Two-body charmed baryon decays

Yu-Kuo Hsiao (萧佑国)
Shanxi Normal university

Workshop on form factor, polarisation and CP violation
in quantum-correlated hyperon-anti-hyperon production

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Outline:

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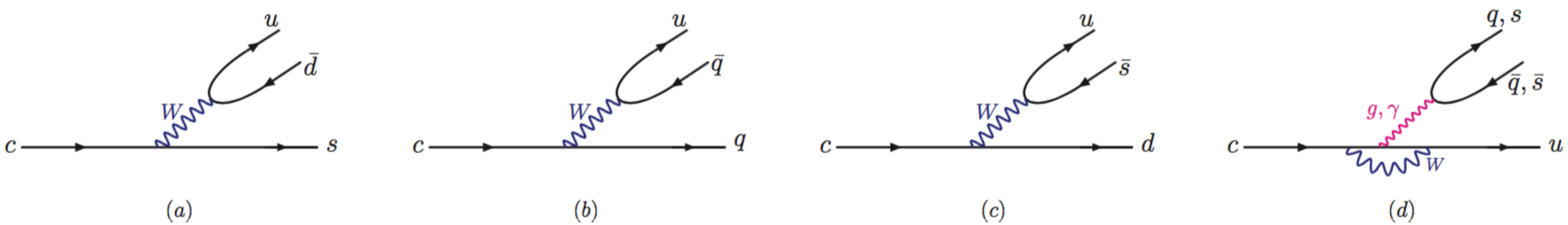
Introduction

- Aboundent measurements at BESIII since 2016, such as the η mode. More data coming. Theoretical study should be renewed also; besides, giving predictions.
- Non-factorizable effects, significant in $\mathbf{B}_c$ decays like $\Lambda_c^+ \to \Xi^0 K^+$, whose nature is unclear.
- The search for CP violation: $\frac{\mathcal{B}(D^0 \to K^+ K^-)}{\mathcal{B}(D^0 \to \pi^+ \pi^-)} = 2.82 \pm 0.07$,

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

Formalism



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

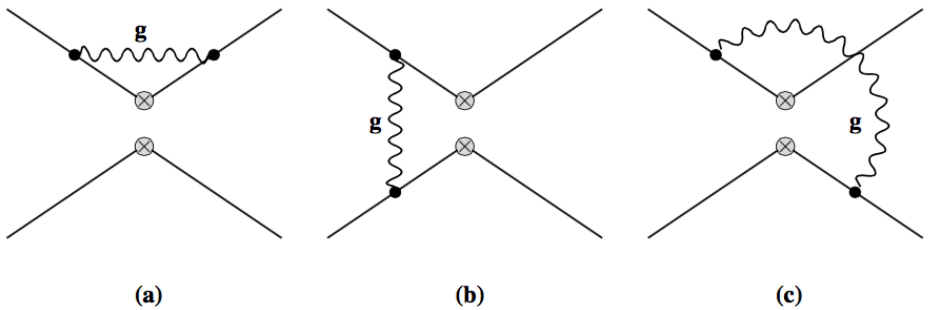
$$(V_{cs}V_{ud}, V_{cd}V_{ud}, V_{cs}V_{us}, V_{cd}V_{us}) = (1, -s_c, s_c, -s_c^2)$$

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

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

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

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



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

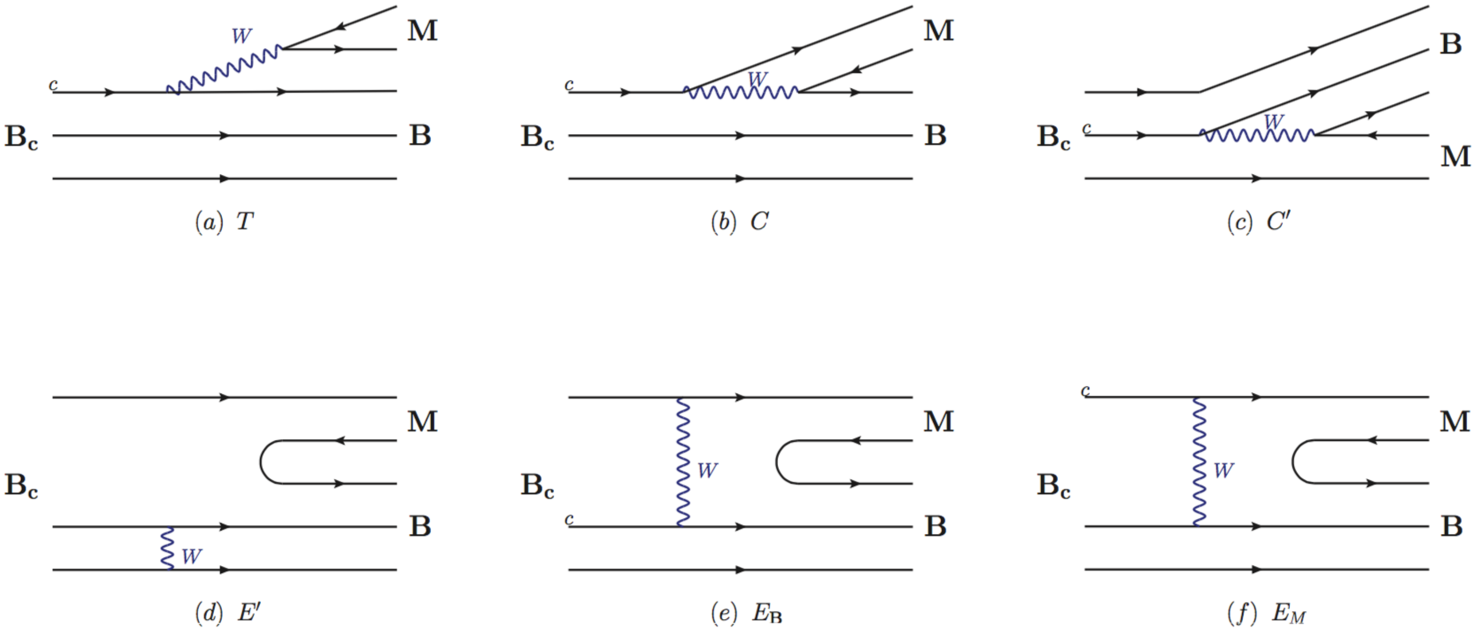


FIG. 1. Topological diagrams for the $\mathbf{B}_c \to \mathbf{B}M$ decays.

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

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

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

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:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

(η, η'), the mixtures of (η_1, η_8)

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

$\eta_q = \sqrt{1/2}(u\bar{u} + d\bar{d})$ 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 $\phi = (39.3 \pm 1.0)^\circ$

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

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

mix with

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

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

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

$$\begin{aligned}
T(\mathbf{B}_c \to \mathbf{B}_n M) &= T(\mathcal{O}_6) + T(\mathcal{O}_{\overline{15}}) \\
T(\mathcal{O}_6) &= a_1 H_{ij}(6) T^{ik} (\mathbf{B}_n)^l_k (M)^j_l + a_2 H_{ij}(6) T^{ik} (M)^l_k (\mathbf{B}_n)^j_l \\
&+ a_3 H_{ij}(6) (\mathbf{B}_n)^i_k (M)^j_l T^{kl} + h H_{ij}(6) T^{ik} (\mathbf{B}_n)^j_k (M)^l_l \,, \\
T(\mathcal{O}_{\overline{15}}) &= a_4 H^k_{li}(\overline{15}) (\mathbf{B}_c)^j (M)^i_j (\mathbf{B}_n)^l_k + a_5 (\mathbf{B}_n)^i_j (M)^l_i H(\overline{15})^{jk}_l (\mathbf{B}_c)_k \\
&+ a_6 (\mathbf{B}_n)^k_l (M)^i_j H(\overline{15})^{jl}_i (\mathbf{B}_c)_k + a_7 (\mathbf{B}_n)^l_i (M)^i_j H(\overline{15})^{jk}_l (\mathbf{B}_c)_k \\
&+ h' H^{jk}_i (\overline{15}) (\mathbf{B}_n)^i_k (M)^l_l (\mathbf{B}_c)_j \,,
\end{aligned}$$

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

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

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

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

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

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

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

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

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

$$\chi^2 = \sum_i \left(\frac{\mathcal{B}^i_{th} - \mathcal{B}^i_{ex}}{\sigma^i_{ex}} \right)^2 + \sum_j \left(\frac{\mathcal{R}^j_{th} - \mathcal{R}^j_{ex}}{\sigma^j_{ex}} \right)^2 ,$$

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

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

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

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

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

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

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

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

Diagrammatic approach

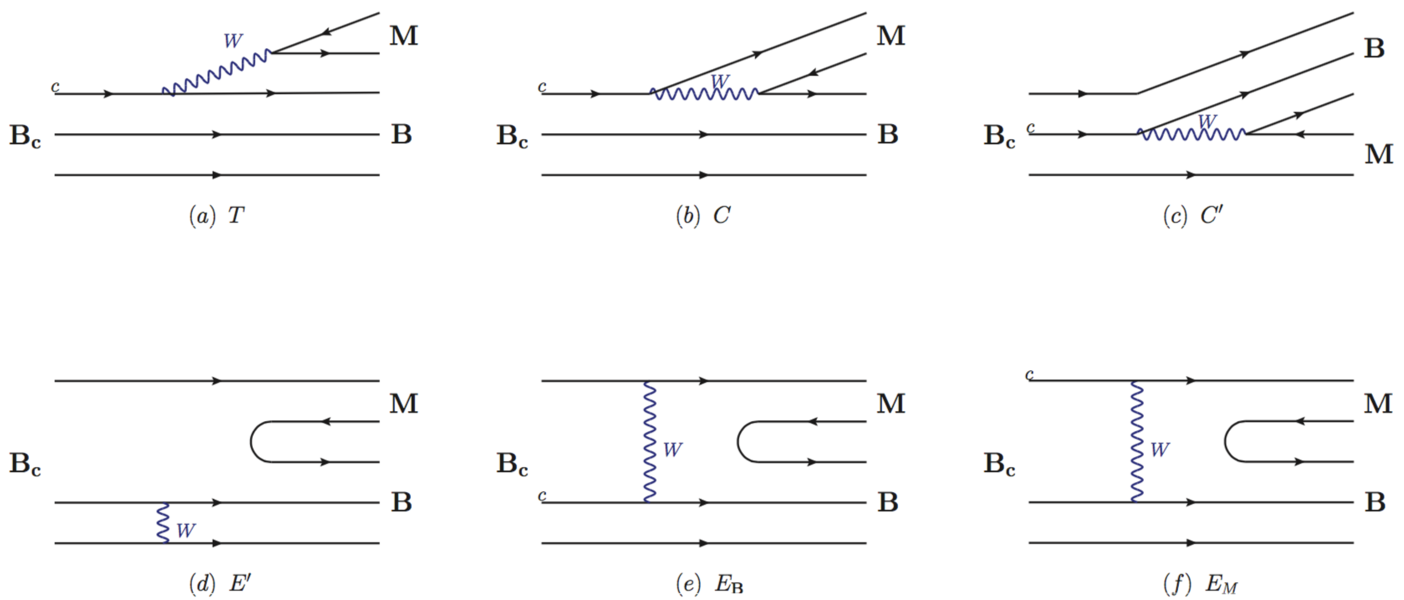
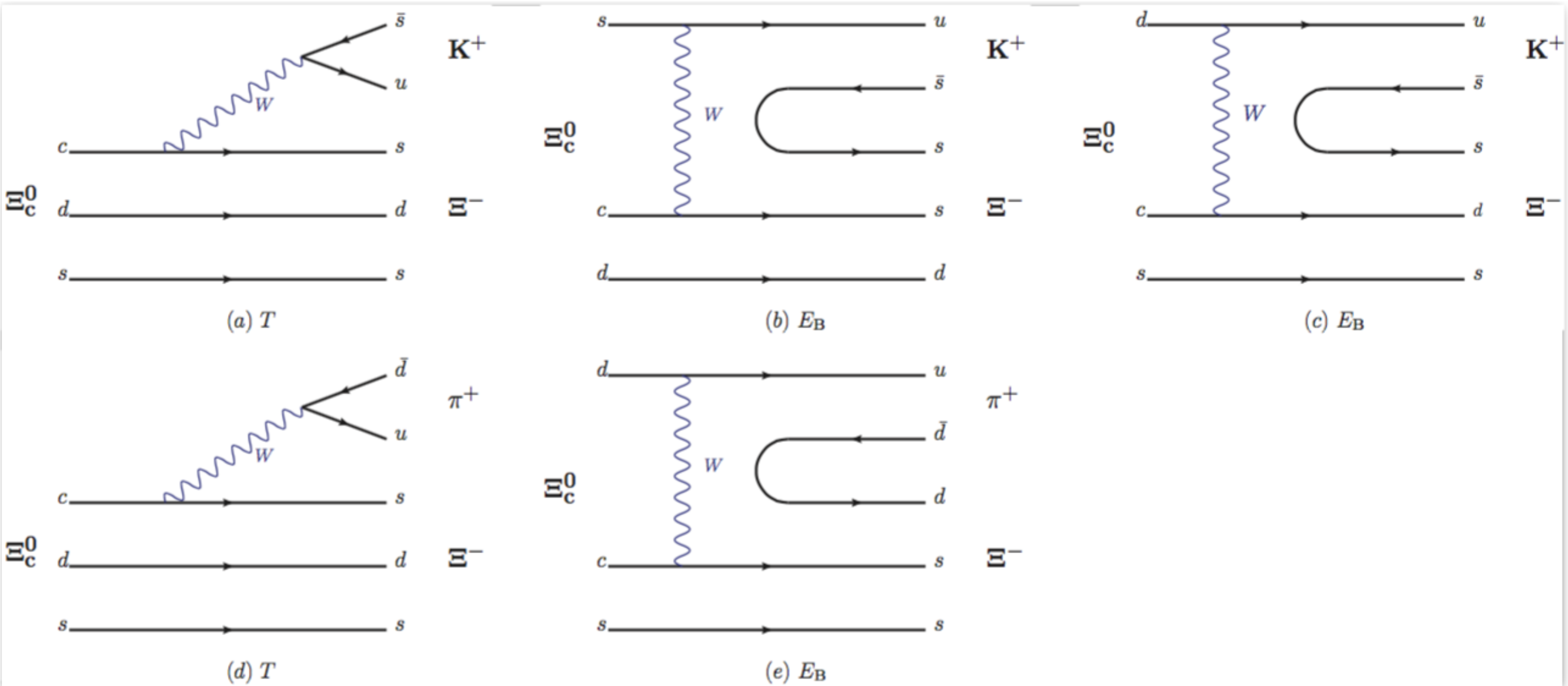


FIG. 1. Topological diagrams for the $\mathbf{B}_c \to \mathbf{B}M$ decays.

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

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

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



(a) T (b) $E_{\mathbf{B}}$ (c) $E_{\mathbf{B}}$

(d) T (e) $E_{\mathbf{B}}$

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

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

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

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

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

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

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

L between MM':

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

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

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

$$\begin{aligned}
T(\mathbf{B}_c \to \mathbf{B}_n V) &= T(\mathcal{O}_6) + T(\mathcal{O}_{\overline{15}})\,, \\
T(\mathcal{O}_6) &= \bar{a}_1 H^{ij}(6) T_{ik} (\mathbf{B}_n)^k_l (V)^l_j + \bar{a}_2 H^{ij}(6) T_{ik} (V)^k_l (\mathbf{B}_n)^l_j \\
&\quad + \bar{a}_3 H^{ij}(6) (\mathbf{B}_n)^k_i (V)^l_j T_{kl} + \bar{h} H^{ij}(6) T_{ik} (\mathbf{B}_n)^k_j (V)^l_l\,, \\
T(\mathcal{O}_{\overline{15}}) &= \bar{a}_4 H^i_{jk}(\overline{15}) (V)^j_l (\mathbf{B}_n)^k_i (\mathbf{B}_c)^l + \bar{a}_5 H(\overline{15})^i_{jk} (\mathbf{B}_c)^j (\mathbf{B}_n)^k_l (V)^l_i \\
&\quad + \bar{a}_6 H(\overline{15})^i_{jk} (\mathbf{B}_n)^j_l (V)^k_i (\mathbf{B}_c)^l + \bar{a}_7 H(\overline{15})^i_{jk} (\mathbf{B}_c)^j (V)^k_l (\mathbf{B}_n)^l_i \\
&\quad + \bar{h}' H^i_{jk}(\overline{15}) (\mathbf{B}_n)^k_i (V)^l_l (\mathbf{B}_c)^j\,,
\end{aligned}$$

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

Λ_c^+	CF T-amp
$\Sigma^0\rho^+$	$-\sqrt{2}(\bar{a}_1-\bar{a}_2-\bar{a}_3-\frac{\bar{a}_5-\bar{a}_7}{2})$
$\Sigma^+\rho^0$	$\sqrt{2}(\bar{a}_1-\bar{a}_2-\bar{a}_3-\frac{\bar{a}_5-\bar{a}_7}{2})$
$\Sigma^+\omega$	$\sqrt{2}(-\bar{a}_1-\bar{a}_2+\bar{a}_3-2\bar{h}$ $+\frac{\bar{a}_5+\bar{a}_7+2\bar{h}'}{2})$
$\Sigma^+\phi$	$\bar{a}_4-2\bar{h}+\bar{h}'$
Ξ^0K^{*+}	$-2(\bar{a}_2-\frac{\bar{a}_4+\bar{a}_7}{2})$
$p\bar{K}^{*0}$	$-2(\bar{a}_1-\frac{\bar{a}_5+\bar{a}_6}{2})$
$\Lambda^0\rho^+$	$-\sqrt{\frac{2}{3}}(\bar{a}_1+\bar{a}_2+\bar{a}_3$ $-\frac{\bar{a}_5-2\bar{a}_6+\bar{a}_7}{2})$
$\Sigma^+\eta$	$\sqrt{2}c\phi(-a_1-a_2+a_3-2h$ $+\frac{a_5+a_7+2h'}{2})$ $+s\phi(-a_4+2h-h')$
$\Sigma^+\eta'$	$\frac{\sqrt{2}s\phi}{2}(-a_1-a_2+a_3-2h$ $+\frac{a_5+a_7+2h'}{2})$ $-c\phi(-a_4+2h-h')$

Λ_c^+	SCS T-amp
Σ^+K^{*0}	$-2(\bar{a}_1-\bar{a}_3-\frac{\bar{a}_4-\bar{a}_5}{2})s_c$
Σ^0K^{*+}	$-\sqrt{2}(\bar{a}_1-\bar{a}_3-\frac{\bar{a}_4+\bar{a}_5}{2})s_c$
$p\rho^0$	$-\sqrt{2}(\bar{a}_2+\bar{a}_3-\frac{\bar{a}_6-\bar{a}_7}{2})s_c$
$p\omega$	$\sqrt{2}(\bar{a}_2-\bar{a}_3+2\bar{h}$ $+\frac{\bar{a}_6-\bar{a}_7-2\bar{h}'}{2})s_c$
$p\phi$	$-2(-\bar{a}_1-\bar{h}$ $+\frac{\bar{a}_4+\bar{a}_5+\bar{a}_6+\bar{h}'}{2})s_c$
$n\rho^+$	$-2(\bar{a}_2+\bar{a}_3-\frac{\bar{a}_4+\bar{a}_7}{2})s_c$
Λ^0K^{*+}	$-\sqrt{\frac{2}{3}}(\bar{a}_1-2\bar{a}_2+\bar{a}_3$ $-\frac{3\bar{a}_4-\bar{a}_5+2\bar{a}_6+2\bar{a}_7}{2})s_c$

Λ_c^+	DCS T-amp
pK^{*0}	$2(\bar{a}_3-\frac{\bar{a}_4+\bar{a}_6}{2})s_c^2$
nK^{*+}	$-2(\bar{a}_3+\frac{\bar{a}_4+\bar{a}_6}{2})s_c^2$

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

$$\chi^2=\sum_i\Big(\frac{\mathcal{B}^i_{th}-\mathcal{B}^i_{ex}}{\sigma^i_{ex}}\Big)^2+\sum_j\Big(\frac{\mathcal{R}^j_{th}-\mathcal{R}^j_{ex}}{\sigma^j_{ex}}\Big)^2,$$

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

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

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

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

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

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

Tested by data:

$$\mathcal{B}(\Lambda_c^+\to\Sigma^+\rho^0,\Lambda^0\rho^+)=(0.61\pm0.46,0.74\pm0.34)\%\,,$$

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

$$\mathcal{B}(\Lambda_c^+\to\Sigma^+\rho^0,\rho^0\to\pi^+\pi^-)=(6.1\pm4.6)\times10^{-3}\,,$$

$$\mathcal{B}(\Lambda_c^+\to\Sigma^0\rho^+,\rho^+\to\pi^+\pi^0)=(6.1\pm4.6)\times10^{-3}\,,$$

$$\mathcal{B}(\Lambda_c^+\to\Lambda^0\rho^+,\rho^+\to\pi^+\pi^0)=(7.4\pm3.4)\times10^{-3}\,,$$

total $\mathbf{B}_{ex}=(4.42\pm0.28,2.2\pm0.8,7.0\pm0.4)\times10^{-2}$

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

isospin symmetry

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

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

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

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

Overestimation?

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

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

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

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

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

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

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

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

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

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

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

Summary

- Within the framework of the $SU(3)_f$ symmetry,

one can study $\mathbf{B}_c \to \mathbf{B}_n M(M'), \mathbf{B}_n V$.

- $\mathbf{B}(\mathbf{B}_c \to \mathbf{B}_n V)$ are accessible to

the BESIII, BELLEII and LHCb measurements.

Thank You