Semileptonic and nonleptonic decays of $B_c$

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Summary. Using our relativistic constituent quark model we present results on the exclusive nonleptonic and semileptonic decays of the $B_c$-meson. The nonleptonic decays are studied in the framework of the factorization approximation. We calculate the branching ratios for a large set of exclusive nonleptonic and semileptonic decays of the $B_c$ meson and compare our results with the results of other models.

1 Introduction

The $B_c$-meson is the lowest bound state of two heavy quarks (charm and bottom) with open flavor. The $B_c$-meson therefore decays weakly via (i) $b$-quark decay, (ii) $c$-quark decay, and (iii) the annihilation channel. Starting from the pioneering paper [1], the modern state of art in the spectroscopy, production and decays of the $B_c$-meson can be found in the review [2].

The first observation of the $B_c$ meson was reported by the CDF Collaboration at Fermilab [3] in the semileptonic decay mode $B_c \rightarrow J/\psi + l + \nu$ with the $J/\psi$ decaying into muon pairs. Values for the mass and the lifetime of the $B_c$ meson were given as $M(B_c) = 6.40 \pm 0.39 \pm 0.13$ GeV and $\tau(B_c) = 0.46^{+0.12}_{-0.16}(\text{stat}) \pm 0.03(\text{syst})$ ps. Recently, CDF reported new value for the mass of $B_c$ meson, $6.2857 \pm 0.0053(\text{stat}) \pm 0.0012(\text{syst})$ GeV with errors significantly smaller than in the first measurement. Also D0 has observed the $B_c$ in the semileptonic mode $B_c \rightarrow J/\psi + \mu + X$ and reported preliminary evidence that $M(B_c) = 5.95^{+0.14}_{-0.13} \pm 0.34$ GeV and $\tau(B_c) = 0.45^{+0.12}_{-0.10} \pm 0.12$ ps [5].

In the following we report on the results of an analysis of almost all accessible low-lying exclusive nonleptonic two-body and semileptonic three-body modes of the $B_c$-decays [6] within our relativistic constituent quark model [7, 8, 9, 10]. In [6] we updated the free parameters of the model by using
the latest experimental data on the $B_c$-mass [4] and the weak decay constant $f_D$ [11]. We give a set of numerical values for the leptonic, semileptonic and nonleptonic partial decay widths of the $B_c$-meson and compare them with the results of other approaches.

2 Results and discussions

The constituent relativistic quark model we employ to study $B_c$ decays was developed in [7, 8, 9, 10] and successfully applied to a very large class of weak decays (see for example [12]). For technical details regarding the model we refer the interested reader to ref [6]. Here we present our results on the semileptonic decays into charmonia, into ($B_s^0, B_s^{*0}, D^0, D^{*0}, B^0, B^{*0}$)(cf. table 1) and on the two body nonleptonic $B_c$ decays (cf. tables 2 and 3). Tables 2 and 3 contain numerical results corresponding to processes with branching ratios larger than 0.1%. For the complete list see the tables in [6].

Table 1. Branching ratios (in %) of exclusive semileptonic $B_c$ decays. $\psi(3836)$. $\tau(B_c) = 0.45$ ps.

| Mode                              | [6] | [13, 14] | [15] | [16] | [17] | [18] |
|-----------------------------------|-----|---------|------|-----|------|------|
| $B_c^- \rightarrow \eta^+ e^\nu$  | 0.81| 0.75    | 0.97 | 0.40| 0.76 | 0.51 |
| $B_c^- \rightarrow \eta^+ \tau^\nu$| 0.22| 0.23    | -    | -   | -    | -    |
| $B_c^- \rightarrow J/\psi e^\nu$  | 2.07| 1.9     | 2.35 | 1.21| 2.01 | 1.44 |
| $B_c^- \rightarrow J/\psi \tau^\nu$| 0.49| 0.48    | -    | -   | -    | -    |
| $B_c^- \rightarrow D^0 e^\nu$     | 0.0035| 0.004    | 0.006| 0.001| 0.003| 0.0014 |
| $B_c^- \rightarrow D^0 \tau^\nu$  | 0.0021| 0.002    | -    | -   | -    | -    |
| $B_c^- \rightarrow D^{*0} e^\nu$  | 0.0038| 0.018    | 0.018| 0.008| 0.013| 0.0023 |
| $B_c^- \rightarrow D^{*0} \tau^\nu$| 0.0022| 0.008    | -    | -   | -    | -    |
| $B_c^- \rightarrow \bar{B}^0 e^\nu$| 1.10| 4.03    | 1.82 | 0.82| 0.98 | 0.92 |
| $B_c^- \rightarrow \bar{B}^0 \tau^\nu$| 2.37| 5.06    | 3.01 | 1.71| 3.45 | 1.41 |
| $B_c^- \rightarrow \bar{B}^{*0} e^\nu$| 0.071| 0.34    | 0.16 | 0.04| 0.078| 0.048 |
| $B_c^- \rightarrow \bar{B}^{*0} \tau^\nu$| 0.063| 0.58    | 0.23 | 0.12| 0.24 | 0.051 |

From the tables we observe that our results are generally close to the QCD sum rule results of [13, 14] and the constituent quark model results of [15, 16, 17] for the $b \rightarrow c$ induced decays. In exception are the ($b \rightarrow c; c \rightarrow (s,d)$) results of [15] which are considerably smaller than our results, and smaller than the results of the other model calculations. Summing up the exclusive contributions one obtains a branching fraction of 8.8%. Considering the fact that the $b \rightarrow c$ contribution to the total rate is expected to be about 20% [2] this leaves plenty of room for nonresonant multibody decays.

For the $c \rightarrow s$ induced decays our branching ratios are considerably smaller than those predicted by QCD sum rules [13, 14] but are generally close to
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Table 2. Branching ratios (in %) of exclusive nonleptonic $B_c$ decays with the choice of Wilson coefficient: $a_1^c = 1.20$ and $a_2^c = -0.317$ for $c$-decay, and $a_1^b = 1.14$ and $a_2^b = -0.20$ for $b$-decay. Modes with branching ratios smaller than 0.1% can be found in table V of ref [6].

| Mode                   | This work | [13, 14] | [15] | [16] | [17] |
|------------------------|-----------|----------|------|------|------|
| $B_c^+ \to \eta^c \pi^-$ | 0.19      | 0.20     | 0.18 | 0.083| 0.14 |
| $B_c^+ \to \eta^c \rho^-$ | 0.45      | 0.42     | 0.49 | 0.20 | 0.33 |
| $B_c^+ \to J/\psi \pi^-$ | 0.17      | 0.13     | 0.18 | 0.060| 0.11 |
| $B_c^+ \to J/\psi \rho^-$ | 0.49      | 0.40     | 0.53 | 0.16 | 0.31 |
| $B_c^- \to \eta^c D_s^+$ | 0.44      | 0.28     | 0.054| -    | 0.26 |
| $B_c^- \to \eta^c D_s^{*-}$ | 0.37      | 0.27     | 0.044| -    | 0.24 |
| $B_c^- \to J/\psi D_s^+$ | 0.34      | 0.17     | 0.041| -    | 0.15 |
| $B_c^- \to J/\psi D_s^{*-}$ | 0.97      | 0.67     | -   | -    | 0.55 |
| $B_c^+ \to \overline{B} \_s \pi^-$ | 3.9       | 16.4     | 5.75 | 2.46 | 4.56 |
| $B_c^- \to \overline{B} \_s \rho^-$ | 2.3       | 7.2      | 4.41 | 1.38 | 3.86 |
| $B_c^- \to \overline{B} \_s^{0} \pi^-$ | 2.1       | 6.5      | 5.08 | 1.58 | 1.23 |
| $B_c^- \to \overline{B} \_s^{0} \rho^-$ | 11        | 20.2     | 14.8 | 10.8 | 16.8 |
| $B_c^- \to \overline{B} \_s K^+$ | 0.29      | 1.06     | 0.41 | 0.21 | 0.17 |
| $B_c^- \to \overline{B} \_s^{0} K^-$ | 0.13      | 0.37     | 0.29 | 0.11 | 0.13 |
| $B_c^- \to \overline{B} \_s^{0} K^{*-}$ | 0.50      | -        | -   | -    | 1.14 |
| $B_c^- \to \overline{B} \_s \pi^-$ | 0.20      | 1.06     | 0.32 | 0.10 | 0.10 |
| $B_c^- \to \overline{B} \_s \rho^-$ | 0.20      | 0.96     | 0.59 | 0.13 | 0.28 |
| $B_c^- \to \overline{B} \_s^{0} \rho^-$ | 0.30      | 2.57     | 1.17 | 0.67 | 0.89 |
| $B_c^- \to B^+ \overline{K}^{*-}$ | 0.38      | 1.98     | 0.66 | 0.23 | 0.27 |
| $B_c^- \to B^- \overline{K}^{*-0}$ | 0.11      | 0.43     | 0.47 | 0.09 | 0.32 |
| $B_c^- \to B^+ \overline{K}^{*-0}$ | 0.32      | 1.67     | 0.97 | 0.82 | 1.70 |

Table 3. The same as of table 2.

| Mode                   | [6] | [20] | [21] | [22] |
|------------------------|-----|------|------|------|
| $B_c^- \to h_2 \pi^-$ | 0.11| 0.05 | 1.60 | -    |
| $B_c^- \to h_2 \rho^-$ | 0.13| 0.072| 3.20 | -    |
| $B_c^- \to h_2 \rho^-$ | 0.25| 0.12 | 5.33 | -    |
| $B_c^- \to h_2 \rho^-$ | 0.12| 0.051| 3.20 | 0.023|

the other constituent quark model results. When we sum up our exclusive branching fractions we obtain a total branching ratio of 27.6% which has to be compared with the 70% expected for the $c \to s$ contribution to the total rate [2]. The sum rule model of [13, 14] gives a summed branching fraction of 73.4% for the $c \to s$ contribution, i.e. the model of [13, 14] predicts that the exclusive channels pretty well saturate the $c \to s$ part of the total rate.
3 Conclusions

In the coming few years one can expect large data samples on exclusive $B_c$ decays at the TEVATRON and at the LHC. We are looking forward to a comparison of our model results with the upcoming experimental data.

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