\( \Upsilon(nl) \) decay into \( B^{(*)}\bar{B}^{(*)} \)

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We have evaluated the decay modes of the \( \Upsilon(4s), \Upsilon(3d), \Upsilon(5s), \Upsilon(6s) \) states into \( B\bar{B}, B\bar{B}^* + c.c., B^*\bar{B}^* + c.c., B_i^*\bar{B}_i^* \) using the \( ^3P_0 \) model to hadronize the \( b\bar{b} \) vector seed, fitting some parameters to the data. We observe that the \( \Upsilon(4s) \) state has an abnormally large amount of meson-meson components in the wave function, while the other states are largely \( b\bar{b} \). We predict branching ratios for the different decay channels which can be contrasted with experiment for the case of the \( \Upsilon(5s) \) state. While globally the agreement is fair, we call the attention to some disagreement that could be a warning for the existence of more elaborate components in the state.

I. INTRODUCTION

The vector \( \Upsilon(nl) \) states are a good example to test quark models with \( b\bar{b} \). The large mass of the \( b \) quark makes them excellent nonrelativistic systems and the theoretical predictions [1] agree well with experiment, at least for the first states, with discrepancies in the mass of only a few MeV. There are many variants of the \( b\bar{b} \) quark model [2–6], producing again similar results for the lowest states and larger discrepancies for the higher excited states. A more complete view can be obtained from Ref. [7]. In particular, discussions on non \( b\bar{b} \) configurations for higher excited states are on going. More concretely, problems stem from the states which can decay into \( B^{(*)}\bar{B}^{(*)} \), starting from the \( \Upsilon(4s) \). In Table I we show predictions for masses of these states and current PDG [8] values.

| State | Ref. [1] | Ref. [6] | PDG |
|-------|---------|---------|-----|
| 4s    | 10630   | 10608   | 10579 |
| 3d    | 10700   | 10682   | 10753 [9] |
| 5s    | 10880   | 10840   | 10889 |
| 4d    | 10899   |         |       |
| 6s    | 11100   |         | 10993 |

The \( \Upsilon(3d) \) state, reported recently by the Belle collaboration with mass 10753 MeV, is close to the quark model predictions (see Table I). Yet, claims that this state could be a tetraquark state are made in Ref. [10]. Similarly, the \( \Upsilon(5s) \) state is questioned as a pure \( b\bar{b} \) state in base to the \( \pi^+\pi^-\Upsilon(nl') \) decay rates, and a mixture of \( \Upsilon(5s) \) plus the lowest \( 1^{--} \) hybrid state [11] is invoked in Ref. [12]. Surprisingly, even if the \( B^{(*)}\bar{B}^{(*)} \) decay modes are open for the states above the \( \Upsilon(4s) \), no theoretical works on these decay modes, nor the role of the meson-meson components in the \( \Upsilon \) states, are available (but there is some work done on the \( B^{(*)}\bar{B}^{(*)}\pi \) decay [13]). The closest work would be the ratios predicted for \( e^+e^- \to B\bar{B}, e^+e^- \to B\bar{B}^* + c.c. \) and \( e^+e^- \to B^*\bar{B}^* + c.c. \) cross sections using heavy quark spin symmetry in Refs. [14, 15], but, as mentioned in Ref. [16], these predictions are in conflict with experiment and it was blamed on the proximity of quarkonium resonances to thresholds of these channels, suggesting the mixture of the \( \Upsilon(nl) \) states with some meson-meson component to solve this conflict [16]. In the present work we address these problems for the \( 4s, 3d, 5s, 6s \) states, for which there are experimental data.

II. FORMALISM

We follow here the formalism used in Refs. [17, 18]. For this we use the \( ^3P_0 \) model to hadronize the \( b\bar{b} \) vector state and generate two \( B^{(*)}\bar{B}^{(*)} \) mesons, as shown in Fig. 1, creating a flavor-scalar state with the quantum numbers of the vacuum.

![FIG. 1. Hadronization of \( b\bar{b} \).](image)

We consider only \( \bar{u}u + \bar{d}d + \bar{s}s \) since the \( \bar{c}c, \bar{b}b \) components give rise to meson-meson states too far away in energy to be relevant in the process. If we write the \( q\bar{q} \)
matrix, \( M \), with the \( u, d, s, c \) quarks we have
\[
M = (q \bar{q}) = \begin{pmatrix}
\bar{u}u & \bar{u}d & \bar{u}s & \bar{u}c \\
\bar{d}u & \bar{d}d & \bar{d}s & \bar{d}c \\
\bar{s}u & \bar{s}d & \bar{s}s & \bar{s}c \\
\bar{c}u & \bar{c}d & \bar{c}s & \bar{c}c
\end{pmatrix}, \tag{1}
\]
and then, after hadronization we find
\[
b \bar{b} \rightarrow \sum_{i=1}^{3} b_i q_i \bar{b} = \sum_{i=1}^{3} M_{4i} M_{i4}. \tag{2}
\]
If we write \( M_{4i} M_{i4} \) in terms of the \( B, B^* \) mesons, we find the combinations
\[
\begin{align*}
B^- B^+ + \bar{B}^0 B^0 + \bar{B}^0 B^0, \\
B^- B^+ + B^0 B^0 + \bar{B}^0 B^0, \\
B^- B^+ + \bar{B}^0 B^0 + \bar{B}^0 B^0, \\
B^- B^+ + B^0 B^0 + B^0 B^0.
\end{align*} \tag{3}
\]
The next step is to see the relationship of the production modes of these four combinations \( PP, PV, VP, VV \) (\( P \) pseudoscalar, \( V \) vector) and for this we use the \( 3P_0 \) model \[19, 20\]. The details of the angular momentum algebra involved are shown in Ref. \[17\], and relative weights for \( PP, PV, VP, VV \) production are obtained to which we shall come back below.

The formalism that we follow relies on the use of the vector propagator which is dressed including the selfenergy due to \( B^{(s)} \bar{B}^{(s)} \) production, as shown in Fig. 2.

![Fig. 2. Selfenergy diagram of the \( \Upsilon \) accounting for \( ii' \equiv B^{(s)} \bar{B}^{(s)} \) intermediate states.](image)

The renormalized vector meson propagator is written as
\[
D_R = \frac{1}{p^2 - M^2_R - \Pi(p)}, \tag{4}
\]
where the selfenergy \( \Pi(p) \) is given by
\[
-i \Pi(p) = \int \frac{d^4q}{(2\pi)^4} \left(-i\right) V_1 (-i) V_2 \frac{i}{q^2 - m^2_{B_i} + i\epsilon} \times \frac{i}{(p-q)^2 - m^2_{B_i' + i\epsilon} + i\epsilon} F^2(q), \tag{5}
\]
and the vertex for \( \Upsilon B_i B_i' \) is of the type
\[
V_R, B_i B_i' = A g_{R_i} |q|, \tag{6}
\]
where \( A \) is an arbitrary constant to be fitted to the data and \( g_{R_i} \) are weights for the different \( B_i B_i' \) states which are evaluated using the \( 3P_0 \) model in Ref. \[17\]. Eq. (6) is an effective vertex which takes into account the sum over polarizations of the vectors in the \( \Pi \) loop in Fig. 2. For a given channel \( B_i B_i' \) the selfenergy is then given by
\[
\Pi_i(p) = i g_{R_i}^2 A^2 \int \frac{d^4q}{(2\pi)^4} q^2 \frac{1}{q^2 - m^2_{B_i} + i\epsilon} \times \frac{1}{(p-q)^2 - m^2_{B_i' + i\epsilon} + i\epsilon} F^2(q), \tag{7}
\]
where the coefficients \( g_{R_i} \) are evaluated with the \( 3P_0 \) model in Ref. \[17\]. The \( q^0 \) integration is done analytically and we find
\[
\Pi(p^0) = A^2 \sum_i g_{R_i}^2 \tilde{G}_i(p^0), \tag{8}
\]
where
\[
\tilde{G}_i(p^0) = \int \frac{dq}{(2\pi)^2} \frac{w_1(q) + w_2(q)}{w_1(q) w_2(q)} \times \frac{q^4}{(p^0)^2 - [w_1(q) + w_2(q)]^2 + i\epsilon} F^2(q), \tag{9}
\]
where \( w_i(q) = \sqrt{m_i^2 + q^2} \) and \( F(q) \) is a form factor that, inspired upon the Blatt-Weisskopf barrier penetration factor \[21\], we take of the type of Ref. \[17\] \((p^0 = \sqrt{s}), \)
\[
F^2(q) = \frac{1 + \left(R q_{on}\right)^2}{1 + (R q)^2}, \quad q_{on} = \frac{\lambda^{1/2}(s, m_1^2, m_2^2)}{2\sqrt{s}}, \tag{10}
\]
with \( q_{on} \) taken zero below threshold, and \( R \) a parameter to be fitted to data.

In order to have a pole at \( M_R \), we define
\[
\Pi'(p) = \Pi(p) - \text{Re}\Pi(M_R), \tag{11}
\]
which renders \( \Pi'(p) \) convergent and then we have the \( \Upsilon \) propagator as
\[
D_R(p) = \frac{1}{p^2 - M^2_R - \Pi'(p)}. \tag{12}
\]
According to Refs. \[17, 22\] the cross section for \( e^+ e^- \rightarrow R \rightarrow \sum_i B_i B_i' \) is given by
\[
\sigma = -f_{R}^2 \text{Im} D_R(p), \tag{13}
\]
and the individual cross section to each channel
\[
\sigma_i = -f_{R_i}^2 \frac{\text{Im}\Pi_i(p)}{|p^2 - M^2_R - \text{Re}\Pi'(p)|^2 + |\text{Im}\Pi(p)|^2}. \tag{14}
\]
It is customary to make an expansion of \( \Pi' \) in Eq. (12) around the resonance mass as
\[
D_R(p) \approx \frac{1}{p^2 - M^2_R - (p^2 - M^2_R) \frac{\partial\text{Re}\Pi(p)}{\partial p^2}|_{p^2=M^2_R} - i\text{Im}\Pi(p)} \approx \frac{Z}{p^2 - M^2_R - iZ \text{Im}\Pi(p)}, \tag{15}
\]
where
with

\[ Z = \frac{1}{1 - \frac{\partial \text{Re} \Pi(p)}{\partial p^2} |_{p^2 = M_R^2}}, \]  

and then the width of the resonance is given by

\[ \Gamma = -\frac{1}{M_R} Z \text{Im} \Pi(p) |_{p^2 = M_R^2}, \]  

and for each individual channel

\[ \Gamma_i = -\frac{1}{M_R} Z \text{Im} \Pi_i(p) |_{p^2 = M_R^2}. \]  

The value of \( Z \) provides the strength of the \( \Upsilon \) vector component (not to be associated to a probability when there are open channels \([17, 23]\)). We shall see that for the \( \Upsilon(4s) \) state the \( Z \) value is relatively different from 1, indicating the importance of the weight of the \( B_i \overline{B}_i \) channels in the state. If \( Z \) is close to 1 we can make a series expansion of \( Z \) in Eq. (16)

\[ Z \approx 1 + \frac{\partial \text{Re} \Pi(p)}{\partial p^2} |_{p^2 = M_R^2} = 1 + \sum_i \frac{\partial \text{Re} \Pi_i(p)}{\partial p^2} |_{p^2 = M_R^2}, \]  

such that each individual value

\[ P_i = -\frac{\partial \text{Re} \Pi_i(p)}{\partial p^2} |_{p^2 = M_R^2} \]  

can be interpreted as the weight of each meson-meson component in the \( \Upsilon \) wave function (see Ref. [23] for the precise interpretation of this quantity, that gives an idea of the weight of each component but cannot be identified with a probability).

The values of the couplings \( g_{Ri} \), obtained from the \( ^3P_0 \) model are given by Refs. [17, 18] as \( g_{Ri}^2 = \frac{1}{12} \left( \frac{1}{12} \right) \) for each of the \( B_i \overline{B}_i \) states of Eq. (3) for \( \Upsilon \) in s-wave (d-wave), \( g_{Ri}^2 = \frac{1}{6} \left( \frac{1}{220} \right) \) for each of the \( B_i \overline{B}_i^*, B_i^* \overline{B}_i \) in s-wave (d-wave), \( g_{Ri}^2 = \frac{1}{12} \left( \frac{1}{220} \right) \) for each of the \( B_i^* \overline{B}_i^* \) in s-wave (d-wave).

### III. RESULTS

The strategy is to fit the parameters \( A, R \) to the shape of the \( e^+e^- \rightarrow \Upsilon(4s) \rightarrow B\overline{B} \) cross section, Eq. (14). The parameter \( f_R \) is irrelevant for the shape. We also fine tune the value of \( M_R \) around the nominal value of the PDG. Then we take the same value of \( R \), which gives a range of the momentum distribution of the internal meson-meson components, and the parameter \( A \) will be adjusted to the width of each of the other states.

### A. \( \Upsilon(4s) \) state

In Fig. 3, we show the data of Ref. [24] for \( e^+e^- \rightarrow \Upsilon(4s) \rightarrow B\overline{B} \), together with a fit to these data that renders the parameters:

\[ M_R = 10586 \text{ MeV}, \quad R = 0.0058 \text{ MeV}^{-1}, \quad A^2 = 13500. \]  

In Table II we show the values of \( -\frac{\partial \Pi(p)}{\partial p^2} |_{p^2 = M_R^2} \) for each channel and the value of \( Z \). As we can see, the value of \( Z \) is 0.687, which still tells us that the strength of the vector component is the largest, but the strength of the meson-meson components is relatively large. The width of the state is \( \Gamma = 20.5 \pm 2.5 \text{ MeV} \) [8], quite large compared to that of the other \( \Upsilon \) states in spite of the limited phase space for the only open channel \( BB \). This feature is what demands a large value of \( A \) that translates into a large fraction of the meson-meson components in the \( \Upsilon \) wave function. From Fig. 3, we obtain \( \Gamma \sim 24 \text{ MeV} \), similar to the value quoted in the PDG [8], and a value around 30 MeV using Eq. (17). More important than these numbers is that we fit the \( BB \) data from BaBar [24]. We can use Eqs. (17) and (18) to get branching ratios and we obtain the results shown in Table III. The good width is a consequence of the fit and the branching ratios, in agreement with experiment, are a consequence of the different phase space for \( B^+B^- \) and \( B^0\overline{B}^0 \), due to their different masses.
We take the PDG mass 10752.7 MeV and fit the width of $\Gamma = 35.5$ MeV and obtain the only free parameter

$$A^2 = 120,$$

with this input we look at the weights for the different channels and we find the results of Table IV. Interestingly, we find now that the value of $Z$ is very close to 1 and the weight of the meson-meson components very small. We could be surprised that $Z$ is bigger than 1 and the individual meson-meson weights for the open channels are complex and have negative real part. This is a consequence of the fact that these weights cannot be interpreted as probabilities. Indeed, as discussed in [20], the individual meson-meson weights correspond to the integral of the wave function squared with a certain phase prescription (not modulus squared), which for the open channels is complex. Even then, this magnitude measures the strength of the meson-meson components and the message from these results is that this strength is small and the $\Upsilon$ remains largely as the original $b\bar{b}$ component.

Similarly, in Table V we show the branching ratios obtained for each channel, for which there are no experimental data. It is remarkable the large strength for $B^*\bar{B}^*$ production in spite of its smaller phase space relative to $BB$ or $BB^* + c.c.$.

### Table III. Branching ratios for $\Upsilon(4s)$ decay.

| Channel     | BR|_{Theo} | BR|_{Exp.} |
|-------------|---------|---------|
| $B^0\bar{B}^0$ | 48.9%   | (48.6 ± 0.6)% |
| $B^+\bar{B}^-$ | 51.1%   | (51.4 ± 0.6)% |

### Table IV. Values of $-\frac{\partial R}{\partial p^2}|_{p^2=M_B^2}$ for the different channels and the value of $Z$ for $\Upsilon(3d)$ state.

| Channel      | $-\frac{\partial R}{\partial p^2}|_{p^2=M_B^2}$ | $Z$ |
|--------------|-----------------|------|
| $B^0\bar{B}^0$ | $-0.005 + 0.005i$ |     |
| $B^+\bar{B}^-$ | $-0.005 + 0.005i$ |     |
| $B^0\bar{B}^{*0} + c.c.$ | $-0.003 + 0.004i$ |     |
| $B^+\bar{B}^{*+} + c.c.$ | $-0.003 + 0.004i$ |     |
| $B^{*0}\bar{B}^0$ | $-0.017 + 0.029i$ |     |
| $B^{*+}\bar{B}^{*-}$ | $-0.017 + 0.029i$ |     |
| $B^{*0}\bar{B}^{*0}$ | $-0.001 + 0.002i$ |     |
| $B^{*+}\bar{B}^{*-} + c.c.$ | 0.001 |     |
| $B^{*0}\bar{B}^{*0} + c.c.$ | 0.001 |     |
| $B^{*+}\bar{B}^{*-}$ | 0.001 |     |

**Total** $-0.050 + 0.078i$ 1.056

### Table V. Branching ratios of $\Upsilon(3d)$ decaying to different channels.

| Channel     | BR|_{Theo} | BR|_{Exp.} |
|-------------|---------|---------|
| $BB$        | 21.3%   |        |
| $BB^* + c.c.$ | 14.3%   |        |
| $B^*\bar{B}^*$ | 64.1%   |        |
| $B_s\bar{B}_s$ | 0.3%    |        |

### Table VI. Values of $-\frac{\partial R}{\partial p^2}|_{p^2=M_B^2}$ for the different channels and the value of $Z$ for $\Upsilon(5s)$ state.

| Channel      | $-\frac{\partial R}{\partial p^2}|_{p^2=M_B^2}$ | $Z$ |
|--------------|-----------------|------|
| $B^0\bar{B}^0$ | $-0.003 + 0.002i$ |     |
| $B^+\bar{B}^-$ | $-0.003 + 0.002i$ |     |
| $B^0\bar{B}^{*0} + c.c.$ | $-0.009 + 0.006i$ |     |
| $B^+\bar{B}^{*+} + c.c.$ | $-0.009 + 0.006i$ |     |
| $B^{*0}\bar{B}^0$ | $-0.012 + 0.010i$ |     |
| $B^{*+}\bar{B}^{*-}$ | $-0.012 + 0.010i$ |     |
| $B^{*0}\bar{B}^{*0}$ | $-0.001 + 0.001i$ |     |
| $B^{*+}\bar{B}^{*-} + c.c.$ | $-0.002 + 0.004i$ |     |
| $B^{*0}\bar{B}^{*0} + c.c.$ | $-0.002 + 0.006i$ |     |

**Total** $-0.053 + 0.044i$ 1.056

### Table VII. Branching ratios for different channels for $\Upsilon(5s)$.

| Channel     | BR|_{Theo} | BR|_{Exp.} |
|-------------|---------|---------|
| $BB$        | 8.5%    | (5.5 ± 1)% |
| $BB^* + c.c.$ | 27.4%   | (13.2 ± 1.6)% |
| $B^*\bar{B}^*$ | 37.2%   | (38.1 ± 3.4)% |
| $B_s\bar{B}_s$ | 1.4%    | (5 ± 5) × 10^{-3} |
| $B_s\bar{B}_s^* + c.c.$ | 3.2%    | (1.35 ± 0.32)% |
| $B_s^*\bar{B}_s^*$ | 2.3%    | (17.6 ± 2.7)% |

**Total** 80.0% 81.25%

We take the nominal PDG mass $M_B = 10889.9$ MeV and fit $A$ to get the 80% of the width of 51 MeV. We obtain

$$A^2 = 31.5.$$

The weights of the meson-meson components and the value of $Z$ are shown in Table VI. Once again we find that $Z$ is very close to 1 and the weights of the meson-meson components are very small. In Table VII we show the branching ratios that we obtain for the different channels and in this case we can compare with the experimental values. Globally, the branching ratios obtained agree in a fair way with experiment. We confirm the small $B\bar{B}$ branching fraction, in spite of the largest phase space,
TABLE VIII. Values of $\frac{\partial R}{\partial m_{|p^2=M^2_R}}$ for different channels and the value of Z for $\Upsilon(6s)$ state.

| Channel          | $\frac{\partial R}{\partial m_{|p^2=M^2_R}}$ | Z  |
|------------------|---------------------------------------------|----|
| $B^* B^*$        | -0.004 + 0.001i                             |    |
| $B^* B^-$        | -0.004 + 0.001i                             |    |
| $B^0 B^{*0} + c.c.$ | -0.011 + 0.004i                           |    |
| $B^+ B^{*-} + c.c.$ | -0.011 + 0.004i                           |    |
| $B^{*0} B^{*0}$  | -0.015 + 0.007i                             |    |
| $B^{*+} B^{*-}$  | -0.015 + 0.007i                             |    |
| $B^0 s B^{*0} + c.c.$ | -0.004 + 0.003i                           |    |
| $B^* s B^*$      | -0.005 + 0.005i                             |    |
| Total            | -0.069 + 0.035i                             | 1.075 |

The weights of the different components and the value of Z are shown in Table VIII. Once again we see that the value of Z is very close to 1 and the weight of the meson-meson components very small. In Table IX we show the branching ratios assuming that the width is exhausted by the $B_s B_s'$ channels. We should nevertheless mention that the proximity of the $B B_s$(5721) threshold at 11000 MeV to the mass of this resonance could have some effect on the selfenergy $\Pi$. However, if the channel is closed for decay it can affect Re$\Pi$ but not the individual Im$\Pi_i$ for the open channels needed in the evaluation of the individual decay rates that we have calculated. It will be interesting to compare our results with data when they become available.

D. $\Upsilon(6s)$ state

We take again the PDG mass of $M_R = 10992.9^{+10.0}_{-3.1}$ MeV and the width of 49$^{+95}_{-15}$ MeV and make a fit to the width, assuming that all of it comes from the $B_s B_s'$ decay channels (there is no information on these decay channels in the PDG). We obtain

$$A^2 = 21.$$ 

The IV. CONCLUSIONS

We have studied the $B B$, $B B^* + c.c.$, $B^* B^*$, $B_s B_s$, $B_s B_{s'} + c.c.$, $B^*_s B^*_{s'}$ decay modes of the $\Upsilon(4s)$, $\Upsilon(3d)$, $\Upsilon(5s)$, $\Upsilon(6s)$ states using the $^3P_0$ model to produce two mesons from the original $b\bar{b}$ vector state. We observed interesting things. The first one is that the $\Upsilon(4s)$ state has an abnormally large width that has as a consequence that the state contains a relatively large admixture of meson-meson components in its wave function. It is one exception to the general rule for vector mesons which are largely $q\bar{q}$ states [25]. On the other hand, the other three states studied had very small meson-meson components and the states remain largely in the original $b\bar{b}$ seed.

We could only test predictions on branching ratios for the $\Upsilon(4s)$ and $\Upsilon(5s)$ states. In the first case only the $B B$ channel is open and the branching ratios for $B^+ B^-$ and $B^0 B^{*0}$ are determined by phase space in agreement with experiment. The other case is the $\Upsilon(5s)$ where there are data on the branching ratios. The agreement is qualitatively good, with the notable exception of the $B^*_s B^*_{s'}$ channel, and also a factor of two discrepancy in the relative rates of the $B B^* + c.c.$ and $B^* B^*$ channels. It would be interesting to see if these discrepancies are a warning that more elaborate components for this state, as suggested in Ref. [12], are at work.

The predictions made for branching ratios for the $\Upsilon(3d)$ and $\Upsilon(6s)$ states should serve as a motivation to measure these magnitudes that will help in advancing our understanding of these bottomium states.

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[1] S. Godfrey and N. Isgur, Phys. Rev. D 32, 189 (1985).
[2] S. Godfrey and K. Moats, Phys. Rev. D 92, no. 5, 054034 (2015).
[3] J. Segovia, P. G. Ortega, D. R. Entem and F. Fernandez, Phys. Rev. D 93, no. 7, 074027 (2016).
[4] J. Ferretti and E. Santopinto, Phys. Rev. D 90, no. 9, 094022 (2014).
[5] J. Vijande, F. Fernandez and A. Valcarce, J. Phys. G 31, 481 (2005).
[6] P. Gonzalez, J. Phys. G 41, 095001 (2014).
[7] J. Z. Wang, Z. F. Sun, X. Liu and T. Matsuki, Eur. Phys. J. C 78, no. 11, 915 (2018).
[8] M. Tanabashi et al. [Particle Data Group], Phys. Rev. D 98, no. 3, 030001 (2018).
[9] A. Abdesselam et al. [Belle Collaboration], JHEP 1910, 220 (2019).
[10] Z. G. Wang, Chin. Phys. C 43, 123102 (2019).
[11] R. Bruschini and P. Gonzalez, Phys. Lett. B 791, 409 (2019).
[12] Pedro Gonzalez, Quark model explanation of Υ(10860), take given in the 18th International Conference on Hadron Spectroscopy and Structure (HADRON2019), 16-21 Aug. 2019, Guilin, China.
[13] X. Z. Weng, L. Y. Xiao, W. Z. Deng, X. L. Chen and S. L. Zhu, Phys. Rev. D 99, no. 9, 094001 (2019).
[14] A. De Rujula, H. Georgi and S. L. Glashow, Phys. Rev. Lett. 38, 317 (1977).
[15] R. Kaiser, A. V. Manohar and T. Mehen, Phys. Rev. Lett. 90, 142001 (2003).
[16] M. B. Voloshin, Phys. Rev. D 85, 034024 (2012).
[17] Q. X. Yu, W. H. Liang, M. Bayar and E. Oset, Phys. Rev. D 99, no. 7, 076002 (2019).
[18] M. Bayar, N. Ikeno and E. Oset, arXiv:1911.12715 [hep-ph].
[19] L. Micu, Nucl. Phys. B 10, 521 (1969).
[20] A. Le Yaouanc, L. Oliver, O. Pene and J. C. Raynal, Phys. Rev. D 8, 2223 (1973).
[21] J. M. Blatt and V. F. Weisskopf, Theoretical Nuclear Physics (Springer, New York, 1979).
[22] S. Coito and F. Giacosa, Nucl. Phys. A 981, 38 (2019).
[23] F. Aceti, L. R. Dai, L. S. Geng, E. Oset and Y. Zhang, Eur. Phys. J. A 50, 57 (2014).
[24] B. Aubert et al. [BaBar Collaboration], Phys. Rev. D 72, 032005 (2005).
[25] J. R. Pelaez, Phys. Rept. 658, 1 (2016).