Exotic Hadrons
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Abstract
In this talk, we review the most recent progress in the searching for the exotic hadrons, including hybrids, multi-quark states, molecules and so on. We only focus on the studies with a charmonium and one or more light mesons in the final states. This covers the $X(3872)$, the $XYZ$ states at around 3.940 GeV, the $Y(4140)$ and $X(4350)$ in two-photon collisions, the $Y$ states from ISR processes, and the charged $Z$ states.

1. Introduction
In the quark model, mesons are composed from one quark and one anti-quark, while baryons are composed from three quarks. Although no solid calculation shows hadronic states with other configurations must exist in QCD, people believe hadrons with no quark (glueball), with excited gluon (hybrid), or with more than three quarks (multi-quark state) exist. Since a proton and a neutron can be bounded to form a deuterion, it is also believed other mesons can also be bounded to produce molecules.

It is a long history of searching for all these kinds of states, however, no solid conclusion was reached until now on the existence of any one of them, except deuteron.

As the $B$-factories accumulate more and more data, lots of new states have been observed in the final states with a charmonium and some light hadrons. All these states populate in the charmonium mass region. They could be candidates for usual charmonium states, however, there are also lots of strange properties shown from these states, these make them more like exotic states rather than conventional states.

In this talk, we show the most recent results on the study of the $X(3872)$, the $XYZ$ states at around 3.940 GeV, the $Y(4140)$ and $X(4350)$, the $Y$ states from ISR processes, and the charged $Z$ states. The $X(3915)$ and $X(4350)$ found in two-photon processes, and the $Y(4140)$ found in $B$ decays are new observations.

2. The $X(3872)$

The $X(3872)$ was discovered by Belle in 2003 [1] as a narrow peak in the $\pi^+\pi^-J/\psi$ invariant mass distribution from $B \rightarrow K\pi^+\pi^-J/\psi$ decays. This discovery mode was remeasured with more statistics both at Belle and at BaBar. Belle reported a new result for the mass of the $X(3872)$ as $M_B(X_{3872}) = 3871.46 \pm 0.37 \pm 0.07$ MeV [2], and BaBar [3] measured $M_{BaBar}(X_{3872}) = 3871.30 \pm 0.60 \pm 0.10$ MeV. The most precise measurement of the mass was reported by CDF using the same decay channel: $M_{CDF}(X_{3872}) = 3871.61 \pm 0.16 \pm 0.19$ MeV [4]. A new world average that includes these new measurements plus other results that use the $\pi^+\pi^-J/\psi$ decay mode is $M_{avg}(X_{3872}) = 3871.46 \pm 0.19$ MeV, which is very close to the $D^{*0}\bar{D}^0$ mass threshold: $m_{D^{*0}} + m_{\bar{D}^0} = 3871.81 \pm 0.36$ MeV [5]. This suggests a binding energy of $-0.35 \pm 0.41$ MeV if $X(3872)$ is interpreted as a $D^{*0}\bar{D}^0$ molecule. Both Belle and BaBar measured the mass difference for the $X(3872)$ produced in neutral and charged $B$-meson decays. They both find mass differences that are consistent with zero: $M_{B^+} - M_{B^0} = 0.2 \pm 0.9 \pm 0.3$ MeV for Belle and $2.7 \pm 1.6 \pm 0.4$ MeV for BaBar. The CDF group tried to fit the $X(3872)$ to $\pi^+\pi^-J/\psi$ peak with two states, they ruled out a mass difference of less than 3.6 MeV (95% C.L.) for two $X$ states with equal production rate [4]. These results do not support the interpretation of the $X(3872)$ as a tightly bound diquark-diquark system [6, 7], which expects two nearby states with mass difference of $8 \pm 3$ MeV.

With a data sample containing $447M BB$ events, Belle observed a near-threshold $D^0\bar{D}^0\pi^0$ mass enhancement in $B \rightarrow KD^0\bar{D}^0\pi^0$ decays that, when interpreted as $X(3872) \rightarrow D^0\bar{D}^0\pi^0$, gave an $X(3872)$ mass of $3875.4 \pm 0.7_{-0.5}^{+1.2}$ MeV [8]. BaBar studied $B \rightarrow KD^0\bar{D}^0$ with a sample of $383M BB$ pairs and found a similar near-threshold enhancement that, if considered to be due to the $X(3872) \rightarrow D^0\bar{D}^0$, gave a mass of $3875.1_{-0.5}^{+0.7} \pm 0.5$ MeV [9]. This state has been considered to be a state different from the $X(3872)$ in literatures. However, a subsequent Belle study of $B \rightarrow KD^0\bar{D}^0$ based on $657M BB$ pairs finds a mass for the near threshold peak of $3872.9_{-0.4}^{+0.3} \pm 0.5$ MeV [10] by fitting the peak with a phase-space modulated Breit-Wigner (BW) function, much closer to the value determined from the $\pi^+\pi^-J/\psi$ decay channel.

The quantum number of the $X(3872)$ was found to be $1^{++}$ preferred. A study of the $\pi^+\pi^-$ mass distribution and the observation of its $\gamma J/\psi$ decays [11] indicate the C-parity of the $X(3872)$ is even, and the angular correlations among the $\pi^+\pi^-J/\psi$ final state particles constrains the $J^{PC}$ for the $X(3872)$ to be $1^{++}$ or $2^{++}$, with $1^{++}$ preferred [12]. Subsequently, the $2^{++}$ assignment has been further disfavored by BaBar’s report of $> 3\sigma$ significance signals for $X(3872)$ decays to both $\gamma J/\psi$ and $\gamma\psi(2S)$ [13]. The radiative transition of a $2^{++}$ state to the $J/\psi$ or $\psi(2S)$ would have to proceed via a higher order multipole term and be highly suppressed. For these reasons, the most likely $J^{PC}$ of the $X(3872)$ is $1^{++}$. The branching fraction of $X(3872) \rightarrow \gamma\psi(2S)$ is found to be larger than that of $X(3872) \rightarrow J/\psi$ [12], this is in contradiction with the molecule interpretation of the $X(3872)$ state [14].

Belle did a study of $X(3872)$ production in association with a $K\pi$ in $B^0 \rightarrow K^+\pi^-\pi^+\pi^- J/\psi$ decays [2]. In a sample of $657M BB$ pairs a signal of about $90 X(3872) \rightarrow \pi^+\pi^- J/\psi$ events was observed. Unlike the $B^0 \rightarrow K^+\pi^- +$ charmonium where $K^+\pi^-$ is mainly from $K^*(892)$ decays, it is evident that most of the $K\pi$ pairs have a phase space-like distribution, with little or no signal for $K^*(892) \rightarrow K\pi$. Belle reports a $K^*(892)$ to $K\pi$ non-resonant ratio of $B(B \rightarrow (K^+\pi^-)K^*(892)\psi) / B(B \rightarrow (K^+\pi^-)NRJ/\psi) < 0.55$, at the 90% C.L. This is another indication that the $X(3872)$ state is not a conventional charmonium state. However, there is no solid calculation of this above ratio assuming different nature of the $X(3872)$ state.
BaBar set an upper limit of the $X(3872)$ production rate in the $B$-meson decays by measuring the momentum distribution of the inclusive kaon from $B$-meson decays [15]:

$$B(B^- \rightarrow K^- X(3872)) < 3.2 \times 10^{-4}$$

at the 90\% C.L. Together with all the other measurements on the product branching fractions $B(B^- \rightarrow K^- X(3872)) \cdot B(X(3872) \rightarrow \text{exclusive})$, one gets

$$2.3\% < B(X(3872) \rightarrow \pi^+\pi^- J/\psi) < 6.6\%,$$

$$1.4 \times 10^{-4} < B(B^- \rightarrow K^- X(3872)) < 3.2 \times 10^{-4},$$

at the 90\% C.L. We find that the decay width of the $X(3872)$ to $\pi^+\pi^- J/\psi$ is larger and the production rate of the $X(3872)$ is smaller than conventional charmonium states such as $\eta_c$, $\psi(2S)$, and $\chi_{c1}$ [5].

3. The $XYZ$ states near 3.94 GeV

In 2005, Belle reported observations of three states with masses near 3940 MeV: the $X(3940)$, seen as a $D^*\bar{D}$ mass peak in exclusive $e^+e^- \rightarrow J/\psi D^*\bar{D}$ annihilations [17]; the $Y(3940)$, seen as an $\omega J/\psi$ mass peak in the decay $B \rightarrow K \omega J/\psi$ [17]; and the $Z(3930)$, seen as a $D\bar{D}$ mass peak in $\gamma\gamma \rightarrow DD$ events [18]. Of these, only the $Z(3930)$ has been assigned to a $2^3P_2 c\bar{c}$ charmonium state, which is commonly called the $\chi_{c2}'$.

The $X(3940)$ is produced in association with a $J/\psi$ in the $e^+e^- \rightarrow J/\psi X(3940)$ annihilation process, which fixes its C-parity as $C = +1$. Furthermore, the only known charmonium states that are seen to be produced via the process $e^+e^- \rightarrow J/\psi(\bar{c}c)$ have $J = 0$, which provides some circumstantial evidence that the $X(3940)$ has $J = 0$. This, taken together with the fact that the $X(3940)$ was discovered via its $D^*\bar{D}$ decay channel and is not seen to decay to $D\bar{D}$ - a decay channel that is preferred for $0^+\pi$ and forbidden for $0^-\pi$ - indicates that $J_{PC} = 0^{-+}$ is its most likely quantum number assignment. The unfilled $0^{-+}$ state with the closest expected mass value is the $3^3S_0 \eta_c'$, which potential model predictions put at 4043 MeV (or higher) [19], well above the $X(3940)$’s measured mass of $3942 \pm 2 \pm 6$ MeV [20].

The $Y(3940)$ mass is well above open-charm mass thresholds for decays to $D\bar{D}$ or $D^*\bar{D}$ finally states, but was discovered via its decay to the hidden charm $\omega J/\psi$ final state. This implies an $\omega J/\psi$ partial width that is much larger than expectations for usual charmonium.

In a recently reported study of $B \rightarrow KD^*\bar{D}$ decays, Belle searched for, but did not find, a signal for $B \rightarrow KY(3940)$; $Y(3940) \rightarrow D^*\bar{D}$ [21]. The quoted upper limit on this mode corresponds to a lower limit on the branching fraction ratio:

$$\frac{B(Y(3940) \rightarrow \omega J/\psi)}{B(Y(3940) \rightarrow D^{*0}\bar{D}^{0})} > 0.75$$

at the 90\% C.L. Likewise, Belle searched for evidence for $X(3940) \rightarrow \omega J/\psi$ by searching for $\omega J/\psi$ systems recoiling from a $J/\psi$ in $e^+e^- \rightarrow \omega 2J/\psi$ annihilations [14]. Here no signal is seen and an upper limit

$$\frac{B(X(3940) \rightarrow \omega J/\psi)}{B(X(3940) \rightarrow D^{*0}\bar{D}^{0})} < 0.60$$

was established at the 90\% C.L. These limits would be contradictory if the $X(3940)$ and the $Y(3940)$ were the same state seen in different production modes. Thus, the best current evidence indicates that these two states are distinct.

In 2008, BaBar [22] reported a study of $B \rightarrow K\omega J/\psi$ in which the $\omega J/\psi$ invariant mass distribution shows a near-threshold peaking that is qualitatively similar to $Y(3940)$ peak previously reported by Belle. However, the BaBar values for mass and width derived from fitting their data are both lower than the corresponding values reported by Belle and are more precise: $M = 3914^{+3.8}_{-3.4} \pm 1.6$ MeV (BaBar) compared to $3943 \pm 11 \pm 13$ MeV (Belle), and $\Gamma = 33^{+12}_{-8} \pm 0.6$ MeV (BaBar) compared to $87 \pm 22 \pm 26$ MeV (Belle). Part of the difference might be attributable to the larger data sample used by BaBar (350 fb$^{-1}$ compared to Belle’s 253 fb$^{-1}$), which enabled them to use smaller $\omega J/\psi$ mass bins in their analysis.

To add more information to the states in this mass region, Belle observed a dramatic and rather narrow peak, $X(3915)$, in the cross section for $\gamma\gamma \rightarrow \omega J/\psi$ [23] that is consistent with the mass and width reported for the $Y(3940)$ by the BaBar Group. The invariant mass distribution for the $\omega J/\psi$ candidates produced in $\gamma\gamma$ collision, shown in Fig. 1, shows a sharp peak near threshold and not much else. The statistical significance of the signal is 7.1$\sigma$.

![Fig. 1.](image)

The $\omega J/\psi$ mass distribution for selected events and the fit with a BW function plus a smooth background function (solid line). The dashed curve shows the fit with no BW term.

The fit with a BW plus a smooth background function gives results for the resonance parameters of the $X(3915)$:

$$M = 3914 \pm 4 \pm 2 \text{ MeV};$$

$$\Gamma = 28 \pm 12^{+5}_{-8} \text{ MeV}.$$ (4)

This value for the mass is about 2$\sigma$ different from that of the $Z(3930)$ ($M = 3929 \pm 5 \pm 2 \text{ MeV}$), indicating that these two peaks may not be different decay channels of the same state. On the other hand, there is good agreement between these preliminary results and the mass and width quoted by BaBar for the $Y(3940)$, which is also seen in $\omega J/\psi$.

The $X(3915)$ production rate depends on the $J^P$ value. Belle determines

$$\Gamma_{\gamma\gamma}(X(3915))B(X(3915) \rightarrow \omega J/\psi) = 69 \pm 16^{+7}_{-18} \text{ eV},$$

or

$$\Gamma_{\gamma\gamma}(X(3915))B(X(3915) \rightarrow \omega J/\psi) = 21 \pm 4^{+2}_{-5} \text{ eV},$$

for $J^P = 0^+$ or $2^+$, respectively.

The nature of the $X(3915)$ is unknown. However, it is very unlikely to be a charmonium state since the partial width of this state to $\gamma\gamma$ or $\omega J/\psi$ is too large.
4. The $Y(4140)$ and $X(4350)$

Using exclusive $B^+ \rightarrow J/\psi K^+$ decays, CDF Collaboration observed a narrow structure near the $J/\psi \phi$ mass threshold with a statistical significance of $3.8\sigma$. The mass and width of this structure are fitted to be $4143.0 \pm 2.9(\text{stat}) \pm 1.2(\text{syst})$ MeV and $11.7_{-5.9}^{+3.7}(\text{stat}) \pm 3.7(\text{syst})$ MeV respectively using an $S$-wave relativistic BW function. This new state, called $Y(4140)$ by the CDF Collaboration, is an isospin singlet state with positive $C$ and $G$ parities since the quantum numbers of both $J/\psi$ and $\phi$ are $I^G(J^{PC}) = 0^+(1^-)$.

It was argued by the CDF Collaboration that the $Y(4140)$ can not be a conventional charmonium state, because a charmonium state with mass about 4143 MeV would dominantly decay into open charm pairs, and the branching fraction into the double OZI forbidden modes $J/\psi \phi$ or $J/\psi \omega$ would be negligible.

There have been a number of different interpretations proposed for the $Y(4140)$, including a $D_s^+ D_s^-$ molecule $[25, 26, 27, 28, 29, 30, 31, 32]$, an exotic $1^-_u$ charmonium hybrid $[28]$, a $c\bar{c}ss$ tetraquark state $[33]$, or a natural consequence of the opening of the $\phi J/\psi$ channel $[34]$. There are also arguments that the $Y(4140)$ should not be a conventional charmonium $\chi_{c0}$ or $\chi_{c1}$ $[35]$, nor a scalar $D_s^+ D_s^-$ molecule $[36, 37]$.

The Belle Collaboration searched for this state using the same process with $772 \times 10^6 BB$ pairs. No significant signal was found, and the upper limit on the production rate $B(B^+ \rightarrow Y(4140) K^+, Y(4140) \rightarrow J/\psi \phi)$ is measured to be $6 \times 10^{-6}$ at the 90% C.L. Although this upper limit is lower than the central value of the CDF measurement ($9.0 \pm 3.4 \pm 2.9 \times 10^{-6}$), it does not contradict with the CDF measurement considering the large error $[24]$.

Assuming the $Y(4140)$ is a $D_s^+ D_s^-$ molecule with quantum number $J^{PC} = 0^{++}$ or $2^{++}$, the authors of Ref. $[25]$ predicted a two-photon partial width of the $Y(4140)$ of the order of 1 keV, which is large and can be tested with experimental data. The Belle Collaboration searched for this state in two-photon process $[39]$ to test this model. This analysis is based on a 825 fb$^{-1}$ data sample collected at the $\Upsilon(4S)$ ($n = 1, 3, 4, 5$) resonance. No $Y(4140)$ signal is observed, and the upper limit on the product of the two-photon decay width and branching fraction of $Y(4140) \rightarrow \phi J/\psi$ is measured to be $\Gamma_{\gamma\gamma}(Y(4140))\mathcal{B}(Y(4140) \rightarrow \phi J/\psi) < 39$ eV for $J^{P} = 0^{+}$, or $<5.7$ eV for $J^{P} = 2^{+}$ at the 90% C.L. for the first time.

The upper limit on $\Gamma_{\gamma\gamma}(Y(4140))\mathcal{B}(Y(4140) \rightarrow \phi J/\psi)$ from this experiment is lower than the prediction of $176_{-93}^{+137}$ eV for $J^{P}C = 0^{+}+\bar{0}$, $189_{-106}^{+147}$ eV for $J^{P}C = 2^{++}$ (calculated by us using the numbers in Ref. $[25]$ and total width of the $Y(4140)$ from CDF $[24]$). This disfavors the scenario of the $Y(4140)$ being a $D_s^+ D_s^-$ molecule with $J^{PC} = 0^{++}$ or $2^{++}$.

Evidence is reported for a narrow structure at 4.35 GeV/$c^2$ in the $\phi J/\psi$ mass spectrum in the above two-photon process $\gamma \gamma \rightarrow \phi J/\psi$ (see Fig. $2$) in Belle experiment. A signal of $8.8^{+4.2}_{-2.3}$ events, with statistical significance of greater than 3.2 standard deviations, is observed. The mass and natural width of the structure (named as $X(4350)$) are measured to be $4350.6_{-5.5}^{+4.3}(\text{stat}) \pm 0.7(\text{syst})$ MeV and $13.3_{-9.1}^{+17.9}(\text{stat}) \pm 4.1(\text{syst})$ MeV, respectively. The products of two-photon decay width and branching fraction to $\phi J/\psi$ is measured to be $\Gamma_{\gamma\gamma}(X(4350))\mathcal{B}(X(4350) \rightarrow \phi J/\psi) = 6.4_{-2.3}^{+3.1} \pm 1.1$ eV for $J^{P} = 0^{+}$, or $1.5_{-0.5}^{+0.7} \pm 0.3$ eV for $J^{P} = 2^{+}$. It is noted that the mass of this structure is well consistent with the predicted values of a $c\bar{c}ss$ tetraquark state with $J^{PC} = 2^{++}$ in Ref. $[33]$ and a $D_s^+ D_s^-$ molecular state in Ref. $[39]$.

5. The $Y$ states in ISR processes

The study of charmonium states via initial state radiation (ISR) at the $B$-factories has proven to be very fruitful. In the process $e^+e^- \rightarrow \gamma_{ISR} \pi^+ \pi^- J/\psi$, the BaBar Collaboration observed the $Y(4260)$ $[40]$. This structure was also observed by the CLEO $[41]$ and Belle Collaborations $[42]$ with the same technique; moreover, there is a broad structure near 4.008 GeV in the Belle data. In a subsequent search for the $Y(4260)$ in the $e^+e^- \rightarrow \gamma_{ISR} \pi^+ \pi^- \psi(2S)$ process, BaBar found a structure at around 4.32 GeV $[43]$, while the Belle Collaboration observed two resonant structures at 4.36 GeV and 4.66 GeV $[44]$. Recently, CLEO collected 13.2 pb$^{-1}$ of data at $\sqrt{s} = 4.26$ GeV and investigated 16 decay modes with charmonium or light hadrons $[45]$. The large $e^+e^- \rightarrow \pi^+ \pi^- J/\psi$ cross section at this energy is confirmed.

Figure $3$ shows the invariant mass distributions of $\pi^- \pi^- J/\psi$ and $\pi^+ \pi^- \psi(2S)$ after all the selection in Belle data $[42, 44]$, together with a fit with coherent resonance terms and a non-coherent background term. Table $1$ shows the fit results, including the $Y(4008)$ and $Y(4260)$ from the $\pi^+ \pi^- J/\psi$ mode, and the $Y(4360)$ and $Y(4660)$ from the $\pi^+ \pi^- \psi(2S)$ mode. It should be noted that there are always two solutions in the fit to each mode, with same mass and width for the resonances but with very different coupling to $e^+e^-$ pair ($\Gamma_{e^+e^-}$).

There is only one unassigned $1^-_-$ charmonium state in this mass region, the $3^3D_1$ level. This might accommodate the $Y(4660)$, but there is no room in the spectrum for all the peaks observed above. A tantalizing feature of all these states is the absence of corresponding peaking features in the total cross section for $e^+e^-$ annihilation into hadrons at the same energy (except the $Y(4008)$ which is close to the $\psi(4040)$). Figure $4$ shows BES measurements of $R_{had} = \sigma(e^+e^- \rightarrow hadrons)/\sigma_{\psi\rho}(e^+e^- \rightarrow \mu^+\mu^-)$ in the same energy region, where the cross section exhibits dips near the locations of the $Y(4260)$ and $Y(4360)$ $[45]$. (The BES $R_{had}$ measurements do not span the $Y(4660)$ region.)
solution I

\[ \pi^+(4360) \rightarrow \pi^+ \pi^- J/\psi \] (upper) and \( \pi^+ \pi^- \psi(2S) \) (lower) invariant mass distributions and the best fit with two coherent resonances together with a background term. The data are from Belle.

\( \psi(2S) \) decays to open charm implies that the \( \pi^+ \pi^- J/\psi \) (\( \pi^+ \pi^- \psi(2S) \)) partial width is large: the analysis of Ref. gives 90% C.L. lower limit \( \Gamma(Y(4260) \rightarrow \pi^+ \pi^- J/\psi) > 508 \text{ MeV} \), which should be compared to the corresponding \( \pi^+ \pi^- J/\psi \) partial widths of established \( \psi(2S) \) and \( \psi(3770) \) states. A fit to the mass distribution of \( \psi(2S) \) and \( \psi(3770) \) states in this energy range gives \( \Gamma = 107^{+96}_{-50} \) MeV.

Belle and BaBar have exploited ISR to make measurements of cross sections for exclusive open-charm final states in this energy range. The exclusive channels that have been measured so far nearly in contradiction with the BaBar 95% C.L. upper limit on \( \psi(2S) \) and the other for the \( \psi(4115) \), plus an incoherent smooth background term give a 90% C.L. upper limit on \( B(Y(4260) \rightarrow D^0 D^{*- \pi^+})/B(Y(4260) \rightarrow \pi^+ \pi^- J/\psi) < 9 \). Similar limits are obtained for the \( Y(4360) \) and \( Y(4660) \).

6. The charged \( Z \) states
Belle’s \( Z(4430)^+ \) signal is the sharp peak in the \( \pi^+ \psi(2S) \) invariant mass distribution from \( B \rightarrow K \pi^+ \psi(2S) \) decays. A fit using a BW function gives \( M = 4433 \pm 4 \pm 2 \) MeV and \( \Gamma = 45^{+189}_{-15} \pm 30 \text{ MeV} \), with an estimated statistical significance of more than 6\( \sigma \). Consistent signals are seen in various subsets of the data: i.e. for both the \( \psi(2S) \) and \( \psi(3770) \) states. A fit to the mass distribution of \( \psi(2S) \) and \( \psi(3770) \) states in this energy range gives \( \Gamma = 107^{+96}_{-50} \) MeV.

The data points in Fig. 7 show the \( M^2(\pi^+ \pi^-) \) Dalitz plot projection with the prominent \( K^+ \) bands removed compared with the results of the fit with no resonant background. The fitted mass, \( M = 4433^{+15}_{-12} \pm 19 \text{ MeV} \), agrees within the systematic errors with the earlier Belle result; the fitted width, \( \Gamma = 107^{+86}_{-74} \pm 30 \text{ MeV} \), is larger, but also within the systematic errors of the previous result. The product branching fraction from the Dalitz fit: \( B(B(4260) \rightarrow K \psi(2S)) \cdot B(Z(4430)^+ \rightarrow \pi^+ \pi^- \psi(2S)) = (3.2^{+1.8}_{-0.9} \pm 1.6) \times 10^{-5} \) is not in strong contradiction with the BaBar 95% C.L. upper limit of \( 3.1 \times 10^{-5} \).

### Table 1

| Parameters | Solution I | Solution II |
|------------|------------|-------------|
| \( M(Y(4008)) \) | 4008 ± 40^{+114}_{-26} | 4008 ± 40^{+114}_{-26} |
| \( \Gamma_{\text{tot}}(Y(4008)) \) | 226 ± 44 ± 87 | 226 ± 44 ± 87 |
| \( B \cdot \Gamma_{e^+e^-}(Y(4008)) \) | 5.0 ± 1.4^{+6.1}_{-0.9} | 12.4 ± 2.4^{+14.8}_{-1.1} |
| \( M(Y(4260)) \) | 4247 ± 12^{+17}_{-32} | 4247 ± 12^{+17}_{-32} |
| \( \Gamma_{\text{tot}}(Y(4260)) \) | 108 ± 19 ± 10 | 108 ± 19 ± 10 |
| \( B \cdot \Gamma_{e^+e^-}(Y(4260)) \) | 6.0 ± 1.2^{+5.7}_{-0.5} | 20.6 ± 2.3^{+9.7}_{-1.7} |
| \( \phi \) | 12 ± 29^{+7.5}_{-5.8} | 12 ± 29^{+7.5}_{-5.8} |

The fitted mass, \( \phi \), and the systematics agree with the earlier BaBar result; the fitted width, \( \Gamma \), is larger, but also within the systematic errors of the previous result. The product branching fraction from the Dalitz fit: \( B(B(4260) \rightarrow K \psi(2S)) \cdot B(Z(4430)^+ \rightarrow \pi^+ \pi^- \psi(2S)) = (3.2^{+1.8}_{-0.9} \pm 1.6) \times 10^{-5} \) is not in strong contradiction with the BaBar 95% C.L. upper limit of \( 3.1 \times 10^{-5} \).
the K no Z nances. M observed recently in charmonium mass region but many 7. Summary three quarks. It is an unambiguous evidence for state with more than non-zero charge, if any one of them is confirmed, to make them decay to charmonium rich final states and shows the M to that for the M fitted masses and widths of these two resonances are: Z over the fit with only one Z resonance by 5.7σ. The fitted masses and widths of these two resonances are: $M_1 = 4051 \pm 14^{+20}_{-14}$ MeV and $\Gamma_1 = 82^{+21}_{-17} - 22^{+47}_{-14}$ MeV and $M_2 = 4248^{+44}_{-29} - 35$ MeV and $\Gamma_2 = 177^{+54}_{-39} - 61^{+316}_{-39}$. The product branching fractions have central values similar to that for the $Z(4430)$ but with large errors. Figure 5 shows the $M(\pi\chi_{c1})$ projection of the Dalitz plot with the $K^*$ bands excluded and the results of the fit with no $Z \rightarrow \pi\chi_{c1}$ resonances and with two $Z \rightarrow \pi\chi_{c1}$ resonances.

Since the $Z$ states have hidden charm and light quarks to make them decay to charmonium rich final states and with non-zero charge, if any one of them is confirmed, it is an unambiguous evidence for state with more than three quarks.

7. Summary

In summary, there are lots of charmonium-like states observed recently in charmonium mass region but many of them show properties different from the naive expectation of conventional charmonium states. All these may suggest the long searching exotic states have been observed. However, due to limited statistics, the experimental information on the properties of any of these states is not enough for us to draw solid conclusion, let alone our poor knowledge on the QCD prediction of the properties of the exotic states or the usual charmonium states.

In the near future, BESIII experiment may accumulate data for center of mass energy between 3 and 4.6 GeV, this will contribute to the understanding of some of these states discussed above; the Belle II experiment under construction, with about 50 ab$^{-1}$ data accumulated, will surely improve our understanding of all these states.

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Fig. 8. The data points show the $M(\pi_{c1}^\mp)$ projection of the Dalitz plot with the $K^*$ bands removed. The histograms show the corresponding projections of the fits with and without the two $Z \rightarrow \pi_{c1}^\mp$ resonance terms.

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