Threshold effect and $\pi^{\pm}\psi(2S)$ peak

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A resonancelike structure in the $\pi^{\pm}\psi(2S)$ mass spectrum arising in $B \to K\pi^{\pm}\psi(2S)$ has recently been reported. It is noted that the mass of this structure, $4433 \pm 4 \pm 2$ MeV, is not far from the threshold for production of $D^*\bar{D}_1(2420)$. A proposed mechanism for production of this state is suggested, and tests are suggested.

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A wealth of charmonium states have recently been reported in B meson decays. (For one review, see Ref. [1].) Until recently, all such states were neutral, implying the possibility of at least some fraction of $c\bar{c}$ in their wave functions. Recently, however, the Belle Collaboration [2] has reported a state produced in $B \to K\pi^{\pm}\psi(2S)$ in which the $\pi^{\pm}\psi(2S)$ system displays a resonancelike structure with mass $M = 4433 \pm 4 \pm 2$ MeV and width $\Gamma = 44^{+17+30}_{-13-11}$ MeV. This would be the first observation of a genuine tetraquark [3] charmonium configuration. The possibility of easily producing such configurations in B decays was noted, for example, in Ref. [4].

The purpose of this short article is to suggest a mechanism for production of this state which relies upon the proximity of its mass to the $D^*(2010)\bar{D}_1(2420)$ threshold. S-wave thresholds appear to be important in a wide variety of resonancelike behavior [5]. The $X(3872)$ state produced (for example) in $B \to KX$ and decaying to $\pi^+\pi^-J/\psi$ lies 0.6 ± 0.6 MeV below $D^0\bar{D}^{*0}$ + c.c. threshold [6]. The $Y(4260)$, seen in the radiative return reaction $e^+e^- \to \gamma + Y(4260)$ and in a direct e^+e^- scan, can be associated with the lowest threshold for which a $c\bar{c}$ pair with $J^{PC} = 1^{--}$ can materialize into a pair of mesons $D\bar{D}_1(2420)$ − c.c. in a relative S wave [5,7].

The production mechanism we suggest for the $\pi^{\pm}\psi(2S)$ resonancelike state is based on the diagram of Fig. 1. The different charge states that can be involved in this process are summarized in Table I.

The quarks q and q' are independent. Isospin invariance implies $\mathcal{B}[B^0 \to K^+\pi^-\psi(2S)] = 2\mathcal{B}[B^0 \to K^0\pi^0\psi(2S)]$ and $\mathcal{B}[B^+ \to K^0\pi^+\psi(2S)] = 2\mathcal{B}[B^+ \to K^+\pi^0\psi(2S)]$.

The proposed mechanism operates by the production of an anticharmed meson $\bar{c}q'$ and a charmed meson $c\bar{q}$ which then rescatter into $c\bar{c} = \psi(2S)$ and $q'\bar{q} = \pi$. A key feature of the data not answered by the present mechanism is why rescattering into $J/\psi\pi$ is not observed. Perhaps the rescattering process is enhanced when the Q-values of the two sides are more nearly equal. The additional Q-value available in rescattering into states containing J/ψ may favor higher pion multiplicities, e.g., $3\pi J/\psi$ or even $5\pi J/\psi$, over $\pi J/\psi$ [8]. [Here we have assumed a definite G-parity $G(Z) = +$.]

The $\bar{c}q'$ meson can be either $\bar{D}_1(2420)$ (the narrow P-wave charmed meson decaying to $\bar{D}^*\pi$) or $\bar{D}^*(2010)$ (the vector meson state decaying to $\bar{D}\pi$). The $c\bar{q}$ meson would then correspondingly be $D^*(2010)$ or $D_1(2420)$. In either case, the final state $D^*\bar{D}^*\pi$ should be visible, with a Dalitz plot showing a strong $\bar{D}_1(2420)$ and/or $D(2420)$ band. Which band is populated can shed light on details of the decay mechanism, such as whether relative orbital angular momentum of zero or one is favored between the $\bar{c}$ and the q' in Fig. 1.

The S-wave states of $D^*(2010) + \bar{D}_1(2420)$ can have spin-parity $J^P = 0^-, 1^-, 2^-$. A 0^- or 1^- state would decay to $\pi\psi(2S)$ via a P-wave, while either P-wave or F-wave decay would be allowed for 2^-. The calculation of acceptance in Ref. [2] assumed a relative S-wave between $\pi^{\pm}$ and $\psi(2S)$. The rather low Q-value for the decay $B \to KZ(4430)$ likely favors a low angular momentum ℓ between K and Z. A low spin $J(Z)$ is then favored since one must have $J(Z) = \ell$ in this decay. For $J^P(Z) = 0^-$, the polarization vector of the $\psi(2S)$ in $Z \to \pi\psi(2S)$ must be parallel to the direction of the recoil π in the rest frame of the $\psi(2S)$. If the polarization of the J/ψ follows that of the $\psi(2S)$ (a good approximation), the leptons in $J/\psi \to \ell^+\ell^-$ will have a $\sin^2\theta$ distribution with respect to the recoil π momentum.

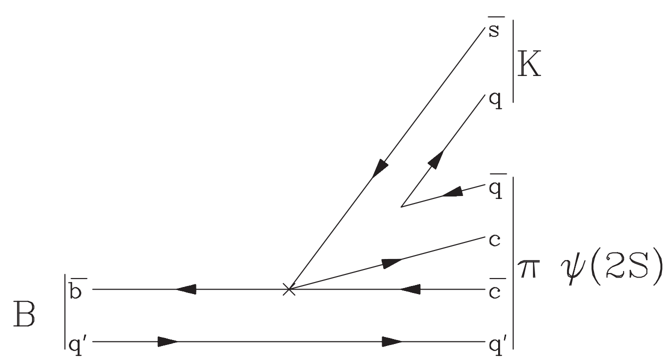

FIG. 1. Diagram illustrating the production of a $\pi\psi(2S)$ state in B decays. The weak subprocess $\bar{b} \to \bar{c}c\bar{s}$ is labeled by $\times$.

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TABLE I. Possible charge states for production of a $\pi\psi(2S)$ state in B decays.

q	q'	B	K	$Z(4430) \to$
u	d	B^0	K^+	$\pi^-\psi(2S)$
d	u	B^+	K^0	$\pi^+\psi(2S)$
u	u	B^+	K^+	$\pi^0\psi(2S)$
d	d	B^0	K^0	$\pi^0\psi(2S)$

If the $q\bar{q}$ pair in Fig. 1 is $s\bar{s}$ rather than $u\bar{u}$ or $d\bar{d}$, one will have final states such as $\phi D_s^{(*)} D^{(*)}$ or even (barely) $\phi D_s(2317)D$ [8]. The charm-anticharm pair could then rescatter into KJ/ψ or (for $D_s D$) $K\psi(2S)$. The decay $B^+ \to K^+\phi J/\psi$ has been observed with a branching ratio of $(5.2 \pm 1.7) \times 10^{-5}$ (average of Ref. [9], based on Refs. [10,11]), and should be examined for bumps in the K^+J/ψ spectrum.

An analogue in charm decays, in which one would search for a $\phi\pi^-$ resonance, would be the Cabibbo-suppressed decay $D^0 \to K^+K^-\pi^+\pi^-$ [8]. If the mechanism of Fig. 1 is responsible for a resonance through rescattering from a $K^{(*)}\bar{K}^{(*)}$ state, D^0 decays will yield a $\phi\pi^-$ resonance while $\bar{D}^0$ decays will yield a $\phi\pi^+$ resonance.

An alternative mechanism for production of a $c\bar{c}\pi$ state, distinct from that shown in Fig. 1, would involve a $\bar{b} \to \bar{s}$ penguin transition, leading to a similar diagram but with the $c\bar{c}$ pair produced from the vacuum rather than at the weak vertex. The presence of a signal in $\pi\psi(2S)$ and its absence in $\pi J/\psi$ would be even more puzzling in this picture. Moreover, the large product branching ratio [2],

$$\mathcal{B}[B \to KZ(4430)]\mathcal{B}[Z(4430) \to \pi^+\psi(2S)] = (4.1 \pm 1.0 \pm 1.3) \times 10^{-5}, \quad (1)$$

is larger than most $\bar{b} \to \bar{s}$ penguin-dominated processes *without* charmed pair production, so this alternative mechanism is highly unlikely to account for the observed signal. A similar statement applies to the case of the weak subprocess $\bar{b} \to \bar{u}u\bar{s}$ accompanied by charmed pair production from the vacuum, as this subprocess is even weaker than the $\bar{b} \to \bar{s}$ penguin process.

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Note added.—Subsequently to this work, a proposal appeared [12] that the $Z(4430)$, whose neutral member has charge conjugation eigenvalue $C = -$, is a tetraquark state representing a radial excitation of an as-yet-unseen $C = -$ state not far in mass from the $X(3872)$. [The $X(3872)$ is identified as having $C = +1$ through its decay to $\gamma J/\psi$ [13,14].] Even more recently, a proposal similar to ours [15] accounts for the apparent enhancement of the ratio $\Gamma[Z(4430) \to \pi\psi(2S)]/\Gamma[Z(4430 \to \pi J/\psi]$ via a rescattering model based on charm exchange, and concludes that $J^P[Z(4430)] = 1^-$ is favored.

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