Bogoliubov Laboratory of Theoretical Physics
JOINT INSTITUTE FOR NUCLEAR RESEARCH

Decays of B_c meson

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in collaboration with:

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Experimental data

Relative decay rates of B_c meson.

Parameter	Measurements	Average
$\mathcal{B}(B_c^- \to J/\psi D_s^-)/\mathcal{B}(B_c^- \to J/\psi\pi^-)$	LHCb [5]: $2.90 \pm 0.57 \pm 0.24$ ATLAS [13]: $3.8 \pm 1.1 \pm 0.4$	3.09 ± 0.55
$\mathcal{B}(B_c^- \to J/\psi D_s^{*-}/\mathcal{B}(B_c^- \to J/\psi D_s^-)$	ATLAS [13]: $2.8\,^{+1.2}_{-0.8} \pm 0.3$ LHCb [5]: $2.37 \pm 0.56 \pm 0.10$	2.69 ± 0.78
$\mathcal{B}(B_c^- \to J/\psi D_s^{*-}/\mathcal{B}(B_c^- \to J/\psi\pi^-)$	ATLAS [13]: $10.4 \pm 3.1 \pm 1.6$	10.4 ± 3.5
$\mathcal{B}(B_c^- \to J/\psi K^-)/\mathcal{B}(B_c^- \to J/\psi\pi^-)$	LHCb [29]: $0.069 \pm 0.019 \pm 0.005$	0.069 ± 0.020
$\mathcal{B}(B_c^- \to J/\psi K^- K^+\pi^-)/\mathcal{B}(B_c^- \to J/\psi\pi^-)$	LHCb [12]: $0.53 \pm 0.10 \pm 0.05$	0.53 ± 0.11
$\mathcal{B}(B_c^- \to J/\psi\pi^+\pi^-\pi^-)/\mathcal{B}(B_c^- \to J/\psi\pi^-)$	LHCb [30]: $3.0 \pm 0.6 \pm 0.4$ LHCb [10]: $2.41 \pm 0.30 \pm 0.33$ CMS [31]: $2.55 \pm 0.80\,^{+0.33}_{-0.33}$	2.57 ± 0.35
$\mathcal{B}(B_c^- \to \psi(2S)\pi^-)/\mathcal{B}(B_c^- \to J/\psi\pi^-)$	LHCb [32]: $0.268 \pm 0.032 \pm 0.009$	0.268 ± 0.033

Covariant quark model

$$\mathcal{L}_{\rm int}^{\rm str}(x) = g_M M(x) \int dx_1 \int dx_2 F_M(x, x_1, x_2)\, \bar{q}_1(x_1)\, \Gamma_M\, q_2(x_2) \,+\, \text{H.c.}$$

$$F_M(x, x_1, x_2) \,=\, \delta^{(4)}(x - \sum_{i=1}^{2} w_i x_i)\, \Phi_M\Big((x_1 - x_2)^2\Big)$$

$$\widetilde{\Phi}_M(-k^2) = \exp(k^2/\Lambda_M^2)$$

* G.V. Efimov and M.A. Ivanov, Int. J. Mod. Phys. A 4 (1989) 2031.

Compositeness condition in covariant quark model

$$Z_M = 1 - g_M^2 \Pi'_M(m_M^2) = 0$$

$$\tilde{\Pi}_P(p^2) = N_c \int \frac{d^4k}{(2\pi)^4 i} \tilde{\Phi}_P^2(-k^2) \mathrm{tr}\Big(\gamma^5 S_1(k+w_1 p)\gamma^5 S_2(k-w_2 p)\Big),$$

$$\begin{aligned}\tilde{\Pi}_V^{\mu\nu}(p) &= N_c \int \frac{d^4k}{(2\pi)^4 i} \tilde{\Phi}_V^2(-k^2) \mathrm{tr}\Big(\gamma^\mu S_1(k+w_1 p)\gamma^\nu S_2(k-w_2 p)\Big) \\ &= g^{\mu\nu}\tilde{\Pi}_V(p^2) + p^\mu p^\nu \tilde{\Pi}_V^{\parallel}(p^2)\end{aligned}$$

*** S. Weinberg, Phys. Rev. 130 (1963) 776.**

*** A. Salam, Nuovo Cim. 25 (1962) 224.**

Model parameters

$m_{u/d}$	m_s	m_c	m_b	λ	
0.241	0.428	1.67	5.05	0.181	GeV

Λ_{B_c}	Λ_{η_c}	$\Lambda_{J/\psi}$	Λ_D	Λ_{D^*}	Λ_{D_s}	$\Lambda_{D_s^*}$	Λ_B	Λ_{B^*}	Λ_{B_s}	
2.73	3.87	1.74	1.6	1.53	1.75	1.56	1.96	1.8	2.05	GeV

m_{B_c}	m_{η_c}	$m_{J/\psi}$	m_D	m_{D^*}	m_{D_s}	$m_{D_s^*}$		τ_{B_c}
6.275	2.984	3.097	1.869	2.010	1.968	2.112	GeV	$0.507ps$

***C. Patrignani et al. [Particle Data Group], Chin. Phys. C 40 (2016) no.10, 100001.**

Leptonic decay constants

$$M(H_{12} \to \bar{l}\nu) = \frac{G_F}{\sqrt{2}} V_{q_1 q_2} \mathcal{M}_H^{\mu}(p)\, \bar{u}_l(k_l)\, O^{\mu}\, u_\nu(k_\nu),$$

$$\mathcal{M}_H^{\mu}(p) = -3\, g_{12} \int \frac{d^4k}{(2\pi)^4 i} \widetilde{\Phi}_{12}\left(-k^2\right) \mathrm{tr}\left[\Gamma_H \widetilde{S}_2(k - c_{12}^2\, p)\, O^{\mu}\, \widetilde{S}_1(k + c_{12}^1\, p)\right],$$

$$\Gamma_P = i\gamma^5, \quad \Gamma_V = \varepsilon_V \cdot \gamma,$$

$$\mathcal{M}_P^{\mu}(p) = -i f_P p^{\mu}, \qquad \mathcal{M}_V^{\mu}(p) = f_V m_V \varepsilon_V^{\mu}.$$

f_{B_c}	f_{η_c}	$f_{J/\psi}$	f_D	f_{D^*}	f_{D_s}	$f_{D_s^*}$
489	628	415	206	244	257	272

*** Dubnicka, Dubnickova, Issadykov, Ivanov, Liptaj, Phys.Rev. D96 (2017) no.7, 076017**

Parameters

TABLE I. Values of the Wilson coefficients.

C_1	C_2	C_3	C_4	C_5	C_6
−0.2632	1.0111	−0.0055	−0.0806	0.0004	0.0009

*S. Descotes-Genon, T. Hurth, J. Matias, and J. Virto, J. High Energy Phys. 05 (2013) 137.

TABLE V. Values of the CKM-matrix elements.

$\|V_{ud}\|$	$\|V_{us}\|$	$\|V_{cd}\|$	$\|V_{cs}\|$	$\|V_{cb}\|$	$\|V_{ub}\|$
0.974	0.225	0.220	0.995	0.0405	0.00409

*C. Patrignani et al. [Particle Data Group], Chin. Phys. C 40 (2016) no.10, 100001.

The Invariant Form factors definition

$$\mathcal{M}^{\mu}_{S=0} = P^{\mu} F_{+}(q^2) + q^{\mu} F_{-}(q^2),$$

$$\mathcal{M}^{\mu}_{S=1} = \frac{1}{m_1 + m_2} \epsilon^{\dagger}_{\nu} \{ -g^{\mu\nu} Pq A_0(q^2) + P^{\mu} P^{\nu} A_{+}(q^2) + q^{\mu} P^{\nu} A_{-}(q^2) + i \varepsilon^{\mu\nu\alpha\beta} P_{\alpha} q_{\beta} V(q^2) \},$$

$$P = p_1 + p_2, \qquad q = p_1 - p_2.$$

Definition of the Helicity Form factors

(a) Spin $S = 0$:

$$\begin{aligned} H_t &= \frac{1}{\sqrt{q^2}} \left\{ (m_1^2 - m_2^2)\, F_+ + q^2\, F_- \right\} , \\ H_\pm &= 0\,, \\ H_0 &= \frac{2\, m_1\, |\mathbf{p_2}|}{\sqrt{q^2}}\, F_+\,. \end{aligned}$$

(b) Spin $S = 1$:

$$\begin{aligned} H_t &= \frac{1}{m_1 + m_2} \frac{m_1\, |\mathbf{p_2}|}{m_2 \sqrt{q^2}} \left\{ (m_1^2 - m_2^2)\,(A_+ - A_0) + q^2 A_- \right\} , \\ H_\pm &= \frac{1}{m_1 + m_2} \left\{ -(m_1^2 - m_2^2)\, A_0 \pm 2\, m_1\, |\mathbf{p_2}|\, V \right\} , \\ H_0 &= \frac{1}{m_1 + m_2} \frac{1}{2\, m_2 \sqrt{q^2}} \left\{ -(m_1^2 - m_2^2)\,(m_1^2 - m_2^2 - q^2)\, A_0 + 4\, m_1^2\, |\mathbf{p_2}|^2\, A_+ \right\} . \end{aligned}$$

Form factors B_c decays

TABLE IV. $q^2 = 0$ results for the various form factors.

	$B_c \to D$	$B_c^+ \to D_s$	$B_c \to \eta_c$
$F_+(0)$	0.186	0.254	0.74
$F_-(0)$	−0.160	−0.202	−0.39
	$B_c \to D^*$	$B_c \to D_s^*$	$B_c \to J/\psi$
$A_0(0)$	0.276	0.365	1.65
$A_+(0)$	0.151	0.190	0.55
$A_-(0)$	−0.236	−0.293	−0.87
$V(0)$	0.230	0.282	0.78

*** Dubnicka, Dubnickova, Issadykov, Ivanov, Liptaj, Phys.Rev. D96 (2017) no.7, 076017**

Form factors B_c decays

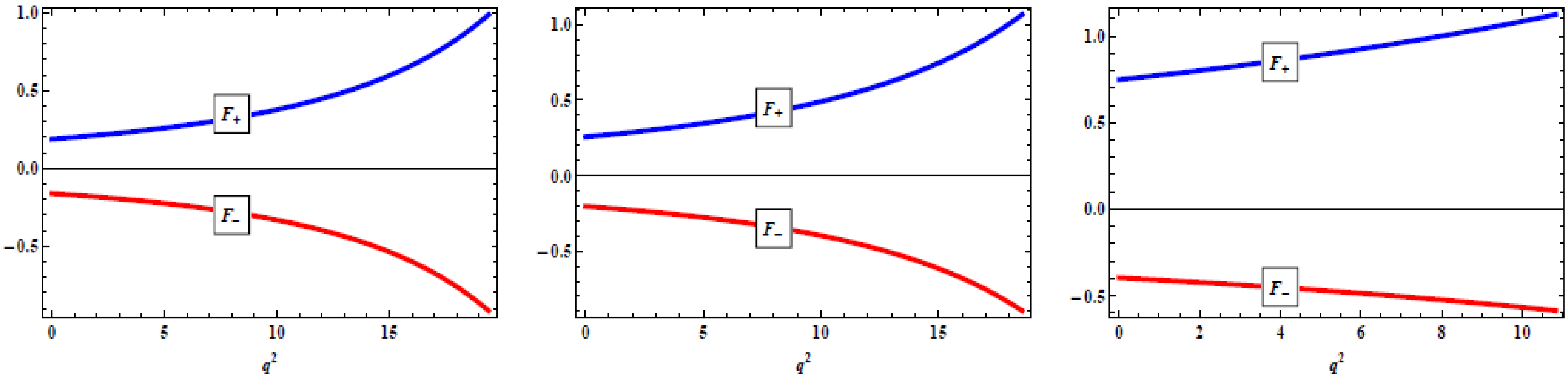


FIG. 1: The $F_+(q^2)$ and $F_-(q^2)$ form factors for $B_c \to D$,$B_c \to D_s$ and $B_c \to \eta_c$ transitions, respectively.

* Dubnicka, Dubnickova, Issadykov, Ivanov, Liptaj, Phys.Rev. D96 (2017) no.7, 076017

Form factors B_c decays

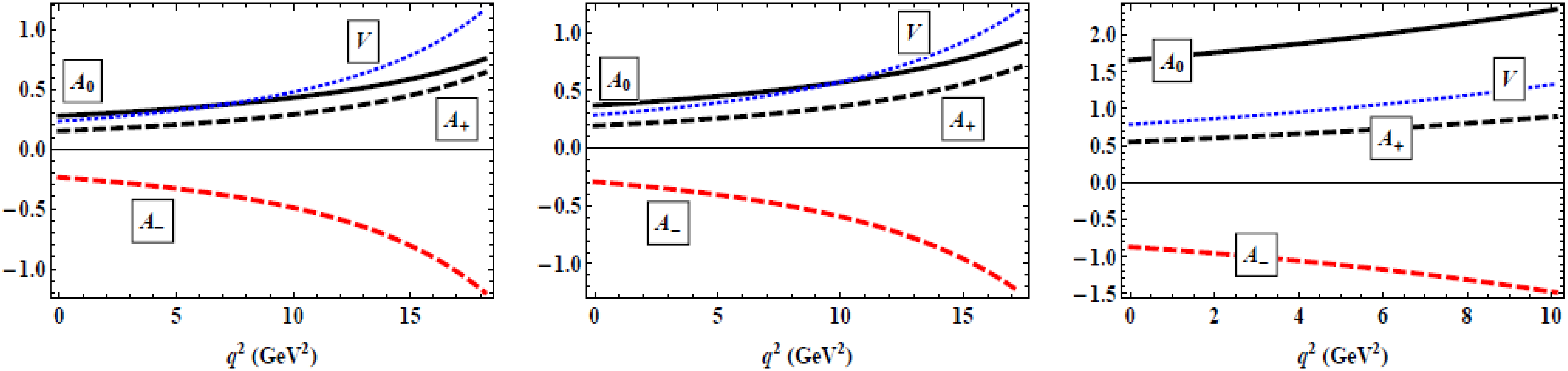
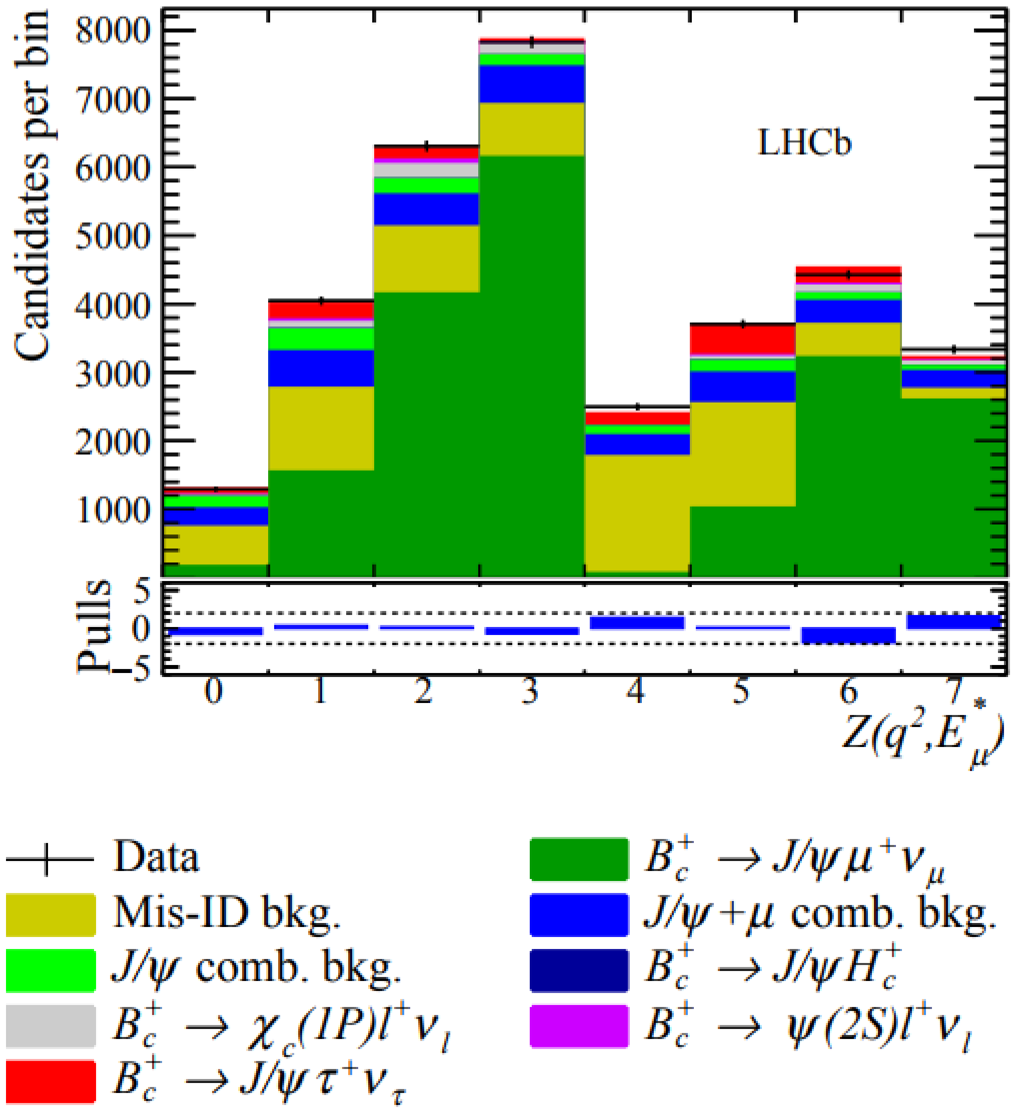


FIG. 2: The A_0, A_-, A_+ and V form factors for $B_c \to D^*$, $B_c \to D_s^*$ and $B_c \to J/\psi$ transitions, respectively.

*** Dubnicka, Dubnickova, Issadykov, Ivanov, Liptaj, Phys.Rev. D96 (2017) no.7, 076017**

Semileptonic decays of B_c meson



$$\frac{\mathcal{B}(B_c^+ \to J/\psi \tau^+ \nu_\tau)}{\mathcal{B}(B_c^+ \to J/\psi \mu^+ \nu_\mu)}$$

$$= 0.71 \pm 0.17(stat) \pm 0.18(syst).$$

***arXiv:1711.05623**

Widths of semileptonic decays of B_c meson in terms of helicity amplitudes

The semileptonic B_c-decay widths are given by

$$\Gamma(B_c^- \to M_{\bar{c}c}\, l\bar{\nu}) = \frac{G_F^2}{(2\pi)^3}|V_{cb}|^2 \int\limits_{m_l^2}^{q_-^2} dq^2 \frac{(q^2-m_l^2)^2\,|\mathbf{p}_2|}{12\,m_1^2\,q^2} \times\left\{\left(1+\frac{m_l^2}{2\,q^2}\right)\sum_{i=\pm,0}\left(H_i^{B_c\to M_{\bar{c}c}}(q^2)\right)^2+\frac{3\,m_l^2}{2\,q^2}\left(H_t^{B_c\to M_{\bar{c}c}}(q^2)\right)^2\right\},$$

$$\Gamma(B_c^- \to \overline{D}^0\, l\bar{\nu}) = \frac{G_F^2}{(2\pi)^3}|V_{ub}|^2 \int\limits_{m_l^2}^{q_-^2} dq^2 \frac{(q^2-m_l^2)^2\,|\mathbf{p}_2|}{12\,m_1^2\,q^2} \times\left\{\left(1+\frac{m_l^2}{2\,q^2}\right)\sum_{i=\pm,0}\left(H_i^{B_c\to \overline{D}^0}(q^2)\right)^2+\frac{3\,m_l^2}{2\,q^2}\left(H_t^{B_c\to \overline{D}^0}(q^2)\right)^2\right\},$$

where $q_-^2 = (m_1-m_2)^2$, $m_1 \equiv m_{B_c}$, and $m_2 \equiv m_f$. Note that $M_{\bar{c}c}$ and $\overline{D}^0$ denote both the pseudoscalar and vector cases.

Semileptonic decays of B_c meson

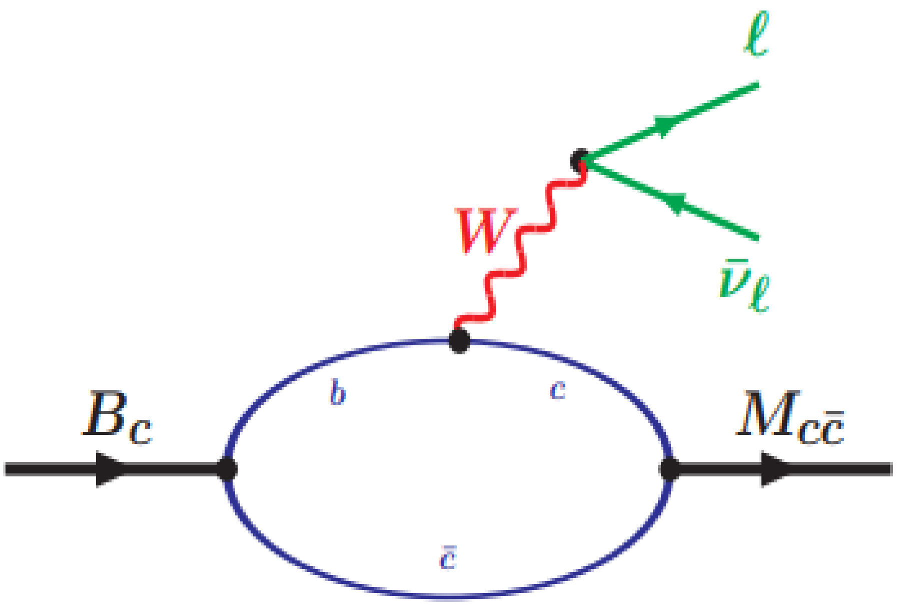


FIG. 3: Pictorial representation of the semileptonic B_c decays.

Branching ratios of semileptonic B_c decays

Table 3. Branching ratios (in %) of semileptonic B_c decays into ground state charmonium states.

Mode	This work	[23]	[7]	[24, 25]	[26]	[27]	[28]
$B_c^- \to \eta_c \ell \nu$	0.95	0.81	0.98	0.75	0.97	0.59	0.44
$B_c^- \to \eta_c \tau \nu$	0.24	0.22	0.27	0.23		0.20	0.14
$B_c^- \to J/\psi \ell \nu$	1.67	2.07	2.30	1.9	2.35	1.20	1.01
$B_c^- \to J/\psi \tau \nu$	0.40	0.49	0.59	0.48		0.34	0.29
$B_c^- \to \overline{D}^- \ell \nu$	0.0033	0.0035	0.018		0.004	0.006	0.0032
$B_c^- \to \overline{D}^- \tau \nu$	0.0021	0.0021	0.0094	0.002			0.0022
$B_c^- \to \overline{D}^{*-} \ell \nu$	0.006	0.0038	0.034		0.018	0.018	0.011
$B_c^- \to \overline{D}^{*-} \tau \nu$	0.0034	0.0022	0.019	0.008			0.006

***Issadykov, Ivanov, Nurbakova, EPJ Web Conf. 158 (2017) 03002**

Branching ratios of semileptonic B_c decays

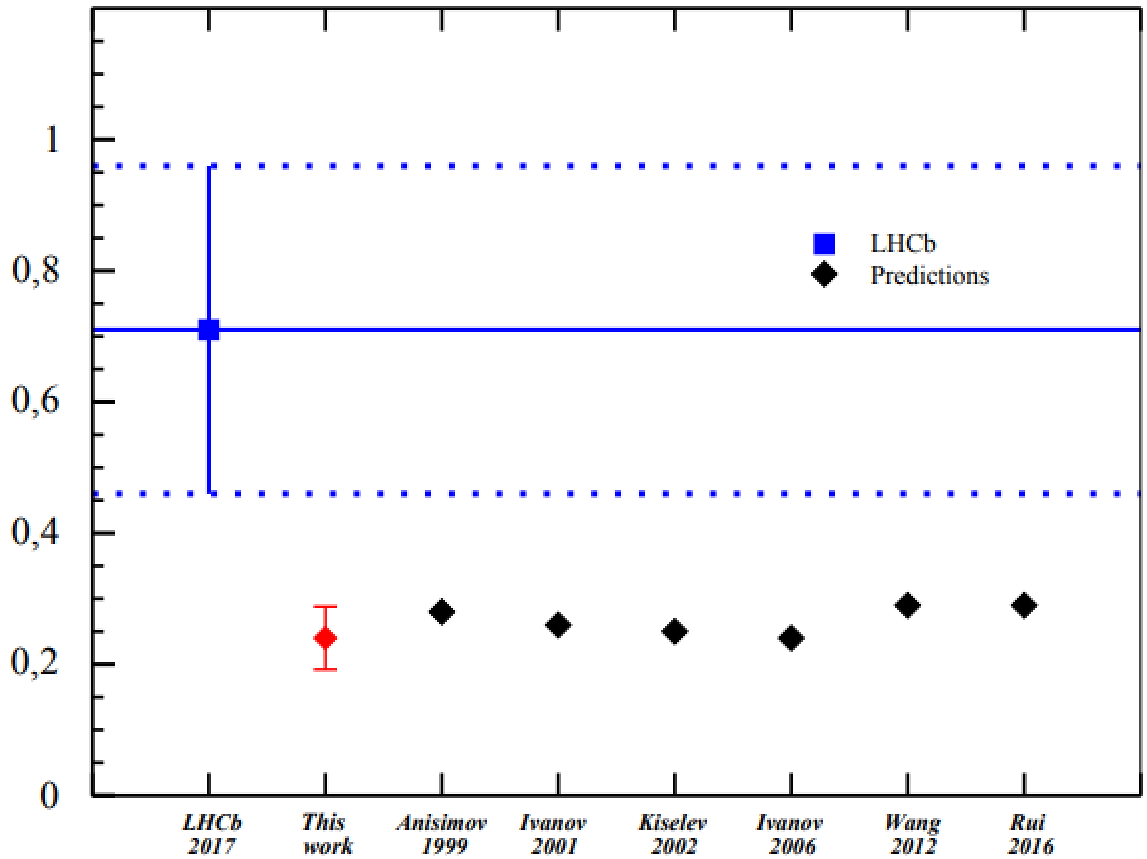
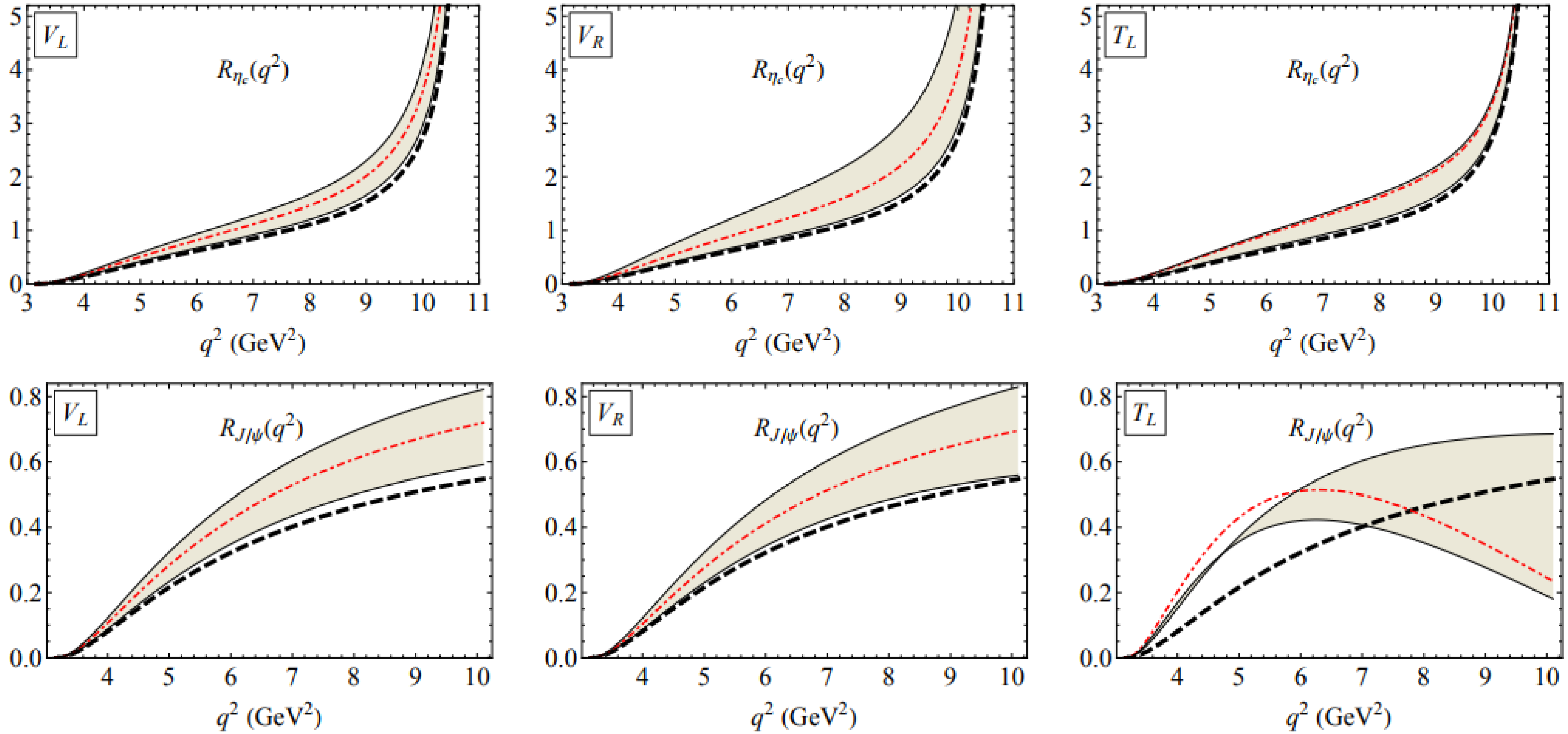


Figure 2: Theoretical predictions vs. LHCb data [15] for the ratio $\mathcal{R}_{\mathcal{J}/\psi}$. Solid line-central experimental value, dotted lines–experimental error bar.

***Aidos Issadykov, Mikhail A. Ivanov, Phys.Lett. B783 (2018) 178-182**

New Physics effects in semileptonic B_c decays



***Tran, Ivanov, Körner, Santorelli. arXiv:1801.06927**

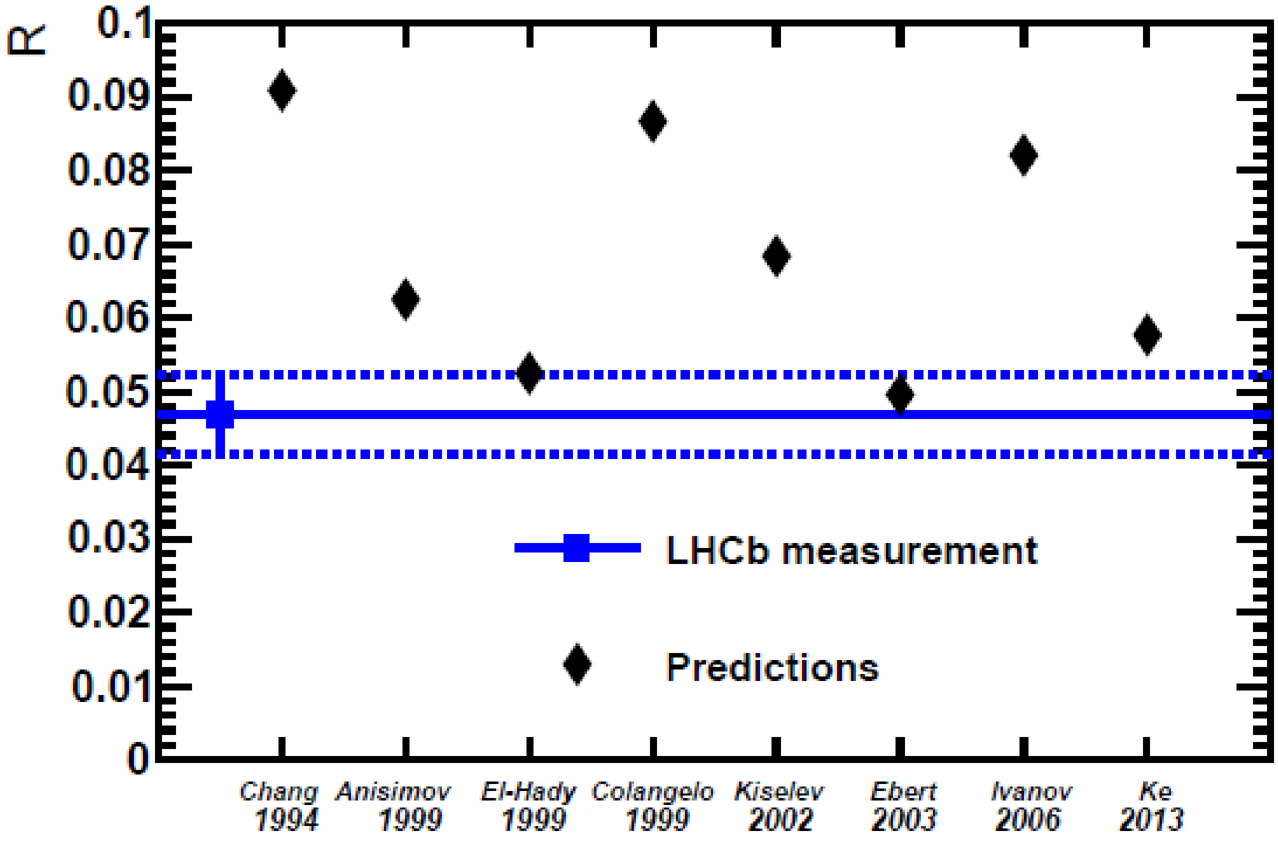
Nonleptonic decays of B_c meson

LHCb collaboration:

$$\frac{B(B_c^+ \to J/\psi\pi^+)}{B(B_c^+ \to J/\psi\ell^+\nu)} = 0.0469 \pm 0.0028(stat) \pm 0.0046(syst).$$

***R. Aaij et al. [LHCb Collaboration], Phys. Rev. D 90 (2014) no.3, 032009**

LHCb data 2014



*R. Aaij et al. [LHCb Collaboration], Phys. Rev. D 90 (2014) no.3, 032009

Nonleptonic decays of B_c meson

LHCb collaboration(nonleptonic):

$$\frac{B(B_c^+ \to J/\psi K^+)}{B(B_c^+ \to J/\psi \pi^+)} = 0.069 \pm 0.0019(stat) \pm 0.005(syst).$$

***R. Aaij et al. [LHCb Collaboration], JHEP 1309 (2013) 075**

The predicted ratio of these branching fractions is proportional to

$$\frac{\mathcal{B}(B_c^+ \to J/\psi K^+)}{\mathcal{B}(B_c^+ \to J/\psi \pi^+)} \approx \left| \frac{V_{us} f_{K^+}}{V_{ud} f_{\pi^+}} \right|^2 = 0.077$$

$$\frac{B(B_c^+ \to J/\psi K^+)}{B(B_c^+ \to J/\psi \pi^+)} = 0.079 \pm 0.007(stat) \pm 0.003(syst).$$

***R. Aaij et al. [LHCb Collaboration], JHEP 1609 (2016) 153**

Effective Hamiltonian

$$
\begin{aligned}
\mathcal{H}_{\text{eff}} &= -\frac{G_F}{\sqrt{2}} V_{cb} V_{cq}^{\dagger} \sum_{i=1}^{6} C_i \mathcal{O}_i, \\
\mathcal{O}_1 &= (\bar{c}_{a_1} b_{a_2})_{V-A} (\bar{q}_{a_2} c_{a_1})_{V-A}, \\
\mathcal{O}_2 &= (\bar{c}_{a_1} b_{a_1})_{V-A}, (\bar{q}_{a_2} c_{a_2})_{V-A}, \\
\mathcal{O}_3 &= (\bar{q}_{a_1} b_{a_1})_{V-A} (\bar{c}_{a_2} c_{a_2})_{V-A}, \\
\mathcal{O}_4 &= (\bar{q}_{a_1} b_{a_2})_{V-A} (\bar{c}_{a_2} c_{a_1})_{V-A}, \\
\mathcal{O}_5 &= (\bar{q}_{a_1} b_{a_1})_{V-A} (\bar{c}_{a_2} c_{a_2})_{V+A}, \\
\mathcal{O}_6 &= (\bar{q}_{a_1} b_{a_2})_{V-A} (\bar{c}_{a_2} c_{a_1})_{V+A}, \qquad (1)
\end{aligned}
$$

where the subscript $V-A$ refers to the usual left-chiral current $O^{\mu} = \gamma^{\mu}(1-\gamma^5)$ and $V+A$ to the usual right-chiral one $O_{+}^{\mu} = \gamma^{\mu}(1+\gamma^5)$. The a_i denote the color indices. The quark q stands for either s or d.

$\mathcal{O}_3 = \mathcal{O}_1$ and $\mathcal{O}_4 = \mathcal{O}_2$.

↑ Fierz transformation

Nonleptonic decays of B_c meson

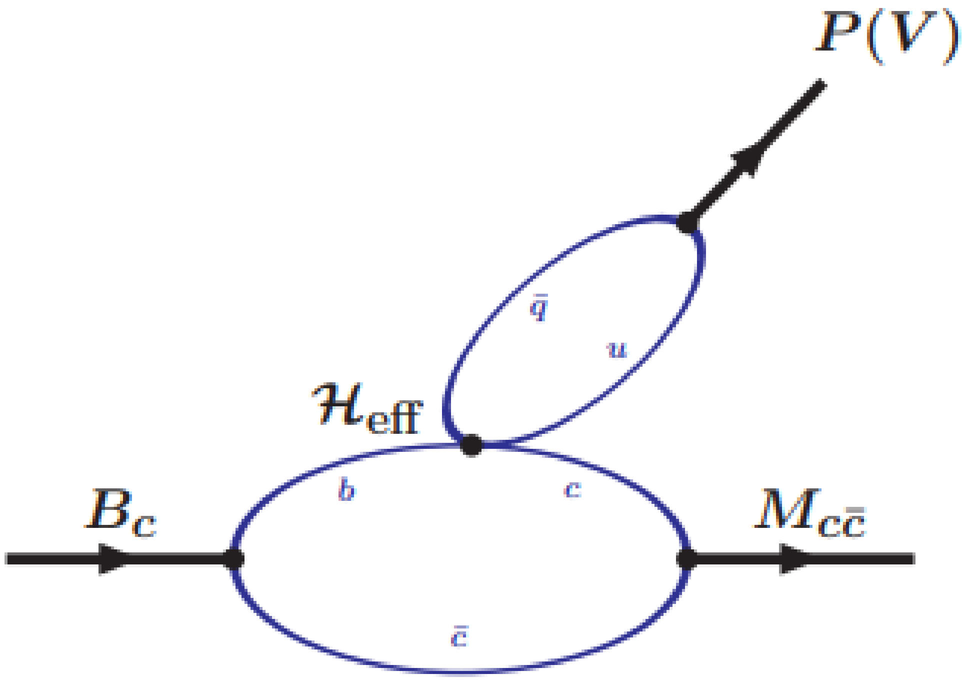


FIG. 2: Pictorial representation of the matrix elements of the nonleptonic B_c decays.

Nonleptonic decays of B_c meson

The nonleptonic B_c decay widths in terms of the helicity amplitudes are given by

$$\Gamma(B_c^+ \to P^+ M_{\bar{c}c}) = \frac{G_F^2}{16\,\pi} \frac{|\mathbf{p}_2|}{m_1^2} \left| V_{cb} V_{uq}^\dagger a_1 f_P m_P \right|^2 \left(H_t^{B_c \to M_{\bar{c}c}}(m_P^2) \right)^2 ,$$
$$(P^+ = \pi^+, K^+, \text{ and } q = d, s, \text{ respectively}),$$

$$\Gamma(B_c^+ \to V^+ M_{\bar{c}c}) = \frac{G_F^2}{16\,\pi} \frac{|\mathbf{p}_2|}{m_1^2} |V_{cb} V_{uq}^\dagger a_1 f_V m_V|^2 \sum_{i=0,\pm} \left(H_i^{B_c \to M_{\bar{c}c}}(m_V^2) \right)^2 ,$$
$$(V^+ = \rho^+, K^{*+}, \text{ and } q = d, s, \text{ respectively}).$$

Model parameters

f_π	f_K	f_ρ	f_{K^*}
130.3	156.0	221.0	226.8

We will use the numerical values of the Wilson coefficients from [24] obtained at the scale $\mu = 4$ GeV at leading order with $\Lambda^{(5)}_{MS} = 225$ MeV. One has $C_2 = 1.141$ and $C_1 = -0.310$ that gives $a_1 = C_2 + \xi C_1 = 1.038$. Note that this value has been also used in the paper [25]. It differs from the most old papers where the color-suppressed factor ξ was set to zero.

Nonleptonic decays of B_c meson

Table 3: Nonleptonic decay widths of the B_c meson in units of $a_1^2 \cdot 10^{-15}$ GeV.

Mode	This work	[2]	[3]	[4]	[5]
$B_c^+ \to \eta_c \pi^+$	2.28 ± 0.46	2.07	1.59	0.28	1.47
$B_c^+ \to \eta_c \rho^+$	3.15 ± 0.63	5.48	3.74	0.75	3.35
$B_c^+ \to \eta_c K^+$	0.17 ± 0.03	0.16	0.12	0.023	0.15
$B_c^+ \to \eta_c K^{*+}$	0.19 ± 0.04	0.29	0.20	0.04	0.24
$B_c^+ \to J/\psi \pi^+$	1.22 ± 0.24	1.97	1.22	1.48	0.82
$B_c^+ \to J/\psi \rho^+$	2.03 ± 0.41	5.95	3.48	4.14	2.32
$B_c^+ \to J/\psi K^+$	0.09 ± 0.02	0.15	0.09	0.08	0.08
$B_c^+ \to J/\psi K^{*+}$	0.13 ± 0.03	0.32	0.20	0.23	0.18

Mode	[8]	[9]	[16]	[26]	
$B_c^+ \to \eta_c \pi^+$	0.93	2.11	1.18 ± 0.10	1.49	
$B_c^+ \to \eta_c \rho^+$	2.3	5.10	$2.89^{+0.51}_{-0.46}$	3.93	
$B_c^+ \to \eta_c K^+$	0.07	0.166	0.092 ± 0.0078	0.12	
$B_c^+ \to \eta_c K^{*+}$	0.12	0.276	0.17 ± 0.02	0.20	
$B_c^+ \to J/\psi \pi^+$	0.67	1.93	1.24 ± 0.11	1.01	
$B_c^+ \to J/\psi \rho^+$	1.8	5.49	$3.59^{+0.64}_{-0.58}$	3.25	
$B_c^+ \to J/\psi K^+$	0.05	0.15	0.095 ± 0.008	0.08	
$B_c^+ \to J/\psi K^{*+}$	0.11	0.31	0.226 ± 0.03	0.17	

Nonleptonic decays of B_c meson

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

Ratios of branching fractions

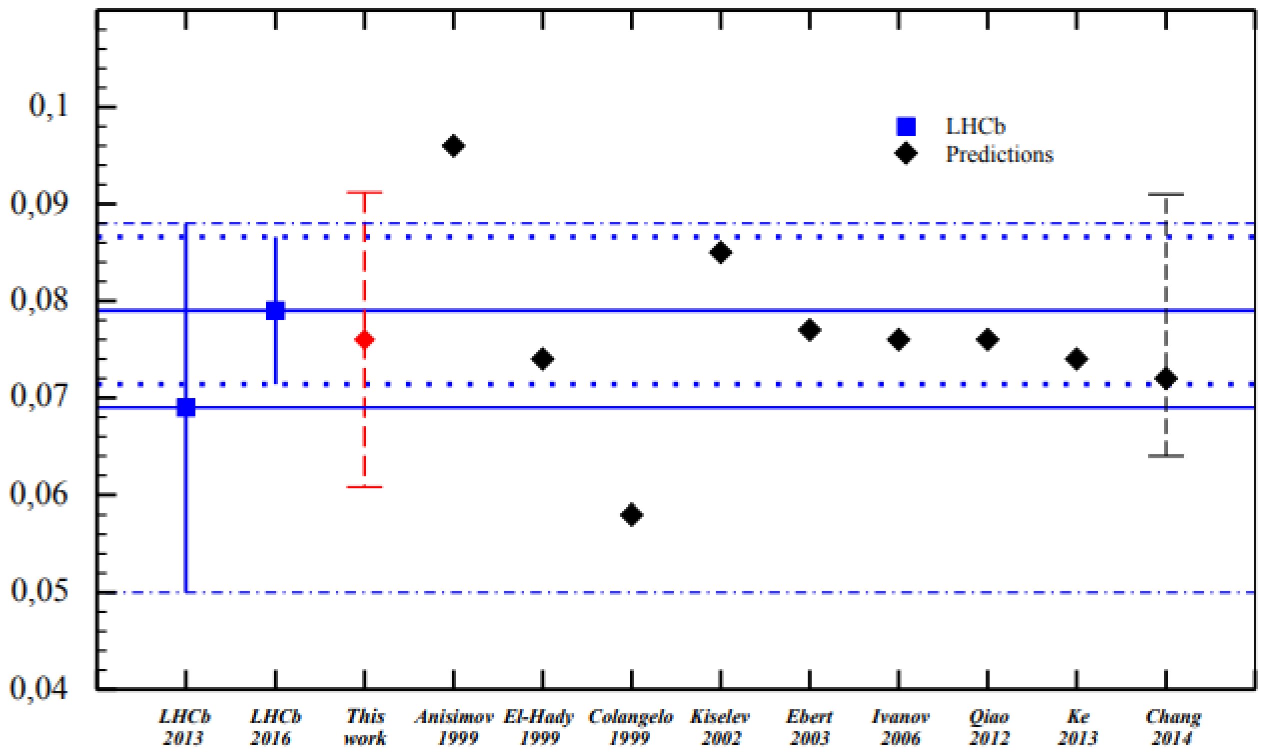


Figure 3: Theoretical predictions vs. LHCb data [10] and [11] for the ratio $\mathcal{R}_{K^+/\pi^+}$. Two solid lines- central experimental values, dash-dotted lines–experimental error bar from [10], dotted lines–experimental error bar from [11].

Ratios of branching fractions

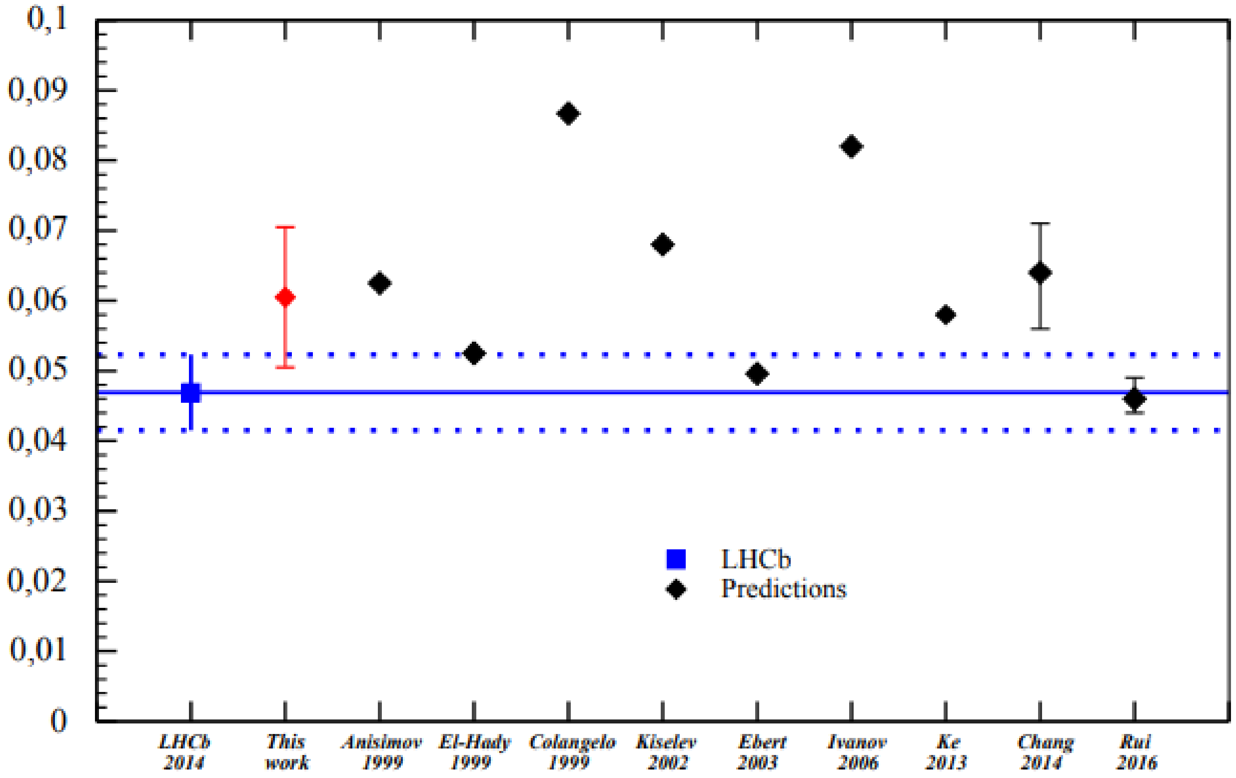


Figure 4: Theoretical predictions vs. LHCb data [1] for the ratio $\mathcal{R}_{\pi^+/\mu^+\nu_\mu}$. Solid line–central experimental value, dotted lines–experimental error bar.

Nonleptonic decays of B_c meson

$$\frac{\mathcal{B}(B_c^+ \to J/\psi D_s^+)}{\mathcal{B}(B_c^+ \to J/\psi \pi^+)} = 2.90 \pm 0.57(\text{stat}) \pm 0.24(\text{syst}).$$

$$\frac{\mathcal{B}(B_c^+ \to J/\psi D_s^{*+})}{\mathcal{B}(B_c^+ \to J/\psi D_s^+)} = 2.37 \pm 0.56(\text{stat}) \pm 0.10(\text{syst}).$$

***R. Aaij et al. (LHCb Collaboration), Phys. Rev. D 87, 112012 (2013); 89, 019901(E) (2014).**

Nonleptonic decays of B_c meson

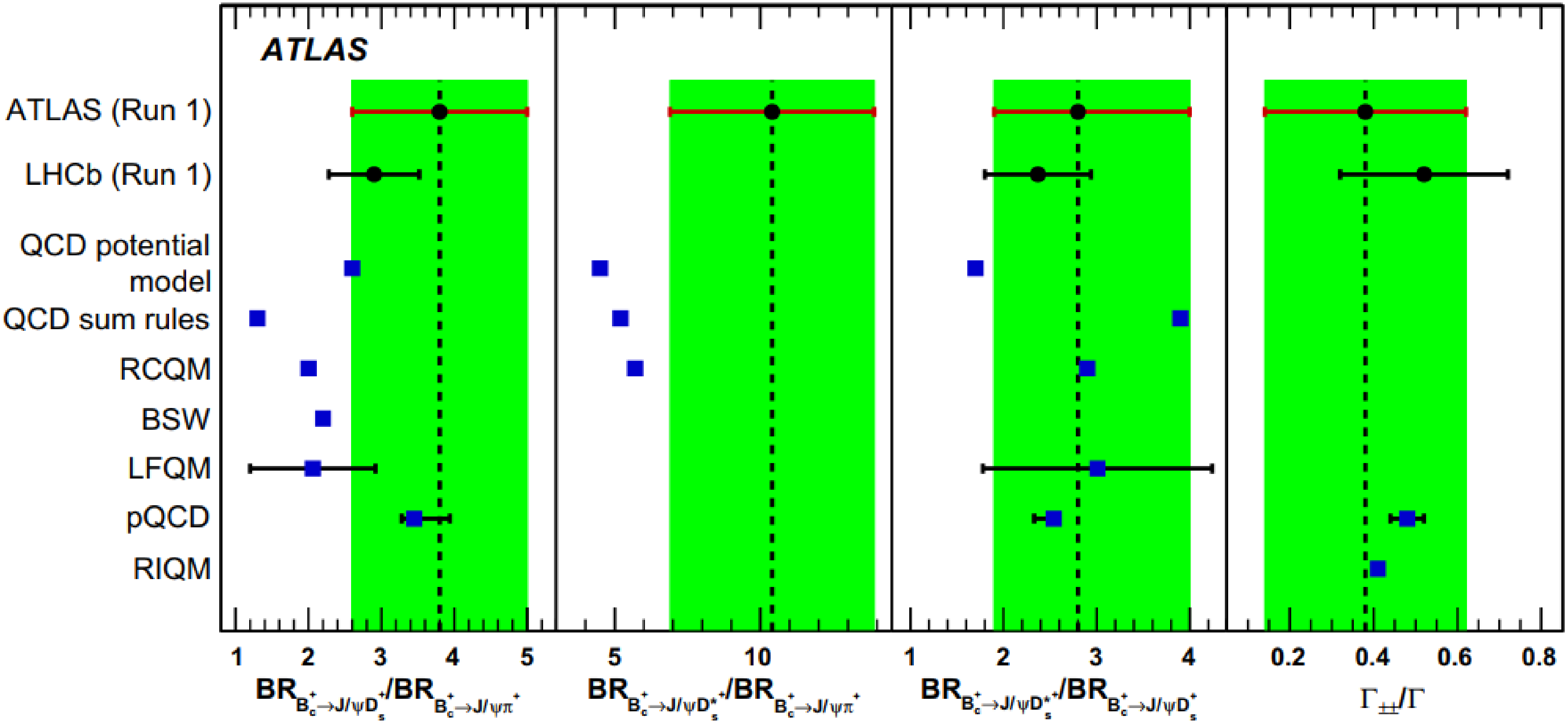
$$\mathcal{R}_{D_s^+/\pi^+} = \frac{\mathcal{B}_{B_c^+ \to J/\psi D_s^+}}{\mathcal{B}_{B_c^+ \to J/\psi \pi^+}} = 3.8 \pm 1.1(\text{stat.}) \pm 0.4(\text{syst.}) \pm 0.2(\text{BF}),$$

$$\mathcal{R}_{D_s^{*+}/\pi^+} = \frac{\mathcal{B}_{B_c^+ \to J/\psi D_s^{*}}}{\mathcal{B}_{B_c^+ \to J/\psi \pi^+}} = 10.4 \pm 3.1(\text{stat.}) \pm 1.5(\text{syst.}) \pm 0.6(\text{BF}),$$

$$\mathcal{R}_{D_s^{*+}/D_s^+} = \frac{\mathcal{B}_{B_c^+ \to J/\psi D_s^{*+}}}{\mathcal{B}_{B_c^+ \to J/\psi D_s^+}} = 2.8^{+1.2}_{-0.8}(\text{stat.}) \pm 0.3(\text{syst.})$$

***G. Aad et al. (ATLAS Collaboration), Eur. Phys. J. C 76, 4 (2016).**

Nonleptonic decays of B_c meson



***G. Aad et al. (ATLAS Collaboration), Eur. Phys. J. C 76, 4 (2016).**

Effective Hamiltonian

$$\mathcal{H}_{\text{eff}} = -\frac{G_F}{\sqrt{2}} V_{cb} V_{cq}^{\dagger} \sum_{i=1}^{6} C_i \mathcal{O}_i,$$

$$\mathcal{O}_1 = (\bar{c}_{a_1} b_{a_2})_{V-A} (\bar{q}_{a_2} c_{a_1})_{V-A},$$

$$\mathcal{O}_2 = (\bar{c}_{a_1} b_{a_1})_{V-A}, (\bar{q}_{a_2} c_{a_2})_{V-A},$$

$$\mathcal{O}_3 = (\bar{q}_{a_1} b_{a_1})_{V-A} (\bar{c}_{a_2} c_{a_2})_{V-A},$$

$$\mathcal{O}_4 = (\bar{q}_{a_1} b_{a_2})_{V-A} (\bar{c}_{a_2} c_{a_1})_{V-A},$$

$$\mathcal{O}_5 = (\bar{q}_{a_1} b_{a_1})_{V-A} (\bar{c}_{a_2} c_{a_2})_{V+A},$$

$$\mathcal{O}_6 = (\bar{q}_{a_1} b_{a_2})_{V-A} (\bar{c}_{a_2} c_{a_1})_{V+A},$$

Nonleptonic decays of B_c meson

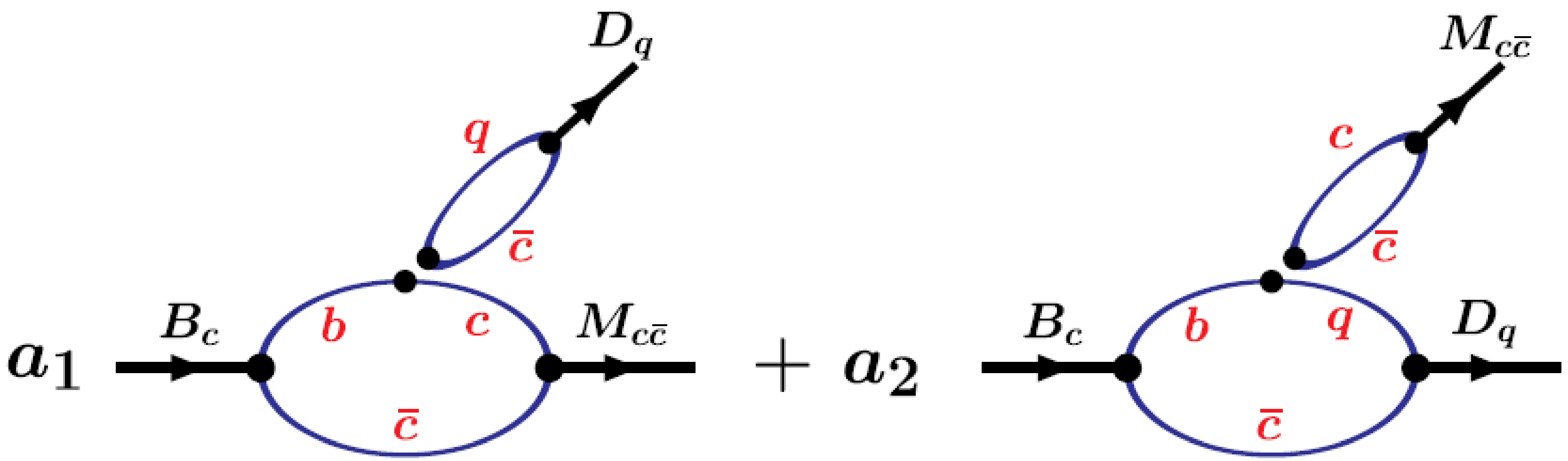


FIG. 1. Pictorial representation of the matrix elements of the nonleptonic B_c decays.

$a_1 = C_2 + C_4 + \xi(C_1 + C_3)$ and $a_2 = C_1 + C_3 + \xi(C_2 + C_4)$

$a_1 = C_2+C_4 = 0.93$ and $a_2 = C_1+C_3 = -0.27$

Nonleptonic decays of B_c meson

The nonleptonic B_c decay widths in terms of the helicity amplitudes are given by

$$\Gamma(B_c \to \eta_c D_q) = N_W\{a_1 f_{D_q^-} m_{D_q^-} H_t^{B_c\to\eta_c}(m_{D_q^-}^2) + a_2 f_{\eta_c} m_{\eta_c} H_t^{B_c\to D_q^-}(m_{\eta_c}^2)\}^2,$$

$$\Gamma(B_c \to \eta_c D_q^*) = N_W\{a_1 f_{D_q^{*-}} m_{D_q^{*-}} H_0^{B_c\to\eta_c}(m_{D_q^{*-}}^2) - a_2 f_{\eta_c} m_{\eta_c} H_t^{B_c\to D_q^{*-}}(m_{\eta_c}^2)\}^2,$$

$$\Gamma(B_c \to J/\psi D_q) = N_W\{-a_1 f_{D_q^-} m_{D_q^-} H_t^{B_c\to J/\psi}(m_{D_q^-}^2) + a_2 f_{J/\psi} m_{J/\psi} H_0^{B_c\to D_q^-}(m_{J/\psi}^2)\}^2,$$

$$\Gamma(B_c \to J/\psi D_q^*)) = N_W \sum_{i=0,\pm}\{a_1 f_{D^{*-}} m_{D_q^{*-}} H_i^{B_c\to J/\psi}(m_{D_q^{*-}}^2) + a_2 f_{J/\psi} m_{J/\psi} H_i^{B_c\to D_q^{*-}}(m_{J/\psi}^2)\}^2,$$

$$N_W \equiv \frac{G_F^2}{16\pi}\frac{|\mathbf{p_2}|}{m_1^2}|V_{cb}V_{cq}^\dagger|^2.$$

Nonleptonic decays of B_c meson

Mode	$a_1 = +0.93$ $a_2 = -0.27$	$a_1 = +1.14$ $a_2 = -0.20$
$B_c \to \eta_c D_s$	0.22	0.50
$B_c \to \eta_c D_s^*$	0.22	0.42
$B_c \to J/\psi D_s$	0.10	0.22
$B_c \to J/\psi D_s^*$	0.41	0.78
$B_c \to \eta_c D$	0.0073	0.016
$B_c \to \eta_c D^*$	0.0098	0.019
$B_c \to J/\psi D$	0.0035	0.0074
$B_c \to J/\psi D^*$	0.017	0.031

$$R_{D_s^{*+}/D_s^+} = \frac{B(B_c^+ \to J/\psi D_s^{*+})}{B(B_c^+ \to J/\psi D_s^+)} = \begin{cases} 3.55 & (a_1 = 1.14, a_2 = -0.20) \\ 3.96 & (a_1 = 0.93, a_2 = -0.27) \end{cases}$$

*** Dubnicka, Dubnickova, Issadykov, Ivanov, Liptaj, Phys.Rev. D96 (2017) no.7, 076017**

Ratios of branching fractions

$\mathcal{R}_{D_s^+/\pi^+}$	$\mathcal{R}_{D_s^{*+}/\pi^+}$	$\mathcal{R}_{D_s^{*+}/D_s^+}$	$\Gamma_{\pm\pm}/\Gamma$	Ref.
3.8 ± 1.2	10.4 ± 3.5	$2.8^{+1.2}_{-0.9}$	0.38 ± 0.24	ATLAS [1]
2.90 ± 0.62	$\cdots$	2.37 ± 0.57	0.52 ± 0.20	LHCb [2]
1.29 ± 0.26	5.09 ± 1.02	3.96 ± 0.80	0.46 ± 0.09	CCQM
2.0	5.7	2.9	$\cdots$	RCQM [3]
2.6	4.5	1.7	$\cdots$	QCD PM [11]
1.3	5.2	3.9	$\cdots$	QCD SR [12]
2.2	$\cdots$	$\cdots$	$\cdots$	BSW RQM [16]
2.06 ± 0.86	$\cdots$	3.01 ± 1.23	$\cdots$	LFQM [17]
$3.45^{+0.49}_{-0.17}$	$\cdots$	$2.54^{+0.07}_{-0.21}$	0.48 ± 0.04	pQCD [18]
$\cdots$	$\cdots$	$\cdots$	0.410	RIQM [19]

$$\frac{\Gamma_{++}}{\Gamma} = \frac{\Gamma_{++}(B_c^+ \to J/\psi D_s^{*+})}{\Gamma(B_c^+ \to J/\psi D_s^{*+})}.$$

*** Dubnicka, Dubnickova, Issadykov, Ivanov, Liptaj, Phys.Rev. D96 (2017) no.7, 076017**

Conclusion

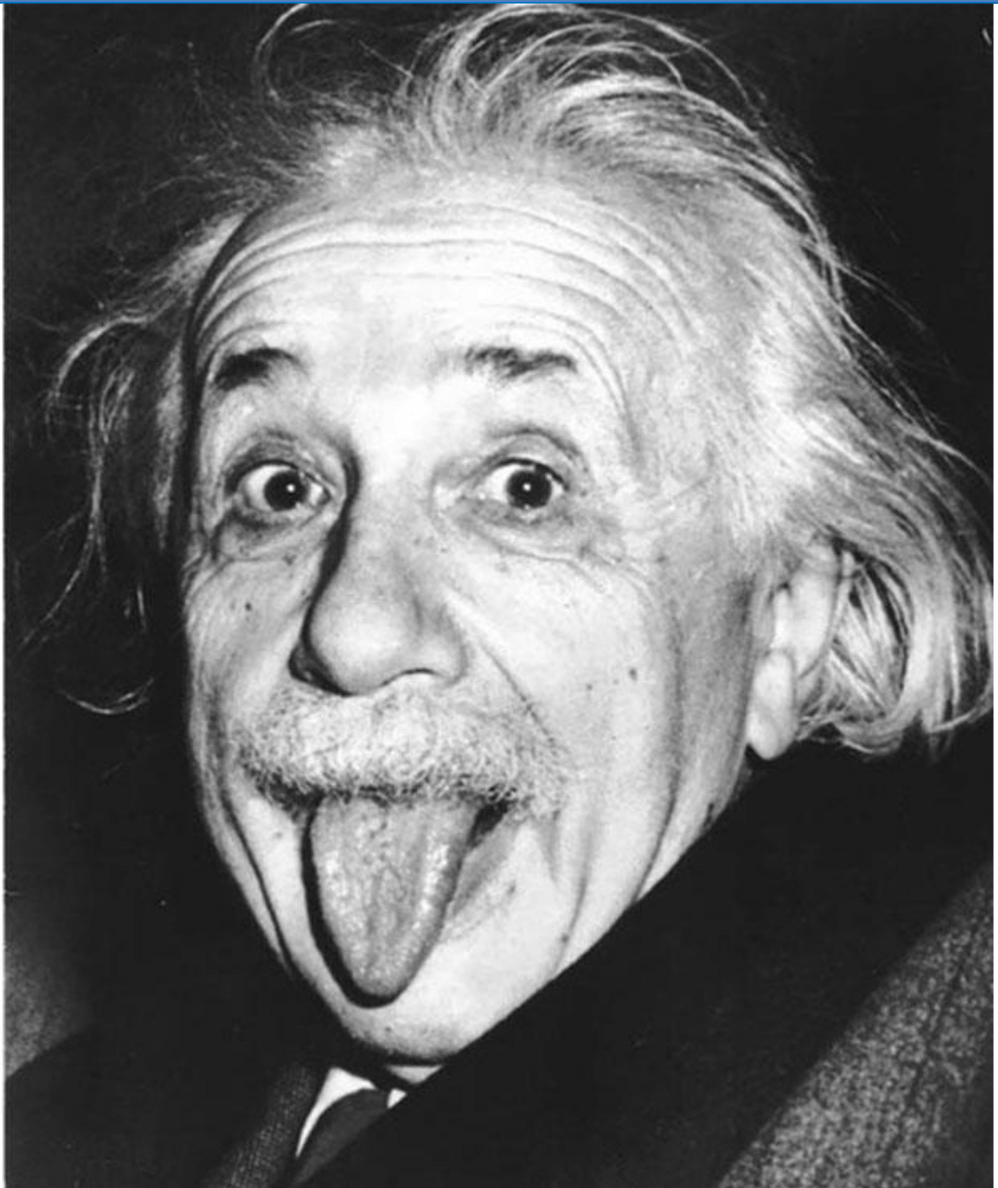
We have found that the theoretical predictions for the ratio $\mathcal{R}_{J/\psi}$ are more than 2 σ less than the experimental data. This may indicate on the possibility of New physics effects in this decay.

At the same time the ratios of the branching fractions $\mathcal{R}_{\pi^+/\mu^+\nu}$ and $\mathcal{R}_{K^+/\pi^+}$ are in good agreement with the LHCb data and other theoretical approaches.

We found that our prediction for the ratios $\mathcal{R}_{D_s^*/D_s}$ and $\Gamma_{\pm\pm}/\Gamma$ are consistent with measurements and other approaches. The results for the ratios $\mathcal{R}_{D_s/\pi^+}$ and $\mathcal{R}_{D_s^*/\pi^+}$ are smaller than the measured values but the discrepancies do not exceed two standard deviations.

Since our result for $\mathcal{R}_{J/\psi}$ is different from the data at the level of 2 σ, we can urge to more precise measurement of the $B_c \to J/\psi\, \ell \bar{\nu}_\ell$ channel which currently has quite large uncertainties.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.

Thank you!



***A. Einstein**