PROCEEDINGS OF SCIENCE

Recent results on spectroscopy of X, Y and Z states at BESIII

Ronggang Ping[*†]
on behalf of the BESIII collaboration
Institute of High Energy Physic, CAS
E-mail: pingrg@ihep.ac.cn

Using data from e^+e^- annihilation collected with the BESIII detector, we investigated the isospin violation decays of $X(3872)$ in the processes $e^+e^- \to \omega J/\psi, \pi^0\chi_{c1}$, and $\pi^+\pi^- J/\psi$. We also measured the cross section for the processes $e^+e^- \to D^{*0}D^{*-}\pi^+, \pi^+\pi^- D^+D^-, D_s^{*+}D_s^{*-}, K^+K^- J/\psi$, and $K_S^0K_S^0 J/\psi$, searching for Y states in the energy-dependence of the cross section. In the analysis of $e^+e^- \to K^+(D_s^-D^{*0} + D_s^{*-}D^0)$, we observed an excess of events above the mass threshold in the K^+ recoil-mass spectrum with a significance larger than 5σ. This marks the first candidate for a charged hidden-charm tetraquark with strangeness. We also searched for the neutral Z_{cs}^0 in the process $e^+e^- \to K_S^0(D_s^+D^{*-} + D_s^{*+}D^-)$, but no signal evidence was observed. Additionally, we investigated the potential excited state Z_{cs}' in the process $e^+e^- \to K^+Z_{cs}'^-$, but no significant signals were observed.

The International Conference on B-Physics at Frontier Machines - BEAUTY2023
3-7 July, 2023
Clermont-Ferrand, France

[*]Speaker.

[†]The work is partly supported by the National Natural Science Foundation of China under Grant No. 12175244 and 11875262.

PoS(BEAUTY2023)014

1. Introduction

In the conventional quark model, mesons consist of quark and antiquark pairs, while (anti-) baryons consist of three (anti-)quarks. Due to the non-abelian properties of quantum chromodynamics (QCD), gluons can interact with themselves, forming glueballs. Despite extensive efforts to search for glueballs, no such state has been established in experiments. Additionally, QCD predicts the existence of hybrid states, which have an additional gluonic component in mesons or baryons, and multiquark states, which have more than three constituent quarks bound in a resonance.

The search for these unconventional (or exotic) states has been ongoing for many years. Some candidates for multiquark states have been suggested in the sector of light quark mesons, but they remain controversial in the physics community. In 2003, the Belle collaboration reported the first observation of an exotic resonance, $X(3872)$, in the $B^{\pm} \to X(3872)K^{\pm}$, $X(3872) \to \pi^+\pi^- J/\psi$ decay [1]. This resonance exhibits some exotic properties, such as a mass very close to the $D^0\bar{D}^{*0}$ pair production threshold , but with an extremely narrow decay width of less than 1.2 MeV. Since then, many exotic states, known as XYZ states, have been reported in experiments conducted by Belle [2, 3], BaBar [4, 5], BESIII [6, 7], and LHC [8, 9].

Compared to the B factory, the τ-charm factory provides us with a laboratory to study the production mechanism of XYZ states. Whether in continuum production or subsequent hadronic decay, these processes conserve the PC parity and/or G parity, which provides valuable information for determining the quantum numbers of XYZ states.

BEPCII/BESIII has accumulated a large amount of data sets above 4 GeV with high integrated luminosity. In this presentation, I will present the measurement results of XYZ states obtained from these data sets using BESIII.

2. $X(3872)$ state

The first exotic state, $X(3872)$, was initially reported by the Belle Collaboration in 2003 [1]. They observed an exceptionally narrow structure in the $\pi^+\pi^- J/\psi$ spectrum in the decays $B^{\pm} \to K^{\pm}\pi^+\pi^- J/\psi$. What makes this discovery particularly intriguing is that the mass of $X(3872)$ is very close to the $D^0\bar{D}^{*0}$ threshold, yet its decay width is less than 1.2 MeV. This behavior stands in stark contrast to the decays of charmonium states with masses above the open charm threshold.

In addition to the mass and decay width of $X(3872)$, its isospin-breaking decays are also noteworthy. In the discovery decay channel of $X(3872) \to \pi^+\pi^- J/\psi$, the kinematic upper limit of $\pi^+\pi^-$ is found to be near the lower end of the mass spectrum of $\rho(770)^0$ [10]. Since $X(3872)$ and J/ψ are isospin-scalar states, the decay $X(3872) \to \rho^0 J/\psi$, where ρ^0 decays into $\pi^+\pi^-$, represents an isospin-breaking decay. Furthermore, the isospin-conserving decay $X(3872) \to \omega J/\psi$ has also been observed, with a branching fraction ratio of $\mathscr{R} = B(X(3872) \to \omega J/\psi)/B(X(3872) \to \pi^+\pi^- J/\psi) = 0.8 \pm 0.3$ [11].

The decays $X(3872) \to \omega J/\psi$ and $\pi^+\pi^- J/\psi$ were investigated using 11.6 fb^{-1} of e^+e^- annihilation data collected at center-of-mass energies ranging from $\sqrt{s} = 4.008$ GeV to 4.600 GeV with the BESIII detector [12]. In the mass distribution of $\omega J/\psi$ shown in Fig. 1, a resonance corresponding to $X(3872)$ was observed with a significance exceeding 5σ. The branching fraction

ratio was determined to be $\mathscr{R} = B(X(3872) \to \omega J/\psi)/B(X(3872) \to \pi^+\pi^- J/\psi) = 1.6^{+0.4}_{-0.3} \pm 0.2$, where the first uncertainty is statistical and the second uncertainty is systematic.

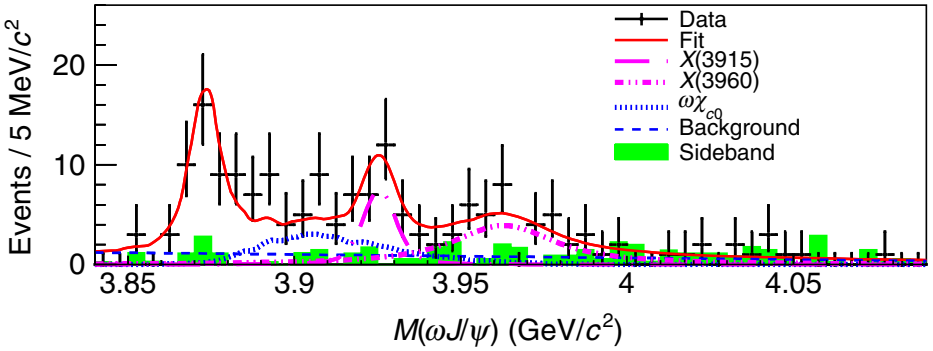

Figure 1: Invariant mass distribution of $\omega J/\psi$ in the process $e^+e^- \to \gamma\omega J/\psi$ for the full data set [12].

Another isospin-breaking decay, $X(3872) \to \pi^0\chi_{c1}$, has also been observed experimentally. Using a total of 9.0 fb^{-1} of e^+e^- collision data collected by the BESIII detector at center-of-mass energies between 4.15 and 4.30 GeV, the decay process $e^+e^- \to \gamma X(3872)$ was studied [13], specifically focusing on $X(3872) \to \pi^0\chi_{cJ}$ with $J = 0,1,2$. Figure 2 displays the mass spectrum of $\gamma J/\psi$ within the $X(3872)$ mass range, clearly showing a significant signal of χ_{c1} with a statistical significance exceeding 5σ. The measured relative branching fraction is $B(X(3872) \to \pi^0\chi_{c1})/B(X(3872) \to \pi^+\pi^- J/\psi) = 0.88^{+0.33}_{-0.27} \pm 0.10$.

Currently, the only experimentally established radiative decay process of $X(3872)$ is $X(3872) \to \gamma J/\psi$[14], with a branching fraction of $(8 \pm 4) \times 10^{-3}$. Other processes, such as $X(3872) \to \gamma J/\psi, \gamma\psi(2S), \gamma D^+D^-$, were investigated using a 9.0 fb^{-1} data sample collected at center-of-mass energies ranging from 4.178 to 4.278 GeV with the BESIII detector [15]. Evidence of $X(3872) \to \gamma J/\psi$ was found with a significance of 3.5σ, and the relative branching fraction was determined to be $B(X(3872) \to \gamma J/\psi)/B(X(3872) \to \pi^+\pi^- J/\psi) = 0.79 \pm 0.28$. However, no significant signals were observed for the $X(3872) \to \gamma\psi(2S)$ and γD^+D^- decays.

3. Y states

3.1 $\psi(4230)/Y(4260)$, $\psi(4360)$, $\psi(4500)$ and $\psi(4660)$ states

The original $Y(4260)$ was observed by the Babar Collaboartion [4] as a peak in the energy dependence of the $e^+e^- \to \pi^+\pi^- J/\psi$ cross section and was confirmed by CLEO [16], Belle [17] and other experiments in the same process. A higher-statistics analysis by BESIII [18] in 2017 revealed an asymmetry in the cross section and resulted in a shift of the peak position to a lower mass. The $Y(4260)$ or $\psi(4260)$ was theorefore renamed $\psi(4230)$ in the PDG book [11].

The Born cross sections of the process $e^+e^- \to D^{*0}D^{*-}\pi^+$ at center-of-mass energies from 4.189 to 4.951 GeV were measured with a BESIII e^+e^- annihilation data samples corresponding to an integrated luminosity of 17.9 fb^{-1} [19]. In the cross section of energy dependence distribution, three vector resonances, $\psi(4230), \psi(4500)$ and $\psi(4660)$ were observed as shown in Fig. 3.

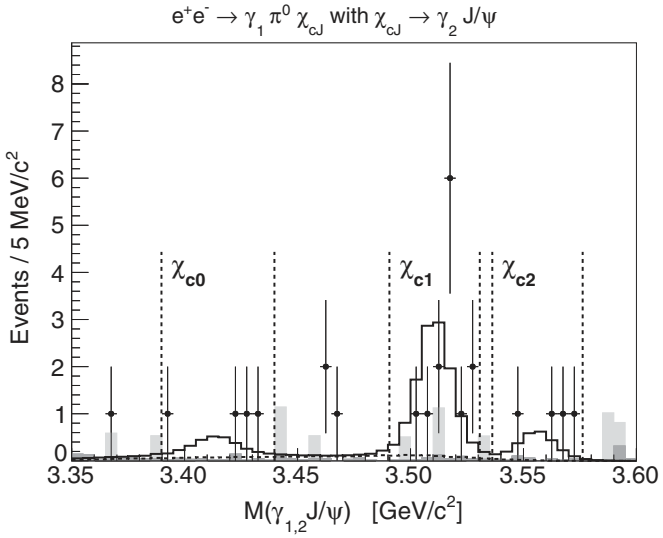

Figure 2: Distribution of $M_{\gamma J/\psi}$ after selecting the $X(3872)$ signal region [13]. Points are data, and shaded histograms shows the backgrounds. The solid line is the signal MC and is scaled using subsequent fits; the dashed line is the component of the signal MC where γ_1 and γ_2 are interchanged. Vertical lines show the χ_{cJ} selection regions.

The resonances have masses of $(4209.6 \pm 4.7 \pm 5.9)$ MeV/c^2, $(4469.1 \pm 26.2 \pm 3.6)$ MeV/c^2, and $(4675.3 \pm 29.5 \pm 3.5)$ MeV/c^2 and widths of $(81.6 \pm 17.8 \pm 9.0)$ MeV, $(246.3 \pm 36.7 \pm 9.4)$ MeV, and $(218.3 \pm 72.9 \pm 9.3)$ MeV, respectively, where the first uncertainties are statistical and the second systematic.

The Born cross sections of the process $e^+e^- \to \pi^+\pi^- D^+D^-$ at center-of-mass energies from 4.190 to 4.946 GeV were measured with the BESIII e^+e^- annihilation data samples corresponding to an integrated luminosity of 17.4 fb^{-1} [20]. In the cross section of energy dependence distribution, the vector resonances, $\psi(4360)$ was observed as shown in Fig. 4. The mass and width of the resonance at about 4.4 GeV are determined to be $(4371.6 \pm 2.5 \pm 9.2)$ MeV/c^2 and $(167 \pm 4 \pm 29)$ MeV, respectively, where the first uncertainties are statistical and the second systematic.

3.2 $\psi(4415)$ state

The process $e^+e^- \to D_s^{*+}D_s^{*-}$ is investigated using a semi-inclusive method with BESIII data samples collected at center-of-mass energies ranging from threshold to 4.95 GeV [21]. The Born cross sections of this process are measured for the first time in this energy region with high precision. Notably, it exhibits a large cross section of a few hundred picobarns, as shown in Fig. 5.

In the energy-dependent cross sections, two resonance structures are observed around 4.2 and 4.4 GeV. The measured masses of these resonances are $4186.8 \pm 8.7 \pm 30$ MeV/c^2 and $(4414.6 \pm 3.4 \pm 6.1)$ MeV/c^2, with widths of $(55 \pm 15 \pm 53)$ MeV and $(122.5 \pm 7.5 \pm 8.1)$ MeV, respectively. The first errors are statistical, while the second errors are systematic. Within the statistical and systematic uncertainties, the mass of the first resonance is consistent with $\psi(4160)$ or $\psi(4230)$.

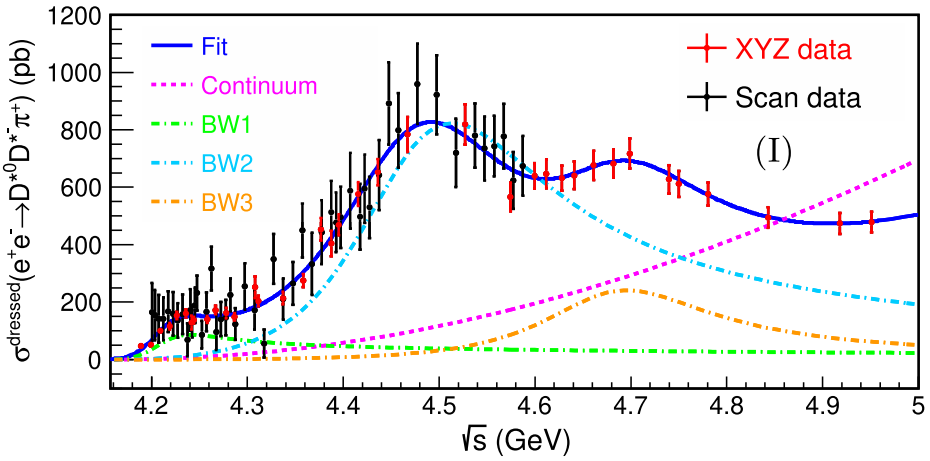

Figure 3: The fit results of the dressed cross section line shape of $e^+e^- \to D^{*0}D^{*-}\pi^+$ [19]. The black and red points with error bars are data, including statistical and systematic uncertainties. The blue curve is the total fit. The green, azure, and orange dashed curves describe three BW functions, and the pink dashed curve is the three body phase space contribution.

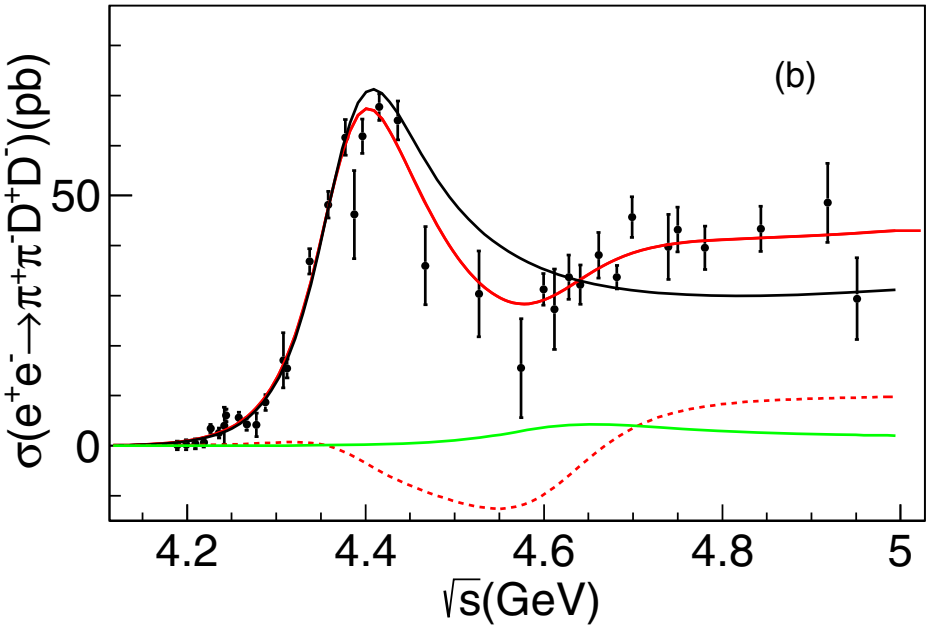

Figure 4: Cross section of the process $e^+e^- \to \pi^+\pi^- D^+D^-$ and fits with two resonances [20]. The black points with error bars are data. The red curve is the total fit. The black and green solid lines correspond to the two Breit-Wigner, and the red dashed line describes the interference between the two resonances.

The mass of the second resonance is consistent with $\psi(4415)$, although the measured width is slightly higher than the world average value with a 3σ deviation.

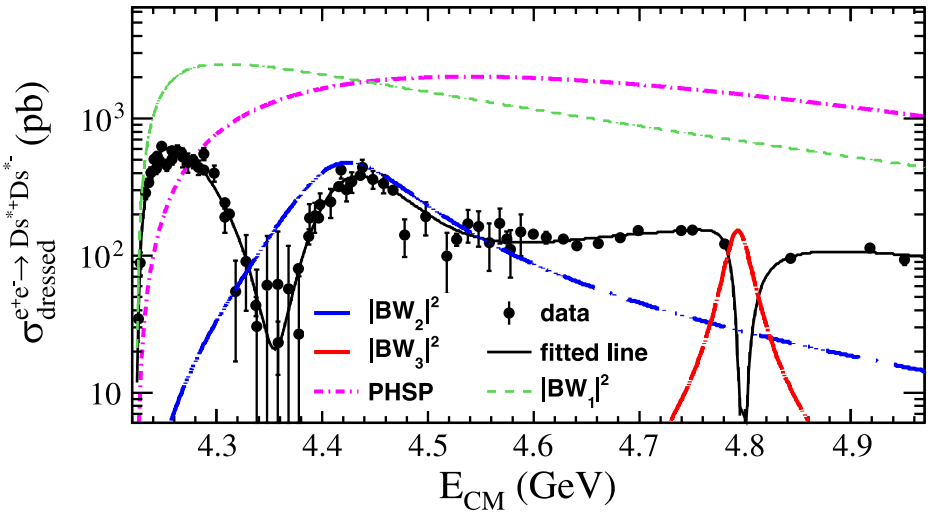

Figure 5: Fitting results for the measured dressed cross sections of $e^+e^- \to D_s^{*+}D_s^{*-}$ [21]. The black dots with error bars are for the measured dressed cross sections. The black curve represents the fit; the green dashed, blue two-dashed, and red long-dashed ones are for the three BW amplitudes from the fit, respectively, and the pink dot-dashed is for the PHSP contributions.

3.3 $Y(4500)$ and $Y(4710)$ states

Unlike the conventional charmonium state, the exotic Y states have a relatively large branching fractions transition into a vector charmonium plus light mesons. For example, the $\psi(3770)$ dominate decays into open charm final state, while $\psi(4230)$ decays into $D^{(*)}\bar{D}^{(*)}$ has not been observed. Many Y states were searched in a few processes with J/ψ plus mesons, such as $\pi^+\pi^-,\eta$ and η', together with additional processes $\pi^+\pi^- h_c, \pi^+\pi^-\psi(3686), \omega\chi_{cJ}$ and so on. Recently, The cross sections of $e^+e^- \to K^+K^- J/\psi$ at center-of-mass energies from 4.127 to 4.600 GeV are measured based on 15.6 fb^{-1} BESIII e^+e^- annihilation data [22]. Two resonant structures, $Y(4230)$ and $Y(4500)$, are observed in the line shape of the cross sections as shown in Fig. 6. The mass and width of the first structure are measured to be $(4225.3\pm2.3\pm21.5)$ MeV/c^2 and $(72.9\pm6.1\pm30.8)$ MeV, respectively. They are consistent with those of the established $Y(4230)$. The second structure, $Y(4500)$, is observed for the first time with a statistical significance greater than 8σ. Its mass and width are determined to be $(4484.7\pm13.3\pm24.1)$ MeV/c^2 and $(111.1\pm30.1\pm15.2)$ MeV, respectively. The first presented uncertainties are statistical and the second ones are systematic.

The neutral kaon process, $e^+e^- \to K_S^0K_S^0J/\psi$ was also investigate with BESIII data [23] with integrated luminosity of 21.2 fb^{-1} taken at center-of-mass energies from 4.128 to 4.950 GeV. Except that $Y(4230)$ state was observed in the energy dependence of the cross section with a statistical significance of 26.0σ, there is no clear structure around 4.484 GeV. In addition, an enhancement around 4.710 GeV, labeled as the $Y(4710)$, is seen with a statistical significance of 4.2σ as shown

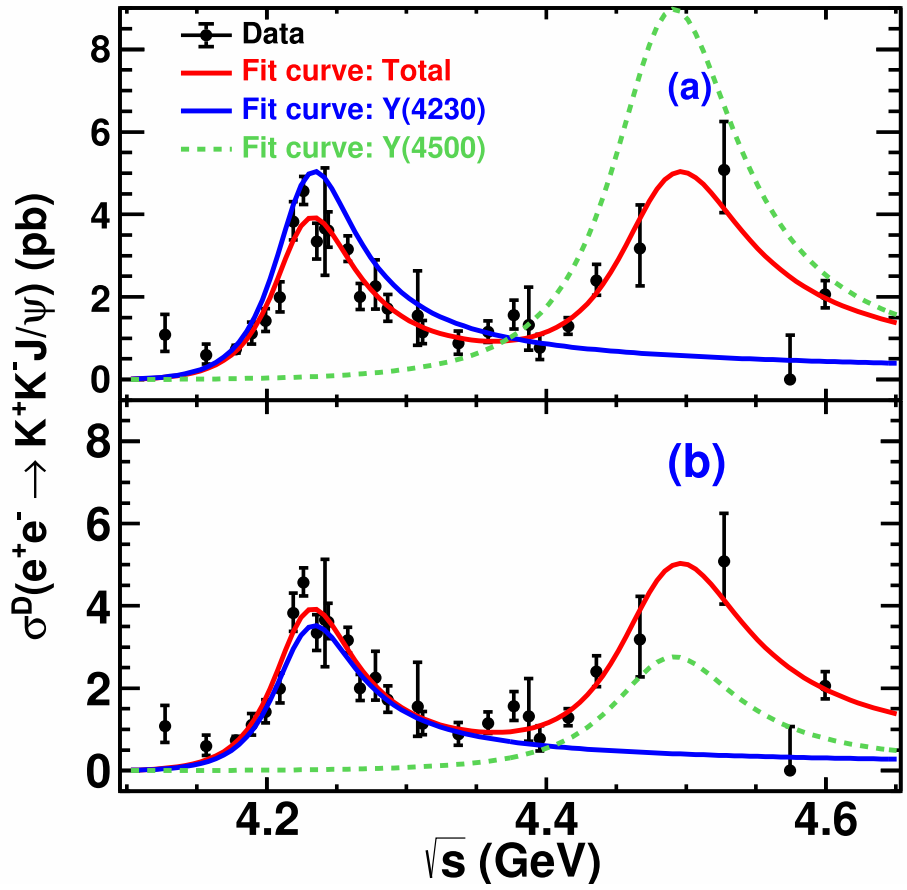

Figure 6: Cross sections of $e^+e^- \to K^+K^-J/\psi$, indicated by error bars with only statistical uncertainties. They are fitted by a coherent sum of two Breit-Wigner functions indicated by red solid curves. The Blue and green dashed curves are the amplitudes describing the resonances $Y(4230)$ and $Y(4500)$, respectively. (a) corresponds to solution I, (b) corresponds to solution II [22].

in Fig. 7, and the mass and width of the $Y(4710)$ state were measured to be $(4704.0 \pm 52.3 \pm 69.5)$ MeV/c^2 and $(183.2 \pm 114.0 \pm 96.1)$ MeV, respectively.

4. $Z_{c(s)}$ states

Since the discovery of the $Z_c^{\pm}(3900)$ states by the BESIII [6] and BELLE [24] experiments, which were subsequently confirmed by the CLEO experiments, several Z_c states have been reported from the analysis of e^+e^- annihilation or b-flavored hadron decays, as summarized in Table 1. These discoveries involve charmonium plus light hadrons or open charm mesons plus light hadrons. However, our understanding of their production and decay properties remains limited, and their intrinsic nature is still unclear, leaving questions unanswered regarding their exotic nature or kinematic effects.

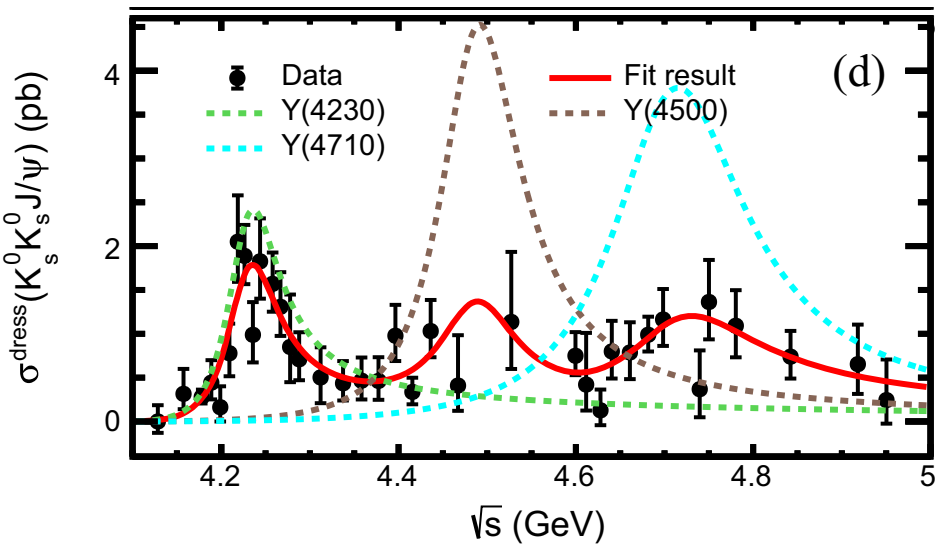

Figure 7: Maximum likelihood fits to the dressed cross sections of $e^+e^- \to K^0_S K^0_S J/\psi$ [23].

Table 1: An overview of Z_c states and their properties: mass, width, J^{PC} quantum numbers, and discovery processes and experiments.

State	M (MeV/c^2)	Γ (MeV)	J^{PC}	Process	Experiment
$Z_c(3900)^{(\pm,0)}$	3888.4 ± 2.5	28.3 ± 2.5	1^{+-}	$e^+e^- \to \pi^{(+,0)}(\pi^{(-,0)}J/\psi)$	BESIII, Belle
				$e^+e^- \to \pi^{(+,0)}(D\bar{D}^*)^{(-,0)}$	BESIII
				$H_b \to X\pi^+(\pi^- J/\psi)$	D0
				$e^+e^- \to \pi^+(\eta_c\rho^-)$	BESIII
$Z_c(4020)^{(\pm,0)}$	4024.1 ± 1.9	13 ± 5	$1^{+-}(?)$	$e^+e^- \to \pi^{(+,0)}(\pi^{(-,0)}h_c)$	BESIII, Belle
				$e^+e^- \to \pi^{(+,0)}(D^*\bar{D}^*)^{(-,0)}$	BESIII
$Z(4050)^{\pm}$	4051^{+24}_{-40}	82^{+50}_{-28}	$?^{?+}$	$\bar{B}^0 \to K^-(\pi^+\chi_{c1})$	Belle
				$e^+e^- \to \pi^{(+,-)}(\pi^{(-,+)}\chi_{c0,1,2})$	BESIII Not Seen!
$Z(4055)^{\pm}$	4054 ± 3.2	45 ± 13	$?^{?-}$	$e^+e^- \to \pi^+(\pi^-\psi(2S))$	Belle
$Z(4100)^{\pm}$	4096 ± 28	152^{+80}_{-70}	$?^{??}$	$B^0 \to K^+(\pi^-\eta_c)$	LHCb
				$e^+e^- \to \pi^{(+,-)}\pi^0(\pi^{(-,+)}\eta_c)$	BESIII Not Seen!
				$e^+e^- \to \pi^{(+,-)}\eta(\pi^{(-,+)}\eta_c)$	BESIII Not Seen!
$Z(4200)^{\pm}$	4196^{+35}_{-32}	370^{+100}_{-150}	1^{+-}	$\bar{B}^0 \to K^-(\pi^+ J/\psi)$	Belle, LHCb
$Z(4250)^{\pm}$	4248^{+190}_{-50}	177^{+320}_{-70}	$?^{?+}$	$\bar{B}^0 \to K^-(\pi^+\chi_{c1})$	Belle
				$e^+e^- \to \pi^{(+,-)}(\pi^{(-,+)}\chi_{c0,1,2})$	BESIII Not Seen!
$Z(4430)^{\pm}$	4478^{+15}_{-18}	181 ± 31	1^{+-}	$B^0 \to K^+(\pi^-\psi(2S))$	Belle, LHCb
				$\bar{B}^0 \to K^-(\pi^+ J/\psi)$	Belle
$R_{c0}(4240)$	4239^{+50}_{-21}	220^{+120}_{-90}	0^{--}	$B^0 \to K^+\pi^-\psi(2S)$	LHCb
$Z_{cs}(3985)^{\pm,0}$	$3982.5^{+2.8}_{-3.4}$	$12.8^{+6.1}_{-5.3}$	?	$e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$	BESIII
				$e^+e^- \to K^0_S(D_s^+ D^{*-} + D_s^{*+} D^-)$	BESIII
$Z_{cs}(4000)^{\pm}$	4003^{+7}_{-15}	131 ± 30	1^+	$B^+ \to \phi(J/\psi K^+)$	LHCb
$Z_{cs}(4220)^{\pm}$	4216^{+49}_{-38}	233^{+110}_{-90}	1^+	$B^+ \to \phi(J/\psi K^+)$	LHCb

4.1 $Z_{cs}(3985)^{\pm}$ state

The processes $e^+e^- \to K^+(D_s^-D^{*0} + D_s^{*-}D^0)$ were studied using the BESIII e^+e^- annihilation samples [25] collected at five center-of-mass energies ranging from 4.628 to 4.698 GeV, with a total integrated luminosity of 3.7 fb^{-1}. An excess of events was observed near the $D_s^-D^{*0}$ and $D_s^{*-}D^0$ mass thresholds in the K^+ recoil-mass spectrum for events collected at $\sqrt{s} = 4.681$ GeV, surpassing the known contributions from charmed mesons (see Fig. 8).

The observed structure exhibits a mass-dependent-width Breit-Wigner line shape, with the pole mass and width determined to be $(3982.5^{+1.8}_{-2.6} \pm 2.1)$ MeV/c^2 and $(12.8^{+5.3}_{-4.4} \pm 3.0)$ MeV, respectively. The first uncertainties represent the statistical uncertainties, while the second uncertainties are systematic in nature.

The significance of the resonance hypothesis is estimated to be 5.3σ above the contributions solely from conventional charmed mesons. This discovery marks the first candidate for a charged hidden-charm tetraquark with strangeness, decaying into $D_s^-D^{*0}$ and $D_s^{*-}D^0$.

4.2 $Z_{cs}(3985)^0$ state

The properties of the Z_{cs} state were further investigated in the neutral mode [26], $e^+e^- \to K_S^0(D_s^+D^{*-} + D_s^{*+}D^-)$. Using five center-of-mass energies ranging from 4.628 to 4.699 GeV, corresponding to an integrated luminosity of 3.8 fb^{-1} collected by the BESIII detector, evidence of a structure near the thresholds for $D_s^+D^{*-}$ and $D_s^{*+}D^-$ production was observed in the K_S^0 recoil-mass spectrum, referred to as the $Z_{cs}(3985)^0$.

By fitting the data with a Breit-Wigner line shape, the mass of the structure was determined to be $3992.2 \pm 1.7 \pm 1.6$ MeV/c^2, and the width was found to be $(7.7^{+4.1}_{-3.8} \pm 4.3)$ MeV. The first uncertainties are statistical, while the second uncertainties are systematic. The significance of the $Z_{cs}(3985)^0$ signal was measured to be 4.6σ, accounting for both statistical and systematic uncertainties. Notably, the mass of the $Z_{cs}(3985)^0$ is close to that of the $Z_{cs}(3985)^+$ (see Fig. 9).

4.3 Search for $Z_{cs}^{\pm} \to K^{\pm}J/\psi$

The search for potential decays of $Z_{cs}^{\pm}$ into $K^{\pm}J/\psi$ was conducted in the process $e^+e^- \to K^+K^-J/\psi$ [22] using a BESIII data sample which has an integrated luminosity of 15.6 pb^{-1} and was collected at center-of-mass energies ranging from 4.127 to 4.600 GeV. Figure 10 illustrates the invariant mass distribution of $K^{\pm}J/\psi$. No clear structure is observed in the invariant mass distributions.

The K^+K^- invariant mass distribution exhibits a slight deviation from the phase space Monte Carlo (MC) events. It can also be described by the intermediate states $f_0(980)$ and $f_2(1270)$. Similarly, the $K^{\pm}J/\psi$ invariant mass distribution can be described by either the $f_0(980)$ and $f_2(1270)$ intermediate states or the phase space events.

4.4 Search for $Z_{cs}^{\prime -} \to D^{*0}D_s^{*-}$

The potential existence of the $Z_{cs}^{\prime -}$ state was investigated in the process $e^+e^- \to K^+Z_{cs}^{\prime -}$, where $Z_{cs}^{\prime -}$ decays into $D^{*0}D_s^{*-}$. The analysis utilized e^+e^- collision data collected at center-of-mass energies of $\sqrt{s} = 4.661$, 4.682, and 4.699 GeV, recorded by the BESIII detector [27]. An excess

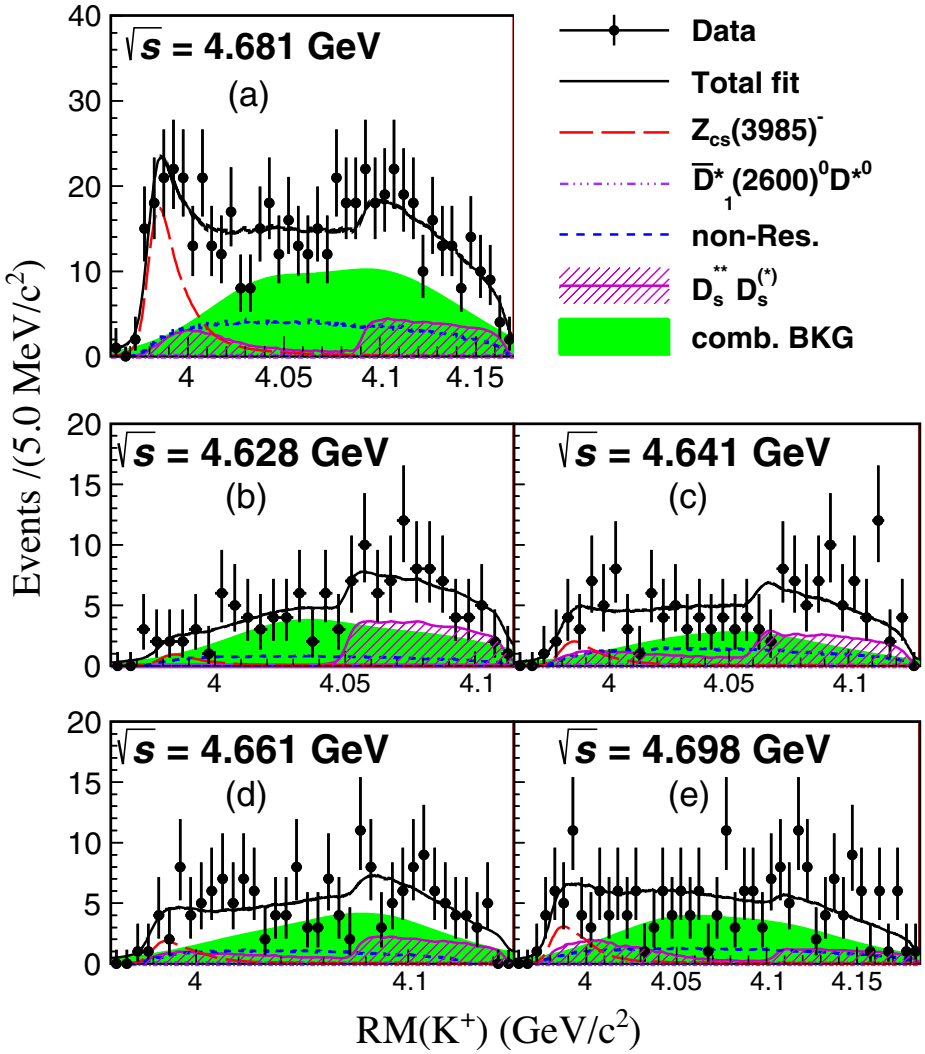

Figure 8: Simultaneous unbinned maximum likelihood fit to the K^+ recoil-mass spectra in data at $\sqrt{s} = 4.628, 4.641, 4.661, 4.681$, and 4.698 GeV [25].

of $Z_{cs}^{\prime -} \to D^{*0} D_s^{*-}$ candidates was observed with a significance of 2.1σ, accounting for systematic uncertainties, at a mass of $4123.5 \pm 0.7_{\rm stat} \pm 4.7_{\rm syst}$ MeV/c^2 as shown in Fig. 11.

However, due to the limited size of the dataset, a precise measurement of the width of this state could not be obtained. Consequently, a range of width hypotheses were tested, and the corresponding p-values were evaluated, as illustrated in Figure 11. A local minimum p-value was found at $m_0 = 4124.1$ MeV/c^2 when assuming $\Gamma_0 = 10$ MeV, resulting in a local statistical significance of 4.1σ.

5. Summary

Using data from e^+e^- annihilation collected with the BESIII detector, we investigated the

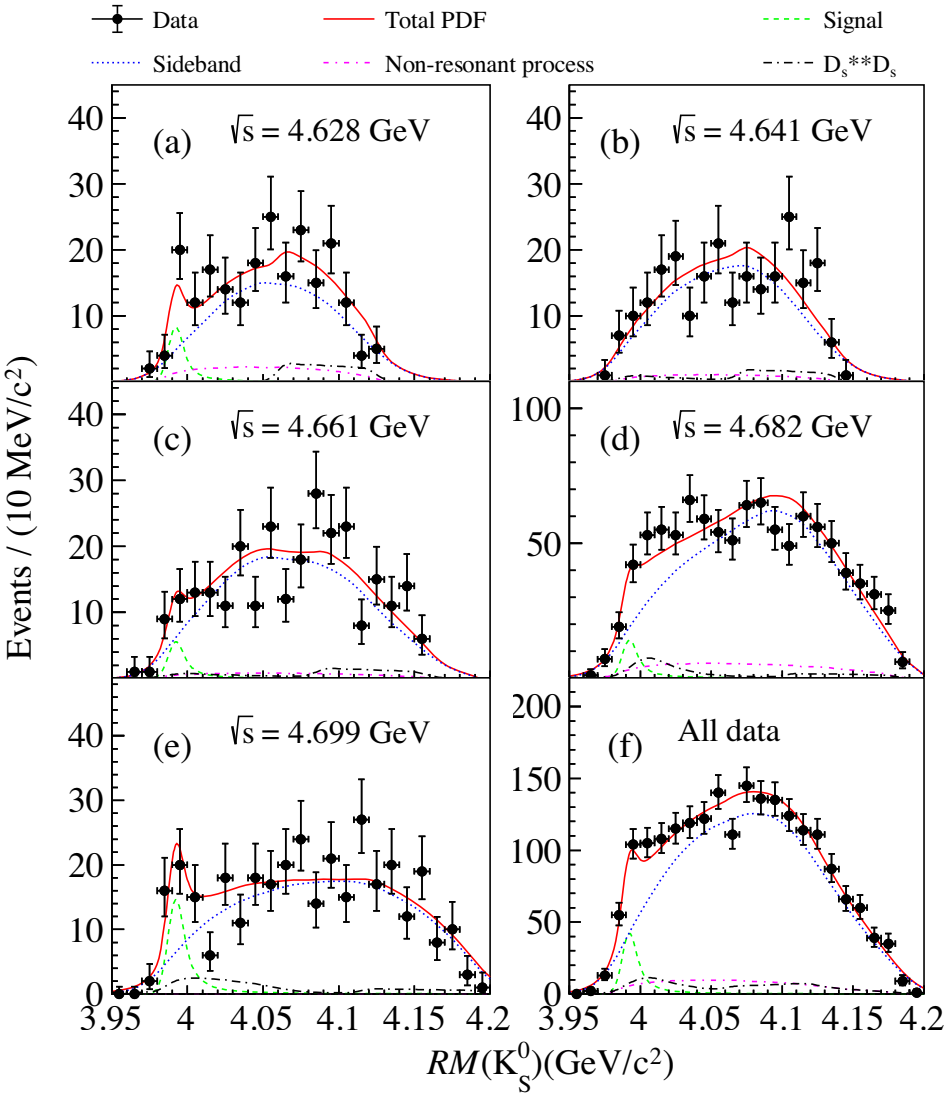

Figure 9: Simultaneous fit to the recoil-mass $RM(K_S^0)$ spectra in all datasets [(a)-(e)], and for all the data points combined (f)[26].

isospin violation decays of $X(3872)$ in the processes $e^+e^- \to \omega J/\psi, \pi^0\chi_{c1}$, and $\pi^+\pi^- J/\psi$. We also measured the cross section for the processes $e^+e^- \to D^{*0}D^{*-}\pi^+$, $\pi^+\pi^- D^+D^-$, $D_s^{*+}D_s^{*-}$, $K^+K^- J/\psi$, and $K_S^0K_S^0 J/\psi$, searching for Y states in the energy-dependence of the cross section. The $X(3872) \to \omega J/\psi$ and $\pi^0\chi_{c1}$ were observed with significance larger than 5σ, and the ratio of branching fraction was determined as $\mathscr{R} = B(X(3872) \to \omega J/\psi)/B(X(3872) \to \pi^+\pi^- J/\psi) = 1.6^{+0.4}_{-0.3} \pm 0.2$, and $B(X(3872) \to \pi^0\chi_{c1})/B(X(3872) \to \pi^+\pi^- J/\psi) = 0.88^{+0.33}_{-0.27} \pm 0.10$.

In the analysis of $e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-}D^0)$, we observed an excess of events above the mass threshold in the K^+ recoil-mass spectrum with a significance larger than 5σ. Its pole mass and width were determined to be $(3982.5^{+1.8}_{-2.6} \pm 2.1)$ MeV/c^2 and $(12.8^{+5.3}_{-4.4} \pm 3.0)$ MeV, respectively This marks the first candidate for a charged hidden-charm tetraquark with strangeness. We also

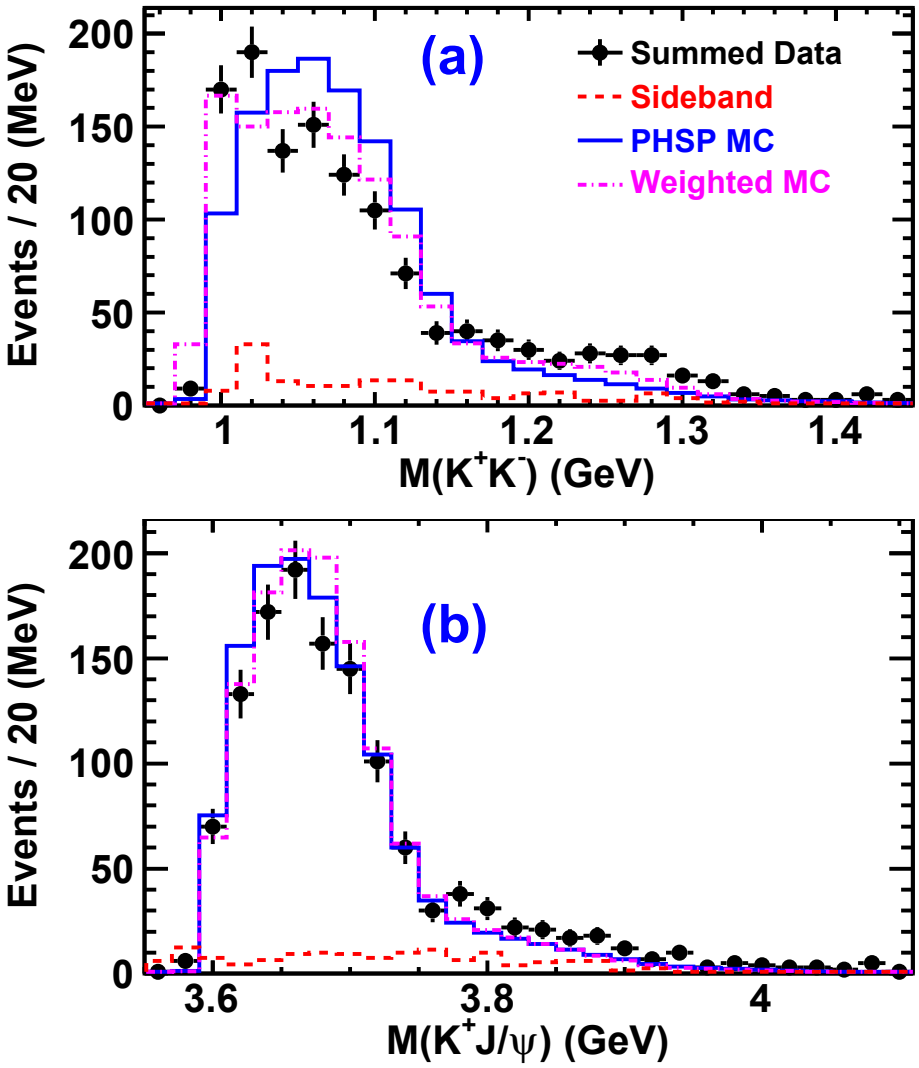

Figure 10: Invariant mass distributions of K^+K^- (a) and K^+J/ψ (b) in the process $e^+e^- \to K^+K^-J/\psi$. The black dots with error bars indicate data from the signal region with all data samples, the red dashed curves indicate data from side band regions, the blue solid curves indicate PHSP signal MC sample, and the pink dashed-dot curves indicated the weighted signal MC sample [22].

searched for the neutral Z_{cs}^0 in the process $e^+e^- \to K_S^0(D_s^+D^{*-} + D_s^{*+}D^-)$, but no signal evidence was observed. Additionally, we investigated the potential excited state Z_{cs}' in the process $e^+e^- \to K^+Z_{cs}'^-$, but no significant signals were observed.

BEPC-II has an updated program known as BEPCII-U [28], which aims to increase the beam energy of e^+e^- collisions up to $\sqrt{s}$ =5.6 GeV. Additionally, it will provide a luminosity three times higher than that of BEPCII over the energy range of $\sqrt{s} = 4.7 \sim 5.0$ GeV. The installation of the upgraded machine is scheduled during the shutdown period from July to December in 2024. The BEPCII-U upgrade will significantly enhance the availability of high luminosity data for studies on

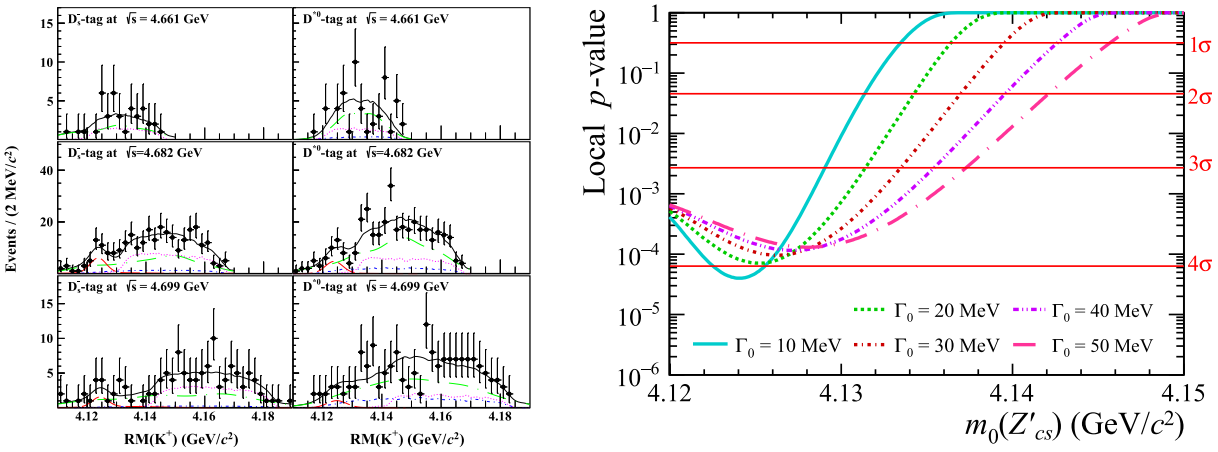

Figure 11: left: The spectra of K^+ recoil mass from D^{*0}-and D_s^--tag methods after all selection criteria at $\sqrt{s} = 4.661, 4.682$ and 4.669 GeV. Right: The local p-value as a function of the mass for various width hypotheses from the simultaneous fit to data samples at $\sqrt{s} = 4.661, 4.682$ and 4.669 GeV [27].

XYZ particles and other physics programs, including the investigation of charmed baryons.

References

[1] S. K. Choi *et al.* [Belle], Phys. Rev. Lett. **91**, 262001 (2003) doi:10.1103/PhysRevLett.91.262001 [arXiv:hep-ex/0309032 [hep-ex]].

[2] X. L. Wang *et al.* [Belle], Phys. Rev. Lett. **99**, 142002 (2007) doi:10.1103/PhysRevLett.99.142002 [arXiv:0707.3699 [hep-ex]].

[3] S. K. Choi *et al.* [Belle], Phys. Rev. Lett. **100**, 142001 (2008) doi:10.1103/PhysRevLett.100.142001 [arXiv:0708.1790 [hep-ex]].

[4] B. Aubert *et al.* [BaBar], Phys. Rev. Lett. **95**, 142001 (2005) doi:10.1103/PhysRevLett.95.142001 [arXiv:hep-ex/0506081 [hep-ex]].

[5] B. Aubert *et al.* [BaBar], Phys. Rev. Lett. **98**, 212001 (2007) doi:10.1103/PhysRevLett.98.212001 [arXiv:hep-ex/0610057 [hep-ex]].

[6] M. Ablikim *et al.* [BESIII], Phys. Rev. Lett. **110**, 252001 (2013) doi:10.1103/PhysRevLett.110.252001 [arXiv:1303.5949 [hep-ex]].

[7] M. Ablikim *et al.* [BESIII], Phys. Rev. Lett. **111**, no.24, 242001 (2013) doi:10.1103/PhysRevLett.111.242001 [arXiv:1309.1896 [hep-ex]].

[8] R. Aaij *et al.* [LHCb], Phys. Rev. Lett. **122**, no.22, 222001 (2019) doi:10.1103/PhysRevLett.122.222001 [arXiv:1904.03947 [hep-ex]].

[9] A. Hayrapetyan *et al.* [CMS], [arXiv:2306.07164 [hep-ex]].

[10] S. L. Olsen, T. Skwarnicki and D. Zieminska, Rev. Mod. Phys. **90**, no.1, 015003 (2018) doi:10.1103/RevModPhys.90.015003 [arXiv:1708.04012 [hep-ph]].

[11] R.L. Workman et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2022, 083C01 (2022) and 2023 update https://doi.org/10.1093/ptep/ptac097

[12] M. Ablikim *et al.* [BESIII], Phys. Rev. Lett. **122**, no.23, 232002 (2019) doi:10.1103/PhysRevLett.122.232002 [arXiv:1903.04695 [hep-ex]].

[13] M. Ablikim *et al.* [BESIII], Phys. Rev. Lett. **122**, no.20, 202001 (2019) doi:10.1103/PhysRevLett.122.202001 [arXiv:1901.03992 [hep-ex]].

[14] V. Bhardwaj *et al.* [Belle], Phys. Rev. Lett. **107**, 091803 (2011) doi:10.1103/PhysRevLett.107.091803 [arXiv:1105.0177 [hep-ex]].

[15] M. Ablikim *et al.* [BESIII], Phys. Rev. Lett. **124**, no.24, 242001 (2020) doi:10.1103/PhysRevLett.124.242001 [arXiv:2001.01156 [hep-ex]].

[16] Q. He *et al.* [CLEO], Phys. Rev. D **74**, 091104 (2006) doi:10.1103/PhysRevD.74.091104 [arXiv:hep-ex/0611021 [hep-ex]].

[17] C. Z. Yuan *et al.* [Belle], Phys. Rev. Lett. **99**, 182004 (2007) doi:10.1103/PhysRevLett.99.182004 [arXiv:0707.2541 [hep-ex]].

[18] M. Ablikim *et al.* [BESIII], Phys. Rev. Lett. **118**, no.9, 092002 (2017) doi:10.1103/PhysRevLett.118.092002 [arXiv:1610.07044 [hep-ex]].

[19] M. Ablikim *et al.* [BESIII], Phys. Rev. Lett. **130**, no.12, 121901 (2023) doi:10.1103/PhysRevLett.130.121901 [arXiv:2301.07321 [hep-ex]].

[20] M. Ablikim *et al.* [BESIII], Phys. Rev. D **106**, no.5, 052012 (2022) doi:10.1103/PhysRevD.106.052012 [arXiv:2208.00099 [hep-ex]].

[21] M. Ablikim *et al.* [BESIII], Phys. Rev. Lett. **131**, no.15, 151903 (2023) doi:10.1103/PhysRevLett.131.151903 [arXiv:2305.10789 [hep-ex]].

[22] M. Ablikim *et al.* [(BESIII), and BESIII], Chin. Phys. C **46**, no.11, 111002 (2022) doi:10.1088/1674-1137/ac945c [arXiv:2204.07800 [hep-ex]].

[23] M. Ablikim *et al.* [BESIII], Phys. Rev. D **107**, no.9, 092005 (2023) doi:10.1103/PhysRevD.107.092005 [arXiv:2211.08561 [hep-ex]].

[24] Z. Q. Liu *et al.* [Belle], Phys. Rev. Lett. **110**, 252002 (2013) [erratum: Phys. Rev. Lett. **111**, 019901 (2013)] doi:10.1103/PhysRevLett.110.252002 [arXiv:1304.0121 [hep-ex]].

[25] M. Ablikim *et al.* [BESIII], Phys. Rev. Lett. **126**, no.10, 102001 (2021) doi:10.1103/PhysRevLett.126.102001 [arXiv:2011.07855 [hep-ex]].

[26] M. Ablikim *et al.* [BESIII], Phys. Rev. Lett. **129**, no.11, 112003 (2022) doi:10.1103/PhysRevLett.129.112003 [arXiv:2204.13703 [hep-ex]].

[27] M. Ablikim *et al.* [(BESIII), and BESIII], Chin. Phys. C **47**, no.3, 033001 (2023) doi:10.1088/1674-1137/acac69 [arXiv:2211.12060 [hep-ex]].

[28] M. Ablikim *et al.* [BESIII], Chin. Phys. C **44**, no.4, 040001 (2020) doi:10.1088/1674-1137/44/4/040001 [arXiv:1912.05983 [hep-ex]].