Charmless final states and *S*- and *D*-wave mixing in the ψ''

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The $\psi''=\psi(3770)$ resonance is expected to be mainly $c\bar{c}(1\,^3D_1)$, but tensor forces and coupling to charmed particle pairs can mix it with $\psi'(2^3S_1)$ and other states. The implications of this mixing for decays of ψ'' to noncharmed final states are discussed. (i) The ratio $\Gamma(\psi''\to\gamma+\chi_{c2})/\Gamma(\psi''\to\gamma+\chi_{c0})$ is expected to be highly suppressed if ψ'' is a pure D-wave state, and is enchanced by mixing. (ii) The expected decay $\psi'\to\rho\pi$ and other "missing" modes can appear as corresponding ψ'' partial widths, enhanced by a factor depending on the mixing angle. General arguments then suggest a branching ratio of about 1%, give or take a factor of 2, for charmless hadronic decays of ψ''. (iii) Enhancements can appear in penguin amplitudes in B decays, $B\to K\eta'$ branching ratios, and direct CP-violating asymmetries in $B\to K\pi$ decays.

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I. INTRODUCTION

The lowest resonance in electron-positron collisions above the charmed particle pair production threshold is the $\psi''=\psi(3770)$, discovered somewhat after the $J/\psi(3097)$ and the $\psi'=\psi(3686)$ [1].[1] It provides a rich source of $D^0\bar{D}^0$ and D^+D^- pairs, as anticipated theoretically [2]. The largest data sample of ψ'' decays studied so far, by the Mark III Collaboration at the Stanford electron-positron collider SPEAR [3], has been 9.56 ± 0.48 pb^{-1}. Plans are under way to accumulate as much as 3 fb^{-1} at the Cornell Electron Storage Ring (CESR), which will permit much more incisive tests of a number of open questions [4]. In the present paper we discuss several of these which involve observation of *noncharmed final states* of the ψ''. These have been studied in two previous papers [5,6] based on the Mark III data.

The ψ'' is the only present candidate for a D-wave ($l=2$) quarkonium level. (Strategies for finding the corresponding $b\bar{b}$ levels have been noted in Refs. [7,8].) Although it is primarily $c\bar{c}(1^3D_1)$,[2] its leptonic width (quoted in Table I [3,9]) indicates a contribution from mixing with S-wave states, such as the nearby $\psi'(2^3S_1)$ and to a lesser extent with $J/\psi(1^3S_1)$ [10] and $n\geq3$ S-wave states above 4 GeV/c^2. Early calculations of this mixing based on contributions from intermediate real and virtual states of charmed particle pairs [2] predicted a ψ'' contribution to the $e^+e^-\to D\bar{D}$ cross section which indicated the utility of this state as a "charm factory" and predicted its leptonic width quite well.[3] It was later found that mixing due to a tensor force based on perturbative QCD also was adequate to explain the observed leptonic width [12]. Probably both perturbative and nonperturbative (e.g., coupled-channel) effects are present.

The mixing of the ψ'' with other states can affect both its decays and those of the other states. In Sec. II we discuss a simplified model for $\psi'-\psi''$ mixing and its implications for leptonic and radiative partial decay rates of these states. The ratio $\Gamma(\psi''\to\gamma+\chi_{c2})/\Gamma(\psi''\to\gamma+\chi_{c0})$ is expected to be highly suppressed if ψ'' is a pure D-wave state, but could be enhanced by mixing [5,7,13–15].

The "missing decay modes" of the ψ' [16], such as $\rho\pi$ and $K^*\bar{K}+$c.c., are a long-standing puzzle [17–21]. Recently Suzuki [22] showed that if a ψ' decay amplitude due to coupling to virtual (but nearly on-shell) charmed particle pairs interferes destructively with the standard three-gluon amplitude, the suppression of these (and other) modes in ψ' final states can be understood. We pursue this suggestion further in Sec. III using the $\psi'-\psi''$ mixing model described earlier. We propose that as a result of coupled-channel effects the expected decay width $\Gamma(\psi'\to\rho\pi)\simeq0.5$ keV and other "missing" modes could show up as corresponding partial widths in ψ'' decays, possibly enhanced by a considerable factor depending on the mixing angle. Since the latter state has a total width nearly 100 times that of the ψ', each of these partial widths still corresponds to a small branching ratio.

If coupling to charmed particle pairs is responsible for mixing the ψ' and the ψ'', and for significant effects on non-charmed final states in decays of both particles, it is likely that virtual or real $D^{(*)}\bar{D}^{(*)}$ pairs produced in low partial waves in other contexts may undergo significant rescattering into non-charmed final states. Foremost among these cases are the decays of B mesons, which can involve such pairs via the subprocesses $\bar{b}\to\bar{c}c\bar{s}$ or $\bar{b}\to\bar{c}c\bar{d}$. The reannihilation of the final $c\bar{c}$ pair can lead to an effective $\bar{b}$

TABLE I. Properties of the $\psi''=\psi(3770)$.

Mass (MeV/c^2)	$\Gamma_{\rm tot}$ (MeV)	Γ_{ee} (keV)	$\mathcal{B}(D^0\bar{D}^0)$	$\mathcal{B}(D^+D^-)$
3769.9 ± 2.5	23.6 ± 2.7	0.26 ± 0.04	58%	42%

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[1]The numbers in parentheses indicate the masses of the particles, in MeV/c^2.

[2]We shall use spectroscopic notation $n^{2S+1}L_J$, where $n=1,2,3,\ldots$ is the radial quantum number; $S=0$ or 1 is the $Q\bar{Q}$ spin; $L=S,P,D,\ldots$ ($l=0,1,2,\ldots$) is the orbital angular momentum; and $J=0,1,2,\ldots$ is the total spin.

[3]For later discussions of mixing due to coupled-channel effects see [11].

TABLE II. Comparison of transitions $\psi''\to\gamma\chi_c$ under the assumptions of a pure *S*-wave or *D*-wave initial state. Coefficients C are those in the expression (1) for electric dipole transitions.

Final state	ω (MeV)	Pure $^3S_1$ C	Pure $^3S_1$ $\Gamma(^3P_J)/\Gamma(^3P_0)$	Pure $^3D_1$ C	Pure $^3D_1$ $\Gamma(^3P_J)/\Gamma(^3P_0)$
$^3P_0$	338	1/9	1	2/9	1
$^3P_1$	250	1/3	1.22	1/6	0.30
$^3P_2$	208	5/9	1.16	1/90	0.012

$\to\bar{s}$ or $\bar{b}\to\bar{d}$ penguin amplitude [19,23–25], which appears to be needed in understanding large branching ratios for $B\to K\eta'$ [26] and $B\to K\pi$. Moreover, Suzuki [22] has proposed that this reannihilation, at least in ψ' decays, is associated with a large final-state phase. We discuss implications of this suggestion for CP violation in B decays in Sec. IV, while Sec. V concludes.

II. RADIATIVE ψ'' DECAYS

The relative branching ratios for radiative decays to χ_c (1^3P_1) states are very different for $2S$ and $1D$ states. The observation of radiative decays $\psi''\to\gamma+\chi_c$ can determine the degree to which the ψ'' is mixed with an *S*-wave state [5,7,13–15].

The rates for electric dipole ($E1$) transitions in quarkonium can be written

$$\Gamma=\tfrac{4}{3}e_Q^2\alpha\omega^3C\langle r\rangle^2, \tag{1}$$

where e_Q is the quark charge (in units of $|e|$), $\alpha=1/137.036$ is the fine-structure constant, ω is the photon energy, and $\langle r\rangle$ is the matrix element of r between initial and final radial wave functions. The coefficients C are summarized in Table II, where we compare relative rates for $E1$ transitions from ψ'' to χ_c states under the two extreme assumptions of a pure *S*-wave or a pure *D*-wave. The distinctive pattern associated with the pure $^3D_1$ configuration is a ratio $\mathcal{B}(\gamma+\chi_{c1})/\mathcal{B}(\gamma+\chi_{c0})=0.3$ and an almost complete suppression of the ratio $\mathcal{B}(\gamma+\chi_{c2})/\mathcal{B}(\gamma+\chi_{c0})$.

A more detailed model can be constructed by assuming that the ψ'' is a mixture of a 1^3D_1 and a 2^3S_1 state [15]

$$|\psi''\rangle=|1^3D_1\rangle\cos\phi+|2^3S_1\rangle\sin\phi,$$

$$|\psi'\rangle=-|1^3D_1\rangle\sin\phi+|2^3S_1\rangle\cos\phi. \tag{2}$$

The leptonic widths of ψ'' and ψ' are then [27]

$$\Gamma(\psi''\to e^+e^-)=\frac{4\alpha^2e_c^2}{M_{\psi''}^2}\left|\sin\phi R_{2S}(0)+\frac{5}{2\sqrt{2}m_c^2}\cos\phi R''_{1D}(0)\right|^2, \tag{3}$$

$$\Gamma(\psi'\to e^+e^-)=\frac{4\alpha^2e_c^2}{M_{\psi'}^2}\left|\cos\phi R_{2S}(0)-\frac{5}{2\sqrt{2}m_c^2}\sin\phi R''_{1D}(0)\right|^2, \tag{4}$$

where $e_c=2/3$, $R_{2S}(0)=(4\pi)^{1/2}\Psi_{2S}(0)$ is the radial $2S$ wave function at $r=0$, and $R''_{1D}(0)$ is the second derivative of the radial $2D$ wave function at the origin. The values $R_{2S}(0)=0.734\ \text{GeV}^{3/2}$ and $5R''_{1D}(0)/(2\sqrt{2}m_c^2)=0.095\ \text{GeV}^{3/2}$ were taken in Ref. [15]. Assuming a common QCD correction to ψ' and ψ'' leptonic widths, we then fit the ratio

$$\frac{M_{\psi''}^2\Gamma(\psi''\to e^+e^-)}{M_{\psi'}^2\Gamma(\psi'\to e^+e^-)}=\left|\frac{0.734\sin\phi+0.095\cos\phi}{0.734\cos\phi-0.095\sin\phi}\right|^2=0.128\pm0.023, \tag{5}$$

with solutions $\phi=(12\pm2)°$ or $\phi=-(27\pm2)°$. These values agree with those of Kuang and Yan [28], whose θ is the same as our $-\phi$. As they note, the smaller $-|\phi|$ solution is consistent with coupled-channel estimates [29,30] and with the ratio of ψ' and ψ'' partial widths to $J/\psi\pi\pi$.

A nonrelativistic calculation along the lines of Ref. [13] then yields the following predictions [15]:

$$\Gamma(\psi''\to\gamma\chi_{c0})=145\ \text{keV}\cos^2\phi(1.73+\tan\phi)^2, \tag{6}$$

$$\Gamma(\psi''\to\gamma\chi_{c1})=176\ \text{keV}\cos^2\phi(-0.87+\tan\phi)^2, \tag{7}$$

$$\Gamma(\psi''\to\gamma\chi_{c2})=167\ \text{keV}\cos^2\phi(0.17+\tan\phi)^2, \tag{8}$$

$$\Gamma(\psi'\to\gamma\chi_{c0})=67\ \text{keV}\cos^2\phi(1-1.73\tan\phi)^2, \tag{9}$$

$$\Gamma(\psi'\to\gamma\chi_{c1})=56\ \text{keV}\cos^2\phi(1+0.87\tan\phi)^2, \tag{10}$$

$$\Gamma(\psi'\to\gamma\chi_{c2})=39\ \text{keV}\cos^2\phi(1-0.17\tan\phi)^2. \tag{11}$$

Other predictions are given, for example, in Ref. [31]. Zhu has apparently neglected to take account of relative signs of *S*-wave and *D*-wave contributions in the first three of the above equations when presenting his results for mixed states (Fig. 1.6.2, Ref. [5]). For small ϕ, as suggested by the ψ' and ψ'' leptonic widths, the experimental rates for the ψ' radiative decays are about a factor of three below these predictions [9], probably as a result of relativistic corrections [12,32]. The ψ' decays are expected to be particularly sensitive to such corrections as a result of the node in the $2S$ wave function; it is possible that the ψ'' predictions could be more reliable, since neither the $1D$ nor $1P$ radial wave functions has a node.

Results for ψ'' radiative decays [5], for $\sigma(e^+e^-\to\psi'')\equiv\sigma(\psi'')=5.0\pm0.5$ nb, are

TABLE III. Total widths, branching ratios, and derived partial widths for J/ψ and ψ' decays.

Decay mode	J/ψ decays [9] $\Gamma_{tot}=87\pm5$ keV $\Gamma_{ee}=5.26\pm0.37$ keV		ψ' decays [33] $\Gamma_{tot}=277\pm31$ keV [9] $\Gamma_{ee}=2.12\pm0.18$ keV [9]		
	$\mathcal{B}$	Γ (keV)	$\mathcal{B}$	Γ (eV)	Γ_{pred}[a] (eV)
$\rho\pi$	$(1.27\pm0.09)\%$	1.10 ± 0.10	$<2.8\times10^{-5}$	<8.6	443 ± 63
$K^+K^{*-}(892)$[b]	$(0.50\pm0.04)\%$	0.44 ± 0.04	$<3.0\times10^{-5}$	<9.2	177 ± 24

[a]Based on prescription given in text.
[b]Plus c.c.

$$\Gamma(\psi''\to\gamma\chi_{c0})=510\pm190 \text{ keV}, \quad (12)$$

$$\Gamma(\psi''\to\gamma\chi_{c1})=440\pm160 \text{ keV}, \quad (13)$$

$$\Gamma(\psi''\to\gamma\chi_{c2})\leq520 \text{ keV } (90\% \text{ C.L.}). \quad (14)$$

These partial widths scale as $1/\sigma(\psi'')$. So far it does not seem possible to reconcile the central values of these results with the values of ϕ suggested earlier.[4] The model for mixing between ψ' and ψ'' may be oversimplified, and relativistic corrections undoubtedly play a role. Nevertheless, the above results bear revisiting with improved statistics. The search for a 338 MeV monochromatic photon in the decays of the ψ'' would represent a worthwhile first step in the determination of this interesting resonance's mixing parameters.

III. MISSING MODES OF THE ψ'

F. A. Harris [33] has summarized a wide class of hadronic decay modes of the ψ', measured by the BES Collaboration at the Beijing Electron-Positron Collider (BEPC), which appear to be suppressed relative to expectations. Of these the foremost is the $\rho\pi$ final state, with $K^+K^{*-}(892)+$c.c. in second place. Let us review the expectations and the data for these two modes. [The decay $\psi'\to K^0\bar{K}^{*0}(892)+$c.c. has been observed with a branching ratio of $(8.1\pm2.4\pm1.6)\times10^{-5}$ which indicates the contribution of a significant one-virtual-photon contribution [18,19,22], and we shall not discuss it further.]

We summarize in Table III the total widths, branching ratios, and derived partial widths for J/ψ and ψ' decays into $\rho\pi$ and $K^+\bar{K}^*(892)^-$, as well as the partial widths predicted for the ψ' decays to these final states. Both hadronic and leptonic decay rates are proportional to the square of the wave function at the origin $|\Psi(0)|^2$. Although one might expect an additional factor of $1/M_V^2$, where M_V is the mass of the decaying vector meson entering into the leptonic width, we shall ignore this effect, since it is probably offset by a (form) factor suppressing the hadronic decay of the higher-mass ψ' into low-multiplicity final states such as $\rho\pi$. Then we expect for any hadronic final state f [17,22,33],

$$\Gamma(\psi'\to f)=\Gamma(J/\psi\to f)\frac{\Gamma_{ee}(\psi')}{\Gamma_{ee}(J/\psi)}. \quad (15)$$

This relation has been used to predict the quantities Γ_{pred} in Table III. One sees that $\psi'\to\rho\pi$ is suppressed by a factor of at least ~50 with respect to naive expectations, while the corresponding factor for $K^+K^{*0}(892)+$c.c. is at least ~20.

Suzuki [22] has proposed that the coupling of ψ' to virtual pairs of charmed particles could provide an amplitude which interferes destructively with the perturbative QCD process $\psi'\to3g$ in the specific cases of $\rho\pi$ and $K\bar{K}^*(892)$ $+$c.c. hadronic decays. If this is the case, and if virtual charmed particle pairs also play a role in mixing ψ' and ψ'', we would expect a similar amplitude to contribute to $\psi''\to D^{(*)}\bar{D}^{(*)}\to\rho\pi$ or $K\bar{K}^*(892)+$c.c.

In the absence of a detailed coupled-channel analysis, let us assume that the main effect on ψ' and ψ'' of their mutual coupling to charmed particle pairs is precisely the mixing discussed in the previous section. Let us assume that this mixing and the couplings of ψ' and ψ'' to $\rho\pi$ and $K\bar{K}^*(892)+$c.c. are such as to cancel the ψ' hadronic widths to these final states [which are related to one another by flavor SU(3)]. In this case we have

$$\langle\rho\pi|\psi'\rangle=\langle\rho\pi|2^3S_1\rangle\cos\phi-\langle\rho\pi|1^3D_1\rangle\sin\phi=0,$$

$$\langle\rho\pi|\psi''\rangle=\langle\rho\pi|2^3S_1\rangle\sin\phi+\langle\rho\pi|1^3D_1\rangle\cos\phi$$
$$=\langle\rho\pi|2^3S_1\rangle/\sin\phi, \quad (16)$$

so that *the missing $\rho\pi$ (and related) decay modes of ψ' show up instead as decay modes of ψ'', enhanced by the factor of* $1/\sin^2\phi$. The possible effects of this enhancement are shown in Table IV for the two solutions for ϕ. One expects $\mathcal{B}(\psi''\to\rho\pi)\simeq10^{-4}$ for $\phi\simeq-27°$ and $\simeq4\times10^{-4}$ for the

TABLE IV. Predicted $\psi''\to\rho\pi$ partial widths and branching ratios for two solutions of mixing angle ϕ.

ϕ (°)	-27 ± 2	12 ± 2
$1/\sin^2\phi$	4.8 ± 0.6	22 ± 6
$\Gamma(\psi''\to\rho\pi)$ (keV)	2.1 ± 0.4	9.8 ± 3.0
$\mathcal{B}(\psi''\to\rho\pi)(10^{-4})$	0.9 ± 0.2	4.1 ± 1.4

[4]The solution with $\phi=12°$, favored by coupled-channel calculations [29,30], predicts $\Gamma(\psi''\to\gamma\chi_{c(0,1,2)})=(524,73,61)$ keV, implying that the χ_{c1} signal of Ref. [5] should not be confirmed.

favored value $\phi \simeq 12°$. Either branching ratio is compatible with the current upper bound $\mathcal{B}(\psi'' \to \rho\pi) < 1.3 \times 10^{-3} \times [5 \text{ nb}/\sigma(\psi'')]$ [5].

An alternative mechanism discussed by Suzuki [22] for introducing an additional nonperturbative ψ' decay amplitude is mixing with a vector glueball state (first discussed in the context of J/ψ decays [34]). In this case the ψ'' is permitted, but not required, to mix with the vector glueball, so there is no particular reason for the missing partial widths for ψ' decays to show up as corresponding ψ'' partial decay rates.

Gérard and Weyers [20] have proposed that the three-gluon decay of the ψ' is absent or suppressed, and that the ψ' decays to hadrons instead mainly via a two-step process involving an intermediate $c\bar{c}(^1P_1)$ state. Feldmann and Kroll [21] have proposed that the $J/\psi \to \rho\pi$ decay is *enhanced* (rather than $\psi' \to \rho\pi$ being suppressed) by mixing of the J/ψ with light-quark states, notably ω and ϕ. Both mechanisms do not imply any special role for ψ'' charmless decays. Arguments against them, based on data summarized in the last of Refs. [17] and in Ref. [33], include the appearance of certain unsuppressed light-quark decay modes of the ψ' and the lack of evidence for helicity suppression in J/ψ decays involving a single virtual photon.

As Suzuki has noted, the cases of suppressed hadronic final states of the ψ' cannot extend to all its decays; indeed, the total hadronic width of ψ' exceeds estimates based on extrapolating from the J/ψ using perturbative QCD by some 60–70 % [22,35]. The non-perturbative effect of coupling to virtual charmed particle pairs, followed by the re-annihilation of these pairs into non-charmed final states, must thus be responsible for some tens of keV of the total width of the ψ' in Suzuki's scheme.

A corresponding effect in the decays of the ψ'', which is about 85 times as wide as the ψ', would contribute at most a percent to its total width. Present searches for non-charmed decays of the ψ'' [5,6] are not sensitive enough to exclude this possibility since they did not compare on-resonance data with data taken off-resonance at a sufficiently close energy [36].

A related method allows one to estimate the partial decay rate of ψ'' to non-charmed final states. The branching ratio $\mathcal{B}(J/\psi \to \rho\pi)$ is $(1.27 \pm 0.09)\%$. Since about 1/3 of J/ψ decays can be ascribed to non-$3g$ mechanisms, we expect $\rho\pi$ to account for about 2% of all *hadronic* J/ψ decays, and thus no more than this percentage of ψ'' hadronic charmless decays. (The availability of more final states undoubtedly reduces the $\rho\pi$ fraction in comparison with J/ψ hadronic decays.) We thus estimate for hadronic charmless decays $\mathcal{B}(\psi'') \gtrsim 2 \times 10^{-4}/2\% \simeq 1\%$, again give or take a factor of 2 depending on the sign of ϕ. This is consistent with our previous estimate.

It is even possible that we have seriously underestimated the role of non-charmed final states in hadronic ψ'' decays. If so, there is a chance of reconciling the smaller cross section for $e^+e^- \to \psi''$ measured by the Mark III Collaboration using a comparison of single-charm and double-charm production, $\sigma(\psi'') = 5.0 \pm 0.5$ nb [3], with higher values obtained by other groups using direct measurement [37–40], whose average I find to be 8.0 ± 0.7 nb.[5] This possible discrepancy was a factor motivating the studies in Refs. [5,6]. Those and related searches need to be performed with greater sensitivity and with off-resonance running in order to determine backgrounds from such processes as $e^+e^- \to \gamma^* \to$ charmless hadrons. In any event, the search for the "missing final states" of the ψ' among the decay products of the ψ'' is a reasonable goal of foreseen studies [4].

IV. IMPLICATIONS FOR *B* DECAYS

A key observation in Ref. [22] with regard to the additional contribution to ψ' hadronic decays is that it is likely to have a large final-state phase, in order to interfere destructively with the pertubative $3g$ contribution in the $\rho\pi$ and $K\bar{K}^*(892)$ + c.c. channels. If this new contribution is due to rescattering into non-charmed final states through charmed particle pairs, it is exactly the type of contribution proposed in Refs. [19,23–25] in which the decay $\bar{b} \to \bar{c}c\bar{s}$ or $\bar{b} \to \bar{c}c\bar{d}$ contributes to a penguin amplitude with a large strong phase. Several implications of this possibility were reviewed in [19], and others have been pointed out in [24]. These include the following:

(1) The semileptonic branching ratio $\mathcal{B}(B \to X l \nu)$ can be diminished with respect to the theoretical prediction if the penguin amplitude leads to a net enhancement of $\bar{b} \to \bar{s}$ and $\bar{b} \to \bar{d}$ transitions. The enhancement need not be large enough to conflict with any experimental upper limits on such transitions, which are in the range of a few percent of all B decays [41].

(2) The number n_c of charmed particles per average B decay can be reduced by the reannihilation of $c\bar{c}$ to light quarks. The degree to which this improves agreement with experiment is a matter of some debate [42], since a recent SLD measurement [43] finds $n_c = 1.238 \pm 0.027 \pm 0.048 \pm 0.006$, closer to theoretical expectations than earlier values [44].

(3) The enhancement of the inclusive branching ratio $\mathcal{B}(B \to \eta' X)$ [45] in comparison with theoretical expectations [46] can be explained.

(4) The required additional contribution [26] to the exclusive branching ratios $\mathcal{B}(B \to K\eta')$ [45], in comparison with the penguin contribution leading to $B^0 \to K^+\pi^-$ or $B^+ \to K^0\pi^+$, can be generated.

(5) In any $B \to K\pi$ process in which the dominant penguin amplitude interferes with tree-amplitude contributions, notably in $B^+ \to \pi^0 K^+$ and $B^0 \to K^+\pi^-$, a CP-violating asymmetry can occur up to the maximum allowed by the ratio of the tree to penguin amplitudes' magnitudes. This asymmetry, estimated to be about 1/3 in Ref. [19], is not yet excluded by experiment [47]. The enhancement of the penguin amplitude by the intrinsically non-perturbative charm rescattering mechanism seems to fall outside the purview of the essentially perturbative approach of Ref. [48], so we would not

[5]The same average was found in [5] without the data of [40].

expect to encounter it in that treatment.

The charm rescattering model for suppression of $\psi' \to \rho\pi$ and related decays has no *a priori necessity* for the final state phase to be large [22]. Additional evidence for such a large final-state phase in closely related processes would be the presence of large direct CP-violating symmetries in $B^+ \to \pi^0 K^+$ and $B^0 \to K^+ \pi^-$, with similar expected asymmetries for the two processes [24,25,49,50]. Since the process $B^+ \to \pi^+ K^0$ is not expected to have a tree contribution, we expect it to have a much smaller CP-violating asymmetry. Present data [47] are consistent at the level of 10–20 % with vanishing asymmetry for all three processes:

$$\mathcal{A}(K^+\pi^-) = -0.04 \pm 0.16,$$

$$\mathcal{A}(K^+\pi^0) = -0.29 \pm 0.23, \quad \mathcal{A}(K_S\pi^+) = 0.18 \pm 0.24. \tag{17}$$

V. CONCLUSION

The coupling of ψ' and ψ'' to charmed particle pairs can lead to S- and D-wave mixing, the distortion of the relative branching ratios of the ψ'' to $\gamma + \chi_c$ final states, and the suppression of some decay modes of ψ' and their appearance instead in products of the ψ''. If ψ'' to $\gamma + \chi_{c2}$ is observed at a branching ratio level exceeding a couple of parts in 10^4, this will be evidence for S- and D-wave mixing, while the branching ratio for ψ'' to $\gamma + \chi_{c0}$ is expected to be a percent, give or take a factor of 2. A similar branching ratio is expected for *hadronic* charmless decays of ψ''. This picture provides a rationale for large observed $\bar{b} \to \bar{s}$ penguin amplitudes in B meson decays, and would be further supported by the observation of large direct CP-violating asymmetries in the decays $B^+ \to \pi^0 K^+$ and $B^0 \to K^+ \pi^-$.

Note added in proof. More stringent limits have now been presented, e.g., $\mathcal{A}(K^+\pi^-) = -00.7 \pm 0.08 \pm 0.02$ [51] and $\mathcal{A}(K^+\pi -{}^+K^+\pi^0$ combined) $= 0.003^{+0.142+0.017}_{-0.126-0.014}$ [52].

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