Experimental review of $e^+e^- \to \pi\pi h_c$ *

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Abstract: We review the recent BESIII measurement of $e^+e^- \to \pi\pi h_c$ in which its line shape is studied between the center-of-mass energies of 3.9 to 4.42 GeV and an iso-vector charmonium-like state $Z_c(4020)$ is observed in the invariant mass of πh_c at the BESIII experiment. The charged $Z_c(4020)^\pm$ is the second observed Z_c state following $Z_c(3900)$, while the $Z_c(4020)^0$ is the first observed neutral Z_c state. The line shape of $\sigma(e^+e^- \to \pi\pi h_c)$ is also re-analyzed in view of searching for the Y state and the existence of the Y(4220) state is confirmed and compared with the previous work of the BESIII experiment.

Keywords: charmonium, exotic state, isospin triplet

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1 Introduction

In the quark model, one quark and one anti-quark form mesons while three quarks form baryons [1]. However, hadronic states with other configurations, called exotic states, are also allowed according to the theory of Quantum Chromodynamics (QCD). These exotic states include glueballs, hybrids, multi-quark states and hadron molecules. There is great interest in searching for these exotic states, but no solid experimental evidence was found until recent breakthroughs in the charmonium region, such as the well-established X(3872) [2–7], Y(4260) [8–11], Y(4660) [12] and so on.

The Y(4260) state was first observed by the BaBar Collaboration in the initial-state-radiation (ISR) process $e^+e^- \to \gamma_{ISR}\pi^+\pi^- J/\psi$ and then confirmed by the CLEO and Belle experiments using the same technique. It carries the quantum number $J^{PC}=1^{--}$. Moreover, there is a broad structure near 4.008 GeV which is labeled as Y(4008) in the Belle data [10]. Recently, both BaBar and Belle updated their results with full data sets, and further confirmed the existence of the Y(4260) [13, 14], as shown in Fig. 1 and Fig. 2.

To further understand the nature of the Y(4260), an investigation into the other hadronic/radiative transition between the Y(4260) and other lower mass charmonium states, like $\pi\pi h_c$, $\eta/\pi^0 J/\psi$ and $\gamma\chi_{cJ}(J=0,1,2)$, is desirable [15–18].

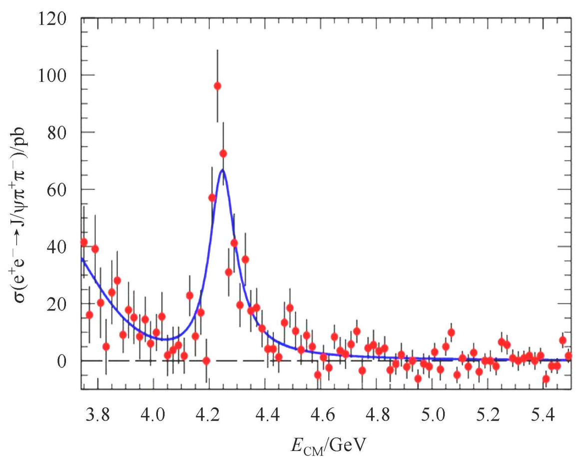

Fig. 1. (color online) The cross section of the decay process of $e^+e^- \to \pi^+\pi^- J/\psi$ by the BaBar experiment [13].

It is important to study different signatures of the established exotic states. The basic properties such as the spin, parity, isospin, and width of these states must be determined experimentally. The most direct way is to search for electrically charged states that can decay

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into hidden charm final states, since such states contain at least four quarks, and therefore cannot be conventional mesons. The Belle Collaboration reported the observation of a similar state with nonzero electric charge: $Z(4430)^+$, in a study of $B \to K\pi^+\psi(2S)$ decays [19] reported in 2008. This state has not been confirmed by BaBar [20] using the same decay process. However, it has recently been confirmed by LHCb in 2014 [21] with very high significance, and the quantum number is determined to be 1^+ [22]. As the minimal quark content of such a state is $c\bar{c}d\bar{u}$, this observation could be interpreted as the first unambiguous evidence for the existence of mesons beyond the traditional $q\bar{q}$ model. The $Z_c(3900)$ state was observed in the $\pi^\pm J/\psi$ mass spectrum in the $e^+e^- \to \pi^+\pi^- J/\psi$ process at BESIII using the data sample collected at the center-of-mass energy (E_{CM}) $E_{CM} = 4.26$ GeV [23]. This state has been confirmed recently by the Belle [14] and CLEO-c experiments [24]. The observation of $Z_c(3900)$ has stimulated considerable interest from both theoretical and experimental sides. Different models have been proposed, such as tetraquark [25], molecule [26], hadroquarkonium states [27], or other configurations [28]. Soon after, the study of the $(D\bar{D}^*)^\pm$, $\pi^\pm h_c$ and $(D^*\bar{D}^*)^\pm$ system in the processes $e^+e^- \to (D\bar{D}^*)^\pm\pi$, $e^+e^- \to (\pi^\mp h_c)\pi^\pm$ and $e^+e^- \to (D^*\bar{D}^*)^\pm\pi$ with the same data sample have been performed at BESIII, and strong near-threshold peaks have been observed, which are named $Z_c(3885)$ [29], $Z_c(4020)$[30] and $Z_c(4025)$ [31], respectively. These states may indicate that a new type of hadron has been established.

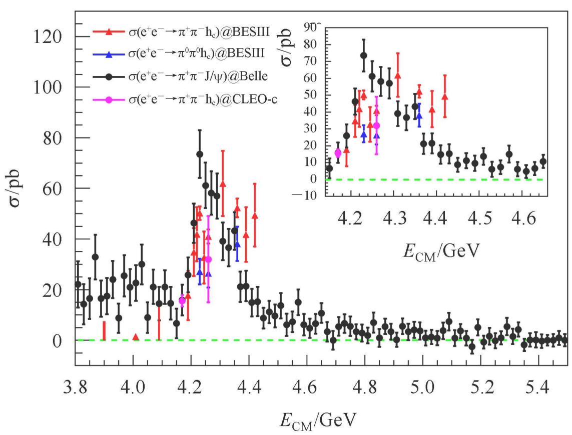

Fig. 2. (color online) Comparison of $\sigma(e^+e^- \to \pi^+\pi^- h_c)$ from BESIII and CLEO-c, $\sigma(e^+e^- \to \pi^0\pi^0 h_c)$ from BESIII and $\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$ from Belle. The enlarged plot between 4.15 and 4.65 GeV is shown at the top of the right corner. The errors are statistical only (the numerical results are from Refs. [23, 30, 32, 33]).

However, the reported charmonium-like states are charged. By contrast, the investigation of neutral charmonium-like states is quite rare. The first attempt was to search for $Z_c(3900)^0$ in the neutral process $e^+e^- \to \pi^0\pi^0 J/\psi$ by CLEO at $E_{CM} = 4.170$ GeV [24], but the significance of the $Z_c(3900)^0$ signal was 3.5σ. The first unambiguous neutral charmonium-like state observed is the $Z_c(4020)^0$ observed in the $\pi^0 h_c$ mass spectrum in the process of $e^+e^- \to \pi^0\pi^0 h_c$ process with the BESIII data (see Ref. [32]) at 4.23, 4.26 and 4.36 GeV. These results are interesting because hybrid models, which are popular, consider the fact that only the neutral Z_c can mix with charmonium states, while their charged partners cannot. Thus, if this mixing is substantial, as it is in the case of some models for the X(3872) at least, we might see surprises in the Z_c^0 width and decay branching fractions, which would be striking evidence for the validity of the hybrid idea.

In this paper, we give a brief review and perspective concerning the line shape of the process $e^+e^- \to \pi\pi h_c$ and the $Z_c(4020)$ state.

2 Born cross section of $e^+e^- \to \pi\pi h_c$

The process $e^+e^- \to \pi^+\pi^- h_c$ process was first observed by CLEO-c using a data sample at $E_{CM} = 4.170$ GeV with 586 pb^{-1}, with the measured cross section $\sigma = (15.6 \pm 2.3 \pm 1.9 \pm 3.0)$ pb. Together with the scan sample around 4.000 and 4.260 GeV, the cross section shows a hint of rising at 4.260 GeV [33]. An improved measurement may shed light on understanding the nature of Y states and may also be used to search for possible charged intermediate charmonium-like states.

The BESIII experiment, operated at the Beijing Electron Positron Collider (BEPC) II, is a tau-charm factory which has collected data from $E_{CM} = 2.0$ to 4.6 GeV [34]. Starting from the end of 2012 to 2013, BESIII detector collected about 3.3 fb^{-1} data samples at 13 energies ranging from 3.900 to 4.420 GeV. Using a full reconstruction of the final state particles, BESIII has reported the cross section measurement of both charged and neutral $e^+e^- \to \pi^+\pi^- h_c$ modes at different energies [30, 32]. Here the h_c is reconstructed via its electric-dipole (E1) transition $h_c \to \gamma\eta_c$ with η_c reconstructed with its 16 hadronic decay modes: $p\bar{p}$, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-p\bar{p}$, $2(K^+K^-)$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$, $2(\pi^+\pi^-)K^+K^-$, $K_SK^\pm\pi^\mp$, $K_SK^\pm\pi^\mp\pi^+\pi^-$, $K^+K^-\pi^0$, $K^+K^-\eta$, $p\bar{p}\pi^0$, $\pi^+\pi^-\eta$, $\pi^+\pi^-\pi^0\pi^0$, $2(\pi^+\pi^-)\eta$, and $2(\pi^+\pi^-\pi^0)$. Here K_S^0 is reconstructed in its $\pi^+\pi^-$ decays, and η in its $\gamma\gamma$ final state. The ratios of cross section between neutral and charged mode ($R_{\pi\pi h_c}$) at each energy point are calculated, where the common systematic uncertainties in the two measurements have canceled. The combined ratio for the 3 energies $R_{\pi\pi h_c}$, obtained with a weighted least squares method [35], is determined to be 0.63 ± 0.09, which agrees within uncertainties with the expectation based on the isospin symmetry (=0.5).

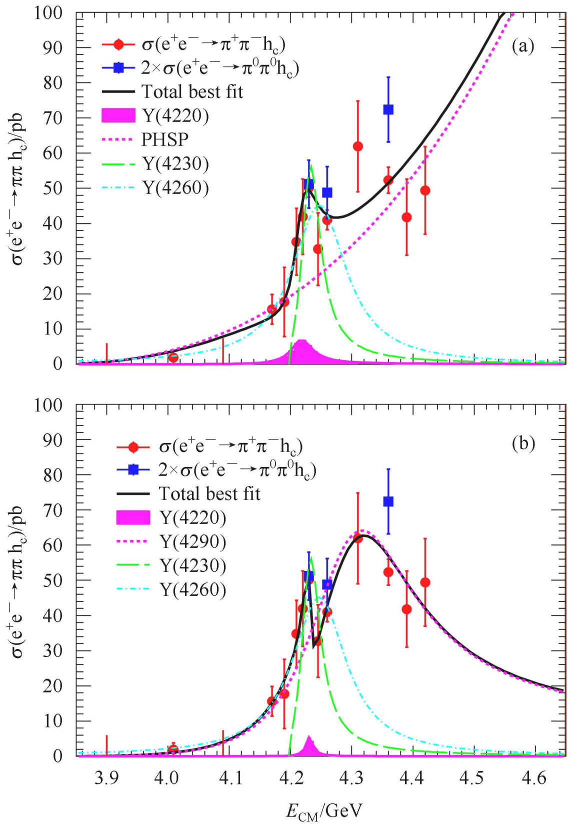

Fig. 3. (color online) The fit to cross section of $e^+e^- \to \pi\pi h_c$ from BESIII and CLEO-c (error bars). Solid curves show the best fits, and the dashed ones are individual components. Panel(a) is the fit with the coherent sum of a phase space amplitude and one BW function (the shaded part), and panel(b) is the coherent sum of two BW functions (from Ref. [36], the shaded region denotes the Y(4220)). Here, $\sigma(e^+e^- \to \pi^0\pi^0 h_c)$ (square with errors) multiplied by a factor of 2 is based on isospin conservation between neutral and charged channels. The dotted-dashed line denotes the Y(4260), while the long-dashed line denotes the potential Y(4230) from the $\omega\chi_{c0}$ line-shape.

Based on the BESIII and CLEO-c measurements, an attempt to fit the $e^+e^- \to \pi^+\pi^- h_c$ line shape has been done by BESIII [36]. The fit to the line shape results in a narrow structure labeled as Y(4220) and a possible wide structure labeled as Y(4290). In this work, we add the measured cross section of the neutral channel, $e^+e^- \to \pi^0\pi^0 h_c$ [30], multiplied by a factor of 2 which accounts for the isospin conservation between charged and neutral channels, to re-fit this line shape closely following the method introduced in Ref. [36].

Assuming that the cross section follows the three-body phase space and that there is a narrow resonance around 4.2 GeV (model I), the fit results are listed in Table 1, where M and $\Gamma_{\rm tot}$ denote mass and width of resonance, respectively. ϕ denotes the interference between phase resonance and phase space, and $\Gamma_{e^+e^-}$ is the partial width. The statistical significance of the Y(4220) is calculated to be 7.9σ by comparing the fit χ^2s with and without the Y(4220) signal and taking into account the change of the number-of-degrees-of-freedom (NDF). Figure 3(a) shows the final fit with the Y(4220).

Assuming that the cross section decreases at high energy, we fit the cross sections with the coherent sum of two relativistic BW functions with constant widths [36] (model II). The fit results are listed in Table 2, in which the definitions of M, $\Gamma_{\rm tot}$ and $\Gamma_{e^+e^-}$ are same as the ones in Table 1. The statistical significance of the Y(4220) is calculated to be 4.6σ with the same method mentioned before. Figure 3(b) shows the final fit with the Y(4220) and Y(4290).

Table 1. Results of fit with model I.

	solution A	solution B
M	(4218±7) MeV/c^2	
$\Gamma_{\rm tot}$	(42±19) MeV	
ϕ	(39.8±21.3)°	(220.1±20.5)°
$\Gamma_{e^+e^-}\times\mathcal{B}(\pi\pi h_c)$	(0.4±0.2) eV	(6.4±2.2) eV
χ^2/NDF	15.75/12	

Table 2. Results of fit with model II.

	solution A	solution B
M_1	(4231±13) MeV/c^2	
$\Gamma^1_{\rm tot}$	(14±36) MeV	
M_2	(4288±12) MeV/c^2	
$\Gamma^2_{\rm tot}$	(210±69) MeV	
ϕ	(315.3±138.2)°	(215.6±12.4)°
$(\Gamma_{e^+e^-}\times\mathcal{B}(\pi\pi h_c))_1$	(0.09±0.10) eV	(3.0±1.4) eV
$(\Gamma_{e^+e^-}\times\mathcal{B}(\pi\pi h_c))_2$	(15.7±2.6) eV	(19.7±2.7) eV
χ^2/NDF	7.01/10	

From the two fits shown in Fig. 3, we conclude that it is very likely that there is a narrow structure at around 4.22 GeV/c^2, although we are not sure if there is a broad resonance at 4.29 GeV/c^2. One can find that these results are strongly consistent with those reported in Ref. [36]. One more point is that the significance of Y(4220) in the two fit model is a bit larger than that in Ref. [36] due to the addition of 3 points from the neutral mode. Nevertheless, the uncertainties of resonant parameters of the Y(4220) are still large. The reason can be attributed to the lack of the measurement above 4.42 GeV and the lack of high precision measurements around the Y(4220) peak, especially between 4.23 and 4.26 GeV. Measurements from the BESIII experiment above 4.42 GeV and more precise data at around the Y(4220) peak will be crucial to settle this problem.

One more interesting thing is that the location of Y(4220) in $e^+e^- \to \pi^+\pi^- h_c$ is similar to the structure observed in $e^+e^- \to \omega\chi_{c0}$. The measured mass and width for this structure are (4230±8±6) MeV/c^2 and (38±12±2) MeV [37], respectively. Similar situations occur in the $e^+e^- \to \pi^+\pi^- J/\psi$ [14] and $\eta J/\psi$ [38]. It is likely that these structures are the same. However, more data samples between 4.15 and 4.25 GeV are needed to confirm such a conjecture. In Ref. [39], the author has treated the structures in the line shape of $\sigma(e^+e^- \to \pi^+\pi^- h_c)$ and $\sigma(e^+e^- \to \omega\chi_{c0})$ as the same and fitted them simultaneously, and obtained the resonant parameters of the Y(4220) with smaller uncertainty. For the broad Breit-Wigner peak around 4.29 GeV, it is difficult to take it as a structure, or a parameterized background. More data are required above 4.42 GeV in order to draw a convincing conclusion. Nevertheless, the Y(4220) can be regarded as a good candidate for a charmonium-hybrid lying in the mass region predicted by QCD-based calculations [40].

3 Charmonium-like state $Z_c(4020)$

In the selection of $\pi^+\pi^- h_c$, the intermediate states are studied by examining the Dalitz plot. Figure 3(a) shows the projection of the $M(\pi^\pm h_c)$ (two entries per event) distribution for the $\pi^+\pi^- h_c$ candidate events. There is a significant peak at around 4.02 GeV/c^2 (named $Z_c(4020)^\pm$ hereafter). Similarly, in the $M(\pi^0 h_c)$ mass distribution for the $e^+e^- \to \pi^0\pi^0 h_c$ events, there is also a significant peak, which could be the isospin partner of $Z_c(4020)^\pm$, at around 4.02 GeV/c^2 (named $Z_c(4020)^0$ hereafter).

The $M(\pi^\pm h_c)$ or $M(\pi^0 h_c)$ distributions summed over the 16 η_c decay modes are fitted simultaneously at three energy points to extract the parameters of the structures and the signal event yield. The mass and width of the $Z_c(4020)^\pm$ are measured to be $4023.6\pm2.2\pm3.8$ MeV/c^2, and $7.9\pm2.7\pm2.6$ MeV, respectively, with a statistical significance of 8.9σ (see Fig. 4(a)), while the mass of $Z_c(4020)^0$ is determined to be (4023.6±2.2±3.8) MeV/c^2 with a statistical significance larger than 5σ (see Fig. 4(a)). Here, the width of the $Z_c(4020)^0$ is fixed as its charged isospin partner due to the limitation of signal events. Details of the various sources of systematic uncertainties in the mass and width measurement of the $Z_c(4020)$ can be found in Refs. [30, 32].

With the same calculating method for the combined ratio $\mathcal{R}_{\pi\pi h_c}$, the combined ratio $\mathcal{R}_{\pi Z_c}$ between the neutral mode $e^+e^- \to \pi^0 Z_c(4020)^0$ and charged mode $e^+e^- \to \pi^\pm Z_c(4020)^\mp$ for 3 energies is determined to be (0.99±0.31) with the same method as for the combined $\mathcal{R}_{\pi\pi h_c}$, which is consistent with the expectation of isospin symmetry (=0.5) within 1.6σ based on the assumption that $Z_c(4020)$ is an iso-triplet.

Table 3 shows the measured resonance parameters of the charged and neutral $Z_c(4020)$ states. The mass difference between the neutral and charged $Z_c(4020)$ is 1.0 ± 2.2 (stat.) MeV/c^2, which is in good agreement with zero within uncertainty. The mass of $Z_c(4020)$ is only ∼6 MeV above $2m_{D^*}$, and this state looks like a charmed-sector version of the $Z_b(10650)$ observed in the process $e^+e^- \to \pi^+\pi^- h_b(np)$ by the Belle experiment [41].

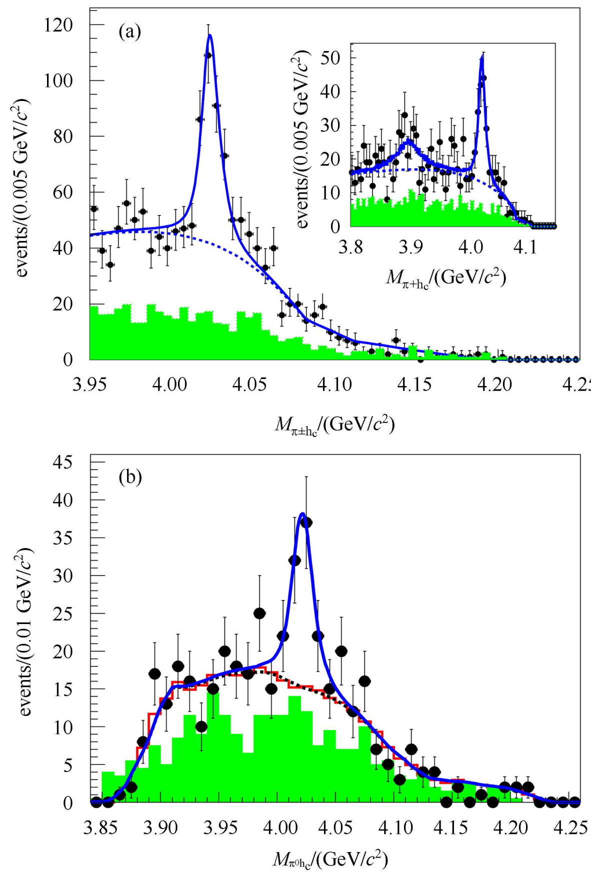

Fig. 4. (color online) The sum of the simultaneous fit to the $M_{\pi^\pm h_c}$ distribution (a) (from Ref. [30]) and sum of the simultaneous fit to the $M_{\pi^0 h_c}$ distribution at $\sqrt{s}$ = 4.23, 4.26 and 4.36 GeV(b) (from Ref. [32]).

Table 3. The resonance parameters of the $Z_c(4020)$ and $Z_c(4025)$.

state	mass (MeV/c^2)	width/MeV
$Z_c(4020)^\pm$	4022.9±0.8±2.7	7.9±2.7±2.6
$Z_c(4020)^0$	4023.9±2.2±3.8	Fixed (=7.9)
$Z_c(4025)^\pm$	4026.3±2.6±3.7	24.6±5.6±3.7
$Z_c(4025)^0$	$4025.5^{+2.0}_{-4.7}\pm3.1$	23.0±6.0±1.0

Compared to the $Z_c(4025)$ observed in the process $e^+e^- \to (D^*\bar{D}^*)^\pm\pi^\mp$ at E_{CM} = 4.26 GeV using an 827 pb^{-1} data sample based on a partial reconstruction technique [31], the resonance parameters of $Z_c(4020)$ agree with that of $Z_c(4025)$ with 1.5σ (see Table 3). If they are the same state, one can obtain $\Gamma(D^*\bar{D}^*)/\Gamma(\pi^\pm h_c)=12\pm5$, which means that the coupling of $Z_c(4020)$ to the $D^*\bar{D}^*$ mode is larger than to the $\pi^\pm h_c$ mode. The observation of both $Z_c(4020)$ and $Z_c(4025)$ states show the existence of at least one isospin triplet just above the $D^*\bar{D}^*$ threshold. If this is the charmed-sector equivalent of the $Z_b(10650)$, then it has $J^P=1^+$, in which case there is, at present, no obvious candidate for an isospin-singlet counterpart. Compared with the similar decay in B factory, if such a state exists with a mass that is above the $2m_{D^*}$ threshold and with a relatively narrow width, it might be accessible in $B^-\to K^-D^*\bar{D}^*$ decays. BaBar has reported large branching fractions for $B^-\to K^-D^{*0}\bar{D}^{*0}$ ($1.1\pm0.1\%$) and $K^-D^{*+}\bar{D}^{*-}$ ($0.13\pm0.02\%$) but did not publish any invariant mass distribution [42].

There is a small bump around 3.9 GeV in the $\pi^\pm h_c$ mass spectrum, and weak evidence of the charged $Z_c(3900)$ signal decaying into $\pi^\pm h_c$ is observed (see the inset of Fig. 4(a) [29]). A significance of 2.1σ is obtained. An upper limit of $\sigma(e^+e^-\to Z_c(3900)^\pm\pi^\mp\to\pi^+\pi^-h_c$ at 90% C.L. is given:

$$\sigma(e^+e^-\to Z_c(3900)^+\pi^-\to\pi^+\pi^-h_c)<11\text{ pb}. \quad (1)$$

By contrast

$$\sigma(e^+e^-\to Z_c(3900)^+\pi^-\to\pi^+\pi^-J/\psi)=(13.5\pm2.1)\text{ pb}. \quad (2)$$

One notices that the production rate of $Z_c(3900)$ to πh_c is much lower than that of to $\pi J/\psi$. Similarly, no $Z_c(4020)$ has been seen by BESIII and Belle in $\pi J/\psi$ mode. However, the strong decays $Z_c^\pm(3900)\to h_c(1P)\pi^\pm$ are OZI super-allowed, since the decays to the $(\pi\pi)_P^\pm$ final states are OZI super-allowed, where $(\pi\pi)_P$ denotes the P-wave $\pi\pi$ system. We expect to observe the $Z_c^\pm(3900)$ in the $h_c(1P)\pi^\pm$ final states once the statistics are large enough.

So far, no precise measurement of the quantum numbers of $Z_c(4020)$ has been performed, but the signature $J^P=1^+$ is favored. The electric charge of $Z_c(4020)^+$ implies that it contains $u\bar{d}$, and decaying to $h_c(1P)\pi^+$ indicates that it contains at least a pair of charm quarks ($c\bar{c}$). Therefore, the quark components of $Z_c(4020)^+$ are $c\bar{c}u\bar{d}$, and the same as that of $Z_c(3900)^+$ which decays to $J/\psi\pi^+$. This may suggest that $Z_c(4020)$ is a tetraquark state. While the spins of c and $\bar{c}$ are in the same direction for J/ψ and are in different directions for h_c, a further study of $Z_c(3900)^\pm$ and $Z_c(4020)^\pm$ decays into $\pi^\pm J/\psi$ and $\pi^\pm h_c$ can provide information about whether the c and $\bar{c}$ in $Z_c(3900)^\pm$ and $Z_c(4020)^\pm$ are tightly bound. The location of $Z_c(4020)^+$, which is close to the $D^*\bar{D}^*$ mass threshold, makes it a possible $D^*\bar{D}^*$ molecule state with constituents $[c\bar{d}][u\bar{c}]$.

It is well known that hybrid mesons are formed by combining a gluonic excitation with quarks ($q\bar{q}g$). Whether $Z_c(4020)^0$ could be a hybrid meson is unknown. In the following, the quantum number, theoretically predicted mass region and decay width for charmonium hybrid mesons will be discussed briefly. Hybrid mesons can have the quantum numbers for spin parity and charge conjugation (J^{PC}) in combinations such as 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, etc., which are unavailable to conventional mesons and as such provide a potential sharp signature for hybrids [43]. Even when hybrid and conventional mesons have the same J^{PC} quantum numbers, they may still be distinguished. The essential reason is that although superficially identical in their overall quantum numbers, the two states have different internal structures which give rise to characteristic selection rules [44, 45]. The flux tube model, which is the most widely cited model for hybrids, predicts theoretically the mass of the lightest charmonium hybrid state $M(H_c)=4.1$–4.2 GeV. Widths of the lightest hybrid charmonia calculated in the this model support the theory that some of these $c\bar{c}$ hybrids are likely to be rather narrow [40]. The first two points about the J^{PC} and mass make the $Z_c(4020)$ the possible candidate for the lightest charmonium hybrid state. However, the width of $Z_c(4020)^0$ is fixed as that of $Z_c(4020)^\pm$ due to the low statistics. Whether the width of $Z_c(4020)^0$ is consistent with that of the charged partner, or not, needs a large data sample to test. Therefore, the probability of $Z_c(4020)$ being a hybrid state is inconclusive based on the current experimental results.

The favored possible models mentioned above for $Z_c(4020)$ are all essentially phenomenological models whose only connection with the fundamental field theory QCD is that they use degrees of freedom from QCD. It would be desirable to have a theoretical framework based firmly on QCD that describes all the XYZ mesons.

4 Summary and outlook

The Born cross section of the isospin process $e^+e^-\to\pi\pi h_c$ is measured and the charmonium-like state $Z_c(4020)$ is observed in the invariant mass of πh_c. Both the ratio of the Born cross section $e^+e^-\to\pi\pi h_c$ and $e^+e^-\to\pi Z_c(4020)$ between charged and neutral modes are generally consistent with the isospin expectation.

The line shape of $\sigma(e^+e^-\to\pi^+\pi^-h_c)$ is very different from that of $\sigma(e^+e^-\to\pi^+\pi^-J/\psi)$. Two possible charmonium-like Y states (Y(4220) and Y(4290)) are fitted in the line shape of $\sigma(e^+e^-\to\pi\pi h_c)$. However, the contribution from Y(4260) cannot be excluded absolutely. The difference in the line shape between $\sigma(e^+e^-\to\pi^+\pi^-h_c)$ and $\sigma(e^+e^-\to\pi^+\pi^-J/\psi)$ implies that the former does not mainly come from Y(4260) decay. However, it is also hard to draw a conclusion as to whether there are any extra Y states in the $\sigma(\pi\pi h_c)$ line shape.

$Z_c(4020)^0$ is the first significant observed neutral Z_c state. There has been other subsequent research on the neutral charmonium-like state, for instance, the significant signal of $Z_c(3900)^0$ in the process $e^+e^- \to \pi^0\pi^0 J/\psi$ and $Z_c(4025)^0$ in the process $e^+e^- \to (D^*\bar{D}^*)^0\pi^0$ have been observed by the BESIII experiment [46, 47]. These results are helpful in understanding the nature of Z_c and even other XYZ particles. For instance, the observation of the isospin triplet $Z_c(4020)/Z_c(3900)$ predicted by isospin conservation and the radiative transition process $Y(4260) \to \gamma X(3872)$ [48], together with the transitions to the charged charmonium-like state $Z_c(3900)$, suggest that there might be some commonality which establishes a relationship among different XYZ particles, for example, the X(3872), Y(4260) and Z_c.

The observation of charged charmonium-like family members together with similar observation in the bottomonium family provides important evidence for the existence of hadrons beyond the conventional quark model. In the near future, more data between 4.0 and 4.6 GeV at BESIII [34] will be accumulated for further study of XYZ states. The basic parameters of $Z_c(4020)$, such as mass, width and quantum number, will be determined more precisely, especially for the neutral partner. Meanwhile, the line shape of $e^+e^- \to \pi\pi h_c$ and its intermediate state $e^+e^- \to \pi Z_c(4020)$ can also be further investigated, aiming at the Y states in the line shape of $e^+e^- \to \pi\pi h_c$ and the quantum number and width of $Z_c(4020)^0$ together with other decay modes of $Z_c(4020)^0$, so as to reveal the internal structure of exotic vector states.

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