

# *Charmed baryon decays with $SU(3)$ flavor symmetry*

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## Outline:

1. Introduction
2. Formalism
3. Results
4. Summary

# Introduction

- Abundant measurements at BESIII since 2016, such as the  $\eta$  mode. More data coming.

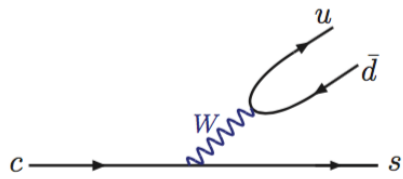
Theoretical study should be renewed also; besides, giving predictions.

- Non-factorizable effects, significant in  $\mathbf{B}_c$  decays like  $\Lambda_c^+ \rightarrow \Xi^0 K^+$ , whose nature is unclear.

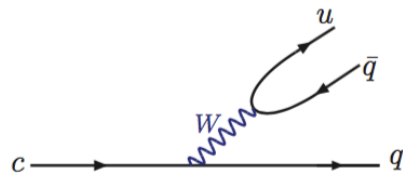
- The search for CP violation:  $\frac{\mathcal{B}(D^0 \rightarrow K^+ K^-)}{\mathcal{B}(D^0 \rightarrow \pi^+ \pi^-)} = 2.82 \pm 0.07$ ,

$$\Delta\mathcal{A}_{CP} \equiv \mathcal{A}_{CP}(D^0 \rightarrow K^+ K^-) - \mathcal{A}_{CP}(D^0 \rightarrow \pi^+ \pi^-)$$
$$= (-15.4 \pm 2.9) \times 10^{-4} \text{ (LHCb)}.$$

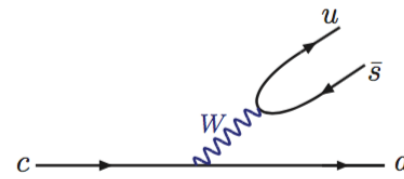
# Formalism



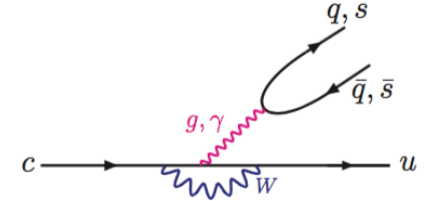
(a)



(b)



(c)



(d)

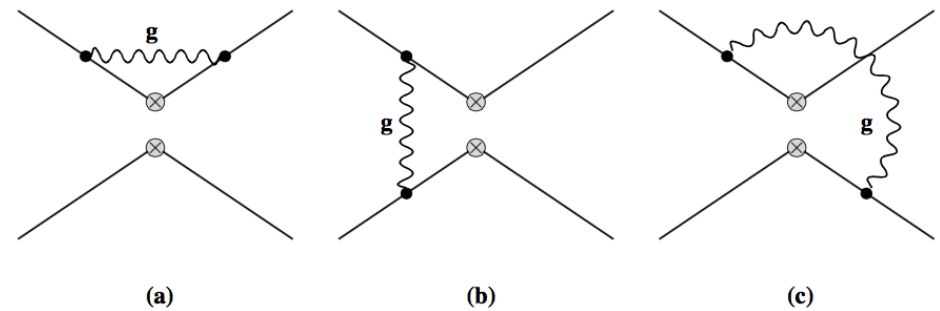
$$\mathcal{H}_{eff} = \sum_{i=+,-} \frac{G_F}{\sqrt{2}} c_i (V_{cs} V_{ud} O_i + V_{cq} V_{uq} O_i^q + V_{cd} V_{us} O'_i)$$

$$(V_{cs} V_{ud}, V_{cd} V_{ud}, V_{cs} V_{us}, V_{cd} V_{us}) = (1, -s_c, s_c, -s_c^2)$$

$$O_{\pm} = \frac{1}{2} [(\bar{u}d)(\bar{s}c) \pm (\bar{s}d)(\bar{u}c)]$$

$$O_{\pm}^q = \frac{1}{2} [(\bar{u}q)(\bar{q}c) \pm (\bar{q}q)(\bar{u}c)]$$

$$O'_{\pm} = \frac{1}{2} [(\bar{u}s)(\bar{d}c) \pm (\bar{d}s)(\bar{u}c)]$$



$$(c_+, c_-) = (0.76, 1.78)$$

$$(\bar{q}_1 q_2) \equiv \bar{q}_1 \gamma_{\mu} (1 - \gamma_5) q_2$$

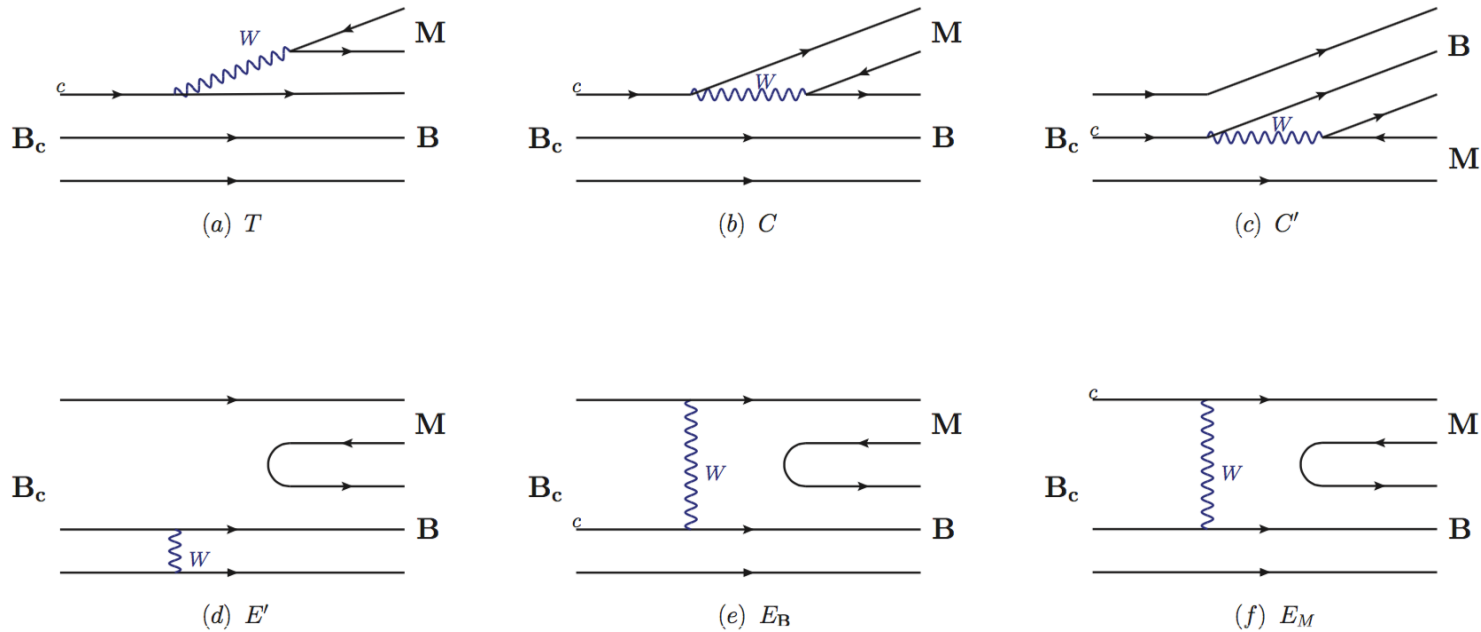


FIG. 1. Topological diagrams for the  $\mathbf{B}_c \rightarrow \mathbf{B}M$  decays.

$$\mathcal{B}(\Lambda_c^+ \rightarrow \Xi^0 K^+) = (5.90 \pm 0.86 \pm 0.39) \times 10^{-3}$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow \Xi^{*0} K^+) = (5.02 \pm 0.99 \pm 0.31) \times 10^{-3}$$

$$\mathcal{A}(\Lambda_c^+ \rightarrow \Xi^0 K^+) \propto V_{cs} V_{ud} (E_{\mathbf{B}} + E')$$

**Factorization doesn't work.**

## SU(3) flavor symmetry

Under the  $SU(3)_f$  symmetry

$$(\bar{q}_1 q_2)(\bar{q}_3 c) \sim (\bar{q}^i q_k \bar{q}^j) c$$

$q_i = (u, d, s)$  represent the triplet of 3

To be decomposed as irreducible forms:

$$(\bar{3} \times 3 \times \bar{3})c = (\bar{3} + \bar{3}' + 6 + \bar{15})c$$

$$O_{-(+)} \sim \mathcal{O}_{6(\bar{15})} = \frac{1}{2}(\bar{u}d\bar{s} \mp \bar{s}d\bar{u})c,$$

$$O_{-(+)}^q \sim \mathcal{O}_{6(\bar{15})}^q = \frac{1}{2}(\bar{u}q\bar{q} \mp \bar{q}q\bar{u})c,$$

$$O'_{-(+)} \sim \mathcal{O}'_{6(\bar{15})} = \frac{1}{2}(\bar{u}s\bar{d} \mp \bar{d}s\bar{u})c,$$

$$\mathcal{H}_{eff} = \sum_{i=+,-} \frac{G_F}{\sqrt{2}} c_i (V_{cs} V_{ud} O_i + V_{cq} V_{uq} O_i^q + V_{cd} V_{us} O_i')$$

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} \left[ c_- \frac{\epsilon^{ijkl}}{2} H(6)_{lk} + c_+ H(\overline{15})_{ij}^k \right],$$

$$H(6) = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 2 & -2s_c \\ 0 & -2s_c & 2s_c^2 \end{pmatrix},$$

$$H(\overline{15}) = \left( \left( \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \begin{pmatrix} 0 & s_c & 1 \\ s_c & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}, \begin{pmatrix} 0 & -s_c^2 & -s_c \\ -s_c^2 & 0 & 0 \\ -s_c & 0 & 0 \end{pmatrix} \right).$$

$$\mathcal{O}_{6(\overline{15})} = \frac{1}{2} (\bar{u} d \bar{s} \mp \bar{s} d \bar{u}) c$$

$\mathbf{B}_c$ , an anti-triplet of  $\bar{\mathbf{3}}$ :

$(ds - sd)c$ ,  $(us - su)c$  and  $(ud - du)c$

$$(\mathbf{B}_c)_i = (\Xi_c^0, -\Xi_c^+, \Lambda_c^+)$$

$$(\mathbf{B}_n)_j^i = \begin{pmatrix} \frac{1}{\sqrt{6}}\Lambda^0 + \frac{1}{\sqrt{2}}\Sigma^0 & \Sigma^+ & p \\ \Sigma^- & \frac{1}{\sqrt{6}}\Lambda^0 - \frac{1}{\sqrt{2}}\Sigma^0 & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\Lambda^0 \end{pmatrix},$$

$$(M)_j^i = \begin{pmatrix} \frac{1}{\sqrt{2}}(\pi^0 + c\phi\eta + s\phi\eta') & \pi^- & K^- \\ \pi^+ & \frac{-1}{\sqrt{2}}(\pi^0 - c\phi\eta - s\phi\eta') & \bar{K}^0 \\ K^+ & K^0 & -s\phi\eta + c\phi\eta' \end{pmatrix},$$

$(\eta, \eta')$ , the mixtures of  $(\eta_1, \eta_8)$

$$\eta_1 = \sqrt{2/3}\eta_q + \sqrt{1/3}\eta_s, \quad \eta_8 = \sqrt{1/3}\eta_q - \sqrt{2/3}\eta_s$$

$$\eta_q = \sqrt{1/2}(u\bar{u} + d\bar{d}) \text{ and } \eta_s = s\bar{s}$$

$\eta - \eta'$  mixing matrix:

$$\begin{pmatrix} \eta \\ \eta' \end{pmatrix} = \begin{pmatrix} \cos \phi & -\sin \phi \\ \sin \phi & \cos \phi \end{pmatrix} \begin{pmatrix} \eta_q \\ \eta_s \end{pmatrix}$$

mixing angle  $\phi = (39.3 \pm 1.0)^\circ$



$$(V)_j^i = \begin{pmatrix} \frac{1}{\sqrt{2}}(\rho^0 + \omega) & \rho^- & K^{*-} \\ \rho^+ & \frac{-1}{\sqrt{2}}(\rho^0 - \omega) & \bar{K}^{*0} \\ K^{*+} & K^{*0} & \phi \end{pmatrix}$$

$$\omega = (u\bar{u} + d\bar{d})/\sqrt{2} \text{ and } \phi = s\bar{s}$$

mix with

$$\omega_1 = (u\bar{u} + d\bar{d} + s\bar{s})/\sqrt{3}$$

$$\omega_8 = (u\bar{u} + d\bar{d} - 2s\bar{s})/\sqrt{6}$$

$$\mathcal{A}(\mathbf{B}_c \rightarrow \mathbf{B}_n M) = \langle \mathbf{B}_n M | \mathcal{H}_{eff} | \mathbf{B}_c \rangle = \frac{G_F}{\sqrt{2}} T(\mathbf{B}_c \rightarrow \mathbf{B}_n M)$$

$$T(\mathbf{B}_c \rightarrow \mathbf{B}_n M) = T(\mathcal{O}_6) + T(\mathcal{O}_{\overline{15}})$$

$$\begin{aligned} T(\mathcal{O}_6) &= a_1 H_{ij}(6) T^{ik}(\mathbf{B}_n)_k^l (M)_l^j + a_2 H_{ij}(6) T^{ik}(M)_k^l (\mathbf{B}_n)_l^j \\ &\quad + a_3 H_{ij}(6) (\mathbf{B}_n)_k^i (M)_l^j T^{kl} + h H_{ij}(6) T^{ik}(\mathbf{B}_n)_k^j (M)_l^l, \end{aligned}$$

$$\begin{aligned} T(\mathcal{O}_{\overline{15}}) &= a_4 H_{li}^k(\overline{15}) (\mathbf{B}_c)^j (M)_j^i (\mathbf{B}_n)_k^l + a_5 (\mathbf{B}_n)_j^i (M)_i^l H(\overline{15})_l^{jk} (\mathbf{B}_c)_k \\ &\quad + a_6 (\mathbf{B}_n)_l^k (M)_j^i H(\overline{15})_i^{jl} (\mathbf{B}_c)_k + a_7 (\mathbf{B}_n)_i^l (M)_j^i H(\overline{15})_l^{jk} (\mathbf{B}_c)_k \\ &\quad + h' H_i^{jk}(\overline{15}) (\mathbf{B}_n)_k^i (M)_l^l (\mathbf{B}_c)_j, \end{aligned}$$

$$T_{ij} \equiv (\mathbf{B}_c)_k \epsilon^{ijk}$$

$$(M)_i^l = \sqrt{3} \eta_1$$

$\Lambda_c^+$	$T\text{-amp}$	$\Sigma^+ K^0$	$-2(a_1 - a_3 - \frac{a_4 - a_5}{2})s_c$	$pK^0$	$2(a_3 - \frac{a_4 + a_6}{2})s_c^2$
$\Sigma^0 \pi^+$	$-\sqrt{2}(a_1 - a_2 - a_3 - \frac{a_5 - a_7}{2})$	$\Sigma^0 K^+$	$-\sqrt{2}(a_1 - a_3 - \frac{a_4 + a_5}{2})s_c$	$nK^+$	$-2(a_3 + \frac{a_4 + a_6}{2})s_c^2$
$\Sigma^+ \pi^0$	$\sqrt{2}(a_1 - a_2 - a_3 - \frac{a_5 - a_7}{2})$	$p\pi^0$	$-\sqrt{2}(a_2 + a_3 - \frac{a_6 - a_7}{2})s_c$		
$\Sigma^+ \eta$	$\sqrt{2}c\phi(-a_1 - a_2 + a_3 - 2h$ $+ \frac{a_5 + a_7 + 2h'}{2})$ $+ s\phi(-a_4 + 2h - h')$	$p\eta$	$[\sqrt{2}c\phi(a_2 - a_3 + 2h$ $+ \frac{a_6 - a_7 - 2h'}{2})$ $+ 2s\phi(-a_1 - h$ $+ \frac{a_4 + a_5 + a_6 + h'}{2})]s_c$		
$\Sigma^+ \eta'$	$\frac{\sqrt{2}s\phi}{2}(-a_1 - a_2 + a_3 - 2h$ $+ \frac{a_5 + a_7 + 2h'}{2})$ $- c\phi(-a_4 + 2h - h')$	$p\eta'$	$[\sqrt{2}s\phi(a_2 - a_3 + 2h$ $+ \frac{a_6 - a_7 - 2h'}{2})$ $- 2c\psi(-a_1 - h$ $+ \frac{a_4 + a_5 + a_6 + h'}{2})]s_c$		
$\Xi^0 K^+$	$-2(a_2 - \frac{a_4 + a_7}{2})$	$n\pi^+$	$-2(a_2 + a_3 - \frac{a_4 + a_7}{2})s_c$		
$p\bar{K}^0$	$-2(a_1 - \frac{a_5 + a_6}{2})$	$\Lambda^0 K^+$	$-\sqrt{\frac{2}{3}}(a_1 - 2a_2 + a_3$ $- \frac{3a_4 - a_5 + 2a_6 + 2a_7}{2})s_c$		
$\Lambda^0 \pi^+$	$-\sqrt{\frac{2}{3}}(a_1 + a_2 + a_3$ $- \frac{a_5 - 2a_6 + a_7}{2})$				

TABLE I. The data of the  $\mathbf{B}_c \rightarrow \mathbf{B}_n M$  decays.

Branching ratios	Data	Branching ratios	Data
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow p \bar{K}^0)$	$3.16 \pm 0.16$	$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow \Lambda K^+)$	$6.1 \pm 1.2$
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Lambda \pi^+)$	$1.30 \pm 0.07$	$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 K^+)$	$5.2 \pm 0.8$
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \pi^0)$	$1.24 \pm 0.10$	$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ K^0)$	—
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 \pi^+)$	$1.29 \pm 0.07$	$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow p \eta)$	$12.4 \pm 3.0$
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Xi^0 K^+)$	$0.59 \pm 0.09$	$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow p \eta')$	—
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \eta)$	$0.70 \pm 0.23$	$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow p \pi^0)$	$0.8 \pm 1.4 (< 0.27)$
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \eta')$	observed	$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow n \pi^+)$	—
$10^2 \mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)$	observed	$\mathcal{R}_1(\Xi_c^0) \equiv \frac{\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- K^+)}{\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)}$	$(0.56 \pm 0.12) s_c^2$
		$\mathcal{R}_2(\Xi_c^0) \equiv \frac{\mathcal{B}(\Xi_c^0 \rightarrow \Lambda^0 \bar{K}^0)}{\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)}$	$0.420 \pm 0.056$

$$\mathcal{H}_{eff} \propto c_- H(6) + c_+ H(\overline{15})$$

$$(c_+, c_-) = (0.76, 1.78)$$

$$(c_+/c_-)^2 \simeq 0.18, \text{ neglecting } H(\overline{15})$$

$$a_1, a_2 e^{i\delta_{a_2}}, a_3 e^{i\delta_{a_3}}, h e^{i\delta_h}.$$

$$\chi^2 = \sum_i \left( \frac{\mathcal{B}_{th}^i - \mathcal{B}_{ex}^i}{\sigma_{ex}^i} \right)^2 + \sum_j \left( \frac{\mathcal{R}_{th}^j - \mathcal{R}_{ex}^j}{\sigma_{ex}^j} \right)^2,$$

$$(a_1, a_2, a_3, h) = (0.244 \pm 0.006, 0.115 \pm 0.014, 0.088 \pm 0.019, 0.105 \pm 0.073) \text{ GeV}^3,$$

$$(\delta_{a_2}, \delta_{a_3}, \delta_h) = (78.1 \pm 7.1, 35.1 \pm 8.7, 10.2 \pm 29.6)^\circ,$$

$$\chi^2/d.o.f = 5.32/3 = 1.77,$$

(Ratios of) Branching ratios	$SU(3)_f$	symmetry	Data
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow p \bar{K}^0)$	$3.3 \pm 0.2$	$2.72 - 3.60$	$3.16 \pm 0.16$
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Lambda^0 \pi^+)$	$1.3 \pm 0.2$	$1.30 \pm 0.17$	$1.30 \pm 0.07$
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 \pi^+)$	$1.3 \pm 0.2$	$1.27 \pm 0.17$	$1.29 \pm 0.07$
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \pi^0)$	$1.3 \pm 0.2$	$1.27 \pm 0.17$	$1.24 \pm 0.10$
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Xi^0 K^+)$	$0.5 \pm 0.1$	$0.50 \pm 0.12$	$0.59 \pm 0.09$
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \eta)$	$0.7_{-0.3}^{+0.4}$		$0.70 \pm 0.23$
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \eta')$	$1.0_{-0.8}^{+1.6}$		

(Ratios of) Branching ratios	$SU(3)_f$	symmetry	Data
$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow p \pi^0)$	$5.7 \pm 1.5$		$0.8 \pm 1.4 (< 0.27)$
$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow n \pi^+)$	$11.3 \pm 2.9$		
$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow \Lambda^0 K^+)$	$4.6 \pm 0.9$		$6.1 \pm 1.2$
$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 K^+)$	$4.0 \pm 0.8$		$5.2 \pm 0.8$
$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ K^0)$	$8.0 \pm 1.6$		
$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow p \eta)$	$12.5_{-3.6}^{+3.8}$		$12.4 \pm 3.0$
$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow p \eta')$	$12.2_{-8.7}^{+14.3}$		

(Ratios of) Branching ratios	$SU(3)_f$ symmetry	Data
$10^4 \mathcal{B}(\Xi_c^0 \rightarrow \Xi^- K^+)$	$7.6 \pm 0.4$	
$10^2 \mathcal{B}(\Xi_c^0 \rightarrow \Lambda^0 \bar{K}^0)$	$0.83 \pm 0.09$ $0.94 \pm 0.16$	
$10^2 \mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)$	$1.57 \pm 0.07$ $2.24 \pm 0.34$	
$\mathcal{R}_1(\Xi_c^0) \equiv \frac{\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- K^+)}{\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)}$	$0.96 s_c^2$	$(0.56 \pm 0.12) s_c^2$
$\mathcal{R}_2(\Xi_c^0) \equiv \frac{\mathcal{B}(\Xi_c^0 \rightarrow \Lambda^0 \bar{K}^0)}{\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)}$	$0.53 \pm 0.06$	$0.42 \pm 0.06$

$$\begin{aligned} \mathcal{B}(\Lambda_c^+ \rightarrow p \pi^0) &\simeq \left( \frac{a_2}{\bar{a}_2} \frac{f_\pi}{2f_K} \frac{V_{cd} V_{ud}}{V_{cs} V_{ud}} \right)^2 \mathcal{B}(\Lambda_c^+ \rightarrow p \bar{K}^0) \\ &= (5.5 \pm 0.3) \times 10^{-4}, \end{aligned}$$

$$\begin{aligned} \mathcal{B}(\Xi_c^0 \rightarrow \Xi^- K^+) &\simeq \left( \frac{a_1}{\bar{a}_1} \frac{f_K}{f_\pi} \frac{V_{cs} V_{us}}{V_{cs} V_{ud}} \right)^2 \mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+) \\ &\simeq 1.4 s_c^2, \end{aligned}$$

# Diagrammatic approach

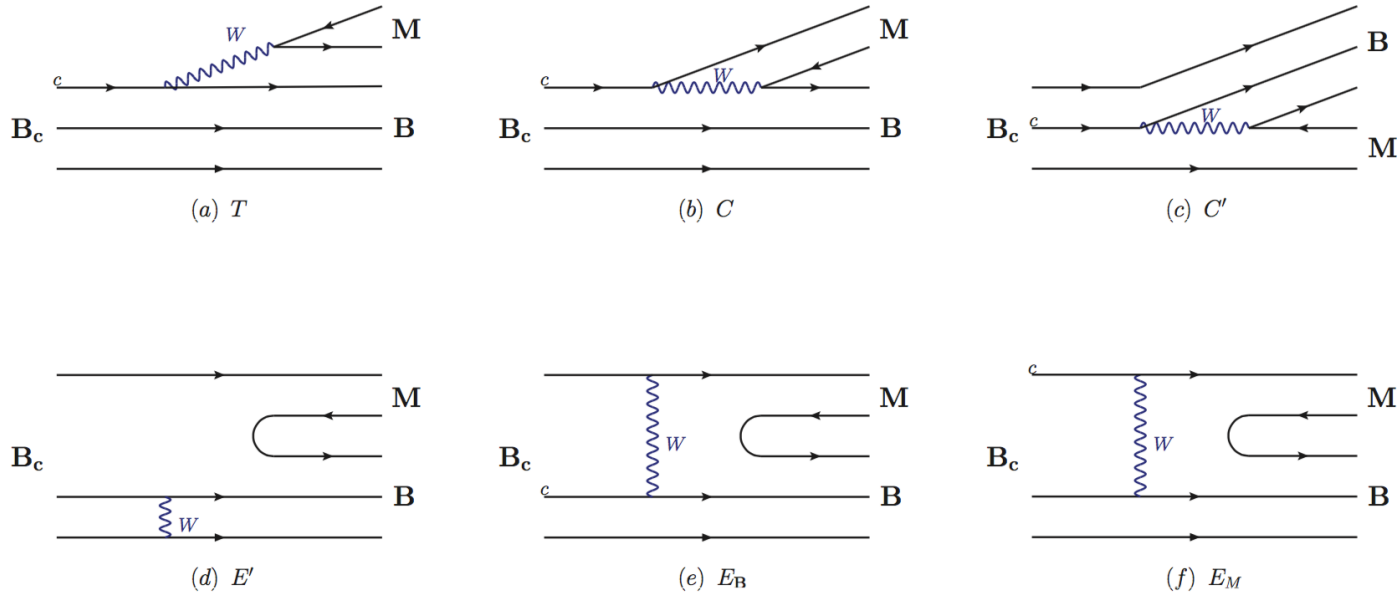


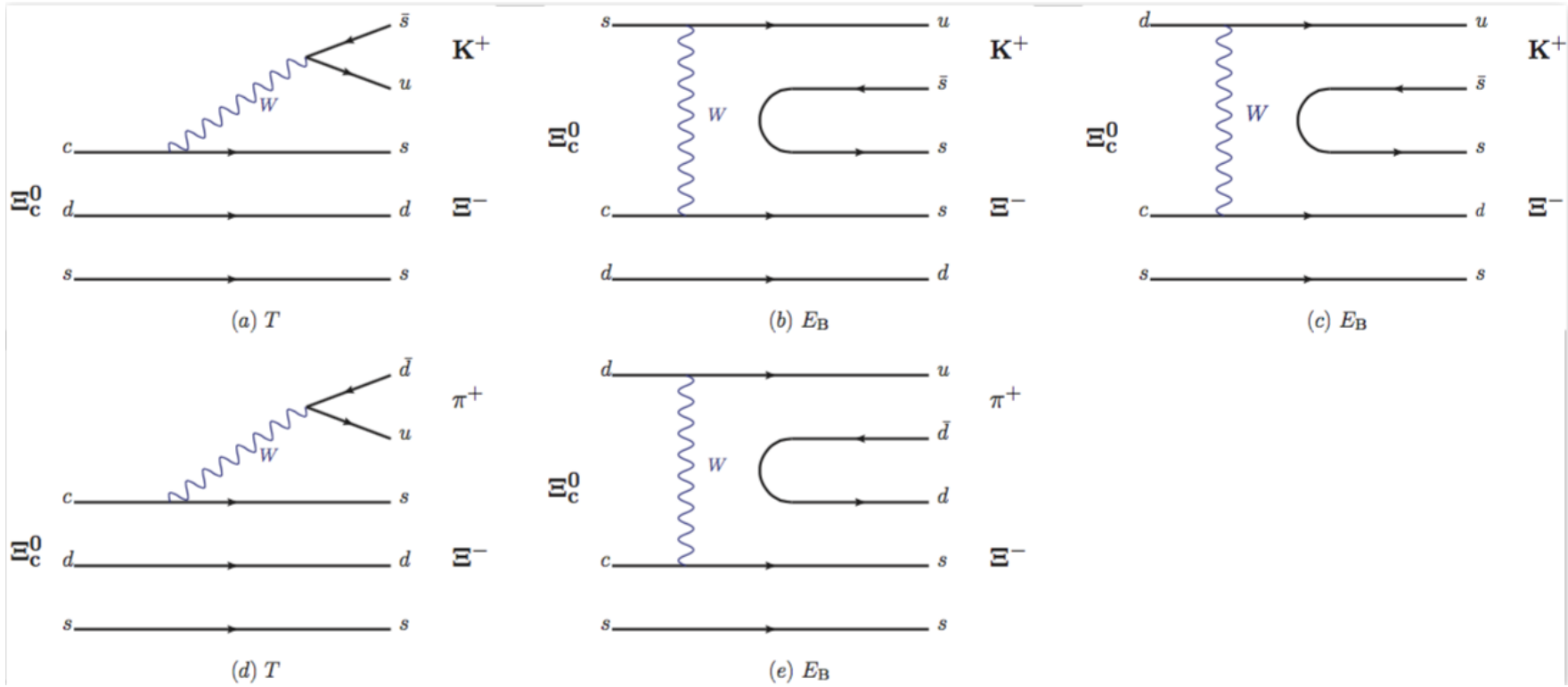
FIG. 1. Topological diagrams for the  $\mathbf{B}_c \rightarrow \mathbf{B}M$  decays.

$$\mathcal{A}(\Lambda_c^+ \rightarrow p\pi^0) \propto V_{cd}V_{ud}\sqrt{\frac{1}{2}}(-C - C' - E_M + E_{\mathbf{B}} + E')$$

$$\mathcal{A}(\Xi_c^0 \rightarrow \Xi^- K^+) \propto V_{cs}V_{us}(T + E_{\mathbf{B}}) + V_{cd}V_{ud}E_{\mathbf{B}} = V_{cs}V_{us}T$$

$$\mathcal{A}(\Xi_c^0 \rightarrow \Xi^- \pi^+) \propto V_{cs}V_{ud}(T + E_{\mathbf{B}})$$





$$\mathcal{A}(\Xi_c^0 \rightarrow \Xi^- K^+) \propto V_{cs} V_{us} (T + E_B) + V_{cd} V_{ud} E_B = V_{cs} V_{us} T$$

$$\mathcal{A}(\Xi_c^0 \rightarrow \Xi^- \pi^+) \propto V_{cs} V_{ud} (T + E_B)$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow p\pi^0) = (0.8 \pm 0.7) \times 10^{-4}$$

$$\mathcal{R}_1(\Xi_c^0) \equiv \frac{\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- K^+)}{\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+)} = (0.56 \pm 0.12) s_c^2$$

$$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+) = (1.91 \pm 0.17)\%$$

$$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+) = (1.80 \pm 0.50 \pm 0.14)\%, \text{ BELLE}$$

$$\begin{aligned}
T(\mathbf{B}_c \rightarrow \mathbf{B}_n MM') = & \\
& a_1(\bar{\mathbf{B}}_n)_i^k (M)_l^m (M')_m^l H(6)_{jk} T^{ij} + a_2(\bar{\mathbf{B}}_n)_i^k (M)_j^m (M')_m^l H(6)_{kl} T^{ij} \\
& + a_3(\bar{\mathbf{B}}_n)_i^k (M)_k^m (M')_m^l H(6)_{jl} T^{ij} + a_4(\bar{\mathbf{B}}_n)_i^k (M)_j^l (M')_k^m H(6)_{lm} T^{ij} \\
& + a_5(\bar{\mathbf{B}}_n)_k^l (M)_j^m (M')_m^k H(6)_{il} T^{ij} + a_6(\bar{\mathbf{B}}_n)_k^l (M)_j^m (M')_l^k H(6)_{im} T^{ij},
\end{aligned}$$

$L$  between  $MM'$ :

S-wave  $MM'$ -pair ( $L = 0$ ), dominant

P-wave one ( $L = 1$ ), neglected

$$\mathcal{A}(\mathbf{B}_c \rightarrow \mathbf{B}_n V) = \langle \mathbf{B}_n V | \mathcal{H}_{eff} | \mathbf{B}_c \rangle = \frac{G_F}{\sqrt{2}} T(\mathbf{B}_c \rightarrow \mathbf{B}_n V)$$

$$T(\mathbf{B}_c \rightarrow \mathbf{B}_n V) = T(\mathcal{O}_6) + T(\mathcal{O}_{\overline{15}}),$$

$$\begin{aligned} T(\mathcal{O}_6) &= \bar{a}_1 H^{ij}(6) T_{ik}(\mathbf{B}_n)_l^k (V)_j^l + \bar{a}_2 H^{ij}(6) T_{ik}(V)_l^k (\mathbf{B}_n)_j^l \\ &+ \bar{a}_3 H^{ij}(6) (\mathbf{B}_n)_i^k (V)_j^l T_{kl} + \bar{h} H^{ij}(6) T_{ik}(\mathbf{B}_n)_j^k (V)_l^l, \end{aligned}$$

$$\begin{aligned} T(\mathcal{O}_{\overline{15}}) &= \bar{a}_4 H_{jk}^i(\overline{15})(V)_l^j (\mathbf{B}_n)_i^k (\mathbf{B}_c)^l + \bar{a}_5 H(\overline{15})_{jk}^i (\mathbf{B}_c)^j (\mathbf{B}_n)_l^k (V)_i^l \\ &+ \bar{a}_6 H(\overline{15})_{jk}^i (\mathbf{B}_n)_l^j (V)_i^k (\mathbf{B}_c)^l + \bar{a}_7 H(\overline{15})_{jk}^i (\mathbf{B}_c)^j (V)_l^k (\mathbf{B}_n)_i^l \\ &+ \bar{h}' H_{jk}^i(\overline{15})(\mathbf{B}_n)_i^k (V)_l^l (\mathbf{B}_c)^j, \end{aligned}$$

$$(V)_l^l = \sqrt{2}\omega + \phi = \sqrt{3}\omega_1$$

$\Lambda_c^+$	CF $T$ -amp	$\Lambda_c^+$	SCS $T$ -amp	$\Lambda_c^+$	DCS $T$ -amp
$\Sigma^0 \rho^+$	$-\sqrt{2}(\bar{a}_1 - \bar{a}_2 - \bar{a}_3 - \frac{\bar{a}_5 - \bar{a}_7}{2})$	$\Sigma^+ K^{*0}$	$-2(\bar{a}_1 - \bar{a}_3 - \frac{\bar{a}_4 - \bar{a}_5}{2})s_c$	$pK^{*0}$	$2(\bar{a}_3 - \frac{\bar{a}_4 + \bar{a}_6}{2})s_c^2$
$\Sigma^+ \rho^0$	$\sqrt{2}(\bar{a}_1 - \bar{a}_2 - \bar{a}_3 - \frac{\bar{a}_5 - \bar{a}_7}{2})$	$\Sigma^0 K^{*+}$	$-\sqrt{2}(\bar{a}_1 - \bar{a}_3 - \frac{\bar{a}_4 + \bar{a}_5}{2})s_c$	$nK^{*+}$	$-2(\bar{a}_3 + \frac{\bar{a}_4 + \bar{a}_6}{2})s_c^2$
$\Sigma^+ \omega$	$\sqrt{2}(-\bar{a}_1 - \bar{a}_2 + \bar{a}_3 - 2\bar{h}$ $+ \frac{\bar{a}_5 + \bar{a}_7 + 2\bar{h}'}{2})$	$p\rho^0$	$-\sqrt{2}(\bar{a}_2 + \bar{a}_3 - \frac{\bar{a}_6 - \bar{a}_7}{2})s_c$		
$\Sigma^+ \phi$	$\bar{a}_4 - 2\bar{h} + \bar{h}'$	$p\omega$	$\sqrt{2}(\bar{a}_2 - \bar{a}_3 + 2\bar{h}$ $+ \frac{\bar{a}_6 - \bar{a}_7 - 2\bar{h}'}{2})s_c$		
$\Xi^0 K^{*+}$	$-2(\bar{a}_2 - \frac{\bar{a}_4 + \bar{a}_7}{2})$	$p\phi$	$-2(-\bar{a}_1 - \bar{h}$ $+ \frac{\bar{a}_4 + \bar{a}_5 + \bar{a}_6 + \bar{h}'}{2})s_c$		
$p\bar{K}^{*0}$	$-2(\bar{a}_1 - \frac{\bar{a}_5 + \bar{a}_6}{2})$	$n\rho^+$	$-2(\bar{a}_2 + \bar{a}_3 - \frac{\bar{a}_4 + \bar{a}_7}{2})s_c$		
$\Lambda^0 \rho^+$	$-\sqrt{\frac{2}{3}}(\bar{a}_1 + \bar{a}_2 + \bar{a}_3$ $- \frac{\bar{a}_5 - 2\bar{a}_6 + \bar{a}_7}{2})$	$\Lambda^0 K^{*+}$	$-\sqrt{\frac{2}{3}}(\bar{a}_1 - 2\bar{a}_2 + \bar{a}_3$ $- \frac{3\bar{a}_4 - \bar{a}_5 + 2\bar{a}_6 + 2\bar{a}_7}{2})s_c$		

$$\Sigma^+ \eta \quad \sqrt{2}c\phi(-a_1 - a_2 + a_3 - 2h$$

$$+ \frac{a_5 + a_7 + 2h'}{2})$$

$$+ s\phi(-a_4 + 2h - h')$$

$$\Sigma^+ \eta' \quad \frac{\sqrt{2}s\phi}{2}(-a_1 - a_2 + a_3 - 2h$$

$$+ \frac{a_5 + a_7 + 2h'}{2})$$

$$- c\phi(-a_4 + 2h - h')$$

$$\bar{a}_1, \bar{a}_2 e^{i\delta_{\bar{a}_2}}, \bar{a}_3 e^{i\delta_{\bar{a}_3}}, \bar{h} e^{i\delta_{\bar{h}}},$$

$$\chi^2 = \sum_i \left( \frac{\mathcal{B}_{th}^i - \mathcal{B}_{ex}^i}{\sigma_{ex}^i} \right)^2 + \sum_j \left( \frac{\mathcal{R}_{th}^j - \mathcal{R}_{ex}^j}{\sigma_{ex}^j} \right)^2,$$

(Ratio of) Branching fraction	Data
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow p \bar{K}^{*0})$	$1.94 \pm 0.27$ [1]
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \omega)$	$1.69 \pm 0.21$ [1]
$10^3 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \phi)$	$3.8 \pm 0.6$ [1]
$\mathcal{R}(\Lambda_c^+) = \frac{\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \rho^0)}{\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \omega)}$	$0.3 \pm 0.2$ [32]
$10^3 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ K^{*0})$	$3.4 \pm 1.0$ [1]
$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow p \omega)$	$9.4 \pm 3.9$ [33]
$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow p \phi)$	$10.6 \pm 1.4$ [1]
$10^4 \mathcal{B}(\Xi_c^0 \rightarrow \Lambda^0 \phi)$	$6.1 \pm 2.2$ [1, 3]
$\mathcal{R}_1(\Xi_c^+) = \frac{\mathcal{B}(\Xi_c^+ \rightarrow p \bar{K}^{*0})}{\mathcal{B}(\Xi_c^+ \rightarrow \Sigma^+ \bar{K}^{*0})}$	$(2.8 \pm 1.0) s_c^2$ [1]
$\mathcal{R}_2(\Xi_c^+) = \frac{\mathcal{B}(\Xi_c^+ \rightarrow \Sigma^+ \phi)}{\mathcal{B}(\Xi_c^+ \rightarrow \Sigma^+ \bar{K}^{*0})}$	$(1.7 \pm 1.2) s_c^2$ [1, 29]

(Ratio of) Branching fraction	This work	Data
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow p \bar{K}^{*0})$	$1.9 \pm 0.3$	$1.94 \pm 0.27$ [1]
$10^2 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \omega)$	$1.6 \pm 0.7$	$1.69 \pm 0.21$ [1]
$10^3 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \phi)$	$3.9 \pm 0.6$	$3.8 \pm 0.6$ [1]
$\mathcal{R}(\Lambda_c^+) = \frac{\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \rho^0)}{\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \omega)}$	$0.4 \pm 0.3$	$0.3 \pm 0.2$ [32]
$10^3 \mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ K^{*0})$	$2.3 \pm 0.6$	$3.4 \pm 1.0$ [1]
$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow p \omega)$	$11.4 \pm 5.4$	$9.4 \pm 3.9$ [33]
$10^4 \mathcal{B}(\Lambda_c^+ \rightarrow p \phi)$	$10.4 \pm 2.1$	$10.6 \pm 1.4$ [1]
$10^4 \mathcal{B}(\Xi_c^0 \rightarrow \Lambda^0 \phi)$	$8.4 \pm 3.9$	$6.1 \pm 2.2$ [1, 3]
$\mathcal{R}_1(\Xi_c^+) = \frac{\mathcal{B}(\Xi_c^+ \rightarrow p \bar{K}^{*0})}{\mathcal{B}(\Xi_c^+ \rightarrow \Sigma^+ \bar{K}^{*0})}$	$(1.6 \pm 0.2) s_c^2$	$(2.8 \pm 1.0) s_c^2$ [1]
$\mathcal{R}_2(\Xi_c^+) = \frac{\mathcal{B}(\Xi_c^+ \rightarrow \Sigma^+ \phi)}{\mathcal{B}(\Xi_c^+ \rightarrow \Sigma^+ \bar{K}^{*0})}$	$(0.4 \pm 0.1) s_c^2$	$(1.7 \pm 1.2) s_c^2$ [1, 29]

$$(\bar{a}_1, \bar{a}_2, \bar{a}_3, \bar{h}) = (0.22 \pm 0.02, 0.23 \pm 0.04, 0.39 \pm 0.05, 0.16 \pm 0.01) \text{ GeV}^3,$$

$$(\delta_{\bar{a}_2}, \delta_{\bar{a}_3}, \delta_{\bar{h}}) = (-85.5 \pm 13.0, 78.4 \pm 8.8, 99.3 \pm 7.7)^\circ,$$

$$\chi^2/n.d.f = 6.3/3 = 2.1,$$

$\Lambda_c^+$	our results	$\Lambda_c^+$	our results	$\Lambda_c^+$	our results
$10^3 \mathcal{B}_{\Sigma^0 \rho^+}$	$6.1 \pm 4.6$	$10^4 \mathcal{B}_{p \rho^0}$	$3.5 \pm 2.9$	$10^4 \mathcal{B}_{p K^{*0}}$	$1.6 \pm 0.5$
$10^3 \mathcal{B}_{\Sigma^+ \rho^0}$	$6.1 \pm 4.6$	$10^4 \mathcal{B}_{n \rho^+}$	$7.0 \pm 5.8$	$10^4 \mathcal{B}_{n K^{*+}}$	$1.6 \pm 0.5$
$10^3 \mathcal{B}_{\Xi^0 K^{*+}}$	$8.7 \pm 2.7$	$10^3 \mathcal{B}_{\Sigma^0 K^{*+}}$	$1.2 \pm 0.3$		
$10^3 \mathcal{B}_{\Lambda^0 \rho^+}$	$7.4 \pm 3.4$	$10^3 \mathcal{B}_{\Lambda^0 K^{*+}}$	$2.0 \pm 0.5$		

Tested by data:

$$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \rho^0, \Lambda^0 \rho^+) = (0.61 \pm 0.46, 0.74 \pm 0.34)\%,$$

$$\mathcal{B}_{ex}(\Lambda_c^+ \rightarrow \Sigma^+ \rho^0, \Lambda^0 \rho^+) < (1.7, 6)\%,$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ \rho^0, \rho^0 \rightarrow \pi^+ \pi^-) = (6.1 \pm 4.6) \times 10^{-3},$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 \rho^+, \rho^+ \rightarrow \pi^+ \pi^0) = (6.1 \pm 4.6) \times 10^{-3},$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda^0 \rho^+, \rho^+ \rightarrow \pi^+ \pi^0) = (7.4 \pm 3.4) \times 10^{-3},$$

$$\text{total } \mathbf{B}_{ex} = (4.42 \pm 0.28, 2.2 \pm 0.8, 7.0 \pm 0.4) \times 10^{-2}$$

$\Rightarrow V \rightarrow MM'$ , minor.



isospin symmetry

$$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 \rho^+, \Sigma^+ \rho^0) = (6.1 \pm 4.6) \times 10^{-3},$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^+ K^{*0}) = 2\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 K^{*+}) = (2.3 \pm 0.6) \times 10^{-3},$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow p\rho^0) = \frac{1}{2}\mathcal{B}(\Lambda_c^+ \rightarrow n\rho^+) = (3.5 \pm 2.9) \times 10^{-4},$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow nK^{*+}, pK^{*0}) = (1.6 \pm 0.5) \times 10^{-4},$$

Overestimation?

$$\frac{1}{\sqrt{2}}T(\Lambda_c^+ \rightarrow p\bar{K}^{*0}) - \frac{1}{s_c}T(\Lambda_c^+ \rightarrow p\rho^0) = T(\Lambda_c^+ \rightarrow \Sigma^0 \rho^+),$$

$$\frac{1}{\sqrt{2}}T(\Lambda_c^+ \rightarrow p\bar{K}^{*0}) + \frac{1}{s_c}T(\Lambda_c^+ \rightarrow p\rho^0) = \sqrt{3}T(\Lambda_c^+ \rightarrow \Lambda^0 \rho^+),$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow p\rho^0)$$

$$\simeq \frac{s_c^2}{2} [3.6\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda^0 \rho^+) + 1.3\mathcal{B}(\Lambda_c^+ \rightarrow \Sigma^0 \rho^+) - 1.1\mathcal{B}(\Lambda_c^+ \rightarrow p\bar{K}^{*0})],$$

$$\mathcal{B}(\Lambda_c^+ \rightarrow \Xi^0 K^{*+}, \Sigma^0 K^{*+}, \Lambda^0 K^{*+})$$

$$= (8.7 \pm 2.7, 1.2 \pm 0.3, 2.0 \pm 0.5) \times 10^{-3},$$

compatible with  $\mathbf{B}(\Lambda_c^+ \rightarrow \mathbf{B}_n M)$ .

$$\mathcal{B}(\Xi_c^+ \rightarrow p\phi) = (1.5 \pm 0.7) \times 10^{-4}$$

$$\mathcal{B}(\Xi_c^+ \rightarrow p\phi) / \mathcal{B}(\Xi_c^+ \rightarrow pK^-\pi^+)$$

$$= (19.8 \pm 0.7 \pm 0.9 \pm 0.2) \times 10^{-3} \text{ [LHCb]}$$

$$\mathcal{B}(\Xi_c^+ \rightarrow pK^-\pi^+) = (0.8 \pm 0.4)\%$$

## Summary

- With the  $SU(3)_f$  symmetry,  
one can study  $\mathbf{B}_c \rightarrow \mathbf{B}_n M(M'), \mathbf{B}_n V$ .
- $\mathbf{B}(\mathbf{B}_c \rightarrow \mathbf{B}_n V)$  are accessible to  
the BESIII, BELLEII and LHCb measurements.

**Thank You**