Perspectives of B_c physics at LHCb

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B_c micro workshop

LHCb A&S week 13/7/2016

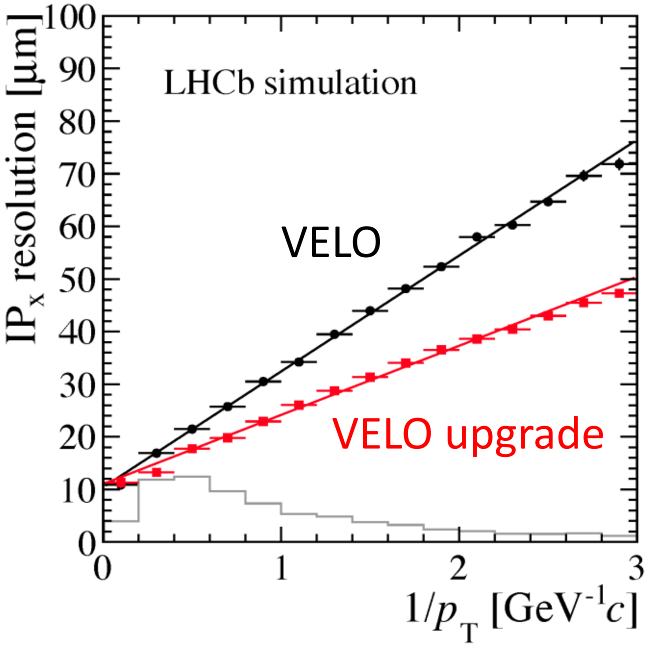
With crucial input from Lucio Anderlini, Liupan An, Alison Tully

Outline

- General remarks
- B_c->DDD: Tetraquarks
- B_c spectroscopy
- B_c->DD : γ

General remarks

- Great outlook for B_c at LHCb:
  - *Unique DAQ, VTX, PID to further improve in upgrade*
- Probe all 3 main types of B_c decays:
  - *b-quark decay, c-quark decay, bc annihilation*
- B_c production
  - *high-precision, associated production*
- Spectroscopy
  - *Search for excited states in B_cX, BD*



Bc->DDD: tetraquarks

- *Esposito, Papinutto, Pilloni, Polosa, Tantalo Phys. Rev. D 88, 054029 (2013)*

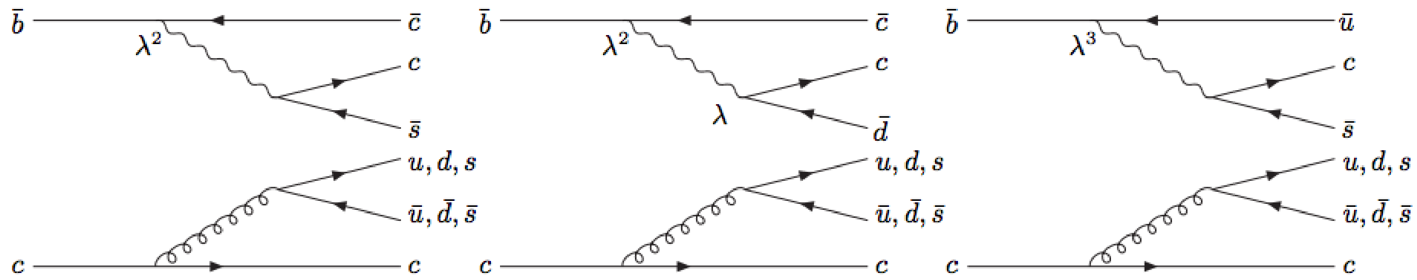


Figure 3. Double- and triple-Cabibbo suppressed Feynman diagrams for the production of the $\mathcal{T}$ particles from B_c^+.

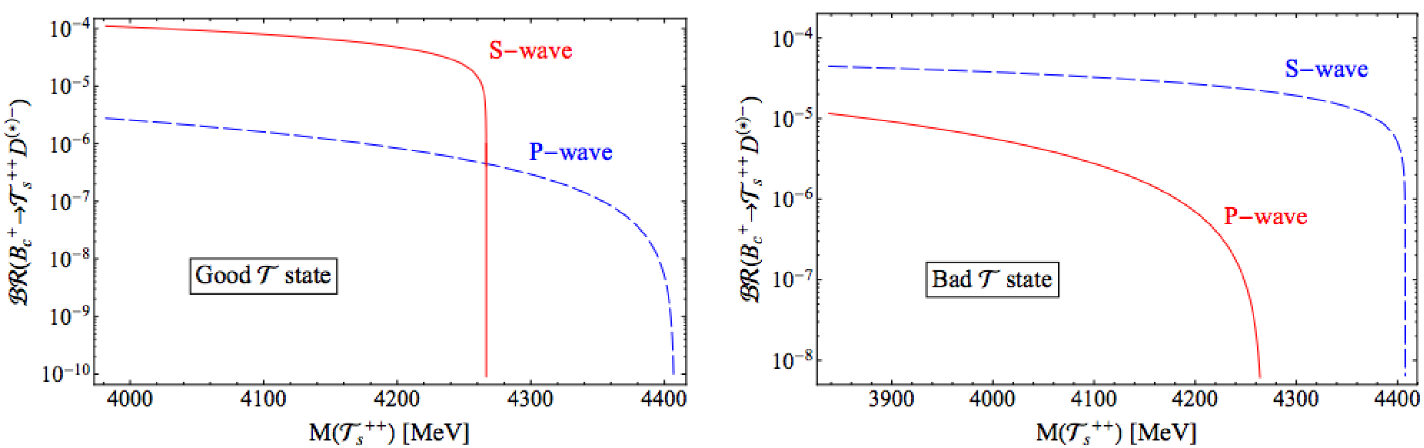
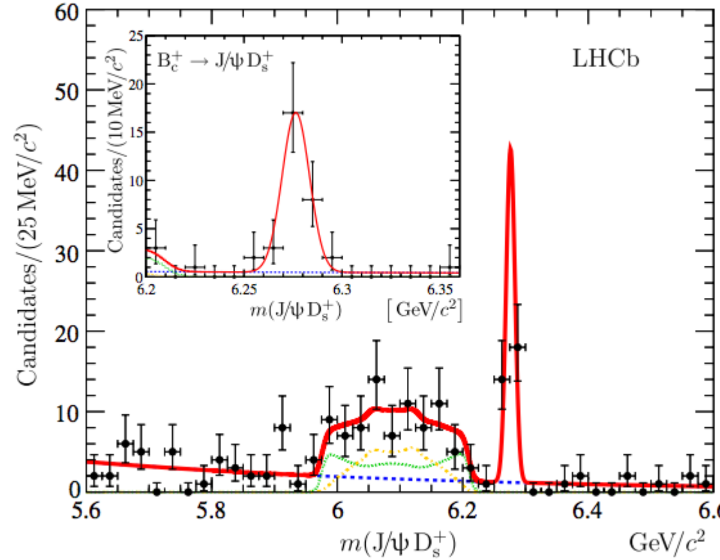
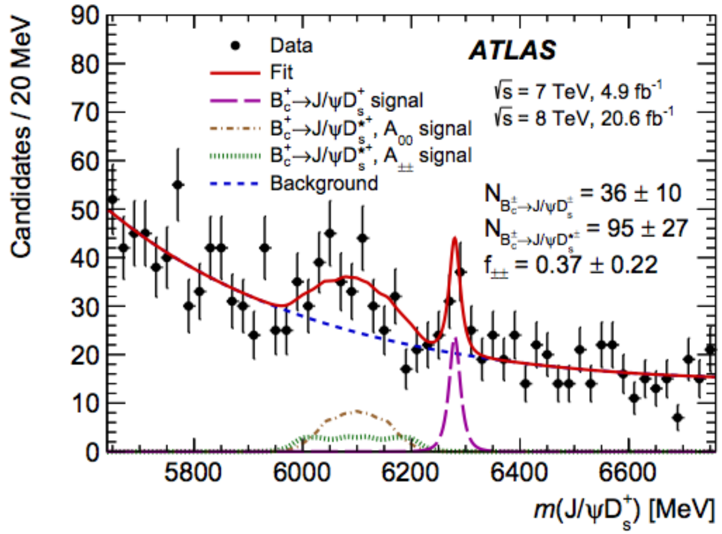


Figure 5. Branching ratios for the production of $B_c^+ \to \mathcal{T}_s^{++} D^-$ (dashed) and $B_c^+ \to \mathcal{T}_s^{++} D^{*-}$ (solid) for the good 1^+ state (left panel) and for the bad 0^+ state (right panel) as a function of the mass of $\mathcal{T}_s^{++}$, in the above-threshold region.

Bc->DDD in LHCb

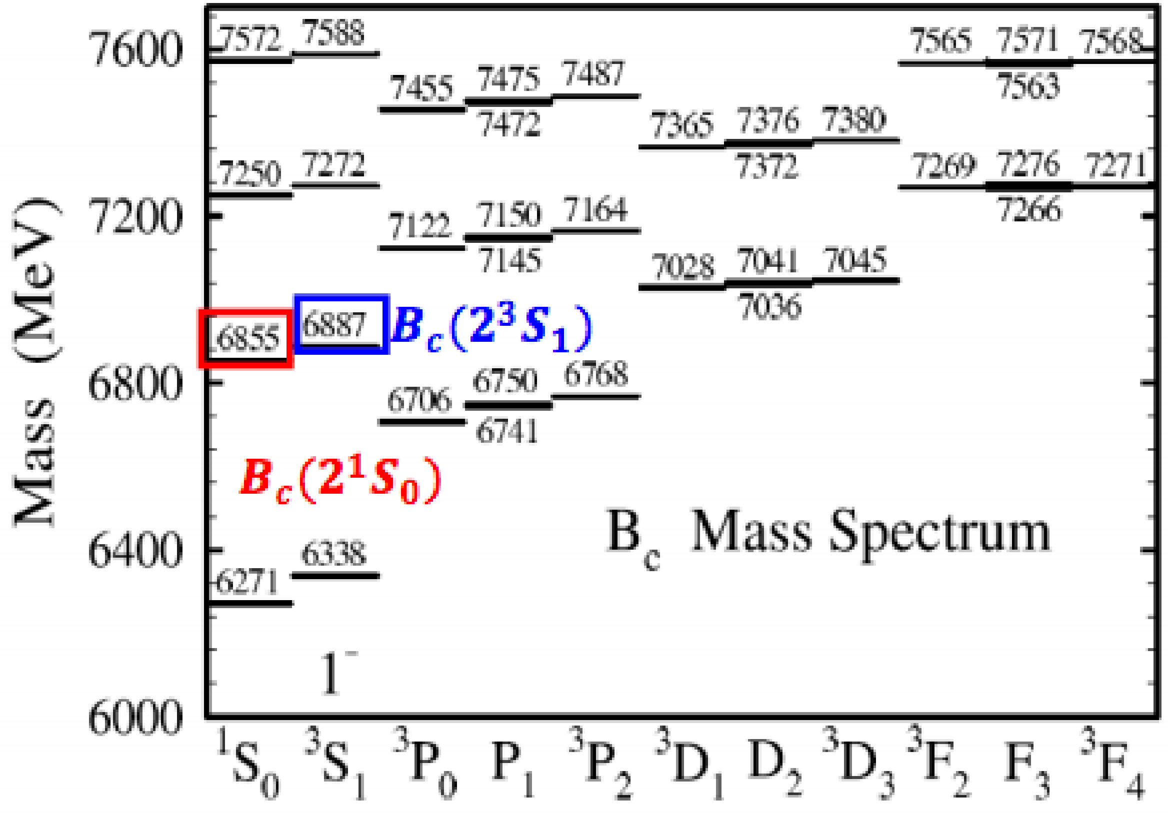
- B_c->Jpsi D_s already observed,
  - *LHCb 3fb^{-1} ATLAS 25fb^{-1}*
- B_c->$D^0 D^0$barD_s ~100x less efficient because of extra D (BF~5%, 2 extra tracks)





B_c spectroscopy

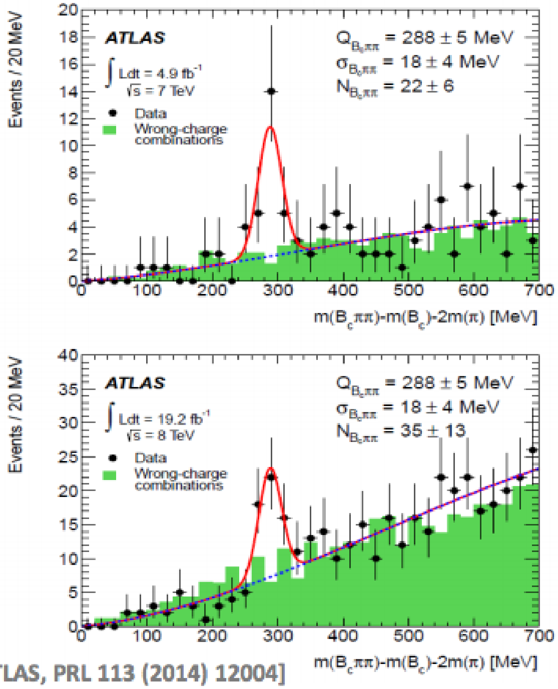
Expect excited Bc states similar as in B^0,B^+ and B_s system
Decay channel depends on mass: $B_c\ \gamma$, $B_c\ \pi^+\pi^-$, BD



[S.Godfrey, PRD 70 (2004) 054017]

Status and outlook

- ATLAS observation consistent with expected 2S state (mass, decay channel)
  - *Not yet confirmed by other experiments*
  - *LHCb Run I B_c yield 10x higher than ATLAS*
  - *If confirmed, will show up clearly in LHCb*
- $B_c\gamma$ final state hard because of low-pT gamma
- BD final state: B^+D^0 or B^0D^+ to be explored

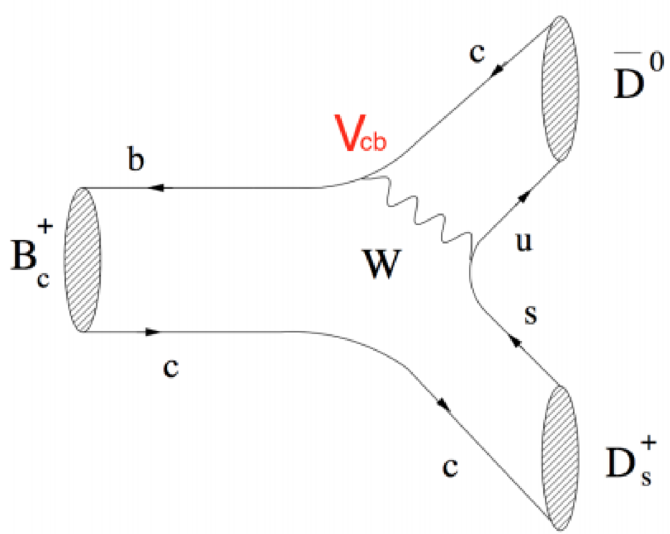


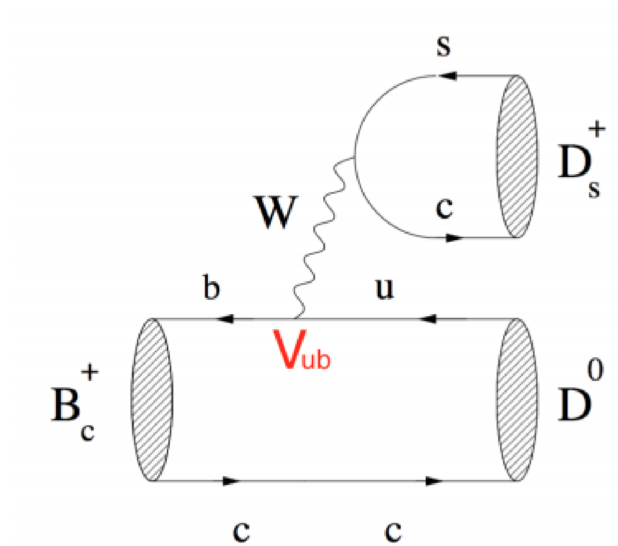
[ATLAS, PRL 113 (2014) 12004]

B_c->DD for gamma: motivation

- γ is the least well constrained of the CKM angles
- $B_c^\pm \to D_s^\pm D$ decays, where $D = \{D^0, \overline{D^0}, D^0_+\}$ are promising for measuring γ (Fleischer & Wyler)
- Sensitivity to γ arises from interference of $b \to c$ and $b \to u$ decays
- **Amplitudes are expected to be similar in size**

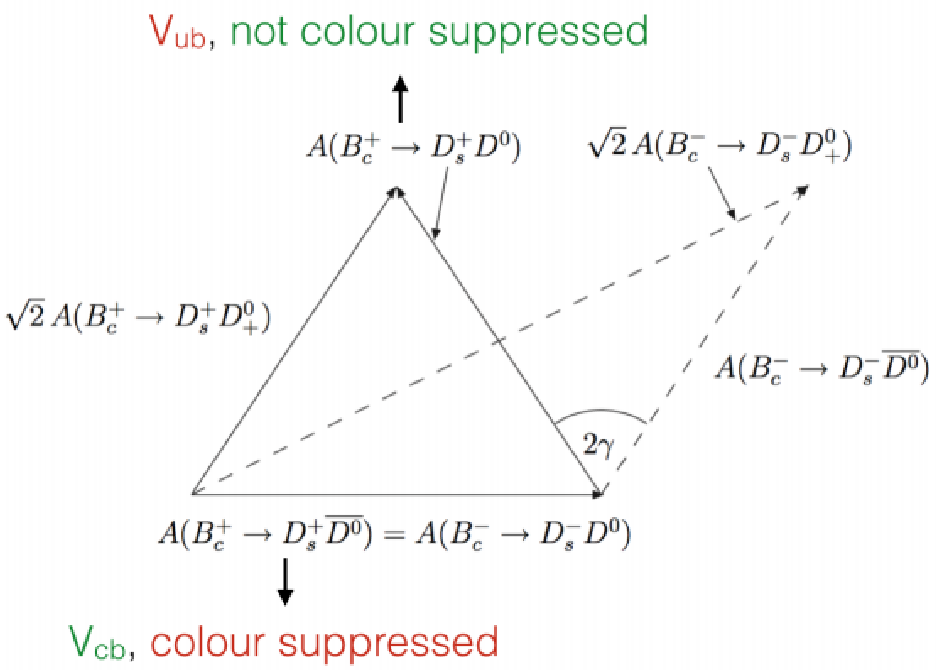
$$\gamma \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$





B_c->DD for gamma: motivation

- All sides of the triangle are of comparable length
- Precise γ measurements needed to test the Standard Model
- $B_c^{\pm} \to D_s^{\pm} D$ proceeds at tree level only $\to$ **theoretically precise**
- Compare with values of γ measured from penguin dominated modes to search for **new physics**



B_c->DD branching ratio predictions

- Phys. Rev. D 86, 074019 Zhou Rui, Zou Zhitian, Cai-Dian Lu:
- Cabibbo-favoured in (/10^{-6})

channels	This work	Kiselev[4]	IKP[5]	IKS[7]	LC[8]	CF[10]
$B_c \to D^+ \bar{D}^0$	32^{+6+1+2}_{-6-1-4}	53	32	33	86	8.4
$B_c \to D_s^+ \bar{D}^0$	$2.3^{+0.4+0.1+0.2}_{-0.4-0.1-0.2}$	4.8	1.7	2.1	4.6	0.6

- Cabibbo-suppressed (/10^{-7})

channels	This work	Kiselev[4]	IKP[5]	IKS[7]
$B_c \to D^+ D^0$	$1.0^{+0.2+0.1+0.0}_{-0.1-0.0-0.0}$	3.2	1.1	3.1
$B_c \to D_s^+ D^0$	30^{+5+3+1}_{-4-2-1}	66	25	74

Note that CS > CF for Ds mode

B_c->DD for gamma: event yield

$$\frac{N(B_c^+ \to D_s^+ \bar{D}^0)}{N(B^+ \to D_s^+ \bar{D}^0)} = \frac{f_c}{f_u} \frac{\epsilon(B_c^+ \to D_s^+ \bar{D}^0)}{\epsilon(B^+ \to D_s^+ \bar{D}^0)} \frac{B(B_c^+ \to D_s^+ \bar{D}^0)}{B(B^+ \to D_s^+ \bar{D}^0)}$$

Combining LHCB measurement with B(Bc->Jpsipi)=0.29%

Rui Zhitian Lu PRD86(2012)074019

$$\frac{f_c}{f_u} = (0.24 \pm 0.04)\%.$$

assuming

$$\frac{\epsilon(B_c^+ \to D_s^+ \bar{D}^0)}{\epsilon(B^+ \to D_s^+ \bar{D}^0)} \approx 0.5$$

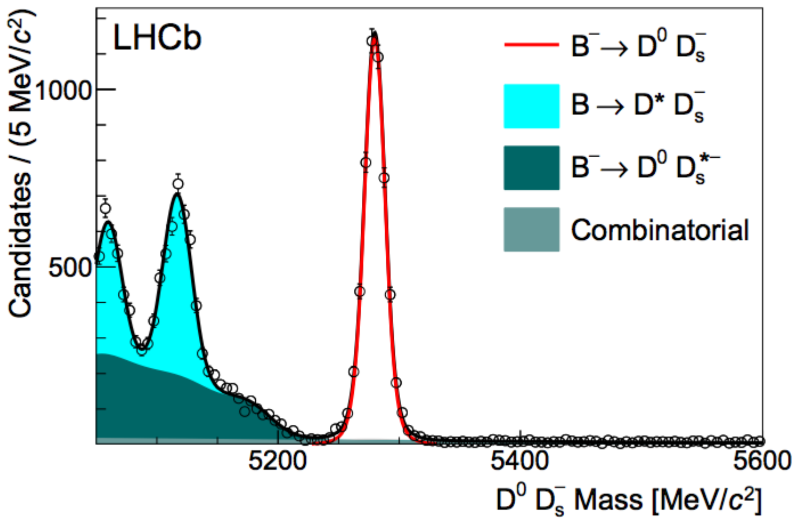
results in

Channel	yield ratio
$B_c^+ \to D^+ \bar{D}^0$	$(4.3 \pm 1.3) \times 10^{-6}$
$B_c^+ \to D^+ D^0$	$(1.3 \pm 0.4) \times 10^{-8}$
$B_c^+ \to D_s^+ \bar{D}^0$	$(3.1 \pm 0.9) \times 10^{-7}$
$B_c^+ \to D_s^+ D^0$	$(4.0 \pm 1.1) \times 10^{-7}$

Yield expectation

With B_c/B^+ rate of 1/200k do not expect signal in Run I data:

5k $B^+ \to D_s D^0$bar in 1 fb^{-1} at 7 TeV
Phys. Rev. D87 (2013) 092007



Expect no signal from Run I but maybe from Run 2 or Run 3

B_c->DD for gamma: outlook

- Predictions are small but differ by an order of magnitude
- Does not look hopeful for competitive gamma measurement
- Need experimental input on BF’s
- Explore other channels with larger BF?

Conclusions

- Bright outlook for B_c physics at LHCb:
  - *larger cross-section in Run 2*
  - *higher efficiency in Run 3*
  - *better vxt resolution in Run 3*
- Updated Run I measurements obvious gains
- Tetraquarks, spectroscopy, γ may be harder

BACKUP

TABLE III: Branching ratios (10^{-6}) of the CKM favored decays with both emission and annihilation contributions, together with results from other models. The errors for these entries correspond to the uncertainties in the input hadronic quantities, from the CKM matrix elements, and the scale dependence, respectively.

	channels	This work	Kiselev[4]	IKP[5]	IKS[7]	LC[8]	CF[10]
1	$B_c \to D^+ \bar{D}^0$	32^{+6+1+2}_{-6-1-4}	53	32	33	86	8.4
2	$B_c \to D^+ \bar{D}^{*0}$	34^{+7+2+3}_{-6-1-3}	75	83	38	75	7.5
3	$B_c \to D^{*+} \bar{D}^0$	12^{+3+1+0}_{-3-0-1}	49	17	9	30	84
4	$B_c \to D^{*+} \bar{D}^{*0}$	34^{+9+2+0}_{-8-1-0}	330	84	21	55	140
5	$B_c \to D_s^+ \bar{D}^0$	$2.3^{+0.4+0.1+0.2}_{-0.4-0.1-0.2}$	4.8	1.7	2.1	4.6	0.6
6	$B_c \to D_s^+ \bar{D}^{*0}$	$2.6^{+0.4+0.1+0.1}_{-0.6-0.1-0.2}$	7.1	4.3	2.4	3.9	0.53
7	$B_c \to D_s^{*+} \bar{D}^0$	$0.7^{+0.1+0.0+0.0}_{-0.2-0.0-0.0}$	4.5	0.95	0.65	1.8	5
8	$B_c \to D_s^{*+} \bar{D}^{*0}$	$2.8^{+0.7+0.1+0.1}_{-0.6-0.1-0.0}$	26	4.7	1.6	3.5	8.4

TABLE IV: Branching ratios (10^{-7}) of the CKM suppressed decays with pure emission contributions, together with results from other models. The errors for these entries correspond to the uncertainties in the input hadronic quantities, from the CKM matrix elements, and the scale dependence, respectively.

	channels	This work	Kiselev[4]	IKP[5]	IKS[7]
1	$B_c \to D^+ D^0$	$1.0^{+0.2+0.1+0.0}_{-0.1-0.0-0.0}$	3.2	1.1	3.1
2	$B_c \to D^+ D^{*0}$	$0.7^{+0.1+0.1+0.0}_{-0.2-0.0-0.0}$	2.8	0.25	0.52
3	$B_c \to D^{*+} D^0$	$0.9^{+0.1+0.1+0.0}_{-0.2-0.0-0.0}$	4.0	3.8	4.4
4	$B_c \to D^{*+} D^{*0}$	$0.8^{+0.2+0.1+0.2}_{-0.1-0.0-0.0}$	15.9	2.8	2.0
5	$B_c \to D_s^+ D^0$	30^{+5+3+1}_{-4-2-1}	66	25	74
6	$B_c \to D_s^+ D^{*0}$	19^{+3+2+0}_{-3-1-1}	63	6	13
7	$B_c \to D_s^{*+} D^0$	25^{+4+2+0}_{-3-2-1}	85	69	93
8	$B_c \to D_s^{*+} D^{*0}$	24^{+3+2+1}_{-3-2-1}	404	54	45

branching ratio calculations

- From arXiv:1607.02718 Y.K. Hsiao and C.Q. Geng

TABLE II. The branching ratios of the $B_c \to J/\psi(M, \ell\bar{\nu}_\ell)$ decays, where the first (second) errors of our results are from the form factors (a_1).

decay modes	our results	QCD models
$B_c^- \to J/\psi\pi^-$	$(10.9 \pm 0.8^{+2.6}_{-1.2}) \times 10^{-4}$	$(20^{+8+0+0}_{-7-1-0}) \times 10^{-4}$ [8]
$B_c^- \to J/\psi K^-$	$(8.8 \pm 0.6^{+2.1}_{-1.0}) \times 10^{-5}$	$(16^{+6+0+0}_{-6-1-0}) \times 10^{-5}$ [8]
$B_c^- \to J/\psi e^- \bar{\nu}_e$	$(1.94 \pm 0.20) \times 10^{-2}$	$(1.49^{+0.01+0.15+0.23}_{-0.03-0.14-0.23}) \times 10^{-2}$ [14]
$B_c^- \to J/\psi \mu^- \bar{\nu}_\mu$	$(1.94 \pm 0.20) \times 10^{-2}$	$(1.49^{+0.01+0.15+0.23}_{-0.03-0.14-0.23}) \times 10^{-2}$ [14]
$B_c^- \to J/\psi \tau^- \bar{\nu}_\tau$	$(4.47 \pm 0.48) \times 10^{-3}$	$(3.70^{+0.02+0.42+0.56}_{-0.05-0.38-0.56}) \times 10^{-3}$ [14]