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Further insights into the “ρπ puzzle” *

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Abstract Based on a systematic investigation of $J/\psi(\psi') \to VP$, where V and P stand for light vector and pseudoscalar mesons, we identify the role played by the electromagnetic (EM) transitions and intermediate meson loop transitions, which are essential ingredients for understanding the J/ψ and ψ′ couplings to VP. We show that on the one hand, the EM transitions have relatively larger interferences in $\psi' \to \rho\pi$ and $K^*\bar{K}+$c.c. as explicitly shown by vector meson dominance (VMD). On the other hand, the strong decay of ψ′ receives relatively larger destructive interferences from the intermediate meson loop transitions. By identifying these mechanisms in an overall study of $J/\psi(\psi') \to VP$, we provide a coherent understanding of the so-called “ρπ puzzle”.

Key words vector-meson dominance, decays of J/ψ, upsilon, other quarkonia, hadronic decays of mesons

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1 Introduction

The decay channels $J/\psi(\psi') \to VP$, which are suppressed in QCD due to the violation of hadronic-helicity conservation [1], have attracted much attention in the past few decades. According to this selection rule, one expects the ratio $BR(\psi' \to \rho\pi)/BR(J/\psi \to \rho\pi) \simeq (M_{J/\psi}/M'_{\psi})^6 \sim 0.35$ [1], which turns out to be much larger than the experimental data [2], $BR(\psi' \to \rho\pi)/BR(J/\psi \to \rho\pi) \simeq (0.2\pm0.1)\%$. This significant discrepancy is known as the so-called “ρπ puzzle”. An alternative expression of the “ρπ puzzle” is via the ratios between J/ψ and ψ′ annihilating into three gluons and a single direct photon:

$$R \equiv \frac{BR(\psi' \to \text{hadrons})}{BR(J/\psi \to \text{hadrons})} \simeq \frac{BR(\psi' \to e^+e^-)}{BR(J/\psi \to e^+e^-)} \approx 12\%, \tag{1}$$

which is empirically called “12% rule”. The puzzle arises from the violation of the above empirical rule in exclusive channels such as ρπ and $K^*\bar{K}$+c.c., where the branching ratio fractions are found to be orders-of-magnitude smaller than the approximate “12%”.

Since the first observation of such a large deviation by Mark-II Collaboration in 1983 [3], many theoretical explanations have been proposed to decipher this puzzle [4–18]. They can be classified into three categories: i) J/ψ-enhancement hypothesis, which attributes the small R-value to the enhanced branching fraction of J/ψ decays; ii) ψ′-suppression hypothesis, which attributes the small R-value to the small branching ratio of ψ′ decays; iii) and other hypotheses which do not simply belong to the above two categories. Unfortunately, so far none of those solutions has been indisputably agreed [19, 20].

In this proceeding, we report our recent efforts on understanding this issue. We shall identify i) the role play by EM transition in $J/\psi(\psi') \to VP$ in a VMD model, which has relatively large interferences in ρπ and $K^*\bar{K}+$c.c. channel; and ii) mechanisms which suppress the strong decay amplitudes for $\psi' \to VP$. We emphasize that our analysis is based on so far the-state-of-art experimental measurements of $J/\psi(\psi') \to VP$ [2]. The systematics exposed in this study can provide some insights into the charmonium hadronic decays on a much more general ground.

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2 Step 1: EM transitions in the VMD model

The importance of EM transitions in $\mathrm{J}/\psi(\psi') \to \mathrm{VP}$ can be recognized by explicit experimental observations. For instance, the branching ratios for isospin-violating decays, $\mathrm{J}/\psi(\psi') \to \rho\eta$, $\rho\eta'$, etc are compatible with those isospin-conserving channels such as $\omega\eta$, $\omega\eta'$, and $\phi\eta$ etc [2]. This is an evidence showing that the strong decay amplitudes become suppressed and have the same order of magnitude as the isospin-violating amplitudes, i.e. EM and strong isospin-violating transition.

The role of the EM can be separately investigated due to the available experimental data for vector meson radiative decays, i.e. ω, ρ, ϕ, K^*, J/ψ and ψ' [2]. Moreover, precise measurements of vector meson decays into lepton pairs such as $\mathrm{e}^+\mathrm{e}^-$ are also available. This allows a well-constraint on the coupling constants required in the VMD model, and only leaves an overall form factor which takes care of the off-shell couplings, to be determined by experimental data. Three independent EM transitions for $\mathrm{V}_1 \to \mathrm{V}_2\mathrm{P}$ are illustrated by Fig. 1.

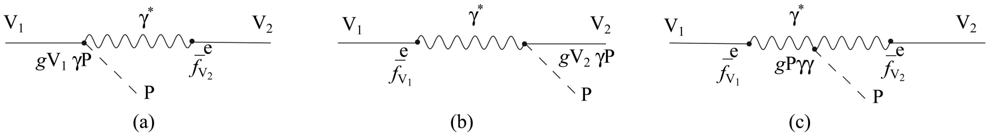

Fig. 1. Schematic diagrams for $\mathrm{J}/\psi(\psi') \to \gamma^* \to \mathrm{VP}$.

Typical effective Lagrangian for the $\mathrm{V}\gamma\mathrm{P}$ coupling are:

$$\mathcal{L}_{\mathrm{V}\gamma\mathrm{P}} = \frac{g_{\mathrm{V}\gamma\mathrm{P}}}{M_{\mathrm{V}}} \epsilon_{\mu\nu\alpha\beta} \partial^\mu V^\nu \partial^\alpha A^\beta P \,, \tag{2}$$

where $V^\nu (= \rho,\ \omega,\ \phi,\ \mathrm{J}/\psi,\ \psi' \ldots)$ and A^β are the vector meson and EM field, respectively; M_{V} is the vector meson mass; $\epsilon_{\mu\nu\alpha\beta}$ is the anti-symmetric Levi-Civita tensor.

The $\mathrm{V}\gamma^*$ coupling is described in VMD model,

$$\mathcal{L}_{\mathrm{V}\gamma} = \sum_{\mathrm{V}} \frac{eM_{\mathrm{V}}^2}{f_{\mathrm{V}}} V_\mu A^\mu \,, \tag{3}$$

where $eM_{\mathrm{V}}^2/f_{\mathrm{V}}$ is a direct photon-vector-meson coupling in Feynman diagram language, and the isospin 1 and 0 component of the EM field are both included.

The invariant transition amplitude for $\mathrm{V}_1 \to \gamma^* \to \mathrm{V}_2\mathrm{P}$ can thus be expressed as:

$$\begin{aligned} &\mathcal{M}_{\mathrm{EM}} \equiv \mathcal{M}_A + \mathcal{M}_B + \mathcal{M}_C = \\ &\left(\frac{e}{f_{\mathrm{V2}}} \frac{g_{\mathrm{V1}\gamma\mathrm{P}}}{M_{\mathrm{V1}}} \mathcal{F}_a + \frac{e}{f_{\mathrm{V1}}} \frac{g_{\mathrm{V2}\gamma\mathrm{P}}}{M_{\mathrm{V2}}} \mathcal{F}_b + \frac{e^2}{f_{\mathrm{V1}} f_{\mathrm{V2}}} \frac{g_{\mathrm{P}\gamma\gamma}}{M_{\mathrm{P}}} \mathcal{F}_c \right) \times \\ &\epsilon_{\mu\nu\alpha\beta} \partial^\mu V_1^\nu \partial^\alpha V_2^\beta P \,, \end{aligned} \tag{4}$$

where $g_{\mathrm{P}\gamma\gamma}$ is the coupling for the neutral pseudoscalar meson decay to two photons; $\mathcal{F}_a$, $\mathcal{F}_b$ and $\mathcal{F}_c$ denote the form factor corrections to the transition of Fig. 1. A monopole (MP) form factor is adopted here,

$$\mathcal{F}(q^2) = \frac{1}{1 - q^2/\Lambda^2} \,, \tag{5}$$

with $\Lambda = 0.542 \pm 0.008$ GeV and $\Lambda = 0.577 \pm 0.011$ GeV determined by the isospin violated channels $\mathrm{J}/\psi(\psi') \to \rho\eta$, $\rho\eta'$, $\omega\pi^0$, and $\phi\pi^0$ with a constructive (MP-C) or destructive phase (MP-D) between Fig. 1(a) and (b), respectively. The form factors are introduced because we think that the non-perturbative QCD effects may play an important role in the transition at J/ψ energy scale.

The form factor $\mathcal{F}_c$ appearing in Eq. (4) can be determined in $\gamma^*\gamma^*$ scatterings. A commonly adopted form factor is

$$\mathcal{F}_c(q_1^2, q_2^2) = \frac{1}{(1 - q_1^2/\Lambda^2)(1 - q_2^2/\Lambda^2)} \,, \tag{6}$$

where $q_1^2 = M_{\mathrm{V1}}^2$ and $q_2^2 = M_{\mathrm{V2}}^2$ are the squared four-momenta carried by the time-like photons. We assume that the Λ is the same as in Eq. (5), thus, $\mathcal{F}_c = \mathcal{F}_a \mathcal{F}_b$.

It should be noted that in Fig. 1 the direct application of $\mathrm{V}\gamma\mathrm{P}$ couplings extracted from experimental data will avoid uncertainties arising from a $\gamma \to \mathrm{V}' \to \mathrm{VP}$ treatment. Unknown energy-dependence of those couplings can then be absorbed into an overall form factor $\mathcal{F}(q^2)$ for which the cut-off energy is determined by fitting those isospin-violating decay branching ratios, i.e. $\mathrm{J}/\psi(\psi') \to \rho\eta$, $\rho\eta'$, $\omega\pi$ and $\phi\pi$.

In fact, one can learn more from the isospin-violating channels. If the EM transition is the dominant transition mechanism, one can expect that the 12% will be reasonably respected given that the J/ψ and ψ' wavefunctions are normal $\mathrm{c}\bar{\mathrm{c}}$ of $(1S)$ and $(2S)$, respectively, and no significant interferences from other processes. As shown in Table 1, one indeed sees that the 12% rule is satisfied though the experimental values still have large uncertainties. There might be contributions from strong isospin-violating transitions. However, the present experimental results suggest that their interferences with the EM transitions in the isospin-violating channel are relatively small.

Table 1. Branching ratio fractions of $\psi' \to \gamma^* \to \mathrm{VP}$ over $\mathrm{J}/\psi \to \gamma^* \to \mathrm{VP}$ for those isospin-violating channels. Here, we only show results with MP-C form factor. The last column is extracted from the experimental date [2].

decay channels	$R^{\mathrm{VP}}(\%)$	Exp.data (%)
ρη	8.97	11.5 ± 5.0
ρη′	9.44	23.5 ± 17.8
ωπ	9.01	5.0 ± 1.8
φπ	7.41	<62.5

3 Step 2: Parameterize the strong decay transitions

For those isospin-conserved decays, i.e. $\mathrm{J}/\psi(\psi') \to \omega\eta$, $\omega\eta'$, $\phi\eta$, $\phi\eta'$, ρπ and $\mathrm{K}^*\bar{\mathrm{K}}+\mathrm{c.c.}$, the strong and EM decay processes are mixed. Recalling that the antisymmetric tensor form is the only coupling for VVP, we thus parameterize the strong decays in a way similar to Refs. [21–24]. Some basic quantities can be defined via Fig. 2: the strength of non-strange singly OZI disconnected process $g_{\mathrm{J}/\psi}$; the parameter reflecting the $SU(3)$ flavor symmetry breaking effects R, and the parameter r describing the relative strength between the DOZI and SOZI transitions. The expressions for the parameterized strong decay amplitudes are listed in Table 2.

Table 2. General expressions for the transition amplitudes for $\mathrm{J}/\psi(\psi') \to \mathrm{VP}$ via strong interactions. Parameter $g_{\mathrm{J}/\psi}$ and $g_{\psi'}$ are proportional to the charmonium wavefunctions at origin and have different values for J/ψ and ψ′, respectively. For η and η′, a glueball mixing is also considered in the wavefunctions.

decay channels	transition amplitude $\mathcal{M}=(\mathcal{M}_1+\mathcal{M}_2+\mathcal{M}_3)$
φη	$g_{\mathrm{J}/\psi(\psi')}R[\sqrt{2}rx_1+R(1+r)y_1+z_1]\mathcal{F}(\boldsymbol{P})$
φη′	$g_{\mathrm{J}/\psi(\psi')}R[\sqrt{2}rx_2+R(1+r)y_2+z_2]\mathcal{F}(\boldsymbol{P})$
ωη	$g_{\mathrm{J}/\psi(\psi')}[(1+2r)x_1+\sqrt{2}Rry_1+\sqrt{2}z_1]\mathcal{F}(\boldsymbol{P})$
ωη′	$g_{\mathrm{J}/\psi(\psi')}[(1+2r)x_2+\sqrt{2}Rry_2+\sqrt{2}z_2]\mathcal{F}(\boldsymbol{P})$
$\rho^0\pi^0$	$g_{\mathrm{J}/\psi(\psi')}\mathcal{F}(\boldsymbol{P})$
$\rho^+\pi^-$ or $\rho^-\pi^+$	$g_{\mathrm{J}/\psi(\psi')}\mathcal{F}(\boldsymbol{P})$
$\mathrm{K}^{*0}\bar{\mathrm{K}}^0$ or $\bar{\mathrm{K}}^{*0}\mathrm{K}^0$	$g_{\mathrm{J}/\psi(\psi')}R\mathcal{F}(\boldsymbol{P})$
$\mathrm{K}^{*+}\mathrm{K}^-$ or $\mathrm{K}^{*-}\mathrm{K}^+$	$g_{\mathrm{J}/\psi(\psi')}R\mathcal{F}(\boldsymbol{P})$

In Ref. [25], different treatments for glueball-$q\bar{q}$ mixing are investigated, which are denoted by Schemes I, II, III. Since the glueball components in η and η′ are rather small, the mixing effects will not change out results on the strong decays of $\mathrm{J}/\psi(\psi') \to \mathrm{VP}$. Details about the parameter definitions and mixings can be found in Ref. [25].

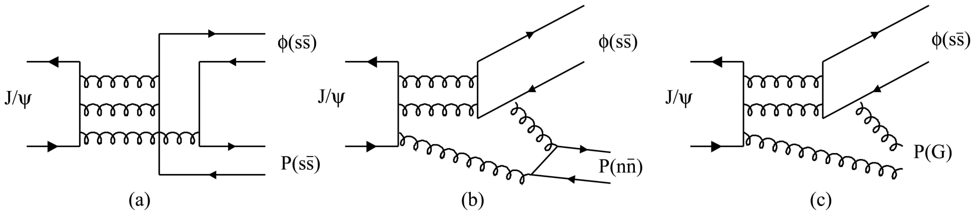

Fig. 2. Schematic diagrams for $\mathrm{J}/\psi \to \phi\mathrm{P}$ via strong interaction, where the production of different components of the pseudoscalar P is demonstrated via (a) SOZI process; (b) DOZI process; and (c) glueball production. Similar processes apply to other VP channels as described in the text.

In order to take into account the size effects from the spatial wavefunctions of the initial and final-state mesons, we apply the commonly used form factor

$$\mathcal{F}^2(\boldsymbol{P}) \equiv |\boldsymbol{P}|^{2l}\exp(-\boldsymbol{P}^2/8\beta^2), \tag{7}$$

where $\boldsymbol{P}$ and the l are the three momentum and the relative orbit angular momentum of the final-state mesons, respectively, in the $\mathrm{J}/\psi(\psi')$ rest frame. We adopt $\beta=0.5$ GeV, which is the same as Refs. [26–29].

In Table 3, we list the values of the strong coupling strengths $g_{\mathrm{J}/\psi}$ and $g_{\psi'}$ which are extracted by overall fittings to the isospin-conserved decay channels of $\mathrm{J}/\psi(\psi') \to \mathrm{VP}$ data including the EM transitions determined in the previous section. The predominant feature is that both values are stable and insensitive to the η-η′-glueball mixing schemes. In case of the absence of the EM contributions, the "12% rule" fraction should be proportional to $(g_{\mathrm{J}/\psi}/g_{\psi'})^2$. By taking the average of the squared values of Table 3, we obtain $(g_{\mathrm{J}/\psi}/g_{\psi'})^2 \approx 1.8\%$ which is much less than the expectation of the “12% rule”, but larger than the experimental data, $\sim(0.2\pm0.1)\%$.

Table 3. Extracted coupling strengths for the SOZI transitions for three different η-η′-glueball mixing schemes with a constructive mode for the EM amplitudes [25].

	$g_{J/\psi}(\times10^{-3})$	$g_{\psi'}(\times10^{-3})$
Scheme- I	18.66 ± 0.63	2.22 ± 0.49
Scheme- II	18.45 ± 0.70	2.54 ± 0.44
Scheme-III	17.52 ± 0.66	2.57 ± 0.42

This is not at all a trivial outcome. Several points can be learned here: i) The suppression to the ψ′ strong decay coupling is not exclusively on $\psi'\to\rho\pi$. Such a suppression is an overall effect on all the exclusive decays. ii) Due to the suppression on the strong decay coupling of the ψ′, the EM transition amplitudes become compatible with the strong decay amplitudes with which the interferences produce deviations from naive expectations based on single transition mechanism. To be more specific, due to the interference, the ρπ decay is further suppressed, i.e. causes the so-called “ρπ puzzle”. The neutral $K^{*0}\bar{K}^0+c.c.$ has larger branching ratio than the charged one $K^{*+}K^-+c.c.$ [2]. iii) As shown in Fig. 2, the DOZI transitions contribute to the isoscalar channels. This suggests that the exclusive decays have different features compared with the inclusive one from which the “12% rule” is embedded.

In Table 4, we list the branching ratio fractions for those isospin-conserved channels and compare them with the experimental data. Within the experimental uncertainties, our results are in good agreement with the data. We also show the branching ratio fractions for exclusive EM transitions, and again, one can see that the “12% rule” is reasonably respected for exclusive transitions.

Table 4. Branching ratio fractions for $\psi'\to\gamma^*\to VP$ over $J/\psi\to\gamma^*\to VP$ for different η-η′-glueball with a MP-C form factor. R^{VP} denotes the ratios with exclusive EM transitions. The last column is extracted from the experimental date [2]. The stars “***” in $\rho^0\pi^0$ channel denotes the unavailability of the data.

decay channels	$R^{VP}(\%)$	scheme I (%)	scheme II (%)	scheme III(%)	Exp. data (%)
$\rho^0\pi^0$	8	0.12	0.16	0.20	***
ρπ	8	0.12	0.15	0.19	0.2 ± 0.1
ωη	8	0.40	0.35	0.28	$<0.6\pm0.1$
ωη′	8	5.33	0.11	0.29	18.5 ± 13.2
ϕη	10	2.78	2.93	3.30	4.1 ± 1.6
ϕη′	10	5.00	5.34	8.86	8.7 ± 5.5
$K^{*+}K^-+c.c.$	9	0.45	0.41	0.39	0.4 ± 0.2
$K^{*0}K^0+c.c.$	9	2.74	2.79	2.67	2.7 ± 0.7

In brief, the parametrization identifies the mechanism which not only causes puzzle in ρπ channel, but also plays a role in other VP channels. since the EM transitions in ρπ and $K^*\bar{K}$+c.c. are relatively large due to large couplings for ργ and K*Kγ, interferences between the suppressed strong decay amplitudes and enhanced EM amplitudes produce significant deviations from the expectation of “12% rule” [25, 30].

4 Step 3: Mechanism suppressing the strong decay amplitudes of $\psi'\to VP$

Now, the last bit of the whole scenario comes to the point, “Why, and how the strong decay coupling $g_{\psi'}$ is suppressed?” In order to demonstrate this, we express the decay amplitudes as

$$\begin{aligned}\mathcal{M}_{J/\psi} &= \frac{1}{M_{J/\psi}}\left(g_{J/\psi}+g^{em}_{J/\psi}e^{i\delta_{J/\psi}}\right)\times\\ &\qquad \epsilon_{\mu\nu\alpha\beta}\,\partial^\mu V^\nu_{J/\psi}\,\partial^\alpha V^\beta_2 P\ ,\\ \mathcal{M}_{\psi'} &= \frac{1}{M_{\psi'}}\left(g_{\psi'}+g^{em}_{\psi'}e^{i\delta_{\psi'}}\right)\epsilon_{\mu\nu\alpha\beta}\,\partial^\mu V^\nu_{\psi'}\,\partial^\alpha V^\beta_2 P\ ,\end{aligned} \tag{8}$$

which again benefits from the property of the antisymmetric tensor coupling among VVP fields. In the above equation, $g_{J/\psi}$ and $g_{\psi'}$ are real numbers fixed by Step 2 [25], while $g^{em}_{J/\psi}$ and $g^{em}_{\psi'}$ are the EM couplings fixed by Step 1 with relative phase angles $\delta_{J/\psi}$ and $\delta_{\psi'}$ fixed in Step 2. Detailed discussions on the phase angles can be found in Ref. [25], of which the values can be compared with those from Ref. [31].

Since any possible mechanism must contribute to the coupling, we can decompose the strong couplings as

$$
\begin{aligned}
g_{\mathrm{J}/\psi} &\equiv g_{\mathrm{J}/\psi}^{\mathrm{pQCD}}+g_{\mathrm{J}/\psi}^{\mathrm{loop}}\equiv g_{\mathrm{J}/\psi}^{\mathrm{pQCD}}(1+q_{\mathrm{J}/\psi}) \ , \\
g_{\psi'} &\equiv g_{\psi'}^{\mathrm{pQCD}}+g_{\psi'}^{\mathrm{loop}}\equiv g_{\psi'}^{\mathrm{pQCD}}(1+q_{\psi'}) \ , \qquad (9)
\end{aligned}
$$

where $g_{\mathrm{J}/\psi}^{\mathrm{pQCD}}$ and $g_{\psi'}^{\mathrm{pQCD}}$ are couplings given by pQCD power counting, while $g_{\mathrm{J}/\psi}^{\mathrm{loop}}$ and $g_{\psi'}^{\mathrm{loop}}$ are given by an additional mechanism due to intermediate meson loop transitions; quantities $q_{\mathrm{J}/\psi}$ and $q_{\psi'}$ are the ratios of those two couplings for J/ψ and ψ′, respectively. Qualitatively, suppression of the $g_{\psi'}$ coupling implies that there exist large cancelations between $g_{\psi'}^{\mathrm{pQCD}}$ and $g_{\psi'}^{\mathrm{loop}}$ while in J/ψ decays effects from $g_{\mathrm{J}/\psi}^{\mathrm{loop}}$ may not be significant.

Quantitative results supporting this require an explicit calculation of both $g_{\mathrm{J}/\psi}^{\mathrm{pQCD}}$ and $g_{\psi'}^{\mathrm{pQCD}}$, for which QCD models have been pursued in the literature. More or less, they respect the “12% rule” since they probe the charmonium wavefunctions at origin. The inclusion of intermediate meson loop transitions will introduce corrections to the couplings via the non-vanishing $q_{\mathrm{J}/\psi}$ and $q_{\psi'}$ in Eq. (9). It is worth noting that the couplings from the IML can be different for different decay channels. In particular, for ρπ channel, it turns that $|q_{\mathrm{J}/\psi}|<|q_{\psi'}|$.

This relation again is not trivial at all. It further narrows down the mechanism that causes the deviations from the pQCD power counting, and also put a constraint on its behavior. As follows, instead of providing detailed calculations for the loops, we summarize the main features about the intermediate meson loop transitions and detailed numerical results will be reported later [32]:

Ⅰ) Since both J/ψ and ψ′ are below the open charm threshold, the intermediate meson loops will contribute to the real part of the couplings. This feature not only justifies the parametrization scheme in Step 2, but also makes the decomposition of the strong couplings in Eq. (9) physically meaningful.

Ⅱ) Since the ψ′ has a mass which is closer to the open $D\bar{D}$ threshold, its amplitude via the $D\bar{D}$ loop will be qualitatively larger than J/ψ due to near-threshold effects.

Ⅲ) Similar behavior due to intermediate $D\bar{D}(D^*)$ and $D\bar{D}^*(D)$ loops also shows up in a coherent study of J/ψ and $\psi'\to\gamma\eta_c$ and $\psi'\to\gamma\eta_c'$ [33].

Ⅳ) Light intermediate meson loops are strongly suppressed due to large off-shell effects.

These features are consistent with a recent study of the “unquenched” effects arising from meson loops in Ref. [34], where it was shown that the intermediate meson loops still play an important role within charmonium states below the $D\bar{D}$ open threshold.

5 Summary

In this proceeding, we carry out a systematic analysis of the problem of “ρπ puzzle”, and clarify it on a more general ground. We show that the EM transitions play an important role in understanding the underlying mechanisms, which can be constrained by the isospin-violating channels. It thus allows us to separate out the EM amplitudes in those isospin-conserved channels.

The nature of the VVP coupling as an antisymmetric tensor is also a key for disentangling the problem since whatever the mechanisms are for the transition, their contributions will simply be a correction to the coupling form factor. This allows a parametrization for the strong decay transitions in $\mathrm{J}/\psi(\psi')\to\mathrm{VP}$. The result shows that there exists an overall suppression on the strong decay amplitudes for $\psi'\to\mathrm{VP}$. Because of such a suppression, the strong decay amplitudes in some of those channels, such as ρπ and $K^*\bar{K}+\mathrm{c.c.}$, become compatible with the EM transition amplitudes, with which the interferences produce significant deviations from the expectation of pQCD power counting rule. We then identify that the suppression on the strong decay amplitudes is originated from intermediate meson loop transitions, such as $D\bar{D}(D^*)$, etc. In particular, the ψ′ is closer to the open $D\bar{D}$ threshold than J/ψ. As a result, it will experience much larger threshold effects, and in this case a destructive interference.

Such effects should be more general, hence may show up in other decay channels. We point out that a larger intermediate meson loop contribution originated from the same mechanism is also found in the study of $\mathrm{J}/\psi(\psi')\to\gamma\eta_c$ and $\psi'\to\gamma\eta_c'$ as an important mechanism interfering with the NRQCD leading amplitudes [33]. Nevertheless, the study of “unquenched” effects in the charmonium spectrum also gives rise to the importance of the intermediate meson loops [34].

In brief, we clarify that the “ρπ puzzle” is not a single problem with the ρπ channel. Instead, it is a rather general observation for all decay channels of $\mathrm{J}/\psi(\psi')\to\mathrm{VP}$. In exclusive decays, multi-mechanisms can easily break down the pQCD power counting due to interference. In this sense, the so-called “ρπ puzzle” should not be surprising. It turns to be more interesting to us that the systematics arising from a coherent study of all those VP decay channels can provide us with much deeper insights into the underlying dynamics. We expect that more precise measurement of those isospin-violating decay branching ratios at BESIII will help solve this long-standing problem [35, 36].

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