

DD^* correlation functions in deciphering the nature of $T_{cc}(3875)^+$ Duo-Lun Ge¹, Zhi-Wei Liu^{2,3,*} and Li-Sheng Geng^{1,4,5,6,†}¹*School of Physics, Beihang University, Beijing 102206, China*²*Institute for Advanced Study in Nuclear Energy and Safety, College of Physics and Optoelectronic Engineering, Shenzhen University, Shenzhen 518060, China*³*Shenzhen Key Laboratory of Nuclear and Radiation Safety, Shenzhen 518060, China*⁴*Sino-French Carbon Neutrality Research Center, École Centrale de Pékin/School of General Engineering, Beihang University, Beijing 100191, China*⁵*Peng Huanwu Collaborative Center for Research and Education,**Beihang University, Beijing 100191, China*⁶*Southern Center for Nuclear-Science Theory (SCNT), Institute of Modern Physics, Chinese Academy of Sciences, Huizhou 516000, China*

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Understanding near-threshold strong interactions is essential for disentangling hadronic molecules and compact multiquark states in heavy-flavor spectroscopy. In this context, the doubly charmed tetraquark candidate $T_{cc}(3875)^+$ serves as a critical benchmark because it lies very close to the $D^* - D$ thresholds. Motivated by the interaction ambiguity reported recently [Phys. Rev. D **113**, L031505 (2026)], we evaluate the $D^* - D$ scattering lengths and femtoscopic correlation functions for the molecular and molecule-compact admixture assignments of the $T_{cc}(3875)^+$. We show that, although these scenarios yield similar invariant-mass line shapes, their corresponding femtoscopic correlation functions differ markedly and remain clearly distinguishable for typical particle-emitting sources created at the LHC. Our results indicate that femtoscopy can serve as a sensitive and complementary probe of the near-threshold dynamics of $T_{cc}(3875)^+$, providing vital theoretical references for future LHC femtoscopy measurements.

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I. INTRODUCTION

In the past two decades, studies of hadron spectroscopy have entered a new era driven by the discovery of numerous exotic hadrons [1–5] beyond the conventional quark-model classification of mesons ($q\bar{q}$) and baryons (qqq) [6–8]. These exotic hadrons provide a unique window into the non-perturbative dynamics of QCD and the mechanism by which quarks and gluons organize themselves into color-singlet hadronic states. A central open question concerns the dominant dynamical picture for these observed exotic states. Depending on the interplay between short- and long-distance QCD dynamics, exotic candidates can be interpreted as either loosely bound hadronic molecules generated by final-state interactions (FSIs) [9–12], compact multiquark states [13,14], admixtures of molecular and compact components [15,16], manifestations of coupled-channel dynamics [17] or

kinematic effects such as triangle singularities and cusp effects [18,19], while hybrid or glueball configurations [20–23] have also been discussed. Since many of the newly observed states lie close to the thresholds of two conventional hadrons [11], understanding near-threshold dynamics has become a key avenue for disentangling these competing interpretations. Systematic overviews of recent progress can be found in the reviews [24–34].

Heavy-flavor near-threshold states provide an especially clean laboratory for studying such threshold dynamics. In particular, a binding energy of $\mathcal{O}(\text{MeV})$ or below implies a large spatial extension of these states and amplifies the impact of coupled channels on both line shapes and pole positions. A compelling example is the doubly charmed tetraquark candidate $T_{cc}(3875)^+$. It was observed by the LHCb Collaboration as a narrow enhancement in the prompt $D^0 D^0 \pi^+$ invariant-mass spectrum just below the $D^{*+} D^0$ threshold [35,36], using pp collision data at $\sqrt{s} = 7, 8$, and 13 TeV. The near-threshold location $\delta m = -360 \pm 40_{-0}^{+4}$ keV and the remarkably small width $\Gamma = 48 \pm 2_{-14}^{+0}$ keV [36] naturally motivate the interpretation of a predominant DD^* hadronic molecule [37–43]. This molecular interpretation is further supported by first-principles lattice QCD studies, where analyses using the Lüscher

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method and the Hadrons to Atomic nuclei from Lattice QCD (HAL QCD) method indicate that the $D^* - D$ interaction is sufficiently attractive to generate a pole very close to threshold [44–47]. At the same time, however, a purely molecular interpretation is not free of tension. For example, difficulties have been pointed out in accommodating T_{cc} together with $X(3872)$ and $X(3960)$ within a unified molecular picture [48]. This leaves room for alternative descriptions, including compact tetraquark scenarios [49,50] and mixed molecule-compact descriptions [51,52], since it is possible for models with pure quark degrees of freedom (d.o.f.) to reproduce the LHCb mass, either through parameter adjustments within theoretical uncertainties or by including additional interaction terms [53–55]. Therefore, the internal structure of $T_{cc}(3875)^+$ remains unresolved [56].

A key reason is that distinct dynamical pictures can reproduce the current $D^0 D^0 \pi^+$ invariant-mass line shape with comparable quality, so such data alone do not uniquely determine the dominant configuration. In existing line-shape studies, the near-threshold dynamics have often been modeled under a pure molecular (FSI-driven) assumption, without introducing an explicit compact bare-state component [38,39,57–59]. As an extension of line-shape analyses, Ampuku *et al.* constructed a coupled-channel framework that explicitly allows molecule-compact mixing and incorporated such mixing in the analysis of the $D^0 D^0 \pi^+$ invariant-mass distributions [52]. By fitting line-shape data, they found three comparable scenarios: one Mol.+Compact solution and two molecular solutions (Mol. 1 and Mol. 2). Crucially, the resulting $\chi^2/\text{d.o.f.}$ values are nearly indistinguishable within current experimental resolution and statistics, so the invariant-mass spectrum alone cannot distinguish the dominant configuration, leaving it an open question. This motivates the use of complementary observables that are likewise sensitive to near-threshold interactions and can help lift the degeneracy among scenarios inferred from line-shape fits.

Femtoscopic correlation functions (CFs) measured in high-energy proton-proton and heavy-ion collisions provide a promising solution. Over the past decade, femtoscopy has developed into a widely used probe of final-state interactions. Numerous hadron-hadron systems have been studied experimentally and theoretically [60–64], providing a solid foundation for applying the method to the heavy-flavor sector. Correlation measurements are sensitive to the two-body interaction at small relative momentum and can therefore provide complementary information to line-shape data, as recently demonstrated in the studies of the $J/\psi J/\psi$ CF related to $X(6200)$ [65], the $D_s^+ D_s^-$ CF related to $X(6900)$ [66], and the $D^0 D^{*-}/D^0 D_s^{*-}$ CFs related to $Z_c(3900)/Z_{cs}(3985)$ [67]. Likewise, $D^{*+} - D^0$ and $D^{*0} - D^+$ CFs can serve as a probe of the near-threshold dynamics of $T_{cc}(3875)^+$. Kamiya *et al.* constructed coupled-channel one-range Gaussian potentials constrained by the low-energy DD^* scattering parameters extracted by

the LHCb Collaboration and computed the $D^0 D^{*+}$ and $D^+ D^{*0}$ correlation functions under the hadronic-molecule assumption, demonstrating the characteristic source-size dependence of a near-threshold shallow bound state [68]. Vidaña *et al.* developed a momentum-space formalism based on the on-shell factorization of scattering amplitudes, showing that the T_{cc} correlation functions are largely governed by the scattering length [69]. We note that correlation functions can also be used to constrain scattering parameters and channel probabilities, offering sensitivity to nonmolecular components [70].

Motivated by the results of Refs. [65–67,70] and the latest analysis of Ref. [52], this work investigates whether femtoscopy can discriminate among the proposed interactions for $T_{cc}(3875)^+$, thereby providing complementary constraints on the nature of $T_{cc}(3875)^+$ beyond invariant-mass distributions. In particular, we restrict ourselves here to the molecular and molecule-compact admixture scenarios that can account for the current invariant-mass spectrum [52]. The paper is organized as follows: Sec. II presents the theoretical formalism, including the basic formulas for calculating scattering lengths and correlation functions. Then, using the interactions determined in Ref. [52], we evaluate the scattering lengths and coupled- and single-channel CFs and discuss their relations to the nature of $T_{cc}(3875)^+$ in Sec. III. In Sec. IV, we summarize our key findings and provide an outlook for future research.

II. THEORETICAL FORMALISM

In this section, we briefly outline the coupled-channel framework employed in the present analysis. Following Ref. [52], we consider two coupled channels $D^{*+} - D^0$ (channel 1) and $D^{*0} - D^+$ (channel 2) and adopt the same interaction, which takes the form

$$V_{ij} = \frac{1}{2} \begin{pmatrix} C_1 + C_0 & C_1 - C_0 \\ C_1 - C_0 & C_1 + C_0 \end{pmatrix} + \frac{1}{2E - m_{4q}} \begin{pmatrix} g_0^2 & -g_0^2 \\ -g_0^2 & g_0^2 \end{pmatrix}, \quad (1)$$

where m_{4q} denotes the bare mass of the compact T_{cc}^+ state. The first term represents the contact interaction, while the second term accounts for the coupling to the compact four-quark configuration. All parameters (C_0 , C_1 , m_{4q} , g_0^2 , etc.) are the same as those in Ref. [52]. The unitarized scattering amplitude is obtained by solving the Bethe-Salpeter equation. Within the on-shell approximation, it reduces to the following algebraic form:

$$T = (I - VG)^{-1}V, \quad (2)$$

where I is the identity matrix and G_{ij} is the nonrelativistic two-body loop function for channel i ,

$$G_{ij}(E) = \delta_{ij} \int_0^{q_{\max}} \frac{d^3 q}{(2\pi)^3} \frac{1}{E - E_{\text{th},i} - q^2/2\mu_i + i\epsilon}$$

$$= \delta_{ij} \int_0^{q_{\max}} \frac{q^2 dq}{2\pi^2} \frac{1}{(k_i^2 - q^2)/2\mu_i + i\epsilon}, \quad (3)$$

where δ_{ij} is the Kronecker symbol, k_i and μ_i denote the relative momentum and reduced mass of channel i , and $E = (m_{i_1} + m_{i_2}) + k_i^2/(2\mu_i)$, where the D^* mass m_{D^*} is replaced by $m_{D^*} - i\Gamma_{D^*}/2$ to account for the effect of the D^* decay width. We have checked that the finite decay width has a negligible numerical impact. The loop integral is evaluated using a sharp momentum cutoff $q_{\max}$.

From the scattering amplitude, low-energy scattering parameters such as the scattering length and effective range can be extracted. The nonrelativistic expression is given by [38,39]

$$a_i = \frac{\mu_i}{2\pi} T_{ii}|_{k=0}, \quad (4)$$

$$r_{\text{eff},i} = 2 \frac{\partial}{\partial k^2} \left[-\frac{2\pi}{\mu_i} (T_{ii})^{-1} + ik \right] \Big|_{k=0}. \quad (5)$$

To connect the interaction with femtoscopic observables, we evaluate the two-particle correlation function. Following the Koonin-Pratt formalism [71,72] and restricting to the S wave, which dominates near threshold, the coupled-channel correlation function is written as [73]

$$C_i(k) = 1 + 4\pi \int dr r^2 S_{12}(r) [|j_0(kr) + T_{ii}\tilde{G}_{ii}|^2 + |T_{ji}\tilde{G}_{jj}(1 - \delta_{ij})|^2 - j_0^2(kr)], \quad (6)$$

where $j_0(kr)$ is the spherical Bessel function describing the S -wave free scattering behavior, and the expression includes the summation of the subscript j , which denotes the j th channel. For comparison and consistency checks, we also evaluate the single-channel CF, calculated within the same coupled-channel framework, except that the term $|T_{ji}\tilde{G}_{jj}(1 - \delta_{ij})|^2$ is omitted to switch off channel coupling. The two-particle source function is assumed to be the widely used Gaussian form

$$S_{12}(r) = \frac{1}{(4\pi R^2)^{\frac{3}{2}}} \exp\left(-\frac{r^2}{4R^2}\right), \quad (7)$$

which satisfies the normalization $\int d^3 r S_{12}(r) = 1$. The parameter R , referred to as the source radius, characterizes the spatial extent of the particle-emitting source in the pair rest frame. The quantity $\tilde{G}$ is given by

$$\tilde{G}_{ij}(E, r) = \delta_{ij} \int_0^{q_{\max}} \frac{d^3 q}{(2\pi)^3} \frac{j_0(qr)}{E - E_{\text{th},i} - q^2/2\mu_i + i\epsilon}. \quad (8)$$

III. RESULTS AND DISCUSSIONS

A. DD* interactions

Before discussing the results in detail, we briefly summarize the three interactions derived in Ref. [52]. They are all obtained by fitting the same near-threshold $D^0 D^0 \pi^+$ line shape [35,36] with comparable quality, but correspond to different dynamical interpretations of the enhancement. In the Mol.+Compact scenario, the contact $D^* D$ interaction is weak, and the near-threshold structure is mainly generated by an explicit compact T_{cc}^+ bare state at 3.8757 GeV. This scenario contains a single near-threshold pole, denoted as “state,” located 311 keV below the $D^{*+} D^0$ threshold. The other two scenarios are purely molecular. In Mol. 1, two poles are found: state 1 lies 81 keV below the $D^{*0} D^+$ threshold and is dominated by the $D^{*0} D^+$ component, while state 2 lies 338 keV below the $D^{*+} D^0$ threshold and is realized as the $D^{*+} D^0$ bound state. In Mol. 2, the contact attraction is stronger, and the off-diagonal elements become less suppressed. The two corresponding poles are denoted as state 1' and state 2': state 1' is located 372 keV below the $D^{*+} D^0$ threshold, or equivalently 1.78 MeV below the $D^{*0} D^+$ threshold, and is denoted as the $D^{*0} D^+$ bound state; state 2' is located 6.16 MeV below the $D^{*+} D^0$ threshold and is associated with the $D^{*+} D^0$ channel. Therefore, Ref. [52] has identified two poles in Mol. 1, two poles in Mol. 2, and one pole in Mol.+Compact. Among these, only state 2 and state 1' fall within the mass uncertainty reported by the LHCb Collaboration.

The calculated scattering lengths are summarized in Table I. Under our convention

$$k \cot \delta = -\frac{1}{a} + \frac{1}{2} r_{\text{eff}} k^2 + \mathcal{O}(k^4), \quad (9)$$

where positive scattering lengths indicate the presence of bound states for all three interactions, consistent with Fig. 2 of Ref. [52]. It is worth noting that the $D^* - D$ scattering length has already been computed in earlier works. Despite differences in the underlying amplitude constructions, our result, especially the Mol. 1 value $a_{D^{*+} D^0} = 7.54 + 0.02i$ fm, is comparable to those obtained using a cutoff

TABLE I. Scattering lengths and effective ranges for different channels under three scenarios.

Interaction	Channel	a (fm)	r_{eff} (fm)
Mol.+Compact	$D^{*+} - D^0$	$0.95 + 0.11i$	$-120.64 + 0.79i$
	$D^{*0} - D^+$	$0.17 - 0.01i$	$-148.01 - 4.29i$
Mol. 1	$D^{*+} - D^0$	$7.54 + 0.02i$	$-0.55 + 0.02i$
	$D^{*0} - D^+$	$11.52 - 5.11i$	$0.25 + 0.39i$
Mol. 2	$D^{*+} - D^0$	$5.30 + 0.05i$	$-4.46 - 0.07i$
	$D^{*0} - D^+$	$3.06 - 0.26i$	$0.14 - 0.14i$

$q_{\max} = 0.5$ GeV in Refs. [38,39]: $a_{D^{*+}D^0} = 8.56(49) - i2.61(32)$ fm, and $a_{D^{*+}D^0} = -7.38_{-0.57}^{+0.46} + i1.96_{-0.67}^{+0.34}$ fm (scheme 1), respectively, as well as the LHCb result $a_{D^{*+}D^0} = (7.16 \pm 0.51) - i(1.85 \pm 0.28)$ fm [36]. Additional values reported in Refs. [68,69], $a_{D^{*+}D^0} = 7.16 - i1.85$ and $a_{D^{*+}D^0} = 7.78 - i1.82$ fm, further support this agreement. It should be noted that the values listed here have been adapted from the original references to match our convention, as defined in Eq. (9). A strict numerical comparison is not expected since these extractions adopt different threshold prescriptions and implement coupled-channel effects and the finite D^* decay width differently. Nevertheless, they all support the same qualitative conclusion that the $D^{*+} - D^0$ system exhibits a large scattering length of order $a \sim \mathcal{O}(7-9)$ fm. A similar comparison can be made for the $D^{*0} - D^+$ channel. For reference, the scattering lengths quoted in Refs. [68,69] are $a_{D^{*0}D^+} = 1.75 - i1.82$ and $a_{D^{*0}D^+} = 2.07 - 1.21i$ fm, respectively. In our calculations, Mol. 2 yields $a_{D^{*0}D^+} = 3.06 - 0.26i$ fm, which is also comparable in magnitude to the above values, whereas Mol. 1 gives a much larger $a_{D^{*0}D^+} = 11.52 - 5.11i$ fm. It should be noted that these determinations are based on near-threshold descriptions that incorporate the relevant coupled-channel hadronic dynamics constrained by unitarity, while not incorporating an explicit compact bare-state pole in the potential. In contrast, the Mol.+Compact interaction yields much smaller scattering lengths in both channels, implying qualitatively different low-energy behavior compared with the molecular scenarios. That is, it leads to a behavior similar to that of a deeply bound system, as shown in Table I.

Regarding the effective range, we again find that the two molecular interactions yield results broadly consistent with previous analyses. In Ref. [36], the LHCb Collaboration reported the range of $-11.9 < r_{D^{*+}D^0} \leq 0$ fm at 90% confidence level. References [38,69] also obtained moderate negative effective ranges for the same channel, namely $r_{D^{*+}D^0} = -2.78$ fm (scheme 1) and $r_{D^{*+}D^0} = -3.49$ fm, respectively. In our calculations, Mol. 1 gives $r_{D^{*+}D^0} = -0.55$ fm, and Mol. 2 yields $r_{D^{*+}D^0} = -4.46$ fm, both lying in the same qualitative range as the above molecular determinations, with the Mol. 2 value being closer to the results mentioned above. By contrast, the Mol.+Compact interaction gives drastically different effective ranges, with $|r_{\text{eff}}| > 100$ fm. Such anomalously large values are naturally expected when an explicit bare state lies extremely close to the relevant thresholds, since in that case the low-energy amplitude is dominated by the nearby bare pole $m_{4q} = 3.8757$ GeV rather than by hadron-hadron interactions. A qualitatively similar trend was found in a study of $X(3872)$ [74] for the scenario with a dominant genuine nonmolecular component, where a small scattering length and a huge effective range were obtained. However, that work also concluded that the available near-threshold data disfavor such a dominant nonmolecular scenario.

Before closing this subsection, we briefly comment on two sources of uncertainty and channel dependence. The sizable differences between the two physical channels in Table I mainly originate from the threshold splitting $\Delta_{\text{th}} \simeq 1.41$ MeV. We have checked that, in the isospin limit with degenerate masses, $m_{D^{*+}} = m_{D^{*0}}$ and $m_{D^+} = m_{D^0}$, the scattering lengths, effective ranges, and correlation functions of the two physical channels become identical, as expected. We have also checked the sensitivity to the cutoff $q_{\max}$ by varying it around the default value $q_{\max} = 0.5$ GeV, while keeping the interaction parameters fixed. The numerical results are given in Tables II and III of the Appendix. The cutoff dependence is scenario dependent: it is pronounced for the two pure molecular interactions dominated by contact interactions, but much weaker for Mol.+Compact, whose near-threshold behavior is mainly driven by the explicit bare state. In molecular scenarios, the extremely small binding energies, typically $E_B \sim 0.1-0.4$ MeV, further amplify changes in the pole positions and hence in the extracted scattering parameters. This cutoff dependence should therefore be regarded as a model uncertainty of the present interaction, especially for the molecular scenarios.

B. Correlation functions

The trend in the scattering lengths discussed above is clearly reflected in the coupled-channel correlation functions shown in Figs. 1 and 2, where each column corresponds to a specific scenario. Specifically, Fig. 1 displays the $D^{*+} - D^0$ CF, while Fig. 2 shows the $D^{*0} - D^+$ CF. In each panel, the dashed, dash-dotted, and solid curves correspond to Gaussian source radii $R = 1, 3$, and 5 fm, respectively (with $q_{\max} = 0.5$ GeV). Since all three scenarios are plotted on the same scale, it is evident that the three scenarios, which yield similar invariant-mass distributions, remain clearly distinguishable for source radii in the typical LHC range, where they span about 1–2 fm in pp and p-Pb collisions and 2–7 fm in Pb-Pb collisions [75]. In particular, the Mol.+Compact interaction exhibits behavior similar to that of a deeply bound system (strongly attractive), whereas Mol. 1 and Mol. 2 correspond to weak binding (moderately attractive) [76]. This underlines the sensitivity of femtoscopy to the underlying near-threshold dynamics.

The narrow enhancement in the $D^{*+} - D^0$ CF for Mol. 1 can be easily understood in terms of the coupled-channel pole structure. Although state 1 is predominantly a $D^{*0} - D^+$ bound state [52], its pole appears in all coupled-channel amplitudes, including T_{11} , with a residue proportional to the effective coupling to channel 1 squared [39]. Because the two thresholds are split by isospin breaking, a pole that lies slightly below the threshold of channel 2 can be located in the physical region of channel 1, where it manifests as a quasibound structure embedded in the $D^{*+} - D^0$ continuum. This explains why the peak position in the CF

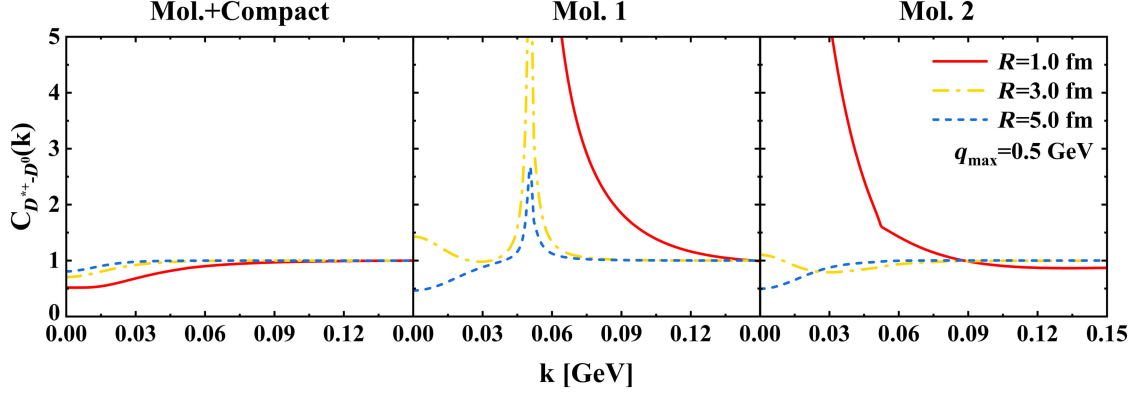


FIG. 1. Coupled-channel femtoscopic correlation functions for the $D^{*+} - D^0$ channel (channel 1) as functions of the relative momentum k , computed for three scenarios: Mol.+Compact (left), Mol. 1 (middle), and Mol. 2 (right). The source radii are taken as $R = 1$ fm (dashed), 3 fm (dash-dotted), and 5 fm (solid), and the momentum cutoff is set to $q_{\max} = 0.5$ GeV. See the main text for more details.

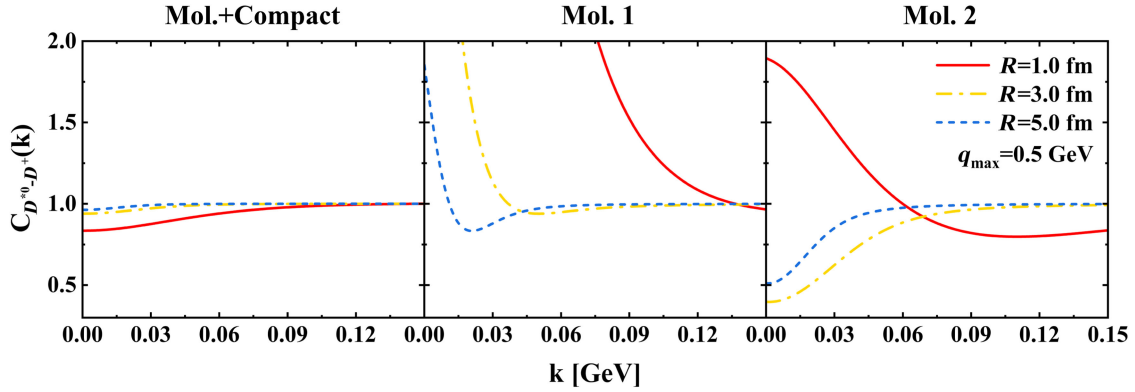


FIG. 2. Same as Fig. 1, but for the $D^{*0} - D^+$ channel (channel 2).

of channel 1 aligns with the pole of state 1. By contrast, state 2, which is dominated by the $D^{*+} - D^0$ component, mainly controls the overall near-threshold enhancement (the $k \rightarrow 0$ behavior) rather than generating the narrow peak.

Single-channel calculations provide an important cross-check and help isolate the role of channel mixing. Figures 3 and 4 compare the coupled-channel results with their single-channel counterparts for $R = 3$ fm, using the same column layout as Figs. 1 and 2. The overall qualitative

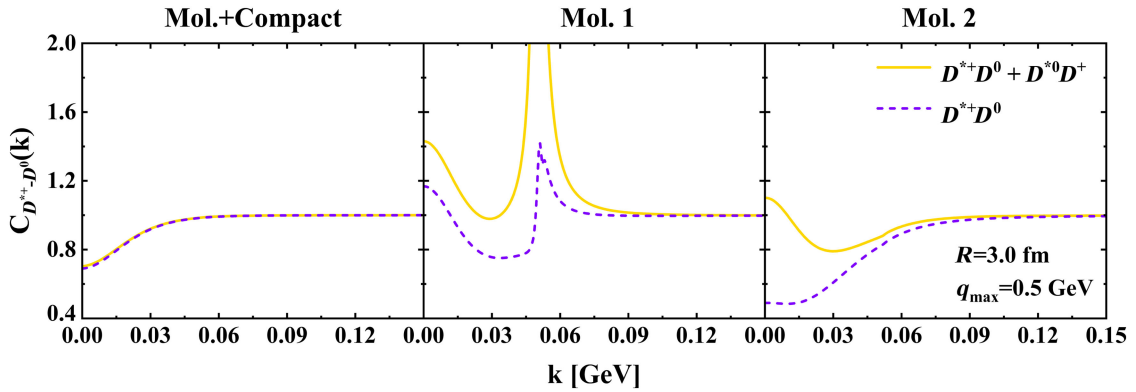
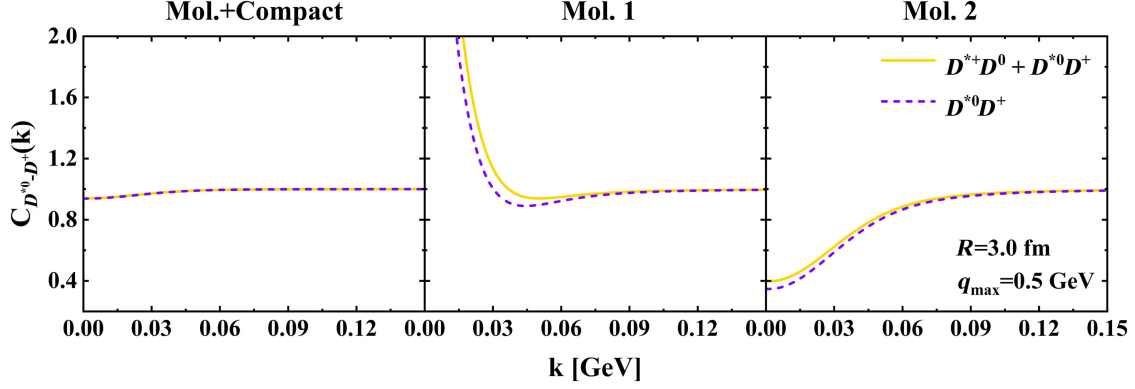


FIG. 3. Comparison between coupled- and single-channel CFs for the $D^{*+} - D^0$ system for $R = 3$ fm ($q_{\max} = 0.5$ GeV), shown for Mol.+Compact (left), Mol. 1 (middle), and Mol. 2 (right). Solid curves denote coupled-channel results, while dashed curves show the corresponding single-channel calculations with the other channel switched off.

FIG. 4. Same as Fig. 3, but for the $D^{*0} - D^+$ system for $R = 3$ fm.

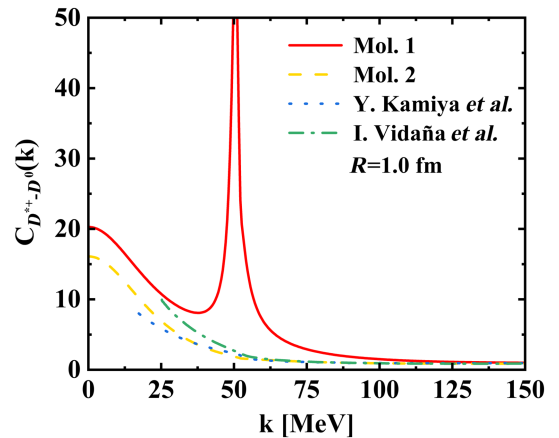
hierarchy persists: Mol. 1 and Mol. 2 behave as shallow near-threshold molecular scenarios, whereas Mol.+Compact follows a qualitatively different pattern despite having a pole only 311 keV below the $D^{*+} - D^0$ threshold. Notably, in Mol.+Compact, although the pole position still corresponds to a shallow binding energy, the scattering length and CF exhibit features more akin to those of a deeply bound state, which should be understood as a consequence of the interaction rather than the pole location alone. Unlike the pure molecular contact interaction, this scenario includes an explicit bare compact state with mass $m_{4q} = 3.8757$ GeV and a relatively weak contact attraction.

Moreover, the coupled-channel effects are substantially more pronounced in Mol. 1 and Mol. 2 than in Mol.+Compact, especially for channel 1. Within the framework of Ref. [52], this difference can be traced to the structure of the interaction in the particle basis. In the pure molecular scenarios, the potential is nearly diagonal, with strongly suppressed off-diagonal elements, whereas in Mol.+Compact, the magnitudes of the off-diagonal elements are comparable to those of the diagonal ones. When constructing the scattering amplitude through $T = (I - VG)^{-1}V$, this leads to much larger off-diagonal components of the T -matrix in the pure molecular scenarios than in Mol.+Compact. Consequently, the coupled-channel effects are significantly enhanced in the former, resulting in sizable differences between coupled- and single-channel correlation functions, while in Mol.+Compact the coupled-channel CF remains almost indistinguishable from the single-channel result.

Additionally, the more pronounced coupled-channel effect in the $D^{*+} - D^0$ correlation function is mainly a consequence of the physical threshold ordering in our framework. The $D^{*+} - D^0$ channel is the lower-threshold channel, and its momentum scan reaches the nearby $D^{*0} - D^+$ threshold at $k \simeq \sqrt{2\mu\Delta_{\text{th}}} \sim 50$ MeV, which lies in the momentum region where the correlation function is most sensitive to final-state interactions. Therefore, structures associated with the upper channel, such as the pole dominated by the $D^{*0} - D^+$ component in the Mol. 1

scenario, can feed into the $D^{*+} - D^0$ correlation function and produce a visible structure. In contrast, for the $D^{*0} - D^+$ correlation function, the lower $D^{*+} - D^0$ channel is already open at the threshold and contributes more smoothly.

To further benchmark our calculations and place the above channel-mixing analysis in a broader context, we additionally compare our femtoscopic CFs with the results reported in Refs. [68,69], as shown in Figs. 5 and 6 for $R = 1$ fm. It is worth emphasizing that, even if the scattering length in a given channel is comparable across different descriptions, the resulting CF can still differ qualitatively because femtoscopia retains more energy dependence of the interaction and is therefore sensitive to additional near-threshold pole structures (such as the state 1). In the near-threshold region, our Mol. 1 and Mol. 2 results for the $D^{*+} - D^0$ CF, as well as the Mol. 2 result for the $D^{*0} - D^+$ CF, are consistent with those earlier calculations. This agreement is expected because, as explicitly demonstrated in Ref. [69], the near-threshold CF is predominantly controlled by the scattering length (with

FIG. 5. Comparison between CFs for the $D^{*+} - D^0$ system for $R = 1$ fm ($q_{\text{max}} = 0.5$ GeV). The solid and dashed curves denote Mol. 1 and Mol. 2 results calculated in this work, respectively. The dotted and dash-dotted curves show the corresponding results of Refs. [68,69], respectively.

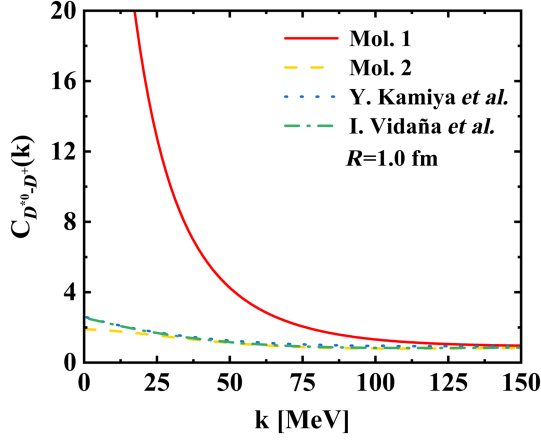


FIG. 6. Same as Fig. 5, but for the $D^{*0} - D^+$ system for $R = 1$ fm.

effective-range effects providing subleading corrections), and the corresponding scattering lengths are comparable in magnitude. In contrast, the $D^{*0} - D^+$ CF for Mol. 1 exhibits a much larger enhancement as $k \rightarrow 0$ than the curves of Refs. [68,69]. This behavior can be traced to the much larger $D^{*0} - D^+$ scattering length in Mol. 1, $a_{D^{*0}D^+} = 11.52 - 5.11i$ fm, compared with $a_{D^{*0}D^+} = 3.06 - 0.26i$ fm in Mol. 2 and the values adopted in Refs. [68,69], which are all of the order of a few femtometers. However, while scattering lengths provide an efficient and robust characterization of the interaction at threshold, they may not fully capture coupled-channel dynamics beyond the near-threshold region. In particular, owing to the presence of the additional near-threshold pole (state 1) in Mol. 1, even a scenario that reproduces the near-threshold behavior of $C_{D^{*0}D^+}(k)$ can still display a qualitatively different structure in the vicinity of the pole, manifested here as the pronounced peak around the corresponding momentum. This observation naturally motivates combining low-energy scattering parameters (e.g., a and r_{eff}) with femtoscopic measurements to discriminate near-threshold dynamics.

IV. SUMMARY AND OUTLOOK

In this work, we studied three scenarios for the nature of the $T_{cc}(3875)^+$ reported in Ref. [52] and evaluated the corresponding $D^* - D$ scattering lengths and femtoscopic correlation functions in a coupled-channel framework. The molecular scenarios (Mol. 1 and Mol. 2) yield $D^{*+} - D^0$ scattering lengths and effective ranges comparable in magnitude to previous determinations, whereas Mol.+Compact yields much smaller scattering lengths and much larger effective ranges in both channels, indicating qualitatively different low-energy dynamics. The resulting correlation functions remain clearly distinguishable for typical LHC source radii, with Mol. 1/Mol. 2 exhibiting weak-binding behavior and Mol.+Compact exhibiting

strong-binding behavior. Moreover, the Mol. 1 $D^{*+} - D^0$ scattering length is similar to those used or derived in earlier CF studies, but its correlation function remains distinct, with a pronounced peak attributed to state 1. Our findings highlight the complementarity among low-energy scattering parameters, spectroscopy, and femtoscopy in resolving near-threshold coupled-channel dynamics.

Recently, the ALICE Collaboration has successfully measured the $D^- - p$ correlation function [77], opening the way to femtoscopy in the charm sector. In this context, future measurements of the $D^{*+} - D^0$ and $D^{*0} - D^+$ correlation functions at the LHC, in particular with the large acceptance and high luminosity foreseen for ALICE 3 [78], are expected to provide independent constraints on the scattering parameters of the $D^* - D$ system and valuable tests of competing scenarios for the structure of $T_{cc}(3875)^+$.

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DATA AVAILABILITY

The data that support the findings of this article are not publicly available. The data are available from the authors upon reasonable request.

APPENDIX: SENSITIVITY TO q_{max}

In this Appendix, we provide the detailed results of the cutoff-dependence study discussed in the main text. The momentum cutoff q_{max} is varied around the default value $q_{\text{max}} = 0.5$ GeV, while all interaction parameters are kept fixed. The resulting pole positions, scattering lengths, and effective ranges are summarized in Tables II and III. This test should therefore be understood as the explicit dependence on the cutoff of the fixed parameter sets, rather than as a refit of the interaction at each cutoff.

The cutoff dependence is scenario dependent. For the two pure molecular scenarios, Mol. 1 and Mol. 2, the results show a pronounced sensitivity to q_{max} . This is expected because the two pure molecular scenarios are mainly driven by contact interactions. With the interaction parameters fixed, a smaller q_{max} removes more high-momentum contributions from the loop integral and weakens the effective attraction, whereas a larger q_{max} has the opposite effect. The relevant poles are extremely close to

TABLE II. Pole positions of the T -matrix obtained with complex D^* masses for different values of $q_{\max}$. The labels (I) and (II) indicate that the real part of the pole is located relative to the $D^{*+} - D^0$ and $D^{*0} - D^+$ thresholds, respectively. The second threshold is higher than the first one by about 1.41 MeV. Here, “not applicable” indicates that no corresponding bound pole is found.

$q_{\max}$ (GeV)	Interaction	m_{poles} (keV)
0.45	Mol.+Compact	$-207.62 + 37.97i$ (I)
	Mol. 1	Not applicable
	Mol. 2	$-2268.40 + 4.22i$ (I) $929.56 - 298.96i$ (I)
0.50	Mol.+Compact	$-311.19 + 38.47i$ (I)
	Mol. 1	$-338.26 + 1.18i$ (I) $-81.82 - 97.23i$ (II)
	Mol. 2	$-6161.09 + 5.46i$ (I) $-372.68 + 7.22i$ (I)
0.55	Mol.+Compact	$-417.27 + 38.78i$ (I)
	Mol. 1	$-2174.00 + 3.52i$ (I) $-1023.96 - 147.36i$ (II)
	Mol. 2	$-12279.37 + 6.11i$ (I) $-4260.52 - 5.89i$ (I)

the thresholds, with typical binding energies of only $E_B \sim 0.1\text{--}0.4$ MeV. As a result, even a moderate cutoff variation can noticeably shift the pole positions and, consequently, the scattering lengths, effective ranges, and femtoscopic correlation functions. For example, in the Mol. 1 scenario, no corresponding bound pole survives at $q_{\max} = 0.45$ GeV, and the scattering lengths become negative in our convention, indicating that the attraction is not strong enough to generate a bound state. Once a shallow bound state is formed, increasing the effective attraction generally moves the pole deeper below threshold. The associated positive scattering length then decreases from its large near-threshold value, as shown in Table III. By contrast, the Mol.+Compact scenario is much less sensitive to $q_{\max}$. In this case, the near-threshold behavior is mainly governed by the explicit bare state rather than solely by the contact interaction, so the pole position and the threshold parameters change more mildly under the same cutoff variation.

Because the information provided in Tables II and III already fully reflects the underlying strong interaction, we do not show the corresponding correlation functions for conciseness.

TABLE III. Scattering lengths and effective ranges obtained for different values of $q_{\max}$ (in GeV). The interaction parameters are kept fixed in this cutoff-dependence study.

$q_{\max}$	Interaction	Channel	a (fm)	r_{eff} (fm)
0.45	Mol.+Compact	$D^{*+} - D^0$	$1.37 + 0.24i$	$-120.15 + 0.79i$
		$D^{*0} - D^+$	$0.18 - 0.01i$	$-147.40 - 4.26i$
	Mol. 1	$D^{*+} - D^0$	$-18.24 + 0.04i$	$0.29 + 0.00i$
		$D^{*0} - D^+$	$-12.15 - 5.10i$	$0.80 + 0.35i$
	Mol. 2	$D^{*+} - D^0$	$1.65 + 0.03i$	$-27.29 + 1.46i$
		$D^{*0} - D^+$	$5.55 - 1.68i$	$-0.14 + 0.18i$
0.50	Mol.+Compact	$D^{*+} - D^0$	$0.95 + 0.11i$	$-120.64 + 0.79i$
		$D^{*0} - D^+$	$0.17 - 0.01i$	$-148.01 - 4.29i$
	Mol. 1	$D^{*+} - D^0$	$7.54 + 0.02i$	$-0.55 + 0.02i$
		$D^{*0} - D^+$	$11.52 - 5.11i$	$0.25 + 0.39i$
	Mol. 2	$D^{*+} - D^0$	$5.30 + 0.05i$	$-4.46 - 0.07i$
		$D^{*0} - D^+$	$3.06 - 0.26i$	$0.14 - 0.14i$
0.55	Mol.+Compact	$D^{*+} - D^0$	$0.73 + 0.07i$	$-121.12 + 0.79i$
		$D^{*0} - D^+$	$0.16 - 0.00i$	$-148.60 - 4.32i$
	Mol. 1	$D^{*+} - D^0$	$0.71 + 0.09i$	$-476.88 + 147.64i$
		$D^{*0} - D^+$	$4.42 - 0.39i$	$0.17 + 0.02i$
	Mol. 2	$D^{*+} - D^0$	$2.22 + 0.00i$	$-0.40 - 0.00i$
		$D^{*0} - D^+$	$2.03 - 0.06i$	$0.29 - 0.15i$

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