Weak Decays of Charmed Baryons

Fu-Sheng Yu (于福升)

Lanzhou University

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Thank Prof. Zheng and Prof. Lyu for the invitation!

In collaboration with Cai-Ping Jia, Hua-Yu Jiang, Di Wang

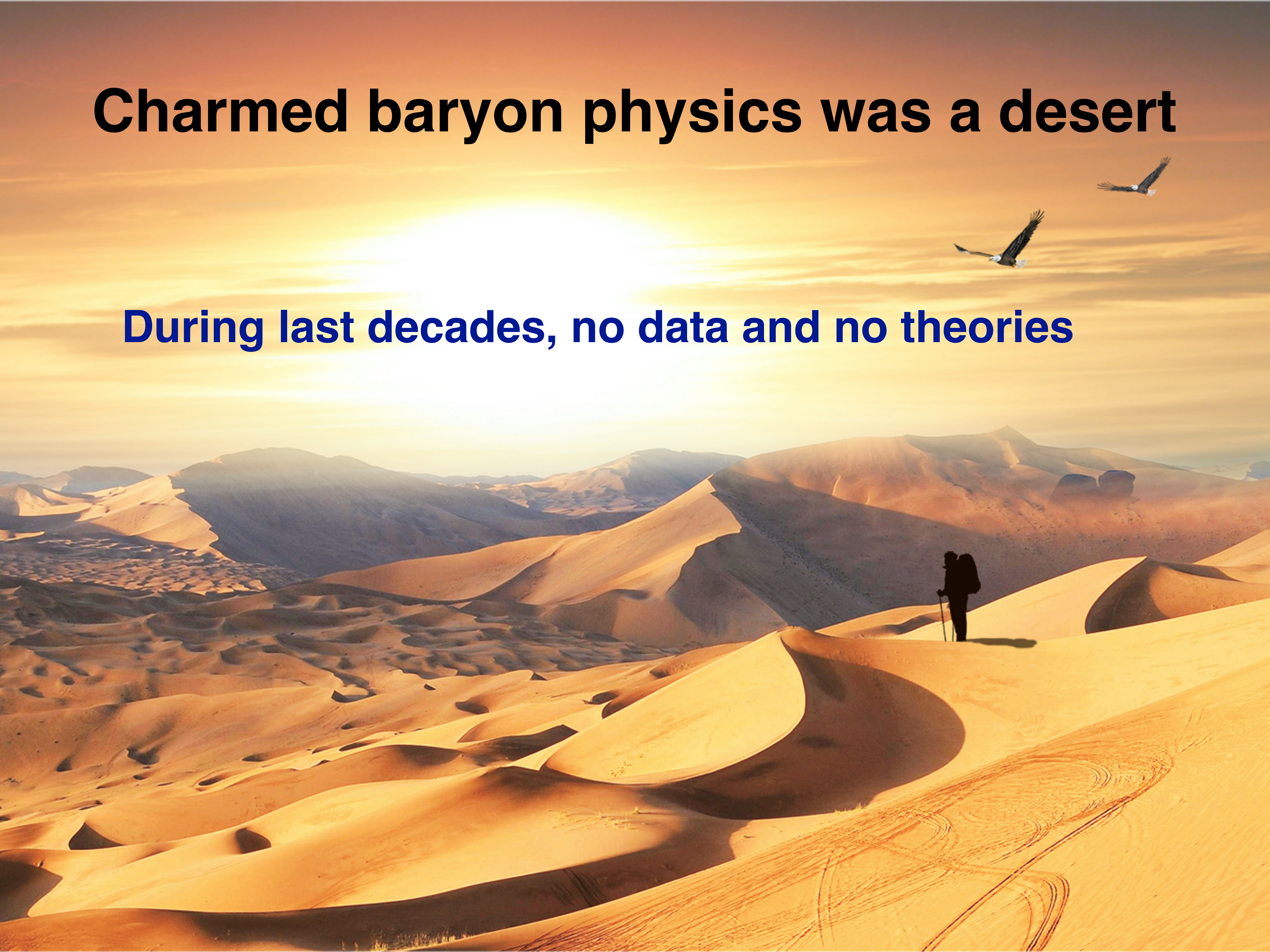
Outline

1. SU(3) analysis
2. Prediction on $\Xi_c^+ \to p K^- \pi^+$
3. Lambda_c^+ -> p KS/KL
4. Final-State Interacting effects.

More discussions than conclusions

Charmed baryon physics was a desert

During last decades, no data and no theories




Now we see some plants
by BESIII
More discoveries are expected

Difficulties in theory

- It is always difficult to understand the dynamics of charm decays, due to large non-perturbative contributions

- Heavy quark effective theory does not work for $1/m_c$

- Topological diagrammatic approach works well in D decays. ΔA_{CP} was predicted to be (-0.06 ~ -0.19)% in 2012 [Li, Lu, **FSY**,PRD86,036012], and confirmed by recent LHCb measurements.

- But it does not work in charmed baryon decays so far, due to less data to fix parameters.

$$B(\Lambda_c^+ \to p\eta) = (1.24 \pm 0.28 \pm 0.10) \times 10^{-3}$$

$$B(\Lambda_c^+ \to p\pi^0) < 2.7 \times 10^{-4}$$

1. SU(3) analysis

[C.D. Lu, W. Wang, FSY, PRD16’][C.P. Jia, FSY, in progress]

SU(3) symmetry

- **Powerful in prediction**
- **To be tested**

$$\mathcal{B}(\Lambda_c \to n e^+ \nu_e) = \frac{3}{2}\frac{|V_{cd}|^2}{|V_{cs}|^2}\mathcal{B}(\Lambda_c \to \Lambda e^+ \nu_e)$$

$$\mathcal{B}(\Lambda_c \to \Lambda e^+ \nu_e)_{\mathrm{BESIII}} = (3.65 \pm 0.38 \pm 0.20)\%$$

$$\mathcal{B}(\Lambda_c \to n e^+ \nu_e)_{\mathrm{SU(3)}} = (2.93 \pm 0.34) \times 10^{-3}$$

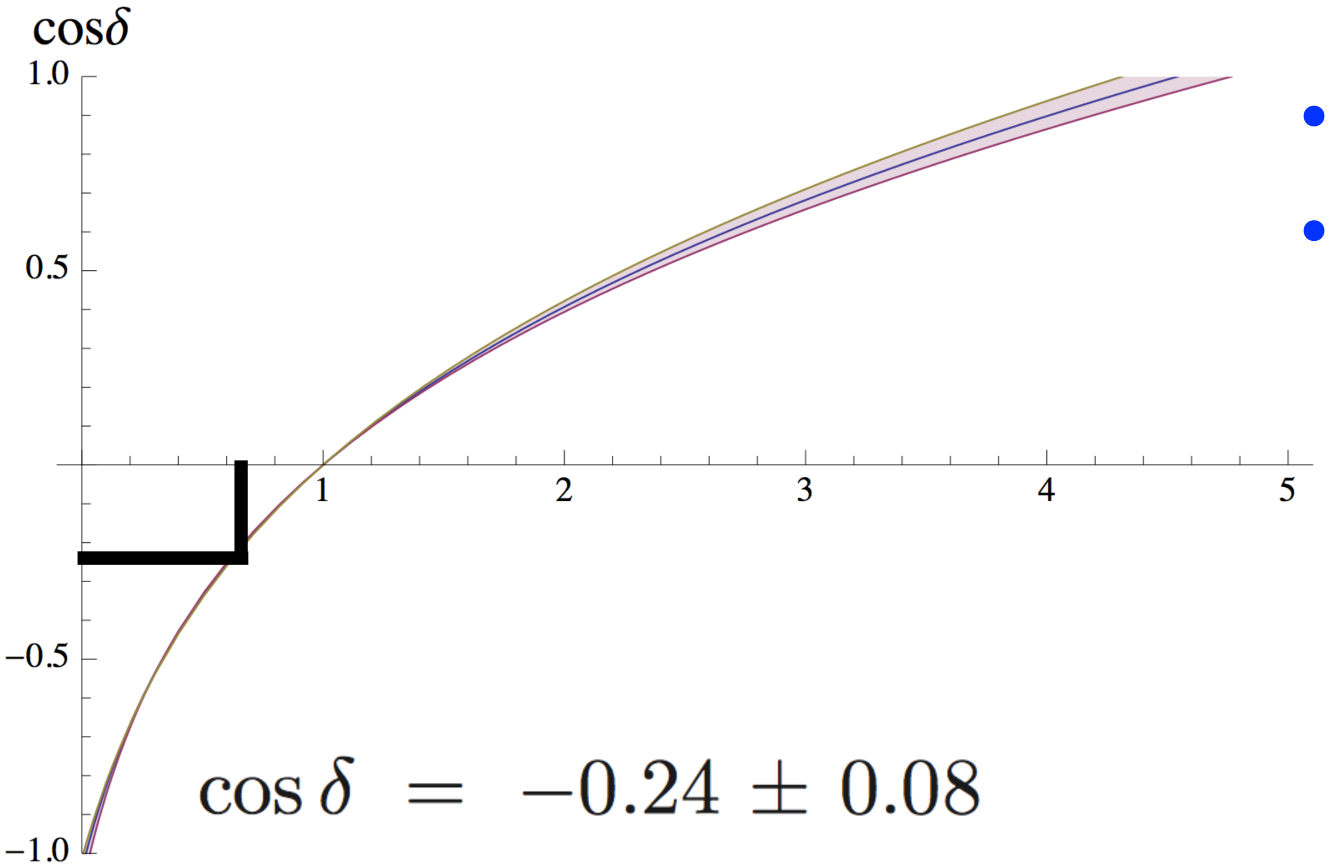
[C.D. Lu, W. Wang, FSY, PRD16']

SU(3) symmetry

- **Powerful in prediction**
- **To be tested**

[C.D. Lu, W. Wang, FSY, PRD16']

$$\sqrt{2}\mathcal{A}(\Lambda_c \to p\overline{K}^0\pi^0) + \mathcal{A}(\Lambda_c \to pK^-\pi^+) + \mathcal{A}(\Lambda_c \to n\overline{K}^0\pi^+) = 0$$



$$\cos\delta \;=\; -0.24 \pm 0.08$$

- Test isospin symmetry
- study final-state interaction

$$R_n = \frac{\mathcal{B}(\Lambda_c \to n\bar{K}^0\pi^+)}{\mathcal{B}(\Lambda_c \to pK^-\pi^+)} = 0.62 \pm 0.09$$

[BESIII, PRL118,112001(2017)]

Systematic SU(3) Analysis

$$(c\bar{s})(d\bar{u}) = \mathcal{O}_6 + \mathcal{O}_{\overline{15}}$$

$$\mathcal{O}_6 = \frac{1}{2}[(c\bar{s})(d\bar{u}) - (c\bar{u})(d\bar{s})]$$
$$\mathcal{O}_{\overline{15}} = \frac{1}{2}[(c\bar{s})(d\bar{u}) + (c\bar{u})(d\bar{s})]$$

$$\begin{aligned} H_{eff} =& aH^a_{bc}(\overline{15})T^b\overline{B}^c_d M^d_a + bH^a_{bc}(\overline{15})T^b M^c_d \overline{B}^d_a + cH^a_{bc}(\overline{15})\overline{B}^b_d M^c_a T^d \\ &+ dH^a_{bc}(\overline{15})M^b_d\overline{B}^c_a T^d + eH^{ab}(6)T_{ac}\overline{B}^c_d M^d_b + fH^{ab}(6)T_{ac}M^c_d\overline{B}^d_b \\ &+ gH^{ab}(6)\overline{B}^c_a M^d_b T_{cd} \end{aligned}$$

$$T^a = (\Xi^0_{c1}, -\Xi^+_{c1}, \Lambda^+_c)$$

$$B^a_b = \begin{pmatrix} \frac{1}{\sqrt{6}}\Lambda^0 + \frac{1}{\sqrt{2}}\Sigma^0 & \Sigma^+ & p \\ \Sigma^- & \frac{1}{\sqrt{6}}\Lambda^0 - \frac{1}{\sqrt{2}}\Sigma^0 & n \\ \Xi^- & \Xi^0 & -\sqrt{2/3}\Lambda^0 \end{pmatrix} \qquad M^a_b = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\sqrt{2/3}\eta \end{pmatrix}$$

Cabibbo-favored processes

Process	Squared matrix element	Process	Squared matrix element
$\Lambda_c^+ \to \Lambda^0\pi^+$	$\frac{1}{6}\|a+b-2c-2e-2f-2g\|^2$	$\Lambda_c^+ \to \Sigma^0\pi^+$	$\frac{1}{2}\|a-b-2e+2f+2g\|^2$
$\Lambda_c^+ \to \Sigma^+\pi^0$	$\frac{1}{2}\|-a+b+2e-2f-2g\|^2$	$\Lambda_c^+ \to \Sigma^+\eta^0$	$\frac{1}{6}\|a+b-2d-2e-2f+2g\|^2$
$\Lambda_c^+ \to P\overline{K}^0$	$\|a+c-2e\|^2$	$\Lambda_c^+ \to \Xi^0 K^+$	$\|b+d-2f\|^2$
$\Xi_c^0 \to \Xi^-\pi^+$	$\|a+c+2e\|^2$	$\Xi_c^0 \to \Xi^0\pi^0$	$\frac{1}{2}\|-a+d-2e+2g\|^2$
$\Xi_c^0 \to \Xi^0\eta^0$	$\frac{1}{6}\|a-2b+d+2e-4f-2g\|^2$	$\Xi_c^0 \to \Lambda^0\overline{K}^0$	$\frac{1}{6}\|-2a+b+c-4e+2f+2g\|^2$
$\Xi_c^0 \to \Sigma^+K^-$	$\|b+d+2f\|^2$	$\Xi_c^0 \to \Sigma^0\overline{K}^0$	$\frac{1}{2}\|-b+c-2f-2g\|^2$
$\Xi_c^+ \to \Xi^0\pi^+$	$\|-c-d-2g\|^2$	$\Xi_c^+ \to \Sigma^+\overline{K}^0$	$\frac{1}{2}\|-c-d+2g\|^2$
$\Lambda_c^+ \to \Sigma^{*+}\pi^0$	$\frac{1}{6}\|-2\alpha+\beta-2\gamma-\delta\|^2$	$\Lambda_c^+ \to \Sigma^{*+}\eta^0$	$\frac{1}{18}\|2\alpha-\beta-2\gamma-3\delta\|^2$
$\Lambda_c^+ \to \Sigma^{*0}\pi^+$	$\frac{1}{6}\|-2\alpha+\beta-2\gamma-\delta\|^2$	$\Lambda_c^+ \to \Delta^{++}K^-$	$\|\beta+\delta\|^2$
$\Lambda_c^+ \to \Delta^+\overline{K}^0$	$\frac{1}{3}\|\beta+\delta\|^2$	$\Lambda_c^+ \to \Xi^{*0}K^+$	$\frac{1}{3}\|\beta-2\gamma-\delta\|^2$
$\Xi_c^+ \to \Sigma^{*+}\overline{K}^0$	$\frac{4}{3}\|\alpha\|^2$	$\Xi_c^+ \to \Xi^{*0}\pi^+$	$\frac{4}{3}\|\alpha\|^2$
$\Xi_c^0 \to \Sigma^{*0}\overline{K}^0$	$\frac{1}{6}\|2\alpha-\beta+2\gamma-\delta\|^2$	$\Xi_c^0 \to \Xi^{*0}\pi^0$	$\frac{1}{6}\|2\alpha-\beta+\delta\|^2$
$\Xi_c^0 \to \Xi^{*0}\eta^0$	$\frac{1}{18}\|-2\alpha+\beta-4\gamma+3\delta\|^2$	$\Xi_c^0 \to \Sigma^{*+}K^-$	$\frac{1}{3}\|-\beta+2\gamma-\delta\|^2$
$\Xi_c^0 \to \Xi^{*-}\pi^+$	$\frac{1}{3}\|-\beta+\delta\|^2$	$\Xi_c^0 \to \Omega^-K^+$	$\|-\beta+\delta\|^2$

Singly Cabibbo-suppressed processes

Process	Squared matrix element($mods_1^2$)	Process	Squared matrix element($mods_1^2$)
$\Lambda_c^+ \to \Lambda^0 K^+$	$\frac{1}{6}\left\|-a+2b+2c+3d+2e-4f+2g\right\|^2$	$\Lambda_c^+ \to \Sigma^0 K^+$	$\frac{1}{2}\left\|-a-d+2e-2g\right\|^2$
$\Lambda_c^+ \to \Sigma^+ K^0$	$\left\|-a+d+2e-2g\right\|^2$	$\Lambda_c^+ \to p\eta^0$	$\frac{1}{6}\left\|2a-b+3c+2d-4e+2f-2g\right\|^2$
$\Lambda_c^+ \to p\pi^0$	$\frac{1}{2}\left\|-b-c+2f+2g\right\|^2$	$\Lambda_c^+ \to n\pi^+$	$\left\|-b+c+2f+2g\right\|^2$
$\Xi_c^0 \to \Sigma^- \pi^+$	$\left\|a+c+2e\right\|^2$	$\Xi_c^0 \to \Lambda^0 \pi^0$	$\frac{1}{12}\left\|-a-b-c+3d-2e-2f+4g\right\|^2$
$\Xi_c^0 \to \Sigma^0 \pi^0$	$\frac{1}{4}\left\|a+b-c-d+2e+2f\right\|^2$	$\Xi_c^0 \to \Lambda^0 \eta^0$	$\frac{1}{4}\left\|-a-b+c+d-2e-2f\right\|^2$
$\Xi_c^0 \to \Sigma^0 \eta^0$	$\frac{1}{12}\left\|-a-b+3c-d-2e-2f-4g\right\|^2$	$\Xi_c^0 \to n\overline{K}^0$	$\left\|a-b+2e-2f-2g\right\|^2$
$\Xi_c^0 \to \Xi^- K^+$	$\left\|-a-c-2e\right\|^2$	$\Xi_c^0 \to \Xi^0 K^0$	$\left\|-a+b-2e+2f+2g\right\|^2$
$\Xi_c^0 \to \Sigma^+ \pi^-$	$\left\|b+d+2f\right\|^2$	$\Xi_c^0 \to pK^-$	$\left\|-b-d-2f\right\|^2$
$\Xi_c^+ \to \Lambda^0 \pi^+$	$\frac{1}{6}\left\|-a-b-c-3d+2e+2f-4g\right\|^2$	$\Xi_c^+ \to \Sigma^0 \pi^+$	$\frac{1}{2}\left\|-a+b+c+d+2e-2f\right\|^2$
$\Xi_c^+ \to \Sigma^+ \pi^0$	$\frac{1}{2}\left\|a-b+c+d-2e+2f\right\|^2$	$\Xi_c^+ \to \Sigma^+ \eta^0$	$\frac{1}{6}\left\|-a-b-3c-d+2e+2f+4g\right\|^2$
$\Xi_c^+ \to p\overline{K}^0$	$\left\|-a+d+2e-2g\right\|^2$	$\Xi_c^+ \to \Xi^0 K^+$	$\left\|-b+c+2f+2g\right\|^2$
$\Lambda_c^+ \to \Delta^+ \pi^0$	$\frac{2}{3}\left\|-\alpha-\gamma-\delta\right\|^2$	$\Lambda_c^+ \to \Delta^+ \eta^0$	$\frac{2}{9}\left\|\alpha+\beta-\gamma\right\|^2$
$\Lambda_c^+ \to \Delta^0 \pi^+$	$\frac{1}{3}\left\|-2\alpha+\beta-2\gamma-\delta\right\|^2$	$\Lambda_c^+ \to \Sigma^{*+} K^0$	$\frac{1}{3}\left\|-2\alpha+\beta+\delta\right\|^2$
$\Lambda_c^+ \to \Sigma^{*0} K^+$	$\frac{1}{6}\left\|2\alpha+\beta-2\gamma-\delta\right\|^2$	$\Lambda_c^+ \to \Delta^{++} \pi^-$	$\left\|\beta+\delta\right\|^2$
$\Xi_c^+ \to \Delta^+ \overline{K}^0$	$\frac{1}{3}\left\|2\alpha-\beta-\delta\right\|^2$	$\Xi_c^+ \to \Sigma^{*0} \pi^+$	$\frac{1}{6}\left\|-2\alpha-\beta+2\gamma+\delta\right\|^2$
$\Xi_c^+ \to \Sigma^{*+} \eta^0$	$\frac{1}{18}\left\|4\alpha+\beta+2\gamma+3\delta\right\|^2$	$\Xi_c^+ \to \Xi^{*0} K^+$	$\frac{1}{3}\left\|2\alpha-\beta+2\gamma+\delta\right\|^2$
$\Xi_c^+ \to \Delta^{++} K^-$	$\left\|-\beta-\delta\right\|^2$	$\Xi_c^+ \to \Sigma^{*+} \pi^0$	$\frac{1}{6}\left\|-\beta+2\gamma+\delta\right\|^2$
$\Xi_c^0 \to \Delta^0 \overline{K}^0$	$\frac{1}{3}\left\|2\alpha-\beta+2\gamma-\delta\right\|^2$	$\Xi_c^0 \to \Sigma^{*0} \pi^0$	$\frac{1}{12}\left\|2\alpha-\beta-2\gamma+3\delta\right\|^2$
$\Xi_c^0 \to \Sigma^{*0} \eta^0$	$\frac{1}{36}\left\|2\alpha-\beta-2\gamma+3\delta\right\|^2$	$\Xi_c^0 \to \Xi^{*0} K^0$	$\frac{1}{3}\left\|2\alpha-\beta+2\gamma-\delta\right\|^2$
$\Xi_c^0 \to \Sigma^{*+} \pi^-$	$\frac{1}{3}\left\|-\beta+2\gamma-\delta\right\|^2$	$\Xi_c^0 \to \Sigma^{*-} \pi^+$	$\frac{4}{3}\left\|-\beta+\delta\right\|^2$
$\Xi_c^0 \to \Xi^{*-} K^+$	$\frac{4}{3}\left\|-\beta+\delta\right\|^2$	$\Xi_c^0 \to \Delta^+ K^-$	$\frac{1}{3}\left\|-\beta+2\gamma-\delta\right\|^2$

Doubly Cabibbo-suppressed processes

Process	Squared matrix element(mod s_1^4)	Process	Squared matrix element(mod s_1^4)
$\Lambda_c^+ \to pK^0$	$\lvert c+d-2g\rvert^2$	$\Lambda_c^+ \to nK^+$	$\lvert c+d+2g\rvert^2$
$\Xi_c^0 \to \Sigma^- K^+$	$\lvert a+c+2e\rvert^2$	$\Xi_c^0 \to \Lambda^0 K^0$	$\frac{1}{6}\lvert a-2b+c+2e+4f-4g\rvert^2$
$\Xi_c^0 \to \Sigma^0 K^0$	$\frac{1}{2}\lvert -a+c-2e\rvert^2$	$\Xi_c^0 \to n\eta^0$	$\frac{1}{6}\lvert -2a+b+d-4e+2f+4g\rvert^2$
$\Xi_c^+ \to \Lambda^0 K^+$	$\frac{1}{6}\lvert -a+2b-c+2e-4f-4g\rvert^2$	$\Xi_c^+ \to \Sigma^0 K^+$	$\frac{1}{2}\lvert -a+c+2e\rvert^2$
$\Xi_c^+ \to \Sigma^+ K^0$	$\lvert -a-c+2e\rvert^2$	$\Xi_c^+ \to p\eta^0$	$\frac{1}{6}\lvert 2a-b-d-4e+2f+4g\rvert^2$
$\Xi_c^+ \to p\pi^0$	$\frac{1}{2}\lvert -b+d+2f\rvert^2$	$\Xi_c^+ \to n\pi^+$	$\lvert -b-d+2f\rvert^2$
$\Lambda_c^+ \to \Delta^+ K^0$	$\frac{4}{3}\lvert\alpha\rvert^2$	$\Lambda_c^+ \to \Delta^0 K^+$	$\frac{4}{3}\lvert\alpha\rvert^2$
$\Xi_c^+ \to \Delta^+ \eta^0$	$\frac{2}{9}\lvert -2\alpha+\beta-\gamma\rvert^2$	$\Xi_c^+ \to \Sigma^{*0} K^+$	$\frac{1}{6}\lvert -2\alpha+\beta-2\gamma-\delta\rvert^2$
$\Xi_c^+ \to \Delta^{++}\pi^-$	$\lvert\beta+\delta\rvert^2$	$\Xi_c^+ \to \Sigma^{*+} K^0$	$\frac{1}{3}\lvert\beta+\delta\rvert^2$
$\Xi_c^+ \to \Delta^0\pi^+$	$\frac{1}{3}\lvert\beta-2\gamma-\delta\rvert^2$	$\Xi_c^+ \to \Delta^+\pi^0$	$\frac{2}{3}\lvert\gamma+\delta\rvert^2$
$\Xi_c^0 \to \Delta^0\eta^0$	$\frac{2}{9}\lvert -2\alpha+\beta-\gamma\rvert^2$	$\Xi_c^0 \to \Sigma^{*0} K^0$	$\frac{1}{6}\lvert -2\alpha+\beta-2\gamma+\delta\rvert^2$
$\Xi_c^0 \to \Delta^+\pi^-$	$\frac{1}{3}\lvert\beta-2\gamma+\delta\rvert^2$	$\Xi_c^0 \to \Delta^-\pi^+$	$\lvert\beta-\delta\rvert^2$
$\Xi_c^0 \to \Sigma^{*-} K^+$	$\frac{1}{3}\lvert\beta-\delta\rvert^2$	$\Xi_c^0 \to \Delta^0\pi^0$	$\frac{2}{3}\lvert\gamma-\delta\rvert^2$

Isospin Relations

$$\mathcal{A}(\Lambda_c^+ \to \Sigma^+\pi^0) + \mathcal{A}(\Lambda_c^+ \to \Sigma^0\pi^+) = 0$$

$$\mathcal{A}(\Lambda_c^+ \to \Delta^{++}K^-) - \sqrt{3}\mathcal{A}(\Lambda_c^+ \to \Delta^+\overline{K}^0) = 0$$

$$\mathcal{A}(\Lambda_c^+ \to \Delta^+K^0) - \mathcal{A}(\Lambda_c^+ \to \Delta^0K^+) = 0$$

$$\mathcal{A}(\Lambda_c^+ \to \Sigma^{*+}\pi^0) - \mathcal{A}(\Lambda_c^+ \to \Sigma^{*0}\pi^+) = 0$$

$$\mathcal{A}(\Xi_c^+ \to \Delta^+\eta^0) - \mathcal{A}(\Xi_c^0 \to \Delta^0\eta^0) = 0$$

U-spin Relations

$$\frac{1}{\sin^2\theta}\mathcal{A}(\Lambda_c^+ \to nK^+) + \mathcal{A}(\Xi_c^+ \to \Xi^0\pi^+) = 0$$

$$\mathcal{A}(\Lambda_c^+ \to \Xi^0 K^+) + \frac{1}{\sin^2\theta}\mathcal{A}(\Xi_c^+ \to n\pi^+) = 0$$

$$\mathcal{A}(\Lambda_c^+ \to n\pi^+) - \mathcal{A}(\Xi_c^+ \to \Xi^0 K^+) = 0$$

$$\mathcal{A}(\Lambda_c^+ \to p\overline{K}^0) + \frac{1}{\sin^2\theta}\mathcal{A}(\Xi_c^+ \to \Sigma^+ K^0) = 0$$

$$\frac{1}{\sin^2\theta}\mathcal{A}(\Lambda_c^+ \to pK^0) + \mathcal{A}(\Xi_c^+ \to \Sigma^+\overline{K}^0) = 0$$

$$\mathcal{A}(\Lambda_c^+ \to \Sigma^+ K^0) - \mathcal{A}(\Xi_c^+ \to p\overline{K}^0) = 0$$

$$\mathcal{A}(\Lambda_c^+ \to \Delta^{++}K^-) - \frac{1}{\sin\theta}\mathcal{A}(\Lambda_c^+ \to \Delta^{++}\pi^-) = 0$$

$$\mathcal{A}(\Lambda_c^+ \to \Delta^+\overline{K}^0) - \frac{1}{\sin^2\theta}(\Xi_c^+ \to \Sigma^{*+}K^0) = 0$$

V-spin Relations

$$\mathcal{A}(\Xi_c^+ \to \Sigma^{*+}\overline{K}^0) - \mathcal{A}(\Xi_c^+ \to \Xi^{*0}\pi^+) = 0$$

$$\mathcal{A}(\Xi_c^+ \to \Delta^{++}\pi^-) - \sqrt{3}\mathcal{A}(\Xi_c^+ \to \Sigma^{*+}K^0) = 0$$

$$2\sqrt{6}\mathcal{A}(\Lambda_c^+ \to \Sigma^{*+}\pi^0) + \mathcal{A}(\Lambda_c^+ \to \Delta^{++}K^-) - \sqrt{3}\mathcal{A}(\Lambda_c^+ \to \Xi^{*0}K^+)$$
$$+ 2\sqrt{6}\mathcal{A}(\Xi_c^0 \to \Xi^{*0}\pi^0) + \sqrt{3}\mathcal{A}(\Xi_c^0 \to \Sigma^{*+}K^-) - \mathcal{A}(\Xi_c^0 \to \Omega^- K^+) = 0$$

$$\sqrt{2}(\Lambda_c^+ \to \Sigma^{*0}\pi^+) + \mathcal{A}(\Lambda_c^+ \to \Delta^+\overline{K}^0) + \sqrt{2}\mathcal{A}(\Xi_c^0 \to \Sigma^{*0}\overline{K}^0) + \mathcal{A}(\Xi_c^0 \to \Xi^{*-}\pi^+) = 0$$

$$\sqrt{3}\mathcal{A}(\Lambda_c^+ \to \Sigma^{*+}K^0) - \mathcal{A}(\Lambda_c^+ \to \Delta^{++}\pi^-) + \sqrt{3}\mathcal{A}(\Xi_c^0 \to \Xi^{*0}K^0)$$
$$- \sqrt{3}\mathcal{A}(\Xi_c^0 \to \Sigma^{*+}\pi^-) = 0$$

$$\mathcal{A}(\Lambda_c^+ \to \Delta^+ K^0) + \sqrt{2}\mathcal{A}(\Xi_c^0 \to \Sigma^{*0}K^0) - \mathcal{A}(\Xi_c^0 \to \Delta^+\pi^-) = 0$$

Test Isospin symmetry

$$\mathcal{A}(\Lambda_c^+ \to \Sigma^+\pi^0) + \mathcal{A}(\Lambda_c^+ \to \Sigma^0\pi^+) = 0$$

$\Sigma^0\pi^+$	$1.27 \pm 0.08 \pm 0.03$
$\Sigma^+\pi^0$	$1.18 \pm 0.10 \pm 0.03$

[BESIII, PRL116,052001(2016)]

Predictions

☞ $$\mathcal{A}(\Lambda_c^+ \to \Xi^0 K^+) + \frac{1}{\sin^2\theta}\mathcal{A}(\Xi_c^+ \to n\pi^+) = 0$$

$$\mathcal{B}(\Xi_c^+ \to n\pi^+) = (3.909 \pm 0.028) \times 10^{-5}$$

☞ $$\mathcal{A}(\Lambda_c^+ \to p\overline{K}^0) + \frac{1}{\sin^2\theta}\mathcal{A}(\Xi_c^+ \to \Sigma^+ K^0) = 0$$

$$\mathcal{B}(\Xi_c^+ \to \Sigma^+ K^0) = (2.471 \pm 0.006) \times 10^{-4}$$

☞ $$\mathcal{A}(\Lambda_c^+ \to \Delta^{++} K^-) - \sqrt{3}\mathcal{A}(\Lambda_c^+ \to \Delta^+ \overline{K}^0) = 0$$

$$\mathcal{B}(\Lambda_c^+ \to \Delta^+ \overline{K}^0) = (1.208 \pm 0.277) \times 10^{-3}$$

☞ $$\mathcal{A}(\Lambda_c^+ \to \Delta^{++} K^-) - \frac{1}{\sin\theta}\mathcal{A}(\Lambda_c^+ \to \Delta^{++}\pi^-) = 0$$

$$\boxed{\mathcal{B}(\Lambda_c^+ \to \Delta^{++}\pi^-) = (6.215 \pm 1.425) \times 10^{-4}}$$

$\Lambda_c^+ \to p\pi^+\pi^-$	$(3.91 \pm 0.28 \pm 0.15 \pm 0.24) \times 10^{-3}$

[BESIII, PRL117,232002(2016)]

Predictions

☞ $$\mathcal{A}(\Lambda_c^+ \to \Delta^+ \overline{K}^0) - \frac{1}{\sin^2\theta}(\Xi_c^+ \to \Sigma^{*+} K^0) = 0$$

$$\mathcal{B}(\Xi_c^+ \to \Sigma^{*+} K^0) = (6.085 \pm 0.007) \times 10^{-6}$$

☞ $$\mathcal{A}(\Lambda_c^+ \to \Delta^{++} K^-) = -\frac{1}{\sin\theta}\mathcal{A}(\Xi_c^+ \to \Delta^{++} K^-)$$

$$\mathcal{B}(\Xi_c^+ \to \Delta^{++} K^-) = (1.235 \pm 0.057) \times 10^{-3}$$

☞ $$\mathcal{A}(\Lambda_c^+ \to \Delta^{++} K^-) = \frac{1}{\sin^2\theta}\mathcal{A}(\Xi_c^+ \to \Delta^{++} \pi^-)$$

$$\mathcal{B}(\Xi_c^+ \to \Delta^{++} \pi^-) = (6.813 \pm 0.057) \times 10^{-5}$$

☞ $$\mathcal{A}(\Lambda_c^+ \to p\overline{K}^0) + \frac{\sqrt{2}}{\sin\theta}\mathcal{A}(\Lambda_c^+ \to p\pi^0) + \sqrt{2}\mathcal{A}(\Lambda_c^+ \to \Sigma^+\pi^0) = 0$$

$$\boxed{(7.146 \pm 1.492) \times 10^{-5} < \mathcal{B}(\Lambda_c^+ \to p\pi^0)} < (4.530 \pm 0.180) \times 10^{-3}$$

$$\mathcal{B}(\Lambda_c^+ \to p\pi^0) < 2.7 \times 10^{-4}$$ [BESIII, 1702.05279]

SU(3) analysis

- More data -> More predictions
- Tested by experimental data
- Check theoretical calculations

2. Prediction on $\Xi_c^+ \to p K^- \pi^+$

$\Xi_c^+ \to pK^-\pi^+$

- **This process is always used to search for new particles and their properties**
  - ✦ New Ω_c states observed by LHCb [PRL118,182001(2017)
    - in $\Xi_c^+ K^-$ with $\Xi_c^+ \to pK^-\pi^+$
  - ✦ $\Xi_b{}'$ and Ξ_b^* states observed by LHCb [PRL114,062004(2014)]
    - in $\Xi_b^0\pi^-$ with $\Xi_b^0 \to \Xi_c^+\pi^-$, $\Xi_c^+ \to pK^-\pi^+$
  - ✦ Mass and lifetime of Ξ_b^0 by LHCb [PRL113,032001(2014)]
    - via $\Xi_b^0 \to \Xi_c^+\pi^-$, $\Xi_c^+ \to pK^-\pi^+$
  - ◉ Suggested to measure $\Xi_{cc}^{++} \to \Xi_c^+\pi^+$ [1703.09086]
- **But its branching ratio not directly measured**

Ξ_c^+

- has the longest lifetime of charmed baryons

$$\tau(\Lambda_c^+) = (200 \pm 6) \times 10^{-15} s, \qquad \tau(\Xi_c^+) = (442 \pm 26) \times 10^{-15} s,$$
$$\tau(\Xi_c^0) = (112^{+13}_{-10}) \times 10^{-15} s, \qquad \tau(\Omega_c^0) = (69 \pm 12) \times 10^{-15} s.$$

⋆ better for measurements

- Mass: m=2467.87+-0.30MeV

mLc=2286.46+-0.14MeV

Branching Ratios of $\Xi_c^+ \rightarrow pK^-\pi^+$

- Absolute value not measured
- But compared to $\Xi_c^+ \rightarrow \Xi^-\pi^+\pi^+$

PDG

$\Gamma(\Xi_c^+ \rightarrow pK^-\pi^+)/\Gamma(\Xi_c^+ \rightarrow \Xi^- 2\pi^+)$

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.21 ± 0.04	**OUR AVERAGE**				
0.194 ±0.054	47 ±11	VAZQUEZ-JAURE..	2008	SELX	Σ^- nucleus, 600 GeV
0.234 ±0.047 ±0.022	202	LINK	2001B	FOCS	γ nucleus

We should know the branching fraction for estimation on events

Branching Ratios of $\Xi_c^+ \to pK^-\pi^+$

Under U-spin symmetry

$$\mathcal{A}(\Xi_c^+ \to p\overline{K}^{*0}) = -\mathcal{A}(\Lambda_c^+ \to \Sigma^+ K^{*0})$$

$\Sigma^+ K^+ \pi^-$	$(2.1 \pm 0.6) \times 10^{-3}$
$\Sigma^+ K^*(892)^0$	$(3.6 \pm 1.0) \times 10^{-3}$

$\Gamma(\ \Xi_c^+ \to p\overline{K}^*(892)^0\ )/\Gamma(\ \Xi_c^+ \to pK^-\pi^+\ )$

PDG

VALUE	DOCUMENT ID		TECN
0.54 ±0.09 ±0.05	LINK	2001B	FOCS

$$\boxed{Br(\Xi_c^+ \to pK^-\pi^+) = (2.2 \pm 0.8)\%}$$

[1703.09086]

Branching Ratios of $\Xi_c^+ \to p K^- \pi^+$

Precision improvements are required

LHCb

$$\mathcal{A}(\Xi_c^+ \to p\overline{K}^{*0}) = -\mathcal{A}(\Lambda_c^+ \to \Sigma^+ K^{*0})$$

BESIII

$\Sigma^+ K^+ \pi^-$	$(2.1 \pm 0.6) \times 10^{-3}$
$\Sigma^+ K^*(892)^0$	$(3.6 \pm 1.0) \times 10^{-3}$

$\Gamma(\, \Xi_c^+ \to p\overline{K}^*(892)^0 \,)/\Gamma(\, \Xi_c^+ \to pK^-\pi^+ \,)$

PDG

VALUE	DOCUMENT ID		TECN
0.54 ±0.09 ±0.05	LINK	2001B	FOCS

$$\boxed{Br(\Xi_c^+ \to pK^-\pi^+) = (2.2 \pm 0.8)\%}$$

[1703.09086]

$\Xi_c^0 \to pK^- K^- \pi^+$

- **This process is always used to search for new particles and their properties**
  - ✦ Mass and lifetime of Ξ_b^- by LHCb [PRL113,242002(2014)]
    - in $\Xi_b^- \to \Xi_c^0 \pi^-$, $\Xi_c^0 \to pK^- K^- \pi^+$
  - ✦ Mass and lifetime of Ω_b^- by LHCb [PRD93,092007(2016)]
    - using calibration of $\Xi_b^- \to \Xi_c^0 \pi^-$, $\Xi_c^0 \to pK^- K^- \pi^+$
  - ✦ Mass and lifetime of Ξ_b^{*0} by LHCb [JHEP1605(2016)161]
    - in $\Xi_b^- \pi^+$ with $\Xi_b^- \to \Xi_c^0 \pi^-$, $\Xi_c^0 \to pK^- K^- \pi^+$
- **But its branching ratio not directly measured**

3. $\boxed{\Lambda_c^+ \to pK_S^0 \text{ and } \Lambda_c^+ \to pK_L^0}$

[D.Wang, FSY, in ready]

Motivation

- Charmed baryon decays have been widespread concerned recently
  - Many new decay modes have been observed
  - They provide a platform to study the heavy-to-light baryonic transitions
- Charmed baryon decays are classified into three types: CF, SCS and DCS decays
- The studies of DCS processes are of great interest
  - DCS decays are highly sensitive to new physics
  - help us to understand the dynamics of charmed hadron decays and test the $SU(3)$ symmetry

Search for two-body DCS

- Searching for the DCS transitions in charmed baryon decays is significant subject
- The first and only evidence of DCS transitions of charmed baryon is found in three-body decays:

$$\mathcal{B}(\Lambda_c^+ \to pK^+\pi^-)/\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (2.35 \pm 0.27 \pm 0.21) \times 10^{-3}$$

S. B. Yang et al. [Belle Collaboration], Phys. Rev. Lett. 117, no. 1, 011801 (2016)

- The two-body DCS decays have not been seen
  - The DCS transitions can manifest themselves through interfering with the CF amplitudes in those modes with neutral kaons
    $\Rightarrow$ $K_S^0 - K_L^0$ asymmetry

    D. Wang, F. S. Yu, P. F. Guo and H. Y. Jiang, Phys. Rev. D **95**, no. 7, 073007 (2017).

Search for CP violation

- Up to now, there is no indication of CP violation in charmed decays
- Direct CP violation in the SCS processes has been studied a lot
  - It is induced by the interference between tree and penguin
- CPV can also occur in the modes with neutral kaons
  - Interference between Cabibbo-favored (CF) and doubly Cabibbo-suppressed (DCS) amplitudes
- A new measurable effect of CPV in D decaying into $K^0_{S,L}$: the interference between charm decay and kaon mixing
  - This comment is still valid in baryon sector

[D.Wang, FSY, H.n.Li, in ready]

- Advantages compared to SCS processes:
  - Only trees, no penguins, less ambiguities in theory
  - Large branching fractions, decrease errors in experiments
- Since we have not found the CP asymmetry of charm in D meson decays, it would be a beneficial attempt to search for the CP violation in charmed baryon decays

This work:

1. Discuss the $K_S^0 - K_L^0$ asymmetry in charmed baryon decays
2. Analyze the time-dependent and the time-integral CP asymmetry in charmed baryon decays

$K_S^0 - K_L^0$ asymmetry

- The $K_S^0 - K_L^0$ asymmetry in charmed-baryon anti-triplet decaying into light baryon octet and neutral kaons is defined as

$$R(B_c(\bar{3}) \to B(8)K_{S,L}^0) \equiv \frac{\Gamma(B_c(\bar{3}) \to B(8)K_S^0) - \Gamma(B_c(\bar{3}) \to B(8)K_L^0)}{\Gamma(B_c(\bar{3}) \to B(8)K_S^0) + \Gamma(B_c(\bar{3}) \to B(8)K_L^0)}$$

- K_S^0 and K_L^0 are the combinations of K^0 and $\overline{K}^0$:

$$|K_{S,L}^0\rangle = p_K|K^0\rangle \mp q_K|\overline{K}^0\rangle,$$

$$p_K = \frac{1+\epsilon}{\sqrt{2(1+|\epsilon|^2)}}, \qquad q_K = \frac{1-\epsilon}{\sqrt{2(1+|\epsilon|^2)}},$$

☞ $K_S^0 - K_L^0$ asymmetry is not sensitive to the CP violating effect in the $K^0 - \overline{K}^0$ mixing, we can neglect the parameter ϵ

- The decay amplitudes of $B_c\overline{(3)} \to B(8)K^0_{S,L}$ can be decomposed as

$$\mathcal{A}(B_c(\overline{3}) \to B(8)K^0_S) = \frac{1}{\sqrt{2}}(V^*_{cd}V_{us}\mathcal{T}_{DCS}\,e^{i\delta_{DCS}} - V^*_{cs}V_{ud}\mathcal{T}_{CF}\,e^{i\delta_{CF}}),$$

$$\mathcal{A}(B_c(\overline{3}) \to B(8)K^0_L) = \frac{1}{\sqrt{2}}(V^*_{cd}V_{us}\mathcal{T}_{DCS}\,e^{i\delta_{DCS}} + V^*_{cs}V_{ud}\mathcal{T}_{CF}\,e^{i\delta_{CF}})$$

- With the conventions of

$$\frac{\mathcal{T}_{DCS}e^{i\delta_{DCS}}}{\mathcal{T}_{CF}e^{i\delta_{CF}}} = r_f\,e^{i\delta_f}, \qquad \frac{V^*_{cd}V_{us}}{V^*_{cs}V_{ud}} \simeq -\tan^2\theta_C\,e^{i\phi} \sim \lambda^2,$$

the $K^0_S - K^0_L$ asymmetry can be expressed as

$$R(B_c(\overline{3}) \to B(8)K^0_{S,L}) \simeq 2r_f\tan^2\theta_C\cos\delta_f$$

☞ $R(B_c(\overline{3}) \to B(8)K^0_{S,L}) \sim \mathcal{O}(10^{-2})$

- $K_S^0 - K_L^0$ asymmetries are proportional to parameter r_f
  - If there is no DCS amplitudes in some decay modes, $r_f = 0$, the $K_S^0 - K_L^0$ asymmetry will be zero
  - The non-zero $K_S^0 - K_L^0$ asymmetry will be the evidence of the DCS decays of charmed baryons
- We suggest to measure $R(\Lambda_c^+ \to pK_{S,L}^0)$:
  - The branching fraction of $\Lambda_c^+ \to pK_S^0$ has been measured:

$$\mathcal{B}(\Lambda_c^+ \to pK_S^0)_{\text{BESIII}} = (1.52 \pm 0.08 \pm 0.03)\%.$$

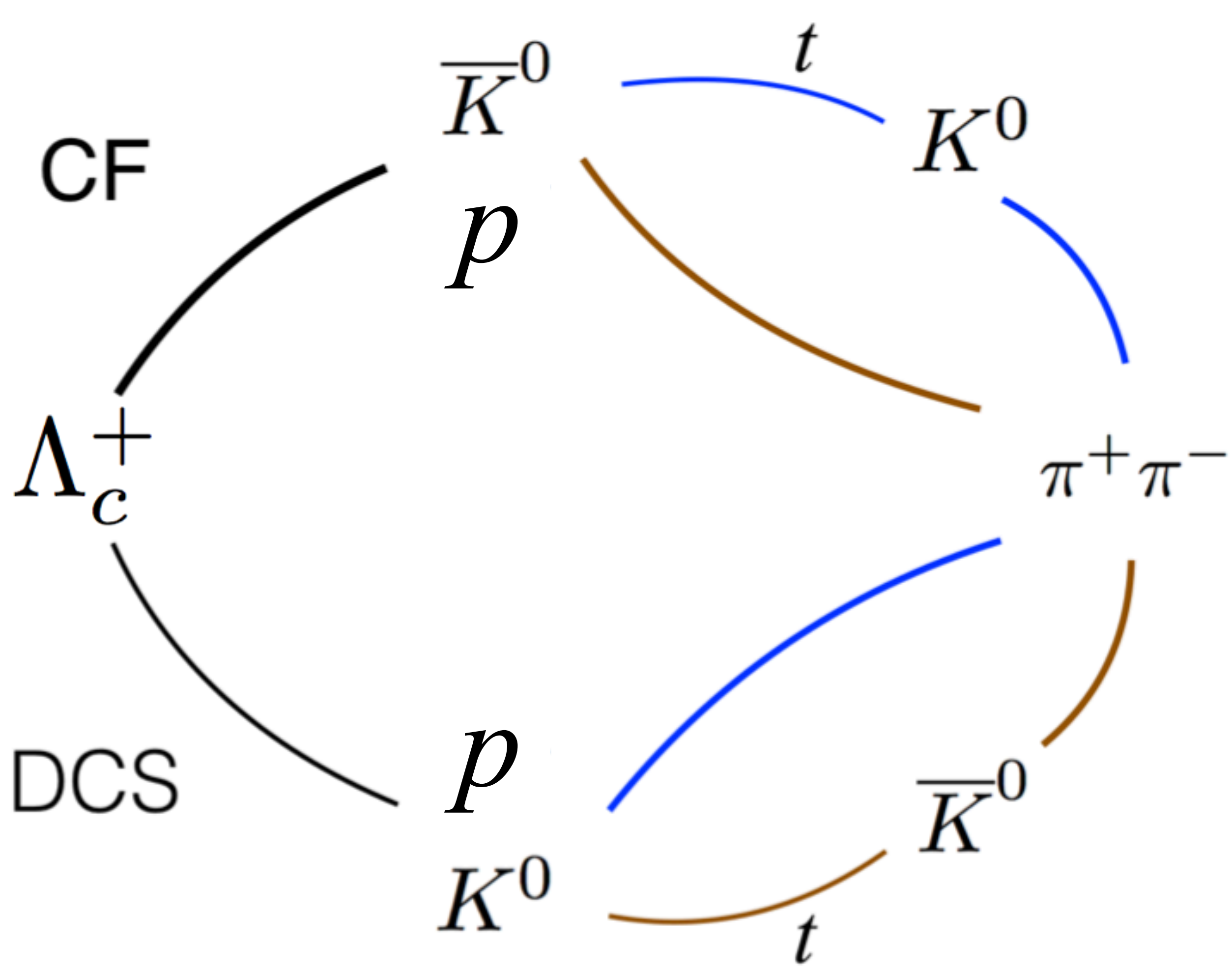
M. Ablikim *et al.* [BESIII Collaboration], Phys. Rev. Lett. **116**, no. 5, 052001 (2016)

- The two-body charmed baryon decays can be generalized to multi-body decays
  - For instance, $\Lambda_c^+ \to pK_{S,L}^0\pi^0$, $\Lambda_c^+ \to pK_{S,L}^0\pi^+\pi^-$ ......

CP asymmetry

- The CP asymmetries of $B_c(\overline{3}) \to B(8)K_S^0$ decays are defined by

$$A_{CP}(B_c(\overline{3}) \to pK_S^0) \equiv \frac{\Gamma(B_c(\overline{3}) \to B(8)K_S^0) - \Gamma(\overline{B}_c(\overline{3}) \to \overline{B}(8)K_S^0)}{\Gamma(B_c(\overline{3}) \to B(8)K_S^0) + \Gamma(\overline{B}_c(\overline{3}) \to \overline{B}(8)K_S^0)}$$



- The time-dependent CPV is obtained as

$$A_{CP}(t) \simeq \frac{A_{CP}^{\overline{K}^0}(t) + A_{CP}^{dir}(t) + A_{CP}^{int}(t)}{S_{\pi\pi}(t)}$$

  - $A_{CP}^{\overline{K}^0}(t)$ is the CP violation in neural kaon mixing

$$A_{CP}^{\overline{K}^0}(t) = 2\mathcal{R}e[\epsilon]e^{-\Gamma_s t} - 2e^{-\Gamma t}(\mathcal{R}e[\epsilon]\cos(\Delta m t) + \mathcal{I}m[\epsilon]\sin(\Delta m t))$$

  - $A_{CP}^{dir}(t)$ is direct CP asymmetry

$$A_{CP}^{dir}(t) = -2e^{-\Gamma_s t}\tan^2\theta_C\, r_f \sin\delta_f \sin\phi$$

  - $A_{CP}^{int}(t)$ is the interference between the charm decays and the $K^0 - \overline{K}^0$ mixing

$$\begin{aligned} A_{CP}^{int}(t) = 4\tan^2\theta_C\, r_f \cos\phi \sin\delta_f (&\mathcal{I}m[\epsilon]e^{-\Gamma_s t} \\ &- e^{-\Gamma t}(\mathcal{I}m[\epsilon]\cos(\Delta m t) - \mathcal{R}e[\epsilon]\sin(\Delta m t))) \end{aligned}$$

  - Denominator: $S_{\pi\pi}(t) = e^{-\Gamma_s t}(1 + 2\tan^2\theta_C\, r_f \cos\delta_f \cos\phi)$

- The time-integral CP asymmetry is defined as

$$A_{CP}(t_1,t_2) \simeq \frac{\int_{t_1}^{t_2} dt\,[A_{CP}^{\overline{K}^0}(t) + A_{CP}^{dir}(t) + A_{CP}^{int}(t)]}{\int_{t_1}^{t_2} dt\, S_{\pi\pi}(t)}$$

- The time-integral CP asymmetry is expressed as

$$A_{CP}(t_1,t_2) \simeq \frac{-2\tan^2\theta_C r_f \sin\delta_f \sin\phi}{1+2\tan^2\theta_C r_f \cos\delta_f \cos\phi} + \frac{2\mathcal{R}e[\epsilon] + 4\tan^2\theta_C r_f \mathcal{I}m[\epsilon]\cos\phi\sin\delta_f}{1+2\tan^2\theta_C r_f \cos\delta_f \cos\phi}$$
$$\times \left[1 - \frac{[c(t_1)-c(t_2)] + \frac{\mathcal{I}m[\epsilon]-2\tan^2\theta_C r_f \mathcal{R}e[\epsilon]\cos\phi\sin\delta_f}{\mathcal{R}e[\epsilon]+2\tan^2\theta_C r_f \mathcal{I}m[\epsilon]\cos\phi\sin\delta_f}[s(t_1)-s(t_2)]}{\tau_S\Gamma\,(1+x^2)(e^{-t_1/\tau_S} - e^{-t_2/\tau_S})}\right],$$

in which $x = \Delta m/\Gamma$, $c(t) = e^{-\Gamma t}[\cos(\Delta m t) - x\sin(\Delta m t)]$, and

$s(t) = e^{-\Gamma t}[x\cos(\Delta m t) + \sin(\Delta m t)]$

- With the approximation of $x = \Delta m/\Gamma \approx 1$, we get

$$A_{CP}(t_1 \ll \tau_S, \tau_S \ll t_2 \ll \tau_L) \simeq \frac{-2\mathcal{I}m[\epsilon] - 2\tan^2\theta_C r_f \sin\delta_f \sin\phi + 4\tan^2\theta_C r_f \mathcal{R}e[\epsilon]\cos\phi\sin\delta_f}{1 + 2\tan^2\theta_C r_f \cos\phi\cos\delta_f}$$

  - $A_{CP}(t_1 \ll \tau_S, \tau_S \ll t_2 \ll \tau_L)$ is dominated by the interference between $\overline{K}^0$ decays with and without $K^0 - \overline{K}^0$ mixing $A_{CP}^{\overline{K}^0}$
  - The interference between charm decays and neutral kaon mixing A_{CP}^{int} is at the order of $\mathcal{O}(10^{-4})$, which would be observed by experiments in the near future
  - We suggest to measure the CP asymmetry in $\Lambda_c^+ \to pK_S^0$ channel

Numerical Analysis via SU(3) symmetry

- We use a *SU*(3) symmetry analysis, in which the amplitudes are extracted by global fit, to estimate these observables we discussed above
- The reason of the *SU*(3) symmetry analysis
  - ☞ The description of charmed baryon decays based on the factorization assumption doesn't work well
  - ☞ The flavor *SU*(3) symmetry analysis has been argued to work better in charmed baryon decays
- SCS processes are expected to have large *SU*(3) breaking effect and not included in our analysis

- The effective Hamiltonian of charmed baryon decays can be expressed as

$$\mathcal{H}_{\text{eff}} = e\mathcal{H}^{ab}(6)B_c(\overline{3})_{ac}\overline{B}(8)^c_d M(8)^d_b + f\mathcal{H}^{ab}(6)B_c(\overline{3})_{ac}M(8)^c_d\overline{B}(8)^d_b$$
$$+ g\mathcal{H}^{ab}(6)\overline{B}(8)^c_a M(8)^d_b B_c(\overline{3})_{cd}$$

$\Rightarrow$ This Hamiltonian is by following hypothesis

- The operators can be decomposed into irreducible representations of $SU(3)$ symmetry group. For example:

$$(\bar{s}c)(\bar{u}d) = \mathcal{O}_6 + \mathcal{O}_{\overline{15}},$$

$$\mathcal{O}_6 = \frac{1}{2}[(\bar{s}c)(\bar{u}d) - (\bar{u}c)(\bar{s}d)], \qquad \mathcal{O}_{\overline{15}} = \frac{1}{2}[(\bar{s}c)(\bar{u}d) + (\bar{u}c)(\bar{s}d)]$$

- The sextet component of the Hamiltonian dominate charmed baryon decays by make an analogy with strange decays

M. J. Savage and R. P. Springer, Phys. Rev. D 42, 1527 (1990)

Modes	Representation	$\mathcal{B}_{\rm exp}(\%)$	$\mathcal{B}_{\rm SU(3)}(\%)$
$\Lambda_c^+ \to \Lambda\pi^+$	$\frac{1}{\sqrt{6}}(-2e-2f-2g)$	1.30±0.07	1.31±1.05
$\Lambda_c^+ \to \Sigma^0\pi^+$	$\frac{1}{\sqrt{2}}(-2e+2f+2g)$	1.29±0.07	1.26±0.86
$\Lambda_c^+ \to \Sigma^+\pi^0$	$\frac{1}{\sqrt{2}}(2e-2f-2g)$	1.24±0.10	1.27±0.87
$\Lambda_c^+ \to pK_S^0$	$\frac{1}{\sqrt{2}}\tan^2\theta_C(-2g)-\frac{1}{\sqrt{2}}(-2e)$	1.58±0.08	1.58±0.13
$\Lambda_c^+ \to pK_L^0$	$\frac{1}{\sqrt{2}}\tan^2\theta_C(-2g)+\frac{1}{\sqrt{2}}(-2e)$		1.88±0.14
$\Lambda_c^+ \to \Xi^0K^+$	$-2f$	0.50±0.12	0.51±0.12
$\Xi_c^0 \to \Xi^-\pi^+$	$2e$		1.66±0.21
$\Xi_c^0 \to \Xi^0\pi^0$	$\frac{1}{\sqrt{2}}(-2e+2g)$		0.43±0.40
$\Xi_c^0 \to \Lambda K_S^0$	$\frac{1}{\sqrt{12}}\tan^2\theta_C(-4e+2f+2g)-\frac{1}{\sqrt{12}}(2e+4f-4g)$		0.41±0.19
$\Xi_c^0 \to \Lambda K_L^0$	$\frac{1}{\sqrt{12}}\tan^2\theta_C(-4e+2f+2g)+\frac{1}{\sqrt{12}}(2e+4f-4g)$		0.46±0.19
$\Xi_c^0 \to \Sigma^+K^-$	$2f$		0.32±0.08
$\Xi_c^0 \to \Sigma^0K_S^0$	$\frac{1}{2}\tan^2\theta_C(-2e)-\frac{1}{2}(-2f-2g)$		0.24±0.39
$\Xi_c^0 \to \Sigma^0K_L^0$	$\frac{1}{2}\tan^2\theta_C(-2e)+\frac{1}{2}(-2f-2g)$		0.21±0.36
$\Xi_c^+ \to \Xi^0\pi^+$	$-2g$		7.62±8.78
$\Xi_c^+ \to \Sigma^+K_S^0$	$\frac{1}{\sqrt{2}}\tan^2\theta_C(2e)-\frac{1}{\sqrt{2}}(2g)$		1.74±2.08
$\Xi_c^+ \to \Sigma^+K_L^0$	$\frac{1}{\sqrt{2}}\tan^2\theta_C(2e)+\frac{1}{\sqrt{2}}(2g)$		2.03±2.25

6 data to fix 5 parameter

$$\mathcal{B}(\Xi_c^0 \to \Lambda K_S^0)/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) = 0.210\pm0.028$$

- the $K_S^0 - K_L^0$ asymmetries are predicted to be

$$\boxed{R(\Lambda_c^+ \to pK_{S,L}^0) = -0.088 \pm 0.052,}\ R(\Xi_c^0 \to \Lambda K_{S,L}^0) = -0.053 \pm 0.028$$
$$R(\Xi_c^0 \to \Sigma^0 K_{S,L}^0) = 0.075 \pm 0.068,\ R(\Xi_c^+ \to \Sigma^+ K_{S,L}^0) = -0.076 \pm 0.045$$

- $A_{CP}(t_1 \ll \tau_S, \tau_S \ll t_2 \ll \tau_L)$ in solution I (in units of 10^{-3}):

$$A_{CP}(\Lambda_c^+ \to pK_S^0)_I = -2.70 \pm 0.29,\ A_{CP}(\Xi_c^0 \to \Lambda K_S^0)_I = -2.26 \pm 0.58$$
$$A_{CP}(\Xi_c^0 \to \Sigma^0 K_S^0)_I = -2.97 \pm 0.59,\ A_{CP}(\Xi_c^+ \to \Sigma^+ K_S^0)_I = -3.21 \pm 0.18$$

- $A_{CP}(t_1 \ll \tau_S, \tau_S \ll t_2 \ll \tau_L)$ solution II (in units of 10^{-3}):

$$A_{CP}(\Lambda_c^+ \to pK_S^0)_{II} = -3.20 \pm 0.11,\ A_{CP}(\Xi_c^0 \to \Lambda K_S^0)_{II} = -3.15 \pm 0.34$$
$$A_{CP}(\Xi_c^0 \to \Sigma^0 K_S^0)_{II} = -3.95 \pm 0.59,\ A_{CP}(\Xi_c^+ \to \Sigma^+ K_S^0)_{II} = -2.77 \pm 0.26$$

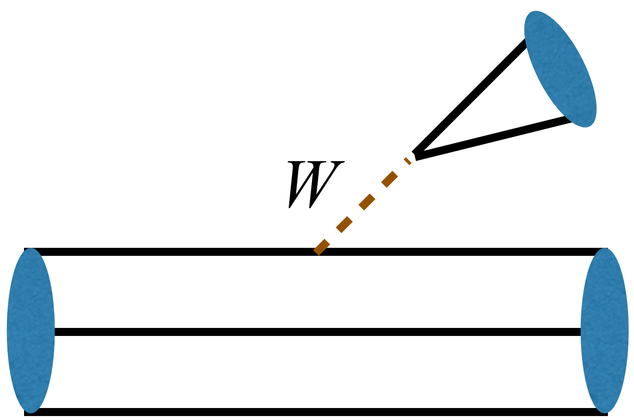
Summary:

- We can search for the doubly Cabibbo-suppressed charmed baryon decays by testing the $K_S^0 - K_L^0$ asymmetry in those channels involving K_S^0 and K_L^0 mesons
- The interference between charm decays and $K^0 - \overline{K}^0$ mixing can induce CP asymmetry, which would be detected in the near future
- A $SU(3)$ asymmetry analysis for charmed-baryon anti-triplet decaying into the light baryon octet and pseudoscalar octet has been presented.

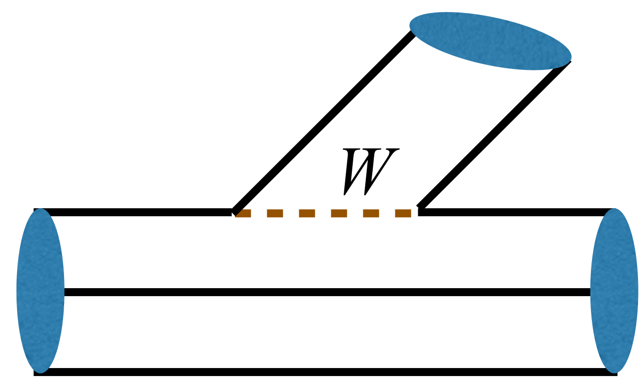
4. Final-state interactions

Dynamics to be understood

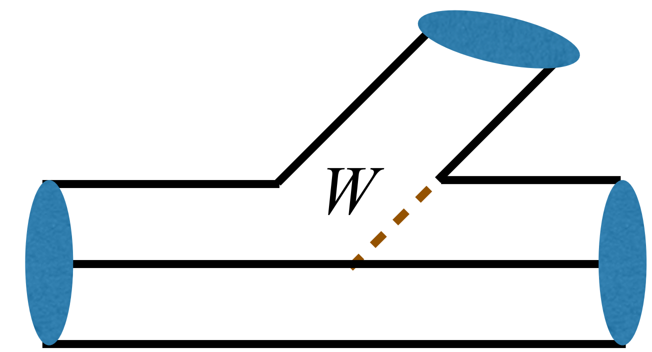
Topologies of two-body non-leptonic charmed baryon decays



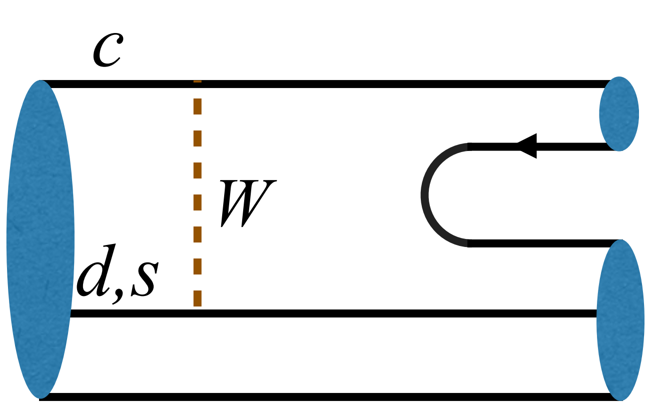
(T)
color-favored tree emitted



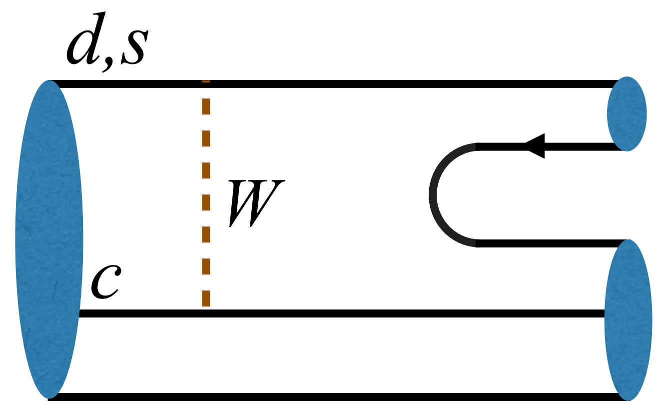
(C)
color-suppressed emitted



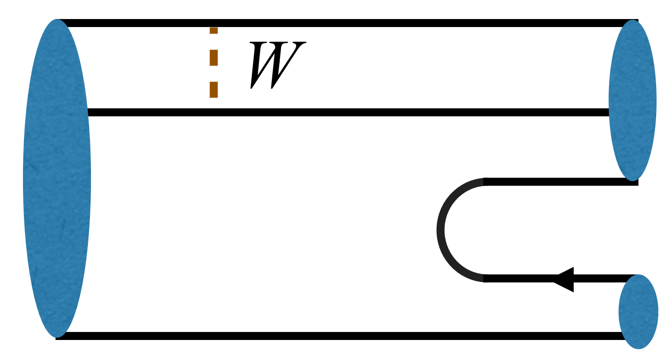
(C′)
color-commensurate



(E_1)
W-exchange 1



(E_2)
W-exchange 2



(B)
Bow tie

Theoretical Framework

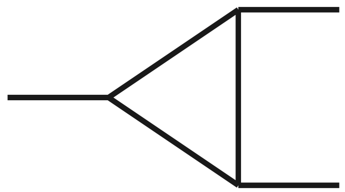
1. To understand factorizable contributions

   — tree emitted (T) diagrams

2. To understand non-factorizable contributions

   — final-state interacting (FSI) effects

- Calculate rescattering effects



$$F(t, m) = \left(\frac{\Lambda^2 - m^2}{\Lambda^2 - t}\right)^n \qquad t \equiv (p_1 - p_3)^2 \qquad n=1$$

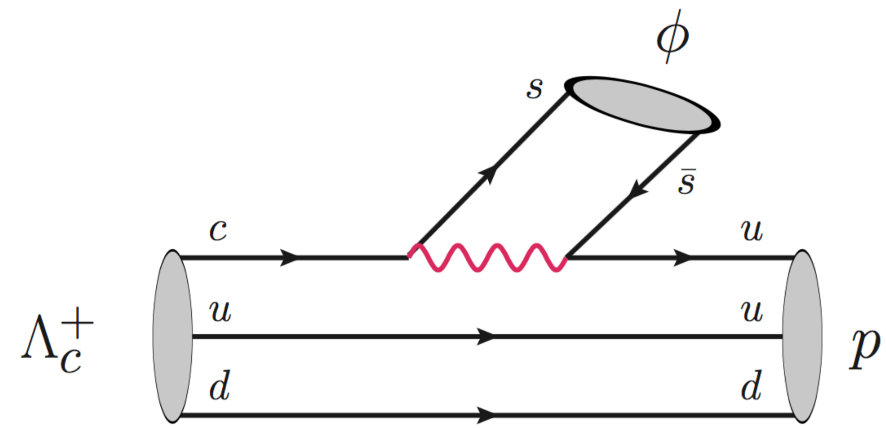
$$\Lambda = m_{\rm exc} + \eta \Lambda_{\rm QCD}$$

[Cheng, Chua, Soni, PRD 71, 014030 (2005)]

Results are very sensitive to the value of η

$$\boxed{\Lambda_c^+ \to p\phi}$$

$V_{cd}^* V_{ud}\, C$ =



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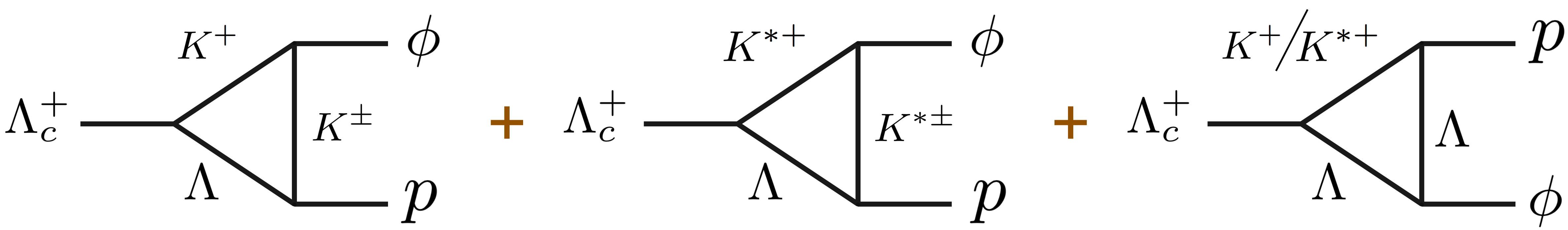

PDG $\mathcal{B}(\Lambda_c^+ \to p\phi) = (1.04 \pm 0.21) \times 10^{-3}$

η~1.3

Summary

- Charm baryon physics is becoming more interesting, benefited by BESIII
- More measurements at BESIII and LHCb, and more theoretical studies are worth for your hard work!

Thank you !