$Z_b(10610)$ and $Z_b(10650)$ structures produced by the initial single pion emission in the $\Upsilon(5S)$ decays

Dian-Yong Chen$^{1,3}$ and Xiang Liu$^{1,2,4}$

$^1$Research Center for Hadron and CSR Physics, Lanzhou University and Institute of Modern Physics of CAS, Lanzhou 730000, China
$^2$School of Physical Science and Technology, Lanzhou University, Lanzhou 730000, China
$^3$Nuclear Theory Group, Institute of Modern Physics of CAS, Lanzhou 730000, China

(Dated: October 11, 2011)

We propose a unique mechanism called Initial Single Pion Emission existing in the $\Upsilon(5S)$ decays, and further study the line shapes of $d\Gamma(\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-)/d\Gamma(\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-) (m = 1, 2, 3)$ and $d\Gamma(\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-)/d\Gamma(\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-) (m = 1, 2)$. We find sharp structures around 10610 MeV and 10650 MeV in the obtained theoretical line shapes of $d\Gamma(\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-)/d\Gamma(\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-)$ and $d\Gamma(\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-)/d\Gamma(\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-)$ distributions, which could naturally correspond to the $Z_b(10610)$ and $Z_b(10650)$ structures newly observed by Belle.

PACS numbers: 13.25.Gv, 14.40.Pq, 13.75.Lb

As the first experimental observation of charged bottomonium-like states, two structures $Z_b(10610)$ and $Z_b(10650)$ were reported by the Belle Collaboration recently by studying the invariant mass spectra of $\Upsilon(nS)\pi^\pm$ $(n = 1, 2, 3)$ and $h_0(mP)\pi^\pm$ $(m = 1, 2)$ of $\Upsilon(5S) \to \Upsilon(nS)\pi^\pm$ and $\Upsilon(5S) \to h_0(mP)\pi^\pm$ decay processes [1]. The average values of the mass and the width of $Z_b(10610)$ and $Z_b(10650)$ are $M_{Z_b(10610)} = 10608.4 \pm 2.0$ MeV/$c^2$, $\Gamma_{Z_b(10610)} = 15.6 \pm 2.5$ MeV/$c^2$, $M_{Z_b(10650)} = 10653.2 \pm 1.5$ MeV/$c^2$, $\Gamma_{Z_b(10650)} = 14.4 \pm 3.2$ MeV/$c^2$ [1]. In Fig. 1 we also list different measurement results of the parameters of $Z_b(10610)$ and $Z_b(10650)$ extracted from their five hidden-bottom decay channels, and compare these results with the $BB^*$ and $B^*B^*$ thresholds. In addition, Belle also indicated that $Z_b(10610)$ and $Z_b(10650)$ favor $I^G(J^P) = 1^+(1^+)$ from the analysis of angular distribution.

| Channels | $Z_b(10610)$ | $Z_b(10650)$ |
|----------|---------------|---------------|
| $\Upsilon(1S)\pi^\pm$ | 10609 \(\pm 3\) \(\pm 2\) | 10606.14 \(\pm 2\) \(\pm 2\) |
| $\Upsilon(2S)\pi^\pm$ | 10616 \(\pm 2\) \(\pm 2\) | 10653 \(\pm 2\) \(\pm 2\) |
| $\Upsilon(3S)\pi^\pm$ | 10608 \(\pm 2\) \(\pm 2\) | 10652 \(\pm 2\) \(\pm 2\) |
| $h_0(1P)\pi^\pm$ | 10605 \(\pm 2\) \(\pm 2\) | 10654 \(\pm 2\) \(\pm 2\) |
| $h_0(2P)\pi^\pm$ | 10596 \(\pm 7\) | 10651 \(\pm 4\) \(\pm 2\) |

FIG. 1: (Color online.) The measured parameters of $Z_b(10610)$ and $Z_b(10650)$ by five different decay channels [1], and the comparison of these parameters with the $BB^*$ and $B^*B^*$ threshold [2]. Here, all values are in units of MeV.

The above experimental information shows that $Z_b(10610)$ and $Z_b(10650)$ are very peculiar since $Z_b(10610)$ and $Z_b(10650)$ not only are charged structures but also close to the thresholds of $BB^*$ and $B^*B^*$ respectively. Thus, the $Z_b(10610)$ and $Z_b(10650)$ structures enrich the observation of bottomonium-like states, and inspire theorists’ extensive interest in revealing what is the source to generate these novel structures at the same time.

Their peculiarities make that $Z_b(10610)$ and $Z_b(10650)$ could be as good candidate of exotic states, i.e., $BB^*$ and $B^*B^*$ molecular states, which were suggested in Refs. [3, 4]. After finding $Z_b(10610)$ and $Z_b(10650)$ structures, many theoretical work has focused on this hot issue of $Z_b(10610)$ and $Z_b(10650)$. In Ref. [5], the decay behavior of $Z_b(10610)$ and $Z_b(10650)$ was discussed by the heavy quark symmetry and the assignment of $Z_b(10610)$ and $Z_b(10650)$ as the $J = 1$ S-wave $BB^*$ and $B^*B^*$ molecular states. Chen, Liu and Zhu [6] found that introducing the intermediate $Z_b(10610)$ and $Z_b(10650)$ contributions to $\Upsilon(5S) \to \Upsilon(2S)\pi^\pm\pi^-$ naturally explains Belle’s previous observation of the anomalous $\Upsilon(2S)\pi^+\pi^-$ production near the peak of $\Upsilon(5S)$ at $\sqrt{s} = 10.87$ GeV [7]. By the QCD sum rule and the constructed $BB^*$ molecular current, the authors in Ref. [8] reproduced the mass of $Z_b(10610)$. In Ref. [9], the mass spectra of the S-wave $[b\bar{q}][b\bar{q}]$, $[b\bar{q}^*][b\bar{q}^*]$, $[b\bar{q}^*][b\bar{q}]$ were calculated in the chiral quark model, which indicates that $Z_b(10610)$ and $Z_b(10650)$ could be as the S-wave $BB^*$ and $B^*B^*$ molecular states. Bugg proposed that $Z_b(10610)$ and $Z_b(10650)$ are from the cusp effect due to the $BB^*$ and $B^*B^*$ thresholds [10]. Two positive C-parity isoscalar states, i.e., a $^3S_1 - ^3D_1$ state with a binding energy of 90-100 MeV and a $^3P_0$ state located about 20-30 MeV below the $BB^*$ threshold, were suggested in Ref. [11]. However, the quantum numbers relevant to these suggested molecular bottomonia are inconsistent with those of the observed two charged Zb states. The authors in Ref. [12] studied the interaction between a light hadron and heavy quarkonium through the transition to a pair of intermediate heavy mesons, and discussed the resonance structures close to the $B^*B^*$ threshold [12]. In Ref. [13], the discussion of $Z_b(10610)$ and $Z_b(10650)$ being tetraquark states was performed by using the chromomagnetic interaction. We notice that the $b\bar{b}q\bar{q}$ tetraquark states with $10.2 - 10.3$ GeV were once predicted in Ref. [14] by using the color-magnetic interaction with the flavor symmetry breaking corrections, where the predicted mass

*Corresponding author
is lower than that obtained in Ref. [13] and consistent with the values extracted from the QCD sum rule [15]. Very recently, the interactions of the $B^*\bar{B}$ and $B^*\bar{B}$ were revisited by the one-boson-exchange model. After considering the S-wave and D-wave mixing, we notice that both $Z_b(10610)^+$ and $Z_b(10650)^+$ can be interpreted as the $B^*\bar{B}$ and $B^*\bar{B}$ molecular states [16].

Generally speaking, these theoretical efforts mentioned above have improved our understanding of the properties of $Z_b(10610)$ and $Z_b(10650)$, especially stimulated the extensive and in-depth study of exotic states, which is an important and valuable research topic in hadron physics at present. If revealing the underlying mechanism behind these novel $Z_b$ structures much more comprehensively, we need to pay more phenomenological efforts from different perspectives. Thus, the study of whether $Z_b(10610)$ and $Z_b(10650)$ can be depicted without introducing any exotic structure explanation is becoming a very valuable research issue. Along this way, we will delve into this subject.

With $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ as an example, we first illustrate the corresponding decay mechanisms of the hidden-bottom decays of $\Upsilon(5S)$. One is that $\Upsilon(5S)$ directly decays into $\Upsilon(nS)\pi^+\pi^-$, which is usually depicted by the QCD Multipole Expansion method [17–19]. Another one is that the dipion in the $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ process could be from the intermediate states $\sigma(600)$, $f_0(980)$ and $f_2(1270)$ just indicated in Ref. [20], where the intermediate hadronic loops constructed by the $B^{(*)}$ mesons play an important role to connect the initial $\Upsilon(5S)$ with the final $\Upsilon(nS)\pi^+\pi^-$. Besides these two production mechanisms, in this work we propose an important mechanism contributing to the $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ decay, which is described in Fig. 2. $\Upsilon(5S)$ transits into $B^{(*)}$ and $\bar{B}^{(*)}$ pair associated with a single pion emission. Due to the emitted pion with continuous energy distribution, $B^{(*)}$ and $\bar{B}^{(*)}$ mesons with the low momentum easily interact with each other and further transit into $\Upsilon(nS)\pi$ by exchanging $B^{(*)}$ meson. We name such new picture presented here as Initial Single Pion Emission (ISPE) mechanism. To some extent, the ISPE mechanism existing in the $\Upsilon$ decays is similar to the well-known Initial State Radiation (ISR) mechanism in $e^+e^-$ collisions, which has stimulated a series of observations of charmonium-like states $X, Y, Z$ in the past years.

The ISPE mechanism exists in the hidden-charm or hidden-bottom dipion decays of higher charmonia or bottomonia. If the mass of higher charmonium/Bottomonium is larger than the sum of the masses of $D^{(*)}\bar{D}^{(*)}/B^{(*)}\bar{B}^{(*)}$ pair and pion, this higher charmonium/Bottomonium can be of open-charm/open-bottom decays associated with a pion production. The emitted single pion plays important role to make $D^{(*)}\bar{D}^{(*)}/B^{(*)}\bar{B}^{(*)}$ with low momenta. Then, $D^{(*)}\bar{D}^{(*)}/B^{(*)}\bar{B}^{(*)}$ into final states occurs via $D^{(*)}/B^{(*)}$ meson exchanges. Thus, under the ISPE mechanism, the hidden-charm/hidden-bottom dipion decays of higher charmonium/Bottomonium are mediated by the hadronic loop constructed by $D^{(*)}/B^{(*)}$ and $\bar{D}^{(*)}/\bar{B}^{(*)}$ mesons. Since in fact hadronic loop effect reflected the coupled channel effect, the ISPE mechanism can be categorized as an important nonperturbative QCD effect.

Since two $Z_b$ structures were observed in the hidden-bottom decays of $\Upsilon(5S)$, we naturally relate the newly observed structures with the $\Upsilon(5S)$ decay via the ISPE mechanism, and further examine whether the $Z_b$ structures can be reproduced in the $\Upsilon(nS)\pi^+\pi^-$ invariant mass spectrum when including the diagrams in Fig. 2.

In the following, we calculate the $\Upsilon(nS)\pi^+\pi^-$ invariant mass spectra of $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ considering the intermediate $B\bar{B}, B^*\bar{B}^*$ + h.c. and $B^*\bar{B}^*$ contributions. Just shown in Fig. 2 the schematic diagrams (a) and (b) correspond to $\Upsilon(5S) \to \pi^+ \to B^{(*)}\bar{B}^{(*)} \to \Upsilon(nS)\pi^+$ and $\Upsilon(5S) \to \pi^+ \to B^{(*)}\bar{B}^{(*)} \to \Upsilon(nS)\pi^+$, respectively. Moreover, the subscript $B^{(*)}\bar{B}^{(*)}$ denotes the exchanged mesons for $B^{(*)}\bar{B}^{(*)} \to \Upsilon(nS)\pi$ transitions. Thus, there exist two, and four independent decay amplitudes for the $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ decays via the intermediate $B\bar{B}, B^*\bar{B}^* + h.c.$ and $B^*\bar{B}^*$ respectively.

The general expressions corresponding to Fig. 2(a) and (b) can be written as

$$
M \left[ \Upsilon(5S) \to \pi^+ \to B^{(*)}\bar{B}^{(*)} \to \Upsilon(nS)\pi^+ \right]_{l_{\rho\nu}} = \int \frac{d^4q}{i} \left\{ 2\pi \delta \left[ (p_2 + q)^2 - m_{B^{(*)}}^2 \right] \right\} \left| \frac{\mu}{\delta \epsilon(\Upsilon(5S))} \right| \left| \frac{\mu}{\delta \epsilon(\Upsilon(nS))} \right| 
$$

where $\mu_{\rho\nu}$ denotes the Lorentz structures constructed by four-momenta $p_1, p_2, p_3$ and $q$, which are obtained by the effective Lagrangian approach [21–23].

\[ L_{B^{(*)}\bar{B}^{(*)}\pi} \]
\[ -ig_{BBB}\varepsilon^{\mu\nu\rho\sigma}T_{\mu}\partial_{\nu}B_{\rho}g_{BB}B_{\sigma} + g_{BBB}B_{\nu}\partial_{\nu}B_{\rho} - ig_{BBB}\varepsilon^{\mu\nu\rho\sigma}T_{\mu}\partial_{\nu}B_{\rho}, \]
\[ L_{BBB} = ig_{BBB}(\partial_{\mu}B_{\nu}\partial_{\rho}B_{\sigma} - B_{\mu}\partial_{\nu}B_{\rho} - B_{\mu}\partial_{\rho}B_{\nu} + B_{\nu}\partial_{\rho}B_{\mu} - B_{\rho}\partial_{\mu}B_{\nu} + B_{\rho}\partial_{\nu}B_{\mu} - B_{\nu}\partial_{\rho}B_{\mu} + B_{\rho}\partial_{\mu}B_{\nu}), \]
\[ L_{(\chi_s^{125})} = \frac{2g_{h_{125}B}}{\sqrt{m_{h_{125}}}}(\partial_{\mu}h_{125}B_{\nu} + ig_{h_{125}B}\varepsilon^{\mu\nu\rho\sigma}T_{\mu}\partial_{\nu}B_{\rho}). \]

In the heavy quark limit, the coupling constants in the above Lagrangians satisfy the relations \( g_{BBB}/\sqrt{m_{BB}} = \frac{2g}{f_{\pi}} = \frac{g_{BBB}}{g_{BBB} - g_{BBB}B_{\nu}} = \frac{m_{Z}}{f_{\pi}} = \frac{g_{h_{125}B}}{g_{h_{125}B}B_{\nu}} = -2g_{1}/\sqrt{m_{h_{125}}}, \)
\( g_{BBB}/\sqrt{m_{BB}} = 2g_{1}/\sqrt{m_{h_{125}}} \) with \( g = 0.88 \) \([2, 4] \), \( f_{\pi} = 132 \) MeV and \( g_{1} = -m_{h_{125}}/f_{\pi} \) \([23] \), where \( f_{\pi} \) and \( f_{\pi} \) denote the decay constants of \( \gamma(nS) \) and \( \gamma(nS) \). The mass parameters of \( B^{(*)} \), \( \gamma(nS) \), \( h_m(mP) \) are taken from Refs. \([2, 23] \).

In Eqs. 1, \( \Pi_{1, i, g} \) denotes the product of all coupling constants involving in three interaction vertices (see Fig. 2). Additionally, we introduce monopole form factor \( F(q^{2}, m_{B}^{2}) = (\alpha^{2} - m_{B}^{2})/(\alpha^{2} - q^{2}) \) reflecting the structure effect of the interaction vertices of \( (q^{2}, m_{B}^{2}) \) transforming \( \gamma(nS) \) into \( \gamma(nS) \). The decays of \( \gamma(nS) \) and \( \gamma(nS) \) are characterized by the \( A \) parameter, which can be parameterized as \( A = m_{B}^{2} + \beta A_{QCD} \) with \( A_{QCD} = 220 \) MeV.

The differential decay width for \( \gamma(nS) \) to \( \gamma(nS) \) is
\[ d\Gamma = \frac{1}{(2\pi)^{3}} \frac{1}{32m_{nS}^{2}} \frac{\varepsilon^{\mu\nu\rho\sigma}}{\Delta m_{\gamma(nS)}} \frac{dm_{\gamma(nS)}}{dm_{\pi^{+}\pi^{-}}} \] with \( m_{\gamma(nS)}^{2} = (p_{1} + p_{2})^{2} \) and \( m_{\pi^{+}\pi^{-}} = (p_{2} + p_{3})^{2} \), where the overline indicates the average over the polarizations of the \( \gamma(nS) \) in the initial state and the sum over the polarization of \( \gamma(nS) \) in the final state.

With the above preparation, we obtain the line shapes of \( d\Gamma(\gamma(nS) \rightarrow \gamma(nS)) \) and \( d\Gamma(\gamma(nS) \rightarrow \gamma(nS)) \), which are presented in Fig. 3. To explicitly illustrate the phenomena of the ISPE effect on \( \gamma(nS) \) to \( \gamma(nS) \) decay, we individually consider the intermediate \( BB^{*} \) and \( B\bar{B}^{*} \) contributions to \( \gamma(nS) \) to \( \gamma(nS) \) process. Thus, we take the coupling constants of \( \gamma(nS) \) interacting with \( BB^{*} \) and \( B\bar{B}^{*} \) as 1, which does not change the line shapes of \( d\Gamma(\gamma(nS) \rightarrow \gamma(nS)) \) and \( d\Gamma(\gamma(nS) \rightarrow \gamma(nS)) \). In our calculation, the parameter \( \beta = 1 \) is taken. We need to specify that these line shapes are weakly dependent on the \( \beta \) value, which makes the qualitative conclusion obtained in this work to be unchanged.

Just shown in the first and the second columns of Fig. 3 combined with the corresponding reflections, the sharp peaks around \( BB^{*} \) and \( B\bar{B}^{*} \) thresholds appear in the \( m_{\gamma(1S)}^{2} \) and \( m_{\gamma(2S)}^{2} \) distributions of \( d\Gamma(\gamma(nS) \rightarrow \gamma(1S)) \) and \( d\Gamma(\gamma(nS) \rightarrow \gamma(2S)) \). The comparison of these results with the Belle data [1] indicates that we indeed can mimic the peak structures similar to the \( Z_{0}(10610) \) and \( Z_{0}(10650) \) reported by Belle if introducing the ISPE mechanism.

The theoretical result of the \( \gamma(nS) \rightarrow \gamma(nS) \) decay further indicates that there also exists a peak around 10610 MeV, which combines with its reflection in the \( m_{\gamma(1S)}^{2} \) distribution to form a broad structure. In addition, a structure at \( \sim 10650 \) MeV and its reflection are reproduced. These results qualitatively and naturally explain why there are three structures appearing in the \( \gamma(nS)^{+} \) invariant mass spectrum just announced by Belle [1].

We continue to extent the ISPE mechanism to study the \( \gamma(nS) \rightarrow \gamma(nS) \) decay. Similar to the situation of \( \gamma(nS) \rightarrow \gamma(1S, 2S) \), we can also find two structures around 10610 MeV and 10650 MeV and their reflections in the theoretical line shape of \( d\Gamma(\gamma(nS) \rightarrow \gamma(nS)) \). The obtained theoretical line shapes of \( d\Gamma(\gamma(nS) \rightarrow \gamma(nS)) \) and the comparison of our result with the Belle data (the third column) [1] show that the first, the second and the fourth columns correspond to the numerical result considering \( BB^{*} \) and \( B\bar{B}^{*} \) intermediate state contributions respectively, while the first, the second and the third rows are the results corresponding to the distributions of \( \gamma(nS) ^{+} \) and \( \gamma(3S)^{+} \) invariant mass spectra. We use the vertical dashed and dotted lines to mark the masses of \( Z_{0}(10610) \) and \( Z_{0}(10650) \), respectively. Here, the maximum of the theoretical line shape is normalized to 1.
The Belle data also give a very intriguing phenomenon, i.e., there does not exist the structure near the $B \bar{B}$ threshold. Our mechanism can provides a direct explanation to it. If only considering the $B \bar{B}$ contribution in Fig. 2 our calculation shows that we cannot find the sharp peak close to the $B \bar{B}$ threshold in the $\Upsilon(nS)\pi^+\pi^-$ and $h_0(mP)\pi^+\pi^-$ invariant mass spectra. Alternately, the smooth line shapes similar to phase space of corresponding decay processes appear in the invariant mass spectra of $\Upsilon(nS)\pi^+\pi^-$ and $h_0(mP)\pi^+\pi^-$. If the ISPE mechanism is a universal mechanism existing in the $\Upsilon(5S)$ decays, this study presented in this letter can be extended to include the theoretical study of the dipion hidden-bottom decays of $\Upsilon(11020)$, and even the dipion hidden-charm decays of higher charmonia $\psi(4040)$, $\psi(4160)$ and $\psi(4415)$, which could produce some other similar structures near the thresholds of $B^{(*)}$ or $D^{(*)}$ meson pair. Further experimental search for these novel phenomenons will be an interesting research topic.

**Acknowledgment:** This project is supported by the National Natural Science Foundation of China under Grants Nos. 1175073, No. 11005129, No. 11035006, No. 11047606, the Ministry of Education of China (FANEDD under Grant No. 200924, DPFIE under Grant No. 2009021120029, NCET under Grant No. NCET-10-0442, the Fundamental Research Funds for the Central Universities), and the West Doctoral Project of Chinese Academy of Sciences.

---

[1] I. Adachi et al. [Belle Collaboration], arXiv:1105.4583 [hep-ex].
[2] K. Nakamura et al. [Particle Data Group], J. Phys. G 37, 075021 (2010).
[3] Y. R. Liu, X. Liu, W. Z. Deng and S. L. Zhu, Eur. Phys. J. C 56, 63 (2008) [arXiv:0801.3540 [hep-ph]].
[4] X. Liu, Z. G. Luo, Y. R. Liu and S. L. Zhu, Eur. Phys. J. C 61, 411 (2009) [arXiv:0808.0073 [hep-ph]].
[5] A. E. Bondar, A. Garmash, A. I. Milstein, R. Mizuk and M. B. Voloshin, arXiv:1105.4473 [hep-ph].
[6] D. Y. Chen, X. Liu and S. L. Zhu, arXiv:1105.5193 [hep-ph].
[7] K. F. Chen et al. [Belle Collaboration], Phys. Rev. Lett. 100, 112001 (2008) [arXiv:0710.2577 [hep-ex]].
[8] J. R. Zhang, M. Zhong and M. Q. Huang, arXiv:1105.5472 [hep-ph].
[9] Y. Yang, J. Ping, C. Deng and H. S. Zong, arXiv:1105.5935 [hep-ph].
[10] D. V. Bugg, arXiv:1105.5492 [hep-ph].
[11] J. Nieves and M. P. Valderrama, arXiv:1106.0600 [hep-ph].
[12] I. V. Danilkin, V. D. Orlovsky and Yu. A. Simonov, arXiv:1106.1552 [hep-ph].
[13] T. Guo, L. Cao, M. Z. Zhou and H. Chen, arXiv:1106.2284 [hep-ph].
[14] Y. Cui, X. L. Chen, W. Z. Deng and S. L. Zhu, High Energy Phys. Nucl. Phys. 31, 7 (2007) [arXiv:hep-ph/0607226].
[15] W. Chen and S. L. Zhu, Phys. Rev. D 83, 034010 (2011) [arXiv:1010.3397 [hep-ph]].
[16] Z. F. Sun, J. He, X. Liu, Z. G. Luo and S. L. Zhu, arXiv:1106.2968 [hep-ph].
[17] Y. P. Kuang and T. M. Yan, Phys. Rev. D 24, 2874 (1981).
[18] T. M. Yan, Phys. Rev. D 22, 1652 (1980).
[19] V. A. Novikov and M. A. Shifman, Z. Phys. C 8, 43 (1981).
[20] D. Y. Chen, J. He, X. Q. Li and X. Liu, arXiv:1105.1672 [hep-ph].
[21] Y. S. Oh, T. Song and S. H. Lee, Phys. Rev. C 63, 034901 (2001) [arXiv:nucl-th/0010064].
[22] R. Casalbuoni, A. Deandrea, N. Di Bartolomeo, R. Gatto, F. Furuglio and G. Nardulli, Phys. Rept. 281, 145 (1997) [arXiv:hep-ph/9605342].

---

**FIG. 4:** (Color online.) The theoretical curves of $d\Gamma(\Upsilon(5S) \rightarrow h_0(1P)\pi^+\pi^-)/dm_{h_0(1P)\pi^+\pi^-}$ (the first column) and $d\Gamma(\Upsilon(5S) \rightarrow h_0(2P)\pi^+\pi^-)/dm_{h_0(2P)\pi^+\pi^-}$ (the second column). For easily comparing our result with the experimental data, one adopts the vertical dashed and dotted lines to denote the masses of $Z_0(10610)$ and $Z_0(10650)$ respectively. The first, the second and the third rows correspond to the numerical result respectively considering $B\bar{B} + h.c.$, $B\bar{B}$ and $B\bar{B}$ intermediate state contributions in Fig. 2. Here, the maximum of the theoretical line shape is normalized to 1.

---

1 Electronic address: xiangliu@lzu.edu.cn
2 Project of Chinese Academy of Sciences.
[23] P. Colangelo, F. De Fazio and T. N. Pham, Phys. Rev. D 69, 054023 (2004) [arXiv:hep-ph/0310084].

[24] C. Isola, M. Ladisa, G. Nardulli and P. Santorelli, Phys. Rev. D 68, 114001 (2003) [arXiv:hep-ph/0307367].

[25] I. Adachi et al. [Belle Collaboration], arXiv:1103.3419 [hep-ex].

[26] To some extent, these theoretical curves with sharp peaks presented in Figs. 3 and 4 are shaped similar to a *kitty* head.