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Comment on the SPEAR Charm Search

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ABSTRACT

We assess the impact of the upper limits for production cross section times branching ratio of narrow mass peaks reported by Boyarski, et al., on the hidden charm interpretation of the new narrow resonances.

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In a recent Letter,[1] Boyarski, et al., have reported the results of a search for narrow peaks in a number of invariant mass distributions in which charmed mesons might be found. We consider here, in the context of the orthodox theory of weak, nonleptonic decays of charmed particles, the implications of these important new data.

One of the attractive features of the hidden charm interpretation of $\psi(3095)$ and $\psi'(3684)$ is that charm predates the experimental developments of last fall. Before the discovery of ψ, there existed a standard form for the hadronic weak current[2] and a plausible enhancement

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scheme (so-called 20-dominance) for the nonleptonic weak Hamiltonian.[3] After the observation of the new states, it was natural to employ this theory for detailed enumerations of the expected decay modes and branching ratios of the conjectured charmed mesons. This work,[4,5] which supplemented the review article by Gaillard, Lee and Rosner,[6] was intended to help sharpen the experimental issues surrounding the charm scheme. In this spirit, we now confront the theoretical expectations with the new data from SPEAR.

To compare the experimental limits on production cross section times branching ratio with the theoretical expectations for branching ratios requires an assumption about the charm production cross section. The total cross section for hadron production in e^+e^- annihilation is

$$\sigma_{\text{hadronic}} = \frac{4\pi}{3} \frac{\alpha^2}{Q^2} R \,, \tag{1}$$

where Q^2 is the square of the total c.m. energy, and $R = R_0 + R_c$ can be partitioned into the contributions of ordinary and charmed final states. Three possibilities suggest themselves for the parameter R_c.

(i) It is the excess of R over the colored SU(3) quark model value of 2.

(ii) It is the excess of R over the constant value of approximately 2.5 observed below $\sqrt{Q^2} = 3.7$ GeV.

(iii) It is the SU(4) quark model value of 0.4 R.

At 4.8 GeV, the experimental value[7] of R is 4.83 ± 0.40. Options

(i) - (iii) then lead to the estimates R_c = 2.83, 2.33, 1.93, respectively. We reject the last because it rests heavily on an argument which predicts R = 10/3 at the energy in question. For our numerical considerations we adopt the value R_c = 2.5 as a reasonable estimate of the magnitude of the charmed hadron production cross section.

We shall assume in the following that the charmed pseudoscalar mesons are the lightest charmed particles, and that they decay weakly via a conventional current-current Hamiltonian.[6] We shall assume SU(3) symmetry and that, for charm-changing transitions, the SU(3) [$\underset{\sim}{15}$] term in the current-current product may be neglected relative to the [$\underset{\sim}{6}$] (sextet enhancement).[3,4,5] We further assume that the charmed final states include one of the pairs D^+D^-, $D^0\bar{D}^0$, and F^+F^-, produced with equal cros sections of 3.14 nb. at $\sqrt{Q^2}$ = 4.8 GeV.

We consider first the channel $(K^-\pi^+ + K^+\pi^-)$, for which a combined upper limit of 0.18 nb is reported for the mass range 1.85 to 2.40 GeV/c^2. (The other mass bands studied in Ref. 1 are of less interest for charm.) The implied branching ratio is

$$B(D^0 \to K^-\pi^+) \leq 2.9\% = \frac{0.09 \text{ nb}}{3.14 \text{ nb.}} . \tag{2}$$

Under the assumption of sextet dominance, the $K^-\pi^+$ rate is 1/3 the rate for $D^0 \to$ 2 pseudoscalars ($\mathscr{P}\mathscr{P}$). Therefore we infer from (2) that

$$B(D^0 \to \mathscr{P}\mathscr{P}) \leq 8.6\%. \tag{3}$$

The observed charged particle multiplicities of produced hadrons[7] suggest that two, three and four body modes exhaust the prominent decays. Thus the result that $B(D^0 \to \mathscr{P}\mathscr{P}) < 10\%$ poses a stern challenge to charm. It is worth recalling, however, that two-body decays of $\rho'(1600)$ constitute $\lesssim 10\%$ of its total width.[8]

The modes $K^{\mp}\pi^{\pm}\pi^{\pm}$ may arise from decays of $D^{\pm}$, and the published limits yield

$$B(D^+ \to K^-\pi^+\pi^+) \leq 7.8\% = \frac{0.245 \text{ nb.}}{3.14 \text{ nb.}} \quad . \tag{4}$$

Whether this is "small" requires further discussion. In the sextet enhancement scheme, the only Cabibbo-favored decays of D^+ must lead to a final state transforming as an SU(3) $[\underset{\sim}{10}]$. Since there are four different ways[9] to couple three pseudoscalars to a $[\underset{\sim}{10}]$, it is difficult, on the basis on the $K^-\pi^+\pi^+$ mode alone, to infer a general statement on the branching ratio to three pseudoscalars. As an illustration in the spirit of our earlier work,[5] we note that, for the pseudoscalar-vector $(\pi^+\overline{K}^{*0})$ mode and the totally symmetric mode $(\{\mathscr{P}\mathscr{P}\mathscr{P}\})$, the branching ratios is 1/3, so neglecting other modes, Eq. (4) implies

$$B(D^+ \to (\mathscr{P}\mathscr{V})_{[\underset{\sim}{10}]}) + B(D^+ \to \{\mathscr{P}\mathscr{P}\mathscr{P}\}_{[\underset{\sim}{10}]}) \leq 23\%$$

In any case, we would have expected the $\cos^4\theta_C$ nonleptonic decays to comprise perhaps 90% of the total D^+ decay rate, which seems unlikely in view of the upper limits expressed in Eq. (4) or Eq. (5). (Recall that there are no $\cos^4\theta_C$ decays into two pseudoscalars or two vectors. If four body decays comprised as large a branching fraction as apparently required by Eq. (5), there may be difficulty explaining the relatively low observed multiplicity.) We see three alternative conclusions: (i) charm is wrong; (ii) the conventional current-current description of nonleptonic decays is wrong; or (iii) decays into a decimet are not enhanced. Alternative (iii) is the most direct and was suggested[6] before the discovery of Ψ. It reflects the fact that the quark-model-exotic decimet is suppressed in the strong interactions. Indeed, Gaillard and Lee[10] and Altarelli and Maiani[11] have speculated that the hadronic wave functions play a key role in the enhancement mechanism. If the decimet is not enhanced, the possibility has been noted[6,5] that the D^+ would have a significant semileptonic branching fraction, which would compete with the decimet, with enhanced but Cabibbo-suppressed decays, and with unenhanced but Cabibbo-favored decays due to the $\underset{\sim}{84}$ piece of the weak Hamiltonian. In this situation, the inequality (5) is not at all stringent. We remark that an experimental bound on $B(D^+ \to \pi^+ \overline{K^{*0}})$ would be of some interest as a measure of the strength of the decay into a $\mathscr{P}\mathscr{V}$ decimet.

Next consider the $K_S \pi^+ \pi^-$ mode, which appears in $D^0 \to \overline{K}^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K^0 \pi^+ \pi^-$. The experimental bound is

$$B(D^0 \to \overline{K}^0 \pi^+ \pi^-) \leq 12.7\% = \frac{0.40 \text{ nb.}}{3.14 \text{ nb.}} . \qquad (6)$$

The final state can be reached in order $\cos^4 \theta_C$ through both the octet and decimet channels. We assume again that the $\mathscr{P}\mathscr{V}$ and $\{\mathscr{P}\mathscr{P}\mathscr{P}\}$

modes exhaust the three pseudoscalar meson final states and that, in view of the preceding discussion, the $[\underset{\sim}{10}]$ is negligible compared with the $[\underset{\sim}{8}]$. Then for the symmetric final state we have

$$B(D^0 \rightarrow \{\bar{K}^0\pi^+\pi^-\}) = \frac{1}{12}\, B(D^0 \rightarrow \{\mathscr{P}\mathscr{P}\mathscr{P}\}). \quad (7)$$

For the $\mathscr{P}\mathscr{V}$ mode, the branching fractions into $\bar{K}^0\rho^0$ and π^+K^{*-} depend upon the unknown relative magnitudes of reduced matrix elements into symmetric and antisymmetric octets so cannot be stated unambiguously.[5] We may, however, note that for either the purely symmetric case or the purely antisymmetric case

$$\begin{aligned} B(D^0 \rightarrow \bar{K}^0\rho^0) &= \frac{1}{12} B(\mathscr{P}\mathscr{V}), \\ B(D^0 \rightarrow \pi^+K^{*-}) &= \frac{1}{6}\, B(\mathscr{P}\mathscr{V}), \end{aligned} \quad (8)$$

so the limit (6) is unrestrictive.

The bound on the modes $\pi^+\pi^-\pi^\pm$ is

$$B(D^+ \rightarrow \pi^+\pi^+\pi^-) + B(F^+ \rightarrow \pi^+\pi^+\pi^-) \leq 6.0\% = \frac{0.19}{3.14}. \quad (9)$$

The decays can proceed through $\pi^+\rho^0$, $\pi^+\pi^+\pi^-$, or other modes not discussed. Upon neglecting the $[\underset{\sim}{10}]$, we find that

$$B(D^+ \text{ or } F^+ \rightarrow \{\pi^+\pi^+\pi^-\}) = \frac{1}{6}\, B(D^+ \text{ or } F^+ \rightarrow \{\mathscr{P}\mathscr{P}\mathscr{P}\}), \quad (10)$$

So, if this were dominant,

$$B(D^+ \rightarrow \{\mathscr{P}\mathscr{P}\mathscr{P}\}) + B(F^+ \rightarrow \{\mathscr{P}\mathscr{P}\mathscr{P}\}) \leq 36\% \quad . \quad (11a)$$

For the $\mathscr{P}\mathscr{V}$ mode the rate is proportional to the matrix element into the antisymmetric octet. If, e.g., this were the dominant amplitude, the $\pi^+\rho^0$ mode would be 1/3 of the $\mathscr{P}\mathscr{V}$ branching fraction, so

$$B(D^+ \xrightarrow{A} \mathscr{P}\mathscr{V}) + B(F^+ \xrightarrow{A} \mathscr{P}\mathscr{V}) \leq 18\% \quad . \tag{11b}$$

So, once again, although it is difficult to interpret the upper limit, Eq. (9), without knowing more about the dynamics, the sort of limits expressed in Eqs. (11a) and (11b) would not appear to be pressing.

The $K_S K^{\pm}$ mode can also arise from both $F^{\pm}$ and $D^{\pm}$, for which

$$B(F^+ \text{ or } D^+ \rightarrow \overline{K}^0 K^+) = \frac{1}{3} B(F^+ \text{ or } D^+ \rightarrow \mathscr{P}\mathscr{P}) \quad . \tag{12}$$

When combined with the experimental bound of

$$B(D^+ \rightarrow \overline{K}^0 K^+) + B(F^+ \rightarrow \overline{K}^0 K^+) \leq 10\% \quad . \tag{13}$$

This requires

$$B(D^+ \rightarrow \mathscr{P}\mathscr{P}) + B(F^+ \rightarrow \mathscr{P}\mathscr{P}) \leq 31\% \tag{14}$$

which is likely to be easily satisfied.

If the decay $D^+ \rightarrow \overline{K}^0 \pi^+$ is not enhanced, as is to be expected theoretically, the upper limits on all the remaining modes, $K_S \pi^{\pm}$, $\pi^+\pi^-$, and K^+K^-, lead to no constraints at all, because these modes are suppressed by $\tan^2 \theta_C$ relative to the dominant modes.

Obviously, the nonobservation of charmed hadrons at SPEAR does little to strengthen the case for the hidden charm interpretation of the newly-discovered bosons. How much the case is weakened by the new data is a topic for subjective interpretation of the bounds we have quoted above. In our minds the most damaging result is that two-body decays of D^0 account for less than 10% of its total width. While such a suppression is neither unthinkable nor unprecedented, we find it disturbing not only because it is so small but also because, if 90% of the nonleptonic decays are to three or more particles, it will be difficult to understand the observed charge particle multiplicity. We disagree with the conclusion of Boyarski, et al., that their upper limit on $B(D^+ \to \bar{K}^0\pi^+$ or $K^-\pi^+\pi^+)$ violates the expectation of the conventional model by a factor of at least three.[12] In fact, in the conventional model with all of its pre-ψ baggage of sextet-enhancement and $[\underset{\smile}{10}]$-suppression, both decays are expected to be absent (i.e., not dominant). An incautious interpretation is that the nonobservation of these modes is good for the model, but we do not wish to go so far. Indeed, it is our feeling that if some of the upper limits, such those given in Eqs. (2), (9) and (13), were decreased by factors of two or three, the conventional charm scheme[2-6] would require modification.

FOOTNOTES AND REFERENCES

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[12] The discussion surrounding Table IV of Ref. 6, on which Boyarski, et al., apparently base their conclusion, clearly warns that these modes may be strongly suppressed.