The hadronic weak decay of charmed baryons

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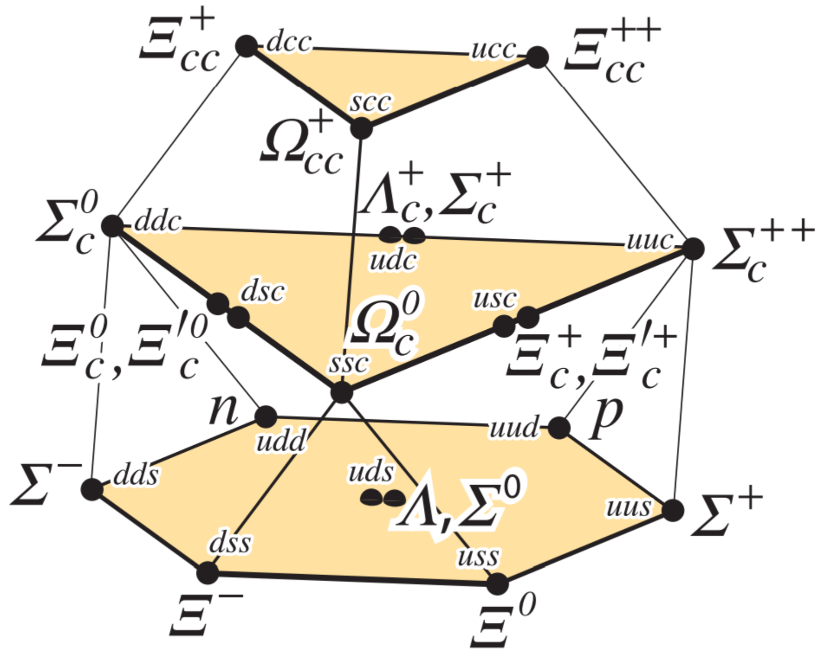
轻强子专题研讨会 河南·安阳

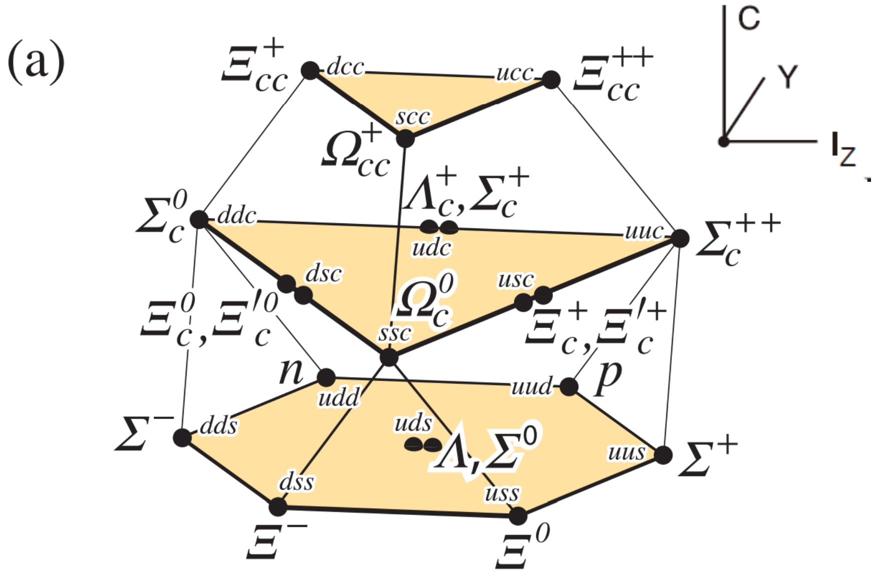
2025. 05. 11

01 Introduction

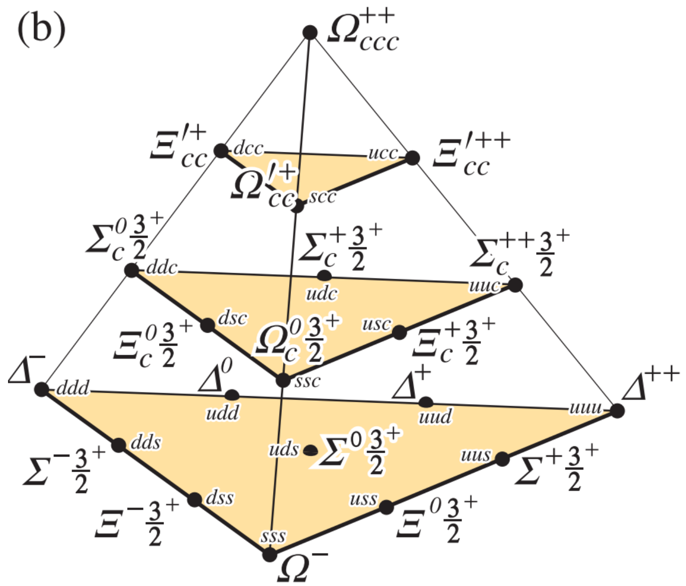


Charmed baryons

SU(4) multiplets of baryons made of u, d, s, and c quarks



The 20-plet with an SU(3) octet ($J^p = \frac{1}{2}^+$).

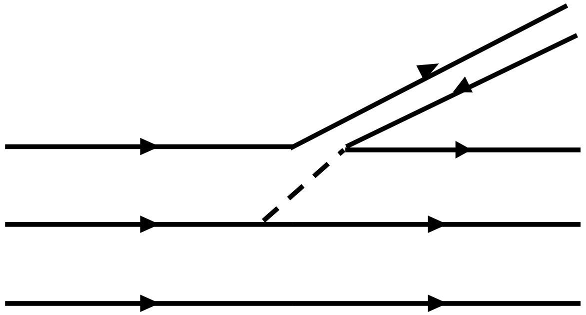


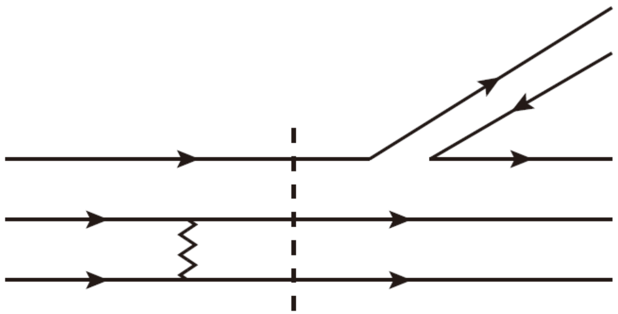
The 20-plet with an SU(3) decuplet ($J^p = \frac{3}{2}^+$).

- Hadronic weak decay of charmed baryons $B_c \to B\ M$
  - I. The hadronic weak decay of Λ_c
  - II. The hadronic weak decay of Ξ_c

Motivation

- High precision measurement of charmed baryon
- Non-factorizable transition mechanisms:
  - Color suppressed contribution
  - Pole term contribution
- The property of light diquark





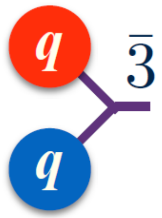
- BES III:
  - Phys. Rev. D 111.012014 (2025)
  - Phys. Rev. Lett 134.021901(2025)
  - Phys. Rev. D 111. L051101(2024)
  - Phys. Rev. Lett 132.031801(2024)
  - Phys. Rev. Lett 128.142001(2022)
  - …
- Belle II and Belle:
  - arXiv: 2503.17643v1
  - Phys. Rev. D 110.032021(2025)
  - JHEP 03. 061(2025)
  - JHEP 10. 045 (2024)
  - Phys. Rev. D 107.032008(2023)
  - …
- LHCb:
  - Phys. Rev. Lett 132.081802(2024)
  - Eur. Phys. J. C 84.237 (2024)
  - Eur. Phys. J. C 84.575 (2024)
  - Phys. Rev. Lett 133.261804(2024)
  - Phys. Rev. D 108.072002(2023)
  - …

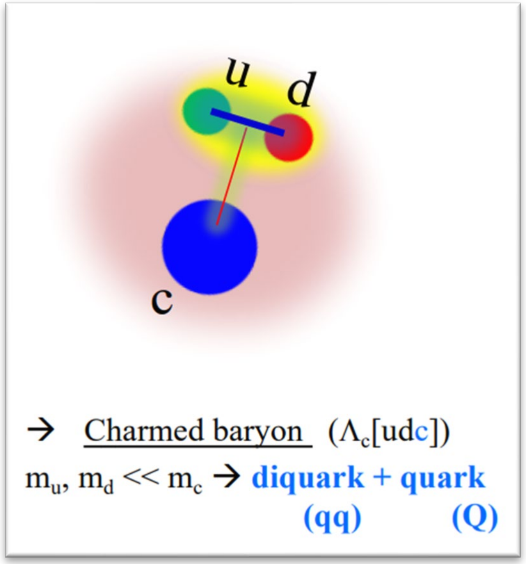
Diquark

- **Diquark: strong color correlation between quarks**

  S-wave color $\bar{3}$ diquarks: S(0$^+$) and A(1$^+$)

  color $3 \otimes 3 = \bar{3} \oplus 6$ **spin :** $\frac{1}{2} \otimes \frac{1}{2} = 0 \oplus 1$





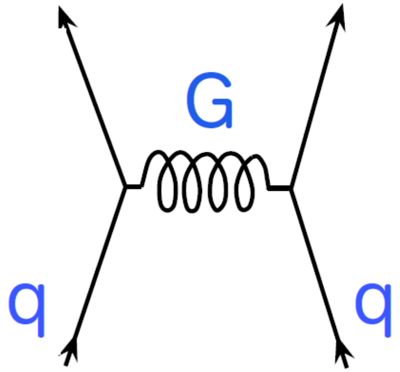
From Xiao-Rui Lyu

- **Spin dependent force from magnetic gluon exchange predicts strong attraction in S(0$^+$).**

  Color-Magnetic Interaction $\Delta_{CM} \equiv \langle -\sum_{i<j} (\vec{\lambda}_i \cdot \vec{\lambda}_j)(\vec{\sigma}_i \cdot \vec{\sigma}_j) \rangle$

  S(0$^+$) color $\bar{3}$ $\Delta_{CM} = -8$ ***aka good diquark***

  A(1$^+$) color $\bar{3}$ $\Delta_{CM} = +8/3$ ***aka bad diquark***



Compact or not

M(A)-M(S) = (2/3) [M(Δ)- M(N)] ~ 200 MeV

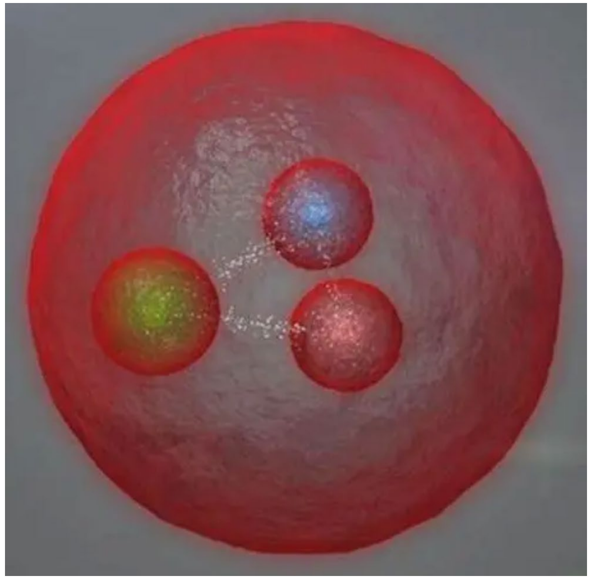
consistent with the splitting of $\Lambda_c - \Sigma_c$

$$M_\Sigma - M_\Lambda = 80 \text{ MeV}$$

02

Frame Work

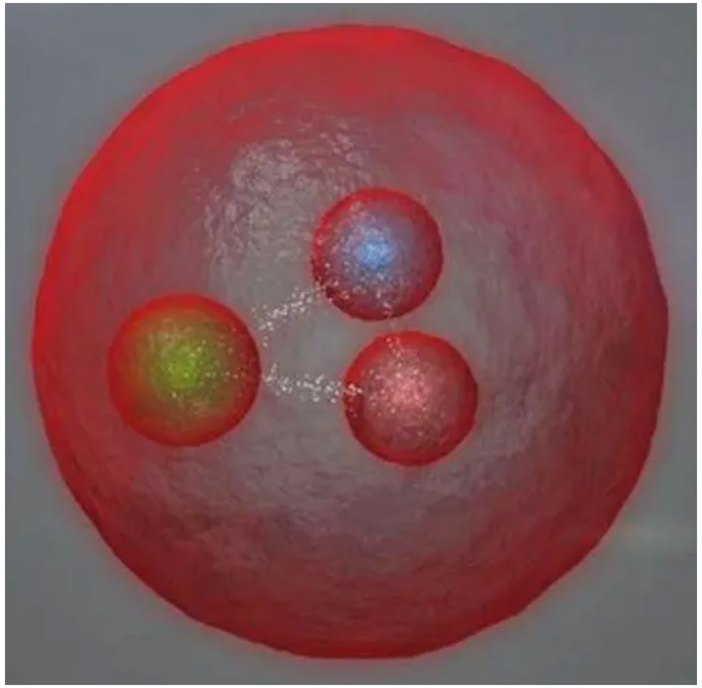
- The wave functions of hadrons
- The effective Hamiltonian



2.1 Wave function of light baryons

Nonrelativistic constituent quark model

Color	$SU(3)$	$3 \otimes 3 \otimes 3$	$= 10_s + 8_\rho + 8_\lambda + 1_a$
Spin	$SU(2)$	$2 \otimes 2 \otimes 2$	$= 4_s + 2_\rho + 2_\lambda,$
Flavor	$SU(3)$	$3 \otimes 3 \otimes 3$	$= 10_s + 8_\rho + 8_\lambda + 1_a,$
Spin-flavor	$SU(6)$	$6 \otimes 6 \otimes 6$	$= 56_s + 70_\rho + 70_\lambda + 20_a,$
Spatial	O(3)	L^P	s, ρ, λ, a



ISGUR N, KARL G. Phys.Rev.D, 1978, 18:4187
F. Hussain and M. Scadron, Nuovo Cim. A **79**, 248 (1984)
LE YAOUANC A, OLIVER L, PENE O, et al. HADRON TRANSITIONS IN THE QUARK MODEL[M]. 1988.

2.1 Wave function of light baryons

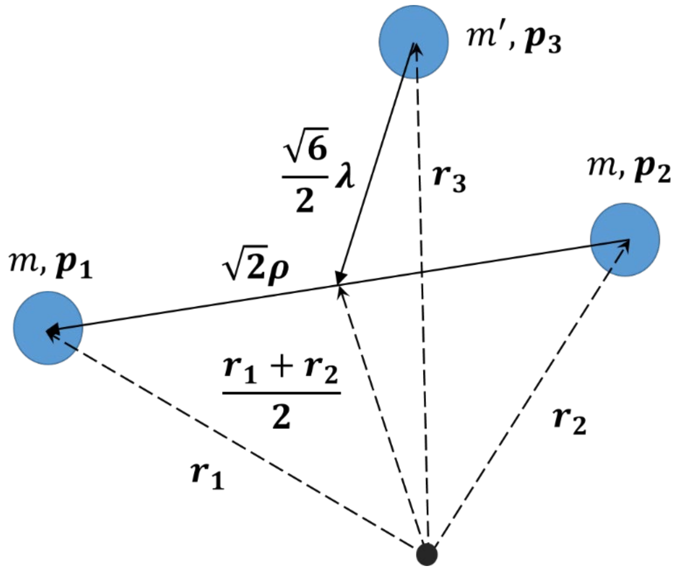
The Hamiltonian of three quark system

$$H = \sum_i \left(m_i + \frac{\boldsymbol{p}_i^2}{2m_i} \right) + \sum_{i<j} V_{conf}^{ij} + H_{hyp}^{ij},$$

where

$$V_{conf}^{ij} = C_{qqq} + \frac{1}{2} b\, r_{ij} - \frac{2}{3}\frac{\alpha_s}{r_{ij}} = \frac{1}{2}\beta r_{ij}^2 + U_{ij},$$

$$H_{hyp}^{ij} = \sum_{i<j} \frac{2\alpha_s(\boldsymbol{r}_{ij})}{3m_i m_j}\left[\frac{8\pi}{3}\boldsymbol{S}_i \cdot \boldsymbol{S}_j \delta^3(\boldsymbol{r}_{ij}) + \frac{1}{r_{ij}^3}\left(\frac{3\boldsymbol{S}_i \cdot \boldsymbol{r}_{ij}\, \boldsymbol{S}_j \cdot \boldsymbol{r}_{ij}}{r_{ij}^2} - \boldsymbol{S}_i \cdot \boldsymbol{S}_i \right) \right].$$



Harmonic oscillator potential: $H = \sum_i \left(m_i + \frac{\boldsymbol{p}_i^2}{2m_i} \right) + \frac{1}{2} K \sum_{i<j} (\boldsymbol{r}_i - \boldsymbol{r}_j)^2$

2.1 The wave functions of hadrons

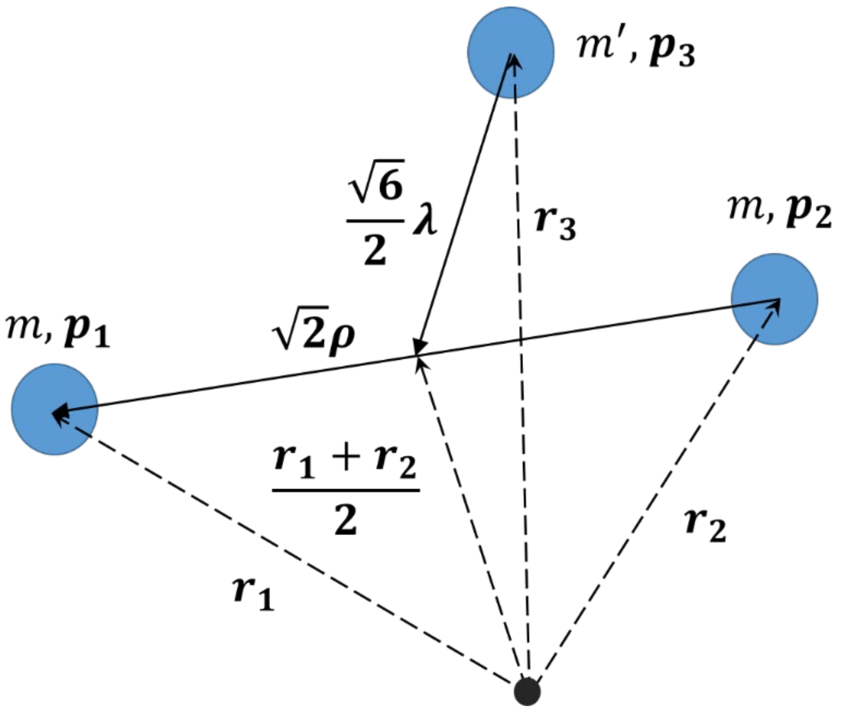
$$\boldsymbol{R}=\frac{m(\boldsymbol{r}_1+\boldsymbol{r}_2)+m'\boldsymbol{r}_3}{M},\qquad \boldsymbol{P}=\boldsymbol{p}_1+\boldsymbol{p}_2+\boldsymbol{p}_3,$$

$$\boldsymbol{\rho}=\frac{1}{\sqrt{2}}(\boldsymbol{r}_1-\boldsymbol{r}_2),\qquad \boldsymbol{p}_\rho=\frac{1}{\sqrt{2}}(\boldsymbol{p}_1-\boldsymbol{p}_2),$$

$$\boldsymbol{\lambda}=\frac{1}{\sqrt{6}}(\boldsymbol{r}_1+\boldsymbol{r}_2-2\boldsymbol{r}_3),\qquad \boldsymbol{p}_\lambda=\frac{1}{\sqrt{6}M}(3m'\boldsymbol{p}_1+3m'\boldsymbol{p}_2-6m\boldsymbol{p}_3).$$

$\Rightarrow$

$$H=\frac{\boldsymbol{P}^2}{2M^2}+\frac{\boldsymbol{p}_\lambda^2}{2m_\lambda^2}+\frac{\boldsymbol{p}_\rho^2}{2m_\rho^2}+\frac{1}{2}m_\rho\omega_\rho^2\boldsymbol{\rho}^2+\frac{1}{2}m_\lambda\omega_\lambda^2\boldsymbol{\lambda}^2,$$



Jacobi coordinates

The total wave function of the momentum space

$$\Psi_{NLM}(\boldsymbol{P},\boldsymbol{p}_\rho,\boldsymbol{p}_\lambda)=\delta^3(\boldsymbol{P}-\boldsymbol{P}')\left[\psi_{n_\rho l_\rho m_\rho}(\boldsymbol{p}_\rho,\alpha_\rho)\psi_{n_\lambda l_\lambda m_\lambda}(\boldsymbol{p}_\lambda,\alpha_\lambda)\right]_{l_\rho,l_{\lambda;L}},$$

where

$$\psi_{nlm}(\boldsymbol{p},\alpha)=i^l(-1)^n\left[\frac{2n!}{\left(n+l+\frac{1}{2}\right)!}\right]^{\frac{1}{2}}\frac{1}{\alpha^{l+\frac{3}{2}}}\,e^{-\frac{\boldsymbol{p}^2}{2\alpha^2}}L_n^{l+\frac{1}{2}}\left(\frac{\boldsymbol{p}^2}{\alpha^2}\right)\mathcal{Y}_{lm}(\boldsymbol{p}).$$

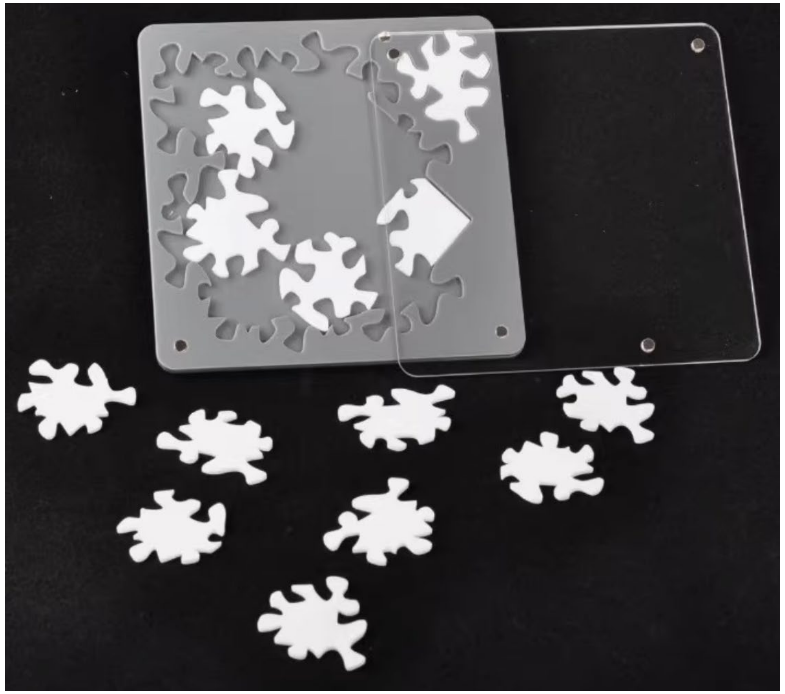
2.1 Wave function of light baryons

Color	$SU(3)$	$3 \otimes 3 \otimes 3$	$= 10_s + 8_\rho + 8_\lambda + \boxed{1_a}$
Spin	$SU(2)$	$2 \otimes 2 \otimes 2$	$= 4_s + 2_\rho + 2_\lambda,$
Flavor	$SU(3)$	$3 \otimes 3 \otimes 3$	$= 10_s + 8_\rho + 8_\lambda + 1_a,$
Spin-flavor	$SU(6)$	$6 \otimes 6 \otimes 6$	$= 56_s + 70_\rho + 70_\lambda + 20_a,$
Spatial	$O(3)$	L^P	s, ρ, λ, a

$$\phi_c|\mathrm{SU}(6) \otimes \mathrm{O}(3)\rangle = \phi_c\left|N_6, {}^{2S+1}N_3, \mathrm{N}, \mathrm{L}, \mathrm{J}\right\rangle$$

Light baryons $\left|56, {}^2 8, 0, 0, \frac{1}{2}\right\rangle$:

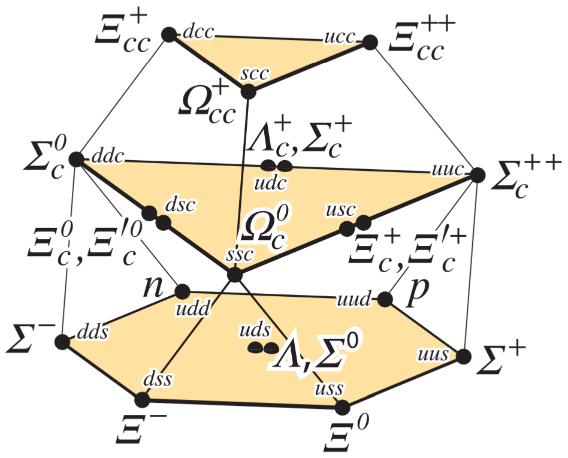
$$\frac{1}{\sqrt{2}}(\phi^\rho\chi^\rho + \phi^\lambda\chi^\lambda)\Psi_{000}(\boldsymbol{p}_\rho, \boldsymbol{p}_\lambda)$$



Baryon wave function as representation of 3-dimension permutation group.

2.1 Wave function of light baryons

$$3 \otimes 3 = \bar{3} \oplus 6$$



$$\phi^c_{\bar{3}} = \begin{cases} \frac{1}{\sqrt{2}}(ud - du)c & \text{for } \Lambda_c^+, \\ \frac{1}{\sqrt{2}}(us - su)c & \text{for } \Xi_c^+, \\ \frac{1}{\sqrt{2}}(ds - sd)c & \text{for } \Xi_c^0; \end{cases}$$

$$\phi^c_{6} = \begin{cases} uuc & \text{for } \Sigma_c^{++}, \\ \frac{1}{\sqrt{2}}(ud + du)c & \text{for } \Sigma_c^+, \\ ddc & \text{for } \Sigma_c^0, \\ \frac{1}{\sqrt{2}}(us + su)c & \text{for } \Xi_c^{\prime +}, \\ \frac{1}{\sqrt{2}}(ds + sd)c & \text{for } \Xi_c^{\prime 0}, \\ ssc & \text{for } \Omega_c^0; \end{cases}$$

Anti-triplet

$\vert {}^{2S+1}L_\sigma J^P\rangle$	Wave function
$\vert {}^2S\tfrac{1}{2}^+\rangle$	$\Psi^s_{00}\chi^\rho_{S_z}\phi_B$
$\vert {}^2P_\lambda\tfrac{1}{2}^-\rangle$	$\Psi^\lambda_{1L_z}\chi^\rho_{S_z}\phi_B$
$\vert {}^2P_\rho\tfrac{1}{2}^-\rangle$	$\Psi^\rho_{1L_z}\chi^\lambda_{S_z}\phi_B$
$\vert {}^4P_\rho\tfrac{1}{2}^-\rangle$	$\Psi^\rho_{1L_z}\chi^s_{S_z}\phi_B$

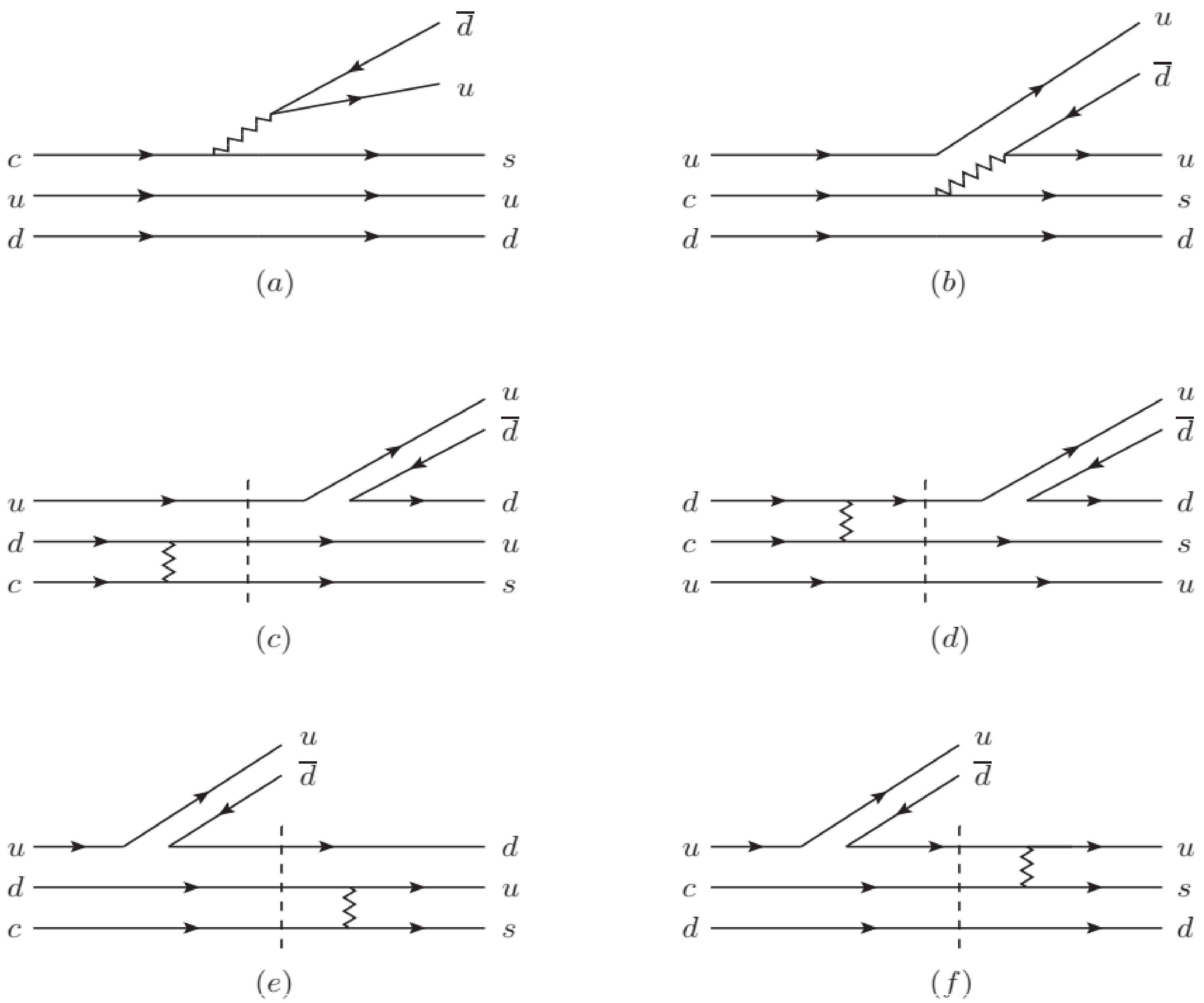
Sextet

$\vert {}^{2S+1}L_\sigma J^P\rangle$	Wave Function
$\vert {}^2S\tfrac{1}{2}^+\rangle$	$\Psi^s_{00}\chi^\lambda_{S_z}\phi_B$
$\vert {}^2P_\lambda\tfrac{1}{2}^-\rangle$	$\Psi^\lambda_{1L_z}\chi^\lambda_{S_z}\phi_B$
$\vert {}^2P_\rho\tfrac{1}{2}^-\rangle$	$\Psi^\rho_{1L_z}\chi^\rho_{S_z}\phi_B$
$\vert {}^4P_\lambda\tfrac{1}{2}^-\rangle$	$\Psi^\lambda_{1L_z}\chi^s_{S_z}\phi_B$

L.A Copley, Isgur N, Karl G. Phys.Rev.D, 20, 758(1978)
Xian-Hui Zhong and Qiang Zhao, PHYSICAL REVIEW D **77,** 074008 (2008)

2.2 Operators

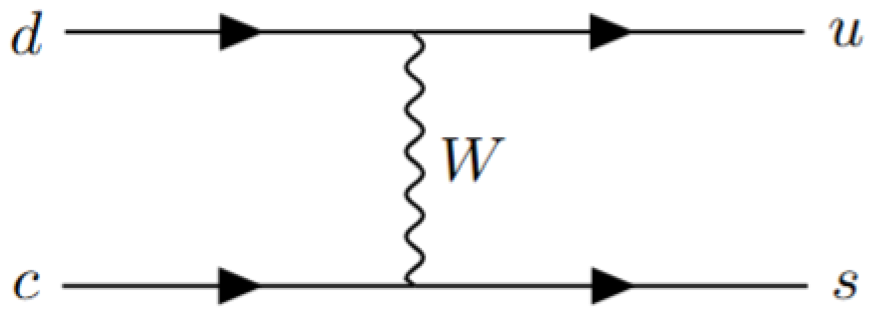
$\Lambda_c \to \Lambda\pi$



- ➢ Weak interaction
- ➢ Strong interaction

2.2 Operators: weak interaction

$H_{W,2\to 2}$:



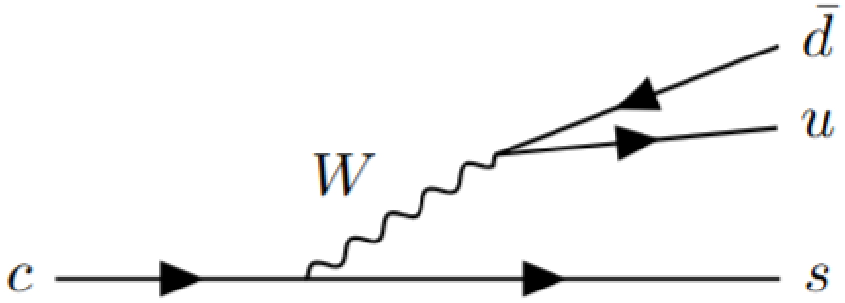
$$H_{W,2\to 2} = \frac{G_F}{\sqrt{2}} V_{ud} V_{cs} \frac{1}{(2\pi)^3} \delta^3(\boldsymbol{p}_i' + \boldsymbol{p}_j' - \boldsymbol{p}_i - \boldsymbol{p}_j) \bar{u}(\boldsymbol{p}_i') \gamma_\mu (1-\gamma_5) u(\boldsymbol{p}_i) \bar{u}(\boldsymbol{p}_j') \gamma^\mu (1-\gamma_5) u(\boldsymbol{p}_j).$$

$$H^{PC}_{W,2\to 2} = \frac{G_F}{\sqrt{2}} V_{ud} V_{cs} \frac{1}{(2\pi)^3} \sum_{i\neq j} \hat{\alpha}_i^{(-)} \hat{\beta}_j^{(+)} \delta^3(\boldsymbol{p}_i' + \boldsymbol{p}_j' - \boldsymbol{p}_i - \boldsymbol{p}_j) \left(1 - \langle s'_{z,i} | \boldsymbol{\sigma}_i | s_{z,i} \rangle \langle s'_{z,j} | \boldsymbol{\sigma}_j | s_{z,j} \rangle \right),$$

$$H^{PV}_{W,2\to 2} = \frac{G_F}{\sqrt{2}} V_{ud} V_{cs} \frac{1}{(2\pi)^3} \sum_{i\neq j} \hat{\alpha}_i^{(-)} \hat{\beta}_j^{(+)} \delta^3(\boldsymbol{p}_i' + \boldsymbol{p}_j' - \boldsymbol{p}_i - \boldsymbol{p}_j)$$
$$\times \Bigg\{ -(\langle s'_{z,i} | \boldsymbol{\sigma}_i | s_{z,i} \rangle - \langle s'_{z,j} | \boldsymbol{\sigma}_j | s_{z,j} \rangle) \left[\left(\frac{\boldsymbol{p}_i}{2m_i} - \frac{\boldsymbol{p}_j}{2m_j} \right) + \left(\frac{\boldsymbol{p}_i'}{2m_i'} - \frac{\boldsymbol{p}_j'}{2m_j'} \right) \right]$$
$$+ i(\langle s'_{z,i} | \boldsymbol{\sigma}_i | s_{z,i} \rangle \times \langle s'_{z,j} | \boldsymbol{\sigma}_j | s_{z,j} \rangle) \left[\left(\frac{\boldsymbol{p}_i}{2m_i} - \frac{\boldsymbol{p}_j}{2m_j} \right) - \left(\frac{\boldsymbol{p}_i'}{2m_i'} - \frac{\boldsymbol{p}_j'}{2m_j'} \right) \right] \Bigg\},$$

2.2 Operators: weak interaction

$H_{W,1\to 3}$:

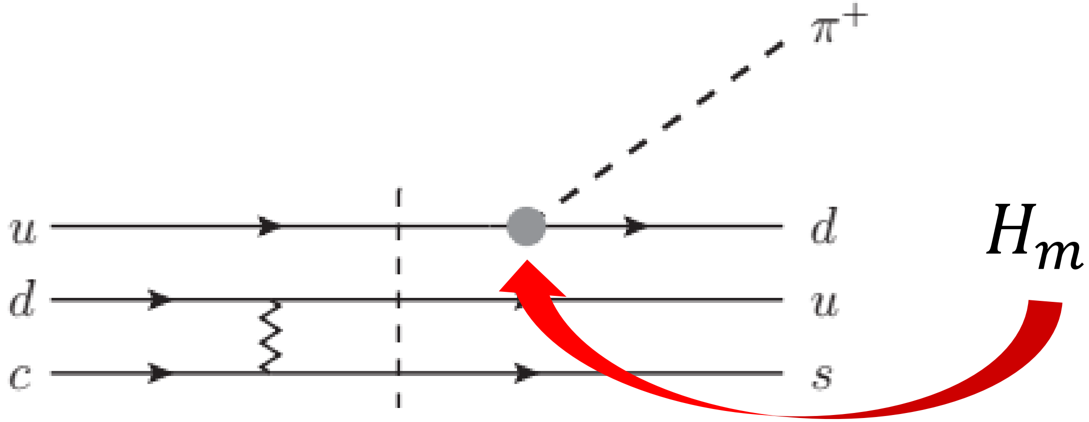


$$H_{W,1\to 3} = \frac{G_F}{\sqrt{2}} V_{ud} V_{cs} \frac{\beta}{(2\pi)^3} \delta^3(\boldsymbol{p}_3 - \boldsymbol{p}_3' - \boldsymbol{p}_5 - \boldsymbol{p}_4) \bar{u}(\boldsymbol{p}_3', m_3') \gamma_\mu (1-\gamma_5) u(\boldsymbol{p}_3, m_3) \bar{u}(\boldsymbol{p}_5, m_5) \gamma^\mu (1-\gamma_5) v(\boldsymbol{p}_4, m_4)$$

$$\begin{aligned} H_{W,1\to 3}^{PC} = \frac{G_F}{\sqrt{2}} V_{ud} V_{cs} \frac{\beta}{(2\pi)^3} \delta^3(\boldsymbol{p}_3 - \boldsymbol{p}_3' - \boldsymbol{p}_4 - \boldsymbol{p}_5) \Bigg\{ & \langle s_3' | I | s_3 \rangle \langle s_5 \bar{s}_4 | \boldsymbol{\sigma} | 0 \rangle \left(\frac{\boldsymbol{p}_5}{2m_5} + \frac{\boldsymbol{p}_4}{2m_4} \right) \\ & - \left[\left(\frac{\boldsymbol{p}_3'}{2m_3'} + \frac{\boldsymbol{p}_3}{2m_3} \right) \langle s_3' | I | s_3 \rangle - i \langle s_3' | \boldsymbol{\sigma} | s_3 \rangle \times \left(\frac{\boldsymbol{p}_3}{2m_3} - \frac{\boldsymbol{p}_3'}{2m_3'} \right) \right] \langle s_5 \bar{s}_4 | \boldsymbol{\sigma} | 0 \rangle \\ & - \langle s_3' | \boldsymbol{\sigma} | s_3 \rangle \left[\left(\frac{\boldsymbol{p}_5}{2m_5} + \frac{\boldsymbol{p}_4}{2m_4} \right) \langle s_5 \bar{s}_4 | I | 0 \rangle - i \langle s_5 \bar{s}_4 | \boldsymbol{\sigma} | 0 \rangle \times \left(\frac{\boldsymbol{p}_4}{2m_4} - \frac{\boldsymbol{p}_5}{2m_5} \right) \right] \\ & + \langle s_3' | \boldsymbol{\sigma} | s_3 \rangle \left(\frac{\boldsymbol{p}_3'}{2m_3'} + \frac{\boldsymbol{p}_3}{2m_3} \right) \langle s_5 \bar{s}_4 | I | 0 \rangle \Bigg\} \hat{\alpha}_3^{(-)} \hat{I}_\pi', \end{aligned}$$

$$H_{W,1\to 3}^{PV} = \frac{G_F}{\sqrt{2}} V_{ud} V_{cs} \frac{\beta}{(2\pi)^3} \delta^3(\boldsymbol{p}_3 - \boldsymbol{p}_3' - \boldsymbol{p}_4 - \boldsymbol{p}_5) \left(- \langle s_3' | I | s_3 \rangle \langle s_5 \bar{s}_4 | I | 0 \rangle + \langle s_3' | \boldsymbol{\sigma} | s_3 \rangle \langle s_5 \bar{s}_4 | \boldsymbol{\sigma} | 0 \rangle \right) \hat{\alpha}_3^{(-)} \hat{I}_\pi',$$

2.2 Operators: chiral quark model



$$H_m = \sum_j \int dx \frac{1}{f_m} \bar{q}_j(\boldsymbol{x}) \gamma_\mu^j \gamma_5^j q_j(\boldsymbol{x}) \partial^\mu \phi_m(\boldsymbol{x})$$

In the non-relativistic limit:

$$H_\mathrm{m} = \frac{1}{\sqrt{(2\pi)^3 2\omega_m}} \sum_j \frac{1}{f_m} \left[\omega_m \left(\frac{\boldsymbol{\sigma} \cdot \boldsymbol{p}_f^j}{2m_f} + \frac{\boldsymbol{\sigma} \cdot \boldsymbol{p}_i^j}{2m_i} \right) - \boldsymbol{\sigma} \cdot \boldsymbol{k} \right] \hat{I}_m^j \delta^3 \left(\boldsymbol{p}_f^j + \boldsymbol{k} - \boldsymbol{p}_i^j \right)$$

The isospin operator $\hat{I}_m^j$ is written as

$$\hat{I}_\pi^j = \begin{cases} b_u^\dagger b_d & \text{for } \pi^- \\ b_d^\dagger b_u & \text{for } \pi^+ \\ \frac{1}{\sqrt{2}} \left[b_u^\dagger b_d - b_d^\dagger b_u \right] & \text{for } \pi^0 \end{cases}$$

2.3 Amplitudes and parity asymmetry parameter

Normalization:

$$\langle M(\boldsymbol{P}_c')_{J,J_z}|M(\boldsymbol{P}_c')_{J,J_z}\rangle = \delta^3(\boldsymbol{P}_c' - \boldsymbol{P}_c),$$

$$\langle B(\boldsymbol{P}_c')_{J,J_z}|B(\boldsymbol{P}_c')_{J,J_z}\rangle = \delta^3(\boldsymbol{P}_c' - \boldsymbol{P}_c).$$

Decay width：

$$\Gamma(A \to B + C) = 8\pi^2 \frac{|\boldsymbol{k}|E_B E_C}{M_A} \frac{1}{2J_A + 1} \sum_{spin} |M|^2,$$

where

$$\delta^3(\boldsymbol{P}_A - \boldsymbol{P}_B - \boldsymbol{P}_C)M \equiv \langle BC|H|A\rangle.$$

The parity asymmetry parameter

$$M = G_F m_\pi^2 \bar{B}_f(\mathrm{A} - \mathrm{B}\gamma_5)B_i$$

The transition rate is proportional to

$$R = 1 + \gamma\,\hat{\boldsymbol{\omega}}_f \cdot \hat{\boldsymbol{\omega}}_i + (1-\gamma)(\hat{\boldsymbol{\omega}}_f \cdot \hat{\mathbf{n}})(\hat{\boldsymbol{\omega}}_i \cdot \hat{\mathbf{n}}) + \alpha(\hat{\boldsymbol{\omega}}_f \cdot \hat{\mathbf{n}} + \hat{\boldsymbol{\omega}}_i \cdot \hat{\mathbf{n}}) + \beta\hat{\mathbf{n}} \cdot (\hat{\boldsymbol{\omega}}_f \times \hat{\boldsymbol{\omega}}_i) \;,$$

$$\alpha = \frac{2\mathrm{Re}(s^* p)}{|s^2| + |p^2|} \qquad s = A, \qquad p = B\frac{|\boldsymbol{p}_f|}{E_f + m_f}$$

$$\alpha = \frac{2\mathrm{Re}(M_{\mathrm{PV}}^* M_{\mathrm{PC}})}{|{M_{\mathrm{PC}}}^2| + |{M_{\mathrm{PV}}}^2|}$$

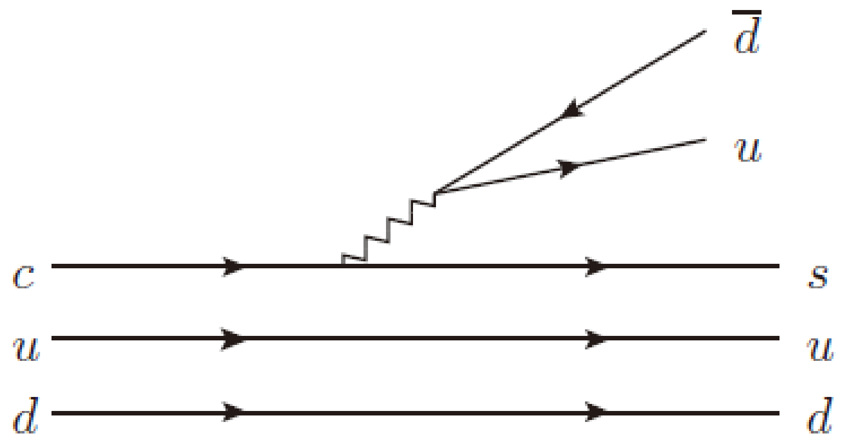
03

The hadronic weak decay of charmed baryons

- The hadronic weak decay of Λ_c
- The hadronic weak decay of Ξ_c

3.1 Previous works: hadronic weak decays of Λ_c

Processes	$\Lambda_c \to \Lambda\pi^+$	$\Lambda_c \to \Sigma^+\pi^0$	$\Lambda_c \to \Sigma^0\pi^+$
DME	✓	×	×
CS	✓	✓	✓
Pole term	✓	✓	✓
Br	1.30%	1.29%	1.24%



$$\phi_{\Lambda_c} = \frac{1}{\sqrt{2}}(ud - du)c,\ \phi_{\Lambda} = \frac{1}{\sqrt{2}}(ud - du)s, \phi_{\Sigma^0} = \frac{1}{\sqrt{2}}(ud + du)s$$

- DPE process should not be the only dominant processes.
- The important of non-factorizable processes

Peng-Yu Niu, Jean-Marc Richard, Qian Wang, and Qiang Zhao, Phys. Rev. D.102.073005

3.1 Previous works: hadronic weak decays of Λ_c

TABLE V: The amplitudes with $J_f^z = J_i^z = -1/2$ for different processes and the unit is 10^{-9} GeV$^{-1/2}$. Amplitudes $A1(PV)$ and $A2(PV)$ are given by the parity-violating intermediate states $\Sigma^{*+}(1620)$ ($[\mathbf{70}, {}^2\mathbf{8}]$) and $\Sigma^{*+}(1750)$ ($[\mathbf{70}, {}^4\mathbf{8}]$), respectively.

Processes	$A(PC)$	$A1(PV)$	$A2(PV)$	$B(PC)$	$B(PV)$	$CS(PC)$	$CS(PV)$	$DPE(PC)$	$DPE(PV)$
$\Lambda_c \to \Lambda\pi^+$	-16.50	$0.74 - 0.023i$	$-2.57 + 0.10i$	$22.33 + 0.021i$	$-10.72 - 0.33i$	3.50	-4.17	-42.47	24.07
$\Lambda_c \to \Sigma^0\pi^+$	19.67	$-3.21 + 0.10i$	$-2.23 + 0.090i$	$-40.73 - 0.040i$	$19.16 + 0.60i$	-6.04	7.53	0	0
$\Lambda_c \to \Sigma^+\pi^0$	19.64	$-3.15 + 0.098i$	$-2.19 + 0.088$	$-40.65 - 0.10i$	$19.28 + 0.52i$	-6.04	7.51	0	0

- The parity-conserving amplitudes of the pole terms are dominant.
- The interferences between factorizable and non-factorizable processes are essential.

	$\mathrm{BR}(\Lambda_c \to \Lambda\pi^+)$	$\mathrm{BR}(\Lambda_c \to \Sigma^0\pi^+)$	$\mathrm{BR}(\Lambda_c \to \Sigma^+\pi^0)$
PDG data [24]	1.30 ± 0.07	1.29 ± 0.07	1.24 ± 0.10
BESIII [20]	$1.24 \pm 0.07 \pm 0.03$	$1.27 \pm 0.08 \pm 0.03$	$1.18 \pm 0.10 \pm 0.03$
SU(3) [39]	1.3 ± 0.2	1.3 ± 0.2	1.3 ± 0.2
Pole model [4]	1.30 ± 0.07	1.29 ± 0.07	1.24 ± 0.10
Current algebra [4]	1.30 ± 0.07	1.29 ± 0.07	1.24 ± 0.10
This work	1.30	1.24	1.26

$(1.31 \pm 0.08 \pm 0.05)\%$ $(1.22 \pm 0.08 \pm 0.07)\%$ BESIII PRL.128.142001(2022)

3.1 Previous works: hadronic weak decays of Λ_c

The asymmetry parameter

	$\Lambda_c \to \Lambda\pi^+$	$\Lambda_c \to \Sigma^0\pi^+$	$\Lambda_c \to \Sigma^+\pi^0$
PDG data [24]	-0.91 ± 0.14	$\cdots$	-0.45 ± 0.32
Pole model [4]	-0.95	0.78	0.78
Current algebra [4]	-0.99	-0.49	-0.49
This work	-0.16 ± 0.27	-0.46 ± 0.20	-0.47 ± 0.19

time. We obtain $\alpha^{\rm avg}_{\Lambda_c^+}(\Lambda_c^+ \to \Lambda\pi^+) = -0.755 \pm 0.005 \pm 0.003$ and $\alpha^{\rm avg}_{\Lambda_c^+}(\Lambda_c^+ \to \Sigma^0\pi^+) = -0.463 \pm 0.016 \pm 0.008$, which are consistent with previous measurements [38]

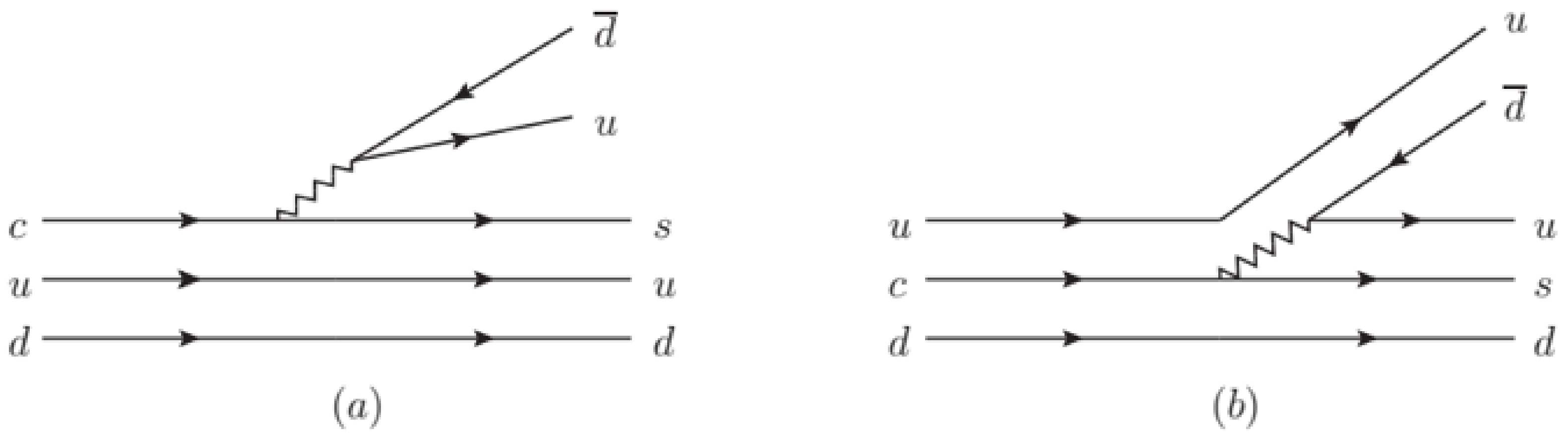
Belle, Sci.Bull. 68 (2023) 583-592

Belle, Phys.Rev.D 107 (2023) 032003

The asymmetry parameter $\alpha_{\Sigma^+\pi^0}$ is measured as

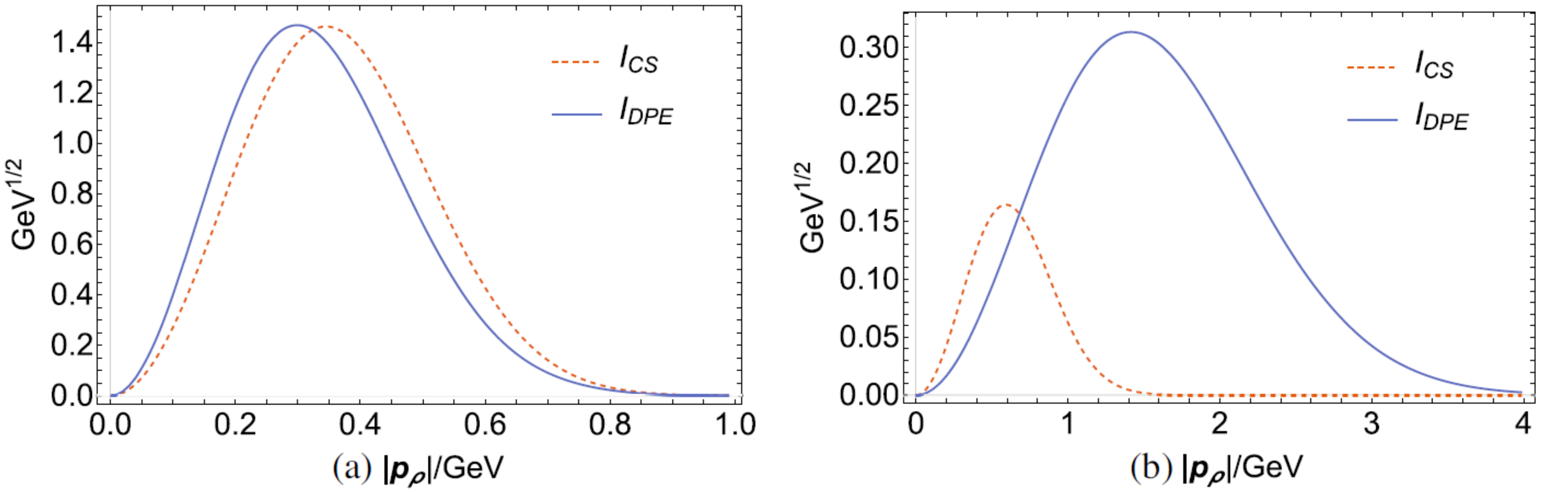
$$\alpha_{\Sigma^+\pi^0} = -0.48 \pm 0.02 \pm 0.02,$$

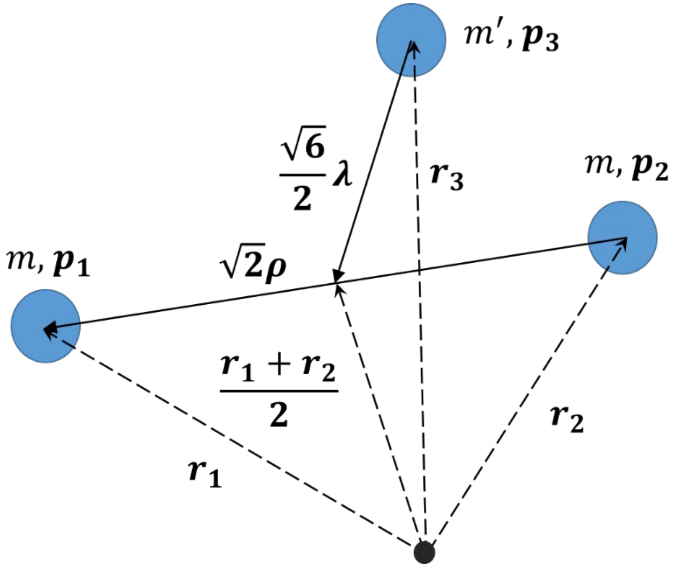
3.1 Previous works: hadronic weak decays of Λ_c



DPE

CS



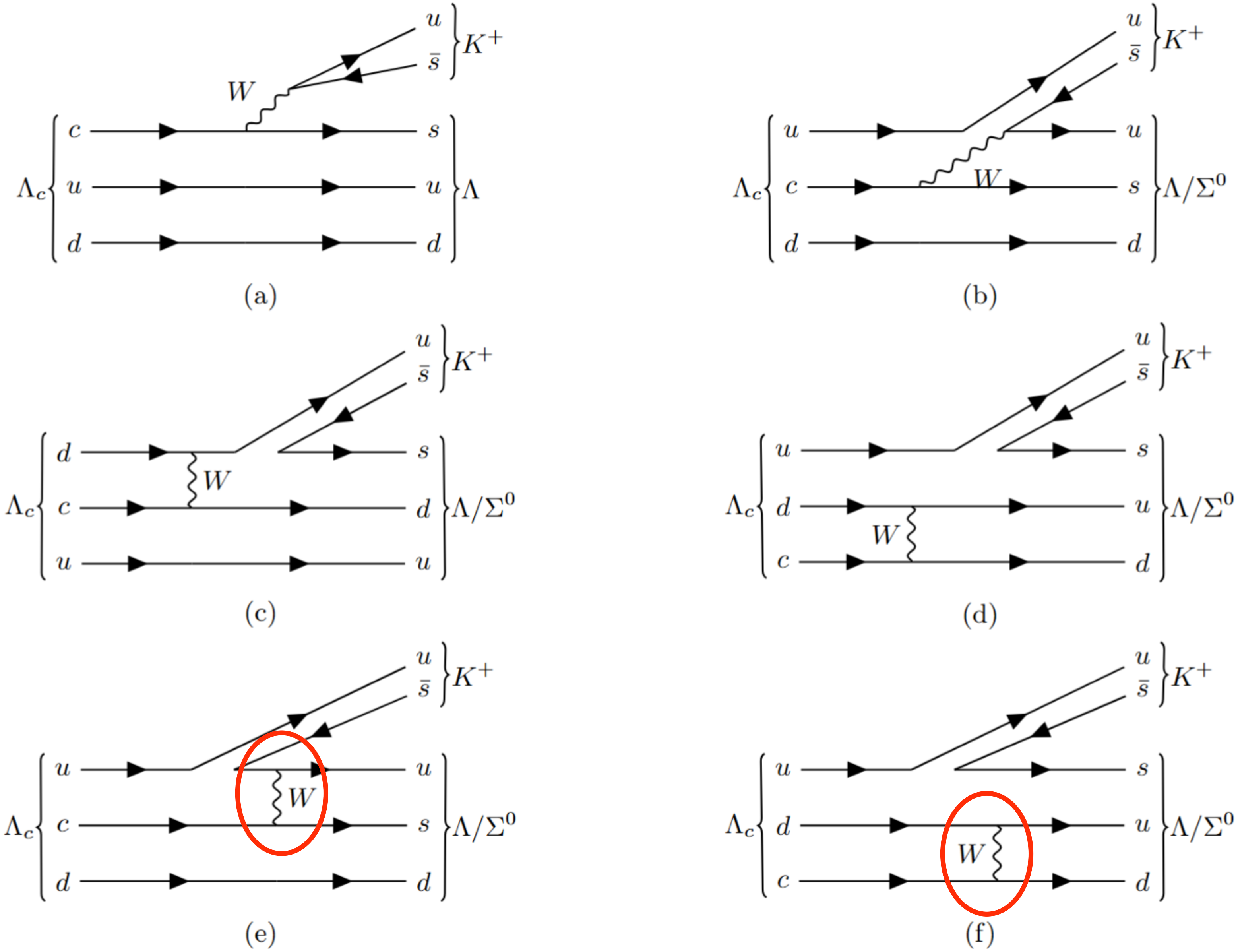


$$\langle \rho^2 \rangle \propto \frac{1}{\alpha_\rho^2}$$

3.2 The diquark revisit (in progress)

$\Lambda_c \to \Lambda/\Sigma\, K^+$

$\Lambda_c \to \Lambda/\Sigma\, \pi^+$



3.2 The diquark revisit (in progress)

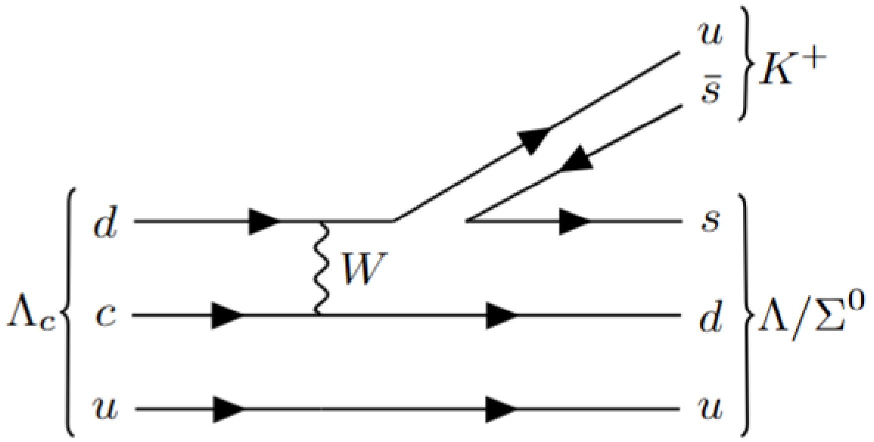
The amplitudes (in unit of 10^{-9} $\mathrm{GeV}^{-1/2}$)

Parity	Processes	States	$\Lambda_c \to \Lambda K^+$ $\theta = 0^\circ$	$\theta = 30^\circ$	$\Lambda_c \to \Sigma^0 K^+$ $\theta = 0^\circ$	$\theta = 30^\circ$
PC	DPE	-	-6.71	-6.29	0	0
	CS	-	0.67	0.63	-1.16	-1.08
	WS	p	-1.89	-2.30	0.36	0.44
	SW	Ξ_c^0	$(0, 0)$	$(0, 0)$	$(0, 0)$	$(0, 0)$
		$\Xi_c'^0$	$(0.60, 1.13)$	1.33	$(-1.14, 0)$	$(-2.45, 0)$
	Total	-	-6.21	-4.11	-1.94	-3.10
PV	DPE	-	4.93	4.48	0	0
	CS	-	-1.10	-1.08	1.97	1.91
	WS	$N(1535)$	$2.67 - 0.15i$	$3.23 - 0.18i$	$0.58 - 0.32i$	$-0.65 + 0.084i$
		$N(1650)$	0	$0.87 - 0.048i$	$4.37 - 0.40i$	$5.24 - 0.47i$
	SW	$\Xi_c^0\vert^2P_\rho\rangle$	$(-0.36, 0.82)$	$(-0.99, 2.20)$	$(0.89, 0.096)$	$(2.28, 0.20)$
		$\Xi_c^0\vert^2P_\lambda\rangle$	$(0, 0)$	$(0, 0)$	$(0, 0)$	$(0, 0)$
		$\Xi_c^0\vert^4P_\rho\rangle$	$(0.55, -1.05)$	$(1.45, -2.75)$	$(-1.05, 0)$	$(-2.67, 0)$
		$\Xi_c'^0\vert^2P_\rho\rangle$	$(0, 0)$	$(0, 0)$	$(0, 0)$	$(0, 0)$
		$\Xi_c'^0\vert^2P_\lambda\rangle$	$(-0.45, -0.80)$	$(-1.19, -2.11)$	$(0.78, 0.043)$	$(2.03, 0.091)$
		$\Xi_c'^0\vert^4P_\lambda\rangle$	$(0.56, 1.06)$	$(1.45, 2.75)$	$(-1.05, 0)$	$(-2.66, 0)$
	Total	-	$6.68 - 0.15i$	$8.32 - 0.23i$	$6.63 - 0.43i$	$5.77 - 0.39i$

The mixing angle of $N(1535)$ and $N(1650)$ is 30°.

Selection Rules

3.2 The diquark revisit (in progress)



$N(1535)$: [70,^{2} 8]
$N(1650)$: [70,^{4} 8]

The spin of u and d must be persevered.

$$|\mathbf{56},^2 8,0,0,\frac{1}{2}\rangle = \frac{1}{\sqrt{2}}(\phi^\rho_B\chi^\rho_{S,S_z} + \phi^\lambda_B\chi^\lambda_{S,S_z})\Psi_{0,0,0},$$

$$|\mathbf{70},^2 8,1,1,J\rangle = \sum_{L_z+S_z=J_z}\langle 1,L_z;\frac{1}{2},S_z|JJ_z\rangle\frac{1}{2}\left[(\phi^\rho_B\chi^\lambda_{S,S_z} + \phi^\lambda_B\chi^\rho_{S,S_z})\Psi^\rho_{1,1,L_z} + (\phi^\rho_B\chi^\rho_{S,S_z} - \phi^\lambda_B\chi^\lambda_{S,S_z})\Psi^\lambda_{1,1,L_z}\right],$$

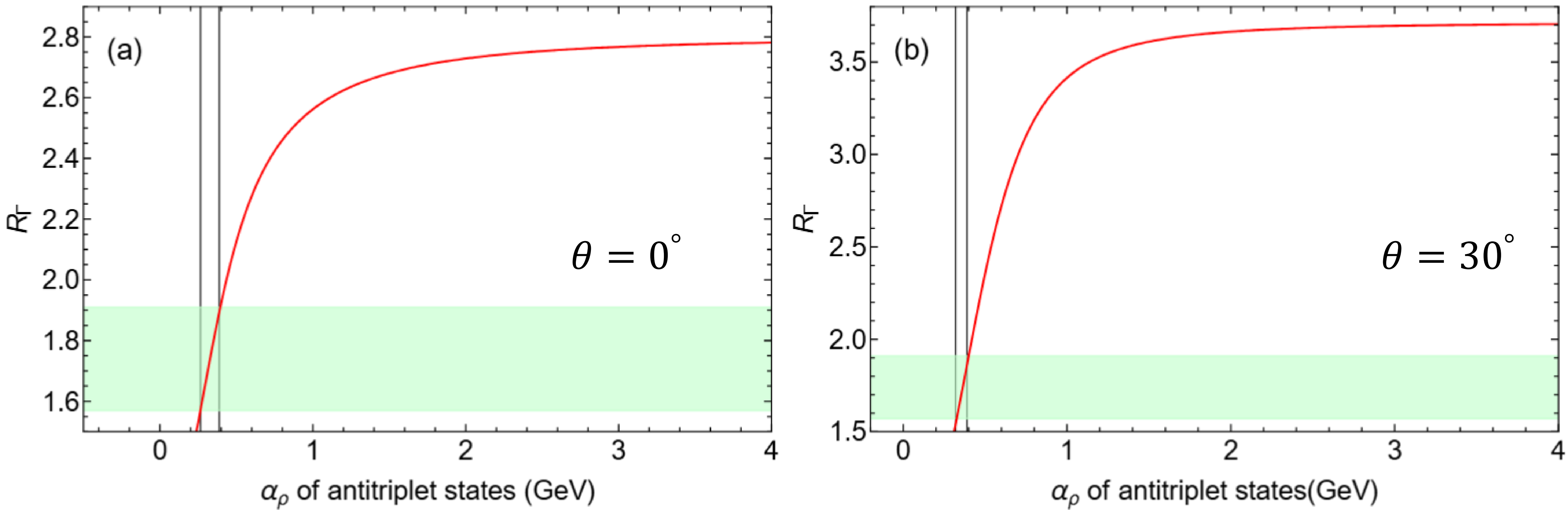
$$|\mathbf{70},^4 8,1,1,J\rangle = \sum_{L_z+S_z=J_z}\langle 1,L_z;\frac{3}{2},S_z|JJ_z\rangle\frac{1}{\sqrt{2}}\left[\phi^\rho_B\chi^s_{S,S_z}\Psi^\rho_{1,1,L_z} + \phi^\lambda_B\chi^s_{S,S_z}\Psi^\lambda_{1,1,L_z}\right].$$

Λ selection rule: leads to the vanishing transition matrix element between $N(1650)$of [70,^{4} 8] and [56,^{2} 8] in $N(1650) \to \Lambda\ K/\ K^*$.

Qiang Zhao and Frank E. Close, arXiv:0711.0151v1

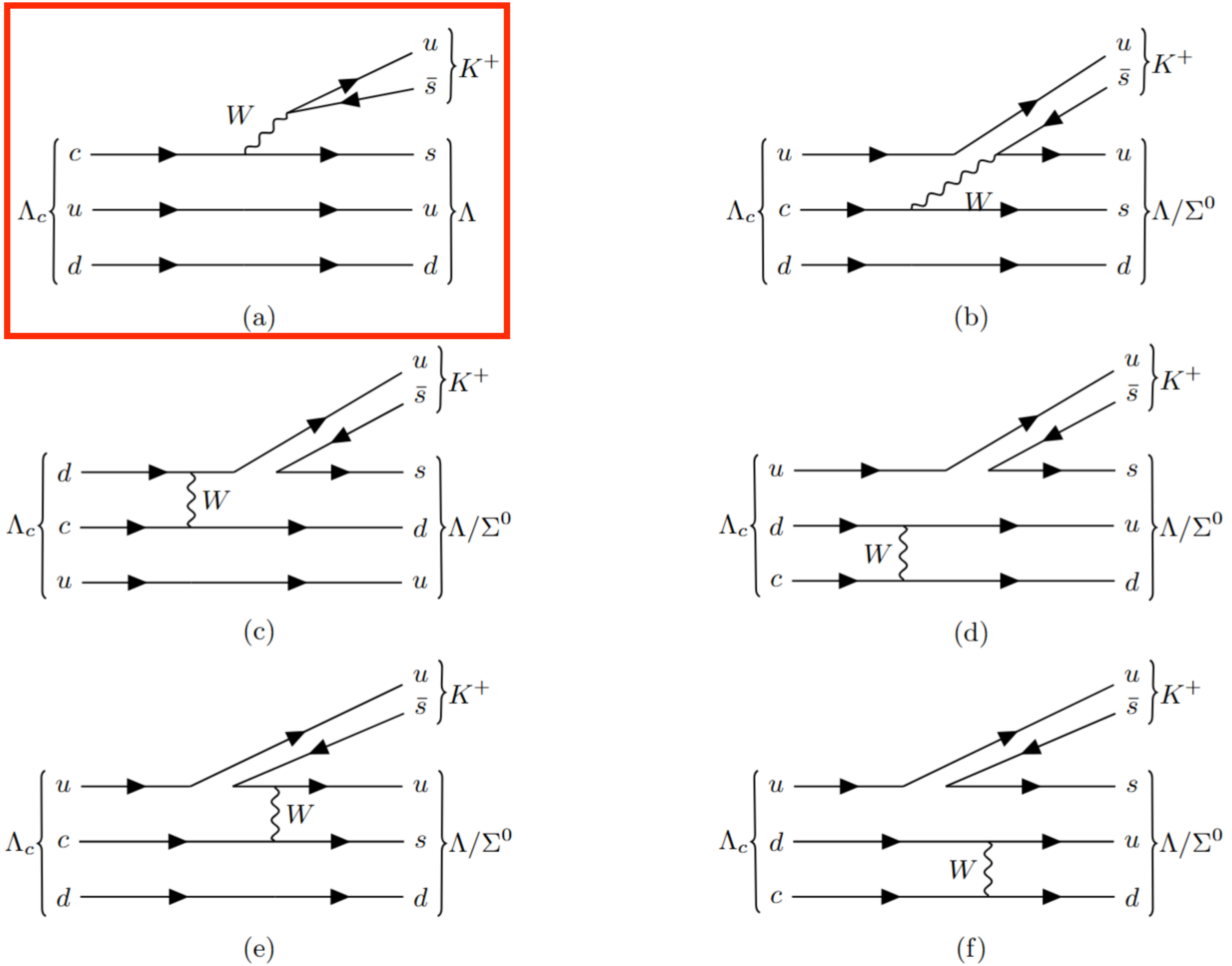
3.2 The diquark revisit (in progress)

Only the α_ρ of anti-triplet charmed baryon are changed



$$R_\Gamma = \frac{\mathrm{Br}(\Lambda_c \to \Lambda K^+)}{\mathrm{Br}(\Lambda_c \to \Sigma^0 K^+)}$$

3.2 The diquark revisit (in progress)



3.2 The diquark revisit (in progress)

$$|\Lambda_c\rangle = |0,0\rangle$$
$$\langle\Lambda| = |0,0\rangle$$
$$\langle\Sigma^0| = |1,0\rangle$$

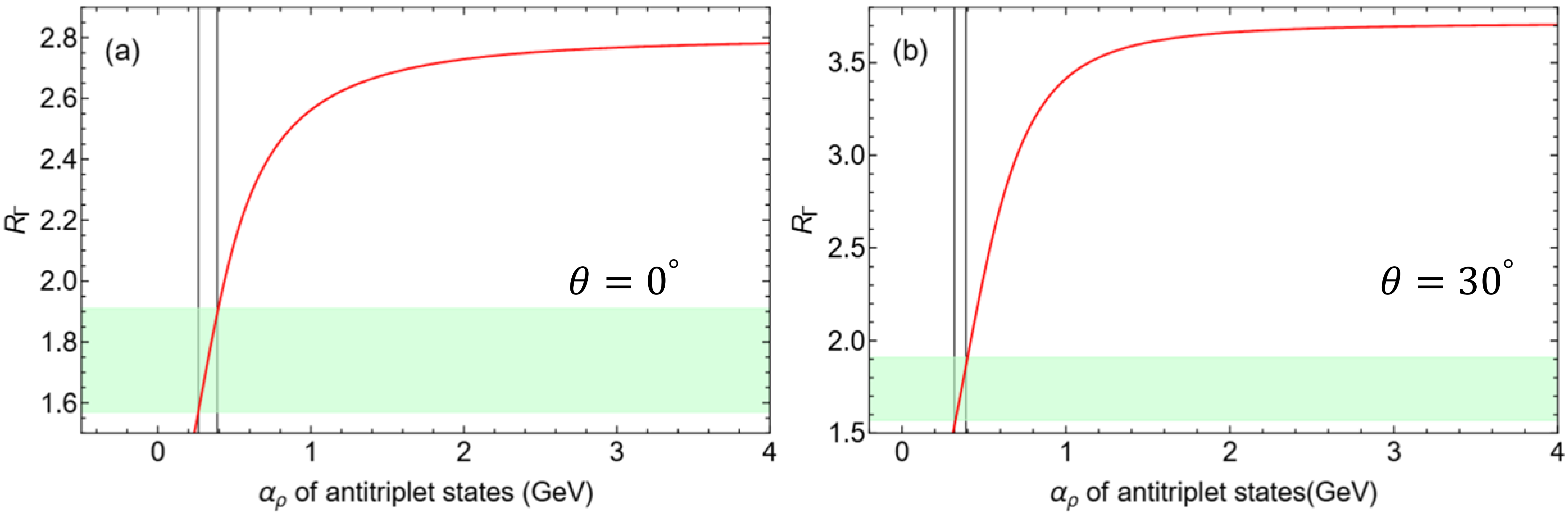
The weak Hamiltonian

$cs \to su, cd \to du$ and $c \to s\,\bar{u}\,s$:

$$\Delta I = \frac{1}{2}, \Delta I_3 = \frac{1}{2} \Rightarrow |H_W\rangle = \left|\frac{1}{2}, \frac{1}{2}\right\rangle$$

$$R_\Gamma \approx \frac{|M(\Lambda_c \to \Lambda K^+)|^2}{|M(\Lambda_c \to \Sigma^0 K^+)|^2} = \frac{|\langle \Lambda K^+|H_W|\Lambda_c\rangle|^2}{|\langle \Sigma^0 K^+|H_W|\Lambda_c\rangle|^2} = \frac{|\langle 0,0;\frac{1}{2},\frac{1}{2}|0,0;\frac{1}{2},\frac{1}{2}\rangle|^2}{|\langle 1,0;\frac{1}{2},\frac{1}{2}|0,0;\frac{1}{2},\frac{1}{2}\rangle|^2} = 3.$$

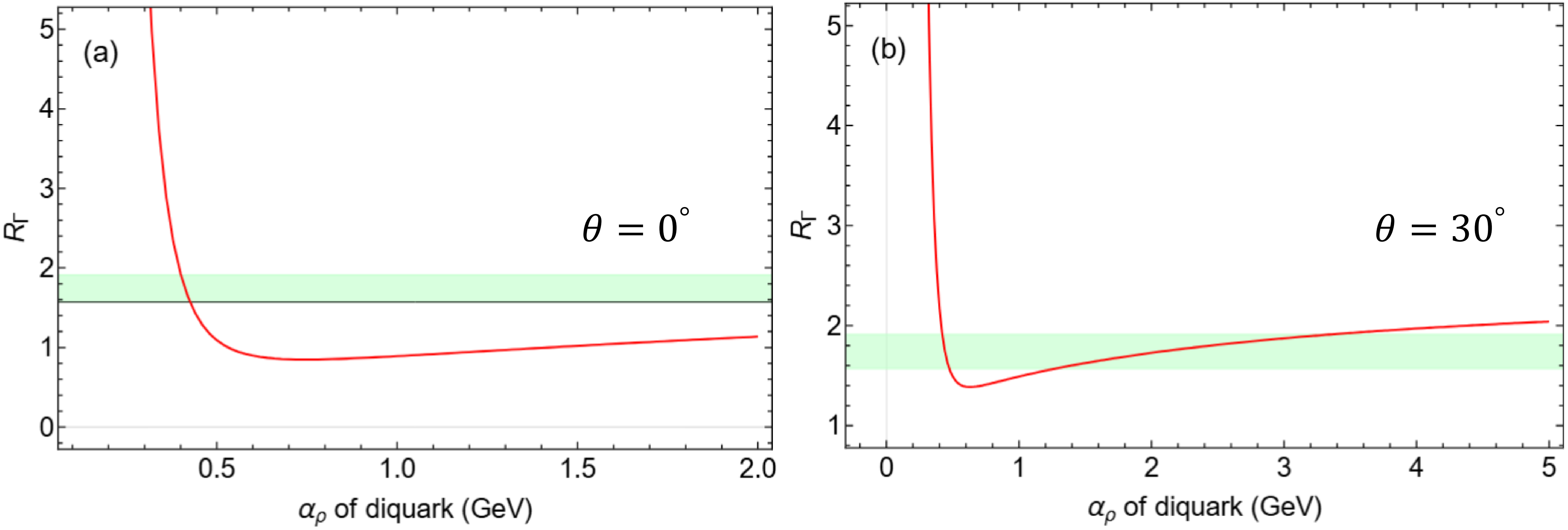
3.2 The diquark revisit (in progress)



$$R_\Gamma \approx \frac{|M(\Lambda_c \to \Lambda K^+)|^2}{|M(\Lambda_c \to \Sigma^0 K^+)|^2} = \frac{|\langle \Lambda K^+ | H_W | \Lambda_c \rangle|^2}{|\langle \Sigma^0 K^+ | H_W | \Lambda_c \rangle|^2} = \frac{|\langle 0,0;\frac{1}{2},\frac{1}{2}|0,0;\frac{1}{2},\frac{1}{2}\rangle|^2}{|\langle 1,0;\frac{1}{2},\frac{1}{2}|0,0;\frac{1}{2},\frac{1}{2}\rangle|^2} = 3.$$

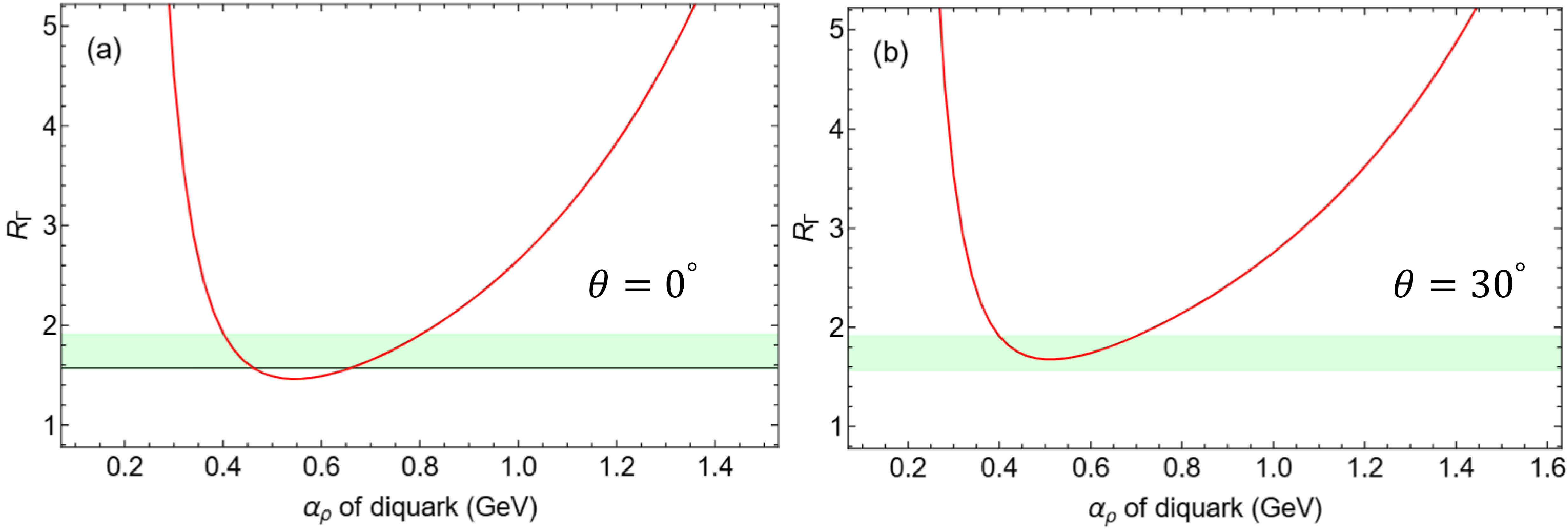
3.2 The diquark revisit (in progress)

The α_ρ of initial and final baryons are changed



3.2 The diquark revisit (in progress)

All the α_ρ of baryons are changed.



3.3 Previous works: heavy quark conserving weak decays

Evidence for the strangeness-changing weak decay $\Xi_b^- \to \Lambda_b^0 \pi^-$ #1

LHCb Collaboration • Roel Aaij (CERN) et al. (Oct 13, 2015)

Published in: *Phys.Rev.Lett.* 115 (2015) 24, 241801 • e-Print: 1510.03829 [hep-ex]

pdf links DOI cite 21 citations

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b}} \mathcal{B}(\Xi_b^- \to \Lambda_b \pi^-) = \left(5.7 \pm 1.8^{+0.8}_{-0.9}\right) \times 10^{-4}$$

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b}} \approx 0.1\sim0.3 \Rightarrow \mathcal{B}(\Xi_b^- \to \Lambda_b \pi^-) = (0.57 \pm 0.21)\%\sim(0.19 \pm 0.07)\%$$

First branching fraction measurement of the suppressed decay $\Xi_c^0 \to \pi^- \Lambda_c^+$ #1

LHCb Collaboration • Roel Aaij (NIKHEF, Amsterdam) et al. (Jul 23, 2020)

Published in: *Phys.Rev.D* 102 (2020) 7, 071101 • e-Print: 2007.12096 [hep-ex]

pdf DOI cite 0 citations

$$\mathcal{B}\left(\Xi_c^0 \to \Lambda_c \pi^-\right) = (0.55 \pm 0.02 \pm 0.18)\%$$

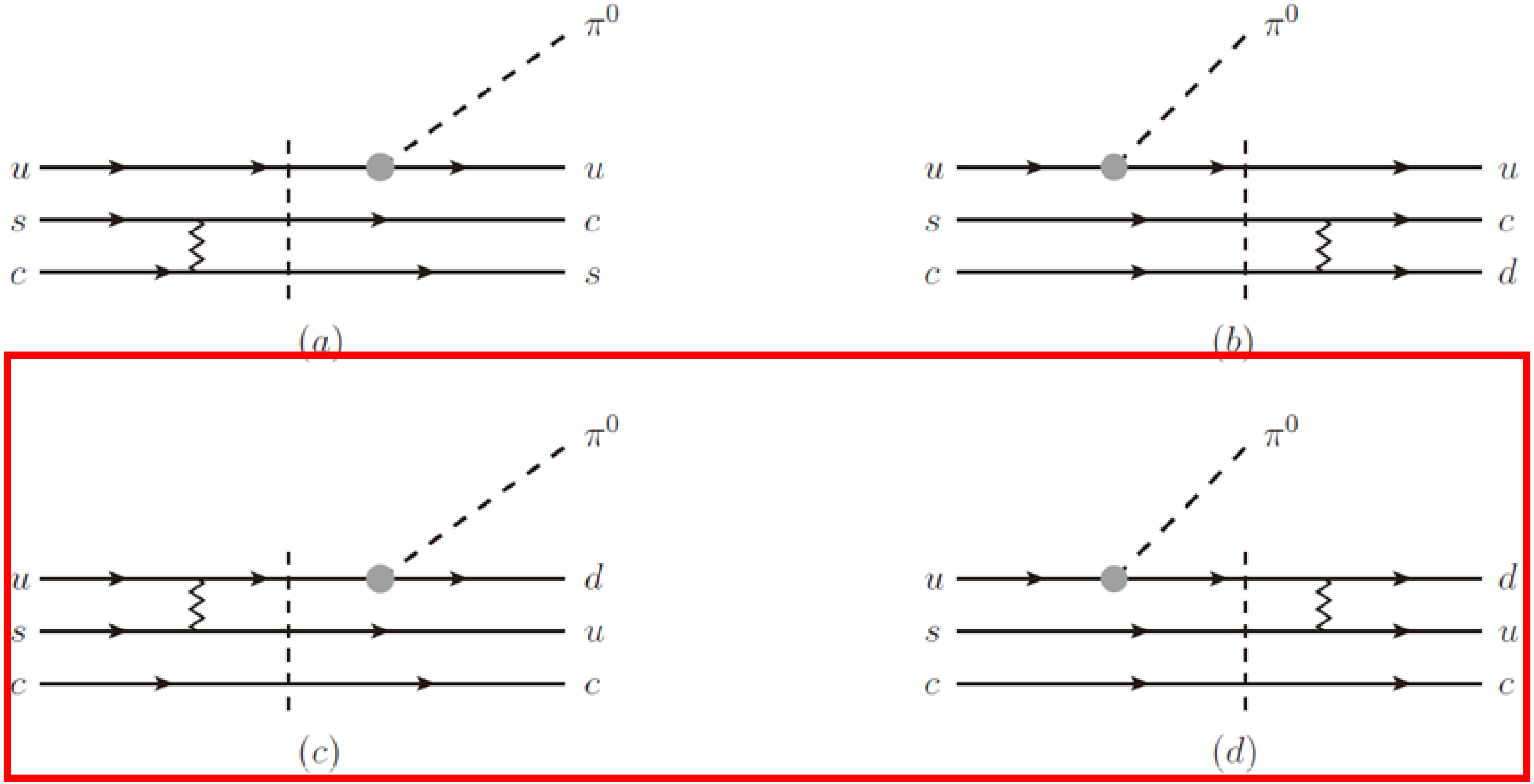
Peng-Yu Niu, Qian Wang, and Qiang Zhao, Phys. Lett. B 826(2022)136916

3.3 Previous works: heavy quark conserving weak decays

Processes	$\Xi_c^+ \to \Lambda_c \pi^0$	$\Xi_c^0 \to \Lambda_c \pi^-$	$\Xi_b^0 \to \Lambda_b \pi^0$	$\Xi_b^- \to \Lambda_b \pi^-$
Exp. Data	$\cdots$	0.55 ± 0.20 [1]	$\cdots$	$0.19 \pm 0.07 \sim 0.57 \pm 0.21$ [2]
MIT bag model [4]	0.0093	0.0087	0.059	0.2
Diquark model [4]	$\cdots$	$\cdots$	0.25	0.69
Duality [5]	$\cdots$	$\cdots$	$\cdots$	0.63 ± 0.42
Current algebra [11]	0.386 ± 0.135	0.194 ± 0.07	$\cdots$	$\cdots$
Current algebra [6]	$\cdots$	$\cdots$	$1 \sim 4$	$2 \sim 8$
Current algebra [10]	< 0.6	< 0.3	$0.09 - 0.37$	$0.19 - 0.76$
Our results	1.11	0.58	0.017	0.14

Larger than the theoretical values

3.3 Previous works: heavy quark conserving weak decays



3.3 Previous works: heavy quark conserving weak decays

			$\Xi_c^+ \to \Lambda_c \pi^0$		$\Xi_c^0 \to \Lambda_c \pi^-$		$\Xi_b^0 \to \Lambda_b \pi^0$		$\Xi_b^- \to \Lambda_b \pi^-$
PC	Pole-A	Σ_c^+	$116.76 - 17.80i$	Σ_c^0	$146.77 - 7.80i$	Σ_b^0	Spin(weak)		
		Λ_c^+	Isospin			Λ_b	Spin(CQM)		
	Pole-B	Ξ_c^+	Spin(CQM)	Ξ_c^+	Spin(CQM)	Ξ_b^0	Spin(CQM)	Ξ_b^0	Spin(CQM)
		$\Xi_c'^+$	-2.61	$\Xi_c'^+$	-3.67	$\Xi_b'^0$	Spin(weak)	$\Xi_b'^0$	Spin(weak)
	DPE		Spin(weak)		Spin(weak)		Spin(weak)		Spin(weak)
	CS		Spin(weak)		Spin(weak)		Spin(weak)		Spin(weak)
	Total		$114.15 - 17.80i$		$143.10 - 7.80i$		0		0
PV	Pole-A	$\Sigma_c^+\|^2P_\rho\rangle$	Spin(CQM)	$\Sigma_c^0\|^2P_\rho\rangle$	Spin(CQM)	$\Sigma_b^0\|^2P_\rho\rangle$	Spin(weak)		
		$\Sigma_c^+\|^2P_\lambda\rangle$	1.59	$\Sigma_c^0\|^2P_\lambda\rangle$	2.72	$\Sigma_b^0\|^2P_\lambda\rangle$	Spatial		
		$\Sigma_c^+\|^4P_\rho\rangle$	-0.94	$\Sigma_c^0\|^4P_\rho\rangle$	-1.34	$\Sigma_b^0\|^4P_\rho\rangle$	Spatial		
		$\Lambda_c^+\|^2P_\rho\rangle$	Isospin			$\Lambda_b\|^2P_\rho\rangle$	Isospin		
		$\Lambda_c^+\|^2P_\lambda\rangle$	Isospin			$\Lambda_b\|^2P_\lambda\rangle$	Isospin		
		$\Lambda_c^+\|^4P_\rho\rangle$	Isospin			$\Lambda_b\|^4P_\rho\rangle$	Isospin		
	Pole-B	$\Xi_c^+\|^2P_\rho\rangle$	-3.32	$\Xi_c^+\|^2P_\rho\rangle$	-6.02	$\Xi_b^0\|^2P_\rho\rangle$	-7.95	$\Xi_b^0\|^2P_\rho\rangle$	-11.25
		$\Xi_c^+\|^2P_\lambda\rangle$	Spin(CQM)	$\Xi_c^+\|^2P_\lambda\rangle$	Spin(CQM)	$\Xi_b^0\|^2P_\lambda\rangle$	Spin(CQM)	$\Xi_b^0\|^2P_\lambda\rangle$	Spin(CQM)
		$\Xi_c^+\|^4P_\rho\rangle$	-1.26	$\Xi_c^+\|^4P_\rho\rangle$	-1.77	$\Xi_b^0\|^4P_\rho\rangle$	-3.57	$\Xi_b^0\|^4P_\rho\rangle$	-5.06
		$\Xi_c'^+\|^2P_\rho\rangle$	Spin(CQM)	$\Xi_c'^+\|^2P_\rho\rangle$	Spin(CQM)	$\Xi_b'^0\|^2P_\rho\rangle$	Spin(CQM)	$\Xi_b'^0\|^2P_\rho\rangle$	Spin(CQM)
		$\Xi_c'^+\|^2P_\lambda\rangle$	0.55	$\Xi_c'^+\|^2P_\lambda\rangle$	0.77	$\Xi_b'^0\|^2P_\lambda\rangle$	Spatial	$\Xi_b'^0\|^2P_\lambda\rangle$	Spatial
		$\Xi_c'^+\|^4P_\lambda\rangle$	-0.41	$\Xi_c'^+\|^4P_\lambda\rangle$	-0.58	$\Xi_b'^0\|^4P_\lambda\rangle$	Spatial	$\Xi_b'^0\|^4P_\lambda\rangle$	Spatial
	DPE		0		-9.73		0		-9.79
	CS		3.40		4.81		4.32		6.11
	Total		$-1.32 + 0.0038i$		$-11.58 + 0.0055i$		$-7.20 - 0.0048i$		$-19.99 - 0.0068$

explain the sizable branching ratio for $\Xi_c^0 \to \Lambda_c \pi$

3.3 Previous works: heavy quark conserving weak decays

Processes	$\Xi_c^+ \to \Lambda_c \pi^0$	$\Xi_c^0 \to \Lambda_c \pi^-$	$\Xi_b^0 \to \Lambda_b \pi^0$	$\Xi_b^- \to \Lambda_b \pi^-$
Exp. Data	$\cdots$	0.55 ± 0.20 [1]	$\cdots$	$0.19 \pm 0.07 \sim 0.57 \pm 0.21$ [2]
MIT bag model [4]	0.0093	0.0087	0.059	0.2
Diquark model [4]	$\cdots$	$\cdots$	0.25	0.69
Duality [5]	$\cdots$	$\cdots$	$\cdots$	0.63 ± 0.42
Current algebra [11]	0.386 ± 0.135	0.194 ± 0.07	$\cdots$	$\cdots$
Current algebra [6]	$\cdots$	$\cdots$	$1 \sim 4$	$2 \sim 8$
Current algebra [10]	< 0.6	< 0.3	$0.09 - 0.37$	$0.19 - 0.76$
Our results	1.11	0.58	0.017	0.14

3.3 Previous works: heavy quark conserving weak decays

Processes	$\Xi_c^+ \to \Lambda_c \pi^0$	$\Xi_c^0 \to \Lambda_c \pi^-$	$\Xi_b^0 \to \Lambda_b \pi^0$	$\Xi_b^- \to \Lambda_b \pi^-$
Exp. Data	$\cdots$	0.55 ± 0.20 [1]	$\cdots$	$0.19 \pm 0.07 \sim 0.57 \pm 0.21$ [2]
MIT bag model [4]	0.0093	0.0087	0.059	0.2
Diquark mo				0.69
Duality [5]				0.63 ± 0.42
Current alge				$\cdots$
Current alge				$2 \sim 8$
Current alge				$0.19 - 0.76$
Our results				0.14

and the remaining six uncertainties as 100% correlated. The resulting value is

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} \mathcal{B}(\Xi_b^- \to \Lambda_b^0 \pi^-) = (7.3 \pm 0.8 \pm 0.6) \times 10^{-4},$$

where the uncertainties are statistical and total systematic, respectively. Using the independent measurement $\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} = (8.2 \pm 0.7 \pm 0.6 \pm 2.5)\%$ [19], the branching fraction is determined to be

$$\mathcal{B}(\Xi_b^- \to \Lambda_b^0 \pi^-) = (0.89 \pm 0.10 \pm 0.07 \pm 0.29)\%,$$

LHCb, PRD 108, 072002 (2023)

3.4 First decay of $\Xi_c^0 \to \Xi^0\pi^0/\eta/\eta'$

FUDAN UNIVERSITY 复旦大學 核科学与技术系

First Study of $\Xi_c^0 \to \Xi^0\pi^0/\eta/\eta'$

PRELIMINARY at Belle + Belle II ~1.4/ab:

BELLE Belle II

First measurements of the branching fractions using combined data:

$$\mathcal{B}(\Xi_c^0 \to \Xi^0\pi^0) = (6.9 \pm 0.3(\text{stat.}) \pm 0.5(\text{syst.}) \pm 1.5(\text{norm.})) \times 10^{-3}$$
$$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta) = (1.6 \pm 0.2(\text{stat.}) \pm 0.2(\text{syst.}) \pm 0.4(\text{norm.})) \times 10^{-3}$$
$$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta') = (1.2 \pm 0.3(\text{stat.}) \pm 0.1(\text{syst.}) \pm 0.3(\text{norm.})) \times 10^{-3}$$

taking $\Xi_c^0 \to \Xi^-\pi^+$ as reference mode (BR error dominate the uncertainties), favoriting predictions in SU(3) flavor symmetry [JHEP 02, 235 (2023)]

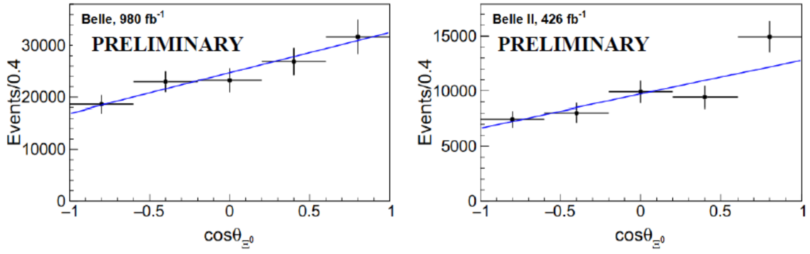
First asymmetry parameter $\alpha(\Xi_c^0 \to \Xi^0\pi^0)$ measurement depending on

$$\frac{dN}{dcos\theta_{\Xi^0}} \propto 1 + \alpha(\Xi_c^0 \to \Xi^0 h^0)\alpha(\Xi^0 \to \Lambda\pi^0)cos\theta_{\Xi^0}$$

through a simultaneous fit to Belle and Belle II data samples

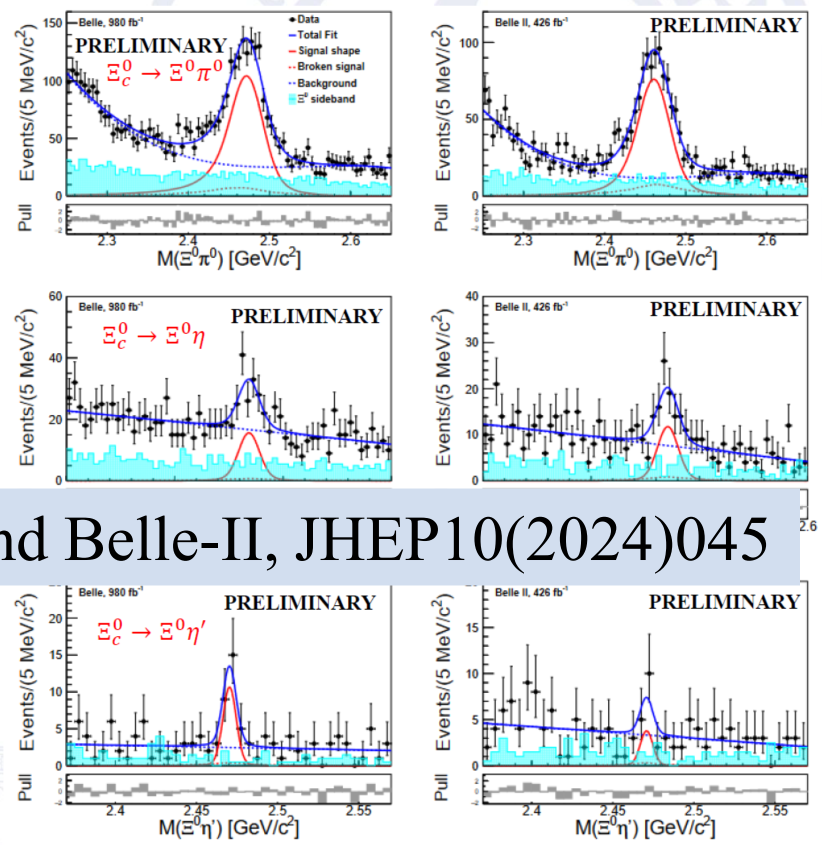
$$\alpha(\Xi_c^0 \to \Xi^0\pi^0) = -0.90 \pm 0.15(\text{stat.}) \pm 0.23(\text{syst.})$$

taking $\alpha(\Xi^0 \to \Lambda\pi^0) = -0.349 \pm 0.009$(PDG)



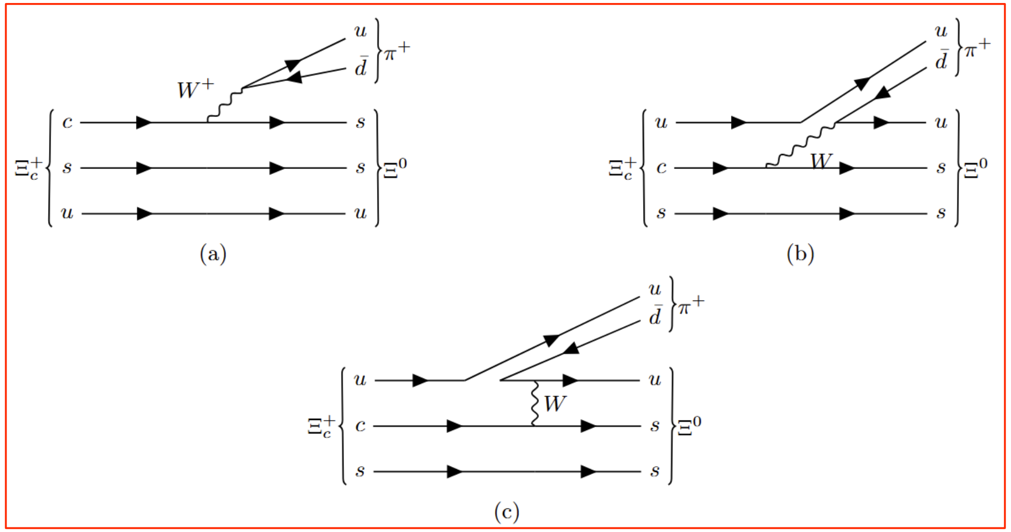
preliminary

Invariant mass spectra for Ξ_c^0 candidates

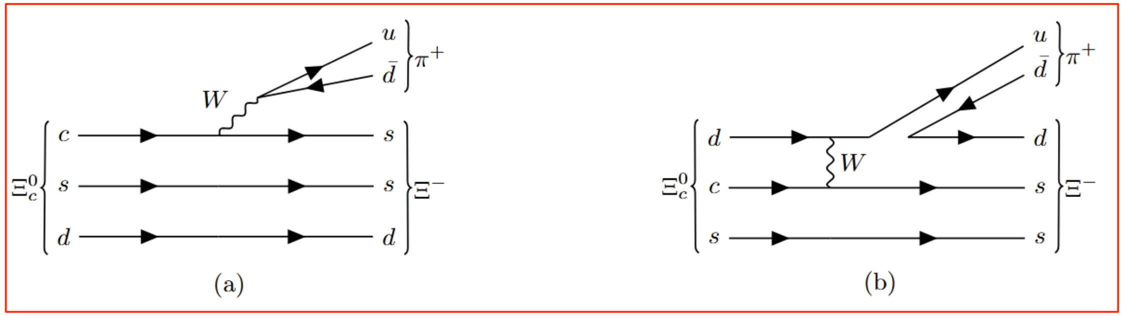


Belle and Belle-II, JHEP10(2024)045

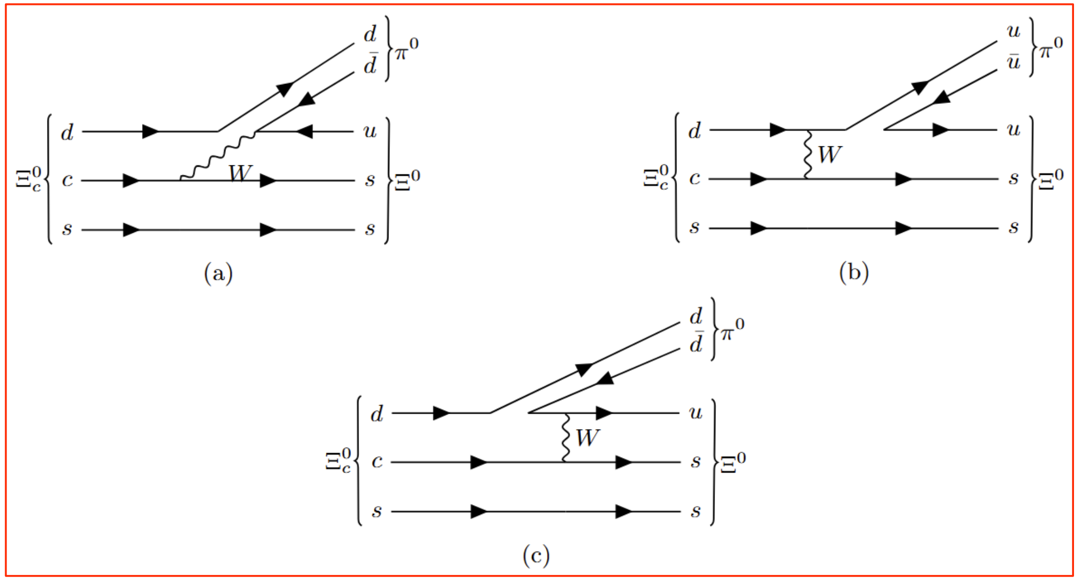
3.4 The Cabibbo-favored hadronic weak decays of the Ξ_c



$$\Xi_c^+ \to \Xi^0 \pi^+$$



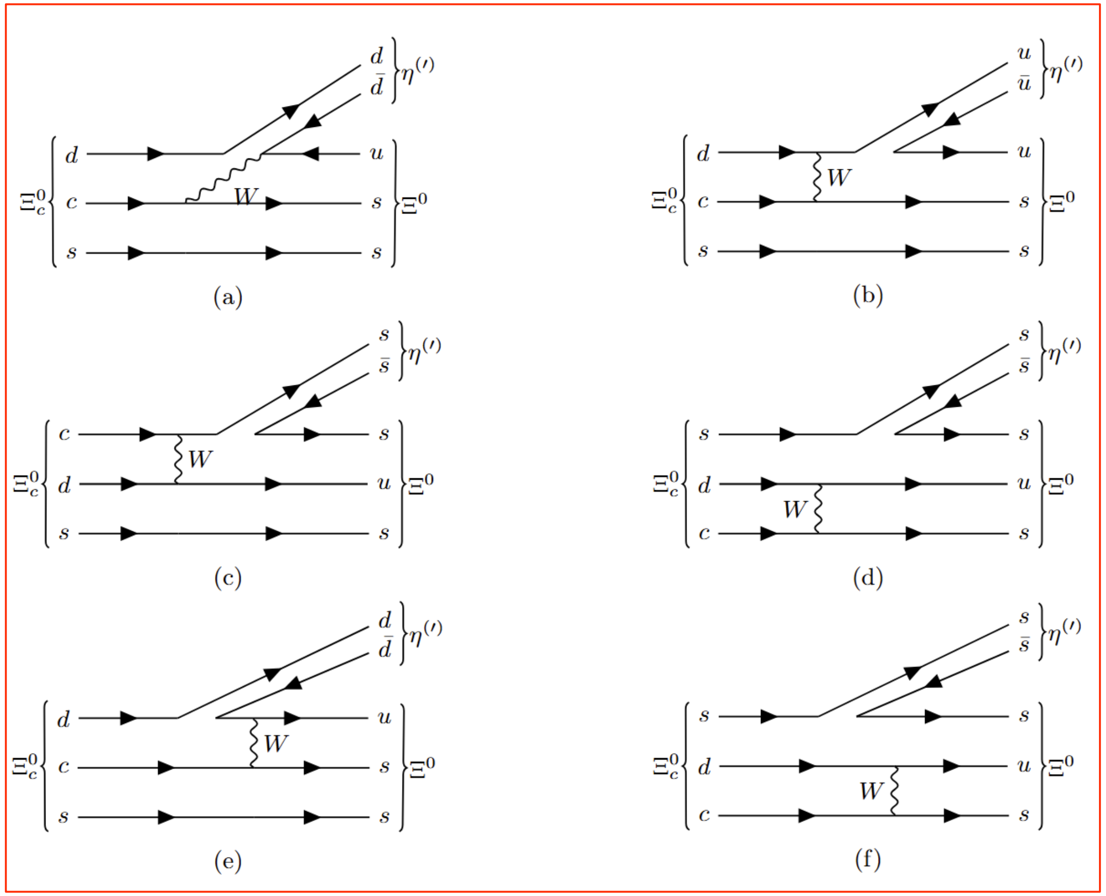
$$\Xi_c^0 \to \Xi^- \pi^+$$



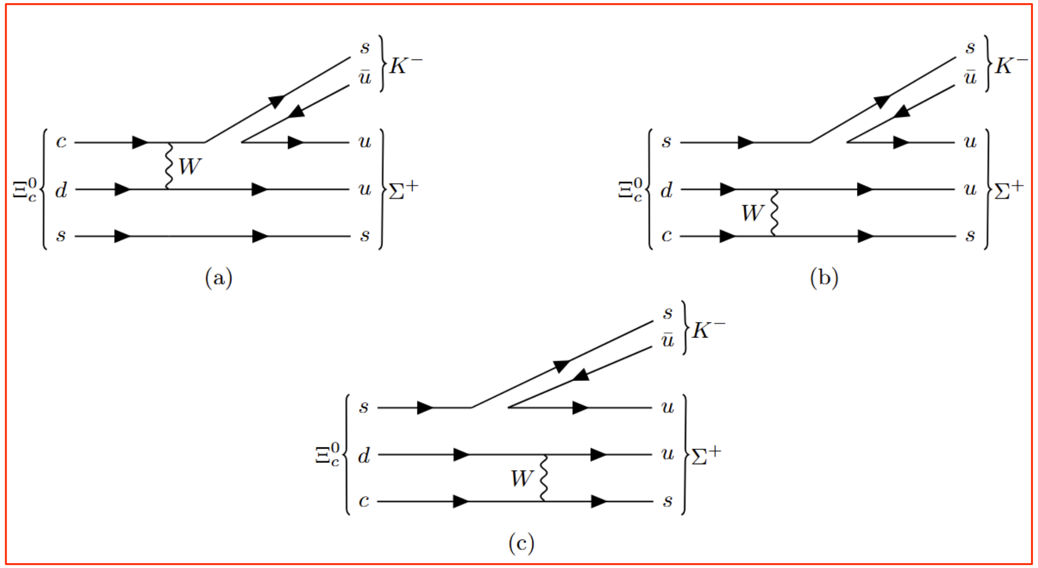
$$\Xi_c^0 \to \Xi^0 \pi^0$$

Peng-Yu Niu, Qian Wang, and Qiang Zhao, arXiv: 2502.04099, Accepted by PRD

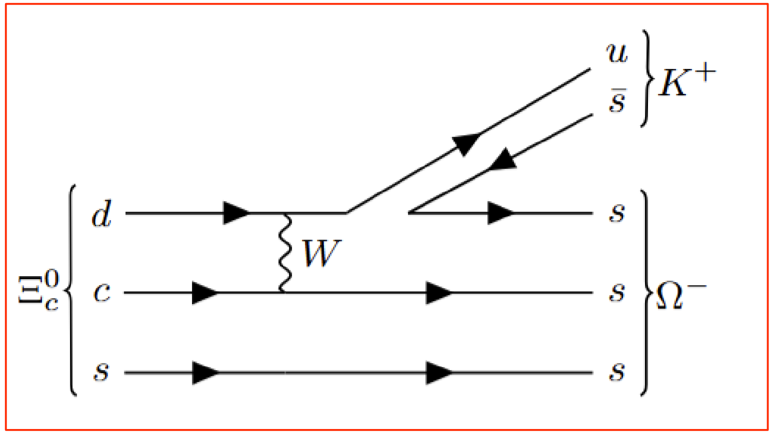
3.4 The Cabibbo-favored hadronic weak decays of the Ξ_c



$\Xi_c^0 \to \Xi^0 \eta^{(\prime)}$



$\Xi_c^0 \to \Sigma^+ K^-$



$\Xi_c^0 \to \Omega^- K^+$

3.4 The Cabibbo-favored hadronic weak decays of the Ξ_c

TABLE X: The amplitudes of $\Xi_c^+ \to \Xi^0\pi^+$ (in unit of 10^{-9} GeV$^{-1/2}$ for the real part and 10^{-13} GeV$^{-1/2}$ for the imaginary part). WS (SW) is used to label the pole terms that baryon weak transition either preceding (following) the strong meson emission.

	DME	CS	WS	SW						Total
	✔	✔	✘	Ξ_c^0			$\Xi_c'^0$			
PC	$(34.41, 0)$	$(-5.62, 0)$	(0,0)	$(0, 0)$			$(-8.47, 0)$			$(20.32, 0)$
	✔	✔	✘	$\|^2P_\rho\rangle$	$\|^2P_\lambda\rangle$	$\|^4P_\rho\rangle$	$\|^2P_\rho\rangle$	$\|^2P_\lambda\rangle$	$\|^4P_\lambda\rangle$	
PV	$(-18.98, 0)$	$(5.34, 0)$	(0,0)	$(2.84, 6.04i)$	(0,0)	$(-4.22, -8.80i)$	(0,0)	$(4.12, 8.98i)$	$(-6.22, -13.26i)$	$(-17.11, -7.03i)$

TABLE XI: The amplitudes of the $\Xi_c^0 \to \Xi^-\pi^+$ in unit of 10^{-9} GeV$^{-1/2}$.

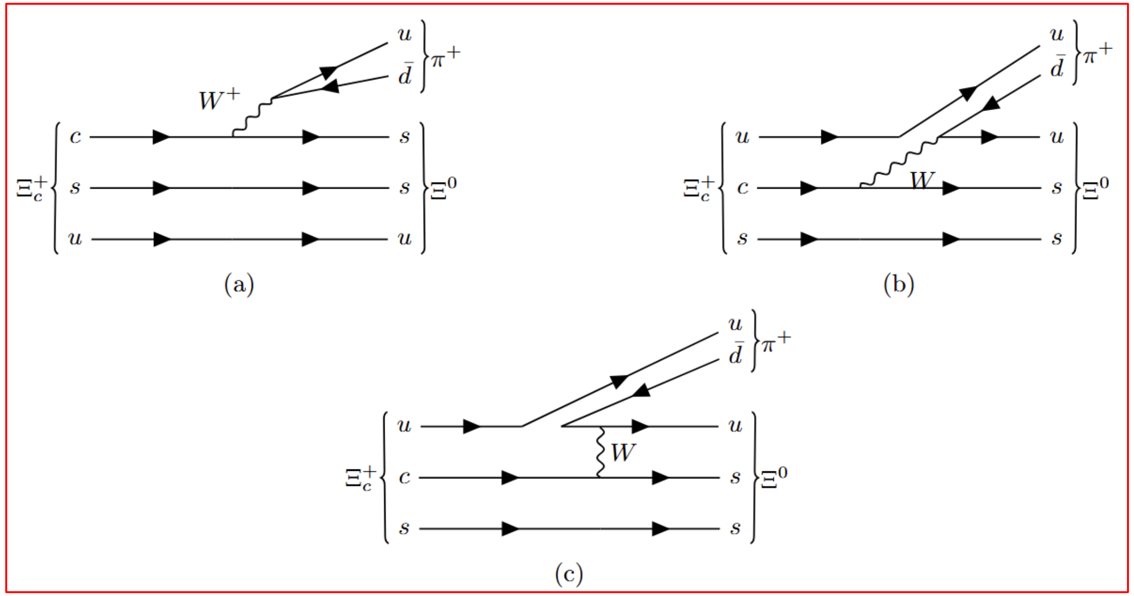
	DME	CS	WS		SW	Total
	✔	✘	Ξ_c^0		✘	
PC	$(34.41, 0)$	(0,0)	$(3.37, -3.04 \times 10^{-2}i)$		(0,0)	$(37.78, -3.04 \times 10^{-2}i)$
	✔	✘	Ξ_c^{*0}	$\Xi_c^0(1690)$	✘	
PV	$(-19.02, 0)$	(0,0)	$(0.36, -5.37 \times 10^{-3}i)$	$(2.92, -3.04 \times 10^{-2}i)$	(0,0)	$(-15.74, -3.58 \times 10^{-2}i)$

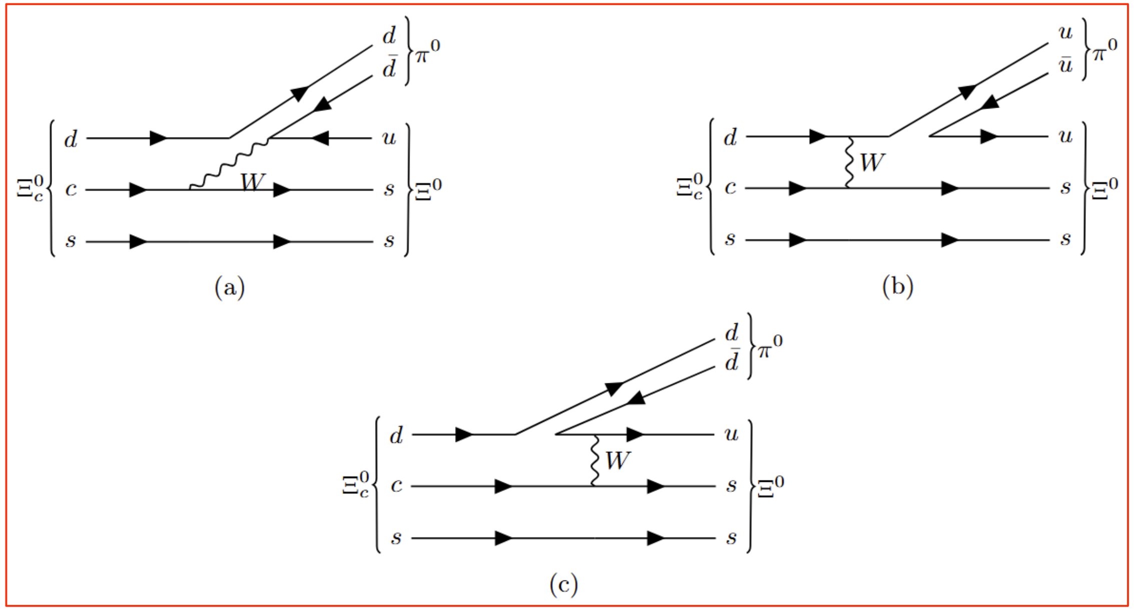
3.4 The Cabibbo-favored hadronic weak decays of the Ξ_c

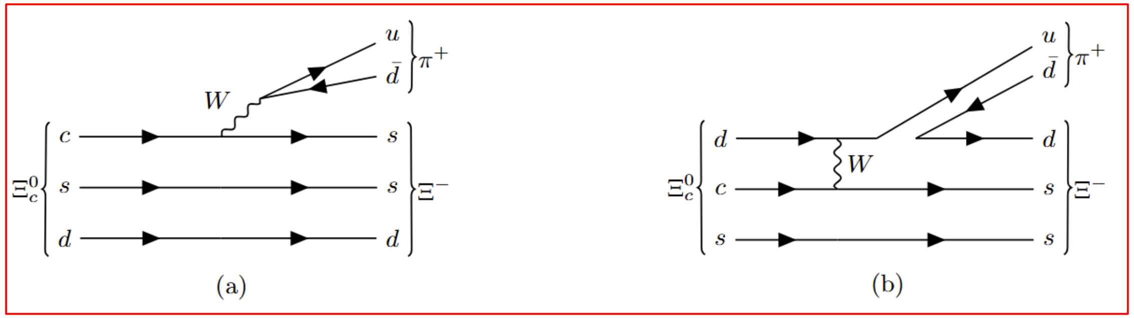
TABLE XII: The amplitudes of $\Xi_c^0 \to \Xi^0\pi^0$ (in unit of 10^{-9} GeV$^{-1/2}$ for the real part and 10^{-12} GeV$^{-1/2}$ for the imaginary part).

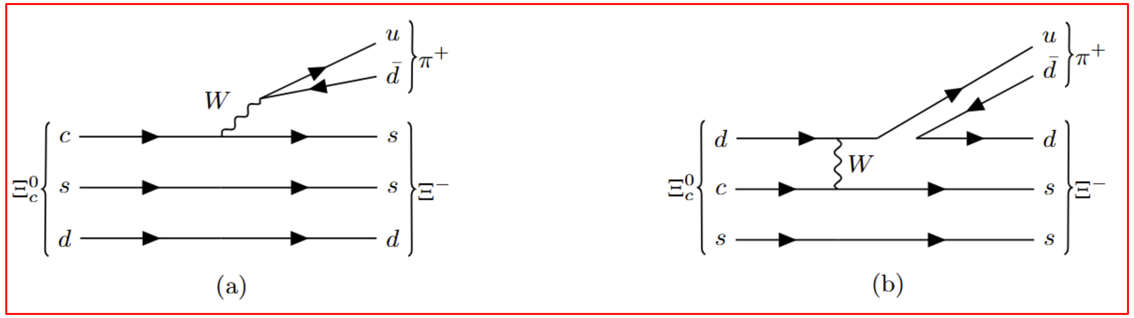
	DME	CS	WS		SW						Total
	✘	✔	Ξ^0		Ξ_c^0			$\Xi_c^{\prime 0}$			
PC	$(0,0)$	$(3.98,0)$	$(2.37,-21.34i)$		$(0,0)$			$(5.95,0)$			$(12.29,-21.34i)$
	✘	✔	Ξ^{*0}	$\Xi^0(1690)$	$\|^2P_\rho\rangle$	$\|^2P_\lambda\rangle$	$\|^4P_\rho\rangle$	$\|^2P_\rho\rangle$	$\|^2P_\lambda\rangle$	$\|^4P_\lambda\rangle$	
PV	$(0,0)$	$(-3.77,0)$	$(0.25,-3.66i)$	$(1.99,-20.73i)$	$(-1.99,-0.42i)$	$(0,0)$	$(2.97,0.62i)$	$(0,0)$	$(-2.90,-0.63i)$	$(4.38,0.93i)$	$(0.92,-23.90i)$

3.4 The Cabibbo-favored hadronic weak decays of the Ξ_c





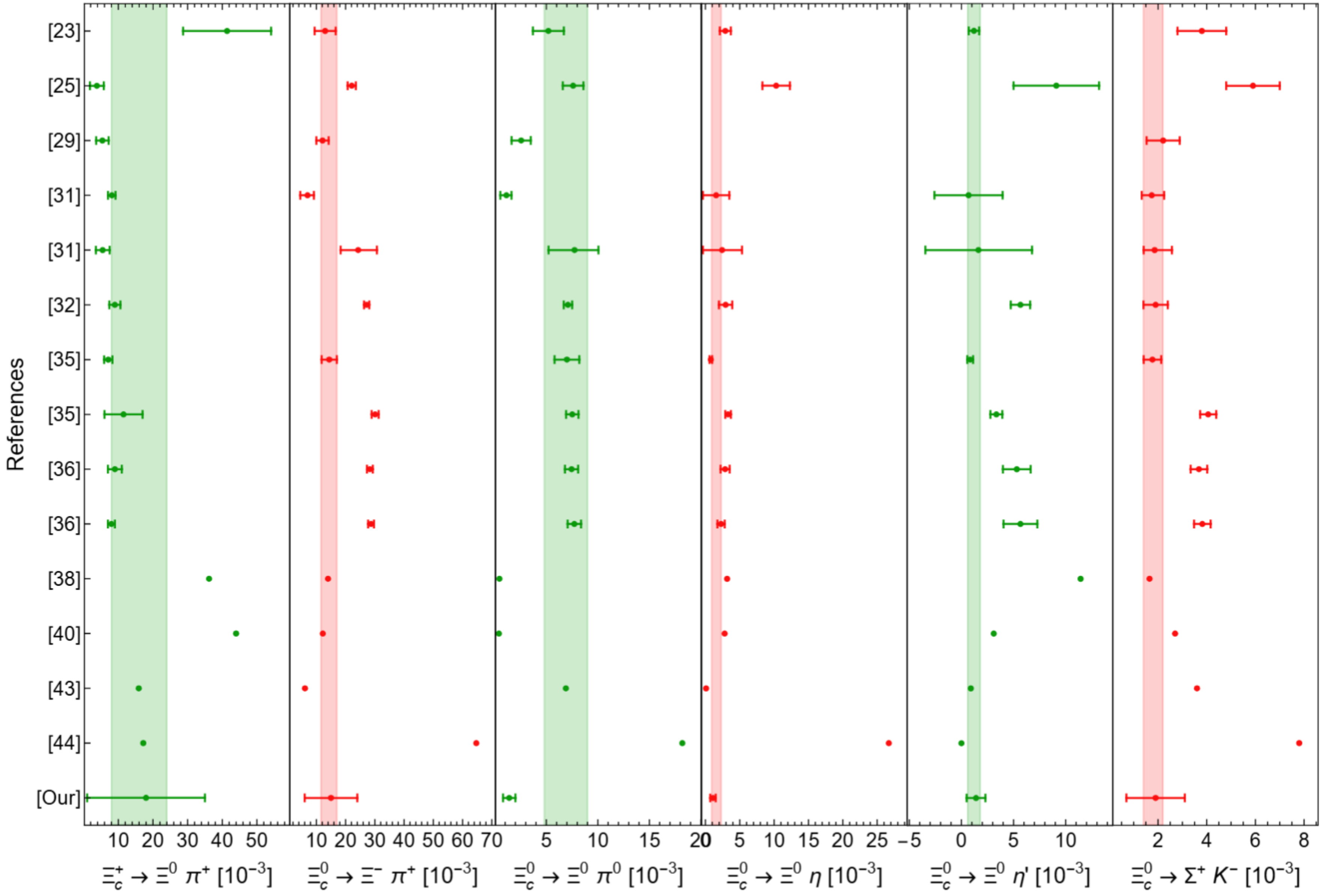




$$\frac{\Gamma_{\Xi_c^+\to\Xi^0\pi^+}}{\Gamma_{\Xi_c^0\to\Xi^-\pi^+}} = \frac{\tau_{\Xi_c^0} \times \mathrm{Br}\left(\Xi_c^+ \to \Xi^0\pi^+\right)}{\tau_{\Xi_c^+} \times \mathrm{Br}\left(\Xi_c^0 \to \Xi^-\pi^+\right)} \approx 0.38$$

$$\frac{\Gamma_{\Xi_c^0\to\Xi^-\pi^+}}{\Gamma_{\Xi_c^0\to\Xi^0\pi^0}} = \frac{\mathrm{Br}\left(\Xi_c^0 \to \Xi^-\pi^+\right)}{\mathrm{Br}\left(\Xi_c^0 \to \Xi^0\pi^0\right)} \approx 2.61$$

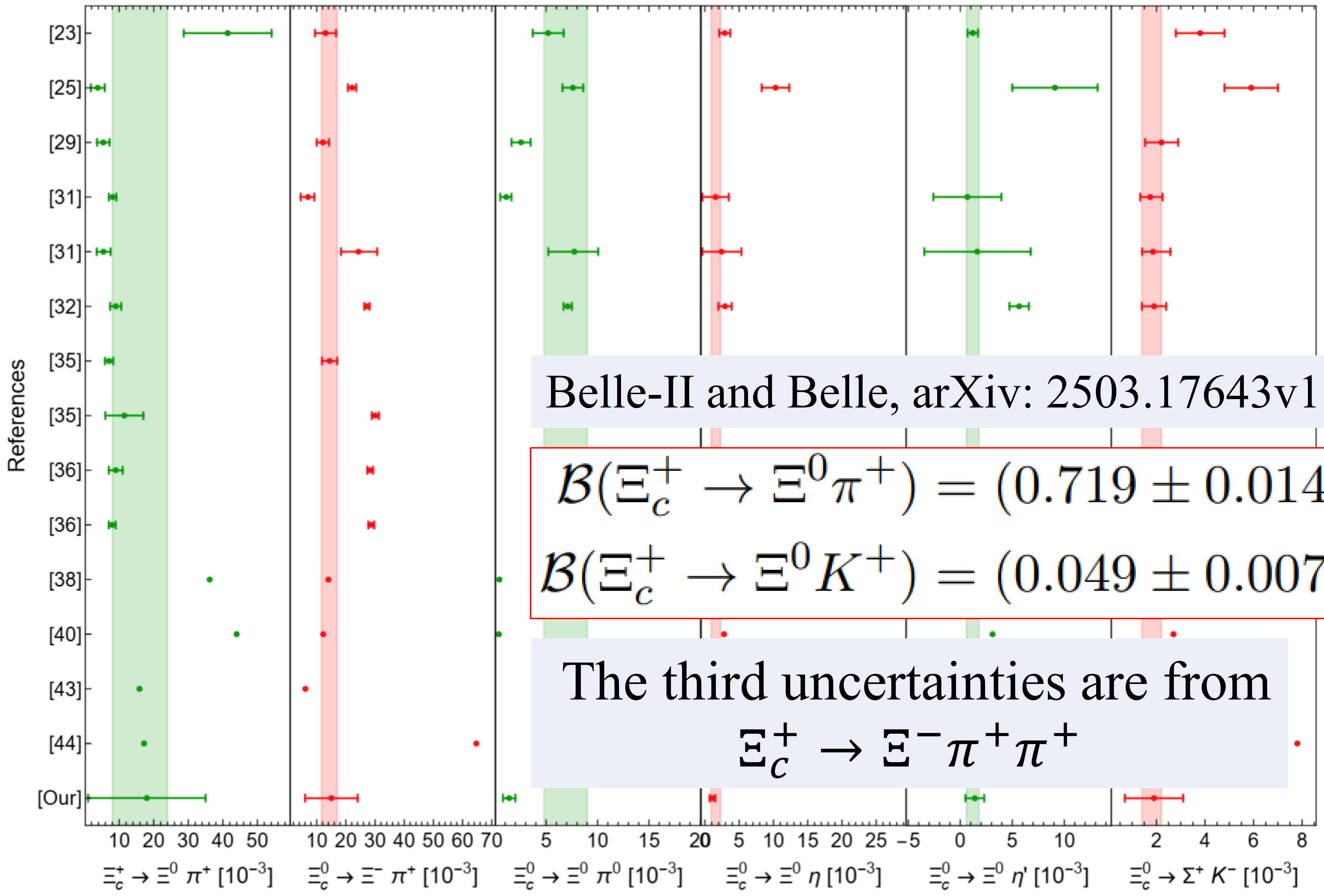
3.4 The Cabibbo-favored hadronic weak decays of the Ξ_c



Branching ratio

$\Xi_c^0 \to \Xi^0 \pi^0$?

3.4 The Cabibbo-favored hadronic weak decays of the Ξ_c



Belle-II and Belle, arXiv: 2503.17643v1

$$\mathcal{B}(\Xi_c^+ \to \Xi^0\pi^+) = (0.719 \pm 0.014 \pm 0.024 \pm 0.322)\%,$$
$$\mathcal{B}(\Xi_c^+ \to \Xi^0 K^+) = (0.049 \pm 0.007 \pm 0.002 \pm 0.022)\%,$$

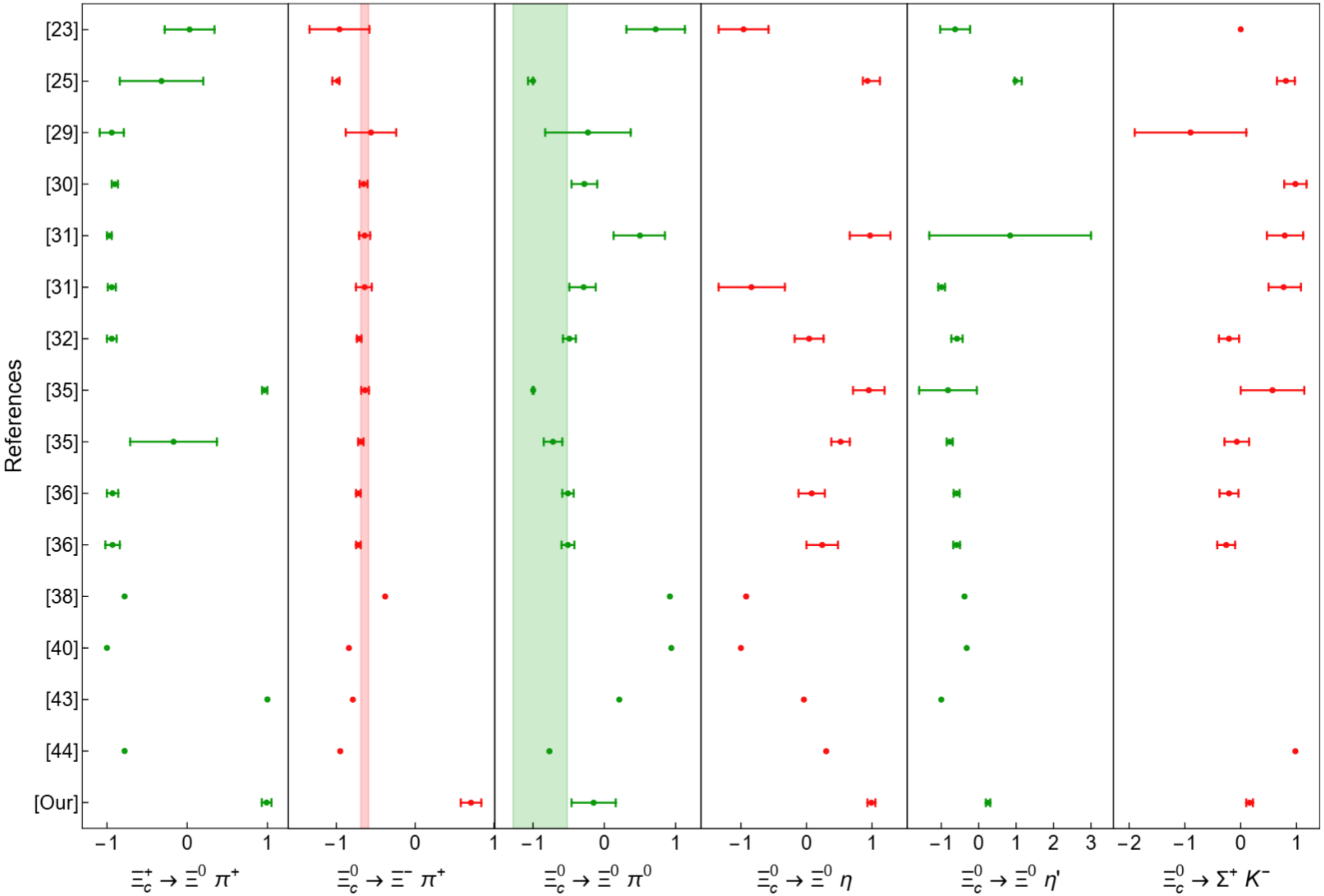
The third uncertainties are from $\Xi_c^+ \to \Xi^-\pi^+\pi^+$

Branching ratio

$\Xi_c^0 \to \Xi^0\pi^0$?

$\mathrm{Br}(\Xi_c^+ \to \Xi^0\pi^+)$
$(1.8 \pm 1.7)\%$

3.4 The Cabibbo-favored hadronic weak decays of the Ξ_c



Asymmetry parameter

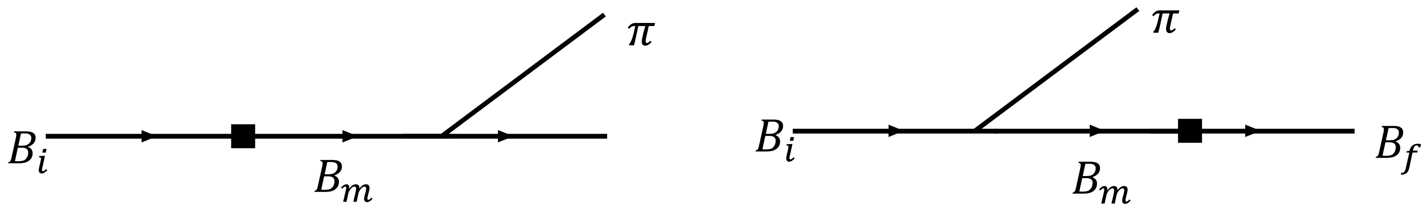
$\Xi_c^0 \to \Xi^- \pi^+$
$\Xi_c^0 \to \Xi^0 \pi^0$

04

Summary

- The hadronic weak decay can be described with the NRCQM framework
- Pole terms play a crucial role. There is direct evidence for pole terms which play a crucial role in Ξ_c
- Prob the light quark correlations inside hadrons

Thank you !



<table>
<tr><th colspan="2">channel</th><th>$\Lambda_c \to \Lambda\pi^+$</th><th>$\Lambda_c \to \Sigma^+\pi^0$</th><th>$\Lambda_c \to \Sigma^0\pi^+$</th></tr>
<tr><td rowspan="2">A-type</td><td>PC</td><td>Σ^+</td><td>Σ^+</td><td>Σ^+</td></tr>
<tr><td>PV</td><td>$\Sigma^{*+}(1620), \Sigma^{*+}(1750)$</td><td>$\Sigma^{*+}(1620), \Sigma^{*+}(1750)$</td><td>$\Sigma^{*+}(1620), \Sigma^{*+}(1750)$</td></tr>
<tr><td rowspan="2">B-type</td><td>PC</td><td>Σ_c^0</td><td>Σ_c^+</td><td>Σ_c^0</td></tr>
<tr><td>PV</td><td>$\Sigma_c^{*0}(2806)$</td><td>$\Sigma_c^{*+}(2792)$</td><td>$\Sigma_c^{*0}(2806)$</td></tr>
</table>

- $\Sigma_c^{*0}(2806)$ and $\Sigma_c^{*+}(2792)$ have not yet be measured.
- The intermediate states are off-shell.

Jacobi coordinates: $m_1 = m_2 = m, m_3 = m'$

$$\boldsymbol{R} = \frac{m(\boldsymbol{r}_1 + \boldsymbol{r}_2) + m'\boldsymbol{r}_3}{M}, \qquad \boldsymbol{P} = \boldsymbol{p}_1 + \boldsymbol{p}_2 + \boldsymbol{p}_3,$$

$$\boldsymbol{\rho} = \frac{1}{\sqrt{2}}(\boldsymbol{r}_1 - \boldsymbol{r}_2), \qquad \boldsymbol{p}_\rho = \frac{1}{\sqrt{2}}(\boldsymbol{p}_1 - \boldsymbol{p}_2),$$

$$\boldsymbol{\lambda} = \frac{1}{\sqrt{6}}(\boldsymbol{r}_1 + \boldsymbol{r}_2 - 2\boldsymbol{r}_3), \qquad \boldsymbol{p}_\lambda = \frac{1}{\sqrt{6}M}(3m'\boldsymbol{p}_1 + 3m'\boldsymbol{p}_2 - 6m\boldsymbol{p}_3).$$

$$H = \frac{\boldsymbol{P}^2}{2M^2} + \frac{\boldsymbol{p}_\lambda^2}{2m_\lambda^2} + \frac{\boldsymbol{p}_\rho^2}{2m_\rho^2} + \frac{1}{2}m_\rho\omega_\rho^2\boldsymbol{\rho}^2 + \frac{1}{2}m_\lambda\omega_\lambda^2\boldsymbol{\lambda}^2,$$

where

$$m_\rho = m,\ m_\lambda = \frac{3mm'}{2m + m'}, \qquad \omega_\rho = \sqrt{3K/m_\rho},\ \omega_\lambda = \sqrt{3K/m_\lambda}.$$

and

$$\alpha_\rho = \sqrt{m_\rho\omega_\rho}, \alpha_\lambda = \sqrt{m_\lambda\omega_\lambda}.$$

The physical states of η and η'

The physical states of η and η' are related to the two states η_q and η_s by the transformation

$$\begin{pmatrix} \eta \\ \eta' \end{pmatrix} = \begin{pmatrix} \cos\zeta & -\sin\zeta \\ \sin\zeta & \cos\zeta \end{pmatrix} \begin{pmatrix} \eta_q \\ \eta_s \end{pmatrix} \tag{19}$$

with the mixing angle $\zeta = (39.3 \pm 1.0)^\circ$ [58]. f_m is the

Input: quark mass

TABLE I: The quark mass used in different references. b is the two-body potential strength.

Inputs	m_q (GeV)	m_s (GeV)	m_c (GeV)	b (GeV^3)
Ref. [36]	0.30	0.51	1.75	0.165
Ref. [37][a]	(0.225, 0.33)	(0.405,0.45)	1.68	0.145
Ref. [38]	0.28	0.56	1.82	0.154
Ref. [39]	0.33	0.50	1.55	–
Ref. [40]	0.338[b]	0.50	1.275	–
Ref. [41]	0.284	0.455	1.606	0.029
Ref. [42]	0.292	0.461	1.607	–
Used	0.30 ± 0.06	0.50 ± 0.10	1.80 ± 0.36	0

[a] The mass of light quark is from the mass of light quark cluster $m_{[qq]}$ and $m_{\{qq\}}$.
[b] The mass of m_u.

parameters

TABLE II. The spring constant K and the harmonic oscillator strengths α_ρ and α_λ. The definition of α_ρ and α_λ can be find in Appendix A. S and C are used to label the strangeness and charmness of the baryons, respectively. The uncertainties of α_ρ and α_λ are from the 20% uncertainties of quark masses and K.

System	$S = 1, C = 0$	$S = 2, C = 0$	$S = 0, C = 1$	$S = 1, C = 1$
K (GeV^3)	0.06 ± 0.012	0.03 ± 0.006	0.02 ± 0.004	0.02 ± 0.004
α_ρ (GeV)	0.48 ± 0.034	0.43 ± 0.027	0.37 ± 0.04	0.39 ± 0.04
α_λ (GeV)	0.52 ± 0.032	0.45 ± 0.030	0.44 ± 0.05	0.47 ± 0.05

TABLE III. The masses, decay constants and R values in the spatial wave function for pseudoscalar mesons.

Meson	$\pi^\pm$	π^0	η	η'	$K^\pm$
Mass [22] (MeV)	139.57	134.98	547.86	957.78	493.68
Decay constant [70] (MeV)	92.4	92.4	$f_q = 1.07 f_\pi$	$f_s = 1.34 f_\pi$	$1.2 f_\pi$
R (GeV)	0.28	0.28	0.4	0.9	0.5

Backup

Input: baryon mass

TABLE IV: The masses of the charmed baryons (in unit of GeV). Only the central values of the masses are listed.

States	Ξ_c^+	Ξ_c^0				$\Xi_c'^0$				Σ_c^+				Λ_c^+			
	$\vert^2S\rangle$	$\vert^2S\rangle$	$\vert^2P_\lambda\rangle$	$\vert^2P_\rho\rangle$	$\vert^4P_\rho\rangle$	$\vert^2S\rangle$	$\vert^2P_\lambda\rangle$	$\vert^2P_\rho\rangle$	$\vert^4P_\lambda\rangle$	$\vert^2S\rangle$	$\vert^2P_\lambda\rangle$	$\vert^2P_\rho\rangle$	$\vert^4P_\lambda\rangle$	$\vert^2S\rangle$	$\vert^2P_\lambda\rangle$	$\vert^2P_\rho\rangle$	$\vert^4P_\rho\rangle$
PDG [2]	2.468	2.470	···	···	···	2.579	···	···	···	2.453	···	···	···	2.286	···	···	···
Ref. [36]	···	···	···	···	···	···	···	···	···	2.460	2.802	2.909	2.826	2.285	2.628	2.890	2.933
Ref. [37]	2.470	2.470	2.793	···	···	2.579	2.839	···	2.900	2.456	2.795	···	2.805	2.286	2.614	···	···
Ref. [38] [a]	2.492	2.492	2.763	···	···	2.592	2.859	···	···	2.455	2.748	···	2.768	2.268	2.625	···	2.816
Ref. [39]	2.476	2.476	2.792	···	···	2.579	2.854	···	2.936	2.443	2.713	···	2.799	2.286	2.598	···	···
Ref. [40] [b]	2.467	2.470	2.796	···	2.803	···	···	···	···	2.452	2.849	···	2.863	2.286	2.629	···	···
Ref. [41] [c]	2.466	2.466	2.788	2.935	2.977	2.571	2.893	3.040	2.935	2.456	2.811	2.994	2.853	2.261	2.616	2.799	2.841
Ref. [42]	2.474	2.474	2.777	2.917	2.950	2.586	2.890	3.029	2.923	2.455	2.789	2.961	2.822	2.281	2.616	2.788	2.821
Ref. [44]	2.461	2.461	2.797	2.951	2.980	2.570	2.905	3.060	2.934	···	···	···	···	···	···	···	···
Used	2.868	2.470	2.788	2.935	2.977	2.579	2.893	3.040	2.935	2.453	2.811	2.944	2.853	2.286	2.616	2.799	2.841

Backup

The numerical results of ranching fractions (in unit of 10^{-3})

Model.	$\Xi_c^+ \to \Xi^0\pi^+$	$\Xi_c^0 \to \Xi^-\pi^+$	$\Xi_c^0 \to \Xi^0\pi^0$	$\Xi_c^0 \to \Xi^0\eta$	$\Xi_c^0 \to \Xi^0\eta'$	$\Xi_c^0 \to \Sigma^+K^-$	$\Xi_c^0 \to \Omega^-K^+$
PDG [2]	16 ± 8	14.3 ± 2.7	-	-	-	1.8 ± 0.4	4.2 ± 0.9
Bell[1]	-	-	6.9 ± 2.1	1.6 ± 0.7	1.2 ± 0.6	-	-
$SU(3)_F$ [3]	41.4 ± 12.7	13.0 ± 3.6	5.2 ± 1.5	2.9 ± 0.8	1.2 ± 0.5	3.8 ± 1.0	-
$SU(3)_F$ [5]	3.8 ± 2.0	22.1 ± 1.4	7.6 ± 1.0	10.3 ± 2.0	9.1 ± 4.1	5.9 ± 1.1	-
$SU(3)_F$ [9]	5.4 ± 1.8	12.1 ± 2.1	2.56 ± 0.93	-	-	2.21 ± 0.68	-
$SU(3)_F$ [10]	8.87 ± 0.8	10.6 ± 2.0	1.30 ± 0.51	$[1.93, 4.46]$	> 0.02	1.88 ± 0.39	-
$SU(3)_F$ [11]	$8.13^{+1.11}_{-1.06}$	$6.98^{+2.48}_{-2.17}$	$1.13^{+0.59}_{-0.49}$	1.56 ± 1.92	$0.683^{+3.272}_{-3.268}$	$1.74^{+0.41}_{-0.51}$	-
$SU(3)_F^{broken}$ [11]	$5.47^{+1.95}_{-2.02}$	$24.3^{+6.0}_{-6.4}$	$7.74^{+2.52}_{-2.32}$	$2.43^{+2.79}_{-2.90}$	$1.63^{+5.09}_{-5.14}$	$1.86^{+0.45}_{-0.71}$	-
$SU(3)_F$ [12]	9.0 ± 1.6	27.2 ± 0.9	7.10 ± 0.41	2.94 ± 0.97	5.66 ± 0.93	1.9 ± 0.5	-
$SU(3)_F^{I}$ [15]	7.1 ± 1.2	14.4 ± 2.6	7 ± 1.2	0.79 ± 0.19	0.84 ± 0.28	1.77 ± 0.36	-
$SU(3)_F^{II}$ [15]	11.5 ± 5.5	30.1 ± 1.2	7.52 ± 0.60	3.30 ± 0.41	3.35 ± 0.57	4.06 ± 0.33	-
$SU(3)_F^{Dia}$ [16]	9 ± 2	28.3 ± 1.0	7.45 ± 0.64	2.87 ± 0.66	5.31 ± 1.33	3.68 ± 0.34	-
$SU(3)_F^{Ir}$ [16]	8 ± 1	$28.7 \pm 1.0,$	7.72 ± 0.65	2.28 ± 0.53	5.66 ± 1.62	3.82 ± 0.34	-
Quark [18][a]	36.2	13.99	0.45	3.16	11.43	1.65	-
Quark [20]	44.0	12.2	0.4	2.8	3.1	2.7	-
Pole [23]	15.90	6.1	6.9	0.1	0.9	3.6	-
Pole [24][b]	17.2	64.7	18.2	26.7	-	7.8	-
our work	19.10	15.01	1.37	1.05	1.41	2.18	1.56

Backup

The numerical results of α

Model.	$\Xi_c^+ \to \Xi^0\pi^+$	$\Xi_c^0 \to \Xi^-\pi^+$	$\Xi_c^0 \to \Xi^0\pi^0$	$\Xi_c^0 \to \Xi^0\eta$	$\Xi_c^0 \to \Xi^0\eta'$	$\Xi_c^0 \to \Sigma^+K^-$	$\Xi_c^0 \to \Omega^-K^+$
PDG [2]	-	-	-	-	-	-	-
Bell[1]	-	-	-0.90 ± 0.38	-	-	-	-
$\mathrm{SU(3)_F}$ [3]	0.03 ± 0.31	-0.96 ± 0.38	0.72 ± 0.41	-0.96 ± 0.38	-0.63 ± 0.40	0.00	-
$\mathrm{SU(3)_F}$ [5]	-0.32 ± 0.52	$-0.98^{+0.07}_{-0.02}$	$-1.00^{+0.07}_{-0.00}$	$0.93^{+0.07}_{-0.19}$	$0.98^{+0.02}_{-0.17}$	0.81 ± 0.16	-
$\mathrm{SU(3)_F}$ [9]	-0.94 ± 0.15	-0.56 ± 0.32	-0.23 ± 0.60	-	-	-0.9 ± 1.0	-
$\mathrm{SU(3)_F}$ [10]	-0.902 ± 0.039	-0.654 ± 0.050	-0.28 ± 0.18	-	-	0.98 ± 0.20	-
$\mathrm{SU(3)_F}$ [11]	-0.97 ± 0.03	-0.64 ± 0.07	$0.50^{+0.37}_{-0.35}$	0.97 ± 0.31	0.84 ± 2.16	$0.79^{+0.32}_{-0.33}$	-
$\mathrm{SU(3)_F^{broken}}$ [11]	-0.94 ± 0.05	$-0.64^{+0.11}_{-0.09}$	$-0.29^{+0.20}_{-0.17}$	$-0.84^{+0.50}_{-0.51}$	-0.99 ± 0.09	$0.77^{+0.27}_{-0.31}$	-
$\mathrm{SU(3)_F}$ [12]	-0.94 ± 0.06	-0.71 ± 0.03	-0.49 ± 0.09	0.04 ± 0.22	-0.58 ± 0.15	-0.21 ± 0.18	-
$\mathrm{SU(3)_F^{I}}$ [15]	0.966 ± 0.033	-0.635 ± 0.049	-0.9982 ± 0.0069	0.95 ± 0.24	-0.82 ± 0.77	0.57 ± 0.57	-
$\mathrm{SU(3)_F^{II}}$ [15]	-0.17 ± 0.54	-0.689 ± 0.034	-0.72 ± 0.13	0.52 ± 0.14	-0.775 ± 0.081	-0.07 ± 0.22	-
$\mathrm{SU(3)_F^{Dia}}$ [16]	-0.93 ± 0.07	-0.72 ± 0.03	-0.51 ± 0.08	0.08 ± 0.20	-0.59 ± 0.08	-0.21 ± 0.17	-
$\mathrm{SU(3)_F^{Ir}}$ [16]	-0.93 ± 0.09	-0.72 ± 0.03	-0.51 ± 0.09	0.24 ± 0.24	-0.59 ± 0.09	-0.26 ± 0.16	-
Quark [18]	-0.78	-0.38	0.92	-0.92	-0.38	0	-
Quark [20]	-1.0	-0.84	0.94	-1.0	-0.32	0	-
Pole [23]	+1.00	-0.79	0.21	-0.04	-1.00	0	-
Pole [24]	-0.78	-0.95	-0.77	0.30	-	0.98	-
our work	0.99	0.71	-0.15	0.99	0.25	0.16	-