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# Recent results from BESIII

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The BESIII experiment is using $e^+e^-$ annihilation in the $\tau$-charm region to study various topics in hadron physics, from the spectroscopy of light and charmonium hadrons, studies on rare and symmetry violating decays to open-charm physics. An overview over a selection of recent BESIII contributions to the field of hadron physics is given, highlighted by the recent observation of a near threshold enhancement in the recoil mass of the $K^+$ in the process $e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$ as a possible $Z_{cs}$ candidate.

*Keywords:* Hadron spectroscopy; charmonium; exotic hadrons; charmed hadrons.

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## 1. Introduction

The BESIII experiment at the Beijing Electron Positron Collider (BEPCII) is recording symmetric $e^+e^-$ collisions in the center-of-mass (c.m.) energy region between $\sqrt{s} = 2.0$ GeV and $4.94$ GeV to study various topics in hadron physics including the spectroscopy of both light hadrons and charmonium(-like) states, searches for rare and forbidden decays and the study of open-charm production and decays. Over the years, large datasets have been accumulated. Around $715$ pb$^{-1}$ of data in the c.m. energy range between $2.0$ GeV and the $J/\psi$ resonance are used to study light vector resonances such as the $\phi(2170)$. A sample of $10^{10}$ $J/\psi$ mesons is used extensively for light hadron spectroscopy, but also acts as a source for $\eta$ and $\eta'$ mesons which present an ideal environment to search for rare and symmetry violating decays. Recently, we have extended our dataset on the $\psi(2S)$ resonance from $4.48 \times 10^8$ to a total of around $2.7 \times 10^9$ events. This new dataset will nicely complement the existing $J/\psi$ data in many topics of light hadron spectroscopy, but also allows highly precise measurements of charmonium transitions. Large datasets of around $2.9$ fb$^{-1}$ and $3.2$ fb$^{-1}$ at $\sqrt{s} = 3.773$ and $4.178$ GeV serve as the primary sources of $D$ and $D_s$ mesons produced in the processes $e^+e^- \to \psi(3770) \to D\bar{D}$ and $e^+e^- \to D_s^{(*)}\bar{D}_s + cc$, respectively. In addition, a dataset corresponding to an integrated luminosity of around $22$ fb$^{-1}$ in the c.m. energy range between the $\psi(3770)$ and $\sqrt{s} = 4.94$ GeV is used for the spectroscopy of charmonium-like $XYZ$ states. Here, we highlight some of the recent contributions of BESIII to the fields of hadron spectroscopy, light meson decays and open-charm physics and give an outlook on the future perspectives of the BESIII experiment.

## 2. On $X(1835)$, $X(2120)$ and $X(2370)$

In 2003, the BESII experiment first reported the observation of a near-threshold enhancement in the $p\bar{p}$-system produced in radiative $J/\psi$ decays [1]. A possible explanation of the excess that was offered is a $p\bar{p}$ bound-state, which should then also appear in mesonic channels as a resonance below the $p\bar{p}$ threshold. A subsequent search in $J\psi \to \gamma\pi^+\pi^-\eta'$ using $5.8 \times 10^7$ $J/\psi$ found the $X(1835)$ resonance [2]. Later studies using $2.25 \times 10^8$ and $1.09 \times 10^9$ $J/\psi$ found additional resonances called $X(2120)$ and $X(2370)$ [3] and an anomalous lineshape of the $X(1835)$ in the $\pi^+\pi^-\eta'$ invariant mass spectrum close to the $p\bar{p}$ threshold [4], respectively. States similar to the $X(1835)$ have since been observed decaying to $\eta K_S^0 K_S^0$, $\gamma\phi$, $\omega\phi$ and $3(\pi^+\pi^-)$ and its quantum numbers have been established as $J^{PC} = 0^{-+}$. However, information on the $X(2120)$ and $X(2370)$ is still lacking. Recent studies of the processes $J/\psi \to \gamma K^+K^-\eta'$ and $J/\psi \to \gamma K_S^0 K_S^0 \eta'$ using $1.31 \times 10^9$ $J/\psi$ decays show a signal for the $X(2370)$ decaying to $K\bar{K}\eta'$, but find no significant $X(2120)$ contribution [5] (see Fig. 1).

In a similar study, the $X(2120)$ and $X(2370)$ were also searched for in the radiative decay $J/\psi \to \eta\eta\eta'$ [6] but no significant contribution was found. However, the invariant mass of the $\eta\eta\eta'$-system does show a clear $\eta_c$ signal, marking the first observation of the decay $\eta_c \to \eta\eta\eta'$. Using the unprecedented data sample of $10^{10}$ $J/\psi$, BESIII will keep providing key input for further investigations of the $X(1835)$, $X(2120)$ and $X(2370)$ states. First results using the full dataset are expected soon.

## 3. $\eta' \to \pi^+\pi^- l^+ l^-$ decays

The $\eta$ and $\eta'$ mesons are widely regarded as ideal testbeds to search for rare and symmetry violating decays, to study low energy QCD and to examine $\chi$PT predictions. Using $1.31 \times 10^9$ ($10^{10}$) $J/\psi$ decays and with $B(J/\psi \to \gamma\eta) = (1.108 \pm 0.027) \times 10^{-3}$ and $B(J/\psi \to \gamma\eta') = (5.25 \pm 0.07) \times 10^{-3}$ [7], large samples of $1.4 \times 10^6$ ($1.1 \times 10^7$) and $6.8 \times 10^6$ ($5.3 \times 10^7$) $\eta$ and $\eta'$ mesons produced in radiative $J/\psi$ decays in BESIII can be used to study rare and symmetry violating decays. Two recent examples of such studies using the smaller $1.31 \times 10^9$ $J/\psi$ sample are works on the decays $\eta' \to \pi^+\pi^-\mu^+\mu^-$ [8] and $\eta' \to \pi^+\pi^- e^+e^-$ [9].

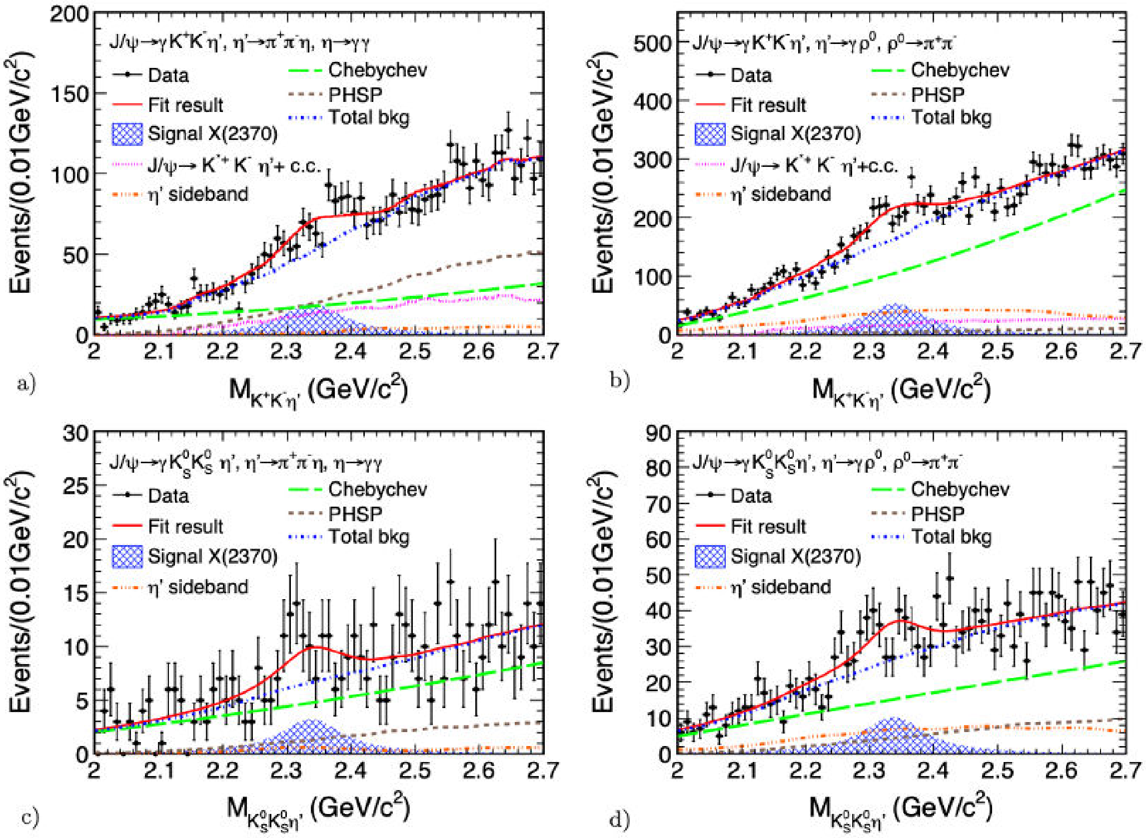


FIGURE 1. Invariant mass of the $K\bar{K}\eta'$-system produced in radiative $J/\psi$ decays for two oppositely charged kaons and subsequent a) $\eta' \to \pi^+\pi^-\eta$ or b) $\eta' \to \gamma\pi^+\pi^-$ decays, and for two neutral $K^0_S$ and subsequent c) $\eta' \to \pi^+\pi^-\eta$ or d) $\eta' \to \gamma\pi^+\pi^-$ decays. Figure taken from Ref. [5] with kind permission of The European Physical Journal (EPJ).

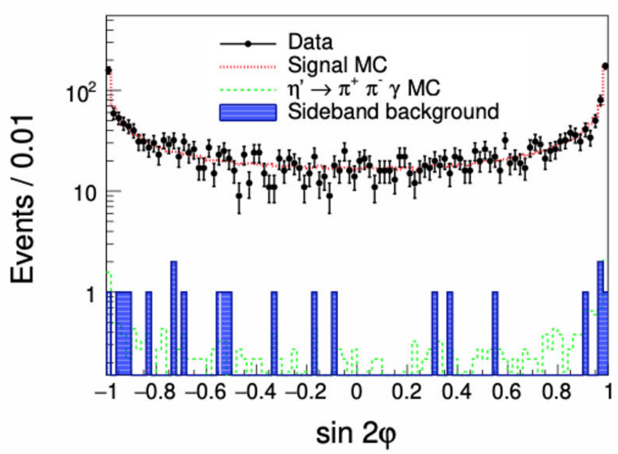


FIGURE 2. Distribution of $\sin 2\phi$, where $\phi$ is the angle between the decay planes of the $e^+e^-$ and the $\pi^+\pi^-$ pairs in the decay $\eta' \to \pi^+\pi^-e^+e^-$. Black points show data, the dotted red line the signal MC simulation for the process $\eta' \to \pi^+\pi^-e^+e^-$, the dashed green line a background MC simulation for $\eta' \to \pi^+\pi^-\gamma$ and the shaded blue histogram the contribution from the $\eta'$ sideband. Figure taken from Ref. [9].

The decay $\eta' \to \pi^+\pi^-\mu^+\mu^-$ is observed for the first time, yielding a branching ratio of $B(\eta' \to \pi^+\pi^-\mu^+\mu^-) = (1.97 \pm 0.33 \pm 0.19) \times 10^{-5}$ [8], where the first uncertainty is statistical and the second is systematic. In case of $\eta' \to \pi^+\pi^-e^+e^-$ on the other hand, the branching ratio is found to be two orders of magnitude larger at $B(\eta' \to \pi^+\pi^-e^+e^-) = (2.42 \pm 0.05 \pm 0.08) \times 10^{-3}$ [9]. This decay allows for a test of $CP$-violation, as an interference between the dominating, $CP$-conserving magnetic transition and a possible $CP$-violating electric dipole transition would generate an asymmetry $A_\phi$ in the $\sin 2\phi$ distribution of the angle between the decay planes of the lepton- and the pion-pair [9–12]. As can be seen from Fig. 2, the observed $\sin 2\phi$ distribution does not exhibit an asymmetry for the decay $\eta' \to \pi^+\pi^-e^+e^-$, and a value of $A_\phi = (2.9 \pm 3.7 \pm 1.1)\%$ is obtained [9] which is consistent with $CP$-conservation and of similar precision as an earlier asymmetry measurement in $K^0_L \to \pi^+\pi^-e^+e^-$ decays [13, 14].

## 4. Search for $J/\psi$ weak decays

Exploiting the full $10^{10}$ $J/\psi$ dataset, we can perform sensitive searches for unexpectedly large couplings to otherwise rare or very rare decay channels. One such example is the search for the weak, semi-leptonic decay $J/\psi \to D^-e^+\nu_e + c.c.$ [15]. In the Standard Model (SM), the branching ratio

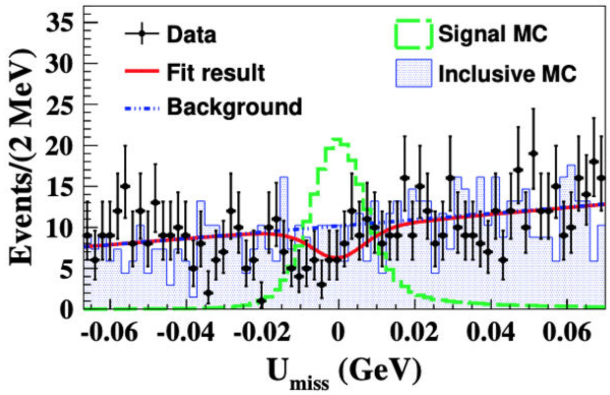


FIGURE 3. Distribution of $U_{\text{miss}}$ from the search for the weak decay $J/\psi \to D^- e^+ \nu_e + c.c.$. Black points show data, the green dashed line indicates what a signal contribution would look like, the shaded blue histogram shows the background prediction from an inclusive MC simulation, while the solid red and dash-dotted blue lines show a fit to the data and the background component of that fit, respectively. Figure taken from Ref. [15].

for weak decays to a single charmed meson is predicted to be of the order of $10^{-8}$ or below (see Ref. [15] and references therein). However, certain models going beyond the SM predict these branching ratios to be significantly larger, reaching values of $10^{-5}$ [16]. In order to search for $J/\psi \to D^- e^+ \nu_e + c.c.$, events with charged hadron candidates $K^+$, $\pi^-$, $\pi^-$ and a charged lepton candidate $e^+$ are reconstructed, where the charged hadrons are used to form the $D^-$ meson. In case of the signal decay, the observable $U_{\text{miss}} = E_{\text{miss}} - c|\vec{p}_{\text{miss}}|$, where $E_{\text{miss}}$ and $\vec{p}_{\text{miss}}$ are the missing energy and momentum between the initial state $J/\psi$ and the reconstructed $K^+$, $\pi^-$, $\pi^-$ and $e^+$, is expected to peak at zero. As can be seen from Fig. 3, no signal is observed and an upper limit is set at $B(J/\psi \to D^- e^+ \nu_e + c.c.) < 7.1 \times 10^{-8}$ at $90\%$ CL [15].

## 5. The doubly Cabibbo-suppressed decay $D^+ \to K^+\pi^+\pi^-\pi^0$

Doubly Cabibbo-suppressed (DCS) decays are a powerful tool to study weak decay mechanisms. Naïvely, one would expect the decay rate of a DCS decay to be smaller by a factor of $\tan^4\theta_C \sim 0.29\%$ compared to its Cabibbo-favored (CF) counterpart, where $\theta_C$ is the Cabibbo mixing angle. This expectation seems to roughly agree with earlier observations of DCS and CF decays [17]. Using $D^+D^-$ pairs produced on the $\psi(3770)$ resonance, we have searched for the DCS decay $D^+ \to K^+\pi^+\pi^-\pi^0$ against three hadronic tag modes ($D^- \to K^+\pi^-\pi^-$, $D^- \to K_S^0\pi^-$ and $D^- \to K^+\pi^-\pi^-\pi^0$) [18]. Removing resonant contributions from $D^+ \to K^+\eta$ and $D^+ \to K^+\omega$, marking the first evidence for the decay $D^+ \to K^+\omega$, a branching ratio of $B(D^+ \to K^+\pi^+\pi^-\pi^0) = (1.13 \pm 0.08 \pm 0.03) \times 10^{-3}$ is reported [18]. Combined with the world-average value for the CF decay $D^+ \to K^-\pi^+\pi^+\pi^0$, an unexpectedly large ratio of the DCS over the CF decay of $B(D^+ \to K^+\pi^+\pi^-\pi^0)/B(D^+ \to K^-\pi^+\pi^+\pi^0) = (1.81 \pm 0.15)\% = (6.28 \pm 0.52)\tan^4\theta_C$ is found [18].

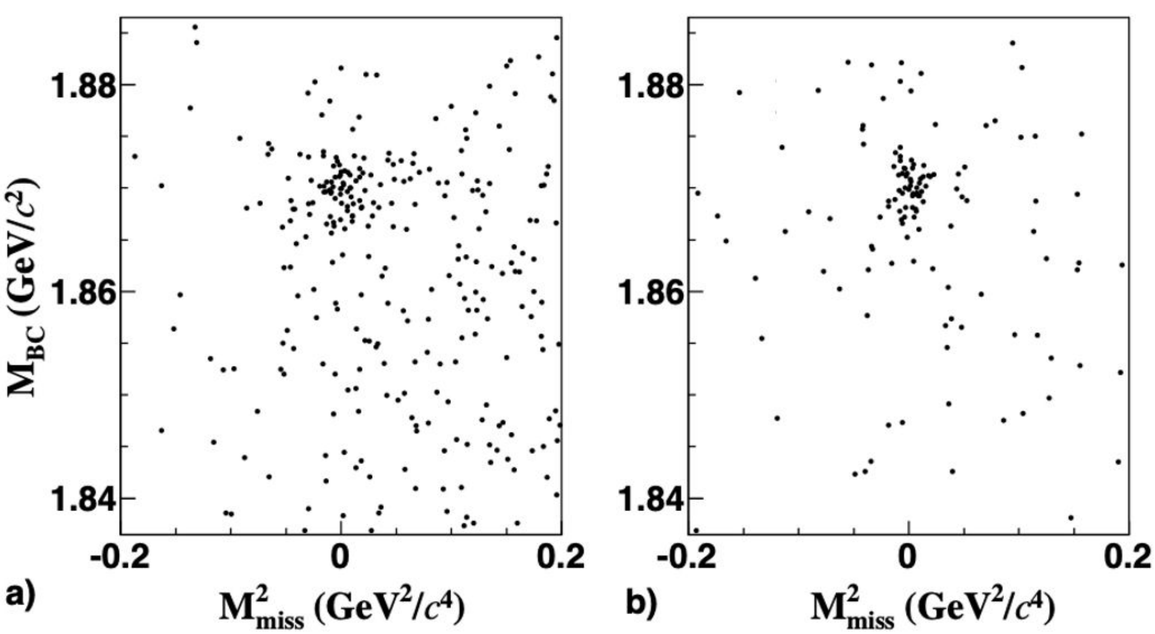


FIGURE 4. Scatter plot of the beam-constrained mass $M_{BC}$ as a function of the missing mass $M^2_{\text{miss}}$ for the semi-leptonic tag modes (a) $D^- \to K^0 e^- \bar{\nu}_e$ and (b) $D^- \to K^+\pi^- e^- \bar{\nu}_e$. Signals from the DCS decay $D^+ \to K^+\pi^+\pi^-\pi^0$ against the semi-leptonic tags are expected around $M_{BC} = m_D$ and $M^2_{\text{miss}} = 0$. Figure taken from Ref. [19].

The search for the same DCS signal decay was repeated using the semi-leptonic tag modes $D^- \to K^0 e^- \bar{\nu}_e$ and $D^- \to K^+\pi^- e^- \bar{\nu}_e$ using the missing mass technique to reconstruct the missing neutrino [19]. Resulting distributions of the beam-constrained (BS) mass $M_{BC} = \sqrt{E^2_{\text{beam}} - |\vec{p}_{D^+}|^2}$ versus the missing mass $M^2_{\text{miss}}$, displayed in Fig. 4, show a clear coincidence of the reconstructed DCS decay $D^+ \to K^+\pi^+\pi^-\pi^0$ in $M_{BC}$ and the missing neutrino. A branching fraction of $B(D^+ \to K^+\pi^+\pi^-\pi^0) = (1.03 \pm 0.12 \pm 0.06) \times 10^{-3}$ is measured, corresponding to $B(D^+ \to K^+\pi^+\pi^-\pi^0)/B(D^+ \to K^-\pi^+\pi^+\pi^0) = (1.65 \pm 0.21)\% = (5.73 \pm 0.73) \tan^4 \theta_C$ [19], confirming the observation of an unexpectedly large DCS decay made in Ref. [18].

Given that the ratio of the DCS decay $D^0 \to K^+\pi^+\pi^+\pi^-$ over its CF counterpart is in agreement with the naïve expectation, contributions from wide resonances or final state interaction effects might play an important role explaining the unexpectedly large branching ratio of $D^+ \to K^+\pi^+\pi^-\pi^0$. A key observation of this study is that the semi-leptonic tag method works well and with similar precision compared to the hadronic tag. This will be especially interesting in the search for DCS decays of neutral $D^0$ mesons in the future, where the use of hadronic tags is difficult given that the DCS decay of the $D^0$ is the CF decay of the $\bar{D}^0$ and vice versa.

It is planned to extend the existing dataset on the $\psi(3770)$ resonance from 2.9 fb$^{-1}$ to 20 fb$^{-1}$ in the upcoming measurement period, paving the way for highly precise open-charm and flavour-physics studies in the future.

## 6. The decay $D_s^+ \to \pi^+\pi^+\pi^-\eta$ and weak annihilation in $D_s^+ \to a_0(980)^+\rho(770)^0$

Using data at center-of-mass energies between $4.178$ and $4.226$ GeV with a total integrated luminosity of $6.32$ fb$^{-1}$, the decay $D_s^+ \to \pi^+\pi^+\pi^-\eta$ was searched for in a double-tag analysis of the process $e^+e^- \to D_s^{*\pm} D_s^{\mp}$, $D_s^{*\pm} \to \gamma D_s^{\pm}$ [20]. Tag-side $D_s^-$ decays are reconstructed in one of eight hadronic decay modes, while the $\eta$ meson on the signal-side is detected in its decay to two photons. A clear signal is observed and the branching fraction $B(D_s^+ \to \pi^+\pi^+\pi^-\eta) = (3.12 \pm 0.13 \pm 0.09)\%$ is measured for the first time [20], where the first uncertainty is statistical and the second is systematic. An amplitude analysis is performed and finds significant contributions of the decays $D_s^+ \to a_1(1260)^+\eta$ (with $a_1(1260)^+ \to \rho(770)^0\pi^+$ and $a_1(1260)^+ \to f_0(500)\pi^+$), $a_0(980)^+\rho(770)^0$, $\eta(1405)\pi^+$ (with $\eta(1405) \to a_0(980)^{\pm}\pi^{\mp}$), $f_1(1420)\pi^+$ (with $f_1(1420) \to a_0(980)^{\pm}\pi^{\mp}$) and the non-resonant processes $D_s^+ \to [a_0(980)^{\pm}\pi^{\mp}]_S\pi^+$, $D_s^+ \to [f_0(980)\eta]_S\pi^+$ and $D_s^+ \to [f_0(500)\eta]_S\pi^+$, where the subscript $S$ indicates that the two particles in square-brackets are in a relative $S$-wave. While the decay $D_s^+ \to a_1(1260)^+\eta$ is the dominant contribution, the $D_s^+ \to a_0(980)^+\rho(770)^0$ decay is of particular interest, as it can proceed through the weak annihilation process shown in Fig. 5.

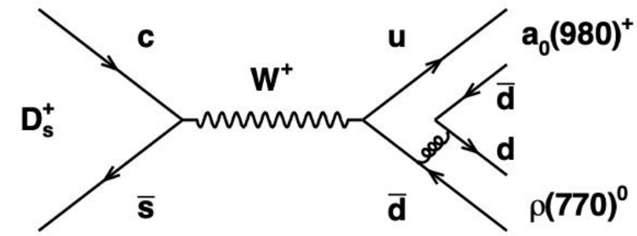


FIGURE 5. Weak annihilation diagram for $D_s^+ \to a_0(980)^+\rho(770)^0$. Figure taken from Ref. [20].

The observed branching ratio $B(D_s^+ \to a_0(980)^+\rho(770)^0) = (0.21 \pm 0.08 \pm 0.05)\%$ [20] is larger than the ones for the pure weak annihilation decays $D_s^+ \to \rho(770)^0\pi^+$ and $\pi^0\pi^+$ by an order of magnitude. Given that the interpretation of the decay as depicted in Fig. 5 depends on the internal structure of the $a_0(980)^+$, the result reported in Ref. [20] offers the opportunity to understand the nature of the $a_0(980)^+$ better as well as to study the importance of rescattering effects in $D_s^+$ decays. More details on the amplitude analysis and the interpretation of its results can be found in Ref. [20].

## 7. Charmonium and Charmonium-like states

Ever since the discovery of the $X(3872)$ by Belle in 2003 [21], a multitude of new, potentially exotic hadrons has been discovered in the charmonium region. An overview over the spectrum of charmonium and a selection of exotic hadron candidates is given in Fig. 6. Despite extensive experimental studies and significant effort from theory, the nature of the exotic hadron candidates in the charmonium region is still not fully understood.

### 7.1. $\psi(4230)$ and $\psi(4360)$

At BESIII, exotic hadrons sharing the quantum numbers $J^{PC} = 1^{--}$ with the photon are directly produced in $e^+e^-$ collisions, resulting in a large number of searches for new decay modes of the $\psi(4230)$ and $\psi(4360)$ as well as detailed measurements of their lineshapes in channels with sizable couplings. A summary of recent measurements of BESIII in terms of observed (Breit Wigner) masses and widths of the $\psi(4230)$ and $\psi(4360)$ is displayed in Fig. 7. Two of the most recent contributions to the investigation of the $\psi(4230)$ and $\psi(4360)$ are an updated measurement of the cross section for the process $e^+e^- \to \eta J/\psi$ [25] and a study of the process $e^+e^- \to \mu^+\mu^-$ [23]. In the former case, two potentially exotic resonances are found in addition to the conventional charmonium state $\psi(4040)$, while the latter case finds only the lower mass exotic state candidate in addition to the conventional charmonia $\psi(4040)$, $\psi(4160)$ and $\psi(4415)$. It is of special interest that the process $e^+e^- \to \mu^+\mu^-$ allows to

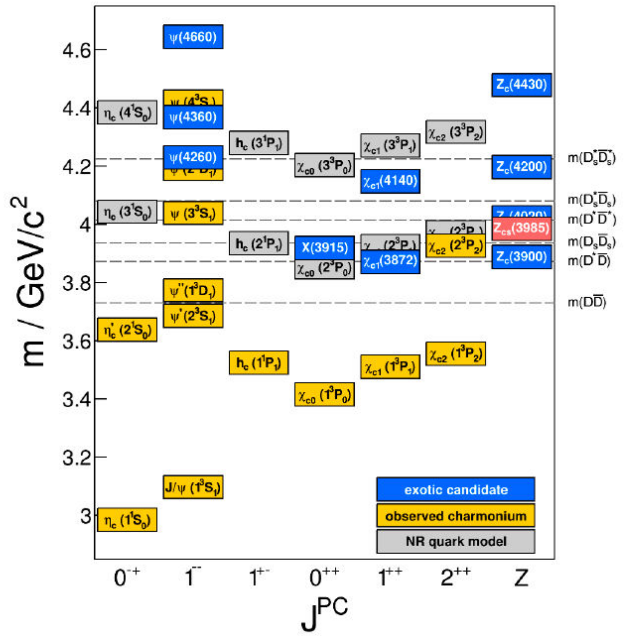


FIGURE 6. Spectrum of charmonium(-like) states, with potential model calculations shown in gray, observed charmonium states shown in orange, and exotic hadron candidates shown in blue. The newly discovered $Z_{cs}$-candidate is shown in red. Potential model results are from Ref. [22].

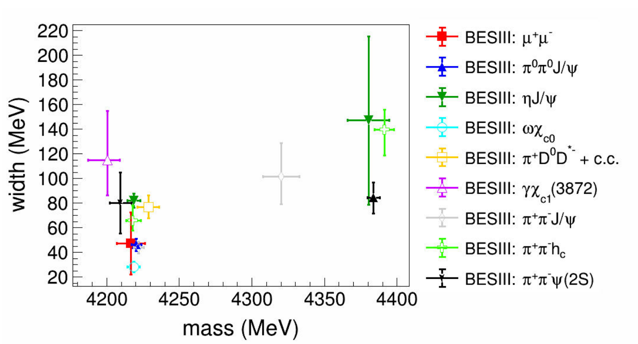


FIGURE 7. Breit Wigner masses and widths of exotic hadron candidates observed at BESIII in the $\psi(4230)$ and $\psi(4360)$ mass regions. Values are taken from Refs. [23–31].

measure the muonic (electronic) width of the contributing resonances under the assumption of lepton universality ($\Gamma_{e^+e^-} = \Gamma_{\mu^+\mu^-}$). Values for eight different, ambiguous fit solutions are reported in Ref. [23].

### 7.2. A potential $Z_{cs}$ candidate in $e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$

Charged charmonium- and bottomonium-like $Z_c$ and $Z_b$ states offer a unique possibility to study hadrons that are unequivocally identified as exotic, containing both a $c\bar{c}$ ($b\bar{b}$) and a light-quark pair. Under the assumption of $SU(3)$ flavor symmetry, strange partner states $Z_{cs}$ with one of the light quarks replaced by a strange quark would be expected. Given that the lightest observed $Z_c$ state lies close to the two-body

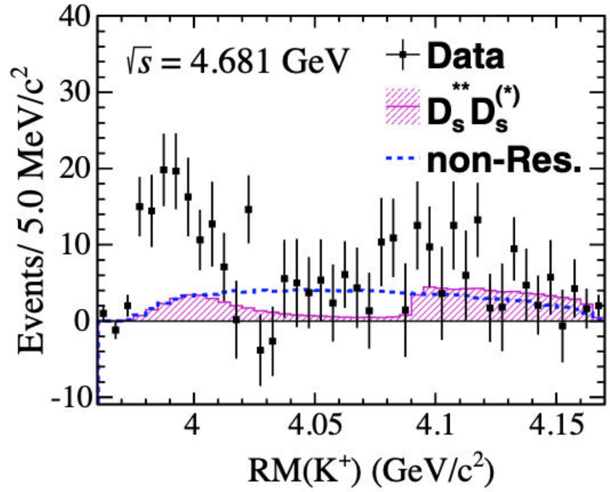


FIGURE 8. Distribution of the mass of the system recoiling against the $K^+$ in $e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$ for data at $\sqrt{s} =$ 4.681 GeV. Combinatorial backgrounds have been subtracted. Figure taken from Ref. [32].

$DD^*$ open-charm threshold, it is natural to expect the strange partner state to have a mass close to the $D_s^- D^{*0}$ and $D_s^{*-} D^0$ thresholds, an assumption that is backed up by various theoretical models (see Ref. [32] and references therein). Using datasets at the c.m. energies 4.628, 4.641, 4.661, 4.681 and 4.698 GeV with a total integrated luminosity of 3.7 fb$^{-1}$, the processes $e^+e^- \to K^+ D_s^- D^{*0}$ and $K^+ D_s^{*-} D^0$ are studied [32]. A partial reconstruction technique is used, reconstructing the $K^+$ and the $D_s^-$ (in the decays $D_s^- \to K^+K^-\pi^-$ and $K_S^0 K^+$) and studying the mass of the system recoiling against the $K^+ D_s^-$ pair to identify the signal processes. Here, $e^+e^- \to K^+ D_s^- D^{*0}$ shows a peak at the $D^{*0}$ mass, whereas the process $e^+e^- \to K^+ D_s^{*-} D^0$ yields a broader distribution in the same mass range. Thus, the two processes can presently not be disentangled. Once the signal process is selected, the mass recoiling against the bachelor $K^+$ shows a strong enhancement close to the $D_s^- D^{*0}$ and $D_s^{*-} D^0$ thresholds for the measurement at $\sqrt{s} = 4.681$ GeV (see Fig. 8) that can not be explained by decays of known, excited open-charm mesons.

If interpreted as a resonant structure decaying to $D_s^- D^{*0} + D_s^{*-} D^0$ described by a mass-dependent-width Breit Wigner line shape, a pole position $m_{\text{pole}} - i\Gamma_{\text{pole}}/2$ of $m_{\text{pole}} = (3982.5^{+1.8}_{-2.6} \pm 2.1)$ MeV$/c^2$ and $\Gamma_{\text{pole}} = (12.8^{+5.3}_{-4.4} \pm 3.0)$ MeV is found [32]. The resonant contribution is estimated to have a significance of $5.3\sigma$ compared to a hypothesis including only conventional charmed hadrons. While a large number of possible contributions from interference between different open-charm production processes has been studied and found to be unable to explain the near threshold excess in Ref. [32], at present other explanations outside of the resonance hypothesis can not be excluded. The LHCb collaboration reported a $Z_{cs}$ candidate at a similar mass but with a larger width decaying to $J/\psi K^+$ [33]. As of now, it is unclear whether the two structures are related. An amplitude analysis based on a sample with larger statistics will be necessary and is anticipated for the future.

### 7.3. Studies on the $\psi_2(3823)$

Charmonium states below the open-charm threshold are studied in high detail in experiment and agree very well with potential model calculations. Above the open-charm threshold, many states predicted from potential model calculations have not yet been found. The lightest charmonium state above the open-charm threshold, the $\psi(3770)$ is a member of the $D$-wave spin-triplet, whose other members are supposedly the $\psi_2(3823)$, first observed by Belle and later confirmed by both BESIII and LHCb and the $\psi_3(3842)$, seen by LHCb. Using a data sample with an integrated luminosity of $19$ fb$^{-1}$ in the energy region between 4.1 and 4.7 GeV, studies on both the production and decays of the $\psi_2(3823)$ have been performed in Ref. [34]. Based on the established production process $e^+e^- \to \pi^+\pi^-\psi_2(3823)$, the decays $\psi_2(3823) \to \gamma\chi_{c0}$, $\gamma\chi_{c1}$, $\gamma\chi_{c2}$, $\pi^+\pi^-J/\psi$, $\pi^0\pi^0J/\psi$, $\eta J/\psi$, and $\pi^0 J/\psi$ are searched for. A significant signal is found for the known decay mode $\psi_2(3823) \to \gamma\chi_{c1}$ and first evidence is reported for $\psi_2(3823) \to \gamma\chi_{c2}$ at the level of $3.2\sigma$, while no significant signal could be found for any of the other decay modes [34]. The relative branching fraction of the decay $\psi_2(3823) \to \gamma\chi_{c2}$ over $\psi_2(3823) \to \gamma\chi_{c1}$ is found to be $\frac{B(\psi_2(3823)\to\gamma\chi_{c2})}{B(\psi_2(3823)\to\gamma\chi_{c1})} = 0.28^{+0.14}_{-0.11} \pm 0.02$ [34]. Upper limits for the other decay channels are reported in Ref. [34]. In addition, first evidence is found for the production process $e^+e^- \to \pi^0\pi^0\psi_2(3823)$ based on the decay $\psi_2(3823) \to \gamma\chi_{c1}$ and the ratio of the cross section compared to the charged-pion channel $\frac{e^+e^-\to\pi^0\pi^0\psi_2(3823)}{e^+e^-\to\pi^+\pi^-\psi_2(3823)} = (0.64^{+0.22}_{-0.20}\pm 0.05)$ is found to be consistent with isospin symmetry [34].

## 8. Summary and Outlook

The BESIII collaboration remains highly active and is making valuable contributions to various active topics in hadron physics, including hadron spectroscopy, searches for rare and symmetry violating decays and studies of both production and decays of open-charm hadrons. Only a small selection of the most recent results could be discussed in this contribution. With data taking on new measurements on the $\psi(2S)$ resonance and in the energy region between $4.6$ and $5.0$ GeV already finished, data taking on an extension of the $\psi(3770)$ dataset starting soon and plans for an accelerator upgrade to increase both the c.m. energy and the instantaneous luminosity, we expect more exciting results to come over the next years. A more detailed account of the BESIII experiment, its physics goals, past achievements and future perspectives can be found in Ref. [35].

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