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

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We report a study of the processes of $e^+e^- \to K^+D_s^-D^{*0}$ 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 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 $\sqrt{s} = 4.681$ GeV. The structure matches a mass-dependent-width Breit-Wigner line shape, whose pole mass and width are determined as $(3982.5^{+1.8}_{-2.6} \pm 2.1)$ MeV$/c^2$ and $(12.8^{+5.3}_{-4.4} \pm 3.0)$ MeV, respectively. The first uncertainties are statistical and the second are systematic. The significance of the resonance hypothesis is estimated to be 5.3 σ 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 $e^+e^- \to K^+ D_s^- D^{*0}$ and $K^+ D_s^{*-} D^0$ [$e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$ 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 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 $D_s^- \to K^+K^-\pi^-$ 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, $e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$, the final-state particles are simulated assuming nonresonant production [27]. For the simulation of the $Z_{cs}(3985)^-$ signal process, $e^+e^- \to K^+ Z_{cs}(3985)^-$, 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 $e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$, we reconstruct combinations of the bachelor K^+ and the decays $D_s^- \to K^+K^-\pi^-$ 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

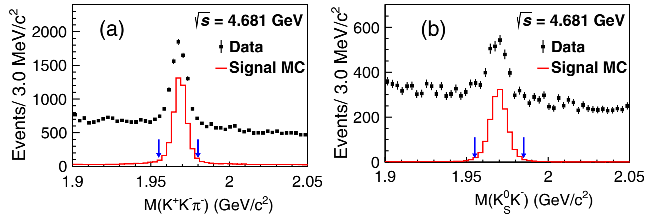

FIG. 1. Distributions of the invariant mass $M(K^+K^-\pi^-)$ (a) and $M(K_S^0 K^-)$ (b) in data and MC simulations at $\sqrt{s} = 4.681$ GeV. The $Z_{cs}(3985)^-$ signal MC component is normalized to the observed D_s^- yield in data. Arrows indicate the mass region requirements.

least four charged tracks and reconstruct the final states of $K^\pm$, $\pi^\pm$, and $K_S^0 \to \pi^+\pi^-$ following the criteria in Ref. [31]. For the candidate of K_S^0, we require its invariant mass within $0.485 < M(\pi^+\pi^-) < 0.511$ GeV$/c^2$. For the decay $D_s^- \to K^+K^-\pi^-$, to improve the signal purity, we only retain the D_s^- candidates within the Dalitz plot regions consistent with $D_s^- \to \phi\pi^-$ or $D_s^- \to K^*(892)^0 K^-$ decays by requiring that the invariant masses satisfy either $M(K^+K^-) < 1.05$ GeV$/c^2$ or $0.850 < M(K^+\pi^-) < 0.930$ 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 $1.955 < M(K^+K^-\pi^-) < 1.980$ GeV$/c^2$ and $1.955 < M(K_S^0 K^-) < 1.985$ 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 reconstructed D_s^- mass, 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

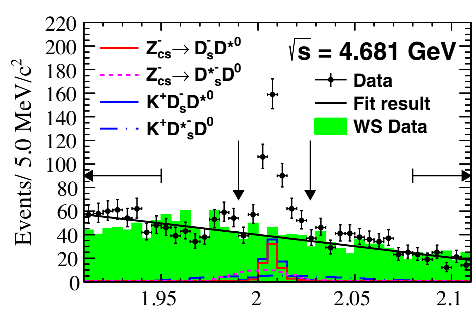

FIG. 2. Distribution of the $K^+D_s^-$ recoil mass in data and signal MC samples at $\sqrt{s} = 4.681$ GeV. Horizontal arrows indicate the sidebands and vertical arrows indicate the signal region. The magnitudes of the three-body nonresonant processes and $Z_{cs}(3985)^-$ signal processes are scaled 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 $(1.990, 2.027)$ 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, $(1.91, 1.95)$ GeV$/c^2$ and $(2.08, 2.11)$ GeV$/c^2$, as shown in Fig. 2. The number of background events within the signal region is estimated to be 282.6 ± 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 $RM(K^+) < 4$ 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 $e^+e^- \to K^+(D_s^-D^{*0} + D_s^{*-}D^0)$. To understand potential contributions from the processes $e^+e^- \to D_s^{(*)-}D_s^{**+}(\to D^{(*)0}K^+)$ or $D^{(*)0}\bar{D}^{**0}(\to D_s^{(*)-}K^+)$, 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 GeV$/c^2$ [28].

The following three processes that contain excited D_s^{**+} background have potential contributions to the $RM(K^+)$ spectrum: (1) $D_s^-D_{s1}^*(2536)^+(\to D^{*0}K^+)$, (2) $D_s^{*-}D_{s2}^*(2573)^+(\to D^0K^+)$, and (3) $D_s^-D_{s1}^*(2700)^+(\to D^{*0}K^+)$. 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 candidates in Fig. 3 is evaluated. For channel (3), a control sample of $e^+e^- \to D_s^-D_{s1}^*(2700)^+(\to D^0K^+)$ is selected by detecting the $D_s^-K^+$ recoiling against a missing D^0. We then use the BF ratio of $\mathcal{B}(D_{s1}^*(2700)^+ \to D^{*0}K^+)/\mathcal{B}(D_{s1}^*(2700)^+ \to D^0K^+) = 0.91 \pm 0.18$ [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 ± 8.0, 19.1 ± 7.6, and 15.0 ± 13.3 events, respectively. For the other energy points, the estimated yields of the three channels are given in Ref. [28].

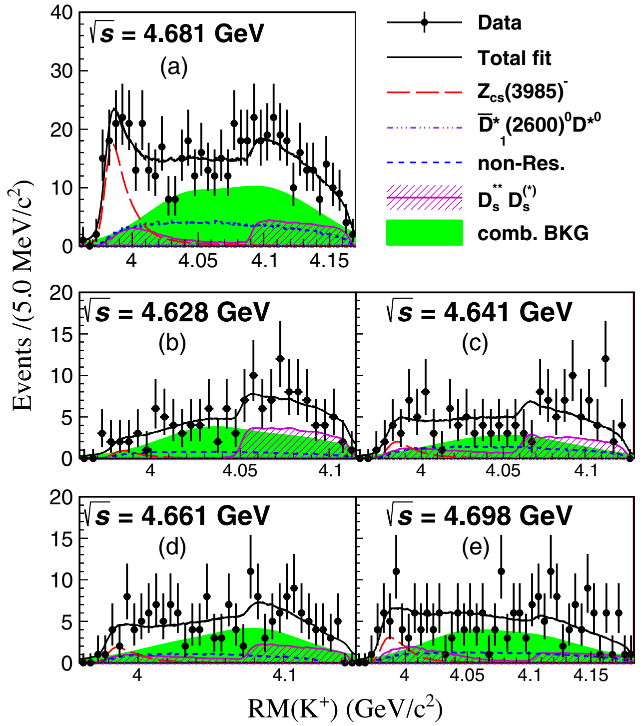

FIG. 3. Simultaneous unbinned maximum likelihood fit to the K^+ recoil-mass spectra in data at $\sqrt{s} = 4.628$, 4.641, 4.661, 4.681, and 4.698 GeV. Note that the size of the $D^{*0}\bar{D}_1^*(2600)^0(\to D_s^-K^+)$ component is consistent with zero.

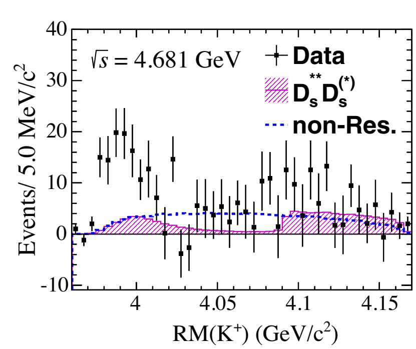

FIG. 4. The K^+ recoil-mass spectrum in data at $\sqrt{s} = 4.681$ GeV after subtraction of the combinatorial backgrounds.

Two processes with excited nonstrange $\bar{D}^{**0}$ states that produce potential enhancements around $4\ \mathrm{GeV}/c^2$ in $RM(K^+)$ are $D^{*0}\bar{D}_1^*(2600)^0(\to D_s^- K^+)$ [29,32] and $D^0\bar{D}_3^*(2750)^0(\to D_s^{*-}K^+)$. 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 $e^+e^- \to D^{*0}\bar{D}_1^*(2600)^0$ $(\to D^-\pi^+)$ at all five energy points. Since the ratio $\mathcal{B}(\bar{D}_1^*(2600)^0 \to D_s^- K^+)/\mathcal{B}(\bar{D}_1^*(2600)^0 \to D^-\pi^+)$ 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 $D^{*0}\bar{D}_1^*(2600)^0(\to D_s^- K^+)$ component at the different energy points. For the second process, no significant signal is observed in the control sample $e^+e^- \to D^0\bar{D}_3^*(2750)^0(\to D^-\pi^+)$. Assuming the relative BF ratio $\mathcal{B}(\bar{D}_3^* \to D_s^{*-}K^+)/\mathcal{B}(\bar{D}_3^* \to D^-\pi^+) = 4.1\%$ [34], the contribution of the $D^0D_3^*(2750)^0$ channel to Fig. 3 is estimated to be 0.0 ± 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 $D_s^- D^{*0}(3975.2\ \mathrm{MeV}/c^2)$ and $D_s^{*-}D^0(3977.0\ \mathrm{MeV}/c^2)$, 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:

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

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 $Z_{cs}(3985)^- \to D_s^- D^{*0}$ and $Z_{cs}(3985)^- \to D_s^{*-}D^0$, respectively. Here, M is the reconstructed mass; m_0 is the resonance mass; Γ_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 jth 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 $5\ \mathrm{MeV}/c^2$ 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 $D^{*0}\bar{D}_1^*(2600)^0(\to D_s^- K^+)$ signals are taken from the MC simulation. The size of the NR component at each energy point and the ratio $\mathcal{B}(\bar{D}_1^*(2600)^0 \to D_s^- K^+)/\mathcal{B}(\bar{D}_1^*(2600)^0 \to D^-\pi^+)$ 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 Γ_0 are determined to be $(3985.2^{+2.1}_{-2.0})\ \mathrm{MeV}/c^2$ and $(13.8^{+8.1}_{-5.2})$ 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 χ^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 5.3σ. 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 $\sigma^B[e^+e^- \to K^+Z_{cs}(3985)^- +$ c.c.$]$ times the sum of BFs of the decays $Z_{cs}(3985)^- \to D_s^- D^{*0} + D_s^{*-}D^0$ is equal to $n_{\mathrm{sig}}/(\mathcal{L}_{\mathrm{int}} f_{\mathrm{corr}} \bar{\varepsilon})$, where n_{sig} is the number of the observed signal events, $\mathcal{L}_{\mathrm{int}}$ is the integrated luminosity, and $\bar{\varepsilon}$ is the BF-weighted detection efficiency. We define $f_{\mathrm{corr}} \equiv (1+\delta_{\mathrm{ISR}})1/(|1-\Pi|^2)$, where $(1+\delta_{\mathrm{ISR}})$ 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)	$\mathcal{L}_{\mathrm{int}}$ (pb^{-1})	n_{sig}	$f_{\mathrm{corr}}\bar{\varepsilon}$(%)	$\sigma^B \cdot \mathcal{B}$ (pb)
4.628	511.1	$4.2^{+6.1}_{-4.2}$	1.03	$0.8^{+1.2}_{-0.8} \pm 0.6(<3.0)$
4.641	541.4	$9.3^{+7.3}_{-6.2}$	1.09	$1.6^{+1.2}_{-1.1} \pm 1.3(<4.4)$
4.661	523.6	$10.6^{+8.9}_{-7.4}$	1.28	$1.6^{+1.3}_{-1.1} \pm 0.8(<4.0)$
4.681	1643.4	$85.2^{+17.6}_{-15.6}$	1.18	$4.4^{+0.9}_{-0.8} \pm 1.4$
4.698	526.2	$17.8^{+8.1}_{-7.2}$	1.42	$2.4^{+1.1}_{-1.0} \pm 1.2(<4.7)$

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 $\sigma^B[e^+e^- \to K^+ Z_{cs}(3985)^-]$. 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 $e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$ based on 3.7 fb^{-1} of data collected at $\sqrt{s} = 4.628$, 4.641, 4.661, 4.681, and 4.698 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 $\sqrt{s} = 4.681$ 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 $(3985.2^{+2.1}_{-2.0} \pm 1.7)$ MeV$/c^2$ and width of $(13.8^{+8.1}_{-5.2} \pm 4.9)$ MeV. This corresponds to a pole position $m_{\rm pole} - i(\Gamma_{\rm pole}/2)$ of

$$m_{\rm pole}[Z_{cs}(3985)^-] = (3982.5^{+1.8}_{-2.6} \pm 2.1)\ {\rm MeV}/c^2,$$
$$\Gamma_{\rm pole}[Z_{cs}(3985)^-] = (12.8^{+5.3}_{-4.4} \pm 3.0)\ {\rm MeV}.$$

The first uncertainties are statistical and the second are systematic. The significance of this resonance hypothesis is estimated to be 5.3σ 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 Born cross sections $\sigma^B[e^+e^- \to K^+ Z_{cs}(3985)^- + {\rm c.c.}]$ times the sum of the branching fractions for $Z_{cs}(3985)^- \to D_s^- D^{*0} + D_s^{*-} D^0$ 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 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.

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 σ
f factor*	0.2	1.0	5.6 σ
Signal model*	1.0	2.6	5.7 σ
Backgrounds*	0.5	0.5	5.6 σ
Efficiencies	0.1	0.2	
$D_{(s)}^{**}$ states*	1.0	3.4	5.4 σ
$\sigma^B[K^+ Z_{cs}(3985)^-]$	0.6	1.7	
Total	1.7	4.9	

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