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JLAB-THY-97-36
RAL-97-036, HUTP97/A-040
FERMILAB-PUB-97/232-T
hep-ph/9708265

Gluonic Hadrons and Charmless B Decays

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Abstract

Hybrid charmonium with mass $\sim$4 GeV could be produced via a $c\bar{c}$ color-octet component in $b \to c\bar{c}s$. These states could be narrow and could have a significant branching ratio to light hadrons, perhaps enhanced by glueballs. Decays to gluonic hadrons could make a sizable contribution to $B \to$ no charm decays. Experimental signatures and search strategies are discussed.

PACS numbers: 13.20.He 13.25.Hw 14.40.Nd 12.39.Mk

3 Hybrid production

A variety of hybrid excitations can be produced in B decays.[3] The production of ψ_g may be significant since in the $b \to c\bar{c}s$ transition the $c\bar{c}$ pair is dominantly produced in colour octet [3, 11, 12] which may strongly couple to the $c\bar{c}$ pair in ψ_g.

The direct ψ production in b decays is $(0.82 \pm 0.08)\%$ [20], and is not well understood theoretically. It appears to be enhanced somewhat over estimates based on the assumption [21] of color-suppressed factorization [22, 23]. The factorization assumption allows for the direct decay $b \to s\,\chi_{c1}$ but not for $b \to s\,\{\chi_{c0}, \chi_{c2}, h_c\}$. Thus, decisive observations of such modes would either necessitate a non-factorizable (such as a direct color-octet) contribution [23] or a feed-down from higher mass metastable states [11], which are expected to cascade to other charmonia observed in B decays as well.

If we take the production of χ_{c2} as a measure of the colour octet production in B decays, we expect from the CLEO datum $Br(B \to \chi_{c2}X) = 0.0025 \pm 0.0010$ [20] that ψ_g should be produced competitively at $Br \geq 0.1\%$. The sum total of ψ_g for all J^{PC} could be $\mathcal{O}(1\%)$, a significant contribution to the "non-charm" B decays though not saturating them. If their production is to saturate these events, then their combined Br should be of $\mathcal{O}(10\%)$ and their preferred decays ought to be to light hadrons. If $Br(B \to \psi_g(\text{all } J^{PC})X) \sim \mathcal{O}(1\%)$, then $Br(\psi_g \to (c\bar{c})X) = \mathcal{O}(10 - 100\%)$ is still consistent with the measured $Br(B \to (c\bar{c}) + X)$. If ψ_g are produced at $\mathcal{O}(10\%)$, saturating the missing "non-charm" decays, then cascades to $(c\bar{c})$ must be a small fraction of the total. Unless some special mechanism causes ψ_g to cascade into h_c or other undetected conventional $(c\bar{c})$ states, the measurements on inclusive η_c, ψ or χ_c production constrain the product of branching ratios $Br(B \to \psi_g X) \times Br(\psi_g \to (c\bar{c})X)$.

[3]The production of hybrid D_g states [$\equiv c\bar{q}g$] could play a non-negligible role in non-leptonic and semi-leptonic B-decays; this contrasts with D or D_s decays where K_g or π_g may mix with the charmed mesons [17]. A moderate production of D_g in semi-leptonic B decays $\overline{B} \to c\bar{q}g + l\nu$ could solve the puzzle of why exclusive $\overline{B} \to (D, D^*, D^{**})l\nu$ transitions do not saturate the inclusive semi-leptonic branching ratio [18, 19].

We note that the $c\bar{c}$ invariant mass distribution for the quark-level $V - A$ transition $b \to c\bar{c}s$ peaks in the 3 – 3.7 GeV mass range [3]; such a process tends to be more inclusive at low $m_{c\bar{c}}$ and exclusive at large $m_{c\bar{c}}$, so we expect that exclusive $B \to \psi_g K^{(*)}$ will be favoured in the vicinity of 4 GeV. Quantitative estimates are model dependent and beyond the scope of this study.

4 Hybrid decays

An important feature of hybrid decays in at least flux-tube or bag models is that decays to two mesons with the same spatial wave function are suppressed. This selection rule [4] is expected to be broken for light flavours and less so for heavy flavours [5]. In the case of ψ_g, decays to $D^{(*)}D^{(*)}$ are suppressed and the sum of the widths is predicted to be $1 - 10$ MeV depending on J^{PC} of the hybrid [5]. The decays $1^{-+} \to \pi\pi$, $\eta^{(\prime)}\eta^{(\prime)}$ are also suppressed [24]. However, the dissimilar nature of η_c and $\eta^{(\prime)}$ suggests that the decay $1^{-+} \to \eta_c\eta^{(\prime)}$ should not be impeded sizably.

The above selection rule would be broken if the hybrid states mix with conventional excitations of $c\bar{c}$. Hybrid states with exotic J^{PC} are particularly interesting as they cannot mix with excited $c\bar{c}$ conventional states and, if below 4.3 GeV in mass, will feed $B \to K+$ "non-charm". States with conventional J^{PC} on the other hand can mix with excited states of the same J^{PC} and thereby "leak" into $D^{(*)}D^{(*)}$ final states. In particular it has been suggested [10, 25] that $\psi(4040)$ and $\psi(4160)$ are strong mixtures of $\psi_{3S}(4100)$ and $\psi_g(4100)$. In addition, hybrid charmonia may mix with glueballs. Such a mixing would enhance the production of light hadrons.

For those ψ_g that mix negligibly with conventional charmonia and have a mass of < 4.3 GeV, the prominent decays will be either by cascade $\psi_g[\equiv c\bar{c}g] \to (gg) + (\psi, \eta_c, \ldots)$ or by annihilation $\psi_g(C = +) \to (gg) \to$ light hadrons. These are at the same order in α_s. The decay $\psi_g \to$ light hadrons is expected to be favoured at least for $C = +$ states for the following reason.

A measure of the relative importance of the cascade width compared to the annihilation width may be provided by $\Gamma(\psi' \to \psi\pi\pi) \simeq \mathcal{O}(0.1 \text{ MeV})$ versus $\Gamma(\eta_c' \to$

charm content. Some decay modes of glueballs into light hadrons are summarized in the last column of Table 1. Predicted J^{PC} and masses of glueballs can be found in Table 2.

There is also the possibility for the K system to resonate as K_g. The lightest of these states is predicted to occur ~ 2 GeV in mass [7, 17] which leaves $\lesssim 3$ GeV available for the mass of the $c\bar{c}$ system. Excitation of K_g is therefore likely only with low mass charmonia (such as ψ, η_c) or with $(\eta^{(\prime)}, \omega, \rho, \ldots)$ if they contain $c\bar{c}$ [26, 29], or with light hadrons. A search for $B \to K_g \eta^{(\prime)}$ could be interesting, in light of the large $B \to K\eta'$.

We note that vertex detectors can utilize the long lifetime of B and D hadrons to reduce backgrounds, and the excellent $p/K/\pi$ separation capabilities at B-facilities will further improve the sensitivities. Full exploration of multibody decays of b-hadrons will require the ability to detect $\pi^0, \eta^{(\prime)}, \gamma$ as well.

6 Conclusions

B decays are a fertile ground for searching and discovering gluonic hadrons, including hybrid charmonia which may be copiously produced in the process $b \to c\bar{c}s$. Some of them may significantly decay to light hadrons contributing to B decays to final states without charm. We have studied the patterns of production and decay of such hybrids, and proposed experimental search strategies.

Acknowledgements

We are grateful to J. Kuti for discussions. PRP acknowledges a Lindemann Fellowship from the English Speaking Union. This work was supported in part by the U.S. Department of Energy under Contract No. DE-AC02-76CH03000.

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Table 1: Some possible experimentally accessible final states of J^{PC} exotic charmed hybrids and glueballs below $D^{**}D$ threshold. Note that open charm modes of ψ_g may be suppressed by a selection rule [4]. For hidden charm modes, the charmonia tend to have the same C as that of the parent ψ_g. The light hadron modes are expected to be enhanced for ψ_g with $C=+$. See the main text for details. Decays to $p\bar{p}\{\pi,\eta^{(\prime)},\omega,\rho,\phi\}$ are allowed for all states listed.

J^{PC}	Open charm	Hidden charm	Light hadrons
0^{+-}	Quantum numbers forbid $D^{(*)}D^{(*)}$	$J/\psi\{f_{\{0,1,2\}},(\pi\pi)_S\}$ $h_c\eta;\ \eta_c h_1$ $\chi_{c0}\omega$ $\chi_{c\{1,2\}}\{\omega,h_1,\gamma\}$	$a_{\{0,1,2\}}\rho;\ a_{\{1,2\}}\{b_1,\gamma\}$ $b_1\pi;\ h_1\eta^{(\prime)}$ $\{(\pi\pi)_S,f_0\}\{\omega,\phi\}$ $f_{\{1,2\}}\{\omega,h_1,\phi,\gamma\}$
0^{--}	D^*D	$h_c(\pi\pi)_S$ $J/\psi\{f_{\{1,2\}},\eta^{(\prime)}\}$ $\chi_{c0}h_1;\ \eta_c\{\omega,\phi\}$ $\chi_{c\{1,2\}}\{\omega,h_1,\gamma\}$	$a_{\{0,1,2\}}b_1;\ a_{\{1,2\}}\{\rho,\gamma\}$ $\rho\pi$ $f_0h_1;\ \eta^{(\prime)}\{\omega,\phi\}$ $f_{\{1,2\}}\{\omega,h_1,\phi,\gamma\}$
1^{-+}	D^*D, D^*D^*	$\chi_{c\{0,1,2\}}(\pi\pi)_S$ $\eta_c\{f_{\{1,2\}},\eta^{(\prime)}\}$ $\chi_{c\{1,2\}}\eta$ $\{h_c,J/\psi\}\{\omega,h_1,\phi,\gamma\}$	$a_{\{0,1,2\}}a_{\{0,1,2\}};\ a_{\{1,2\}}\pi$ $f_{\{0,1,2\}}f_{\{0,1,2\}};\ f_{\{1,2\}}\eta^{(\prime)}$ $\{\rho,\gamma\}\{\rho,b_1\};\ b_1b_1$ $\{\omega,h_1,\phi,\gamma\}\{\omega,h_1,\phi,\gamma\}$
2^{+-}	D^*D, D^*D^*	$\{h_c,J/\psi\}\{f_{\{0,1,2\}},(\pi\pi)_S\}$ $\{h_c,J/\psi\}\eta^{(\prime)}$ $\{\eta_c,\chi_{c\{0,1,2\}}\}\{\omega,h_1,\phi,\gamma\}$	$a_{\{0,1,2\}}\{\rho,b_1,\gamma\}$ $\{\rho,\gamma,b_1\}\pi$ $\{\eta^{(\prime)},f_{\{0,1,2\}}\}\{\omega,h_1,\phi,\gamma\}$

Table 2: Glueball masses in GeV in the $3-4.5$ GeV mass range accessed by $B\to K^{(*)}$+glueball, according to lattice gauge theory [30]. The 0^{--} glueball mass is poorly determined. No J^{PC} exotic glueballs are expected below 3 GeV.

J^{PC}	1^{+-}	2^{-+}	3^{++}	1^{++}	2^{--}	1^{--}
Mass	2.9 ± 0.3	3.0 ± 0.2	3.9 ± 0.5	4.0 ± 0.3	4.0 ± 0.4	4.6 ± 0.5
J^{PC}	1^{-+}	0^{+-}	2^{+-}			
Mass	$\lesssim 4.1$	$\lesssim 3.7$	3.9 ± 0.7			