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Y(2175): An Intriguing Hadron Observed in BaBar, BES and Belle Experiments*

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Abstract: Since the BaBar Collaboration announced a new hadron Y(2175) observed in the $\phi f_0(980)$ invariant mass spectrum of $e^+e^- \to \phi f_0(980)$, both BES and Belle confirmed BaBar's observation. Meanwhile, the theorist also carries out the study to reveal the underlying properties of Y(2175). In this review paper, we give a detailed review of the present experimental and theoretical statues of Y(2175). In terms of the published experimental data of Y(2175), we also discuss the possibility of searching for other enhancement structuresafter 2175 MeV in the $\phi f_0(980)$ invariant mass spectrum.

Key word: new hadron state; strangenium; exotic state

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1 Introduction

Among the newly observed hadron states, Y(2175) is an intriguing light hadron, which was first reported by the BaBar Collaboration by analyzing the $\phi f_0(980)$ invariant mass spectrum in the process of $e^+e^- \to \phi f_0(980)$ via initial-state radiation (ISR)[1]. Later, the BES Collaboration confirmed the observation of Y(2175) by a different

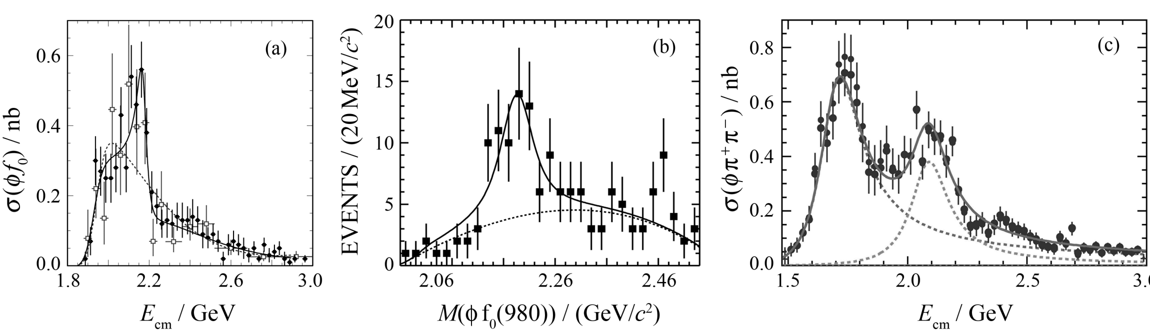

Fig. 1 (a) The invariant mass spectrum of $\phi f_0(980)$ in $e^+e^- \to \phi f_0(980)$ from BaBar data; (b) the invariant mass spectrum of $\phi f_0(980)$ in $J/\psi \to \eta\phi f_0(980)$ from BES data; (c) the invariant mass spectrum of $\phi\pi^+\pi^-$ in $e^+e^- \to \phi\pi^+\pi^-$ from Belle data.

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process $J/\psi \to \eta\phi f_0(980)$[2], and the Belle Collaboration also observed Y(2175) in $e^+e^- \to \phi\pi^+\pi^-$ and $e^+e^- \to \phi f_0(980)$[3]. The enhancement structure Y(2175) existing in the invariant mass spectrum of $\phi f_0(980)$ or $\phi\pi^+\pi^-$, which is reported in the above three experiments, is shown in Fig. 1 [1-3].

In addition, the experimentalist tries to search for Y(2175) by its other decay processes. Recently the BES Collaboration reported that no evidence of Y(2175) is seen by analyzing the $K^{*0}\bar{K}^{*0}$ invariant mass spectrum in $J/\psi \to \eta K^{*0}\bar{K}^{*0}$[4]. The BaBar Collaboration observed an enhancement structure around 2127 MeV in the $\phi\eta$ invariant mass spectrum of $e^+e^- \to \phi\eta$ via the ISR mechanism[5]. In Table. 1, we summarize the experimental information relevant to Y(2175).

Table 1 The experimental measurement relevant to Y(2175). Here, we use underline to mark the analyzed invariant mass spectrum corresponding to the experimental search for Y(2175)

Experiment	Channel	Mass/MeV	Width/MeV	Remark
BaBar[1]	$e^+e^+ \to \gamma_{ISR}\underline{\phi f_0(980)}$	$2175\pm10\pm15$	$58\pm16\pm20$	
BES[2]	$J/\psi \to \eta\,\underline{\phi f_0(980)}$	$2186\pm10\pm6$	$65\pm23\pm17$	
BELLE[3]	$e^+e^+ \to \gamma_{ISR}\underline{\phi f_0(980)}$	$2079\pm13^{+79}_{-28}$	$192\pm23^{+25}_{-61}$	
	$e^+e^+ \to \gamma_{ISR}\underline{\phi\pi^+\pi^-}$			
BES[4]	$J/\psi \to \eta\,\underline{K^{*0}\bar{K}^{*0}}$	—	—	No evidence
BaBar[5]	$e^+e^- \to \gamma_{ISR}\underline{\phi\eta}$	2127 ± 24	60 ± 50	

After the BaBar's observation of Y(2175), the theorist is dedicated to understand its underlying structure. In the following, we will give a systematical review of the theoretical study status of Y(2175). In section III, we will discuss whether there exist more enhancements after 2175 MeV of the announced experimental data. Finally a short summary is given.

2 The Theoretical Explanation to Y(2175)

Since Y(2175) is observed in e^+e^- annihilation via ISR mechanism, the quantum number J^{PC} of Y(2175) must be 1^{--}. The decay channel $\phi f_0(980)$ of Y(2175) indicates that Y(2175) should be of $s\bar{s}$ component. In terms of the above important information, the theorist tries to explain Y(2175) from the point of view of the conventional quarkonium or exotic state.

Before the observation of Y(2175), there exist two established strangenium ($s\bar{s}$ state) listed in particle data group (PDG), i. e., $\phi(1020)$ and $\phi(1680)$, which are of quantum numbers $n\,^{2S+1}L_J = 1^3S_1$, 2^3S_1 respectively. Here, n, S, L, J denote the radial excitation, spin, orbital angular momentum and total angular momentum, respectively. If explaining Y(2175) as a strangenium with the higher radial excitation, the possible quantum number of Y(2175) is 2^3D_1 or 3^3S_1 since the masses of 2^3D_1 and 3^3S_1 states predicted in a relativized quark model with chromodynamics[6] are consistent with that of Y(2175) if considering the experimental error. In Refs. [7-8], Barnes et al. once studied the two-body strong decay of the strangenium with 3^3S_1 by the $^3P_0$ model[9]. The mass of the strangenium with 3^3S_1 is put as 2.05 GeV, which is lower than that of Y(2175). Further the predicted total decay width of the strangenium with 3^3S_1 is about 380 MeV, which shows that the strangenium with 3^3S_1 is a rather broad state[8]. The dominant decay modes of the 3^3S_1 state are predicted to be K^*K^*, $KK^*(1414)$ and

$KK_1(1273)$. Comparing the result in Ref. [8] with the experimental result of Y(2175), we can fully exclude 3^3S_1 strangenium assignment to Y(2175) since the width of Y(2175) is far less than the obtained theoretical total width of 3^3S_1 $s\bar{s}$ state.

Testing the 2^3D_1 $s\bar{s}$ assignment to Y(2175) was performed in Ref. [10]. Ding and Yan applied two effective models, i. e. the $^3P_0$ model and the flux tube model, to calculate the partial decay width and the total decay width of Y(2175). The results obtained under these two models are consistent with each other. The total decay widths from the $^3P_0$ model and the flux tube model are 167.21 MeV and 211.9 MeV, respectively, which are larger than the width of Y(2175) to some extent. The main decay modes for the 2^3D_1 $s\bar{s}$ strangenium scenario are $K\bar{K}$, K^*K^*, K(1460)K, $h_1(1380)\eta$.

By the Resonance Spectrum Expansion (RSE), the authors in Ref. [11] carried out a multichannel calculation of excited 1^{--} $s\bar{s}$ states. The included S- and P-wave two-meson channels comprisethe lowest pseudoscalar, vector, scalar, and axial-vector mesons, while in the $s\bar{s}$ sector both the 3^3S_1 and 2^3D_1 states are coupled. The numerical result indicates adynamical resonance pole which is found at (2186−i246) MeV[11]. Although the mass predicted in RSE model is consistent with that from the experiment, the calculated width is huge. As indicated in Ref. [11], further improvements of the model are needed to the calculation of the pole mass.

Besides giving strangenium explanation to Y(2175), theorist also tries to explore the underlying structure of Y(2175) from the point of view of exotic state. Here, before reviewing the exotic explanation relevant to Y(2175), we need to introduce two previous experimental observations:

(1) In 2004, the Belle Collaboration reported an enhancement named as Y(4260) in $J/\psi\pi^+\pi^-$ invariant mass spectrum of $e^+e^-\to\gamma_{ISR} J/\psi\pi^+\pi^-$[12]. Due to the difficulty to put Y(4260) into the conventional vector charmonium, later a $c\bar{c}g$ hybrid state explanation to Y(4260) was proposed in Refs. [13−15].

(2) In 2007, the Belle Collaboration reported that the measured width of $Y(10870)\to\Upsilon(1S, 2S)\pi^+\pi^-$ is 2—3 order larger than those of $\Upsilon(nS)\to\Upsilon(mS)\pi^+\pi^-$ (n=2, 3, 4 and $m<n$)[16]. Suggestion of Y(10870) as a $b\bar{b}$ counterpart of Y(4260) was proposed in Refs. [17−18]. Thus, if Y(4260) is a $c\bar{c}g$ hybrid, Y(10870) can be recommended as $b\bar{b}g$ hybrid.

Just considering the similarities of Y(2175), Y(4260) and Y(10870) (see Table. 2), one can extend $b\bar{b}g$ and $c\bar{c}g$ to $s\bar{s}g$, which is related to Y(2175). The decay behavior of Y(2175) as a $s\bar{s}g$ state was calculated in Ref. [19] by the flux tube model. The total decay width of Y(2175) can reach up to 148.7 MeV. Meanwhile, K^*K^* is forbidden. Combining the above mentioned 2^3D_1 $s\bar{s}$ decay channels in Ref. [10], Ding et al. indicated that searching for K^*K^* channel of Y(2175) can be as an important criteria to distinguish $s\bar{s}$ strangenium and $s\bar{s}g$ explanations to Y(2175).

Table 2 The comparison of Y(2175), Y(4260), Y(10870) and the corresponding hybrid explanation

States	Y(2175)	Y(4260)	Y(10870)
Quantum number	1^{--}	1^{--}	1^{--}
Decay channel	$\phi\pi^+\pi^-$	$J/\psi\pi^+\pi^-$	$\Upsilon(1S, 2S)\pi^+\pi^-$
Hybrid explanation	$s\bar{s}g$	$c\bar{c}g$	$b\bar{b}g$

Besides $s\bar{s}g$ assignment to Y(2175), a resonance state of $\phi K\bar{K}$ system was proposed for explaining Y(2175)[20]. By solving the Faddeev equations of describing three-body interaction of $\phi K\bar{K}$, they obtained a neat resonance peak around a total mass of 2150 MeV and an invariant mass for the $K\bar{K}$ system around 970 MeV, very close to the $f_0(980)$ mass, which also explain why Y(2175) decays into $\phi f_0(980)$[20].

Wang studied Y(2175) as a tetraquark state $s\bar{s}s\bar{s}$ by using QCD sum rule and suggested that there may be some tetraquark components in the state Y(2175)[21]. Later a more detailed analysis in QCD sum rule was performed. In Ref. [22], the authors studied the mass of the state Y(2175) of $J^{PC}=1^{--}$ in the QCD sum rule. By constructing both the diquark-antidiquark currents $(ss)(\bar{s}\bar{s})$ and the meson-meson currents $(s\bar{s})(s\bar{s})$, they found two independent currents for both cases, and derived the relations between them. The OPE convergence of these two currents is sufficiently fast, which enables us to perform good sum rule analysis. Both the SVZ sum rule and the finite energy sum rule lead to a mass around (2.3±0.4) GeV, which is consistent with the observed mass within the uncertainties of the present QCD sumrule. The coupling of the four-quark currents to the lower lying states such as $\phi(1020)$ turns out to be rather small. The possible decay properties of Y(2175) were discussed if it is a tetraquark state.

In addition, a $\Lambda\bar{\Lambda}$ interpretation was proposed in Ref. [23], which is similar to the $\Lambda_c\bar{\Lambda}_c$ bound state assignment to Y(4260) as indicated in Ref. [24].

In Table 3, one further summarizes the possible explanation to Y(2175) just reviewed in the above.

Table 3　The possible interpretations of Y(2175)

Strangenium	$s\bar{s}$ (2^3D_1)
Hybrid	$s\bar{s}g$
Three-body system	ϕ $K\bar{K}$
Molecular state	$\Lambda\bar{\Lambda}$

3　Do There Exist More Enhancement Structures after 2175 MeV in the Experimental Data?

Besides Y(2175), one can find an extra enhancement around 2360 MeV in the $\phi f_0(980)$ invariant mass spectrum. As indicated by the preliminary result given in Ref. [25], this corresponding enhancement structure (named as Y(2360)) with 2.5σ significance is of mass $m=(2360\pm46)$ MeV and width $\Gamma=(124\pm105)$ MeV, which is observed not only in Belle data[3] but also in BES data[2].

If putting Y(2360) into conventional $s\bar{s}$ state, we can fully exclude 3^3S_1 quantum number assignment to Y(2360) due to the width of Y(2360) being far smaller than that of 3^3S_1. Thus the most possible quantum number of Y(2360) should be 4^3S_1 or 3^3D_1. Under conventional $s\bar{s}$ state with higher radial excitation, Y(2360) can decay into $\phi f_0(980)$, $\phi\eta$, KK, KK^*, K^*K^*, KK(1460), $KK_1(1270)$, $KK_1(1400)$ and $KK_2(1430)$.

The theoretical calculation of the decay behavior is encouraged, which will be helpful to establish Y(2360) in the experiment, especially in BESIII with a large database.

4　Summary

In this review, we briefly introduce the experimental observation of Y(2175), which is an intriguing new hadron state observed by BaBar, BES and Belle. Theorist carried out the study on the underlying structure of Y(2175). The explanations of the structure of Y(2175) mainly include $s\bar{s}$ with 3^3S_1, $s\bar{s}g$ hybrid, $K\bar{K}\phi$ system and $\Lambda\bar{\Lambda}$ molecular state. Thus, further experimental and theoretical study on how to distinguish the existed theoretical assignments to Y(2175) is not only an interesting topic, but also important to reveal the underlying structure of Y(2175).

Meanwhile, we still need to try our best to put Y(2175) into the conventional $s\bar{s}$ family before giving the exotic explanation to Y(2175). Recently BES result announced no evidence of Y(2175)→$K^{*0}\bar{K}^{*0}$[4], which seems to exclude $s\bar{s}g$ hybrid explanation. We noticed that the theoretical result of the decay width of Y(2175) under 2^3D_1 $s\bar{s}$ state is larger than the measurement value of Y(2175). Exploring the strong decay of Y(2175) under the assignment of the mixing of 3^3S_1 and 2^3D_1 $s\bar{s}$ states is encouraged, which can alleviate the difference of the theoretical result and the experimental value of the width of Y(2175).

Considering the existence of the new enhancement structure Y(2360) after 2175 in the $\phi f_0(980)$ invariant mass spectrum, a detailed study of the underlying structure and decay behavior of Y(2360) is not only helpful to establishthis new enhancement, but also improves our understanding of Y(2360) combing with the study of Y(2175).

BESIII experiment will provide us a good platform to further test the existed theoretical explanation and the prediction of Y(2175) and Y(2360).

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Y(2175)：一个在 BaBar、BES 和 Belle 实验上发现的新强子*

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摘 要：BaBar 合作组在 $e^+e^-\to\phi f_0(980)$ 衰变道的 $\phi f_0(980)$ 不变质量谱上发现了一个新强子态Y(2175)。随后，BES 和 Belle 实验都相继证实了这一发现。与此同时，理论家们也对 Y(2175)的内部性质进行了大量的研究。本工作对目前 Y(2175)在实验和理论上的进展进行了详细的评述。同时，讨论了在 $\phi f_0(980)$ 不变质量谱中的 2175 MeV 以上能区寻找其它增长结构的可能性。

关 键 词：新强子态；奇异偶素；奇特态

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