Orbitally Excited Meson Emitting Decays of B_c

Neelesh Sharma

High 1-2014

KIAS-NCTS Joint workshop on Particle Physics, String Theory and Cosmology

Feb. 9-15, 2014

INTRODUCTION

- Weak currents in the Standard Model generate leptonic, semileptonic and hadronic decays of the heavy flavor hadrons.

- Since the quarks are confined inside the colorless hadrons, matching between theory and experiment requires an exact knowledge of the low energy strong interactions.

- The weak decays of heavy quark hadrons provide a unique opportunity to learn more about QCD particularly on the interface between the perturbative and nonperturbative regimes, to determine SM parameters and finally to search for the physics lying beyond the model.

- In the present work, we study Axial Vector emitting decays of B_c meson in the Standard Model Framework. Preliminary estimates of Branching Ratios for these decays are presented in this work.

B_c MESON

- The B_c meson discovered at Fermilab , is a unique quark-antiquark bound state composed of two heavy quarks with different flavors and are thus flavor asymmetric.

- A peculiarity of B_c decays, w.r.t. the B and B_s Decays, is that both quarks (b, c) can involve in weak decays.

- The decay processes of the B_c meson can be broadly divided into three classes:
  - i) involving the decay of b quark with c being spectator,
  - ii) involving the decay of c quark with b being spectator and
  - iii) the two component annihilate, b and c , weakly.

Processes i) and ii), as mentioned above, can contribute to semileptonic and nonleptonic weak decays, while the process iii) can only contribute to leptonic decays.

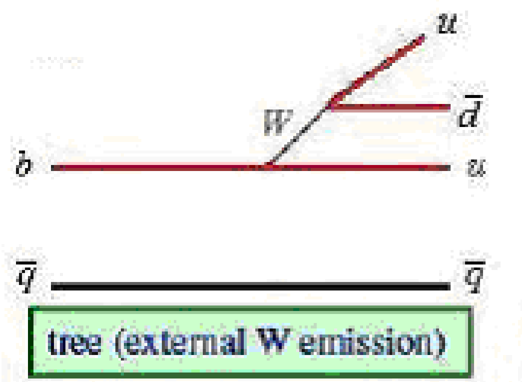
- There have been many theoretical efforts to study the bottom meson emitting decays involving *s-wave* mesons ($B_c \rightarrow PP/PV/VV$) i.e. pseudoscalar (P) and vector (V) mesons using the factorization scheme.

- B_c mesons being heavy, can also emit *p-wave* mesons i.e. axial-vector (A), tensor (T) and scalar (S) mesons, so far, relatively less attention is paid to these decays. However, we restrict our self only emission of axial vector meson in the final state.

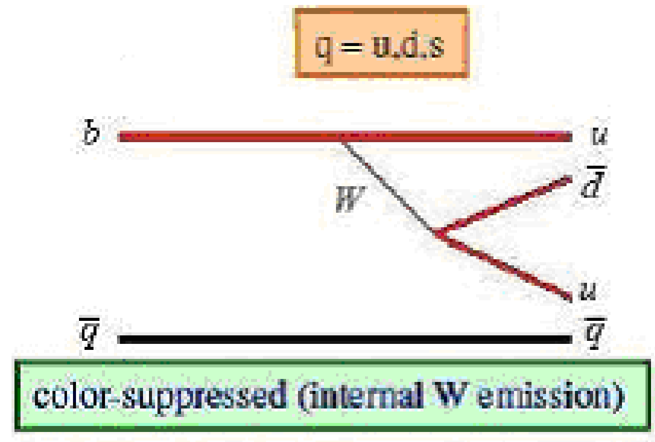
- A new era of Bc has started with an expected production cross-section of $\sim 0.4\ \mu b$ at centre-of-mass energy ($\sqrt{s}$ =) 7 TeV at the LHC. Very recently, the LHC-b has reported an observation of decays like $B_c^+ \to \psi(2S)\,\pi^+$, $B_c^+ \to J/\psi\ \pi^+\pi^+\pi^-$ and $B_c^+ \to J/\psi\ \pi^+$ [LHCb Collaboration, PRL 108, 251802 (2012) ; PRL 109, 232001 (2012); PRD 87, 071103 (2013); EPJ C38, 267 (2004)].

- These experimental efforts have opened up new investigation concerning the structure of strong and weak interactions for heavy flavor sector. Also, B_c meson attracts the interest of experimentalists for testing the predictions of various theoretical efforts in the laboratory.

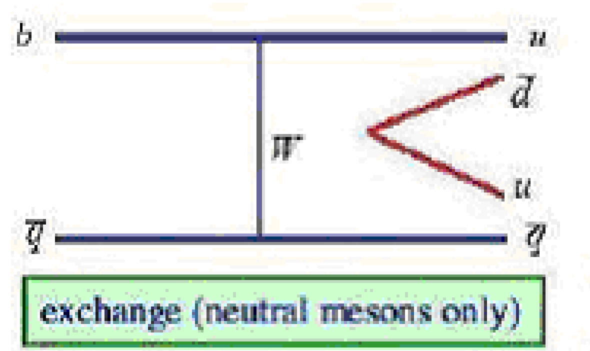
VARIOUS QUARK LEVEL PROCESSES THAT CONTIBUTE TO THE NONLEPTONIC DECAYS



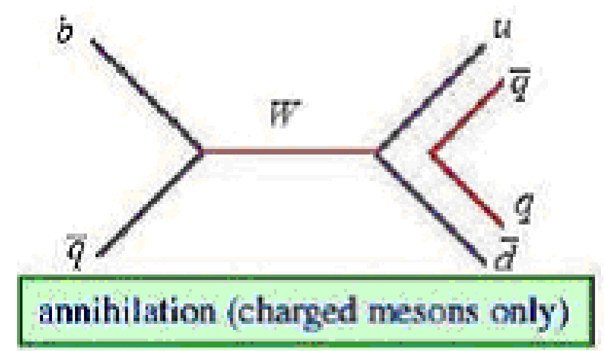
(a) W-external emission,



(b) W-internal emission,



(c) W-exchange,



(d) W-annihilation,

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:

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

The decay amplitude is given by

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

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

BOTTOM CHANGING DECAYS

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

$$c_1(\mu) = 1.26, c_2(\mu) = -0.51 at \mu \approx m_c^2,$$
$$c_1(\mu) = 1.12, c_2(\mu) = -0.26 at \mu \approx m_b^2.$$

Some More Details

Sandwiching the weak Hamiltonian between the initial and the final states, the decay amplitudes for various $B_c \rightarrow MA$ decay modes ($M = V$ *or* A) can be obtained for the following three categories :

- Class I transitions: decay amplitudes are proportional to $\boldsymbol{a_1}$.
- Class II transitions: decay amplitudes in this class are proportional to $\boldsymbol{a_2}$.
- Class III transitions: these decays are caused by the interference of color singlet and color neutral currents i.e. the amplitudes $\boldsymbol{a_1}$ and $\boldsymbol{a_2}$ interfere.

where $\boldsymbol{a_{1,2}(\mu) = c_{1,2} + (1/N_c)\, c_{2,1}(\mu)}$, and N_c **is the number of colors**.

➢It may be noted that N_c, number of color degrees of freedom, may be treated as a phenomenological parameter in weak meson decays, which **account for non-factorizable contributions**. It implies that the effective expansion parameter is something like, $1/(4\pi)\, N_c$, $(1/N_c)^2$... or non-leading $1/N_c$ terms are suppressed by some reason.

➢Taking in to account the **constructive interference observed for *B* meson decays involving both the color favored and color suppressed diagrams**. We use the ratio a_2/a_1 to be positive in the present calculations.

AXIAL-VECTOR MESON SPECTROSCOPY

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

$$^{3}P_{1}(J^{PC}=1^{++}) \qquad \text{and} \qquad ^{1}P_{1}(J^{PC}=1^{+-})$$

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

$$K_1(1.270) = K_{1A}\sin\theta_1 + K_{1A'}\cos\theta_1,$$
$$\underline{K}_1(1.400) = K_{1A}\cos\theta_1 - K_{1A'}\sin\theta_1. \qquad \theta_1 = -58^0(-37^0)$$

Mixing of Charmed and Strange Charmed states

However, in the heavy quark limit, heavy quark spin and the total angular momentum of light quark can be used as good quantum numbers, thus, the physical mass eigen states with $J^P = 1^+$ are $P_1^{3/2}$ and $P_1^{1/2}$ rather than ${}^3P_1$ and ${}^1P_1$ states,

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

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

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

DECAY AMPLITUDES AND RATES for B_c to 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

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

The matrix element of current between mesons states are expressed as

$$\langle A(k_A,\in)|A_{\mu}|0\rangle = \in_{\mu}^{*} m_A f_A$$

$$\langle A'(k_{A'},\in)|A_{\mu}|0\rangle = \in_{\mu}^{*} m_{A'} f_{A'}$$

$$\langle A(k_A,\in)|V_{\mu}|B(k_B)\rangle = l\in_{\mu}^{*} + c_{+}(\in^{*}\cdot k_B)(k_B + k_A)_{\mu} + c_{-}(\in^{*}\cdot k_B)(k_B - k_A)_{\mu},$$

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

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

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

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

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

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

DECAY CONSTANTS 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 ± 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 θ_1 i.e. f_{K_1} (1.400) = (–0.109 ± 0.12) GeV, for $\theta_1 = -37^\circ$ used in the present work .**

- ❖ Numerous analysis based on phenomenological studies indicate that strange axial vector meson states mixing angle θ_K lies in the vicinity of $\sim 35^\circ$ and $\sim 55^\circ$. Recently, it has been pointed out [H.Y. Cheng, PLB 707, 116 (2012)] that mixing angle $\theta_K \sim 35^\circ$ is preferred over $\sim 55^\circ$, we use $\theta_K = -37^\circ$ in our numerical calculations.

- ❖ **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.**

- ❖ In case of non-strange axial vector mesons, used mixing angle for strange axial vector mesons and SU(3) symmetry to determine $f_{a1} = 0.223$ 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 AND VECTOR MESONS

$$f_{\pi} = 0.131, \quad f_K = 0.160, \quad f_D = 0.223, \quad f_{D_s} = 0.294,$$

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

$$f_{\rho} = 0.221 \quad f_{K*} = 0.220 \quad f_{D*} = 0.245 \quad f_{D_s^*} = 0.273$$

$$f_{J/\psi} \approx 0.411$$

ISGW II MODEL

The new features are:

- Heavy quark symmetry constraints on the relations between form factor from zero-recoil are respected and slopes of form factors near zero-recoil are built
- The naive currents of the quark model are related to the full weak currents via the matching conditions of heavy quark effective theory
- Heavy-quark-symmetry-breaking color magnetic interactions are included, whereas ISGW only included the symmetry breaking due to the heavy quark kinetic energy,
- The ISGW prescription for connecting its quark model form factor to physical form factors is modified to the consistent with the constraints of heavy quark symmetry breaking at order 1/mQ
- Relativistic corrections to the axial vector coupling constants are taken into account
- More realistic form factor shapes based on the measured pion form factor, are employed

CALCULATION OF THE FORM FACTORS IN ISGW II MODEL

Expressions for $B_c \to A$ Transition Form Factors

$$
\begin{aligned}
l &= \tilde{m}_{B_c}\beta_{B_c}\left[\frac{1}{\mu_-} + \frac{m_c\tilde{m}_A(\tilde{\omega}-1)}{\beta_{B_c}^2}\left(\frac{5+\tilde{\omega}}{6m_q} - \frac{m_c\beta_{B_c}^2}{2\mu_-\beta_{B_cA}^2}\right)\right] F_5^{(l)}, \\
c_+ + c_- &= -\frac{\tilde{m}_A}{2m_{B_c}\beta_{B_c}}\left(1 - \frac{m_c^2\beta_{B_c}^2}{2m_A\mu_-\beta_{B_cA}^2}\right) F^{(c_+ + c_-)}, \\
c_+ - c_- &= -\frac{\tilde{m}_A}{2m_{B_c}\beta_{B_c}}\left(\frac{\tilde{\omega}+2}{3} - \frac{m_c^2\beta_{B_c}^2}{2m_A\mu_-\beta_{B_cA}^2}\right) F^{(c_+ - c_-)}, \\
q' &= \frac{m_c}{2\tilde{m}_A\beta_{B_c}}\left(\frac{5+\tilde{\omega}}{6m_q}\right) F_5^{(q)},
\end{aligned}
$$

where

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

Expressions for $B_c \to A$` Transition Form Factors

$$r = \frac{\tilde{m}_{B_c}\beta_{B_c}}{\sqrt{2}}[\frac{1}{\mu_+} + \frac{\tilde{m}_A}{3\beta^2_{B_c}}(\tilde{\omega}-1)^2]\, F_5^{(r)},$$

$$s_+ + s_- = \frac{m_c}{\sqrt{2}\tilde{m}_{B_c}\beta_{B_c}}\left(\frac{m_c\beta^2_{B_c}}{2\mu_+\beta^2_{B_cA}}\right) F^{(s_+ + s_-)},$$

$$s_+ - s_- = \frac{1}{\sqrt{2}\beta_{B_c}}\left(\frac{4-\tilde{\omega}}{3} - \frac{m_c^2\beta^2_{B_c}}{2\tilde{m}_A\mu_+\beta^2_{B_cA}}\right) F^{(s_+ - s_-)},$$

$$v = [\frac{\tilde{m}_{B_c}\beta_{B_c}}{4\sqrt{2}m_c\tilde{m}_A} + \frac{(\tilde{\omega}-1)m_c}{6\sqrt{2}\tilde{m}_A\beta_{B_c}}]F_5^{(q)},$$

with appropriate

$$F_5^{(l)} = F_5^{(r)} = F_5(\frac{\bar{m}_{B_c}}{\tilde{m}_{B_c}})^{1/2}(\frac{\bar{m}_A}{\tilde{m}_A})^{1/2},$$

$$F_5^{(c_+ + c_-)} = F_5^{(s_+ + s_-)} = F_5(\frac{\bar{m}_{B_c}}{\tilde{m}_{B_c}})^{-3/2}(\frac{\bar{m}_A}{\tilde{m}_A})^{1/2},$$

$$F_5^{(c_+ - c_-)} = F_5^{(s_+ - s_-)} = F_5(\frac{\bar{m}_{B_c}}{\tilde{m}_{B_c}})^{-1/2}(\frac{\bar{m}_A}{\tilde{m}_A})^{-1/2}$$

$$F_5^{(q')} = F_5^{(v)} = F_5(\frac{\bar{m}_{B_c}}{\tilde{m}_{B_c}})^{-1/2}(\frac{\bar{m}_A}{\tilde{m}_A})^{-1/2}$$

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

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

and

$$F_5 = \left(\frac{\tilde{m}_A}{\tilde{m}_{B_c}}\right)^{1/2} \left(\frac{\beta_{B_c}\beta_A}{\beta_{B_cA}}\right)^{5/2} \left[1 + \frac{1}{18}\chi^2(t_m - t)\right]^{-3},$$

with

$$\chi^2 = \frac{3}{4m_b m_c} + \frac{3m_c^2}{2\bar{m}_{B_c}\bar{m}_A\beta_{B_cA}^2} + \frac{1}{\bar{m}_{B_c}\bar{m}_A}\left(\frac{16}{33 - 2n_f}\right)\ln[\frac{\alpha_S(\mu_{QM})}{\alpha_S(m_c)}],$$

and

$$\beta_{B_cA}^2 = \frac{1}{2}\left(\beta_{B_c}^2 + \beta_A^2\right).$$

It may be noted that B_c *to A/A′* transition form factors in ISGW II (Isgur-Scora-Grintein-Wise) framework are related to BSW (Bauer-Stech-Wirbel) type form factor notations:

$$\begin{aligned} A(q^2) &= -q'(q^2)[m_{B_c} + m_A]; \\ V_1(q^2) &= l(q^2)/(m_{B_c} + m_A); \\ V_2(q^2) &= -c_+(q^2)(m_{B_c} + m_A); \\ V_0(q^2) &= \frac{1}{(2m_A)}[(m_{B_c} + m_A)V_1(q^2) - (m_{B_c} - m_A)V_2(q^2) - q^2 c_-(q^2)]. \end{aligned}$$

It helps to draw a direct analogy to compare *p-wave* emitting decays to s-wave emitting decays of B_c

The values of parameter β for *s-wave* and *p-wave* mesons in the ISGW II quark model

Quark content	$u\bar{d}$	$u\bar{s}$	$s\bar{s}$	$c\bar{u}$	$c\bar{s}$	$u\bar{b}$	$s\bar{b}$	$c\bar{c}$	$b\bar{c}$
β_s (GeV)	0.41	0.44	0.53	0.45	0.56	0.43	0.54	0.88	0.92
β_P (GeV)	0.28	0.30	0.33	0.33	0.38	0.35	0.41	0.52	0.60

Form factors of $B_c \to A$ transition at $q^2 = t_m$

Modes	Transition	l	c_+	c_-	q'
$\Delta b = 1, \Delta C = 0, \Delta S = -1$	$B_c \to D_1$	$-3.529^{+0.504}_{-0.430}$	-0.048 ± 0.001	-0.006 ± 0.00	-0.074 ± 0.002
	$B_c \to D_{s1}$	-2.860 ± 0.258	-0.061 ± 0.001	-0.006 ± 0.001	-0.095 ± 0.002
$\Delta b = 1, \Delta C = 1, \Delta S = 0$	$B_c \to \chi_{c1}(c\bar{c})$	-1.182 ± 0.038	-0.103 ± 0.003	-0.006 ± 0.001	-0.130 ± 0.003
$\Delta b = 1, \Delta C = 0, \Delta S = -1$	$B_c \to a_1$	-0.243 ± 0.008	-0.036 ± 0.001	0.015 ± 0.001	-0.074 ± 0.002
	$B_c \to f_1$	-0.242 ± 0.008	-0.036 ± 0.001	0.015 ± 0.001	-0.074 ± 0.002
	$B_c^- \to f_1'$	-0.363 ± 0.010	-0.049 ± 0.002	0.018 ± 0.001	-0.095 ± 0.002

Due to variation of quark masses (~ 10%)

Form factors of $B_c \to A'$ transition at $q^2 = t_m$

Modes	Transition	r	s_+	s_-	v
$\Delta b = 1, \Delta C = 0, \Delta S = -1$	$B \to \underline{D}_1$	$2.825^{+0.355}_{-0.306}$	0.083 ± 0.000	$-0.055^{+0.005}_{-0.003}$	$0.057^{+0.009}_{-0.006}$
	$B_c \to \underline{D}_{s1}$	2.464 ± 0.193	0.102 ± 0.001	-0.060 ± 0.002	0.046 ± 0.003
$\Delta b = 1, \Delta C = 1, \Delta S = 0$	$B_c \to h_{c1}(c\bar{c})$	1.674 ± 0.044	0.143 ± 0.004	-0.039 ± 0.001	0.019 ± 0.001
$\Delta b = 1, \Delta C = 0, \Delta S = -1$	$B_c \to b_1$	0.344 ± 0.007	0.053 ± 0.001	-0.028 ± 0.001	0.010 ± 0.000
	$B_c \to h_1$	0.337 ± 0.007	0.054 ± 0.001	-0.029 ± 0.000	0.011 ± 0.001
	$B_c^- \to h_1'$	0.512 ± 0.010	0.074 ± 0.002	-0.037 ± 0.001	0.014 ± 0.001

Due to variation of quark masses (~ 10%)

For $B_c \to P/V$ transition, we use form factors obtained in our previous work which employs flavor dependence in BSW framework

Form factors of $B_c \to P$ transition

Modes	Transition	$F_1^{B_cP}(0)$ (using flavor dependent ω)
$\Delta b = 0$, $\Delta C = -1$, $\Delta S = -1$	$B_c \to B_s$	0.55
	$B_c \to B$	0.41
$\Delta b = 1$, $\Delta C = 0$, $\Delta S = -1$	$B_c \to D$	0.075
	$B_c \to D_s$	0.15
$\Delta b = 1$, $\Delta C = 1$, $\Delta S = 0$	$B_c \to \eta_c(c\bar{c})$	0.58

Branching Ratios $B_c \to PA$

- Naively, the $c \to d, s$ decay channels are expected to be kinematically suppressed, however, the large value of the CKM matrix elements along with the large value of $c \to d, s$ transition form factors overcome this suppression. As a result, branching ratios of the charm changing mode are enhanced as compare to the bottom changing modes.

- The dominant decay for charm changing and bottom conserving are:

$$B(B_c^+ \to \pi^+ B_{s1}^0) = \boxed{2.9\times10^{-2},} \quad B(B_c^+ \to \bar{K}^0 B_1^+) = \boxed{0.54\times10^{-2},}$$

$$B(B_c^+ \to \pi^+ \underline{B}_{s1}^0) = 0.47\times10^{-2}, \quad B(B_c^+ \to \pi^+ B_1^0) = 0.24\times10^{-2} \text{ and}$$

$$B(B_c^+ \to \bar{K}^0 \underline{B}_1^+) = 0.10\times10^{-2}.$$

- For bottom changing transitions the dominating decays (an order smaller) are:

$$B(B_c^- \to \eta_c a_1^-) = \boxed{0.31\times10^{-2},} \quad B(B_c^- \to D_s^- h_{c1}) = \boxed{0.15\times10^{-2}}$$

$$\text{and} \quad B(B_c^- \to D_s^- \chi_{c1}) = 0.10\times10^{-2}.$$

DECAY AMPLITUDES AND RATES B_c to VA/AA

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

$$\langle MA|H_w|B_c\rangle \cong \langle M|J^{\mu}|0\rangle\langle A|J_{\mu}|B_c\rangle + \langle A|J^{\mu}|0\rangle\langle M|J_{\mu}|B_c\rangle, \; M = V \, or \, A.$$

The matrix element of current between mesons states are expressed as

$$\langle A(k_A,\in)|A_{\mu}|0\rangle = \in^{*}_{\mu} m_A f_A$$

$$\langle A'(k_{A'},\in)|A_{\mu}|0\rangle = \in^{*}_{\mu} m_{A'} f_{A'}$$

$$\langle A(k_A,\in)|V_{\mu}|B_c(k_{B_c})\rangle = l\in^{*}_{\mu} + c_{+}(\in^{*}\cdot k_{B_c})(k_{B_c}+k_A)_{\mu} + c_{-}(\in^{*}\cdot k_{B_c})(k_{B_c}-k_A)_{\mu},$$

$$\langle A'(k_{A'},\in)|V_{\mu}|B_c(k_{B_c})\rangle = r\in^{*}_{\mu} + s_{+}(\in^{*}\cdot k_{B_c})(k_{B_c}+k_{A'})_{\mu} + s_{-}(\in^{*}\cdot k_{B_c})(k_{B_c}-k_{A'})_{\mu}$$

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

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

Since, final states of $B_c \to VA/AA$ carry spin degrees of freedom, the decay amplitudes in terms of helicities, like those in the $B_c \to VV$ decays, can be generally described by

$$A(B \to MA) \equiv \varepsilon^*_{M\mu}\varepsilon^*_{A\nu}[ag^{\mu\nu} + bk^{\mu}_{B_c}k^{\nu}_{B_c} + ic\epsilon^{\mu\nu\alpha\beta}k_{B_c\alpha}k_{M\beta}].$$

Because, B_c is a pseudoscalar, the two outgoing vector mesons A and V have to carry the same helicity. Consequently, the amplitudes with different helicities can be decomposed as

$$H_{\pm1} = a \pm c(x^2-1)^{1/2}, \quad H_0 = -ax - b(x^2-1),$$

$$x = \frac{m^2_{B_c} - m^2_M - m^2_A}{2m_A m_M},$$

where k is the magnitude of vector momenta of vector/axial-vector mesons.

In addition, we can also write the amplitudes in terms of polarizations as

$$A_L = H_{00} A_{\|(\perp)} = \frac{1}{\sqrt{2}}(H_{--} \pm H_{++}).$$

Accordingly, the polarization fractions can be defined to be

$$R_i = \frac{|A_i|^2}{|A_L|^2 + |A_\||^2 + |A_\perp^2|}, \qquad (i = L, \|, \perp),$$

representing longitudinal, transverse parallel and transverse perpendicular components, respectively. In sum, the decay rate expressed by

$$\Gamma(B_c \to MA) = \frac{p_c}{8\pi\, m_{B_c}^2}(|H_0|^2 + |H_{+1}|^2 + |H_{-1}|^2),$$

$$p_c = \frac{1}{2m_{B_c}}\{[m_{B_c}^2 - (m_M + m_A)^2][m_{B_c}^2 - (m_M - m_A)^2]\}^{1/2}.$$

Form factors for $B_c \rightarrow V$ transitions

Modes	Transition	$V(0)$	$A_0(0)$	$A_1(0)$	$A_2(0)$
$\Delta b = 0, \Delta C = -1, \Delta S = -1$	$B_c \rightarrow B_s^*$	5.19	0.57	0.79	3.24
	$B_c \rightarrow B^*$	4.77	0.42	0.63	2.74
$\Delta b = 1, \Delta C = 0, \Delta S = -1$	$B_c \rightarrow D^*$	0.16	0.081	0.095	0.11
	$B_c \rightarrow D_s^*$	0.29	0.16	0.18	0.20
$\Delta b = 1, \Delta C = 1, \Delta S = 0$	$B_c \rightarrow J/\psi(c\bar{c})$	0.91	0.58	0.63	0.74

Branching Ratios for B_c VA decays

- It may be noted that charm changing and bottom conserving decay modes are kinematically forbiden in case of B_c → *VA* decays. For bottom changing transitions:

CKM FAVORED

$$\mathrm{Br}(B_c^- \to J/\psi a_1^-) = 4.14 \pm 0.26 \pm 0.05 \times 10^{-3}$$
$$\mathrm{Br}(B_c^- \to \rho^- \chi_{c1}) = 1.47 \pm 0.15 \pm 0.01 \times 10^{-3}$$
$$\mathrm{Br}(B_c^- \to \rho^- h_{c1}) = 1.24 \pm 0.08 \pm 0.01 \times 10^{-3}$$
$$\mathrm{Br}(B_c^- \to J/\psi D_{s1}^-) = 2.35 \pm 0.25 \pm 0.01 \times 10^{-3}$$
$$\mathrm{Br}(B_c^- \to D_s^{*-} \chi_{c1}) = 1.08 \pm 0.08 \pm 0.01 \times 10^{-3}$$
$$\mathrm{Br}(B_c^- \to D_s^{*-} h_{c1}) = 8.11 \pm 0.48 \pm 0.12 \times 10^{-4}$$
$$\mathrm{Br}(B_c^- \to J/\psi \underline{D}_{s1}^-) = 6.33 \boxed{\pm 0.49} \boxed{\pm 0.06} \times 10^{-4}$$

Effective variation of parameter N_c

Variation of quark masses (≈ 10%)

CKM SUPPRESSED

$$\mathrm{Br}(B_c^- \to J/\psi \underline{K}_1^-) = 2.36 \pm 0.14 \pm 0.03 \times 10^{-4}$$

$$\mathrm{Br}(B_c^- \to J/\psi K_1^-) = 1.49 \pm 0.09 \pm 0.02 \times 10^{-4}$$

$$\mathrm{Br}(B_c^- \to K^{*-} \chi_{c1}) = 7.07 \pm 0.43 \pm 0.0.04 \times 10^{-5}$$

$$\mathrm{Br}(B_c^- \to K^{*-} h_{c1}) = 6.18 \pm 0.37 \pm 0.06 \times 10^{-5}$$

$$\mathrm{Br}(B_c^- \to J/\psi D_1^-) = 1.39 \pm 0.14 \pm 0.03 \times \boxed{10^{-4}}$$

$$\mathrm{Br}(B_c^- \to D^{*-} \chi_{c1}) = 4.95 \pm 0.33 \pm 0.03 \times 10^{-5}$$

$$\mathrm{Br}(B_c^- \to D^{*-} h_{c1}) = 3.88 \pm 0.23 \pm 0.04 \times 10^{-5}$$

$$\mathrm{Br}(B_c^- \to J/\psi \underline{D}_1^-) = 3.45 \pm 0.28 \pm 0.03 \times 10^{-5}$$

$$\mathrm{Br}(B_c^- \to \rho^- \bar{D}_1^0) = 1.01 \pm 0.05^{+0.20}_{-0.11} \times \boxed{10^{-5}}$$

Well in reach of experiments

Branching Ratios for $B_c \rightarrow AA$ decays

In general the branching ratios for these decay channels is expected to be roughly of the same order as for $B_c \rightarrow VA$ decays:

CKM FAVORED

$$\mathrm{Br}(B_c^- \rightarrow \chi_{c1} a_1^-) = 1.81 \pm 0.11 \pm 0.01 \times 10^{-4}$$

$$\mathrm{Br}(B_c^- \rightarrow h_{c1} a_1^-) = 1.36 \pm 0.08 \pm 0.10 \times 10^{-4}$$

$$\mathrm{Br}(B_c^- \rightarrow D_{s1}^- \chi_{c1}) = 1.22 \pm 0.15 \pm 0.05 \times 10^{-4}$$

$$\mathrm{Br}(B_c^- \rightarrow h_{c1} D_{s1}^-) = 3.15 \pm 0.19 \pm 0.18 \times 10^{-5}$$

$$\mathrm{Br}(B_c^- \rightarrow \underline{D}_{s1}^- \chi_{c1}) = 2.88 \pm 0.27 \pm 0.06 \times 10^{-5}$$

$$\mathrm{Br}(B_c^- \rightarrow h_{c1} \underline{D}_{s1}^-) = 1.77 \pm 0.07 \pm 0.06 \times 10^{-5}$$

CKM SUPPRESSED

$$\mathrm{Br}(B_c^- \to \chi_{c1}\underline{K}_1^-) = 1.18 \pm 0.07 \pm 0.01 \times 10^{-5}$$

$$\mathrm{Br}(B_c^- \to \chi_{c1}K_1^-) = 6.76 \pm 0.40 \pm 0.04 \times 10^{-6}$$

$$\mathrm{Br}(B_c^- \to h_{c1}\underline{K}_1^-) = 6.63 \pm 0.40 \pm 0.45 \times 10^{-6}$$

$$\mathrm{Br}(B_c^- \to h_{c1}K_1^-) = 4.99 \pm 0.30 \pm 0.34 \times 10^{-6}$$

$$\mathrm{Br}(B_c^- \to D_1^- \chi_{c1}) = 7.48 \pm 0.92 \pm 0.50 \times 10^{-6}$$

$$\mathrm{Br}(B_c^- \to \bar{D}_1^0 a_1^-) = 3.41 \pm 0.20^{+1.30}_{-0.77} \times 10^{-6}$$

$$\mathrm{Br}(B_c^- \to \underline{D}_1^- \chi_{c1}) = 1.60 \pm 0.15 \pm 0.04 \times 10^{-6}$$

$$\mathrm{Br}(B_c^- \to D_1^- h_{c1}) = 1.79 \pm 0.11 \pm 0.01 \times 10^{-6}$$

Recent measurements of the order of 10^6 has been reported in PDG for various *p-wave* final states of B meson decays

Detailed Results for $B_c \rightarrow VA$ Decays

Branching ratios and helicity amplitudes of $B_c \to VA$ decays for CKM-favored $(\Delta b = 1, \Delta C = 0, \Delta S = -1)$ mode.

Decays	Branching Ratios	Helicity Amplitudes		
		$\|H_0\|$	$\|H_+\|$	$\|H_-\|$
$B_c^- J/\psi a_1^-$	$4.14 \pm 0.26 \pm 0.05 \times 10^{-3}$	$1.66 \pm 0.05 \pm 0.01 \times 10^{-1}$	$3.68 \pm 0.11 \pm 0.08 \times 10^{-2}$	$1.04 \pm 0.03 \pm 0.01 \times 10^{-1}$
$B_c^- J/\psi b_1^-$	$2.90 \pm 0.18 \pm 0.04 \times 10^{-8}$	$4.38 \pm 0.13 \pm 0.02 \times 10^{-4}$	$9.77 \pm 0.33 \pm 0.23 \times 10^{-5}$	$2.74 \pm 0.07 \pm 0.03 \times 10^{-4}$
$B_c^- \to \rho^- \chi_{c1}$	$1.47 \pm 0.15 \pm 0.01 \times 10^{-3}$	$1.16 \pm 0.04 \pm 0.01 \times 10^{-1}$	$2.70 \pm 0.08 \pm 0.01 \times 10^{-2}$	$3.83 \pm 0.12 \pm 0.31 \times 10^{-3}$
$B_c^- \to \rho^- h_{c1}$	$1.24 \pm 0.08 \pm 0.01 \times 10^{-3}$	$1.12 \pm 0.04 \pm 0.01 \times 10^{-1}$	$1.05 \pm 0.03 \pm 0.03 \times 10^{-2}$	$5.10 \pm 0.15 \pm 0.17 \times 10^{-3}$
$B_c^- \to D^{*0} D_1^-$	$2.92 \pm 0.84^{+0.52}_{-0.28} \times 10^{-5}$	$1.52 \pm 0.22^{+0.11}_{-0.9} \times 10^{-2}$	$5.64 \pm 0.83^{+0.61}_{-0.37} \times 10^{-3}$	$2.67 \pm 0.30^{+0.40}_{-0.26} \times 10^{-3}$
$B_c^- \to D^{*0} \underline{D}_1^-$	$2.43 \pm 0.70^{+0.44}_{-0.23} \times 10^{-6}$	$4.38 \pm 0.64^{+0.47}_{-0.28} \times 10^{-3}$	$1.52 \pm 0.22 \pm 0.02 \times 10^{-3}$	$0.91 \pm 0.14^{+2.04}_{-1.60} \times 10^{-3}$
$B_c^- \to D^{*-} D_1^0$	$1.19 \pm 0.34 \pm 0.16 \times 10^{-6}$	$1.96 \pm 0.29 \pm 0.16 \times 10^{-3}$	$1.35 \pm 0.20 \pm 0.28 \times 10^{-4}$	$2.67 \pm 0.39 \pm 0.22 \times 10^{-3}$
$B_c^- \to D^{*-} \underline{D}_1^0$	$3.71 \pm 1.06 \pm 0.51 \times 10^{-7}$	$1.09 \pm 0.16 \pm 0.93 \times 10^{-3}$	$7.43 \pm 1.09 \pm 1.55 \times 10^{-5}$	$1.49 \pm 0.22 \pm 0.12 \times 10^{-3}$

Branching ratios and helicity amplitudes of $B_c \to VA$ decays for CKM-suppressed $(\Delta b = 1, \Delta C = 1, \Delta S = -1)$ mode.

Decays	Branching Ratios	Helicity Amplitudes		
		$\lvert H_0 \rvert$	$\lvert H_+ \rvert$	$\lvert H_- \rvert$
$B_c^- J/\psi D_{s1}^-$	$2.35 \pm 0.25 \pm 0.01 \times 10^{-3}$	$1.26 \pm 0.18 \pm 0.01 \times 10^{-1}$	$7.06 \pm 0.49 \pm 0.02 \times 10^{-2}$	$1.04 \pm 0.05 \pm 0.00 \times 10^{-1}$
$B_c^- J/\psi \underline{D}_{s1}^-$	$6.33 \pm 0.49 \pm 0.06 \times 10^{-4}$	$6.18 \pm 0.25 \pm 0.02 \times 10^{-2}$	$3.73 \pm 0.19 \pm 0.05 \times 10^{-2}$	$6.57 \pm 0.22 \pm 0.02 \times 10^{-2}$
$B_c^- \to D_s^{*-} \chi_{c1}$	$1.08 \pm 0.08 \pm 0.01 \times 10^{-3}$	$9.85 \pm 0.20 \pm 0.02 \times 10^{-2}$	$8.05 \pm 0.25 \pm 0.03 \times 10^{-2}$	$3.10 \pm 1.40 \pm 0.92 \times 10^{-2}$
$B_c^- \to D_s^{*-} h_{c1}$	$8.11 \pm 0.48 \pm 0.12 \times 10^{-4}$	$1.02 \pm 0.03 \pm 0.05 \times 10^{-1}$	$3.97 \pm 0.11 \pm 0.09 \times 10^{-2}$	$2.61 \pm 0.08 \pm 0.07 \times 10^{-2}$
$B_c^- \to K^{*-} \bar{D}_1^0$	$5.29 \pm 0.31^{+1.12}_{-0.57} \times 10^{-7}$	$2.04 \pm 0.06^{+0.20}_{-0.12} \times 10^{-3}$	$3.10 \pm 0.09^{+0.35}_{-0.21} \times 10^{-4}$	$1.04 \pm 0.03^{+0.22}_{-0.14} \times 10^{-4}$
$B_c^- \to K^{*-} \underline{\bar{D}}_1^0$	$6.08 \pm 0.37^{+1.35}_{-0.67} \times 10^{-8}$	$6.92 \pm 0.20^{+0.74}_{-0.42} \times 10^{-4}$	$8.57 \pm 0.26 \pm 0.40 \times 10^{-5}$	$5.12 \pm 0.15^{+1.26}_{-0.92} \times 10^{-5}$
$B_c^- \to \bar{D}^{*0} K_1^-$	$3.92 \pm 0.23 \pm 0.73 \times 10^{-8}$	$4.57 \pm 0.13 \pm 0.45 \times 10^{-4}$	$1.82 \pm 0.05 \pm 0.39 \times 10^{-5}$	$3.12 \pm 0.09 \pm 0.29 \times 10^{-4}$
$B_c^- \to \bar{D}^{*0} \underline{K}_1^-$	$6.29 \pm 0.36 \pm 1.17 \times 10^{-8}$	$5.66 \pm 0.14 \pm 0.55 \times 10^{-4}$	$2.72 \pm 0.08 \pm 0.51 \times 10^{-5}$	$4.19 \pm 0.12 \pm 0.39 \times 10^{-4}$
$B_c^- \to D_s^{*-} a_1^0$	$1.43 \pm 0.41 \pm 0.08 \times 10^{-9}$	$0.89 \pm 0.13 \pm 0.31 \times 10^{-5}$	$5.36 \pm 0.78 \pm 0.54 \times 10^{-6}$	$5.58 \pm 0.82 \pm 0.21 \times 10^{-5}$
$B_c^- \to D_s^{*-} f_1$	$1.44 \pm 0.41 \pm 0.08 \times 10^{-9}$	$0.89 \pm 0.13 \pm 0.31 \times 10^{-5}$	$5.55 \pm 0.81 \pm 0.54 \times 10^{-5}$	$5.79 \pm 0.85 \pm 0.21 \times 10^{-5}$
$B_c^- \to \phi D_{s1}^-$	$6.61 \pm 1.90 \pm 0.30 \times 10^{-9}$	$2.27 \pm 0.33 \pm 0.06 \times 10^{-4}$	$3.73 \pm 0.55 \pm 0.10 \times 10^{-5}$	$0.95 \pm 0.14 \pm 0.07 \times 10^{-5}$
$B_c^- \to \phi \underline{D}_{s1}^-$	$4.79 \pm 1.38 \pm 0.20 \times 10^{-10}$	$6.08 \pm 0.90 \pm 0.16 \times 10^{-5}$	$1.32 \pm 0.19 \pm 0.15 \times 10^{-5}$	$3.68 \pm 0.54 \pm 0.47 \times 10^{-6}$
$B_c^- \to \rho^0 D_{s1}^-$	$6.65 \pm 1.94 \pm 0.30 \times 10^{-9}$	$2.27 \pm 0.33 \pm 0.06 \times 10^{-4}$	$2.79 \pm 0.41 \pm 0.10 \times 10^{-5}$	$7.02 \pm 1.03 \pm 0.72 \times 10^{-6}$
$B_c^- \to \rho^0 \underline{D}_{s1}^-$	$5.00 \pm 1.44 \pm 0.20 \times 10^{-10}$	$6.22 \pm 0.91 \pm 0.15 \times 10^{-5}$	$1.00 \pm 0.15 \pm 0.02 \times 10^{-5}$	$2.79 \pm 0.41 \pm 0.47 \times 10^{-6}$
$B_c^- \to \omega D_{s1}^-$	$4.15 \pm 1.19 \pm 0.18 \times 10^{-10}$	$5.67 \pm 0.83 \pm 0.15 \times 10^{-5}$	$7.08 \pm 1.04 \pm 0.25 \times 10^{-6}$	$1.78 \pm 0.26 \pm 0.18 \times 10^{-6}$
$B_c^- \to \omega \underline{D}_{s1}^-$	$3.12 \pm 0.90 \pm 0.12 \times 10^{-11}$	$1.55 \pm 0.23 \pm 0.04 \times 10^{-5}$	$2.53 \pm 0.37 \pm 0.04 \times 10^{-6}$	$7.08 \pm 1.04 \pm 1.10 \times 10^{-7}$

Detailed Results for $B_c \rightarrow AA$ Decays

Branching ratios and helicity amplitudes of $B_c \to AA$ decays for CKM-favored $(\Delta b = 1, \Delta C = 1, \Delta S = 0)$ mode.

Decays	Branching Ratios	Helicity Amplitudes		
		$\lvert H_0\rvert$	$\lvert H_+\rvert$	$\lvert H_-\rvert$
$B_c^- \to \chi_{c1} a_1^-$	$1.81 \pm 0.11 \pm 0.01 \times 10^{-4}$	$2.15 \pm 0.06 \pm 0.17 \times 10^{-4}$	$6.20 \pm 0.19 \pm 0.52 \times 10^{-3}$	$4.36 \pm 0.13 \pm 0.02 \times 10^{-2}$
$B_c^- \to b_1^- \chi_{c1}$	$1.26 \pm 0.07 \pm 0.01 \times 10^{-9}$	$5.61 \pm 0.17 \pm 0.45 \times 10^{-7}$	$1.64 \pm 0.05 \pm 0.13 \times 10^{-5}$	$1.15 \pm 0.03 \pm 0.00 \times 10^{-4}$
$B_c^- \to h_{c1} a_1^-$	$1.36 \pm 0.08 \pm 0.10 \times 10^{-4}$	$3.32 \pm 0.10 \pm 0.19 \times 10^{-2}$	$8.57 \pm 0.25 \pm 0.29 \times 10^{-3}$	$1.72 \pm 0.05 \pm 0.05 \times 10^{-2}$
$B_c^- \to h_{c1} b_1^-$	$9.52 \pm 0.58 \pm 0.67 \times 10^{-10}$	$8.77 \pm 0.26 \pm 0.50 \times 10^{-5}$	$2.27 \pm 0.07 \pm 0.08 \times 10^{-5}$	$4.55 \pm 0.14 \pm 0.13 \times 10^{-5}$
$B_c^- \to D_1^- D_1^0$	$3.10 \pm 0.90^{+0.81}_{-0.49} \times 10^{-6}$	$4.18 \pm 0.61^{+0.72}_{-0.51} \times 10^{-3}$	$1.33 \pm 0.19^{+0.23}_{-0.16} \times 10^{-3}$	$3.50 \pm 0.50^{+0.41}_{-0.23} \times 10^{-3}$
$B_c^- \to \underline{D}_1^0 D_1^-$	$1.00 \pm 0.30^{+0.25}_{-0.15} \times 10^{-6}$	$2.33 \pm 0.34^{+0.41}_{-0.28} \times 10^{-3}$	$7.42 \pm 1.09 \pm 0.10 \times 10^{-4}$	$1.95 \pm 0.28^{+0.21}_{-0.13} \times 10^{-3}$
$B_c^- \to \underline{D}_1^- D_1^0$	$3.66 \pm 1.01^{+0.60}_{-0.30} \times 10^{-7}$	$1.60 \pm 0.23^{+0.14}_{-0.09} \times 10^{-3}$	$5.53 \pm 0.91^{+1.26}_{-0.95} \times 10^{-4}$	$0.94 \pm 0.14^{+0.02}_{-0.00} \times 10^{-3}$
$B_c^- \to \underline{D}_1^- \underline{D}_1^0$	$1.14 \pm 0.33^{+0.18}_{-0.09} \times 10^{-7}$	$0.89 \pm 0.13^{+0.08}_{-0.05} \times 10^{-3}$	$3.08 \pm 0.45^{+0.71}_{-0.53} \times 10^{-4}$	$5.20 \pm 0.76^{+0.10}_{-0.03} \times 10^{-4}$

Branching ratios and helicity amplitudes of $B_c \to AA$ decays for CKM-favored $(\Delta b = 1, \Delta C = 0, \Delta S = -1)$ mode.

Decays	Branching Ratios	Helicity Amplitudes		
		$\lvert H_0 \rvert$	$\lvert H_+ \rvert$	$\lvert H_- \rvert$
$B_c^- \to h_{c1} D_{s1}^-$	$3.15 \pm 0.19 \pm 0.18 \times 10^{-5}$	$5.59 \pm 0.17 \pm 0.79 \times 10^{-3}$	$1.40 \pm 0.46 \pm 0.03 \times 10^{-2}$	$1.96 \pm 0.06 \pm 0.04 \times 10^{-2}$
$B_c^- \to \chi_{c1} D_{s1}^-$	$1.22 \pm 0.15 \pm 0.05 \times 10^{-4}$	$1.66 \pm 0.15 \pm 0.15 \times 10^{-2}$	$2.91 \pm 0.71 \pm 1.11 \times 10^{-3}$	$4.51 \pm 0.27 \pm 0.05 \times 10^{-2}$
$B_c^- \to \underline{D}_{s1}^- \chi_{c1}$	$2.88 \pm 0.27 \pm 0.06 \times 10^{-5}$	$8.28 \pm 0.54 \pm 0.58 \times 10^{-3}$	$2.98 \pm 0.72 \pm 0.10 \times 10^{-3}$	$2.31 \pm 0.11 \pm 0.01 \times 10^{-2}$
$B_c^- \to h_{c1} \underline{D}_{s1}^-$	$1.17 \pm 0.07 \pm 0.06 \times 10^{-5}$	$4.89 \pm 0.15 \pm 0.44 \times 10^{-3}$	$8.93 \pm 0.27 \pm 0.21 \times 10^{-3}$	$1.21 \pm 0.04 \pm 0.02 \times 10^{-2}$
$B_c^- \to \underline{K}_1^- \bar{D}_1^0$	$1.90 \pm 0.12^{+0.70}_{-0.42} \times 10^{-7}$	$1.16 \pm 0.03^{+0.24}_{-0.15} \times 10^{-3}$	$1.73 \pm 0.05^{+0.33}_{-0.23} \times 10^{-4}$	$5.10 \pm 0.15^{+0.59}_{-0.33} \times 10^{-4}$
$B_c^- \to \underline{\bar{D}}_1^0 K_1^-$	$1.30 \pm 0.08^{+0.23}_{-0.10} \times 10^{-8}$	$3.08 \pm 0.09^{+0.26}_{-0.14} \times 10^{-4}$	$6.18 \pm 0.19^{+1.50}_{-1.12} \times 10^{-4}$	$1.04 \pm 0.04 \pm 0.02 \times 10^{-4}$
$B_c^- \to \bar{D}_1^0 K_1^-$	$1.22 \pm 0.07^{+0.48}_{-0.27} \times 10^{-7}$	$9.35 \pm 0.28^{+1.75}_{-1.24} \times 10^{-4}$	$1.25 \pm 0.04^{+0.23}_{-0.17} \times 10^{-4}$	$3.70 \pm 0.11^{+0.42}_{-0.24} \times 10^{-4}$
$B_c^- \to \underline{\bar{D}}_1^0 \underline{K}_1^-$	$2.00 \pm 0.10^{+0.34}_{-0.15} \times 10^{-8}$	$3.78 \pm 0.12^{+0.32}_{-0.17} \times 10^{-4}$	$8.39 \pm 0.25^{+0.20}_{-0.15} \times 10^{-5}$	$1.41 \pm 0.05 \pm 0.03 \times 10^{-4}$
$B_c^- \to \underline{D}_{s1}^- a_1^0$	$2.84 \pm 0.82 \pm 0.09 \times 10^{-10}$	$4.57 \pm 0.68 \pm 0.10 \times 10^{-5}$	$4.51 \pm 0.66 \pm 0.75 \times 10^{-6}$	$1.62 \pm 0.24 \pm 0.02 \times 10^{-5}$
$B_c^- \to \underline{D}_{s1}^- f_1$	$2.75 \pm 0.79 \pm 0.90 \times 10^{-10}$	$4.49 \pm 0.66 \pm 0.10 \times 10^{-5}$	$4.71 \pm 0.70 \pm 0.75 \times 10^{-6}$	$1.65 \pm 0.25 \pm 0.03 \times 10^{-5}$
$B_c^- \to D_{s1}^- a_1^0$	$1.02 \pm 0.29 \pm 0.16 \times 10^{-9}$	$7.88 \pm 1.16 \pm 0.90 \times 10^{-5}$	$1.15 \pm 0.17 \pm 0.12 \times 10^{-5}$	$4.54 \pm 0.67 \pm 0.16 \times 10^{-5}$
$B_c^- \to D_{s1}^- f_1$	$1.02 \pm 0.29 \pm 0.16 \times 10^{-9}$	$7.83 \pm 1.16 \pm 0.90 \times 10^{-5}$	$1.20 \pm 0.18 \pm 0.13 \times 10^{-5}$	$4.71 \pm 0.69 \pm 0.16 \times 10^{-5}$

SUMMARY AND CONCLUSIONS

❖We have studied the hadronic weak decays of uniquely observed bottom-charm (B_c) meson made up of both heavy quarks

❖For the B_c to A transition form factors appearing in the decay matrix elements, we employ ISGW II model because it provide the more reliable form factors as compared to other models. We obtained the decay amplitude and consequently predicted the branching ratios for B_c *to PA /VA* decays.

❖In case of B_c meson, one naively expects the bottom conserving modes (*c* to *u, s transitions*) to be kinematically suppressed in comparison to the bottom changing ones. However, the large CKM angle involved in the charm changing modes overcomes the kinematics suppression. Consequently, bottom changing decays get suppressed in comparison to bottom conserving decays.

❖In general, branching ratios of B_c to VA decays involving axial-vector mesons $A(^3P_1)$ in the final state are larger compared to the decays involving axial-vector mesons $A(^1P_1)$ in the final state.

❖For most of the decays, the magnitude of the helicity component of the longitudinal polarization amplitude is larger compared to the transverse amplitudes.

❖Since LHC and LHC-b are expected to accumulate data for more than 10^{10} B_c events per year, we hope that predicted BRs will soon be measured in these experiments Measurements of their branching ratios provide a useful test of our model.

THANK YOU