CHARMED BARYON THREE-BODY DECAYS

Tien-Hsueh Tsai

(National Tsing-Hua University)

Advisor: Chao-Qiang Geng

December 31, 2018

OUTLINE

- Motivation
- SU(3) method
- Irreducible Amplitudes
- Numerical Results
- Summary

MOTIVATION

- Rich experimental data in three-body processes
- Complicated structure of Hadrons
- Direct calculation of three-body processes are extremely hard

[1] C. Q. Geng, Y. K. Hsiao, C. W. Liu and T. H. Tsai, JHEP **1711**, 147 (2017)

[2] C. Q. Geng, Y. K. Hsiao, C. W. Liu and T. H. Tsai, Phys. Rev. D **97**, no. 7, 073006 (2018)

[3] C. Q. Geng, Y. K. Hsiao, C. W. Liu and T. H. Tsai, Eur. Phys. J. C **78**, no. 7, 593 (2018)

[4] C. Q. Geng, Y. K. Hsiao, C. W. Liu and T. H. Tsai, arXiv:1810.01079 [hep-ph].

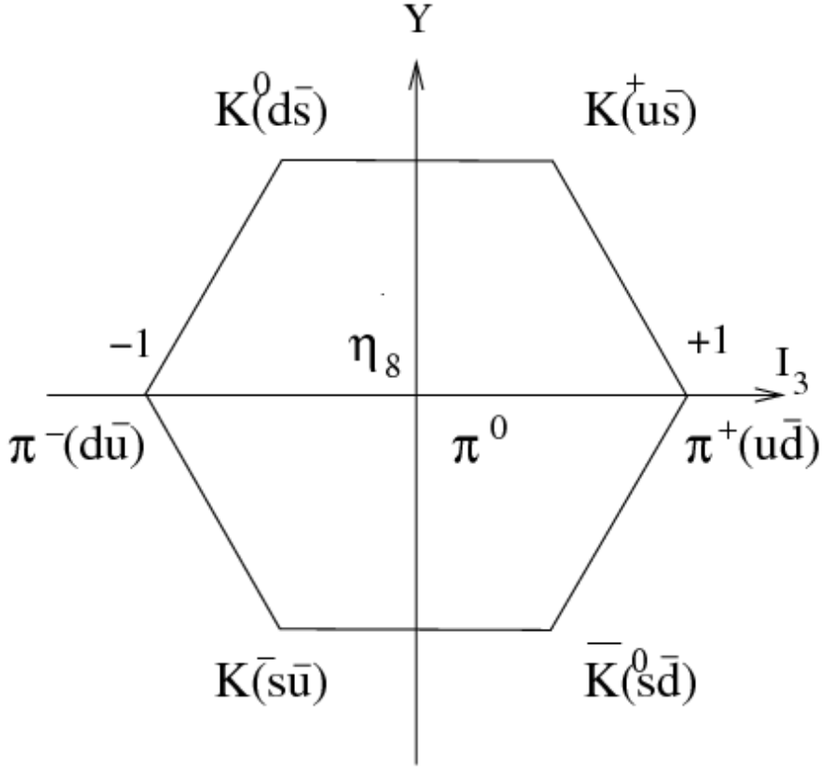
SU(3) FLAVOR SYMMETRY

- Quark triplet

$$q^i = \begin{bmatrix} u \\ d \\ s \end{bmatrix}$$

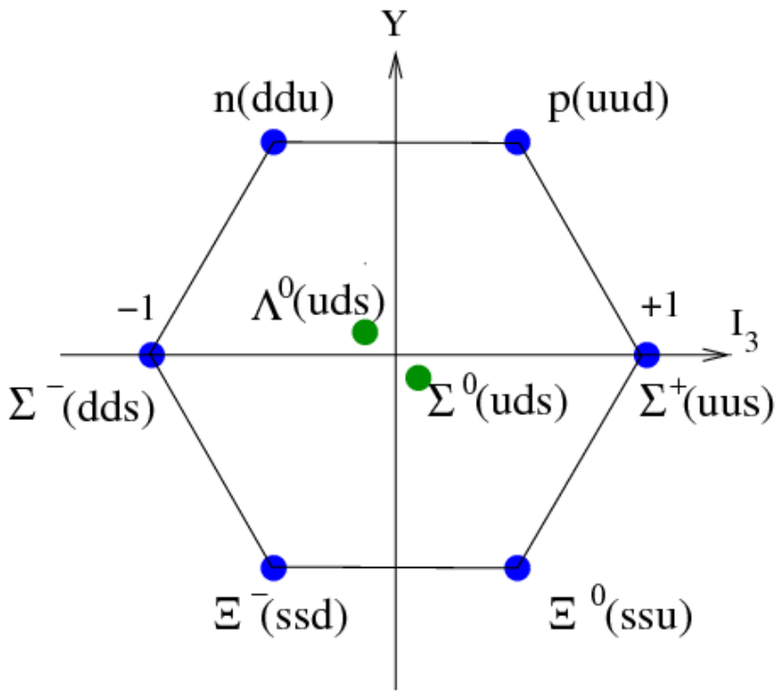
- Meson octet $q^i \bar{q}_j$

$$M = \begin{bmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^- & K^- \\ \pi^+ & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \bar{K}^0 \\ K^+ & K^0 & -\sqrt{\frac{2}{3}}\eta \end{bmatrix}$$



- Baryon octet $q^i q^j q^k$

$$\mathbf{B} = \begin{bmatrix} \frac{1}{\sqrt{6}}\Lambda + \frac{1}{\sqrt{2}}\Sigma^0 & \Sigma^+ & p \\ \Sigma^- & \frac{1}{\sqrt{6}}\Lambda - \frac{1}{\sqrt{2}}\Sigma^0 & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\Lambda \end{bmatrix}$$



- Charmed baryon anti-triplet $q^i q^j c$

$$B_c = \begin{bmatrix} \Xi_c^0 & -\Xi_c^+ & \Lambda_c^+ \end{bmatrix}$$

EFFECTIVE HAMILTONIAN IN SU(3) LANGUAGE

- Effective Hamiltonian :

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}}\{V_{cs}V_{ud}(c_+O_+^f + c_-O_-^f + V_{cd}V_{ud}(c_+O_+^s + c_-O_-^s) + V_{cd}V_{us}(c_+O_+^{ds} + c_-O_-^{ds})\}$$

$$O_\pm^f = \frac{1}{2}(\bar{u}d)(\bar{s}c) \pm (\bar{s}d)(\bar{u}c) \qquad (c_-, c_+) = (1.78, 0.76)$$

$$O_\pm^s = \sum_{q',q=d,s} \frac{1}{2}\epsilon_{uqq'}(\bar{u}q)(\bar{q}c) \mp (\bar{q}'q')(\bar{u}c)$$

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

EFFECTIVE HAMILTONIAN IN SU(3) LANGUAGE

- Effective Hamiltonian :

$$\mathcal{H}_{SU(3)} = \frac{G_F}{\sqrt{2}}[c_- H(6)^{ij} + c_+ H(\overline{15})^k_{lm}] \qquad s_c = \sin\theta_c$$

$$H(6) = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 2 & -2s_c \\ 0 & -2s_c & 2s_c^2 \end{pmatrix} \qquad (c_-, c_+) = (1.78, 0.76)$$

$$H^2_{13}(\overline{15}) = H^2_{31}(\overline{15}) = 1$$

$$H^2_{12}(\overline{15}) = H^2_{21}(\overline{15}) = -H^3_{13}(\overline{15}) = -H^3_{31}(\overline{15}) = s_c$$

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CHARMED BARYON DECAY

$$\mathbf{B_c} \rightarrow \mathbf{B} M M'$$

$$\bar{3} \rightarrow 8 \otimes 8 \otimes 8$$

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MESON PAIR FLAVOR TENSOR

$$|MM'\rangle = |spacial\rangle \otimes |color\rangle \otimes |spin\rangle \otimes |flavor\rangle$$

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$$(M)^i_j (M')^k_l \Rightarrow 8 \otimes 8 = (1 \oplus 8 \oplus 27)_{Sym} \oplus (8 \oplus 10 \oplus \overline{10})_{Asy}$$

MESON PAIR FLAVOR TENSOR

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SU(3) IRREDUCIBLE AMPLITUDES

$$\langle \mathbf{B_c}|H(6)|\mathbf{B_n}MM'\rangle =$$

$$a_1(\bar{\mathbf{B}}_n)^k_i(M)^m_l(M')^l_m H(6)_{jk}T^{ij} + a_2(\bar{\mathbf{B}}_n)^k_i(M)^m_j(M')^l_m H(6)_{kl}T^{ij}$$
$$+a_3(\bar{\mathbf{B}}_n)^k_i(M)^m_k(M')^l_m H(6)_{jl}T^{ij} + a_4(\bar{\mathbf{B}}_n)^k_i(M)^l_j(M')^m_k H(6)_{lm}T^{ij}$$
$$+a_5(\bar{\mathbf{B}}_n)^l_k(M)^m_j(M')^k_m H(6)_{il}T^{ij} + a_6(\bar{\mathbf{B}}_n)^l_k(M)^m_j(M')^k_l H(6)_{im}T^{ij}$$

DATA INPUT AND REPRODUCTION

	data	our results
$10^2\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$	3.4 ± 0.4	3.3 ± 1.0
$10^2\mathcal{B}(\Lambda_c^+ \to p\bar{K}^0\eta)$	1.6 ± 0.4	0.9 ± 0.1
$10^3\mathcal{B}(\Lambda_c^+ \to \Lambda^0 K^+\bar{K}^0)$	5.6 ± 1.1	5.7 ± 1.1
$10^2\mathcal{B}(\Lambda_c^+ \to \Lambda^0\pi^+\eta)$	2.2 ± 0.5	2.1 ± 0.9
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+\pi^+\pi^-)$	4.4 ± 0.3	4.4 ± 3.5
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+)$	1.9 ± 0.2	1.9 ± 1.3
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^0\pi^+\pi^0)$	2.2 ± 0.8	1.0 ± 0.8
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+\pi^0\pi^0)$	1.3 ± 0.1	1.3 ± 1.3
$10^3\mathcal{B}(\Lambda_c^+ \to \Sigma^+K^+\pi^-)$	2.1 ± 0.6	3.0 ± 0.4

	data	our results
$10^3\mathcal{B}(\Lambda_c^+ \to \Xi^-K^+\pi^+)$	6.2 ± 0.6	6.3 ± 0.6
$10^2\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$	6.1 ± 3.1	7.2 ± 2.0
$10^3\mathcal{B}(\Lambda_c^+ \to p\pi^-\pi^+)$	4.2 ± 0.4	4.7 ± 1.6
$10^4\mathcal{B}(\Lambda_c^+ \to pK^-K^+)$	5.2 ± 1.2	5.1 ± 2.1
$10^4\mathcal{B}(\Lambda_c^+ \to pK^+\pi^-)$	1.0 ± 0.1	1.0 ± 0.1

MINIMUM CHI-SQUARE FITTING

$$(|a_1|, |a_2|, |a_3|, |a_4|, |a_5|, |a_6|) = (9.1 \pm 0.6, 4.6 \pm 0.2, 8.2 \pm 0.3, 2.9 \pm 0.4 \\ , 15.4 \pm 1.4, 4.2 \pm 0.2) GeV^2$$

$$(\delta_{a_2}, \delta_{a_3}, \delta_{a_4}, \delta_{a_5}, \delta_{a_6}) = (164 \pm 5, 135 \pm 5, -30 \pm 13, 24 \pm 3, 120 \pm 10)^\circ$$

$$\chi^2/d.o.f = 8.4/3 = 2.8\,,$$

SOME PREDICTIONS

$$\mathcal{B}_{\mathbf{B_n}MM'} \equiv \mathcal{B}(\Lambda_c^+ \to \mathbf{B_n}MM')$$

CF mode	our result	CS mode	our result	DCS mode	our result
$10^2\mathcal{B}_{\Sigma^+\pi^0\eta^0}$	3.5 ± 0.8	$10^4\mathcal{B}_{\Sigma^+\pi^0 K^0}$	8.6 ± 2.6	$10^6\mathcal{B}_{\Sigma^+ K^0 K^0}$	2.0 ± 0.5
$10^3\mathcal{B}_{\Sigma^+ K^0 \bar{K}^0}$	5.2 ± 1.2	$10^5\mathcal{B}_{\Sigma^+ K^0 \eta^0}$	3.5 ± 0.4	$10^6\mathcal{B}_{\Sigma^0 K^0 K^+}$	2.0 ± 0.6
$10^3\mathcal{B}_{\Sigma^+ K^+ K^-}$	3.0 ± 0.7	$10^3\mathcal{B}_{\Sigma^0\pi^0 K^+}$	1.2 ± 0.3	$10^6\mathcal{B}_{\Sigma^- K^+ K^+}$	2.0 ± 0.5
$10^7\mathcal{B}_{\Sigma^+\eta^0\eta^0}$	2.8 ± 0.6	$10^4\mathcal{B}_{\Sigma^0\pi^+ K^0}$	8.3 ± 2.5	$10^5\mathcal{B}_{p\pi^0 K^0}$	5.0 ± 0.5
$10^2\mathcal{B}_{\Sigma^0\pi^+\eta^0}$	3.4 ± 0.8	$10^5\mathcal{B}_{\Sigma^0 K^+\eta^0}$	1.8 ± 0.2	$10^5\mathcal{B}_{n\pi^0 K^+}$	5.0 ± 0.5
$10^2\mathcal{B}_{\Sigma^0 K^+ \bar{K}^0}$	0.5 ± 0.1	$10^4\mathcal{B}_{\Sigma^-\pi^+ K^+}$	3.3 ± 2.3	$10^4\mathcal{B}_{n\pi^+ K^0}$	1.0 ± 0.1
$10^2\mathcal{B}_{\Xi^0\pi^0 K^+}$	4.5 ± 0.8	$10^3\mathcal{B}_{p\pi^0\pi^0}$	2.4 ± 0.8		
$10^2\mathcal{B}_{\Xi^0\pi^+ K^0}$	8.7 ± 1.7	$10^3\mathcal{B}_{p\pi^0\eta^0}$	3.7 ± 0.9		
$10^2\mathcal{B}_{p\pi^0 \bar{K}^0}$	2.8 ± 0.6	$10^3\mathcal{B}_{pk^0 \bar{K}^0}$	4.3 ± 1.0		
$10^2\mathcal{B}_{n\pi^+ \bar{K}^0}$	0.9 ± 0.8	$10^4\mathcal{B}_{p\eta^0\eta^0}$	4.7 ± 1.0		
		$10^3\mathcal{B}_{n\pi^+\eta^0}$	7.3 ± 1.8		
		$10^3\mathcal{B}_{nK^+ \bar{K}^0}$	5.9 ± 1.3		
		$10^3\mathcal{B}_{\Lambda^0\pi^0 K^+}$	4.5 ± 0.8		
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SOME PREDICTIONS

$$\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\pi^0) = 0$$

$$\mathcal{B}_{\mathbf{B_n}MM'} \equiv \mathcal{B}(\Lambda_c^+ \to \mathbf{B_n}MM')$$

CF mode	our result	CS mode	our result	DCS mode	our result
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$10^3\mathcal{B}_{\Sigma^+K^+K^-}$	3.0 ± 0.7	$10^3\mathcal{B}_{\Sigma^0\pi^0K^+}$	1.2 ± 0.3	$10^6\mathcal{B}_{\Sigma^-K^+K^+}$	2.0 ± 0.5
$10^7\mathcal{B}_{\Sigma^+\eta^0\eta^0}$	2.8 ± 0.6	$10^4\mathcal{B}_{\Sigma^0\pi^+K^0}$	8.3 ± 2.5	$10^5\mathcal{B}_{p\pi^0K^0}$	5.0 ± 0.5
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$10^2\mathcal{B}_{\Sigma^0K^+\bar{K}^0}$	0.5 ± 0.1	$10^4\mathcal{B}_{\Sigma^-\pi^+K^+}$	3.3 ± 2.3	$10^4\mathcal{B}_{n\pi^+K^0}$	1.0 ± 0.1
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$10^2\mathcal{B}_{p\pi^0\bar{K}^0}$	2.8 ± 0.6	$10^3\mathcal{B}_{pk^0\bar{K}^0}$	4.3 ± 1.0		
$10^2\mathcal{B}_{n\pi^+\bar{K}^0}$	0.9 ± 0.8	$10^4\mathcal{B}_{p\eta^0\eta^0}$	4.7 ± 1.0		
		$10^3\mathcal{B}_{n\pi^+\eta^0}$	7.3 ± 1.8		
		$10^3\mathcal{B}_{nK^+\bar{K}^0}$	5.9 ± 1.3		
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		$10^4\mathcal{B}_{\Lambda^0K^+\eta^0}$	1.9 ± 0.6		

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2018 Review of Particle Physics.
M. Tanabashi *et al.* (Particle Data Group), Phys. Rev. D **98**, 030001 (2018)

$\Lambda_c^+ \to \Lambda\pi^+\pi^0$

INSPIRE search

▸ expand all datablocks

▸ $\Gamma(\Lambda_c^+ \to \Lambda\pi^+\pi^0)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$ Γ_{29}/Γ_2

▾ $\Gamma(\Lambda_c^+ \to \Lambda\pi^+\pi^0)/\Gamma_{\text{total}}$ Γ_{29}/Γ

VALUE (%)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
7.0 ± 0.4	**OUR FIT** Error includes scale factor of 1.1.				
7.01 ±0.37 ±0.19	1497	ABLIKIM	2016	BES3	$e^+ e^- \to \Lambda_c\overline{\Lambda}_c$, 4.599 GeV

References:

ABLIKIM	2016	PRL 116 052001	Measurements of Absolute Hadronic Branching Fractions of Λ_c^+ Baryon

see fit info

SOME PREDICTIONS

$$\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\pi^0) = 0$$

$$\because \langle \Lambda_c^+ | H(6) | \Lambda\pi^+\pi^0 \rangle = 0$$ For I=0 (even)

SOME PREDICTIONS

$$\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\pi^0) = 0$$

$$\because \langle \Lambda_c^+ | \mathcal{H}_{SU(3)} | \Lambda\pi^+\pi^0 \rangle = 0$$ For I=0 (even)

SUMMARY

- Decay amplitudes of different $\mathbf{B_c} \to \mathbf{B_n} M M'$ are linked by SU(3) flavor symmetry
- $\mathcal{B}(\Lambda_c^+ \to \Lambda \pi^+ \pi^0)$ only have contributions of odd angular momentum of meson pair.

HAPPY
NEW YEAR
2019