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BESIII Collaboration; Ablikim, M.; Achasov, M.N.; Adlarson, P.; Ahmed, S.; Albrecht, M.; Aliberti, R.; Amoroso, A.; Bakina, O.; Kalantar-Nayestanaki, Nasser

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## Observation of a Near-Threshold Structure in the $K^+$ Recoil-Mass Spectra in $e^+e^- \rightarrow K^+(D_s^-D^{*0} + D_s^* - D^0)$

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We report a study of the processes of  $e^+e^- \rightarrow K^+D_s^-D^{*0}$  and  $K^+D_s^{*-}D^0$  based on  $e^+e^-$  annihilation samples collected with the BESIII detector operating at BEPCII at five center-of-mass energies ranging from 4.628 to 4.698 GeV with a total integrated luminosity of  $3.7 \text{ fb}^{-1}$ . An excess of events over the known contributions of the conventional charmed mesons is observed near the  $D_s^-D^{*0}$  and  $D_s^{*-}D^0$  mass thresholds in the  $K^+$  recoil-mass spectrum for events collected at  $\sqrt{s} = 4.681 \text{ GeV}$ . The structure matches a mass-dependent-width Breit-Wigner line shape, whose pole mass and width are determined as  $(3982.5_{-2.6}^{+1.8} \pm 2.1) \text{ MeV}/c^2$  and  $(12.8_{-4.4}^{+5.3} \pm 3.0) \text{ MeV}$ , respectively. The first uncertainties are statistical and the second are systematic. The significance of the resonance hypothesis is estimated to be  $5.3 \sigma$  over the contributions only from the conventional charmed mesons. This is the first candidate for a charged hidden-charm tetraquark with strangeness, decaying into  $D_s^-D^{*0}$  and  $D_s^{*-}D^0$ . However, the properties of the excess need further exploration with more statistics.

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Recent observations of nonstrange hidden-charm tetraquark candidates with quark content  $c\bar{c}q\bar{q}'$  ( $q^{(\prime)} = u$  or  $d$ ), referred to as the  $Z_c$  states, have opened a new chapter in hadron spectroscopy [1–6]. In electron-positron annihilation, in particular, both the charged and neutral  $Z_c(3900)$  and  $Z_c(4020)$  have been observed at the BESIII, Belle, and CLEO experiments in a variety of decay modes [7–16].

Assuming SU(3) flavor symmetry, one would expect the existence of strange partners to the  $Z_c$ , denoted as  $Z_{cs}$ , with quark content  $c\bar{c}s\bar{q}$  [17]. No experimental searches for  $Z_{cs}$  states have yet been reported.

The existence of a  $Z_{cs}$  state with a mass lying around the  $D_s^- D^{*0}$  and  $D_s^{*-} D^0$  thresholds has been predicted in several theoretical models, including tetraquark scenarios [18,19], the  $D_s \bar{D}^*$  molecular model [20,21], the hadro-quarkonium model [19], and in the initial-single-chiral-particle-emission mechanism [22]. Like the  $Z_c$  states, the decay rate of the  $Z_{cs}$  to open-charm final states is expected to be larger than the decay rate to charmonium final states [5]. Hence, one promising method to search for the  $Z_{cs}$  state is through its decays to  $D_s^- D^{*0}$  and  $D_s^{*-} D^0$ .

In this Letter, we report on a study of the process  $e^+e^- \rightarrow K^+ D_s^- D^{*0}$  and  $K^+ D_s^{*-} D^0$  [ $e^+e^- \rightarrow K^+(D_s^- D^{*0} + D_s^{*-} D^0)$  for short] at center-of-mass energies  $\sqrt{s} = 4.628, 4.641, 4.661, 4.681,$  and  $4.698$  GeV. The data samples have a total integrated luminosity of  $3.7 \text{ fb}^{-1}$  and were accumulated by the BESIII detector at the BEPCII collider. Details about BEPCII and BESIII can be found in Refs. [23–25]. To improve the signal-selection efficiency, a partial-reconstruction technique is implemented in which only the charged  $K^+$  (the *bachelor*  $K^+$ ) and the  $D_s^-$  are reconstructed. Here and elsewhere, charge-conjugate modes are always implied, unless explicitly stated otherwise. To improve the signal purity, we only reconstruct the decays  $D_s^- \rightarrow K^+ K^- \pi^-$  and  $K_S^0 K^-$ , which have large branching fractions (BFs). By reconstructing the  $D_s^-$  meson, the flavors of the missing  $D^0$  and the bachelor  $K^+$  are fixed. We observe an enhancement 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 and carry out a fit to the enhancement with a possible new  $Z_{cs}$  candidate, denoted as  $Z_{cs}(3985)^-$ , in the  $K^+$  recoil-mass spectra at different energy points.

Monte Carlo (MC) simulation samples are produced under a GEANT4-based [26] framework, as detailed in Ref. [27]. For the three-body nonresonant (NR) signal process,  $e^+e^- \rightarrow K^+(D_s^- D^{*0} + D_s^{*-} D^0)$ , the final-state particles are simulated assuming nonresonant production [27]. For the simulation of the  $Z_{cs}(3985)^-$  signal process,  $e^+e^- \rightarrow K^+ Z_{cs}(3985)^-$ , we let the  $Z_{cs}(3985)^-$  decay into the  $D_s^- D^{*0}$  and  $D_s^{*-} D^0$  final states with equal rates. The  $Z_{cs}(3985)^-$  state is assigned a spin parity of  $1^+$ , as the corresponding production and subsequent decay processes are both in the most favored  $S$  wave. However, other spin-parity assignments are allowed, and these are tested as systematic variations.

To identify the processes  $e^+e^- \rightarrow K^+(D_s^- D^{*0} + D_s^{*-} D^0)$ , we reconstruct combinations of the bachelor  $K^+$  and the decays  $D_s^- \rightarrow K^+ K^- \pi^-$  or  $K_S^0 K^-$ . Data taken at all five center-of-mass energy points are analyzed using the same procedure, but two-third of the data set at  $\sqrt{s} = 4.681$  GeV was kept blinded until after the analysis strategy was established and validated [28]. We select events with at

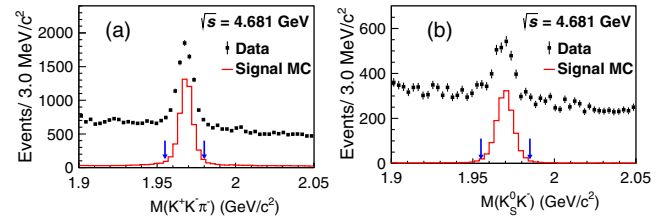


FIG. 1. Distributions of the invariant mass  $M(K^+ K^- \pi^-)$  (a) and  $M(K_S^0 K^-)$  (b) in data and MC simulations at  $\sqrt{s} = 4.681$  GeV. The  $Z_{cs}(3985)^-$  signal MC component is normalized to the observed  $D_s^-$  yield in data. Arrows indicate the mass region requirements.

least four charged tracks and reconstruct the final states of  $K^\pm, \pi^\pm,$  and  $K_S^0 \rightarrow \pi^+ \pi^-$  following the criteria in Ref. [31]. For the candidate of  $K_S^0$ , we require its invariant mass within  $0.485 < M(\pi^+ \pi^-) < 0.511 \text{ GeV}/c^2$ . For the decay  $D_s^- \rightarrow K^+ K^- \pi^-$ , to improve the signal purity, we only retain the  $D_s^-$  candidates within the Dalitz plot regions consistent with  $D_s^- \rightarrow \phi \pi^-$  or  $D_s^- \rightarrow K^*(892)^0 K^-$  decays by requiring that the invariant masses satisfy either  $M(K^+ K^-) < 1.05 \text{ GeV}/c^2$  or  $0.850 < M(K^+ \pi^-) < 0.930 \text{ GeV}/c^2$ .

Figure 1 shows the  $K^+ K^- \pi^-$  and  $K_S^0 K^-$  invariant mass distributions for events at  $\sqrt{s} = 4.681$  GeV, in which  $D_s^-$  peaks are clearly evident. All combinations with invariant mass in the region  $1.955 < M(K^+ K^- \pi^-) < 1.980 \text{ GeV}/c^2$  and  $1.955 < M(K_S^0 K^-) < 1.985 \text{ GeV}/c^2$  are identified as  $D_s^-$  meson candidates. Figure 2 shows the  $K^+ D_s^-$  recoil-mass spectrum for  $D_s^-$  candidate events at  $\sqrt{s} = 4.681$  GeV, calculated using  $RM(K^+ D_s^-) + M(D_s^-) - m(D_s^-)$ . Here,  $RM(X) = ||p_{e^+e^-} - p_X||$ , where  $p_{e^+e^-}$  is the four-momentum of the initial  $e^+e^-$  system and  $p_X$  is the four-momentum of the system  $X$ ,  $M(D_s^-)$  is the mass of the reconstructed  $D_s^-$  meson, and  $m(D_s^-)$  is the mass of the  $D_s^-$  reported by the PDG [29]. The variable  $RM(K^+ D_s^-) + M(D_s^-) - m(D_s^-)$  provides improved

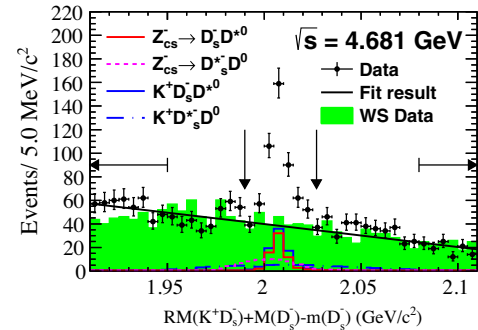


FIG. 2. Distribution of the  $K^+ D_s^-$  recoil mass in data and signal MC samples at  $\sqrt{s} = 4.681$  GeV. Horizontal arrows indicate the sidebands and vertical arrows indicate the signal region. The magnitudes of the three-body nonresonant processes and  $Z_{cs}(3985)^-$  signal processes are scaled arbitrarily. The histogram of wrong-sign (WS) events is scaled by a factor of 1.18 to match the sideband data.

resolution compared to  $RM(K^+D_s^-)$  [10]. A clear peak is seen in this distribution at the nominal  $D^{*0}$  mass, which corresponds to the final state  $K^+D_s^-D^{*0}$ . There is also a contribution from  $K^+D_s^{*-}D^0$ , which appears as a broader structure beneath the  $K^+D_s^-D^{*0}$  signal. Therefore, we require  $RM(K^+D_s^-) + M(D_s^-) - m(D_s^-)$  to be in the interval  $(1.990, 2.027)$   $\text{GeV}/c^2$  to isolate the signal candidates of both signal processes.

To estimate the shape of combinatorial background, we use wrong-sign (WS) combinations of  $D_s^-$  and  $K^-$  candidates, rather than the right-sign  $D_s^-$  and  $K^+$  candidates. The WS  $K^-D_s^-$  recoil-mass distribution, scaled by a factor of 1.18, agrees with the data distribution in the sideband regions,  $(1.91, 1.95)$   $\text{GeV}/c^2$  and  $(2.08, 2.11)$   $\text{GeV}/c^2$ , as shown in Fig. 2. The number of background events within the signal region is estimated to be  $282.6 \pm 12.0$  by a fit to the sideband data with a linear function, whose slope is determined from the WS data. In addition, the WS events are used to represent the combinatorial-background distribution of the recoil mass of the bachelor  $K^+$ . This technique has been used previously in the observation of the  $Z_c(4025)^+$  at BESIII [10]. We validate the use of the WS data-driven background modeling of both the  $RM(K^+D_s^-)$  and  $RM(K^+)$  spectra by comparing the corresponding distributions between WS combinations and background-only contributions. Furthermore, the  $RM(K^+)$  distribution of the events in the sideband regions in Fig. 2 agrees well with that of the corresponding WS data.

Figure 3(a) shows the  $RM(K^+)$  distribution for events at  $\sqrt{s} = 4.681$  GeV; an enhancement is evident in the region  $RM(K^+) < 4$   $\text{GeV}/c^2$  compared to the expectation from the WS events. This is clearly illustrated in the  $RM(K^+)$  distribution in data with subtraction of the WS component in Fig. 4. The enhancement cannot be attributed to the NR signal processes  $e^+e^- \rightarrow K^+(D_s^-D^{*0} + D_s^{*-}D^0)$ . To understand potential contributions from the processes  $e^+e^- \rightarrow D_s^{(*)-}D_s^{*+}(\rightarrow D^{*0}K^+)$  or  $D^{*0}\bar{D}_1^{*0}(\rightarrow D_s^{(*)-}K^+)$ , we examine all known  $D_s^{*+}$  excited states [29,32] using MC simulation samples. Dedicated exclusive MC studies show that none of these processes, including possible interference effects, exhibit a narrow structure below  $4.0$   $\text{GeV}/c^2$  [28].

The following three processes that contain excited  $D_s^{*+}$  background have potential contributions to the  $RM(K^+)$  spectrum: (1)  $D_s^-D_{s1}^*(2536)^+(\rightarrow D^{*0}K^+)$ , (2)  $D_s^{*-}D_{s2}^*(2573)^+(\rightarrow D^0K^+)$ , and (3)  $D_s^-D_{s1}^*(2700)^+(\rightarrow D^{*0}K^+)$ . We estimate their production cross sections by studying several control samples. The yields for channel (1) are estimated by analyzing the  $D_{s1}^*(2536)^+$  peak in the  $D^{*0}K^+$  mass spectra using two separate partially reconstructed samples:  $K^+D_s^-$  (with  $D^{*0}$  missing) and  $K^+D^{*0}$  (with  $D_s^-$  missing). For channel (2), control samples are selected by reconstructing  $D^0K^+\gamma$  (with missing  $D_s^-$ ) or  $K^+D_s^{*-}$  (with missing  $D^0$ ). The  $D_{s2}^*(2573)^+$  yield is obtained from combined fits to the  $D^0K^+$  mass spectra. From this, the contribution from channel (2) to the signal

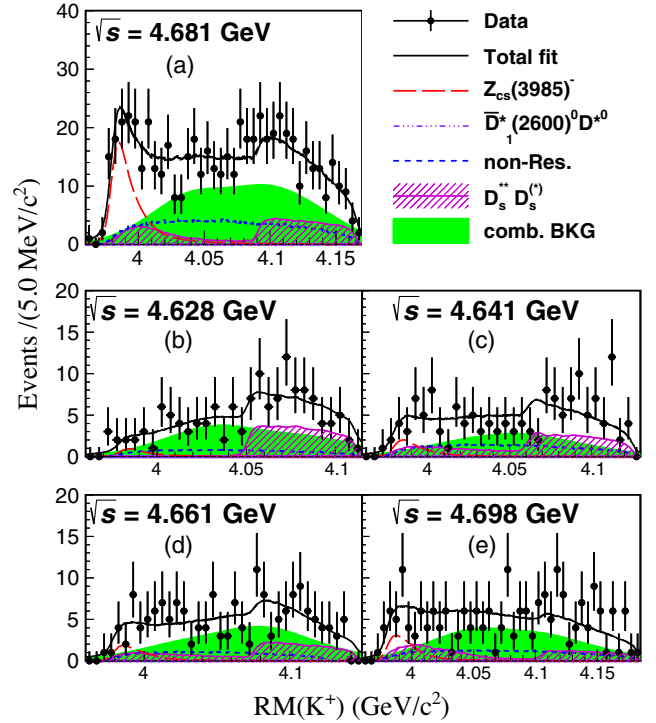


FIG. 3. Simultaneous unbinned maximum likelihood fit to the  $K^+$  recoil-mass spectra in data at  $\sqrt{s} = 4.628, 4.641, 4.661, 4.681,$  and  $4.698$  GeV. Note that the size of the  $D^{*0}\bar{D}_1^*(2600)^0(\rightarrow D_s^-K^+)$  component is consistent with zero.

candidates in Fig. 3 is evaluated. For channel (3), a control sample of  $e^+e^- \rightarrow D_s^-D_{s1}^*(2700)^+(\rightarrow D^0K^+)$  is selected by detecting the  $D_s^-K^+$  recoiling against a missing  $D^0$ . We then use the BF ratio of  $\mathcal{B}(D_{s1}^*(2700)^+ \rightarrow D^{*0}K^+)/\mathcal{B}(D_{s1}^*(2700)^+ \rightarrow D^0K^+) = 0.91 \pm 0.18$  [33] to estimate the strength of this background contribution. The shapes in  $RM(K^+)$  of these three channels are extracted from MC samples, whereas the normalization is derived from the control samples. The estimated background contributions of the channels (1), (2), and (3) in the  $RM(K^+)$  spectrum at  $\sqrt{s} = 4.681$  GeV are  $54.4 \pm 8.0, 19.1 \pm 7.6,$  and  $15.0 \pm 13.3$  events, respectively. For the other energy points, the estimated yields of the three channels are given in Ref. [28].

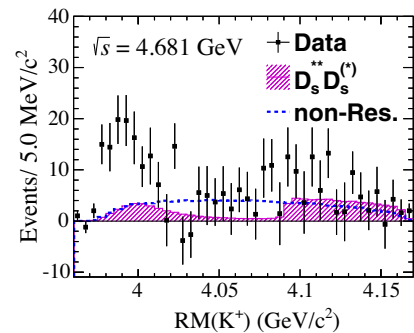


FIG. 4. The  $K^+$  recoil-mass spectrum in data at  $\sqrt{s} = 4.681$  GeV after subtraction of the combinatorial backgrounds.

Two processes with excited nonstrange  $\bar{D}^{*0}$  states that produce potential enhancements around 4 GeV/ $c^2$  in  $RM(K^+)$  are  $D^{*0}\bar{D}_1^*(2600)^0(\rightarrow D_s^-K^+)$  [29,32] and  $D^0\bar{D}_3^*(2750)^0(\rightarrow D_s^-K^+)$ . In these processes, the  $RM(K^+)$  spectrum is distorted due to limited production phase space. The first process is studied using an amplitude analysis of the control sample  $e^+e^- \rightarrow D^{*0}\bar{D}_1^*(2600)^0(\rightarrow D^-\pi^+)$  at all five energy points. Since the ratio  $\mathcal{B}(\bar{D}_1^*(2600)^0 \rightarrow D_s^-K^+)/\mathcal{B}(\bar{D}_1^*(2600)^0 \rightarrow D^-\pi^+)$  is unknown, it is difficult to project the results of the amplitude analysis into our signal channel. Instead, we determine the ratio in our nominal fit, providing a constraint on the size of the  $D^{*0}\bar{D}_1^*(2600)^0(\rightarrow D_s^-K^+)$  component at the different energy points. For the second process, no significant signal is observed in the control sample  $e^+e^- \rightarrow D^0\bar{D}_3^*(2750)^0(\rightarrow D^-\pi^+)$ . Assuming the relative BF ratio  $\mathcal{B}(\bar{D}_3^* \rightarrow D_s^-K^+)/\mathcal{B}(\bar{D}_3^* \rightarrow D^-\pi^+) = 4.1\%$  [34], the contribution of the  $D^0\bar{D}_3^*(2750)^0$  channel to Fig. 3 is estimated to be  $0.0 \pm 0.4$  events, and the corresponding upper limit is taken into account as a source of systematic uncertainty.

As no known processes explain the observed enhancement in the  $RM(K^+)$  spectrum, which is very close to the threshold of  $D_s^-D^{*0}(3975.2 \text{ MeV}/c^2)$  and  $D_s^*-D^0(3977.0 \text{ MeV}/c^2)$ , we consider the possibility of describing the structure as a  $D_s^-D^{*0}$  and  $D_s^*-D^0$  resonance with a mass-dependent-width Breit-Wigner line shape, denoted as  $Z_{cs}(3985)^-$ . A simultaneous unbinned maximum likelihood fit is performed to the  $RM(K^+)$  spectra at all five energy points, as shown in Fig. 3. The  $Z_{cs}(3985)^-$  component is modeled by the product of an  $S$ -wave Breit-Wigner shape with a mass-dependent width of the following form:

$$\mathcal{F}_j(M) \propto \left| \frac{\sqrt{q \cdot p_j}}{M^2 - m_0^2 + im_0(f\Gamma_1(M) + (1-f)\Gamma_2(M))} \right|^2,$$

where  $\Gamma_j(M) = \Gamma_0 \cdot (p_j/p_j^*) \cdot (m_0/M)$  with subscript  $j = 1$  and  $j = 2$  standing for the decays of  $Z_{cs}(3985)^- \rightarrow D_s^-D^{*0}$  and  $Z_{cs}(3985)^- \rightarrow D_s^*-D^0$ , respectively. Here,  $M$  is the reconstructed mass;  $m_0$  is the resonance mass;  $\Gamma_0$  is the width;  $q$  is the  $K^+$  momentum in the initial  $e^+e^-$  system;  $p_1$  ( $p_2$ ) is the  $D_s^-$  ( $D_s^*$ ) momentum in the rest frame of the  $D_s^-D^{*0}$  ( $D_s^*-D^0$ ) system;  $p_1^*$  ( $p_2^*$ ) is the  $D_s^-$  ( $D_s^*$ ) momentum in the rest frame of the  $D_s^-D^{*0}$  ( $D_s^*-D^0$ ) system at  $M = m_0$ . We define  $f = [\mathcal{B}_1/(\mathcal{B}_1 + \mathcal{B}_2)]$ , where  $\mathcal{B}_j$  is the BF of the  $j$ th decay. We assume  $f = 0.5$  in the nominal fit and take variations of  $f$  into account in the studies of systematic uncertainty.

The  $Z_{cs}(3985)^-$  signal shape, which is used in the fit depicted in Fig. 3, is the  $f$ -dependent sum of the efficiency-weighted  $\mathcal{F}_j$  functions convolved with a resolution function, which is obtained from MC simulation. The resolution is about 5 MeV/ $c^2$  and is asymmetric due to the contribution from initial state radiation (ISR). The parametrization of the

combinatorial-background shape is derived from the kernel estimate [35] of the WS distribution, whose normalization is fixed to the number of the fitted background events within the decorrelated  $RM(K^+D_s^-)$  signal window. The shapes of the NR and  $D^{*0}\bar{D}_1^*(2600)^0(\rightarrow D_s^-K^+)$  signals are taken from the MC simulation. The size of the NR component at each energy point and the ratio  $\mathcal{B}(\bar{D}_1^*(2600)^0 \rightarrow D_s^-K^+)/\mathcal{B}(\bar{D}_1^*(2600)^0 \rightarrow D^-\pi^+)$  are free parameters in the fit. In addition, a component that describes the total contributions of the excited  $D_s^{*+}$  processes is included, whose shape is taken from MC simulation and its size is fixed according to the yields estimated from the control-sample studies.

From the fit, the parameters  $m_0$  and  $\Gamma_0$  are determined to be  $(3985.2_{-2.0}^{+2.1})$  MeV/ $c^2$  and  $(13.8_{-5.2}^{+8.1})$  MeV, respectively. The significance of the signal is calculated taking into account the look-elsewhere effect [36], where 5000 pseudo-datasets are produced with the sum of null- $Z_{cs}(3985)^-$  models and fitted with the same strategy as the nominal fit to obtain the distribution of  $-2 \ln(L_0/L_{\max})$ , where  $L_0$  and  $L_{\max}$  are fitted likelihood values under the null- $Z_{cs}(3985)^-$  hypothesis and alternative hypothesis, respectively. In the generation of the pseudodata, the systematic uncertainties relevant to determine the signal yields, as marked in Table II in Ref. [28], are considered. The resulting distribution is found to be well described by a  $\chi^2$  distribution with 13.8 degrees of freedom. With an observed value of  $-2 \ln(L_0/L_{\max}) = 59.14$ , we obtain a significance of  $5.3\sigma$ . The number of  $Z_{cs}(3985)^-$  events observed at  $\sqrt{s} = 4.681$  GeV is the most prominent compared to the other four energy points. If we fit only to data at  $\sqrt{s} = 4.681$  GeV, we obtain consistent  $Z_{cs}(3985)^-$  resonance parameters.

The Born cross section  $\sigma^B[e^+e^- \rightarrow K^+Z_{cs}(3985)^- + \text{c.c.}]$  times the sum of BFs of the decays  $Z_{cs}(3985)^- \rightarrow D_s^-D^{*0} + D_s^*-D^0$  is equal to  $n_{\text{sig}}/(\mathcal{L}_{\text{int}}f_{\text{corr}}\bar{\epsilon})$ , where  $n_{\text{sig}}$  is the number of the observed signal events,  $\mathcal{L}_{\text{int}}$  is the integrated luminosity, and  $\bar{\epsilon}$  is the BF-weighted detection efficiency. We define  $f_{\text{corr}} \equiv (1 + \delta_{\text{ISR}})1/(|1 - \Pi|^2)$ , where  $(1 + \delta_{\text{ISR}})$  is the radiative-correction factor and  $1/(|1 - \Pi|^2)$  is the vacuum-polarization factor [37]. The numerical results are listed in Table I.

TABLE I. The results for the cross section measurement at each energy point. The upper limits in the parenthesis correspond to 90% confidence level after considering the systematic uncertainties.

$\sqrt{s}$ (GeV)	$\mathcal{L}_{\text{int}}$ (pb $^{-1}$ )	$n_{\text{sig}}$	$f_{\text{corr}}\bar{\epsilon}$ (%)	$\sigma^B \cdot \mathcal{B}$ (pb)
4.628	511.1	$4.2_{-4.2}^{+6.1}$	1.03	$0.8_{-0.8}^{+1.2} \pm 0.6 (< 3.0)$
4.641	541.4	$9.3_{-6.2}^{+7.3}$	1.09	$1.6_{-1.1}^{+1.2} \pm 1.3 (< 4.4)$
4.661	523.6	$10.6_{-7.4}^{+8.9}$	1.28	$1.6_{-1.1}^{+1.3} \pm 0.8 (< 4.0)$
4.681	1643.4	$85.2_{-15.6}^{+17.6}$	1.18	$4.4_{-0.8}^{+0.9} \pm 1.4$
4.698	526.2	$17.8_{-7.2}^{+8.1}$	1.42	$2.4_{-1.0}^{+1.1} \pm 1.2 (< 4.7)$

Sources of systematic uncertainties on the measurement of the  $Z_{cs}(3985)^-$  resonance parameters and the cross section are studied, as explained in Ref. [28]. The main sources include the mass scaling, detector resolution, the signal model, background models, and the input cross section line shape for  $\sigma^B[e^+e^- \rightarrow K^+Z_{cs}(3985)^-]$ . The contributions to the systematic uncertainties on the resonance parameters and cross sections are given in Table II and Ref. [28], respectively. In addition, the global signal significances after taking into account the look-elsewhere effect under different systematic effects are listed in Table II.

In summary, we study the reactions  $e^+e^- \rightarrow K^+(D_s^-D^{*0} + D_s^{*-}D^0)$  based on  $3.7 \text{ fb}^{-1}$  of data collected at  $\sqrt{s} = 4.628, 4.641, 4.661, 4.681, \text{ and } 4.698 \text{ GeV}$ , and observe an enhancement near the  $D_s^-D^{*0}$  and  $D_s^{*-}D^0$  mass thresholds in the  $K^+$  recoil-mass spectrum for events collected at  $\sqrt{s} = 4.681 \text{ GeV}$ . While the known charmed mesons cannot explain the excess, it matches a hypothesis of a  $D_s^-D^{*0}$  and  $D_s^{*-}D^0$  resonant structure  $Z_{cs}(3985)^-$  with a mass-dependent-width Breit-Wigner line shape well; a fit gives the resonance mass of  $(3985.2^{+2.1}_{-2.0} \pm 1.7) \text{ MeV}/c^2$  and width of  $(13.8^{+8.1}_{-5.2} \pm 4.9) \text{ MeV}$ . This corresponds to a pole position  $m_{\text{pole}} - i(\Gamma_{\text{pole}}/2)$  of

$$m_{\text{pole}}[Z_{cs}(3985)^-] = (3982.5^{+1.8}_{-2.6} \pm 2.1) \text{ MeV}/c^2,$$

$$\Gamma_{\text{pole}}[Z_{cs}(3985)^-] = (12.8^{+5.3}_{-4.4} \pm 3.0) \text{ MeV}.$$

The first uncertainties are statistical and the second are systematic. The significance of this resonance hypothesis is estimated to be  $5.3\sigma$  over the pure contributions from the conventional charmed mesons. The  $Z_{cs}(3985)^-$  candidate reported here would couple to at least one of  $D_s^-D^{*0}$  and  $D_s^{*-}D^0$ , and has unit charge, the quark composition is most likely  $c\bar{c}s\bar{u}$ . Hence, it would become the first  $Z_{cs}$  tetraquark candidate observed. The measured mass is close to the mass threshold of  $D_s\bar{D}^*$  and  $D_s^*\bar{D}$ , which is consistent with the theoretical calculations in Ref. [18,20–22]. In addition, the

TABLE II. Summary of systematic uncertainties on the  $Z_{cs}(3985)^-$  resonance parameters. The total systematic uncertainty corresponds to a quadrature sum of all individual items. The global signal significance after taking into account the systematic item marked with \* is listed.

Source	Mass(MeV/ $c^2$ )	Width (MeV)	Significance
Mass scale	0.5		
Resolution*	0.2	1.0	5.7 $\sigma$
$f$ factor*	0.2	1.0	5.6 $\sigma$
Signal model*	1.0	2.6	5.7 $\sigma$
Backgrounds*	0.5	0.5	5.6 $\sigma$
Efficiencies	0.1	0.2	
$D_{(s)}^{**}$ states*	1.0	3.4	5.4 $\sigma$
$\sigma^B[K^+Z_{cs}(3985)^-]$	0.6	1.7	
Total	1.7	4.9	

Born cross sections  $\sigma^B[e^+e^- \rightarrow K^+Z_{cs}(3985)^- + \text{c.c.}]$  times the sum of the branching fractions for  $Z_{cs}(3985)^- \rightarrow D_s^-D^{*0} + D_s^{*-}D^0$  decays are measured at the five energy points. Because of the limited size of the statistics, only a one-dimensional fit is implemented and the potential interference effects are neglected. As shown in Figs. 5 and 6 of Ref. [28], we find no evidence for enhancements due to interference below  $4 \text{ GeV}/c^2$ . Even so, the properties of the observed excess might not be fully explored and there exist other possibilities of explaining the near-threshold enhancement. To further improve studies of the excess, more statistics are necessary in order to carry out an amplitude analysis.

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