

Observed $D_s(2317)$ and Tentative $D(2100\text{--}2300)$ as the Charmed Cousins of the Light Scalar Nonet

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(Received 5 May 2003; published 3 July 2003)

The very recently observed $D_{sJ}^*(2317)^+$ meson is described as a quasibound scalar $c\bar{s}$ state in a unitarized meson model, owing its existence to the strong 3P_0 Okubo-Zweig-Iizuka-allowed coupling to the nearby S -wave DK threshold. By the same mechanism, a scalar $D_0^*(2100\text{--}2300)$ resonance is predicted above the $D\pi$ threshold. These scalars are the charmed cousins of the light scalar nonet $f_0(600)$, $f_0(980)$, $K_0^*(800)$, and $a_0(980)$, reproduced by the same model. The standard $c\bar{n}$ and $c\bar{s}$ charmed scalars D_0 and D_{s0} , cousins of the scalar nonet $f_0(1370)$, $f_0(1500)$, $K_0^*(1430)$, and $a_0(1450)$, are predicted to lie at about 2.64 and 2.79 GeV, respectively, both with a width of some 200 MeV.

DOI: 10.1103/PhysRevLett.91.012003

PACS numbers: 14.40.Lb, 13.25.Ft, 13.75.Lb, 12.40.Yx

The $D_{sJ}^*(2317)^+$ [or simply $D_s(2317)$] charmed meson, just discovered [1] by the BABAR Collaboration (see also Ref. [2]), is claimed [3] to “send theorists back to their drawing boards,” in view of its low mass. If, indeed, the tentative $J^P = 0^+$ assignment gets confirmed, there appears to be a discrepancy with typical quark potential models, which predict a mass of 2.48 [4] or 2.49 GeV [5] for this state.

The aim of this Letter is to demonstrate that there is no difficulty [6] to obtain a low-mass scalar $D_s(2317)$, with a standard $c\bar{s}$ configuration, *provided* one takes into account its Okubo-Zweig-Iizuka(OZI)-allowed coupling to the nearby but closed DK threshold at about 2.36 GeV. The strong 3P_0 coupling to this S -wave threshold will turn out to conjure up a nonperturbative pole, *not* related to the confinement spectrum, which is forced to settle down on the real energy axis due to the lack of phase space. Conversely, the same threshold pushes the ground-state *confinement* pole to much higher energies, which may thus have precluded its detection so far. By the same token and as a spin-off, we shall also predict two additional charmed scalar mesons, i.e., with a $c\bar{n}$ ($n = u$ or d) configuration, still needing experimental confirmation.

The mechanism responsible for the low-mass charmed scalar mesons is precisely the same that produces the light scalar-meson nonet, i.e., the $f_0(600)$, $f_0(980)$, $a_0(980)$ [7], and $K_0^*(800)$ [8]. The latter scalar mesons were predicted with great accuracy in Ref. [9], in the framework of a unitarized quark model for all mesons. In more detail, and employing a simpler yet less model-dependent formulation, it has been shown [10–12] how unitarization leads to structures in the scattering amplitude for S -wave meson-meson scattering which are not and even *cannot be* anticipated by the naive quark model. Especially, from the behavior of the scattering poles near threshold [13,14], we learn that, in the limit of decoupling from

the meson-meson continuum, all members of the light scalar-meson nonet disappear into the background. On the other hand, all other mesons end up as genuine $q\bar{q}$ states in this limit.

Now, it is straightforward to apply the latter, simple model to charmed mesons: one just has to replace one of the model’s effective-quark-mass parameters by the charmed mass. If we then take the other parameters fixed, which, e.g., yield an excellent fit to the S -wave $K\pi$ phase shifts up to 1.6 GeV [10], we obtain the movement of complex-energy poles as depicted in Figs. 1 and 2, corresponding to the $c\bar{n}$ and $c\bar{s}$ states, respectively.

Next, we interpret with some care each of the two figures, in both of which the relevant parts of the complex E plane are depicted, where E represents the total invariant mass for elastic meson-meson scattering in an S wave. Figure 1 refers to $D\pi$ and Fig. 2 to DK scattering. Each figure displays two trajectories, representing the positions, as a function of the overall coupling parameter λ , of the lowest two of an infinity of singularities in the corresponding scattering amplitudes.

The S matrix of our unitarized meson model contains, in principle, all possible two-meson scattering channels. In the model of Refs. [9–14], one single set of parameters applies to all channels, from the light flavors to bottom. These parameters are four constituent quark masses, $m_u = m_d$, m_s , m_c , and m_b , one confinement parameter, ω , one overall coupling constant, λ , and two shape parameters of the transition potential.

When studying $D\pi$ elastic scattering, one could then select this particular channel from a larger S matrix. For the purpose of the present investigation, we use here, as mentioned above, a simplified version of the model, discussed in Ref. [10], which contemplates just one scattering channel. Nevertheless, the parameters are kept unaltered with respect to the light scalar mesons, except

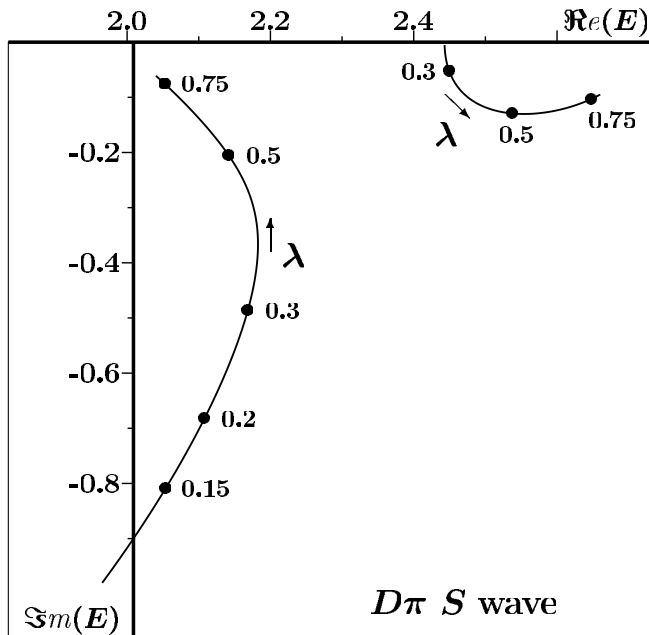


FIG. 1. S -matrix poles for $D\pi$ S -wave scattering as a function of the coupling constant λ . Threshold is at 2.009 GeV; units are in GeV.

for the quark masses, of course. By comparing the results of the full model [9] with those of the one-channel limit of Ref. [10], we verify that the higher, closed channels do not have much influence on the general scattering properties, but have some effect on the precise pole positions.

The two singularities studied in each of Figs. 1 and 2 are the two lowest-lying poles of the scattering amplitude. We study their positions as a function of the overall coupling constant λ . The here chosen physical value of λ equals 0.75, as in Refs. [10–14]. However, by just showing the respective pole positions at $\lambda = 0.75$ in Figs. 1 and 2, important information on their differences would be concealed. Moreover, the display of the pole trajectories reveals what could happen if Nature were to choose a somewhat different value for λ . We shall come back to this point further on.

As one observes from the two figures, the behavior upon decoupling ($\lambda \downarrow 0$) is completely different. Whereas the higher of the two singularities in each figure ends up at the genuine $c\bar{n}/\bar{s}$ confinement ground states, which are at 2.44 GeV for $c\bar{n}$ and 2.55 GeV for $c\bar{s}$, respectively, for our model parameters, the lower poles disappear into the background, with ever increasing width. A similar behavior has been observed for the S -matrix poles of the light scalar mesons [13,14].

The lower pole in $D\pi$ scattering (Fig. 1) does not end up below threshold when the overall coupling λ is increased to the physical value $\lambda = 0.75$, and settles at $E = 2.03 - 0.075i$ GeV. Hence, in experiment it will be observed as a structure from threshold upwards in the partial-wave scattering cross section. For the given pole

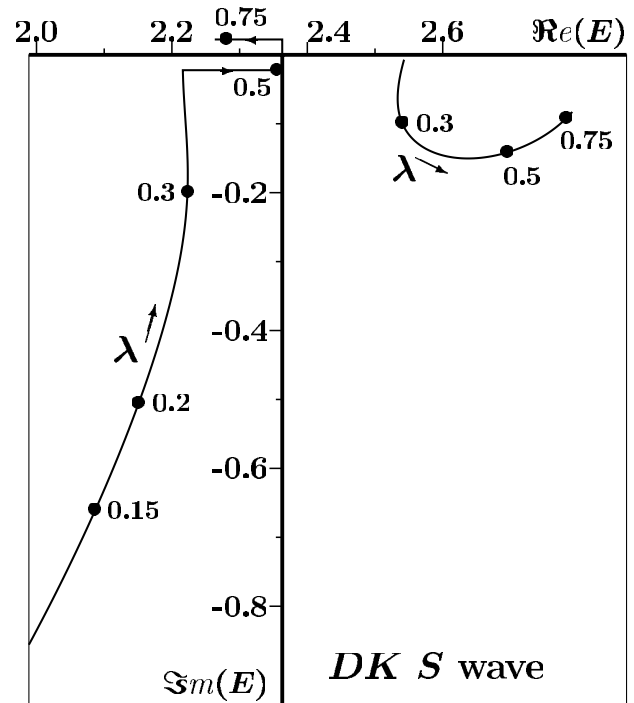


FIG. 2. S -matrix poles for DK S -wave scattering as a function of the coupling constant λ . Threshold is at 2.363 GeV; units are in GeV. The trajectory of the left-hand branch partly coincides with the real axis. For clarity, we have displaced the virtual bound states slightly downwards, and the real bound states upwards. Notice that for $\lambda = 0.75$ (physical value) one has a real bound state in this model.

position, this corresponds to a peak at about 2.1 GeV, with a width of 150 MeV, thus coming out some 70 MeV higher than the real part of the pole. This shift is manifest in our description of resonances, getting more and more sizable as the resonance width increases. For instance, in our fit of the S -wave $K\pi$ phase shifts, the cross-section peak shows up more than 100 MeV above the $K_0^*(800)$ pole [10]. On the other hand, one should also realize from Fig. 1 that a very modest decrease of $\lambda = 0.75$ would give rise not only to a larger real part of the pole position, but also of the imaginary part, thereby amplifying the mentioned shift upwards. Such a decrease of λ can be justified on the basis of flavor symmetry [15]. Therefore, we expect a D_0^* resonance somewhere in the energy interval 2.1–2.3 GeV, possibly with a width of several hundred MeV [15]. This may correspond to the preliminary $D_0^*(2290)$ resonance reported by the BELLE Collaboration [16], with a mass of 2.29 GeV and a width of 305 MeV.

The lower pole in DK scattering (Fig. 2) settles on the real axis for $\lambda \geq 0.335$. However, for the sake of clarity we have depicted its trajectory slightly away from the real axis. The pole trajectory for increasing λ ends up on the real axis at 2.21 GeV, i.e., well below threshold. Then it moves upwards as a virtual bound state, towards threshold, where for $\lambda \approx 0.5$ it turns into a real

bound state. For $\lambda = 0.75$ we find the pole at 2.28 GeV. Such a behavior was already forecast in Ref. [17]. If we were to decrease λ a little, again owing to flavor symmetry, we would find [15] a bound-state pole even closer to the experimental value of 2.317 GeV.

The higher poles in $D\pi$ and DK scattering, which stem from the scalar radial ground states at 2.44 GeV for $c\bar{n}$ and 2.55 GeV for $c\bar{s}$, move upwards in the second Riemann sheet. For the physical value of the overall coupling $\lambda = 0.75$, they constitute resonance poles. These poles come out some 200 MeV higher than what at first sight would be expected, not only from the naive quark model, but also from the central resonance positions of $D_1(2420)$ and $D_2^*(2460)$ with respect to D_0 , and $D_{sJ}^*(2573)$ with respect to D_{s0} . However, one should just compare this with the following situations, in order to understand why our findings are not unreasonable: (a) $a_0(1450)$, with respect to $a_1(1260)$ and $a_2(1320)$; (b) $f_0(1370)$, with respect to $f_1(1285)$ and $f_2(1270)$. Actually, in our full unitarized model, both the $a_0(1450)$ and $f_0(1370)$ stem from coinciding poles, connected to the model's $q\bar{q}$ scalar ground state at 1.29 GeV in the decoupling limit.

To summarize, we have demonstrated in the foregoing how a low-mass scalar D_s meson can be easily obtained by including its coupling to the most relevant OZI-allowed two-meson channel, i.e., DK . However, this bound state is of a highly nonperturbative nature, which in no way can be obtained in single-channel quark models, no matter how sophisticated the used confinement mechanism. In particular, we have employed a simple unitarized model, which successfully reproduces the light scalar nonet, so as to obtain a value of 2.28 GeV for the lowest scalar D_s state, when leaving the parameters unchanged with the exception of the quark masses. Therefore, we conclude that the recently discovered $D_s(2317)$ is probably a scalar meson of the latter type, being a cousin of the light scalar mesons, rather than belonging to the scalar $q\bar{q}$ confinement spectrum, such as, we believe, the $D_{s1}(2536)$ and $D_{sJ}^*(2573)$. Because of a similar coupling to the $D\pi$ threshold, we predict a $D_0^*(2100-2300)$ resonance, which may have been found already [16]. As a final remark concerning the $D_s(2317)$, we note that it becomes a bound state—actually a quasibound state owing to the, here disregarded, isospin-violating $D_s\pi$ decay mode—contrary to the $D_0^*(2100-2300)$ and the light scalar mesons, which are all resonances. This peculiarity is due to the high value of the lowest OZI-allowed threshold (DK), while the $D_0^*(2100-2300)$ as well as *all* light scalar mesons have a threshold involving at least one pion, which thus lie lower on a relative scale.

Besides the latter results, we have also obtained some additional predictions for charmed scalar mesons. For the standard charmed $q\bar{q}$ spectrum we expect the lowest S -wave resonances to occur at about 2.64 GeV for D , and at about 2.79 GeV for D_s , both with a width of some 200 MeV. However, these values may be subject to a

modest change when flavor-symmetry arguments are applied as above [15]. In any case, note that also these two states, though being perturbative in the sense that they can easily be linked to the confinement spectrum, turn out to suffer a drastic, quite nonperturbative effect from unitarization.

We thank F. Kleefeld for useful information on the distribution of S -matrix poles in the complex E and k planes. This work was partly supported by the *Fundação para a Ciência e a Tecnologia* of the *Ministério da Ciência e da Tecnologia* of Portugal under Contract No. POCTI/FNU/49555/2002.

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- [1] BABAR Collaboration, B. Aubert *et al.*, hep-ex/0304021.
- [2] CLEO Collaboration, D. Besson *et al.*, hep-ex/0305100; hep-ex/0305017.
- [3] SLAC Press Release, <http://www.slac.stanford.edu/slac/media-info/20030428/index.html>.
- [4] Stephen Godfrey and Nathan Isgur, Phys. Rev. D **32**, 189 (1985); S. Godfrey and R. Kokoski, Phys. Rev. D **43**, 1679 (1991).
- [5] M. Di Pierro and E. Eichten, Phys. Rev. D **64**, 114004 (2001).
- [6] For alternative explanations or interpretations, see the following papers: M. A. Nowak, M. Rho, and I. Zahed, Phys. Rev. D **48**, 4370 (1993); W. A. Bardeen and C. T. Hill, Phys. Rev. D **49**, 409 (1994); D. Ebert, T. Feldmann, and H. Reinhardt, Phys. Lett. B **388**, 154 (1996); R. N. Cahn and J. D. Jackson, hep-ph/0305012; T. Barnes, F. E. Close, and H. J. Lipkin, hep-ph/0305025; W. A. Bardeen, E. J. Eichten, and C. T. Hill, hep-ph/0305049; A. P. Szczepaniak, hep-ph/0305060; S. Godfrey, hep-ph/0305122; P. Colangelo and F. De Fazio, hep-ph/0305140; G. S. Bali, hep-ph/0305209; K. Terasaki, hep-ph/0305213.
- [7] Particle Data Group Collaboration, K. Hagiwara *et al.*, Phys. Rev. D **66**, 010001 (2002).
- [8] E791 Collaboration, E. M. Aitala *et al.*, Phys. Rev. Lett. **89**, 121801 (2002).
- [9] E. van Beveren, T. A. Rijken, K. Metzger, C. Dullemond, G. Rupp, and J. E. Ribeiro, Z. Phys. C **30**, 615 (1986).
- [10] Eef van Beveren and George Rupp, Eur. Phys. J. C **22**, 493 (2001).
- [11] Eef van Beveren and George Rupp, in *Hadron Spectroscopy*, Proceedings of the Ninth International Conference on Hadron Spectroscopy, AIP Conf. Proc. No. 619 (AIP, New York, 2002), p. 209.
- [12] Eef van Beveren and George Rupp, in *Proceedings of the Workshop on Recent Developments in Particle and Nuclear Physics, Coimbra, Portugal, 2001* (Universidade de Coimbra, Coimbra, 2002), ISBN , pp. 1–16 [hep-ph/0201006].
- [13] Eef van Beveren and George Rupp, contribution to the 31st International Conference on High Energy Physics (ICHEP 2002), Amsterdam, The Netherlands, 2002,

- Session 9, Paper ABS22 [hep-ph/0207022]; E. van Beveren, G. Rupp, N. Petropoulos, and F. Kleefeld, in *Hadron Physics: Effective Theories of Low Energy QCD*, Proceedings of the Second International Workshop on Hadron Physics, AIP Conf. Proc. No. 660 (AIP, New York, 2003), p. 353.
- [14] E. van Beveren and G. Rupp, hep-ph/0304105 [Int. J. Theor. Phys. Group Theor. Nonlin. Opt. (to be published)].
- [15] Eef van Beveren and George Rupp (to be published).
- [16] Belle Collaboration, K. Abe *et al.*, contribution to the 31st International Conference on High Energy Physics (ICHEP 2002), Amsterdam, The Netherlands, 2002, Session 8, Paper ABS724 [Report No. BELLE-CONF-02-35]; P. Krokovny, for the BELLE Collaboration, hep-ex/0210037.
- [17] E. van Beveren, T. A. Rijken, C. Dullemond, and G. Rupp, Lect. Notes Phys. **211**, 331 (1984).