

CP Violation in nonleptonic two-body decays of D Mesons

Pietro Santorelli

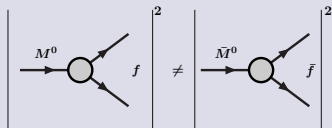
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CP Violation in the Decays: The Direct CPV

This occurs when the decay amplitudes for CP conjugate processes into final states f and \bar{f} are different in modulus

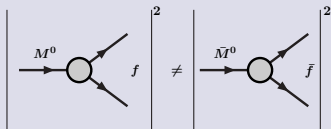
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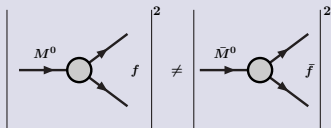
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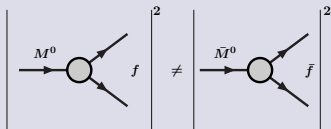
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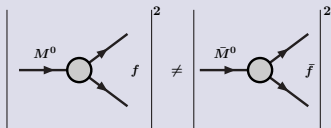
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$$a_{\text{CP}}^{\text{dir}} = \frac{|\mathcal{A}|^2 - |\bar{\mathcal{A}}|^2}{|\mathcal{A}|^2 + |\bar{\mathcal{A}}|^2} = \frac{2 \Im(A_1^* A_2) \sin(\delta_1 - \delta_2)}{|A_1|^2 + |A_2|^2 + 2 \Re(A_1^* A_2) \cos(\delta_1 - \delta_2)}$$

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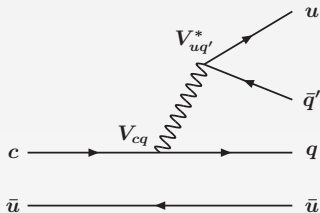
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Hadronic two-body Decays of D Meson (1)

In the Standard Model flavour changing transitions are induced by exchange of W bosons:



- CKM hierarchy leads to two-generation dominance

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

	UT _{fit}
λ	0.22534 ± 0.00065
A	0.821 ± 0.012
ρ	0.136 ± 0.024
η	0.361 ± 0.014

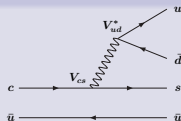
Hadronic two-body Decays of D Meson (2)

Due to the CKM hierarchy we can classify decay processes into three classes

Cabibbo Favoured (CF)

$$|V_{cs} V_{ud}^*| \approx \lambda^0 \text{ as,}$$

for example, $D^0 \rightarrow K^- \pi^+$



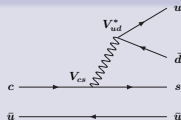
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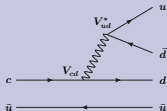
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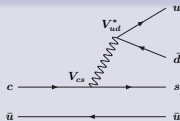
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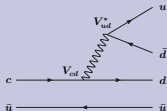
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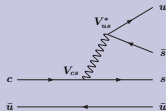
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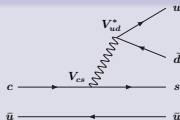
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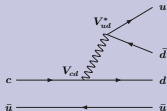
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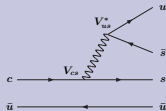
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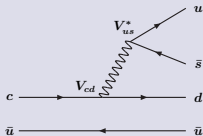
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Double Cabibbo Suppressed (DCS)

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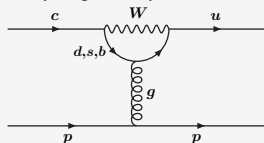
Weak Effective Hamiltonian: The SCS case

$$O_2^{q,q'} = [\bar{q}^\alpha \gamma^\mu (1 - \gamma_5) c_\alpha] [\bar{u}^\beta \gamma_\mu (1 - \gamma_5) d'_\beta] \quad O_1^{q,q'} = [\bar{q}^\alpha \gamma^\mu (1 - \gamma_5) c_\beta] [\bar{u}^\beta \gamma_\mu (1 - \gamma_5) d'_\alpha]$$

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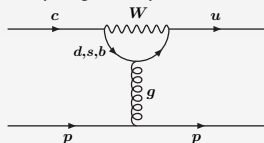
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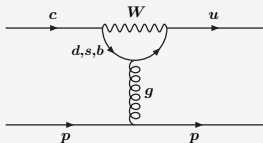
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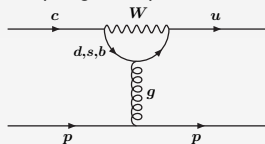
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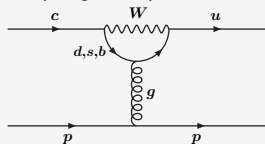
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$$- \frac{G_F}{\sqrt{2}} V_{ub} V_{cb}^* \sum_{i=3}^6 C_i(\mu) O_i(\mu) + h.c.$$

CP Asymmetries: The SCS case

The amplitudes are made of two parts. For the D^0 , for example, we have:

$$\mathcal{A}^{\text{SCS}} = \frac{1}{2}(V_{cs}^* V_{us} - V_{cd}^* V_{ud})A^{(1,2)} e^{i\delta} - \frac{1}{2}V_{cb}^* V_{ub}A^{(P)} e^{i\delta'}$$

and so the direct CP asymmetry is given by

$$a_{CP}^{\text{dir}} \approx \eta A^2 \lambda^4 \sin(\delta - \delta') \left[\frac{A^{(P)}}{A^{(1,2)}} \right] \approx (6 \times 10^{-4}) \sin(\delta - \delta') \left[\frac{A^{(P)}}{A^{(1,2)}} \right]$$

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- Penguin amplitude of the order of tree amplitude

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$$\begin{aligned} \Delta A_{CP} &= (-0.82 \pm 0.21 \pm 0.11)\% && \text{(LHCb (2012))} \\ &= (-0.62 \pm 0.21 \pm 0.10)\% && \text{(CDF (2012))} \\ &= (-0.87 \pm 0.41 \pm 0.06)\% && \text{(Belle (2012))} \end{aligned}$$

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$$\Delta A_{CP} = -(0.16 \pm 0.19)\%$$

HFAG (July 2016)

Amplitude calculations

The main point is the evaluation of the amplitudes:

$$A(D \rightarrow f) = \langle f | H_w | D \rangle = \frac{G_F}{\sqrt{2}} VV^* C_j(\mu) \langle f | O_j(\mu) | D \rangle$$

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 - HQET is expected to do not work well, due to the large Λ_{QCD}/m_c corrections
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see also talks by A. Lenz, A. El-Khadra, G. Martinelli

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- see also talks by A. Lenz, A. El-Khadra, G. Martinelli
- Models of calculations can be useful to estimate them
 - Factorization & Final state Interactions
 - Flavour symmetries ($SU(3)_F$, isospin, U-spin, etc.)

Amplitude calculations: the $SU(3)_F$ approach

The idea to study charmed particles by assuming $SU(3)_F$ flavour symmetry is very old

Altarelli, Cabibbo, and Maiani (1975)
 Kingsley, Treiman, Wilczek, and Zee (1975)
 Einhorn and Quigg (1975)
 Voloshin, Zakharov, and Okun (1975)
 Cabibbo and Maiani (1978)
 Quigg (1980)

and quite simple (in principle):

$$(\bar{3}c)(\bar{u}s) \sim \mathbf{3} \otimes \bar{\mathbf{3}} \otimes \mathbf{3} \sim \mathbf{3} \oplus \mathbf{3}' \oplus \bar{\mathbf{6}} \oplus \mathbf{15}$$

Due to the fact that

$$(D^0, D^+, D_s) \sim \bar{\mathbf{3}}$$

$$PP \sim (\mathbf{8} \otimes \mathbf{8})_S = \mathbf{1} \oplus \mathbf{8} \oplus \mathbf{27}$$

$$\langle PP | \mathcal{H} | D \rangle \sim \langle \mathbf{1} \oplus \mathbf{8} \oplus \mathbf{27} | (\mathbf{3} \oplus \bar{\mathbf{6}} \oplus \mathbf{15}) | \bar{\mathbf{3}} \rangle$$

Neglecting the $\mathbf{3} \propto V_{cb}^* V_{ub}$ we have

B. Grinstein and R.F. Lebed PRD 53 (1996) 6344
 I. Hinchliffe and T.A. Kaeding, PRD 54 (1996) 914

$$\mathcal{H} = \frac{V_{cd}^* V_{us}}{\sqrt{2}} H_0^6 + \frac{(V_{cd}^* V_{ud} - V_{cs}^* V_{us})}{2} H_{1/2}^6 - \frac{V_{cs}^* V_{ud}}{\sqrt{2}} H_1^6 - \frac{(V_{cd}^* V_{ud} - 3V_{cs}^* V_{us})}{2\sqrt{6}} H_{1/2}^{15} + \frac{(V_{cd}^* V_{us} + V_{cs}^* V_{ud})}{\sqrt{2}} H_1^{15} + \frac{V_{cd}^* V_{ud}}{\sqrt{3}} H_{3/2}^{15}$$

see also talk by A.Paul

Using Wigner-Eckart theorem we have

$$\langle \mathbf{8} | \mathbf{15} | \bar{\mathbf{3}} \rangle \quad \langle \mathbf{27} | \mathbf{15} | \bar{\mathbf{3}} \rangle \quad \langle \mathbf{8} | \bar{\mathbf{6}} | \bar{\mathbf{3}} \rangle$$

What about Experimental data and $SU(3)_F$ Symmetry?

In the limit of $SU(3)$ flavour symmetry

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PDG (2014)

$$a_{CP}^{dir}(\pi^+ \pi^-) = (+0.00 \pm 0.15)\%$$

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HFAG (July 2016)

Regarding D^+ , $SU(3)_F$ predicts

$$\tan \theta_C \underbrace{A(D^+ \rightarrow \bar{K}^0 \pi^+)}_{CF} = \sqrt{2} \underbrace{A(D^+ \rightarrow \pi^0 \pi^+)}_{SCS}$$

$$\frac{Br(D^+ \rightarrow \pi^0 \pi^+)}{Br(D^+ \rightarrow K_S \pi^+)} = \tan^2(\theta_C) \frac{PhS(D^+ \rightarrow \pi^0 \pi^+)}{PhS(D^+ \rightarrow \bar{K}^0 \pi^+)} = 0.057 (0.077 \pm 0.004)$$

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Regarding D^0 decays, $SU(3)_F$ predicts

$$\frac{Br(D^0 \rightarrow K^+ \pi^-)}{Br(D^0 \rightarrow K^- \pi^+)} = \tan^4(\theta_C) = 0.0029 (0.00356 \pm 0.00008)$$

$$A(D^0 \rightarrow K^0 \bar{K}^0) = 0 (Br(D^0 \rightarrow K_S K_S) = (0.18 \pm 0.04) \times 10^{-3})$$

PDG (2014)

$SU(3)_F$: D into PP channels

An Analysis with the inclusion of linear $SU(3)_F$ Breaking

- The $Br(D \rightarrow PP)$ are **seventeen**;
- The Wigner-Eckart Theorem gives **five** (complex) Reduced Matrix Elements (including **3**)

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A BRUTE FORCE ANALYSIS CANNOT BE DONE

Grinstein and Lebed (1996), Hinchliffe and Kaeding (1996), Grossman and Robinson (2013), Hiller, Jung and Schacht (2013)

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- They include in the fit the $a_{CP}^{dir}(f)$ (25 data, 25 parameters)
- The agreement with the data is good (No, assumptions)
- Very large enhancement of Penguin contributions, **3**, for large Δa_{CP}

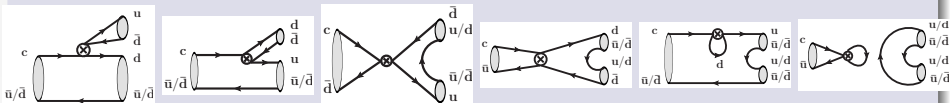
G. Hiller, M. Jung and S. Schacht, PRD 87 (2013) 014024

$SU(3)_F$ & topological amplitudes in D into PP

L.-L. Chau (1983), L.-L. Chau, H.-Y. Cheng (1986) and (1987)

S. Müller, U. Nierste, and S. Schacht, PRD 92 (2015) 014004

- $A(D \rightarrow PP)$, in the $SU(3)_F$ limit, are written in terms of Topological Amplitudes;

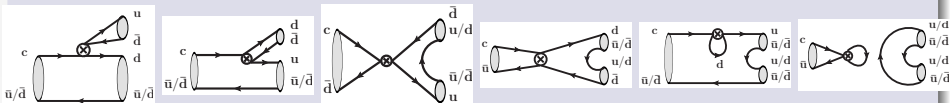


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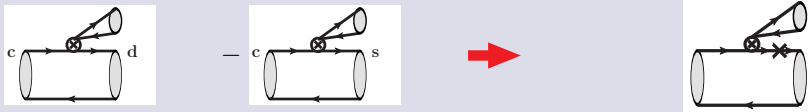
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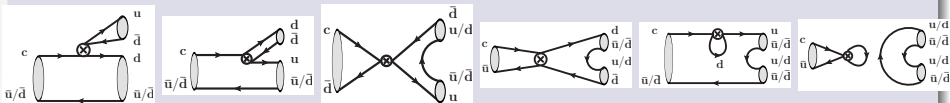


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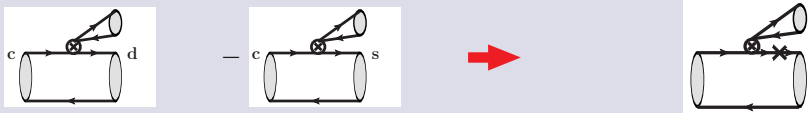
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- Redundancies as in the case of RME
- $1/N_c$ counting rules: $(T, A) \approx \text{Factorization} + \delta_{T,A}$, where $\delta_{T,A} \sim 1/N_c^2$
- $SU(3)_F$ -breaking corrections $< 50\%$, corrections $1/N_c^2 < 15\%$ of the factorized ones: $\chi^2 = 0$ (# parameters \geq # data)

$SU(3)_F$ & topological amplitudes in D into $PP(2)$

What about direct CP asymmetries?

- Penguins and Penguins annihilations are not constrained by Branching ratios

IT IS NOT POSSIBLE TO PREDICT CP ASYMMETRIES

$SU(3)_F$ & topological amplitudes in D into $PP(2)$

What about direct CP asymmetries?

- Penguins and Penguins annihilations are not constrained by Branching ratios

IT IS NOT POSSIBLE TO PREDICT CP ASYMMETRIES

- But one can build combinations of CP asymmetries containing only those topological amplitudes obtained by the fit: **sum rules of CP asymmetries**
 - $D^0 \rightarrow K^+ K^-$, $D^0 \rightarrow \pi^+ \pi^-$ and $D^0 \rightarrow \pi^0 \pi^0$;
 - $D^+ \rightarrow \bar{K}^0 K^+$, $D_s^+ \rightarrow K^0 \pi^+$ and $D_s^+ \rightarrow K^+ \pi^0$.

S. Müller, U. Nierste, and S. Schacht, PRL 115 (2015) 251802

- $a_{\text{CP}}^{\text{dir}}(D^0 \rightarrow K_S K_S)$ receives contribution from **E** (obtained in their previous paper) and **PA** diagrams. A perturbative estimation of PA allows to give

$$a_{\text{CP}}^{\text{dir}}(D^0 \rightarrow K_S K_S) \leq 1.1\%$$

U. Nierste, and S. Schacht, PRD 92 (2015) 054036

A pure topological amplitudes analysis in D into PP (SCS)

R. Dhir, C. S. Kim, and S. Oh, Int. J. Mod. Phys. A30 (2015) 1550104

- Fit the topological amplitudes to all the $D \rightarrow PP$ SCS channels (including final state with $\eta^{(\prime)}$) and measured CP asymmetries
- All possible topological amplitudes
- The $SU(3)_F$ breaking effects are included (a parameter for any different type of final state, $\Delta_{\pi\pi}$, $\Delta_{K\pi}$, $\Delta_{\pi\eta}$, Δ_{KK} and $\Delta_{K\eta}$)

Results

- 23 exp. data and 22 parameters: $\chi^2/d.o.f \sim 10$ (essentially due to the CP asymmetries)
- They predict

Mode	a_{CP}^{dir}	Exp. (HFAG, July 2016)
$D^0 \rightarrow \pi^+ \pi^-$	$+3.3 \times 10^{-4}$	$(-0.0 \pm 1.5) \times 10^{-3}$
$D^0 \rightarrow K^+ K^-$	-7.3×10^{-4}	$(-1.6 \pm 1.2) \times 10^{-3}$
$D^0 \rightarrow K_S K_S$	-5.8×10^{-4}	$(-46 \pm 54) \times 10^{-3}$
$D^0 \rightarrow \pi^0 \eta$	-4.7×10^{-4}	—
$D^0 \rightarrow \pi^0 \eta'$	-3.3×10^{-4}	—

Improved Factorization & FSI (1)

A. Biswas, N. Sinha, and G. Abbas, PRD 92 (2015), 014032

- Improved factorization (T, C)

$$\begin{aligned} a_1(\mu) &= C_1(\mu) + C_2(\mu) \left(\frac{1}{N_c} + \alpha(\mu) \chi_1 e^{i\phi_1} \right) \\ a_2(\mu) &= C_2(\mu) + C_1(\mu) \left(\frac{1}{N_c} + \alpha(\mu) \chi_2 e^{i\phi_2} \right) \end{aligned} \quad \mu = \sqrt{\Lambda m_D (1 - r_2^2)} \quad r_2^2 = m_{P_2}^2 / m_D^2$$

- W-emission (E) and W-annihilation (A) contributions are considered ($C_i(\mu)$ at $\mu = \sqrt{\Lambda m_D (1 - r_1^2)(1 - r_2^2)}$)
- Form factors from experimental data(semileptonic decays) and Lattice results; q^2 -dependence by "z-expansion"
- Resonant FSI are considered by K-matrix approach (for $l = 0$ $f_0(1710)$, $l = 1$ $a_0(1450)$ and $l = 1/2$ $K_0^*(1950)$)
- 13 parameters, 28 experimental data (BRs)

Improved Factorization & FSI (2)

A. Biswas, N. Sinha, and G. Abbas, PRD 92 (2015), 014032

Modes	Fit result (10^{-3})	Experimental Value (10^{-3})
$D^0 \rightarrow \pi^+ \pi^-$	1.44 ± 0.027	1.402 ± 0.026
$D^0 \rightarrow \pi^0 \pi^0$	1.14 ± 0.56	0.8209 ± 0.035
$D^0 \rightarrow K^+ K^-$	4.06 ± 0.77	3.96 ± 0.08
$D^0 \rightarrow K^0 \bar{K}^0$	0.342 ± 0.052	0.34 ± 0.08
$D^0 \rightarrow \pi^0 \eta$	1.47 ± 0.90	0.68 ± 0.07
$D^0 \rightarrow \pi^0 \eta'$	2.17 ± 0.65	0.90 ± 0.14
$D^0 \rightarrow \eta \eta$	1.27 ± 0.27	1.67 ± 0.20
$D^0 \rightarrow \eta \eta'$	0.953 ± 0.183	1.05 ± 0.26
$D^+ \rightarrow \pi^+ \pi^0$	0.889 ± 0.451	1.19 ± 0.06
$D^+ \rightarrow K^+ \bar{K}^0$	3.75 ± 0.63	5.66 ± 0.32
$D^+ \rightarrow \pi^+ \eta$	4.72 ± 0.21	3.53 ± 0.21
$D^+ \rightarrow \pi^+ \eta'$	6.76 ± 2.19	4.67 ± 0.29
$D_s^+ \rightarrow \pi^+ K^0$	1.96 ± 0.90	2.42 ± 0.12
$D_s^+ \rightarrow \pi^0 K^+$	0.817 ± 0.464	0.63 ± 0.21
$D_s^+ \rightarrow K^+ \eta$	1.50 ± 0.75	1.76 ± 0.35
$D_s^+ \rightarrow K^+ \eta'$	0.707 ± 0.049	1.8 ± 0.6

$$\chi^2 = \sum_i \frac{(Br_i^{th} - Br_i^{exp})^2}{\sigma_{Br_i^{th}}^2 + \sigma_{Br_i^{exp}}^2}$$

$SU(3)_F$ & FSI (1)

F. Buccella, M. Lusignoli, A. Pugliese and P.S., PRD 88 (2013) 074011
F. Buccella, E. Franco, M. Lusignoli, A. Paul, A. Pugliese, P.S., L. Silvestrini, in preparation

D^0 SCS & U-spin Symmetry

- ★ D^0 is U-spin singlet

$$H = H_{\Delta U=1} + H_{\Delta U=0} = \underbrace{\sin \theta_C \cos \theta_C}_{\sim \lambda} \tilde{H}_{\Delta U=1} + \underbrace{V_{ub} V_{cb}^*}_{\sim \lambda^3 \cdot \lambda^2} \tilde{H}_{\Delta U=0}$$

- ★ Two RME (we choose them reals and call T' and C')
- ★ $SU(3)_F$ violation from FSI

D^0 CF and DCS and all D^+ , D_s decays

- ★ Three RME (T, C, D): $\langle 8 | 15 | \bar{3} \rangle$ $\langle 27 | 15 | \bar{3} \rangle$ $\langle 8 | \bar{6} | \bar{3} \rangle$
- ★ A parameter (K) takes into account the non conservation of the current $\bar{s} \gamma_\mu (1 - \gamma_5) q$ with an opposite sign in the CF and in the DCS.

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Final State Interactions

We describe the FSI as the effect of resonances in the scattering of the final particles.

In other words, strong phases are generated by the resonances responsible for rescattering of final states.

Assuming no exotic resonances belonging to the 27 representation, the possible resonances have $SU(3)_F$ and isospin quantum numbers $(8, I=1)$, $(8, I=1/2)$, $(8, I=0)$ and $(1, I=0)$. Moreover, the two states with $I=0$ can be mixed, yielding two resonances:

$$|f_0\rangle = +\sin\phi |8, I=0\rangle + \cos\phi |1, I=0\rangle$$

$$|f'_0\rangle = -\cos\phi |8, I=0\rangle + \sin\phi |1, I=0\rangle$$

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F. Buccella, M. Lusignoli, A. Pugliese and P.S., PRD 88 (2013) 074011
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$$\begin{aligned} |f_0\rangle &= +\sin\phi |8, I=0\rangle + \cos\phi |1, I=0\rangle \\ |f'_0\rangle &= -\cos\phi |8, I=0\rangle + \sin\phi |1, I=0\rangle \end{aligned}$$

The mixing angle ϕ and the strong phases $\delta_0, \delta'_0, \delta_1$ and $\delta_{1/2}$ are our model parameters together with the amplitudes T, T', C, C', D , and K . Moreover, we assume that

$$T' = T(1 + \varepsilon) \text{ and } C' = C(1 - \varepsilon)$$

The phases for the decay modes of D_s^+ is expected to be different from those coming in the D^0 and D^+ :

$$\delta'_1 = \delta_1(1 - \varepsilon_\delta) \text{ and } \delta'_{\frac{1}{2}} = \delta_{\frac{1}{2}}(1 - \varepsilon_\delta)$$

Comparison with data

F. Buccella, E. Franco, M. Lusignoli, A. Paul, A. Pugliese, P.S., L. Silvestrini, in preparation

Channel	Fit ($\times 10^{-3}$)	Exp. ($\times 10^{-3}$)
CF		
$BR(D^+ \rightarrow \pi^+ K_S)$	15.72 ± 0.41	15.3 ± 0.6
$BR(D^+ \rightarrow \pi^+ K_L)$	14.34 ± 0.37	14.6 ± 0.5
$BR(D^0 \rightarrow \pi^+ K^-)$	39.31 ± 0.40	39.3 ± 0.4
$BR(D^0 \rightarrow \pi^0 K_S)$	11.9 ± 0.33	12.0 ± 0.4
$BR(D^0 \rightarrow \pi^0 K_L)$	9.39 ± 0.27	10.0 ± 0.7
$BR(D_s^+ \rightarrow K^+ K_S)$	15.0 ± 0.5	15.0 ± 0.5
SCS		
$BR(D^0 \rightarrow \pi^+ \pi^-)$	1.42 ± 0.03	1.421 ± 0.025
$BR(D^0 \rightarrow \pi^0 \pi^0)$	0.83 ± 0.04	0.826 ± 0.035
$BR(D^+ \rightarrow \pi^+ \pi^0)$	1.22 ± 0.06	1.24 ± 0.06
$BR(D^0 \rightarrow K^+ K^-)$	4.02 ± 0.06	4.01 ± 0.07
$BR(D^0 \rightarrow K_S K_S)$	0.17 ± 0.04	0.18 ± 0.04
$BR(D^+ \rightarrow K^+ K_S)$	2.89 ± 0.12	2.95 ± 0.15
$BR(D_s^+ \rightarrow \pi^0 K^+)$	1.03 ± 0.04	0.63 ± 0.21
$BR(D_s^+ \rightarrow \pi^+ K_S)$	1.24 ± 0.06	1.22 ± 0.06
DCS		
$BR(D^+ \rightarrow \pi^0 K^+)$	0.155 ± 0.005	0.189 ± 0.025
$BR(D^0 \rightarrow \pi^- K^+)$	0.140 ± 0.003	0.1399 ± 0.0027

$$\chi^2/NdF \approx 8/(16 - 11) = 1.6$$

Channel	Fit ($\times 10^{-3}$)	Exp. ($\times 10^{-3}$)
CF		
$BR(D^0 \rightarrow K_S \eta)$	3.56 ± 0.1	4.85 ± 0.3
$BR(D_s^+ \rightarrow \pi^+ \eta)$	34.1 ± 1.5	17.0 ± 0.9
SCS		
$BR(D^0 \rightarrow \eta \eta)$	0.96 ± 0.1	1.70 ± 0.20
$BR(D^+ \rightarrow \pi^+ \eta)$	2.84 ± 0.22	3.66 ± 0.22
$BR(D^0 \rightarrow \pi^0 \eta)$	0.70 ± 0.04	0.69 ± 0.07
$BR(D_s^+ \rightarrow K^+ \eta)$	1.14 ± 0.07	1.77 ± 0.35
DCS		
$BR(D^+ \rightarrow K^+ \eta)$	0.047 ± 0.002	0.112 ± 0.018

$$\frac{a_{CP}^{\text{dir}}(\pi^+ \pi^-)}{a_{CP}^{\text{dir}}(K^+ K^-)} \approx -2$$

Conclusions

- The $D \rightarrow PP$ is an interesting laboratory to study CP Violation
- The $SU(3)_F$ flavour symmetry is a powerful guide to study these processes, but it is not exhaustive if you want to predict CPV asymmetries
- Many approaches has been used (with $SU(3)_F$) but a lot of work should be done.

Backup Slides

$D \rightarrow PV$ and $SU(3)_F$

L. L. Chau and H. Y. Cheng, PRD 36, 137 (1987)
F. Buccella, M. Lusignoli, G. Miele, A. Pugliese, and P. S., PRD 51, 3478 (1995)
B. Bhattacharya and J. L. Rosner, PRD 79, 034016 (2009)
H. Y. Cheng and C.W. Chiang, PRD 81, 074021 (2010)
Z. T. Zou, C. Li, and C. D. Liu, Chin. Phys. C 37, 093101 (2013)
Q. Qin, H.-n. Li, C.-D. Liu, and F.-S. Yu, PRD 89, 054006 (2014).
H.-Y. Cheng, C.-W. Chiang, and A.-L. Kuo, PRD 93 (2016), 114010

- $D \rightarrow PV$ modes by using Topological Diagram approach
- $SU(3)_F$ symmetry reduces the number of amplitudes to four: **T, C, E, A**
- Depending on the spectator quark is in the V or in the P we have \mathcal{A}_V and \mathcal{A}_P , respectively
- Amplitudes: $T_P, T_V, C_P, C_V, E_P, E_V, A_P, A_V$ and so 15 free real parameters
- Measured CF Branching ratios: sixteen
- Many solutions but the favoured one reproduces the Br for SCS and DCS decay modes

"Exact flavor $SU(3)$ -symmetric approach is still sufficiently adequate to provide an overall explanation for the current data"

see also talk by B. Loiseau