Phenomenological study of the isovector tensor meson family

Cheng-Qun Pang1,2,∗ Li-Ping He1,4 Xiang Liu1,2,5 and Takayuki Matsuki3
1School of Physical Science and Technology, Lanzhou University, Lanzhou 730000, China
2Research Center for Hadron and CSR Physics, Lanzhou University & Institute of Modern Physics of CAS, Lanzhou 730000, China
3Tokyo Kasei University, 1-18-1 Kaga, Itabashi, Tokyo 173-8602, Japan

In this work, we study all the observed a2 states and group them into the a2 meson family, where their total and two-body Okubo-Zweig-Iizuka allowed strong decay partial widths are calculated via the quark pair creation model. Taking into account the present experimental data, we further give the corresponding phenomenological analysis, which is valuable to test whether each a2 state can be assigned into the a2 meson family. What is more important is that the prediction of their decay behaviors will be helpful for future experimental study of the a2 states.

PACS numbers: 14.40.Be, 12.38.Lg, 13.25.Jx

I. INTRODUCTION

Among the observed light hadrons, isovector tensor mesons form the a2 meson family, which has the quantum number $J^P = 1^{2-+}$. In Particle Data Group (PDG) [1], seven a2 states are collected, i.e., a2(1320), a2(1700), a2(1950), a2(1990), a2(2030), a2(2175), and a2(2255). Here, their experimental information including the resonance parameters and the observed decay channels, is given in Table I.

$a2(1320)$ can be well established to be the $1^3P_2$ state [4, 5] which is the ground state of the a2 meson family, while a2(1700) is the first radial excitation of a2(1320) [6–10]. As shown in Table I, there are five a2 states listed as further states in PDG. a2(1950) was observed in the $\pi f_2(1270)$ decay channel by SPEC [2] when fitting it with the Crystal Barrel data. In addition, a2(1950) was also observed in the process $p\bar{p} \rightarrow n\pi\pi\pi$ [11]. Anisovich et al. indicated that there exists a2(1990) [or named a2(1890)] in the reactions $p\bar{p} \rightarrow n\pi\pi$, $p\bar{p} \rightarrow n\eta\pi$ [12]. Furthermore, in an analysis combined with the consistent resonance parameters in all three sets of data, $(p\bar{p} \rightarrow n\pi\pi, n\eta\pi, 3\pi)$, the authors in Ref. [2] updated their analyzed results, in which the former resonances a2(1990), a2(2270) [12], a2(2100), and a2(2280) [12] are replaced with a2(1950), a2(2030), a2(2175), and a2(2255). Thus, in the 2002 PDG edition [13], a2(1990) was still listed while the updated states a2(1950), a2(2030), a2(2175), and a2(2255) were also included [14]. In Ref. [15], the a2 state with resonance parameters, the mass $M = 2050 \pm 10 \pm 40$ MeV and width $\Gamma = 190 \pm 22 \pm 100$ MeV, was reported in the process $\gamma\gamma \rightarrow \pi^+\pi^-\pi^0$, where this a2 is considered as the same state as a2(2030). In addition, the observed a2 resonance with the mass $2003 \pm 10 \pm 19$ MeV and width $249 \pm 23 \pm 30$ MeV is treated as a2(1990) since its resonance parameters are close to those of a2(1990) [16].

Although many a2 states were reported by experiments, we notice that these states are not established, especially for the states listed as further states in PDG, which is the main reason why we are interested in the study of the a2 states. It is obvious that the detailed information on the partial decay widths of the a2 states is helpful for further experimental study on these. Comparing our theoretical results with the measured resonance parameters, we can further test whether they are suitably categorized into the a2 meson family. In the next section, we briefly review the possible assignments of the states in the a2 meson family. Considering the present research status of these states, we notice that a systematic and phenomenological study of the a2 is still absent. Hence, in this work we carry out the calculation of the Okubo-Zweig-Iizuka (OZI) allowed partial decay widths of these states, where the quark pair creation (QPC) model proposed by Micu [17] will be applied to the whole calculation. The systematical study will give us the valuable partial and total decay widths of the discussed a2 states in detail.

This paper is organized as follows. In the next section, we briefly introduce different categorizations of the states in the a2 meson family. Further, we calculate the corresponding two-body OZI-allowed strong decays. After combining the present experimental data with our theoretical results, a phenomenological analysis will be given. The final section is devoted to a summary of our work.

II. MASS SPECTRUM ANALYSIS AND CALCULATION OF TWO-BODY STRONG DECAYS

A. Mass spectrum analysis of the a2 states

Before calculating the OZI-allowed two-body strong decay widths, we briefly review the status of the mass spectrum analysis of the a2 states. Usually, the analysis of the Regge trajectories can be an effective approach to study the categorization of mesons. In Refs. [2, 18, 19], Anisovich et al. studied the light meson spectrum via the analysis of the Regge trajectories. As indicated in Ref. [2], a2(1320), a2(1700), a2(1950), and a2(2175) can be assigned to $1^3P_2$, $2^3P_2$, $3^3P_2$, and $4^3P_2$ states, respectively, while a2(2030) and
TABLE I: The resonance parameters and observed decay channels of the $a_2$ states collected in PDG [1]. Here, the states listed as further states in PDG are marked by the superscript $\dagger$.

| State | Mass (MeV) | Width (MeV) | Decay channel |
|-------|------------|-------------|---------------|
| $a_2(1320)$ | 1318.3$^{+0.5}_{-0.6}$ | 105.0$^{+16}_{-16}$ | $\pi\rho$, $\pi\eta$, $KK$, $\eta'$; $\pi f_2(1270)$, $\pi f(1450)$ [1] |
| $a_2(1700)$ | 1732 $\pm$ 16 | 194 $\pm$ 40 | $\pi\rho$, $\pi\eta$, $KK$, $\pi f_2(1270)$, $\rho \omega$ [1] |
| $a_2(1950)^\dagger$ | 1950$^{+30}_{-70}$ | 180$^{+30}_{-70}$ | $\pi f_2(1270)$ [2] |
| $a_2(1990)^\dagger$ | 2050 $\pm$ 10 $\pm$ 40 | 190 $\pm$ 22 $\pm$ 100 | $\pi\eta$, $\pi\eta'$ [2, 3] |
| $a_2(2030)^\dagger$ | 2030 $\pm$ 20 | 205 $\pm$ 30 | $\pi f_2(1270)$, $\pi\eta$, $\pi\eta'$ [2, 3] |
| $a_2(2175)^\dagger$ | 2175 $\pm$ 40 | 310$^{+30}_{-30}$ | $\pi f_2(1270)$ [2, 3] |
| $a_2(2255)^\dagger$ | 2255 $\pm$ 20 | 230 $\pm$ 15 | $\pi f_2(1950)$, $\eta\eta$ [2, 3] |

$\frac{3}{2}^+L_J$ A. Anisovich [2, 3, 20] V. Anisovich [21, 22] Masjuan [14] $a_2(2255)$ are good candidates for the $1^3F_2$ and $2^3F_2$ states, respectively [2, 3, 20]. However, in Refs. [21, 22] $a_2(2175)$ was not included in their analysis. Alternatively, $a_2(2255)$ is treated as the $4^3P_2$ state and $a_2(2310)$ as the $2^3F_2$ state [22]. Recently, Masjuan et al. [14] pointed out that $a_2(1950)$ and $a_2(2030)$ might be the same state. Their analysis indicates that $a_2(1320)$, $a_2(1700)$, and $a_2(2175)$ are $1^3P_2$, $2^3P_2$, and $3^3P_2$ states, respectively. Furthermore, the $4^3P_2$ state with the mass 2.42(17) GeV was predicted in their trajectory analysis. The obtained assignments to $a_2(2030)$ and $a_2(2255)$ in Ref. [14] are consistent with those in Ref. [2]. In Table II, we summarize the three different categorizations mentioned above.

| $n^{2S+1}L_J$ | A. Anisovich [2, 3, 20] | V. Anisovich [21, 22] | Masjuan [14] |
|---------------|----------------------|----------------------|----------------------|
| $1^3P_2$      | $a_2(1320)$          | $a_2(1320)$          | $a_2(1320)$          |
| $2^3P_2$      | $a_2(1700)$          | $a_2(1700)$          | $a_2(1700)$          |
| $3^3P_2$      | $a_2(1950)$          | $a_2(1950)$          | $a_2(2175)$          |
| $4^3P_2$      | $a_2(2175)$          | $a_2(2255)$          | $a_2(2420)^\dagger$ |
| $1^1F_2$      | $a_2(2030)$          | $a_2(2030)$          | $a_2(2030)$          |
| $2^1F_2$      | $a_2(2255)$          | $a_2(2310)^\dagger$ | $a_2(2255)$          |

where $P_{BC}$ denotes the three-momentum of the final particle $B(C)$. $M_L$ ($i = A, B, C$) is the orbital magnetic momentum of the corresponding meson in the decay, $M_A^{M_\alpha M_B M_C}$ is the helicity amplitude. The $T$ operator reads as

$$T = -3\gamma \sum_m \langle 1m|1 - m|00 \rangle \int d\pmb{p}_3 d\pmb{p}_4 \delta^3(\pmb{p}_3 + \pmb{p}_4) \times \mathcal{Y}_{1m} \left( \frac{\pmb{P}_3 - \pmb{P}_4}{2} \right) \chi_{1m} \phi_0 \left( \rho^4 \hat{b}^j_{13} (\pmb{P}_3) \hat{d}^j_{14} (\pmb{P}_4) \right),$$

where $\gamma$ is a parameter that takes the value 8.7 or 8.7/ $\sqrt{3}$ depending on whether the quark-antiquark pair created from the vacuum is $u\bar{u}(d\bar{d})$ or $s\bar{s}$ [43]. The quark and antiquark created from the vacuum are marked by the subscripts 3 and 4, respectively $i/j$ denotes the color indices. $\chi$, $\phi$, and $\omega$ are the spin, flavor, and color wave functions, respectively. In addition, $\mathcal{Y}_{1m}(\pmb{p}) = |\pmb{p}| \mathcal{Y}_{1m}(\pmb{p})$ is the solid harmonic polynomial (see Refs. [47, 48] for more details). Using the Jacob-Wick formula [49], the helicity amplitude $M_A^{M_\alpha M_B M_C}$ can be converted into the partial wave amplitude $M_A^{J_L}(\pmb{P})$, i.e.,

$$M_A^{J_L}(\pmb{P}) = \frac{\sqrt{2L + 1}}{2J_\Lambda + 1} \sum_{M_\Lambda M_C} \langle L0; J_\Lambda M_{J_\lambda} |A M_{J_\mu} \rangle \times \langle J_\alpha M_{J_\alpha}; J_\beta M_{J_\beta} |A J_M |J_\lambda M_{J_\lambda} \rangle M^{J_\alpha J_\beta} M_{J_\mu} M_C.$$
Finally, the decay width can be given by
\[
\Gamma = \frac{\pi^2|P|^2}{m_A^2} \sum_{LL} |M^{LL}(\mathbf{p})|^2, \tag{4}
\]
where \(m_A\) is the mass of the initial meson \(A\). In the concrete calculation, we use the harmonic oscillator wave function to describe the meson spacial wave function, where we approximately take the harmonic oscillator potential to describe the potential between quark and antiquark [50]. The harmonic oscillator wave function has the following expression:
\[
\Psi_{\text{lin}}(R, \mathbf{p}) = \mathcal{R}_m(R, \mathbf{p})\Psi_{\text{lin}}(\mathbf{p}), \tag{5}
\]
where \(R\) is a parameter, which is given in Ref. [33] for the mesons involved in our calculation.

The two-body OZI-allowed strong decay channels, which are allowed by the conservation law and calculated by us, are listed in Table III for \(a_2(1320), a_2(1700), a_2(1950), a_2(2175), a_2(2030),\) and \(a_2(2255)\).

C. Phenomenological analysis of two-body decays

1. \(a_2(1320), a_2(1700), \) and \(a_2(2030)\)

From Table II, we notice that different groups obtained the consistent conclusion of the assignments to \(a_2(1320), a_2(1700), \) and \(a_2(2030),\) which are the \(1^3P_2, 2^3P_2, \) and \(1^3F_2\) states, respectively. In the following, we discuss the decay behaviors of \(a_2(1320), a_2(1700), \) and \(a_2(2030).\)

As for \(a_2(1320),\) there are four allowed decay channels. We present the dependence of total and partial decay widths on the \(R\) value in Fig. 1, and compare the obtained total decay width with the experimental data. The calculated total decay width of \(a_2(1320)\) is consistent with the experimental data measured by Ref. [51] when taking \(R = 3.85\) GeV\(^{-1}\) [33]. Our result also shows that \(\rho \omega\) is the dominant decay mode and \(\pi \eta\) is another main decay mode. Since there is the abundant experimental information on \(a_2(1320),\) we list the comparison between theoretical and experimental results of five typical ratios and two partial decay widths in Table IV, which indicates that our calculation is comparable with the present experimental data. Thus, \(a_2(1320)\) as the \(1^3P_2\) state is well tested by our study.

From PDG [1], we also notice there were the measurement results of \(a_2(1320) \rightarrow \omega \pi \pi\) and \(a_2(1320) \rightarrow 3\pi,\) where the breaching ratios of \(a_2(1320) \rightarrow \omega \pi \pi\) and \(a_2(1320) \rightarrow 3\pi\) can reach up to (70.1 \(\pm\) 2.7)\% and (10.6 \(\pm\) 3.2)\%, respectively. This information also stimulates our interest in investigating these three-body decays. The two-body decay behavior of \(a_2(1320)\) indicates that the \(\rho \pi\) channel is its dominant decay mode, where \(\rho\) dominantly decays into \(2\pi\) [branching ratios \(B(\rho \rightarrow \pi \pi) \sim 100\%\)]. In addition, the \(2\pi\) in \(a_2(1320) \rightarrow \omega \pi \pi\) can be from the intermediate \(\rho.\) Thus, we consider \(a_2(1320) \rightarrow \rho \pi \rightarrow 3\pi\) and \(a_2(1320) \rightarrow \omega \rho \omega \pi\) processes, where the decay amplitudes of \(a_2(1320) \rightarrow \rho \pi\) and \(a_2(1320) \rightarrow \omega \rho\) can be obtained by the QPC model. And then we apply the general expressions for three-body decays, i.e.,
\[
\Gamma_{A \rightarrow B + C + 1 + 2 + C} = \frac{\pi^2|P|^2}{m_A^2} \sum_{LL} |M^{LL}(\mathbf{p})|^2 \frac{dE}{2\pi} \frac{\Gamma_A \rightarrow B + C \Gamma_B \rightarrow 1 + 2}{(E - m_B)^2 + \Gamma_B^2/4}, \tag{6}
\]
where \(\Gamma_B\) is the total width of meson \(B\) and \(E\) is the energy of particle \(B.\) By the calculation, finally we obtain \(\Gamma_{a_2(1320) \rightarrow 3\pi} \approx \)

### Table III: The OZI-allowed two-body decay channels of the discussed \(a_2\) states.

| Channel          | \(a_2(1320)\) | \(a_2(1700)\) | \(a_2(1950)\) | \(a_2(2030)\) | \(a_2(2175)\) | \(a_2(2255)\) |
|------------------|---------------|---------------|---------------|---------------|---------------|---------------|
| \(\pi \eta\)     | ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\pi \rho\)     | ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(K K\)          | ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\pi f_1(1325)\)| ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(K K^*\)        | ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\pi f_1(1270)\)| ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\pi f_1(1280)\)| ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\pi f_1(1295)\)| ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\rho \omega\)  | ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\rho \rho\)    | ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\rho a_1(1900)\)| ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\rho \eta\)    | ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\rho a_1(2010)\)| ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\pi f_1(1320)\)| ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(K K^*\)        | ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\pi \rho\)     | ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\omega \rho\)  | ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\rho \eta\)    | ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |
| \(\rho a_1(1450)\)| ✓             | ✓             | ✓             | ✓             | ✓             | ✓             |

---

\(\eta\) and \(\eta'\) denote \(\rho(770), \omega(782), \eta(548),\) and \(\eta(958),\) respectively. We use \(\sqrt{\ }\) to mark the allowed decay channels.

---

\(K\) is the mass of the initial meson. \(\pi\) and \(\rho\) are allowed by the conservation law and calculated by us, are listed in Table III for \(a_2(1320), a_2(1700), a_2(1950), a_2(2175), a_2(2030),\) and \(a_2(2255).\)
90 MeV and $\Gamma_{a_2(1320)}^{\pi^{-}\pi^{+}\pi^{-}} \approx 15$ MeV, which are comparable with the corresponding experimental data [1].

In addition, $a_2(1320) \rightarrow \pi^{+}\gamma$ can from $a_2(1320) \rightarrow \pi^{+}\rho \rightarrow \pi^{+}\gamma$ when one considers the Vector-Meson-Dominance mechanism. Since in this work we only focus on the strong decays, we do not discuss the $a_2(1320) \rightarrow \pi^{+}\gamma$ radiative decay.

As for $a_2(1700)$, more decay channels open as shown in Table II. In Fig. 2 we list the variation of the total and partial decay widths of $a_2(1700)$ in terms of the $R$ value. When $R = 4.55$ GeV$^{-1}$ [33], the central value of the experimental total width of $a_2(1700)$ from L3 [56] can be reproduced by our calculation. The main decay modes of $a_2(1700)$ include $\pi\rho$, $\rho\omega$, $\pi\eta$, and $\eta\pi(1235)$. Additionally, $\pi f_1(1285)$, $\eta f_1(1295)$, $\rho(1450)$, and $KK$ are important decay channels for $a_2(1700)$. In Table V, further theoretical values of $\Gamma_{Total}$, $\Gamma_{\eta}\pi$, $\pi f_1(1270)$, and $\Gamma_{\eta}\pi/\Gamma_{f_1(1270)}$ are presented by making the comparison with the corresponding experimental results, where most theoretical values are consistent with the experimental data if one considers the experimental errors. The above study supports $a_2(1700)$ as a $2^{1}P_{2}$ state in the $a_2$ meson family.

![Figure 1](image1.png)  
**FIG. 1:** The partial and total decay widths of $a_2(1320)$ as the $1^{3}P_{2}$ state dependent on the $R$ value. Here, the dashed line with the yellow band is the experimental total width from Ref. [51]. All results are in units of MeV.

![Figure 2](image2.png)  
**FIG. 2:** The dependence of the partial and total decay widths of $a_2(1700)$ as the $2^{1}P_{2}$ state on the $R$ value. Here, the dashed line with the yellow band denotes the experimental total width given in Ref. [56]. All results are in units of MeV.

| Item                  | This work | Experimental data |
|-----------------------|-----------|-------------------|
| $\Gamma_{\eta}\pi$   | 0.18      | (0.15 $\pm$ 0.04) [52] |
| $\Gamma_{KK}$        | 0.016     | (0.049 $\pm$ 0.008) [1] |
| $\Gamma_{\eta}\pi/\Gamma_{Total}$ | $5.4 \times 10^{-3}$ | $(5.3 \pm 0.9) \times 10^{-3}$ [1] |
| $\Gamma_{KK}/\Gamma_{\eta}\pi$ | 0.092 | 0.08 $\pm$ 0.02 [1, 53] |
| $\Gamma_{\eta}\pi/\Gamma_{KK}$ | 0.030 | 0.032 $\pm$ 0.009 [1, 54] |
| $\Gamma_{\eta}$ | 23        | 18.5 $\pm$ 3.0 [1, 55] |
| $\Gamma_{KK}$       | 2.1       | $7.0^{+2.0}_{-1.5}$ [1, 55] |

| Item                  | This work | Experimental data |
|-----------------------|-----------|-------------------|
| $\Gamma_{Total}$     | 161       | 194 $\pm$ 40 [1] |
| $\Gamma_{\eta}\pi$  | 35        | 9.5 $\pm$ 2.0 [1, 55] |
| $\Gamma_{KK}$        | 5.4       | 5.0 $\pm$ 3.0 [1, 55] |
| $\Gamma_{\eta}\pi/\Gamma_{\eta}\pi(1270)$ | 8.4 | $3.4 \pm 0.4 \pm 0.1$ [1, 15] |

Along with investigating the decay behaviors of $a_2(1320)$ and $a_2(1700)$, the reliability of the QPC model can be further tested in this work, which makes us safely apply this model to the remaining $a_2$ states.

In the following, we illustrate the decay behavior of $a_2(2030)$ as a $1^{3}F_{2}$ state, where its total and partial decay widths are shown in Fig. 3. Our calculation shows that $a_2(2030)$ as a $1^{3}F_{2}$ state has a very broad width, i.e., the total width can reach up to (730–830) MeV corresponding to $R = (4.00 \sim 5.00)$ GeV$^{-1}$, which is not strongly dependent on the $R$ value. When comparing the calculated total width with the experimental result, we find that the theoretical result is far larger than the experimental width of $a_2(2030)$ [2]. At present, $a_2(2030)$ was only reported in Ref. [2, 15]. Thus, we suggest further experimental study to measure the resonance parameters of $a_2(2030)$, which is important to clarify the difference between theory and experiment. From Fig. 3, we obtain that $\pi h_{1}(1235)$, $\rho h_{1}(1170)$, $\pi f_{2}(1645)$, $\eta f_{2}(1260)$, and $\pi f_{2}(1270)$ are main decay modes of $a_2(2030)$, where $\pi f_{2}(1270)$ was al-

| Item                  | This work | Experimental data |
|-----------------------|-----------|-------------------|
| $\Gamma_{Total}$     | 161       | 194 $\pm$ 40 [1] |
| $\Gamma_{\eta}\pi$  | 35        | 9.5 $\pm$ 2.0 [1, 55] |
| $\Gamma_{KK}$        | 5.4       | 5.0 $\pm$ 3.0 [1, 55] |
| $\Gamma_{\eta}\pi/\Gamma_{\eta}\pi(1270)$ | 8.4 | $3.4 \pm 0.4 \pm 0.1$ [1, 15] |
ready observed in the Crystal Barrel experiments [2, 3, 20]. The details of other decay information of \(a_2(2030)\) can be found in Fig. 3. The predicted decay behaviors of \(a_2(2030)\) are valuable to confirm this state by future experiments.

2. The possibility of \(a_2(1950)\) or \(a_2(2175)\) as the \(3^3P_2\) state

As shown in Table II, there are two possible candidates for the \(3^3P_2\) state, i.e., \(a_2(1950)\) and \(a_2(2175)\). Thus, the study of the decay behaviors of \(a_2(1950)\) and \(a_2(2175)\) is helpful to distinguish these two possibilities. In Table III, the allowed decay channels of \(a_2(1950)\) and \(a_2(2175)\) are listed. In the following calculation, we separately discuss the decay behaviors of \(a_2(1950)\) and \(a_2(2175)\) under the \(3^3P_2\) assignment.

In Fig. 4, we show the total and partial decay widths of \(a_2(1950)\) dependent on the \(R\) value. Here, the calculated total width overlaps with the SPEC experimental data [2] with \(R = (4.73 \sim 5.14)\) GeV\(^{-1}\). The result of the corresponding partial decay width shows that \(a_2(1950)\) dominantly decays into \(\pi\rho\), \(\pi\eta\), \(\rho\omega\), and \(\eta'\) (see Fig. 4 for more details). In addition, we also select some typical ratios in Table VI that are weakly dependent on the \(R\) values.

### Table VI: The typical ratios relevant to the decay behavior of \(a_2(1950)\).

| Ratios | Value | Ratios | Value |
|--------|-------|--------|-------|
| \(\Gamma_{\pi\rho}/\Gamma_{Total}\) | 0.229 \sim 0.364 | \(\Gamma_{\pi\eta}/\Gamma_{Total}\) | 0.200 \sim 0.285 |
| \(\Gamma_{\rho\omega}/\Gamma_{Total}\) | 0.0613 \sim 0.0763 | \(\Gamma_{\pi\rho}/\Gamma_{\pi\rho}\) | 0.210 \sim 0.267 |
| \(\Gamma_{\pi\eta}/\Gamma_{\pi\eta}\) | 0.215 \sim 0.381 | \(\Gamma_{\pi\eta}/\Gamma_{Total}\) | 0.0520 \sim 0.0663 |
| \(\Gamma_{\rho\omega}/\Gamma_{\rho\omega}\) | 0.233 \sim 0.260 | \(\Gamma_{\rho\omega}/\Gamma_{\rho\omega}\) | 0.681 \sim 1.08 |
| \(\Gamma_{\rho\omega}/\Gamma_{\rho\omega}\) | 0.229 \sim 0.333 | \(\Gamma_{\rho\omega}/\Gamma_{\rho\omega}\) | 0.881 \sim 1.43 |
| \(\Gamma_{KK}/\Gamma_{Total}\) | 0.0360 \sim 0.0449 | \(\Gamma_{KK}/\Gamma_{\pi\pi}\) | 0.158 \sim 0.180 |
| \(\Gamma_{KK}/\Gamma_{KK}\) | 0.472 \sim 0.732 | \(\Gamma_{KK}/\Gamma_{\pi\pi}\) | 0.676 \sim 0.692 |
| \(\Gamma_{KK}/\Gamma_{KK}\) | 0.796 \sim 0.897 | \(\Gamma_{KK}/\Gamma_{\pi\pi}\) | 0.735 \sim 1.03 |

If \(a_2(2175)\) is the \(3^3P_2\) state, the obtained total decay width can be fitted with the present experimental width of \(a_2(2175)\) when taking \(R = (4.20 \sim 4.72)\) GeV\(^{-1}\). Thus, its partial decay behavior is crucial when we want to distinguish \(a_2(1950)\) and \(a_2(2175)\) as the \(3^3P_2\) state. Here, we get that the main decay channels of \(a_2(2175)\) are \(\pi\rho\), \(\rho\omega\), and \(\eta'\). The detailed decay information of \(a_2(2175)\) is collected in Fig. 5. By this study, we can see that the partial decay behavior of \(a_2(2175)\) is indeed different from that of \(a_2(1950)\). In particular, there are slight differences in the corresponding typical ratios listed in Tables VI and VII. We expect further experimental study on \(a_2(1950)\) and \(a_2(2175)\) to confirm these theoretical results in future.

3. The possibility of \(a_2(2175)\) or \(a_2(2255)\) as the \(4^3P_2\) state

The mass spectrum analysis [2, 21] shows that both \(a_2(2175)\) and \(a_2(2255)\) can be the candidates of the \(4^3P_2\) state. In the following discussion, we combine the experimental data with the calculated result to predict the partial decay width of \(a_2(2175)\) and \(a_2(2255)\) under the assignment of the \(4^3P_2\) state.

If \(a_2(2175)\) is the \(4^3P_2\) state, we find that the obtained total decay width can reproduce the experimental data in Ref. [2], where the \(R\) range is taken as \((5.46 \sim 5.78)\) GeV\(^{-1}\). The corresponding partial decay widths are also listed in Fig. 6, which shows that \(\pi\rho\) and \(\pi\eta\) are main decay modes. Further giving more abundant information to future experiments, we also collect the typical ratios weakly dependent on the \(R\) value in Table VII.

Similarly, we also get the total and partial decay widths of \(a_2(2255)\) as the \(4^3P_2\) state, which are shown in Fig. 7. The main decay modes of \(a_2(2255)\) as the \(4^3P_2\) state are \(\pi\rho\) and \(\pi\eta\). In Table VIII, we predict some typical ratios, which can test the \(4^3P_2\) state assignment to \(a_2(2255)\) in future experiments.

4. \(a_2(2255)\) as the \(2^3F_2\) state

Finally, we need to discuss the possibility of \(a_2(2255)\) as the \(2^3F_2\) state by studying decay behavior. The comparison between the calculated total decay width and the experimental one of \(a_2(2255)\) is shown in Fig. 8, which shows that the experimental data cannot be reproduced, i.e., our result is larger...
than the experimental value. There are two possibilities for this:

1. The $2^3 F_2$ assignment to $a_2(2255)$ is not suitable. However, before definitely adopting this conclusion, a more precise measurement of the resonance parameters of $a_2(2255)$ is necessary since there is only one experiment relevant to $a_2(2255)$ [2] at present.

2. If $a_2(2255)$ is a $2^3 F_2$ state, the corresponding partial decay widths are listed in Fig. 8. Here, $\rho\omega$ and $\rho\omega_1(1260)$ are main decay channels. Thus, carrying out the search for these predicted main decay modes will be helpful to clarify whether $a_2(2255)$ as the $2^3 F_2$ state is suitable or not.

III. SUMMARY

In this work, we have systematically calculated the two-body OZI-allowed strong decays of the observed $a_2$ states when they are categorized into the $a_2$ meson family. By comparing our results with the present experimental data, the $n^{2S+1} L_J$ assignments to the observed states can be tested. What is more important is that in this work we have predicted the partial decay widths of the $a_2$ states, which provides important and valuable information on further experimental searches for the $a_2$ states.

As indicated in the review of the experimental status of the $a_2$ states in Sec. I, the experimental data of these states are not abundant at present, especially the $a_2$ states with higher mass. Hopefully our work can inspire the experimentalist’s interest in exploring the $a_2$ states. We also suggest future experiments to measure the resonance parameters of the observed $a_2$ states since these parameters are crucial to establish the $a_2$ meson family.

The BESIII experiment and the forthcoming PANDA experiment will be good platforms to carry out the experimental study of $a_2$, and we expect further experimental progress on the $a_2$ states.

Acknowledgments

This project is supported by the National Natural Science Foundation of China under Grants No. 11222547, No. 11175073 and No. 11035006, the Ministry of Education of China (SRFDP) under Grant No. 20120211100, and the Fok Ying Tung Education Foundation (Grant No. 131006).

[1] J. Beringer et al. [Particle Data Group Collaboration], Phys. Rev. D 86, 010001 (2012).

[2] A. V. Anisovich, C. A. Baker, C. J. Batty, D. V. Bugg, et al. [Particle Data Group Collaboration], Phys. Rev. D 86, 010001 (2012).
FIG. 4: The dependence of the partial and total decay widths of $a_2(1950)$ as the $3^3P_2$ state on the $R$ value. Here, the dashed line with the yellow band is the experimental total width from Ref. [2]. All results are in units of MeV.

V. A. Nikonov, A. V. Sarantsev, V. V. Sarantsev and B. S. Zou, Phys. Lett. B 517, 261 (2001) [arXiv:1110.0278 [hep-ex]].

[3] D. V. Bugg, Phys. Rept. 397, 257 (2004) [hep-ex/0412045].

[4] C. Caso et al. [Particle Data Group Collaboration], Eur. Phys. J. C 3, 1 (1998).

[5] L. Burakovsky and P. R. Page, Eur. Phys. J. C 12, 489 (2000) [hep-ph/9906282].

[6] J. D. Anderson, M. H. Austern and R. N. Cahn, Phys. Rev. D 43, 2094 (1991).

[7] E. S. Ackleh and T. Barnes, Phys. Rev. D 45, 232 (1992).

[8] C. R. Munz, Nucl. Phys. A 609, 364 (1996) [hep-ph/9601206].

[9] T. Barnes, F. E. Close, P. R. Page and E. S. Swanson, Phys. Rev. D 55, 4157 (1997) [hep-ph/9609339].

[10] C. Amsler et al. [Particle Data Group Collaboration], Phys. Lett. B 667, 1 (2008).

[11] A. V. Anisovich, C. A. Baker, C. J. Batty, D. V. Bugg, V. A. Nikonov, A. V. Sarantsev, V. V. Sarantsev and B. S. Zou, Phys. Lett. B 517, 273 (2001) [arXiv:1109.6817 [hep-ex]].

[12] A. V. Anisovich et al. [Crystal Barrel Collaboration], Phys. Lett. B 452, 173 (1999).

[13] K. Hagiwara et al. [Particle Data Group Collaboration], Phys. Rev. D 66, 010001 (2002).

[14] P. Masjuan, E. R. Arriola and W. Broniowski, Phys. Rev. D 85, 094006 (2012) [arXiv:1203.4782 [hep-ph]].

[15] V. A. Shchegelsky, A. V. Sarantsev, A. V. Anisovich and M. P. Levchenko, Eur. Phys. J. A 27, 199 (2006).

[16] M. Lu et al. [E852 Collaboration], Phys. Rev. Lett. 94, 032002 (2005) [hep-ex/0405044].

[17] L. Micu, Nucl. Phys. B 10, 521 (1969).

[18] A. V. Anisovich et al. [Crystal Barrel Collaboration], Phys. Lett. B 452, 187 (1999).

[19] A. V. Anisovich, V. V. Anisovich and A. V. Sarantsev, Phys. Rev. D 62, 051502 (2000) [hep-ph/0003113].

[20] D. V. Bugg, Phys. Rev. D 84, no. 11, 118501 (2011) [arXiv:1209.3481 [hep-ph]].

[21] V. V. Anisovich, Usp. Fiz. Nauk 1450, 489 (2000) [hep-ph/0405044].

[22] V. V. Anisovich, AIP Conf. Proc. 717, 441 (2004) [hep-
FIG. 5: The decay behavior of $a_2(2175)$ as a $3^3P_2$ state. Here, the dashed line with the yellow band is the experimental total width given in Ref. [2]. All results are in units of MeV.

FIG. 6: The obtained total and partial decay widths of $a_2(2175)$ as a $4^3P_2$ state on the $R$ value. Here, the dashed line with the yellow band is the experimental total width in Ref. [2]. All results are in units of MeV.
TABLE VIII: The typical ratios relevant to the decay behavior of $a_2(2255)$ as the $4^3P_2$ state. Here, these results correspond to the range $R = (5.09 \sim 5.16)$ GeV$^{-1}$.

| Ratios                              | Value   | Ratios                              | Value   |
|-------------------------------------|---------|-------------------------------------|---------|
| $\Gamma_{np}/\Gamma_{\text{Total}}$| 0.300−0.314 | $\Gamma_{n\eta}/\Gamma_{\text{Total}}$ | 0.195−0.209 |
| $\Gamma_{np}/\Gamma_{np}$          | 0.620−0.696 | $\Gamma_{nh(1235)}/\Gamma_{np}$    | 0.0651−0.0690 |
| $\Gamma_{np}/\Gamma_{np}$          | 0.207−0.2300 | $\Gamma_{nh(1235)}/\Gamma_{np}$    | 0.330−0.334 |
| $\Gamma_{np}/\Gamma_{np}$          | 0.0623−0.0655 | $\Gamma_{np}/\Gamma_{np}$          | 0.198−0.218 |
| $\Gamma_{np}/\Gamma_{np}$          | 0.314−0.320 | $\Gamma_{np}/\Gamma_{nh(1235)}$   | 0.949−0.957 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.0532−0.0565 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.169−0.188 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.271−0.273 | $\Gamma_{np(1295)}/\Gamma_{nh(1235)}$ | 0.817−0.819 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.854−0.863 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.0408−0.0443 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.136−0.144 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.195−0.228 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.591−0.681 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.623−0.712 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.722−0.834 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.0335−0.0349 |
| $\Gamma_{KK}/\Gamma_{np}$          | 0.107−0.116 | $\Gamma_{KK}/\Gamma_{np}$          | 0.167−0.172 |
| $\Gamma_{KK}/\Gamma_{np}$          | 0.505−0.515 | $\Gamma_{KK}/\Gamma_{np}$          | 0.532−0.538 |
| $\Gamma_{KK}/\Gamma_{np}$          | 0.617−0.631 | $\Gamma_{KK}/\Gamma_{np}$          | 0.756−0.855 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.0013−0.0342 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.0996−0.114 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.161−0.164 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.491−0.496 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.502−0.522 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.589−0.605 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.705−0.839 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.933−0.982 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.0201−0.0275 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.0669−0.0875 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.0962−0.141 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.291−0.422 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.307−0.441 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.355−0.517 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.493−0.619 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.576−0.819 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.587−0.878 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.0268−0.0272 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.0868−0.0893 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.128−0.140 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.388−0.419 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.409−0.438 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.794−0.813 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.614−0.657 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.794−0.813 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.784−0.871 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.992−1.33  | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.0217−0.0225 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.693−0.7051 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.108−0.112 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.327−0.334 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.344−0.349 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.399−0.409 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.490−0.553 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.645−0.649 | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.659−0.695 |
| $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.792−1.12  | $\Gamma_{np(1295)}/\Gamma_{np}$   | 0.798−0.841 |
FIG. 7: The total and partial decay widths of $\alpha_2(2255)$ as a $4^3P_2$ state. Here, the dashed line with the band is the experimental total width from Ref. [2]. All results are in units of MeV.

FIG. 8: The variation of the total and partial decay widths of $\alpha_2(2255)$ to the $R$ value. Here, $\alpha_2(2255)$ is assigned to be a $2^3F_2$ state. The dashed line with the band is the experimental total width from Ref. [2]. All results are in units of MeV.
[24] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Rev. D 8, 2223 (1973).
[25] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Rev. D 9, 1415 (1974).
[26] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Rev. D 11, 1272 (1975).
[27] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 71, 397 (1977).
[28] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 72, 57 (1977).
[29] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 73, 370 (1996) [hep-ph/9508264].
[30] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 74, 617 (2007) [hep-ph/0609013].
[31] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 75, 115 (2007) [hep-ph/0610127].
[32] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 76, 177 (2007) [hep-ph/0610136].
[33] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 77, 177 (2007) [hep-ph/0610146].
[34] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 78, 177 (2007) [hep-ph/0610147].
[35] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 79, 177 (2007) [hep-ph/0610148].
[36] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 80, 177 (2007) [hep-ph/0610149].
[37] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 81, 177 (2007) [hep-ph/0610150].
[38] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 82, 177 (2007) [hep-ph/0610151].
[39] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 83, 177 (2007) [hep-ph/0610152].
[40] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 84, 177 (2007) [hep-ph/0610153].
[41] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 85, 177 (2007) [hep-ph/0610154].
[42] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 86, 177 (2007) [hep-ph/0610155].
[43] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 87, 177 (2007) [hep-ph/0610156].
[44] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 88, 177 (2007) [hep-ph/0610157].
[45] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 89, 177 (2007) [hep-ph/0610158].
[46] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 90, 177 (2007) [hep-ph/0610159].
[47] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 91, 177 (2007) [hep-ph/0610160].
[48] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 92, 177 (2007) [hep-ph/0610161].
[49] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 93, 177 (2007) [hep-ph/0610162].
[50] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 94, 177 (2007) [hep-ph/0610163].
[51] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 95, 177 (2007) [hep-ph/0610164].
[52] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Lett. B 96, 177 (2007) [hep-ph/0610165].