Semileptonic decays of B_c involving vector mesons in self-consistent covariant light-front quark model

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Introduction

The form factors of semileptonic $B_c \to V$ meson decays are calculated in the framework of covariant light-front quark model. We have investigated the self-consistency in these form factors by studying type-I scheme. We find that the form factors obtained by covariant light-front approach within type-I correspondence scheme are inconsistent. But this can be resolved by employing generalized correspondence type-II scheme, which advocates an additional replacement $M \to M_0$relative to the traditional type-I scheme. Further, we predicted total branching fractions of various semileptonic decays of B_c mesons on the basis of these form factors and helicity formalism.

Self-consistent Covariant Light-Front Quark Model

Inconsistency Puzzle : $[\mathcal{Q}]^{\lambda=0}_{CLF} \neq [\mathcal{Q}]^{\lambda=\pm}_{CLF}$

Type-I correspondence:

$$\sqrt{2N_c}\frac{\chi_V(x_1, \mathbf{k}_\perp^{'('')})}{x_2} \to \frac{\psi_V(x_1, \mathbf{k}_\perp^{'('')})}{\sqrt{x_1 x_2}\hat{M}_0^{'('')}}, \qquad D^{'('')}_{V,con} \to D^{'('')}_{V,LF},$$

where $\hat{M}_0^{'('')} \equiv \sqrt{M_0^{'('')} - (m_1^{'('')} - m_2)^2}$.

$D^{'('')}_{V,con} = M^{'('')} + m_1^{'('')} + m_2$ and $D^{'('')}_{V,LF} = M_0^{'('')} + m_1^{'('')} + m_2$.

$$M_0^{'('')} = \sqrt{\frac{m_1^{'('')2} + k_\perp^{'('')2}}{x_1} + \frac{m_2^2 + k_\perp^{'('')2}}{x_2}} \quad \text{with } \mathbf{k}''_\perp = \mathbf{k}'_\perp - x_2 \mathbf{q}_\perp.$$

A suitable choice for the radial wave function is the phenomenological Gaussian-type wave function, *i.e.*,

$$\psi(x_1, \mathbf{k}'_\perp) = 4\frac{\pi^{\frac{3}{4}}}{\beta^{\frac{3}{2}}}\sqrt{\frac{\partial k'_z}{\partial x_1}}\exp\left[-\frac{k_z'^2 + k_\perp'^2}{2\beta^2}\right]$$

Type-II correspondence:

$$\sqrt{2N_c}\frac{\chi_V(x_1, \mathbf{k}_\perp^{'('')})}{x_2} \to \frac{\psi_V(x_1, \mathbf{k}_\perp^{'('')})}{\sqrt{x_1 x_2}\hat{M}_0^{'('')}}, \qquad M^{'('')} \to M_0^{'('')}.$$

B_c to V Form Factors

$$\langle V(P'', \varepsilon'')|V_\mu|B_c(P')\rangle = \epsilon_{\mu\nu\alpha\beta}\varepsilon''^{*\nu}P^\alpha q^\beta g(q^2),$$

$$\langle V(P'', \varepsilon'')|A_\mu|B_c(P')\rangle = -i\{\varepsilon''^* f(q^2) + \epsilon^{*''}.P[P_\mu a_+(q^2) + q_\mu a_-(q^2)]\}$$

The form factors $g(q^2)$, $f(q^2)$, $a_+(q^2)$, $a\_(q^2)$ are related to the commonly used BSW form factors $V(q^2)$, $A_0(q^2)$, $A_1(q^2)$, $A_2(q^2)$, $A_3(q^2)$:

$$V^{B_cV}(q^2) = -\left(M_{B_c} + M_V\right)g(q^2)$$

$$A_1^{B_cV}(q^2) = -\frac{f(q^2)}{M_{B_c} + M_V}$$

$$A_2^{B_cV}(q^2) = \left(M_{B_c} + M_V\right)a_+(q^2)$$

$$A_3^{B_cV}(q^2) - A_0^{B_cV}(q^2) = \frac{q^2}{2M_V}a\_(q^2)$$

q^2 dependence

The form factor is expressed as:

$$F(q^2) = \frac{1}{1 - \frac{q^2}{M_{pole}^2}}\sum_{k=0}^{K} a'_k[z(q^2) - z(0)]^k$$

where a'_k are real coefficients and $z(q^2) \equiv z(q^2, t_0)$ is the function

$$z(q^2) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}}$$

$t_+ = (M_{B_c} + M_V)^2$ and $t_0 = (M_{B_c} + M_V)(\sqrt{M_{B_c}} - \sqrt{M_V})^2$.

Semileptonic decays

The differential distribution of the B_c meson semileptonic decay to the final ground state vector meson V has the following expression:

$$\frac{d\Gamma(B_c \to V l \nu_l)}{dq^2} = \frac{G_F^2}{(2\pi)^3}|V_{q_1 q_2}|^2\frac{q^2\sqrt{\lambda}}{24 M_{B_c}^3}\left(1 - \frac{m_l^2}{q^2}\right)^2 H_{total}$$

Total helicity structure: $H_{total} = \left(H_U + H_L\right)\left(1 + \frac{m_l^2}{2q^2}\right) + \frac{3m_l^2}{2q^2}H_s$

$$\lambda = M_{B_c}^4 + M_V^4 + q^4 - 2(M_{B_c}^2 M_V^2 + M_V^2 q^2 + M_{B_c}^2 q^2)$$

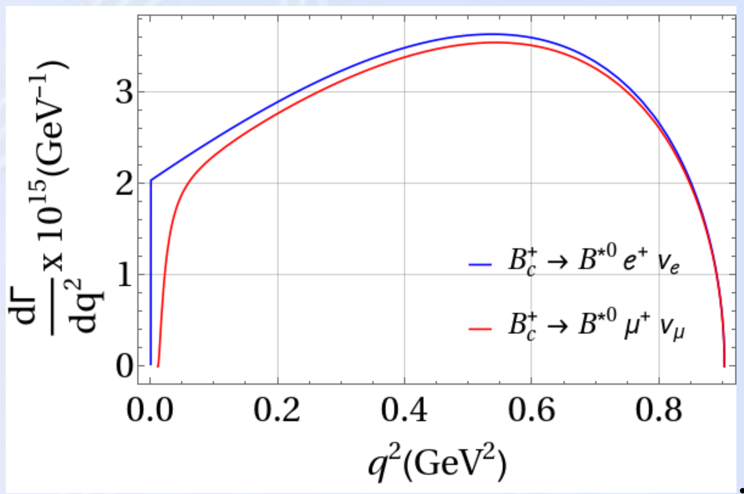
$$H_U = |H_+|^2 + |H_-|^2; \quad H_L = |H_0|^2; \quad H_S = |H_t|^2$$

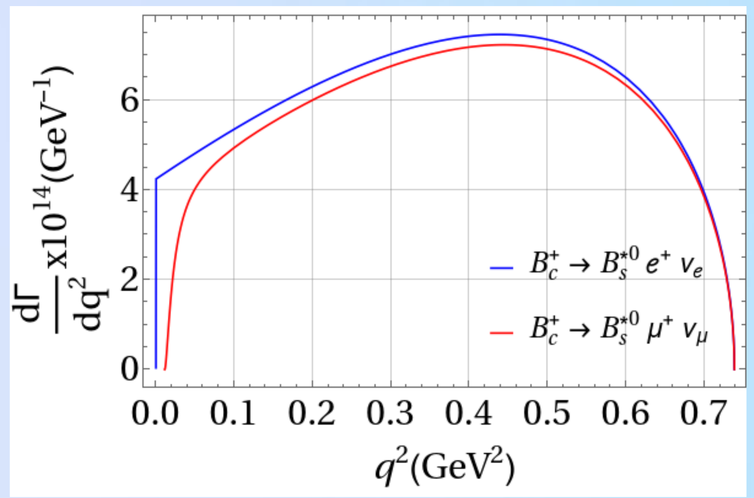
$$H_\pm(q^2) = \left(M_{B_c} + M_V\right)A_1(q^2) \mp \frac{\sqrt{\lambda}}{M_{B_c} + M_V}V(q^2)$$

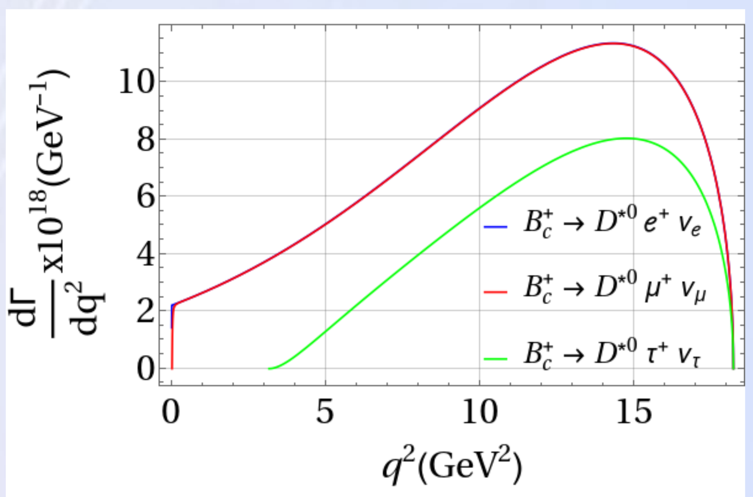
$$H_0(q^2) = \frac{1}{2M_V\sqrt{q^2}}(M_{B_c} + M_V)(M_{B_c}^2 - M_V^2 - q^2)A_1(q^2) - \frac{\lambda}{M_{B_c} + M_V}A_2(q^2)$$

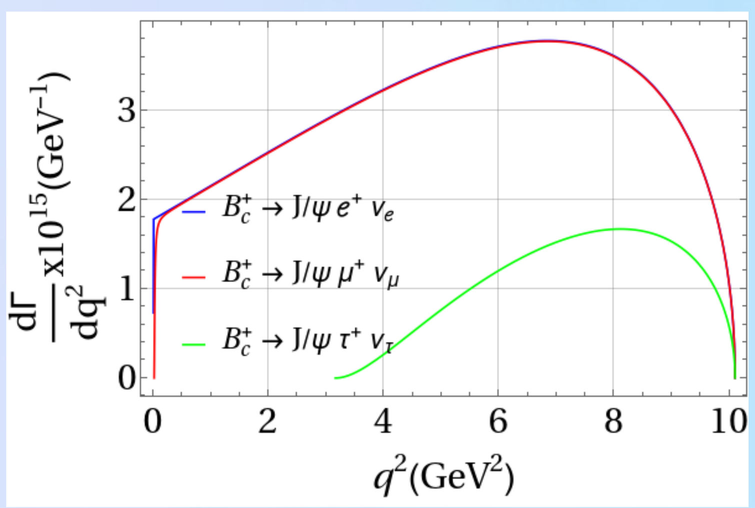
$$H_t(q^2) = \frac{\sqrt{\lambda}}{\sqrt{q^2}}A_0(q^2)$$

Results









- Numerical results for the Type-II scheme are larger by (50− 60)% for bottom-conserving semileptonic decays, (57− 78)% for $B_c \to D^*$, and around 20% for $B_c \to J/\psi$ as compared to the branching ratios in the Type-I scheme.
- Decay width ratios of bottom-conserving semileptonic decays involving pseudoscalar meson (B_s^0 and B^0) in final state for T2B match well with LQCD expectations.

	Ours	LQCD
$\frac{\Gamma(B_c^+ \to B_s^0 e^+\nu_e)\lvert V_{cd}\rvert^2}{\Gamma(B_c^+ \to B^0 e^+\nu_e)\lvert V_{cs}\rvert^2} =$	$0.82^{+0.19+0.02}_{-0.20-0.00}$	$0.759 \pm 0.044;$
$\frac{\Gamma(B_c^+ \to B_s^0 \mu^+\nu_\mu)\lvert V_{cd}\rvert^2}{\Gamma(B_c^+ \to B^0 \mu^+\nu_\mu)\lvert V_{cs}\rvert^2} =$	$0.81^{+0.19+0.02}_{-0.20-0.00}$	$0.759 \pm 0.044;$

- Our **LFU ratio** involving $b \to c\tau\nu_\tau$ for J/ψ in the final state match well with LQCD and other theoretical models; however, are smaller than the experimental measurement ($\mathcal{R}^{LHCb}_{J/\psi} = 0.71 \pm 0.18 \pm 0.17$; $\mathcal{R}^{CMS}_{J/\psi}$= 0.49±0.26).

	Ours	LQCD
$\mathcal{R}_{J/\psi} = \frac{\mathcal{B}(B_c^+ \to J/\psi\tau^+\nu_\tau)}{\mathcal{B}(B_c^+ \to J/\psi e(\mu)^+\nu_{e(\mu)})} =$	$0.25^{+0.05+0.02}_{-0.06-0.00}$	**0.2582±0.0038.**

References

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