Oddball Y(4140) as the molecular cousin of Y(3930) *

LIU Xiang(刘翔)[1,2;1)]

[1] School of Physical Science and Technology, Lanzhou University, Lanzhou 730000, China
[2] Research Center for Hadron and CSR Physics, Lanzhou University &
Institute of Modern Physics of CAS, Lanzhou 730000, China

Abstract In my talk, we present the dynamical study of Y(4140) and Y(3930) under the $D_s^*\bar{D}_s^*$ and $D^*\bar{D}^*$ molecular assignments respectively. The importance to theoretically and experimentally study their open-charm decay, hidden-charm decay, radiative decay and double-photon decay is proposed combing with the theoretical calculation of the decay behavior of Y(4140) and Y(3930). According to the recent new experimental progress made by Belle, we further indicate the reasonability of molecular explanation to Y(4140). Another event cluster around 4270 MeV in the J/ψφ invariant mass spectrum of B → KJ/ψφ can provide us more hints to reveal the creation mechanism of molecular structure in B meson decay, which will be helpful to clarify the underlying structure of Y(4140) and Y(3930).

Key words molecular state, charmonium-like state

PACS 12.39.Pn, 12.40.Yx, 13.75.Lb

Recently the CDF Collaboration announced a new charmonium-like state Y(4140) by analyzing the J/ψφ invariant mass spectrum in B → KJ/ψφ channel, which results in the *C*-parity and *G*-parity of Y(4143) being even. The measured mass and width of Y(4140) are 4143.0±2.9(stat)±1.2(syst) MeV and $11.7^{+8.3}_{-5.0}$(stat)±3.7(syst) MeV [1], respectively.

By comparing Y(4140) with a series of charmonium-like states X, Y, Z, one notices that Y(4140) is similar to Y(3930), which is a charmonium state with $m = 3943\pm 11(\mathrm{stat})\pm 13(\mathrm{syst})$ and $\Gamma = 87\pm 22(\mathrm{stat})\pm 26(\mathrm{syst})$ reported by the Belle Collaboration [2] and confirmed by the BABAR Collaboration [3]. Both Y(4140) and Y(3930) were observed in the mass spectrum of J/ψ+light vector meson in B meson decay

$$\mathrm{B}\to \mathrm{K}+\begin{cases}\underline{\mathrm{J}/\psi\phi} \Longrightarrow \mathrm{Y}(4140)\\ \underline{\mathrm{J}/\psi\omega} \Longrightarrow \mathrm{Y}(3930)\end{cases}.$$

The mass difference between Y(4140) and Y(3930) is approximately equal to that between φ and ω mesons:

$$M_{\mathrm{Y}(4140)} - M_{\mathrm{Y}(3930)} \sim M_{\phi} - M_{\omega}.$$

Additionally, Y(4140) and Y(3930) are close to the thresholds of $D_s^*\bar{D}_s^*$ and $D^*\bar{D}^*$ respectively, and satisfy an almost exact mass relation

$$M_{\mathrm{Y}(4140)} - 2M_{\mathrm{D}_s^*} \approx M_{\mathrm{Y}(3930)} - 2M_{\mathrm{D}^*}.$$

The above similarities provoke a uniform molecular picture to reveal the underlying structure of Y(4140) and Y(3930) [4, 5]. The flavor wave functions of Y(4140) and Y(3930) are [4, 5]

$$|\mathrm{Y}(4140)\rangle = |\mathrm{D}_s^{*+}\mathrm{D}_s^{*-}\rangle,$$
$$|\mathrm{Y}(3930)\rangle = \frac{1}{\sqrt{2}}\Big[|\mathrm{D}^{*0}\bar{\mathrm{D}}^{*0}\rangle + |\mathrm{D}^{*+}\mathrm{D}^{*-}\rangle\Big].$$

A select rule of the quantum number of Y(4140) and Y(3930) is observed under the $D_s^*\bar{D}^*$ and $D^*\bar{D}$ molecular state assignments to Y(3930) and Y(4140), respectively. The possible quantum numbers of the *S*-wave vector-vector system are $J^P = 0^+, 1^+, 2^+$. However for the neutral $D^*\bar{D}^*$ system with $C = +$, we can have $J^P = 0^+$ and 2^+ only since $C = (-1)^{L+S}$ and $J = S$ with $L = 0$ [4], which provide important criterion to test molecular state explanation of Y(3930) and Y(4140).

Received 19 January 2010

* Supported by National Natural Science Foundation of China (10705001), Foundation for Author of National Excellent Doctoral Dissertation of P.R. China (FANEDD) and Doctoral Program Foundation of Institutions of Higher Education of China

1) E-mail: xiangliu@lzu.edu.cn

To answer whether $D^*\bar{D}^*$ or $D_s^*\bar{D}_s^*$ system can be bound, a dynamical calculation was performed in Ref. [5] by the effective Lagrangian approach. Here, the exchanged mesons between $D^*\bar{D}^*$ ($D_s^*\bar{D}_s^*$) include the pseudoscalar, vector and σ mesons (see Ref. [5] for the details of the derivation of the exchange potential). The variation of the binding energy E and and the root mean square radius $r_{\rm rms}$ with the cutoff Λ is presented in Fig. 1. For Y(4140) and Y(3930) states with $J^P=0^+,2^+$, the molecular solution can be found. Later, the study in Refs. [6–10] further supports the molecular explanation for Y(4140) and Y(3930).

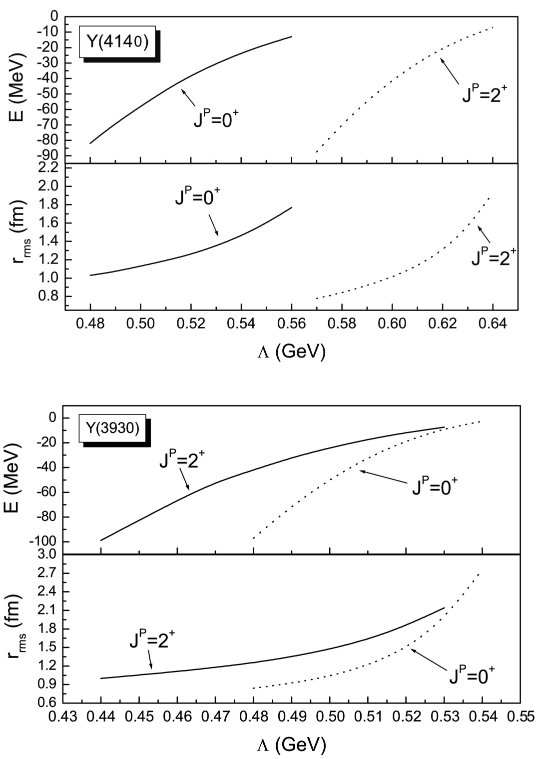

Fig. 1. The dependence of the binding energy E and and the root mean square radius $r_{\rm rms}$ on the cutoff Λ for Y(4140) and Y(3930).

Besides the dynamical study of Y(4140) and Y(3930), investigating the decay behavior of Y(4140) and Y(3930) is an important research topic, which includes the hidden-charm decay, the open-charm decay, radiative decay and double-photon decay. In Ref. [11], we study the hidden-charm decay of Y(4140) assuming Y(4140) as the second radial excitation of the P-wave charmonium χ''_{cJ} $(J=0,1)$. The result indicates that the upper limit of the branching ratio of the hidden charm decay Y(4140) → J/ψϕ is on the order of $10^{-4}\sim10^{-3}$ for both of the charmonium assumptions for Y(4140), which disfavors the large hidden charm decay pattern indicated by the CDF experiment. It seems to reveal that the pure second radial excitation of the P-wave charmonium χ''_{cJ} $(J=0,1)$ is problematic [11].

As indicated in Ref. [4], the line shapes of the photon spectrum of $Y(4140)\to D_s^{*+}D_s^-\gamma$ and $Y(3930)\to D^{*+}D^-\gamma$ are crucial to test the molecular state assignment to Y(4140) and Y(3930). Later a calculation of the radiative decay of Y(4140) and Y(3930) was performed [12]. According to the result of the photon spectrum in $Y(4140)\to D_s^{*+}D_s^-\gamma$ and $Y(3930)\to D^{*+}D^-\gamma$ listed in Fig. 2, we suggest further experimental study of the radiative decay of Y(4140) and Y(3930).

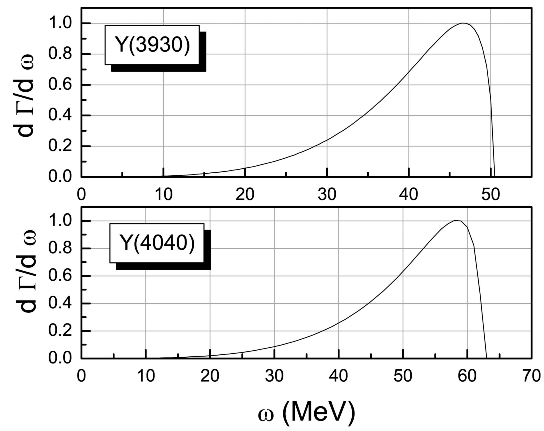

Fig. 2. Photon spectrum in $Y(4140)\to D_s^{*+}D_s^-\gamma$ (top) and $Y(3930)\to D^{*+}D^-\gamma$ (bottom). Here the maximums of $d\Gamma/d\omega$ is normalized to one.

In the following, two new experimental progresses of searching for Y(4140) should be mentioned. After the observation of Y(4140) by CDF, the Belle Collaboration carried out the search for Y(4140) by $B^+\to K^+J/\psi\phi$. The preliminary result indicates that the signal of Y(4140) in the J/ψϕ invariant mass spectrum is not significant. The significance of Y(4140) is about 1.9 σ, which is lower than that (3.8 σ) shown by CDF. Meanwhile, the upper limit of production rate $\mathcal{B}[B^+\to Y(4140)K^+]\cdot\mathcal{B}[Y(4140)\to J/\psi\phi]=6\times10^{-6}$, which is consistent with the CDF measured result $\mathcal{B}[B^+\to Y(4140)K^+]\cdot\mathcal{B}[Y(4140)\to J/\psi\phi]=(9.0\pm3.4\pm2.9)\times10^{-6}$ [13–15]. Present Belle data of Y(4140) is not enough to confirm the CDF observation of Y(4140). Thus, we have to wait for Super B and even LHCb experiment to further study the J/ψϕ invariant mass spectrum of B decay.

After studying J/ϕϕ invariant mass spectrum of the $\gamma\gamma\to J/\phi\phi$ process, Belle indicates that no Y(4140) signal is observed. However, a new charmonium-like state Y(4350) is reported [13–15].

$\gamma\gamma$ fusion process is good platform to create P-wave charmonium. Belle once analyzed $\gamma\gamma \to D\bar{D}$ process and reported Z(3930), which is a charmonium-like state with mass $m = 3929 \pm (\text{stat})5 \pm 2(\text{syst})$ MeV and $\Gamma = 29 \pm 10(\text{stat}) \pm 2(\text{syst})$ MeV [16]. The angular distribution in the $\gamma\gamma$ center of mass frame shows $J^{PC} = 2^{++}$, which indicates that Z(3930) is a good candidate of χ'_{c2}, i.e., a charmonium with $n^{2s+1}J_L = 2^3P_2$ [16]. No Y(4140) signal observed in $\gamma\gamma \to J/\phi\phi$ shows that the possibility of Y(4140) as the second radial excitation of the P-wave charmonium χ''_{cJ} can be excluded, which is supported by Ref. [12]. On the contrary, as a newly observed charmonium-like in the $J/\phi\phi$ invariant mass spectrum of $\gamma\gamma$ fusion, Y(4350) can explain as χ''_{c2} extremely well by analyzing the mass spectrum of P-wave charmonium family as well as by calculating the open-charm strong decay of X(4350), which are consistent with the existed experimental findings [17].

To some extent, the creation mechanism of Y(4140) in B decay results in the reasonability of Y(4140) as a molecular state $D_s^*\bar{D}_s^*$. Generally in the weak decays of B meson, $c\bar{c}$ pair creation is mainly resulted from the color-octet mechanism. Meanwhile, a color-octet $s\bar{s}$ pair is easily popped out by a gluon. Thus c and $\bar{c}$ respectively capture $\bar{s}$ and s to form a pair of charm-strange mesons. By this mechanism, a pair of charm-strange mesons with the low momentum easily interact with each other and even form the molecular system. To further test the molecular state proposal for Y(4140) and Y(3930), theoretical and experimental studies of Y(4140) and Y(3930) are still important topic presently.

By checking the CDF data [1], we also notice that there exists another enhancement structure around 4270 MeV besides Y(4140) signal in the $J/\psi\phi$ mass spectrum of $B^+ \to J/\psi\phi K^+$, which is of lower significance than that of Y(4140) as shown in Fig. 3. Recently the CDF preliminary result also noticed the existence of this event cluster [18]. We refer to this new structure by the name Y(4270) in this talk. The study of Y(4270) is encouraged, which should bring us some new insights of the creation mechanism of the molecular state constructed by heavy flavor mesons associating with the observed Y(4140) and Y(3930).

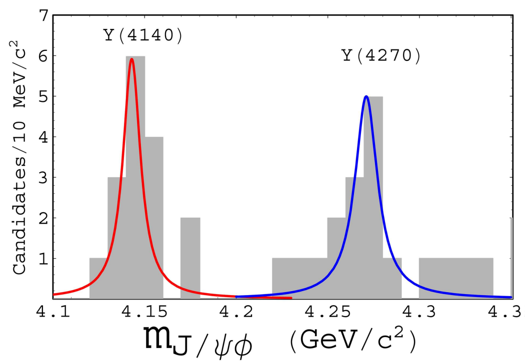

Fig. 3. (color online). Using a simple Breit-Wigner formula to depict the CDF data (histogram) of the $J/\psi\phi$ mass spectrum in $B^+ \to K^+J/\psi\phi$. Besides Y(4140), one explicit enhancement appears around 4270 MeV. Here red and blue line shapes are the fitting result with fitting parameters $m = 4143$ MeV, $\Gamma = 11.7$ MeV and $m = 4270$ MeV, $\Gamma = 15$ MeV by two simple Breit-Wigner formulas.

X.L enjoys the collaboration with Professor Shi-Lin Zhu and Dr. Hong-Wei Ke.

References

1 Aaltonen T et al (CDF collaboration), Phys. Rev. Lett. 2009, **102**: 242002 [arXiv:0903.2229 [hep-ex]]
2 Abe K et al (Belle collaboration), Phys. Rev. Lett. 2005, **94**: 182002 [arXiv:hep-ex/0408126]
3 Aubert B et al (BABAR collaboration), Phys. Rev. Lett. 2008, **101**: 082001 [arXiv:0711.2047 [hep-ex]]
4 LIU X, ZHU S L. Phys. Rev. D, 2009, **79**: 094026 [arXiv:0903.2529 [hep-ph]]
5 LIU X, LUO Z G, LIU Y R, ZHU S L. Eur. Phys. J. C, 2009, **61**: 411–428 [arXiv:0808.0073 [hep-ph]]
6 Mahajan N. Phys. Lett. B, 2009, **679**: 228 [arXiv:0903.3107 [hep-ph]]
7 Branz T, Gutsche T, Lyubovitskij V E. Phys. Rev. D, 2009, **80**: 054019 [arXiv:0903.5424 [hep-ph]]
8 Albuquerque R M, Bracco M E, Nielsen M. Phys. Lett. B, 2009, **678**: 186 [arXiv:0903.5540 [hep-ph]]
9 DING G J. Eur. Phys. J. C, 2009, **64**: 297 [arXiv:0904.1782 [hep-ph]]
10 ZHANG J R, HUANG M Q. arXiv:0905.4178 [hep-ph]
11 LIU X. Phys. Lett. B, 2009, **680**: 137 [arXiv:0904.0136 [hep-ph]]
12 LIU X, KE H W. Phys. Rev. D, 2009, **80**: 034009 [arXiv:0907.1349 [hep-ph]]
13 YUAN C Z. arXiv:0910.3138 [hep-ex]
14 Pakhlova G, (Belle collaboration). talk given in The 5-th International Conference on Quarks and Nuclear Physics, Institue of High Energy Physics, Beijing, 21–26 September 2009
15 SHEN C P (Belle collaboration). talk given in International Workshop on e^+e^- collisions from phi to psi (PHIPSI09), Institue of High Energy Physics, Beijing, China, 12–16 October 2009
16 Uehara S et al (Belle collaboration). Phys. Rev. Lett. 2006, **96**: 082003 [arXiv:hep-ex/0512035]
17 LIU X, LUO Z G, SUN Z F. arXiv:0911.3694 [hep-ph]
18 YI K. arXiv:0906.4996 [hep-ex]