CPV in charmed baryons

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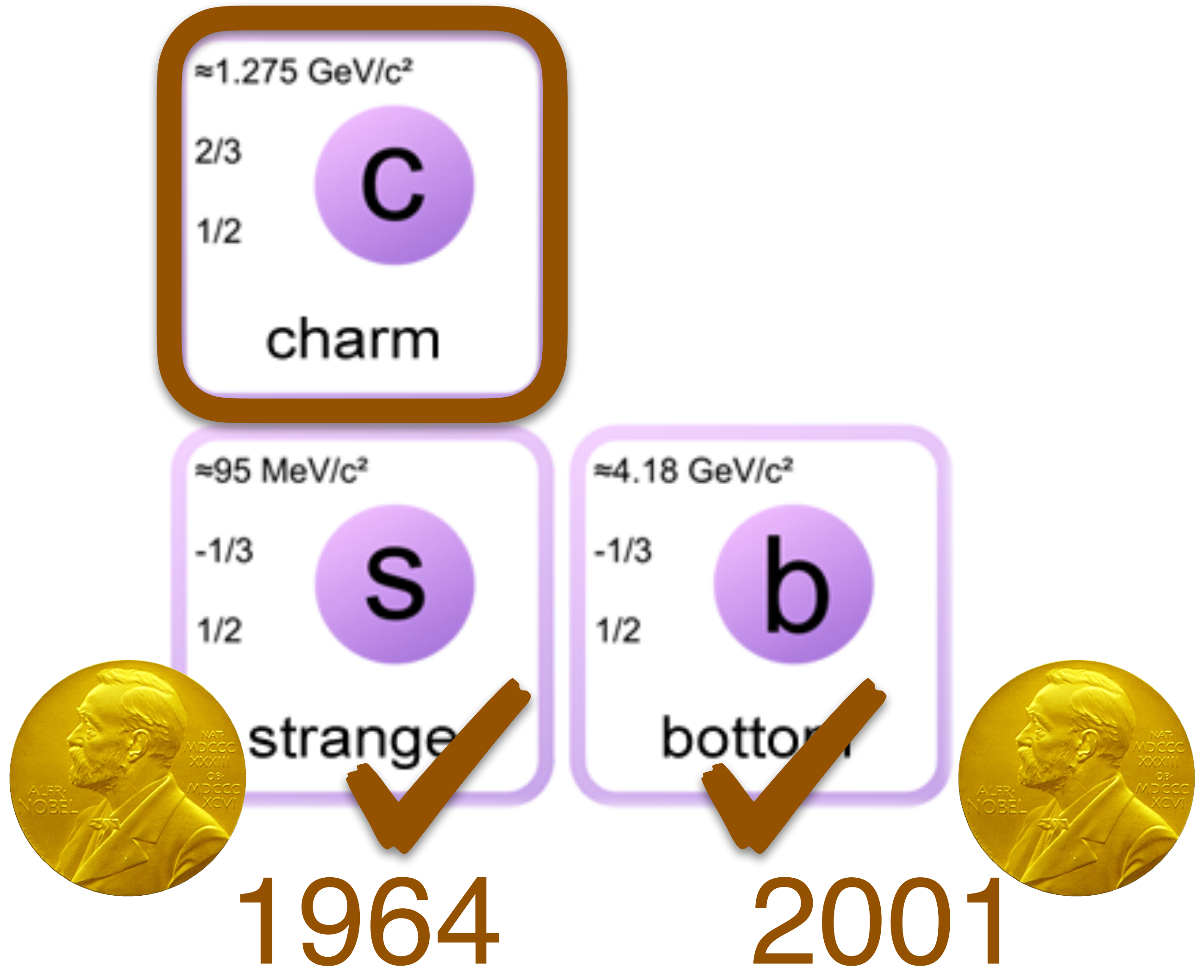
Outline

- Introduction to charm CP violation
- charmed baryon decays
- Final-state interactions
- Summary

CP violation in charm?

- **CP violation** is required for the matter-antimatter asymmetry in the Universe [Sakharov, 1967]
- CPV in the SM is not large enough, thus a window to New Physics
- CPV in strange and bottom mesons have been well established.
- But how about **charm CPV?**



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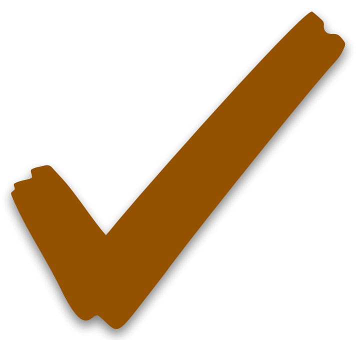
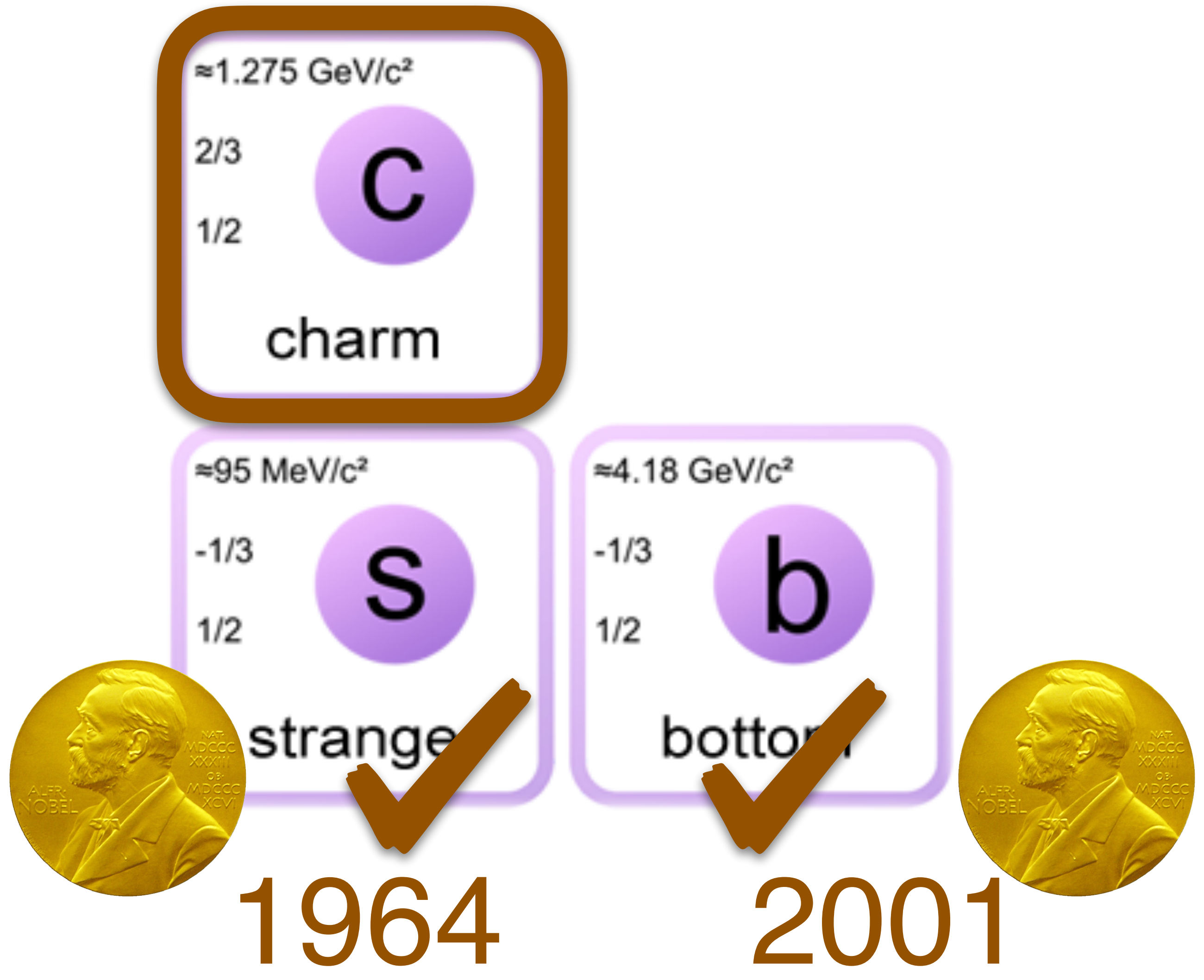
- But how about **charm CPV?**
  - **Before 2019, Yes or No?**



  - **After 2019, SM or NP?**



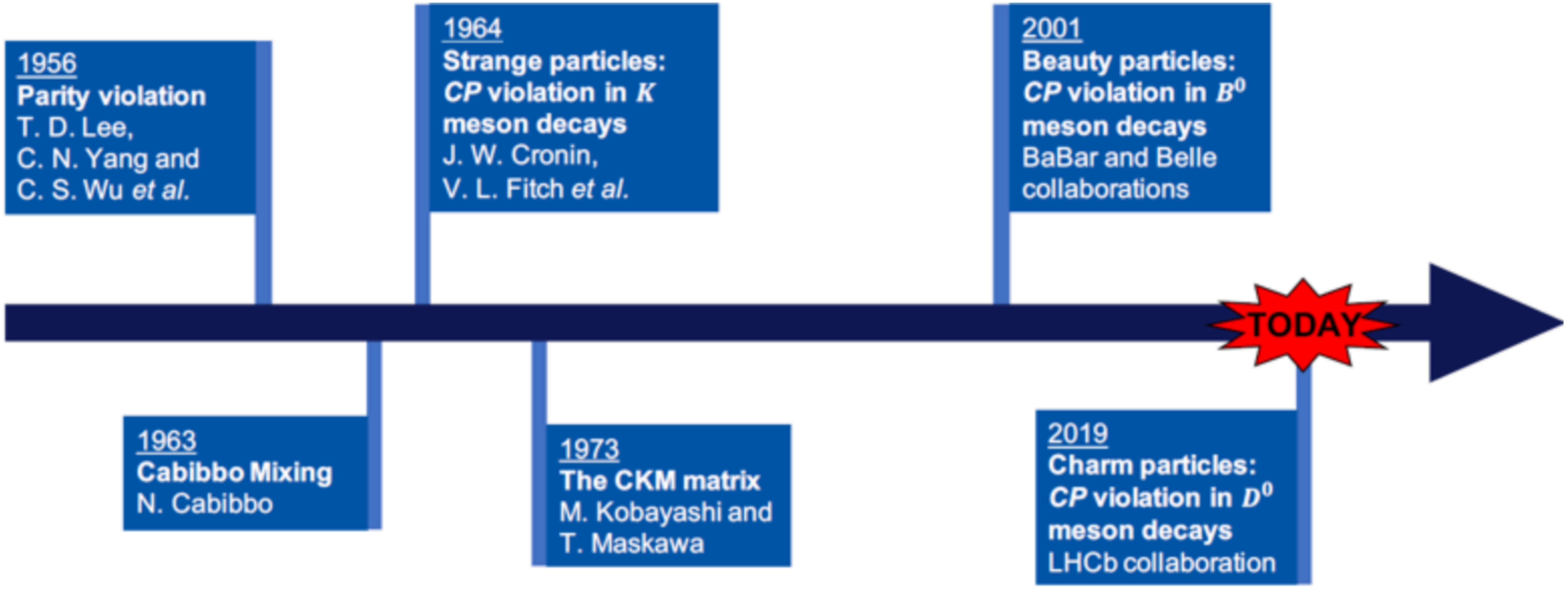
Observation of charm CPV

21 March 2019: Discovery of CP violation in charm particle decays.

An important milestone in the history of particle physics.

[ΔA_{CP} = (-0.154±0.029)%]

LHCb, PRL122, 211803 (2019)



History of charm CPV

$$\frac{V_{ub}V_{cb}}{V_{us}V_{cs}}\frac{\alpha_s}{\pi} \sim 10^{-4}$$

Bigi;Grossman,Kagan,Nir

1990-2010

$$\Delta A_{CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$$

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LHCb

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$$\sim -1 \times 10^{-3}$$

Li,Lu,**FSY**; Cheng,Chiang

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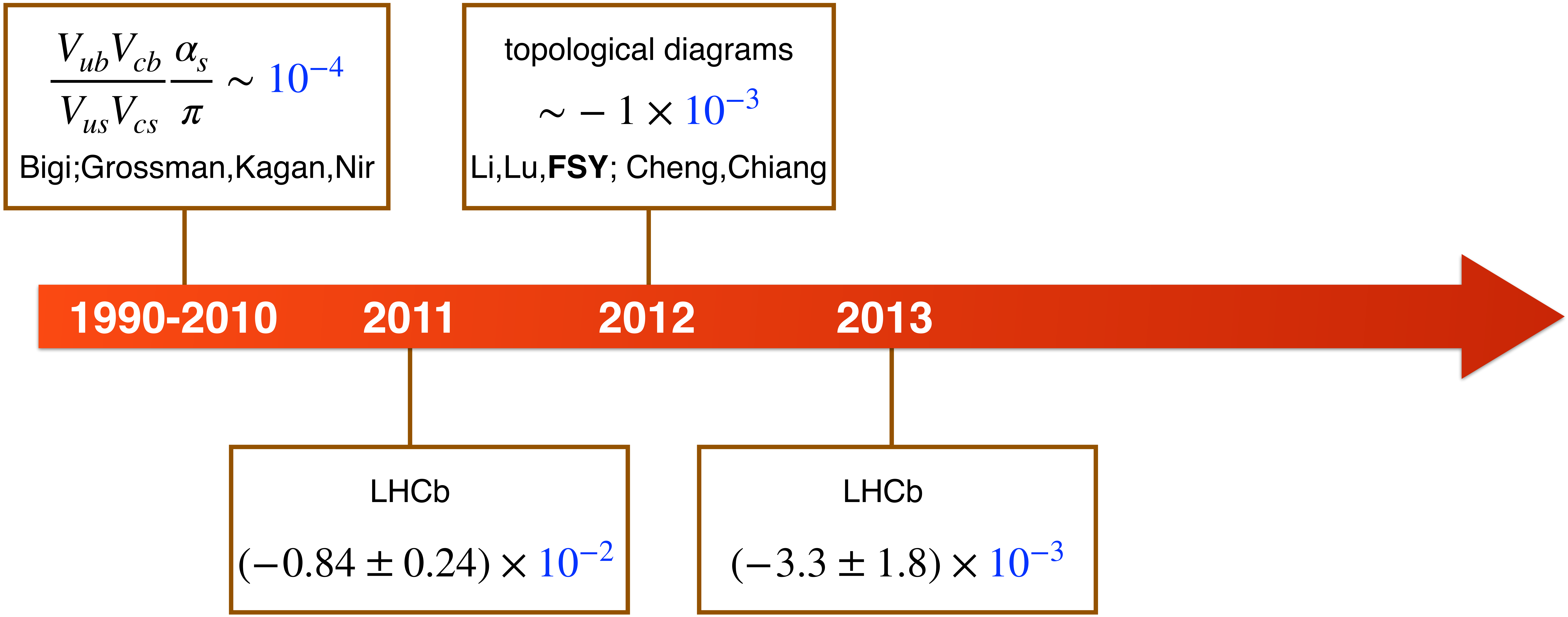

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$$(-3.3 \pm 1.8) \times 10^{-3}$$

2017

light-cone sum rules

$$< 2 \times 10^{-4}$$

Khodjamirian, Petrov

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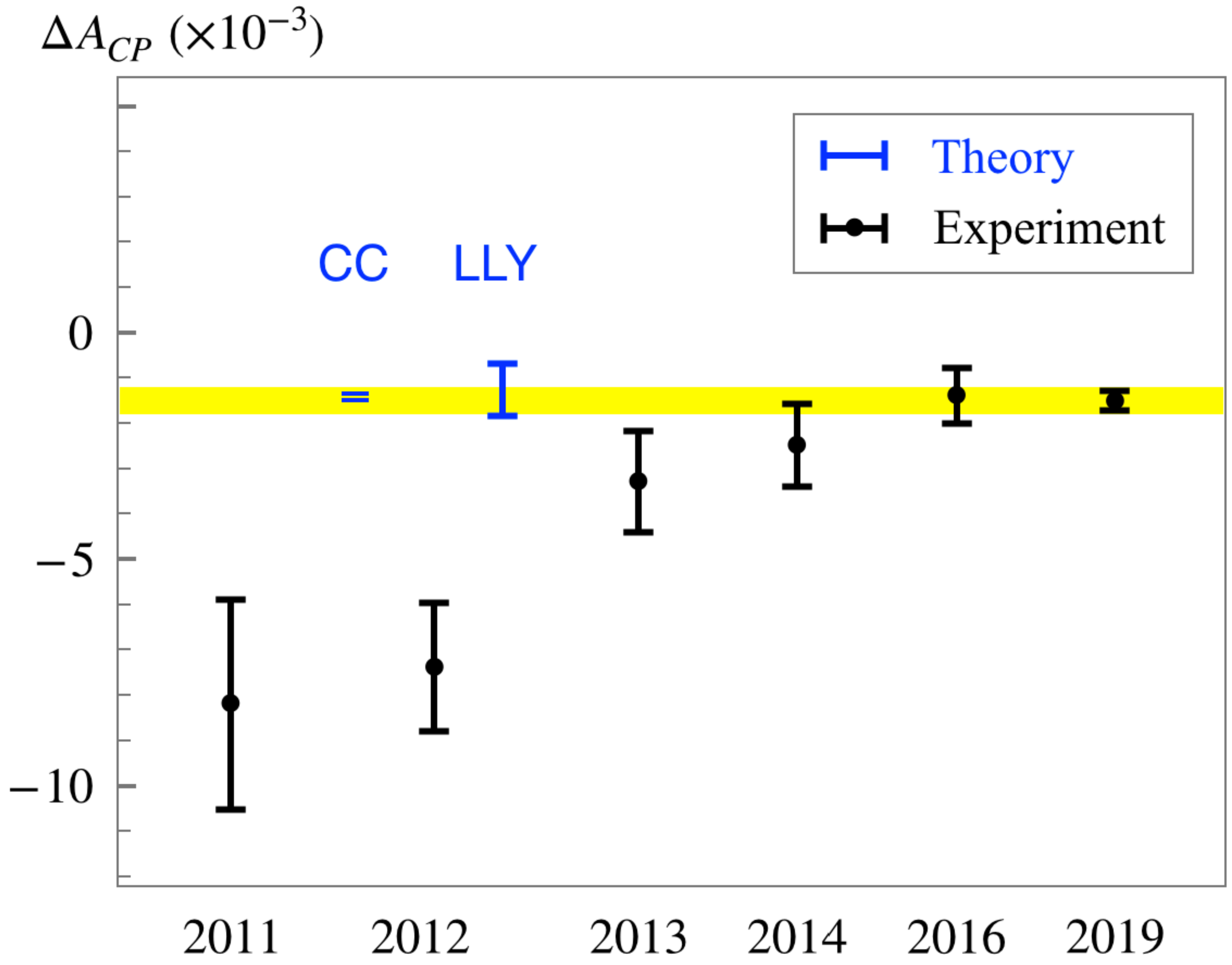


Th: the only predictions of $O(10^{-3})$

CC: topological approach + QCDF

Cheng, Chiang, 2012

LLY: factorization-assisted topology (FAT)

Li, Lu, **FSY**, 2012

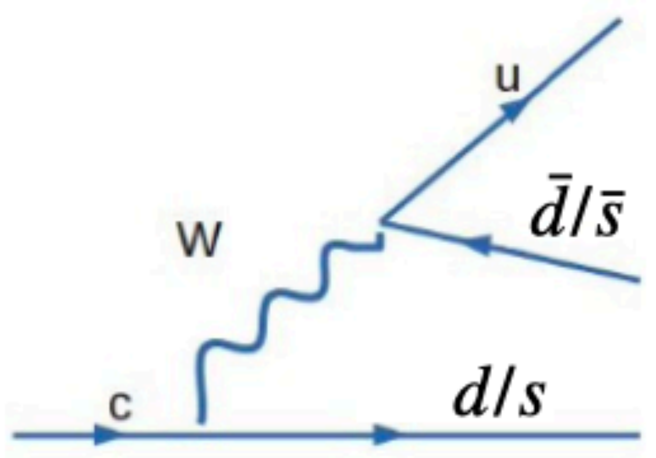
Exp: LHCb, PRL122, 211803 (2019)

Saur, **FSY**, Sci.Bull.2020

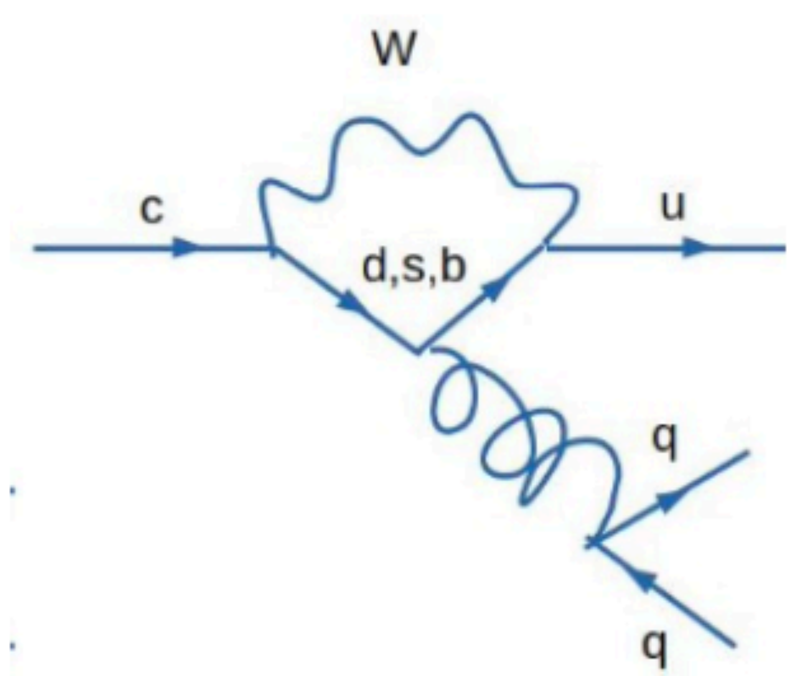
Implications of charm CPV

$$\mathcal{A}(D^0 \to K^+K^-) = \lambda_s \mathcal{T}^{KK} + \lambda_b \mathcal{P}^{KK},$$

$$\mathcal{A}(D^0 \to \pi^+\pi^-) = \lambda_d \mathcal{T}^{\pi\pi} + \lambda_b \mathcal{P}^{\pi\pi},$$



Tree



Penguin

$$\Delta A_{CP}^{\exp} = (-1.54 \pm 0.29) \times 10^{-3} \quad \Rightarrow \quad \left(\frac{|\mathcal{P}^{KK}|}{|\mathcal{T}^{KK}|} \sin \delta^{KK} + \frac{|\mathcal{P}^{\pi\pi}|}{|\mathcal{T}^{\pi\pi}|} \sin \delta^{\pi\pi} \right) \approx 1$$

✓ **Charm is different from bottom**

$$|\mathcal{P}/\mathcal{T}|_{\text{charm}} \sim \mathcal{O}(1) \quad v.s. \quad |\mathcal{P}/\mathcal{T}|_{\text{bottom}} \sim \mathcal{O}(0.1)$$

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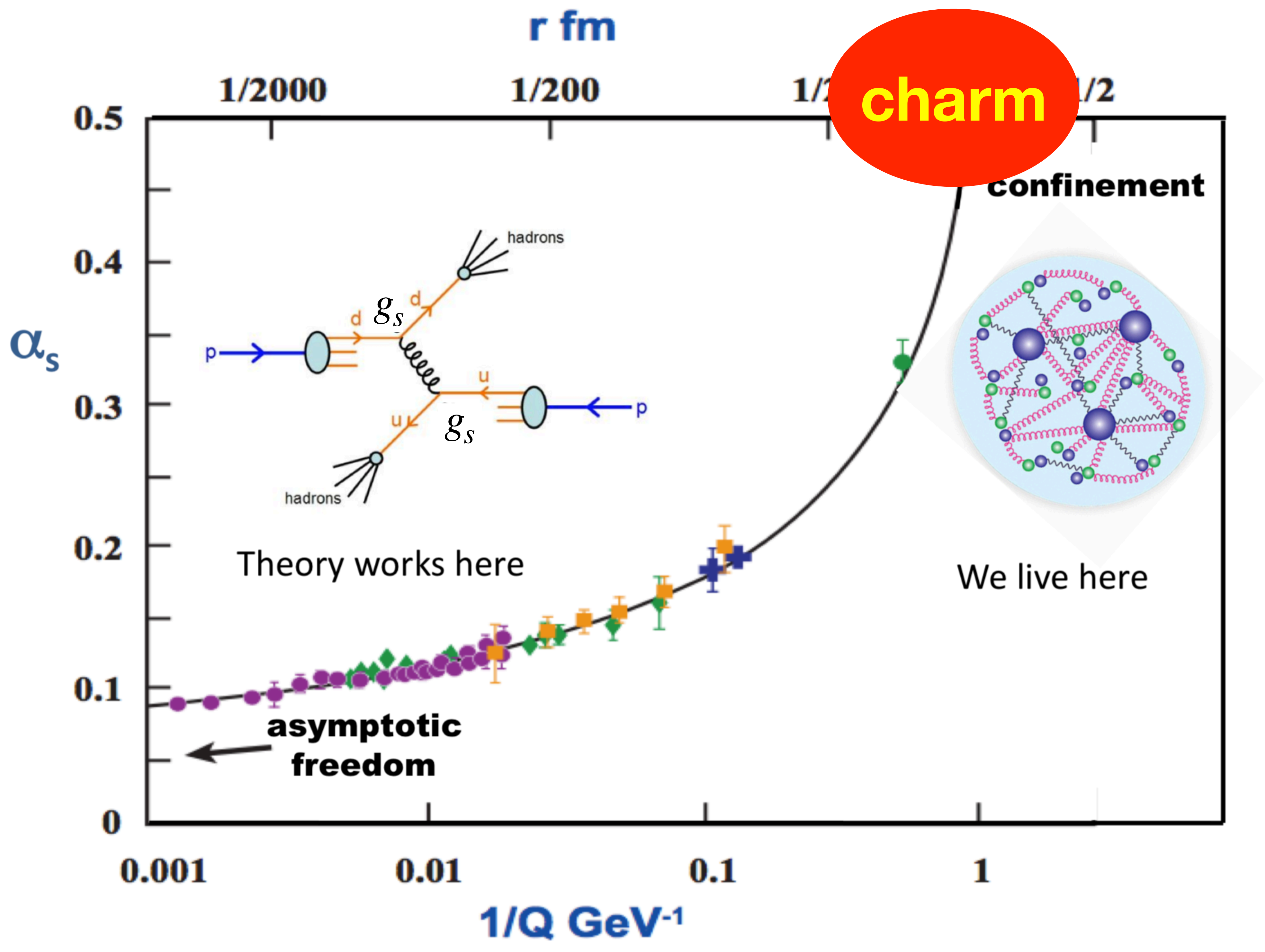
$$|\mathcal{P}/\mathcal{T}|_{\text{charm}} \sim \mathcal{O}(1) \quad v.s. \quad |\mathcal{P}/\mathcal{T}|_{\text{bottom}} \sim \mathcal{O}(0.1)$$



from S.Olsen

✓ **Large non-perturbative contributions in charmed hadron decays**

$$\frac{C_{3-6}}{C_{1,2}} \sim \mathcal{O}(0.1) \quad \ll \quad \frac{\mathcal{P}}{\mathcal{T}} \sim \mathcal{O}(1)$$

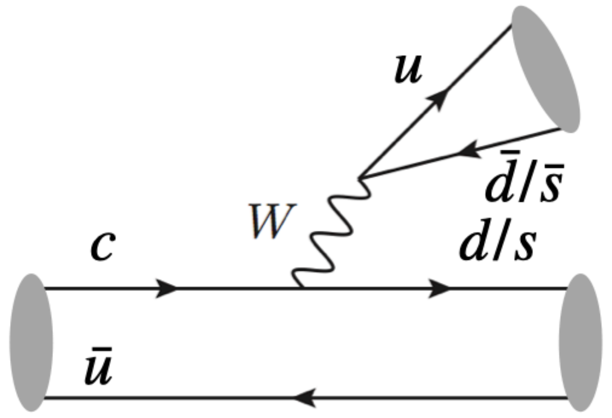
The observation of ΔA_{CP} is SM or NP?

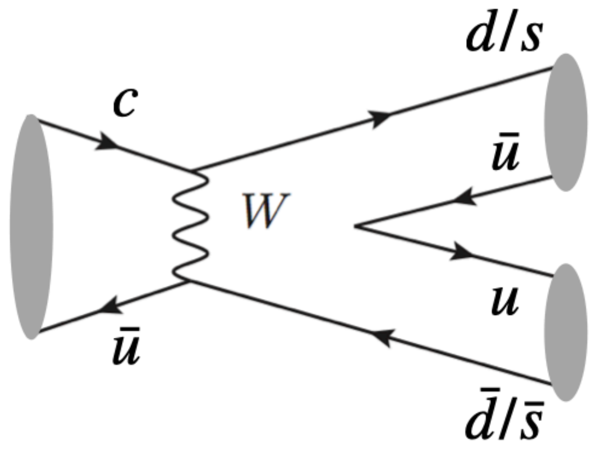
Chala, Lenz, Rusov, Scholtz, ’19

It requires dynamics !

Dynamics of hadronic charm decays

Tree

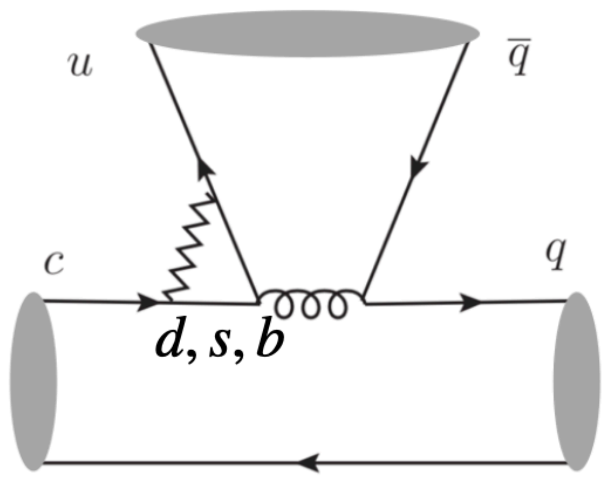


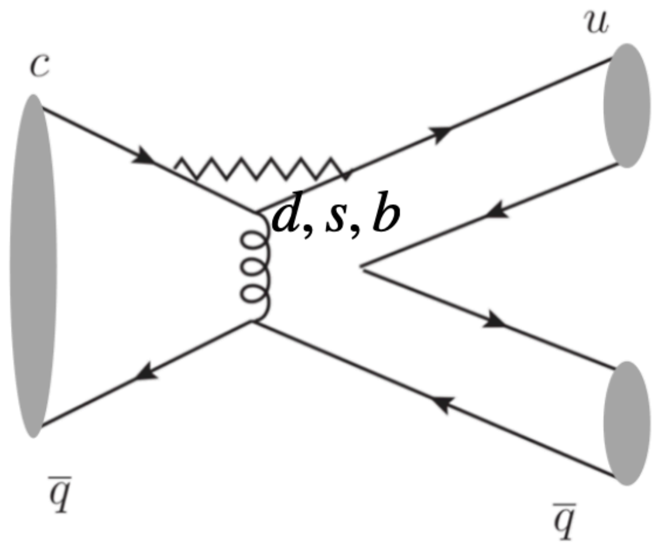


Tree diagrams are determined by data of branching fractions

Understand the dynamics at 1GeV

Penguin





Relate the penguins to the trees, with the known dynamics at 1GeV

CPV

$$\Delta A_{CP} = -2r \sin\gamma \left(\frac{|\mathcal{P}^{KK}|}{|\mathcal{T}^{KK}|} \sin\delta^{KK} + \frac{|\mathcal{P}^{\pi\pi}|}{|\mathcal{T}^{\pi\pi}|} \sin\delta^{\pi\pi} \right)$$

Then reliably predict charm CPV

Modes	Br(exp)	Br(this work)
$D^0 \to \pi^+\pi^-$	1.45 ± 0.05	1.43
$D^0 \to K^+K^-$	4.07 ± 0.10	4.19
$D^0 \to K^0\bar{K}^0$	0.320 ± 0.038	0.36
$D^0 \to \pi^0\pi^0$	0.81 ± 0.05	0.57
$D^0 \to \pi^0\eta$	0.68 ± 0.07	0.94
$D^0 \to \pi^0\eta'$	0.91 ± 0.13	0.65
$D^0 \to \eta\eta$	1.67 ± 0.18	1.48
$D^0 \to \eta\eta'$	1.05 ± 0.26	1.54
$D^+ \to \pi^+\pi^0$	1.18 ± 0.07	0.89
$D^+ \to K^+\bar{K}^0$	6.12 ± 0.22	5.95
$D^+ \to \pi^+\eta$	3.54 ± 0.21	3.39
$D^+ \to \pi^+\eta'$	4.68 ± 0.29	4.58
$D_S^+ \to \pi^0K^+$	0.62 ± 0.23	0.67
$D_S^+ \to \pi^+K^0$	2.52 ± 0.27	2.21
$D_S^+ \to K^+\eta$	1.76 ± 0.36	1.00
$D_S^+ \to K^+\eta'$	1.8 ± 0.5	1.92

@ BESIII & CLEO

1. Understand QCD dynamics @ 1GeV by Branching Ratios

2. then predict charm CPV

H.n.Li, C.D.Lu, F.S.Yu, PRD2012

Modes	Br(exp)	Br(this work)	$A_{CP}^{SM} \times 10^{-3}$
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$D_S^+ \to K^+\eta$	1.76 ± 0.36	1.00	0.70
$D_S^+ \to K^+\eta'$	1.8 ± 0.5	1.92	-1.60

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$$\Delta A_{CP}^{SM} = -1 \times 10^{-3}$$

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Charmed baryon decays

- Charmed baryon decays are the next opportunity and challenge of charm physics
- **No CPV has been yet observed in charmed baryon decays.**

process	CPV observables	
$\Lambda_c^+ \to \Lambda\pi^+$	$A_{CP}^{\alpha} = -0.07 \pm 0.19 \pm 0.24$	*FOCUS,PLB (2006)*
$\Lambda_c^+ \to \Lambda K^+$	$A_{CP}^{dir} = 0.021 \pm 0.026 \pm 0.001$	*Belle, Sci.Bull. (2023)*
	$A_{CP}^{\alpha} = -0.023 \pm 0.086 \pm 0.071$	
$\Lambda_c^+ \to \Sigma^0 K^+$	$A_{CP}^{dir} = 0.025 \pm 0.054 \pm 0.004$	
	$A_{CP}^{\alpha} = 0.08 \pm 0.35 \pm 0.14$	
$\Xi_c^0 \to \Xi^-\pi^+$	$A_{CP}^{\alpha} = 0.024 \pm 0.052 \pm 0.014$	*Belle, PRL (2021)*
$\Lambda_c^+ \to pK^+K^-$	$A_{CP}^{dir}(\Lambda_c^+ \to pK^+K^-) - A_{CP}^{dir}(\Lambda_c^+ \to p\pi^+\pi^-) = (0.30 \pm 0.91 \pm 0.61)\%$	*LHCb, JHEP (2018)*
$\Lambda_c^+ \to p\pi^+\pi^-$		
$\Xi_c^+ \to pK^-\pi^+$	NO CP violation	*LHCb, EPJC (2020)*

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most precise to date

Charmed baryon decays

- Charmed baryon decays are the next opportunity and challenge of charm physics
- CP asymmetry sum rules based on SU(3) flavor symmetry are firstly obtained [Grossman and Schacht, PRD (2019)][Di Wang, EPJC (2019)]

$$A_{CP}(\Lambda_c^+ \to pK^-K^+) + A_{CP}(\Xi_c^+ \to \Sigma^+\pi^-\pi^+) = 0,$$

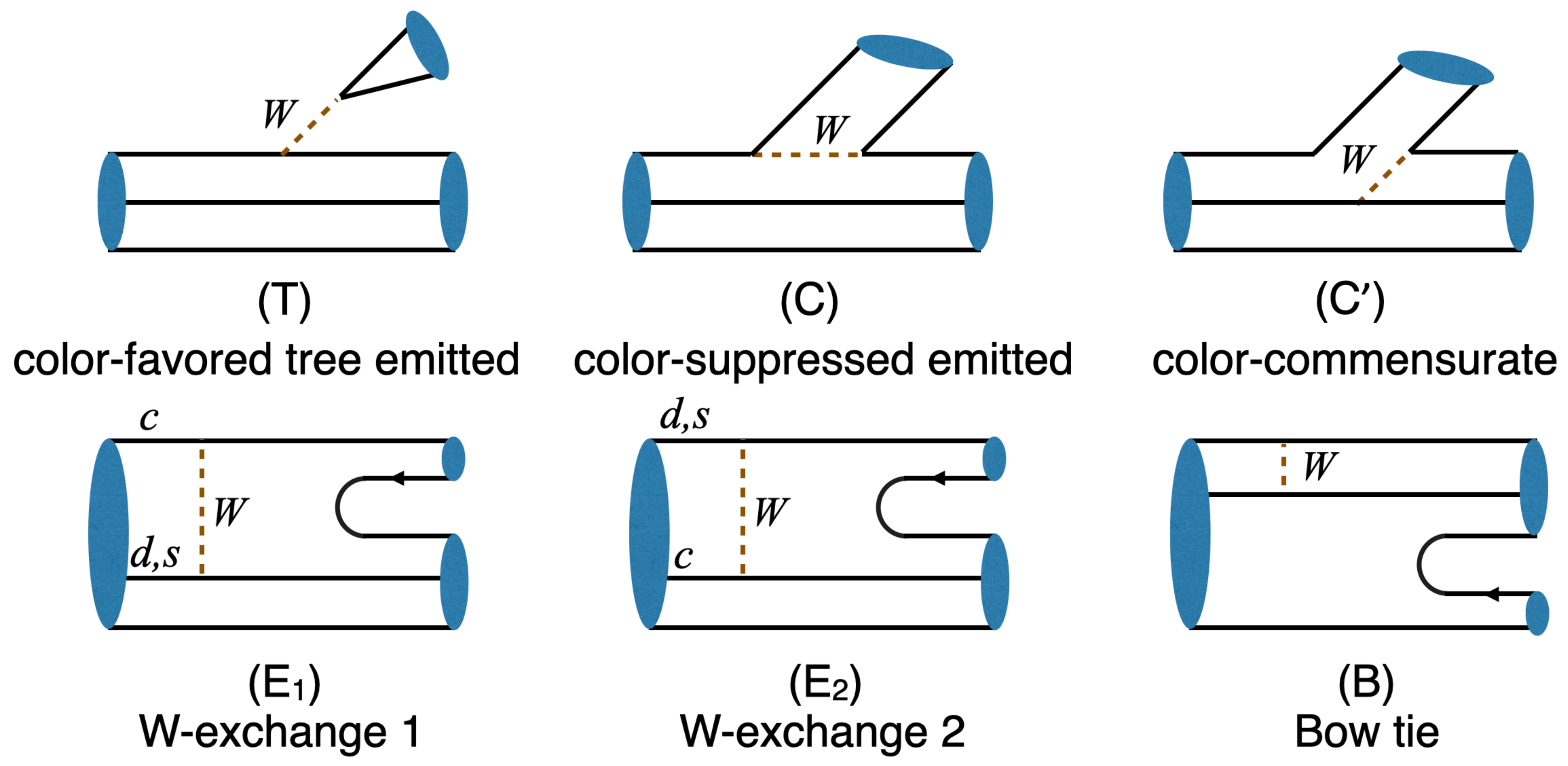
$$A_{CP}(\Lambda_c^+ \to \Sigma^+\pi^-K^+) + A_{CP}(\Xi_c^+ \to pK^-\pi^+) = 0,$$

$$A_{CP}(\Lambda_c^+ \to p\pi^-\pi^+) + A_{CP}(\Xi_c^+ \to \Sigma^+K^-K^+) = 0.$$

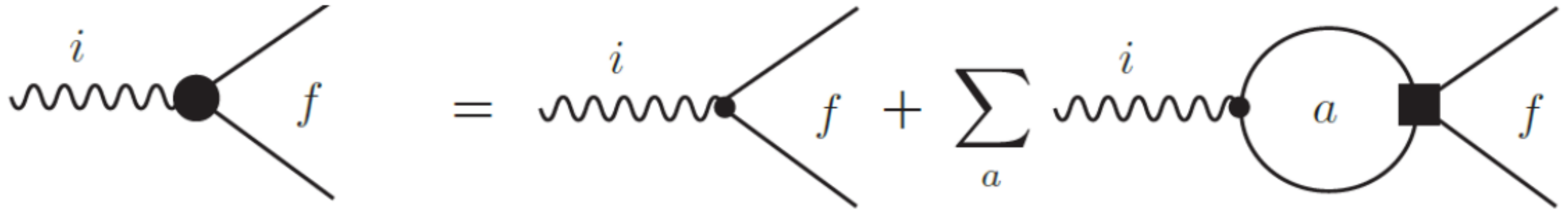
- **No any numerical prediction on CPV of charm-baryon decays**

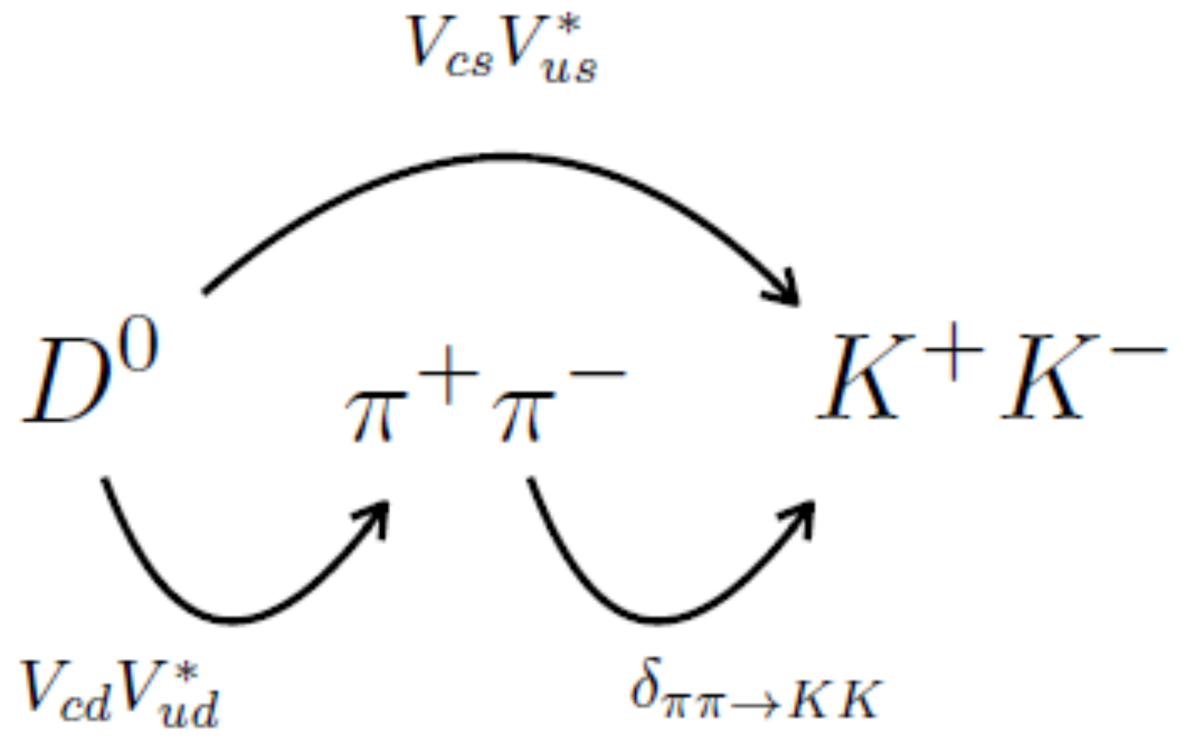
Charmed baryon decays

- Charmed baryon decays are the next opportunity and challenge of charm physics
- No any real CPV predictions
- Dynamics are more complicated
    - Many more topological diagrams + more partial waves
    - SU(3) irreducible representations cannot provide information on penguins
    - Final-state interactions (FSI) are necessary



Final-state interactions





- Rescattering mechanism for charm CPV [Bediaga, Frederico, Magalhaes, PRL2023; Pich, Solomonidi, Silva, PRD2023]
  - Data-driven extraction of magnitudes and phases of the $\pi\pi \to KK$ scatterings

$$|\Delta A_{CP}^{\text{short-distance}}| < 2 \times 10^{-4} \qquad \text{v.s.} \qquad \Delta A_{CP}^{\text{FSI}} = -(6.4 \pm 1.8) \times 10^{-4}$$

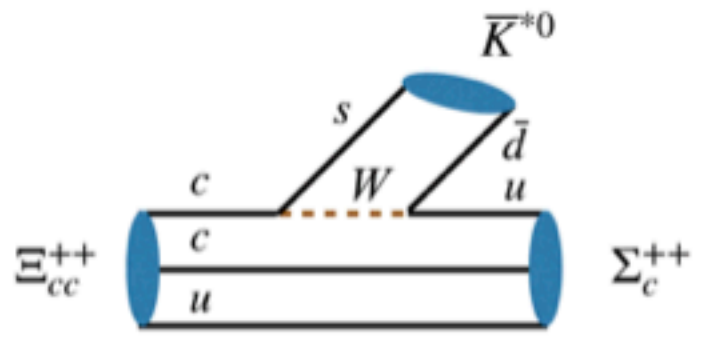
Model-independently manifest on the enhancement of final-state interactions!!!

  - Power of predictions is limited due to only few channels of available data

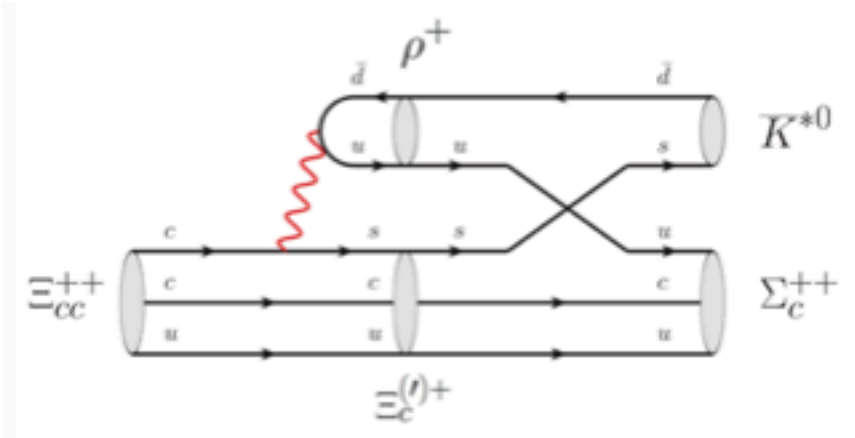
$$\Delta A_{CP}^{\text{exp}} = -(15.4 \pm 2.9) \times 10^{-4}$$

Rescattering mechanism

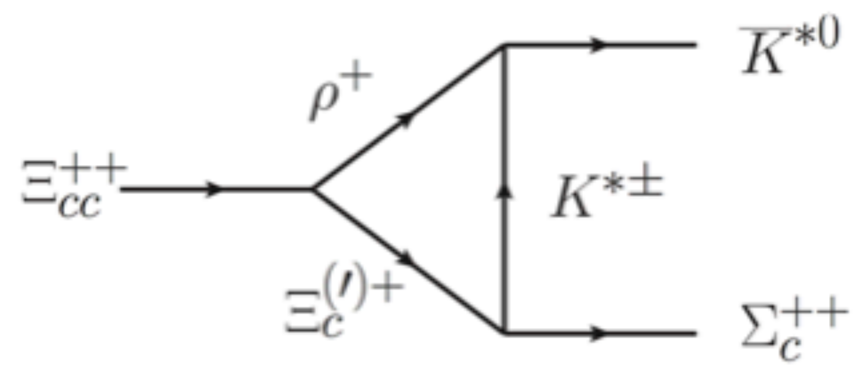
- Rescattering mechanism have been successfully used to predict the discovery channel of $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ [FSY, Jiang, Li, Lu, Wang, Zhao, '17]



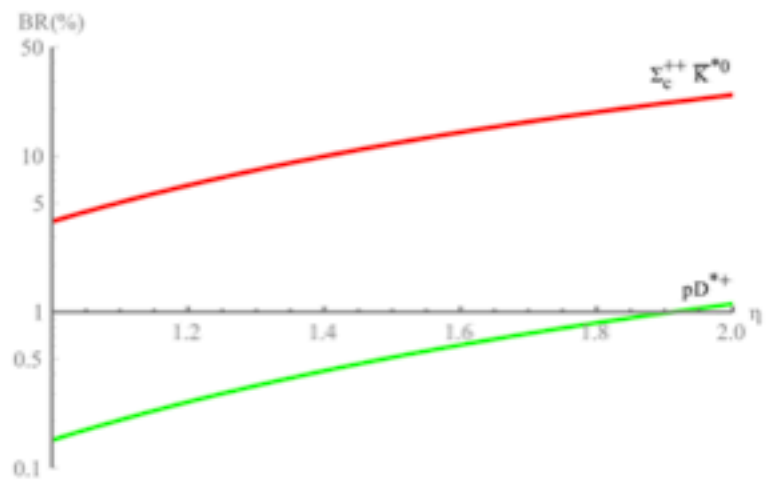
Topology: C



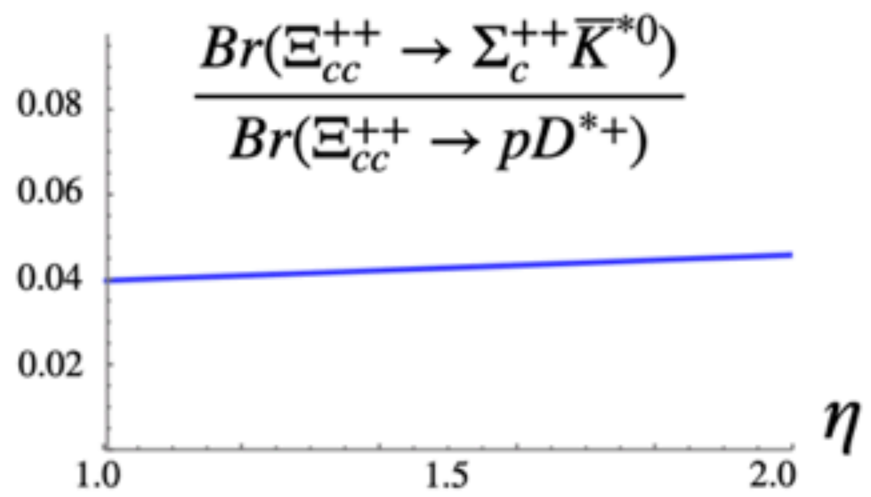
quark exchange



hadronic triangle



- Theoretical uncertainty is under control in the **ratio** of branching fractions of different processes



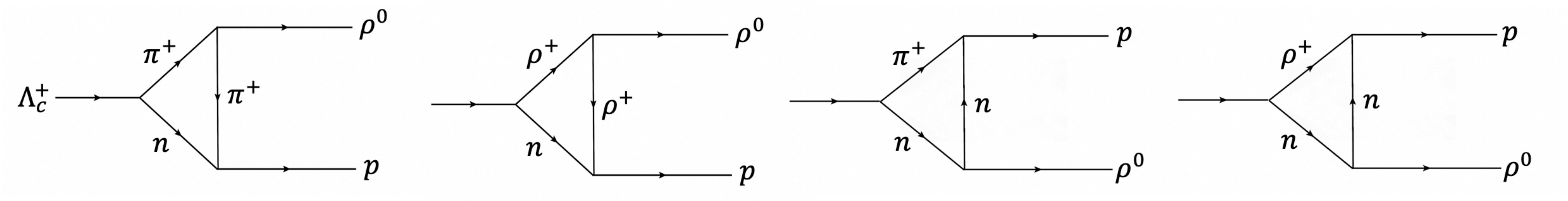
1703.09086
2102.00961

- It deserves to develop the rescattering mechanism to study CPV of charmed baryons

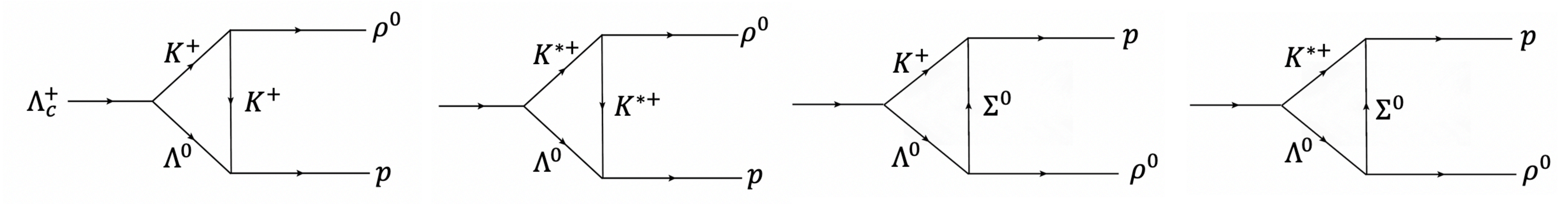
Triangle diagrams

- Much more channels are included in the rescattering mechanism

$V_{ud}V_{cd}^{*}$



$V_{us}V_{cs}^{*}$

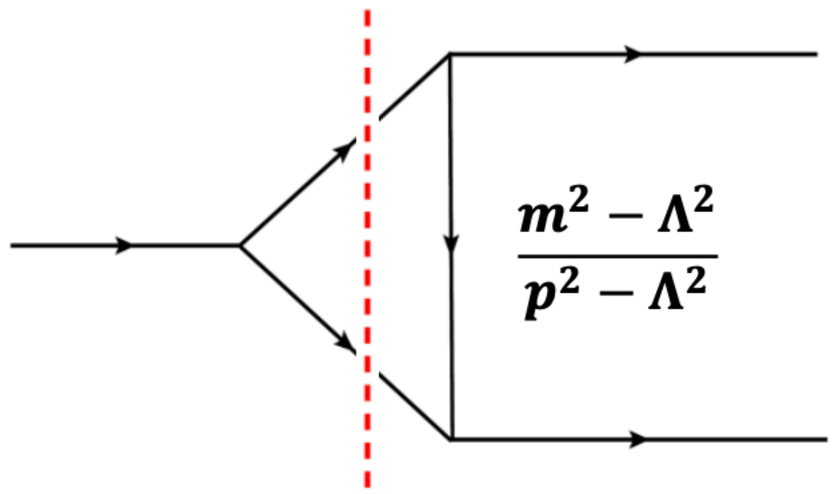


CPV can be easily obtained within the rescattering mechanism

$$\lambda_d\, A_d + \lambda_s\, A_s$$

➢ **Conventional method：** optical theorem + Cutkosky cutting rule

- H. Y. Cheng, C. K. Chua and A. Soni, Phys. Rev. D 71, 014030 (2005)……..



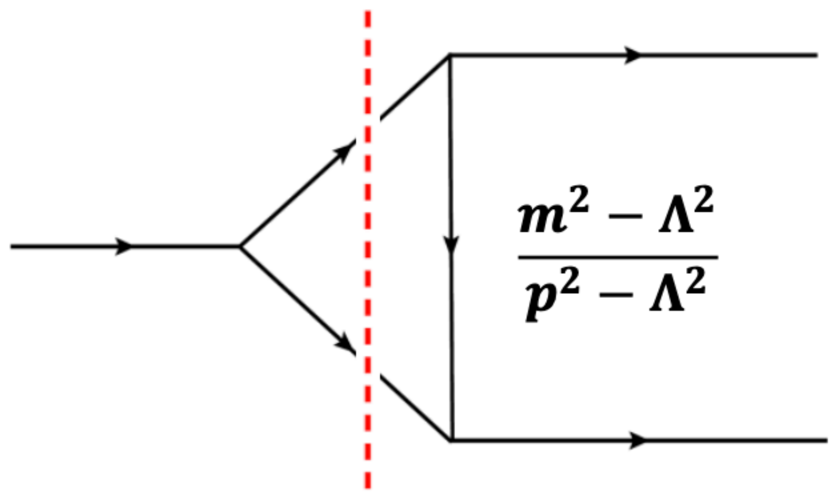
$$\Lambda = m_k + \eta\Lambda_{QCD}$$

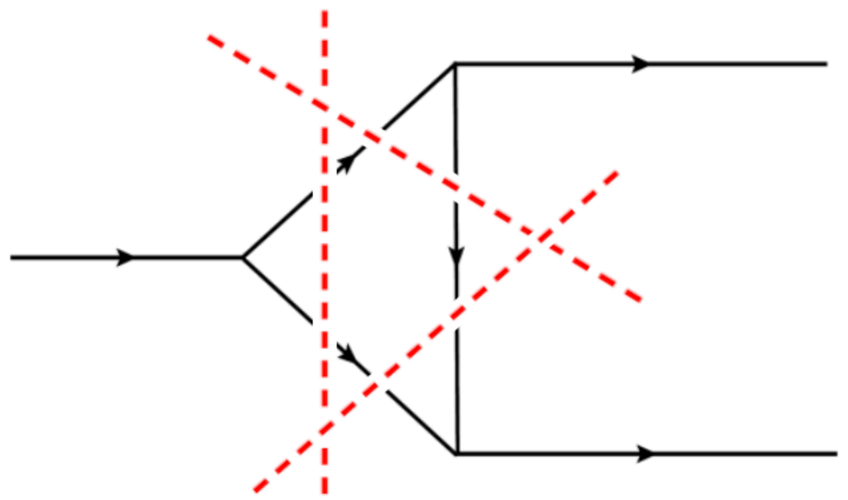
$$\mathcal{A}bs[\mathcal{M}(P_i \to P_3P_4)]$$
$$= \frac{1}{2}\sum_{\{P_1P_2\}}\int\frac{d^3p_1}{(2\pi)^3 2E_1}\int\frac{d^3p_2}{(2\pi)^3 2E_2}(2\pi)^4\delta^4(p_3+p_4-p_1-p_2)$$
$$\cdot M(P_i \to \{P_1P_2\})T^*(P_3P_4 \to \{P_1P_2\}).$$

- **Strong model-dependent in charmed baryon decay：**

decay mode	Topology diagram	Experiment(%)	Short-distance	η
$\Lambda_c^+ \to \Sigma^+\phi$	E_1	0.39 ± 0.06	-	6.5
$\Lambda_c^+ \to p\omega$	C, C', E_1, E_2, B	0.09 ± 0.04	2.83×10^{-6}	0.65

- **Only a part of the imaginary contribution is included……**

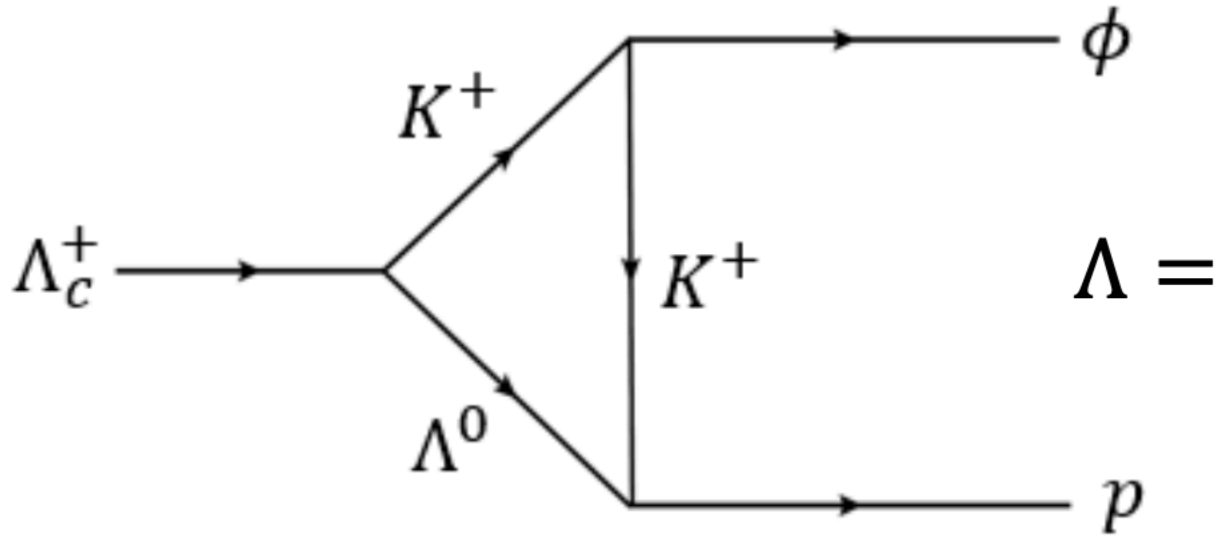




- Off-shell effects
- Lost contribution

- J.J. Han, H.Y. Jiang, W. Liu, Z.J. Xiao, and F.S. Yu, ” Chin. Phys. C 45, 053105 (2021).

➢ Improving method： Loop integral



$$\Lambda = m_k + \eta\Lambda_{QCD}$$

$$\mathcal{M}[P,B;V]$$
$$= -i\int\frac{d^4p_1}{(2\pi)^4}g_{BBP}g_{VPP}\bar{u}(p_4,s_4)\gamma_5(\not{p_2}+m_2)(A+B\gamma_5)u(p,s)\epsilon^{\star}_{\mu}(p_3,\lambda_3)(p_1+k)^{\mu}$$
$$\times\frac{1}{(p_1^2-m_1^2+i\epsilon)(p_2^2-m_2^2+i\epsilon)(k^2-m_k^2+i\epsilon)}\boxed{\left(\frac{\Lambda_1^2-m_1^2}{\Lambda_1^2-p_1^2}\right)\left(\frac{\Lambda_2^2-m_2^2}{\Lambda_2^2-p_2^2}\right)\left(\frac{\Lambda_k^2-m_k^2}{\Lambda_k^2-k^2}\right)}$$

- The complete amplitudes with real part and strong phase

$$\begin{pmatrix} \{0.,\ 0.,\ -1.57956\times10^{-7}+6.40596\times10^{-8}\,i\} & \{4.65132\times10^{-7}+1.10998\times10^{-6}\,i,\ 0.,\ 0.\} \\ \{0.,\ \underline{-1.00635\times10^{-6}+1.46048\times10^{-7}\,i},\ 0.\} & \{0.,\ 0.,\ 4.56956\times10^{-7}-2.83047\times10^{-7}\,i\} \end{pmatrix}$$

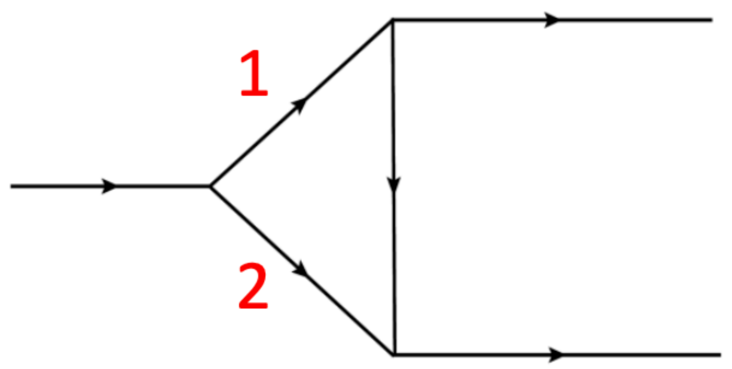
- The process dependence of the parameters is greatly reduced

The contribution of the real part is on the same order as the contribution of the imaginary part!

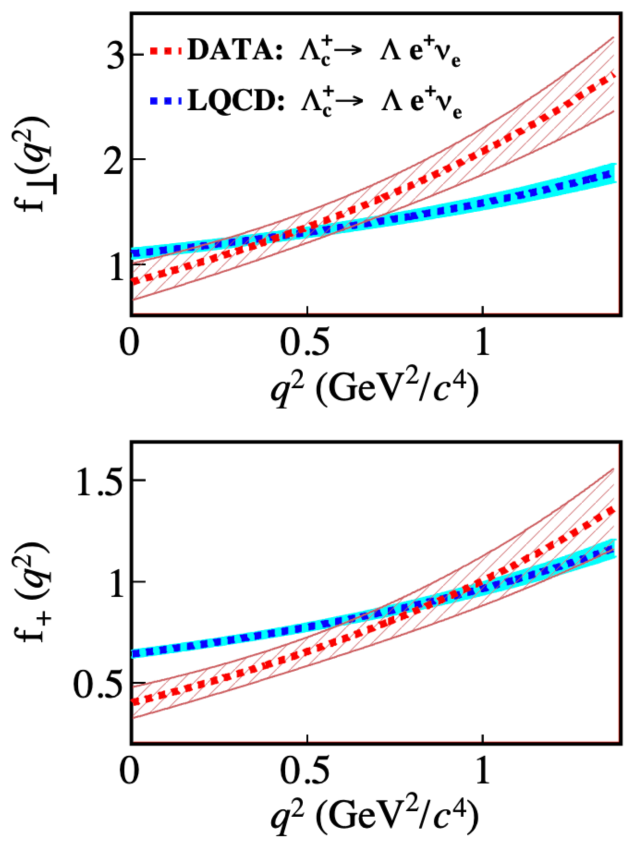
Only one parameter explain all the 8 experimental data!

- **Branching ratio:** $\eta = 0.6 \pm 0.1$

$$\Gamma(\mathcal{B}_c \to \mathcal{B}_8 V) = \frac{p_c}{8\pi m_i^2} \frac{1}{2} \sum_{\lambda\lambda'\sigma} |\mathcal{A}(\mathcal{B}_c \to \mathcal{B}_8 V)|^2$$



decay mode	topology	experiment(%)	Short-distance	prediction(%)
$\Lambda_c^+ \to \Lambda^0 \rho^+$	T, C', E_2, B	4.06 ± 0.52	4.91%	8 ± 0.8
$\Lambda_c^+ \to p\phi$	C	0.106 ± 0.014	1.92×10^{-6}	0.09 ± 0.03
$\Lambda_c^+ \to \Sigma^+ \phi$	E_1	0.39 ± 0.06	-	0.49 ± 0.22
$\Lambda_c^+ \to p\omega$	C, C', E_1, E_2, B	0.09 ± 0.04	2.83×10^{-6}	0.08 ± 0.04
$\Lambda_c^+ \to \Sigma^+ \rho^0$	C', E_2, B	< 1.7	-	2.0 ± 1.0
$\Lambda_c^+ \to \Sigma^0 \rho^+$	C', E_2, B	Isospin	-	Isospin
$\Lambda_c^+ \to \Sigma^+ \omega$	C', E_2, B	1.7 ± 0.21	-	1.8 ± 0.7
$\Lambda_c^+ \to p\bar{K}^{*0}$	C, E_1	1.96 ± 0.27	3.47×10^{-5}	2.9 ± 1.2
$\Lambda_c^+ \to \Sigma^+ K^{*0}$	C', E_1	0.35 ± 0.1	-	0.28 ± 0.13

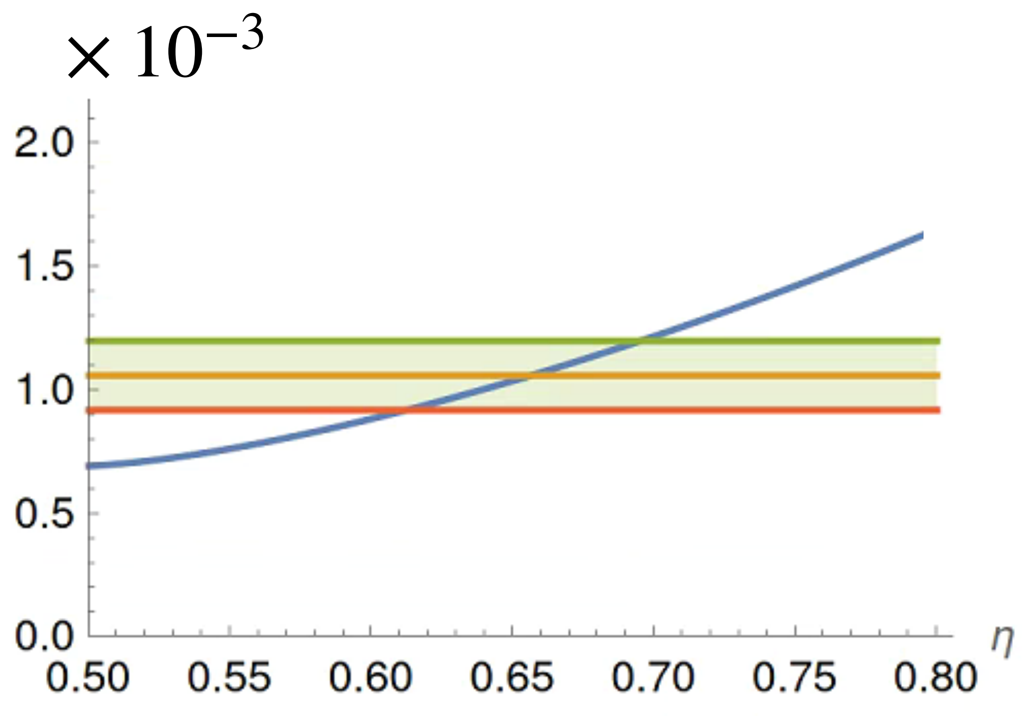


Preliminary results by C.P.Jia, H.Y.Jiang, FSY

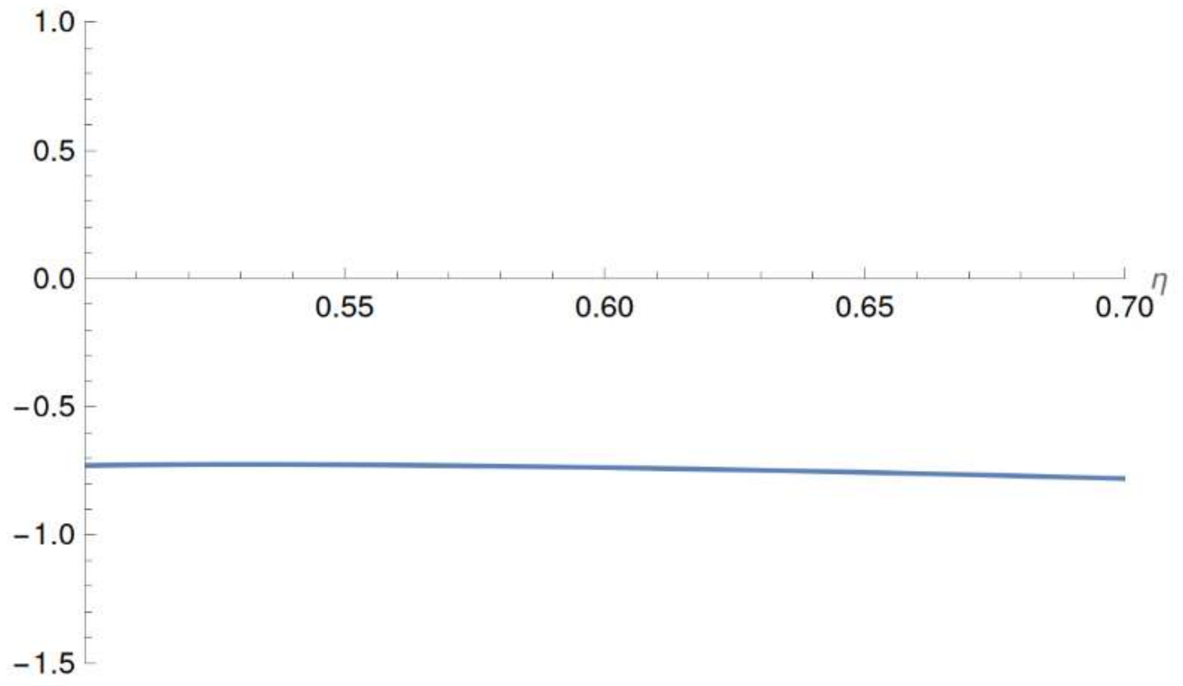
Dependence on η

$\Lambda_c^+ \to p\phi$

Branching fractions



Decay asymmetry α

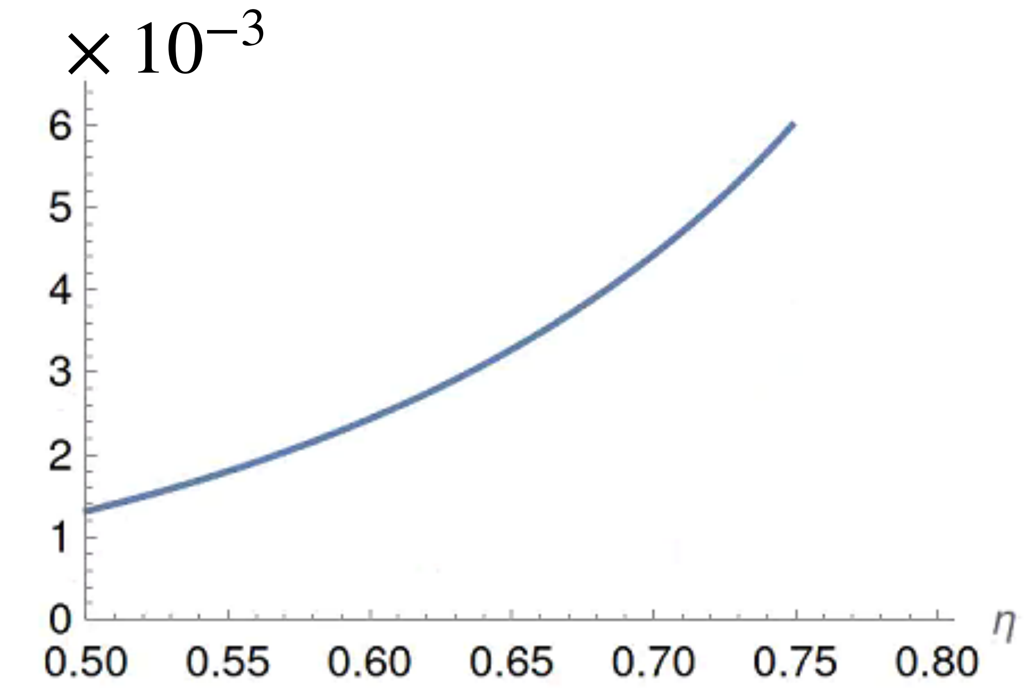


- The decay asymmetries and CPV are insensitive to η, whose dependences are mostly cancelled by the ratios

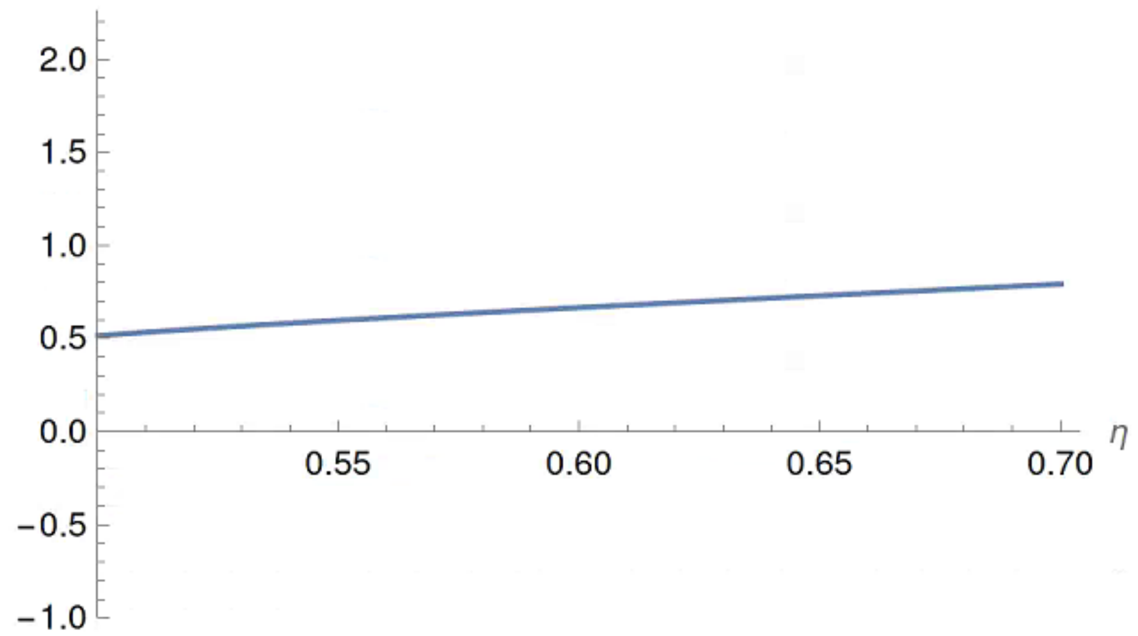
$$\alpha = \frac{\left|H_{1,\frac{1}{2}}\right|^2 - \left|H_{-1,-\frac{1}{2}}\right|^2}{\left|H_{1,\frac{1}{2}}\right|^2 + \left|H_{-1,-\frac{1}{2}}\right|^2} \qquad A_{CP} = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}$$

$\Lambda_c^+ \to p\rho^0$

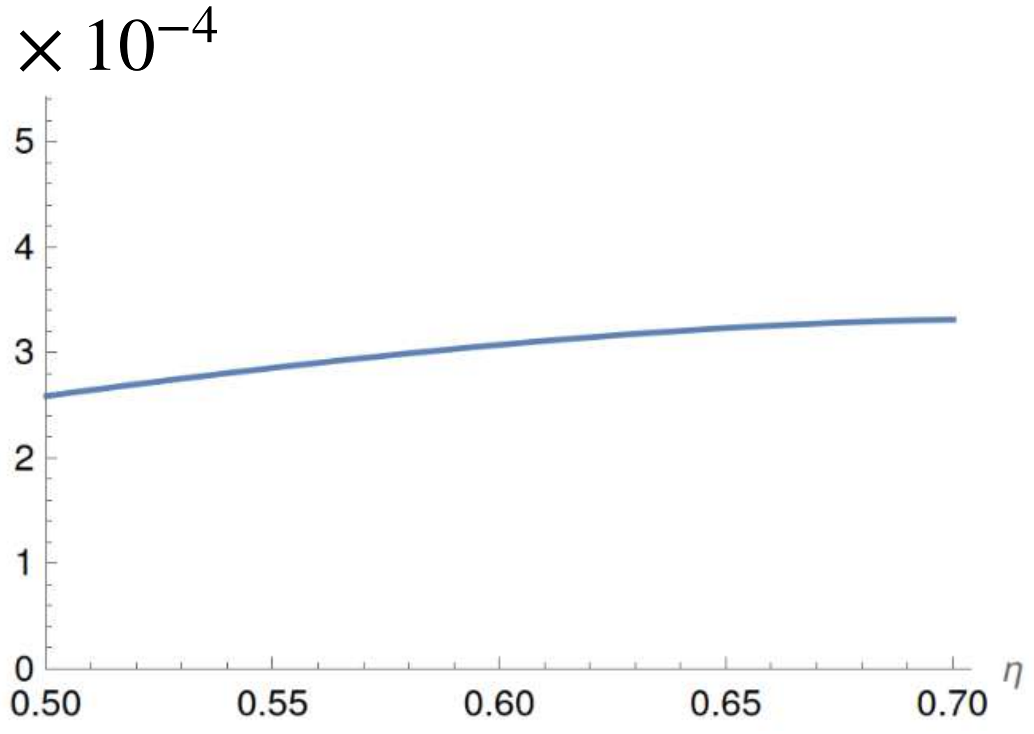
Branching fractions



Decay asymmetry α



Direct CPV



$BR(\Lambda_c^+ \to p\pi^+\pi^-) = (4.60 \pm 0.26) \times 10^{-3}$

Preliminary results by C.P.Jia, H.Y.Jiang, FSY

Comment on CEPC measurements

- Comparison between theoretical predictions and experimental measurements are very important to make it clear whether the observed charm CPV is from SM or NP.
- Theoretical calculations are more reliable for two-body decays than three-body ones.
- LHCb has the largest data sample, but is better for charged particles, such as $\Lambda_c^+ \to pK^+K^-$, $p\pi^+\pi^-$ which are always three-body decays for Λ_c^+
- Electron-positron colliders have advantages on neutral particles, such as $\Lambda_c^+ \to p\pi^0$ which is a two-body decay and better for the comparison between theory and experiment.

Summary

- The discovery of charm CPV is a milestone of particle physics
- Charmed baryon decays are the next opportunity and challenge of charm physics
- CPV of charmed baryon decays have never been observed
- Rescattering mechanism of final-state interactions is developed to predict CPV of charmed baryon decays.
- It is an opportunity to search for CPV in charmed baryon decays at CEPC

Thank you very much!

Backups

$$\left(\frac{|\mathcal{P}^{KK}|}{|\mathcal{T}^{KK}|}\sin\delta^{KK} + \frac{|\mathcal{P}^{\pi\pi}|}{|\mathcal{T}^{\pi\pi}|}\sin\delta^{\pi\pi}\right) \approx 1 \quad \longrightarrow \quad \boxed{\frac{|\mathcal{P}|}{|\mathcal{T}|}\sin\delta \sim 1/2}$$

topological approach

Li, Lu, **FSY**, ’12; Cheng, Chiang, ’12

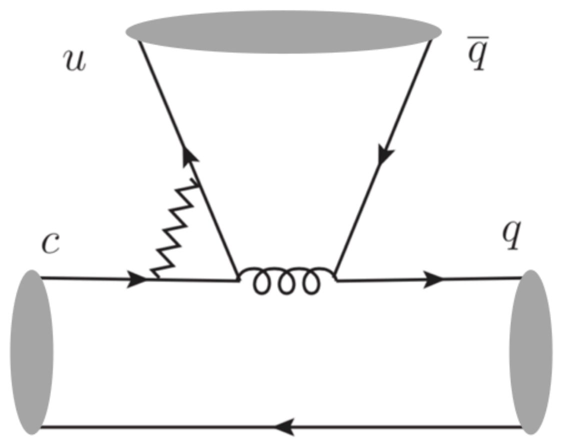
$$\frac{\mathcal{P}^{\pi\pi}}{\mathcal{T}^{\pi\pi}} = 0.66e^{i134^\circ}, \quad \text{and} \quad \frac{\mathcal{P}^{KK}}{\mathcal{T}^{KK}} = 0.45e^{i131^\circ}$$

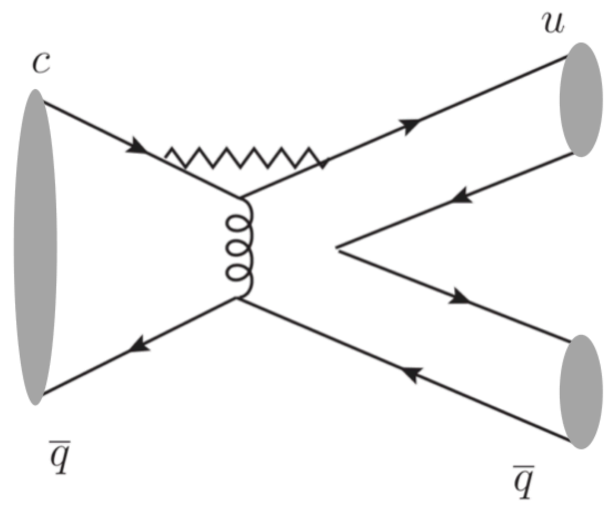
$\Delta U = 0$ over $\Delta U = 1$

Grossman, Schacht, ‘19

$$|\tilde{p}_0|\sin(\delta_{\text{strong}}) = 0.65 \pm 0.11$$

Key: **Long-distance non-perturbative**





Understand: tree —> penguin; Branching ratio —> CPV

Theoretical methods for hadronic weak decays

Theoretical approaches	Advantages	Disadvantages
QCD-inspired : QCDF, PQCD, SCET	(Almost) first-principle for dynamics, very predictive for B decays	Difficult for non-perturbative contributions, thus difficult for charm
Final-state interaction	Dynamics for non-perturbations	Suffer very large theoretical uncertainties
SU(3) irreducible representation	Based on approximate flavor symmetry, no additional assumptions	No link to dynamics
Topological diagrams	Include non-perturbations, successful for charm phenomenology	Mathematical foundation is not clear

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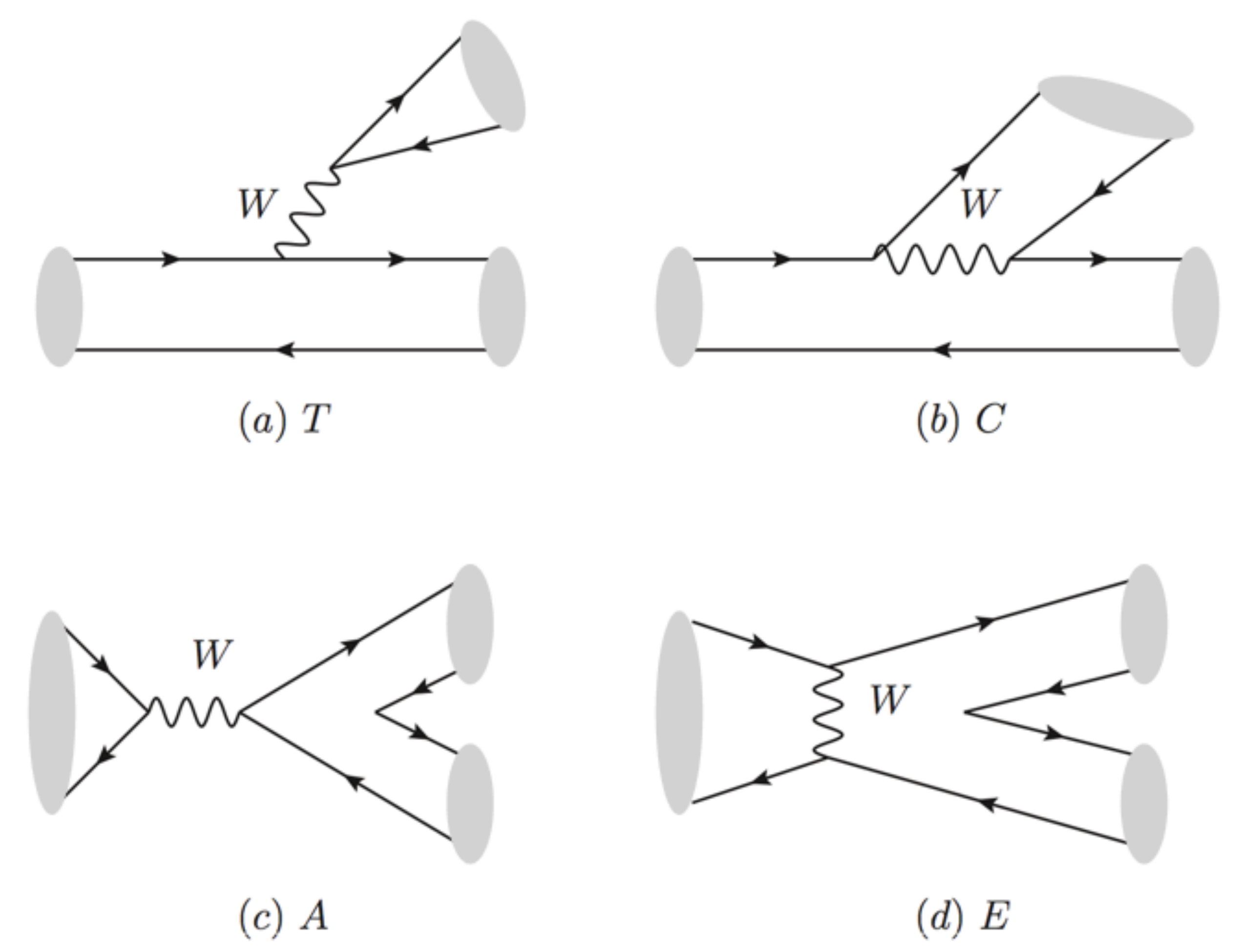
Li,Lu,**FSY,** 2012; Cheng,Chiang, 2012

Topological Diagrams

- According to the weak flavour flows
- **Including all strong interaction effects** : short distance + long distance
- Amplitudes extracted from data

Chau,'86; Chau,Cheng,'87;



Meson	Mode	Representation	$\mathcal{B}_{\text{exp}}$ (%)	$\mathcal{B}_{\text{fit}}$ (%)
D^0	$K^-\pi^+$	$V_{cs}^* V_{ud}(T+E)$	3.91 ± 0.08	3.91 ± 0.17
	$\bar{K}^0\pi^0$	$\frac{1}{\sqrt{2}} V_{cs}^* V_{ud}(C-E)$	2.38 ± 0.09	2.36 ± 0.08
	$\bar{K}^0\eta$	$V_{cs}^* V_{ud}[\frac{1}{\sqrt{2}}(C+E)\cos\phi - E\sin\phi]$	0.96 ± 0.06	0.98 ± 0.05
	$\bar{K}^0\eta'$	$V_{cs}^* V_{ud}[\frac{1}{\sqrt{2}}(C+E)\sin\phi + E\cos\phi]$	1.90 ± 0.11	1.91 ± 0.09
D^+	$\bar{K}^0\pi^+$	$V_{cs}^* V_{ud}(T+C)$	3.07 ± 0.10	3.08 ± 0.36
D_s^+	$\bar{K}^0 K^+$	$V_{cs}^* V_{ud}(C+A)$	2.98 ± 0.17	2.97 ± 0.32
	$\pi^+\pi^0$	0	<0.037	0
	$\pi^+\eta$	$V_{cs}^* V_{ud}(\sqrt{2}A\cos\phi - T\sin\phi)$	1.84 ± 0.15	1.82 ± 0.32
	$\pi^+\eta'$	$V_{cs}^* V_{ud}(\sqrt{2}A\sin\phi + T\cos\phi)$	3.95 ± 0.34	3.82 ± 0.36

$$T = 3.14 \pm 0.06,$$

$$C = (2.61 \pm 0.08)e^{-i(152\pm1)^\circ},$$

$$E = (1.53^{+0.07}_{-0.08})e^{i(122\pm2)^\circ},$$

$$A = (0.39^{+0.13}_{-0.09})e^{i(31^{+20}_{-33})^\circ}$$

Cheng, Chiang,'10

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- According to the weak flavour flows
- **Including all strong interaction effects :**
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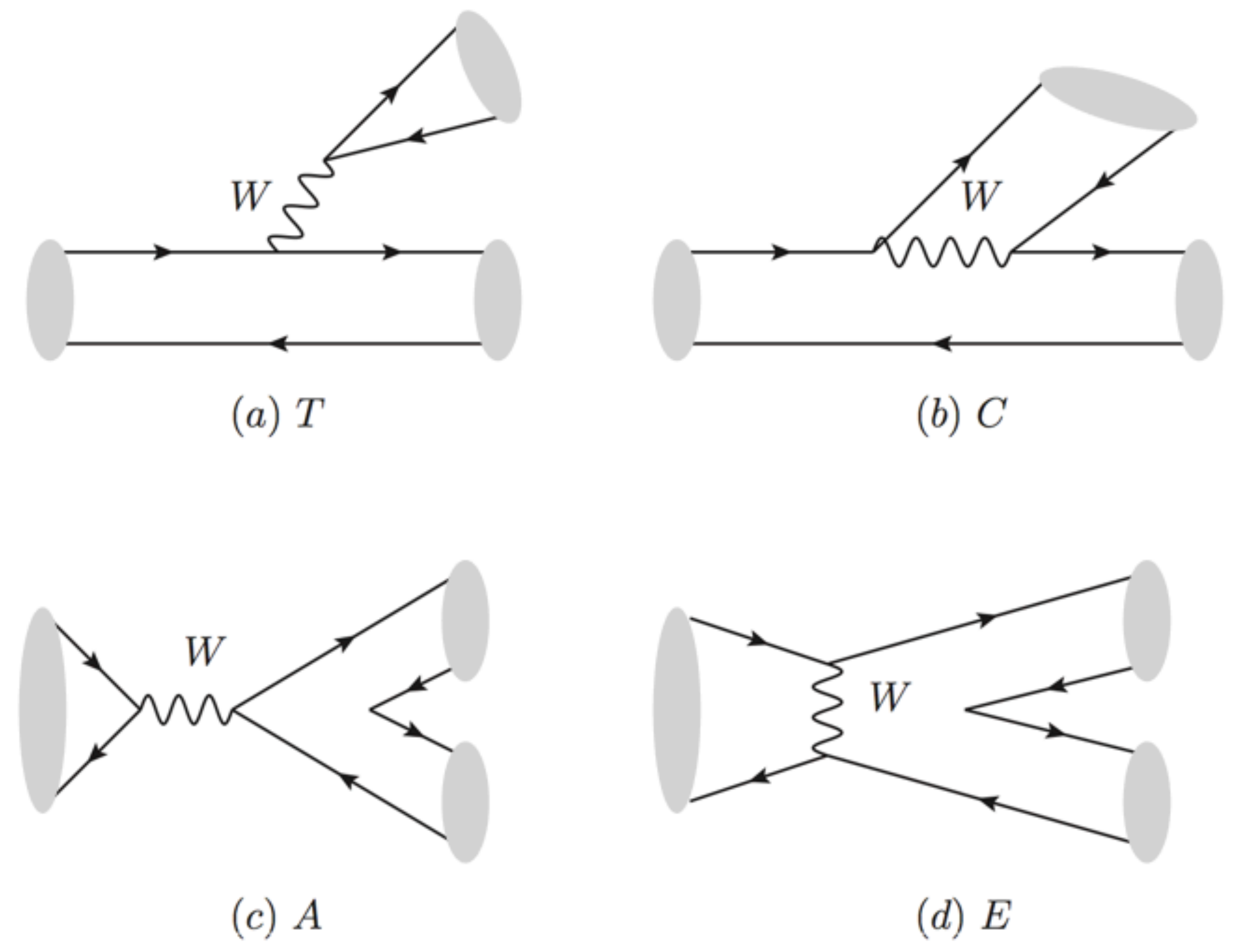

$$T = 3.14 \pm 0.06, \qquad C = (2.61 \pm 0.08)e^{-i(152\pm1)^\circ}, \qquad E = (1.53^{+0.07}_{-0.08})e^{i(122\pm2)^\circ}, \qquad A = (0.39^{+0.13}_{-0.09})e^{i(31^{+20}_{-33})^\circ}$$

$$\left|\frac{C}{T}\right| \sim 0.8 \qquad \gg \qquad \frac{a_2(\mu_c)}{a_1(\mu_c)} \sim 0.1$$

long-distance dominated in charm decays

Cheng, Chiang,'10

Li, Lu, FSY, '12

Flavor SU(3) breaking

- Flavor SU(3) symmetry breaking effects are important in the singly Cabibbo-suppressed modes

Meson	Mode	Representation	$\mathcal{B}_{\rm exp}$ $(\times 10^{-3})$	$\mathcal{B}_{\rm theory}$ $(\times 10^{-3})$
D^0	$\pi^+\pi^-$	$V_{cd}^* V_{ud}(T' + E')$	1.45 ± 0.05	2.24 ± 0.10
	K^+K^-	$V_{cs}^* V_{us}(T' + E')$	4.07 ± 0.10	1.92 ± 0.08
	$K^0\bar{K}^0$	$V_{cd}^* V_{ud} E_s' + V_{cs}^* V_{us} E_d'$ [a]	0.64 ± 0.08	0

→ same in the SU(3) limit

→ vanish in the SU(3) limit

- Li, Lu, FSY, '12: **factorization hypothesis** $\frac{G_F}{\sqrt{2}} V_{\rm CKM} b_{q,s}^{E,A}(\mu) f_D m_D^2 \left(\frac{f_{P_1} f_{P_2}}{f_\pi^2}\right)$
- Cheng, Chiang, '12, '19: **similar to factorization** $E^d = 1.10\, e^{i15.1^\circ} E\,, \qquad E^s = 0.62\, e^{-i19.7^\circ} E$
- Muller, Nierste, Schacht, '15: **linear SU(3) breaking** $H_{\not{SU(3)}_F} = (m_s - m_d)\bar{s}s$

Implications of charm CPV

- LHCb 2019: Observation $\Delta A_{CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-) = (-1.54 \pm 0.29) \times 10^{-3}$

→ $|\mathcal{P}/\mathcal{T}|_{\rm charm} \sim \mathcal{O}(1)$ SM or NP?

✓ **Long-distance contributions**

- LHCb 2022: $A_{CP}(D^0 \to K^+K^-) = (0.77 \pm 0.57) \times 10^{-3}, \quad A_{CP}(D^0 \to \pi^+\pi^-) = (2.31 \pm 0.61) \times 10^{-3}$

→ U-spin anomaly, so NP?

- **Charmed baryon decays** are the next opportunity and challenge of charm physics

CP violation in baryons

- Sakharov conditions for **Baryogenesis:**

  1) **baryon** number violation

  2) C and **CP violation**

  3) out of thermal equilibrium

- **CPV: SM < BAU. => new source of CPV, NP**

- CPV well established in K, B and D mesons,

  but CPV never established in any baryon

- **Comparison between precise prediction and measurement is helpful to test the SM and search for NP**