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Implications of a DK molecule at 2.32 GeV

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We discuss the implications of a possible quasinuclear DK bound state at 2.32 GeV. Evidence for such a state was recently reported in $D_s^+\pi^0$ by the BaBar Collaboration. We first note that a conventional quark model $c\bar{s}$ assignment is implausible, and then consider other options involving multiquark systems. An $I=0$ $cs\bar{n}\bar{n}$ baryonium assignment is one possibility. We instead favor a DK meson molecule assignment, which can account for the mass and quantum numbers of this state. The higher-mass scalar $c\bar{s}$ state expected at 2.48 GeV is predicted to have a very large DK coupling, which would encourage formation of an $I=0$ DK molecule. Isospin mixing is expected in hadron molecules, and a dominantly $I=0$ DK state with some $I=1$ admixture could explain both the narrow total width of the 2.32 GeV state as well as the observed decay to $D_s^+\pi^0$. Additional measurements that can be used to test this and related scenarios are discussed.

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I. INTRODUCTION

The BaBar Collaboration recently reported a narrow state near 2.32 GeV, known as the $D_{sJ}^*(2317)^+$, decaying to $D_s^+\pi^0$ [1]. The observed width is consistent with experimental resolution, which gives a limit of $\lesssim 10$ MeV for the total width. For reference purposes we show the new state at 2.32 GeV in Fig. 1, together with the Godfrey-Isgur-Kokoski predictions for the spectrum of $c\bar{s}$ mesons [2,3], DK thresholds, and the experimental spectrum of charm-strange states [4].

One might *a priori* consider a new resonance observed in $D_s^+\pi^0$ in this mass region to be a candidate $c\bar{s}$ quark model state, decaying to $D_s^+\pi^0$ through an isospin-violating strong decay. Since the $D_{sJ}(2573)$ is already well established as a plausible ${}^3P_2$ $c\bar{s}$ candidate, the only available assignment would be the ${}^3P_0$ D_{s0}^* level.

Identification of the 2.32 GeV signal with a conventional ${}^3P_0$ $c\bar{s}$ quark model state appears implausible due to the low mass. The mass predicted by Godfrey and Isgur for this $c\bar{s}$ state is 2.48 GeV, 160 MeV higher than the BaBar state. Since the scalar ${}^3P_0$ $c\bar{s}$ belongs to the $j=1/2$ heavy quark symmetry doublet, both the ${}^3P_0$ $c\bar{s}$ and its D_{s1} partner are expected to be much broader than the states in the $j=3/2$ doublet. The $j=3/2$ doublet is usually identified with the rather narrow $D_{sJ}(2573)$ and $D_{s1}(2536)$, which have experimental total widths of 15_{-4}^{+5} MeV and <2.3 MeV (90% C.L.) respectively. In contrast, a total width of 270–990 MeV (depending on the decay model assumed) was predicted for the ${}^3P_0$ $c\bar{s}$ scalar by Godfrey and Kokoski [3], assuming a mass of 2.48 GeV.

II. MULTIQUARKS OPTIONS

Assuming that the new 2.32 GeV state is being observed in a strong or electromagnetic decay to $D_s^+\pi^0$, it must at least possess c and $\bar{s}$ quarks. Given the implausibility of identifying this signal with a conventional $c\bar{s}$ quark model state, as discussed above, we are led to the consideration of states with additional valence quarks. The proximity to the lightest $c\bar{s}$ states suggests the first available color-singlet combination, $cn\bar{s}\bar{n}$ (where n generically represents either of u,d).

Four-quark states [5] may be classified as "baryonia" if the spatial wave function is well described as a single multiquark cluster, or "molecules" if they are dominantly quasinuclear, weakly bound pairs of $q\bar{q}$ mesons. A subcategory of baryonia are the "heavy-light" systems, which possess a heavy pair and a light pair, such as $QQ\bar{n}\bar{n}$ or $Qn\bar{Q}\bar{n}$. These states are interesting because the heavy pair is spatially localized and should be dominantly in a particular color state [6]. The DK system was previously suggested as a possibility for four-quark bound states of both baryonium and molecular types by Lipkin [7,8] and Isgur and Lipkin [9].

For our initial discussion we will treat these as distinct categories of multiquark states, although this is clearly a rather qualitative distinction. One may actually find significant amplitudes for both types of spatial configurations in some resonances; see for example the discussion of the $f_0/a_0(980)$ in Ref. [10].

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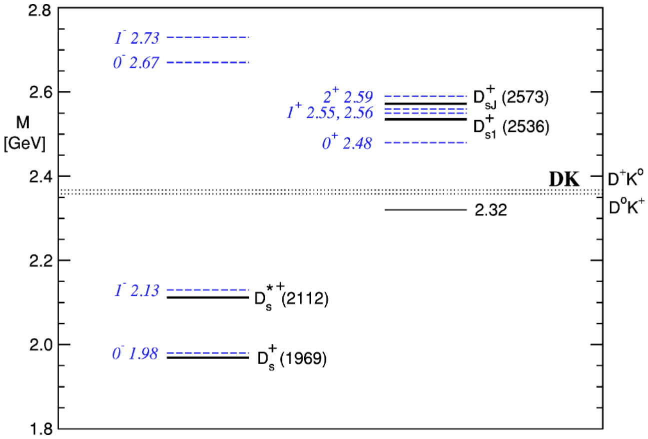

FIG. 1. The experimental (solid) and theoretical (dashed) spectrum of $c\bar{s}$ mesons. DK thresholds and the 2.32 GeV BaBar state are also shown.

A. Baryonia

Baryonia composed of light quarks do not require an interaction to dissociate into light meson pairs; this is known as "fall-apart" decay. This effect implies that light baryonia may not exist as resonances at all, or if they do exist they are expected to be extremely broad [5]. For this reason it would be difficult to identify the 2.32 GeV BaBar signal with an $I=1$ $cn\overline{sn}$ baryonium state; it would have a fall-apart decay to $D_s^+\pi$, and so should be extremely broad or nonresonant.

An $I=0$ $cn\overline{sn}$ baryonium state is a more interesting possibility; there is no accessible fall-apart mode, since DK does not open until 2.36 GeV. The channel $D_s^+\pi^0$ would be open to isospin-violating transitions, but this coupling might be sufficiently weak to allow an $I=0$ $cn\overline{sn}$ cluster to appear as a resonance. If we assume that the 2.32 GeV signal is indeed an $I=0$ $cn\overline{sn}$ baryonium, other $I=0$ $cn\overline{sn}$ states with different angular quantum numbers may also lie below DK threshold. If baryonium models instead predict no other $cn\overline{sn}$ states below 2.36 GeV, it may prove difficult to distinguish between $I=0$ $cn\overline{sn}$ baryonium and DK molecule assignments. The proximity of the DK threshold to 2.32 GeV is of course an argument in favor of a DK molecule, since this would be accidental for a baryonium state.

If attractive interquark forces do form an $I=0$ $cn\overline{sn}$ baryonium bound state at 2.32 GeV, one might also anticipate $I=1$ and $cs\overline{nn}$ partners nearby in mass. A natural spin-parity $I=1$ $cn\overline{sn}$ baryonium above 2.25 GeV would have a fall-apart mode to $D_s^+\pi$ and hence should be very broad or nonresonant. The presence of such a hypothetical resonance might be observable in e^+e^- annihilation (see our subsequent discussion). In contrast, in the DK molecule scenario an $I=1$ bound state is less likely, as we shall explain in the following section.

Exotic-flavor $cs\overline{nn}$ baryonium partner states would provide dramatic support for the baryonium picture. If these states were below 2.36 GeV ($D\bar{K}$ threshold) they would only decay weakly (see subsequent discussion of baryonia). If the baryonium scenario is correct, $cs\overline{nn}$ states should be produced in e^+e^- at a rate comparable to the BaBar state.

B. Molecules

Hadronic molecules are systems that to a good approximation are weakly bound states of color-singlet hadrons. Nuclei and hypernuclei are the most familiar examples of these states, although there are several often-cited candidates for meson-meson molecules, notably the $f_0(980)$ and $a_0(980)$ [10,11] and $\psi(4040)$ [12–15], and at least one meson-baryon candidate, the $\Lambda(1405)$ [16,17].

The best studied candidates for meson-meson molecules are the $f_0(980)$ and $a_0(980)$, which are widely believed to have large or perhaps dominant $K\bar{K}$ components. This sector of the quark model was studied in detail by Weinstein and Isgur [11], who concluded that conventional quark model forces give rise to attractions in the $I=0$ and $I=1$ $K\bar{K}$ channels that are sufficiently strong to form bound states. Their conclusions regarding the nature of these attractive forces may also be relevant for the 2.32 GeV BaBar signal, as the $K\bar{K}$ and DK systems share several important features.

Weinstein and Isgur found that the dominant attraction in the S-wave $K\bar{K}$ system arose from level repulsion between the low-mass $K\bar{K}$ continuum and scalar $q\bar{q}$ states. The $q\bar{q}$ scalars were assumed to lie near 1.3 GeV, and to have strong couplings to two-pseudoscalar channels. These scalar mesons play a crucial role as "shepherd states" which drive the two-meson continuum into bound states just below threshold. Additional nonresonant forces between pseudoscalar meson pairs were found by Weinstein and Isgur in their variational study of the $sn\overline{sn}$ system [11]; these were subsequently identified as arising mainly from the one-gluon-exchange contact spin-spin interaction, which dominates constituent-interchange scattering [18]. In the final Weinstein-Isgur paper this interaction couples several two-pseudoscalar channels, and provides additional attraction in both $K\bar{K}$ channels.

Since the residual forces that bind hadrons into molecules are relatively weak and short-ranged, simple qualitative signatures for hadron-pair molecules can be abstracted from the Weinstein-Isgur results. These are (i) J^{PC} and flavor quantum numbers of an $L=0$ hadron pair, (ii) a binding energy of at most about 50–100 MeV, (iii) strong couplings to constituent channels, and (iv) anomalous electromagnetic couplings relative to expectations for a quark model state. The justification for each of these proposed molecule signatures is discussed in Ref. [19], together with a review of earlier experimental candidates.

III. A DK MOLECULE?

A. DK and molecule signatures

The 2.32 GeV BaBar signal appears to be an obvious candidate for a scalar DK molecule, since what is known about this state satisfies the first two of the molecule signatures quoted above. First, the (assumed strong or electromagnetic) decay to $D_s^+\pi^0$ implies natural spin-parity, so $J^P=0^+$ is allowed. (Note further that for strong decays the combined observation in $D_s^+\pi$ and absence in $D_s^{*+}\pi$ would uniquely select $J^{\mathrm{P}}=0^+$.) Second, the DK thresholds are $m(D^0K^+)=2358$ MeV, $m(D^0K^0)=2362$ MeV, $m(D^+K^+)=2363$ MeV and $m(D^+K^0)=2367$ MeV, so a DK molecule at 2.32 GeV would have a plausible binding energy of ≈ 40 MeV. The third signature is more problematic since the only open strong mode for a $J^{\mathrm{P}}=0^+$ DK molecule is $D_s^+\pi$, and this may be an isospin-suppressed decay; this will be discussed subsequently. The final signature can be used as a test of the molecule assignment, through a measurement of $D_{sJ}^*(2317)^+\to D_s^{*+}\gamma$; this E1 transition rate can be calculated for a $^3P_0$ $c\bar{s}$ quark model state at 2.32 GeV, which predicts $\Gamma_{\gamma D_s^{*+}}\approx 2$ keV [20]. If this is indeed a non-$c\bar{s}$ state, one would expect a rather different rate for the E1 transition. This comparison is well known for $\phi\to\gamma f_0/a_0(980)$; the rate for a molecule was computed in Ref. [21]. The analogous computation for a DK molecule would require knowledge of its coupling strength to both DK and D_s^{*+}.

If this state is a DK molecule or a baryonium resonance, power counting rules [22] imply that its elastic form factor should fall as $1/Q^6$, in contrast to the $1/Q^2$ expected for a "normal" $c\bar{s}$ state. At CLEO-c one could pair produce the open-charm meson states, including the BaBar state as well as conventional charmed quark meson pairs, near threshold. The anomalous Q^2-dependence of the exclusive cross section could then confirm its four-quark nature, or conversely, if established as a multiquark system, could provide a novel further test of the quark counting rules. Note that at large Q^2 one would expect to see a weakened $1/Q^2$ dependence from the $c\bar{s}$ component of the BaBar state, which is expected to be present at some level due to mixing effects.

B. Previous studies of the DK system

Motivated by Jaffe's study of light baryonium states in the bag model and the suggested classification of light scalars as four-quark states [5], Lipkin [7] suggested that four-quark baryonium systems of the type $c\bar{s}n\bar{n}$ and $cs\bar{n}\bar{n}$ might also be observed as resonances. In the cluster wave functions tacitly assumed in this paper the dominant binding force was taken to be the one-gluon-exchange color magnetic force, as in the MIT bag model. Decay systematics of the various possible states were discussed, and it was noted that for masses between $D_s^+\pi$ and DK the $I=1$ $c\bar{s}n\bar{n}$ state "$\tilde{F}_I$" could decay strongly to $D_s^+\pi$, but a pure $I=0$ $c\bar{s}n\bar{n}$ "F_x^+" would only have electromagnetic modes, such as $D_s^+\pi^0$, $D_s^+\gamma\gamma$ and $D_s^+\pi^0\gamma$. Although the states were assumed to be baryonia, the decay systematics apply to molecular bound states with the same quantum numbers as well.

Isgur and Lipkin [9] stressed the important distinction between four-quark baryonium clusters and hadronic molecules, and observed that the determination of which type of configuration best describes the ground state of a given bound system is a problem with "no simple model-independent answer." The 980 MeV states are cited as examples near the molecular limit, "just barely bound states of the $\mathrm{K\bar{K}}$ system." It is suggested that "similar bound states of $\mathrm{D\bar{K}}$ and DK . . . " (hence molecules rather than clusters) " . . . should exist near and possibly below the DK threshold." Assuming as in [7] that the dominant interaction is the color magnetic spin-spin hyperfine interaction, Isgur and Lipkin gave estimates of the masses of $c\bar{s}n\bar{n}$ and $cs\bar{n}\bar{n}$ systems relative to DK. Although their estimates find masses above DK threshold by 205 and 140 MeV respectively, they argued that the smaller kinetic energies of charmed systems suggest that weakly bound DK and perhaps $\mathrm{D\bar{K}}$ molecules exist. The mode $\mathrm{D\bar{K}}\to\bar{K}^0\bar{K}^0$ was proposed for searches for a $\mathrm{D\bar{K}}$ molecule, for example in $B\to(\mathrm{D\bar{K}})\ K^0\to(\bar{K}^0\bar{K}^0)K^0$.

In discussing early results for light multiquark systems one should note that Weinstein and Isgur [11] subsequently found that level repulsion against higher-mass $q\bar{q}$ states gave a larger attraction than the color magnetic interaction. This additional force will contribute to binding in the $I=0$ DK case, but not in $I=1$ DK or any $\mathrm{D\bar{K}}$ channel.

An additional development has been the realization that isospin mixing is important in molecular states, which was not appreciated in the early references. In particular this allows "isospin violating" strong decays from a dominantly $I=0$ DK molecule, as we shall discuss below.

Lipkin [8] has also considered four-quark systems containing both heavy and light quark pairs, such as $cc\bar{u}\bar{d}$. For sufficiently large heavy quark mass these systems take on a baryon-like spatial configuration, with the two heavy quarks acting as a single heavy antiquark. These heavy-light systems constitute a distinct category of four-quark state, and for sufficiently large heavy quark mass are expected to be strongly stable [6,8]. The Coulomb-like color electric attraction between the two heavy quarks produces binding in this model, whereas the color-magnetic interaction is inversely proportional to quark mass and so is neglected for the heavy quarks. The strange quark is not heavy enough to produce a bound state in this heavy-light model; its color-magnetic interaction was crucial for binding in the other early studies [7,9].

Reference [8] considered only heavy-light baryonia with identical heavy quarks, and concluded that $cc\bar{u}\bar{d}$ is probably not bound but $bb\bar{u}\bar{d}$ may well be. Extending this approach to states with nonidentical heavy quarks leads to the conclusion that $cs\bar{u}\bar{d}$ is not bound, but $bc\bar{u}\bar{d}$ may be [23]. This state would decay only weakly, either by b-quark decay into two charmed mesons or c-quark decay into a B meson and a strange meson. The corresponding signature in a vertex detector would be a secondary vertex with a multiparticle decay, one or two subsequent heavy quark decays, and either one or no tracks from the primary vertex to the secondary.

C. DK isospin and isospin mixing

The isospin of the purported DK molecule is a nontrivial issue. Were isospin a good quantum number, the narrow width would suggest $I=0$; there are then no open strong modes, so the state would be very narrow, and the observed decay to $D_s^+\pi^0$ would be a suppressed isospin-violating transition. $I=0$ is also favored by the dominant molecule-binding mechanism found for K$\overline{\text{K}}$ by Weinstein and Isgur, which is repulsion of the lower continuum against a higher-mass scalar $q\overline{q}$ state. For $I=0$ we do have such a state, the $^3P_0$ $c\overline{s}$ $D^*_{s0}(2.48)$ of Godfrey and Isgur [2], which was predicted by Godfrey and Kokoski [3] to have a very strong coupling to the DK continuum, as required to induce binding.

In contrast, for a pure $I=1$ molecule there can be no DK attraction due to level repulsion against a $q\overline{q}$, since $c\overline{s}$ has $I=0$. Binding might instead arise from diagonal DK forces and repulsion against other two-meson channels, such as $D_s^{*+}\rho$. Note however that the diagonal DK interaction in $I=1$ should be weak, since constituent interchange is purely off-diagonal, $(c\overline{n})(n'\overline{s})\rightarrow(c\overline{s})(n'\overline{n})$.

The $I=1$ DK molecule option can be tested by searching for $I_z=\pm 1$ partner states. Assuming that the BaBar state is produced strongly, starting from $e^+e^-\rightarrow\gamma\rightarrow c\overline{c}$, the overall hadronic system would have $I=0$. Partitioning the final hadronic state as

$$|\mathcal{F}\rangle_{I=0}=|\text{DK}\rangle_{I=1}\otimes|\text{everything else}\rangle_{I=1} \tag{1}$$

the CG coefficients in $0\subset 1\otimes 1$ imply that I, $I_z=1,\pm 1$ partner DK states would each be produced at the same rate as an I, $I_z=1$, 0 DK molecule. The partner states would decay into $D_s^+\pi^\pm$ at the same isospin-allowed rate as the I, $I_z=1,0$ state. Thus one can test the possibility of an $I=1$ DK molecule quite easily by searching for $D_s^+\pi^\pm$ events at 2.32 GeV; if the BaBar state is $I=1$, one should see similar numbers of $D_s^+\pi^+$, $D_s^+\pi^-$ and $D_s^+\pi^0$ events. In contrast, if it is dominantly $I=0$, the signal in $e^+e^-\rightarrow(D_s^+\pi^0)X^-$ should greatly exceed that in $e^+e^-\rightarrow(D_s^+\pi^+)X^{--}$ and $e^+e^-\rightarrow(D_s^+\pi^-)X^0$; naive isospin rules predict that it should be completely absent in the charged-pion reactions.

Although the $I=0$ channel is favored theoretically for DK molecule formation through the Weinstein-Isgur mechanism, we emphasize that a nominally $I=0$ DK molecule is actually expected to show significant isospin mixing with the $|I,I_z\rangle=|1,0\rangle$ DK basis state. Indeed, this isospin mixing is one of the characteristic features of molecules [24,25], and has probably been observed in the $f_0/a_0(980)$ states (see for example [26] and [27]). The reason for this isospin mixing is that hadrons within an isomultiplet typically have ≈ 5 MeV mass splittings, which is significant on the scale of molecule binding energies.

We can illustrate this effect using a simple two-state model. Consider a Hamiltonian that couples the nondegenerate two-meson states $|D^+K^0\rangle=|A\rangle$ and $|D^0K^+\rangle=|B\rangle$ through an $I=0$ s-channel interaction,

$$\text{H}=\begin{bmatrix} m_0+\frac{1}{2}\delta m & \\ & m_0-\frac{1}{2}\delta m \end{bmatrix}+\frac{v}{2}\begin{bmatrix} -1 & 1 \\ 1 & -1 \end{bmatrix}. \tag{2}$$

In the weak coupling limit ($v\ll\delta m$) the ground state approaches $|\psi_0\rangle=|B\rangle=(|1,0\rangle-|0,0\rangle)/\sqrt{2}$, a linear combination of $I=0$ and $I=1$ states with equal weight (thus maximally violating isospin). For very large coupling ($v\gg\delta m$) isospin symmetry is restored, and the system approaches a pure $I=0$ ground state, $|\psi_0\rangle=(|A\rangle-|B\rangle)/\sqrt{2}=|0,0\rangle$, with energy $\text{E}_0=m_0-v$. For moderately large coupling, as is presumably appropriate here, the ground state is close to $I=0$ but has a significant $I=1$ component,

$$|\psi_0\rangle=|0,0\rangle-\frac{\delta m}{2v}|1,0\rangle+O\left(\frac{\delta m}{v}\right)^2. \tag{3}$$

In DK there is a rather large splitting between free two-meson states,

$$\delta m=m(D^+K^0)-m(D^0K^+)=9.3\pm 1.1\ \text{MeV} \tag{4}$$

so we expect that a DK bound state with $\text{E}_\text{B}\approx 40$ MeV would retain a significantly larger amplitude for $|B\rangle=|D^0K^+\rangle$ than for $|A\rangle=|D^+K^0\rangle$ in its state vector. This is equivalent to having some admixture of the symmetric $|I,I_z\rangle=|1,0\rangle$ DK state in addition to the dominant, antisymmetric $|I,I_z\rangle=|0,0\rangle$ DK state. The presence of an important $|I,I_z\rangle=|1,0\rangle$ component in the dominantly $I=0$ DK molecule may account for the observed transition to $D_s^+\pi^0$.

IV. PROSPECTS FOR ADDITIONAL MOLECULES

If the 2.32 GeV state seen by BaBar is indeed a DK molecule, we might anticipate other heavy-quark molecular bound states in other channels that possess similar attractive forces. In the Weinstein-Isgur binding mechanism these are channels in which a $q\overline{q}$ state lies not far above the two-meson continuum and has a strong decay coupling to S-wave meson pairs.

There are many such possibilities. One that is rather similar to DK is the channel D*K, which has a threshold of 2.50 GeV. A broad $c\overline{s}$ 1^+ state which can provide attraction through level repulsion is expected at 2.55 GeV [3]. The second BaBar signal, reported at a mass of 2.46 GeV [1], is an obvious candidate for this molecular state; the mass difference of 2.46–2.32 GeV can be understood as being essentially equal to M(D^*)-M(D). (This assumes that the DK and D*K binding energies are comparable.) As an important test, an S-wave D*K molecule would have $J^\text{P}=1^+$.

The $\text{D}_s\overline{\text{K}}$ system is analogous to DK in that mixing with $q\overline{q}$ intermediates is allowed, however in this case the important mixing states are the *lighter* $c\overline{n}$ mesons, which are below $\text{D}_s\overline{\text{K}}$ threshold; an effective $\text{D}_s\overline{\text{K}}$ repulsion should result. Thus we would not expect molecular states in this channel. Molecules with pions are also not expected, as they would have much smaller reduced masses that discourage the formation of bound states.

A state analogous to DK in the $c\overline{b}$ system would be a BD molecule, with a $B_c^+\pi$ decay mode that is isospin-conserving for $I=1$ or isospin-violating for $I=0$. As this is a heavy-light system, these states may more closely resemble Qqq baryons. Here too the masses are very different from the DK problem, and lead to a completely different experimental signature, with a high energy pion. M(B)+M(D)

$\approx$7145 MeV, whereas M(B_c)$\approx$6400$\pm$400 MeV. So, a BD molecule just below threshold would simply rearrange the four quarks into $B_c^+\pi$ and fall apart, either with or without isospin violation, giving a neutral or charged pion having a well defined (but currently not well determined) energy of $\approx$750$\pm$400 MeV, with the precision improved by better measurements. Prospects for observing a relatively narrow BD molecule appear better for an $I=0$ state, which involves an isospin-violating decay to $B_c^+\pi$. This state might be observed as a resonance with a pion accompanying the B_c^+, with an invariant mass too high to be confused with a conventional $q\bar{q}$ state.

V. SUMMARY OF EXPERIMENTAL TESTS

In summary, challenges for experiment, which may help to determine the nature and dynamics of this state, include the following.

A better measure of the width to see if it may be much narrower than 10 MeV.

A search for the mode $D_s^{*+}\pi$; the presence of $D_s^+\pi$ and absence of $D_s^{*+}\pi$ would uniquely select $J^{\mathrm{P}}=0^+$ (assuming strong or electromagnetic transitions).

A search for the purely electromagnetic decay mode $D_s^+\gamma$ (which is forbidden if the state is 0^+) and the E1 transition to $D_s^{*+}\gamma$, to establish whether this partial width is markedly different from the 2 keV predicted for a $c\bar{s}$ state.

A search for charged partners appearing in $D_s^+\pi^\pm$ that should exist if this is an isovector state.

Search for the ${}^3P_0$ $D_s(0^+)$ $c\bar{s}$ state with a mass of $\approx$2.5 GeV; mass shifts relative to the $D_{sJ=1,2}$ partners may help quantify the dynamics leading to a DK bound state; seek other possible narrow states below 2.36 GeV, and determine their J^{P}.

Search in B decays for a possible D$\bar{\mathrm{K}}$ molecule, to determine the dynamics of DK binding; one possible signature could be $D^+K^-\to K^-K^-\pi^+\pi^+$, as in $\bar{\mathrm{B}}^0\to(D^+K^-)K^0\to K^-K^-\pi^+\pi^+K^0$.

In e^+e^- annihilation, measure the Q^2 dependence of the production cross section; compare with the dependence observed for other charmed mesons and with the counting rules for multiquark states; see if this dependence hardens at larger Q^2 due to a short range "conventional" $c\bar{s}$ content; compare with the behavior of $e^+e^-\to a_0(980)^+a_0(980)^-$.

Precision data from CLEO-c in the 4.3–5 GeV region could determine whether the threshold production process is $e^+e^-\to D_{sJ}(2317)\bar{D}_s^*(2112)$ in S-wave from $\sqrt{s}\geqslant$4.43 GeV, or $e^+e^-\to D_{sJ}(2317)\bar{D}_{sJ}(2317)$ in P-wave, from $\sqrt{s}\geqslant$4.64 GeV; these can be compared with the threshold production of well-established charmed meson pairs.

If the $D_{sJ}(2317)$ is indeed a DK molecule, search for further examples; there are many possibilities, including D^*K, and a BD molecule that might be observed in $B_c^+\pi$.

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