Non-Leptonic Weak Decays of Strange B Mesons

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YongPyong-High1 2015

Joint Winter Conference on Particle Physics, String and Cosmology

Jan. 25 - 31, 2015

High1 resort

Outline of talk

- **Introduction (Motivation)**
- **Axial Vector Meson Spectroscopy**
- **Methodology**
- **Decay Constants and Form Factors**
- **Summary**

Introduction

- The less explained/understood spectrum of *p*-wave mesons has posed serious problems in studies involving these particles. Therefore, the *p*-wave emitting decays of heavy flavor hadrons has always been challenging.
- Over the years, a lot of interest has been developed in study of these decay channels due to experimental observation of many decay modes.
- Also, recent observations by LHCb on CP-asymmetries of decays of strange bottom (B_s) meson have taken much attention. The study of B_s meson decays can shed some light on underlying dynamics involving heavy flavor hadrons within and beyond the Standard Model.
- With intensive efforts underway at several laboratories, one expects a complete understanding of the hadronic aspects or even perhaps New Physics (NP) in B meson sector.
- In the present work, we give preliminary estimates of axial-vector meson emitting weak decays of B_s meson.

AXIAL-VECTOR MESON SPECTROSCOPY

Experimentally, two types of the axial-vector mesons exist i.e.

$^3P_1(J^{PC}=1^{++})$ and $^1P_1(J^{PC}=1^{+-})$

For 1^{++}

Isovector : $a_1(1.230): a_1^+, a_1^-, a_1^0$

Isoscalars:

$$f_1(1.285)=\frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d})\cos\phi_A+(s\bar{s})\sin\phi_A$$

$$f_1'(1.512)=\frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d})\sin\phi_A-(s\bar{s})\cos\phi_A$$

$$\chi_{c1}(3.511)=(c\bar{c})$$

where

$$\phi_A=\theta(ideal)-\theta_A(physical)$$

For 1^{+-}

Isovector :

$$b_1(1.229): b_1^+,\ b_1^-,\ b_1^0$$

Isoscalars:

$$h_1(1.170)=\frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d})\cos\phi_{A'}+(s\bar{s})\sin\phi_{A'}$$

$$h_1'(1.380)=\frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d})\sin\phi_{A'}-(s\bar{s})\cos\phi_{A'}$$

$$h_{c1}(3.526)=(c\bar{c})$$

where

$$\phi_{A'}=\theta(ideal)-\theta_{A'}(physical)$$

with

$$\phi_A=\phi_{A'}=0^\circ$$

MIXING IN STARNGE AND CHARM AXIAL-VECTOR MESONS

$A(1^{++})$ and $A'(1^{+-})$

Mixing of Strange states

$$K_1(1.270) = K_{1A}\sin\theta_1 + K_{1A'}\cos\theta_1,$$
$$\underline{K}_1(1.400) = K_{1A}\cos\theta_1 - K_{1A'}\sin\theta_1.$$

$$\theta_1 = -58^0(-37^0)$$

Mixing of Charmed and Strange Charmed states

$$D_1(2.427) = D_{1A}\sin\theta_{D_1} + D_{1A'}\cos\theta_{D_1},$$
$$\underline{D}_1(2.422) = D_{1A}\cos\theta_{D_1} - D_{1A'}\sin\theta_{D_1},$$

&

$$D_{s1}(2.460) = D_{s1A}\sin\theta_{D_{s1}} + D_{s1A'}\cos\theta_{D_{s1}},$$
$$\underline{D}_{s1}(2.535) = D_{s1A}\cos\theta_{D_{s1}} - D_{s1A'}\sin\theta_{D_{s1}},$$

However, in the heavy quark limit, the physical mass eigenstates with $J^P = 1^+$ are $P_1^{3/2}$ and $P_1^{1/2}$ rather than $^3P_1$ and $^1P_1$ states as the heavy quark spin decouples from the other degrees of freedom so that

$$|P_1^{1/2}> = -\sqrt{\frac{1}{3}}\,|^1P_1> + \sqrt{\frac{2}{3}}\,|^3P_1>,$$

$$|P_1^{3/2}> = \sqrt{\frac{2}{3}}\,|^1P_1> + \sqrt{\frac{1}{3}}\,|^3P_1>.$$

Mixing of Charmed states

$$D_1(2.427) = D_1^{1/2}\cos\theta_2 + D_1^{3/2}\sin\theta_2,$$

$$\underline{D}_1(2.422) = -D_1^{1/2}\sin\theta_2 + D_1^{3/2}\cos\theta_2.$$

Mixing of strange-Charmed states

$$D_{s1}(2.460) = D_{s1}^{1/2}\cos\theta_3 + D_{s1}^{3/2}\sin\theta_3,$$

$$\underline{D}_{s1}(2.535) = -D_{s1}^{1/2}\sin\theta_3 + D_{s1}^{3/2}\cos\theta_3.$$

with

$$\theta_2 = (-5.7 \pm 2.4)^\circ \qquad \theta_3 \approx 7^\circ$$

For η and η' pseudoscalar states, we use

$$\eta(0.547) = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})\sin\phi_P - (s\bar{s})\cos\phi_P,$$

$$\eta'(0.958) = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})\cos\phi_P + (s\bar{s})\sin\phi_P,$$

where $\phi_P = \theta(ideal) - \theta_P(physical)$. $\theta_P(physical) = -15.4^\circ$. η_c is taken as

$$\eta_c(2.979) = (c\bar{c}) .$$

Methodology

FACTORIZATION SCHEME (Preliminary Estimates of BRs)

Factorization is the assumption that the two-body hadronic decays of B mesons can be expressed as the product of two independent hadronic currents:

$$< M_1 M_2 | J_\mu J^{\mu\dagger} | B > \approx < M_1 | J_\mu | 0 >< M_2 | J^{\mu\dagger} | B >$$

The decay amplitude is given by

$$B \to M_1 + M_2 = \frac{G_F}{\sqrt{2}} (\mathit{Cabibbo\ factors} \times \mathit{QCD\ factors}) \times$$
$$\left\{ \langle M_1 | J_\mu | 0 \rangle \langle M_2 | J^{\mu\dagger} | B \rangle + \langle M_2 | J_\mu | 0 \rangle \langle M_1 | J^{\mu\dagger} | B \rangle \right\}.$$

Three classes of the decays:

1. Class I transition (caused by color favored),
2. Class II transition (caused by color suppressed) and
3. Class III transition (caused by both color favored and color suppressed diagrams).

WEAK HAMILTONIAN

a. The CKM favored $b \to c$ transition,

$$H_W = \frac{G_F}{\sqrt{2}} \{V_{cb}V_{ud}^*[c_1(\bar{c}b)(\bar{d}u) + c_2(\bar{d}b)(\bar{c}u)] + V_{cb}V_{cs}^*[c_1(\bar{c}b)(\bar{s}c) + c_2(\bar{s}b)(\bar{c}c)] +$$

$$V_{cb}V_{us}^*[c_1(\bar{c}b)(\bar{s}u) + c_2(\bar{s}b)(\bar{c}u)] + V_{cb}V_{cd}^*[c_1(\bar{c}b)(\bar{d}c) + c_2(\bar{d}b)(\bar{c}c)]\},$$

b. The CKM suppressed $b \to u$ transition,

$$H_W = \frac{G_F}{\sqrt{2}} \{V_{ub}V_{cs}^*[c_1(\bar{u}b)(\bar{s}c) + c_2(\bar{s}b)(\bar{u}c)] + V_{ub}V_{ud}^*[c_1(\bar{u}b)(\bar{d}u) + c_2(\bar{d}b)(\bar{u}u)] +$$

$$V_{ub}V_{us}^*[c_1(\bar{u}b)(\bar{s}u) + c_2(\bar{s}b)(\bar{u}u)] + V_{ub}V_{cd}^*[c_1(\bar{u}b)(\bar{d}c) + c_2(\bar{d}b)(\bar{u}c)]\},$$

Where $\bar{q}q = \bar{q}\gamma_\mu(1-\gamma_5)q$ and

$$c_1(\mu) = 1.26, c_2(\mu) = -0.51 at \mu \approx m_c^2,$$

$$c_1(\mu) = 1.12, c_2(\mu) = -0.26 at \mu \approx m_b^2.$$

DECAY AMPLITUDES AND RATES for *B ->PA*

$$\Gamma(B \to P\,A) = \frac{p_c^3}{8\pi m_A^2}\left|A(B \to P\,A)\right|^2$$

where

$$p_c = \frac{1}{2m_B}\{[m_B^2 - (m_P + m_A)^2][m_B^2 - (m_P - m_A)^2]\}^{1/2}$$

The factorization Scheme expresses the decay amplitudes as a product of matrix element of the weak currents

$$\langle PA|H_w|B\rangle \square \langle P|J^\mu|0\rangle\langle A|J_\mu|B\rangle + \langle A|J^\mu|0\rangle\langle P|J_\mu|B\rangle,$$

$$\langle PA'|H_w|B\rangle \square \langle P|J^\mu|0\rangle\langle A'|J_\mu|B\rangle + \langle A'|J^\mu|0\rangle\langle P|J_\mu|B\rangle.$$

The matrix element of current between mesons states are expressed as

$$\langle P|J_\mu|0\rangle = -if_P k_\mu\,,$$

$$\langle A|J_\mu|0\rangle = \in_\mu^* m_A f_A\,,$$

$$\langle A'|J_\mu|0\rangle = \in_\mu^* m_{A'} f_{A'}\,,$$

$$\langle A(P_A)|J_\mu|B(P_B)\rangle = l \in_\mu^* + c_+(\in^* \cdot P_B)(P_B+P_A)_\mu + c_-(\in^* \cdot P_B)(P_B-P_A)_\mu,$$

$$\langle A'(P_{A'})|J_\mu|B(P_B)\rangle = r \in_\mu^* + s_+(\in^* \cdot P_B)(P_B+P_{A'})_\mu + s_-(\in^* \cdot P_B)(P_B-P_{A'})_\mu,$$

and

$$\langle P(P_P)|J_\mu|B(P_B)\rangle = (P_{B\mu}+P_{P\mu}-\frac{m_B^2-m_P^2}{q^2}q_\mu)F_1^{BP}(q^2)+\frac{m_B^2-m_P^2}{q^2}q_\mu F_0^{BP}(q^2).$$

$$\langle A(k_A, \in) | A_\mu | B(k_B) \rangle = iq' \varepsilon_{\mu\nu\alpha\beta} \in^\nu (k_B + k_A)^\alpha (k_B - k_A)^\beta,$$

$$\langle A'(k_A, \in) | A_\mu | B(k_B) \rangle = i\, v \varepsilon_{\mu\nu\alpha\beta} \in^\nu (k_B + k_{A'})^\alpha (k_B - k_{A'})^\beta$$

Finally the decay amplitude becomes

$$A(B \to PA) = (\, 2m_A f_A F_1^{B\to P}(m_A^2) + f_P F^{B\to A}(m_P^2)),$$

$$A(B \to PA') = (\, 2m_{A'} f_{A'} F_1^{B\to P}(m_{A'}^2) + f_P F^{B\to A'}(m_P^2))$$

where

$$F^{\,B\to A}(m_P^2) = l(m_P^2) + (m_B^2 - m_A^2)\; c_+(m_P^2) + m_P^2\; c_-(m_P^2),$$

$$F^{\,B\to A'}(m_P^2) = r\,(m_P^2) + (m_B^2 - m_{A'}^2)\; s_+(m_P^2) + m_P^2\; s_-(m_P^2).$$

$B \to A / A'$ Transition Form Factors in ISGW II quark Model

The form factors have the following expressions in the ISGW II model

$$l = -\tilde{m}_B \beta_B [\frac{1}{\mu_-} + \frac{m_2 \tilde{m}_A (\tilde{\omega} - 1)}{\beta_B^2} (\frac{5 + \tilde{\omega}}{6 m_1} - \frac{m_2 \beta_B^2}{2 \mu_- \beta_{BA}^2})] F_5^{(l)},$$

$$c_+ + c_- = -\frac{m_2 \tilde{m}_A}{2 m_1 \tilde{m}_B \beta_B} \left(1 - \frac{m_1 m_2 \beta_B^2}{2 \tilde{m}_A \mu_- \beta_{BA}^2} \right) F^{(c_+ + c_-)},$$

$$c_+ - c_- = -\frac{m_2 \tilde{m}_A}{2 m_1 \tilde{m}_B \beta_B} \left(\frac{\tilde{\omega} + 2}{3} - \frac{m_1 m_2 \beta_B^2}{2 \tilde{m}_A \mu_- \beta_{BA}^2} \right) F^{(c_+ - c_-)},$$

$$r = \frac{\tilde{m}_B \beta_B}{\sqrt{2}} [\frac{1}{\mu_+} + \frac{m_2 \tilde{m}_A}{3 m_1 \beta_B^2} (\tilde{\omega} - 1)^2] F_5^{(r)},$$

$$s_+ + s_- = -\frac{m_2}{2 \tilde{m}_B \beta_B} \left(1 - \frac{m_2}{m_1} + \frac{m_2 \beta_B^2}{2 \mu_+ \beta_{BA}^2} \right) F^{(s_+ + s_-)},$$

$$s_+ - s_- = -\frac{m_2}{2 m_1 \beta_B} \left(\frac{4 - \tilde{\omega}}{3} - \frac{m_1 m_2 \beta_B^2}{2 \tilde{m}_A \mu_+ \beta_{BA}^2} \right) F^{(s_+ - s_-)}$$

The $t(\equiv q^2)$ dependence is given by

$$\tilde{\omega} - 1 = \frac{t_m - t}{2\bar{m}_B \bar{m}_A},$$

and

$$F_5 = \left(\frac{\tilde{m}_A}{\tilde{m}_B}\right)^{1/2} \left(\frac{\beta_B \beta_A}{B_{BA}}\right)^{5/2} \left[1 + \frac{1}{18} h^2 (t_m - t)\right]^{-3}$$

Inverse size of meson

where

$$h^2 = \frac{3}{4m_c m_q} + \frac{3m_d^2}{2\bar{m}_B \bar{m}_A \beta_{BA}^2} + \frac{1}{\bar{m}_B \bar{m}_A}\left(\frac{16}{33 - 2n_f}\right) \ln\left[\frac{\alpha_S(\mu_{QM})}{\alpha_S(m_q)}\right]$$

$$\beta_{BA}^2 = \frac{1}{2}\left(\beta_B^2 + \beta_A^2\right)$$

→ Flavor dependence w.r.t. size

$$\mu_{\pm} = \left(\frac{1}{m_q} \pm \frac{1}{m_b}\right)^{-1}$$

The parameter β for s-wave and p-wave mesons in the ISGW II model

Quark content	$u\bar{d}$	$u\bar{s}$	$s\bar{s}$	$c\bar{u}$	$c\bar{s}$	$u\bar{b}$	$s\bar{b}$	$c\bar{c}$
β_s (GeV)	0.41	0.44	0.53	0.45	0.56	0.43	0.54	0.88
β_p (GeV)	0.28	0.30	0.33	0.33	0.38	0.35	0.41	0.52

Form factors of $\mathrm{B}(0^-) \to A(1^+)$ transition at $q^2 = t_m$ in the ISGW II quark Model

Transition	l	c_+	c_-
$B_s \to f_1'$	-1.847	-0.043	-0.0067
$B_s \to K_1$	-2.623	-0.038	-0.0085
$B_s \to D_{s1}$	-0.661	-0.062	-0.0040

Form factors of $\mathrm{B}(0^-) \to A'(1^+)$ transition at $q^2 = t_m$ in the ISGW II quark Model

Transition	r	s_+	s_-
$B_s \to h_1'$	2.388	0.143	-0.107
$B_s \to \underline{K}_1$	2.124	0.128	-0.096
$B_s \to \underline{D}_{s1}$	0.965	0.124	-0.048

Form factors of $B(0^-) \rightarrow P(0^-)$ transition

Transition	$F_0^{B_c P}(0)$
$B_s \rightarrow \eta'$	0.35
$B_s \rightarrow D_s$	0.67
$B_s \rightarrow K$	0.35

These form factors are calculated in relativistic quark model with flavor dependent effects. **[Rohit Dhir, Neelesh Sharma and RC Verma, J.Phys. G 35, 085002 (2008)]**

DECAY CONSTANTS (in GeV) OF THE AXIAL-VECTOR MESONS

➢The decay constants for axial-vector mesons are defined by the matrix elements given previouly (slide 13). It may be pointed out that the axial-vector meson states are represented by 3×3 matrix and they transform under the charge conjugation as

$$M_a^b(^3P_1) \to M_b^a(^3P_1), \qquad M_a^b(^1P_1) \to -M_b^a(^1P_1), \quad (a = 1, 2, 3).$$

➢Since the weak axial-vector current transfers as $(A_\mu)_a^b \to (A_\mu)_b^a$ under charge conjugation, the decay constant of the $^1P_1$ meson should vanish in the SU(3) flavor limit [M. Suzuki PRD 47, 1252 (1993); 55, 2840 (1997)].

➢Experimental information based on τ decays gives decay constant $f_{K_1}(1270) = 0.175 \pm 0.019$ GeV [H. Y. Cheng, PRD 67, 094007 (2003)], while decay constant for $K_1(1.400)$ can be obtained from relation $f_{K_1}(1.400)/f_{K_1}(1.270) = \cot\theta_1$ i.e. $f_{K_1}(1.400) = (-0.087 \pm 0.012)$ GeV, for $\theta_1 = -58^\circ$.

- Numerous analysis based on phenomenological studies indicate that strange axial vector meson states mixing angle θ_K lies in the vicinity of ~ 35◦ and ~ 55◦. Recently, it has been pointed out [H.Y. Cheng, PLB 707, 116 (2012)] that mixing angle $\theta_K \sim 35^\circ$ is preferred over ~ 55◦. It is based on the observation that choice of angle for $f - f'$ and $h - h'$ mixing schemes (which are close to ideal mixing) are intimately related to choice of mixing angle θ_1. However, we use $\theta_K = -58^\circ$ in our numerical calculations.

- In case of non-strange axial vector mesons, the mixing angle for strange axial vector mesons and SU(3) symmetry determines $f_{a1} = 0.223$ GeV. Since, a_1 and f_1 lies in the same nonet we assume $f_{f1} \approx f_{a1}$ under SU(3) symmetry. Due to charge conjugation invariance decay constants for $^1P_1$ nonstrange neutral mesons b_0, $h_1(1.235)$, $h_1(1.170)$, and $h'_1(1.380)$ vanish. Also, owing to G-parity conservation in the isospin limit decay constant $f_{b1} = 0$.

SUMMARIZED DECAY CONSTANTS (in GeV)

$$f_{K_1(1270)} = 0.175, \quad f_{\underline{K}_1(1.400)} = -0.087, \quad f_{a_1} = 0.203, \quad f_{f_1} \approx f_{a_1}$$

$$f_{D_{1A}} = -0.127, \quad f_{D_{1B}} = 0.045, \quad f_{D_{s1A}} = -0.121, \quad f_{D_{s1B}} = 0.038,$$

$$f_{\chi_{c1}} \approx -0.160.$$

PSEUDOSCALAR MESON

$$f_{\pi} = 0.131, \quad f_{K} = 0.160, \quad f_{D} = 0.223, \quad f_{D_s} = 0.294,$$

$$f_{\eta_c} \approx 0.400.$$

Branching ratios for $B \to PA$ decays in CKM-favored mode involving $b \to c$ transition

Decays	Branching ratios	Decays	Branching ratios
$\Delta b = 1, \Delta C = 1, \Delta S = 0$		$\Delta b = 1, \Delta C = 0, \Delta S = -1$	
$\bar{B}_s^0 \to K^0 D_1^0$	9.1×10^{-5}	$\bar{B}_s^0 \to \eta\chi_{c1}$	4.3×10^{-5}
$\bar{B}_s^0 \to K^0 \underline{D}_1^0$	1.8×10^{-6}	$\bar{B}_s^0 \to \eta'\chi_{c1}$	3.8×10^{-5}
$\bar{B}_s^0 \to \pi^- D_{s1}^+$	3.6×10^{-3}	$\bar{B}_s^0 \to D_s^+ D_{s1}^-$	2.1×10^{-3}
$\bar{B}_s^0 \to \pi^- \underline{D}_{s1}^+$	3.0×10^{-4}	$\bar{B}_s^0 \to D_s^+ \underline{D}_{s1}^-$	6.3×10^{-5}
$\bar{B}_s^0 \to D^0 K_1^0$	1.4×10^{-3}	$\bar{B}_s^0 \to D_s^- D_{s1}^+$	6.9×10^{-3}
$\bar{B}_s^0 \to D^0 \underline{K}_1^0$	7.3×10^{-7}	$\bar{B}_s^0 \to D_s^- \underline{D}_{s1}^+$	9.3×10^{-4}
$\bar{B}_s^0 \to D_s^+ a_1^-$ O(10^{-2}) ←	9.9×10^{-3}	$\bar{B}_s^0 \to \eta_c f_1'$	1.1×10^{-3}
$\bar{B}_s^0 \to D_s^+ b_1^-$	8.9×10^{-8}	$\bar{B}_s^0 \to \eta_c h_1'$	9.4×10^{-4}

Branching ratios for $B \to PA$ decays in CKM-suppressed mode involving $b \to c$ transition

Decays	Branching ratios	Decays	Branching ratios
$\Delta b = 1, \Delta C = 1, \Delta S = -1$		$\Delta b = 1, \Delta C = 0, \Delta S = 0$	
$\overline{B}_s^0 \to \eta D_1^0$	2.4×10^{-6}	$\overline{B}_s^0 \to K^0 \chi_{c1}$	4.5×10^{-6}
$\overline{B}_s^0 \to \eta \underline{D}_1^0$	5.0×10^{-8}	$\overline{B}_s^0 \to D_s^+ D_1^-$	1.3×10^{-4}
$\overline{B}_s^0 \to K^- D_{s1}^+$	2.7×10^{-4}	$\overline{B}_s^0 \to D_s^+ \underline{D}_1^-$	2.5×10^{-6}
$\overline{B}_s^0 \to K^- \underline{D}_{s1}^+$	2.3×10^{-5}	$\overline{B}_s^0 \to D^- D_{s1}^+$	2.4×10^{-4}
$\overline{B}_s^0 \to \eta' D_1^0$	2.6×10^{-6}	$\overline{B}_s^0 \to D^- \underline{D}_{s1}^+$	3.0×10^{-5}
$\overline{B}_s^0 \to \eta' \underline{D}_1^0$	5.4×10^{-8}	$\overline{B}_s^0 \to \eta_c K_1^0$	1.4×10^{-4}
$\overline{B}_s^0 \to D^0 f_1'$	3.9×10^{-5}	$\overline{B}_s^0 \to \eta_c \underline{K}_1^0$	1.2×10^{-6}
$\overline{B}_s^0 \to D^0 h_1'$	2.3×10^{-5}		
$\overline{B}_s^0 \to D_s^+ K_1^-$	4.1×10^{-4}		
$\overline{B}_s^0 \to D_s^+ \underline{K}_1^-$	1.2×10^{-4}		

Branching ratios for $B \to PA$ decays involving $b \to u$ transition

Decays	Branching ratios
$\Delta b = 1, \Delta C = -1, \Delta S = -1$	
$\bar{B}_s^0 \to K^+ D_{s1}^-$	1.5×10^{-5}
$\bar{B}_s^0 \to K^+ \underline{D}_{s1}^-$	7.6×10^{-7}
$\bar{B}_s^0 \to \eta \bar{D}_1^0$	4.5×10^{-7}
$\bar{B}_s^0 \to \eta \underline{\bar{D}}_1^0$	1.6×10^{-8}
$\bar{B}_s^0 \to \eta' \bar{D}_1^0$	4.9×10^{-7}
$\bar{B}_s^0 \to \eta' \underline{\bar{D}}_1^0$	1.8×10^{-8}
$\bar{B}_s^0 \to \bar{D}^0 f_1'$	5.9×10^{-6}
$\bar{B}_s^0 \to \bar{D}^0 h_1'$	3.5×10^{-6}
$\bar{B}_s^0 \to D_s^- K_1^+$	3.3×10^{-4}
$\bar{B}_s^0 \to D_s^- \underline{K}_1^+$	2.6×10^{-7}

Decays	Branching ratios	
	This Work	CMV
$\Delta b = 1, \Delta C = 0, \Delta S = 0$		
$\bar{B}_s^0 \to K^+ a_1^-$	36.37×10^{-6}	19.2×10^{-6}
$\bar{B}_s^0 \to K^+ b_1^-$	3.07×10^{-10}	-
$\bar{B}_s^0 \to K^0 a_1^0$	9.78×10^{-9}	0.09×10^{-6}
$\bar{B}_s^0 \to K^0 f_1$	1.16×10^{-6}	0.03×10^{-6}
$\bar{B}_s^0 \to \pi^0 K_1^0$	2.28×10^{-6}	-
$\bar{B}_s^0 \to \pi^0 \underline{K}_1^0$	8.56×10^{-10}	-
$\bar{B}_s^0 \to \pi^- K_1^+$	81.86×10^{-6}	-
$\bar{B}_s^0 \to \pi^- \underline{K}_1^+$	3.13×10^{-8}	-
$\bar{B}_s^0 \to \eta K_1^0$	1.40×10^{-6}	-
$\bar{B}_s^0 \to \eta \underline{K}_1^0$	3.58×10^{-10}	-
$\bar{B}_s^0 \to \eta' K_1^0$	8.13×10^{-7}	-
$\bar{B}_s^0 \to \eta' \underline{K}_1^0$	6.05×10^{-11}	-

Calderon, Munoz and Vera, PRD 76, 094019 (2007)

Branching ratios for $B \to PA$ decays involving $b \to u$ transition

Decays	Branching ratios: This Work	Branching ratios: CMV
$\Delta b = 1, \Delta C = 0, \Delta S = -1$		
$\bar{B}_s^0 \to K^+ K_1^-$	1.5×10^{-6}	3.3×10^{-6}
$\bar{B}_s^0 \to K^+ \underline{K}_1^-$	4.6×10^{-7}	1.8×10^{-6}
$\bar{B}_s^0 \to \pi^0 f_1'$	7.5×10^{-8}	-
$\bar{B}_s^0 \to \pi^0 h_1'$	3.5×10^{-8}	-
$\bar{B}_s^0 \to \eta a_1^0$	2.6×10^{-8}	0.14×10^{-6}
$\bar{B}_s^0 \to \eta f_1$	3.08×10^{-8}	0.19×10^{-6}
$\bar{B}_s^0 \to \eta f_1'$	4.55×10^{-8}	-
$\bar{B}_s^0 \to \eta h_1'$	2.16×10^{-8}	-
$\bar{B}_s^0 \to K^- K_1^+$	6.31×10^{-3}	-
$\bar{B}_s^0 \to K^- \underline{K}_1^+$	1.80×10^{-9}	-
$\bar{B}_s^0 \to \eta' a_1^0$	2.96×10^{-8}	0.14×10^{-6}
$\bar{B}_s^0 \to \eta' a_1^0$	2.96×10^{-8}	0.14×10^{-6}
$\bar{B}_s^0 \to \eta' f_1$	3.51×10^{-8}	0.18×10^{-6}
$\bar{B}_s^0 \to \eta' f_1'$	2.59×10^{-8}	-
$\bar{B}_s^0 \to \eta' h_1'$	1.28×10^{-8}	-

Decays	Branching ratios: This Work
$\Delta b = 1, \Delta C = -1, \Delta S = 0$	
$\bar{B}_s^0 \to K^+ D_1^-$	8.7×10^{-7}
$\bar{B}_s^0 \to K^+ \underline{D}_1^-$	3.0×10^{-8}
$\bar{B}_s^0 \to K^0 \bar{D}_1^0$	4.7×10^{-8}
$\bar{B}_s^0 \to K^0 \underline{\bar{D}}_1^0$	1.6×10^{-9}
$\bar{B}_s^0 \to D^- K_1^+$	1.0×10^{-5}
$\bar{B}_s^0 \to D^- \underline{K}_1^+$	5.4×10^{-9}
$\bar{B}_s^0 \to \bar{D}^0 K_1^0$	5.7×10^{-7}
$\bar{B}_s^0 \to \bar{D}^0 \underline{K}_1^0$	3.0×10^{-10}

Highly suppressed

Summary

- The BRs of *p*-wave meson emitting decays are naively expected to be kinematically suppressed. However, we find that BRs of B_s decays emitting p-wave meson in the final state is of the same order that of *B* to *PP*/*VP*/*VV*
- Some of the charm conserving (*b* -> *c*) modes have rather large BRs of the O($10^{-2}/10^{-3}$) involving D_s meson in the final state.
- The next order branching ratios are observed in a few *b* -> *u* transition modes but others remain suppressed.
- CKM suppressed $\Delta C = 0, \Delta S = -1$ & $\Delta C = -1, \Delta S = 0$ modes in

  b-> *u* remain highly suppressed but these may acquire possible penguin contributions.

THANK YOU