Is the anomalous decay ratio of $D_{sJ}(2632)$ due to isospin breaking?

L. Maiani[*]

Università di Roma "La Sapienza" and I.N.F.N., Roma, Italy

F. Piccinini[†]

I.N.F.N. Sezione di Pavia and Dipartimento di Fisica Nucleare e Teorica, via A. Bassi, 6, I-27100 Pavia, Italy

A. D. Polosa[‡]

Centro Studi e Ricerche "E. Fermi," via Panisperna 89/A-00184 Roma, Italy

V. Riquer[§]

CERN Theory Department, CH-1211, Switzerland

Quark pair annihilation into gluons is suppressed at large momenta due to the asymptotic freedom. As a consequence, mass eigenvalues of heavy states should be almost diagonal with respect to up and down quark masses, thereby breaking isospin. We suggest the particle observed by the SELEX Collaboration, $D_{sJ}(2632)$, to be to a good extent a $[cd][\bar{d}\,\bar{s}]$ state, which would explain why its $D^0 K^+$ mode is anomalously suppressed with respect to $D_s^+ \eta$. Predictions for the rates of the yet unobserved modes $D_s^+ \pi^0$ and $D^+ K^0$ are given.

The SELEX Collaboration [1] at Fermilab claims a 7σ observation of a narrow charmed meson, $D_{sJ}(2632)$, decaying into $D_s^+ \eta$ and $D^0 K^+$. The ratio between the $D^0 K^+$ and the $D_s^+ \eta$ modes reported is about 0.16 ± 0.06. As the collaboration points out, this is quite an anomalous result, given also that the decay momentum of the first mode is about twice that of the second. This result would be totally at variance with the attribution of the $D_{sJ}(2632)$ to a $c\bar{s}$ state. Pending confirmation of this effect and a determination of the particle quantum numbers, we point out in this note that this result would arise quite naturally if the $D_{sJ}(2632)$ were a bound state of a diquark-antidiquark pair, in particular, an S-wave scalar [2]. The suppression of quark pair annihilation into gluons, due to the asymptotic freedom, causes the mass eigenvalues to align with states diagonal with respect to quark masses, even for the light, up and down quarks. The possibility of such an effect for pentaquark states was pointed out in Ref. [3]. In our case it is supported by the close degeneracy of $a(980)$ and $f(980)$ mesons, which should become more pronounced for the analogous states at the charm energy scale. The $D_{sJ}(2632)$ would be essentially a $[cd][\bar{d}\,\bar{s}]$ state (not an isospin eigenstate) whose decay into $D^0 K^+$ is forbidden by the Okubo-Zweig-Iizuka (OZI) *et al.* rule [4]. The interpretation proposed here is vulnerable to very simple tests, which we hope may be performed in the near future: (i) The

same $D_{sJ}(2632)$ resonance should decay into $D_s^+ \pi^0$ and $D^+ K^0$, with sizable branching ratios which we predict within narrow bounds. Simultaneous decay into $D_s^+ \eta$ and $D_s^+ \pi^0$ is direct proof of isospin breaking. (ii) A charge $+2$ state, very close in mass, should exist and be produced with sizable cross section, mostly decaying into $D_s^+ \pi^+$ and $D^+ K^+$.

In [2], we propose that scalar mesons below 1 GeV are four-quark states of the form $[qq][\bar{q}\,\bar{q}]$ ($q =$ up, down, strange), where brackets represent states which are completely antisymmetric in color, flavor, and spin. We show that this interpretation gives a good explanation of the spectrum and decay modes, except for the OZI rule violating mode $f \to \pi\pi$, which turns out to be larger than predicted. Decays are computed in terms of a single coupling, representing the amplitude for the switch of a $q\bar{q}$ pair between the diquarks, transforming the state into a pair of colorless mesons. A firm prediction of the scheme is the existence of similar scalar mesons with one light quark replaced by a heavy quark, e.g., charm. As discussed in [2], we expect such particles to occur in a reducible $\mathbf{6} \oplus \bar{\mathbf{3}}$ of flavor SU(3). States with $C = S = +1$, of the form $[cq][\bar{s}\,\bar{q}]$ (q is now restricted to up and down quarks) form an $I = 1$ and $I = 0$ complex of four states with electric charges 0, $+1$, $+2$. There are two states with electric charge $+1$: $I = 1$, $I_3 = 0$, and $I = 0$. By analogy with the light scalar meson complex, $a(980)$ and $f(980)$, we call the two states $a_{c\bar{s}}^+$ and $f_{c\bar{s}}^+$.

If isospin were strictly conserved, the two states would be pure mass eigenstates belonging, respectively, to the $\mathbf{6}$ and to the $\bar{\mathbf{3}}$ and different decay modes. One expects [2] the four decay channels:

*[*]Electronic address: luciano.maiani@roma1.infn.it
[†]Electronic address: fulvio.piccinini@pv.infn.it
[‡]Electronic address: antonio.polosa@cern.ch
[§]Electronic address: veronica.riquer@cern.ch

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$$a_{c\bar{s}}^+ = \frac{([cu][\bar{u}\,\bar{s}] - [cd][\bar{d}\,\bar{s}])}{\sqrt{2}} \rightarrow D_s^+ \pi^0, (DK)_{\substack{I=1\\I_3=0}},$$

$$f_{c\bar{s}}^+ = \frac{([cu][\bar{u}\,\bar{s}] + [cd][\bar{d}\,\bar{s}])}{\sqrt{2}} \rightarrow D_s^+ \eta, (DK)_{I=0}.$$

The mesons $a(980)$ and $f(980)$ are degenerate within, say, 10 MeV [5]. As seen in [2], this reflects the smallness of the OZI violating contributions to the mass matrix, which would align the mass eigenstates to pure SU(3) representations. We expect OZI violations to be even smaller in heavy meson systems (as exemplified by the narrow width of the J/Ψ) and mass eigenstates to align strictly on the quark composition rather than the SU(3), or even SU(2) representations. This happens when the diagonal masses of the $I = 1$ and $I = 0$ states become degenerate within a few MeV, comparable to the non-diagonal matrix element induced by the up and down quark mass difference (in a different context, a second order weak interaction is sufficient to maximally mix K^0 and $\bar{K}^0$, due the degeneracy of the diagonal masses implied by CPT). The issue of SU(2) violation in mass eigenstates has been analyzed recently in Ref. [3] with the conclusion that considerable mixing between $I = 3/2$ and $I = 1/2$ should occur already at the level of the pentaquark baryons [6].

A large mixing between $a_{c\bar{s}}^+$ and $f_{c\bar{s}}^+$ leads to decays of the mass eigenstates that do not respect the isospin symmetric pattern given above. To be quantitative, assume that the mass eigenstates are a superposition of the two, OZI conserving, eigenvectors:

$$|S_u\rangle = [cu][\bar{u}\,\bar{s}], \qquad |S_d\rangle = [cd][\bar{d}\,\bar{s}]. \qquad (1)$$

According to

$$\begin{aligned} |D_h\rangle &= \cos\theta |S_u\rangle + \sin\theta |S_d\rangle, \\ |D_l\rangle &= -\sin\theta |S_u\rangle + \cos\theta |S_d\rangle. \end{aligned} \qquad (2)$$

Decay amplitudes of four-quark states are computed following Ref. [2], in terms of a single amplitude A. Keeping into account the antisymmetric structure of the diquarks, one easily finds the results in Table I. X_q is the projection on the η meson of the isosinglet pseudoscalar state η_q:

$$\eta_q = \frac{(u\bar{u} + d\bar{d})}{\sqrt{2}}, \qquad X_q = \frac{(\cos\phi + \sqrt{2}\sin\phi)}{\sqrt{3}} \simeq 0.72, \quad (3)$$

where ϕ is the $\eta\eta'$ meson mixing angle, $\sin\phi \simeq 0.19$ (quadratic mass formulas).

The particle produced in strong reactions is a mixture of the two eigenstates according to the respective probabilities: P = probability of producing D_h, $(1 - P)$ = probabilities of producing D_l. Apart from a normalization factor,

$$P = |A^{(0)}(\cos\theta + \sin\theta)/\sqrt{2} + A^{(1)}(\cos\theta - \sin\theta)/\sqrt{2}|^2, \quad (4)$$

and $A^{(0,1)}$ are the amplitudes to produce the isospin 1 and 0 states, a and f. The decay probability of the D_h/D_l mixture into a given channel, X, is

$$\Gamma(X) = P\Gamma_h(X) + (1 - P)\Gamma_l(X). \qquad (5)$$

The ratio of the $D^0 K^+$ to the $D_s^+ \eta$ rates is computed assuming S-wave decays. Using the amplitudes of Table I, we find

$$\begin{aligned} R^0 &= \frac{\Gamma(D^0 K^+)}{\Gamma(D_s^+ \eta)} \frac{X_q^2 p_{D_s\eta}}{2 p_{D^0 K^+}} \approx 0.027 \\ &= \frac{P\cos^2\theta + (1 - P)\sin^2\theta}{(1 + \sin2\theta)P + (1 - \sin2\theta)(1 - P)}. \end{aligned} \qquad (6)$$

We give in Fig. 1 the curve representing (6) in the $\theta - P$ plane. The very small value of R^0 reflects into an allowed region with very small P and θ. We find

$$-0.19 < \sin\theta < +0.14, \qquad P < 0.03. \qquad (7)$$

The picture that emerges is that $D_{sJ}(2632)$ is to high precision D_l, which in turn is mainly S_d, whose decay into $D^0 K^+$ is OZI forbidden with only a small component along S_u for which $D^0 K^+$ is OZI allowed. We report in the
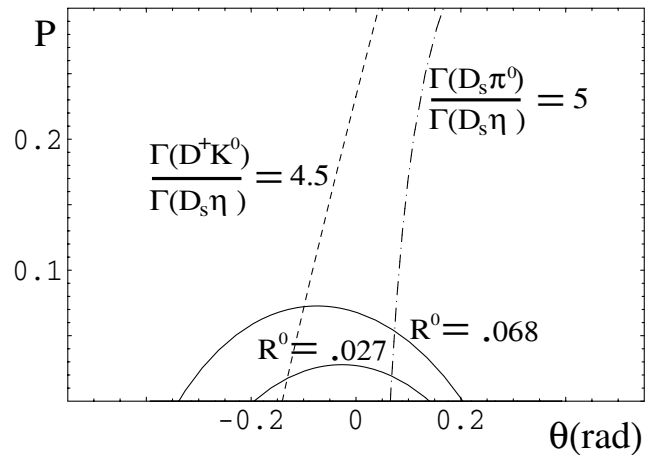

FIG. 1. Solid lines: P versus $\sin\theta$ according to Eq. (6) for $R^0 = 0.027$ (see text) and 0.068. Dashed and dot-dashed lines are the corresponding curves for $D^+ K^0$ and $D_s^+ \pi^0$ modes. Bounds on the rates given in the text normalized to the $D_s^+ \eta$ rate are found by requiring these curves to intersect the solid line with $R^0 = 0.027$.

TABLE I. Amplitudes for the decays of D_h and D_l in the OZI allowed channels.

	$D_s^+ \eta$	$D_s^+ \pi^0$	$D^0 K^+$	$D^+ K^0$
D_h	$\frac{A(\cos\theta + \sin\theta)X_q}{\sqrt{2}}$	$\frac{A(\cos\theta - \sin\theta)}{\sqrt{2}}$	$-A\cos\theta$	$-A\sin\theta$
D_l	$\frac{A(\cos\theta - \sin\theta)X_q}{\sqrt{2}}$	$-\frac{A(\cos\theta + \sin\theta)}{\sqrt{2}}$	$A\sin\theta$	$-A\cos\theta$

same figure two similar curves referring to the $D^0 K^+$ and $D_s^+ \pi^0$ modes, computed for the indicated value of the ratio of the rates to the $D_s^+ \eta$ mode. These curves intersect the first one for values in the intervals:

$$4 < \frac{\Gamma(D^+ K^0)}{\Gamma(D_s^+ \eta)} < 7.6; \qquad 1.7 < \frac{\Gamma(D_s^+ \pi^0)}{\Gamma(D_s^+ \eta)} < 6.5. \qquad (8)$$

A last comment refers to the doubly charged, exotic state: $a_{c\bar{s}}^{++} = [cu][\bar{d}\,\bar{s}]$, expected to decay into $D_s^+ \pi^+$ or $D^+ K^+$. The smallness of P indicates an almost complete cancellation: $A(0) + A(1) \simeq 0$. However, the state $a_{c\bar{s}}^{++}$ is produced with the amplitude $A(1)$ only and is thus expected to be produced about as much as the $D_{sJ}(2632)$.

Note added.—After submission of this work, similar interpretations of $D_{sJ}(2632)$ have been advanced by Nicolescu and de Melo [7] and by Chen and Li [8].

[1] A. V. Evdokimov *et al.*, hep-ex/0406045.
[2] L. Maiani, F. Piccinini, A. D. Polosa, and V. Riquer, hep-ph/0407017.
[3] G. C. Rossi and G. Veneziano, hep-ph/0404262. Baryonium was considered in an earlier paper by the same authors: Phys. Lett. B **70**, 255 (1977).
[4] G. Zweig, CERN Report No. S419/TH412, 1964;
S. Okubo, Phys. Lett. **5**, 165 (1963); I. Iizuka, K. Okuda, and O. Shito, Prog. Theor. Phys. **35**, 1061 (1966).
[5] S. Eidelman *et al.*, Phys. Lett. B **592**, 1 (2004).
[6] R. L. Jaffe and F. Wilczek, Phys. Rev. Lett. **91**, 232003 (2003).
[7] B. Nicolescu and J. P. B. C. de Melo, hep-ph/0407088.
[8] Y. Q. Chen and X. Q. Li, hep-ph/0407062.