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Nonleptonic B decays to radially excited charmless mesons

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Outline

1. Introduction.

2. Framework.

3. Branching ratios.

4. CP violating asymmetries.

5. Conclusions.

1. Introduction.

CKM matrix, four parameters.
Unitary matrix
Universality of weak interactions

$$\lambda = 0.2257^{+0.0009}_{-0.0010}, \qquad A = 0.814^{+0.021}_{-0.022}$$
$$\bar{\rho} = 0.135^{+0.031}_{-0.016}, \qquad \bar{\eta} = 0.349^{+0.015}_{-0.017}$$

$B^0 \to \text{charmonium } K^0_{S,L}$

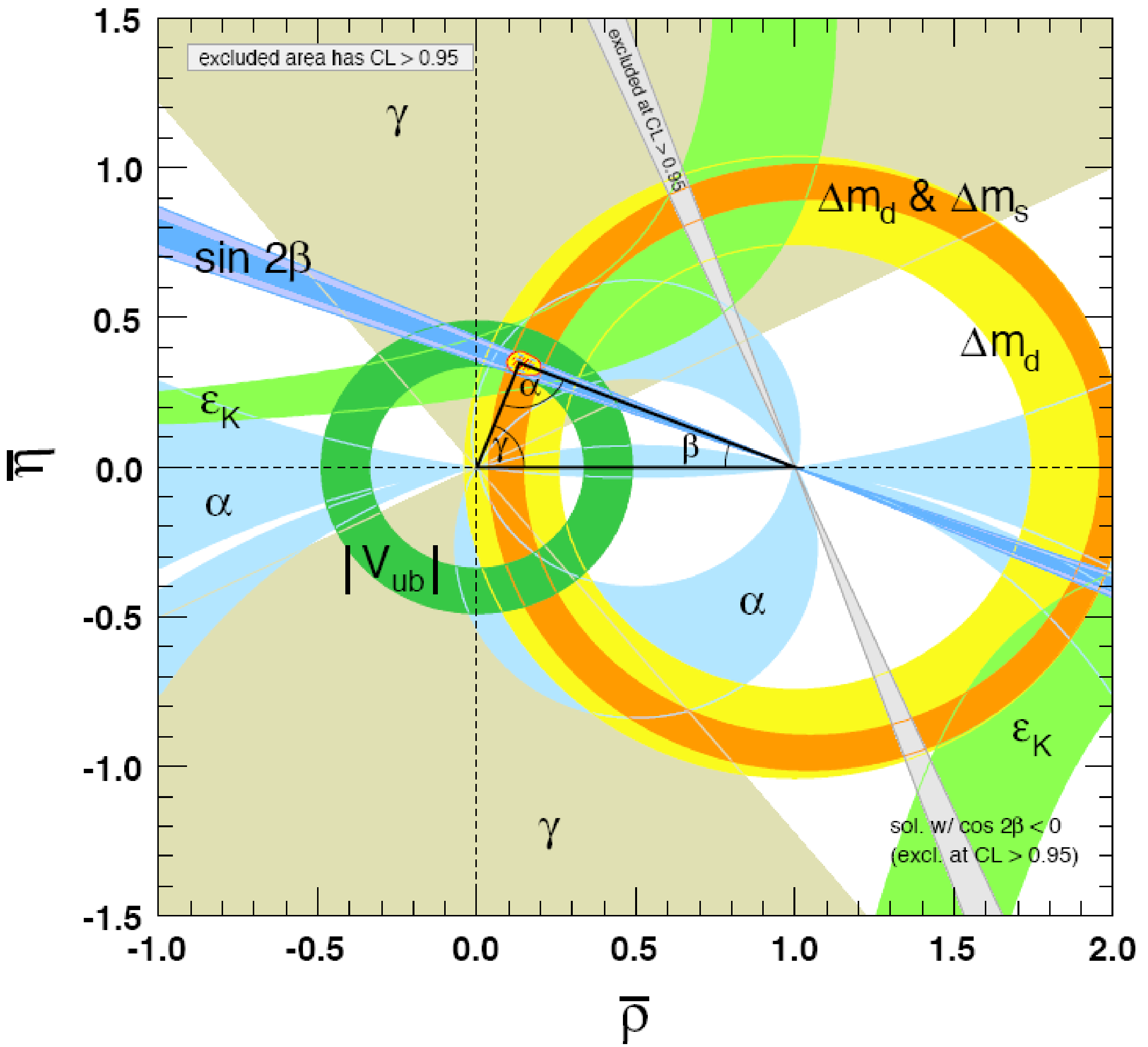
$\sin 2\beta = 0.681 \pm 0.025$

$B \to \pi\pi$

$$S_{\pi^+\pi^-} = -0.61 \pm 0.08, \qquad \alpha = (88^{+6}_{-5})^\circ$$

$$C_{\pi^+\pi^-} = -0.38 \pm 0.07$$

$B^\pm \to DK^\pm$ $\qquad \gamma = (77^{+30}_{-32})^\circ$



Observables:
Branching ratios
CP violation asymmetries

To test:
Approximations
Models
Parameters in the Standard Model

Quark model of mesons $q\bar{q}'$

Orbital angular momentum l, and Spin J $n^{2s+1}l_J$

Spectroscopic notation

Ground states
Angular excitations
Radial excitations

Pseudoscalars and Vectors have orbital angular momentum l = 0.
Scalars, Axial and Tensors, l = 1.
Radial excitations are denoted by principal quantum numbre n = 2.

$\pi(1300) \quad 2^1S_0$

$\rho(1450) \quad 2^3S_1$

$B \to P\pi', B \to V\pi'$ $\quad\quad \pi, \eta^{(\prime)}$ and K $\quad\quad \rho, \omega, K^*$ and ϕ

$B \to P\rho' \quad B \to V\rho'$

Alternative channels. Over constrain parameters.

$n\,^{2s+1}\ell_J$	J^{PC}	I = 1 $u\bar{d}$, $\bar{u}d$, $\frac{1}{\sqrt{2}}(d\bar{d}-u\bar{u})$	I = $\frac{1}{2}$ $u\bar{s}$, $d\bar{s}$; $\bar{d}s$, $-\bar{u}s$	I = 0 f'	I = 0 f	θ_{quad} [°]	θ_{lin} [°]
$1\,^1S_0$	0^{-+}	**π**	**K**	**η**	**$\eta'(958)$**	−11.5	−24.6
$1\,^3S_1$	1^{--}	**$\rho(770)$**	**$K^*(892)$**	**$\phi(1020)$**	**$\omega(782)$**	38.7	36.0
$1\,^1P_1$	1^{+-}	**$b_1(1235)$**	**$K_{1B}{}^\dagger$**	$h_1(1380)$	**$h_1(1170)$**		
$1\,^3P_0$	0^{++}	**$a_0(1450)$**	**$K_0^*(1430)$**	**$f_0(1710)$**	**$f_0(1370)$**		
$1\,^3P_1$	1^{++}	**$a_1(1260)$**	**$K_{1A}{}^\dagger$**	**$f_1(1420)$**	**$f_1(1285)$**		
$1\,^3P_2$	2^{++}	**$a_2(1320)$**	**$K_2^*(1430)$**	**$f_2'(1525)$**	**$f_2(1270)$**	29.6	28.0
$1\,^1D_2$	2^{-+}	**$\pi_2(1670)$**	**$K_2(1770)^\dagger$**	$\eta_2(1870)$	**$\eta_2(1645)$**		
$1\,^3D_1$	1^{--}	**$\rho(1700)$**	**$K^*(1680)$**		**$\omega(1650)$**		
$1\,^3D_2$	2^{--}		**$K_2(1820)$**				
$1\,^3D_3$	3^{--}	**$\rho_3(1690)$**	**$K_3^*(1780)$**	**$\phi_3(1850)$**	**$\omega_3(1670)$**	32.0	31.0
$1\,^3F_4$	4^{++}	**$a_4(2040)$**	**$K_4^*(2045)$**		**$f_4(2050)$**		
$1\,^3G_5$	5^{--}	$\rho_5(2350)$					
$1\,^3H_6$	6^{++}	$a_6(2450)$			$f_6(2510)$		
$2\,^1S_0$	0^{-+}	**$\pi(1300)$**	$K(1460)$	**$\eta(1475)$**	**$\eta(1295)$**		
$2\,^3S_1$	1^{--}	**$\rho(1450)$**	**$K^*(1410)$**	**$\phi(1680)$**	**$\omega(1420)$**		

$n\,^{2s+1}\ell_J$	J^{PC}	I = 0 $c\bar{c}$	I = 0 $b\bar{b}$	I = $\frac{1}{2}$ $c\bar{u}$, $c\bar{d}$; $\bar{c}u$, $\bar{c}d$	I = 0 $c\bar{s}$; $\bar{c}s$	I = $\frac{1}{2}$ $b\bar{u}$, $b\bar{d}$; $\bar{b}u$, $\bar{b}d$	I = 0 $b\bar{s}$; $\bar{b}s$	I = 0 $b\bar{c}$; $\bar{b}c$
$1\,^1S_0$	0^{-+}	$\boldsymbol{\eta_c(1S)}$	$\eta_b(1S)$	$\boldsymbol{D}$	$\boldsymbol{D_s^{\pm}}$	$\boldsymbol{B}$	$\boldsymbol{B_s^0}$	$\boldsymbol{B_c^{\pm}}$
$1\,^3S_1$	1^{--}	$\boldsymbol{J/\psi(1S)}$	$\boldsymbol{\Upsilon(1S)}$	$\boldsymbol{D^*}$	$\boldsymbol{D_s^{*\pm}}$	$\boldsymbol{B^*}$	B_s^*	
$1\,^1P_1$	1^{+-}	$h_c(1P)$		$\boldsymbol{D_1(2420)}$	$\boldsymbol{D_{s1}(2536)^{\pm}}$			
$1\,^3P_0$	0^{++}	$\boldsymbol{\chi_{c0}(1P)}$	$\boldsymbol{\chi_{b0}(1P)}$	$D_0^*(2400)$	$\boldsymbol{D_{s0}^*(2317)^{\pm\dagger}}$			
$1\,^3P_1$	1^{++}	$\boldsymbol{\chi_{c1}(1P)}$	$\boldsymbol{\chi_{b1}(1P)}$		$\boldsymbol{D_{s1}(2460)^{\pm\dagger}}$			
$1\,^3P_2$	2^{++}	$\boldsymbol{\chi_{c2}(1P)}$	$\boldsymbol{\chi_{b2}(1P)}$	$\boldsymbol{D_2^*(2460)}$	$\boldsymbol{D_{s2}(2573)^{\pm}}$			
$1\,^3D_1$	1^{--}	$\boldsymbol{\psi(3770)}$						
$2\,^1S_0$	0^{-+}	$\boldsymbol{\eta_c(2S)}$						
$2\,^3S_1$	1^{--}	$\boldsymbol{\psi(2S)}$	$\boldsymbol{\Upsilon(2S)}$					
$2\,^3P_{0,1,2}$	$0^{++}, 1^{++}, 2^{++}$		$\boldsymbol{\chi_{b0,1,2}(2P)}$					

2. Framework.

Effective weak Hamiltonian: OPE and RG

$$H_{eff} = \frac{G_F}{\sqrt{2}}\left[\sum_{j=u,c} V_{jb}V_{jq}^{*}\left(C_1(\mu)O_1^j(\mu)+C_2(\mu)O_2^j(\mu)\right) - V_{tb}V_{tq}^{*}\left(\sum_{i=3}^{10} C_i(\mu)O_i(\mu)\right)\right] + H.c.$$

For $\Delta B = 1$ transitions,

$$C_1=1.117, \quad C_2=-0.257,$$
$$C_3=0.017, \quad C_4=-0.044,$$
$$C_5=0.011, \quad C_6=-0.056,$$
$$C_7=-1\times 10^{-5}, \quad C_8=5\times 10^{-4},$$
$$C_9=-0.010, \quad C_{10}=0.002,$$

$$\begin{aligned}
O_1^j &= \bar{q}_\alpha \gamma^\mu L u_\alpha \cdot \bar{u}_\beta \gamma_\mu L b_\beta \\
O_2^j &= \bar{q}_\alpha \gamma^\mu L u_\beta \cdot \bar{u}_\beta \gamma_\mu L b_\alpha \\
O_{3(5)} &= \bar{q}_\alpha \gamma^\mu L b_\alpha \cdot \sum_{q'} \bar{q}'_\beta \gamma_\mu L(R) q'_\beta \\
O_{4(6)} &= \bar{q}_\alpha \gamma^\mu L b_\beta \cdot \sum_{q'} \bar{q}'_\beta \gamma_\mu L(R) q'_\alpha \\
O_{7(9)} &= \frac{3}{2}\bar{q}_\alpha \gamma^\mu L b_\alpha \cdot \sum_{q'} e_{q'} \bar{q}'_\beta \gamma_\mu R(L) q'_\beta \\
O_{8(10)} &= \frac{3}{2}\bar{q}_\alpha \gamma^\mu L b_\beta \cdot \sum_{q'} e_{q'} \bar{q}'_\beta \gamma_\mu R(L) q'_\alpha
\end{aligned}$$

Nonleptonic two body B decays

$$\mathcal{M}(B \to M_1 M_2) = \langle M_1 M_2 | H_{eff} | B \rangle = \frac{G_F}{\sqrt{2}} \sum_i C_i(\mu) \langle O_i(\mu) \rangle$$

Amplitude probability

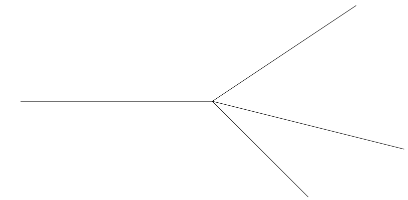
Matrix element $\langle M_1 M_2 | O_i(\mu) | B \rangle$

$$\langle P_1 \; P_2 | \mathcal{H}_{eff} | B \rangle = Z_1 \langle P_1 | j^\mu | 0 \rangle \langle P_2 | j_\mu | B \rangle$$

Naïve factorization: NO CP violation

Factorization in semileptonic decays

$M_1 \to M_2 l \nu$



$$\begin{aligned}\mathcal{M}(M_1 \to M_2\ l\ \nu) &= \langle M_2\ l\ \nu|\mathcal{H}_{eff}^{semi}|M_1\rangle \\ &= \frac{G_F}{\sqrt{2}}\ V_{12}\ \overline{u}_\nu \gamma^\mu (1-\gamma_5) u_l\ \langle M_2|\overline{q}_2\ \gamma_\mu (1-\gamma_5) q_1|M_1\rangle\end{aligned}$$

$$\langle M_2|\overline{q}_2 \gamma_\mu (1-\gamma_5) q_1|M_1\rangle$$

Factorization in nonleptonic decays

$$\langle M_1 M_2|O_i(\mu)|B\rangle$$

$B \to D\pi$

$$\begin{aligned}\mathcal{M} &\propto \langle D^+\pi^-|(\overline{c}b)_{V-A}(\overline{d}u)_{V-A}|\overline{B}\rangle \\ &\to \langle \pi^-|(\overline{d}u)_{V-A}|0\rangle\langle D^+|(\overline{c}b)_{V-A}|\overline{B}\rangle \\ &= f_\pi\ p_\pi^\mu\ \{f_+(p_B+p_D)_\mu + f_-(p_B-p_D)_\mu\}\end{aligned}$$

Approximation

Generalized naïve factorization

$$\sum_i C_i(\mu)\langle O_i(\mu)\rangle = \sum_i C_i(\mu) g_i(\mu)\langle O_i\rangle_{tree} = \sum_i c_i^{eff}\langle O_i\rangle_{tree}$$

$$a_i \equiv c_i^{eff} + \frac{1}{N_c} c_{i+1}^{eff} \ (i = odd)$$
$$a_i \equiv c_i^{eff} + \frac{1}{N_c} c_{i-1}^{eff} \ (i = even)$$

c_i^{eff}	$b \to d$	$b \to s$
c_1^{eff}	1.1680	1.1680
ac_2^{eff}	-0.3652	-0.3652
c_3^{eff}	0.0231 + i 0.0038	0.0233 + i 0.0043
c_4^{eff}	-0.0477 - i 0.0113	-0.0482 - i 0.0129
c_5^{eff}	0.0139 + i 0.0038	0.0140 + i 0.0043
c_6^{eff}	-0.0499 - i 0.0113	-0.0503 - i 0.0129
c_7^{eff}/α	-0.0303 - i 0.0326	-0.0311 - i 0.0356
c_8^{eff}/α	0.0551	0.0551
c_9^{eff}/α	-1.4268 - i 0.0326	-1.4276 - i 0.0356
c_{10}^{eff}/α	0.4804	0.4804

a_i	$b \to d$	$b \to s$
a_1	1.046	1.046
a_2	0.024	0.024
a_3	72	72
a_4	-400 - i 101	-404 - i 114
a_5	-28	-28
a_6	-453 - i 101	-457 - i 114
a_7	-0.87 - i 2.38	-0.93 - i 2.60
a_8	3.28 - i 0.79	3.26 - i 0.87
a_9	-92.5 - i 2.38	-92.5 - i 2.60
a_{10}	0.35 - i 0.79	0.33 - i 0.87

$$\langle P(p_P)|V_\mu|B(p_B)\rangle \equiv \left[(p_B+p_P)_\mu - \frac{m_B^2-m_P^2}{q^2}\, q_\mu\right]F_1(q^2) + \left[\frac{m_B^2-m_P^2}{q^2}\right]q_\mu F_0(q^2)$$

$$\langle V(p_V,\epsilon)|(V_\mu - A_\mu)|B(p_B)\rangle \equiv -\epsilon_{\mu\nu\alpha\beta}\epsilon^{\nu *} p_B^\alpha p_V^\beta \frac{2V(q^2)}{(m_B+m_V)} - i\left[\left(\epsilon_\mu^* - \frac{\epsilon^*\cdot q}{q^2}q_\mu\right)(m_B+m_V)A_1(q^2)\right.$$
$$\left. - \left((p_B+p_V)_\mu - \frac{(m_B^2-m_V^2)}{q^2}q_\mu\right)(\epsilon^*\cdot q)\frac{A_2(q^2)}{(m_B+m_V)} + \frac{2m_V(\epsilon^*\cdot q)}{q^2}q_\mu A_0(q^2)\right]$$

$$f(q^2) = \frac{f(0)}{(1-q^2/m_*^2)}$$

Bauer-Stech-Wirbel (WSB) Light-Cone-Sume-Rule (LCSR)

Transition	$F_1 = F_0$	V	A_1	A_2	A_0
$B \to \pi$	0.333 [0.258]				
$B \to K$	0.379 [0.331]				
$B \to \eta$	0.168 [0.275]				
$B \to \eta'$	0.114 [-]				
$B \to \rho$		0.329 [0.323]	0.283 [0.242]	0.283 [0.221]	0.281 [0.303]
$B \to \omega$		0.232 [0.311]	0.199 [0.233]	0.199 [0.181]	0.198 [0.363]
$B \to K^*$		0.369 [0.293]	0.328 [0.219]	0.331 [0.198]	0.321 [0.281]

$f_\pi = 130$ MeV

$f_\rho = 212$ MeV

$f_{\pi'} = 26$ MeV

$f_{\rho'} = 128$ MeV

Isgur-Scora-Grinstein-Wise (ISGW)

Transition	$F_1 = F_0$	V	A_1	A_2	A_0
$B \to \pi'$	0.25				
$B \to \rho'$		0.456	0.118	-0.118	0.397

Amplitudes:

$B \to P\pi'$

$$\mathcal{M}(\bar{B}^0 \to \pi^-\pi'^+) = -i\frac{G_F}{\sqrt{2}} f_{\pi'} F_0^{B\to\pi}(m_{\pi'}^2)(m_B^2 - m_\pi^2)$$
$$\left\{V_{ub}V_{ud}^* a_1 - V_{tb}V_{td}^* \left[a_4 + a_{10} + 2(a_6 + a_8)\frac{m_{\pi'}^2}{(m_b - m_u)(m_d + m_u)}\right]\right\}$$

$$\mathcal{M}(\bar{B}^0 \to \pi^0\pi'^0) = i\frac{G_F}{\sqrt{2}} f_\pi F_0^{B\to\pi'}(m_\pi^2)(m_B^2 - m_{\pi'}^2)$$
$$\left\{V_{ub}V_{ud}^* a_2 - V_{tb}V_{td}^* \left[-a_4 + \frac{1}{2}a_{10} - \frac{3}{2}(a_7 - a_9) - (2a_6 - a_8)\frac{m_\pi^2}{(m_b - m_d)(m_d + m_d)}\right]\right\}$$
$$+i\frac{G_F}{\sqrt{2}} f_{\pi'} F_0^{B\to\pi}(m_{\pi'}^2)(m_B^2 - m_\pi^2)$$
$$\left\{V_{ub}V_{ud}^* a_2 - V_{tb}V_{td}^* \left[-a_4 + \frac{1}{2}a_{10} - \frac{3}{2}(a_7 - a_9) - (2a_6 - a_8)\frac{m_{\pi'}^2}{(m_b - m_d)(m_d + m_d)}\right]\right\}$$

$$\mathcal{M}(B^- \to \pi^-\pi'^0) = -i\frac{G_F}{\sqrt{2}} f_\pi F_0^{B\to\pi'}(m_\pi^2)(m_B^2 - m_{\pi'}^2)\left\{V_{ub}V_{ud}^* a_1\right\}$$
$$-i\frac{G_F}{\sqrt{2}} f_{\pi'} F_0^{B\to\pi}(m_{\pi'}^2)(m_B^2 - m_\pi^2)$$
$$\left\{V_{ub}V_{ud}^* a_2 - V_{tb}V_{td}^* \frac{3}{2}\left[a_9 + a_{10} - a_7 + 2a_8\frac{m_{\pi'}^2}{(m_b - m_u)(m_d + m_u)}\right]\right\}$$

$B \to V\pi'$

$$\mathcal{M}(\bar{B}^0 \to \rho^- \pi'^+) = \sqrt{2} G_F f_\rho F_1^{B\to\pi'}(m_\rho^2) m_\rho (\epsilon \cdot p_{\pi'}) \left\{ V_{ub}V_{ud}^* a_1 - V_{tb}V_{td}^* [a_4 + a_{10}] \right\}$$

$$\begin{aligned}\mathcal{M}(\bar{B}^0 \to \rho^+ \pi'^-) &= \sqrt{2} G_F f_{\pi'} A_0^{B\to\rho}(m_{\pi'}^2) m_\rho (\epsilon \cdot p_{\pi'}) \\ &\left\{ V_{ub}V_{ud}^* a_1 - V_{tb}V_{td}^* \left[a_4 + a_{10} - 2(a_6 + a_8) \frac{m_{\pi'}^2}{(m_b + m_u)(m_u + m_d)} \right] \right\}\end{aligned}$$

$B \to V\rho'$

$$\mathcal{M}(\bar{B}^0 \to \rho^- \rho'^+) = X^{(\bar{B}^0 \rho'^+, \rho^-)} \left\{ V_{ub}V_{ud}^* a_1 - V_{tb}V_{td}^* [a_4 + a_{10}] \right\}$$

$$\mathcal{M}(\bar{B}^0 \to \rho^0 \rho'^0) = \left[X^{(\bar{B}^0 \rho^0, \rho'^0)} + X^{(\bar{B}^0 \rho'^0, \rho^0)} \right] \left\{ V_{ub}V_{ud}^* a_2 + V_{tb}V_{td}^* \left[a_4 - \frac{1}{2} a_{10} - \frac{3}{2}(a_7 + a_9) \right] \right\}$$

$$\mathcal{M}(B^- \to \rho^- \rho'^0) = X^{(B^- \rho^-, \rho'^0)} \left\{ V_{ub}V_{ud}^* a_2 \right\} + X^{(B^- \rho'^0, \rho^-)} \left\{ V_{ub}V_{ud}^* a_1 - V_{tb}V_{td}^* \frac{3}{2}(a_7 + a_9 + a_{10}) \right\}$$

$$\begin{aligned}X^{B\rho', V} &= \langle V | (\bar{q}_3 q_2)_{V-A} | 0 \rangle \langle \rho' | (\bar{q}_1 b)_{V-A} | B \rangle \\ &= -i f_V m_V \left[(\epsilon_V^* \cdot \epsilon_{\rho'}^*)(m_B + m_{\rho'}) A_1^{B\rho'}(m_V^2) - (\epsilon_V^* \cdot p_B)(\epsilon_{\rho'}^* \cdot p_B) \frac{2A_2^{B\rho'}(m_V^2)}{(m_B + m_{\rho'})} + i\epsilon_{\mu\nu\alpha\beta} \epsilon_V^\mu \epsilon_{\rho'}^\nu p_B^\alpha p_{\rho'}^\beta \frac{2V^{B\rho'}(m_V^2)}{(m_B + m_{\rho'})} \right]\end{aligned}$$

3. Branching ratios.

B -> PP, PV, VV

$$\Gamma(B\to P\pi') = \frac{\lambda^{1/2}(m_B^2, m_P^2, m_{\pi'}^2)}{16\pi\, m_B^3}|\mathcal{M}(B\to P\pi')|^2,$$

$$|\epsilon_V\cdot p_{\pi'}|^2 = \frac{\lambda(m_B^2, m_P^2, m_{\pi'}^2)}{4m_V^2}$$

Branching ratios in unit 10^-6:

Process	B	Process	B
$\bar{B}^0\to\pi^+\pi'^-$	5.3	$\bar{B}^0\to\rho^-\pi'^+$	13.9
$\bar{B}^0\to\pi^-\pi'^+$	39.4	$\bar{B}^0\to\rho^+\pi'^-$	24.4
$\bar{B}^0\to\pi^0\pi'^0$	6.8	$\bar{B}^0\to\rho^0\pi'^0$	2.8
$B^-\to\pi^-\pi'^0$	6.0	$B^-\to\rho^0\pi'^-$	14.6
$B^-\to\pi^0\pi'^-$	0.47	$B^-\to\rho^-\pi'^0$	16.97
$\bar{B}^0\to\eta\pi'^0$	4.2	$\bar{B}^0\to\omega\pi'^0$	7.03
$B^-\to\eta\pi'^-$	14.2	$B^-\to\omega\pi'^-$	10.95
$\bar{B}^0\to\eta'\pi'^0$	2.3	$\bar{B}^0\to K^{*-}\pi'^+$	3.9
$B^-\to\eta'\pi'^-$	8.1	$\bar{B}^0\to K^{*0}\pi'^0$	0.76
$\bar{B}^0\to K^-\pi'^+$	7.4	$B^-\to K^{*-}\pi'^0$	2.3
$\bar{B}^0\to K^0\pi'^0$	4.0	$B^-\to\bar{K}^{*0}\pi'^-$	3.6
$B^-\to K^-\pi'^0$	4.3	$\bar{B}^0\to\phi\pi'^0$	0.004
$B^-\to\bar{K}^0\pi'^-$	7.9	$B^-\to\phi\pi'^-$	0.008

Process	B	Process	B
$\bar{B}^0\to\pi^+\rho'^-$	9.9	$\bar{B}^0\to\rho^-\rho'^+$	36.8
$\bar{B}^0\to\pi^-\rho'^+$	13.1	$\bar{B}^0\to\rho^+\rho'^-$	28.3
$\bar{B}^0\to\pi^0\rho'^0$	0.24	$\bar{B}^0\to\rho^0\rho'^0$	0.04
$B^-\to\pi^0\rho'^-$	7.0	$B^-\to\rho^0\rho'^-$	20.1
$B^-\to\pi^-\rho'^0$	6.2	$B^-\to\rho^-\rho'^0$	7.8
$\bar{B}^0\to\eta\rho'^0$	0.012	$\bar{B}^0\to\omega\rho'^0$	0.03
$B^-\to\eta\rho'^-$	3.2	$B^-\to\omega\rho'^-$	3.4
$\bar{B}^0\to\eta'\rho'^0$	0.046	$\bar{B}^0\to K^{*-}\rho'^+$	10.2
$B^-\to\eta'\rho'^-$	1.97	$\bar{B}^0\to K^{*0}\rho'^0$	6.6
$\bar{B}^0\to K^-\rho'^+$	1.3	$B^-\to K^{*-}\rho'^0$	7.5
$\bar{B}^0\to K^0\rho'^0$	0.13	$B^-\to\bar{K}^{*0}\rho'^-$	9.5
$B^-\to K^-\rho'^0$	0.74	$\bar{B}^0\to\phi\rho'^0$	0.01
$B^-\to\bar{K}^0\rho'^-$	0.013	$B^-\to\phi\rho'^-$	0.02

Experimental branching ratios measured, PDG2008.

Process	B
$\bar{B}^0 \to \pi^+\pi^-$	5.13 ± 0.24
$\bar{B}^0 \to \pi^0\pi^0$	1.62 ± 0.31
$\bar{B}^- \to \pi^0\pi^-$	5.7 ± 0.5
$\bar{B}^0 \to K^0\pi^0$	9.8 ± 0.6
$\bar{B}^0 \to K^-\pi^+$	19.4 ± 0.6
$B^- \to \bar{K}^0\pi^+$	23.1 ± 1.0
$B^- \to K^-\pi^0$	12.9 ± 0.6
$B^- \to a_1^+\bar{K}^0$	30.5 ± 7
$\bar{B}^0 \to a_1^-K^+$	16 ± 4

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Nonleptonic two-body *B* decays including axial-vector mesons in the final state

4. CP violating asymmetries.

Charged and neutral B decays:
Direct CP violation.
In the Mixing.
Interfering in Mixing and Direct.

$$A_{CP} = \frac{\Gamma(B^+ \to f^+) - \Gamma(B^- \to f^-)}{\Gamma(B^+ \to f^+) + \Gamma(B^- \to f^-)}$$

$$\mathcal{M} = V_{ub} V_{uq}^* T - V_{tb} V_{tq}^* P$$

$$\mathcal{M} = e^{i\phi_1} e^{i\delta_1} T' + e^{i\phi_2} e^{i\delta_2} P'$$
$$\bar{\mathcal{M}} = e^{-i\phi_1} e^{i\delta_1} T' + e^{-i\phi_2} e^{i\delta_2} P'$$

$$A_{CP} = \frac{|\mathcal{M}|^2 - |\bar{\mathcal{M}}|^2}{|\mathcal{M}|^2 + |\bar{\mathcal{M}}|^2} = \frac{2\sin(\Delta\phi)\sin(\Delta\delta) r}{1 + r^2 + 2r\cos(\Delta\phi)\cos(\Delta\delta)}$$

$r = P'/T'$; $\Delta\phi = \phi_1 - \phi_2$ $\Delta\delta = \delta_1 - \delta_2$

Direct CP violation asymmetries in percent:

Process	A_{CP}	Process	A_{CP}
$B^\pm \to \pi^\pm \pi'^0$	-1.4	$B^\pm \to \rho^0 \pi'^\pm$	-5.6
$B^\pm \to \pi^0 \pi'^\pm$	-0.4	$B^\pm \to \rho^\pm \pi'^0$	-20.7
$B^\pm \to \eta \pi'^\pm$	4.8	$B^\pm \to \omega \pi'^\pm$	-6.3
$B^\pm \to \eta' \pi'^\pm$	5.3	$B^\pm \to K^{*\pm} \pi'^0$	-25.4
$B^\pm \to K^\pm \pi'^0$	-12.5	$B^\pm \to \bar{K}^{*0} \pi'^\pm$	0.0
$B^\pm \to \bar{K}^0 \pi'^\pm$	0.0	$B^\pm \to \phi \pi'^\pm$	0

Process	A_{CP}	Process	A_{CP}
$B^\pm \to \pi^0 \rho'^\pm$	-3.9	$B^\pm \to \rho^0 \rho'^\pm$	0.38
$B^\pm \to \pi^\pm \rho'^0$	5.3	$B^\pm \to \rho^\pm \rho'^0$	0.39
$B^\pm \to \eta \rho'^\pm$	5.2	$B^\pm \to \omega \rho'^\pm$	17.5
$B^\pm \to \eta' \rho'^\pm$	4.98	$B^\pm \to K^{*\pm} \rho'^0$	-20.2
$B^\pm \to K^\pm \rho'^0$	-21.1	$B^\pm \to \bar{K}^{*0} \rho'^\pm$	0.0
$B^\pm \to \bar{K}^0 \rho'^\pm$	0.0	$B^\pm \to \phi \rho'^\pm$	0.0

$$A_f(t) = \frac{\Gamma(B^0(t) \to f) - \Gamma(\bar{B}^0 \to \bar{f})}{\Gamma(B^0(t) \to f) + \Gamma(\bar{B}^0 \to \bar{f})} \qquad \lambda_f = \frac{V_{tb}^* V_{td} \langle f | H_{eff} | \bar{B}^0 \rangle}{V_{tb} V_{td}^* \langle \bar{f} | H_{eff} | B^0 \rangle} \qquad C_f = \frac{1 - |\lambda_f|^2}{1 + |\lambda_f|^2}$$

$$A_f(t) = C_f \cos(\Delta m t) + S_f \sin(\Delta m t) \qquad S_f = \frac{-2Im(\lambda_f)}{1 + |\lambda_f|^2}$$

Process	C_f	S_f	Process	C_f	S_f
$\overset{(-)}{B^0} \to \pi^0 \pi'^0$	-0.6	-2.7	$\overset{(-)}{B^0} \to \rho^0 \pi'^0$	1.2	5.8
$\overset{(-)}{B^0} \to \eta \pi'^0$	0.4	1.6	$\overset{(-)}{B^0} \to \omega \pi'^0$	0.8	3.6
$\overset{(-)}{B^0} \to \eta' \pi'^0$	0.5	1.9	$\overset{(-)}{B^0} \to K^{*\mp} \pi'^\pm$	-27.7	-17.7
$\overset{(-)}{B^0} \to K^\mp \pi'^\pm$	-13.6	30.1	$\overset{(-)}{B^0} \to K^{*0} \pi'^0$	0.09	71.1
$\overset{(-)}{B^0} \to K^0 \pi'^0$	-0.1	70.7	$\overset{(-)}{B^0} \to \phi \pi'^0$	0.0	0.0

Process	C_f	S_f	Process	C_f	S_f
$\overset{(-)}{B^0} \to \pi^0 \rho'^0$	-48.8	-83.7	$\overset{(-)}{B^0} \to \rho^0 \rho'^0$	-20.6	-58.0
$\overset{(-)}{B^0} \to \eta \rho'^0$	-40.1	-91.6	$\overset{(-)}{B^0} \to \omega \rho'^0$	20.0	46.6
$\overset{(-)}{B^0} \to \eta' \rho'^0$	-5.1	-48.4	$\overset{(-)}{B^0} \to K^{*\mp} \rho'^\pm$	-27.7	-17.8
$\overset{(-)}{B^0} \to K^\mp \rho'^\pm$	-14.96	-16.0	$\overset{(-)}{B^0} \to K^{*0} \rho'^0$	-0.3	66.3
$\overset{(-)}{B^0} \to K^0 \rho'^0$	0.8	65.7	$\overset{(-)}{B^0} \to \phi \rho'^0$	0.0	0.0

$$g = \langle f | H_{eff} | B^0 \rangle,\ h = \langle f | H_{eff} | \bar{B}^0 \rangle,\ \bar{g} = \langle \bar{f} | H_{eff} | \bar{B}^0 \rangle,\ \bar{h} = \langle \bar{f} | H_{eff} | B^0 \rangle$$

Process	a_ϵ	$a_{\epsilon+\epsilon'}$	$a_{\bar{\epsilon}}$	$a_{\epsilon+\bar{\epsilon}'}$
$\overset{(-)}{B^0} \to \pi^+ \pi'^-, \pi^- \pi'^+$	78.3	-72.3	61.5	66.5
$\overset{(-)}{B^0} \to \rho^+ \pi'^-, \rho^- \pi'^+$	22.7	-22.7	-97.3	-89.8
$\overset{(-)}{B^0} \to \pi^+ \rho'^-, \pi^- \rho'^+$	14.2	-9.1	4.2	3.9
$\overset{(-)}{B^0} \to \rho^+ \rho'^-, \rho^- \rho'^+$	15.4	-5.8	13.9	14.0

5. Conclusions.

Some branching ratios are of order 10^-5.

Accumulated data in B factories.

CP violations Asymmetries of order 10 percent.

These channels are clearly an alternative.

Radially excited mesons with strange quark content, in progress.

Charmonium modes, in progress.