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CP Violation in Two-Body Hadronic D Meson Decays

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Hai-Yang Cheng and CWC, PRD 100 (2019) 9, 093002

Outline of Our Work

- Introduction
- Flavor diagram approach
- Story of $\Delta A_{CP}(K^+K^- - \pi^+\pi^-)$
- Global fits to CF $D \to PP$, VP BR's
- BR's and A_{CP}'s for SCS modes
- Summary

INTRODUCTION

D Meson Decays

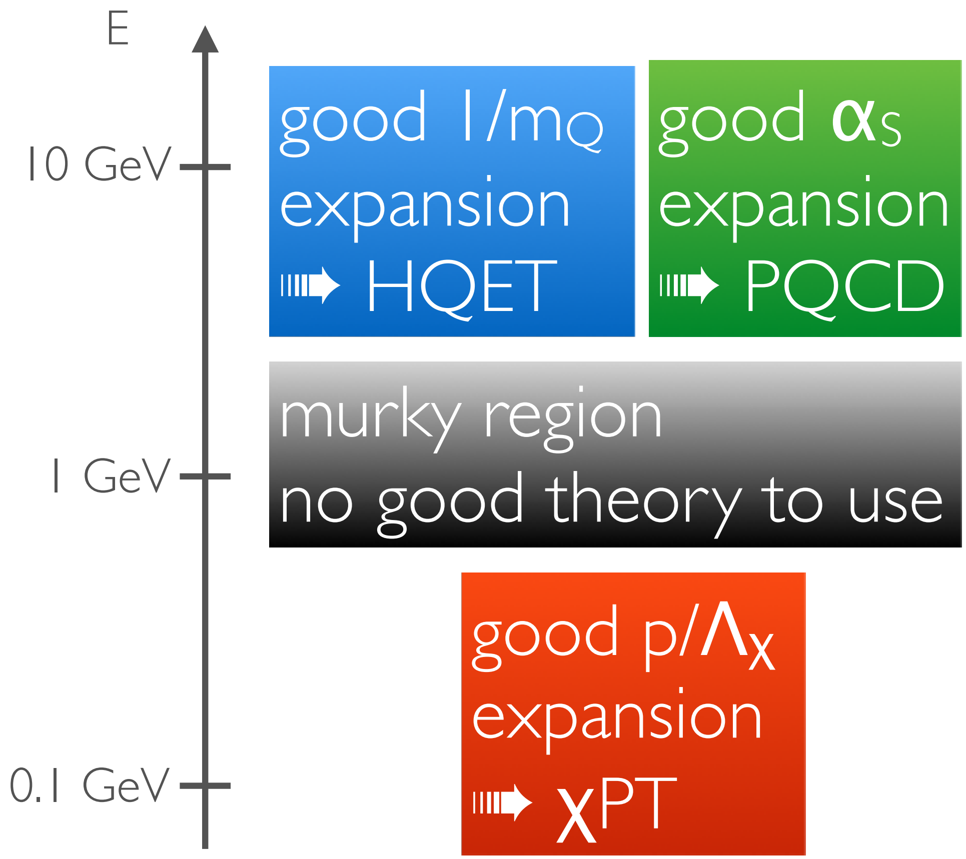
- D mesons decay dominantly (~84%) into hadronic final states, 3/4 of which are two-body modes.
  - ➠ cf. B meson decays

Mode	BR
PP	$\sim 10\%$
VP	$\sim 28\%$
VV	$\sim 10\%$
SP	$\sim 4.2\%$
AP	$\sim 10\%$
TP	$\sim 0.3\%$
2-body	$\sim 63\%$
hadronic	$\sim 84\%$
semileptonic	$\sim 16\%$

– most dominant ones

P: pseudoscalar meson
V: vector meson
A: axial vector meson
T: tensor meson

Peculiarities of Charm Systems



- Many resonances around
  ➠ nonperturbative rescattering effects kicking in
- Flavor SU(3) symmetry for decays to light mesons
- Good realm to test all these approaches

Purposes of This Work

- Improve the analysis of A_{CP}'s in $D \to PP$ decays.
  - Use updated input data.
  - Consider uncertainties in penguin exchange diagrams with final-state rescattering that were not done in 2012.
  - Check whether new physics is still needed.

- Extend our study to A_{CP}'s in $D \to VP$ decays.
  - We focused only on neutral charmed mesons before, for there was no information about W-annihilation amplitudes.
  - Thanks to the BABAR measurement of $D_s^+ \to \pi^+\rho^0$, the amplitudes $A_{V,P}$ could be extracted recently. Cheng, CWC, Kuo 2016
  - Propose other channels to see more CPV.

FLAVOR DIAGRAM APPROACH

Partial Width

- Partial decay widths of D → PP and VP decays are related to their decay amplitudes as follows:

magnitude of 3-momentum
of final-state particle

$$\Gamma(D \to PP) = \frac{p_c}{8\pi m_D^2} |\mathcal{M}|^2$$

P-wave state

$$\Gamma(D \to VP) = \frac{p_c^3}{8\pi m_V^2} |\mathcal{M}|^2 \quad \text{(polarizations summed)}$$

due to polarization sum

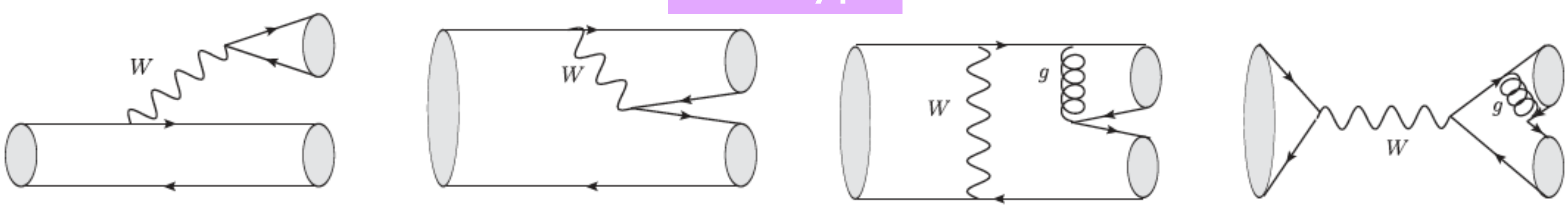
- SU(3) breaking due to phase space difference is removed.
- Approximate flavor SU(3) assumed at the amplitude level (decay strength and strong phase).

Flavor Diagrams

- Diagrams for 2-body hadronic D meson decays can be classified according to flavor topology into the tree- and loop-types:

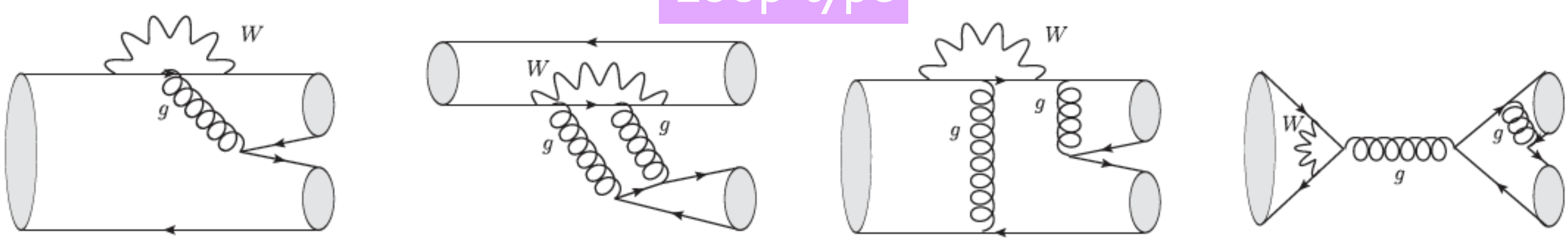
Zeppenfeld 1981
Chau and Cheng 1986, 1987, 1991
Savage and Wise 1989
Grinstein and Lebed 1996
Gronau et. al. 1994, 1995, 1995
Cheng and Oh 2011

Tree-type



(a) T (b) C (e) E (f) A

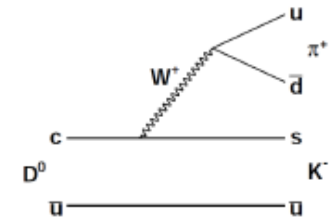
Loop-type



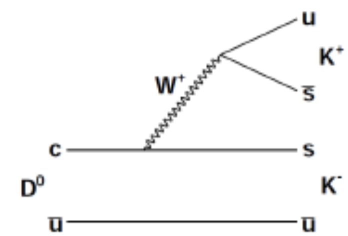
(c) $P,\ P^C_{\mathrm{EW}}$ (d) $S,\ P_{\mathrm{EW}}$ (g) $PE,\ PE_{\mathrm{EW}}$ (h) $PA,\ PA_{\mathrm{EW}}$

Cabibbo Hierarchy

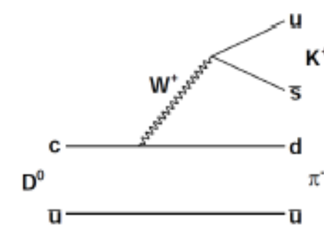
- Cabibbo-favored (CF):
  involving $V_{ud}{}^*V_{cs} \sim 1-\lambda^2 \sim 0.95$



- Singly Cabibbo-suppressed (SCS):
  involving $V_{us}{}^*V_{cs}$ / $V_{ud}{}^*V_{cd} \sim \lambda \sim 0.22$



- Doubly Cabibbo-suppressed (DCS):
  involving $V_{us}{}^*V_{cd} \sim \lambda^2 \sim 0.05$



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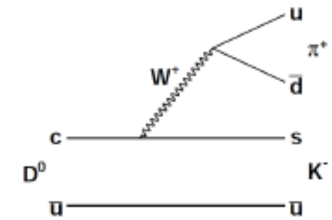

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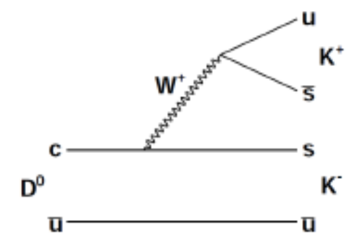

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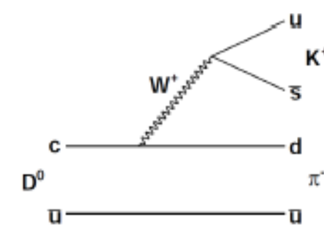


- Only SCS decays involve diagrams with different CKM phases and thus have CPA's: (after using unitarity identity)

$$\begin{aligned}\mathrm{Amp} = {} & V_{cd}^{*}V_{ud}(\mathrm{trees} + \mathrm{penguins}) \\ & + V_{cs}^{*}V_{us}(\mathrm{trees} + \mathrm{penguins})\end{aligned}$$

small phase difference

CP Violation in SCS Decays

- CPA's in SCS decay modes are expected only at O(10^{-3}) or smaller:

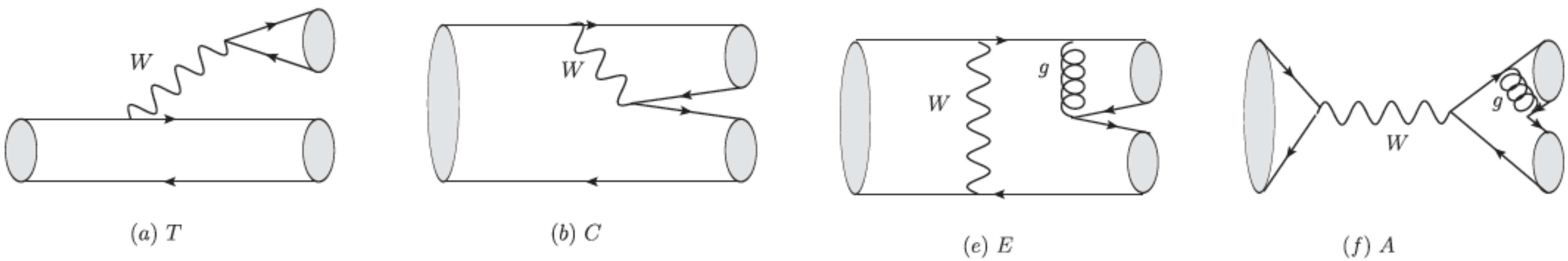
$$a_{CP}^{\rm dir} = \frac{2{\rm Im}(V_{cd}^* V_{ud} V_{cs} V_{us}^*)}{|V_{cd}^* V_{ud}|^2} \left|\frac{A_2}{A_1}\right| \sin\delta = 2 \left|\frac{V_{cb}^* V_{ub}}{V_{cd}^* V_{ud}}\right| \sin\gamma \left|\frac{A_2}{A_1}\right| \sin\delta$$

$$\sim 10^{-3} \left|\frac{A_2}{A_1}\right| \sin\delta \qquad (\delta = \text{relative strong phase})$$

➠ new physics, if measured to be sizable

Flavor Diagrams

- As far as BR's are concerned, penguin diagrams negligible because of GIM $V_{cd}V_{ud}^* = -V_{cs}V_{us}^*$ and $V_{cb}V_{ub}^* \sim A^2\lambda^5$.
  ➠ tree-type diagrams are dominant in determining BR's



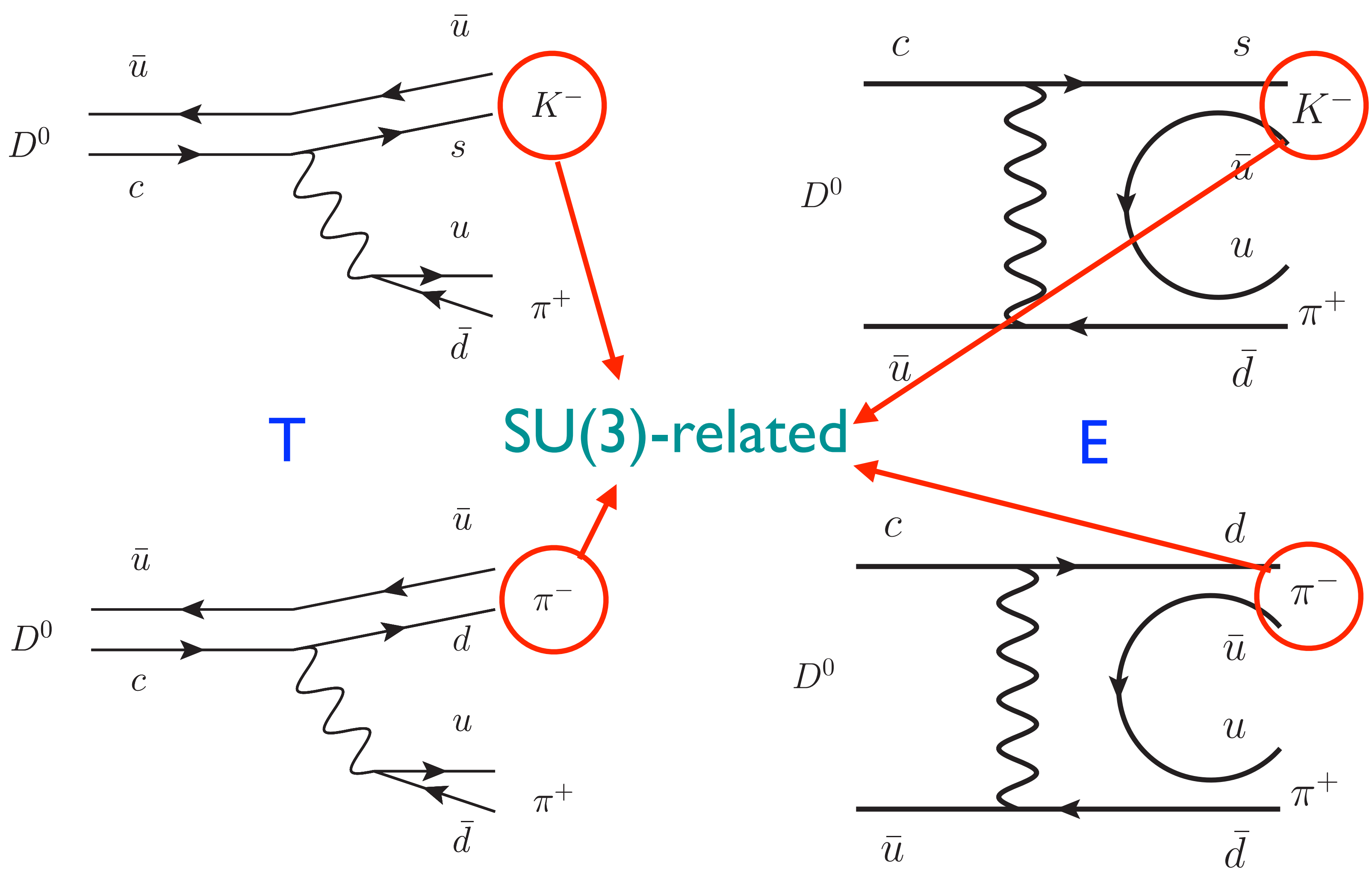
- Because the spectator quark may end up in P or V meson in the final state, these two types of diagrams of the same flavor topology have no relation a priori and should be distinguished.
- For example, $T \to T_P$ or T_V.

Examples

- One CF and one SCS modes:

$$D^0 \to \pi^+ K^-$$

$$D^0 \to \pi^+ \pi^-$$



Our Approach

- We perform a χ^2 fit to (only) the branching fractions of all CF modes, extracting magnitudes and phases of all flavor diagrams.
- There are degeneracies in χ^2-minimum solutions when all the strong phases simultaneously flip signs.
- We make SU(3) symmetry breaking corrections as required by data.
- We incorporate penguin amplitudes, particularly PE enhanced by rescattering, to induce large direct A_{CP}.
- Using the extracted information, we make predictions of BR's and A_{CP}'s for SCS modes.
  ➠ testable by future data

PROBLEMS WITH K^+K^- AND $\pi^+\pi^-$ MODES

Decay Amplitudes

- These two modes are closely related:

$$A_{\pi^+\pi^-} = \frac{1}{2}(\lambda_d - \lambda_s)(T + E + \Delta P)_{\pi\pi} - \frac{1}{2}\lambda_b(T + E + \Sigma P)_{\pi\pi}$$
$$\to \lambda_d(T + E) - \lambda_b \Sigma P \qquad [\text{SU(3) limit}]$$
$$A_{K^+K^-} = \frac{1}{2}(\lambda_s - \lambda_d)(T + E - \Delta P)_{KK} - \frac{1}{2}\lambda_b(T + E + \Sigma P)_{KK}$$
$$\to \lambda_s(T + E) - \lambda_b \Sigma P \qquad [\text{SU(3) limit}]$$

opposite in sign ➠ opposite in CPA

$$\Sigma P = (P + PE + PA)_d + (P + PE + PA)_s$$
$$\Delta P = (P + PE + PA)_d - (P + PE + PA)_s$$
$$\lambda_q = V_{cq}^* V_{uq}$$

quark involved in penguin loop

Large SU(3) Breaking

- For a long time, $D \to \pi^+\pi^-$, K^+K^- modes are known to deviate significantly from naive expectations: with negligible penguin amplitudes (as far as CPA is concerned), the two modes have identical decay strength, but with different phase spaces.
  ➠ expect $BR(\pi^+\pi^-) > BR(K^+K^-)$

- Empirically, however, the ratio of their decay rates

$$\frac{\Gamma(K^+K^-)}{\Gamma(\pi^+\pi^-)} \simeq 2.8$$

  is noticeably larger than 1 in the SU(3) limit.

CP Asymmetry Difference

- Time-integrated asymmetry to first order in the average decay time ⟨t⟩:

$$A_{CP}(f) \equiv \frac{\Gamma(D^0 \to f) - \Gamma(\bar{D}^0 \to \bar{f})}{\Gamma(D^0 \to f) + \Gamma(\bar{D}^0 \to \bar{f})}$$

$$\simeq a_{CP}^{\rm dir}(f) + \frac{\langle t \rangle}{\tau_D} a_{CP}^{\rm ind}$$

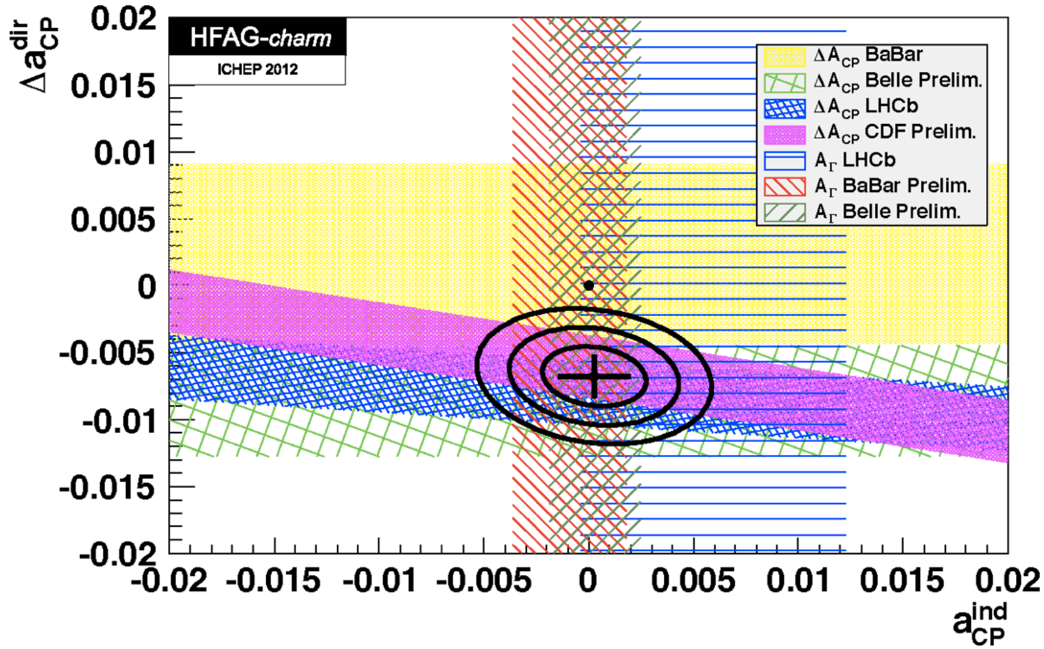
- Consider

$$\Delta A_{CP} \equiv A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$$

$$\simeq a_{CP}^{\rm dir}(K^+K^-) - a_{CP}^{\rm dir}(\pi^+\pi^-) + \frac{\Delta\langle t \rangle}{\tau_D} a_{CP}^{\rm ind}$$

(1) common systematic factors cancel out;
(2) insensitive to indirect CPV;
(3) each with opposite signs in SM and most NP models.

ΔA_{CP} IN 2012



HFAG 2012

- World average:

$$a_{CP}^{\text{ind}} = -(0.027 \pm 0.163)\%,$$

$$\Delta a_{CP}^{\text{dir}} = -(0.678 \pm 0.147)\%.$$ ➠ 4.6σ from no CPV

➠ ~30 theory papers immediately followed (including many new physics attempts)

Large Penguin within SM

- Brod, Grossman, Kagan, Zupan 2012:
  - Assume different and large enhancements in d,s-quark penguins $P_{d,s}$ relative to T.
  - Require U-spin breaking in $(T+E)_{\pi\pi} \neq (T+E)_{KK}$ by about O(30%).
  - Large ΣP explains Δa_{CP}^{dir}, while large ΔP explains the large rate disparity between K^+K^- and $\pi^+\pi^-$.

    ➠ A fit to data shows $|(P_d - P_s)/T| \sim 0.5$!

- Bhattacharya, Gronau, Rosner 2012:
  - Assume a smaller ΔP and $E_{KK} = E_{\pi\pi}$.

    ➠ A fit to data shows $|(P_d - P_s)/T| \sim 0.15$

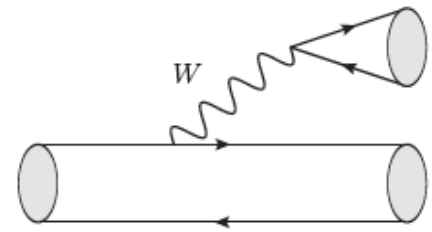
    ➠ requiring $|P_b| \sim |T|$ (attributed to "unforeseen QCD effects")

- Both invoked agnostic large penguin amplitudes.

Our Explanation

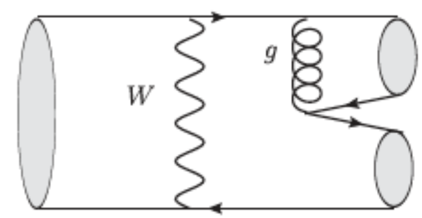
- SU(3) breaking in T:

$$\frac{T(K^+K^-)}{T(\pi^+\pi^-)} \simeq \frac{f_K}{f_\pi}\frac{F_+^{DK}(m_K^2)}{F_+^{D\pi}(m_\pi^2)} \simeq 1.38$$



➠ only partial explanation, insufficient to account for data

- SU(3) breaking in E:



opposite sign between them

$$A(D \to K^0\overline{K^0}) = \lambda_d\,(E_d + 2PA_d) + \lambda_s\,(E_s + 2PA_s)$$

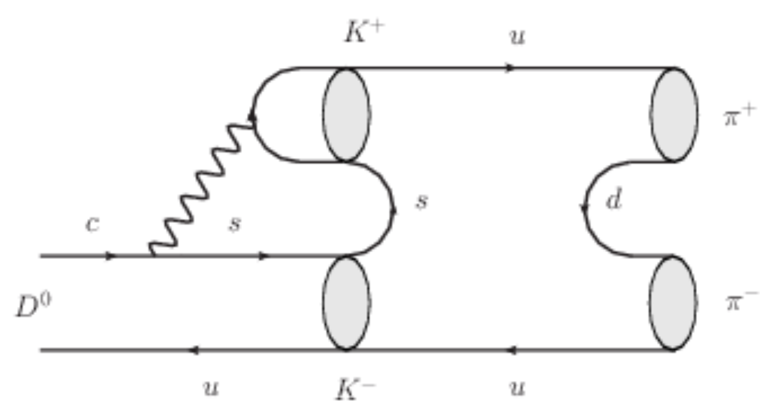
diagrams of $c\underline{u} \to q\underline{q}$ ($q = d, s$)

➠ explaining the observed nonzero rate, otherwise vanishing in SU(3) limit

No attempt to fit Δa_{CP}^{dir} !

Penguin Amplitudes

- Short-distance weak penguin exchange/annihilation diagrams are seen to be small
  ➠ $|PE/T| \sim 0.04 \;\; \text{and} \;\; |PA/T| \sim 0.02$
- Large long-distance contribution to PE can possibly arise from $D^0 \to K^+K^-$ followed by a resonance-like final-state rescattering



Chen et al 2006;
Cheng, Chua and Liu 2003

- It is plausible to have PE ~ E, thereby enlarging CPV.
- Use QCDF to estimate other penguin amplitudes.
  ➠ negligible ΔP

Our A_{CP} Predictions

pQCD results

Decay Mode	$a_{dir}^{(tree)}$(this work)	$a_{dir}^{(tree)}$[22]	$a_{dir}^{(tot)}$(this work)	$a_{dir}^{(tot)}$[22]	Expt.
$D^0 \to \pi^+\pi^-$	0	0	0.96 ± 0.04	0.74	2.0 ± 2.2
$D^0 \to \pi^0\pi^0$	0	0	0.83 ± 0.04	0.26	1 ± 48
$D^0 \to \pi^0\eta$	0.82 ± 0.03	-0.29	0.06 ± 0.04	-0.61	
$D^0 \to \pi^0\eta'$	-0.39 ± 0.02	0.43	0.01 ± 0.02	1.67	
$D^0 \to \eta\eta$	-0.28 ± 0.01	0.29	-0.58 ± 0.02	0.18	
	-0.42 ± 0.02	0.29	-0.74 ± 0.02	0.18	
$D^0 \to \eta\eta'$	0.49 ± 0.02	-0.30	0.53 ± 0.03	0.97	
	0.38 ± 0.02	-0.30	0.33 ± 0.02	0.97	
$D^0 \to K^+K^-$	0	0	-0.42 ± 0.01	-0.54	-2.3 ± 1.7
	0	0	-0.54 ± 0.02	-0.54	
$D^0 \to K^0\overline{K}^0$	-0.73	0.69	-0.67 ± 0.01	0.90	
	-1.73	0.69	-1.90 ± 0.01	0.90	
$D^+ \to \pi^+\pi^0$	0	0	0	0	29 ± 29
[illegible]	[illegible]	.46	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	.30	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	.08	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	.75	[illegible]	[illegible]	[illegible]
$D_s^+ \to K^+\eta'$	0.35 ± 0.04	-0.48	-0.29 ± 0.12	1.83	60 ± 189

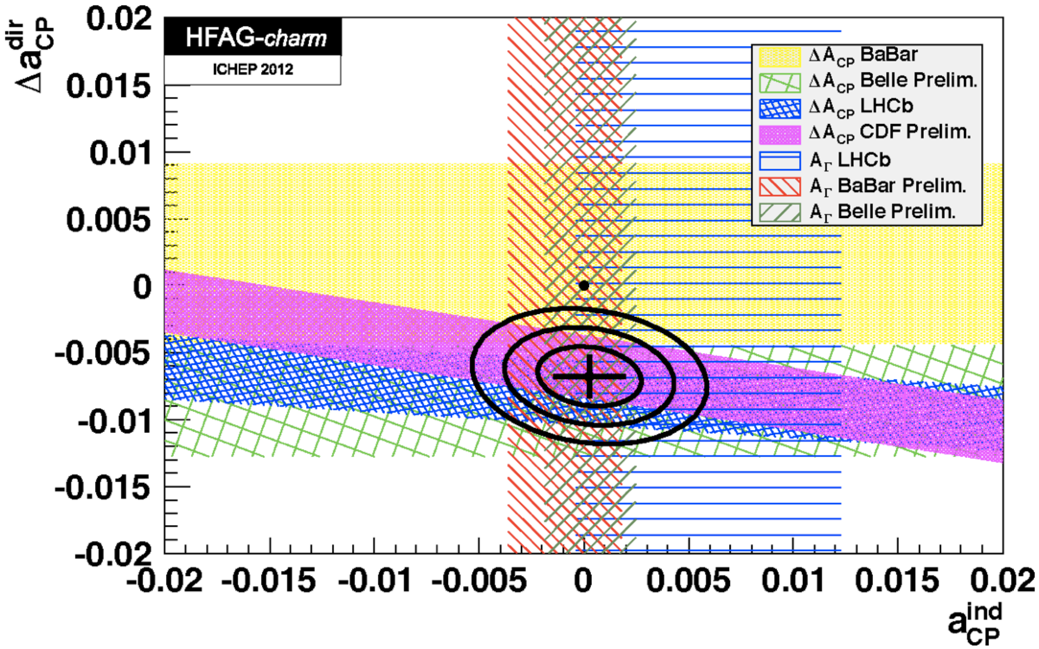
$\Delta a_{CP}^{dir} = -(0.139 \pm 0.004)\%$ (I)
$-(0.151 \pm 0.004)\%$ (II)
~3.6σ from $-(0.678 \pm 0.147)\%$

even if PE~T, $\Delta a_{CP}^{dir} = -0.27\%$,
an upper bound in SM,
still ~2.8σ from data

in units of 10^{-3}

Cheng and CWC 2012

ΔA_{CP} in 2012



HFAG 2012

- World average:

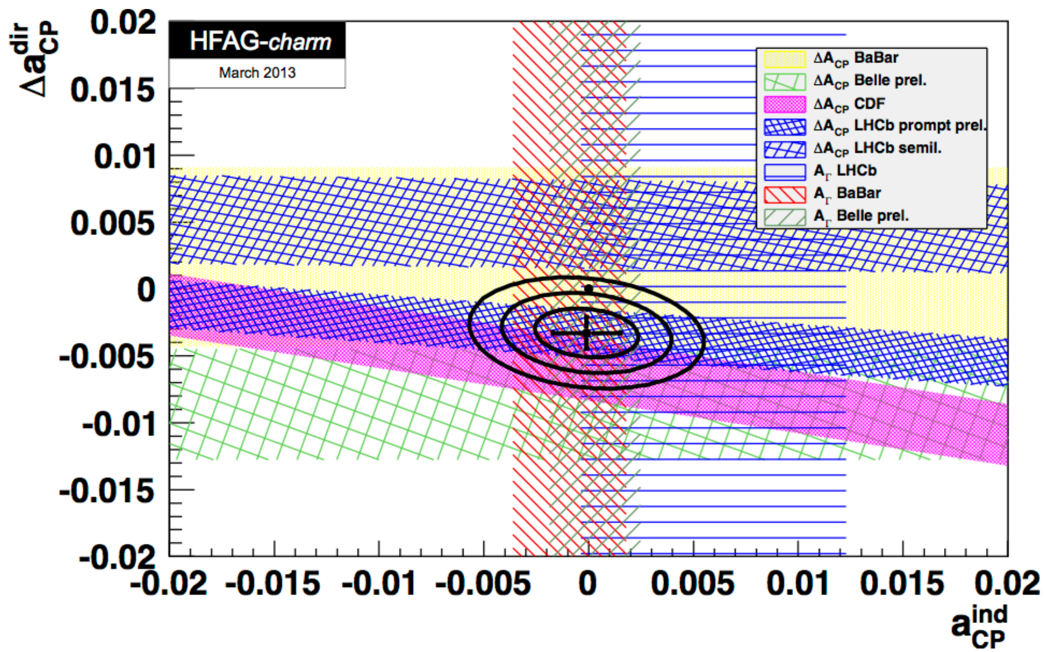
$$a_{CP}^{\text{ind}} = -(0.027 \pm 0.163)\%,$$

$$\Delta a_{CP}^{\text{dir}} = -(0.678 \pm 0.147)\%.$$

➠ 4.6σ from no CPV; 3.6σ from our prediction in 2012

➠ ~30 theory papers followed

ΔA$_{CP}$ IN 2013



HFAG 2013

- World average:

$$a_{CP}^{\rm ind} = -(0.010 \pm 0.162)\%,$$

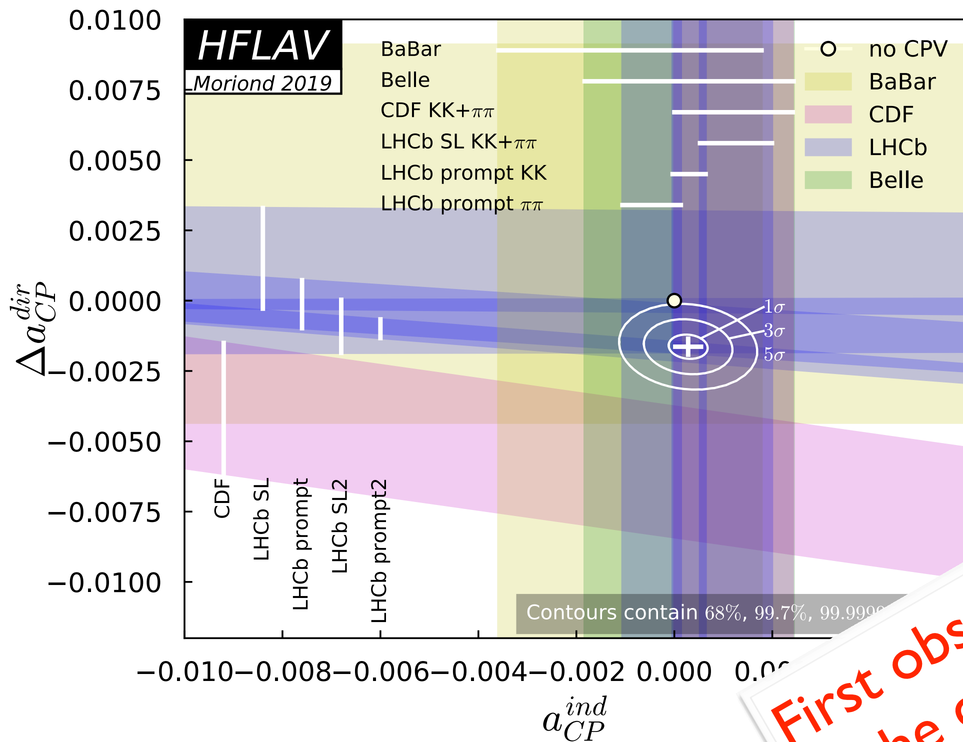
$$\Delta a_{CP}^{\rm dir} = -(0.329 \pm 0.121)\%.$$

➡ 2.7σ from no CPV; 1.5σ from our prediction in 2012

after updated 1.0 /fb of LHCb dataset of 2011

ΔA$_{CP}$ IN 2019

HFAG 2019



First observation of CPV in the charm system!

- World average:

$$a_{CP}^{\text{ind}} = (0.028 \pm 0.026)\%,$$

$$\Delta a_{CP}^{\text{dir}} = -(0.164 \pm 0.028)\%.$$

➡ consistent w/ our prediction in 2012!

after updated 5.9 /fb of LHCb dataset of 2016

PP MODES

Long-Distance Effects

- Global fit to CF PP modes gives:

modulus in units of 10^{-6}

$$T = 3.113 \pm 0.011$$ — assumed to be real

$$C = (2.767 \pm 0.029)e^{-i(151.3\pm0.3)^\circ}$$

$$E = (1.48 \pm 0.04)e^{i(120.9\pm0.4)^\circ}$$

large strong phases

$$A = (0.55 \pm 0.03)e^{i(23+7)^\circ}$$

$$\begin{cases} \mathrm{I}: & E_d = 1.10e^{i15.1^\circ}E, \quad E_s = 0.62e^{-i19.7^\circ}E \\ \mathrm{II}: & E_d = 1.10e^{i15.1^\circ}E, \quad E_s = 1.42e^{-i13.5^\circ}E \end{cases}$$

- All the flavor amplitudes except for T are dominated by nonfactorizable long-distance effects, e.g., from T and C:

$$a_1(\bar{K}\pi) \approx 1.22 \quad \text{and} \quad a_2(\bar{K}\pi) \approx 0.82e^{-i(151)^\circ}$$ — data

$$a_1 \simeq 1.09 \quad \text{and} \quad a_2 \simeq -0.11$$ — naive factorization

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- Short-distance E and A are helicity-suppressed, but receive large $1/m_c$ corrections from FSI's (due to nearby resonances).

Amplitude Decomposition

- CS D→ PP modes:

SU(3)-breaking factors

	Mode	Representation
D^0	$\pi^+\pi^-$	$\lambda_d(0.96T + E_d) + \lambda_p(P_p + PE_p + PA_p)$
	$\pi^0\pi^0$	$\frac{1}{\sqrt{2}}\lambda_d(-0.78C + E_d) + \frac{1}{\sqrt{2}}\lambda_p(P_p + PE_p + PA_p)$
	$\pi^0\eta$	$-\lambda_d(E_d)\cos\phi - \frac{1}{\sqrt{2}}\lambda_s(1.28C)\sin\phi + \lambda_p(P_p + PE_p)\cos\phi$
	$\pi^0\eta'$	$-\lambda_d(E_d)\sin\phi + \frac{1}{\sqrt{2}}\lambda_s(1.28C)\cos\phi + \lambda_p(P_p + PE_p)\sin\phi$
	$\eta\eta$	$\frac{1}{\sqrt{2}}\lambda_d(0.78C + E_d)\cos^2\phi + \lambda_s(-\frac{1}{2}1.08C\sin 2\phi + \sqrt{2}E_s\sin^2\phi) + \frac{1}{\sqrt{2}}\lambda_p(P_p + PE_p + PA_p)\cos^2\phi$
	$\eta\eta'$	$\frac{1}{2}\lambda_d(0.78C + E_d)\sin 2\phi + \lambda_s(\frac{1}{\sqrt{2}}1.08C\cos 2\phi - E_s\sin 2\phi) + \frac{1}{2}\lambda_p(P_p + PE_p + PA_p)\sin 2\phi$
	K^+K^-	$\lambda_s(1.27T + E_s) + \lambda_p(P_p + PE_p + PA_p)$
	$K^0\bar{K}^0$	$\lambda_d(E_d) + \lambda_s(E_s) + 2\lambda_p(PA_p)$
D^+	$\pi^+\pi^0$	$\frac{1}{\sqrt{2}}\lambda_d(0.97T + 0.78C)$
	$\pi^+\eta$	$\frac{1}{\sqrt{2}}\lambda_d(0.82T + 0.93C + 1.19A)\cos\phi - \lambda_s(1.28C)\sin\phi + \sqrt{2}\lambda_p(P_p + PE_p)\cos\phi$
	$\pi^+\eta'$	$\frac{1}{\sqrt{2}}\lambda_d(0.82T + 0.93C + 1.61A)\sin\phi + \lambda_s(1.28C)\cos\phi + \sqrt{2}\lambda_p(P_p + PE_p)\sin\phi$
	$K^+\bar{K}^0$	$\lambda_d(0.85A) + \lambda_s(1.28T) + \lambda_p(P_p + PE_p)$
D_s^+	π^+K^0	$\lambda_d(1.00T) + \lambda_s(0.84A) + \lambda_p(P_p + PE_p)$
	π^0K^+	$\frac{1}{\sqrt{2}}[-\lambda_d(0.81C) + \lambda_s(0.84A) + \lambda_p(P_p + PE_p)]$
	$K^+\eta$	$\frac{1}{\sqrt{2}}\lambda_p[0.92C\delta_{pd} + 1.14A\delta_{ps} + P_p + PE_p]\cos\phi - \lambda_p[(1.31T + 1.27C + 1.14A)\delta_{ps} + P_p + PE_p]\sin\phi$
	$K^+\eta'$	$\frac{1}{\sqrt{2}}\lambda_p[0.92C\delta_{pd} + 1.14A\delta_{ps} + P_p + PE_p]\sin\phi + \lambda_p[(1.31T + 1.27C + 1.14A)\delta_{ps} + P_p + PE_p]\cos\phi$

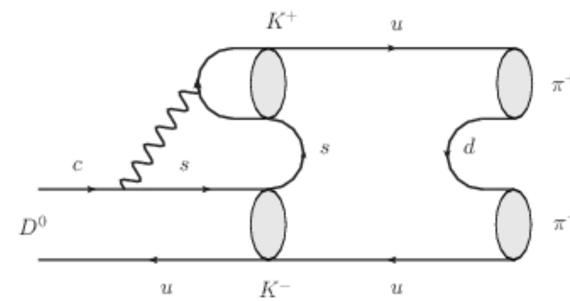
Predictions vs Data

in units of 10^{-3}

Decay Mode	$\mathcal{B}_{\text{SU(3)}}$	$\mathcal{B}_{\text{SU(3)-breaking}}$	$\mathcal{B}_{\text{expt}}$
$D^0 \to \pi^+\pi^-$	2.28 ± 0.02	1.47 ± 0.02	1.455 ± 0.024
$D^0 \to \pi^0\pi^0$	1.50 ± 0.03	0.82 ± 0.02	0.826 ± 0.025
$D^0 \to \pi^0\eta$	0.83 ± 0.02	0.92 ± 0.02	0.63 ± 0.06
$D^0 \to \pi^0\eta'$	0.75 ± 0.02	1.36 ± 0.03	0.92 ± 0.10
$D^0 \to \eta\eta$	1.52 ± 0.03	1.82 ± 0.04	2.11 ± 0.19
	1.52 ± 0.03	2.11 ± 0.04	
$D^0 \to \eta\eta'$	1.28 ± 0.05	0.69 ± 0.03	1.01 ± 0.19
	1.28 ± 0.05	1.63 ± 0.08	
$D^0 \to K^+K^-$	1.91 ± 0.02	4.03 ± 0.03	4.08 ± 0.06
	1.91 ± 0.02	4.05 ± 0.05	
$D^0 \to K_SK_S$	0	0.141 ± 0.007	0.141 ± 0.005
	0	0.141 ± 0.007	
$D^+ \to \pi^+\pi^0$	0.89 ± 0.02	0.93 ± 0.02	1.247 ± 0.033
$D^+ \to \pi^+\eta$	1.90 ± 0.16	4.08 ± 0.16	3.77 ± 0.09
$D^+ \to \pi^+\eta'$	4.21 ± 0.12	4.69 ± 0.08	4.97 ± 0.19
$D^+ \to K^+K_S$	2.29 ± 0.09	4.25 ± 0.10	3.04 ± 0.09
$D_s^+ \to \pi^+K_S$	1.20 ± 0.04	1.27 ± 0.04	1.22 ± 0.06
$D_s^+ \to \pi^0K^+$	0.86 ± 0.04	0.56 ± 0.02	0.63 ± 0.21
$D_s^+ \to K^+\eta$	0.91 ± 0.03	0.86 ± 0.03	1.77 ± 0.35
$D_s^+ \to K^+\eta'$	1.23 ± 0.06	1.49 ± 0.08	1.8 ± 0.6

Large PE Amplitude

- In view of possible large rescattering, as employed to explain the rate disparity between K^+K^- and $\pi^+\pi^-$, we take



$$E \approx (PE)^{\rm LD}_{d,s} = (1.48 \pm 0.30) e^{i(120.9\pm 30.0)^\circ}$$

same flavor topology 20% uncertainty 30° uncertainty

assuming flavor independence.

- We then update our predictions as

$$\Delta a^{\rm dir}_{\rm CP} = \begin{cases} (-1.14 \pm 0.26) \times 10^{-3} & \text{Sol I} \\ (-1.25 \pm 0.25) \times 10^{-3} & \text{Sol II} \end{cases}$$

$$cf. \quad -(0.164 \pm 0.028)\% \quad (\text{World Avg})$$

Predictions vs Data

in units of 10^{-3}

Decay mode	$a_{\rm dir}^{\rm (tree)}$	$a_{\rm dir}^{\rm (t+p)}$	$a_{\rm dir}^{\rm (t+pa)}$	$a_{\rm dir}^{\rm (tot)}$ (this work)	$a_{\rm dir}^{\rm (tot)}$ [53]
$D^0 \to \pi^+\pi^-$	0	0.03 ± 0.01	0.78 ± 0.22	0.80 ± 0.22	$1.17 \pm 0.20/1.18 \pm 0.20$
$D^0 \to \pi^0\pi^0$	0	0.27 ± 0.01	0.55 ± 0.30	0.82 ± 0.30	$0.04 \pm 0.09/0.79 \pm 0.10$
$D^0 \to \pi^0\eta$	0.78 ± 0.01	0.48 ± 0.01	0.24 ± 0.28	-0.05 ± 0.28	
$D^0 \to \pi^0\eta'$	-0.43 ± 0.01	-0.56 ± 0.01	-0.01 ± 0.17	-0.15 ± 0.17	
$D^0 \to \eta\eta$	-0.28 ± 0.01	-0.28 ± 0.01	-0.51 ± 0.07	-0.52 ± 0.07	
	-0.37 ± 0.01	-0.44 ± 0.01	-0.58 ± 0.07	-0.65 ± 0.07	
$D^0 \to \eta\eta'$	0.51 ± 0.00	0.09 ± 0.00	0.72 ± 0.22	0.29 ± 0.21	
	0.46 ± 0.01	0.16 ± 0.00	0.52 ± 0.15	0.22 ± 0.15	
$D^0 \to K^+K^-$	0	0.08 ± 0.00	-0.41 ± 0.14	-0.33 ± 0.14	$-0.47 \pm 0.08/-0.46 \pm 0.08$
	0	-0.01 ± 0.00	-0.43 ± 0.12	-0.44 ± 0.12	
$D^0 \to K_S K_S$	-1.05	-1.05	-1.05	-1.05	$0.43 \pm 0.07/0.38 \pm 0.07$
	-1.99	-1.99	-1.99	-1.99	
$D^+ \to \pi^+\pi^0$	0	0	0	0	
$D^+ \to \pi^+\eta$	0.37 ± 0.02	0.07 ± 0.01	-0.34 ± 0.22	-0.63 ± 0.23	
$D^+ \to \pi^+\eta'$	-0.26 ± 0.02	-0.45 ± 0.03	0.30 ± 0.18	0.11 ± 0.18	
$D^+ \to K^+K_S$	-0.07 ± 0.02	0.10 ± 0.02	-0.46 ± 0.18	-0.30 ± 0.18	$-0.40 \pm 0.07/-0.26 \pm 0.05$
$D_s^+ \to \pi^+K_S$	0.09 ± 0.03	-0.08 ± 0.03	0.61 ± 0.24	0.42 ± 0.24	$-0.40 \pm 0.07/-0.36 \pm 0.07$
$D_s^+ \to \pi^0K^+$	-0.04 ± 0.06	-0.02 ± 0.04	0.89 ± 0.27	0.91 ± 0.27	$0.48 \pm 0.06/-0.03 \pm 0.04$
$D_s^+ \to K^+\eta$	-0.75 ± 0.01	-0.92 ± 0.02	-0.64 ± 0.08	-0.81 ± 0.08	
$D_s^+ \to K^+\eta'$	0.34 ± 0.02	0.63 ± 0.03	-0.22 ± 0.24	0.07 ± 0.25	

Buccella et al 2019

PREDICTIONS VS DATA

in units of 10^{-3}

Decay mode	$a_{\rm dir}^{\rm (tree)}$	$a_{\rm dir}^{\rm (t+p)}$	$a_{\rm dir}^{\rm (t+pa)}$	$a_{\rm dir}^{\rm (tot)}$ (this work)	$a_{\rm dir}^{\rm (tot)}$ [53]
$D^0 \to \pi^+\pi^-$	0	0.03 ± 0.01	0.78 ± 0.22	0.80 ± 0.22	$1.17 \pm 0.20/1.18 \pm 0.20$
$D^0 \to \pi^0\pi^0$					$/0.79 \pm 0.10$
$D^0 \to \pi^0\eta$					
$D^0 \to \pi^0\eta'$					
$D^0 \to \eta\eta$					
$D^0 \to \eta\eta'$					
$D^0 \to K^+K^-$	[illegible]	[illegible]	[illegible]	[illegible]	-0.46 ± 0.08
	0	-0.01 ± 0.00	-0.43 ± 0.12	-0.44 ± 0.12	
$D^0 \to K_S K_S$	-1.05	-1.05	-1.05	-1.05	$0.43 \pm 0.07/0.38 \pm 0.07$
	-1.99	-1.99	-1.99	-1.99	
$D^+ \to \pi^+\pi^0$	0	0	0	0	
	[illegible]	[illegible]	-0.34 ± 0.22	0.63 ± 0.23	
			$0.30 \pm$		
			$-0.46 \pm$		-0.26 ± 0.05
			$0.61 \pm$		-0.36 ± 0.07
			$0.89 \pm$		0.03 ± 0.04
			-0.64 ± 0.08	-0.81 ± 0.08	
$D_s^+ \to K^+\eta$	0.34 ± 0.02	0.65 ± 0.03	-0.22 ± 0.24	0.07 ± 0.25	

Interference between E_d and E_s:

$$a_{\rm dir}^{\rm (tree)} = 1.3 \times 10^{-3} \frac{|E_d E_s|}{|E_d - E_s|^2} \underbrace{\sin\delta_{ds}}_{<0}$$

➠ good observable to test our idea and various models

Other theory predictions:

- 1.11×10^{-3} Li, Lu, Yu 2012
- -1.8×10^{-3} Hiller, Jung, Schacht 2013
- 0.6% Brod et al 2012

opposite sign primarily because of their choice of the other set of strong phases

Predictions vs Data

in units of 10^{-3}

Decay mode	$a_{\rm dir}^{\rm (tree)}$	$a_{\rm dir}^{\rm (t+p)}$	$a_{\rm dir}^{\rm (t+pa)}$	$a_{\rm dir}^{\rm (tot)}$ (this work)	$a_{\rm dir}^{\rm (tot)}$ [53]
$D^0 \to \pi^+\pi^-$	0	0.03 ± 0.01	0.78 ± 0.22	0.80 ± 0.22	$1.17 \pm 0.20/1.18 \pm 0.20$
$D^0 \to \pi^0\pi^0$					$/0.79 \pm 0.10$
$D^0 \to \pi^0\eta$					
$D^0 \to \pi^0\eta'$					
$D^0 \to \eta\eta$					
$D^0 \to \eta\eta'$					
$D^0 \to K^+K^-$					-0.46 ± 0.08
	0	-0.01 ± 0.00	-0.43 ± 0.12	-0.44 ± 0.12	
$D^0 \to K_S K_S$	-1.05	-1.05	-1.05	-1.05	$0.43 \pm 0.07/0.38 \pm 0.07$
	-1.99	-1.99	-1.99	-1.99	
$D^+ \to \pi^+\pi^0$	0	0	0	0	
			$-0.34 \pm$		
			$0.30 \pm$		
			$-0.46 \pm$		
			$0.61 \pm$		
			$0.89 \pm$		
			$-0.64 \pm$		
$D_s^+ \to K^+\eta$			-0.22 ± 0.24		

Interference between E_d and E_s:

$$a_{\rm dir}^{\rm (tree)} = 1.3 \times 10^{-3} \frac{|E_d E_s|}{|E_d - E_s|^2} \underbrace{\sin \delta_{ds}}_{<0}$$

➠ good observable to test our idea and various models

Other theory predictions:

$$\begin{cases} 1.11 \times 10^{-3} & \text{Li, Lu Yu 2012} \\ -1.8 \times 10^{-3} & \text{Hiller, Jung, Schacht 2013} \\ 0.6\% & \text{Brod et al 2012} \end{cases}$$

Current data:

$$\begin{cases} (-2.9 \pm 5.2 \pm 2.2)\% & \text{LHCb 2015} \\ (4.3 \pm 3.4 \pm 1.0)\% & \text{LHCb 2018} \\ (-0.02 \pm 1.53 \pm 0.17)\% & \text{Belle 2017} \end{cases}$$

VP MODES

Extracted Parameters

- A global fit to CF D → VP modes gives 6 best solutions with $\chi^2_{min} < 10$.

modulus in units of 10^{-6}

	(S1)	(S2)	(S3)	(S4)	(S5)	(S6)
$\lvert T_V\rvert$	$2.18^{+0.06}_{-0.07}$	$2.18^{+0.06}_{-0.07}$	2.17 ± 0.06	$2.19^{+0.06}_{-0.07}$	$2.18^{+0.06}_{-0.07}$	2.18 ± 0.06
$\lvert T_P\rvert$	3.41 ± 0.06	3.36 ± 0.06	3.51 ± 0.06	3.48 ± 0.06	3.50 ± 0.06	3.39 ± 0.06
δ_{T_P}	69 ± 3	286 ± 3	40^{+3}_{-4}	307^{+4}_{-3}	79^{+3}_{-4}	12 ± 3
$\lvert C_V\rvert$	1.76 ± 0.04	1.76 ± 0.04	1.74 ± 0.04	1.75 ± 0.04	1.74 ± 0.04	1.76 ± 0.04
δ_{C_V}	278 ± 3	76 ± 3	195^{+4}_{-3}	152^{+3}_{-4}	235^{+4}_{-3}	221 ± 3
$\lvert C_P\rvert$	2.10 ± 0.03	2.07 ± 0.03	2.04 ± 0.03	2.14 ± 0.03	2.07 ± 0.03	2.07 ± 0.03
δ_{C_P}	201 ± 1	201 ± 1	201 ± 1	159 ± 1	159 ± 1	201 ± 1
$\lvert E_V\rvert$	0.27 ± 0.04	0.26 ± 0.04	0.40 ± 0.06	0.33 ± 0.05	0.38 ± 0.05	0.26 ± 0.04
δ_{E_V}	260^{+50}_{-20}	69^{+46}_{-21}	245^{+8}_{-9}	113^{+14}_{-11}	282^{+8}_{-10}	224^{+22}_{-40}
$\lvert E_P\rvert$	$1.66^{+0.05}_{-0.06}$	$1.66^{+0.05}_{-0.06}$	1.66 ± 0.05	$1.66^{+0.05}_{-0.06}$	1.66 ± 0.05	$1.66^{+0.05}_{-0.06}$
δ_{E_P}	108 ± 3	108 ± 3	107 ± 3	251 ± 3	252 ± 3	108 ± 3
$\lvert A_V\rvert$	0.19 ± 0.02	0.20 ± 0.03	0.22 ± 0.03	0.25 ± 0.02	0.26 ± 0.02	0.24 ± 0.03
δ_{A_V}						68 ± 8
$\lvert A_P\rvert$						0.16 ± 0.03
δ_{A_P}						98^{+11}_{-17}
χ^2_{min}						7.956
Fit quality						0.047

- Certain parameters are more stable across solutions.
- Hierarchy $|T_P| > |T_V| \sim |C_{V,P}| > |E_P| > |E_V| \sim |A_{V,P}|$
- The relation $E_V \approx -E_P$ advocated by some analyses is disfavored by the data. Rosner 1999

CF $D \to$ VP Decays

- Amplitude decomposition and our predictions:

in units of %

Meson	Mode	Representation	$\mathcal{B}_{\text{exp}}$	$\mathcal{B}_{\text{theory}}(S3)$	$\mathcal{B}_{\text{theory}}(S6)$
D^0	$K^{*-}\pi^+$	$\lambda_{sd}(T_V + E_P)$	5.34 ± 0.41	5.39 ± 0.40	5.35 ± 0.40
	$K^-\rho^+$	$\lambda_{sd}(T_P + E_V)$	11.3 ± 0.7	11.4 ± 0.6	11.7 ± 0.8
	$\bar{K}^{*0}\pi^0$	$\frac{1}{\sqrt{2}}\lambda_{sd}(C_P - E_P)$	3.74 ± 0.27	3.67 ± 0.21	3.69 ± 0.21
	$\bar{K}^0\rho^0$	$\frac{1}{\sqrt{2}}\lambda_{sd}(C_V - E_V)$	$1.26^{+0.12}_{-0.16}$	1.30 ± 0.12	1.35 ± 0.13
	$\bar{K}^{*0}\eta$	$\lambda_{sd}\left[\frac{1}{\sqrt{2}}(C_P + E_P)c_\phi - E_V s_\phi\right]$	1.02 ± 0.30	0.92 ± 0.08	0.86 ± 0.12
	$\bar{K}^{*0}\eta'$	$-\lambda_{sd}\left[\frac{1}{\sqrt{2}}(C_P + E_P)s_\phi + E_V c_\phi\right]$	<0.10	0.0048 ± 0.0004	0.0052 ± 0.0007
	$\bar{K}^0\omega$	$-\frac{1}{\sqrt{2}}\lambda_{sd}(C_V + E_V)$	2.22 ± 0.12	2.23 ± 0.16	2.17 ± 0.16
	$\bar{K}^0\phi$	$-\lambda_{sd}E_P$	0.830 ± 0.061	0.835 ± 0.054	0.838 ± 0.054
D^+	$\bar{K}^{*0}\pi^+$	$\lambda_{sd}(T_V +$ [illegible]	[illegible]	[illegible]5	1.58 ± 0.15
	$\bar{K}^0\rho^+$	$\lambda_{sd}(T_P +$ [illegible]	[illegible]	[illegible]5	12.3 ± 1.5
D_s^+	$\bar{K}^{*0}K^+$	$\lambda_{sd}(C_P + A_V)$	3.92 ± 0.14	3.94 ± 0.18	3.94 ± 0.18
	$\bar{K}^0K^{*+}$	$\lambda_{sd}(C_V + A_P)$	5.4 ± 1.2	3.39 ± 0.21	3.10 ± 0.21
	$\rho^+\pi^0$	$\frac{1}{\sqrt{2}}\lambda_{sd}(A_P - A_V)$	$\cdots$	0.024 ± 0.014	0.025 ± 0.016
	$\rho^+\eta$	$\lambda_{sd}\left[\frac{1}{\sqrt{2}}(A_P + A_V)c_\phi - T_P s_\phi\right]$	8.9 ± 0.8	9.02 ± 0.37	8.86 ± 0.38
	$\rho^+\eta'$	$\lambda_{sd}\left[\frac{1}{\sqrt{2}}(A_P + A_V)s_\phi + T_P c_\phi\right]$	5.8 ± 1.5	3.25 ± 0.12	2.92 ± 0.11
	$\pi^+\rho^0$	$\frac{1}{\sqrt{2}}\lambda_{sd}(A_V - A_P)$	0.020 ± 0.012	0.023 ± 0.014	0.024 ± 0.016
	$\pi^+\omega$	$\frac{1}{\sqrt{2}}\lambda_{sd}(A_V + A_P)$	0.19 ± 0.03[a]	0.19 ± 0.04	0.19 ± 0.04
	$\pi^+\phi$	$\lambda_{sd}T_V$	4.5 ± 0.4	4.45 ± 0.24	4.49 ± 0.25

number from 3 decades ago by CLEO in 1989 ➠ need an update

CF D→ VP Decays

- Amplitude decomposition and our predictions:

in units of %

Meson	Mode	Representation	$\mathcal{B}_{\text{exp}}$	$\mathcal{B}_{\text{theory}}(S3)$	$\mathcal{B}_{\text{theory}}(S6)$
D^0	$K^{*-}\pi^+$	$\lambda_{sd}(T_V + E_P)$	5.34 ± 0.41	5.39 ± 0.40	5.35 ± 0.40
	$K^-\rho^+$	$\lambda_{sd}(T_P + E_V)$	11.3 ± 0.7	11.4 ± 0.6	11.7 ± 0.8
	$\bar{K}^{*0}\pi^0$	$\frac{1}{\sqrt{2}}\lambda_{sd}(C_P - E_P)$	3.74 ± 0.27	3.67 ± 0.21	3.69 ± 0.21
	$\bar{K}^0\rho^0$	$\frac{1}{\sqrt{2}}\lambda_{sd}(C_V - E_V)$	$1.26^{+0.12}_{-0.16}$	1.30 ± 0.12	1.35 ± 0.13
	$\bar{K}^{*0}\eta$	$\lambda_{sd}\left[\frac{1}{\sqrt{2}}(C_P + E_P)c_\phi - E_V s_\phi\right]$	1.02 ± 0.30	0.92 ± 0.08	0.86 ± 0.12
	$\bar{K}^{*0}\eta'$		<0.10	0.0048 ± 0.0004	0.0052 ± 0.0007
	$\bar{K}^0\omega$				0.16
	$\bar{K}^0\phi$				0.054
D^+	$\bar{K}^{*0}\pi^+$				0.15
	$\bar{K}^0\rho^+$				1.5
D_s^+	$\bar{K}^{*0}K^+$				0.18
	$\bar{K}^0K^{*+}$				0.21
	$\rho^+\pi^0$				0.016
	$\rho^+\eta$	$\lambda_{sd}\left[\frac{1}{\sqrt{2}}(A_P + A_V)c_\phi - T_P s_\phi\right]$	8.9 ± 0.8	9.02 ± 0.37	8.86 ± 0.38
	$\rho^+\eta'$	$\lambda_{sd}\left[\frac{1}{\sqrt{2}}(A_P + A_V)s_\phi + T_P c_\phi\right]$	5.8 ± 1.5	3.25 ± 0.12	2.92 ± 0.11
	$\pi^+\rho^0$	$\frac{1}{\sqrt{2}}\lambda_{sd}(A_V - A_P)$	0.020 ± 0.012	0.023 ± 0.014	0.024 ± 0.016
	$\pi^+\omega$	$\frac{1}{\sqrt{2}}\lambda_{sd}(A_V + A_P)$	0.19 ± 0.03[a]	0.19 ± 0.04	0.19 ± 0.04
	$\pi^+\phi$	$\lambda_{sd}T_V$	4.5 ± 0.4	4.45 ± 0.24	4.49 ± 0.25

The amplitude sum rule

$$\mathcal{M}\left(\pi^+\omega\right) = \cos\phi\,\mathcal{M}\left(\rho^+\eta\right) + \sin\phi\,\mathcal{M}\left(\rho^+\eta'\right)$$

implies the bound

$$1.6\% < \mathcal{B}\left(D_s^+ \to \rho^+\eta'\right) < 3.9\% \quad (1\sigma)$$

CF D→ VP Decays

- Amplitude decomposition and our predictions:

in units of %

Meson	Mode	Representation	$\mathcal{B}_{\rm exp}$	$\mathcal{B}_{\rm theory}(S3)$	$\mathcal{B}_{\rm theory}(S6)$
D^0	$K^{*-}\pi^+$	$\lambda_{sd}(T_V+E_P)$	5.34 ± 0.41	5.39 ± 0.40	5.35 ± 0.40
	$K^-\rho^+$	$\lambda_{sd}(T_P+E_V)$	11.3 ± 0.7	11.4 ± 0.6	11.7 ± 0.8
	$\bar{K}^{*0}\pi^0$	$\frac{1}{\sqrt{2}}\lambda_{sd}(C_P-E_P)$	3.74 ± 0.27	3.67 ± 0.21	3.69 ± 0.21
	$\bar{K}^0\rho^0$	$\frac{1}{\sqrt{2}}\lambda_{sd}(C_V-E_V)$	$1.26^{+0.12}_{-0.16}$	1.30 ± 0.12	1.35 ± 0.13
	$\bar{K}^{*0}\eta$	$\lambda_{sd}\left[\frac{1}{\sqrt{2}}(C_P+E_P)c_\phi-E_Vs_\phi\right]$	1.02 ± 0.30	0.92 ± 0.08	0.86 ± 0.12
	$\bar{K}^{*0}\eta'$	$-\lambda_{sd}\left[\frac{1}{\sqrt{2}}(C_P+E_P)s_\phi+E_Vc_\phi\right]$	<0.10	0.0048 ± 0.0004	0.0052 ± 0.0007
	$\bar{K}^0\omega$	$-\frac{1}{\sqrt{2}}\lambda_{sd}(C_V+E_V)$	2.22 ± 0.12	2.23 ± 0.16	2.17 ± 0.16
	$\bar{K}^0\phi$	$-\lambda_{sd}E_P$	0.830 ± 0.061	0.835 ± 0.054	0.838 ± 0.054
D^+	$\bar{K}^{*0}\pi^+$	$\lambda_{sd}(T_V+C_P)$	1.57 ± 0.13	1.59 ± 0.15	1.58 ± 0.15
	$\bar{K}^0\rho^+$	$\lambda_{sd}(T_P+C_V)$	$12.3^{+1.2}_{-0.7}$	12.5 ± 1.5	12.3 ± 1.5
D_s^+	$\bar{K}$				
	$\bar{K}$				
	ρ^+				
	ρ^+				
	$\rho^+\eta'$	$\lambda_{sd}\left[\frac{1}{\sqrt{2}}(A_P+A_V)s_\phi+T_Pc_\phi\right]$	5.8 ± 1.5	3.25 ± 0.12	2.92 ± 0.11
	$\pi^+\rho^0$	$\frac{1}{\sqrt{2}}\lambda_{sd}(A_V-A_P)$	0.020 ± 0.012	0.023 ± 0.014	0.024 ± 0.016
	$\pi^+\omega$	$\frac{1}{\sqrt{2}}\lambda_{sd}(A_V+A_P)$	0.19 ± 0.03[a]	0.19 ± 0.04	0.19 ± 0.04
	$\pi^+\phi$	$\lambda_{sd}T_V$	4.5 ± 0.4	4.45 ± 0.24	4.49 ± 0.25

These two modes imply that $A_{V,P}$ should be roughly in phase to have destruction/constructive interferences, respectively.

SCS D→ VP Decays (I)

- SCS D→ VP modes:

in units of 10^{-3}

	Mode	Representation	$\mathcal{B}_{\text{exp}}$	$\mathcal{B}_{\text{theo}}(S3)$	$\mathcal{B}_{\text{theo}}(S6)$
D^0	$\pi^+\rho^-$	$\lambda_d(T_V+E_P)+\lambda_p(P_V^p+PA_P+PE_P)$	5.15 ± 0.25	4.72 ± 0.35	4.68 ± 0.35
	$\pi^-\rho^+$	$\lambda_d(T_P+E_V)+\lambda_p(P_P^p+PA_V+PE_V)$	10.1 ± 0.4	8.81 ± 0.46	9.14 ± 0.60
	$\pi^0\rho^0$	$\frac{1}{2}\lambda_d(-C_P-C_V+E_P+E_V)$ $+\lambda_p(P_P^p+P_V^p+PA_P+PA_V+PE_P+PE_V)$	3.86 ± 0.23	3.18 ± 0.19	3.92 ± 0.20
	K^+K^{*-}	$\lambda_s(T_V+E_P)+\lambda_p(P_V^p+PE_P+PA_P)$	1.65 ± 0.11	1.81 ± 0.14	1.79 ± 0.13
	K^-K^{*+}	$\lambda_s(T_P+E_V)+\lambda_p(P_P^p+PE_V+PA_V)$	4.56 ± 0.21	3.35 ± 0.17	3.44 ± 0.23
	$K^0\bar{K}^{*0}$	$\lambda_dE_V+\lambda_sE_P+\lambda_p(PA_P+PA_V)$	0.246 ± 0.048	1.27 ± 0.10	1.04 ± 0.14
	$\bar{K}^0K^{*0}$	$\lambda_dE_P+\lambda_sE_V+\lambda_p(PA_P+PA_V)$	0.336 ± 0.063	1.27 ± 0.10	1.04 ± 0.14
	$\pi^0\omega$	$\frac{1}{2}\lambda_d(-C_V+C_P-E_P-E_V)+\lambda_p(P_P^p+P_V^p+PE_P+PE_V)$	0.117 ± 0.035	0.53 ± 0.09	0.22 ± 0.06
	$\pi^0\phi$	$\frac{1}{\sqrt{2}}\lambda_sC_P$	1.20 ± 0.04[a]	0.64 ± 0.02	0.65 ± 0.02
	$\eta\omega$	$\frac{1}{2}[\lambda_d(C_V+C_P+E_V+E_P)\cos\phi-\lambda_sC_V\sin\phi$ $+\lambda_p(P_P^p+P_V^p+PE_P+PE_V+PA_P+PA_V)\cos\phi]$	1.98 ± 0.18	2.96 ± 0.13	2.56 ± 0.14

- No SU(3) breaking factors for T and C amplitudes required. For example,

$$\frac{|T_V+E_P|_{\pi^+\rho^-}}{|T_V+E_P|_{K'K^+}}\simeq 1.08,\qquad \frac{|T_P+E_V|_{\pi^-\rho^+}}{|T_V+E_P|_{K^-K^-}}\simeq 0.91$$

- Only (S3) and (S6) have better predictions for SCS modes in general.

SCS D→ VP Decays (I)

- SCS D→ VP modes:

in units of 10^{-3}

	Mode	Representation	$\mathcal{B}_{\text{exp}}$	$\mathcal{B}_{\text{theo}}$(S3)	$\mathcal{B}_{\text{theo}}$(S6)
D^0	$\pi^+\rho^-$	$\lambda_d(T_V + E_P) + \lambda_p(P_V^p + PA_P + PE_P)$	5.15 ± 0.25	4.72 ± 0.35	4.68 ± 0.35
	$\pi^-\rho^+$	$\lambda_d(T_P + E_V) + \lambda_p(P_P^p + PA_V + PE_V)$	10.1 ± 0.4	8.81 ± 0.46	9.14 ± 0.60
	$\pi^0\rho^0$	$\frac{1}{2}\lambda_d(-C_P - C_V + E_P + E_V)$	3.86 ± 0.23	3.18 ± 0.19	3.92 ± 0.20
		$+\lambda_p(P_P^p + P_V^p + PA_P + PA_V + PE_P + PE_V)$			
	K^+K^{*-}	$\lambda_s(T_V + E_P) + \lambda_p(P_V^p + PE_P + PA_P)$	1.65 ± 0.11	1.81 ± 0.14	1.79 ± 0.13
	K^-K^{*+}	$\lambda_s(T_P + E_V) + \lambda_p(P_P^p + PE_V + PA_V)$	4.56 ± 0.21	3.35 ± 0.17	3.44 ± 0.23
	$K^0\bar{K}^{*0}$	$\lambda_d E_V + \lambda_s E_P + \lambda_p(PA_P + PA_V)$	0.246 ± 0.048	1.27 ± 0.10	1.04 ± 0.14
	$\bar{K}^0 K^{*0}$	$\lambda_d E_P + \lambda_s E_V + \lambda_p(PA_P + PA_V)$	0.336 ± 0.063	1.27 ± 0.10	1.04 ± 0.14
	$\pi^0\omega$	$\frac{1}{2}\lambda_d(-C_V + C_P - E_P - E_V) + \lambda_p(P_P^p + P_V^p + PE_P + PE_V)$	0.117 ± 0.035	0.53 ± 0.09	0.22 ± 0.06
	$\pi^0\phi$	$\frac{1}{\sqrt{2}}\lambda_s C_P$	1.20 ± 0.04[a]	0.64 ± 0.02	0.65 ± 0.02
	$\eta\omega$	$\frac{1}{2}[\lambda_d(C_V + C_P + E_V + E_P)\cos\phi - \lambda_s C_V \sin\phi$	1.98 ± 0.18	2.96 ± 0.13	2.56 ± 0.14
		$+\lambda_p(P_P^p + P_V^p + PE_P + PE_V + PA_P + PA_V)\cos\phi]$			
	$\eta'\omega$	$\frac{1}{2}[\lambda_d(C_V + C_P + E_V + E_P)\sin\phi + \lambda_s C_V \cos\phi$	$\cdots$	0.03 ± 0.00	0.05 ± 0.01
	$\eta\rho^0$	$\frac{1}{2}[\lambda_d(C_V - C_P - E_V - E_P)\sin\phi + \lambda_s\sqrt{2}C_V\cos\phi$	$\cdots$	0.11 ± 0.01	0.10 ± 0.01
		$+\lambda_p(P_P^p + P_V^p + PE_P + PE_V)\sin\phi]$			

The small BR($\pi^0\omega$), the sizable BR($\eta\omega$) and the large BR($\pi^0\rho^0$) imply that the strong phases of C_V and C_P should be close to each other.
➡ (S3) and (S6) favored

SCS D→ VP Decays (I)

- SCS D→ VP modes:

in units of 10^{-3}

	Mode	Representation	$\mathcal{B}_{\rm exp}$	$\mathcal{B}_{\rm theo}$(S3)	$\mathcal{B}_{\rm theo}$(S6)
D^0	$\pi^+\rho^-$	$\lambda_d(T_V+E_P)+\lambda_p(P_V^p+PA_P+PE_P)$	5.15 ± 0.25	4.72 ± 0.35	4.68 ± 0.35
	$\pi^-\rho^+$	$\lambda_d(T_P+E_V)+\lambda_p(P_P^p+PA_V+PE_V)$	10.1 ± 0.4	8.81 ± 0.46	9.14 ± 0.60
	$\pi^0\rho^0$	$\frac{1}{2}\lambda_d(-C_P-C_V+E_P+E_V)$ $+\lambda_p(P_P^p+P_V^p+PA_P+PA_V+PE_P+PE_V)$	3.86 ± 0.23	3.18 ± 0.19	3.92 ± 0.20
	K^+K^{*-}	$\lambda_s(T_V+E_P)+\lambda_p(P_V^p+PE_P+PA_P)$	1.65 ± 0.11	1.81 ± 0.14	1.79 ± 0.13
	K^-K^{*+}	$\lambda_s(T_P+E_V)+\lambda_p(P_P^p+PE_V+PA_V)$	4.56 ± 0.21	3.35 ± 0.17	3.44 ± 0.23
	$K^0\bar{K}^{*0}$	$\lambda_dE_V+\lambda_sE_P+\lambda_p(PA_P+PA_V)$	0.246 ± 0.048	1.27 ± 0.10	1.04 ± 0.14
	$\bar{K}^0K^{*0}$	$\lambda_dE_P+\lambda_sE_V+\lambda_p(PA_P+PA_V)$	0.336 ± 0.063	1.27 ± 0.10	1.04 ± 0.14
	$\pi^0\omega$	$\frac{1}{2}\lambda_d(-C_V+C_P-E_P-E_V)+\lambda_p(P_P^p+P_V^p+PE_P+PE_V)$	0.117 ± 0.035	0.53 ± 0.09	0.22 ± 0.06
	$\pi^0\phi$	$\frac{1}{\sqrt{2}}\lambda_sC_P$	1.20 ± 0.04[a]	0.64 ± 0.02	0.65 ± 0.02
	$\eta\omega$	$\frac{1}{2}[\lambda_d(C_V+C_P+E_V+E_P)\cos\phi-$ [illegible] $+\lambda_p(P_P^p+P_V^p+PE_P+PE_V+$ [illegible]	[illegible]	[illegible]	[illegible]4
	$\eta'\omega$	$\frac{1}{2}[\lambda_d(C_V+C_P+E_V+E_P)\sin\phi+$ [illegible] $+\lambda_p(P_P^p+P_V^p+PE_P+PE_V+PA_P+PA_V)\sin\phi]$	[illegible]	[illegible]	[illegible]1
	$\eta\phi$	$\lambda_s[\frac{1}{\sqrt{2}}C_P\cos\phi-(E_V+E_P)\sin\phi]+\lambda_p(PA_P+PA_V)\sin\phi$	0.167 ± 0.034[a]	0.24 ± 0.02	0.29 ± 0.03
	$\eta\rho^0$	$\frac{1}{2}[\lambda_d(C_V-C_P-E_V-E_P)\cos\phi-\lambda_s\sqrt{2}C_V\sin\phi$ $+\lambda_p(P_P^p+P_V^p+PE_P+PE_V)\cos\phi]$	$\cdots$	0.31 ± 0.05	0.84 ± 0.10
	$\eta'\rho^0$	$\frac{1}{2}[\lambda_d(C_V-C_P-E_V-E_P)\sin\phi+\lambda_s\sqrt{2}C_V\cos\phi$ $+\lambda_p(P_P^p+P_V^p+PE_P+PE_V)\sin\phi]$	$\cdots$	0.11 ± 0.01	0.10 ± 0.01

employ SU(3) breaking in d,s-type $E_{V,P}$ as in the PP sector

SCS D→ VP Decays (II)

in units of 10^{-3}

	Mode	Representation	$\mathcal{B}_{\text{exp}}$	$\mathcal{B}_{\text{theo}}$(S3)	$\mathcal{B}_{\text{theo}}$(S6)
D^+	$\pi^+\rho^0$	$\frac{1}{\sqrt{2}}[\lambda_d(T_V + C_P - A_P + A_V) + \lambda_p(P_V^p - P_P^p + PE_P - PE_V)]$	0.83 ± 0.15	0.70 ± 0.10	0.61 ± 0.10
	$\pi^0\rho^+$	$\frac{1}{\sqrt{2}}[\lambda_d(T_P + C_V + A_P - A_V) + \lambda_p(P_P^p - P_V^p + PE_V - PE_P)]$	$\cdots$	4.43 ± 0.61	4.53 ± 0.64
	$\pi^+\omega$	$\frac{1}{\sqrt{2}}[\lambda_d(T_V + C_P + A_P + A_V) + \lambda_p(P_P^p + P_V^p + PE_P + PE_V)]$	0.28 ± 0.06	0.22 ± 0.06	0.26 ± 0.07
	$\pi^+\phi$	$\lambda_s C_P$	5.68 ± 0.11[a]	3.27 ± 0.11	3.35 ± 0.11
	[illegible]	[illegible]	$\cdots$	1.53 ± 0.49	1.02 ± 0.34
	[illegible]	[illegible]	$\cdots$	1.16 ± 0.11	1.03 ± 0.11
	[illegible]	[illegible]	$3.83^{+0.14}_{-0.21}$	3.87 ± 0.23	3.82 ± 0.25
	[illegible]	[illegible]	34 ± 16	10.20 ± 0.40	9.80 ± 0.41
[illegible]	[illegible]	[illegible]	2.13 ± 0.36	3.69 ± 0.23	3.65 ± 0.24
	$\pi^0 K^{*+}$	$\frac{1}{\sqrt{2}}[\lambda_d C_V - \lambda_s A_V - \lambda_p(P_V^p + PE_P)]$	$\cdots$	1.12 ± 0.07	1.02 ± 0.07
	$K^+\rho^0$	$\frac{1}{\sqrt{2}}[\lambda_d C_P - \lambda_s A_P - \lambda_p(P_P^p + PE_V)]$	2.5 ± 0.4	2.10 ± 0.10	2.10 ± 0.10
	$K^0\rho^+$	$\lambda_d T_P + \lambda_s A_P + \lambda_p(P_P^p + PE_V)$	$\cdots$	11.80 ± 0.47	11.47 ± 0.48
	ηK^{*+}	$\frac{1}{\sqrt{2}}\{[\lambda_d C_V + \lambda_s A_V + \lambda_p(P_V^p + PE_P)]\cos\phi$ $-[\lambda_s(T_P + C_V + A_P) + \lambda_p(P_P^p + PE_V)]\sin\phi\}$	$\cdots$	0.60 ± 0.21	0.64 ± 0.20
	$\eta' K^{*+}$	$\frac{1}{\sqrt{2}}\{[\lambda_d C_V + \lambda_s A_V + \lambda_p(P_V^p + PE_P)]\sin\phi$ $-[\lambda_s(T_P + C_V + A_P) + \lambda_p(P_P^p + PE_V)]\cos\phi\}$	$\cdots$	0.38 ± 0.02	0.33 ± 0.02
	$K^+\omega$	$\frac{1}{\sqrt{2}}[\lambda_d C_P + \lambda_s A_P + \lambda_p(P_P^p + PE_V)]$	0.87 ± 0.25[b]	2.02 ± 0.09	2.12 ± 0.10
	$K^+\phi$	$\lambda_s(T_V + C_P + A_V) + \lambda_p(P_V^p + PE_P)$	0.182 ± 0.041	0.13 ± 0.02	0.12 ± 0.02

T_V and C_P give destructive interference according to the fit.

➡ rates thus sensitive to phases of $A_{V,P}$

➡ (S3) and (S6) favored

SCS D→ VP Decays (II)

in units of 10^{-3}

Mode	Representation	$\mathcal{B}_{\rm exp}$	$\mathcal{B}_{\rm theo}$(S3)	$\mathcal{B}_{\rm theo}$(S6)
D^+ $\pi^+\rho^0$	$\frac{1}{\sqrt{2}}[\lambda_d(T_V+C_P-A_P+A_V)+\lambda_p(P_V^p-P_P^p+PE_P-PE_V)]$	0.83 ± 0.15	0.70 ± 0.10	0.61 ± 0.10
$\pi^0\rho^+$	$\frac{1}{\sqrt{2}}[\lambda_d(T_P+C_V+A_P-A_V)+\lambda_p(P_P^p-P_V^p+PE_V-PE_P)]$	$\cdots$	4.43 ± 0.61	4.53 ± 0.64
$\pi^+\omega$	$\frac{1}{\sqrt{2}}[\lambda_d(T_V+C_P+A_P+A_V)+\lambda_p(P_P^p+P_V^p+PE_P+PE_V)]$	0.28 ± 0.06	0.22 ± 0.06	0.26 ± 0.07
$\pi^+\phi$	$\lambda_s C_P$	5.68 ± 0.11[a]	3.27 ± 0.11	3.35 ± 0.11
$\eta\rho^+$	$\frac{1}{\sqrt{2}}[\lambda_d(T_P+C_V+A_V+A_P)\cos\phi-\lambda_s\sqrt{2}C_V\sin\phi$ $+\lambda_p(P_P^p+P_V^p+PE_P+PE_V)\cos\phi]$	$\cdots$	1.53 ± 0.49	1.02 ± 0.34
$\eta'\rho^+$	$\frac{1}{\sqrt{2}}[\lambda_d(T_P+C_V+A_V+A_P)\sin\phi+\lambda_s\sqrt{2}C_V\cos\phi$ $+\lambda_p(P_P^p+P_V^p+PE_P+PE_V)\sin\phi]$	$\cdots$	1.16 ± 0.11	1.03 ± 0.11
$K^+\bar{K}^{*0}$	$\lambda_d A_V+\lambda_s T_V+\lambda_p(P_V^p+PE_P)$	$3.83^{+0.14}_{-0.21}$	3.87 ± 0.23	3.82 ± 0.25
$\bar{K}^0K^{*+}$	$\lambda_d A_P+\lambda_s T_P+\lambda_p(P_P^p+PE_V)$	34 ± 16	10.20 ± 0.40	9.80 ± 0.41
D_s^+ π^+K^{*0}	$\lambda_d T_V+\lambda_s A_V+\lambda_p(P_V^p+PE_P)$	2.13 ± 0.36	3.69 ± 0.23	3.65 ± 0.24
π^0K^{*+}	$\frac{1}{\sqrt{2}}[\lambda_d C_V-\lambda_s A_V-\lambda_p(P_V^p+PE_P)]$	$\cdots$	1.12 ± 0.07	1.02 ± 0.07
$K^+\rho^0$	$\frac{1}{\sqrt{2}}[\lambda_d C_P-\lambda_s A_P-\lambda_p(P_P^p+PE_V)]$	2.5 ± 0.4	2.10 ± 0.10	2.10 ± 0.10
$K^0\rho^+$	$\lambda_d T_P+\lambda_s A_P+\lambda_p(P_P^p+PE_V)$	$\cdots$	11.80 ± 0.47	11.47 ± 0.48
ηK^{*+}	$\frac{1}{\sqrt{2}}\{[\lambda_d C_V+\lambda_s A_V+\lambda_p(P_V^p+PE_P)]$ c… $-[\lambda_s(T_P+C_V+A_P)+\lambda_p(P_P^p+$ P…			…$.20$
$\eta' K^{*+}$	$\frac{1}{\sqrt{2}}\{[\lambda_d C_V+\lambda_s A_V+\lambda_p(P_V^p+PE_P)]$ si… $-[\lambda_s(T_P+C_V+A_P)+\lambda_p(P_P^p+PE_V)]\cos\phi\}$			…$.02$
$K^+\omega$	$\frac{1}{\sqrt{2}}[\lambda_d C_P+\lambda_s A_P+\lambda_p(P_P^p+PE_V)]$	0.87 ± 0.25[b]	2.02 ± 0.09	2.12 ± 0.10
$K^+\phi$	$\lambda_s(T_V+C_P+A_V)+\lambda_p(P_V^p+PE_P)$	0.182 ± 0.041	0.13 ± 0.02	0.12 ± 0.02

$|C_P| \gg |A_P|$ ➠ roughly same rate

➠ check future data

BR's for Tests

	Mode	$\mathcal{B}$(This work)	$\mathcal{B}$(FAT)	$\mathcal{B}$(FAT[mix])	$\mathcal{B}_{\rm exp}$
D^0	$\pi^+\rho^-$	5.12 ± 0.29	4.74	4.66	5.15 ± 0.25
	$\pi^-\rho^+$	10.21 ± 0.91	10.2	10.0	10.1 ± 0.4
	$\pi^0\rho^0$	3.90 ± 0.26	3.55	3.83	3.86 ± 0.23
	K^+K^{*-}	1.68 ± 0.11	1.72	1.73	1.65 ± 0.11
	K^-K^{*+}	4.43 ± 0.31	4.37	4.37	4.56 ± 0.21
	K^0K^{*0}	0.27 ± 0.06	1.1	1.1	0.246 ± 0.048
	$\bar{K}^0K^{*0}$	0.32 ± 0.09	1.1	1.1	0.336 ± 0.063
	$\pi^0\omega$	0.12 ± 0.05	0.85	0.18	0.117 ± 0.035
	$\pi^0\phi$	1.22 ± 0.04	1.11	1.11	1.20 ± 0.04
	$\eta\omega$	2.25 ± 0.14	2.4	2.0	1.98 ± 0.18
	$\eta'\omega$	0.01 ± 0.00	0.04	0.02	$\cdots$
	$\eta\phi$	0.16 ± 0.02	0.19	0.18	0.167 ± 0.034
	$\eta\rho^0$	0.59 ± 0.07	0.54	0.45	$\cdots$
	$\eta'\rho^0$	0.06 ± 0.01	0.21	0.27	$\cdots$
D^+	$\pi^+\rho^0$	0.61 ± 0.10	0.42	0.58	0.83 ± 0.15
	$\pi^0\rho^+$	4.53 ± 0.64	2.7	2.5	$\cdots$
	$\pi^+\omega$	0.26 ± 0.07	0.95	0.80	0.28 ± 0.06
	$\pi^+\phi$	6.29 ± 0.20	5.65	5.65	5.68 ± 0.11
	$\eta\rho^+$	1.02 ± 0.34	0.7	2.2	$\cdots$
	$\eta'\rho^+$	1.03 ± 0.11	0.7	0.8	$\cdots$
	$K^+\bar{K}^{*0}$	3.82 ± 0.25	3.61	3.60	$3.83^{+0.14}_{-0.21}$
	$\bar{K}^0K^{*+}$	9.80 ± 0.41	11	11	34 ± 16
D_s^+	π^+K^{*0}	3.65 ± 0.24	2.52	2.35	2.13 ± 0.36
	π^0K^{*+}	1.02 ± 0.07	0.8	1.0	$\cdots$
	$K^+\rho^0$	2.10 ± 0.10	1.9	2.5	2.5 ± 0.4
	$K^0\rho^+$	11.47 ± 0.48	9.1	9.6	$\cdots$
	ηK^{*+}	0.64 ± 0.20	0.2	0.2	$\cdots$
	$\eta'K^{*+}$	0.33 ± 0.02	0.2	0.2	$\cdots$
	$K^+\omega$	2.12 ± 0.10	0.6	0.07	0.87 ± 0.25
	$K^+\phi$	0.12 ± 0.02	0.166	0.166	0.182 ± 0.041

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CPA' for Tests

	Mode	$a_{\rm dir}^{\rm (tree)}$	$a_{\rm dir}^{\rm (t+p)}$	$a_{\rm dir}^{\rm (t+pa)}$	$a_{\rm dir}^{\rm (tot)}$ (this work)	$a_{\rm dir}^{\rm (tot)}$ [69]
D^0	$\pi^+\rho^-$	0	0.01 ± 0.00	0.76 ± 0.22	0.77 ± 0.22	-0.03
	$\pi^-\rho^+$	0	-0.09 ± 0.01	-0.05 ± 0.04	-0.14 ± 0.04	-0.01
	$\pi^0\rho^0$	0	-0.03 ± 0.00	0.40 ± 0.15	0.37 ± 0.15	-0.03
	K^+K^{*-}	0	-0.19 ± 0.01	-0.56 ± 0.37	-0.75 ± 0.37	-0.01
	K^-K^{*+}	0	0.11 ± 0.01	0.05 ± 0.04	0.15 ± 0.04	0
	$K^0\bar{K}^{*0}$	-0.15 ± 0.21	-0.15 ± 0.21	-0.15 ± 0.21	-0.15 ± 0.21	-0.7
	$\bar{K}^0K^{*0}$	-0.34 ± 0.16	-0.34 ± 0.16	-0.34 ± 0.16	-0.34 ± 0.16	-0.7
	$\pi^0\omega$	0	0.18 ± 0.04	-2.31 ± 0.96	-2.14 ± 0.95	[illegible]
	$\pi^0\phi$	0	0	0	[illegible]	[illegible]
	$\eta\omega$	-0.10 ± 0.01	-0.08 ± 0.01	[illegible]	[illegible]	[illegible]
	$\eta'\omega$	2.40 ± 0.34	[illegible]	[illegible]	[illegible]	2.2
	$\eta\phi$	0	[illegible]	[illegible]	0	0.003
	$\eta\rho^0$	[illegible]	[illegible]	[illegible]	0.10 ± 0.30	1.0
	[illegible]	[illegible]	[illegible]	0.12 ± 0.22	0.16 ± 0.22	-0.1
[illegible]	[illegible]	0	1.44 ± 0.11	0.78 ± 1.30	2.20 ± 1.38	0.5
	[illegible]	0	-0.40 ± 0.03	0.90 ± 0.37	0.49 ± 0.37	0.2
	$\pi^+\omega$	0	-0.13 ± 0.03	0.84 ± 2.05	0.74 ± 2.03	-0.05
	$\pi^+\phi$	0	0	0	0	-0.0001
	$\eta\rho^+$	1.55 ± 0.26	2.12 ± 0.36	1.22 ± 0.65	1.78 ± 0.69	-0.6
	$\eta'\rho^+$	-0.25 ± 0.05	-0.24 ± 0.04	0.10 ± 0.12	0.08 ± 0.11	0.5
	$K^+\bar{K}^{*0}$	-0.14 ± 0.02	-0.27 ± 0.02	-0.94 ± 0.30	-1.06 ± 0.30	0.2
	$\bar{K}^0K^{*+}$	-0.06 ± 0.01	0.06 ± 0.01	-0.01 ± 0.04	0.10 ± 0.04	0.04
D_s^+	π^+K^{*0}	0.14 ± 0.02	0.24 ± 0.02	0.94 ± 0.30	1.05 ± 0.30	-0.1
	π^0K^{*+}	0.10 ± 0.03	0.04 ± 0.04	1.21 ± 0.39	1.15 ± 0.40	-0.2
	$K^+\rho^0$	0.10 ± 0.02	-0.02 ± 0.02	0.03 ± 0.07	-0.08 ± 0.07	0.3
	$K^0\rho^+$	0.06 ± 0.01	-0.03 ± 0.01	0.01 ± 0.04	-0.08 ± 0.04	0.3
	ηK^{*+}	-1.03 ± 0.17	-0.33 ± 0.06	-0.61 ± 0.47	0.10 ± 0.48	1.1
	$\eta'K^{*+}$	0.25 ± 0.04	0.24 ± 0.03	-0.11 ± 0.14	-0.12 ± 0.13	-0.5
	$K^+\omega$	-0.09 ± 0.02	-0.03 ± 0.02	-0.05 ± 0.07	0.01 ± 0.08	-2.3
	$K^+\phi$	0	0	0	0	-0.8

Golden modes because of their large BR's and CPA's

CPA' for Tests

	Mode	$a_{\rm dir}^{\rm (tree)}$	$a_{\rm dir}^{\rm (t+p)}$	$a_{\rm dir}^{\rm (t+pa)}$	$a_{\rm dir}^{\rm (tot)}$ (this work)	$a_{\rm dir}^{\rm (tot)}$ [69]
D^0	$\pi^+\rho^-$	0	0.01 ± 0.00	0.76 ± 0.22	0.77 ± 0.22	-0.03
	$\pi^-\rho^+$	0	-0.09 ± 0.01	-0.05 ± 0.04	-0.14 ± 0.04	-0.01
	$\pi^0\rho^0$	0	-0.03 ± 0.00	0.40 ± 0.15	0.37 ± 0.15	-0.03
	K^+K^{*-}	0	-0.19 ± 0.01	-0.56 ± 0.37	-0.75 ± 0.37	-0.01
	K^-K^{*+}	0	0.11 ± 0.01	0.05 ± 0.04	0.15 ± 0.04	0
	$K^0\bar{K}^{*0}$	-0.15 ± 0.21	-0.15 ± 0.21	-0.15 ± 0.21	-0.15 ± 0.21	-0.7
	$\eta'\omega$	2.40 ± 0.34	1.91 ± 0.25	1.42 ± 0.71	0.96 ± 0.66	2.2
	$\eta\phi$	0	0	0	0	0.003
	$\eta\rho^0$	0.39 ± 0.05	0.59 ± 0.08	-0.10 ± 0.29	0.10 ± 0.30	1.0
	$\eta'\rho^0$	-0.55 ± 0.07	-0.51 ± 0.07	0.12 ± 0.22	0.16 ± 0.22	-0.1
D^+	$\pi^+\rho^0$	0	1.44 ± 0.11	0.78 ± 1.30	2.20 ± 1.38	0.5
	$\pi^0\rho^+$	0	-0.40 ± 0.03	0.90 ± 0.37	0.49 ± 0.37	0.2
	$\pi^+\omega$	0	-0.13 ± 0.03	0.84 ± 2.05	0.74 ± 2.03	-0.05
	$\pi^+\phi$	0	0	0	0	-0.0001
	$\eta\rho^+$	1.55 ± 0.26	2.12 ± 0.36	1.22 ± 0.65	1.78 ± 0.69	-0.6
	$\eta'\rho^+$	-0.25 ± 0.05	-0.24 ± 0.04	0.10 ± 0.12	0.08 ± 0.11	0.5
	$K^+\bar{K}^{*0}$	-0.14 ± 0.02	-0.27 ± 0.02	-0.94 ± 0.30	-1.06 ± 0.30	0.2
	$\bar{K}^0K^{*+}$	-0.06 ± 0.01	0.06 ± 0.01	-0.01 ± 0.04	0.10 ± 0.04	0.04
D_s^+	π^+K^{*0}	0.14 ± 0.02	0.24 ± 0.02	0.94 ± 0.30	1.05 ± 0.30	-0.1
	π^0K^{*+}	0.10 ± 0.03	0.04 ± 0.04	1.21 ± 0.39	1.15 ± 0.40	-0.2
	$K^+\rho^0$	0.10 ± 0.02	-0.02 ± 0.02	0.03 ± 0.07	-0.08 ± 0.07	0.3
	$K^0\rho^+$	0.06 ± 0.01	-0.03 ± 0.01	0.01 ± 0.04	-0.08 ± 0.04	0.3
	ηK^{*+}	-1.03 ± 0.17	-0.33 ± 0.06	-0.61 ± 0.47	0.10 ± 0.48	1.1
	$\eta' K^{*+}$	0.25 ± 0.04	0.24 ± 0.03	-0.11 ± 0.14	-0.12 ± 0.13	-0.5
	$K^+\omega$	-0.09 ± 0.02	-0.03 ± 0.02	-0.05 ± 0.07	0.01 ± 0.08	-2.3
	$K^+\phi$	0	0	0	0	-0.8

$$\Delta a_{CP}^{VP}\left(K^+K^{*-} - \pi^+\rho^-\right) \simeq (-1.52 \pm 0.43) \times 10^{-3}$$

Summary

- Updated analyses of SCS D to PP and VP decays
- Current $\Delta A_{CP}(K^+K^- - \pi^+\pi^-)$ measurement is consistent with our predictions from 2012 and this year
- Employed flavor SU(3) symmetry and included symmetry breaking effects as required by data
- Wait for data of yet observed modes (particularly the golden modes) and better precision on observed modes to test theory models

Thank You!