

# Color-allowed Bottom Baryon to s-wave and p-wave Charmed Baryon non-leptonic Decays

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PRD99 (2019) no.1, 014023, CKC  
arXiv:1905.00153, CKC



# Introduction

- LHCb found five narrow  $\Omega_c$  states in 2017:

$\Omega_c(3000), \Omega_c(3050), \Omega_c(3065), \Omega_c(3090), \Omega_c(3120)$

- So far there are 40 charmed baryons observed
- 16 out of 40 have unspecified quantum numbers, these include:

$\Lambda_c(2765), \Sigma_c(2800)^{++,+,0}, \Xi_c(2930)^0, \Xi_c(2970)^{+,0}, \Xi_c(3055)^+,$   
 $\Xi_c(3080)^{+,0}, \Xi_c(3123)^+,$

$\Omega_c(3000), \Omega_c(3050), \Omega_c(3065), \Omega_c(3090), \Omega_c(3120)$

- In addition there are two QN assignments for  $\Lambda_c(2940)$ :  
 $3/2^-$  (LHCb 2017, PDG) and  $1/2^-$  (Cheng, Chiang 2017)

State	$J^P$	$n$	$(L_K, L_k)$	$S_{[qq]}^P$	$J_\ell^{P_\ell}$	Mass	Width	Decay modes
$\Lambda_c^+$	$\frac{1}{2}^+$	1	(0,0)	$0^+$	$0^+$	$2286.46 \pm 0.14$		weak
$\Lambda_c(2595)^+$	$\frac{1}{2}^-$	1	(1,0)	$0^+$	$1^-$	$2592.25 \pm 0.28$	$2.6 \pm 0.6$	$\Lambda_c \pi \pi, \Sigma_c \pi$
$\Lambda_c(2625)^+$	$\frac{3}{2}^-$	1	(1,0)	$0^+$	$1^-$	$2628.11 \pm 0.19$	$< 0.97$	$\Lambda_c \pi \pi, \Sigma_c \pi$
$\Lambda_c(2765)^+$	??	?	?	?	?	$2766.6 \pm 2.4$	50	$\Sigma_c \pi, \Lambda_c \pi \pi$
$\Lambda_c(2860)^+$	$\frac{3}{2}^+$	1	(2,0)	$0^+$	$2^+$	$2856.1^{+2.3}_{-6.0}$	$68^{+12}_{-22}$	$\Sigma_c^{(*)} \pi, D^0 p, D^+ n$
$\Lambda_c(2880)^+$	$\frac{5}{2}^+$	1	(2,0)	$0^+$	$2^+$	$2881.63 \pm 0.24$	$5.6^{+0.8}_{-0.6}$	$\Sigma_c^{(*)} \pi, \Lambda_c \pi \pi, D^0 p$
$\Lambda_c(2940)^+$	$\frac{3}{2}^-$	2	(1,0)	$0^+$	$1^-$	$2939.6^{+1.3}_{-1.5}$	$20^{+6}_{-5}$	$\Sigma_c^{(*)} \pi, \Lambda_c \pi \pi, D^0 p$
$\Sigma_c(2455)^{++}$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2453.97 \pm 0.14$	$1.89^{+0.09}_{-0.18}$	$\Lambda_c \pi$
$\Sigma_c(2455)^+$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2452.9 \pm 0.4$	$< 4.6$	$\Lambda_c \pi$
$\Sigma_c(2455)^0$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2453.75 \pm 0.14$	$1.83^{+0.11}_{-0.19}$	$\Lambda_c \pi$
$\Sigma_c(2520)^{++}$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2518.41^{+0.21}_{-0.19}$	$14.78^{+0.30}_{-0.40}$	$\Lambda_c \pi$
$\Sigma_c(2520)^+$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2517.5 \pm 2.3$	$< 17$	$\Lambda_c \pi$
$\Sigma_c(2520)^0$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2518.48 \pm 0.20$	$15.3^{+0.4}_{-0.5}$	$\Lambda_c \pi$
$\Sigma_c(2800)^{++}$	??	?	?	?	?	$2801^{+4}_{-6}$	$75^{+22}_{-17}$	$\Lambda_c \pi, \Sigma_c^{(*)} \pi, \Lambda_c \pi \pi$
$\Sigma_c(2800)^+$	??	?	?	?	?	$2792^{+14}_{-5}$	$62^{+60}_{-40}$	$\Lambda_c \pi, \Sigma_c^{(*)} \pi, \Lambda_c \pi \pi$
$\Sigma_c(2800)^0$	??	?	?	?	?	$2806^{+5}_{-7}$	$72^{+22}_{-15}$	$\Lambda_c \pi, \Sigma_c^{(*)} \pi, \Lambda_c \pi \pi$
$\Xi_c^+$	$\frac{1}{2}^+$	1	(0,0)	$0^+$	$0^+$	$2467.87 \pm 0.30$		weak
$\Xi_c^0$	$\frac{1}{2}^+$	1	(0,0)	$0^+$	$0^+$	$2470.87^{+0.28}_{-0.31}$		weak
$\Xi_c'^+$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2577.4 \pm 1.2$		$\Xi_c \gamma$
$\Xi_c'^0$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2578.8 \pm 0.5$		$\Xi_c \gamma$

State	$J^P$	$n$	$(L_K, L_k)$	$S_{[qq]}^P$	$J_\ell^{P\ell}$	Mass	Width	Decay modes
$\Xi_c(2645)^+$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2645.53 \pm 0.31$	$2.14 \pm 0.19$	$\Xi_c \pi$
$\Xi_c(2645)^0$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2646.32 \pm 0.31$	$2.35 \pm 0.22$	$\Xi_c \pi$
$\Xi_c(2790)^+$	$\frac{1}{2}^-$	1	(1,0)	$0^+$	$1^-$	$2792.0 \pm 0.5$	$8.9 \pm 1.0$	$\Xi'_c \pi$
$\Xi_c(2790)^0$	$\frac{1}{2}^-$	1	(1,0)	$0^+$	$1^-$	$2792.8 \pm 1.2$	$10.0 \pm 1.1$	$\Xi'_c \pi$
$\Xi_c(2815)^+$	$\frac{3}{2}^-$	1	(1,0)	$0^+$	$1^-$	$2816.67 \pm 0.31$	$2.43 \pm 0.26$	$\Xi_c^* \pi, \Xi_c \pi \pi, \Xi'_c \pi$
$\Xi_c(2815)^0$	$\frac{3}{2}^-$	1	(1,0)	$0^+$	$1^-$	$2820.22 \pm 0.32$	$2.54 \pm 0.25$	$\Xi_c^* \pi, \Xi_c \pi \pi, \Xi'_c \pi$
$\Xi_c(2930)^0$	??	?	?	?	?	$2931 \pm 6$	$36 \pm 13$	$\Lambda_c \bar{K}$
$\Xi_c(2970)^+$	??	?	?	?	?	$2969.4 \pm 0.8$	$20.9_{-3.5}^{+2.4}$	$\Sigma_c \bar{K}, \Lambda_c \bar{K} \pi, \Xi_c \pi \pi$
$\Xi_c(2970)^0$	??	?	?	?	?	$2967.8 \pm 0.8$	$28.1_{-4.0}^{+3.4}$	$\Sigma_c \bar{K}, \Lambda_c \bar{K} \pi, \Xi_c \pi \pi$
$\Xi_c(3055)^+$	??	?	?	?	?	$3055.9 \pm 0.4$	$7.8 \pm 1.9$	$\Sigma_c \bar{K}, \Lambda_c \bar{K} \pi, D\Lambda$
$\Xi_c(3080)^+$	??	?	?	?	?	$3077.2 \pm 0.4$	$3.6 \pm 1.1$	$\Sigma_c \bar{K}, \Lambda_c \bar{K} \pi, D\Lambda$
$\Xi_c(3080)^0$	??	?	?	?	?	$3079.9 \pm 1.4$	$5.6 \pm 2.2$	$\Sigma_c \bar{K}, \Lambda_c \bar{K} \pi, D\Lambda$
$\Xi_c(3123)^+$	??	?	?	?	?	$3122.9 \pm 1.3$	$4 \pm 4$	$\Sigma_c^* \bar{K}, \Lambda_c \bar{K} \pi$
$\Omega_c^0$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2695.2 \pm 1.7$		weak
$\Omega_c(2770)^0$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2765.9 \pm 2.0$		$\Omega_c \gamma$
$\Omega_c(3000)^0$	??	?	?	?	?	$3000.4 \pm 0.4$	$4.5 \pm 0.7$	$\Xi_c \bar{K}$
$\Omega_c(3050)^0$	??	?	?	?	?	$3050.2 \pm 0.33$	$< 1.2$	$\Xi_c \bar{K}$
$\Omega_c(3065)^0$	??	?	?	?	?	$3065.6 \pm 0.4$	$3.5 \pm 0.4$	$\Xi_c \bar{K}$
$\Omega_c(3090)^0$	??	?	?	?	?	$3090.2 \pm 0.7$	$8.7 \pm 1.3$	$\Xi_c^{(\prime)} \bar{K}$
$\Omega_c(3120)^0$	??	?	?	?	?	$3119.1 \pm 1.0$	$< 2.6$	$\Xi_c^{(\prime)} \bar{K}$

- The study of bottom baryon to charmed baryon weak decays may shed light on the quantum numbers of some charmed baryons
- Up to now only several color allowed  $\Lambda_b \rightarrow \Lambda_c P$  decay rates have been measured (LHCb 2014):

$$\Lambda_b \rightarrow \Lambda_c \pi^-, \Lambda_c K^-, \Lambda_c D^-, \Lambda_c D_s^-$$

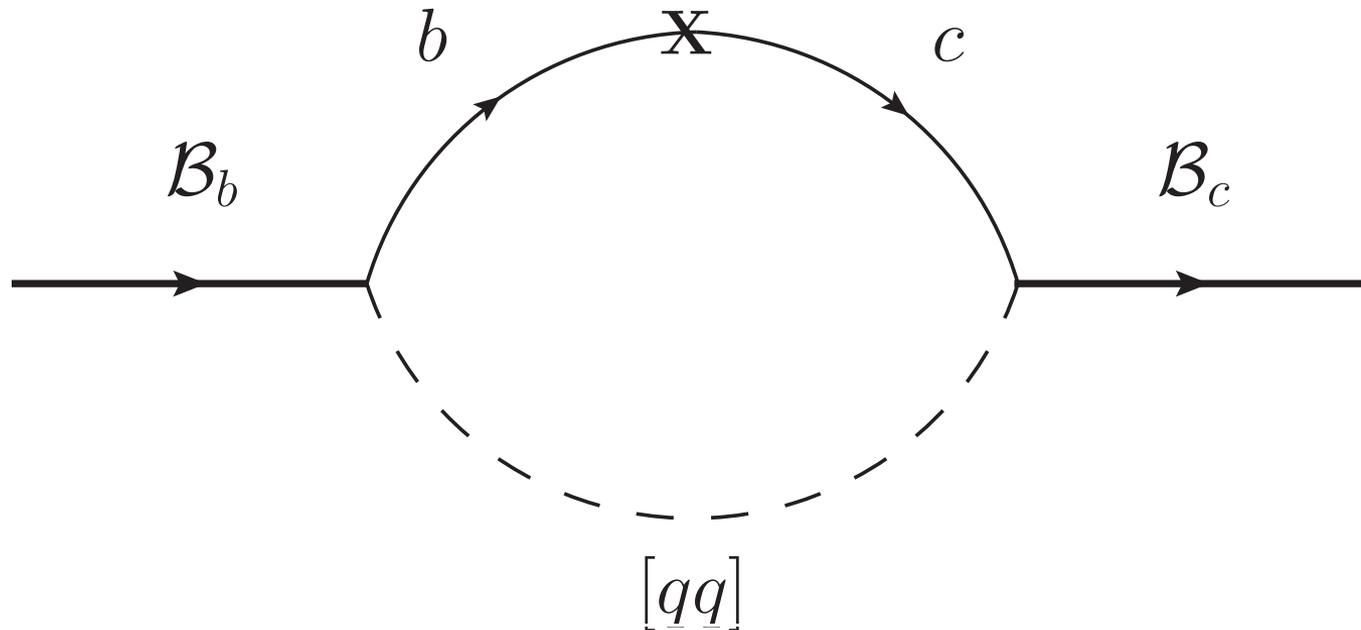
- We expect more to come
- In general, baryon decays are complicated processes
- Decay processes of  $b \rightarrow c$  transition with spectating light quarks are simpler

# Weakly decay bottom baryons:

State	$J^P$	$n$	$(L_K, L_k)$	$S_{[qq]}^P$	$J_\ell^{P_\ell}$	Mass	Width	Decay modes
$\Lambda_b^0$	$\frac{1}{2}^+$	1	(0,0)	$0^+$	$0^+$	$5619.60 \pm 0.17$		weak
$\Lambda_b(5912)^0$	$\frac{1}{2}^-$	1	(1,0)	$0^+$	$1^-$	$5912.20 \pm 0.21$	$< 0.66$	$\Lambda_b \pi \pi$
$\Lambda_b(5920)^0$	$\frac{3}{2}^-$	1	(1,0)	$0^+$	$1^-$	$5919.92 \pm 0.19$	$< 0.63$	$\Lambda_b^0 \pi \pi$
$\Sigma_b^+$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$5811.3 \pm 1.9$	$9.7_{-3.0}^{+4.0}$	$\Lambda_b \pi$
$\Sigma_b^-$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$5815.5 \pm 1.8$	$4.9_{-2.4}^{+3.3}$	$\Lambda_b \pi$
$\Sigma_b^{*+}$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$5832.1 \pm 1.9$	$11.5 \pm 2.8$	$\Lambda_b \pi$
$\Sigma_b^{*-}$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$5835.1 \pm 1.9$	$7.5 \pm 2.3$	$\Lambda_b \pi$
$\Xi_b^0$	$\frac{1}{2}^+$	1	(0,0)	$0^+$	$0^+$	$5791.9 \pm 0.5$		weak
$\Xi_b^-$	$\frac{1}{2}^+$	1	(0,0)	$0^+$	$0^+$	$5794.5 \pm 1.4$		weak
$\Xi_b'(5935)^-$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$5935.02 \pm 0.05$	$< 0.08$	$\Xi_b^0 \pi^-$
$\Xi_b(5945)^0$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$5949.8 \pm 1.4$	$0.90 \pm 0.18$	$\Xi_b \pi$
$\Xi_b(5955)^-$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$5955.33 \pm 0.13$	$1.65 \pm 0.33$	$\Xi_b \pi$
$\Xi_b(6227)^-$	??	?	?	?	?	$6226.9 \pm 2.0 \pm 0.3 \pm 0.2$	$18.1 \pm 5.4 \pm 1.8$	$\Lambda_b K^-, \Xi_b \pi^-$
$\Omega_b^0$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$6046.1 \pm 1.7$		weak

$\Lambda_b(\bar{3}_f), \Xi_b(\bar{3}_f), \Omega_b(6_f)$  have  $0^+$  and  $1^+$  diquarks

# $b \rightarrow c$ transitions with spectating diquarks



- $[qq] = 0^+$  or  $1^+$  diquark
- The diquark is spectating in the transition

# We consider 6 transition types: (i-iii) s-wave (iv-vi) p-wave Q[qq]

Type	$(n, L_K, S_{[qq]}^P, J_L^P, J^P)_b \rightarrow (n', L'_K, S_{[qq]}^P, J_L'^P, J'^P)_c$	$\mathcal{B}_b \rightarrow \mathcal{B}_c$
(i)	$(1, 0, 0^+, 0^+, \frac{1}{2}^+) \rightarrow (1, 0, 0^+, 0^+, \frac{1}{2}^+)$	$\Lambda_b^0 \rightarrow \Lambda_c^+, \Xi_b^{0(-)} \rightarrow \Xi_c^{+(0)}$
(i)*	$(1, 0, 0^+, 0^+, \frac{1}{2}^+) \rightarrow (2, 0, 0^+, 0^+, \frac{1}{2}^+)$	$\Lambda_b^0 \rightarrow \Lambda_c(2765)^+(\dagger)$
(ii)	$(1, 0, 1^+, 1^+, \frac{1}{2}^+) \rightarrow (1, 0, 1^+, 1^+, \frac{1}{2}^+)$	$\Omega_b^- \rightarrow \Omega_c^0$
(ii)*	$(1, 0, 1^+, 1^+, \frac{1}{2}^+) \rightarrow (2, 0, 1^+, 1^+, \frac{1}{2}^+)$	$\Omega_b^- \rightarrow \Omega_c(3090)^0(\dagger)$
(iii)	$(1, 0, 1^+, 1^+, \frac{1}{2}^+) \rightarrow (1, 0, 1^+, 1^+, \frac{3}{2}^+)$	$\Omega_b^- \rightarrow \Omega_c(2770)^0$
(iii)*	$(1, 0, 1^+, 1^+, \frac{1}{2}^+) \rightarrow (2, 0, 1^+, 1^+, \frac{3}{2}^+)$	$\Omega_b^- \rightarrow \Omega_c(3120)^0(\dagger)$
(iv)	$(1, 0, 1^+, 1^+, \frac{1}{2}^+) \rightarrow (1, 1, 1^+, 2^-, \frac{3}{2}^-)$	$\Omega_b^- \rightarrow \Omega_c(3050)^0(\dagger)$
(v)	$(1, 0, 0^+, 0^+, \frac{1}{2}^+) \rightarrow (1, 1, 0^+, 1^-, \frac{1}{2}^-)$	$\Lambda_b^0 \rightarrow \Lambda_c(2595)^+, \Xi_b^{0(-)} \rightarrow \Xi_c(2790)^{+(0)}$
(v)*	$(1, 0, 0^+, 0^+, \frac{1}{2}^+) \rightarrow (2, 1, 0^+, 1^-, \frac{1}{2}^-)$	$\Lambda_b^0 \rightarrow \Lambda_c(2940)^+(\dagger)$
(vi)	$(1, 0, 0^+, 0^+, \frac{1}{2}^+) \rightarrow (1, 1, 0^+, 1^-, \frac{3}{2}^-)$	$\Lambda_b^0 \rightarrow \Lambda_c(2625)^+, \Xi_b^{0(-)} \rightarrow \Xi_c(2815)^{+(0)}$
(vi)*	$(1, 0, 0^+, 0^+, \frac{1}{2}^+) \rightarrow (2, 1, 0^+, 1^-, \frac{3}{2}^-)$	$\Lambda_b^0 \rightarrow \Lambda_c(2940)^+$

$$(i) \mathcal{B}_b(\bar{3}_f, 1/2^+) \rightarrow \mathcal{B}_c(\bar{3}_f, 1/2^+)$$

$$(iv) \mathcal{B}_b(6_f, 1/2^+) \rightarrow \mathcal{B}_c(6_f, 3/2^-)$$

$$(ii) \mathcal{B}_b(6_f, 1/2^+) \rightarrow \mathcal{B}_c(6_f, 1/2^+)$$

$$(v) \mathcal{B}_b(\bar{3}_f, 1/2^+) \rightarrow \mathcal{B}_c(\bar{3}_f, 1/2^-)$$

$$(iii) \mathcal{B}_b(6_f, 1/2^+) \rightarrow \mathcal{B}_c(6_f, 3/2^+)$$

$$(vi) \mathcal{B}_b(\bar{3}_f, 1/2^+) \rightarrow \mathcal{B}_c(\bar{3}_f, 3/2^-)$$

- All together 17 transitions, diquarks  $0^+, 1^+, *$  = radial excited
- QN for states with dagger are taken from (Cheng-Chiang 17)

# Transition Form Factors (s-wave)

- $\mathcal{B}_b\left(\frac{1}{2}^+\right) \rightarrow \mathcal{B}_c\left(\frac{1}{2}^+\right)$  transition MA, 3+3 F.F.

$$\langle \mathcal{B}_c(P', J'_z) | \bar{c} \gamma_\mu b | \mathcal{B}_b(P, J_z) \rangle = \bar{u}(P', J'_z) \left[ f_1^V(q^2) \gamma_\mu + i \frac{f_2^V(q^2)}{M + M'} \sigma_{\mu\nu} q^\nu + \frac{f_3^V(q^2)}{M + M'} q_\mu \right] u(P, J_z),$$

$$\langle \mathcal{B}_c(P', J'_z) | \bar{c} \gamma_\mu \gamma_5 b | \mathcal{B}_b(P, J_z) \rangle = \bar{u}(P', J'_z) \left[ g_1^A(q^2) \gamma_\mu + i \frac{g_2^A(q^2)}{M - M'} \sigma_{\mu\nu} q^\nu + \frac{g_3^A(q^2)}{M - M'} q_\mu \right] \gamma_5 u(P, J_z),$$

- $\mathcal{B}_b\left(\frac{1}{2}^+\right) \rightarrow \mathcal{B}_c\left(\frac{3}{2}^+\right)$  transition MA, 4+4 F.F.

$$\langle \mathcal{B}_c(P', J'_z) | \bar{c} \gamma_\mu b | \mathcal{B}_b(P, J_z) \rangle = \bar{u}^\nu(P', J'_z) \left[ \bar{f}_1^V(q^2) g_{\nu\mu} + \frac{\bar{f}_2^V(q^2)}{M} P_\nu \gamma_\mu + \frac{\bar{f}_3^V(q^2)}{MM'} P_\nu P'_\mu + \frac{\bar{f}_4^V(q^2)}{M^2} P_\nu P_\mu \right] \gamma_5 u(P, J_z),$$

$$\langle \mathcal{B}_c(P', J'_z) | \bar{c} \gamma_\mu \gamma_5 b | \mathcal{B}_b(P, J_z) \rangle = \bar{u}^\nu(P', J'_z) \left[ \bar{g}_1^A(q^2) g_{\nu\mu} + \frac{\bar{g}_2^A(q^2)}{M} P_\nu \gamma_\mu + \frac{\bar{g}_3^A(q^2)}{MM''} P_\nu P'_\mu + \frac{\bar{g}_4^A(q^2)}{M^2} P_\nu P_\mu \right] u(P, J_z),$$

# Transition Form Factors (p-wave)

- $\mathcal{B}_b\left(\frac{1}{2}^+\right) \rightarrow \mathcal{B}_c\left(\frac{1}{2}^-\right)$  transition MA, 3+3 F.F.

$$\langle \mathcal{B}_c(P', J'_z) | \bar{c} \gamma_\mu b | \mathcal{B}_b(P, J_z) \rangle = \bar{u}(P', J'_z) \left[ g_1^V(q^2) \gamma_\mu + i \frac{g_2^V(q^2)}{M - M'} \sigma_{\mu\nu} q^\nu + \frac{g_3^V(q^2)}{M - M'} q_\mu \right] \gamma_5 u(P, J_z),$$

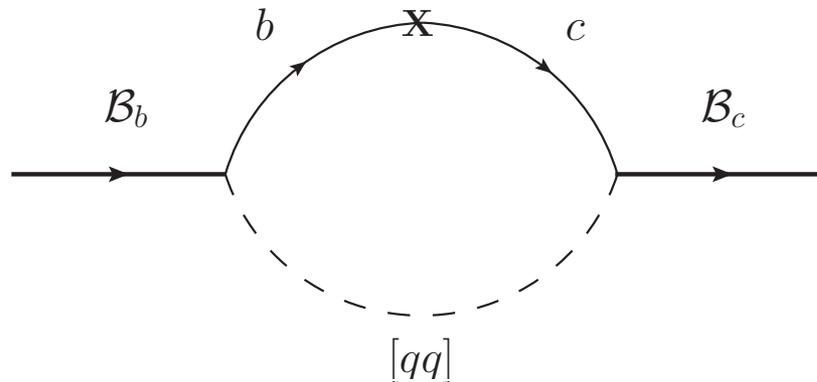
$$\langle \mathcal{B}_c(P', J'_z) | \bar{c} \gamma_\mu \gamma_5 b | \mathcal{B}_b(P, J_z) \rangle = \bar{u}(P', J'_z) \left[ f_1^A(q^2) \gamma_\mu + i \frac{f_2^A(q^2)}{M + M'} \sigma_{\mu\nu} q^\nu + \frac{f_3^A(q^2)}{M + M'} q_\mu \right] u(P, J_z),$$

- $\mathcal{B}_b\left(\frac{1}{2}^+\right) \rightarrow \mathcal{B}_c\left(\frac{3}{2}^-\right)$  transition MA, 4+4 F.F.

$$\langle \mathcal{B}_c(P', J'_z) | \bar{c} \gamma_\mu b | \mathcal{B}_b(P, J_z) \rangle = \bar{u}^\nu(P', J'_z) \left[ \bar{g}_1^V(q^2) g_{\nu\mu} + \frac{\bar{g}_2^V(q^2)}{M} P_\nu \gamma_\mu + \frac{\bar{g}_3^V(q^2)}{MM'} P_\nu P'_\mu + \frac{\bar{g}_4^V(q^2)}{M^2} P_\nu P_\mu \right] u(P, J_z),$$

$$\langle \mathcal{B}_c(P', J'_z) | \bar{c} \gamma_\mu \gamma_5 b | \mathcal{B}_b(P, J_z) \rangle = \bar{u}^\nu(P', J'_z) \left[ \bar{f}_1^A(q^2) g_{\nu\mu} + \frac{\bar{f}_2^A(q^2)}{M} P_\nu \gamma_\mu + \frac{\bar{f}_3^A(q^2)}{MM'} P_\nu P'_\mu + \frac{\bar{f}_4^A(q^2)}{M^2} P_\nu P_\mu \right] \gamma_5 u(P, J_z),$$

# Our approach



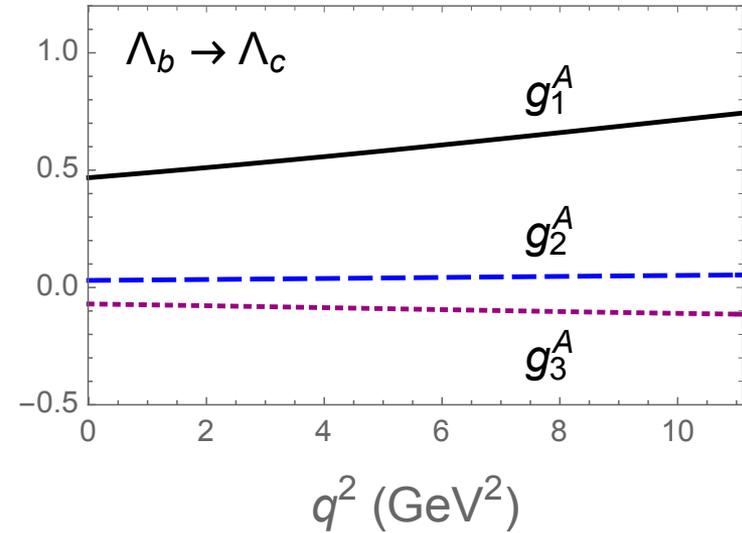
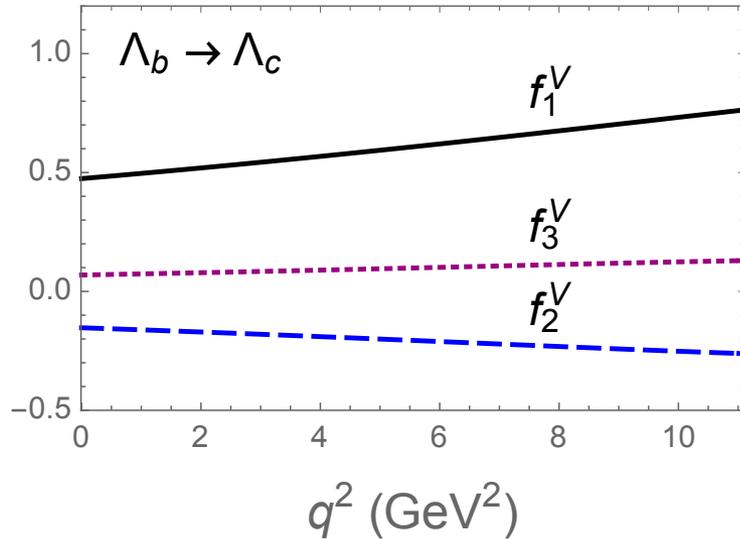
- We use light-front quark model to calculate transition form factors
- Light-front quark model has been used in many form factor calculations (Jaus; CKC, Cheng, Hwang, Ke ...)
- We derive all vertex functions (mostly new)
- We extract all form factors.

# Inputs

TABLE V: The input parameters  $m_{[qq']}^S$ ,  $m_{[qq']}^A$ ,  $m_q$  and  $\beta$ 's appearing in the Gaussian-type wave function (5) (in units of GeV). The superscript  $S$  and  $A$  denote scalar and axial vector diquarks, respectively.

$m_{[ud]}^S$	$m_{[us],[ds]}^S$	$m_{[ss]}^A$	$m_b$	$m_c$	$\beta(\Lambda_b)$	$\beta(\Xi_b^{0,-})$
0.65	0.86	1.10	4.44	1.42	0.750	0.850
$\beta(\Omega_b)$	$\beta(\Lambda_c)$	$\beta[\Lambda_c(2595)]$	$\beta[\Lambda_c(2625)]$	$\beta[\Lambda_c(2765)]$	$\beta[\Lambda_c(2940, \frac{1}{2}^-)]$	$\beta[\Lambda_c(2940, \frac{3}{2}^-)]$
0.900	0.345	0.350	0.450	0.345	0.350	0.450
$\beta(\Xi_c^{+,0})$	$\beta[\Xi_c^{+,0}(2790)]$	$\beta[\Xi_c^{+,0}(2815)]$	$\beta(\Omega_c)$	$\beta[\Omega_c(2770)]$	$\beta[\Omega_c(3050)]$	$\beta[\Omega_c(3090)]$
0.370	0.365	0.550	0.300	0.370	0.420	0.300
$\beta[\Omega_c(3120)]$						
0.370						

# (i) $\mathcal{B}_b(\bar{3}_f, 1/2^+) \rightarrow \mathcal{B}_c(\bar{3}_f, 1/2^+)$ transition



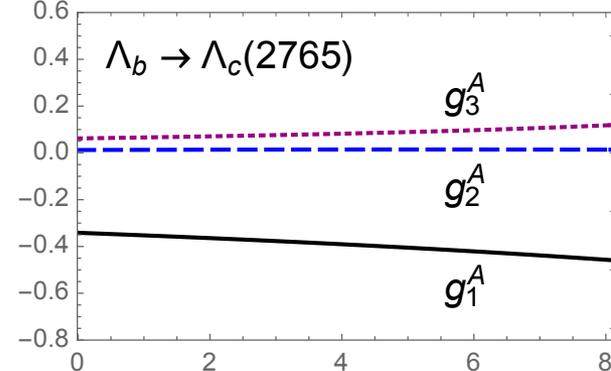
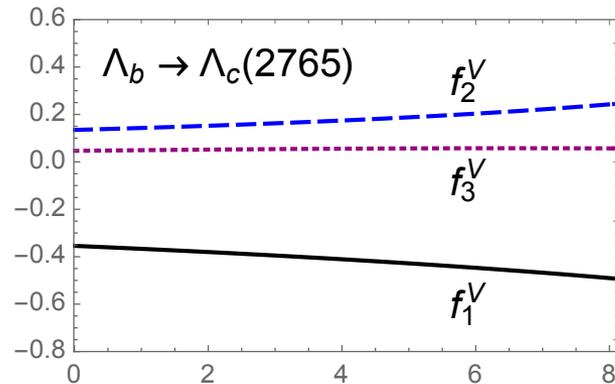
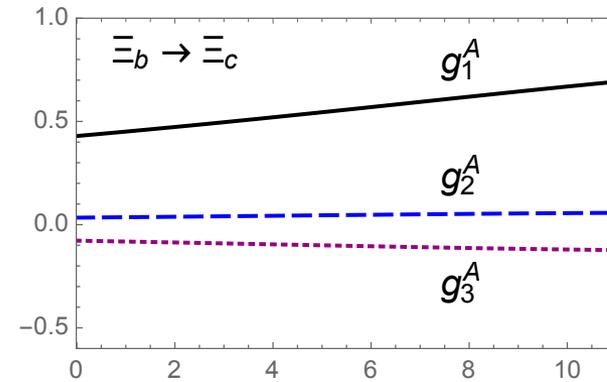
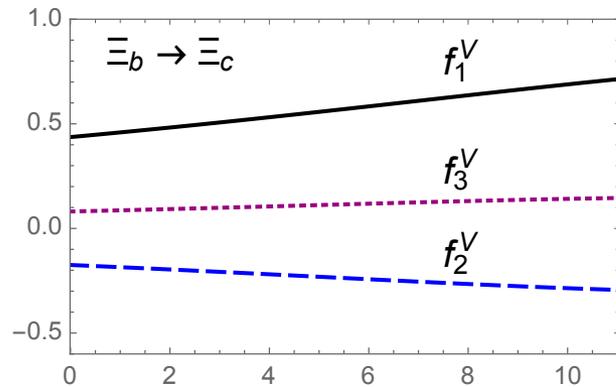
- Close to expectations from HQS: Isgur, Wise; Yan et al; Cheng, ...

$$f_1^V(\bar{3}_f) = g_1^A(\bar{3}_f) = \zeta(\omega)$$

$$f_{2,3}^V(\bar{3}_f) = g_{2,3}^A(\bar{3}_f) = 0$$

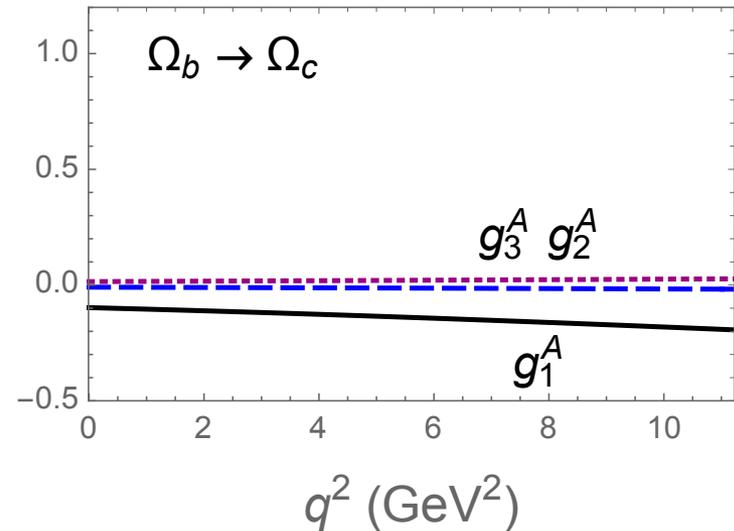
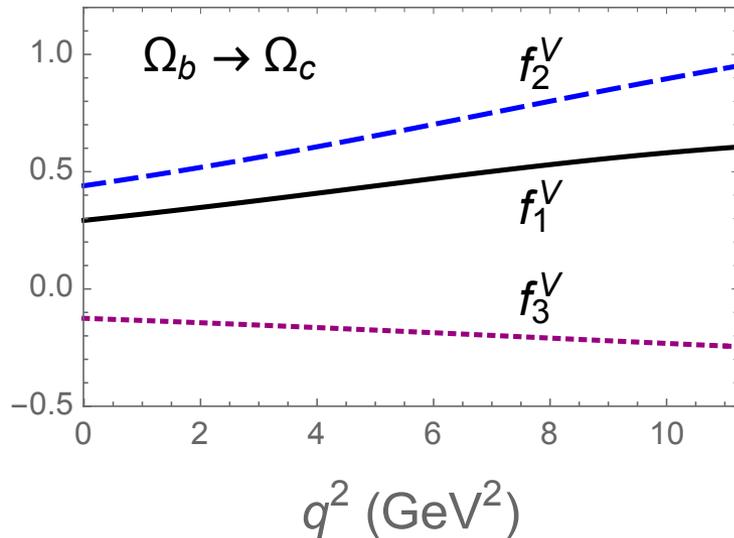
- We use heavy but finite  $m_b$  and  $m_c$ .
- The overlapping integral = 0.66 not 1,  $\beta(\mathcal{B}_b) \neq \beta(\mathcal{B}_c)$

# (i) $\mathcal{B}_b(\bar{3}_f, 1/2^+) \rightarrow \mathcal{B}_c(\bar{3}_f, 1/2^+)$ transition



- $\Lambda_c(2765)$  a radial excitation, the overlapping integral = -0.53 not 0, as  $\beta(\mathcal{B}_b) \neq \beta(\mathcal{B}_c)$

## (ii) $\mathcal{B}_b(6_f, 1/2^+) \rightarrow \mathcal{B}_c(6_f, 1/2^+)$ transition



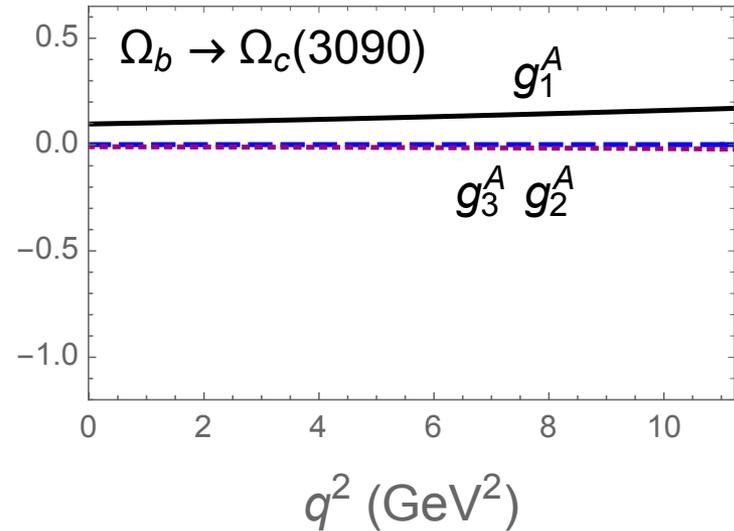
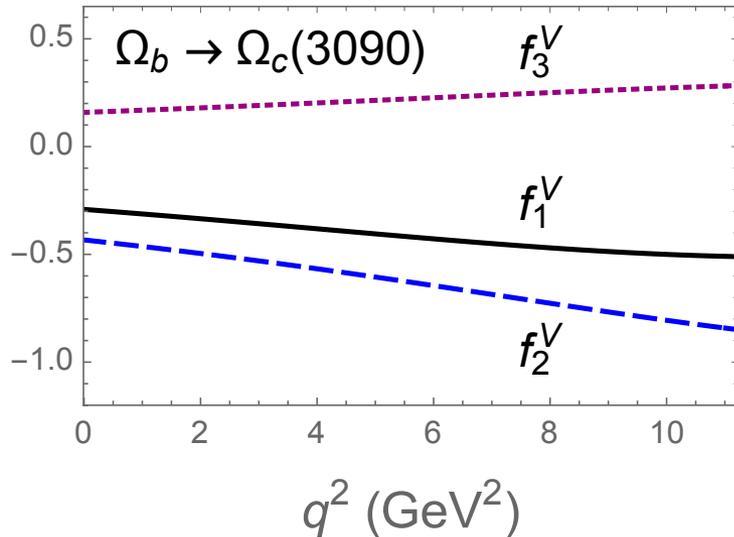
- Close to expectations from HQS+large  $N_c$ :  
(at  $\omega = 1, q^2 = q_{max}^2$ ) Isgur, Wise; Yan et al; Chow; Cheng, ...

$$(f_1^V, f_2^V, f_3^V) = (1.23, 1.56, -0.60)$$

$$(g_1^A, g_2^A, g_3^A) = (-0.33, 0, 0)$$

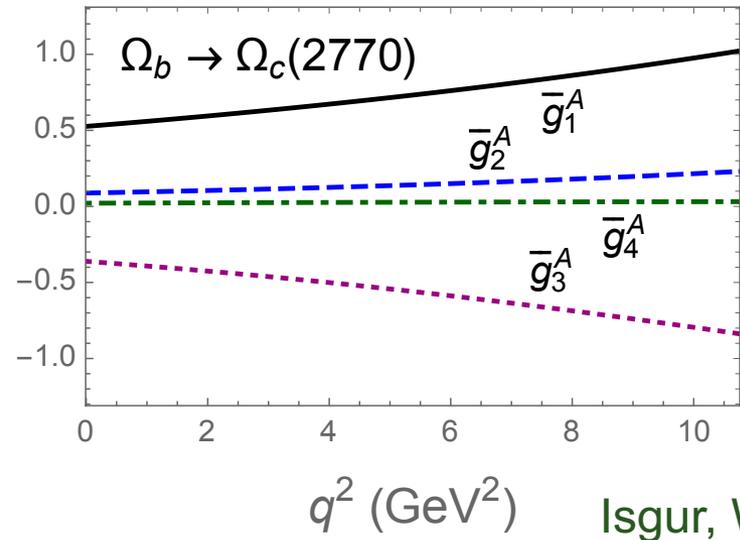
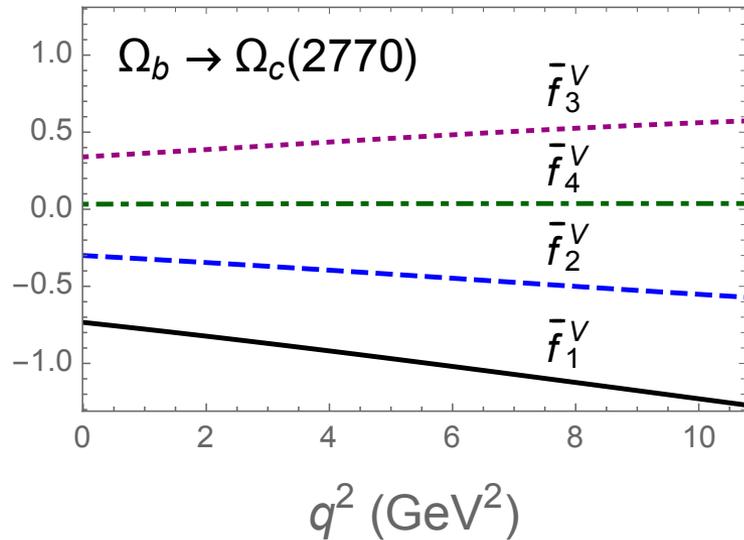
- The overlapping integral=0.46 not 1,  $\beta(\mathcal{B}_b) \neq \beta(\mathcal{B}_c)$

(ii)  $\mathcal{B}_b(6_f, 1/2^+) \rightarrow \mathcal{B}_c(6_f, 1/2^+)$  transition



- Compared to the previous case, F.F. similar in sizes, but opposite in signs
- $\Omega_c(3090)$  a radial excitation, the overlapping integral = -0.46 not 0, as  $\beta(\mathcal{B}_b) \neq \beta(\mathcal{B}_c)$

### (iii) $\mathcal{B}_b(6_f, 1/2^+) \rightarrow \mathcal{B}_c(6_f, 3/2^+)$ transition



Isgur, Wise; Yan et al; Chow; Cheng, ...

#### Close to expectations from HQS+LNc:

$$\bar{f}_1^V = -\bar{g}_1^V = -\frac{2}{\sqrt{3}} \xi_1(\omega)$$

$$\bar{f}_3^V = -\bar{g}_3^V = -\frac{2}{\sqrt{3}} \xi_2(\omega)$$

$$\bar{f}_4^V = \bar{g}_4^V = 0$$

$$\bar{f}_2^V = -\frac{1}{\sqrt{3}}[\xi_1(\omega) + (1-\omega)\xi_2(\omega)]$$

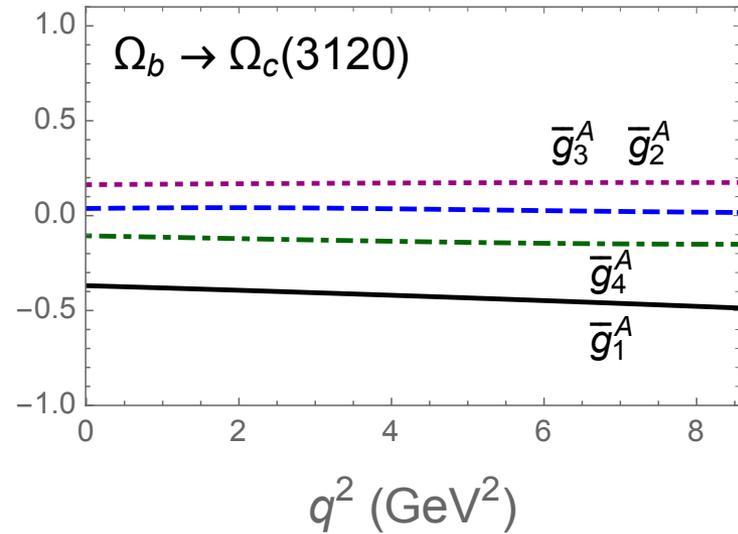
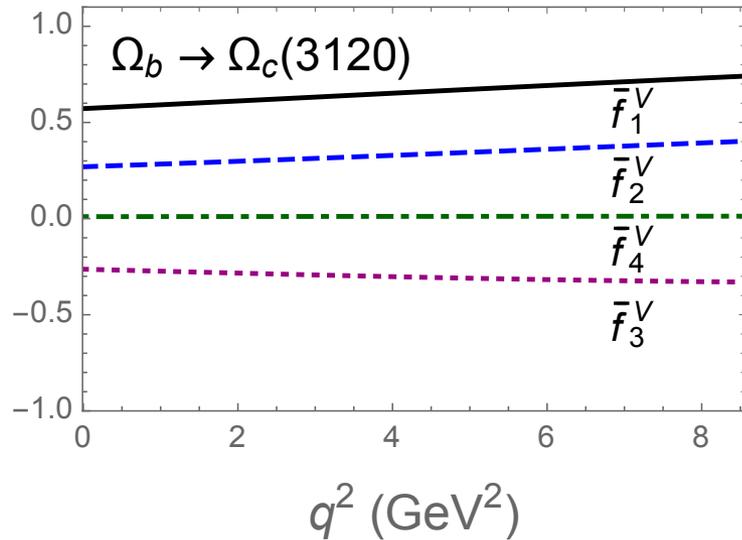
$$\bar{g}_2^V = -\frac{1}{\sqrt{3}}[\xi_1(\omega) - (1+\omega)\xi_2(\omega)]$$

$$\xi_1(\omega) = (1 + \omega) \xi_2(\omega)$$

$$(\bar{f}_1^V, \bar{f}_2^V, \bar{f}_3^V, \bar{f}_4^V) = (-1.15, -0.58, 0.58, 0) \quad (\bar{g}_1^A, \bar{g}_2^A, \bar{g}_3^A, \bar{g}_4^A) = (1.15, 0, -0.58, 0)$$

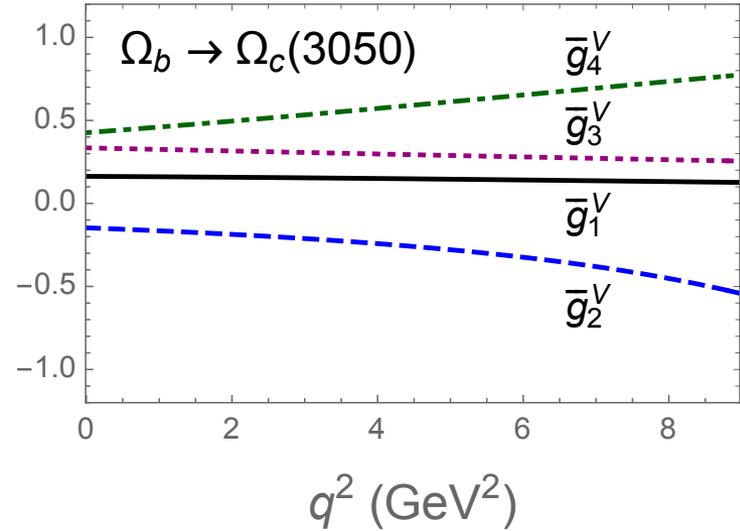
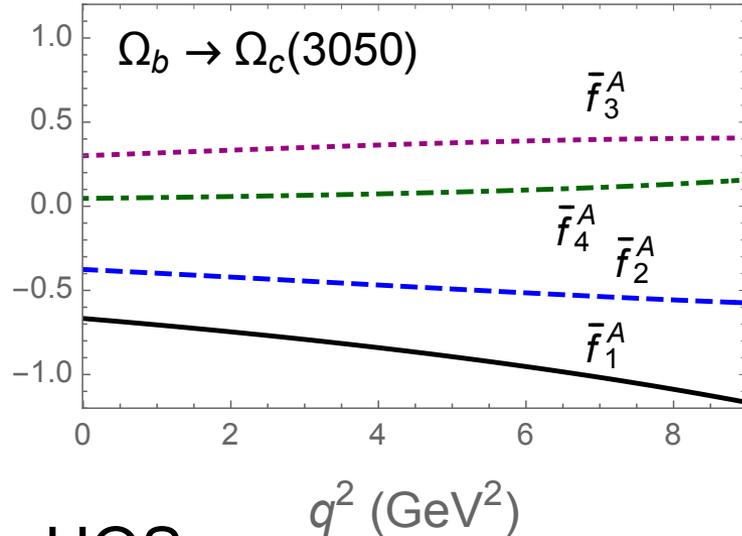
#### The overlapping integral=0.56 not 1, $\beta(\mathcal{B}_b) \neq \beta(\mathcal{B}_c)$

### (iii) $\mathcal{B}_b(6_f, 1/2^+) \rightarrow \mathcal{B}_c(6_f, 3/2^+)$ transition



- Compared to the previous case, F.F. similar in sizes, opposite in signs
- $\Omega_c(3120)$  a radial excitation, the overlapping integral = -0.51 not 0, as  $\beta(\mathcal{B}_b) \neq \beta(\mathcal{B}_c)$

# (iv) $\mathcal{B}_b(6_f, 1/2^+) \rightarrow \mathcal{B}_c(6_f, 3/2^-)$ transition



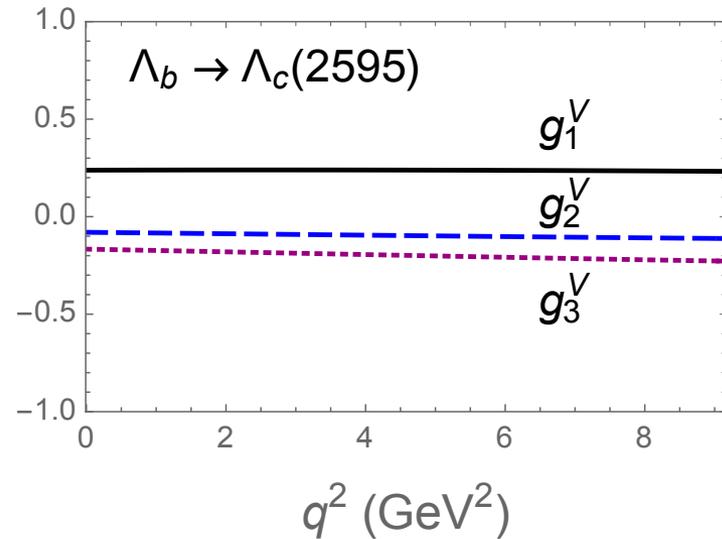
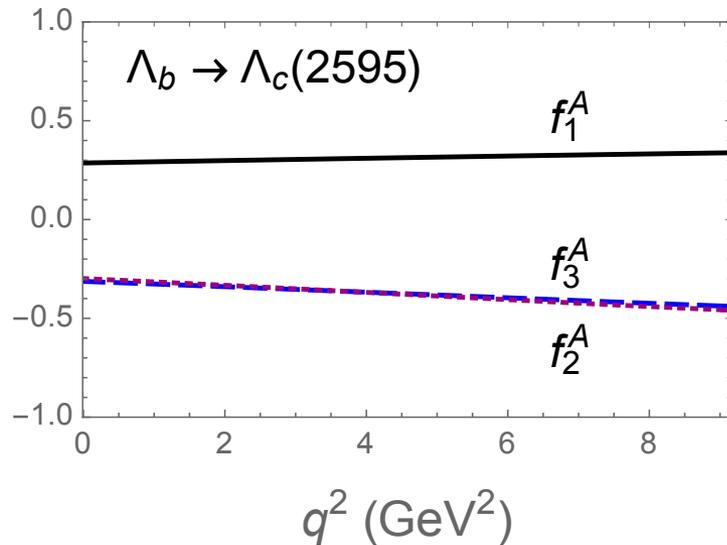
## ■ HQS:

Xu 1993

$$\begin{aligned} \bar{f}_1^A(\mathbf{6}_f) &= -\frac{2}{\sqrt{30}}(1+\omega)\xi_5(\omega), & \bar{f}_2^A(\mathbf{6}_f) &= -\frac{2}{\sqrt{30}}[(1+\omega)\xi_5(\omega) + (1-\omega^2)\xi_6(\omega)], \\ \bar{f}_3^A(\mathbf{6}_f) &= -\frac{2}{\sqrt{30}}[\xi_5(\omega) - 2(1+\omega)\xi_6(\omega)], & \bar{f}_4^A(\mathbf{6}_f) &= \frac{4}{\sqrt{30}}[\xi_5(\omega) - (1+\omega)\xi_6(\omega)], \\ \bar{g}_1^V(\mathbf{6}_f) &= -\frac{2}{\sqrt{30}}(1-\omega)\xi_5(\omega), & \bar{g}_2^V(\mathbf{6}_f) &= \frac{1}{\sqrt{30}}[(1-2\omega)\xi_5(\omega) - 2(1-\omega^2)\xi_6(\omega)], \\ \bar{g}_3^V(\mathbf{6}_f) &= \frac{2}{\sqrt{30}}[\xi_5(\omega) + 2(1-\omega)\xi_6(\omega)], & \bar{g}_4^V(\mathbf{6}_f) &= \frac{4}{\sqrt{30}}[\xi_5(\omega) + (1-\omega)\xi_6(\omega)]; \end{aligned}$$

- Naively obtain:  $\xi_5(1) \approx 1.4_{-0.7}^{+0.2}$ ,  $\xi_6(1) \approx 0.7$ , except from  $\bar{g}_2$  we have  $\xi_5(1) \approx 3.0$

# $(v) \mathcal{B}_b(\bar{3}_f, 1/2^+) \rightarrow \mathcal{B}_c(\bar{3}_f, 1/2^-)$ transition



- Close to expectations from HQS: Isgur, Wise, Youssefmir 1991

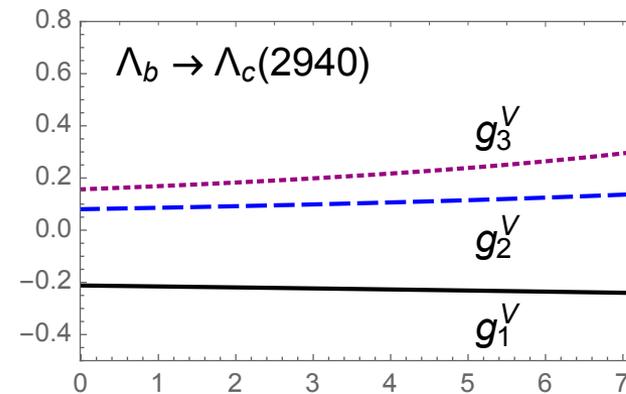
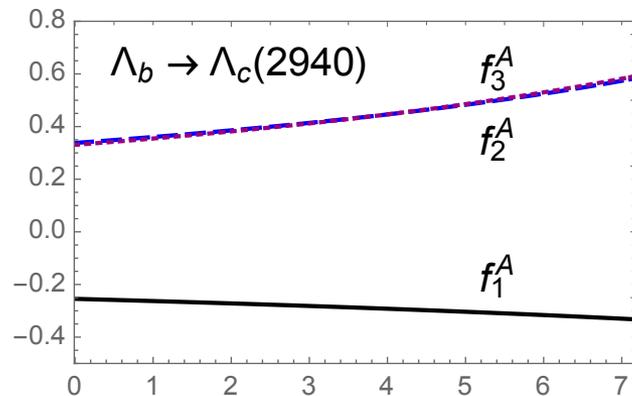
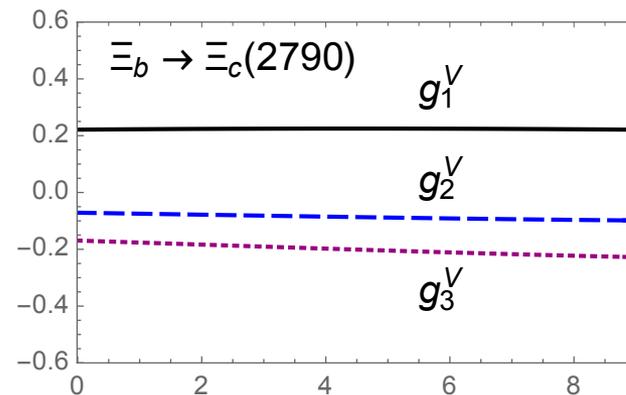
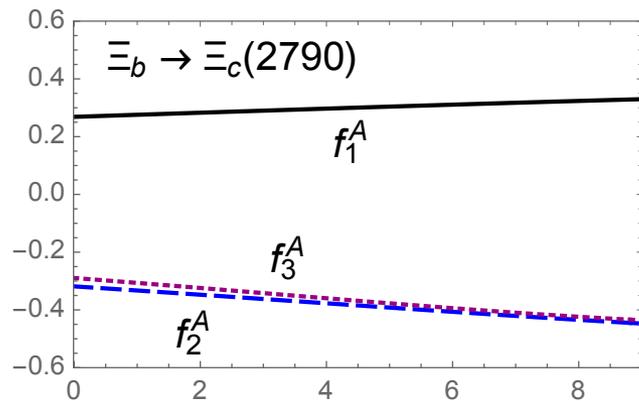
$$f_1^A = g_1^V = \left(\omega - \frac{M'}{M}\right) \frac{\sigma(\omega)}{\sqrt{3}}$$

$$f_2^A = f_3^A = -\left(1 + \frac{M'}{M}\right) \frac{\sigma(\omega)}{\sqrt{3}}$$

$$g_2^V = g_3^V = -\left(1 - \frac{M'}{M}\right) \frac{\sigma(\omega)}{\sqrt{3}}$$

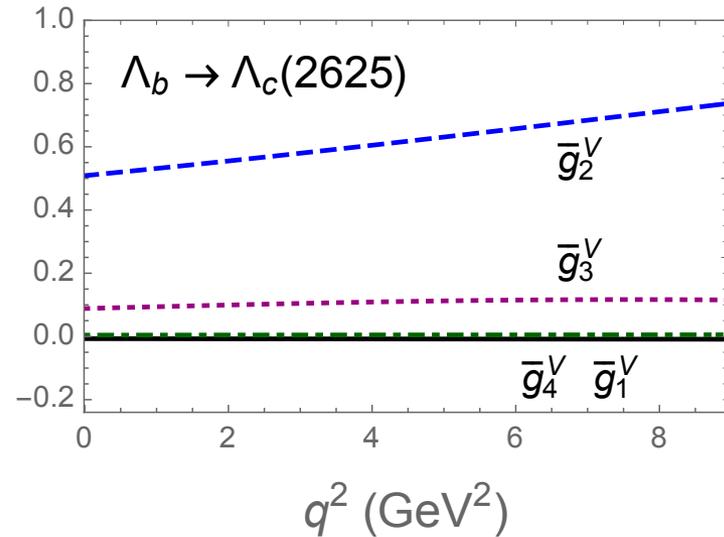
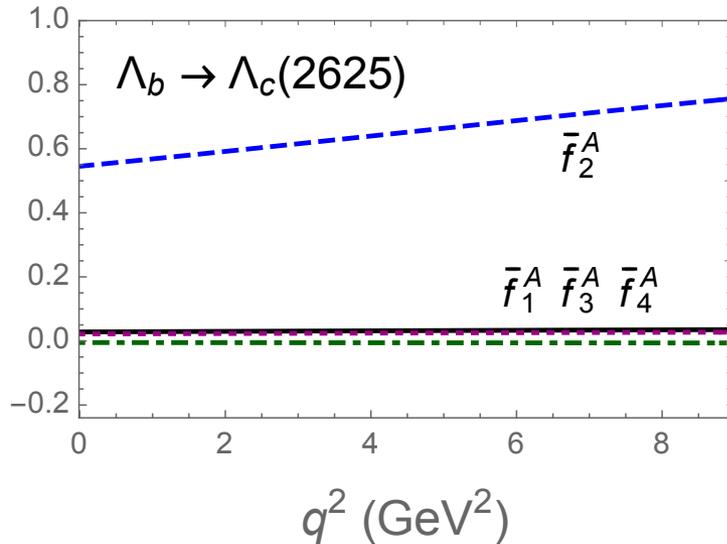
- Naively obtain:  $\sigma(1) \approx 0.7_{-0.3}^{+0.5}$

# (v) $\mathcal{B}_b(\bar{3}_f, 1/2^+) \rightarrow \mathcal{B}_c(\bar{3}_f, 1/2^-)$ transition



- $\Lambda_c(2940)$  a radial excitation,  $\sigma^{(*)}(1) \approx -0.8_{-0.4}^{+0.3}$
- the overlapping integral = -0.53 not 0, as  $\beta(\mathcal{B}_b) \neq \beta(\mathcal{B}_c)$

# (vi) $\mathcal{B}_b(\bar{3}_f, 1/2^+) \rightarrow \mathcal{B}_c(\bar{3}_f, 3/2^-)$ transition



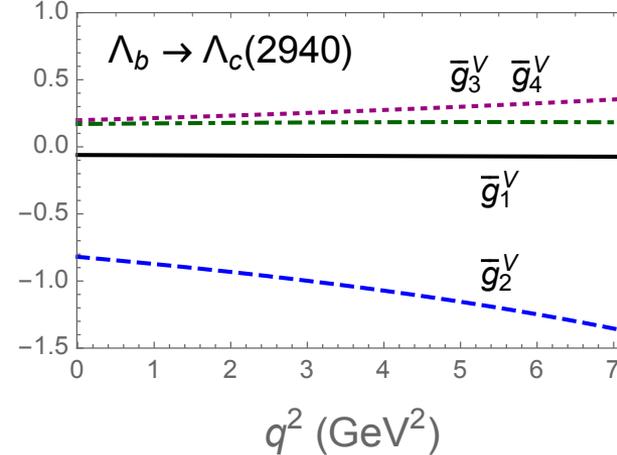
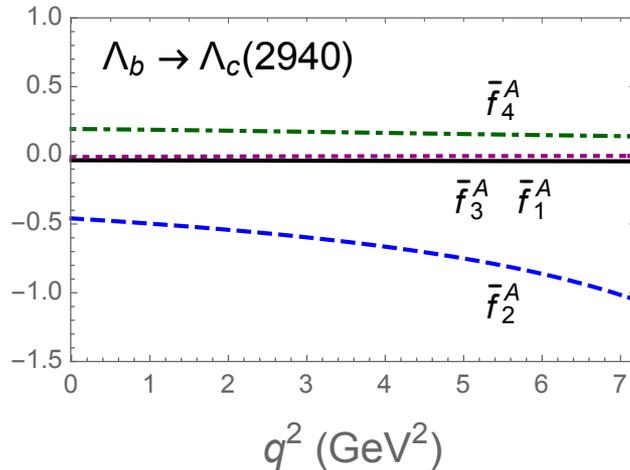
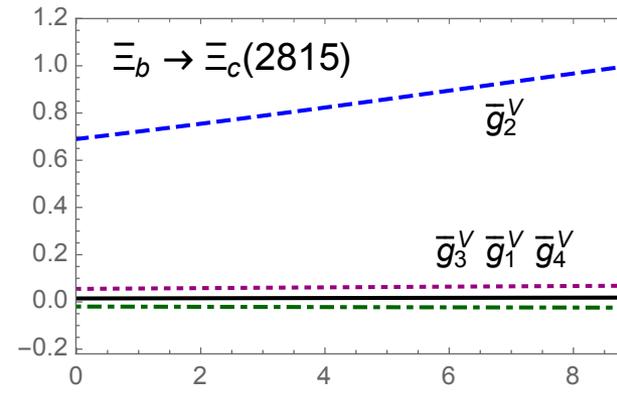
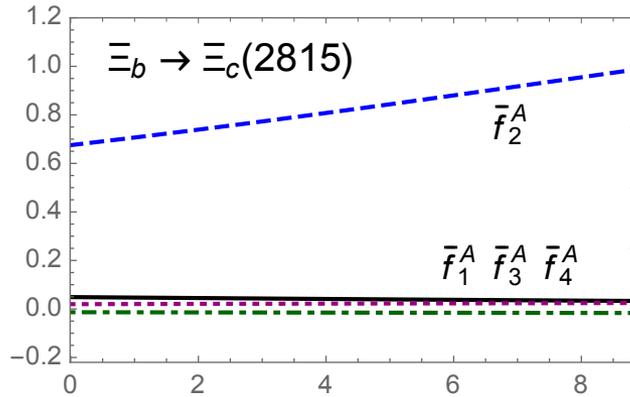
- Close to expectations from HQS: Isgur, Wise, Youssefmir 1991

$$\bar{f}_2^A(\bar{3}_f) = \bar{g}_2^V(\bar{3}_f) = \sigma(\omega)$$

$$\bar{f}_{1,3,4}^A(\bar{3}_f) = \bar{g}_{1,3,4}^V(\bar{3}_f) = 0$$

- Naively obtain:  $\sigma(1) \approx 0.7, 0.8$
- Close to the one obtained in the previous case

# (vi) $\mathcal{B}_b(\bar{3}_f, 1/2^+) \rightarrow \mathcal{B}_c(\bar{3}_f, 3/2^-)$ transition



- $\Lambda_c(2940)$  a radial excitation,  $\sigma^{(*)}(1) \approx -1.0, -1.4$
- Similar to the one obtained in the previous case

# Br in unit of $10^{-3}$

Transition type	Mode	$P = \pi^-$	$P = K^-$	$P = D^-$	$P = D_s^-$
(i) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^+)$	$Br(\Lambda_b \rightarrow \Lambda_c P)$	$4.16_{-1.73}^{+2.43}$	$0.31_{-0.13}^{+0.18}$	$0.47_{-0.21}^{+0.30}$	$11.92_{-5.28}^{+7.69}$
(v) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^-)$	$Br[\Lambda_b \rightarrow \Lambda_c(2595)P]$	$1.09_{-0.51}^{+0.76}$	$0.08_{-0.04}^{+0.06}$	$0.07_{-0.04}^{+0.07}$	$1.72_{-1.01}^{+1.71}$
(vi) $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^-)$	$Br[\Lambda_b \rightarrow \Lambda_c(2625)P]$	$2.40_{-1.82}^{+4.09}$	$0.17_{-0.13}^{+0.30}$	$0.13_{-0.10}^{+0.22}$	$2.88_{-2.16}^{+4.92}$
(i)* $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^+)$	$Br[\Lambda_b \rightarrow \Lambda_c(2765)P]$	$1.70_{-0.52}^{+0.69}$	$0.13_{-0.04}^{+0.05}$	$0.15_{-0.05}^{+0.07}$	$3.54_{-1.24}^{+1.73}$
(v)* $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^-)$	$Br[\Lambda_b \rightarrow \Lambda_c(2940)P]$	$0.68_{-0.21}^{+0.21}$	$0.05_{-0.02}^{+0.02}$	$0.04_{-0.02}^{+0.02}$	$0.87_{-0.38}^{+0.46}$
(vi)* $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^-)$	$Br[\Lambda_b \rightarrow \Lambda_c(2940)P]$	$1.00_{-0.83}^{+2.00}$	$0.07_{-0.06}^{+0.14}$	$0.07_{-0.05}^{+0.10}$	$1.69_{-1.23}^{+2.30}$
(i) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^+)$	$Br(\Xi_b^- \rightarrow \Xi_c^0 P)$	$3.88_{-1.69}^{+2.43}$	$0.29_{-0.13}^{+0.18}$	$0.45_{-0.21}^{+0.31}$	$11.54_{-5.34}^{+7.98}$
(i) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^+)$	$Br(\Xi_b^0 \rightarrow \Xi_c^+ P)$	$3.66_{-1.59}^{+2.29}$	$0.28_{-0.12}^{+0.17}$	$0.43_{-0.20}^{+0.29}$	$10.87_{-5.03}^{+7.51}$
(v) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^-)$	$Br[\Xi_b^- \rightarrow \Xi_c^0(2790)P]$	$1.03_{-0.48}^{+0.79}$	$0.08_{-0.04}^{+0.06}$	$0.07_{-0.04}^{+0.08}$	$1.70_{-0.99}^{+1.88}$
(v) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^-)$	$Br[\Xi_b^0 \rightarrow \Xi_c^-(2790)P]$	$0.97_{-0.45}^{+0.74}$	$0.07_{-0.03}^{+0.06}$	$0.07_{-0.04}^{+0.07}$	$1.60_{-0.93}^{+1.76}$
(vi) $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^-)$	$Br[\Xi_b^- \rightarrow \Xi_c^0(2815)P]$	$3.53_{-2.80}^{+6.46}$	$0.26_{-0.20}^{+0.47}$	$0.20_{-0.15}^{+0.35}$	$4.65_{-3.48}^{+8.08}$
(vi) $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^-)$	$Br[\Xi_b^0 \rightarrow \Xi_c^+(2815)P]$	$3.32_{-2.63}^{+6.08}$	$0.24_{-0.19}^{+0.44}$	$0.19_{-0.14}^{+0.33}$	$4.34_{-3.25}^{+7.54}$
(ii) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^+)$	$Br(\Omega_b \rightarrow \Omega_c P)$	$1.10_{-0.55}^{+0.85}$	$0.08_{-0.04}^{+0.07}$	$0.15_{-0.08}^{+0.14}$	$4.03_{-2.21}^{+3.72}$
(iii) $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^+)$	$Br[\Omega_b \rightarrow \Omega_c(2770)P]$	$1.37_{-1.19}^{+3.01}$	$0.11_{-0.09}^{+0.23}$	$0.28_{-0.20}^{+0.38}$	$7.46_{-5.04}^{+9.63}$
(iv) $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^-)$	$Br[\Omega_b \rightarrow \Omega_c(3050)P]$	$3.40_{-2.25}^{+4.45}$	$0.24_{-0.16}^{+0.31}$	$0.09_{-0.07}^{+0.15}$	$1.78_{-1.38}^{+3.16}$
(ii)* $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^+)$	$Br[\Omega_b \rightarrow \Omega_c(3090)P]$	$0.85_{-0.35}^{+0.50}$	$0.06_{-0.03}^{+0.04}$	$0.10_{-0.05}^{+0.07}$	$2.43_{-1.15}^{+1.79}$
(iii)* $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^+)$	$Br[\Omega_b \rightarrow \Omega_c(3120)P]$	$0.96_{-0.52}^{+0.95}$	$0.07_{-0.04}^{+0.07}$	$0.10_{-0.05}^{+0.08}$	$2.37_{-1.10}^{+1.81}$

Use naïve factorization approach, include penguins in D, D<sub>s</sub> modes

$$Br[\Lambda_b \rightarrow \Lambda_c(2940, 3/2^-)P] \simeq (1.5 \sim 2) \times Br[\Lambda_b \rightarrow \Lambda_c(2940, 1/2^-)P]$$

# Br in unit of $10^{-3}$

Type	Mode	$M = \rho^-$	$M = K^{*-}$	$M = D^{*-}$	$M = D_s^{*-}$	$M = a_1^-$
(i)	$Br(\Lambda_b \rightarrow \Lambda_c M)$	$12.28^{+7.19}_{-5.11}$	$0.63^{+0.37}_{-0.26}$	$0.84^{+0.51}_{-0.36}$	$17.49^{+10.60}_{-7.48}$	$11.91^{+6.98}_{-4.97}$
(v)	$Br[\Lambda_b \rightarrow \Lambda_c(2595)M]$	$2.99^{+2.20}_{-1.44}$	$0.15^{+0.11}_{-0.07}$	$0.12^{+0.11}_{-0.07}$	$2.28^{+2.21}_{-1.29}$	$2.57^{+2.01}_{-1.29}$
(vi)	$Br[\Lambda_b \rightarrow \Lambda_c(2625)M]$	$4.38^{+6.78}_{-3.17}$	$0.22^{+0.33}_{-0.16}$	$0.13^{+0.17}_{-0.08}$	$2.41^{+2.98}_{-1.52}$	$3.50^{+5.11}_{-2.45}$
(i)*	$Br[\Lambda_b \rightarrow \Lambda_c(2765)M]$	$4.84^{+2.01}_{-1.50}$	$0.25^{+0.10}_{-0.08}$	$0.26^{+0.12}_{-0.09}$	$5.29^{+2.54}_{-1.84}$	$4.45^{+1.91}_{-1.42}$
(v)*	$Br[\Lambda_b \rightarrow \Lambda_c(2940)M]$	$1.85^{+0.63}_{-0.60}$	$0.09^{+0.03}_{-0.03}$	$0.06^{+0.03}_{-0.03}$	$1.16^{+0.62}_{-0.48}$	$1.57^{+0.59}_{-0.54}$
(vi)*	$Br[\Lambda_b \rightarrow \Lambda_c(2940)M]$	$1.93^{+3.19}_{-1.43}$	$0.10^{+0.15}_{-0.07}$	$0.06^{+0.06}_{-0.03}$	$1.11^{+1.07}_{-0.62}$	$1.58^{+2.26}_{-1.08}$
(i)	$Br(\Xi_b^- \rightarrow \Xi_c^0 M)$	$11.56^{+7.25}_{-5.04}$	$0.60^{+0.37}_{-0.26}$	$0.82^{+0.53}_{-0.37}$	$17.26^{+11.2}_{-7.70}$	$11.37^{+7.14}_{-4.97}$
(i)	$Br(\Xi_b^0 \rightarrow \Xi_c^+ M)$	$10.88^{+6.83}_{-4.74}$	$0.56^{+0.35}_{-0.24}$	$0.77^{+0.50}_{-0.35}$	$16.24^{+10.54}_{-7.25}$	$10.70^{+6.72}_{-4.67}$
(v)	$Br[\Xi_b^- \rightarrow \Xi_c^0(2790)M]$	$2.86^{+2.28}_{-1.36}$	$0.14^{+0.12}_{-0.07}$	$0.12^{+0.12}_{-0.06}$	$2.25^{+2.33}_{-1.26}$	$2.48^{+2.10}_{-1.23}$
(v)	$Br[\Xi_b^0 \rightarrow \Xi_c^+(2790)M]$	$2.69^{+2.15}_{-1.28}$	$0.13^{+0.11}_{-0.06}$	$0.11^{+0.11}_{-0.06}$	$2.11^{+2.19}_{-1.19}$	$2.33^{+1.98}_{-1.16}$
(vi)	$Br[\Xi_b^- \rightarrow \Xi_c^0(2815)M]$	$6.49^{+10.58}_{-4.84}$	$0.32^{+0.51}_{-0.24}$	$0.20^{+0.26}_{-0.13}$	$3.74^{+4.58}_{-2.32}$	$5.24^{+7.92}_{-3.72}$
(vi)	$Br[\Xi_b^0 \rightarrow \Xi_c^+(2815)M]$	$6.10^{+9.95}_{-4.55}$	$0.30^{+0.48}_{-0.22}$	$0.19^{+0.24}_{-0.12}$	$3.51^{+4.30}_{-2.18}$	$4.92^{+7.45}_{-3.50}$
(ii)	$Br(\Omega_b \rightarrow \Omega_c M)$	$3.07^{+2.41}_{-1.53}$	$0.16^{+0.12}_{-0.08}$	$0.16^{+0.13}_{-0.08}$	$3.18^{+2.69}_{-1.61}$	$2.76^{+2.20}_{-1.37}$
(iii)	$Br[\Omega_b \rightarrow \Omega_c(2770)M]$	$2.37^{+4.68}_{-1.85}$	$0.13^{+0.24}_{-0.10}$	$0.28^{+0.30}_{-0.16}$	$6.20^{+6.19}_{-3.49}$	$2.78^{+4.35}_{-1.93}$
(iv)	$Br[\Omega_b \rightarrow \Omega_c(3050)M]$	$4.09^{+5.62}_{-2.71}$	$0.20^{+0.27}_{-0.13}$	$0.08^{+0.10}_{-0.05}$	$1.43^{+1.78}_{-0.88}$	$2.84^{+3.88}_{-1.86}$
(ii)*	$Br[\Omega_b \rightarrow \Omega_c(3090)M]$	$2.29^{+1.36}_{-0.94}$	$0.11^{+0.07}_{-0.05}$	$0.09^{+0.06}_{-0.04}$	$1.69^{+1.06}_{-0.71}$	$1.92^{+1.15}_{-0.79}$
(iii)*	$Br[\Omega_b \rightarrow \Omega_c(3120)M]$	$1.50^{+1.37}_{-0.76}$	$0.08^{+0.07}_{-0.04}$	$0.11^{+0.07}_{-0.04}$	$2.37^{+1.33}_{-0.88}$	$1.55^{+1.21}_{-0.71}$

Mode	Data [4]	This work	[21]	[22]	[23, 24]	[25]	[26]	[27]	[33]	[35]	[36]
$\Lambda_b \rightarrow \Lambda_c \pi^-$	$4.9 \pm 0.4$	$4.16_{-1.73}^{+2.43}$	$4.6_{-3.1}^{+2.0}$	4.6	5.62	3.91	—	1.75	4.96	—	5.67
$\Lambda_b \rightarrow \Lambda_c K^-$	$0.359 \pm 0.030$	$0.31_{-0.13}^{+0.18}$	—	—	—	—	—	0.13	0.393	—	0.46
$\Lambda_b \rightarrow \Lambda_c D^-$	$0.46 \pm 0.06$	$0.47_{-0.21}^{+0.30}$	—	—	—	—	—	0.30	0.522	—	0.76
$\Lambda_b \rightarrow \Lambda_c D_s^-$	$11.0 \pm 1.0$	$11.92_{-5.28}^{+7.69}$	$23_{-4}^{+3}$	13.7	—	12.91	22.3	7.70	12.4	14.78	19.94
$\Lambda_b \rightarrow \Lambda_c \rho^-$	—	$12.28_{-5.11}^{+7.19}$	$6.6_{-4.0}^{+2.4}$	12.9	—	10.82	—	4.91	8.65	—	16.71
$\Lambda_b \rightarrow \Lambda_c K^{*-}$	—	$0.63_{-0.26}^{+0.37}$	—	—	—	—	—	0.27	0.441	—	0.87
$\Lambda_b \rightarrow \Lambda_c D^{*-}$	—	$0.84_{-0.36}^{+0.51}$	—	—	—	—	—	0.49	0.520	—	1.38
$\Lambda_b \rightarrow \Lambda_c D_s^{*-}$	—	$17.49_{-7.48}^{+10.60}$	$17.3_{-3.0}^{+2.0}$	21.8	—	19.83	32.6	14.14	10.5	25.16	30.86
$\Lambda_b \rightarrow \Lambda_c a_1^-$	—	$11.91_{-4.97}^{+6.98}$	—	—	—	—	—	5.32	—	—	16.53
$\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$	—	$3.66_{-1.59}^{+2.29}$	—	4.9	7.08	—	—	—	—	—	—
$\Xi_b^- \rightarrow \Xi_c^0 \pi^-$	—	$3.88_{-1.69}^{+2.43}$	—	5.2	10.13	—	—	—	—	—	—
$\Xi_b^0 \rightarrow \Xi_c^+ D^-$	—	$0.43_{-0.20}^{+0.29}$	—	—	—	—	—	—	—	0.45	—
$\Xi_b^0 \rightarrow \Xi_c^+ D_s^-$	—	$10.87_{-5.03}^{+7.51}$	—	14.6	—	—	—	—	—	—	—
$\Xi_b^0 \rightarrow \Xi_c^+ D^{*-}$	—	$0.77_{-0.35}^{+0.50}$	—	—	—	—	—	—	—	0.95	—
$\Xi_b^0 \rightarrow \Xi_c^+ D_s^{*-}$	—	$16.24_{-7.25}^{+10.54}$	—	23.1	—	—	—	—	—	—	—
$\Omega_b \rightarrow \Omega_c \pi^-$	—	$1.10_{-0.55}^{+0.85}$	—	4.92	5.81	—	—	—	—	1.88	—
$\Omega_b \rightarrow \Omega_c D_s^-$	—	$4.03_{-2.21}^{+3.72}$	—	17.9	—	—	—	—	—	—	—
$\Omega_b \rightarrow \Omega_c \rho^-$	—	$3.07_{-1.53}^{+2.41}$	—	12.8	—	—	—	—	—	5.43	—
$\Omega_b \rightarrow \Omega_c D_s^{*-}$	—	$3.18_{-1.61}^{+2.69}$	—	11.5	—	—	—	—	—	—	—
$\Omega_b \rightarrow \Omega_c^* \pi^-$	—	$1.37_{-1.19}^{+3.01}$	—	2.69	—	—	—	—	—	1.70	—
$\Omega_b \rightarrow \Omega_c^* D^-$	—	$0.28_{-0.20}^{+0.38}$	—	—	—	—	—	—	—	0.16	—
$\Omega_b \rightarrow \Omega_c^* D_s^-$	—	$7.46_{-5.04}^{+9.63}$	—	3.53	—	—	—	—	—	—	—
$\Omega_b \rightarrow \Omega_c^* \rho^-$	—	$2.37_{-1.85}^{+4.68}$	—	3.81	—	—	—	—	—	5.58	—
$\Omega_b \rightarrow \Omega_c^* D^{*-}$	—	$0.28_{-0.16}^{+0.30}$	—	—	—	—	—	—	—	0.58	—
$\Omega_b \rightarrow \Omega_c^* D_s^{*-}$	—	$6.20_{-3.49}^{+6.19}$	—	3.93	—	—	—	—	—	—	—

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[4]	PDG
[21]	Mannel, Roberts, 1993
[22]	HY Cheng, 1997
[23,24]	Ivanov, Korner, Lyubovitskij, Rusetsky, 1998, 1998
[25]	Giri, Maharana, Mohanta, 1998
[26]	Fayyazuddin, Riazuddin, 1998
[27]	Mohanta, Giri, Khanna, M Ishida, S Ishida, Oda, 1999
[33]	Zhu, Wei, Ke, 2019
[35]	Gutsche, Ivanov, Korner, Lyubovitskij, 2018
[36]	Ke, Hao, Li, 2019

# Up-down asymmetry in unit of %

Type	Mode	$P = \pi^-$	$P = K^-$	$P = D^-$	$P = D_s^-$
(i) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^+)$	$\alpha(\Lambda_b \rightarrow \Lambda_c P)$	$-99.99^{+4.70}_{-0.00}$	$-99.97^{+5.02}_{-0.01}$	$-99.45^{+7.94}_{-0.55}$	$-99.19^{+8.59}_{-0.81}$
(v) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^-)$	$\alpha[\Lambda_b \rightarrow \Lambda_c(2595)P]$	$-98.33^{+12.89}_{-1.67}$	$-98.12^{+13.51}_{-1.88}$	$-88.05^{+26.57}_{-11.95}$	$-86.49^{+27.83}_{-13.51}$
(vi) $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^-)$	$\alpha[\Lambda_b \rightarrow \Lambda_c(2625)P]$	$-97.76^{+39.39}_{-2.24}$	$-97.64^{+39.37}_{-2.36}$	$-97.44^{+37.86}_{-2.56}$	$-97.07^{+38.04}_{-2.93}$
(i)* $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^+)$	$\alpha[\Lambda_b \rightarrow \Lambda_c(2765)P]$	$-99.93^{+1.65}_{-0.02}$	$-99.87^{+1.87}_{-0.11}$	$-98.03^{+5.04}_{-1.97}$	$-97.23^{+5.70}_{-2.70}$
(v)* $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^-)$	$\alpha[\Lambda_b \rightarrow \Lambda_c(2940)P]$	$-98.32^{+2.86}_{-1.47}$	$-98.10^{+3.11}_{-1.64}$	$-86.24^{+11.11}_{-9.26}$	$-84.04^{+12.19}_{-10.66}$
(vi)* $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^-)$	$\alpha[\Lambda_b \rightarrow \Lambda_c(2940)P]$	$-99.41^{+65.88}_{-0.59}$	$-99.06^{+61.14}_{-0.94}$	$-89.25^{+31.59}_{-10.75}$	$-86.81^{+30.72}_{-13.19}$
(i) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^+)$	$\alpha(\Xi_b^- \rightarrow \Xi_c^0 P)$	$-99.98^{+5.73}_{-0.00}$	$-99.96^{+6.10}_{-0.00}$	$-99.29^{+9.61}_{-0.71}$	$-98.99^{+10.34}_{-1.01}$
(i) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^+)$	$\alpha(\Xi_b^0 \rightarrow \Xi_c^+ P)$	$-99.98^{+5.73}_{-0.00}$	$-99.96^{+6.10}_{-0.00}$	$-99.29^{+9.61}_{-0.71}$	$-98.99^{+10.34}_{-1.01}$
(v) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^-)$	$\alpha[\Xi_b^- \rightarrow \Xi_c^0(2790)P]$	$-98.13^{+14.56}_{-1.87}$	$-97.88^{+15.26}_{-2.11}$	$-86.62^{+28.66}_{-13.38}$	$-84.85^{+29.84}_{-15.15}$
(v) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^-)$	$\alpha[\Xi_b^0 \rightarrow \Xi_c^-(2790)P]$	$-98.13^{+14.56}_{-1.87}$	$-97.88^{+15.26}_{-2.11}$	$-86.60^{+28.67}_{-13.40}$	$-84.83^{+29.85}_{-15.16}$
(vi) $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^-)$	$\alpha[\Xi_b^- \rightarrow \Xi_c^0(2815)P]$	$-97.63^{+42.32}_{-2.37}$	$-97.48^{+42.09}_{-2.52}$	$-96.48^{+38.46}_{-3.52}$	$-95.89^{+38.40}_{-4.11}$
(vi) $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^-)$	$\alpha[\Xi_b^0 \rightarrow \Xi_c^+(2815)P]$	$-97.70^{+42.27}_{-2.30}$	$-97.56^{+42.03}_{-2.44}$	$-96.71^{+38.31}_{-3.29}$	$-96.16^{+38.26}_{-3.84}$
(ii) $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^+)$	$\alpha(\Omega_b \rightarrow \Omega_c P)$	$59.94^{+21.34}_{-18.76}$	$59.39^{+21.45}_{-18.70}$	$56.04^{+23.79}_{-19.29}$	$55.16^{+23.98}_{-19.18}$
(iii) $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^+)$	$\alpha[\Omega_b \rightarrow \Omega_c(2770)P]$	$2.60^{+97.40}_{-102.23}$	$1.17^{+98.43}_{-100.15}$	$-11.02^{+55.88}_{-59.25}$	$-11.70^{+50.63}_{-55.10}$
(iv) $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^-)$	$\alpha[\Omega_b \rightarrow \Omega_c(3050)P]$	$18.07^{+52.52}_{-41.45}$	$17.73^{+53.31}_{-42.50}$	$9.16^{+75.06}_{-71.89}$	$7.09^{+78.45}_{-76.03}$
(ii)* $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^+)$	$\alpha[\Omega_b \rightarrow \Omega_c(3090)P]$	$59.75^{+14.13}_{-13.17}$	$59.15^{+14.21}_{-13.16}$	$54.01^{+16.49}_{-13.95}$	$52.73^{+16.61}_{-13.86}$
(iii)* $(\frac{1}{2}^+ \rightarrow \frac{3}{2}^+)$	$\alpha[\Omega_b \rightarrow \Omega_c(3120)P]$	$4.58^{+42.35}_{-41.22}$	$3.81^{+41.17}_{-40.26}$	$-3.74^{+22.18}_{-24.05}$	$-4.20^{+20.50}_{-22.52}$

Type	Mode	$M = \rho^-$	$M = K^{*-}$	$M = D^{*-}$	$M = D_s^{*-}$	$M = a_1^-$
(i)	$\alpha(\Lambda_b \rightarrow \Lambda_c M)$	$-86.96_{-0.87}^{+5.60}$	$-82.96_{-1.11}^{+6.02}$	$-36.85_{-4.88}^{+7.08}$	$-32.69_{-5.05}^{+6.82}$	$-70.00_{-2.30}^{+7.00}$
(v)	$\alpha[\Lambda_b \rightarrow \Lambda_c(2595)M]$	$-85.6_{-3.85}^{+12.41}$	$-81.65_{-4.46}^{+12.21}$	$-33.47_{-11.40}^{+15.76}$	$-28.68_{-11.88}^{+15.97}$	$-68.66_{-6.19}^{+11.32}$
(vi)	$\alpha[\Lambda_b \rightarrow \Lambda_c(2625)M]$	$-91.48_{-3.89}^{+42.04}$	$-89.01_{-4.91}^{+41.55}$	$-53.92_{-18.71}^{+34.18}$	$-49.80_{-20.08}^{+33.31}$	$-80.52_{-8.58}^{+39.81}$
(i)*	$\alpha[\Lambda_b \rightarrow \Lambda_c(2765)M]$	$-86.15_{-1.04}^{+2.71}$	$-81.89_{-1.47}^{+3.24}$	$-31.54_{-4.91}^{+5.31}$	$-26.87_{-4.82}^{+5.07}$	$-67.99_{-2.94}^{+4.60}$
(v)*	$\alpha[\Lambda_b \rightarrow \Lambda_c(2940)M]$	$-84.01_{-3.07}^{+4.44}$	$-79.56_{-3.51}^{+4.84}$	$-24.77_{-9.27}^{+10.24}$	$-19.04_{-9.71}^{+10.34}$	$-64.97_{-4.97}^{+6.29}$
(vi)*	$\alpha[\Lambda_b \rightarrow \Lambda_c(2940)M]$	$-87.25_{-7.21}^{+66.15}$	$-84.14_{-8.45}^{+63.92}$	$-48.02_{-18.07}^{+36.43}$	$-45.28_{-18.13}^{+33.21}$	$-73.90_{-12.00}^{+56.57}$
(i)	$\alpha(\Xi_b^- \rightarrow \Xi_c^0 M)$	$-86.61_{-1.09}^{+6.57}$	$-82.52_{-1.38}^{+7.04}$	$-36.00_{-5.51}^{+8.09}$	$-31.85_{-5.73}^{+7.78}$	$-69.34_{-2.69}^{+8.13}$
(i)	$\alpha(\Xi_b^0 \rightarrow \Xi_c^+ M)$	$-86.61_{-1.09}^{+6.57}$	$-82.52_{-1.38}^{+7.04}$	$-35.98_{-5.51}^{+8.08}$	$-31.84_{-5.72}^{+7.78}$	$-69.33_{-2.69}^{+8.13}$
(v)	$\alpha[\Xi_b^- \rightarrow \Xi_c^0(2790)M]$	$-85.14_{-4.14}^{+13.71}$	$-81.11_{-4.77}^{+13.40}$	$-32.40_{-11.43}^{+16.14}$	$-27.57_{-11.88}^{+16.30}$	$-67.92_{-6.55}^{+12.18}$
(v)	$\alpha[\Xi_b^0 \rightarrow \Xi_c^+(2790)M]$	$-85.13_{-4.15}^{+13.71}$	$-81.09_{-4.78}^{+13.40}$	$-32.35_{-11.43}^{+16.14}$	$-27.52_{-11.88}^{+16.30}$	$-67.90_{-6.55}^{+12.17}$
(vi)	$\alpha[\Xi_b^- \rightarrow \Xi_c^0(2815)M]$	$-91.55_{-4.08}^{+46.65}$	$-89.08_{-5.17}^{+45.9}$	$-55.07_{-18.5}^{+35.28}$	$-51.32_{-19.77}^{+34.12}$	$-80.63_{-8.94}^{+43.30}$
(vi)	$\alpha[\Xi_b^0 \rightarrow \Xi_c^+(2815)M]$	$-91.48_{-4.15}^{+46.84}$	$-89.00_{-5.27}^{+46.09}$	$-54.83_{-18.69}^{+35.37}$	$-51.06_{-20.08}^{+34.18}$	$-80.52_{-9.07}^{+43.48}$
(ii)	$\alpha(\Omega_b \rightarrow \Omega_c M)$	$61.63_{-19.83}^{+22.03}$	$62.20_{-20.19}^{+22.22}$	$72.15_{-25.51}^{+22.11}$	$73.53_{-26.05}^{+21.54}$	$64.27_{-21.45}^{+22.74}$
(iii)	$\alpha[\Omega_b \rightarrow \Omega_c(2770)M]$	$-5.22_{-88.99}^{+82.03}$	$-7.51_{-85.12}^{+78.52}$	$-22.24_{-51.42}^{+45.94}$	$-22.62_{-48.63}^{+42.82}$	$-13.64_{-74.18}^{+68.97}$
(iv)	$\alpha[\Omega_b \rightarrow \Omega_c(3050)M]$	$24.95_{-59.79}^{+60.39}$	$24.72_{-60.40}^{+59.86}$	$13.22_{-62.37}^{+49.96}$	$10.39_{-61.11}^{+49.66}$	$23.53_{-62.28}^{+57.68}$
(ii)*	$\alpha[\Omega_b \rightarrow \Omega_c(3090)M]$	$61.51_{-13.97}^{+14.81}$	$62.10_{-14.24}^{+15.02}$	$73.1_{-17.68}^{+15.51}$	$74.63_{-17.81}^{+14.95}$	$64.31_{-15.17}^{+15.63}$
(iii)*	$\alpha[\Omega_b \rightarrow \Omega_c(3120)M]$	$1.15_{-48.55}^{+44.49}$	$-0.31_{-46.29}^{+41.58}$	$-11.06_{-24.74}^{+21.35}$	$-11.43_{-22.92}^{+19.79}$	$-4.44_{-39.57}^{+33.80}$

Mode	This work	[21]	[22]	[23, 24]	[26]	[27]	[33]	[35]	[36]
$\Lambda_b \rightarrow \Lambda_c \pi^-$	$-99.99_{-0.00}^{+4.70}$	-100	-99	-99	-	-99.9	-99.8	-	-100
$\Lambda_b \rightarrow \Lambda_c K^-$	$-99.97_{-0.01}^{+5.02}$	-	-	-	-	-100	-100	-	-100
$\Lambda_b \rightarrow \Lambda_c D^-$	$-99.45_{-0.55}^{+7.94}$	-	-	-	-	-98.7	-99.9	-98.9	-98.3
$\Lambda_b \rightarrow \Lambda_c D_s^-$	$-99.19_{-0.81}^{+8.59}$	-99.1	-99	-	-98	-98.4	-100	-98.6	-97.8
$\Lambda_b \rightarrow \Lambda_c \rho^-$	$-86.96_{-0.87}^{+5.60}$	-90.3	-88	-	-	-89.8	-88.8	-	-87.5
$\Lambda_b \rightarrow \Lambda_c K^{*-}$	$-82.96_{-1.11}^{+6.02}$	-	-	-	-	-86.5	-85.9	-	-83.6
$\Lambda_b \rightarrow \Lambda_c D^{*-}$	$-36.85_{-4.88}^{+7.08}$	-	-	-	-	-45.9	-47.8	-	-37.1
$\Lambda_b \rightarrow \Lambda_c D_s^{*-}$	$-32.69_{-5.05}^{+6.82}$	-43.7	-36	-	-40	-41.9	-43.9	-36.4	-32.7
$\Lambda_b \rightarrow \Lambda_c a_1^-$	$-70.00_{-2.30}^{+7.00}$	-	-	-	-	-75.8	-	-	-70.9
$\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$	$-99.98_{-0.00}^{+5.73}$	-	-100	-100	-	-	-	-	-
$\Xi_b^- \rightarrow \Xi_c^0 \pi^-$	$-99.98_{-0.00}^{+5.73}$	-	-100	-97	-	-	-	-	-
$\Xi_b^0 \rightarrow \Xi_c^+ D_s^-$	$-98.99_{-1.01}^{+10.34}$	-	-99	-	-	-	-	-	-
$\Xi_b^0 \rightarrow \Xi_c^- D_s^{*-}$	$-31.84_{-5.72}^{+7.78}$	-	-36	-	-	-	-	-	-
$\Omega_b \rightarrow \Omega_c \pi^-$	$59.94_{-18.76}^{+21.34}$	-	51	60	-	-	-	-	-
$\Omega_b \rightarrow \Omega_c D_s^-$	$55.16_{-19.18}^{+23.98}$	-	42	-	-	-	-	-	-
$\Omega_b \rightarrow \Omega_c \rho^-$	$61.63_{-19.83}^{+22.03}$	-	53	-	-	-	-	-	-
$\Omega_b \rightarrow \Omega_c D_s^{*-}$	$73.53_{-26.05}^{+21.54}$	-	64	-	-	-	-	-	-
$\Omega_b \rightarrow \Omega_c(2770)\pi^-$	$2.60_{-102.23}^{+97.40}$	-	-38	-	-	-	-	-	-
$\Omega_b \rightarrow \Omega_c(2770)D_s^-$	$-11.70_{-55.10}^{+50.63}$	-	-22	-	-	-	-	-	-
$\Omega_b \rightarrow \Omega_c(2770)\rho^-$	$-5.22_{-88.99}^{+82.03}$	-	-75	-	-	-	-	-	-
$\Omega_b \rightarrow \Omega_c(2770)D_s^{*-}$	$-22.62_{-48.63}^{+42.82}$	-	-31	-	-	-	-	-	-

# Conclusion:

- We study  $\mathcal{B}_b\left(\frac{1^+}{2}\right) \rightarrow \mathcal{B}_c\left(\frac{1^\pm}{2}, \frac{3^\pm}{2}\right) M, M = P, V, A$  color-allowed decays (6 types of transitions)
- Form Factors are calculated using LFQM
- Close to expectations from HQS (+Large  $N_c$ )
- Rates and asymmetries are predicted, close to existing data and results from other works
- Can be checked experimentally
- May shed light on the QN of some charm baryons

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$[\Lambda_c(2765), \Lambda_c(2940), \Omega_c(3050), \Omega_c(3090), \Omega_c(3120)]$



$\psi(\text{color})$	$L_K$	$L_k$	$\psi(\text{flavor})$	$\psi(\text{spin})$	$S_{[qq]}$	parity( $[qq]$ )	parity( $Qqq$ )
$(\bar{\mathbf{3}}_c)_A$	even	even	$(\bar{\mathbf{3}}_f)_A$	$(\mathbf{1}_{\text{sp}})_A$	$L_k$	+	+
$(\bar{\mathbf{3}}_c)_A$	even	even	$(\mathbf{6}_f)_S$	$(\mathbf{3}_{\text{sp}})_S$	$ L_k - 1 , \dots, L_k + 1$	+	+
$(\bar{\mathbf{3}}_c)_A$	odd	odd	$(\bar{\mathbf{3}}_f)_A$	$(\mathbf{3}_{\text{sp}})_S$	$L_k - 1, L_k, L_k + 1$	-	+
$(\bar{\mathbf{3}}_c)_A$	odd	odd	$(\mathbf{6}_f)_S$	$(\mathbf{1}_{\text{sp}})_A$	$L_k$	-	+
$(\bar{\mathbf{3}}_c)_A$	even	odd	$(\bar{\mathbf{3}}_f)_A$	$(\mathbf{3}_{\text{sp}})_S$	$L_k - 1, L_k, L_k + 1$	-	-
$(\bar{\mathbf{3}}_c)_A$	even	odd	$(\mathbf{6}_f)_S$	$(\mathbf{1}_{\text{sp}})_A$	$L_k$	-	-
$(\bar{\mathbf{3}}_c)_A$	odd	even	$(\bar{\mathbf{3}}_f)_A$	$(\mathbf{1}_{\text{sp}})_A$	$L_k$	+	-
$(\bar{\mathbf{3}}_c)_A$	odd	even	$(\mathbf{6}_f)_S$	$(\mathbf{3}_{\text{sp}})_S$	$ L_k - 1 , \dots, L_k + 1$	+	-

$n$	$L_K$	$L_k$	flavor	$S_{qq}$	$S_{[qq]}^P$	$J_l^P$	$J^P$	$\mathcal{B}_c$
1	0	0	$\bar{\mathbf{3}}_f$	0	$0^+$	$0^+$	$\frac{1}{2}^+$	$\Lambda_c^+, \Xi_c^{+,0}$
2	0	0	$\bar{\mathbf{3}}_f$	0	$0^+$	$0^+$	$\frac{1}{2}^+$	$\Lambda_c(2765)^+(\dagger)$
1	0	0	$\mathbf{6}_f$	1	$1^+$	$1^+$	$\frac{1}{2}^+$	$\Sigma_c(2455)^{++,+,0}, \Xi_c'^{+,0}, \Omega_c^0$
2	0	0	$\mathbf{6}_f$	1	$1^+$	$1^+$	$\frac{1}{2}^+$	$\Xi_c'(2970)^{+,0}(\dagger), \Omega_c(3090)^0(\dagger)$
1	0	0	$\mathbf{6}_f$	1	$1^+$	$1^+$	$\frac{3}{2}^+$	$\Sigma_c(2520)^{++,+,0}, \Xi_c(2645)^{+,0}, \Omega_c(2770)^0$
2	0	0	$\mathbf{6}_f$	1	$1^+$	$1^+$	$\frac{3}{2}^+$	$\Omega_c(3120)^0(\dagger)$
1	1	0	$\bar{\mathbf{3}}_f$	0	$0^+$	$1^-$	$\frac{1}{2}^-$	$\Lambda_c(2595)^+, \Xi_c(2790)^{+,0}$
2	1	0	$\bar{\mathbf{3}}_f$	0	$0^+$	$1^-$	$\frac{1}{2}^-$	$\Lambda_c(2940)^+(\dagger)$
1	1	0	$\bar{\mathbf{3}}_f$	0	$0^+$	$1^-$	$\frac{3}{2}^-$	$\Lambda_c(2625)^+, \Xi_c(2815)^{+,0}$
2	1	0	$\bar{\mathbf{3}}_f$	0	$0^+$	$1^-$	$\frac{3}{2}^-$	$\Lambda_c(2940)^+$
1	1	0	$\mathbf{6}_f$	1	$1^+$	$2^-$	$\frac{3}{2}^-$	$\Sigma_c(2800)^{++,+,0}(\dagger), \Xi_c'(2930)^{+,0}(\dagger), \Omega_c(3050)^0(\dagger)$
1	1	0	$\mathbf{6}_f$	1	$1^+$	$2^-$	$\frac{5}{2}^-$	$\Omega_c(3066)^0(\dagger)$

State	$J^P$	$n$	$(L_K, L_k)$	$S_{[qq]}^P$	$J_\ell^{P_\ell}$	Mass	Width	Decay modes
$\Lambda_c^+$	$\frac{1}{2}^+$	1	(0,0)	$0^+$	$0^+$	$2286.46 \pm 0.14$		weak
$\Lambda_c(2595)^+$	$\frac{1}{2}^-$	1	(1,0)	$0^+$	$1^-$	$2592.25 \pm 0.28$	$2.6 \pm 0.6$	$\Lambda_c \pi \pi, \Sigma_c \pi$
$\Lambda_c(2625)^+$	$\frac{3}{2}^-$	1	(1,0)	$0^+$	$1^-$	$2628.11 \pm 0.19$	$< 0.97$	$\Lambda_c \pi \pi, \Sigma_c \pi$
$\Lambda_c(2765)^+$	??	?	?	?	?	$2766.6 \pm 2.4$	50	$\Sigma_c \pi, \Lambda_c \pi \pi$
$\Lambda_c(2860)^+$	$\frac{3}{2}^+$	1	(2,0)	$0^+$	$2^+$	$2856.1^{+2.3}_{-6.0}$	$68^{+12}_{-22}$	$\Sigma_c^{(*)} \pi, D^0 p, D^+ n$
$\Lambda_c(2880)^+$	$\frac{5}{2}^+$	1	(2,0)	$0^+$	$2^+$	$2881.63 \pm 0.24$	$5.6^{+0.8}_{-0.6}$	$\Sigma_c^{(*)} \pi, \Lambda_c \pi \pi, D^0 p$
$\Lambda_c(2940)^+$	$\frac{3}{2}^-$	2	(1,0)	$0^+$	$1^-$	$2939.6^{+1.3}_{-1.5}$	$20^{+6}_{-5}$	$\Sigma_c^{(*)} \pi, \Lambda_c \pi \pi, D^0 p$
$\Sigma_c(2455)^{++}$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2453.97 \pm 0.14$	$1.89^{+0.09}_{-0.18}$	$\Lambda_c \pi$
$\Sigma_c(2455)^+$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2452.9 \pm 0.4$	$< 4.6$	$\Lambda_c \pi$
$\Sigma_c(2455)^0$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2453.75 \pm 0.14$	$1.83^{+0.11}_{-0.19}$	$\Lambda_c \pi$
$\Sigma_c(2520)^{++}$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2518.41^{+0.21}_{-0.19}$	$14.78^{+0.30}_{-0.40}$	$\Lambda_c \pi$
$\Sigma_c(2520)^+$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2517.5 \pm 2.3$	$< 17$	$\Lambda_c \pi$
$\Sigma_c(2520)^0$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2518.48 \pm 0.20$	$15.3^{+0.4}_{-0.5}$	$\Lambda_c \pi$
$\Sigma_c(2800)^{++}$	??	?	?	?	?	$2801^{+4}_{-6}$	$75^{+22}_{-17}$	$\Lambda_c \pi, \Sigma_c^{(*)} \pi, \Lambda_c \pi \pi$
$\Sigma_c(2800)^+$	??	?	?	?	?	$2792^{+14}_{-5}$	$62^{+60}_{-40}$	$\Lambda_c \pi, \Sigma_c^{(*)} \pi, \Lambda_c \pi \pi$
$\Sigma_c(2800)^0$	??	?	?	?	?	$2806^{+5}_{-7}$	$72^{+22}_{-15}$	$\Lambda_c \pi, \Sigma_c^{(*)} \pi, \Lambda_c \pi \pi$
$\Xi_c^+$	$\frac{1}{2}^+$	1	(0,0)	$0^+$	$0^+$	$2467.87 \pm 0.30$		weak
$\Xi_c^0$	$\frac{1}{2}^+$	1	(0,0)	$0^+$	$0^+$	$2470.87^{+0.28}_{-0.31}$		weak
$\Xi_c'^+$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2577.4 \pm 1.2$		$\Xi_c \gamma$
$\Xi_c'^0$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2578.8 \pm 0.5$		$\Xi_c \gamma$

State	$J^P$	$n$	$(L_K, L_k)$	$S_{[qq]}^P$	$J_\ell^{P_\ell}$	Mass	Width	Decay modes
$\Xi_c(2645)^+$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2645.53 \pm 0.31$	$2.14 \pm 0.19$	$\Xi_c \pi$
$\Xi_c(2645)^0$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2646.32 \pm 0.31$	$2.35 \pm 0.22$	$\Xi_c \pi$
$\Xi_c(2790)^+$	$\frac{1}{2}^-$	1	(1,0)	$0^+$	$1^-$	$2792.0 \pm 0.5$	$8.9 \pm 1.0$	$\Xi'_c \pi$
$\Xi_c(2790)^0$	$\frac{1}{2}^-$	1	(1,0)	$0^+$	$1^-$	$2792.8 \pm 1.2$	$10.0 \pm 1.1$	$\Xi'_c \pi$
$\Xi_c(2815)^+$	$\frac{3}{2}^-$	1	(1,0)	$0^+$	$1^-$	$2816.67 \pm 0.31$	$2.43 \pm 0.26$	$\Xi_c^* \pi, \Xi_c \pi \pi, \Xi'_c \pi$
$\Xi_c(2815)^0$	$\frac{3}{2}^-$	1	(1,0)	$0^+$	$1^-$	$2820.22 \pm 0.32$	$2.54 \pm 0.25$	$\Xi_c^* \pi, \Xi_c \pi \pi, \Xi'_c \pi$
$\Xi_c(2930)^0$	??	?	?	?	?	$2931 \pm 6$	$36 \pm 13$	$\Lambda_c \bar{K}$
$\Xi_c(2970)^+$	??	?	?	?	?	$2969.4 \pm 0.8$	$20.9_{-3.5}^{+2.4}$	$\Sigma_c \bar{K}, \Lambda_c \bar{K} \pi, \Xi_c \pi \pi$
$\Xi_c(2970)^0$	??	?	?	?	?	$2967.8 \pm 0.8$	$28.1_{-4.0}^{+3.4}$	$\Sigma_c \bar{K}, \Lambda_c \bar{K} \pi, \Xi_c \pi \pi$
$\Xi_c(3055)^+$	??	?	?	?	?	$3055.9 \pm 0.4$	$7.8 \pm 1.9$	$\Sigma_c \bar{K}, \Lambda_c \bar{K} \pi, D\Lambda$
$\Xi_c(3080)^+$	??	?	?	?	?	$3077.2 \pm 0.4$	$3.6 \pm 1.1$	$\Sigma_c \bar{K}, \Lambda_c \bar{K} \pi, D\Lambda$
$\Xi_c(3080)^0$	??	?	?	?	?	$3079.9 \pm 1.4$	$5.6 \pm 2.2$	$\Sigma_c \bar{K}, \Lambda_c \bar{K} \pi, D\Lambda$
$\Xi_c(3123)^+$	??	?	?	?	?	$3122.9 \pm 1.3$	$4 \pm 4$	$\Sigma_c^* \bar{K}, \Lambda_c \bar{K} \pi$
$\Omega_c^0$	$\frac{1}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2695.2 \pm 1.7$		weak
$\Omega_c(2770)^0$	$\frac{3}{2}^+$	1	(0,0)	$1^+$	$1^+$	$2765.9 \pm 2.0$		$\Omega_c \gamma$
$\Omega_c(3000)^0$	??	?	?	?	?	$3000.4 \pm 0.4$	$4.5 \pm 0.7$	$\Xi_c K$
$\Omega_c(3050)^0$	??	?	?	?	?	$3050.2 \pm 0.33$	$< 1.2$	$\Xi_c \bar{K}$
$\Omega_c(3065)^0$	??	?	?	?	?	$3065.6 \pm 0.4$	$3.5 \pm 0.4$	$\Xi_c \bar{K}$
$\Omega_c(3090)^0$	??	?	?	?	?	$3090.2 \pm 0.7$	$8.7 \pm 1.3$	$\Xi_c^{(\prime)} \bar{K}$
$\Omega_c(3120)^0$	??	?	?	?	?	$3119.1 \pm 1.0$	$< 2.6$	$\Xi_c^{(\prime)} \bar{K}$

# Parameterization of F. F.

$$F(q^2) = \frac{F(0)}{1 - a(q^2/M^2) + b(q^2/M^2)^2}$$

$$F(q^2) = \frac{F(0)}{(1 - q^2/M^2)[1 - a(q^2/M^2) + b(q^2/M^2)^2]},$$