D physics theory overview

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Outline

1. Charm meson leptonic and semileptonic decays
2. $D^0 - \overline{D}^0$ oscillations
3. CP asymmetry in D nonleptonic decays

Questions:

1. SM improvements?

2. Search for new physics?

Correlation of NP in $\Delta C = 2$ and $\Delta C = 1$ transitions

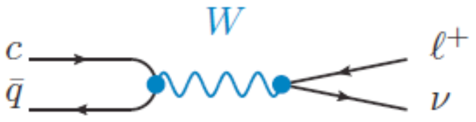
NP signals in charm and relations with top NP

NP in up- quark sector $\leftrightarrow$ NP in down-quark sector

Motivation to study charm meson leptonic and semileptonic decays

- Independent determination of CKM matrix elements V_{cs} and V_{cd} (CKM fitter);
- Possibility to test theoretical tools - lattice QCD;
- HQE & OPE determination of power corrections.

Leptonic charm decays

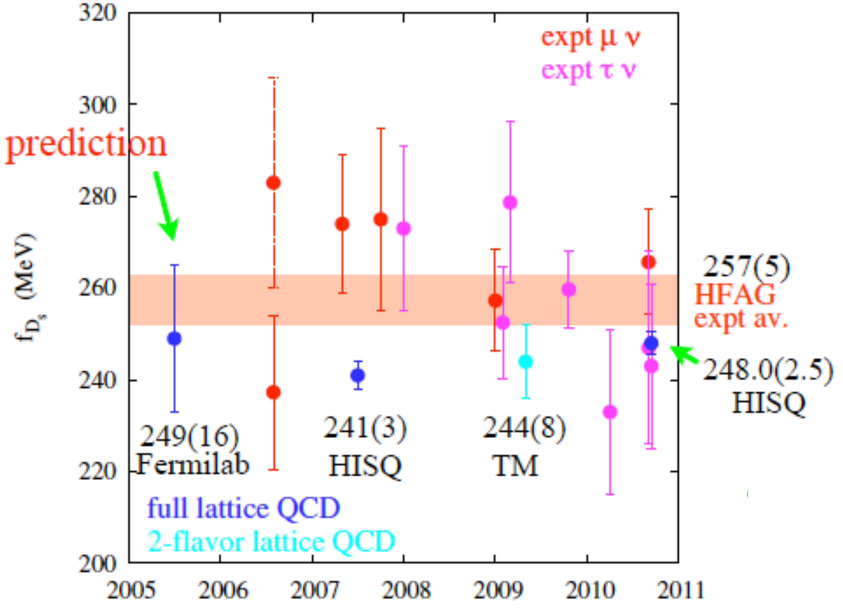


"D_s puzzle" since 2005
resolved in 2009

Although, there is no any more D_s puzzle,
still, we obtain bounds to variety of NP models!

$$\Gamma(D_q \to \ell\nu) = \frac{G_f^2}{8\pi} m_\ell^2 \left(1 - \frac{m_\ell^2}{M_{D_q}^2}\right)^2 M_{D_q} f_{D_q}^2 |V_{cq}|^2$$

$$f_{D_s}/f_D = 1.26(5)$$



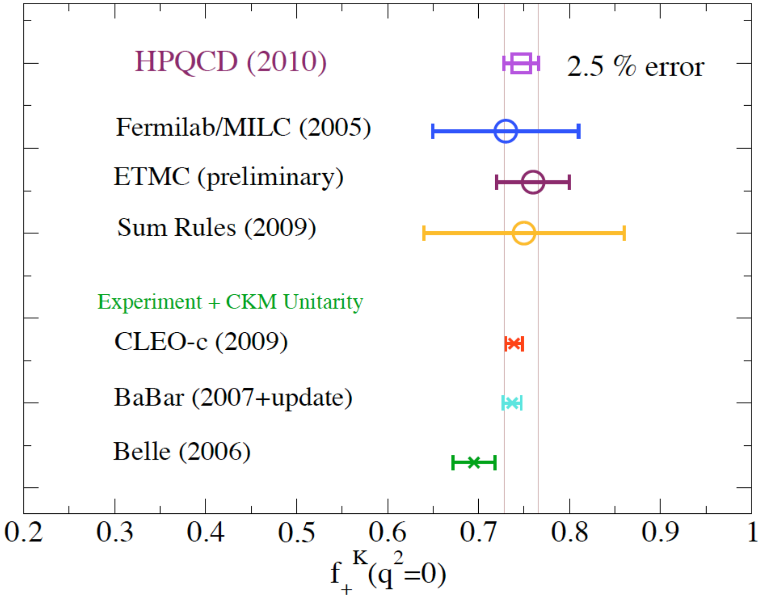
from C. Davies, Lattice 2011

Exclusive charm meson semileptonic decay modes

Experiment and lattice

- extraction of V_{cq}
- extraction of form-factors

D to K – errors 1% and 3 %
D to π – errors 3 % and 10%



$$\langle P(p)|\,\bar{q}\gamma^{\mu}c\,|D(p')\rangle \;=\; f_+(q^2)\left[P^{\mu}-\frac{m_D^2-m_P^2}{q^2}q^{\mu}\right]+f_0(q^2)\frac{m_D^2-m_P^2}{q^2}q^{\mu}$$

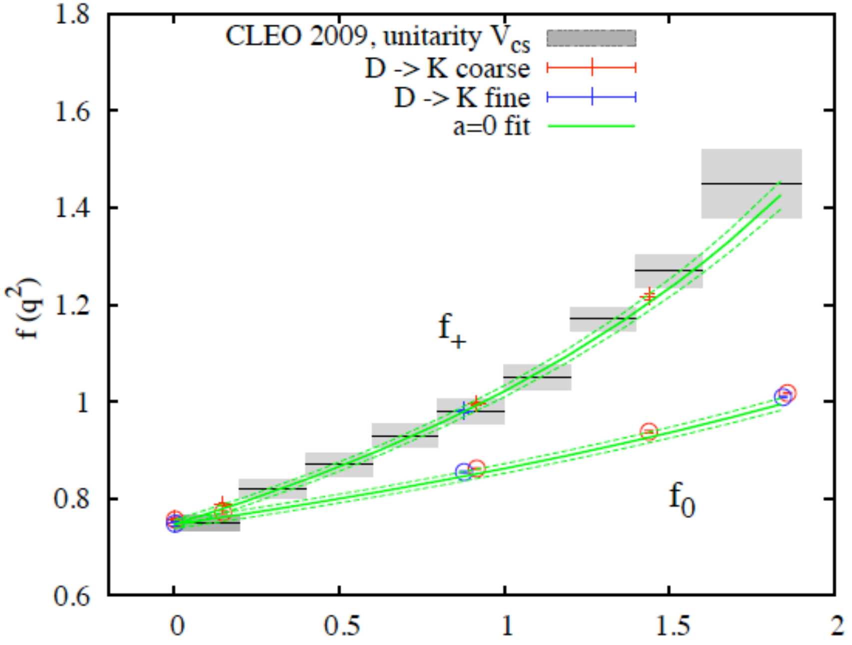
$$f_+(q^2)=\frac{1}{P(q^2)\phi(q^2,t_0)}\sum_{k=0}^{\infty}a_k(t_0)[z(q^2,t_0)]^k$$

$$q^2 \longrightarrow z \qquad z=\frac{\sqrt{t_+-q^2}-\sqrt{t_+-t_0}}{\sqrt{t_+-q^2}+\sqrt{t_+-t_0}}$$

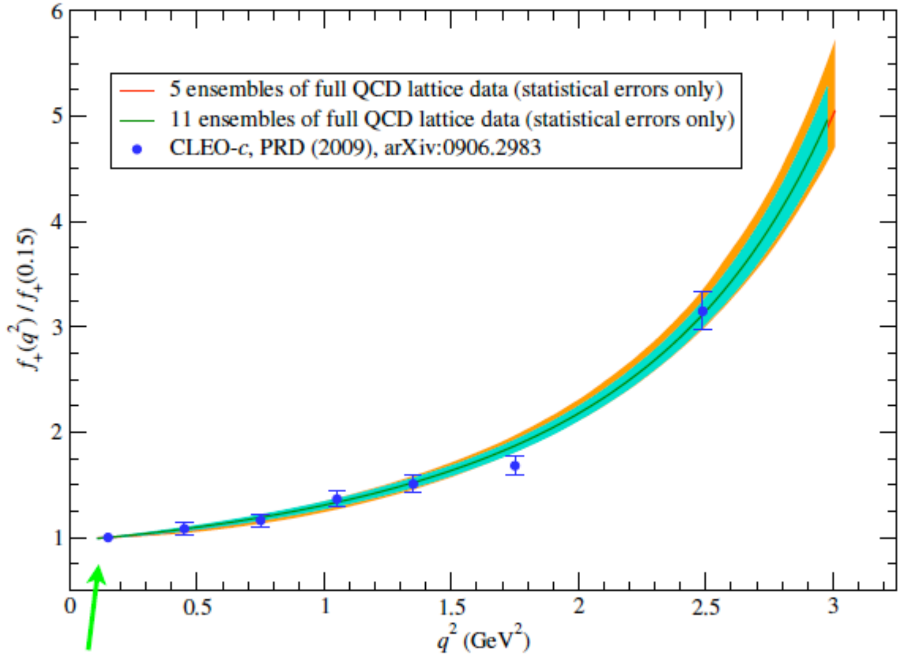
Becher & Hill, (2005), parametrization using dispersion relations;

Becirevic& Kaidalov parameterization of form-factors still agrees well with experimental results

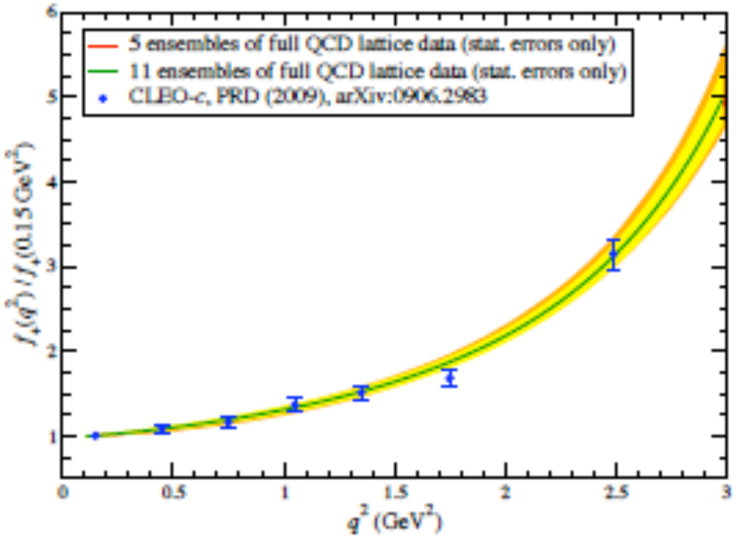
$D \to K$

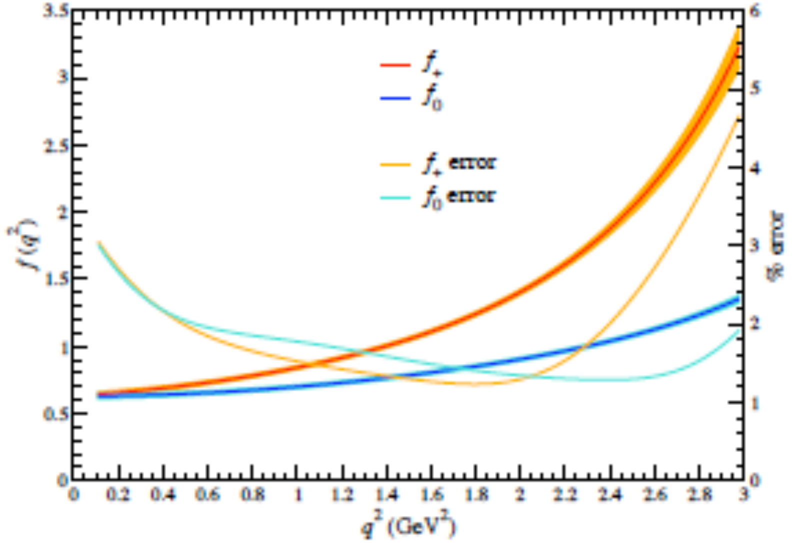


$D \to \pi$



Fermilab MILC

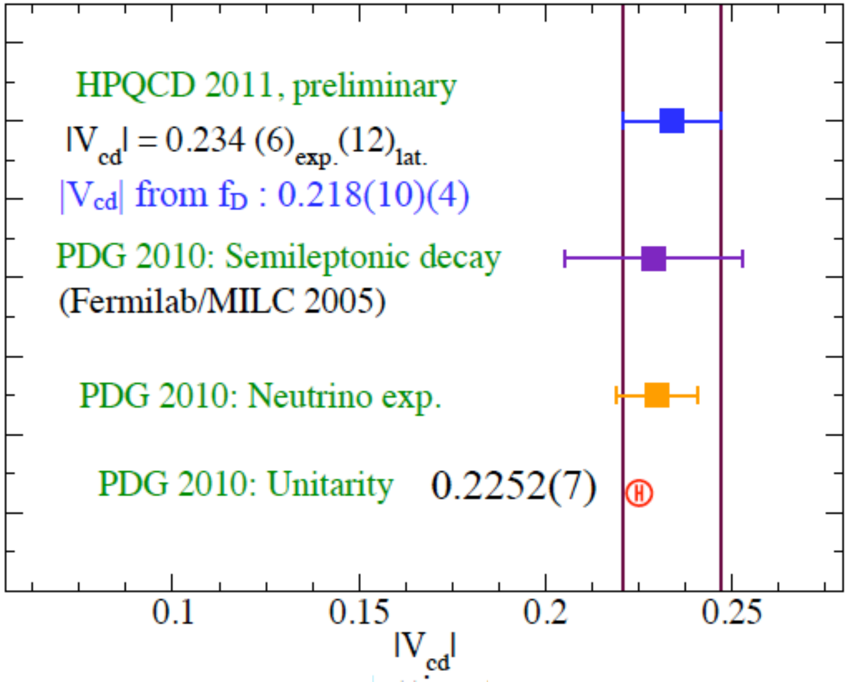




J. Bailey et al., arXiv:111.5471

form factors and their statistical errors

Direct determination V_{cd}



second row unitarity from lattice QCD:

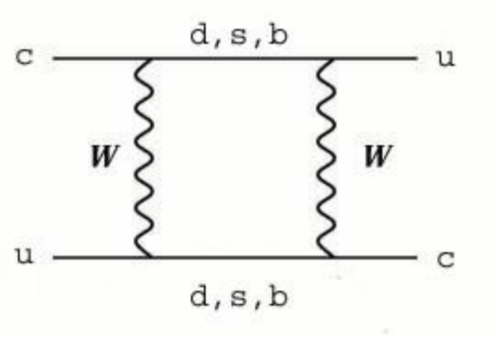
$$|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2 = 0.98(5)$$

$$0.234(13) \quad 0.961(26) \quad 39.7(1.0) \times 10^{-3}$$

$D^0 - \bar{D}^0$ oscillations and indirect CP violation

The neutral D meson system is the only one created out of the up-type quarks.

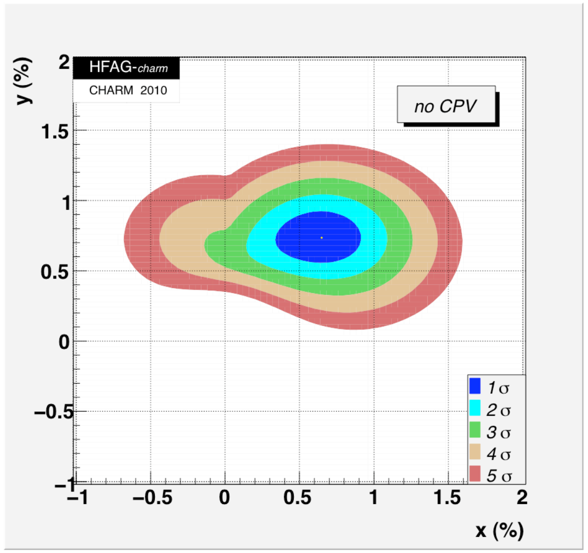
Standard model

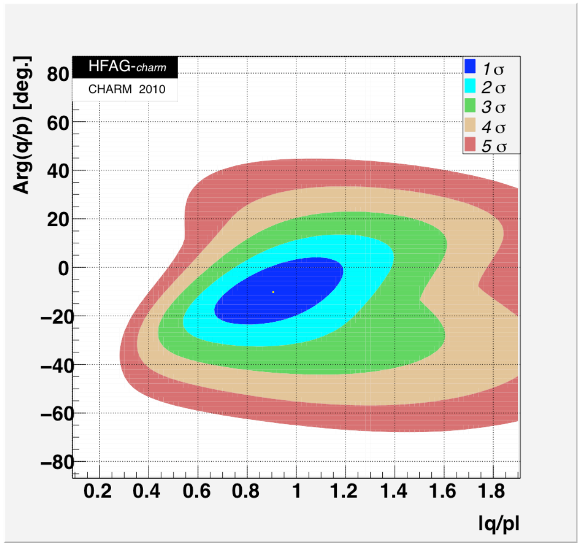


$$|D_1\rangle = \frac{1}{\sqrt{|p|^2 + |q|^2}} \left(p|D^0\rangle + q|\bar{D}^0\rangle\right)$$

$$|D_2\rangle = \frac{1}{\sqrt{|p|^2 + |q|^2}} \left(p|D^0\rangle - q|\bar{D}^0\rangle\right)$$

- intermediate down-type quarks
- due to CKM contribution of b – quark negligible;
- in the SU(3) limit 0;
- long distance contributions important;





$$\langle D^0 | \mathcal{H} | \bar{D}^0 \rangle = M_{12} - \frac{i}{2}\Gamma_{12}$$

$$y_{12} \equiv \frac{|\Gamma_{12}|}{\Gamma}, \quad x_{12} \equiv 2\frac{|M_{12}|}{\Gamma}, \quad \phi_{12} \equiv \arg\left(\frac{M_{12}}{\Gamma_{12}}\right)$$

$$x_{12} \in [0.25,\, 0.99]\,\%$$

$$y_{12} \in [0.59,\, 0.99]\,\%$$

$$\phi_{12} \in [-7.1^\circ,\, 15.8^\circ]$$

Φ_{12} q/p $\Big\}$ they give variable which inform us about CP violation

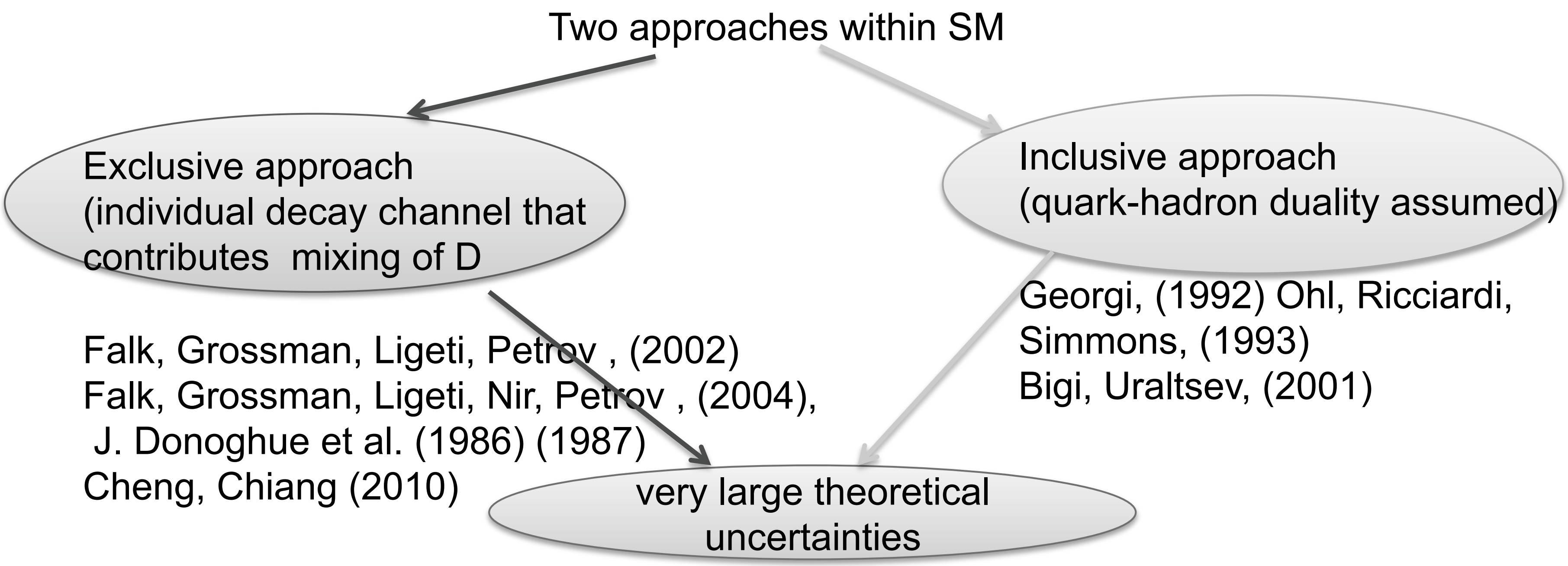
$$a_f(t) \equiv \frac{\Gamma(D^0(t) \to f) - \Gamma(\bar{D}^0(t) \to f)}{\Gamma(D^0(t) \to f) + \Gamma(\bar{D}^0(t) \to f)}$$

x, y → CP conserving

sensitive to q/p

Standard model: recent developments

$$\left(M-\frac{i}{2}\Gamma\right)_{12}=\frac{1}{2M_{\mathrm{D}}}\langle\overline{D}^0|\mathscr{H}_w^{\Delta C=-2}|D^0\rangle+\frac{1}{2M_{\mathrm{D}}}\sum_n\frac{\langle\overline{D}^0|\mathscr{H}_w^{\Delta C=-1}|n\rangle\,\langle n|\mathscr{H}_w^{\Delta C=-1}|D^0\rangle}{M_{\mathrm{D}}-E_n+i\varepsilon}$$



Two approaches within SM

Exclusive approach
(individual decay channel that
contributes mixing of D

Falk, Grossman, Ligeti, Petrov , (2002)
Falk, Grossman, Ligeti, Nir, Petrov , (2004),
J. Donoghue et al. (1986) (1987)
Cheng, Chiang (2010)

Inclusive approach
(quark-hadron duality assumed)

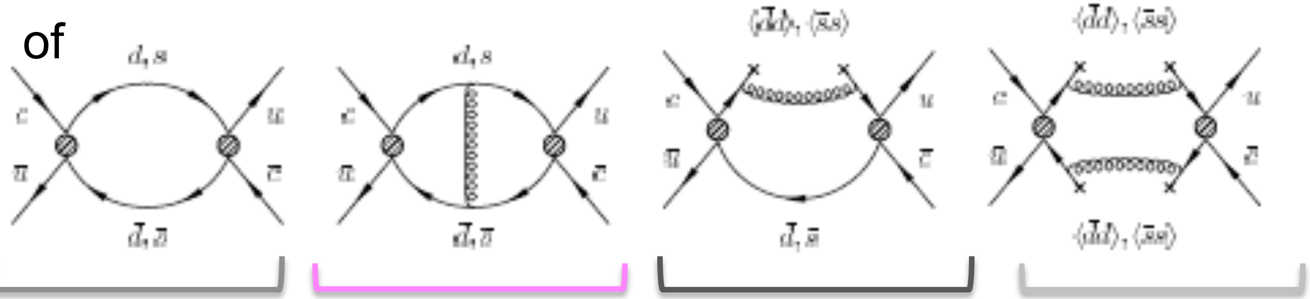
Georgi, (1992) Ohl, Ricciardi,
Simmons, (1993)
Bigi, Uraltsev, (2001)

very large theoretical
uncertainties

Heavy – quark expansion in D system

Absorptive part of

$$\Gamma_{12}$$



Leading dim 6 QCD corrected

Dim 9

Dim 12
might be even dominant!

Severe GIM cancellation

$$y^{theory} \ll y^{exp}$$

If y^{theory} remains small:

- HQE does not work for D system;
- NP in D system

Lenz et al.: Higher order can be important, - enhancement of $\mathcal{O}(15)$

$$\boxed{y = \frac{1}{\Gamma}\sum_n \rho_n \langle \overline{D}^0 | \mathcal{H}_W^{\Delta C=1} | n \rangle \langle n | \mathcal{H}_W^{\Delta C=1} | D^0 \rangle}$$

Recent development within SM: Bobrowski and Lenz, 0904.3971
Bobrowski, Lenz, Riedl, Rohrwild 1002.4794
Attempt to use QCD to its limits!

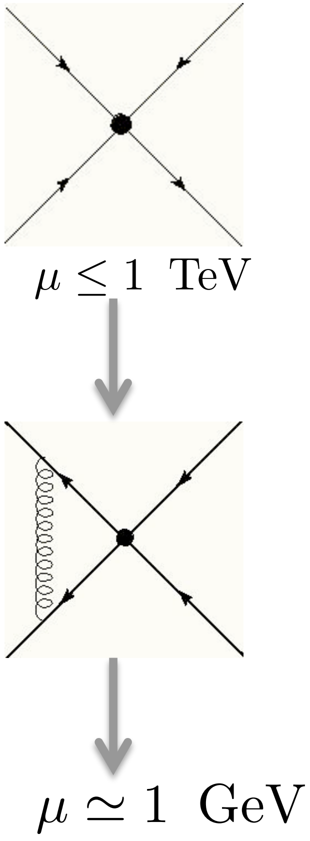
New Physics in $\Delta C = 2$ transition

Most general effective Hamiltonian at scale $\Lambda_{\rm NP} \gg m_W$

$$\boxed{\mathcal{H}_{\rm eff}^{\Delta C=2} = \frac{1}{\Lambda_{\rm NP}^2}\left(\sum_{i=1}^{5} z_i Q_i^{cu} + \sum_{i=1}^{3} \tilde{z}_i \tilde{Q}_i^{cu}\right)}$$

$L \leftrightarrow R.$

$$\begin{aligned}
Q_1^{cu} &= \bar{u}_L^{\alpha}\gamma_\mu c_L^{\alpha}\bar{u}_L^{\beta}\gamma^\mu c_L^{\beta} \\
Q_2^{cu} &= \bar{u}_R^{\alpha}c_L^{\alpha}\bar{u}_R^{\beta}c_L^{\beta}, \\
Q_3^{cu} &= \bar{u}_R^{\alpha}c_L^{\beta}\bar{u}_R^{\beta}c_L^{\alpha}, \\
Q_4^{cu} &= \bar{u}_R^{\alpha}c_L^{\alpha}\bar{u}_L^{\beta}c_R^{\beta}, \\
Q_5^{cu} &= \bar{u}_R^{\alpha}c_L^{\beta}\bar{u}_L^{\beta}c_R^{\alpha},
\end{aligned}$$



$\mu \le 1$ TeV

$\mu \simeq 1$ GeV

RG running of Wilson coefficients relates NP from higher scale up to the 1 GeV

$$\left.\begin{array}{l}
|z_1| \lesssim 5.7 \times 10^{-7} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2 \\
|z_2| \lesssim 1.6 \times 10^{-7} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2 \\
|z_3| \lesssim 5.8 \times 10^{-7} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2 \\
|z_4| \lesssim 5.6 \times 10^{-8} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2 \\
|z_5| \lesssim 1.6 \times 10^{-7} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2
\end{array}\right\}
\begin{array}{c}
\\ \\ \\
x_{12}^{\rm NP} \lesssim 0.012 \\
x_{12}^{\rm NP} \sin\phi_{12}^{\rm NP} \lesssim 0.0022
\end{array}
\left\{\begin{array}{l}
\mathcal{I}m(z_1) \lesssim 1.1 \times 10^{-7} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2 \\
\mathcal{I}m(z_2) \lesssim 2.9 \times 10^{-8} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2 \\
\mathcal{I}m(z_3) \lesssim 1.1 \times 10^{-7} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2 \\
\mathcal{I}m(z_4) \lesssim 1.1 \times 10^{-8} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2 \\
\mathcal{I}m(z_5) \lesssim 3.0 \times 10^{-8} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2
\end{array}\right.$$

Isidori, Nir, Perez, 1002.0900

Gedalia et al. 0906.1879,
Golowich et al, 0705.3650; Bigi et al. 0904.1545,
Altmannshofer et al. 0909.1333, 1001.3835

Direct CP violation in charm meson decays

2011/12 New Results

$$\Delta a_{CP} = \frac{\Gamma(D^0 \to f) - \Gamma(\bar{D}^0 \to \bar{f})}{\Gamma(D^0 \to f) + \Gamma(\bar{D}^0 \to \bar{f})} = a_{CP}^{dir}(f) + \underbrace{\frac{<t>_f}{\tau_{D^0}} a_{CP}^{ind}}_{\text{negligible}}$$

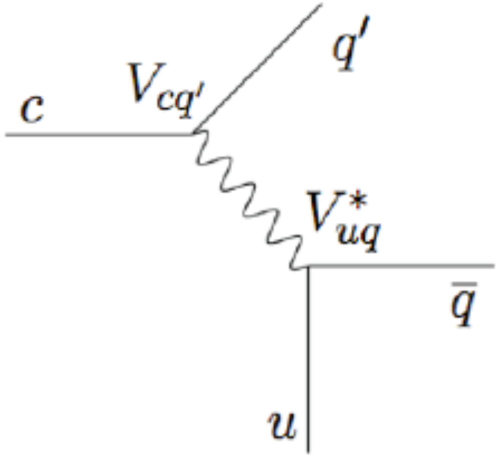
$$\Delta a_{CP} = a_{CP}(K^+K^-) - a_{CP}(\pi^+\pi^-) = \begin{cases} [-0.82 \pm 0.21 \pm 0.11]\% & \text{LHCb result} \\ [-0.62 \pm 0.21 \pm 0.10]\% & \text{CDF (combined individual results)} \end{cases}$$

$$\boxed{\Delta a_{CP}^{W} = [-0.645 \pm 0.180]\%}$$

(HFAG)

There are individual measurements of A_{CP} by BaBar, Belle and CLEO, (very large errors)!

Nonleptonic charm weak decays



$q, q' = s, d$

- Cabibbo allowed q'=s, q=d;

$\boxed{A_T \sim V_{cs} V_{ud} \sim 1}$ $\quad D^0 \to K^- \pi^+$

- Cabibbo single suppressed q'=s(d) , q=s (d);

$\boxed{A_T \sim V_{cs} V_{us}, \;\; V_{cd} V_{ud} \sim \lambda}$ $D^0 \to \pi^- \pi^+, \;\; D^0 \to K^- K^+$

- Cabibbo double suppressed q'=d , q=s'

$\boxed{A_T \sim V_{cd} V_{us} \sim \lambda^2}$ $\quad D^0 \to \pi^- K^+$

$$\mathcal{H}^q_{|\Delta c|=1} = \frac{G_F}{\sqrt{2}} \sum_{i=1,2} C^q_i Q^s_i + \text{H.c.}\,, \qquad q = s, d,$$
$$Q^q_1 = (\bar{u}q)_{V-A}\,(\bar{q}c)_{V-A}\,,$$
$$Q^q_2 = (\bar{u}_\alpha q_\beta)_{V-A}\,(\bar{q}_\beta c_\alpha)_{V-A}\,,$$

It looks simple, however
no reliable framework!
(e.g. Buccella et al.,
PRD 51, (1995) 3478 - FSI)

SCS decays charm meson decays

$$\begin{aligned} A_f(D \to f) &= A_f^T[1 + r_f e^{i(\delta_f - \gamma)}] \\ \bar{A}_{\bar{f}}(\bar{D} \to \bar{f}) &= A_f^T[1 + r_f e^{i(\delta_f + \gamma)}] \end{aligned}$$

strong phase

tree level amplitude

penguin/tree contribution

Direct CP asymmetry

$$\boxed{a_f^{dir} = \frac{|A_f|^2 - |\bar{A}_{\bar{f}}|^2}{|A_f|^2 + |\bar{A}_{\bar{f}}|^2} = 2r_f sin\gamma\, sin\delta_f}$$

$sin\gamma = 0.9$ for $\delta_f \sim O(1)$

$$\boxed{a_f^{dir} \sim 2r_f}$$

SM features of CPV in D

- CPV in D - D̄ mixing suppressed due to $\mathcal{O}(V_{cb}V_{ub}^*/V_{cs}V_{us}^*) \sim 10^{-3}$
- direct CPV suppressed due to $\mathcal{O}([V_{cb}V_{ub}^*/V_{cs}V_{us}^*]\alpha_s/\pi) \sim 10^{-4}$

Are there any possibility that direct CPV is increased within SM?

Exp. $$\left\{ \begin{array}{l} a_{K^+K^-} = (-0.23 \pm 0.17)\% \\ a_{\pi^+\pi^-} = (0.20 \pm 0.22)\% \end{array} \right\}$$

Brod, Kagan, Zupan, 1111.600
Franco, Mishima, Silvestrini 1203.3131
Bhattacharaya, Gronau, Rosner 1201.2351
Bigi and Paul, 1110.2862
Goldenand Grinstein, PLB 222 (1989) 501.

SU(3) fits (Chiang, Cheng, 1001.0987, 1201.0785; Bhattacharaya, Gronau, Rosner 1201.2351; Pirtskhalava, Uttayarat 1112.5451)

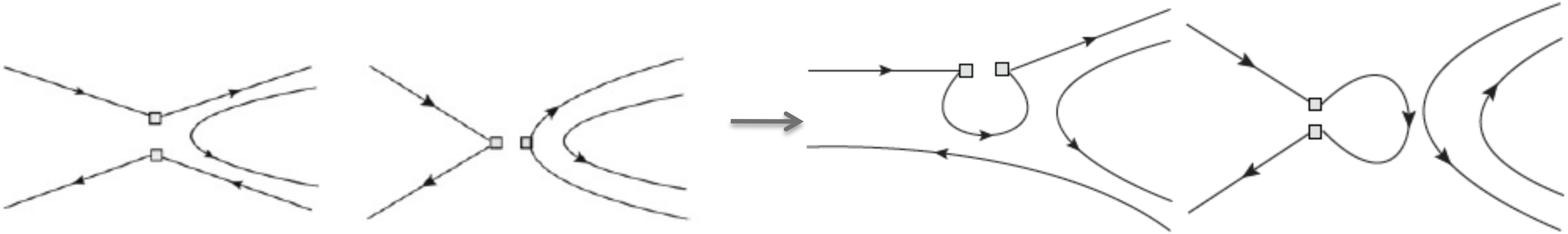
for max. strong phase: $\Delta a_{CP} = 4r_f \xrightarrow{\hspace{2cm}} r_f \sim 0.15\%$

naive estimation $r_f \sim \mathcal{O}([V_{cb}V_{ub}^*/V_{cs}V_{us}^*]\alpha_s/\pi) \sim 0.01\%$

- Wilson coefficients - perturbative; (Brod, Kagan, Zupan)
- matrix elements – leading term + power corrections $1/m_c$
- tree amplitudes from experiment;
- relate penguin amplitudes to tree amplitudes

$$r^{\mathrm{LP}} \equiv \left| \frac{A^P(\text{leading power})}{A^T(\text{exp})} \right|$$

using naive factorisation + $O(\alpha_s)$, rough estimate



$$\begin{aligned} A_K &= \lambda_s(A_K^s - A_K^d) + \lambda_b(A_K^b - A_K^d) \\ A_\pi &= \lambda_s(A_\pi^s - A_\pi^s) + \lambda_b(A_\pi^b - A_\pi^s) \end{aligned}$$

$$\lambda_q = V_{cq}V_{uq}^*$$

using CKM unitarity $\lambda_s + \lambda_d + \lambda_b = 0$

These tree topologies do not give A_K^d, A_π^s

"Penguin contraction" create A_K^d, A_π^s

SM explanation possible!

$$\boxed{\Delta a_{CP} = (0.05 - 0.1)\%}$$

This model leads to explanation of long-standing puzzle

$$\boxed{\mathrm{Br}(D^0 \to K^+K^-) \approx 2.8 \times \mathrm{Br}(D^0 \to \pi^+\pi^-)}$$

Brod, Kagan, Zupan (arxive:1203.6659)

General isospin parametrization

Franco, Mishima, Silvestrini, (1203.3131)

$$A(D^+ \to \pi^+\pi^0) = \frac{\sqrt{3}}{2}\mathcal{A}_2^\pi\,,$$

$$A(D^0 \to \pi^+\pi^-) = \frac{\mathcal{A}_2^\pi - \sqrt{2}(\mathcal{A}_0^\pi + i r_{\mathrm{CKM}}\mathcal{B}_0^\pi)}{\sqrt{6}}\,,$$

$$A(D^0 \to \pi^0\pi^0) = \frac{\sqrt{2}\mathcal{A}_2^\pi + \mathcal{A}_0^\pi + i r_{\mathrm{CKM}}\mathcal{B}_0^\pi}{\sqrt{3}}\,,$$

$$A(D^+ \to K^+\bar{K}^0) = \frac{\mathcal{A}_{13}^K}{2} + \mathcal{A}_{11}^K + i r_{\mathrm{CKM}}\mathcal{B}_{11}^K\,,$$

$$A(D^0 \to K^+K^-) = \frac{-\mathcal{A}_{13}^K + \mathcal{A}_{11}^K - \mathcal{A}_0^K + i r_{\mathrm{CKM}}\mathcal{B}_{11}^K - i r_{\mathrm{CKM}}\mathcal{B}_0^K}{2}\,,$$

$$A(D^0 \to K^0\bar{K}^0) = \frac{-\mathcal{A}_{13}^K + \mathcal{A}_{11}^K + \mathcal{A}_0^K + i r_{\mathrm{CKM}}\mathcal{B}_{11}^K + i r_{\mathrm{CKM}}\mathcal{B}_0^K}{2}\,.$$

$\mathcal{A}(\mathcal{B})$ CP even(odd)

$$|\mathcal{A}_2^\pi| = (3.08 \pm 0.08) \times 10^{-7}\ \mathrm{GeV}\,,$$

$$|\mathcal{A}_0^\pi| = (7.6 \pm 0.1) \times 10^{-7}\ \mathrm{GeV}\,,$$

$$\arg(\mathcal{A}_2^\pi/\mathcal{A}_0^\pi) = (\pm 93 \pm 3)^\circ\,.$$

re-scattering constrains the I=0 amplitudes in the ππ and KK channels

With the present accuracy, observed asymmetries are marginally compatible with SM.

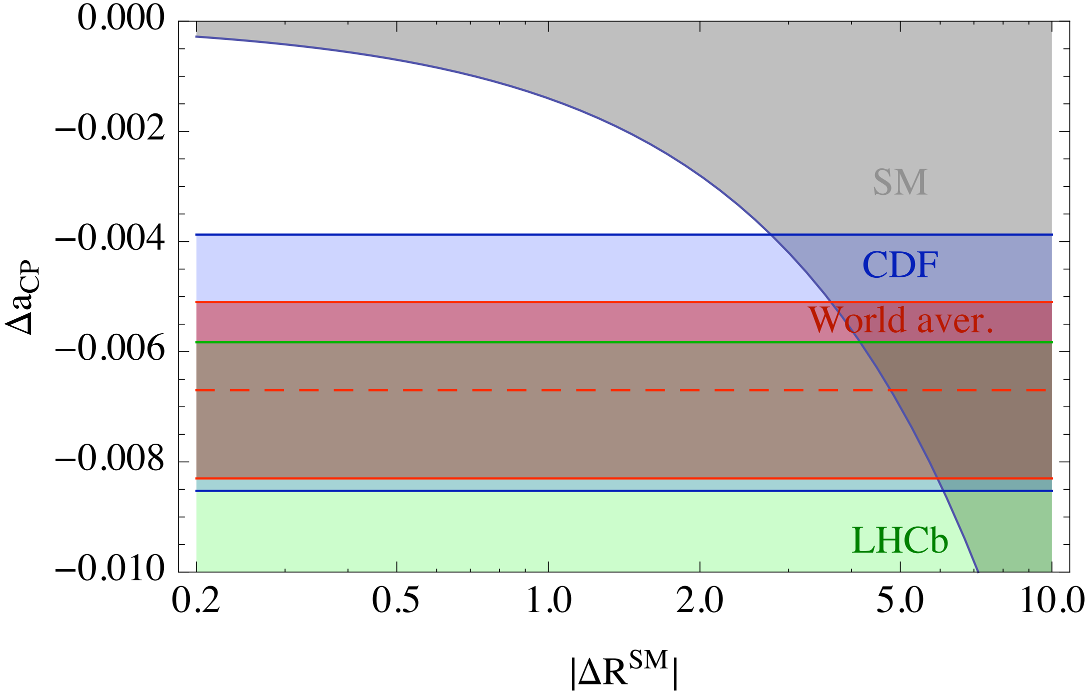
New physics possibilities in CPV charm decays

$$R_K^{SM} = \frac{A_K^b - A_K^d}{A_K^s - A_K^d},$$

$$R_\pi^{SM} = \frac{A_\pi^b - A_\pi^s}{A_\pi^s - A_\pi^s}$$

$$\Delta a_{CP} \simeq 0.13\% Im(\Delta R^{SM})$$

$$\Delta R^{SM} = R_K^{SM} + R_\pi^{SM}$$



(Kamenik's figure)
Isidori, Kamenik, Ligeti and Perez, 1111.600

In order to explain experimental result $\Delta R^{SM} \sim O(2-5)$

Isidori, Kamenik, Ligeti, Perez, 1111.4987

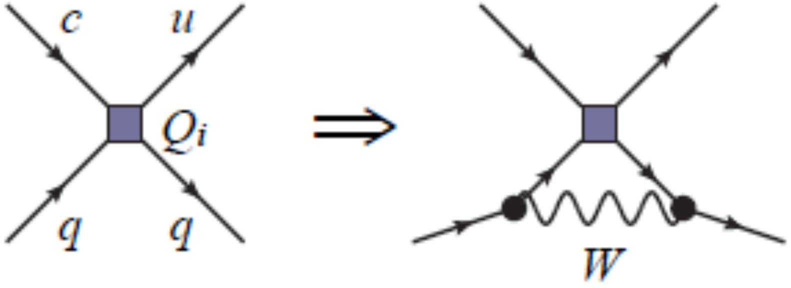
$$\begin{aligned}
\mathcal{H}^{q}_{|\Delta c|=1} &= \frac{G_F}{\sqrt{2}} \sum_{i=1,2} C_i^q Q_i^s + \text{H.c.}\,, \qquad\qquad q = s, d, \\
Q_1^q &= (\bar{u} q)_{V-A}\, (\bar{q} c)_{V-A}\,, \\
Q_2^q &= (\bar{u}_\alpha q_\beta)_{V-A}\, (\bar{q}_\beta c_\alpha)_{V-A}\,,
\end{aligned}$$

$$\begin{aligned}
\mathcal{H}^{\text{eff}-\text{NP}}_{|\Delta c|=1} &= \frac{G_F}{\sqrt{2}} \sum_{i=1,2,5,6} \sum_{q} (C_i^q Q_i^q + C_i^{q\prime} Q_i^{q\prime}) \\
&+ \frac{G_F}{\sqrt{2}} \sum_{i=7,8} (C_i Q_i + C_i' Q_i') + \text{H.c.}\,,
\end{aligned}$$

$$\begin{aligned}
Q_5^q &= (\bar{u} c)_{V-A}\, (\bar{q} q)_{V+A}\,, \\
Q_6^q &= (\bar{u}_\alpha c_\beta)_{V-A}\, (\bar{q}_\beta q_\alpha)_{V+A}\,, \\
Q_7 &= -\frac{e}{8\pi^2}\, m_c\, \bar{u} \sigma_{\mu\nu} (1+\gamma_5) F^{\mu\nu}\, c\,, \\
Q_8 &= -\frac{g_s}{8\pi^2}\, m_c\, \bar{u} \sigma_{\mu\nu} (1+\gamma_5) T^a G_a^{\mu\nu}\, c\,,
\end{aligned}$$

$$\boxed{\Delta a_{CP} \approx (0.13\%)\text{Im}(\Delta R^{\text{SM}}) + 8.9 \sum_i \text{Im}(C_i^{\text{NP}})\, \text{Im}(\Delta R_i^{\text{NP}})}$$

$$\Delta R^{\text{SM,NP}} = R_K^{\text{SM,NP}} + R_\pi^{\text{SM,NP}}$$



highly UV sensitive, model dependent

- LL 4q operators excluded;
- LR 4q operators still allowed – possible effect in D - $\bar{D}$ and ε'/ε;
- RR 4q operators unconstrained in EFT.

D^0 – $\bar{D}^0$ oscillation and ε'/ε (CPV in K→ππ give important constraints on the size of direct CPV in charm decays)

Interesting result (Gedalia, Kamenik, Perez 1202.5038) on universality of |Δ F=1| left-left operators, charm and kaon physics dominated by 2 generations

$$\mathcal{O}_L = \left[(X_L)^{ij} \, \overline{Q}_i \gamma^\mu Q_j \right] L_\mu$$

$$\boxed{\mathrm{Im}(X_L^u)_{12} = \mathrm{Im}(X_L^d)_{12} \propto \mathrm{Tr}\,(X_L \cdot J)}$$

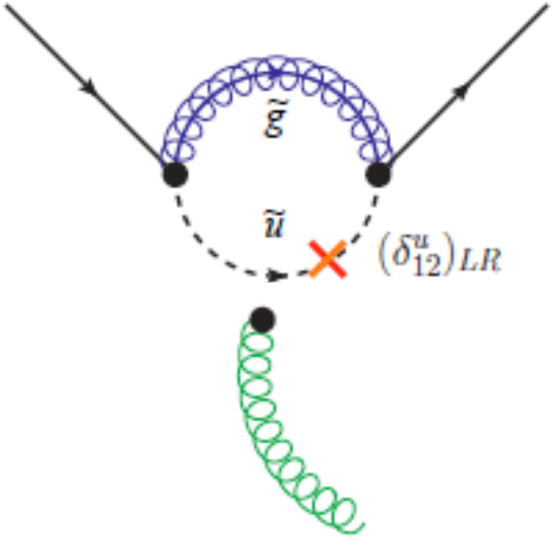
$$\mathrm{Br}(K_L \to \pi^0 e^+ e^-) < 2.8 \times 10^{-10} \quad \text{(mostly CPV process)}$$

$$\Downarrow$$

$$a_e^D \equiv \frac{\mathrm{Br}(D^+ \to \pi^+ e^+ e^-) - \mathrm{Br}(D^- \to \pi^- e^+ e^-)}{\mathrm{Br}(D^+ \to \pi^+ e^+ e^-) + \mathrm{Br}(D^- \to \pi^- e^+ e^-)} \lesssim 0.02$$

SUSY Models

Grossman, Kagan, Nir
hep-ph/0609178,
Giudice, Isidori, Paradisi 1201.6204,



general parametrization of NP $\Delta C = 1$
chromomagnetic (imaginary) operator
is not constraint

$$|\Delta a_{CP}^{\rm SUSY}| \approx 0.6\% \left(\frac{|{\rm Im}\,(\delta^u_{12})_{LR}|}{10^{-3}}\right)\left(\frac{\rm TeV}{\tilde{m}}\right)$$

SUSY models: “primary source of flavor violation comes from large LR squark mixing (Giudice, Isidori, Paradisi 1201.6204)

1) “disoriented A-terms” (universality in squark masses and trilinear terms are proportional to corresponding Yukawa matrix;
2) split families.

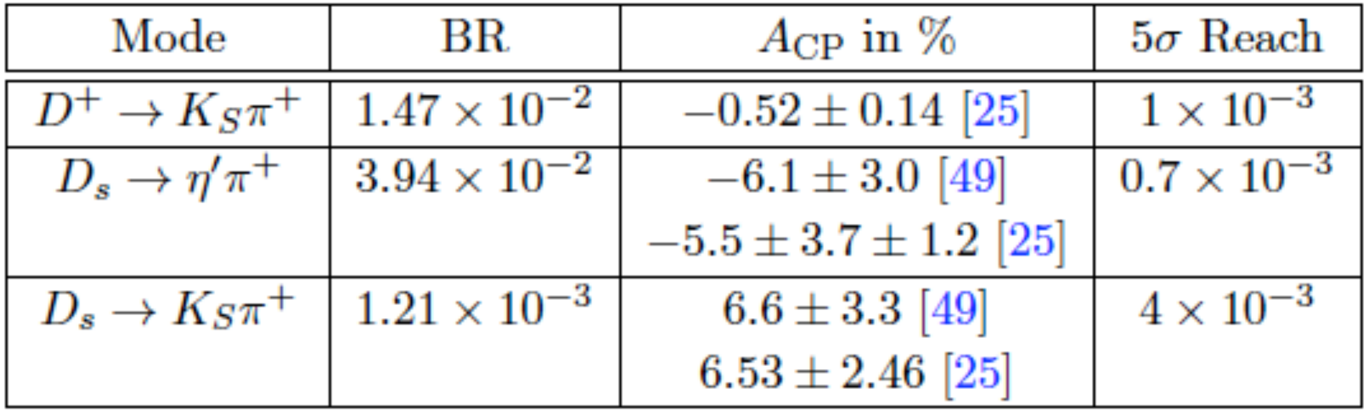
Both scenarios passed all other constraints EDM, FCNC top decays, rare B decays…

4^{th} generation

3 gen CKM non-unitarity + b' penguin: (Feldman, Nandi, Soni, 1202.3795)

$\Delta a_{CP} \propto 4\,\mathrm{Im}\left[\frac{\lambda_{b'}}{\lambda_d - \lambda_s}\right]$ size of this contribution can as large as SM onre

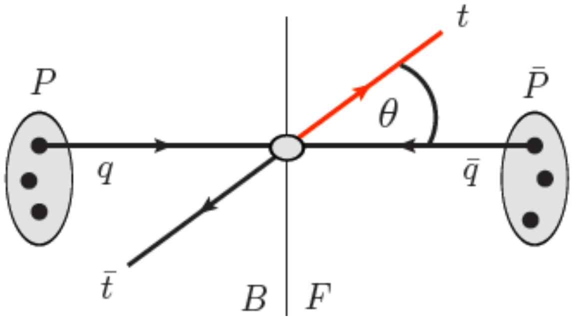
Branching ratios for $D^0 \to \pi^+\pi^-, \pi^+K^-, K^+K^-$ require U-spin violation O(1) from LD dynamics



Mode	BR	$A_{\rm CP}$ in %	5σ Reach
$D^+ \to K_S\pi^+$	1.47×10^{-2}	-0.52 ± 0.14 [25]	1×10^{-3}
$D_s \to \eta'\pi^+$	3.94×10^{-2}	-6.1 ± 3.0 [49] $-5.5 \pm 3.7 \pm 1.2$ [25]	0.7×10^{-3}
$D_s \to K_S\pi^+$	1.21×10^{-3}	6.6 ± 3.3 [49] 6.53 ± 2.46 [25]	4×10^{-3}

5σ possible if LHCb will produce 10^9 charm mesons

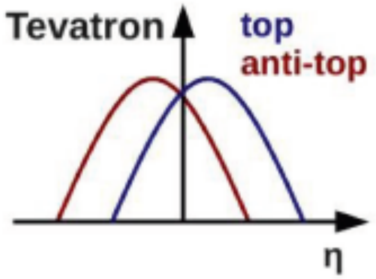
Top-quark physics ⟷ charm physics



Double top production at Tevatron

$$\sigma_F \equiv \int_0^1 \frac{d\sigma}{d\cos\theta} d\cos\theta, \qquad \sigma_B \equiv \int_{-1}^0 \frac{d\sigma}{d\cos\theta} d\cos\theta$$

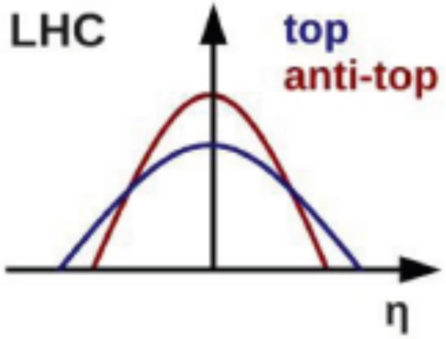
Forward-backward asymmetry



$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

$$\Delta y = y_t - y_{\bar{t}}$$

Double top production at LHC

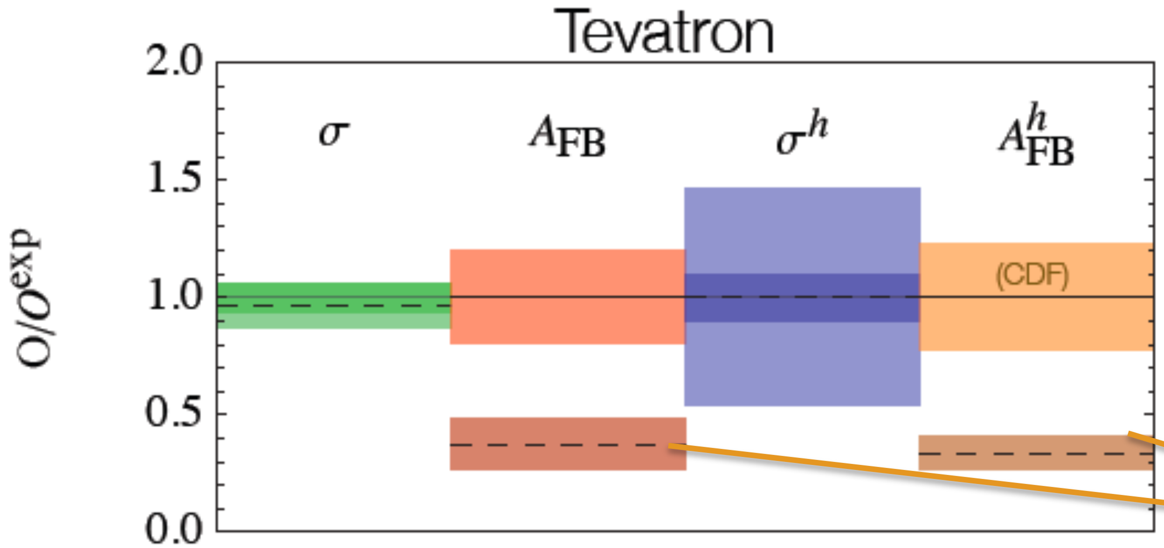


Charged asymmetry

$$A_C = \text{sign}(Y) \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{N(\Delta y^2 > 0) - N(\Delta y^2 < 0)}{N(\Delta y^2 > 0) + N(\Delta y^2 < 0)}$$

$$Y = y_t + y_{\bar{t}}$$

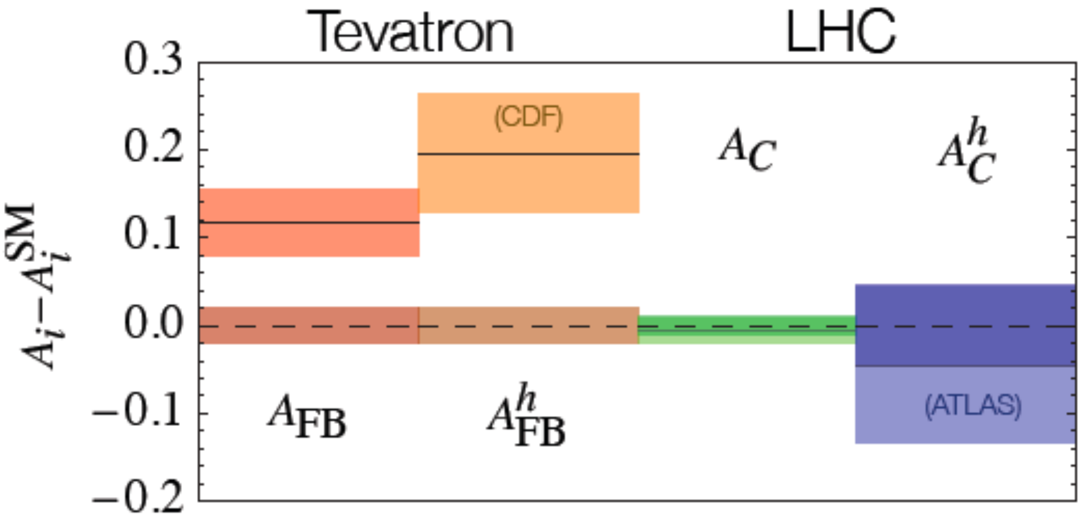
$$\Delta y^2 = y_t^2 - y_{\bar{t}}^2$$



Kuhn and Rodrigo, hep-ph/9807420, 1109.6830
Kidonakis, 1009.4935, 1105.3481
Beneke et al, 1109.1536
Ahrens et al, 1003.5827

$\sim 2.8\,\sigma$

$\sigma^h = \sigma(700\mathrm{GeV} < m_{t\bar{t}} < 800\mathrm{GeV})$ $A^h_{FB} = A_{FB}(m_{t\bar{t}} > 450\mathrm{GeV})$



$A_C = 0.001 \pm 0.014$ *

$A^h_C = -0.008 \pm 0.047$ (ATLAS)

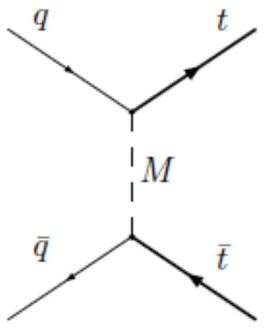
ATLAS: no deviations from SM!

Are there any consequences of Tevatron anomaly in double top production on charm physics?

existing scenarios explaining anomaly in $t\bar{t}$ production:

- axigluon → s-channel
- color triplet → u-channel
- color sextet
- doublet
- W’
- Z’

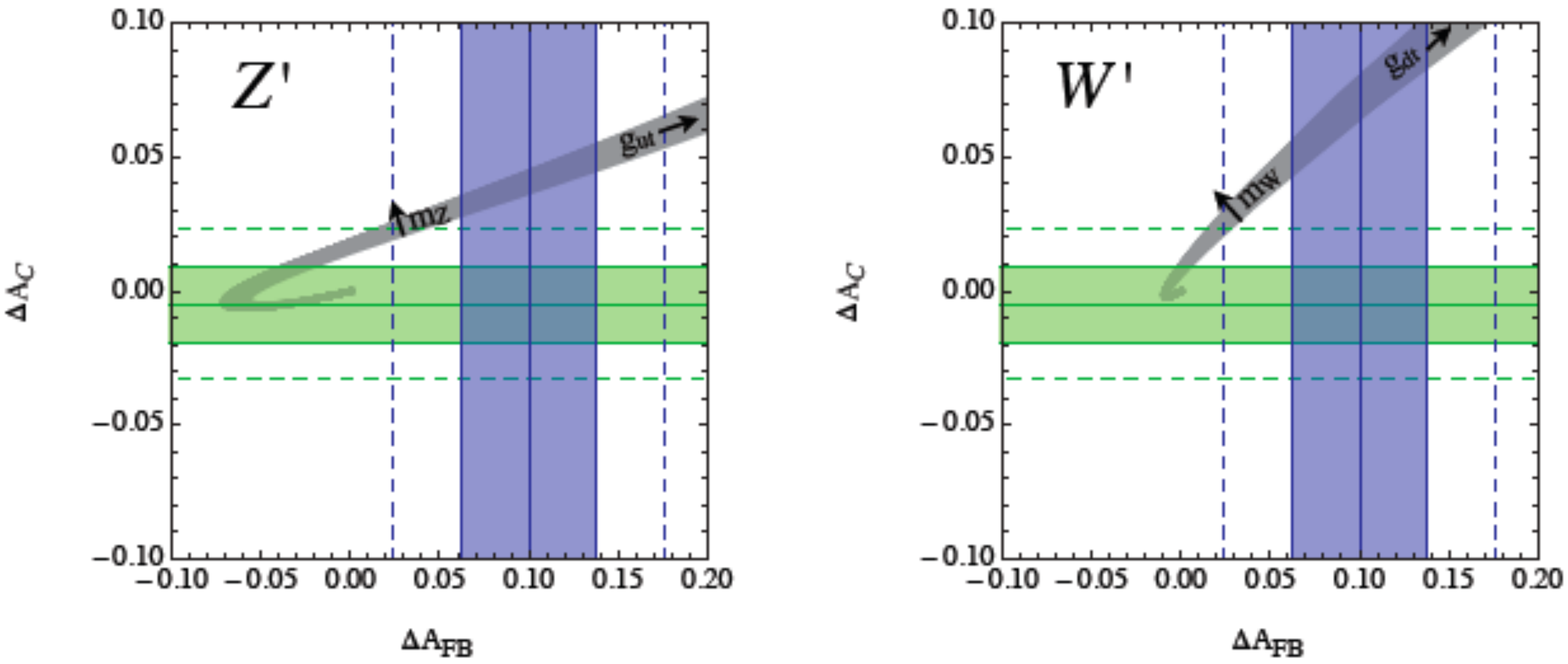
color sextet, doublet, W’, Z’ → t-channel



Our recent fit of SM + NP:(S.F., JF. Kamenik and B. Melic in preparation)
Forward-backward asymmetry, charge asymmetry at Atlas, cross-section at Tevatron

A: $\sigma^{h}_{\mathrm{TEV}} = (80 \pm 0.37)\,\mathrm{fb}$ next-to-last bin $m_{t\bar{t}} \in [700, 800]\ \mathrm{GeV}$

B: $m_{t\bar{t}}$ bin spectrum at CDF, no cross - section



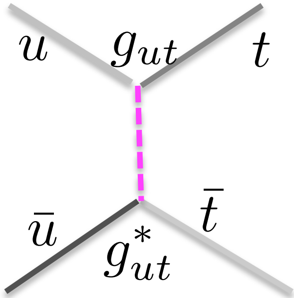
Z’ and W’ cannot satisfy both results Tevatrpn A_{FB} and A_c

Viable NP scenarios explaining observed anomaly top – anti-top production: axigluon, in the both cases A and B, scalar doublet, colored triplet and sextet are good candidate for NP in the case B (the CDF result on invariant mass spectrum is not taken into account)!

Comparison of NP in $t\bar{t}$ production an charm physics

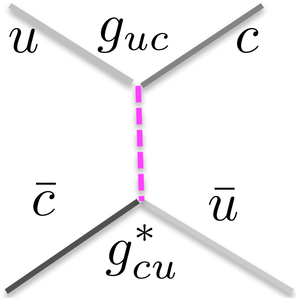
both contribution a tree level:

$u\bar{u} \to t\bar{t}$



Z', sextet,...

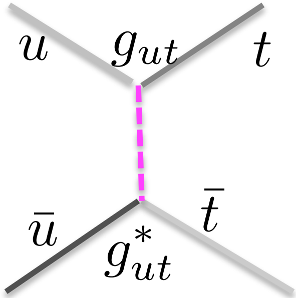
$D^0 - \bar{D}^0$



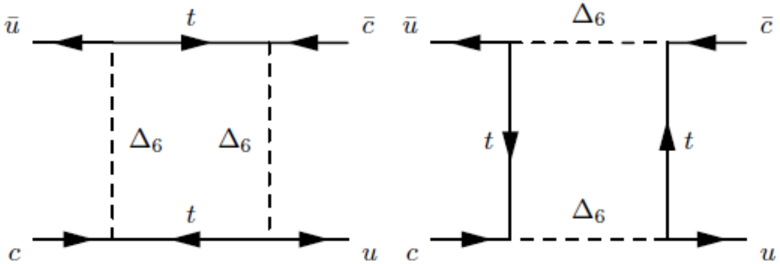
$\boxed{|g_{ut}| \simeq 1}$

$\boxed{|g_{uc}| \sim 0.01}$

tree and box



triplet



$\boxed{|g_{uc}| \ll |g_{ut}|}$

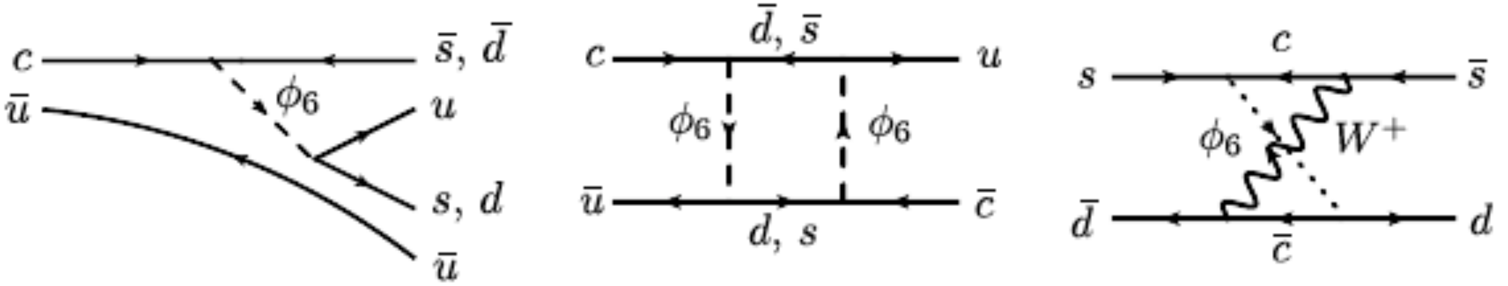
$x_{12} < 9.6 \cdot 10^{-3}$

$x_{12}|sin\Phi_{12}| < 4.4 \cdot 10^{-3}$

Dorsner, S.F. J.F.Kamenik, Kosnik,
1007.2604

Color sextet in CPV in D – $\bar{D}$ mixing

Altmanshofer et al, 1202. 2866

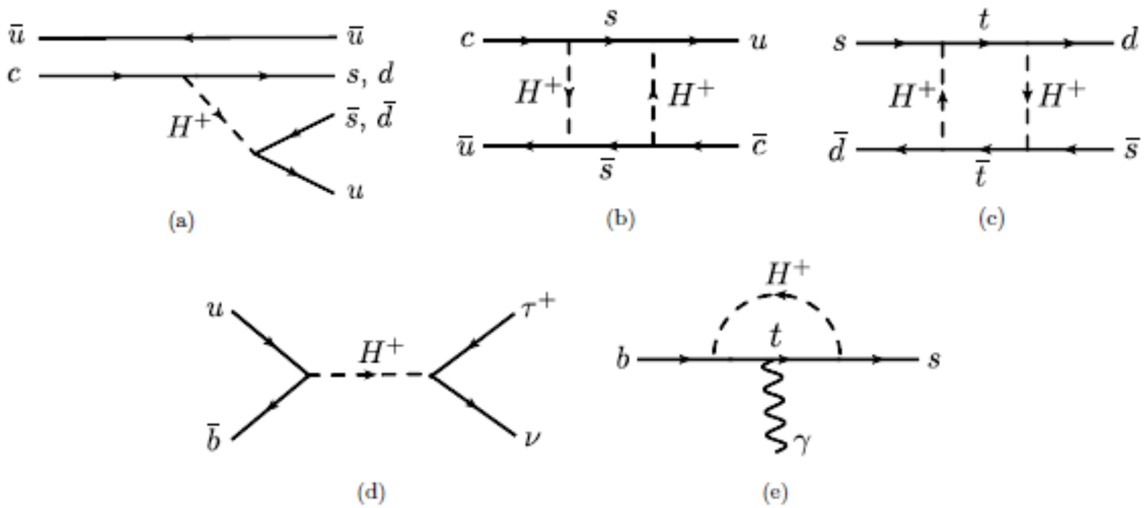


Constraints from direct CPV in charm, kaon mixing and ε'/ε cannot be simultaneously satisfied!

2HDM

Altmanshofer et al, 1202. 2866

Direct CP asymmetry possible to obtain for low charged Higgs mass and the large $\tan\beta \sim \mathcal{O}(100)$



New scalar doublet

$$\Phi \sim (1,2)_{-1/2} = \begin{pmatrix} \phi^0 \\ \phi^- \end{pmatrix}$$

Hochberg and Nir, 1112.5268

Direct CP in D decays and A_{FB} in $t\bar{t}$

scalar doublet contributes to CPV ΔA_{CP} at tree level!

For $t\bar{t}$

$$u\bar{u} \to t\bar{t}$$

$$X_{13} q_{l1}^\dagger \Phi t_R, \quad X_{31} q_{l1}^\dagger \Phi u_R$$

constraints from

$$\overbrace{K^0 - \bar{K}^0, \quad D^0 - \bar{D}^0}$$

Possible to explain Tevatron anomaly and direct CPV in charm!

Perspective for CPV in charm decays

- to improve precision in measurements of ΔA_{CP} for D -> KK and D -> ππ

- In decays $\left\{\begin{array}{l} D^0 \to K^{*\pm}K^{\mp}, \;\; D^0 \to \rho^{\pm}\pi^{\mp} \\ D^+ \to \Phi\pi^+, \;\; D_s^+ \to \Phi K^+ \end{array}\right.$ the same operators appear

- to determine asymmetries in D three body decays

Summary

- lattice and experiment good agreement in leptonic charm decays.

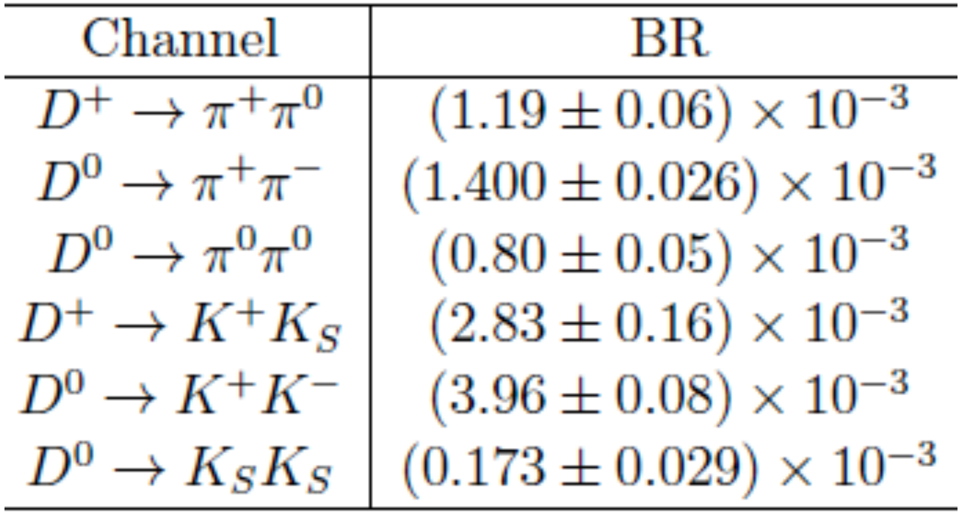
- 2.8 σ deviation of observed CPV in charm decays:
- dilemma: SM effect or NP?

- correlations of NP in D oscillations and CPV D decays;
- interplay of NP in B, K and charm.

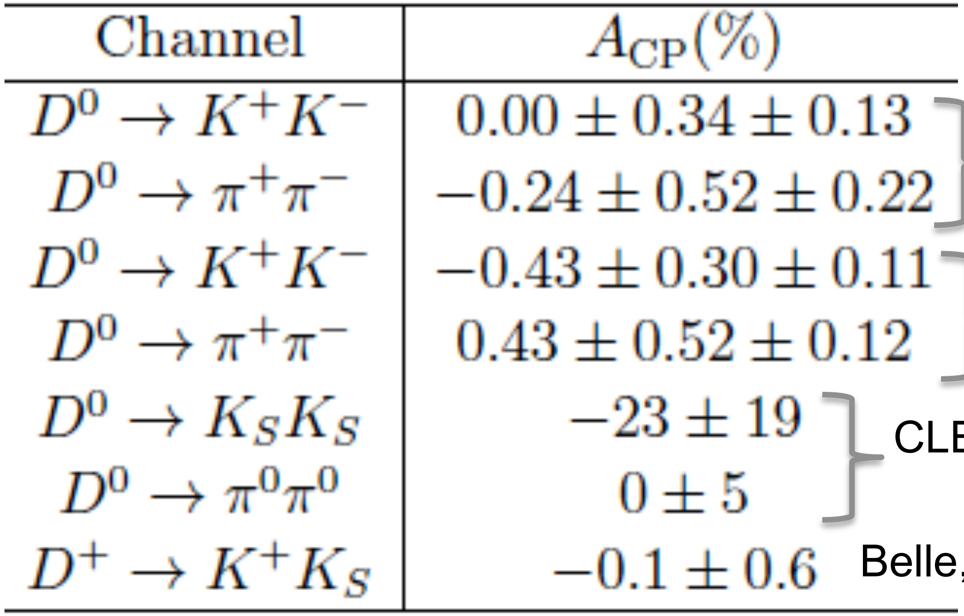
-experimental results in double top production – new possibilities for NP in the up - quark sector!

- are the any consequence on the charm?

Experimental results



Channel	BR
$D^+ \to \pi^+\pi^0$	$(1.19 \pm 0.06) \times 10^{-3}$
$D^0 \to \pi^+\pi^-$	$(1.400 \pm 0.026) \times 10^{-3}$
$D^0 \to \pi^0\pi^0$	$(0.80 \pm 0.05) \times 10^{-3}$
$D^+ \to K^+K_S$	$(2.83 \pm 0.16) \times 10^{-3}$
$D^0 \to K^+K^-$	$(3.96 \pm 0.08) \times 10^{-3}$
$D^0 \to K_SK_S$	$(0.173 \pm 0.029) \times 10^{-3}$



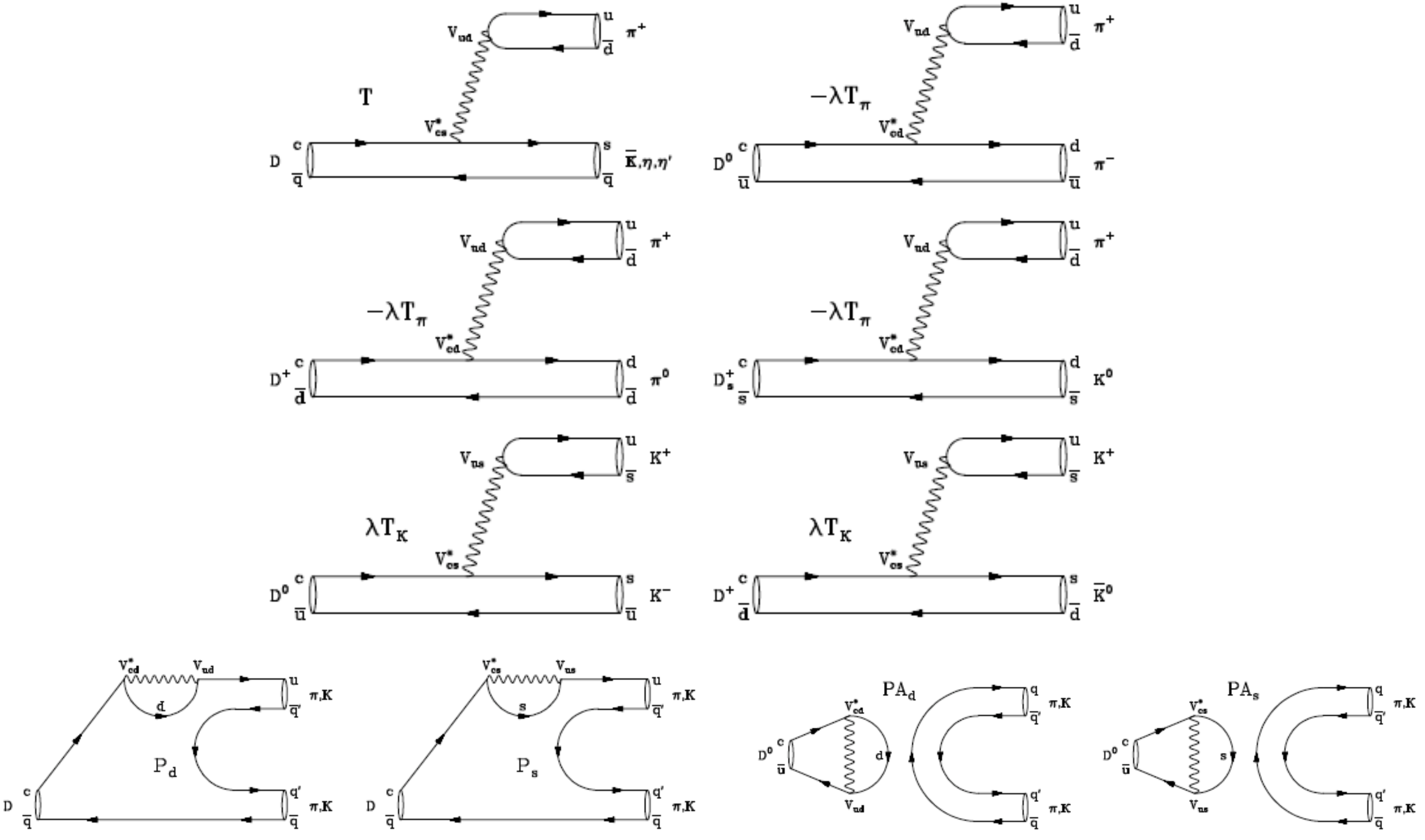
Channel	$A_{\rm CP}(\%)$
$D^0 \to K^+K^-$	$0.00 \pm 0.34 \pm 0.13$
$D^0 \to \pi^+\pi^-$	$-0.24 \pm 0.52 \pm 0.22$
$D^0 \to K^+K^-$	$-0.43 \pm 0.30 \pm 0.11$
$D^0 \to \pi^+\pi^-$	$0.43 \pm 0.52 \pm 0.12$
$D^0 \to K_SK_S$	-23 ± 19
$D^0 \to \pi^0\pi^0$	0 ± 5
$D^+ \to K^+K_S$	-0.1 ± 0.6

BaBar,0709.2571

Belle,0807.0148

CLEO,hep-ex/ 0012054

Belle, 1001.3202, PDG 2010



Bhattacharaya, Gronau, Rosner 1201.2351