Is there any New Physics?

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Abstract

In the wake of the recent measurements of the decays $B_c \to J/\psi\, \pi(K)$ and $B_c \to J/\psi\, \ell\nu_\ell$ reported by the LHCb Collaboration we calculate the form factors for the $B_c \to J/\psi$ and $B_c \to \eta_c$ transitions in full kinematical region within covariant confined quark model. Then we use the calculated form factors to evaluate the partial decay widths of the above-mentioned semileptonic and nonleptonic decays of the B_c meson. We find that the theoretical predictions on the ratios of $R_{K+/\pi+}$ and $R_{\pi+/\mu+\nu}$ are in good agreement with last LHCb-data. However, the prediction for the $R_{J/\psi}$ is found to be underestimated.

Motivation

The first measurement that relates semileptonic and hadronic decay rates of the B^+_c meson was performed by the LHCb Collaboration [1]. The measured value of the ratio of branching fractions,

$$R_{\pi+/\mu+\nu} = B(B^+_c \to J/\psi\, \pi^+) / B(B^+_c \to J/\psi\, \mu^+ \nu_\mu) = 0.0469 \pm 0.0028(\text{stat}) \pm 0.0046(\text{syst}),$$

was found at the lower end of available theoretical predictions.

The decay $B^+_c \to J/\psi\, K^+$ was observed for the first time by the LHCb Collaboration [10]. The ratio of the branching fractions were measured to be

$$R_{K+/\pi+} = B(B^+_c \to J/\psi\, K^+) B(B^+_c \to J/\psi\, \pi^+) = \begin{cases} 0.069 \pm 0.019(\text{stat}) \pm 0.005(\text{syst})\ [10] \\ 0.079 \pm 0.007(\text{stat}) \pm 0.003(\text{syst})\ [11] \end{cases}$$

The **theoretical predictions** for this ratio lie in the range from **0.054 to 0.088.**

Recently, LHCb collaboration reported about measurement of the ratio of semileptonic branching fractions $R_{J/\psi}$ [15]:

$$R_{J/\psi} = B(B^+_c \to J/\psi\, \tau^+ \nu_\tau) B(B^+_c \to J/\psi\, \mu^+ \nu_\mu) = 0.71 \pm 0.17(\text{stat}) \pm 0.18(\text{syst}).$$

This result lies within 2 standard deviations above the predictions obtained in several theoretical models based on the Standard Model. Note that the semileptonic B_c decays provide an excellent laboratory to measure the CKM-matrix elements: V_{cb}, V_{ub}, V_{cs} and V_{cd}. The theoretical description of semileptonic and nonleptonic decays is, however, nontrivial problem because one needs to know the transition form factors characterizing the strong transition of the B_c to the charmonium.

Covariant Confined Quark Model

The effective Lagrangian describing the transition of a meson $M(q_1\bar{q}_2)$ to its constituent quarks q_1 and $\bar{q}_2$ in model looks like

$$\mathbb{L}_{int}(x) = g_M\, M(x) \cdot J_M(x) + h.c.,$$

$$J_M(x) = \int dx_1 \int dx_2\, F_M(x, x_1, x_2)\, \bar{q}_2(x_2) \Gamma_M q_1(x_1),$$

with Γ_M a Dirac matrix which projects onto the spin quantum number of the meson field $M(x)$. The vertex function F_M characterizes the finite size of the meson. Translational invariance requires the function F_M to fulfill the identity $F_M(x + a, x_1 + a, x_2 + a) = F_M(x, x_1, x_2)$ for any four-vector a. A specific form for the vertex function is

$$F_M(x, x_1, x_2) = \delta(x - w_1 x_1 - w_2 x_2)\, \Phi_M((x_1 - x_2)^2),$$

where Φ_M is the correlation function of the two constituent quarks with masses m_{q1}, m_{q2} and the mass ratios $w_i = m_{qi} / (m_{q1} + m_{q2})$. A simple Gaussian form of the vertex function $\bar{\Phi}_M(-k^2)$ is selected

$$\bar{\Phi}_M(-k^2) = \exp\left(k^2/\Lambda^2_M\right),$$

with the parameter Λ_M linked to the size of the meson. The minus sign in the argument is chosen to indicate that we are working in the Minkowski space.

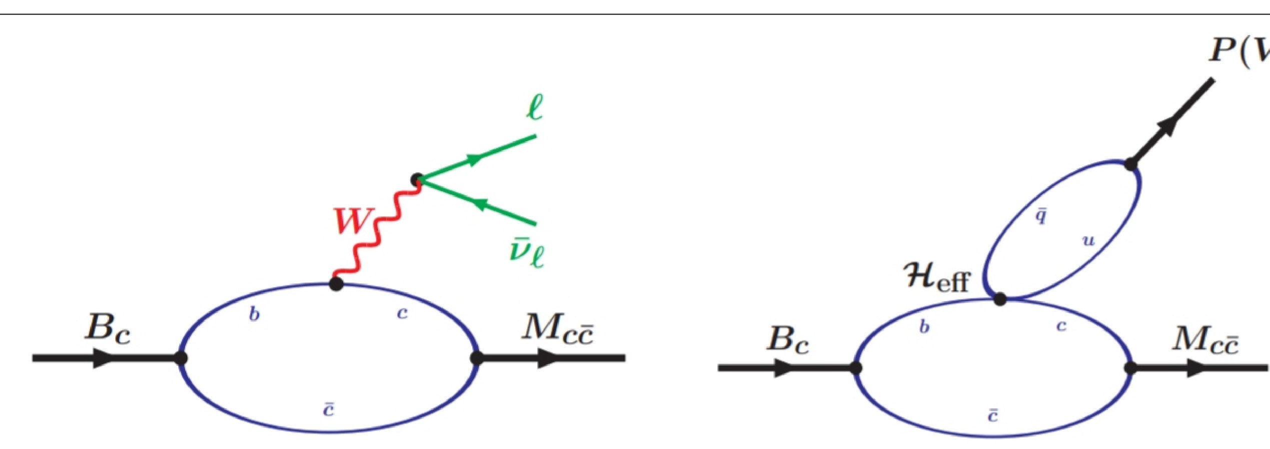

Figure 1: Pictorial representation of the semileptonic and nonleptonic B_c decays.

Results

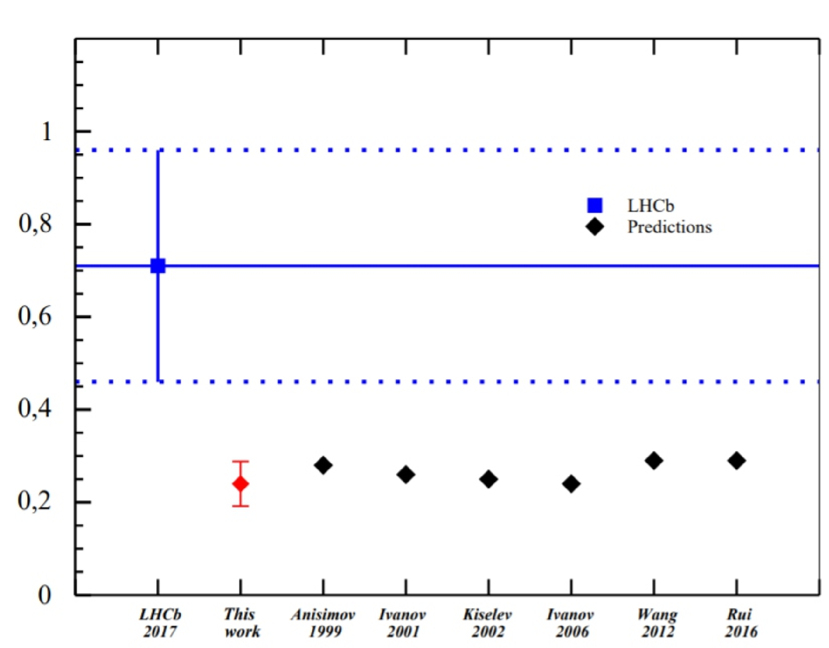

Figure 2: Theoretical predictions vs. LHCb data [15] for the ratio $\mathcal{R}_{J/\psi}$. Solid line-central experimental value, dotted lines–experimental error bar.

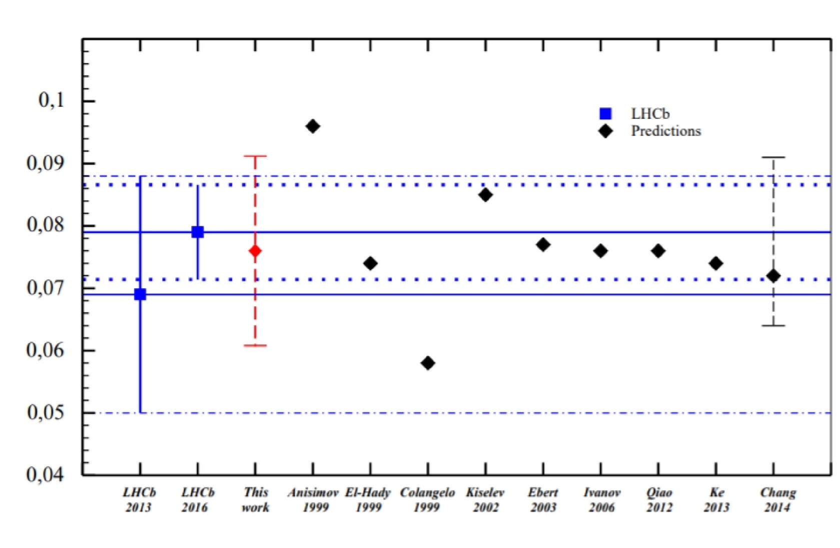

Figure 3: Theoretical predictions vs. LHCb data [10] and [11] for the ratio $\mathcal{R}_{K^+/\pi^+}$. Two solid lines- central experimental values, dash-dotted lines–experimental error bar from [10], dotted lines–experimental error bar from [11].

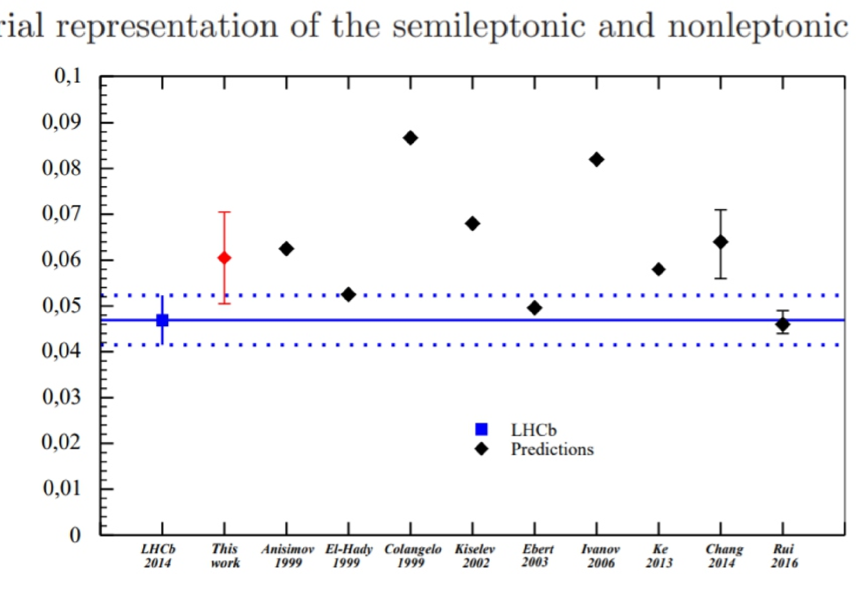

Figure 4: Theoretical predictions vs. LHCb data [1] for the ratio $\mathcal{R}_{\pi^+/\mu^+\nu_\mu}$. Solid line-central experimental value, dotted lines–experimental error bar.

Table 5: The ratios of branching fractions.

Ref.	$\mathcal{R}_{\pi^+/\mu^+\nu}$	$\mathcal{R}_{K^+/\pi^+}$	$\mathcal{R}_{\eta_c}$	$\mathcal{R}_{J/\psi}$
LHCb [1]	0.0469 ± 0.0054			
LHCb[10]		0.069 ± 0.019		
LHCb [11]		0.079 ± 0.0076		
LHCb[15]				0.71 ± 0.25
This work	0.0605 ± 0.012	0.076 ± 0.015	0.26 ± 0.05	0.24 ± 0.05
[3]	0.0525	0.074		
[4]	0.0866	0.058		
[5]	0.0625	0.096	0.34	0.28
[6]	0.058	0.075		
[7]	0.068	0.085	0.31	0.25
[8]	0.0496	0.077		
[9]	0.082	0.076	0.27	0.24
[14]		0.075		
[16]	$0.064^{+0.007}_{-0.008}$	$0.072^{+0.019}_{-0.008}$		
[18, 27]	$0.046^{+0.003}_{-0.002}$	0.082	0.63 ± 0.0	$0.29^{+0.01}_{-0.00}$
[19]			0.31	0.29
[22]			0.28	0.26

Summary & Discussion

- We have calculated the semileptonic and nonleptonic decays of the B_c meson within CCQM and found that the ratios of the branching fractions $R_{\pi+/\mu+\nu}$ and $R_{K+/\pi+}$ are in good agreement with the LHCb data and other theoretical approaches. At the same time theoretical predictions for the ratio $R_{J/\psi}$ are more than $2\,\sigma$ less than the experimental data. This may indicate on the possibility of New physics effects in this decay.

- **The last data for the R_{D^*}** reported by Belle Coll. [29] are consistent with the theoretical predictions of the Standard Model, the average data given by HFAG [30] **are still different from the SM at the level of $4\,\sigma$**. Since our result for **$R_{J/\psi}$ is different from the data at the level of $2\,\sigma$**, we can urge to more precise measurement of the $B_c \to J/\psi\, \ell\nu_\ell$ channel which currently has quite large uncertainties . At the same time we found that **the theoretical predictions for the ratio $R_{K/\pi}$ are well consistent with the experimental data**. This might be very important since **it may imply that the new physics (if there is any) has strong couplings to the leptons but not hadrons**.

References are given in Phys.Lett. B783 (2018) 178-182