Rare Weak Decays of B_c^* and B_s^* Meson

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Plan of the talk

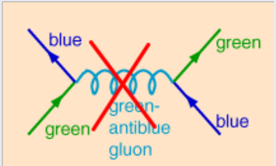
- B_c^* and B_s^* Meson
- Decays of B_c^* Meson
- Theoretical Framework
- Form factors and Wavefunction
- Results

B_c^* and B_s^* Meson

- B_c^* Meson is one of the crucial particle.
- Around 10^5 B_c^* Events can be expected in one operation year [2].
- B_s^* Meson has higher branching ratio than B_c^* Meson

Strong decays

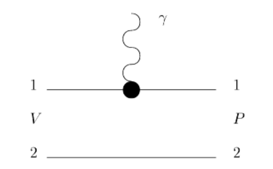
Strong decays are Forbidden



Feynman diagram for an interaction between quarks generated by a gluon.

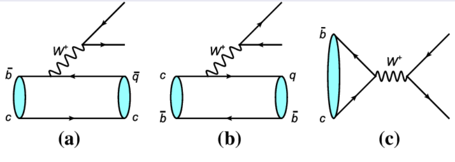
Decays of B_c^* Meson

Radiative decays



Weak decays

Diagrams for weak decays



Theoretical Framework

Effective Hamiltonian

Effective Hamiltonian for $b \to c$ decays

$$\mathcal{H}_{eff} = \frac{G_f}{\sqrt{2}} V_{cb}^* V_{qq'} \left[c_1 Q_1 + c_2 Q_2 \right],$$

$$Q_1 = \left(\bar{b}_\alpha c_\beta\right)_{V-A} \left\{ \left(\bar{u}_\beta d_\alpha\right)_{V-A} + \left(\bar{u}_\beta s_\alpha\right)_{V-A} + \left(\bar{c}_\beta d_\alpha\right)_{V-A} + \left(\bar{c}_\beta s_\alpha\right)_{V-A} \right\},$$

$$Q_2 = \left(\bar{b}_\alpha c_\alpha\right)_{V-A} \left\{ \left(\bar{u}_\beta d_\beta\right)_{V-A} + \left(\bar{u}_\beta s_\beta\right)_{V-A} + \left(\bar{c}_\beta d_\beta\right)_{V-A} + \left(\bar{c}_\beta s_\beta\right)_{V-A} \right\}$$

- G_f - Fermi coupling constant,
- V_{ij} - CKM mixing matrix element,
- c_i - Wilson coefficient.

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{\mathrm{ud}} & V_{\mathrm{us}} & V_{\mathrm{ub}} \\ V_{\mathrm{cd}} & V_{\mathrm{cs}} & V_{\mathrm{cb}} \\ V_{\mathrm{td}} & V_{\mathrm{ts}} & V_{\mathrm{tb}} \end{pmatrix}$$

Decaywidth and amplitude relations

- For $B_c^* \to P_1 P_2$ decays

$$\Gamma\left(B_c^* \to P_1 P_2\right) = \frac{p_c^3}{24\pi m_{B_c^*}^2} \left|A\left(B_c^* \to P_1 P_2\right)\right|^2 \tag{1}$$

- For $B_c^* \to PV$ decays

$$\Gamma\left(B_c^* \to PV\right) = \frac{p_c^3}{24\pi m_{B_c^*}^2} \left|A\left(B_c^* \to PV\right)\right|^2, \tag{2}$$

$$p_c = \frac{1}{2m_{B_c^*}} \left\{ \left[m_{B_c^*}^2 - \left(m_{P_1} + m_{P_2}\right)^2 \right] \left[m_{B_c^*}^2 - \left(m_{P_1} - m_{P_2}\right)^2 \right] \right\}^{\frac{1}{2}} \tag{3}$$

Decay amplitudes

$A\big(B_c^* \to P_1 P_2\big) \sim \langle P_1 P_2 | \mathcal{H}_{eff} | B_c^* \rangle \sim \langle P_1 | J^\mu | 0 \rangle \langle P_2 | J_\mu | B_c^* \rangle,$
$A\big(B_c^* \to PV\big) \sim \langle V | J^\mu | 0 \rangle \langle P | J_\mu | B_c^* \rangle,$
$\langle P_1 | J^\mu | 0 \rangle = -i f_p k_\mu$
$\langle V | J^\mu | 0 \rangle = \epsilon_\mu f_V m_V$

- Current matrix element

$$\begin{aligned}\langle P | J_\mu | B_c^* \rangle &= \frac{1}{m_{B_c^*} + m_p} \varepsilon_{\mu\nu\rho\sigma} \varepsilon^\nu_{B_c^*} \big(P_{B_c^*} + P_p\big)^\rho q^\sigma V\big(q^2\big) \\ &\quad -i(m_{B_c^*} + m_P) \varepsilon^\mu_{B_c^*} A_1\big(q^2\big) \\ &\quad -i \frac{\varepsilon_{B_c^*}}{m_{B_c^*} + m_P} \big(P_{B_c^*} + P_p\big)^\mu A_2\big(q^2\big) \\ &\quad +i \frac{\varepsilon_{B_c^*}.q}{q^2} \big(2 m_{B_c^*}\big) q^\mu A_3\big(q^2\big) \\ &\quad -i \frac{\varepsilon_{B_c^*}.q}{q^2} \big(2 m_{B_c^*}\big) q^\mu A_0\big(q^2\big) \qquad (4)\end{aligned}$$

BSW Model

Form factors

$$A_0^{B_c^* P}(0) = A_3^{B_c^* P} = \int d^2\mathbf{p_T} \int_0^1 dx \left(\psi^{*1,0}_{B_c^*}(\mathbf{p_T}, x)\sigma_z^0 \psi_P(\mathbf{p_T}, x)\right)$$

$$I = \sqrt{2} \int d^2\mathbf{p_T} \int_0^1 \frac{dx}{x} \left(\psi^{*-1,1}_{B_c^*}(\mathbf{p_T}, x) i\sigma_y^1 \psi_P(\mathbf{p_T}, x)\right)$$

$$V(0) = \frac{m_{q_1(B_c^*)} - m_{q_1(V)}}{m_{B_c^*} - m_P} I,$$

$$A_1(0) = \frac{m_{q_1(B_c^*)} + m_{q_1(V)}}{m_{B_c^*} + m_P} I.$$

$A_2(0)$ can be written in terms of the $A_1(0)$ and $A_0(0)$

wavefunction

$$\Psi_m(\mathbf{p_T}, x) = N_m \sqrt{x(1-x)} \exp\left(-\frac{\mathbf{p_T}^2}{2\omega^2}\right) \exp\left(-\frac{m^2}{2\omega^2}\left(x - \frac{1}{2} - \frac{m_{q_1^2} - m_{q_2^2}}{2m^2}\right)^2\right)$$

- N_m is the normalization constant.
- $x = \frac{p_z}{\mathbf{P}}$, $\mathbf{p_T} = (p_x, p_y)$ are the fraction of the longitudinal and transverse quark momentum of the non spectator quark.

Flavor Dependent Effects

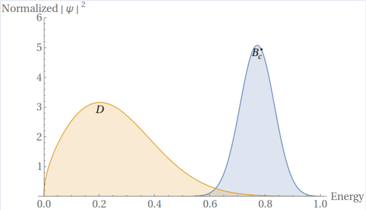
ω is the dimensional quantity that represent the average transverse quark momentum $\omega = \langle p_T^2 \rangle$

$|\Psi(0)|^2 = constant \times \omega^3$

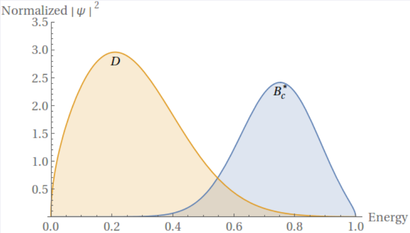
$|\Psi(0)|^2 = \frac{9 m_i m_j}{32 \alpha_s \pi}(m_V - m_P)$

Overlap of wave functions of B_c^* and D Mesons

$\omega = 0.40$

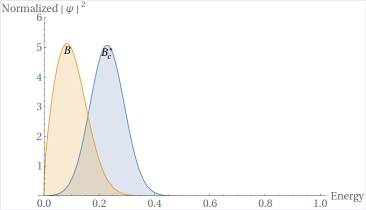


$\omega = 0.87$ and $\omega = 0.43$



Overlap of wave functions of B_c^* and B Mesons

$\omega = 0.40$



$\omega = 0.87$ and $\omega = 0.43$

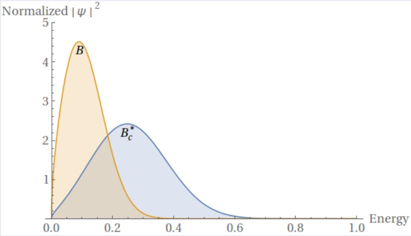


Table : $|\Psi(0)|^2$ and ω values for vector and pseudoscalar mesons

Meson	$\|\Psi(0)\|^2$ in (GeV^3)	Flavor dependent ω in (GeV)
$K(K^*)$	0.011	0.32
$\rho(\pi)$	0.011	0.32
$\eta(\omega)$	0.004	0.23
$\eta'(\phi)$	0.001	0.14
$D(D^*)$	0.025	0.42
$D_s(D_s^*)$	0.040	0.50
$\eta_c(\psi)$	0.114	0.71
$B(B^*)$	0.03	0.46
$B_s(B_s^*)$	0.05	0.54
$B_c(B_c^*)$	0.21	0.87

Formfactors

Table : Formfactors for B_c^* decays .

Decay	V	A_0	A_1	A_2
$B_c^{*+} \to B^+$	5.192	0.443	0.681	2.193
$B_c^{*-} \to \bar{D}^0$	0.117	0.0638	0.0725	-0.047
$\bar{B}_s^{*0} \to K^+$	0.302	0.261	0.284	-0.234
$\bar{B}_s^{*0} \to D_s^+$	0.772	0.667	0.722	-0.551
$B_c^{*-} \to \eta_c$	0.836	0.555	0.602	-0.422
$\bar{B}_s^{*0} \to \eta_c$	0.462	0.200	0.163	-0.327

Numerical results of Branching ratios

Table : Branching ratios for CKM enhanced modes

Mode	Transition $B_c^* \to PP$	Flavor dependent
Bottom Changing decays ($\Delta b = 1$)		
$\Delta C = 0, \Delta S = -1$	$B_c^{*-} \to \eta_c D_s^-$	1.59×10^{-8}
$\Delta C = 1, \Delta S = 0$	$B_c^{*-} \to \eta_c \pi^-$	1.41×10^{-9}
	$B_c^{*-} \to D^- D^0$	5.69×10^{-10}
Bottom Conserving decays ($\Delta b = 0$)		
$\Delta C = -1, \Delta S = -1$	$B_c^{*+} \to B_s^0 \pi^+$	4.89×10^{-7}
	$B_c^{*+} \to B^+ \bar{K}^0$	9.21×10^{-8}

- Bottom conserving modes are enhanced upto $\mathcal{O}(10^{-7})$.

Numerical results of Branching ratios

Table : Branching ratios for CKM enhanced modes

Mode	Transition $B_c^* \to PV$	Flavor dependent
Bottom Changing decays ($\Delta b = 1$)		
$\Delta C = 0, \Delta S = -1$	$B_c^{*-} \to \eta_c D_s^{*-}$	2.81×10^{-5}
	$B_c^{*-} \to \bar{D}^0 K^{*-}$	2.05×10^{-12}
$\Delta C = 1, \Delta S = 0$	$B_c^{*-} \to \eta_c \rho^-$	2.73×10^{-8}
	$B_c^{*-} \to D^- D^{*0}$	5.50×10^{-10}
Bottom Conserving decays ($\Delta b = 0$)		
$\Delta C = -1, \Delta S = -1$	$B_c^{*+} \to B_s^0 \rho^+$	1.11×10^{-6}
	$B_c^{*+} \to B^+ \bar{K}^{*0}$	1.48×10^{-7}

Numerical results of Branching ratios

Table : Branching ratios for CKM enhanced modes

Mode	Transition $B_s^* \to PP$	Flavor dependent
Bottom Changing decays ($\Delta b = 1$)		
$\Delta C = 0, \Delta S = -1$	$\bar{B}_s^{*0} \to D_s^- D_s^+$	3.33×10^{-8}
	$\bar{B}_s^{*0} \to \eta_c \eta$	1.48×10^{-9}
	$\bar{B}_s^{*0} \to \eta_c \eta'$	2.65×10^{-10}
$\Delta C = 1, \Delta S = 0$	$\bar{B}_s^{*0} \to D_s^+ \pi^-$	1.23×10^{-8}
	$\bar{B}_s^{*0} \to D^0 K^0$	9.61×10^{-10}

Numerical results of Branching ratios

Table : Branching ratios for CKM enhanced modes

Mode	Transition $B_s^* \to PV$	Flavor dependent
Bottom Changing decays ($\Delta b = 1$)		
$\Delta C = 0, \Delta S = -1$	$\bar{B}_s^{*0} \to D_s^- D_s^{*+}$	2.08×10^{-4}
	$\bar{B}_s^{*0} \to K^- K^{*+}$	2.01×10^{-4}
	$\bar{B}_s^{*0} \to \eta_c \omega$	2.33×10^{-5}
	$\bar{B}_s^{*0} \to \eta' \omega$	6.62×10^{-6}
	$\bar{B}_s^{*0} \to \eta \omega$	4.89×10^{-7}
	$\bar{B}_s^{*0} \to \eta_c \phi$	1.85×10^{-8}
	$\bar{B}_s^{*0} \to \eta' \phi$	5.27×10^{-9}
$\Delta C = 1, \Delta S = 0$	$\bar{B}_s^{*0} \to D^0 K^{*0}$	1.83×10^{-6}
	$\bar{B}_s^{*0} \to D_s^+ \rho^-$	2.12×10^{-8}

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