L L^\mu U_L^\dagger$ |
| $\mathbf{R}^{\mu\nu}(t,\vec{x}) := T^{\mu\nu}(t,\vec{x}) - A_2^{\mu\nu}(t,\vec{x})$ | $\mathbf{L}_{\mu\nu}(t,-\vec{x})$ | $(\mathbf{L}^{\mu\nu}(t,\vec{x}))^t$ | $U_R \mathbf{R}^{\mu\nu} U_R^\dagger$ |
| $\mathbf{L}^{\mu\nu}(t,\vec{x}) := T^{\mu\nu}(t,\vec{x}) + A_2^{\mu\nu}(t,\vec{x})$ | $\mathbf{R}_{\mu\nu}(t,-\vec{x})$ | $(\mathbf{R}^{\mu\nu}(t,\vec{x}))^t$ | $U_L \mathbf{L}^{\mu\nu} U_L^\dagger$ |

**Table 1:** Transformations of the chiral multiplets under P, C, and $U_R(3) \times U_L(3)$.

The chiral invariant Lagrangian that generates the masses of the spin-2 mesons reads

$$\mathcal{L}_{\text{mass}} = \text{Tr}\Big[\Big(\frac{m_{\text{ten}}^2}{2} + \Delta^{\text{ten}}\Big)\Big(\mathbf{L}_{\mu\nu}^2 + \mathbf{R}_{\mu\nu}^2\Big) + \mathbf{R}^{\mu\nu}\mathbf{R}_{\mu\nu}\Big] + 2h_3^{\text{ten}}\text{Tr}\Big[\Phi\mathbf{R}^{\mu\nu}\Phi^\dagger\mathbf{L}_{\mu\nu}\Big], \tag{1}$$

where $\Delta^{\text{ten}} = \text{diag}\{0\,,0\,,\delta_S^{\text{ten}} = m_{K_2}^2 - m_{\mathbf{a}_2}^2\}$.

The following three equations are coming from the extended version of the above lagrangian and relate the masses of spin-2 chiral partners:

$$m_{\rho_2}^2 = m_{a_2}^2 - h_3^{\text{ten}}\phi_N^2, \quad m_{K_{2A}}^2 = m_{K_2}^2 - \sqrt{2}h_3^{\text{ten}}\phi_N\phi_S, \quad m_{\omega_{2,S}}^2 = m_{f_{2,S}}^2 - 2h_3^{\text{ten}}\phi_S^2\,, \tag{2}$$

which leads to $m_{\rho_2} = 1663$ MeV where we have assumed $m_{K_{2A}} = m_{K_2(1820)}$. The same assumption in the last term of Eq (1) implies $\Gamma(\rho_2 \to a_2(1320))\pi \approx 88$ MeV which is 200 MeV in [10]. Our prediction for the mass of $\rho_2$ from the spontaneous breaking of the chiral symmetry is near to the prediction in [7].

The simplest Lagrangian which describes tree level decays has the following form

$$\mathcal{L} = \frac{g_2^{\text{ten}}}{2}\Big(\text{Tr}\Big[\mathbf{L}_{\mu\nu}\{L^\mu, L^\nu\}\Big] + \text{Tr}\Big[\mathbf{R}_{\mu\nu}\{R^\mu, R^\nu\}\Big]\Big)\,. \tag{3}$$

We firstly present the results for $a_2(1320)$ with the quantum number $J^{PC} = 2^{++}$ based on the Lagrangian (3). Secondly, we present the results in Table 3 for the missing $\rho_2$. Note that, we have

| Decay process (in model) | eLSM [9] | PDG [1] |
|---|---|---|
| $a_2(1320) \longrightarrow \bar{K}\,K$ | $4.06 \pm 0.14$ | $7.0^{+2.0}_{-1.5}$ |
| $a_2(1320) \longrightarrow \pi\,\eta$ | $25.37 \pm 0.87$ | $18.5 \pm 3.0$ |
| $a_2(1320) \longrightarrow \pi\,\eta'(958)$ | $1.01 \pm 0.03$ | $0.58 \pm 0.10$ |

**Table 2:** Decay rates of the $a_2(1320)$ into the pseudoscalar mesons in MeV.

used the PDG data in Table 2 to obtain the coupling $g_2^{\text{ten}}$ for presenting the results in the second row of the Table 3. We expect the dominant $\rho_2$ decay widths in the interval between the second and the third rows of the following table which implies it is being broad despite some uncertainties.

| Decay process (in model) | eLSM | eLSM (LQCD) | LQCD [8] |
|---|---|---|---|
| $\rho_2(?) \longrightarrow \rho(770)\,\eta$ | 87 | 30 | – |
| $\rho_2(?) \longrightarrow \bar{K}^*(892)\,K + \text{c.c.}$ | 77 | 27 | 36 |
| $\rho_2(?) \longrightarrow \omega(782)\,\pi$ | 376 | 122 | 125 |
| $\rho_2(?) \longrightarrow \phi(1020)\,\pi$ | 0.8 | 0.3 | – |

**Table 3:** Decay rates of $\rho_2$ into the vector and the pseudoscalar mesons in MeV.

We finally present the result for the well-established tensor meson $\rho_3(1690)$ in Table 4. The decay channel of $\Gamma(\rho_3(1690) \to \omega(782)\pi)$ which is measured experimentally too, is 5-6 times smaller than $\Gamma(\rho_2 \to \omega(782)\pi)$ within LQCD simulations in spite of having the same mass.

| Decay process (in model) | PDG [1] | eLSM [6] | LQCD [8] |
|---|---|---|---|
| $\rho_3(1690) \longrightarrow \rho(770)\,\eta$ | – | $3.8 \pm 0.8$ | – |
| $\rho_3(1690) \longrightarrow \bar{K}^*(892)\,K + \text{c.c.}$ | – | $3.4 \pm 0.7$ | 2 |
| $\rho_3(1690) \longrightarrow \omega(782)\,\pi$ | $25.8 \pm 9.8$ | $35.8 \pm 7.4$ | 22 |
| $\rho_3(1690) \longrightarrow \phi(1020)\,\pi$ | – | $0.036 \pm 0.007$ | – |

**Table 4:** Decay rates of $\rho_3(1690)$ into the vector and the pseudoscalar mesons in MeV.

## 3. Conclusion

We have studied $\rho_2$ axial-tensor meson, chiral partner of the tensor meson $a_2(1320)$ in the framework of a chiral model for low-energy QCD. We predict its mass to be around 1.663 GeV similar to the Relativistic Quark model prediction. Because of the chiral symmetry, the parameter determined in the tensor sector allows to make predictions for unknown ground-state axial-tensor resonance. The effective model fitting to the LQCD results is also presented.

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