2026 年 Belle II 中国组冬季学校

拓扑图与粲重子衰变

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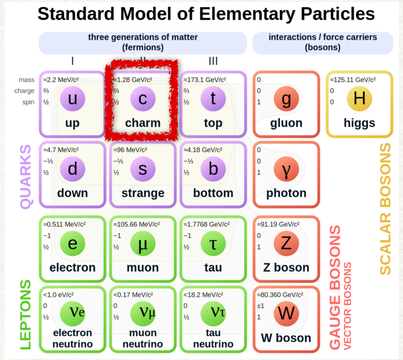
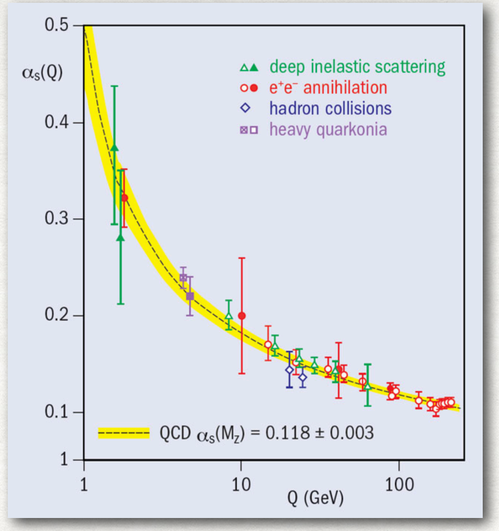
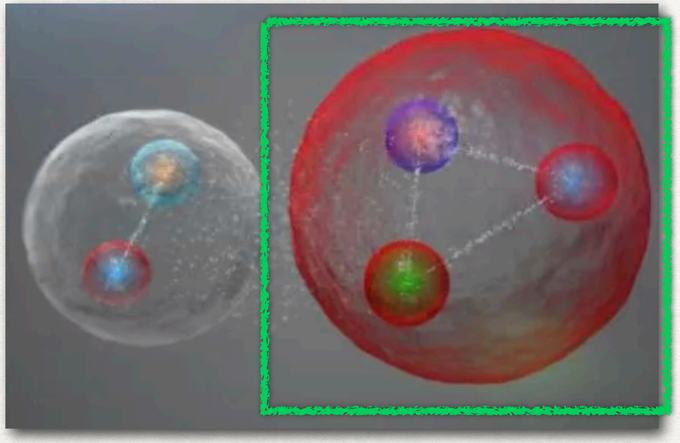
OUTLINE

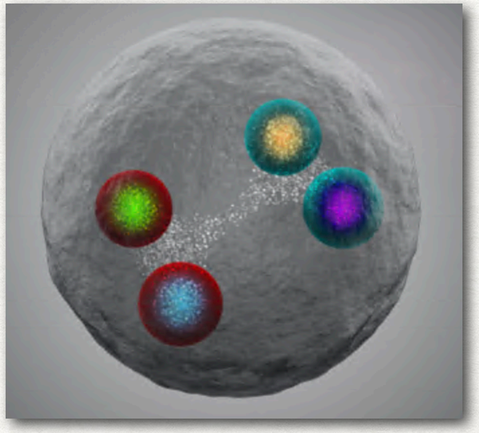
- Introduction：kinematics
- TDA framework
  - $\mathscr{B}_c \to BP$
  - $\mathscr{B}_c \to BV$
  - $\mathscr{B}_c \to B_D P$
- Numerical results and implications
- Summary

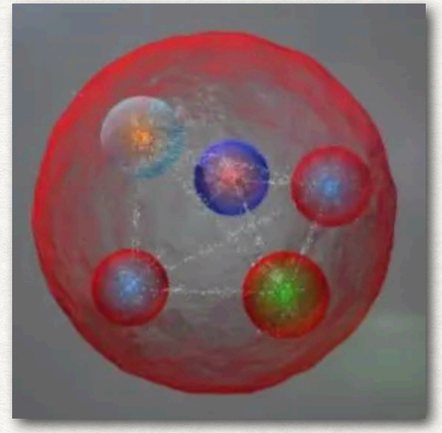
INTRODUCTION


Standard Model of Elementary Particles
three generations of matter (fermions)
interactions / force carriers (bosons)
I
II
III
mass
charge
spin
≈2.2 MeV/c²
≈1.28 GeV/c²
≈173.1 GeV/c²
≈125.11 GeV/c²
u
up
c
charm
t
top
g
gluon
H
higgs
≈4.7 MeV/c²
≈96 MeV/c²
≈4.18 GeV/c²
d
down
s
strange
b
bottom
γ
photon
QUARKS
≈0.511 MeV/c²
≈105.66 MeV/c²
≈1.7768 GeV/c²
≈91.19 GeV/c²
e
electron
μ
muon
τ
tau
Z
Z boson
LEPTONS
<1.0 eV/c²
<0.17 MeV/c²
<18.2 MeV/c²
≈80.360 GeV/c²
νe
electron neutrino
νμ
muon neutrino
ντ
tau neutrino
W
W boson
GAUGE BOSONS
VECTOR BOSONS
SCALAR BOSONS

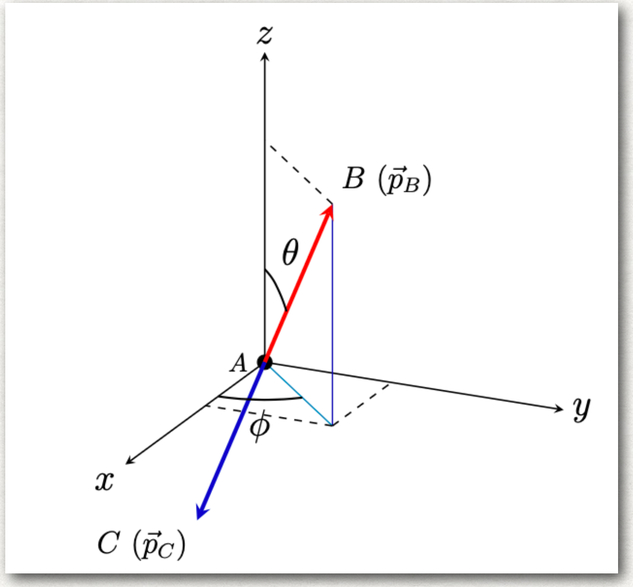

0.5
0.4
0.3
0.2
0.1
1
αS(Q)
deep inelastic scattering
e+e− annihilation
hadron collisions
heavy quarkonia
QCD αS(MZ) = 0.118 ± 0.003
1
10
100
Q (GeV)

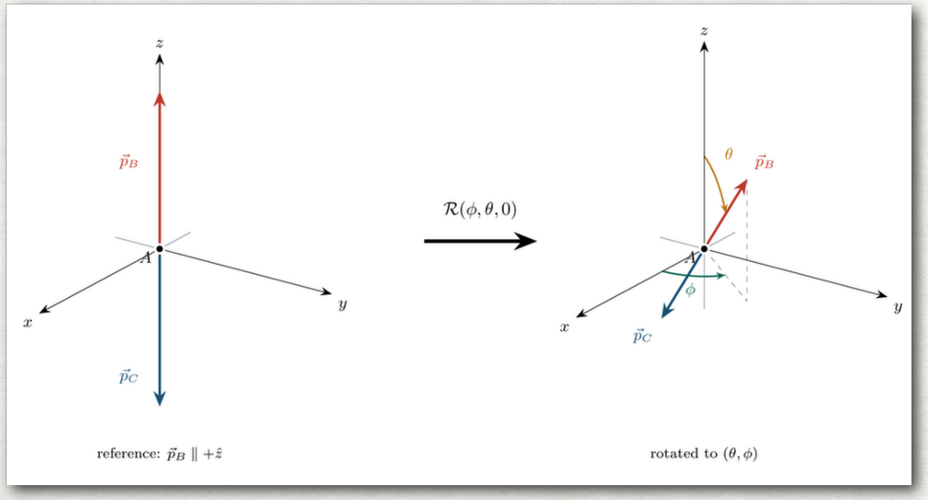






Two-body decay Kinematics





♢ In the rest frame of A,

$$\vec{p}_C = -\vec{p}_B, \qquad \vec{p}_B = |\vec{p}_B|(\sin\theta\cos\phi,\ \sin\theta\sin\phi,\ \cos\theta)$$

♢ The treatment of spinors oriented in an arbitrary direction is somewhat involved

$$u(\vec{p}_B, s) = \begin{pmatrix} \sqrt{E+m}\,\chi_s(\theta,\phi) \\ \dfrac{\vec{\sigma}\cdot\vec{p}_B}{\sqrt{E+m}}\,\chi_s(\theta,\phi) \end{pmatrix}, \quad \chi_+(\theta,\phi) = \begin{pmatrix} \cos\frac{\theta}{2} \\ e^{i\phi}\sin\frac{\theta}{2} \end{pmatrix}, \quad \chi_-(\theta,\phi) = \begin{pmatrix} -\sin\frac{\theta}{2} \\ e^{i\phi}\cos\frac{\theta}{2} \end{pmatrix}$$

♢ Daughter particle emission in the z-direction of a reference frame

$$u(p_B,\lambda) = \begin{pmatrix} \sqrt{E_B+m_B}\,\chi_\lambda \\ 2\lambda\sqrt{E_B-m_B}\,\chi_\lambda \end{pmatrix}, \qquad \chi_+ = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \qquad \chi_- = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

$$\vdots$$

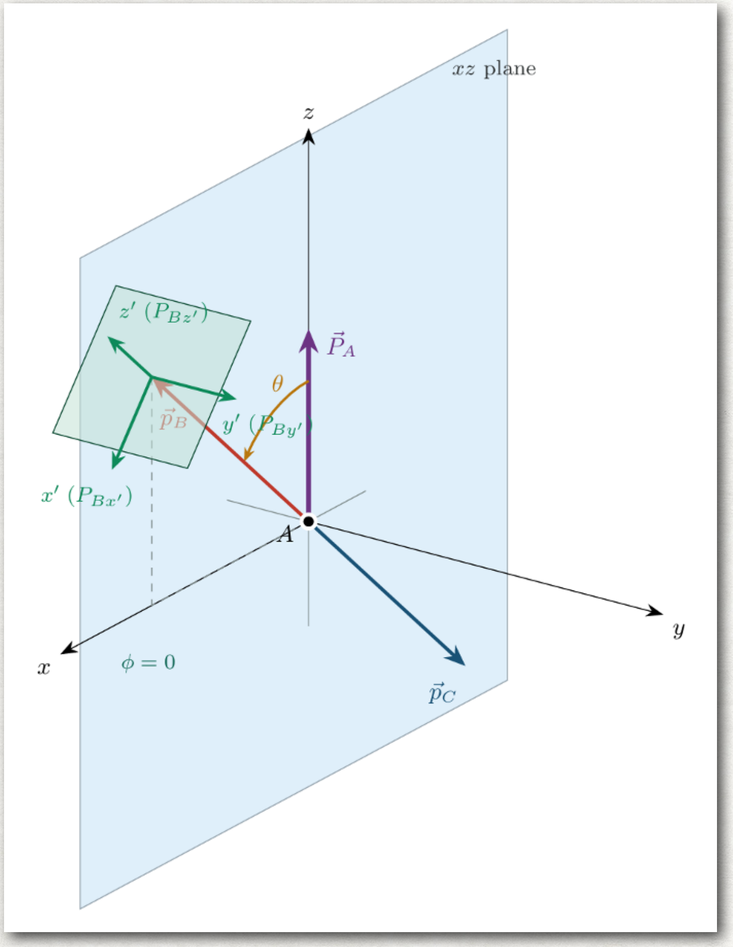
♢ By first writing the final state in a reference frame in which B moves along the $+z$ axis and then rotating it into the (θ,ϕ) direction (Wigner D function $D^J_{M_J,\lambda}(\phi,\theta,0)$)

$$\begin{aligned} |\theta,\phi,\lambda_B,\lambda_C\rangle &= \mathcal{R}(\phi,\theta,0)\,|0,0,\lambda_B,\lambda_C\rangle \\ &= \sum_J \sum_{M_J=-J}^{+J} \sqrt{\frac{2J+1}{4\pi}}\,|J,M_J,\lambda_B,\lambda_C\rangle\langle J,M_J,\lambda_B,\lambda_C|\mathcal{R}(\phi,\theta,0)|J,\lambda,\lambda_B,\lambda_C\rangle \\ &= \sum_J \sum_{M_J=-J}^{+J} \sqrt{\frac{2J+1}{4\pi}}\,D^J_{M_J,\lambda}(\phi,\theta,0)\,|J,M_J,\lambda_B,\lambda_C\rangle \end{aligned}$$

♢ Decay amplitude

$$\begin{aligned} \mathcal{M} &= \sqrt{\frac{2J_A+1}{4\pi}}\,D^{J_A*}_{\lambda_A,\lambda}(\phi,\theta,0)\,\langle J_A,\lambda_A,\lambda_B,\lambda_C|\mathcal{T}|J_A,\lambda_A\rangle \\ &= \sqrt{\frac{2J_A+1}{4\pi}}\,e^{i(\lambda_A-\lambda)\phi}\,d^{J_A}_{\lambda_A,\lambda}(\theta)\,H_{\lambda_B,\lambda_C}\,, \end{aligned}$$

Observables in $\frac{1}{2}^+ \to \frac{1}{2}^+ + 0^-$



- Differential decay rate (angular distribution)

$$\frac{d\Gamma}{d\cos\theta} \propto \mathrm{Tr}(\rho_B) \propto 1 + \alpha P_A \cos\theta, \qquad \alpha \equiv \frac{|H_{+1/2}|^2 - |H_{-1/2}|^2}{|H_{+1/2}|^2 + |H_{-1/2}|^2}$$

- Daughter baryon polarization vector $\vec{P}_B = \mathrm{Tr}(\vec{\sigma}\rho_B)/\mathrm{Tr}(\rho_B)$

$$P_{Bz'} = \frac{\mathrm{Tr}(\sigma_z \rho_B)}{\mathrm{Tr}(\rho_B)} = \frac{\alpha + P_A \cos\theta}{1 + \alpha P_A \cos\theta},$$

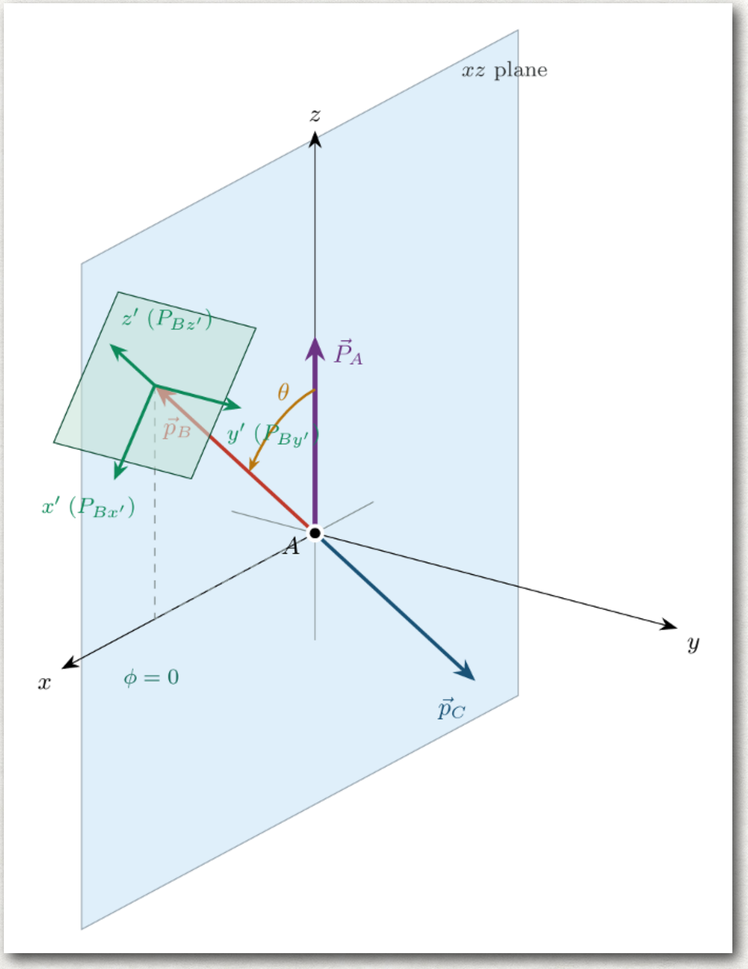
$$P_{Bx'} = \frac{\mathrm{Tr}(\sigma_x \rho_B)}{\mathrm{Tr}(\rho_B)} = \frac{-\gamma\, P_A \sin\theta}{1 + \alpha P_A \cos\theta}, \qquad \gamma \equiv \frac{2\,\mathrm{Re}(H_{+1/2} H^*_{-1/2})}{|H_{+1/2}|^2 + |H_{-1/2}|^2},$$

$$P_{By'} = \frac{\mathrm{Tr}(\sigma_y \rho_B)}{\mathrm{Tr}(\rho_B)} = \frac{-\beta\, P_A \sin\theta}{1 + \alpha P_A \cos\theta}, \qquad \beta \equiv \frac{2\,\mathrm{Im}(H_{+1/2} H^*_{-1/2})}{|H_{+1/2}|^2 + |H_{-1/2}|^2}$$

- Three Lee-Yang parameters in this process satisfy the unit-sphere constraint

$$\alpha^2 + \beta^2 + \gamma^2 = 1$$

Observables in $\frac{1}{2}^+ \to \frac{1}{2}^+ + 1^-$



◇ Differential decay rate (angular distribution)

$$\frac{d\Gamma}{d\cos\theta} \propto \mathrm{Tr}(\rho_B) \propto 1 + \alpha P_A \cos\theta, \qquad \alpha \equiv \frac{|H_{+1/2,0}|^2 + |H_{-1/2,-1}|^2 - |H_{+1/2,+1}|^2 - |H_{-1/2,0}|^2}{|H_{+1/2,0}|^2 + |H_{-1/2,-1}|^2 + |H_{+1/2,+1}|^2 + |H_{-1/2,0}|^2}$$

◇ Daughter baryon polarization vector $\vec{P}_B = \mathrm{Tr}(\vec{\sigma}\rho_B)/\mathrm{Tr}(\rho_B)$

$$P_{Bz'} = \frac{\mathrm{Tr}(\sigma_z \rho_B)}{\mathrm{Tr}(\rho_B)} = \frac{\alpha_B + \eta P_A \cos\theta}{1 + \alpha P_A \cos\theta}$$

where α_B measures the polarization asymmetry of the daughter baryon B, and η describes the longitudinal–transverse polarization asymmetry of the vector meson C

$$\alpha_B = \frac{|H_{+1/2,0}|^2 + |H_{+1/2,+1}|^2 - |H_{-1/2,0}|^2 - |H_{-1/2,-1}|^2}{|H_{+1/2,0}|^2 + |H_{-1/2,-1}|^2 + |H_{+1/2,+1}|^2 + |H_{-1/2,0}|^2},$$

$$\eta = \frac{|H_{+1/2,0}|^2 - |H_{+1/2,+1}|^2 + |H_{-1/2,0}|^2 - |H_{-1/2,-1}|^2}{|H_{+1/2,0}|^2 + |H_{-1/2,-1}|^2 + |H_{+1/2,+1}|^2 + |H_{-1/2,0}|^2}$$

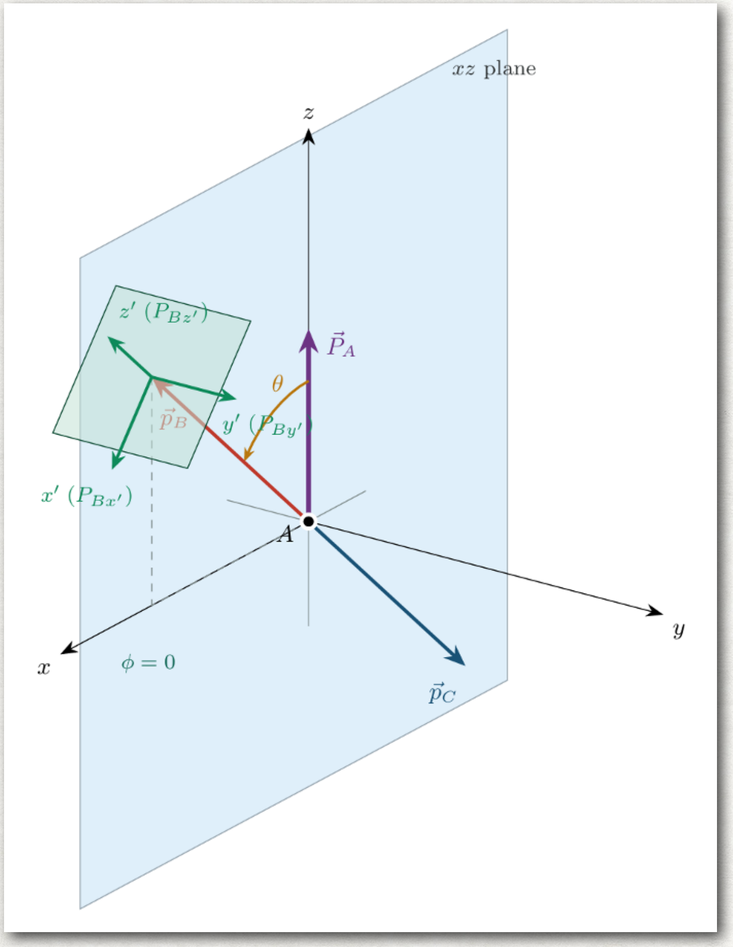
$$P_{Bx'} = \frac{\mathrm{Tr}(\sigma_x \rho_B)}{\mathrm{Tr}(\rho_B)} = \frac{-\gamma\, P_A \sin\theta}{1 + \alpha P_A \cos\theta}, \qquad \gamma_B = \frac{2\,\mathrm{Re}(H_{+1/2,0} H^*_{-1/2,0})}{|H_{+1/2,0}|^2 + |H_{-1/2,-1}|^2 + |H_{+1/2,+1}|^2 + |H_{-1/2,0}|^2},$$

$$P_{By'} = \frac{\mathrm{Tr}(\sigma_y \rho_B)}{\mathrm{Tr}(\rho_B)} = \frac{-\beta\, P_A \sin\theta}{1 + \alpha P_A \cos\theta}, \qquad \beta_B = \frac{2\,\mathrm{Im}(H_{+1/2,0} H^*_{-1/2,0})}{|H_{+1/2,0}|^2 + |H_{-1/2,-1}|^2 + |H_{+1/2,+1}|^2 + |H_{-1/2,0}|^2},$$

◇ α_B, β_B, and γ_B in this process do not satisfy a unit-sphere constraint, i.e.,

$$\alpha_B^2 + \beta_B^2 + \gamma_B^2 \neq 1$$

Observables in $\frac{1}{2}^+ \to \frac{3}{2}^+ + 0^-$



♢ Differential decay rate (angular distribution)

$$\frac{d\Gamma}{d\cos\theta} \propto \mathrm{Tr}(\rho_B) \propto 1 + \alpha P_A \cos\theta, \qquad \alpha \equiv \frac{|H_{+1/2}|^2 - |H_{-1/2}|^2}{|H_{+1/2}|^2 + |H_{-1/2}|^2}$$

♢ Daughter baryon polarization vector $\vec{P}_B = 2/3\mathrm{Tr}(\vec{S}\rho_B)/\mathrm{Tr}(\rho_B)$ (by helicity conservation daughter baryon density matrix has support only on the central $\pm 1/2$ subspace, the spin-3/2 operators reduce to $S_x \to \sigma_1$, $S_y \to \sigma_2$, and $S_z \to \frac{1}{2}\sigma_3$)

$$P_{Bz'} = \frac{2}{3}\frac{\mathrm{Tr}(\sigma_z\rho_B)}{\mathrm{Tr}(\rho_B)} = \frac{1}{3}\frac{\alpha + P_A\cos\theta}{1 + \alpha P_A\cos\theta},$$

$$P_{Bx'} = \frac{2}{3}\frac{\mathrm{Tr}(\sigma_x\rho_B)}{\mathrm{Tr}(\rho_B)} = \frac{2}{3}\frac{-\gamma\, P_A\sin\theta}{1 + \alpha P_A\cos\theta}, \qquad \gamma \equiv \frac{2\,\mathrm{Re}(H_{+1/2}H^*_{-1/2})}{|H_{+1/2}|^2 + |H_{-1/2}|^2},$$

$$P_{By'} = \frac{2}{3}\frac{\mathrm{Tr}(\sigma_y\rho_B)}{\mathrm{Tr}(\rho_B)} = \frac{2}{3}\frac{-\beta\, P_A\sin\theta}{1 + \alpha P_A\cos\theta}, \qquad \beta \equiv \frac{2\,\mathrm{Im}(H_{+1/2}H^*_{-1/2})}{|H_{+1/2}|^2 + |H_{-1/2}|^2}$$

♢ α, β, and γ in this process satisfy the unit-sphere constraint

$$\alpha^2 + \beta^2 + \gamma^2 = 1$$

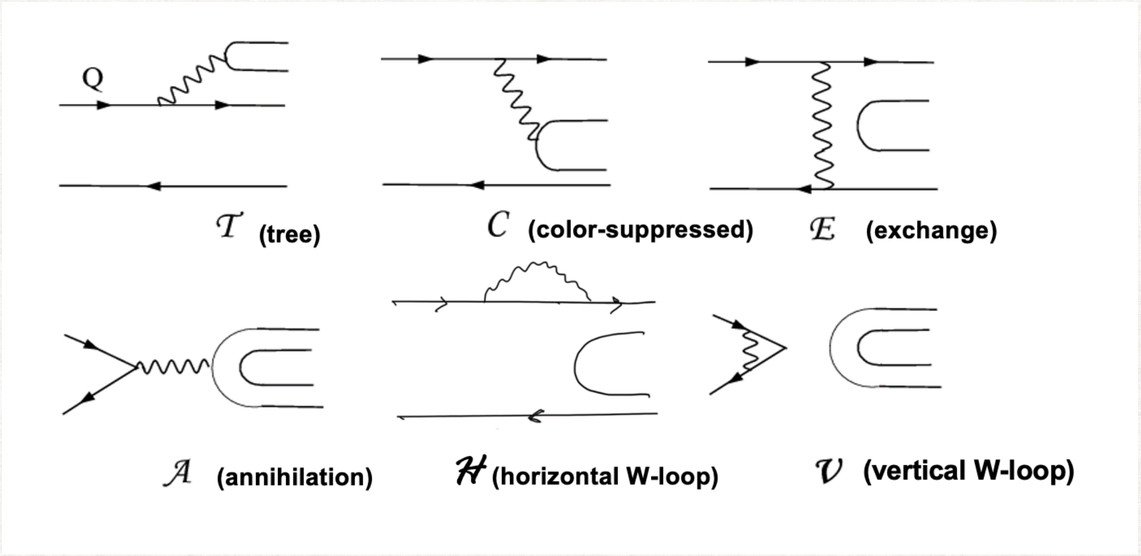
with Feng-Zhi Chen

History of Topological Diagram (1)

Charmed meson

- two-body decays can be expressed in terms of six distinct topological diagrams [Chau (1980,1983); Chau, Cheng(1986)]

L.-L. Chau in *Proceedings of 1980 Guangzhou Conference on Theoretical Particle Physics*

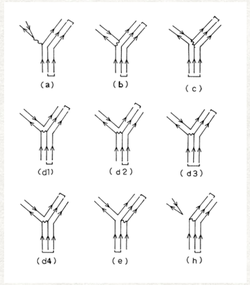


both magnitude and strong phase of each tree diagram can be determined

History of Topological Diagram (2)

Charmed baryon: early investigation

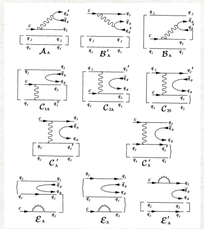
- Kohara(1991): parameterize by antisymmetric (12) and (23) for octet baryon wave function



$$\mathcal{A} = a\bar{B}^{3[ab]}B_{[ab]}M_2^1 + b\bar{B}^{1[ab]}B_{[ab]}M_2^3 + c\bar{B}^{b[13]}B_{[ab]}M_2^a + d_1\bar{B}^{a[1b]}B_{[2b]}M_a^3 + d_2\bar{B}^{b[1a]}B_{[2b]}M_a^3 + d_3\bar{B}^{a[3b]}B_{[2b]}M_a^1 + d_4\bar{B}^{b[3a]}B_{[2b]}M_a^1 + e\bar{B}^{a[13]}B_{[2b]}M_a^b + h\bar{B}^{b[13]}B_{[2b]}M_a^a ,$$

$$|\tilde{\mathcal{B}}^{m,k}(8)\rangle = \alpha|\chi^m(1/2)_{A_{12}}\rangle|\psi^k(8)_{A_{12}}\rangle + \beta|\chi^m(1/2)_{A_{23}}\rangle|\psi^k(8)_{A_{23}}\rangle$$

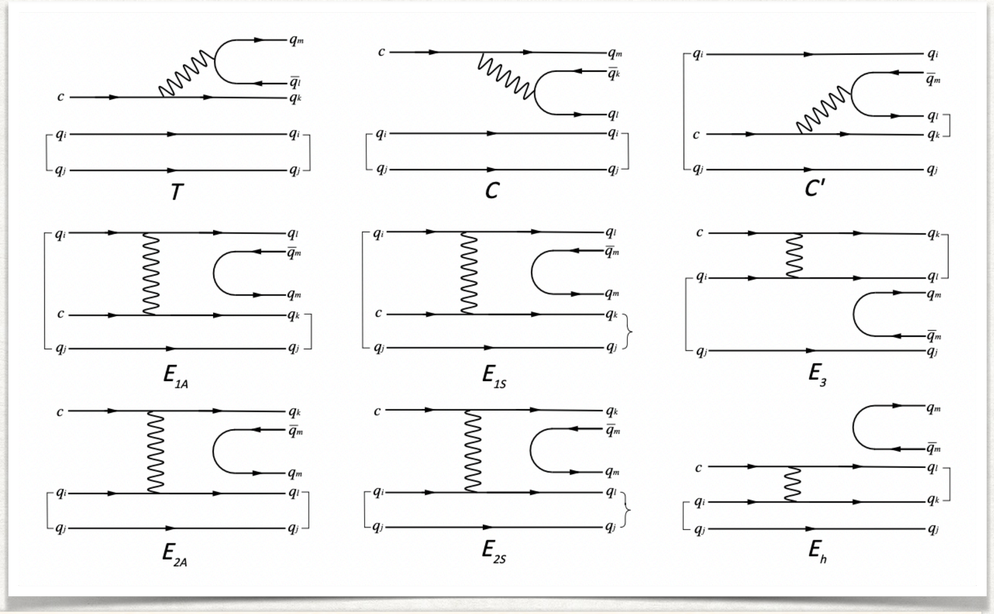
- Chau, Cheng, Tseng(1996): parameterize symmetric and antisymmetric (12) for octet baryon wave function



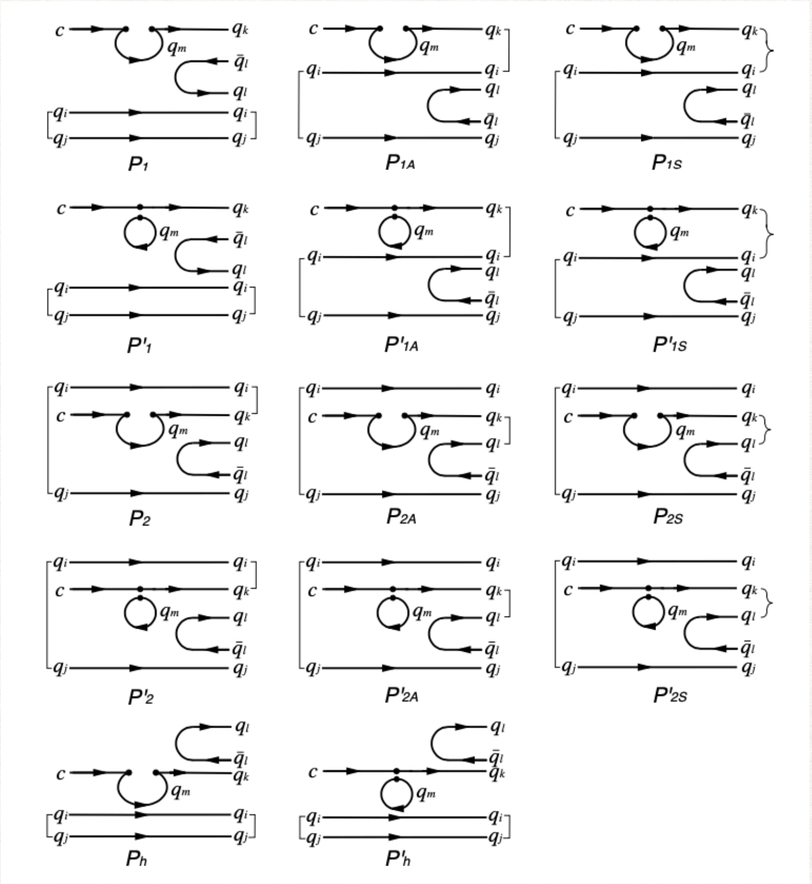
$$|\mathcal{B}^{m,k}(8)\rangle = a|\chi^m(1/2)_{A_{12}}\rangle|\psi^k(8)_{A_{12}}\rangle + b|\chi^m(1/2)_{S_{12}}\rangle|\psi^k(8)_{S_{12}}\rangle$$

- Kohara(1997): physics is independent of the chosen convention

Recent developments in Topological Diagram



$$
\begin{aligned}
\mathcal{A}_{\mathrm{TDA}} = \quad & T(\mathcal{B}_c)^{ij} H_l^{km} M_m^l \left[b_1 (\mathcal{B}_8)_{ijk} + b_2 (\mathcal{B}_8)_{ikj} + b_3 (\mathcal{B}_8)_{jki} \right] \\
& + C(\mathcal{B}_c)^{ij} H_k^{ml} M_m^k \left[b_4 (\mathcal{B}_8)_{ijl} + b_5 (\mathcal{B}_8)_{ilj} + b_6 (\mathcal{B}_8)_{jli} \right] \\
& + C'(\mathcal{B}_c)^{ij} H_m^{kl} M_i^m \left[b_7 (\mathcal{B}_8)_{klj} + b_8 (\mathcal{B}_8)_{kjl} + b_9 (\mathcal{B}_8)_{ljk} \right] \\
& + E_1(\mathcal{B}_c)^{ij} H_i^{kl} M_l^m \left[b_{10} (\mathcal{B}_8)_{jkm} + b_{11} (\mathcal{B}_8)_{jmk} + b_{12} (\mathcal{B}_8)_{kmj} \right] \\
& + E_2(\mathcal{B}_c)^{ij} H_i^{kl} M_k^m \left[b_{13} (\mathcal{B}_8)_{jlm} + b_{14} (\mathcal{B}_8)_{jml} + b_{15} (\mathcal{B}_8)_{lmj} \right] \\
& + E_3(\mathcal{B}_c)^{ij} H_i^{kl} M_j^m \left[b_{16} (\mathcal{B}_8)_{klm} + b_{17} (\mathcal{B}_8)_{kml} + b_{18} (\mathcal{B}_8)_{lmk} \right] \\
& + E_h(\mathcal{B}_c)^{ij} H_i^{kl} M_m^m \left[b_{19} (\mathcal{B}_8)_{jkl} + b_{20} (\mathcal{B}_8)_{jlk} + b_{21} (\mathcal{B}_8)_{klj} \right] ,
\end{aligned}
$$



$\mathscr{B}_c \to BP$

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Analysis of hadronic weak decays of charmed baryons in the topological diagrammatic approach

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Hadronic weak decays of charmed baryons in the topological diagrammatic approach: An update

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CP violation in hadronic weak decays of charmed baryons in the topological diagrammatic approach

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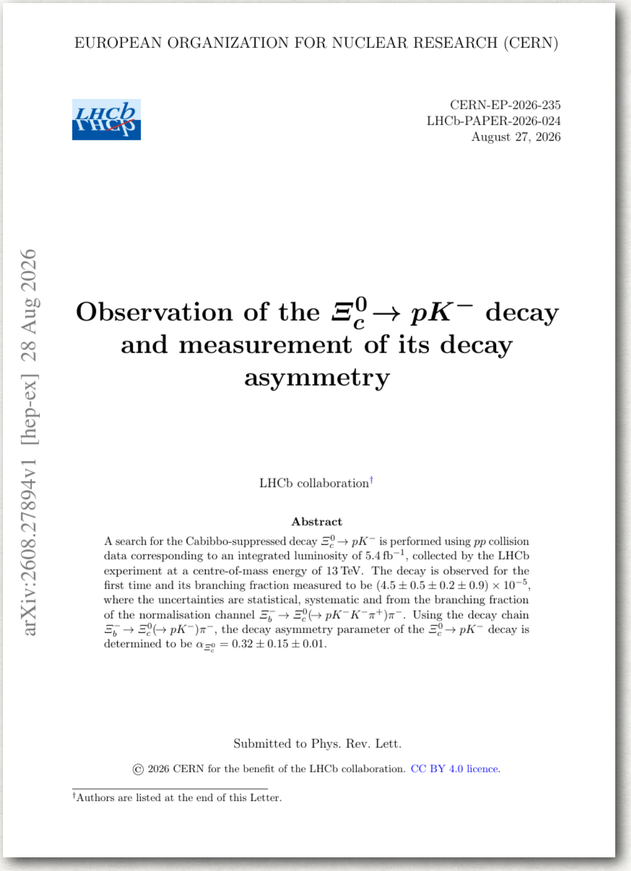
LATEST EXPERIMENTS

TABLE VII. Updated experimental data on branching fractions and Lee-Yang parameters. The upper entries correspond to those used in the earlier analysis [22], while the lower entries include the latest measurements from Belle and Belle II [24,25].

Observable	PDG [56]	BESIII	Belle	LHCb	Average
$10^2\mathcal{B}(\Lambda_c^+ \to \Lambda^0\pi^+)$	1.29 ± 0.05				1.29 ± 0.05
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^0\pi^+)$	1.27 ± 0.06				1.27 ± 0.06
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+\pi^0)$	1.24 ± 0.09				1.24 ± 0.09
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+\eta)$	0.32 ± 0.05				0.32 ± 0.05
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+\eta')$	0.41 ± 0.08				0.41 ± 0.08
$10^2\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)$	0.55 ± 0.07				0.55 ± 0.07
$10^4\mathcal{B}(\Lambda_c^+ \to \Lambda^0 K^+)$	6.42 ± 0.31				6.42 ± 0.31
$10^4\mathcal{B}(\Lambda_c^+ \to \Sigma^0 K^+)$	3.70 ± 0.31				3.70 ± 0.31
$10^4\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K_S)$	4.7 ± 1.4				4.7 ± 1.4
$10^4\mathcal{B}(\Lambda_c^+ \to n\pi^+)$	6.6 ± 1.3				6.6 ± 1.3
$10^4\mathcal{B}(\Lambda_c^+ \to p\pi^0)$	< 0.8	$1.56^{+0.75}_{-0.61}$			$1.56^{+0.75}_{-0.61}$
$10^2\mathcal{B}(\Lambda_c^+ \to pK_S)$	1.59 ± 0.07				1.59 ± 0.07
$10^3\mathcal{B}(\Lambda_c^+ \to p\eta)$	1.57 ± 0.12	1.63 ± 0.33			1.58 ± 0.11
$10^4\mathcal{B}(\Lambda_c^+ \to p\eta')$	4.8 ± 0.9				4.8 ± 0.9
$10^2\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$	1.43 ± 0.27		1.80 ± 0.52		1.80 ± 0.52
$10^2 \frac{\mathcal{B}(\Xi_c^0 \to \Xi^- K^+)}{\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)}$	2.75 ± 0.57				2.75 ± 0.57
$10^2 \frac{\mathcal{B}(\Xi_c^0 \to \Lambda K_S^0)}{\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)}$	22.5 ± 1.3				22.5 ± 1.3
$10^2 \frac{\mathcal{B}(\Xi_c^0 \to \Sigma^0 K_S^0)}{\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)}$	3.8 ± 0.7				3.8 ± 0.7
$10^2 \frac{\mathcal{B}(\Xi_c^0 \to \Sigma^+ K^-)}{\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)}$	12.3 ± 1.2				12.3 ± 1.2
$10^3\mathcal{B}(\Xi_c^0 \to \Xi^0\pi^0)$			6.9 ± 1.6		6.9 ± 1.6
$10^3\mathcal{B}(\Xi_c^0 \to \Xi^0\eta)$			1.6 ± 0.5		1.6 ± 0.5
$10^3\mathcal{B}(\Xi_c^0 \to \Xi^0\eta')$			1.2 ± 0.4		1.2 ± 0.4
$10^2\mathcal{B}(\Xi_c^+ \to \Xi^0\pi^+)$	1.6 ± 0.8		0.719 ± 0.323 [24]		0.84 ± 0.48
$\alpha(\Lambda_c^+ \to \Lambda^0\pi^+)$	-0.755 ± 0.006			-0.782 ± 0.010	-0.762 ± 0.006
$\alpha(\Lambda_c^+ \to \Sigma^0\pi^+)$	-0.466 ± 0.018				-0.466 ± 0.018
$\alpha(\Lambda_c^+ \to pK_S)$	0.18 ± 0.45			-0.744 ± 0.015	-0.743 ± 0.028
$\alpha(\Lambda_c^+ \to \Sigma^+\pi^0)$	-0.484 ± 0.027				-0.484 ± 0.027
$\alpha(\Lambda_c^+ \to \Sigma^+\eta)$	-0.99 ± 0.06				-0.99 ± 0.06
$\alpha(\Lambda_c^+ \to \Sigma^+\eta')$	-0.46 ± 0.07				-0.46 ± 0.07
$\alpha(\Lambda_c^+ \to \Lambda^0 K^+)$	-0.585 ± 0.052			-0.569 ± 0.065	-0.579 ± 0.041
$\alpha(\Lambda_c^+ \to \Sigma^0 K^+)$	-0.54 ± 0.20				-0.54 ± 0.20
$\alpha(\Lambda_c^+ \to \Xi^0 K^+)$		0.01 ± 0.16			0.01 ± 0.16
$\alpha(\Xi_c^0 \to \Xi^-\pi^+)$	-0.64 ± 0.05				-0.64 ± 0.05
$\alpha(\Xi_c^0 \to \Xi^0\pi^0)$			-0.90 ± 0.27		-0.90 ± 0.27
$\beta(\Lambda_c^+ \to \Lambda^0\pi^+)$				0.368 ± 0.021	0.368 ± 0.021
$\beta(\Lambda_c^+ \to \Lambda^0 K^+)$				0.35 ± 0.13	0.35 ± 0.13
$\gamma(\Lambda_c^+ \to \Lambda^0\pi^+)$				0.502 ± 0.017	0.502 ± 0.017
$\gamma(\Lambda_c^+ \to \Lambda^0 K^+)$				-0.743 ± 0.071	-0.743 ± 0.071
$10^2\mathcal{B}(\Xi_c^+ \to \Sigma^+ K_S^0)$			0.194 ± 0.090 [24]		0.194 ± 0.090
$10^2\mathcal{B}(\Xi_c^+ \to \Xi^0\pi^+)$			0.719 ± 0.323 [24]		0.719 ± 0.323
$10^2\mathcal{B}(\Xi_c^+ \to \Xi^0 K^+)$			0.049 ± 0.023 [24]		0.049 ± 0.023
$10^4\mathcal{B}(\Xi_c^+ \to pK_S^0)$			7.16 ± 3.25 [25]		7.16 ± 3.25
$10^4\mathcal{B}(\Xi_c^+ \to \Lambda\pi^+)$			4.52 ± 2.09 [25]		4.52 ± 2.09
$10^4\mathcal{B}(\Xi_c^+ \to \Sigma^0\pi^+)$			1.20 ± 0.55 [25]		1.20 ± 0.55

— up to 2025

- BF: 29
- alpha: 11
- beta: 2
- gamma:2



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2026-235
LHCb-PAPER-2026-024
August 27, 2026

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Observation of the $\Xi_c^0 \to pK^-$ decay and measurement of its decay asymmetry

LHCb collaboration[†]

Abstract

A search for the Cabibbo-suppressed decay $\Xi_c^0 \to pK^-$ is performed using pp collision data corresponding to an integrated luminosity of $5.4\,\text{fb}^{-1}$, collected by the LHCb experiment at a centre-of-mass energy of 13 TeV. The decay is observed for the first time and its branching fraction measured to be $(4.5 \pm 0.5 \pm 0.2 \pm 0.9) \times 10^{-5}$, where the uncertainties are statistical, systematic and from the branching fraction of the normalisation channel $\Xi_b^- \to \Xi_c^0(\to pK^-K^-\pi^+)\pi^-$. Using the decay chain $\Xi_b^- \to \Xi_c^0(\to pK^-)\pi^-$, the decay asymmetry parameter of the $\Xi_c^0 \to pK^-$ decay is determined to be $\alpha_{\Xi_c^0} = 0.32 \pm 0.15 \pm 0.01$.

Submitted to Phys. Rev. Lett.

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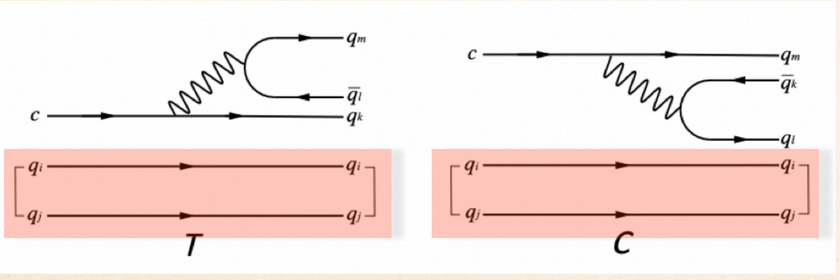
[†]Authors are listed at the end of this Letter.

Summer, 2026

$$
\begin{aligned}
\mathcal{A}_{\rm TDA} = \; & T(\mathcal{B}_c)^{ij} H_l^{km} M_m^l \left[b_1 \left(\mathcal{B}_8\right)_{ijk} + b_2 \left(\mathcal{B}_8\right)_{ikj} + b_3 \left(\mathcal{B}_8\right)_{jki} \right] \\
& + C(\mathcal{B}_c)^{ij} H_k^{ml} M_m^k \left[b_4 \left(\mathcal{B}_8\right)_{ijl} + b_5 \left(\mathcal{B}_8\right)_{ilj} + b_6 \left(\mathcal{B}_8\right)_{jli} \right] \\
& + C'(\mathcal{B}_c)^{ij} H_m^{kl} M_i^m \left[b_7 \left(\mathcal{B}_8\right)_{klj} + b_8 \left(\mathcal{B}_8\right)_{kjl} + b_9 \left(\mathcal{B}_8\right)_{ljk} \right] \\
& + E_1(\mathcal{B}_c)^{ij} H_i^{kl} M_l^m \left[b_{10} \left(\mathcal{B}_8\right)_{jkm} + b_{11} \left(\mathcal{B}_8\right)_{jmk} + b_{12} \left(\mathcal{B}_8\right)_{kmj} \right] \\
& + E_2(\mathcal{B}_c)^{ij} H_i^{kl} M_k^m \left[b_{13} \left(\mathcal{B}_8\right)_{jlm} + b_{14} \left(\mathcal{B}_8\right)_{jml} + b_{15} \left(\mathcal{B}_8\right)_{lmj} \right] \\
& + E_3(\mathcal{B}_c)^{ij} H_i^{kl} M_j^m \left[b_{16} \left(\mathcal{B}_8\right)_{klm} + b_{17} \left(\mathcal{B}_8\right)_{kml} + b_{18} \left(\mathcal{B}_8\right)_{lmk} \right] \\
& + E_h(\mathcal{B}_c)^{ij} H_i^{kl} M_m^m \left[b_{19} \left(\mathcal{B}_8\right)_{jkl} + b_{20} \left(\mathcal{B}_8\right)_{jlk} + b_{21} \left(\mathcal{B}_8\right)_{klj} \right] ,
\end{aligned}
$$

$$b_3 = -b_2$$

$$b_6 = -b_5$$



$$(\mathcal{B}_8)_{ijk} = \epsilon_{ijl} (\mathcal{B}_8^T)^l_k$$

$$
\begin{aligned}
\mathcal{A}_{\rm TDA} = \; & T(\mathcal{B}_c)^{ij} H_l^{km} M_m^l \left[b_1 (\mathcal{B}_8)_{ijk} + b_2 (\mathcal{B}_8)_{ikj} + b_3 (\mathcal{B}_8)_{jki} \right] \\
& + C(\mathcal{B}_c)^{ij} H_k^{ml} M_m^k \left[b_4 (\mathcal{B}_8)_{ijl} + b_5 (\mathcal{B}_8)_{ilj} + b_6 (\mathcal{B}_8)_{jli} \right] \\
& + C'(\mathcal{B}_c)^{ij} H_m^{kl} M_i^m \left[b_7 (\mathcal{B}_8)_{klj} + b_8 (\mathcal{B}_8)_{kjl} + b_9 (\mathcal{B}_8)_{ljk} \right] \\
& + E_1(\mathcal{B}_c)^{ij} H_i^{kl} M_l^m \left[b_{10} (\mathcal{B}_8)_{jkm} + b_{11} (\mathcal{B}_8)_{jmk} + b_{12} (\mathcal{B}_8)_{kmj} \right] \\
& + E_2(\mathcal{B}_c)^{ij} H_i^{kl} M_k^m \left[b_{13} (\mathcal{B}_8)_{jlm} + b_{14} (\mathcal{B}_8)_{jml} + b_{15} (\mathcal{B}_8)_{lmj} \right] \\
& + E_3(\mathcal{B}_c)^{ij} H_i^{kl} M_j^m \left[b_{16} (\mathcal{B}_8)_{klm} + b_{17} (\mathcal{B}_8)_{kml} + b_{18} (\mathcal{B}_8)_{lmk} \right] \\
& + E_h(\mathcal{B}_c)^{ij} H_i^{kl} M_m^m \left[b_{19} (\mathcal{B}_8)_{jkl} + b_{20} (\mathcal{B}_8)_{jlk} + b_{21} (\mathcal{B}_8)_{klj} \right] ,
\end{aligned}
$$

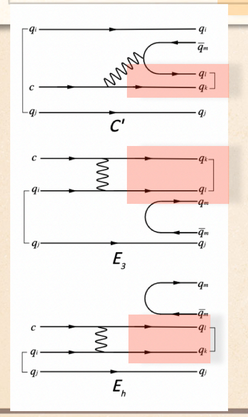
$$b_3 = -b_2$$

$$b_6 = -b_5$$

$$b_9 = -b_8$$

$$b_{18} = -b_{17}$$

$$b_{20} = -b_{19}$$



Korner-Pati-Woo theorem:

quark pair in a baryon produced by weak interactions
is required to be antisymmetric in flavor —> [l, k] asymmetric

$$
\begin{aligned}
\mathcal{A}_{\rm TDA} = \;& T(\mathcal{B}_c)^{ij} H_l^{km} M_m^l \left[b_1 (\mathcal{B}_8)_{ijk} + b_2 (\mathcal{B}_8)_{ikj} + b_3 (\mathcal{B}_8)_{jki} \right] \\
& + C(\mathcal{B}_c)^{ij} H_k^{ml} M_m^k \left[b_4 (\mathcal{B}_8)_{ijl} + b_5 (\mathcal{B}_8)_{ilj} + b_6 (\mathcal{B}_8)_{jli} \right] \\
& + C'(\mathcal{B}_c)^{ij} H_m^{kl} M_i^m \left[b_7 (\mathcal{B}_8)_{klj} + b_8 (\mathcal{B}_8)_{kjl} + b_9 (\mathcal{B}_8)_{ljk} \right] \\
& + E_1(\mathcal{B}_c)^{ij} H_i^{kl} M_l^m \left[b_{10} (\mathcal{B}_8)_{jkm} + b_{11} (\mathcal{B}_8)_{jmk} + b_{12} (\mathcal{B}_8)_{kmj} \right] \\
& + E_2(\mathcal{B}_c)^{ij} H_i^{kl} M_k^m \left[b_{13} (\mathcal{B}_8)_{jlm} + b_{14} (\mathcal{B}_8)_{jml} + b_{15} (\mathcal{B}_8)_{lmj} \right] \\
& + E_3(\mathcal{B}_c)^{ij} H_i^{kl} M_j^m \left[b_{16} (\mathcal{B}_8)_{klm} + b_{17} (\mathcal{B}_8)_{kml} + b_{18} (\mathcal{B}_8)_{lmk} \right] \\
& + E_h(\mathcal{B}_c)^{ij} H_i^{kl} M_m^m \left[b_{19} (\mathcal{B}_8)_{jkl} + b_{20} (\mathcal{B}_8)_{jlk} + b_{21} (\mathcal{B}_8)_{klj} \right] ,
\end{aligned}
$$

$$b_3 = -b_2$$

$$b_6 = -b_5$$

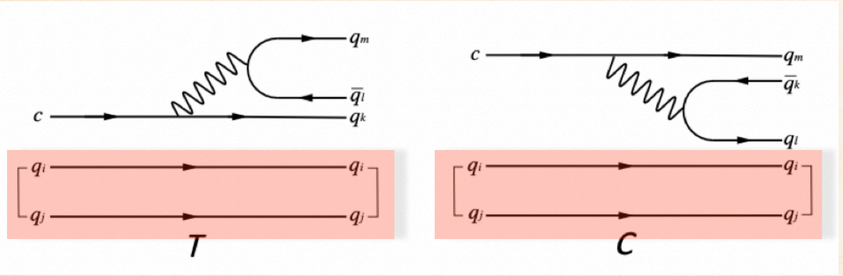
$$b_9 = -b_8$$

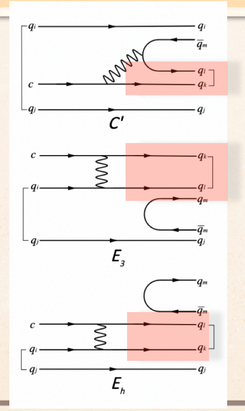
$$b_{12} = b_{11}$$

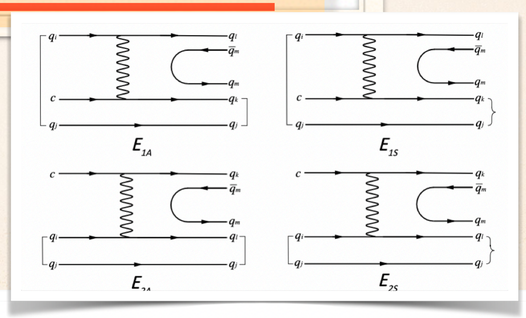
$$b_{15} = b_{14}$$

$$b_{18} = -b_{17}$$

$$b_{20} = -b_{19}$$

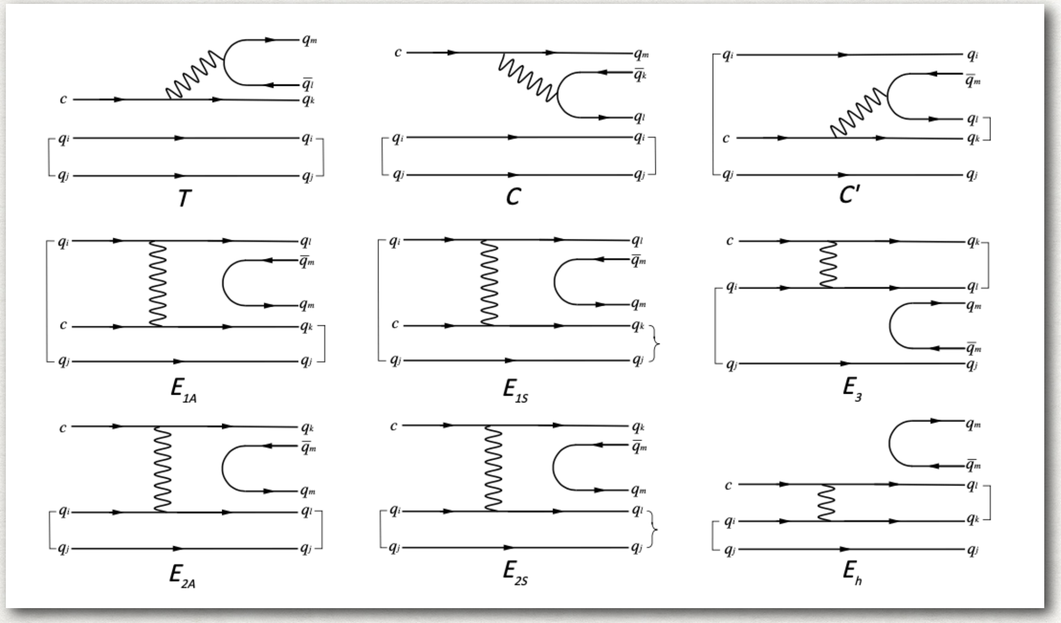






$$|\mathcal{B}^{m,k}(8)\rangle = a|\chi^m(1/2)_{A_{12}}\rangle|\psi^k(8)_{A_{12}}\rangle + b|\chi^m(1/2)_{S_{12}}\rangle|\psi^k(8)_{S_{12}}\rangle$$

DYNAMICS: TOPOLOGICAL DIAGRAMS



$$\mathcal{A}_{\rm TDA} = T(\mathcal{B}_c)^{ij}H_l^{km}(\mathcal{B}_8)_{ijk}M_m^l + C(\mathcal{B}_c)^{ij}H_k^{ml}(\mathcal{B}_8)_{ijl}M_m^k + C'(\mathcal{B}_c)^{ij}H_m^{kl}(\mathcal{B}_8)_{klj}M_i^m$$
$$+ E_{1A}(\mathcal{B}_c)^{ij}H_i^{kl}(\mathcal{B}_8)_{jkm}M_l^m + E_{1S}(\mathcal{B}_c)^{ij}H_i^{kl}M_l^m[(\mathcal{B}_8)_{jmk} + (\mathcal{B}_8)_{kmj}]$$
$$+ E_{2A}(\mathcal{B}_c)^{ij}H_i^{kl}(\mathcal{B}_8)_{jlm}M_k^m + E_{2S}(\mathcal{B}_c)^{ij}H_i^{kl}M_k^m[(\mathcal{B}_8)_{jml} + (\mathcal{B}_8)_{lmj}]$$
$$+ E_3(\mathcal{B}_c)^{ij}H_i^{kl}(\mathcal{B}_8)_{klm}M_j^m + E_h(\mathcal{B}_c)^{ij}H_i^{kl}(\mathcal{B}_8)_{klj}M_m^m,$$

$H_m^{kl}(\bar{q}_k c)(\bar{q}_l q^m)$ Weak interaction

- reduce independent diagrams to 7

$$E_{2A} = -E_{1A}, \qquad E_{2S} = -E_{1S}.$$ (KPW theorem)

- further reduction to 5 by redefinition

$$\tilde{T} = T - E_{1S}, \quad \tilde{C} = C + E_{1S}, \quad \tilde{C}' = C' - 2E_{1S},$$
$$\tilde{E}_1 = E_{1A} + E_{1S} - E_3, \quad \tilde{E}_h = E_h + 2E_{1S}.$$

$$M_j^i = \begin{pmatrix} \frac{\pi^0+\eta_q}{\sqrt{2}} & \pi^+ & K^+ \\ \pi^- & \frac{-\pi^0+\eta_q}{\sqrt{2}} & K^0 \\ K^- & \bar{K}^0 & \eta_s \end{pmatrix}, \quad (\mathcal{B}_c)^{ij} = \begin{pmatrix} 0 & \Lambda_c^+ & \Xi_c^+ \\ -\Lambda_c^+ & 0 & \Xi_c^0 \\ -\Xi_c^+ & -\Xi_c^0 & 0 \end{pmatrix}$$

$$(\mathcal{B}_8)_j^i = \begin{pmatrix} \frac{1}{\sqrt{6}}\Lambda^0 + \frac{1}{\sqrt{2}}\Sigma^0 & \Sigma^+ & p \\ \Sigma^- & \frac{1}{\sqrt{6}}\Lambda^0 - \frac{1}{\sqrt{2}}\Sigma^0 & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\Lambda^0 \end{pmatrix}.$$

AMPLITUDES & OBSERVABLES

TABLE I. TDA amplitudes for Cabibbo-favored (upper part) and singly Cabibbo-suppressed (lower part) $\mathcal{B}_c(\bar{3}) \to \mathcal{B}(8)M(8+1)$ decays. Expressions of $\widetilde{\text{TDA}}$ amplitudes are obtained using Eq. (20).

Channel	TDA	$\widetilde{\text{TDA}}$
$\Lambda_c^+ \to \Lambda\pi^+$	$\frac{1}{\sqrt{6}}(-4T + C' + E_{1A} + 3E_{1S} - E_3)$	$\frac{1}{\sqrt{6}}(-4\tilde{T} + \tilde{C}' + \tilde{E}_1)$
$\Lambda_c^+ \to \Sigma^0\pi^+$	$\frac{1}{\sqrt{2}}(-C' - E_{1A} + E_{1S} + E_3)$	$\frac{1}{\sqrt{2}}(-\tilde{C}' - \tilde{E}_1)$
$\Lambda_c^+ \to \Sigma^+\pi^0$	$\frac{1}{\sqrt{2}}(C' + E_{1A} - E_{1S} - E_3)$	$\frac{1}{\sqrt{2}}(\tilde{C}' + \tilde{E}_1)$
$\Lambda_c^+ \to \Sigma^+\eta_8$	$\frac{1}{\sqrt{6}}(-C' + E_{1A} + 3E_{1S} - E_3)$	$\frac{1}{\sqrt{6}}(-\tilde{C}' + \tilde{E}_1)$
$\Lambda_c^+ \to \Sigma^+\eta_1$	$\frac{1}{\sqrt{3}}(-C' + E_{1A} - 3E_{1S} - E_3 - 3E_h)$	$\frac{1}{\sqrt{3}}(-\tilde{C}' + \tilde{E}_1 - 3\tilde{E}_h)$
$\Lambda_c^+ \to \Xi^0 K^+$	$E_{1A} + E_{1S} - E_3$	$\tilde{E}_1$
$\Lambda_c^+ \to p\bar{K}^0$	$2C + 2E_{1S}$	$2\tilde{C}$
$\Xi_c^0 \to \Lambda\bar{K}^0$	$\frac{1}{\sqrt{6}}(2C - C' - E_{1A} + 3E_{1S} + E_3)$	$\frac{1}{\sqrt{6}}(2\tilde{C} - \tilde{C}' - \tilde{E}_1)$
$\Xi_c^0 \to \Sigma^0\bar{K}^0$	$\frac{1}{\sqrt{2}}(2C + C' + E_{1A} + E_{1S} - E_3)$	$\frac{1}{\sqrt{2}}(2\tilde{C} + \tilde{C}' + \tilde{E}_1)$
$\Xi_c^0 \to \Sigma^+ K^-$	$-E_{1A} - E_{1S} + E_3$	$-\tilde{E}_1$
$\Xi_c^0 \to \Xi^0\pi^0$	$\frac{1}{\sqrt{2}}(-C' + 2E_{1S})$	$\frac{1}{\sqrt{2}}(-\tilde{C}')$
$\Xi_c^0 \to \Xi^0\eta_8$	$\frac{1}{\sqrt{6}}(C' + 2E_{1A} - 2E_3)$	$\frac{1}{\sqrt{6}}(\tilde{C}' + 2\tilde{E}_1)$
$\Xi_c^0 \to \Xi^0\eta_1$	$\frac{1}{\sqrt{3}}(C' + 3E_{1S} - E_{1A} + E_3 + 3E_h)$	$\frac{1}{\sqrt{3}}(\tilde{C}' - \tilde{E}_1 + 3\widetilde{E_h})$
$\Xi_c^0 \to \Xi^-\pi^+$	$2T - 2E_{1S}$	$2\tilde{T}$
$\Xi_c^+ \to \Sigma^+\bar{K}^0$	$-2C - C'$	$-2\tilde{C} - \tilde{C}'$
$\Xi_c^+ \to \Xi^0\pi^+$	$-2T + C'$	$-2\tilde{T} + \tilde{C}'$

$$|\tilde{T}|_S e^{i\delta_S^{\tilde{T}}}, \quad |\tilde{C}|_S e^{i\delta_S^{\tilde{C}}}, \quad |\tilde{C}'|_S e^{i\delta_S^{\tilde{C}'}}, \quad |\tilde{E}_1|_S e^{i\delta_S^{\tilde{E}_1}}, \quad |\tilde{E}_h|_S e^{i\delta_S^{\tilde{E}_h}},$$
$$|\tilde{T}|_P e^{i\delta_P^{\tilde{T}}}, \quad |\tilde{C}|_P e^{i\delta_P^{\tilde{C}}}, \quad |\tilde{C}'|_P e^{i\delta_P^{\tilde{C}'}}, \quad |\tilde{E}_1|_P e^{i\delta_P^{\tilde{E}_1}}, \quad |\tilde{E}_h|_P e^{i\delta_P^{\tilde{E}_h}},$$

$$M(\mathcal{B}_c \to \mathcal{B}_f + P) = i\bar{u}_f(A - B\gamma_5)u_c,$$

$$\Gamma = \frac{p_c}{8\pi}\frac{(m_i + m_f)^2 - m_P^2}{m_i^2}(|A|^2 + \kappa^2|B|^2),$$
$$\alpha = \frac{2\kappa|A^*B|\cos(\delta_P - \delta_S)}{|A|^2 + \kappa^2|B|^2}, \qquad \beta = \frac{2\kappa|A^*B|\sin(\delta_P - \delta_S)}{|A|^2 + \kappa^2|B|^2},$$
$$\gamma = \frac{|A|^2 - \kappa^2|B|^2}{|A|^2 + \kappa^2|B|^2}, \tag{44}$$

FITTED PARAMETERS

TABLE II. The TDA coefficients and FSR parameters. The upper entries are tree-level coefficients obtained from the global fit in Case I. The middle ones are FSR parameters extracted from Eq. (70) while the lower entries associated with penguin diagrams are solved from Eq. (71). In the calculation, we have adopted $\rho_+ = -21$ and $r_- = 2.5$.

	$\lvert X_i\rvert_S$	$\lvert X_i\rvert_P$	$\delta_S^{X_i}$	$\delta_P^{X_i}$
	$(10^{-2} G_F\ \mathrm{GeV}^2)$		(in radian)	
$\tilde{T}$	4.31 ± 0.11	12.11 ± 0.31	$\cdots$	2.39 ± 0.04
$\tilde{C}$	3.23 ± 0.48	11.35 ± 0.93	3.10 ± 0.11	-0.72 ± 0.16
$\tilde{C}'$	5.84 ± 0.35	17.74 ± 0.92	0.02 ± 0.04	2.27 ± 0.11
$\tilde{E}_1$	2.79 ± 0.19	10.41 ± 0.47	-2.81 ± 0.06	1.83 ± 0.09
$\tilde{E}_h$	4.30 ± 0.50	13.26 ± 1.83	2.70 ± 0.11	-1.85 ± 0.20

	Case I		Case II	
	TDA	IRA	TDA	IRA
χ^2	65.47	65.47	89.53	90.08
χ^2/d.o.f.	3.27	3.27	3.73	3.75

RESULTS

TABLE VIII. The fit results based on the tilde TDA (upper) and tilde IRA (lower) in Case I. S- and P-wave amplitudes are in units of $10^{-2}G_F\text{GeV}^2$ and $\delta_P-\delta_S$ in radian.

Channel	$10^2\mathcal{B}$	α	β	γ	$\lvert A\rvert$	$\lvert B\rvert$	$\delta_P-\delta_S$	$10^2\mathcal{B}_{\text{exp}}$	α_{exp}	β_{exp}/γ_{exp}
$\Lambda_c^+\to\Lambda^0\pi^+$	1.25 ± 0.04	-0.76 ± 0.01	0.39 ± 0.02	0.51 ± 0.01	5.46 ± 0.10	9.04 ± 0.19	2.67 ± 0.02	1.29 ± 0.05	-0.762 ± 0.006	0.368 ± 0.021
	1.25 ± 0.04	-0.76 ± 0.01	0.39 ± 0.02	0.51 ± 0.01	5.46 ± 0.10	9.04 ± 0.19	2.67 ± 0.02			0.502 ± 0.017
$\Lambda_c^+\to\Sigma^0\pi^+$	1.21 ± 0.05	-0.47 ± 0.01	0.48 ± 0.09	-0.74 ± 0.06	2.22 ± 0.24	18.51 ± 0.50	2.35 ± 0.10	1.27 ± 0.06	-0.466 ± 0.018	
	1.21 ± 0.05	-0.47 ± 0.01	0.48 ± 0.09	-0.74 ± 0.06	2.22 ± 0.24	18.51 ± 0.50	2.35 ± 0.10			
$\Lambda_c^+\to\Sigma^+\pi^0$	1.22 ± 0.05	-0.47 ± 0.01	0.47 ± 0.09	-0.75 ± 0.06	2.22 ± 0.24	18.51 ± 0.50	2.35 ± 0.10	1.24 ± 0.09	-0.484 ± 0.027	
	1.22 ± 0.05	-0.47 ± 0.01	0.47 ± 0.09	-0.75 ± 0.06	2.22 ± 0.24	18.51 ± 0.50	2.35 ± 0.10			
$\Lambda_c^+\to\Sigma^+\eta$	0.35 ± 0.04	-0.91 ± 0.04	-0.08 ± 0.13	0.42 ± 0.09	3.03 ± 0.21	7.02 ± 0.68	-3.05 ± 0.15	0.32 ± 0.05	-0.99 ± 0.06	
	0.35 ± 0.04	-0.91 ± 0.04	-0.08 ± 0.13	0.42 ± 0.10	3.03 ± 0.21	7.02 ± 0.68	-3.05 ± 0.14			
$\Lambda_c^+\to\Sigma^+\eta'$	0.40 ± 0.07	-0.43 ± 0.07	0.87 ± 0.07	0.22 ± 0.24	4.22 ± 0.71	21.01 ± 2.55	2.03 ± 0.08	0.41 ± 0.08	-0.46 ± 0.07	
	0.40 ± 0.07	-0.43 ± 0.07	0.87 ± 0.07	0.22 ± 0.24	4.22 ± 0.71	21.01 ± 2.53	2.03 ± 0.08			
$\Lambda_c^+\to\Xi^0K^+$	0.33 ± 0.03	-0.07 ± 0.12	-0.99 ± 0.01	0.13 ± 0.09	2.65 ± 0.18	9.90 ± 0.45	-1.64 ± 0.12	0.55 ± 0.07	0.01 ± 0.16	
	0.33 ± 0.03	-0.07 ± 0.12	-0.99 ± 0.01	0.13 ± 0.09	2.65 ± 0.18	9.90 ± 0.45	-1.64 ± 0.12			
$\Lambda_c^+\to pK_S$	1.57 ± 0.06	-0.74 ± 0.03	0.59 ± 0.12	-0.32 ± 0.21	4.36 ± 0.66	15.43 ± 1.28	2.47 ± 0.10	1.59 ± 0.07	-0.743 ± 0.028	
	1.57 ± 0.06	-0.74 ± 0.03	0.59 ± 0.12	-0.32 ± 0.21	4.36 ± 0.66	15.43 ± 1.29	2.47 ± 0.10			
$\Xi_c^0\to\Xi^-\pi^+$	2.96 ± 0.08	-0.72 ± 0.03	0.67 ± 0.02	0.17 ± 0.04	8.20 ± 0.20	23.01 ± 0.58	2.39 ± 0.04	1.80 ± 0.52	-0.64 ± 0.05	
	2.96 ± 0.08	-0.72 ± 0.03	0.67 ± 0.03	0.17 ± 0.04	8.20 ± 0.20	23.01 ± 0.58	2.39 ± 0.04			
$\Xi_c^0\to\Xi^0\pi^0$	0.73 ± 0.04	-0.62 ± 0.07	0.78 ± 0.05	0.08 ± 0.10	3.93 ± 0.24	11.92 ± 0.61	2.25 ± 0.09	$0.69\pm0.16^{\text{a}}$	$-0.90\pm0.27^{\text{a}}$	
	0.73 ± 0.04	-0.62 ± 0.07	0.78 ± 0.05	0.08 ± 0.10	3.93 ± 0.23	11.92 ± 0.61	2.25 ± 0.09			
$\Xi_c^0\to\Xi^0\eta$	0.24 ± 0.04	0.23 ± 0.15	0.04 ± 0.15	-0.97 ± 0.03	0.38 ± 0.24	11.91 ± 0.98	0.19 ± 0.68	$0.16\pm0.05^{\text{a}}$		
	0.24 ± 0.04	0.23 ± 0.15	0.04 ± 0.15	-0.97 ± 0.03	0.38 ± 0.24	11.91 ± 0.97	0.19 ± 0.68			
$\Xi_c^0\to\Xi^0\eta'$	0.44 ± 0.06	-0.68 ± 0.06	0.73 ± 0.06	-0.02 ± 0.25	4.04 ± 0.69	23.43 ± 2.48	2.32 ± 0.08	$0.12\pm0.04^{\text{a}}$		
	0.44 ± 0.06	-0.68 ± 0.06	0.73 ± 0.06	-0.02 ± 0.24	4.04 ± 0.68	23.43 ± 2.45	2.32 ± 0.08			
$\Xi_c^+\to\Xi^0\pi^+$	0.85 ± 0.10	-0.89 ± 0.07	0.37 ± 0.10	0.27 ± 0.13	2.65 ± 0.19	6.63 ± 0.73	2.75 ± 0.12	0.84 ± 0.48		
	0.85 ± 0.10	-0.89 ± 0.07	0.37 ± 0.11	0.27 ± 0.13	2.65 ± 0.19	6.63 ± 0.74	2.75 ± 0.12			
$\Lambda_c^+\to\Lambda^0K^+$	0.0635 ± 0.0029	-0.57 ± 0.04	0.41 ± 0.07	-0.71 ± 0.04	0.57 ± 0.04	4.41 ± 0.11	2.52 ± 0.10	0.0642 ± 0.0031	-0.579 ± 0.041	0.35 ± 0.13
	0.0635 ± 0.0029	-0.57 ± 0.04	0.41 ± 0.07	-0.71 ± 0.04	0.57 ± 0.04	4.41 ± 0.11	2.52 ± 0.10			-0.743 ± 0.071
$\Lambda_c^+\to\Sigma^0K^+$	0.0393 ± 0.0022	-0.62 ± 0.07	0.77 ± 0.05	0.15 ± 0.10	0.90 ± 0.05	2.75 ± 0.14	2.25 ± 0.09	0.0370 ± 0.0031	-0.54 ± 0.20	
	0.0393 ± 0.0021	-0.62 ± 0.07	0.77 ± 0.05	0.15 ± 0.10	0.90 ± 0.05	2.75 ± 0.14	2.25 ± 0.09			
$\Lambda_c^+\to\Sigma^+K_S$	0.0394 ± 0.0022	-0.62 ± 0.07	0.77 ± 0.05	0.15 ± 0.10	0.90 ± 0.05	2.75 ± 0.14	2.25 ± 0.09	0.047 ± 0.014		
	0.0394 ± 0.0021	-0.62 ± 0.07	0.77 ± 0.05	0.15 ± 0.10	0.90 ± 0.05	2.75 ± 0.14	2.25 ± 0.09			
$\Lambda_c^+\to n\pi^+$	0.061 ± 0.006	-0.51 ± 0.11	-0.72 ± 0.04	0.46 ± 0.11	1.20 ± 0.06	1.76 ± 0.23	-2.19 ± 0.12	0.066 ± 0.013		
	0.061 ± 0.006	-0.51 ± 0.12	-0.72 ± 0.04	0.46 ± 0.11	1.20 ± 0.06	1.76 ± 0.23	-2.19 ± 0.12			
$\Lambda_c^+\to p\pi^0$	0.0188 ± 0.0033	-0.46 ± 0.36	-0.88 ± 0.26	-0.15 ± 0.47	0.51 ± 0.13	1.41 ± 0.36	-2.05 ± 0.45	$0.0156^{+0.0075}_{-0.0061}$		
	0.0188 ± 0.0033	-0.46 ± 0.36	-0.88 ± 0.26	-0.15 ± 0.47	0.51 ± 0.13	1.41 ± 0.36	-2.05 ± 0.45			
$\Lambda_c^+\to p\eta$	0.163 ± 0.009	-0.64 ± 0.06	0.49 ± 0.18	-0.59 ± 0.17	1.11 ± 0.24	5.60 ± 0.31	2.49 ± 0.18	0.158 ± 0.011		
	0.163 ± 0.009	-0.64 ± 0.06	0.49 ± 0.18	-0.59 ± 0.17	1.11 ± 0.24	5.60 ± 0.31	2.49 ± 0.18			

Channel	$10^2\mathcal{B}$	α	β	γ	$\lvert A\rvert$	$\lvert B\rvert$	$\delta_P-\delta_S$	$10^2\mathcal{B}_{\text{exp}}$	α_{exp}	β_{exp}/γ_{exp}
$\Lambda_c^+\to p\eta'$	0.052 ± 0.008	-0.46 ± 0.10	0.69 ± 0.17	-0.56 ± 0.2	0.77 ± 0.16	4.70 ± 0.54	2.17 ± 0.17	0.048 ± 0.009		
	0.052 ± 0.008	-0.46 ± 0.10	0.69 ± 0.17	-0.56 ± 0.2	0.77 ± 0.16	4.70 ± 0.54	2.17 ± 0.17			
$\Xi_c^+\to pK_S$	0.151 ± 0.008	-0.60 ± 0.06	0.75 ± 0.07	-0.26 ± 0.09	0.90 ± 0.05	2.75 ± 0.14	2.25 ± 0.09	0.0716 ± 0.0325		
	0.151 ± 0.008	-0.60 ± 0.06	0.75 ± 0.07	-0.26 ± 0.09	0.90 ± 0.05	2.75 ± 0.14	2.25 ± 0.09			
$\Xi_c^+\to\Lambda^0\pi^+$	0.021 ± 0.004	-0.27 ± 0.40	0.14 ± 0.25	0.95 ± 0.10	0.52 ± 0.05	0.22 ± 0.23	2.67 ± 1.17	0.0452 ± 0.0209		
	0.021 ± 0.004	-0.27 ± 0.41	0.14 ± 0.25	0.95 ± 0.10	0.52 ± 0.05	0.22 ± 0.23	2.67 ± 1.34			
$\Xi_c^+\to\Sigma^0\pi^+$	0.316 ± 0.009	-0.59 ± 0.02	0.57 ± 0.05	-0.57 ± 0.04	0.94 ± 0.05	5.19 ± 0.10	2.38 ± 0.06	0.120 ± 0.055		
	0.316 ± 0.009	-0.59 ± 0.02	0.57 ± 0.05	-0.57 ± 0.04	0.94 ± 0.05	5.19 ± 0.10	2.38 ± 0.06			
$\Xi_c^+\to\Sigma^+K_S$	0.191 ± 0.065	-0.76 ± 0.67	-0.07 ± 0.38	-0.65 ± 0.76	0.69 ± 0.67	4.64 ± 1.74	-3.05 ± 0.54	0.194 ± 0.090		
	0.191 ± 0.065	-0.76 ± 0.67	-0.07 ± 0.38	-0.65 ± 0.76	0.69 ± 0.67	4.64 ± 1.73	-3.05 ± 0.54			
$\Xi_c^+\to\Xi^0K^+$	0.114 ± 0.010	-0.40 ± 0.1	-0.57 ± 0.03	0.72 ± 0.07	1.20 ± 0.06	1.76 ± 0.23	-2.19 ± 0.12	0.049 ± 0.023		
	0.114 ± 0.010	-0.40 ± 0.1	-0.57 ± 0.03	0.72 ± 0.07	1.20 ± 0.06	1.76 ± 0.23	-2.19 ± 0.12			

Channel	$10^2\mathcal{R}_X$	α	β	γ	$\lvert A\rvert$	$\lvert B\rvert$	$\delta_P-\delta_S$	$10^2(\mathcal{R}_X)_{\text{exp}}$	α_{exp}	β_{exp}
$\Xi_c^0\to\Lambda K_S^0$	22.79 ± 0.76	-0.61 ± 0.02	0.60 ± 0.09	-0.51 ± 0.12	2.66 ± 0.32	13.15 ± 0.52	2.36 ± 0.08	22.9 ± 1.3		
	22.79 ± 0.76	-0.61 ± 0.02	0.60 ± 0.09	-0.51 ± 0.12	2.66 ± 0.32	13.15 ± 0.52	2.36 ± 0.08			
$\Xi_c^0\to\Sigma^0K_S^0$	3.76 ± 0.63	-0.54 ± 0.41	-0.81 ± 0.14	0.24 ± 0.50	1.72 ± 0.41	4.15 ± 1.30	-2.16 ± 0.43	3.8 ± 0.7		
	3.76 ± 0.63	-0.54 ± 0.41	-0.81 ± 0.14	0.24 ± 0.50	1.72 ± 0.41	4.15 ± 1.30	-2.16 ± 0.43			
$\Xi_c^0\to\Sigma^+K^-$	13.76 ± 0.94	-0.07 ± 0.12	-0.98 ± 0.02	-0.19 ± 0.09	2.65 ± 0.18	9.90 ± 0.45	-1.64 ± 0.12	12.3 ± 1.2		
	13.76 ± 0.94	-0.07 ± 0.12	-0.98 ± 0.02	-0.19 ± 0.09	2.65 ± 0.18	9.90 ± 0.45	-1.64 ± 0.12			
$\Xi_c^0\to\Xi^-K^+$	4.40 ± 0.02	-0.71 ± 0.03	0.66 ± 0.02	0.25 ± 0.04	1.89 ± 0.05	5.30 ± 0.13	2.39 ± 0.04	2.75 ± 0.57		
	4.40 ± 0.02	-0.71 ± 0.03	0.66 ± 0.02	0.25 ± 0.04	1.89 ± 0.05	5.30 ± 0.13	2.39 ± 0.04			

$\Xi_c^0\to pK^-$	0.31 ± 0.02	-0.06 ± 0.11	-0.90 ± 0.04	-0.44 ± 0.07	0.61 ± 0.04	2.28 ± 0.10	-1.64 ± 0.12			
	0.31 ± 0.02	-0.06 ± 0.11	-0.90 ± 0.04	-0.44 ± 0.07	0.61 ± 0.04	2.28 ± 0.10	-1.64 ± 0.12			

UPDATED RESULTS

preliminary

Table 1: Theory predictions and experimental averages for channels with at least one experimental value. Both theoretical and experimental branching fractions are given in units of $10^2\mathcal{B}$.

Channel	$10^2\mathcal{B}$	α	β	γ	$10^2\lvert A\rvert$	$10^2\lvert B\rvert$	$\delta_P-\delta_S$	$10^2\mathcal{B}_{\rm exp}$	$\alpha_{\rm exp}$	$\beta/\gamma_{\rm exp}$
$\Lambda_c^+\to\Lambda^0K^+$	0.0507 ± 0.0025	-0.654 ± 0.026	0.617 ± 0.030	-0.437 ± 0.033	0.713 ± 0.031	3.613 ± 0.085	2.385 ± 0.040	0.0642 ± 0.0031	-0.579 ± 0.041	0.35 ± 0.13, -0.743 ± 0.071
$\Lambda_c^+\to\Sigma^0K^+$	0.0414 ± 0.0011	-0.605 ± 0.015	0.776 ± 0.011	-0.179 ± 0.025	0.784 ± 0.018	3.315 ± 0.048	2.233 ± 0.019	0.0370 ± 0.0031	-0.54 ± 0.20	
$\Lambda_c^+\to\Sigma^+K_S$	0.0414 ± 0.0011	-0.605 ± 0.015	0.775 ± 0.011	-0.182 ± 0.025	0.784 ± 0.018	3.315 ± 0.048	2.233 ± 0.019	0.047 ± 0.014	0.01 ± 0.16	
$\Lambda_c^+\to p\pi^0$	0.0160 ± 0.0019	0.845 ± 0.083	-0.34 ± 0.13	0.41 ± 0.11	0.603 ± 0.037	0.93 ± 0.12	-0.38 ± 0.16	$0.0156^{+0.0075}_{-0.0075}$		
$\Lambda_c^+\to p\eta$	0.1585 ± 0.0080	-0.671 ± 0.038	0.657 ± 0.043	-0.344 ± 0.053	1.377 ± 0.061	5.09 ± 0.17	2.366 ± 0.058	0.158 ± 0.01		
$\Lambda_c^+\to p\eta'$	0.0553 ± 0.0078	-0.458 ± 0.061	0.35 ± 0.12	-0.819 ± 0.060	0.510 ± 0.084	5.25 ± 0.40	2.50 ± 0.17	0.048 ± 0.009		
$\Lambda_c^+\to n\pi^+$	0.0643 ± 0.0031	-0.578 ± 0.029	-0.676 ± 0.033	0.457 ± 0.035	1.227 ± 0.034	1.803 ± 0.070	-2.278 ± 0.045	0.066 ± 0.013		
$\Lambda_c^+\to\Lambda\pi^+$	1.256 ± 0.032	-0.7653 ± 0.0055	0.414 ± 0.014	0.493 ± 0.012	5.442 ± 0.074	9.28 ± 0.16	2.645 ± 0.015	1.29 ± 0.05	-0.762 ± 0.006	0.368 ± 0.021, 0.502 ± 0.017
$\Lambda_c^+\to\Sigma^0\pi^+$	1.192 ± 0.034	-0.469 ± 0.014	0.439 ± 0.027	-0.766 ± 0.017	2.100 ± 0.092	18.49 ± 0.25	2.390 ± 0.035	1.27 ± 0.06	-0.466 ± 0.018	
$\Lambda_c^+\to\Sigma^+\pi^0$	1.202 ± 0.034	-0.468 ± 0.014	0.437 ± 0.027	-0.768 ± 0.017	2.100 ± 0.092	18.49 ± 0.25	2.390 ± 0.035	1.24 ± 0.09	-0.484 ± 0.027	
$\Lambda_c^+\to\Sigma^+\eta$	0.276 ± 0.024	-0.942 ± 0.026	0.237 ± 0.086	0.237 ± 0.059	2.53 ± 0.11	7.18 ± 0.46	2.895 ± 0.092	0.32 ± 0.05	-0.99 ± 0.06	
$\Lambda_c^+\to\Sigma^+\eta'$	0.309 ± 0.041	-0.691 ± 0.065	0.659 ± 0.100	-0.30 ± 0.15	2.80 ± 0.40	23.8 ± 1.7	2.38 ± 0.11	0.41 ± 0.08	-0.46 ± 0.07	
$\Lambda_c^+\to p\bar{K}^0$	3.09 ± 0.11	-0.732 ± 0.026	0.652 ± 0.032	-0.197 ± 0.044	6.64 ± 0.20	20.62 ± 0.55	2.414 ± 0.041	1.59 ± 0.07	-0.743 ± 0.028	
$\Xi_c^0\to\Xi^0\pi^0$	0.784 ± 0.020	-0.596 ± 0.016	0.765 ± 0.011	-0.244 ± 0.024	3.394 ± 0.077	14.35 ± 0.21	2.233 ± 0.019	0.719 ± 0.323		
$\Xi_c^0\to\Xi^0\eta$	0.250 ± 0.023	-0.002 ± 0.074	0.235 ± 0.067	-0.972 ± 0.016	0.40 ± 0.12	12.27 ± 0.57	1.58 ± 0.32	0.69 ± 0.16		
$\Xi_c^0\to\Xi^0\eta'$	0.387 ± 0.049	-0.618 ± 0.061	0.693 ± 0.079	-0.37 ± 0.14	3.04 ± 0.44	25.4 ± 1.7	2.299 ± 0.089	0.16 ± 0.05		
$\Xi_c^0\to pK^-$	0.01236 ± 0.00067	0.392 ± 0.056	-0.881 ± 0.034	-0.264 ± 0.081	0.444 ± 0.026	1.353 ± 0.060	-1.153 ± 0.064	0.0045 ± 0.0010	0.32 ± 0.15	
$\Xi_c^0\to\Xi^-\pi^+$	2.926 ± 0.040	-0.7116 ± 0.0052	0.6881 ± 0.0055	0.142 ± 0.012	8.062 ± 0.077	23.22 ± 0.20	2.3729 ± 0.0075	1.80 ± 0.52	-0.64 ± 0.05	
$\Xi_c^+\to\Lambda^0\pi^+$	0.0281 ± 0.0024	-0.349 ± 0.068	0.857 ± 0.034	-0.378 ± 0.079	0.338 ± 0.026	1.340 ± 0.070	1.958 ± 0.074	0.0452 ± 0.0209		
$\Xi_c^+\to\Sigma^0\pi^+$	0.2829 ± 0.0079	-0.622 ± 0.014	0.640 ± 0.017	-0.452 ± 0.019	1.004 ± 0.025	4.717 ± 0.065	2.342 ± 0.022	0.0120 ± 0.0055		
$\Xi_c^+\to\Sigma^+\eta$	0.084 ± 0.011	-0.734 ± 0.094	-0.13 ± 0.11	0.67 ± 0.10	1.020 ± 0.067	1.43 ± 0.26	-3.0 ± 1.2	0.69 ± 0.16	-0.90 ± 0.27	
$\Xi_c^+\to\Sigma^+\eta'$	0.126 ± 0.015	-0.374 ± 0.065	0.832 ± 0.055	-0.41 ± 0.12	0.90 ± 0.11	5.80 ± 0.40	1.994 ± 0.073	0.16 ± 0.05		
$\Xi_c^+\to\Xi^0K^+$	0.1197 ± 0.0060	-0.455 ± 0.024	-0.532 ± 0.030	0.714 ± 0.021	1.227 ± 0.034	1.803 ± 0.070	-2.278 ± 0.045	0.049 ± 0.023		
$\Xi_c^+\to pK_{S/L}$	0.1809 ± 0.0045	-0.520 ± 0.016	0.667 ± 0.012	-0.534 ± 0.019	0.784 ± 0.018	3.315 ± 0.048	2.233 ± 0.019	0.0716 ± 0.0325		
$\Xi_c^+\to\Sigma^+\bar{K}^0$	0.375 ± 0.067	-0.03 ± 0.18	0.35 ± 0.20	0.936 ± 0.074	2.29 ± 0.20	1.28 ± 0.77	1.65 ± 0.53	0.194 ± 0.090		
$\Xi_c^+\to\Xi^0\pi^+$	1.232 ± 0.085	-0.898 ± 0.017	-0.009 ± 0.045	0.439 ± 0.034	3.40 ± 0.13	7.01 ± 0.31	-3.1 ± 4.9	0.719 ± 0.323		

Observation of the $\Xi_c^0\to pK^-$ decay and measurement of its decay asymmetry

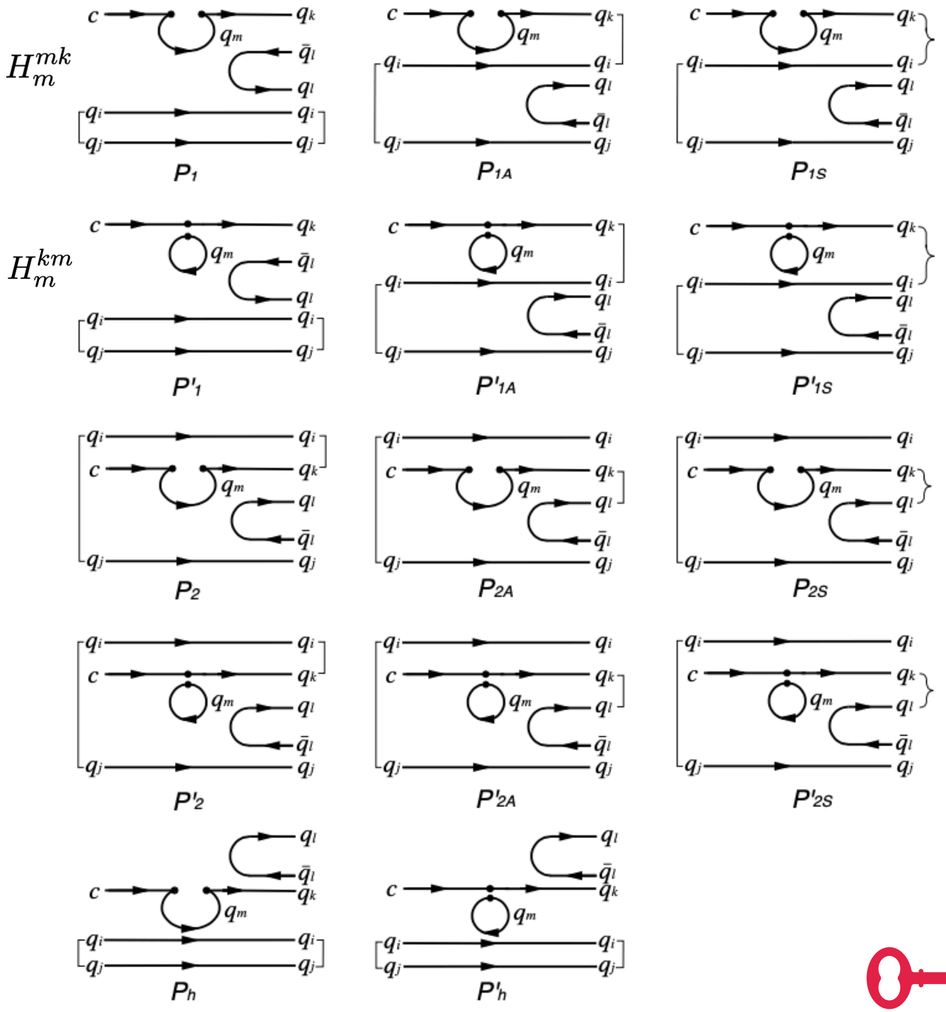
LHCb collaboration[†]

Abstract

Cabibbo-suppressed decay $\Xi_c^0\to pK^-$ is performed using pp collision ding to an integrated luminosity of $5.4\,\text{fb}^{-1}$, collected by the LHCb a centre-of-mass energy of 13 TeV. The decay is observed for the ts branching fraction measured to be $(4.5\pm0.5\pm0.2\pm0.9)\times10^{-5}$, rtainties are statistical, systematic and from the branching fraction sation channel $\Xi_b^-\to\Xi_c^0(\to pK^-K^-\pi^+)\pi^-$. Using the decay chain $K^-)\pi^-$, the decay asymmetry parameter of the $\Xi_c^0\to pK^-$ decay is be $\alpha_{\Xi_c^0}=0.32\pm0.15\pm0.01$.

TOPOLOGICAL DIAGRAM @ PENGUIN

H.Y. Cheng, FX, H. L. Zhong, PRD 111 (2025), 034011



Similar to tree diagrams

$$\begin{aligned}\mathcal{A}_{\rm TDA} = \quad & P_h(\mathcal{B}_c)^{ij} H_m^{mk} \left(\overline{\mathcal{B}}_8\right)_{ijk} (P^\dagger)_l^l + P_1(\mathcal{B}_c)^{ij} H_m^{mk} \left(\overline{\mathcal{B}}_8\right)_{ijl} (P^\dagger)_k^l \\ & + P_{2A}(\mathcal{B}_c)^{ij} H_m^{mk} \left(\overline{\mathcal{B}}_8\right)_{kil} (P^\dagger)_j^l + P_{2S}(\mathcal{B}_c)^{ij} H_m^{mk} (P^\dagger)_j^l \left[\left(\overline{\mathcal{B}}_8\right)_{kli} + \left(\overline{\mathcal{B}}_8\right)_{ilk}\right] \\ & + P'_h(\mathcal{B}_c)^{ij} H_m^{km} \left(\overline{\mathcal{B}}_8\right)_{ijk} (P^\dagger)_l^l + P'_1(\mathcal{B}_c)^{ij} H_m^{km} \left(\overline{\mathcal{B}}_8\right)_{ijl} (P^\dagger)_k^l \\ & + P'_{2A}(\mathcal{B}_c)^{ij} H_m^{km} \left(\overline{\mathcal{B}}_8\right)_{kil} (P^\dagger)_j^l + P'_{2S}(\mathcal{B}_c)^{ij} H_m^{km} (P^\dagger)_j^l \left[\left(\overline{\mathcal{B}}_8\right)_{kli} + \left(\overline{\mathcal{B}}_8\right)_{ilk}\right]\end{aligned}$$

$$H_k^{ij} = \frac{1}{2}\left[(H_{15})_k^{ij} + (H_{\overline{6}})_k^{ij}\right] + \delta_k^j \left(\frac{3}{2}(H_{3p})^i - \frac{1}{2}(H_{3t})^i\right) + \delta_k^i \left(\frac{3}{2}(H_{3t})^j - \frac{1}{2}(H_{3p})^j\right)$$

$$\begin{aligned}\mathcal{A}_{\rm TDA}^{\lambda_b} = \quad & \tilde{b}_1(\mathcal{B}_c)_i \, (H_3)^j \, (\overline{\mathcal{B}}_8)_j^i (P^\dagger)_l^l + \tilde{b}_2(\mathcal{B}_c)_i \, (H_3)^j \, (\overline{\mathcal{B}}_8)_j^l (P^\dagger)_l^i + \tilde{b}_3(\mathcal{B}_c)_i \, (H_3)^i \, (\overline{\mathcal{B}}_8)_j^l (P^\dagger)_l^j \\ & + \tilde{b}_4(\mathcal{B}_c)_i \, (H_3)^l \, (\overline{\mathcal{B}}_8)_j^i (P^\dagger)_l^j + \tilde{b}_5(\mathcal{B}_c)_i \, (H_{15^b})_l^{jk} \, (\overline{\mathcal{B}}_8)_j^i (P^\dagger)_k^l,\end{aligned}$$

$$\begin{aligned}\tilde{b}_1 &= \frac{1}{4}(\tilde{T} - 3\tilde{C}) - \frac{1}{2}\tilde{C}' - \frac{1}{2}\tilde{E}_h - 2\tilde{P}_h - 2\tilde{P}_{2S}, \\ \tilde{b}_2 &= \frac{1}{2}\tilde{C}' + 2\tilde{P}_{2S}, \\ \tilde{b}_3 &= -\frac{1}{2}\tilde{C}' + \frac{1}{2}\tilde{E}_{1A} - \tilde{P}_{2A} - \tilde{P}_{2S}, \\ \tilde{b}_4 &= -\frac{1}{4}(3\tilde{T} - \tilde{C}) + \frac{1}{2}\tilde{C}' + \frac{1}{2}\tilde{E}_1 - 2\tilde{P}_1 + \tilde{P}_{2A} + \tilde{P}_{2S}, \\ \tilde{b}_5 &= \tilde{T} + \tilde{C},\end{aligned}$$

$$\begin{aligned}\tilde{P}_1 &= P_1 + E_{1S} - \frac{1}{2}E_3, & \tilde{P}_h &= P_h - E_{1S}, \\ \tilde{P}_{2S} &= P_{2S} + E_{1S}, & \tilde{P}_{2A} &= P_{2A} + E_{1S} - E_3, \\ \tilde{P}'_1 &= P'_1 - E_{1S} + \frac{1}{2}E_3, & \tilde{P}'_h &= P'_h + E_{1S}, \\ \tilde{P}'_{2S} &= P'_{2S} - E_{1S}, & \tilde{P}'_{2A} &= P'_{2A} - E_{1S} + E_3.\end{aligned}$$

contribute to CPV

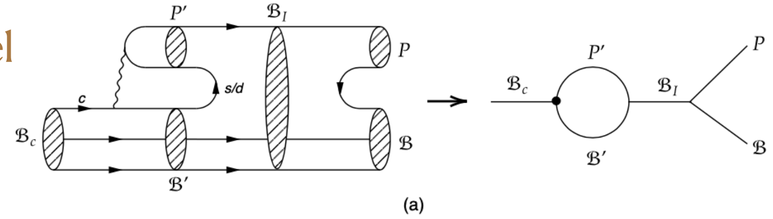
FINAL-STATE RESCATTERING

Factorizable contribution: $\mathcal{L}_{\mathcal{B}_c\mathcal{B}P} = \sum_{P,\mathcal{B},\mathcal{B}_c} F_{\mathcal{B}_c\mathcal{B}P} P^\dagger \overline{\mathcal{B}} \mathcal{B}_c = (P^\dagger)^k_j (\overline{\mathcal{B}})^l_i \left(\tilde{F}_V^+ (H_+)^{ij}_k + \tilde{F}_V^- (H_-)^{ij}_k \right) (\mathcal{B}_c)_l,$

X.G. He, C.W. Liu, Sci. Bull. 70 (2025) 2598

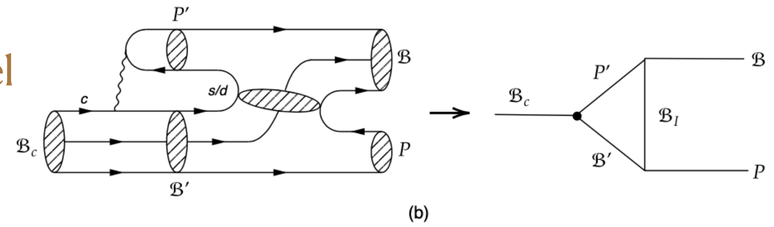
Non-factorizable contribution: FSR

s-channel



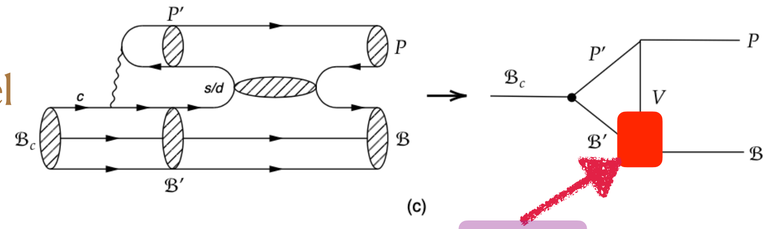
$$A^s = S^- \left[-\frac{1}{3}(r_- + 4)\tilde{f}^b - \frac{1}{3}(r_-^2 + 4r_-)\tilde{f}^c - \frac{1}{6}(7r_- - 2)\tilde{f}_3^b + \frac{1}{18}(r_- + 1)(7r_- - 2)\tilde{f}_3^c - \frac{1}{6}r_-(7r_- - 2)\tilde{f}_3^d \right],$$

t-channel



$$A^t = \sum_{\lambda=\pm} T_\lambda^- \left[-\frac{1}{9}(2r_\lambda^2 + 4r_\lambda + 11)\tilde{f}^a + \frac{1}{3}(2r_\lambda^2 - r_\lambda)\tilde{f}^b + \frac{1}{3}(r_\lambda^2 - 2r_\lambda + 3)\tilde{f}^c + \frac{1}{3}(2r_\lambda^2 - 2r_\lambda - 4)\tilde{f}^d - \frac{1}{18}(10r_\lambda^2 + 2r_\lambda + 1)\tilde{f}_3^a + \frac{1}{3}(r_\lambda^2 - \frac{5}{2}r_\lambda + 1)\tilde{f}_3^b - \frac{1}{18}(r_\lambda^2 + 11r_\lambda + 1)\tilde{f}_3^c + \frac{1}{6}(r_\lambda + 1)^2\tilde{f}_3^d \right],$$

u-channel



$$A^u = U^- \left[\frac{2}{3}(1 - 2\rho_+)\tilde{f}^b + \tilde{f}^d - \frac{1}{2}\tilde{f}_3^a + \frac{1}{6}(1 + 2\rho_+)\tilde{f}_3^b - \frac{1}{18}(1 + 10\rho_+)\tilde{f}_3^c + \frac{1}{6}(1 - 2\rho_+)\tilde{f}_3^d \right],$$

$$\mathcal{L}_{V\mathcal{B}'\mathcal{B}} = f_{V\mathcal{B}'\mathcal{B}} \mathrm{Tr}(\overline{\mathcal{B}}' \gamma_\mu V^\mu \mathcal{B}) + \frac{\tilde{f}_{V\mathcal{B}'\mathcal{B}}}{m_{\mathcal{B}'} + m_{\mathcal{B}}} \mathrm{Tr}(\overline{\mathcal{B}}' \sigma_{\mu\nu} \mathcal{B}\, \partial^\mu V^\nu).$$

tensor coupling dominated

H.Y. Cheng, FX, H.L. Zhong, PRD 112 (2025) 5, 054022

1. LCSR indicates tensor coupling one order of magnitude larger T.M. Aliev et. al., PRD 80 (2009), 016010

2. Realistic calculation in $B_c \to BV$ implies two traces are of the same order C. P. Jia et. al., JHEP 11, 072 (2024)

MATCHING FSR & IRA (TDA)

$$A^{\text{FSR}} = A^{\text{IRA}}$$

$$\begin{aligned}
\tilde{f}^a &= -\frac{1}{3}(2r_-^2+4r_-+11)T^- \\
\tilde{f}^b &= \tilde{F}_V^- - (r_-+4)S^- - 2(2\rho_+-1)U^- + (2r_-^2-r_-)T^-, \\
\tilde{f}^c &= -r_-(r_-+4)S^- + (r_-^2-2r_-+3)T^-, \\
\tilde{f}^d &= \tilde{F}_V^- + 3U^- + (2r_-^2-2r_--4)T^-, \\
\tilde{f}^e &= \tilde{F}_V^+,
\end{aligned}$$

$$\begin{aligned}
\tilde{f}_3^a &= \frac{1}{4}(-\tilde{F}_V^+ + 2\tilde{F}_V^-) - \frac{3}{2}U^- - \frac{1}{6}(10r_-^2+2r_-+1)T^-, \\
\tilde{f}_3^b &= -\frac{1}{2}(7r_--2)S^- + \frac{1}{2}(1+2\rho_+)U^- + \frac{1}{2}(2r_-^2-5r_-+2)T^-, \\
\tilde{f}_3^c &= \frac{1}{6}(r_-+1)(7r_--2)S^- - \frac{1}{6}(r_-^2+11r_-+1)T^- - \frac{1}{6}(10\rho_++1)U^-, \\
\tilde{f}_3^d &= -\frac{1}{4}(\tilde{F}_V^+ + 2\tilde{F}_V^-) - \frac{1}{2}r_-(7r_--2)S^- + \frac{1}{2}U^- + \frac{1}{2}(r_-+1)^2T^-,
\end{aligned}$$

$r_- = r_+ = 2.5 \pm 0.8$ X.G. He, C.W. Liu, Sci. Bull. 70 (2025) 2598

$\tilde{\rho}_+ = -21$ T.M. Aliev et. al., PRD 80 (2009), 016010

$$A^{\text{FSR}} = A^{\text{TDA}}$$

$$\begin{aligned}
\tilde{T} &= \frac{1}{2}(\tilde{F}_V^+ + \tilde{F}_V^-) - \frac{1}{2}(r_-+4)S^- + \frac{1}{2}(2r_-^2-r_-)T^- - (2\rho_+-1)U^-, \\
\tilde{C} &= \frac{1}{2}(\tilde{F}_V^+ - \tilde{F}_V^-) + \frac{1}{2}(r_-+4)S^- - \frac{1}{2}(2r_-^2-r_-)T^- + (2\rho_+-1)U^-, \\
\tilde{C}' &= -(r_-+4)S^- + (r_-+4)T^- - (4\rho_++1)U^-, \\
\tilde{E}_1 &= r_-(r_-+4)S^- - (r_-^2-2r_-+3)T^-, \\
\tilde{E}_h &= -\frac{1}{3}(2r_-^2+4r_-+11)T^-,
\end{aligned}$$

$$\begin{aligned}
\tilde{b}_1 &= \frac{1}{4}(-\tilde{F}_V^+ + 2\tilde{F}_V^-) - \frac{1}{6}(10r_-^2+2r_-+1)T^- - \frac{3}{2}U^-, \\
\tilde{b}_2 &= -\frac{1}{2}(7r_--2)S^- + \frac{1}{2}(2r_-^2-5r_-+2)T^- + \frac{1}{2}(2\rho_++1)U^-, \\
\tilde{b}_3 &= \frac{1}{6}(r_-+1)(7r_--2)S^- - \frac{1}{6}(r_-^2+11r_-+1)T^- - \frac{1}{6}(10\rho_++1)U^-, \\
\tilde{b}_4 &= -\frac{1}{4}(\tilde{F}_V^+ + 2\tilde{F}_V^-) - \frac{1}{2}r_-(7r_--2)S^- + \frac{1}{2}(r_-+1)^2T^- + \frac{1}{2}U^-,
\end{aligned}$$

FITTED PARAMETERS

	$\lvert X_i\rvert_S$	$\lvert X_i\rvert_P$	$\delta_S^{X_i}$	$\delta_P^{X_i}$
	$(10^{-2}G_F\ \mathrm{GeV}^2)$		(in radian)	
$\tilde{T}$	4.31 ± 0.11	12.11 ± 0.31	–	2.39 ± 0.04
$\tilde{C}$	3.23 ± 0.48	11.35 ± 0.93	3.10 ± 0.11	-0.72 ± 0.16
$\tilde{C}'$	5.84 ± 0.35	17.74 ± 0.92	0.02 ± 0.04	2.27 ± 0.11
$\tilde{E}_1$	2.79 ± 0.19	10.41 ± 0.47	-2.81 ± 0.06	1.83 ± 0.09
$\tilde{E}_h$	4.30 ± 0.50	13.26 ± 1.83	2.70 ± 0.11	-1.85 ± 0.20
$\tilde{F}_V^+$	1.10 ± 0.43	0.83 ± 0.46	0.13 ± 0.35	2.01 ± 1.37
$\tilde{F}_V^-$	0.48 ± 0.43	7.01 ± 1.79	0.69 ± 1.02	-2.81 ± 0.15
S^-	0.12 ± 0.01	0.92 ± 0.05	-2.20 ± 0.11	1.66 ± 0.08
T^-	0.39 ± 0.04	1.19 ± 0.16	-0.45 ± 0.11	1.29 ± 0.20
U^-	0.04 ± 0.00	0.22 ± 0.01	0.17 ± 0.08	2.43 ± 0.08
$\tilde{b}_1$	4.57 ± 0.78	16.04 ± 2.43	2.89 ± 0.13	-2.00 ± 0.18
$\tilde{b}_2$	0.49 ± 0.11	10.00 ± 0.22	1.30 ± 0.25	-1.11 ± 0.07
$\tilde{b}_3$	1.38 ± 0.30	10.89 ± 1.13	2.93 ± 0.19	2.47 ± 0.11
$\tilde{b}_4$	3.16 ± 0.37	11.94 ± 0.93	0.23 ± 0.10	-0.96 ± 0.15
$\tilde{b}_5$	1.10 ± 0.43	0.83 ± 0.46	0.13 ± 0.35	2.01 ± 1.37

fit directly

	Case I		Case II	
	TDA	IRA	TDA	IRA
χ^2	65.47	65.47	89.53	90.08
$\chi^2/d.o.f.$	3.27	3.27	3.73	3.75

$$|T^-| > |S^-| > |U^-|$$

- S^- is not negligible
- U^- is not negligible: compensated by large ρ^+
- $\tilde{b}_1$ is not negligible: hairpin is contained.

PREDICTION 1: CPV

TABLE III: The predicted CP observables calculated with $\rho_+ = -21$ and $r_- = 2.5$ in both TDA (upper) and IRA (lower).

Channel	$10^3\mathcal{B}$	$10^4 A_{CP}$	$10^4 A_{CP}^S$	$10^4 A_{CP}^P$	$10^4 A_\alpha$	$10^4 R_\beta$
$\Lambda_c^+ \to \Lambda^0 K^+$	0.64 ± 0.03	0.49 ± 0.87	5.07 ± 2.27	-0.30 ± 0.83	6.89 ± 0.82	-7.66 ± 1.67
	0.64 ± 0.03	0.49 ± 0.91	5.07 ± 2.30	-0.30 ± 0.87	6.89 ± 0.82	-7.66 ± 1.68
$\Lambda_c^+ \to \Sigma^0 K^+$	0.39 ± 0.02	-1.33 ± 0.27	-1.04 ± 0.25	-1.73 ± 0.64	-4.68 ± 0.97	2.93 ± 0.50
	0.39 ± 0.02	-1.33 ± 0.28	-1.04 ± 0.25	-1.73 ± 0.67	-4.68 ± 0.98	2.93 ± 0.50
$\Lambda_c^+ \to \Sigma^+ K_S$	0.39 ± 0.02	-1.33 ± 0.27	-1.04 ± 0.25	-1.73 ± 0.64	-4.68 ± 0.97	2.93 ± 0.50
	0.39 ± 0.02	-1.33 ± 0.28	-1.04 ± 0.25	-1.73 ± 0.67	-4.68 ± 0.98	2.93 ± 0.50
$\Lambda_c^+ \to p\pi^0$	0.19 ± 0.03	-7.88 ± 2.92	-0.86 ± 4.46	-13.13 ± 2.76	6.97 ± 9.17	-0.78 ± 2.09
	0.19 ± 0.03	-7.88 ± 2.95	-0.86 ± 4.57	-13.13 ± 2.75	6.97 ± 9.78	-0.78 ± 2.21
$\Lambda_c^+ \to p\eta$	1.63 ± 0.09	2.55 ± 0.23	2.55 ± 0.58	2.54 ± 0.24	0.45 ± 0.31	-0.77 ± 0.44
	1.63 ± 0.09	2.55 ± 0.22	2.55 ± 0.59	2.54 ± 0.24	0.45 ± 0.31	-0.77 ± 0.44
$\Lambda_c^+ \to p\eta'$	0.52 ± 0.08	-14.40 ± 1.26	-17.31 ± 4.08	-13.57 ± 1.78	-1.81 ± 2.62	-0.69 ± 2.33
	0.52 ± 0.08	-14.40 ± 1.26	-17.31 ± 4.06	-13.57 ± 1.78	-1.81 ± 2.76	-0.69 ± 2.35
$\Lambda_c^+ \to n\pi^+$	0.61 ± 0.06	-5.16 ± 0.90	-0.65 ± 0.84	-17.36 ± 2.48	-5.55 ± 3.86	-2.99 ± 1.43
	0.61 ± 0.06	-5.16 ± 0.90	-0.65 ± 0.86	-17.36 ± 2.54	-5.55 ± 3.89	-2.99 ± 1.47
$\Xi_c^0 \to \Lambda^0 \pi^0$	0.07 ± 0.01	1.76 ± 2.31	0.92 ± 0.41	29.36 ± 57.57	51.88 ± 308.2	-23.28 ± 31.01
	0.07 ± 0.02	1.76 ± 2.32	0.92 ± 0.41	29.36 ± 57.67	51.88 ± 69.69	-23.28 ± 16.56
$\Xi_c^0 \to \Lambda^0 \eta$	0.40 ± 0.05	3.97 ± 0.79	1.79 ± 0.55	9.15 ± 2.95	-4.07 ± 0.87	3.52 ± 1.69
	0.40 ± 0.05	3.97 ± 0.82	1.79 ± 0.54	9.15 ± 3.17	-4.07 ± 0.88	3.52 ± 1.71
$\Xi_c^0 \to \Lambda^0 \eta'$	0.63 ± 0.08	-3.96 ± 0.38	-4.29 ± 1.00	-3.84 ± 0.61	0.32 ± 0.52	-0.51 ± 0.52
	0.63 ± 0.08	-3.96 ± 0.38	-4.29 ± 1.01	-3.84 ± 0.62	0.32 ± 0.53	-0.51 ± 0.52
$\Xi_c^0 \to \Sigma^0 \pi^0$	0.34 ± 0.03	-3.26 ± 0.72	-2.55 ± 0.68	-5.40 ± 2.71	-0.40 ± 0.58	-2.45 ± 2.90
	0.34 ± 0.03	-3.26 ± 0.74	-2.55 ± 0.69	-5.40 ± 2.85	-0.40 ± 0.59	-2.45 ± 3.07
$\Xi_c^0 \to \Sigma^0 \eta$	0.17 ± 0.03	11.58 ± 1.55	5.20 ± 1.37	16.52 ± 4.41	-0.60 ± 2.46	-14.72 ± 37.07
	0.17 ± 0.03	11.58 ± 1.62	5.20 ± 1.41	16.52 ± 4.58	-0.60 ± 2.64	-14.72 ± 25.20
$\Xi_c^0 \to \Sigma^0 \eta'$	0.18 ± 0.03	4.73 ± 0.96	5.56 ± 2.11	4.07 ± 1.86	-1.29 ± 1.72	0.54 ± 0.48
	0.18 ± 0.03	4.73 ± 0.96	5.56 ± 2.17	4.07 ± 1.98	-1.29 ± 1.79	0.54 ± 0.48
$\Xi_c^0 \to \Sigma^+ \pi^-$	0.26 ± 0.02	1.61 ± 1.04	-5.19 ± 1.02	5.64 ± 1.44	-41.25 ± 68.74	-1.19 ± 0.62
	0.26 ± 0.02	1.61 ± 1.07	-5.19 ± 1.02	5.64 ± 1.52	-41.26 ± 361.3	-1.19 ± 0.64
$\Xi_c^0 \to \Sigma^- \pi^+$	1.80 ± 0.05	-1.63 ± 0.46	-1.47 ± 0.39	-1.80 ± 0.68	-1.28 ± 0.34	1.46 ± 0.30
	1.80 ± 0.05	-1.63 ± 0.47	-1.47 ± 0.40	-1.80 ± 0.70	-1.28 ± 0.34	1.46 ± 0.30
$\Xi_c^0 \to \Xi^0 K_{S/L}$	0.38 ± 0.01	1.50 ± 0.50	-0.18 ± 1.31	1.81 ± 0.59	-5.86 ± 0.48	4.38 ± 1.48
	0.38 ± 0.01	1.50 ± 0.53	-0.18 ± 1.32	1.81 ± 0.62	-5.86 ± 0.48	4.38 ± 1.48
$\Xi_c^0 \to \Xi^- K^+$	1.31 ± 0.04	1.59 ± 0.43	1.47 ± 0.39	1.80 ± 0.68	1.32 ± 0.34	-1.43 ± 0.32
	1.31 ± 0.04	1.59 ± 0.44	1.47 ± 0.40	1.80 ± 0.70	1.32 ± 0.34	-1.43 ± 0.32
$\Xi_c^0 \to pK^-$	0.31 ± 0.02	-2.61 ± 1.11	5.19 ± 1.02	-5.64 ± 1.44	41.98 ± 67.85	2.19 ± 0.69
	0.31 ± 0.02	-2.61 ± 1.16	5.19 ± 1.02	-5.64 ± 1.52	41.98 ± 307.3	2.19 ± 0.71
$\Xi_c^0 \to n K_{S/L}$	0.83 ± 0.04	-1.67 ± 0.54	0.18 ± 1.31	-1.82 ± 0.59	6.03 ± 0.51	-4.21 ± 1.52
	0.83 ± 0.04	-1.67 ± 0.57	0.18 ± 1.32	-1.81 ± 0.62	6.02 ± 0.51	-4.21 ± 1.52
$\Xi_c^+ \to \Lambda^0 \pi^+$	0.21 ± 0.04	3.15 ± 3.95	1.26 ± 0.60	81.20 ± 171.2	62.14 ± 548.6	-53.44 ± 76.39
	0.21 ± 0.04	3.15 ± 4.09	1.26 ± 0.59	81.20 ± 91.49	62.15 ± 180.3	-53.44 ± 188.1
$\Xi_c^+ \to \Sigma^0 \pi^+$	3.16 ± 0.09	0.16 ± 0.65	-1.32 ± 0.81	0.56 ± 0.73	-3.66 ± 0.46	2.85 ± 0.47
	3.16 ± 0.09	0.16 ± 0.68	-1.32 ± 0.83	0.56 ± 0.76	-3.66 ± 0.46	2.85 ± 0.47
$\Xi_c^+ \to \Sigma^+ \pi^0$	2.57 ± 0.11	0.03 ± 0.74	-4.80 ± 2.96	0.65 ± 0.68	-6.20 ± 1.82	6.64 ± 4.41
	2.57 ± 0.11	0.03 ± 0.73	-4.80 ± 2.96	0.65 ± 0.68	-6.20 ± 1.94	6.64 ± 4.66
$\Xi_c^+ \to \Sigma^+ \eta$	1.02 ± 0.17	11.59 ± 1.55	5.20 ± 1.37	16.52 ± 4.41	-0.62 ± 2.45	-14.73 ± 37.07
	1.02 ± 0.16	11.59 ± 1.62	5.20 ± 1.41	16.52 ± 4.58	-0.62 ± 2.64	-14.73 ± 25.21
$\Xi_c^+ \to \Sigma^+ \eta'$	1.09 ± 0.17	4.73 ± 0.96	5.56 ± 2.11	4.07 ± 1.86	-1.29 ± 1.73	0.54 ± 0.48
	1.09 ± 0.18	4.73 ± 0.96	5.56 ± 2.17	4.07 ± 1.98	-1.29 ± 1.79	0.54 ± 0.48
$\Xi_c^+ \to \Xi^0 K^+$	1.15 ± 0.10	3.02 ± 0.73	0.65 ± 0.84	17.35 ± 2.48	7.70 ± 3.62	5.12 ± 1.62
	1.15 ± 0.10	3.02 ± 0.73	0.65 ± 0.86	17.35 ± 2.53	7.70 ± 3.64	5.12 ± 1.69
$\Xi_c^+ \to p K_{S/L}$	1.52 ± 0.08	-1.47 ± 0.39	-1.04 ± 0.25	-1.73 ± 0.64	-4.54 ± 1.07	3.07 ± 0.59
	1.52 ± 0.08	-1.47 ± 0.40	-1.04 ± 0.25	-1.73 ± 0.67	-4.54 ± 1.09	3.07 ± 0.59

21

- Large CPV modes: promising to be measured in **STCF**

$$\mathcal{A}_{CP}(\Lambda_c \to p\pi^0) = -(0.8 \pm 0.3) \times 10^{-3}, \quad \mathcal{A}_{CP}(\Lambda_c \to p\eta') = (1.4 \pm 0.1) \times 10^{-3},$$
$$\mathcal{A}_{CP}(\Xi_c^0 \to \Sigma^0\eta) = (1.2 \pm 0.2) \times 10^{-3}, \quad \mathcal{A}_{CP}(\Xi_c^+ \to \Sigma^+\eta) = (1.2 \pm 0.2) \times 10^{-3}.$$

- The large CPV modes containing one of the neutral pseudo- scalar, π^0, η, η', some of which indicate a significant role of hairpin diagram E_h.

- U-spin symmetry relation also observed as:

$$\mathcal{A}_{CP}(\Lambda_c^+ \to n\pi^+) = -\mathcal{A}_{CP}(\Xi_c^+ \to \Xi^0 K^+),$$
$$\mathcal{A}_{CP}(\Lambda_c^+ \to \Sigma^+ K_{S,L}) = -\mathcal{A}_{CP}(\Xi_c^+ \to pK_{S.L}),$$
$$\mathcal{A}_{CP}(\Xi_c^0 \to \Xi^0 K_{S,L}) = -\mathcal{A}_{CP}(\Xi_c^0 \to nK_{S,L}),$$
$$\mathcal{A}_{CP}(\Xi_c^0 \to \Sigma^- \pi^+) = -\mathcal{A}_{CP}(\Xi_c^0 \to \Xi^- K^+),$$
$$\mathcal{A}_{CP}(\Xi_c^0 \to \Sigma^+ \pi^-) = -\mathcal{A}_{CP}(\Xi_c^0 \to pK^-),$$

X.G. He, Y.J. Shi, W. Wang, EPJC 80 (2020), 359

D. Wang, EPJC 79 (2020), 429

DISCUSSION I

- TDA (IRA) serves as a tool to study series of observables in charmed baryons.
- A preliminary update is done based on 2026 data.
- Penguin contribution needs to be considered to study CPV.
- FSR u, s, t channels are calculated.
- FSR plays a role to connect tree and penguin parameters in TDA.
- CPV of about 30 channels are calculated, 4 of them found to have large CPV of $\mathcal{O}(10^{-3})$: $\Lambda_c \to p\pi^0, \Lambda_c \to p\eta, \Xi_c^0 \to \Sigma^0\eta, \Xi_c^+ \to \Sigma^+\eta$.

$\mathcal{B}_c \to B V$

PHYSICAL REVIEW D **114,** 034013 (2026)

Topological diagram analysis of charmed baryon decays with vector mesons

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LATEST EXPERIMENTS

- BF: 19
- alpha: 5

arXiv > hep-ex > arXiv:2410.16912

High Energy Physics - Experiment

[Submitted on 22 Oct 2024]

Measurement of the branching fractions of the decays $\Lambda_c^+ \to \Lambda K_S^0 K^+$ $\Lambda_c^+ \to \Lambda K_S^0 \pi^+$ and $\Lambda_c^+ \to \Lambda K^{*+}$

TABLE VI. The comparison of the measured BFs (in 10^{-3}) with the PDG average and theoretical calculations.

Decay mode	PDG [6]	Theory [7] [8]	This work
$\Lambda K_S^0 K^+$	2.85 ± 0.55	2.8 ± 0.6	$3.04 \pm 0.30 \pm 0.16$
$\Lambda K_S^0 \pi^+$	-	4.4 ± 0.7	$1.73 \pm 0.26 \pm 0.10$
ΛK^{*+} (no interference)	-	1.97	$2.40 \pm 0.58 \pm 0.11$
ΛK^{*+} ($\theta_0 = 109°$)			$5.21 \pm 0.71 \pm 0.25$
ΛK^{*+} ($\theta_0 = 221°$)			$1.29 \pm 0.44 \pm 0.06$

TABLE IV. Experimental measurements of the branching fractions and the longitudinal decay asymmetry P_L in the decays of $\mathcal{B}_c \to \mathcal{B}V$. The order of magnitude of the branching fractions in the first, second and third rows is 10^{-2}, 10^{-3}, and 10^{-4}, respectively. The data are taken from Ref. [16] unless specified.

Mode	$\mathcal{B}$ PDG	$\mathcal{B}$ BES III	$\mathcal{B}$ Belle	$\mathcal{B}$ LHCb	$\mathcal{B}$ Average	P_L
$\Lambda_c^+ \to p\bar{K}^{*0}$	1.40 ± 0.07				1.40 ± 0.07	-0.835 ± 0.215 [1,26][a]
$\Lambda_c^+ \to \Lambda\rho^+$	4.1 ± 0.5				4.1 ± 0.5	-0.76 ± 0.07
$\Lambda_c^+ \to \Sigma^+\rho^0$	<1.7				<1.7	
$\Lambda_c^+ \to \Sigma^+\omega$	1.72 ± 0.20				1.72 ± 0.20	
$\Xi_c^+ \to \Sigma^+\bar{K}^{*0}$	2.3 ± 1.1				2.3 ± 1.1	
$\Lambda_c^+ \to p\phi$	1.05 ± 0.14	1.21 ± 0.14 [27]			1.13 ± 0.10	
$\Lambda_c^+ \to \Sigma^+\phi$	4.0 ± 0.5				4.0 ± 0.5	
$\Lambda_c^+ \to \Sigma^+K^{*0}$	3.5 ± 1.0				3.5 ± 1.0	
$\Lambda_c^+ \to p\rho^0$	1.5 ± 0.4				1.5 ± 0.4	
$\Lambda_c^+ \to \Lambda K^{*+}$		1.29 ± 0.44 [28][b]			1.29 ± 0.44	
$\Lambda_c^+ \to \Sigma^0K^{*+}$		1.23 ± 0.57 [13]			1.23 ± 0.57	
$\Xi_c^+ \to p\bar{K}^{*0}$	3.3 ± 1.7				3.3 ± 1.7	0.303 ± 0.121 [1,24][a]
$\Xi_c^+ \to \Sigma^+\phi$	<3.2				<3.2	
$\Xi_c^0 \to \Lambda\bar{K}^{*0}$	2.6 ± 0.6				2.6 ± 0.6	0.15 ± 0.22
$\Xi_c^0 \to \Sigma^0\bar{K}^{*0}$	9.9 ± 1.9				9.9 ± 1.9	
$\Xi_c^0 \to \Sigma^+K^{*-}$	4.9 ± 1.3				4.9 ± 1.3	-0.50 ± 0.30
$\Lambda_c^+ \to p\omega$	8.9 ± 1.1			9.82 ± 3.30 [29]	9.0 ± 1.0	
$\Xi_c^+ \to p\phi$	1.2 ± 0.6				1.2 ± 0.6	
$\Xi_c^0 \to \Lambda\phi$	4.9 ± 1.3				4.9 ± 1.3	

[a]The numbers quoted here have been recalculated by the authors of [1] based on the data reported in [24,26], after reconciling the different conventions for the asymmetry parameter α adopted by BESIII and LHCb. In the present work, this quantity is denoted by the longitudinal polarization P_L.

[b]Among all the three results in [28], the branching fractions 2.40 ± 0.59, 5.21 ± 0.75, and 1.29 ± 0.44 correspond $\theta_0 = 0$ (no interference), 109° and 221°, respectively.

— up to 2026

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Partial wave analysis of the charmed baryon hadronic decay $\Lambda_c^+ \to \Lambda\pi^+\pi^0$

The BESIII collaboration

BESIII

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ABSTRACT: Based on e^+e^- collision samples corresponding to an integrated luminosity of 4.4 fb^{-1} collected with the BESIII detector at center-of-mass energies between 4.6 GeV and 4.7 GeV, a partial wave analysis of the charmed baryon hadronic decay $\Lambda_c^+ \to \Lambda\pi^+\pi^0$ is performed, and the decays $\Lambda_c^+ \to \Lambda\rho(770)^+$ and $\Lambda_c^+ \to \Sigma(1385)\pi$ are studied for the first time. Making use of the world-average branching fraction $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\pi^0)$, their branching fractions are determined to be

$$\begin{aligned}\mathcal{B}(\Lambda_c^+ \to \Lambda\rho(770)^+) &= (4.06 \pm 0.30 \pm 0.35 \pm 0.23) \times 10^{-2},\\ \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\pi^0) &= (5.86 \pm 0.49 \pm 0.52 \pm 0.35) \times 10^{-3},\\ \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^0\pi^+) &= (6.47 \pm 0.59 \pm 0.66 \pm 0.38) \times 10^{-3},\end{aligned}$$

where the first uncertainties are statistical, the second are systematic, and the third are from the uncertainties of the branching fractions $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\pi^0)$ and $\mathcal{B}(\Sigma(1385) \to \Lambda\pi)$. In addition, the decay asymmetry parameters are measured to be $\alpha_{\Lambda\rho(770)^+} = -0.763 \pm 0.053 \pm 0.045$, $\alpha_{\Sigma(1385)^+\pi^0} = -0.917 \pm 0.069 \pm 0.056$, and $\alpha_{\Sigma(1385)^0\pi^+} = -0.789 \pm 0.098 \pm 0.056$.

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\Theta_\Lambda} \propto 1 + \alpha_{\Lambda\rho(770)^+} \cdot \alpha_\Lambda \cdot \cos\Theta_\Lambda, \tag{4.27}$$

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Measurements of branching fractions and asymmetry parameters of $\Xi_c^0 \to \Lambda\bar{K}^{*0}$, $\Xi_c^0 \to \Sigma^0\bar{K}^{*0}$, and $\Xi_c^0 \to \Sigma^+K^{*-}$ decays at Belle

BELLE

The Belle collaboration

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5 Asymmetry parameter extraction

For $\Xi_c^0 \to \Lambda\bar{K}^{*0}$, the differential decay rate [7] is given by:

$$\frac{dN}{d\cos\theta_\Lambda} \propto 1 + \alpha(\Xi_c^0 \to \Lambda\bar{K}^{*0})\alpha(\Lambda \to p\pi^-)\cos\theta_\Lambda, \tag{5.1}$$

where $\alpha(\Xi_c^0 \to \Lambda\bar{K}^{*0})$ and $\alpha(\Lambda \to p\pi^-)$ are the asymmetry parameters of $\Xi_c^0 \to \Lambda\bar{K}^{*0}$ and $\Lambda \to p\pi^-$, and θ_Λ is the angle between the proton momentum vector and the opposite of Ξ_c^0 momentum vector in the Λ rest frame.

For $\Xi_c^0 \to \Sigma^0\bar{K}^{*0}$, the differential decay rate [7] is shown as:

$$\frac{dN}{d\cos\theta_{\Sigma^0}} \propto 1 + \alpha(\Xi_c^0 \to \Sigma^0\bar{K}^{*0})\alpha(\Sigma^0 \to \gamma\Lambda)\cos\theta_{\Sigma^0}, \tag{5.2}$$

For $\Xi_c^0 \to \Sigma^+K^{*-}$, the differential decay rate [7] can be described with:

$$\frac{dN}{d\cos\theta_{\Sigma^+}} \propto 1 + \alpha(\Xi_c^0 \to \Sigma^+K^{*-})\alpha(\Sigma^+ \to p\pi^0)\cos\theta_{\Sigma^+}, \tag{5.3}$$

where the uncertainties are statistical, systematic, and from $\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$, respectively. The asymmetry parameters $\alpha(\Xi_c^0 \to \Lambda\bar{K}^{*0})$ and $\alpha(\Xi_c^0 \to \Sigma^+K^{*-})$ are $0.15 \pm 0.22(\text{stat.}) \pm 0.04(\text{syst.})$ and $-0.52 \pm 0.30(\text{stat.}) \pm 0.02(\text{syst.})$, respectively, where the uncertainties are statistical followed by systematic.

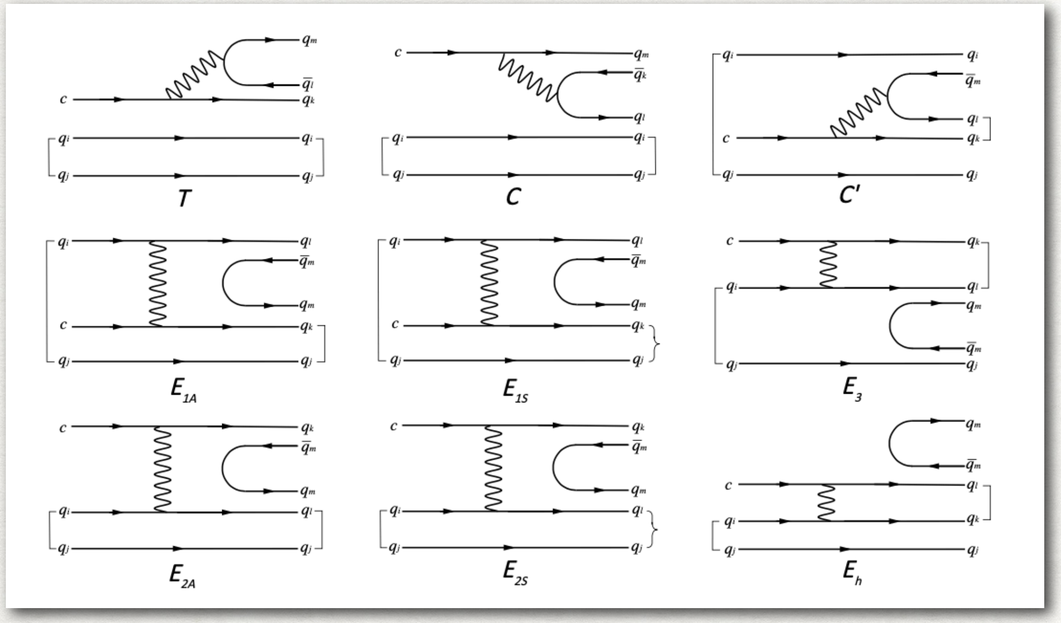
BESIII

$$\alpha_{\Lambda\rho(770)^+} = \frac{|H^\rho_{\frac{1}{2},1}|^2 - |H^\rho_{-\frac{1}{2},-1}|^2 + |H^\rho_{\frac{1}{2},0}|^2 - |H^\rho_{-\frac{1}{2},0}|^2}{|H^\rho_{\frac{1}{2},1}|^2 + |H^\rho_{-\frac{1}{2},-1}|^2 + |H^\rho_{\frac{1}{2},0}|^2 + |H^\rho_{-\frac{1}{2},0}|^2} = \frac{\sqrt{\frac{1}{9}} \cdot 2 \cdot \Re\left(g^\rho_{0,\frac{1}{2}} \cdot \bar{g}^\rho_{1,\frac{1}{2}} - g^\rho_{1,\frac{3}{2}} \cdot \bar{g}^\rho_{2,\frac{3}{2}}\right) - \sqrt{\frac{8}{9}} \cdot 2 \cdot \Re\left(g^\rho_{0,\frac{1}{2}} \cdot \bar{g}^\rho_{1,\frac{3}{2}} + g^\rho_{1,\frac{1}{2}} \cdot \bar{g}^\rho_{2,\frac{3}{2}}\right)}{|g^\rho_{0,\frac{1}{2}}|^2 + |g^\rho_{1,\frac{1}{2}}|^2 + |g^\rho_{1,\frac{3}{2}}|^2 + |g^\rho_{2,\frac{3}{2}}|^2}. \tag{4.29}$$

LHCb

$$\alpha = \frac{|\mathcal{H}_{1/2,0}|^2 + |\mathcal{H}_{1/2,-1}|^2 - |\mathcal{H}_{-1/2,0}|^2 - |\mathcal{H}_{-1/2,1}|^2}{|\mathcal{H}_{1/2,0}|^2 + |\mathcal{H}_{1/2,-1}|^2 + |\mathcal{H}_{-1/2,0}|^2 + |\mathcal{H}_{-1/2,1}|^2}.$$

DYNAMICS: TOPOLOGICAL DIAGRAMS



$$\begin{aligned}\mathcal{A} = & T(\mathcal{B}_c)^{ij} H_l^{km} (\mathcal{B}_8)_{ijk} V_m^l + C(\mathcal{B}_c)^{ij} H_k^{ml} (\mathcal{B}_8)_{ijl} V_m^k + C'(\mathcal{B}_c)^{ij} H_m^{kl} (\mathcal{B}_8)_{klj} V_i^m \\ & + E_{1A}(\mathcal{B}_c)^{ij} H_i^{kl} (\mathcal{B}_8)_{jkm} V_l^m + E_{1S}(\mathcal{B}_c)^{ij} H_i^{kl} \left[(\mathcal{B}_8)_{jmk} + (\mathcal{B}_8)_{kmj}\right] V_l^m \\ & + E_{2A}(\mathcal{B}_c)^{ij} H_i^{kl} (\mathcal{B}_8)_{jlm} V_k^m + E_{2S}(\mathcal{B}_c)^{ij} H_i^{kl} \left[(\mathcal{B}_8)_{jml} + (\mathcal{B}_8)_{lmj}\right] V_k^m \\ & + E_3(\mathcal{B}_c)^{ij} H_i^{kl} (\mathcal{B}_8)_{klm} V_j^m + E_h(\mathcal{B}_c)^{ij} H_i^{kl} (\mathcal{B}_8)_{klj} V_m^m .\end{aligned}$$

$H_m^{kl}(\bar{q}_k c)(\bar{q}_l q^m)$ Weak interaction

- reduce independent diagrams to 7

$$E_{2A} = -E_{1A}, \qquad E_{2S} = -E_{1S}.$$ (KPW theorem)

- further reduction to 5 by redefinition

$$\tilde{T} = T - E_{1S}, \quad \tilde{C} = C + E_{1S}, \quad \tilde{C}' = C' - 2E_{1S},$$
$$\tilde{E}_1 = E_{1A} + E_{1S} - E_3, \quad \tilde{E}_h = E_h + 2E_{1S}.$$

$$V_j^i = \begin{pmatrix} \frac{\rho^0+\omega}{\sqrt{2}} & \rho^+ & K^{*+} \\ \rho^- & \frac{-\rho^0+\omega}{\sqrt{2}} & K^{*0} \\ K^{*-} & \overline{K}^{*0} & \phi \end{pmatrix}, \quad (\mathcal{B}_c)^{ij} = \begin{pmatrix} 0 & \Lambda_c^+ & \Xi_c^+ \\ -\Lambda_c^+ & 0 & \Xi_c^0 \\ -\Xi_c^+ & -\Xi_c^0 & 0 \end{pmatrix}$$

$$(\mathcal{B}_8)^i_j = \begin{pmatrix} \frac{1}{\sqrt{6}}\Lambda^0 + \frac{1}{\sqrt{2}}\Sigma^0 & \Sigma^+ & p \\ \Sigma^- & \frac{1}{\sqrt{6}}\Lambda^0 - \frac{1}{\sqrt{2}}\Sigma^0 & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\Lambda^0 \end{pmatrix}.$$

AMPLITUDES & OBSERVABLES

$$\mathcal{M}(\mathcal{B}_c \to \mathcal{B}V) = \bar{u}_f(p_f)\,\epsilon^{*\mu}\left[A_1\gamma_\mu\gamma_5 + A_2\frac{p_{f\mu}}{m_i}\gamma_5 + B_1\gamma_\mu + B_2\frac{p_{f\mu}}{m_i}\right]u_i(p_i),$$

TABLE I. The expansions of Cabbibo-favored decay amplitudes, in which the common CKM factor $V_{cs}V_{ud}$ has been ignored.

Channel	TDA	$\widetilde{\text{TDA}}$
$\Lambda_c^+ \to \Xi^0 K^{*+}$	$E_{1A} + E_{1S} - E_3$	$\tilde{E}_1$
$\Lambda_c^+ \to \Lambda\rho^+$	$\frac{1}{\sqrt{6}}(-4T + C' + E_{1A} + 3E_{1S} - E_3)$	$\frac{1}{\sqrt{6}}(-4\tilde{T} + \tilde{C}' + \tilde{E}_1)$
$\Lambda_c^+ \to p\bar{K}^0$	$2C + 2E_{1S}$	$2\tilde{C}$
$\Lambda_c^+ \to \Sigma^0\rho^+$	$\frac{1}{\sqrt{2}}(-C' - E_{1A} + E_{1S} + E_3)$	$\frac{1}{\sqrt{2}}(-\tilde{C}' - \tilde{E}_1)$
$\Lambda_c^+ \to \Sigma^+\rho^0$	$\frac{1}{\sqrt{2}}(C' + E_{1A} - E_{1S} - E_3)$	$\frac{1}{\sqrt{2}}(\tilde{C}' + \tilde{E}_1)$
$\Lambda_c^+ \to \Sigma^+\phi$	$-E_h - 2E_{1S}$	$-\tilde{E}_h$
$\Lambda_c^+ \to \Sigma^+\omega$	$\frac{1}{\sqrt{2}}(-C' + E_{1A} - E_{1S} - E_3 - 2E_h)$	$\frac{1}{\sqrt{2}}(-\tilde{C}' + \tilde{E}_1 - 2\tilde{E}_h)$
$\Xi_c^0 \to \Lambda\bar{K}^{*0}$	$\frac{1}{\sqrt{6}}(2C - C' - E_{1A} + 3E_{1S} + E_3)$	$\frac{1}{\sqrt{6}}(2\tilde{C} - \tilde{C}' - \tilde{E}_1)$
$\Xi_c^0 \to \Sigma^0\bar{K}^{*0}$	$\frac{1}{\sqrt{2}}(2C + C' + E_{1A} + E_{1S} - E_3)$	$\frac{1}{\sqrt{2}}(2\tilde{C} + \tilde{C}' + \tilde{E}_1)$
$\Xi_c^0 \to \Sigma^+ K^{*-}$	$-E_{1A} - E_{1S} + E_3$	$-\tilde{E}_1$
$\Xi_c^0 \to \Xi^0\rho^0$	$\frac{1}{\sqrt{2}}(-C' + 2E_{1S})$	$\frac{1}{\sqrt{2}}(-\tilde{C}')$
$\Xi_c^0 \to \Xi^0\phi$	$-E_{1A} + E_{1S} + E_3 + E_h$	$-\tilde{E}_1 + \tilde{E}_h$
$\Xi_c^0 \to \Xi^0\omega$	$\frac{1}{\sqrt{2}}(C' + 2E_{1S} + 2E_h)$	$\frac{1}{\sqrt{2}}(\tilde{C}' + 2\tilde{E}_h)$
$\Xi_c^0 \to \Xi^-\rho^+$	$2T - 2E_{1S}$	$2\tilde{T}$
$\Xi_c^+ \to \Sigma^+\bar{K}^{*0}$	$-2C - C'$	$-2\tilde{C} - \tilde{C}'$
$\Xi_c^+ \to \Xi^0\rho^+$	$-2T + C'$	$-2\tilde{T} + \tilde{C}'$

$$\mathcal{L}_{\mathcal{B}'\mathcal{B}V} = g_{\mathcal{B}'\mathcal{B}V}\,\mathrm{Tr}(\overline{\mathcal{B}}'\gamma_\mu V^\mu \mathcal{B}) + \frac{f_{\mathcal{B}'\mathcal{B}V}}{m_{\mathcal{B}'} + m_{\mathcal{B}}}\mathrm{Tr}(\overline{\mathcal{B}}'\sigma_{\mu\nu}\mathcal{B}\,\partial^\mu V^\nu)$$

pole model

$$A_1 = -\sum_{\mathcal{B}_{n^*}(1/2^-)}\left[\frac{g_{\mathcal{B}_f\mathcal{B}_{n^*}V}b_{n^*i}}{m_i - m_n} + \frac{b_{fn^*}g_{\mathcal{B}_{n^*}\mathcal{B}_iV}}{m_f - m_n}\right],$$
$$B_1 = -\sum_{\mathcal{B}_n}\left[\frac{g_{\mathcal{B}_f\mathcal{B}_nV}a_{ni}}{m_i - m_n} + \frac{a_{fn}g_{\mathcal{B}_n\mathcal{B}_iV}}{m_f - m_n}\right],$$
$$A_2 = B_2 = 0,$$

$$A_1 = -\frac{m_i - m_f}{2(m_i + m_f)}\sum_{\mathcal{B}_{n^*}(1/2^-)}\left[\frac{f_{\mathcal{B}_f\mathcal{B}_{n^*}V}b_{n^*i}}{m_i - m_n} + \frac{b_{fn^*}f_{\mathcal{B}_{n^*}\mathcal{B}_iV}}{m_f - m_n}\right],$$
$$A_2 = \frac{2m_i}{m_i - m_f}A_1,$$
$$B_1 = \frac{1}{2}\sum_{\mathcal{B}_n}\left[\frac{f_{\mathcal{B}_f\mathcal{B}_nV}a_{ni}}{m_i - m_n} + \frac{a_{fn}f_{\mathcal{B}_n\mathcal{B}_iV}}{m_f - m_n}\right],$$
$$B_2 = -\frac{2m_i}{m_i + m_f}B_1.$$

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$$\Gamma = \frac{p_c}{4\pi}\frac{E_f + m_f}{m_i}\left[2\left(|S|^2 + |P_2|^2\right) + \frac{E_V^2}{m_V^2}\left(|S + D|^2 + |P_1|^2\right)\right]$$

$$S = -A_1,$$
$$P_1 = -\frac{p_c}{E_V}\left(\frac{m_i + m_f}{E_f + m_f}B_1 + B_2\right),$$
$$P_2 = \frac{p_c}{E_f + m_f}B_1,$$
$$D = -\frac{p_c^2}{E_V(E_f + m_f)}(A_1 - A_2).$$

$$\alpha = \frac{2E_V^2\,\mathrm{Re}[(S + D)^* P_1] + 4m_V^2\,\mathrm{Re}(S^* P_2)}{2m_V^2\left(|S|^2 + |P_2|^2\right) + E_V^2\left(|S + D|^2 + |P_1|^2\right)},$$

$$P_L = \frac{2E_V^2\,\mathrm{Re}[(S + D)^* P_1] - 4m_V^2\,\mathrm{Re}(S^* P_2)}{2m_V^2\left(|S|^2 + |P_2|^2\right) + E_V^2\left(|S + D|^2 + |P_1|^2\right)}.$$

FITTED PARAMETERS

TABLE V. The fitted partial-wave components of TDA amplitudes in units of 10^{-6}.

	S	P_1	P_2	D
$\tilde{T}$	0.45 ± 0.33	0.60 ± 0.40	-0.30 ± 0.40	-0.70 ± 0.60
$\tilde{C}$	0.12 ± 0.06	0.30 ± 0.04	0.02 ± 0.06	0.09 ± 0.08
$\tilde{C}'$	-0.28 ± 0.13	0.08 ± 0.10	-0.31 ± 0.20	0.06 ± 0.16
$\tilde{E}_1$	-0.02 ± 0.13	0.43 ± 0.11	0.28 ± 0.15	-0.07 ± 0.24
$\tilde{E}_h$	-0.15 ± 0.12	0.28 ± 0.14	0.34 ± 0.12	-0.30 ± 0.21

TABLE VI. The fitted form-factor components of TDA amplitudes in units of 10^{-6}.

	A_1	B_1	A_2	B_2
$\tilde{T}$	0.56 ± 0.18	0.50 ± 0.70	1.40 ± 2.40	-1.40 ± 1.50
$\tilde{C}$	-0.17 ± 0.05	0.47 ± 0.11	-1.68 ± 0.22	-0.27 ± 0.21
$\tilde{C}'$	0.36 ± 0.07	-1.04 ± 0.28	2.30 ± 0.70	2.00 ± 0.50
$\tilde{E}_1$	0.15 ± 0.07	1.70 ± 0.29	0.20 ± 1.70	-2.30 ± 0.50
$\tilde{E}_h$	0.40 ± 0.05	2.00 ± 0.40	2.20 ± 2.20	-3.20 ± 0.80

- $\tilde{T}$ gives the largest contribution in each partial wave;
- $\tilde{C}$ seems to have tiny contribution in P_2 and D waves;
- $\tilde{C}'$ seems to have tiny contribution in P_1 and D waves;

- Both A_2 and B_2 are comparable in magnitude to their corresponding one;

PREDICTIONS: SELECTED

TABLE VII. Predictions of observables in Cabibbo-favored decays.

Mode	$10^2\mathcal{B}$	α	P_L	α_V
$\Lambda_c^+ \to \Xi^0 K^{*+}$	0.29 ± 0.09	-0.31 ± 0.27	-0.18 ± 0.72	1.67 ± 4.04
$\Lambda_c^+ \to \Lambda \rho^+$	4.10 ± 0.49	-0.76 ± 0.07	0.32 ± 1.31	0.02 ± 2.61
$\Lambda_c^+ \to p\overline{K}^{*0}$	1.38 ± 0.07	0.87 ± 0.03	0.79 ± 0.27	12.71 ± 16.67
$\Lambda_c^+ \to \Sigma^0 \rho^+$	0.53 ± 0.13	-0.63 ± 0.38	-0.72 ± 0.52	5.01 ± 7.77
$\Lambda_c^+ \to \Sigma^+ \rho^0$	0.53 ± 0.13	-0.63 ± 0.38	-0.72 ± 0.52	5.03 ± 7.80
$\Lambda_c^+ \to \Sigma^+ \phi$	0.40 ± 0.05	-0.83 ± 0.29	-0.13 ± 0.49	1.30 ± 2.36
$\Lambda_c^+ \to \Sigma^+ \omega$	1.63 ± 0.16	-0.37 ± 0.30	-0.22 ± 0.60	4.31 ± 7.63
$\Xi_c^0 \to \Lambda \overline{K}^{*0}$	0.30 ± 0.05	0.23 ± 0.21	0.04 ± 0.55	2.03 ± 3.10
$\Xi_c^0 \to \Sigma^0 \overline{K}^{*0}$	1.08 ± 0.15	0.20 ± 0.30	0.20 ± 0.29	$5.80^{+22.41}_{-4.75}$
$\Xi_c^0 \to \Sigma^+ K^{*-}$	0.52 ± 0.12	-0.34 ± 0.26	-0.22 ± 0.68	2.73 ± 5.64
$\Xi_c^0 \to \Xi^0 \rho^0$	0.27 ± 0.15	0.64 ± 0.06	-0.92 ± 0.21	-0.46 ± 0.37
$\Xi_c^0 \to \Xi^0 \phi$	0.15 ± 0.05	0.45 ± 0.62	0.70 ± 0.49	7.94 ± 27.86
$\Xi_c^0 \to \Xi^0 \omega$	2.23 ± 0.23	-0.87 ± 0.13	-0.43 ± 0.52	5.01 ± 7.52
$\Xi_c^0 \to \Xi^- \rho^+$	5.52 ± 1.33	-0.81 ± 0.25	0.04 ± 1.28	1.24 ± 5.12
$\Xi_c^+ \to \Sigma^+ \overline{K}^{*0}$	3.14 ± 0.93	0.51 ± 0.24	0.43 ± 0.41	9.44 ± 19.07
$\Xi_c^+ \to \Xi^0 \rho^+$	17.00 ± 2.79	-0.42 ± 0.22	0.06 ± 1.38	0.32 ± 3.22

$$M(\Lambda_c^+ \to \Sigma^0 \rho^+) = M(\Lambda_c^+ \to \Sigma^+ \rho^0),$$

isospin symmetry respected

- promising to be measured soon!

PREDICTIONS: SELECTED

TABLE VIII. Predictions of observables in singly Cabibbo-suppressed decays.

Mode	$10^3\mathcal{B}$	α	P_L	α_V
$\Lambda_c^+ \to \Lambda K^{*+}$	2.4 ± 0.53	-0.44 ± 0.21	-0.26 ± 1.21	2.30 ± 7.33
$\Lambda_c^+ \to \Sigma^0 K^{*+}$	0.13 ± 0.07	0.71 ± 0.06	-0.94 ± 0.17	-0.59 ± 0.28
$\Lambda_c^+ \to \Sigma^+ K^{*0}$	0.25 ± 0.15	0.71 ± 0.06	-0.94 ± 0.17	-0.59 ± 0.28
$\Lambda_c^+ \to p\rho^0$	1.01 ± 0.14	0.20 ± 0.30	0.20 ± 0.29	$7.58^{+28.30}_{-5.99}$
$\Lambda_c^+ \to p\phi$	1.04 ± 0.11	0.16 ± 0.32	0.73 ± 0.29	3.79 ± 3.17
$\Lambda_c^+ \to p\omega$	0.91 ± 0.10	-0.92 ± 0.23	-0.79 ± 0.47	16.58 ± 41.44
$\Lambda_c^+ \to n\rho^+$	3.96 ± 1.40	-0.36 ± 0.35	0.63 ± 1.03	-0.04 ± 2.34
$\Xi_c^0 \to \Lambda\rho^0$	0.11 ± 0.09	0.59 ± 0.62	-0.48 ± 0.62	-0.71 ± 0.53
$\Xi_c^0 \to \Lambda\phi$	0.59 ± 0.07	0.34 ± 0.33	0.44 ± 0.48	4.55 ± 7.46
$\Xi_c^0 \to \Lambda\omega$	1.36 ± 0.16	-0.93 ± 0.13	-0.56 ± 0.49	7.38 ± 12.82
$\Xi_c^0 \to \Sigma^0\rho^0$	0.43 ± 0.05	0.63 ± 0.20	0.40 ± 0.35	13.35 ± 19.01
$\Xi_c^0 \to \Sigma^0\phi$	0.33 ± 0.04	-0.49 ± 0.31	-0.42 ± 0.32	31.86 ± 87.95
$\Xi_c^0 \to \Sigma^0\omega$	0.69 ± 0.10	0.35 ± 0.36	0.70 ± 0.31	7.26 ± 8.98
$\Xi_c^0 \to \Sigma^+\rho_-$	0.36 ± 0.08	-0.35 ± 0.27	-0.25 ± 0.66	3.60 ± 6.95
$\Xi_c^0 \to \Sigma^-\rho^+$	3.36 ± 0.97	-0.80 ± 0.31	-0.01 ± 1.29	1.54 ± 5.79
$\Xi_c^0 \to \Xi^0 K^{*0}$	0.37 ± 0.09	-0.60 ± 0.40	-0.71 ± 0.55	4.35 ± 6.92
$\Xi_c^0 \to \Xi^- K^{*+}$	2.21 ± 0.42	-0.82 ± 0.17	0.12 ± 1.27	0.83 ± 4.18
$\Xi_c^0 \to pK^{*-}$	0.34 ± 0.08	-0.35 ± 0.27	-0.25 ± 0.66	3.50 ± 6.79
$\Xi_c^0 \to n\overline{K}^{*0}$	0.56 ± 0.13	-0.66 ± 0.35	-0.74 ± 0.46	6.24 ± 9.37
$\Xi_c^+ \to \Lambda\rho^+$	2.84 ± 0.69	0.16 ± 0.40	-0.33 ± 1.18	0.78 ± 3.83
$\Xi_c^+ \to \Sigma^0\rho^+$	6.89 ± 2.56	-0.63 ± 0.3	-0.36 ± 1.09	5.25 ± 14.24
$\Xi_c^+ \to \Sigma^+\rho^0$	0.86 ± 0.23	0.09 ± 0.41	0.71 ± 0.40	3.42 ± 5.25
$\Xi_c^+ \to \Sigma^+\phi$	1.50 ± 0.34	-0.97 ± 0.13	-0.88 ± 0.43	23.5 ± 71.26
$\Xi_c^+ \to \Sigma^+\omega$	4.13 ± 0.63	0.35 ± 0.36	0.70 ± 0.31	7.26 ± 8.98
$\Xi_c^+ \to \Xi^0 K^{*+}$	7.55 ± 2.59	-0.41 ± 0.28	0.65 ± 1.00	-0.21 ± 1.92
$\Xi_c^+ \to p\overline{K}^{*0}$	0.89 ± 0.51	0.61 ± 0.06	-0.92 ± 0.22	-0.40 ± 0.41

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$$\sqrt{2}\,M(\Lambda_c^+ \to \Sigma^0 K^{*+}) = M(\Lambda_c^+ \to \Sigma^+ K^{*0}) = M(\Xi_c^+ \to p\,\overline{K}^{*0}),$$

isospin symmetry respected

v-spin symmetry broken?

- kinematic factor effect

COMPARISON (1)

Mode	$\mathcal{B}_{\rm theo}$	$\mathcal{B}_{\rm exp}$	$\alpha_{\rm theo}$	$\alpha_{\rm exp}$
$\Lambda_c^+ \to p\overline{K}^{*0}$	1.38 ± 0.07	1.4 ± 0.07	0.87 ± 0.03	0.87 ± 0.03
$\Lambda_c^+ \to \Lambda\rho^+$	4.10 ± 0.49	4.1 ± 0.5	-0.76 ± 0.07	-0.76 ± 0.07
$\Lambda_c^+ \to \Sigma^+\rho^0$	0.53 ± 0.13	< 1.7		
$\Lambda_c^+ \to \Sigma^+\omega$	1.63 ± 0.16	1.72 ± 0.20		
$\Xi_c^+ \to \Sigma^+\overline{K}^{*0}$	3.14 ± 0.93	2.3 ± 1.1		
$\Lambda_c^+ \to p\phi$	1.04 ± 0.11	1.05 ± 0.14		
$\Lambda_c^+ \to \Sigma^+\phi$	4.00 ± 0.49	4.0 ± 0.5		
$\Lambda_c^+ \to \Sigma^+K^{*0}$	0.25 ± 0.15	3.5 ± 1.0		
$\Lambda_c^+ \to \Sigma^0K^{*+}$	0.13 ± 0.07	1.23 ± 0.57		
$\Lambda_c^+ \to p\rho^0$	1.01 ± 0.14	1.5 ± 0.4		
$\Lambda_c^+ \to \Lambda K^{*+}$	2.40 ± 0.53	2.40 ± 0.59		
$\Lambda_c^+ \to p\omega$	0.91 ± 0.10	0.90 ± 0.1		
$\Xi_c^0 \to \Lambda\overline{K}^{*0}$	3.04 ± 0.55	2.6 ± 0.6	0.23 ± 0.21	0.15 ± 0.22
$\Xi_c^0 \to \Sigma^0\overline{K}^{*0}$	10.81 ± 1.53	9.9 ± 1.9		
$\Xi_c^0 \to \Sigma^+K^{*-}$	5.18 ± 1.25	4.9 ± 1.3	-0.34 ± 0.26	-0.50 ± 0.30
$\Xi_c^0 \to \Lambda\phi$	0.59 ± 0.07	0.49 ± 0.13		
$\Xi_c^+ \to p\phi$	0.12 ± 0.01	0.12 ± 0.06		
$\Xi_c^+ \to p\overline{K}^{*0}$	0.89 ± 0.51	3.3 ± 1.7	0.61 ± 0.06	0.613 ± 0.065
$\Xi_c^+ \to \Sigma^+\phi$	1.98 ± 0.00	< 3.2		

- Most modes are consistent well with experiments
- The three modes within SU(3) symmetry, however, have deviation from experiments.

[21] J. M. Link *et al.* (FOCUS), Measurements of Relative Branching Ratios of Λ_c^+ Decays into States Containing Σ, Phys. Lett. B **540**, 25 (2002), arXiv:hep-ex/0206013.

[11] M. Ablikim *et al.* (BESIII), Measurements of branching fractions of $\Lambda_c^+ \to \Sigma^0 K_S^0 \pi^+$ and $\Lambda_c^+ \to \Sigma^0 K_S^0 K^+$, (2026), arXiv:2602.22754 [hep-ex].

[26] J. M. Link *et al.* (FOCUS), Measurement of the Relative Branching Ratio BR($\Xi_c^+ \to p^+K^-\pi^+$) / BR($\Xi_c^+ \to \Xi^-\pi^+\pi^+$), Phys. Lett. B **512**, 277 (2001), arXiv:hep-ex/0102040.

- More experimental progress is anticipated!

DISCUSSION II

- Current $\mathscr{B}_c \to \mathscr{B}V$ data can support a serious fit.
- TDA has successfully been extended to $\mathscr{B}_c \to \mathscr{B}V$.
- All the four form factors are important, hence cannot be neglected.
- Four partial waves are extracted.
- The importance of tensor coupling is channel dependent.
- TDA predictions mostly agree well with experiments, the remaining requires more data.

$$\mathscr{B}_c \to B_D P$$

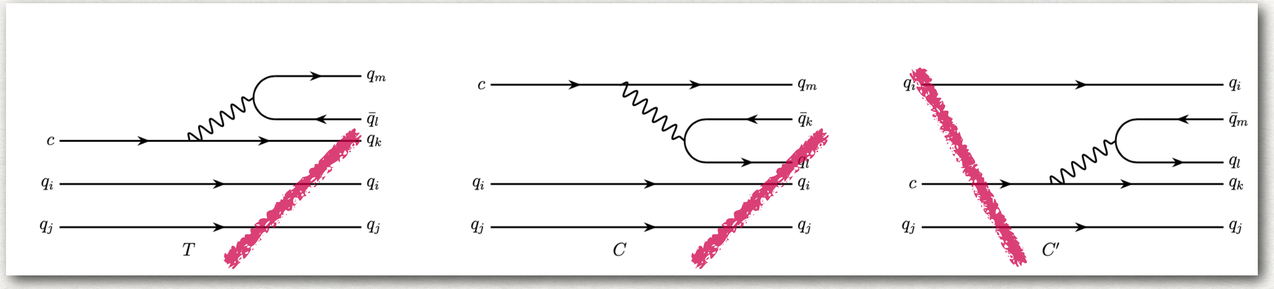
to appear,
with Hai-Yang Cheng and Ruoli Lu

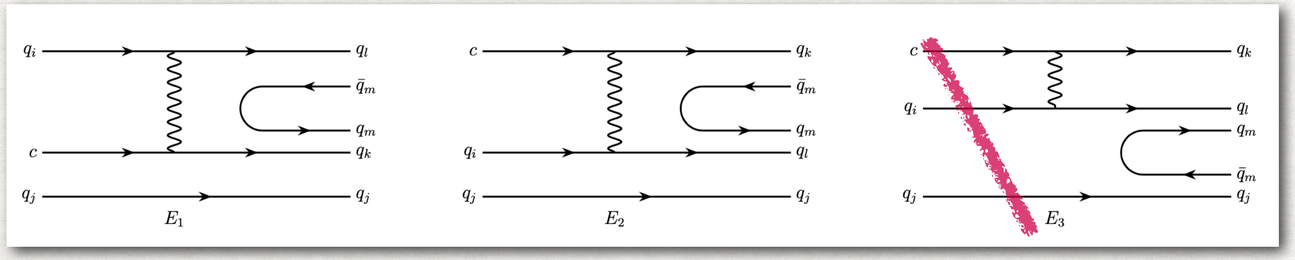
LATEST EXPERIMENTS

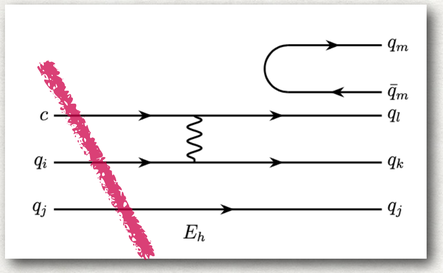
Mode	$\mathcal{B}$	α
$\Lambda_c^+ \to \Delta^{++} K^-$	18.0 ± 0.8	0.55 ± 0.04
$\Lambda_c^+ \to \Sigma^{*+} \pi^0$	5.1 ± 0.7	-0.92 ± 0.09
$\Lambda_c^+ \to \Sigma^{*0} \pi^+$	5.7 ± 0.8	-0.79 ± 0.11
$\Lambda_c^+ \to \Sigma^{*+} \eta$	6.78 ± 0.76	-0.61 ± 0.16 [10]
$\Lambda_c^+ \to \Xi^{*0} K^+$	4.9 ± 0.6	
$\Xi_c^+ \to \Sigma^{*+} \overline{K}^0$	29 ± 20	
$\Xi_c^+ \to \Xi^{*0} \pi^+$	< 2.9	
$\Xi_c^+ \to \Delta^{++} K^-$	1.1 ± 0.5	
$\Xi_c^0 \to \Omega^- K^+$	4.2 ± 0.9	

- BF: 9
- alpha: 4

DYNAMICS: TOPOLOGICAL DIAGRAMS







$$E_2 = -E_1$$ KPW theorem ?

$$\begin{aligned}
\mathcal{A}_{\mathrm{TDA}} =& T(\mathcal{B}_c)^{ij} H_l^{km} M_m^l \left[b_1 (\mathcal{B}_D)_{ijk} + b_2 (\mathcal{B}_D)_{ikj} + b_3 (\mathcal{B}_D)_{jki}\right] \\
&+ C(\mathcal{B}_c)^{ij} H_k^{ml} M_m^k \left[b_4 (\mathcal{B}_D)_{ijl} + b_5 (\mathcal{B}_D)_{ilj} + b_6 (\mathcal{B}_D)_{jli}\right] \\
&+ C'(\mathcal{B}_c)^{ij} H_m^{kl} M_i^m \left[b_7 (\mathcal{B}_D)_{klj} + b_8 (\mathcal{B}_D)_{kjl} + b_9 (\mathcal{B}_D)_{ljk}\right] \\
&+ E_1(\mathcal{B}_c)^{ij} H_i^{kl} M_l^m \left[b_{10} (\mathcal{B}_D)_{jkm} + b_{11} (\mathcal{B}_D)_{jmk} + b_{12} (\mathcal{B}_D)_{kmj}\right] \\
&+ E_2(\mathcal{B}_c)^{ij} H_i^{kl} M_k^m \left[b_{13} (\mathcal{B}_D)_{jlm} + b_{14} (\mathcal{B}_D)_{jml} + b_{15} (\mathcal{B}_D)_{lmj}\right] \\
&+ E_3(\mathcal{B}_c)^{ij} H_i^{kl} M_j^m \left[b_{16} (\mathcal{B}_D)_{klm} + b_{17} (\mathcal{B}_D)_{kml} + b_{18} (\mathcal{B}_D)_{lmk}\right] \\
&+ E_h(\mathcal{B}_c)^{ij} H_i^{kl} M_m^m \left[b_{19} (\mathcal{B}_D)_{jkl} + b_{20} (\mathcal{B}_D)_{jlk} + b_{21} (\mathcal{B}_D)_{klj}\right],
\end{aligned}$$

$$\begin{aligned}
\mathcal{A} =& C'(\mathcal{B}_c)^{ij} H_m^{kl} (\mathcal{B}_D)_{klj} M_i^m \\
&+ E_1(\mathcal{B}_c)^{ij} H_i^{kl} (\mathcal{B}_D)_{jkm} M_l^m \\
&+ E_2(\mathcal{B}_c)^{ij} H_i^{kl} (\mathcal{B}_D)_{jlm} M_k^m \\
&+ E_3(\mathcal{B}_c)^{ij} H_i^{kl} (\mathcal{B}_D)_{klm} M_j^m \\
&+ E_h(\mathcal{B}_c)^{ij} H_i^{kl} (\mathcal{B}_D)_{klj} M_m^m .
\end{aligned}$$

allowing SU(3) symmetry breaking

AMPLITUDES & OBSERVABLES

The expansions of Cabibbo-favored decay amplitudes, in which the common CKM factor $V_{cs}V_{ud}$ has been ignored.

Channel	TDA	Channel	TDA
$\Lambda_c^+ \to \Delta^{++}K^-$	$-E_2$	$\Xi_c^0 \to \Xi^{*0}\pi^0$	$\frac{1}{\sqrt{6}}(-C'+E_1)$
$\Lambda_c^+ \to \Delta^+\overline{K}^0$	$-\frac{1}{\sqrt{3}}E_2$	$\Xi_c^0 \to \Xi^{*0}\eta_1$	$\frac{1}{3}(C'+E_1+E_2+E_3+3E_h)$
$\Lambda_c^+ \to \Sigma^{*+}\eta_1$	$-\frac{1}{3}(C'+E_1+E_2+E_3+3E_h)$	$\Xi_c^0 \to \Xi^{*0}\eta_8$	$\frac{1}{3\sqrt{2}}(C'+E_1-2E_2-2E_3)$
$\Lambda_c^+ \to \Sigma^{*+}\eta_8$	$-\frac{1}{3\sqrt{2}}(C'+E_1-2E_2+E_3)$	$\Xi_c^0 \to \Xi^{*-}\pi^+$	$\frac{1}{\sqrt{3}}E_1$
$\Lambda_c^+ \to \Sigma^{*+}\pi^0$	$\frac{1}{\sqrt{6}}(C'-E_1-E_3)$	$\Xi_c^0 \to \Sigma^{*0}\overline{K}^0$	$\frac{1}{\sqrt{6}}(-C'+E_2+E_3)$
$\Lambda_c^+ \to \Sigma^{*0}\pi^+$	$\frac{1}{\sqrt{6}}(C'-E_1-E_3)$	$\Xi_c^0 \to \Sigma^{*+}K^-$	$\frac{1}{\sqrt{3}}(E_2+E_3)$
$\Lambda_c^+ \to \Xi^{*0}K^+$	$-\frac{1}{\sqrt{3}}(E_1+E_3)$	$\Xi_c^0 \to \Omega^-K^+$	E_1
$\Xi_c^+ \to \Xi^{*0}\pi^+$	$\frac{1}{\sqrt{3}}C'$	$\Xi_c^+ \to \Sigma^{*+}\overline{K}^0$	$-\frac{1}{\sqrt{3}}C'$

$$M(\mathcal{B}_c \to \mathcal{B}_D P) = iq_\mu \bar{\omega}^\mu (C + D\gamma_5)u$$

$$\Gamma = \frac{p_c}{16\pi m_i^2}\frac{Q_+Q_-}{3m_f^2}\left[Q_+|C|^2 + Q_-|D|^2\right],$$

$$\alpha = -\frac{2\kappa\,\mathrm{Re}(C^*D)}{|C|^2+\kappa^2|D|^2}, \qquad \beta = -\frac{2\kappa\,\mathrm{Im}(C^*D)}{|C|^2+\kappa^2|D|^2},$$

$$\gamma = \frac{|C|^2-\kappa^2|D|^2}{|C|^2+\kappa^2|D|^2},$$

FITTED PARAMETERS

TABLE V. Fitted TDA parameters in units of 10^{-9}, with profile-likelihood 1σ intervals. The sign convention $C_{E_2} > 0$ is chosen.

Parameter	Best fit	Parameter	Best fit
$C_{C'}$	$0.520\,^{+0.113}_{-0.184}$	$D_{C'}$	$0.468\,^{+1.698}_{-1.873}$
C_{E1}	$0.931\,^{+0.112}_{-1.707}$	D_{E1}	$1.126\,^{+4.879}_{-0.000}$
C_{E2}	0.853 ± 0.020	D_{E2}	-0.943 ± 0.078
C_{E3}	$0.730\,^{+0.000}_{-0.215}$	D_{E3}	$2.039\,^{+5.648}_{-7.151}$
C_{Eh}	$-0.369\,^{+0.539}_{-0.411}$	D_{Eh}	$10.038\,^{+4.717}_{-4.310}$

$$\chi^2_{\rm min} = 31.64\,, \qquad \frac{\chi^2_{\rm min}}{\rm d.o.f.} = 10.5\,,$$

$$\text{d.o.f.} = 13 - 10 = 3.$$

RESULTS

Mode	$10^3\mathcal{B}$	α	γ
$\Lambda_c^+ \to \Delta^{++} K^-$	16.59 ± 0.58	$+0.544 \pm 0.030$	$+0.839 \pm 0.020$
$\Lambda_c^+ \to \Delta^+ \bar{K}^0$	5.49 ± 0.19	$+0.543 \pm 0.030$	$+0.840 \pm 0.019$
$\Lambda_c^+ \to \Sigma^{*+} \pi^0$	5.43 ± 0.38	-0.864 ± 0.055	$+0.504 \pm 0.116$
$\Lambda_c^+ \to \Sigma^{*0} \pi^+$	5.41 ± 0.38	-0.863 ± 0.055	$+0.504 \pm 0.116$
$\Lambda_c^+ \to \Xi^{*0} K^+$	4.77 ± 0.41	-0.533 ± 0.183	$+0.846 \pm 0.129$
$\Xi_c^+ \to \Xi^{*0} \pi^+$	4.45 ± 1.61	-0.400 ± 0.643	$+0.916 \pm 0.462$
$\Xi_c^+ \to \Sigma^{*+} \bar{K}^0$	4.87 ± 1.92	-0.431 ± 0.660	$+0.902 \pm 0.484$
$\Xi_c^0 \to \Xi^{*0} \pi^0$	0.51 ± 2.75	-0.656 ± 0.687	$+0.755 \pm 0.688$
$\Xi_c^0 \to \Xi^{*-} \pi^+$	4.92 ± 2.81	-0.522 ± 0.691	$+0.853 \pm 0.691$
$\Xi_c^0 \to \Sigma^{*0} \bar{K}^0$	5.06 ± 0.35	-0.880 ± 0.052	$+0.475 \pm 0.119$
$\Xi_c^0 \to \Sigma^{*+} K^-$	14.92 ± 21.28	-0.340 ± 0.654	$+0.941 \pm 0.351$
$\Xi_c^0 \to \Omega^- K^+$	4.20 ± 0.89	-0.357 ± 0.707	$+0.934 \pm 0.707$
$\Lambda_c^+ \to \Sigma^{*+} \eta$	6.70 ± 0.45	-0.610 ± 0.129	-0.792 ± 0.117
$\Xi_c^0 \to \Xi^{*0} \eta$	2.69 ± 7.59	$+0.728 \pm 0.699$	-0.686 ± 0.640
$\Lambda_c^+ \to \Sigma^{*+} \eta'$	40.82 ± 14.54	-0.540 ± 0.242	-0.842 ± 0.275
$\Xi_c^0 \to \Xi^{*0} \eta'$	39.55 ± 13.50	-0.629 ± 0.191	-0.777 ± 0.295

$$Q_+ \hat{C}_{E_1}^2 + Q_- \hat{D}_{E_1}^2 = 15.16\,, \qquad \hat{C}_{E_3} = 1.661 - \hat{C}_{E_1}\,, \qquad \hat{D}_{E_3} = 3.165 - \hat{D}_{E_1}\,, \tag{15}$$

TABLE VI. Branching fractions in units of 10^{-3} (for all CKM classes) of the unmeasured channels that are most sensitive to the one-parameter degeneracy of Eq. (15). The middle column gives the value at the best fit and the last column the range spanned along the degenerate family described in the text. The decay asymmetries of these modes vary over a comparably wide interval.

Mode	$\mathcal{B}_{\rm fit}$	Range
$\Xi_c^0 \to \Sigma^{*+} K^-$	14.9	14.9–74.8
$\Xi_c^0 \to \Xi^{*0} \eta$	2.69	0.605–22.2
$\Xi_c^0 \to \Xi^{*0} \eta'$	39.6	35.5–51.7
$\Xi_c^0 \to \Xi^{*0} \pi^0$	0.507	0.473–7.55
$\Xi_c^0 \to \Delta^+ K^-$	1.30	1.29–7.18
$\Xi_c^0 \to \Xi^{*-} \pi^+$	4.92	4.72–11.0
$\Xi_c^0 \to \Sigma^{*+} \pi^-$	1.11	1.10–5.79
$\Xi_c^0 \to \Delta^0 \bar{K}^0$	0.577	0.574–5.41
$\Xi_c^0 \to \Sigma^{*-} \pi^+$	1.65	1.53–5.12
$\Xi_c^0 \to \Sigma^{*0} \pi^0$	0.010	0.005–5.12
$\Xi_c^0 \to \Sigma^{*0} \eta$	0.854	0.035–2.16
$\Xi_c^0 \to \Xi^{*0} K^0$	0.190	0.190–1.48

COMPARISON

Mode	$\mathcal{B}_{\rm TDA}$	$\mathcal{B}_{\rm exp}$	$\alpha_{\rm TDA}$	$\alpha_{\rm exp}$	Pull
$\Lambda_c^+ \to \Delta^{++} K^-$	16.59 ± 0.58	18.00 ± 0.80	$+0.54 \pm 0.03$	0.55 ± 0.04	-1.77 -0.15
$\Lambda_c^+ \to \Sigma^{*+} \pi^0$	5.43 ± 0.38	5.10 ± 0.70	-0.86 ± 0.05	-0.92 ± 0.09	0.47 0.62
$\Lambda_c^+ \to \Sigma^{*0} \pi^+$	5.41 ± 0.38	5.70 ± 0.80	-0.86 ± 0.05	-0.79 ± 0.11	-0.36 -0.67
$\Lambda_c^+ \to \Sigma^{*+} \eta$	6.70 ± 0.45	6.70 ± 0.60	-0.61 ± 0.13	-0.61 ± 0.16	0.00 -0.00
$\Lambda_c^+ \to \Xi^{*0} K^+$	4.77 ± 0.41	4.90 ± 0.60	-0.53 ± 0.18	–	-0.22
$\Xi_c^+ \to \Sigma^{*+} \bar{K}^0$	4.87 ± 1.92	29.00 ± 20.00	-0.43 ± 0.66	–	-1.21
$\Xi_c^+ \to \Delta^{++} K^-$	3.63 ± 0.13	1.10 ± 0.50	$+0.61 \pm 0.03$	–	+5.05
$\Xi_c^0 \to \Omega^- K^+$	4.20 ± 0.89	4.20 ± 0.90	-0.36 ± 0.71	–	+0.00
$\Xi_c^+ \to \Xi^{*0} \pi^+$	4.45 ± 1.61	< 2.9	-0.40 ± 0.64	–	+0.53

DISCUSSION III

- TDA works in $\mathscr{B}_c \to \mathscr{B}_D P$.
- Flavor symmetry breaks manifestly since $E_1 \neq E_2$.
- Current data cannot discriminate E_1 and E_3.
- Λ_c^+ sector is described well.
- A tension exist in $\Xi_c^+ \to \Delta^{++} K^-$.

SUMMARY

SUMMARY

- TDA has been established!
- CPV observable is more promising in $\mathscr{B}_c \to \mathscr{B}P$.
- Polarization observables are rich in $\mathscr{B}_c \to \mathscr{B}V$.
- Flavor breaking effect has been manifested in $\mathscr{B}_c \to \mathscr{B}_D P$.
- In the three types of decay, more efforts are anticipated in $\Xi_c^{0,+}$ sector.
- Therefore, more achievement on $\Xi_c^{0,+}$ will be made by Belle II.