New Physics Search in D Meson Decays

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Overview

1) Motivation;

2) New physics in charged current transitions;

3) LFV in charm meson semileptonic decays;

4) New physics in FCNC processes;

5) Summary.

Motivation

In B physics there are three puzzles:

1) $$R_{D^{(*)}} = \frac{BR(B \to D^{(*)} \tau \nu_\tau)}{BR(B \to D^{(*)} \mu \nu_\mu)}$$ 3.5σ — charged current

2) P_5' in $B \to K^* \mu^+ \mu^-$ 3σ

3) $$R_K = \frac{\Gamma(B \to K \mu\mu)}{\Gamma(B \to K ee)}$$ in the dilepton invariant mass bin $1\ \mathrm{GeV}^2 \leq q^2 \leq 6\ \mathrm{GeV}^2$ — FCNC

2.6σ

Question: Is there any chance to see NP in charm ?

Charm decays and CKM

(Semi)leptonic charm inputs to the CKM fit

$\mathcal{B}(B^- \to \tau^- \overline{\nu}_\tau)$	$(1.08 \pm 0.21) \times 10^{-4}$
$\mathcal{B}(D_s^- \to \mu^- \overline{\nu}_\mu)$	$(5.57 \pm 0.24) \times 10^{-3}$
$\mathcal{B}(D_s^- \to \tau^- \overline{\nu}_\tau)$	$(5.55 \pm 0.24) \times 10^{-2}$
$\mathcal{B}(D^- \to \mu^- \overline{\nu}_\mu)$	$(3.74 \pm 0.17) \times 10^{-4}$
$\mathcal{B}(K^- \to e^- \overline{\nu}_e)$	$(1.581 \pm 0.008) \times 10^{-5}$
$\mathcal{B}(K^- \to \mu^- \overline{\nu}_\mu)$	0.6355 ± 0.0011
$\mathcal{B}(\tau^- \to K^- \overline{\nu}_\tau)$	$(0.6955 \pm 0.0096) \times 10^{-2}$
$\mathcal{B}(K^- \to \mu^- \overline{\nu}_\mu)/\mathcal{B}(\pi^- \to \mu^- \overline{\nu}_\mu)$	1.3365 ± 0.0032
$\mathcal{B}(\tau^- \to K^- \overline{\nu}_\tau)/\mathcal{B}(\tau^- \to \pi^- \overline{\nu}_\tau)$	$(6.43 \pm 0.09) \times 10^{-2}$
$\mathcal{B}(B_s \to \mu\mu)$	$(2.8^{+0.7}_{-0.6}) \times 10^{-9}$
$\lvert V_{cd}\rvert f_+^{D\to\pi}(0)$	0.148 ± 0.004
$\lvert V_{cs}\rvert f_+^{D\to K}(0)$	0.712 ± 0.007

CKMFitter (using unitarity)

$$|V_{cd}| = 0.22529^{+0.00041}_{-0.00032}$$

$$|V_{cs}| = 0.973394^{+0.000074}_{-0.000096}$$

Direct extraction using lattice (HFAG+FLAG

Leptonic

$$|V_{cd}| = 0.2164(63)$$

$$|V_{cs}| = 1.008(21)$$

Semileptonic

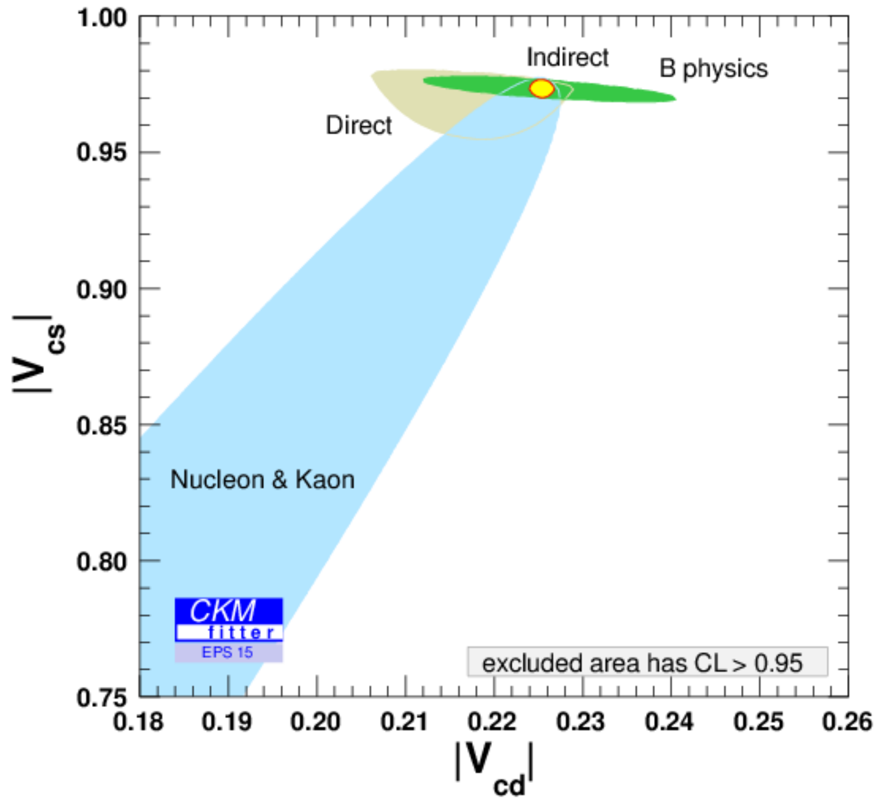
$$|V_{cd}| = 0.214(12)$$

$$|V_{cs}| = 0.975(32)$$

• Great advance in lattice determination of decay constants and form factors enables progress in testing consistency of the SM

• Assuming unitarity of V_{CKM}, the Values of V_{cs} and V_{cd} are dominated by V_{cb} measurement and nuclear & kaon data;

• V_{cs} and V_{cd} values are largely driven by indirect constraints;



Search for NP in charged current transitions (charm mesons)

- Effective Lagrangian approach describing NP in $c \to s l \nu_l$ transition;

  - Pseudoscalar operator
  - Scalar operator

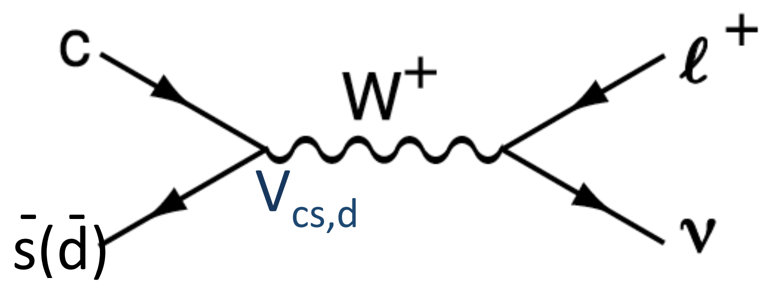
  } Wilson coefficients

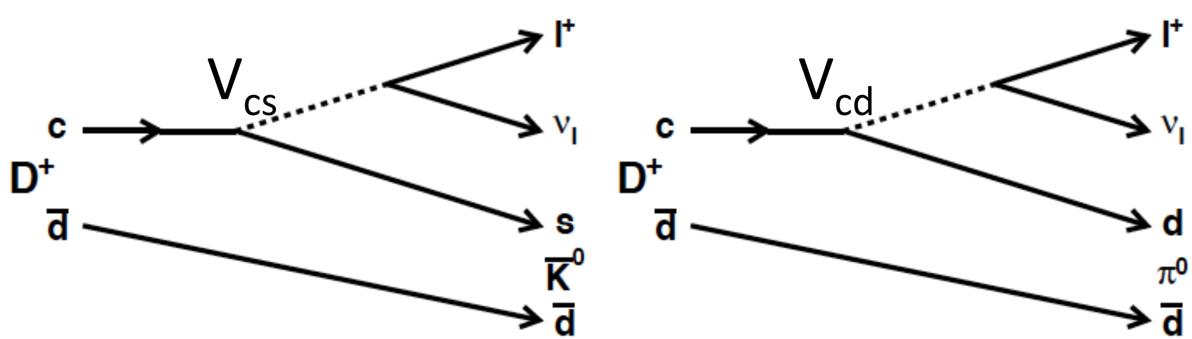
- NP in branching ratios, forward-backward asymmetry transversal muon polarization;

1502.07488, S.F., I. Nišandžić, U. Rojec
1404.0454, J. Barranco et al.,

Why to search for NP in charm meson semileptonic decays?

- Important to know CKM matrix elements V_{cs} and V_{cd};
- High precision results for the decay constants, or form- factors required!
- In $\mathrm{B} \to \mathrm{D}^{(*)} \tau \nu_{\tau}$ observed disagreement of experimental and SM prediction.





Questions for theory:

- Can current precision on charm meson decay constants/form factors enables to search for New Physics in charm?

- What are the most appropriate observables?

Approach:

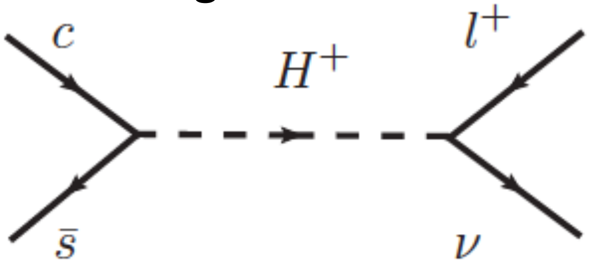
Effective Lagrangian to describe NP in $c \to s l \nu_l$ transition

$$\mathcal{L}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{cs} \sum_{\ell=e,\mu,\tau} \sum_i c_i^{(\ell)} \mathcal{O}_i^{(\ell)} + \mathrm{H.c.}$$

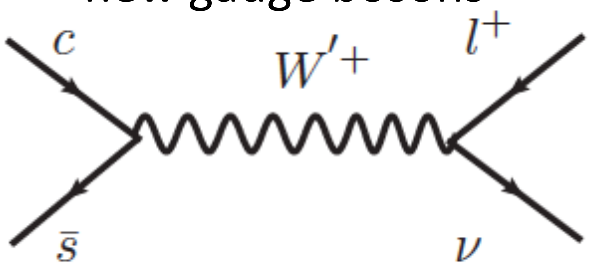
$$\mathcal{O}_{SM}^{(\ell)} = (\bar{s}\gamma_\mu P_L c)(\bar{\nu}_\ell \gamma^\mu P_L \ell) \qquad c_{SM}^{(\ell)} = 1$$

NP proposals in $c \to s l \nu_l$

charged scalar

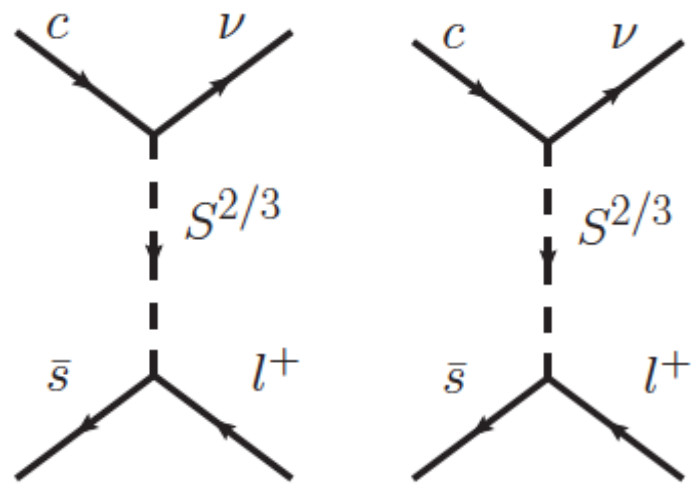


new gauge bosons



J. Barranco et al. 1303.3896;
Akeyrod and Chen, hep-ph/0701078

leptoquarks



e.g.I.Dorsner, S.F.J.F. Kamenik,
N. Kosnik, 0906.5585

$\not{R}$ SUSY A.G. Akeroyd, S. Recksiegel,
hep-ph/0210376.

Simplest proposal for NP - scalar/pseudoscalar operators:

$$\begin{cases} \mathcal{O}^{(\ell)}_{L(R)} = \left(\bar{s} P_{L(R)} c\right)\left(\bar{\nu}_\ell P_R \ell\right) \\ \mathcal{O}^{(\ell)}_{V,R} = \left(\bar{s}\gamma_\mu P_R c\right)\left(\bar{\nu}_\ell \gamma^\mu P_L \ell\right) \end{cases}$$

Examples:

a) THDM type-III, originating from non-holomorpfic Yukawa couplings in the fermion mass-basis;

b) Aligned THDM (Yukawa couplings to neutral scalar flavor diagonal, the complex Yukawa couplings to charged scalar.

New physics might modify branching ratios

$$\mathcal{B}(D_s \to \ell\nu_\ell) = \tau_{Ds}\frac{m_{Ds}}{8\pi} f^2_{Ds}\left(1 - \frac{m_\ell^2}{m_{Ds}^2}\right)^2 G_F^2 \, |V_{cs}|^2 m_\ell^2 \left|1 - c_P^{(\ell)} \frac{m_{Ds}^2}{(m_c + m_s) m_\ell}\right|^2$$

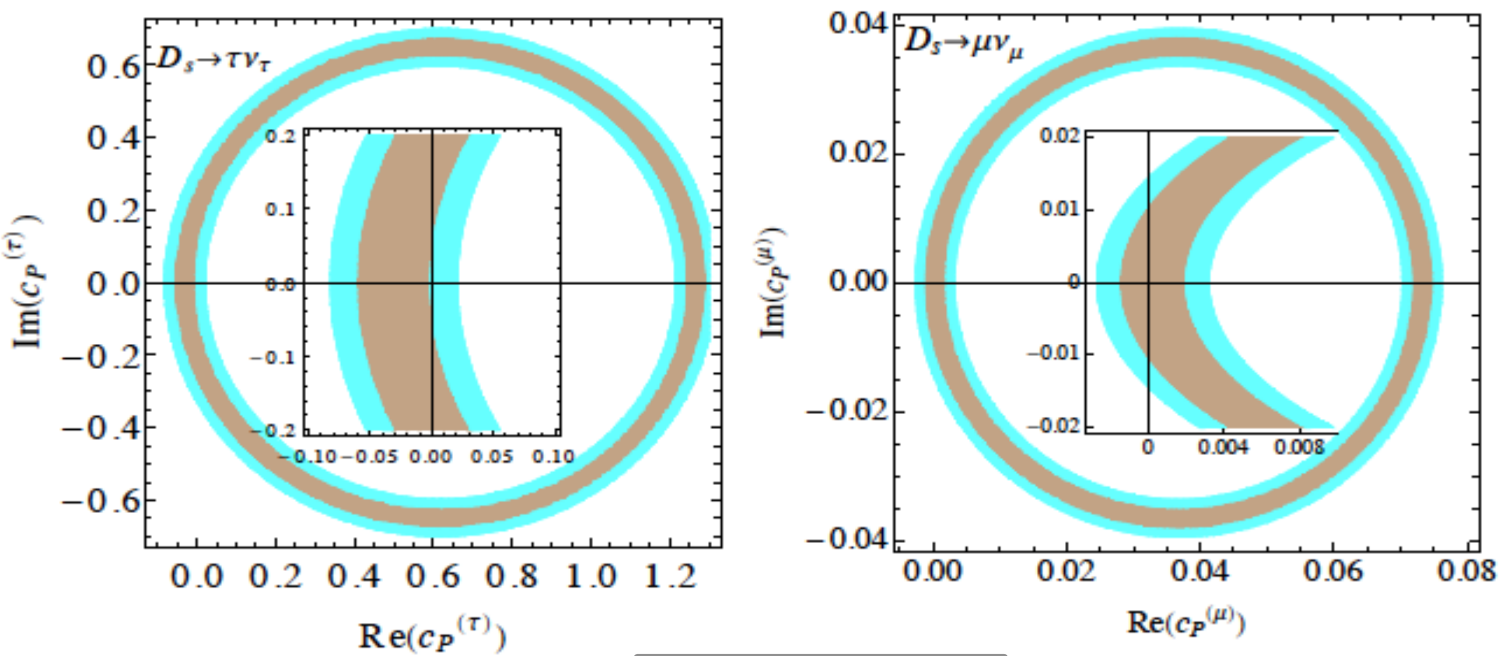
$$c_P^{(\ell)} \equiv c_R^{(\ell)} - c_L^{(\ell)}$$

$$\mathcal{B}(D_s \to \ell\nu_\ell) = \begin{cases} (5.7 \pm 0.21^{+0.31}_{-0.3})\%, & D_s \to \tau\nu_\tau, \\ (0.531 \pm 0.028 \pm 0.020)\%, & D_s \to \mu\nu_\mu, \\ < 1.0 \cdot 10^{-4}\,,\ 95\%\,\text{C.L.}, & D_s \to e\nu_e. \end{cases}$$

For $f_{D_s} = 249.0(0.3)(^{+1.1}_{-1.5})\,\text{MeV}$ (lattice, Fermilab & MILC)

and $V_{cs} = 0.97317^{+0.00053}_{-0.00059}$ obtained from global CKM unitarity fit,

allowed parameter space of new physics coupling:



$$|c_P^{(e)}| < 0.005$$

$D \to K^* l \nu_l$

$c_P^{(l)}$ can contribute to $D \to K^* l \nu_l$ (four form-factors necessary!)

Using helicity formalism:

$$H_\pm(q^2) = \mp \frac{\sqrt{\lambda(m_P^2, m_V^2, q^2)}}{m_P + m_V} V(q^2) + (m_P + m_V) A_1(q^2)$$

$$H_0(q^2) = \frac{1}{2m_V\sqrt{q^2}} \left[(m_P + m_V)(m_P^2 - m_V^2 - q^2) A_1(q^2) - \frac{\lambda(m_P^2, m_V^2, q^2)}{m_P + m_V} A_2(q^2) \right]$$

$$H_t(q^2) = \left[1 - c_P^{(\ell)} \frac{q^2}{m_\ell(m_q + m_{\bar{q}})} \right] \frac{\sqrt{\lambda(m_P^2, m_V^2, q^2)}}{\sqrt{q^2}} A_0(q^2).$$

$c_P^{(l)}$ modifies H_t $\quad H_t \to \left(1 - c_P^{(\ell)} \frac{q^2}{m_\ell(m_c + m_s)} \right) H_t$

Rather weak knowledge of form-factors. FOCUS performed non-parametric measurements of helicity amplitudes (errors too big), hep-ph /0509027; BaBar (1012.1810) single pole parameterization used in our fit: $$\mathrm{R}_{\mathrm{L/T}} = \frac{\Gamma_{\mathrm{L}}}{\Gamma_{\mathrm{T}}}$$

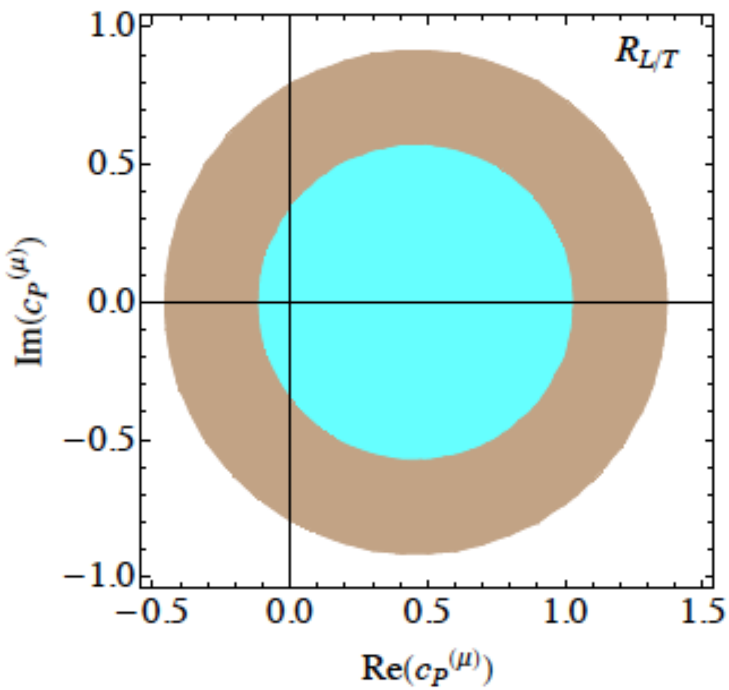
$$V(0)/A_1(0) = 1.463 \pm 0.035$$
$$A_2(0)/A_1(0) = 0.801 \pm 0.03$$
$$A_1(0) = 0.6200 \pm 0.0057.$$

PDG:
$R_{L/T}$ =1.13±0.08

$$\frac{d\Gamma_L}{dq^2} = \mathcal{N}(q^2)\left(1-\frac{m_\ell^2}{q^2}\right)^2\left[(1+\frac{m_\ell^2}{2q^2})|H_0|^2 + \frac{3m_\ell^2}{2q^2}|H_t|^2\right] \quad \frac{d\Gamma_T}{dq^2} = \mathcal{N}(q^2)\left(1-\frac{m_\ell^2}{q^2}\right)^2\left[(1+\frac{m_\ell^2}{2q^2})(|H_+|^2 + |H_-|^2)\right]$$

$$\mathcal{N}(q^2) = G_F^2|V_{cs}|^2 q^2|\mathbf{q}|/(96\pi^3 m_D^2)$$

Not competitive with the constraints coming from pure leptonic decay!



The Wilson coefficient of the scalar operator

NP in $D \to K l \nu_l$

$$\langle K(k')|\bar{s}\gamma_\mu c|D(k)\rangle = f_+(q^2)\left((k+k')_\mu - \frac{m_D^2 - m_K^2}{q^2} q_\mu\right) + f_0(q^2)\frac{m_D^2 - m_K^2}{q^2} q_\mu$$

$$f_+(0) = f_0(0)$$

Helicity amplitudes

$$h_0(q^2) = \frac{\sqrt{\lambda(m_D^2, m_K^2, q^2)}}{\sqrt{q^2}} f_+(q^2)$$

$$h_t(q^2) = \left(1 + c_S^{(l)} \frac{q^2}{m_\ell(m_s - m_c)}\right)\frac{m_D^2 - m_K^2}{\sqrt{q^2}} f_0(q^2)$$

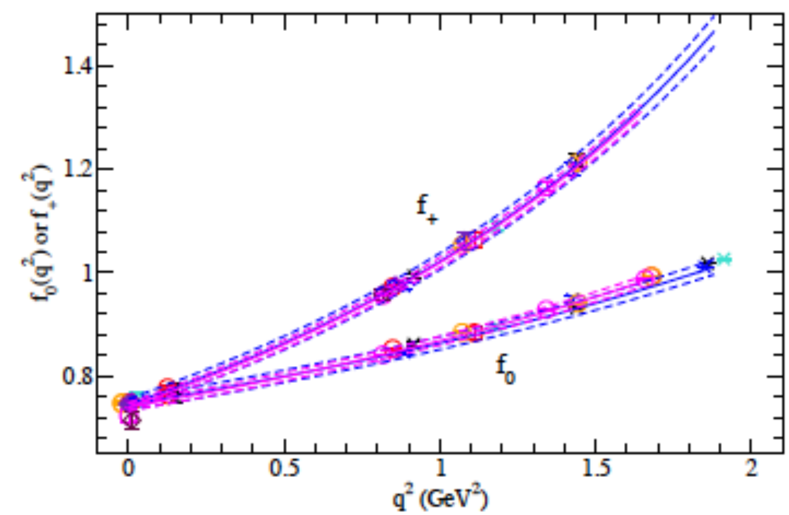
$$\frac{d\Gamma^{(\ell)}}{dq^2} = \frac{G_F^2 |V_{cs}|^2 |\mathbf{q}| q^2}{96\pi^3 m_D^2}\left(1 - \frac{m_\ell^2}{q^2}\right)^2 \left[|h_0(q^2)|^2\left(1 + \frac{m_\ell^2}{2q^2}\right) + \frac{3m_\ell^2}{2q^2}|h_t(q^2)|^2\right]$$

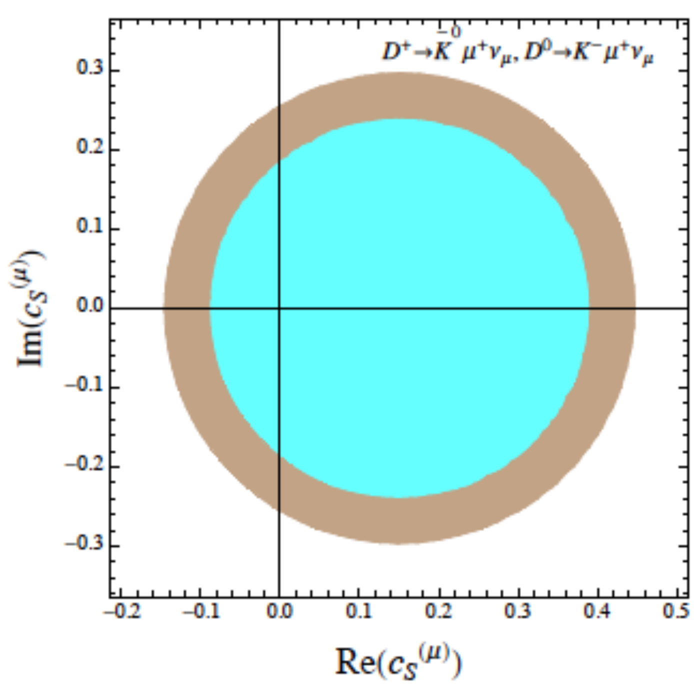
$$\mathcal{B}(D \to K\ell\nu_\ell) = \begin{cases} (8.83 \pm 0.22)\%, & D^+ \to \bar{K}^0 e^+ \nu_e, \\ (9.2 \pm 0.6)\%, & D^+ \to \bar{K}^0 \mu^+ \nu_\mu, \\ (3.55 \pm 0.04)\%, & D^0 \to K^- e^+ \nu_e, \\ (3.30 \pm 0.13)\%, & D^0 \to K^- \mu^+ \nu_\mu. \end{cases}$$

Form-factors calculated by lattice collaboration HPQCD (1305.1462)

crosses $\mathrm{D} \to \mathrm{K}$

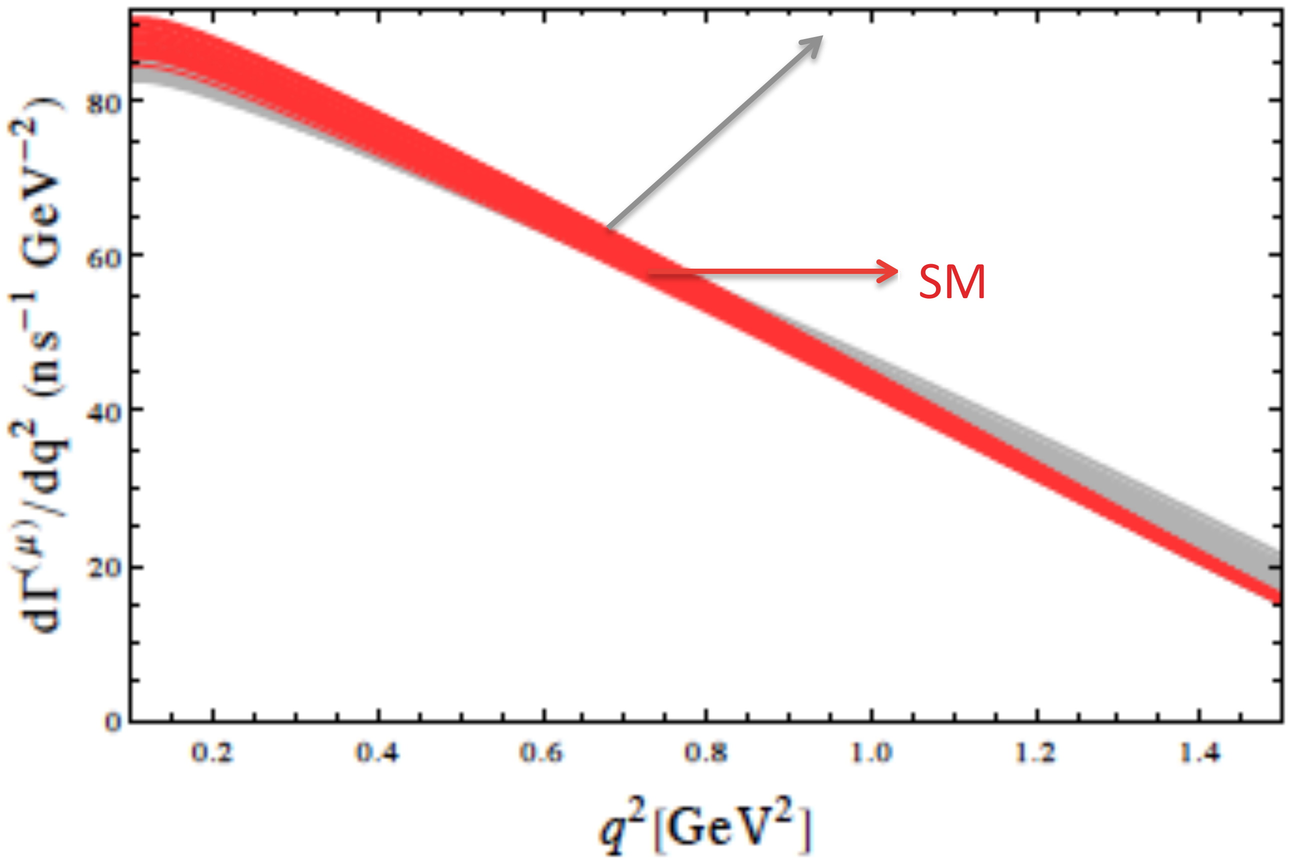
circles $\mathrm{D_s} \to \eta$





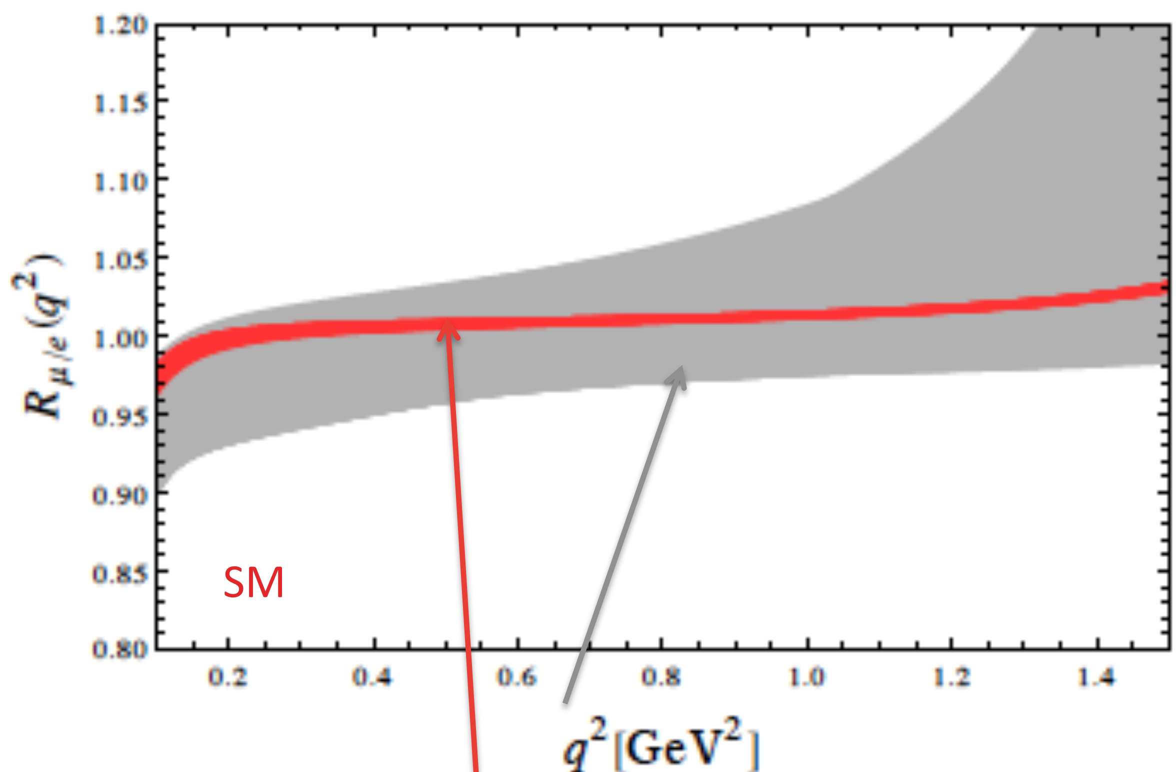
Allowed region for c_s from $BR(D \to K l \nu_l)$

NP in differential width distribution



NP, allowed by constraint from the fit of c_S from the branching ratio

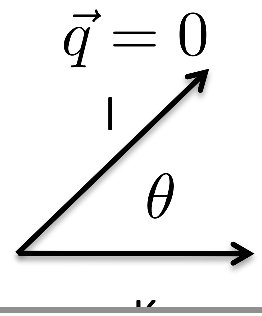
Check of lepton universality



NP, allowed by constraint from the fit to the branching ratio which gives constraint on c_S, assuming $c_S^{(e)} = 0$

$$R_{\mu/e}(q^2) \equiv \frac{d\Gamma^{(\mu)}}{dq^2} / \frac{d\Gamma^{(e)}}{dq^2}$$

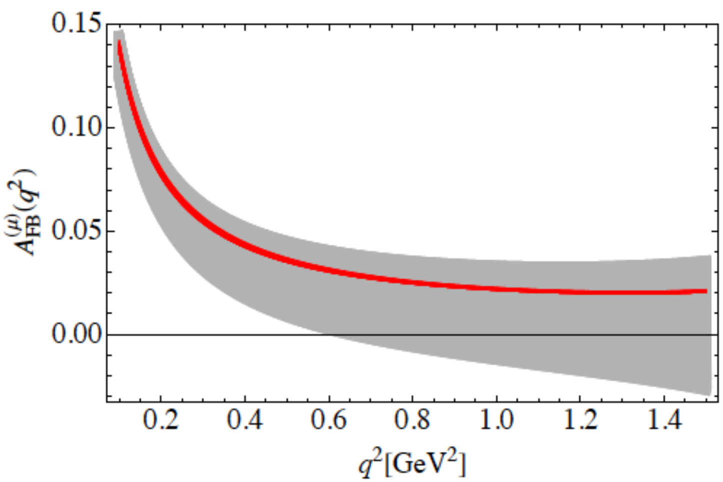
Forward-backward asymmetry in $D \to K l \nu_l$



$$\frac{d^2\Gamma^{(\ell)}}{dq^2 d\cos\theta_\ell} = a_\ell(q^2) + b_\ell(q^2)\cos\theta_\ell + c_\ell(q^2)\cos^2\theta_\ell.$$

$$b_\ell(q^2) = -\frac{G_F^2|V_{cs}|^2|\mathbf{q}|q^2}{128\pi^3 m_D^2}\left(1-\frac{m_\ell^2}{q^2}\right)^2 \frac{m_\ell^2}{q^2} 2Re(h_0 h_t^*)$$

$$A_{FB}^{(\ell)}(q^2) \equiv \frac{\int_{-1}^{0} \frac{d^2\Gamma^{(\ell)}(q^2)}{dq^2 d\cos\theta_\ell} d\cos\theta_\ell - \int_0^1 \frac{d^2\Gamma^{(\ell)}(q^2)}{dq^2 d\cos\theta_\ell} d\cos\theta_\ell}{d\Gamma^{(\ell)}/dq^2(q^2)} = -\frac{b_\ell(q^2)}{d\Gamma^{(\ell)}(q^2)/dq^2}$$



Sensitive on the real part of c_s!

SM value: $\langle A_{FB}^{(\mu)} \rangle = 0.055(2)$

Forward-backward asymmetry would not show deviation from SM!

THDM with more general flavor structure might lead to different c_S and c_P and A_{FB} can differ from SM.

NP in transversal muon polarization

The relative complex phase between nonstandard scalar Wilson coefficient and V_{cs} is a possible new source of the CP violation.

The measurement of the T-odd transverse polarization of charge lepton might give information on that effect. In SM it is vanishing effect.

$$P_{\perp}^{(\mu)} = \frac{|\mathcal{A}(\vec{s})|^2 - |\mathcal{A}(-\vec{s})|^2}{|\mathcal{A}(\vec{s})|^2 + |\mathcal{A}(-\vec{s})|^2}$$

$\mathcal{A}(\pm\vec{s})$ amplitude for spin projection along $\vec{s}$

$$\vec{s} \equiv (\vec{p}_K \times \vec{p}_\ell)/|\vec{p}_K \times \vec{p}_\ell|$$

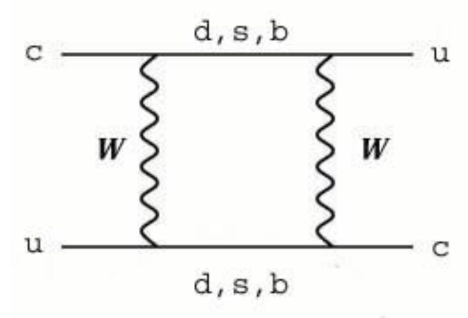
$$P_{\perp}^{(\mu)}(q^2, E_\mu) = \left(\frac{d\Gamma}{dq^2 dE_\mu}\right)^{-1} \kappa(q^2, E_\mu)\,\mathrm{Im}\left(h_0(q^2) h_t^*(q^2)\right)$$

For allowed value of $c_S^{(\mu)} \simeq \pm 0.1\, i$

$$\langle P_{\perp}^{(\mu)} \rangle \simeq \pm 0.2$$

New physics in charm FCNC processes

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



- SM and $D^0 - \bar{D}^0$ oscillations;
- SM in rare charm decays;

NP in charm

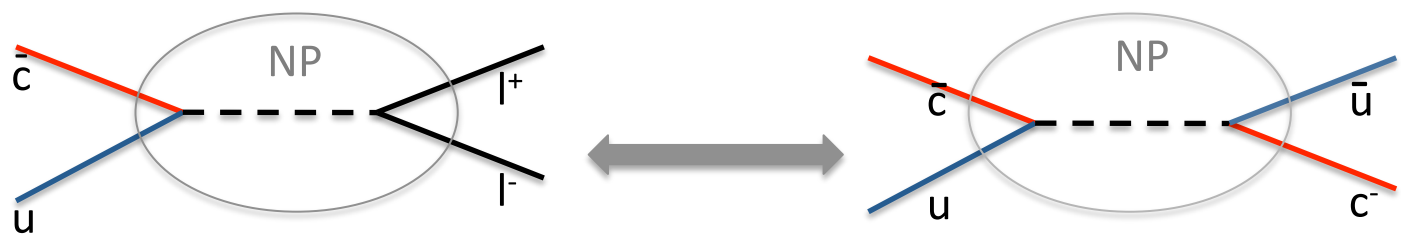
Constraints from K, B physics

Constraints from EW physics, oblique corrections, $Z \to b\bar{b}$

Constraints from LHC: top physics

NP in $c \to u l^+ l^-$

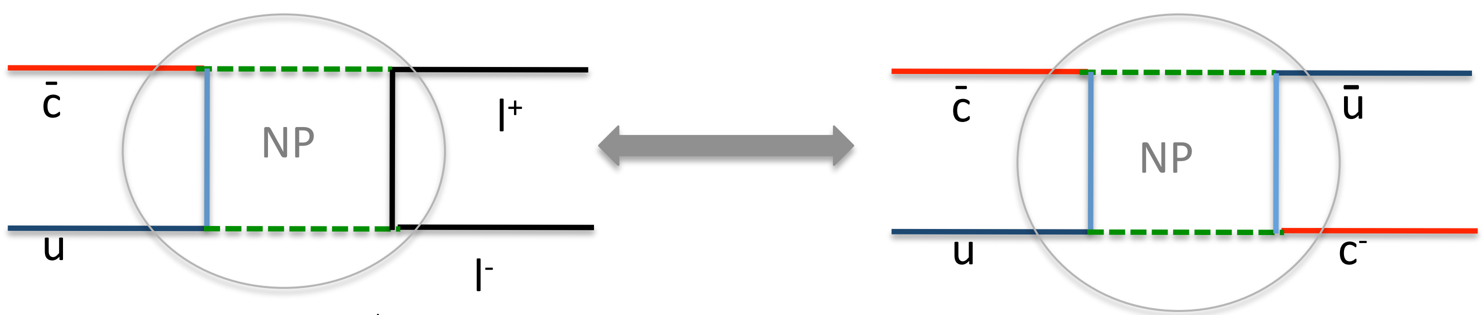
Tree level FCNC



The same couplings immediately create contributions to $D^0 - \bar{D}^0$

Loop level

(e.g.)

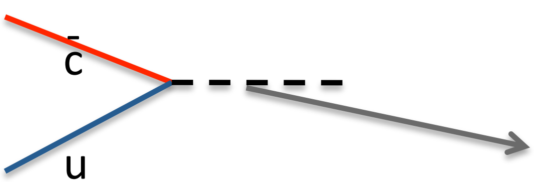


$c \to u l^+ l^-$ $\quad$ $D^0 - \bar{D}^0$

Properties of FCNC in charm rare decays

- conspiracy: d,s, b quarks are in the loops;
- very strong GIM suppression;
- $m_{s,d} \ll \Lambda_{QCD}$

long distance contribution dominant!



a weak singlet, doublet or triplet

up quark weak doublet "talks" to down quark via CKM!

SM effective Hamiltonian

$$\mathcal{H}_{\text{eff}} = \lambda_d \mathcal{H}^d + \lambda_s \mathcal{H}^s - \frac{4G_F \lambda_b}{\sqrt{2}} \sum_{i=3,\ldots,10,S,P,\ldots} C_i \mathcal{O}_i$$

Tree-level 4-quark operators

(Short-distance) penguin operators

1) At scale m_W all penguin contributions vanish due to GIM;

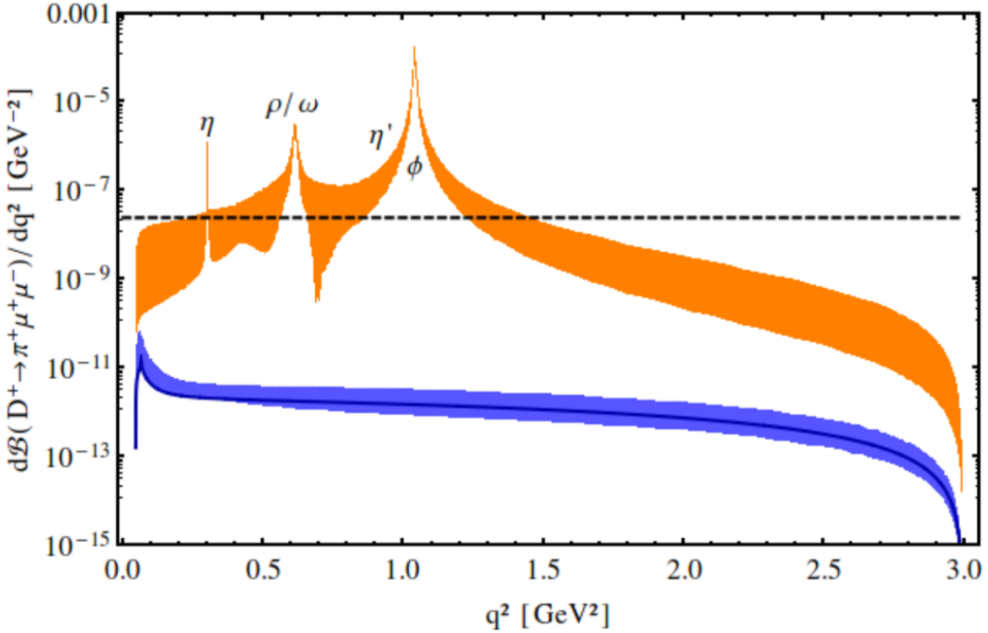
2) SM contributions to $C_{7\ldots10}$ at scale mc entirely due to mixing of tree-level operators into penguin ones under QCD

(de Boer, Hiller, 1510.00311)

3) SM values at m_c $C_7 = 0.12, \qquad C_9 = -0.41$

4) All operators' contributions to $D\rightarrow\pi ll$ can be absorbed into q^2 dependent effective Wilsons $C_{7,9\text{eff}}(q^2)$

Breit-Wigner model for the qq resonances



SM short distance rate not accessible

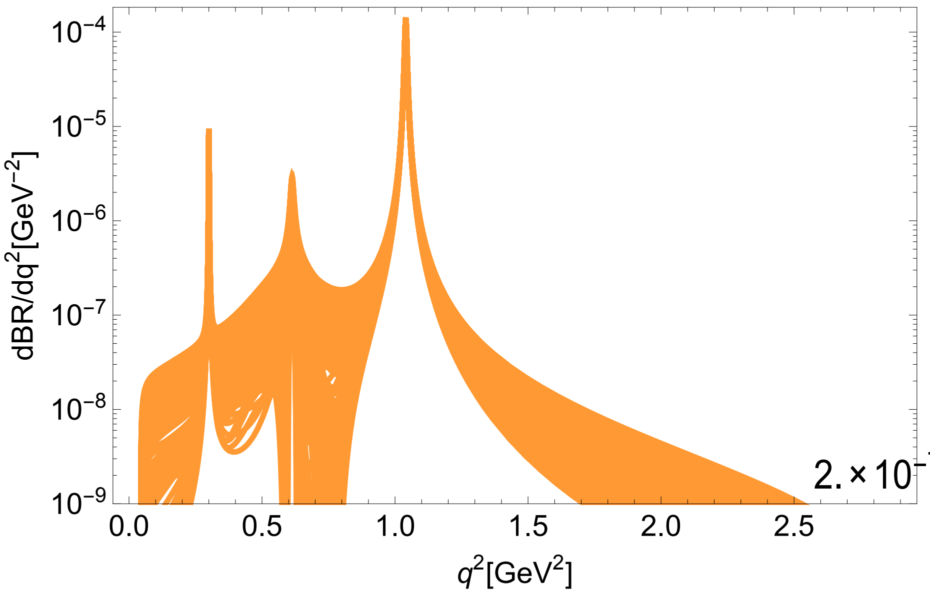
(borrowed from de Boer, Hiller, 1510.00311)

$$C_9^{\rm res} = \frac{\lambda_d}{\lambda_b}\left[a_\rho \frac{m_\rho^2}{q^2 - m_\rho^2 + i\sqrt{q^2}\Gamma_\rho} + \cdots\right]$$

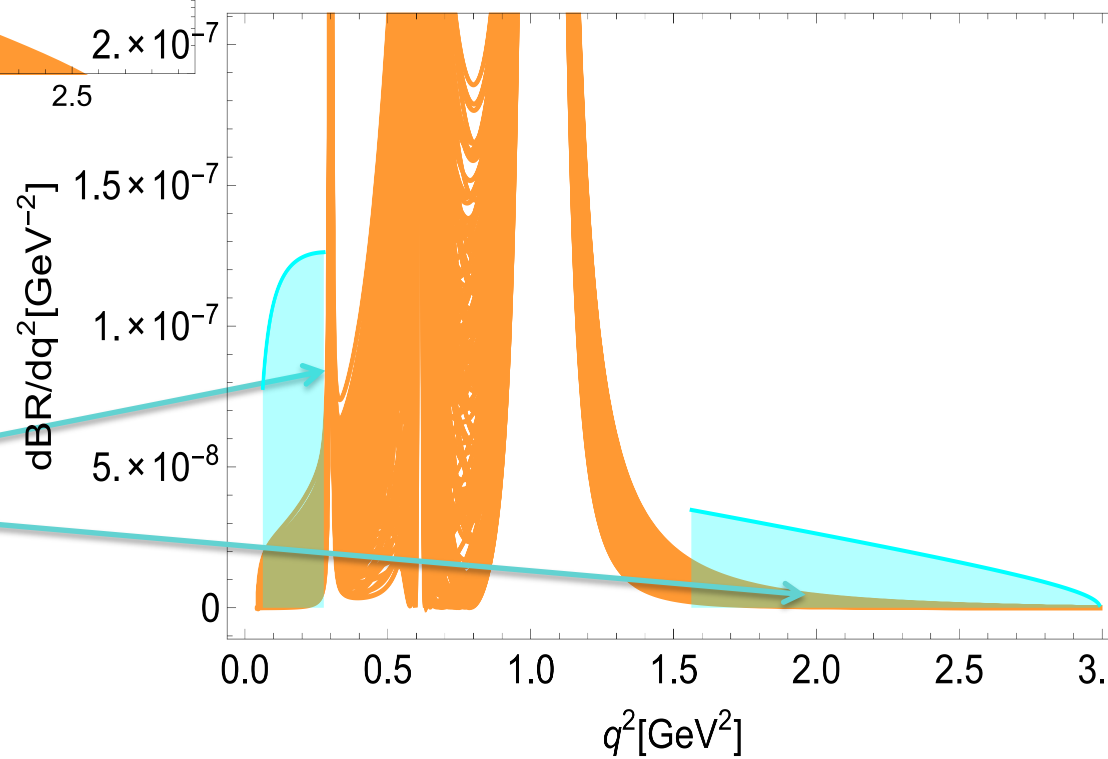
$$C_S^{\rm res} = \frac{\lambda_d}{\lambda_b}\left[\frac{a_\eta m_\eta^2}{q^2 - m_\eta^2 + i m_\eta \Gamma_\eta} + \cdots\right]$$

Fix $|a_X|$ from measured D→Xπ, X→ll

We marginalise over the unknown phase of a_X

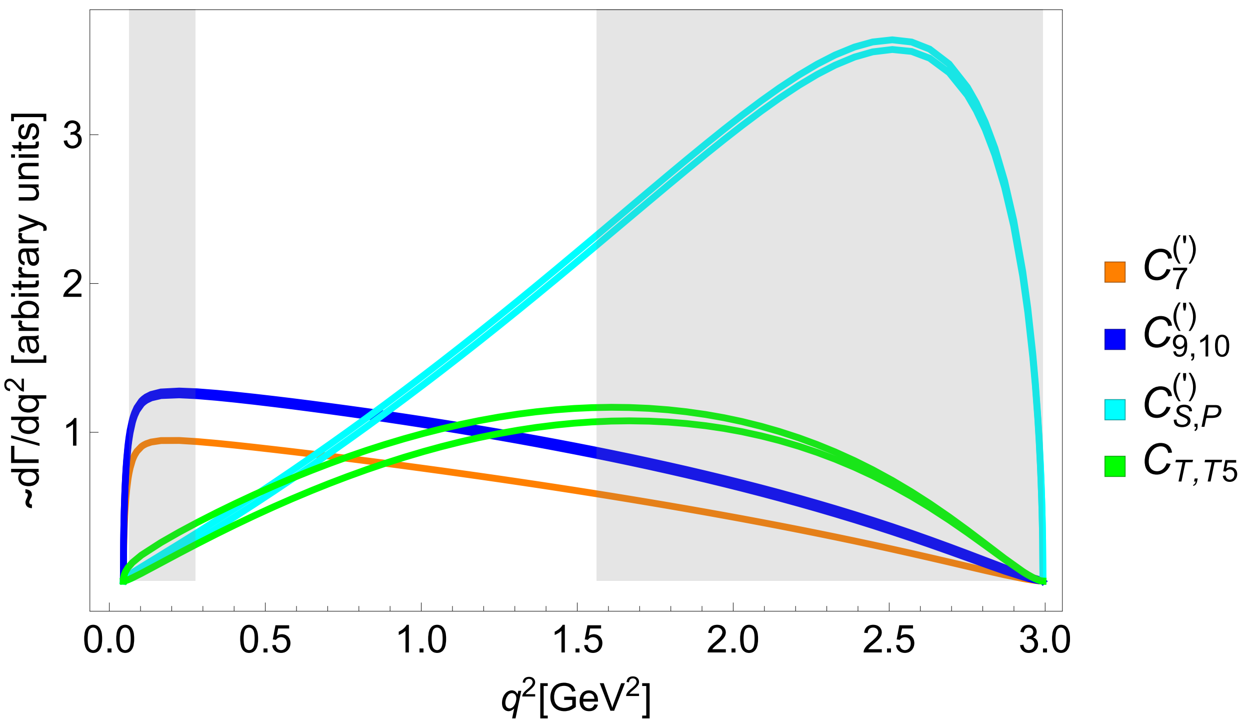


SM prediction
(peaks at ρ,ω,φ and η
resonances)



LHCb bound- assumption –
constant amplitude

Maximally allowed values of the Wilson coefficents in the low and high energy bins



$$\mathrm{BR}(\pi^+\mu^+\mu^-)_{\mathrm{I}} \equiv \mathrm{BR}(D^+ \to \pi^+\mu^+\mu^-)_{q^2\in[0.0625,0.276]\ \mathrm{GeV}^2} < 2.5\times 10^{-8}$$

$$\mathrm{BR}(\pi^+\mu^+\mu^-)_{\mathrm{II}} \equiv \mathrm{BR}(D^+ \to \pi^+\mu^+\mu^-)_{q^2\in[1.56,4.00]\ \mathrm{GeV}^2} < 2.9\times 10^{-8}$$

	$\lvert\tilde{C}_i\rvert_{\max}$		
	$\mathrm{BR}(\pi\mu\mu)_{\mathrm{I}}$	$\mathrm{BR}(\pi\mu\mu)_{\mathrm{II}}$	$\mathrm{BR}(D^0 \to \mu\mu)$
$\tilde{C}_7$	2.4	1.6	-
$\tilde{C}_9$	2.1	1.3	-
$\tilde{C}_{10}$	1.4	0.92	0.63
$\tilde{C}_S$	4.5	0.38	0.049
$\tilde{C}_P$	3.6	0.37	0.049
$\tilde{C}_T$	4.1	0.76	-
$\tilde{C}_{T5}$	4.4	0.74	-
$\tilde{C}_9 = \pm\tilde{C}_{10}$	1.3	0.81	0.63

$$|\tilde{C}_i| = |V_{ub}V_{cb}^{*}C_i|$$

region I

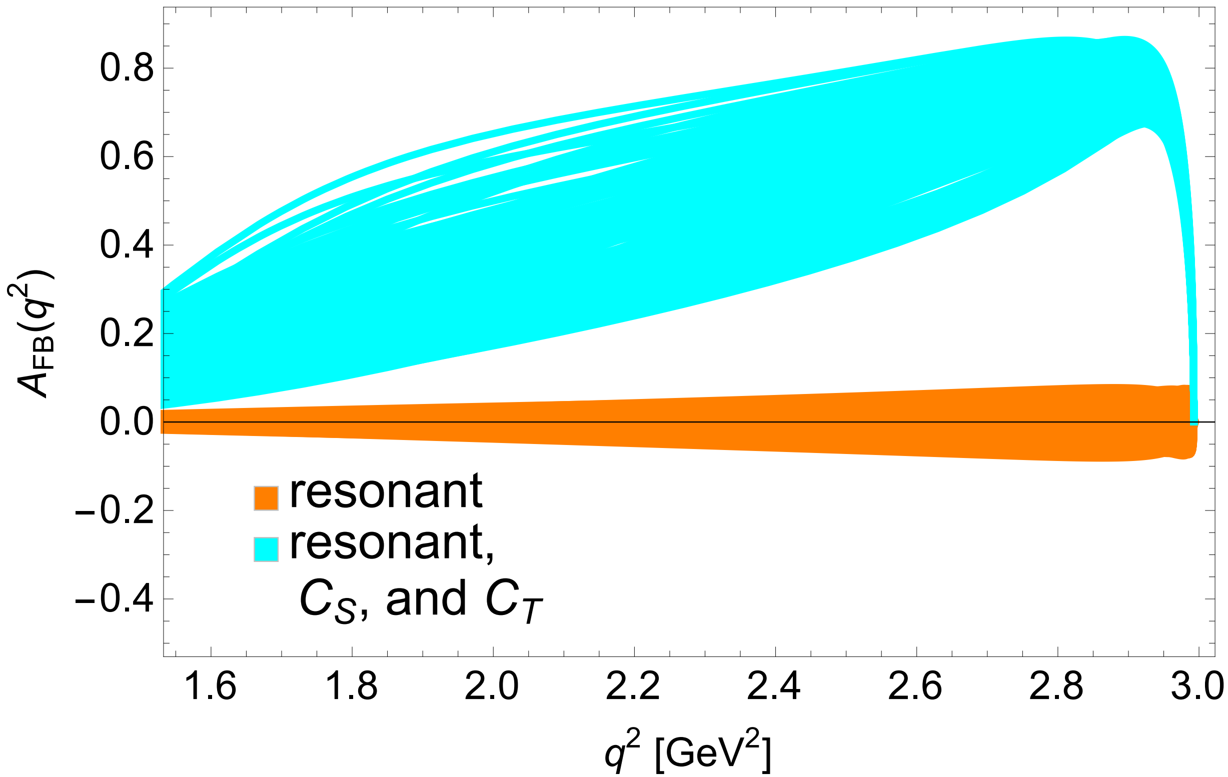
$$q^2 \in [0.0625, 0.276]\, GeV^2$$

region II

$$q^2 \in [1.56, 4.00]\, GeV^2$$

$$\mathrm{BR}(D^0 \to \mu^+\mu^-) < 7.6 \times 10^{-9}$$

$$A_{\rm FB}(q^2) \equiv \frac{\left(\int_0^1 - \int_{-1}^0\right) \mathrm{d}\cos\theta \, \frac{\mathrm{d}\Gamma(D\to\pi\ell\ell)}{\mathrm{d}q^2\,\mathrm{d}\cos\theta}}{\mathrm{d}\Gamma(D\to\pi\ell\ell)/\mathrm{d}q^2} = \frac{b_\ell(q^2)}{a_\ell(q^2) + \frac{1}{3}c_\ell(q^2)}$$



$b_l(q^2)$

↓

S,T_5 necessary!

Forward-backward asymmetry for the resonant background itself (orange) and in the scenario $C_S = 0.049/\lambda_b \quad C_T = 0.2/\lambda_b$

Test of lepton flavour universality violation

In 1510.0311 (de Beor and Hiller) it was pointed out that bounds on electron-positron mode are weaker:

$$BR(D^+ \to \pi^+ e^+ e^-) < 1.1 \times 10^{-6}$$

$$BR(D^0 \to e^+ e^-) < 7.9 \times 10^{-8}$$

$$\left| C_{S,P}^{(e)} - C_{S,P}^{(e)\prime} \right| \lesssim 0.3 \,,$$

$$\left| C_{9,10}^{(e)} - C_{9,10}^{(e)\prime} \right| \lesssim 4 \,,$$

$$\left| C_{T,T5}^{(e)} \right| \lesssim 5 \,, \quad \left| C_7 \left(C_9^{(e)} - C_9^{(e)\prime} \right) \right| \lesssim 2$$

In 1510.0965 (S.F. and N. Košnik) it was suggested, assuming as in the case $B \to K e^+ e^-$ that NP does not affect electron-positron mode, that tests of LFU can be performed either in I or II bin

$$R_\pi^{\mathrm{I}} = \frac{\mathrm{BR}(D^+ \to \pi^+ \mu^+ \mu^-)_{q^2 \in [0.25^2, 0.525^2]\mathrm{GeV}^2}}{\mathrm{BR}(D^+ \to \pi^+ e^+ e^-)_{q^2 \in [0.25^2, 0.525^2]\mathrm{GeV}^2}}$$

$$R_\pi^{\mathrm{II}} = \frac{\mathrm{BR}(D^+ \to \pi^+ \mu^+ \mu^-)_{q^2 \in [1.25^2, 1.73^2]\mathrm{GeV}^2}}{\mathrm{BR}(D^+ \to \pi^+ e^+ e^-)_{q^2 \in [1.25^2, 1.73^2]\mathrm{GeV}^2}}$$

	$\lvert\tilde{C}_i\rvert_{\max}$	R_π^{II}
SM	-	0.999 ± 0.001
$\tilde{C}_7$	1.6	$\sim$ 6–100
$\tilde{C}_9$	1.3	$\sim$ 6–120
$\tilde{C}_{10}$	0.63	$\sim$ 3–30
$\tilde{C}_S$	0.05	$\sim$ 1–2
$\tilde{C}_P$	0.05	$\sim$ 1–2
$\tilde{C}_T$	0.76	$\sim$ 6–70
$\tilde{C}_{T5}$	0.74	$\sim$ 6–60
$\tilde{C}_9 = \pm\tilde{C}_{10}$	0.63	$\sim$ 3–60
$\tilde{C}'_9 = -\tilde{C}'_{10}\big\rvert_{\mathrm{LQ}(3,2,7/6)}$	0.34	$\sim$ 1–20

$$R_\pi^{I,SM} = 0.87 \pm 0.09$$

$$R_\pi^{II,SM} = 0.999 \pm 0.001$$

Assumptions:

- e^+e^- mode are SM-like;
- NP enters in $\mu^+\mu^-$ mode only;
- listed Wilson coefficients are maximally allowed by current LHCb data.

Lepton flavor violation

1510.0311 (de Beor and Hiller) $c \to u\mu^{\pm}e^{\mp}$

$$\mathcal{L}_{\rm eff}^{\rm weak}(\mu \sim m_c) = \frac{4G_F}{\sqrt{2}}\frac{\alpha_e}{4\pi}\sum_i \left(K_i^{(e)}O_i^{(e)} + K_i^{(\mu)}O_i^{(\mu)}\right)$$

$$O_9^{(e)} = (\bar{u}\gamma_\mu P_L c)\,(\bar{e}\gamma^\mu \mu) \qquad O_9^{(\mu)} = (\bar{u}\gamma_\mu P_L c)\,(\overline{\mu}\gamma^\mu e)$$

$$BR(D^0 \to e^+\mu^- + e^-\mu^+) < 2.6\times 10^{-7}$$
$$BR(D^+ \to \pi^+ e^+\mu^-) < 2.9\times 10^{-6}$$
$$BR(D^+ \to \pi^+ e^-\mu^+) < 3.6\times 10^{-6}$$

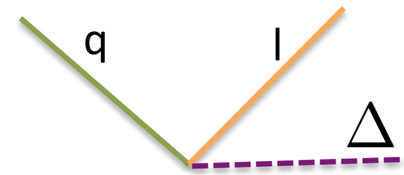
$$\left|K_{S,P}^{(l)} - K_{S,P}^{(l)\prime}\right| \lesssim 0.4\,,$$
$$\left|K_{9,10}^{(l)} - K_{9,10}^{(l)\prime}\right| \lesssim 6\,, \quad \left|K_{T,T5}^{(l)}\right| \lesssim 7\,,$$

$$l = e, \mu$$

$$BR(D^0 \to e^{\pm}\tau^{\mp}) < 7\times 10^{-15}$$

Specific models

Scalar Leptoquaks (3,2,7/6)



$$\mathcal{L}^{(5/3)} = (\bar{\ell}_R Y_L u_L)\,\Delta^{(5/3)*} - (\bar{u}_R Y_R \ell_L)\,\Delta^{(5/3)} + \text{h.c.}$$

generates S, P, T,T_5, V and A

In the case of Δ C= 2 in $D^0 - \bar{D}^0$ oscillation there is also a LQ contribution

$$\mathcal{H} = C_6 (\bar{u}_R \gamma^\mu c_R)(\bar{u}_R \gamma_\mu c_R)$$

$$C_6(m_\Delta) = -\frac{\left(Y^{R*}_{c\mu} Y^R_{u\mu}\right)^2}{64\pi^2 m_\Delta^2} = -\frac{(G_F \alpha)^2}{32\pi^4}\, m_\Delta^2 (\tilde{C}'_{10})^2$$

$$|C_6(m_\Delta)| < 2.5 \times 10^{-13}\ \text{GeV}^{-2} \qquad \Longrightarrow \qquad |\tilde{C}'_9, \tilde{C}'_{10}| < 0.34$$

Bound from ΔC =2 slightly stronger, but comparable to the bound coming from $D^0 \to \mu^+\mu^-$

$$-\tilde{C}'_{10} = \tilde{C}'_9 = 0.63\,,$$

$$4\tilde{C}_T = 4\tilde{C}_{T5} = \tilde{C}_P = \tilde{C}_S = -0.049$$

Vector Leptoquark (3,1,5/3)

$$\mathcal{L} = Y_{ij}\,(\bar{\ell}_i \gamma_\mu P_R u_j)\,V^{(5/3)\mu} + \text{h.c.}\,.$$

$$C_9' = C_{10}' = \frac{\pi}{\sqrt{2} G_F \lambda_b \alpha} \frac{Y_{\mu c} Y_{\mu u}^*}{m_V^2}$$

$$C_6(m_V) = \frac{(Y_{\mu u} Y_{\mu c}^*)^2}{32\pi^2 m_V^2} = \frac{(G_F \alpha)^2}{16\pi^4} m_V^2 (\tilde{C}_{10}')^2$$

$$|\tilde{C}_9', \tilde{C}_{10}'| < 0.24$$

$D \to \pi \mu^+ \mu^-$ In the high q^2 region branching ratio is 1.4×10^{-8}
two times smaller then the experimental bound

Two Higgs doublet model type III

Two neutral scalars, h and H, one pseudoscalar A, two charged $H^{\pm}$;
Flavor changing neutral couplings at tree level generated.

$$\tan\beta = \frac{v_u}{v_d}$$

$$\mathcal{L} = \frac{y_{ij}^{(\ell)H_k}}{\sqrt{2}} H_k \bar{\ell}_{L,i}\ell_{R,j} + \frac{y_{ij}^{(u)H_k}}{\sqrt{2}} H_k \bar{u}_{L,i} u_{R,j} + \text{h.c.} \qquad H_k = (H, h, A)$$

$$-C_P = C_S = \frac{\pi}{4\sqrt{2}G_F\alpha\lambda_b}\,\frac{m_\mu}{v}\,\frac{\epsilon_{12}^{u*}\tan\beta}{m_H^2}$$

$$C'_P = C'_S = \frac{\pi}{4\sqrt{2}G_F\alpha\lambda_b}\,\frac{m_\mu}{v}\,\frac{\epsilon_{21}^{u}\tan\beta}{m_H^2}$$

from $\mathrm{BR}(D^0 \to \mu^+\mu^-)$

$$|\tilde{C}_S - \tilde{C}'_S| \leq 0.05$$

$$|\tilde{C}_P - \tilde{C}'_P| \leq 0.05$$

Z' model

Anomalies in B decays often explained by Z'.

$D^0 - \bar{D}^0$ transitions constrain $C_6(m_{Z'}) = \dfrac{|C^u|^2}{2m_{Z'}^2}$

$c \to u\mu^+\mu^-$

$m_{Z'} \sim 1\ \text{TeV} \quad |C_9| \lesssim 8 \quad |C_{10}| \lesssim 100$ negligible effects!

Model	Effect	Size of the effect
Spin-1 weak triplet	$C_9 = -C_{10}$	$C_9 < 10$
Scalar leptoquark (3,2,7/6)	$C_S, C_P, C_S', C_P', C_T, C_{T5}, C_9, C_{!0}, C_9', C_{10}'$	$V_{cb}V_{ub}\|C_{9,}\ C_{10}\| < 0.34$
Vector leptoquark (3,1,5/3)	$C_9' = C_{10}'$	$V_{cb}V_{ub}\|C_9'_{,}\ C_{10}'\| < 0.24$
Two Higgs doublet Model type III	C_S, C_P, C_S', C_P'	$V_{cb}V_{ub}\|C_S - C_S'\| < 0.005$ $V_{cb}V_{ub}\|C_P - C_P'\| < 0.005$
Z' model	C_9', C_{10}'	$V_{cb}V_{ub}\|C_9'_{,}\| < 0.001$ $V_{cb}V_{ub}\|C_{10}'\| < 0.014$

Summary

a) Prospect of NP in charged current D meson transitions

- Scalar and pseudoscalar operators describing NP contributions considered in Cabibbo allowed leptonic and semileptonic charmed meson decays;

- A number of variables suitable to test NP contributions were discussed as: differential branching ratio, forward-backward asymmetry, transversal muon asymmetry for $D \to K l \nu_l$ and $R_{L/T}$ for $D \to K^* l \nu_l$;

- In order to get tight constraints on NP one needs:

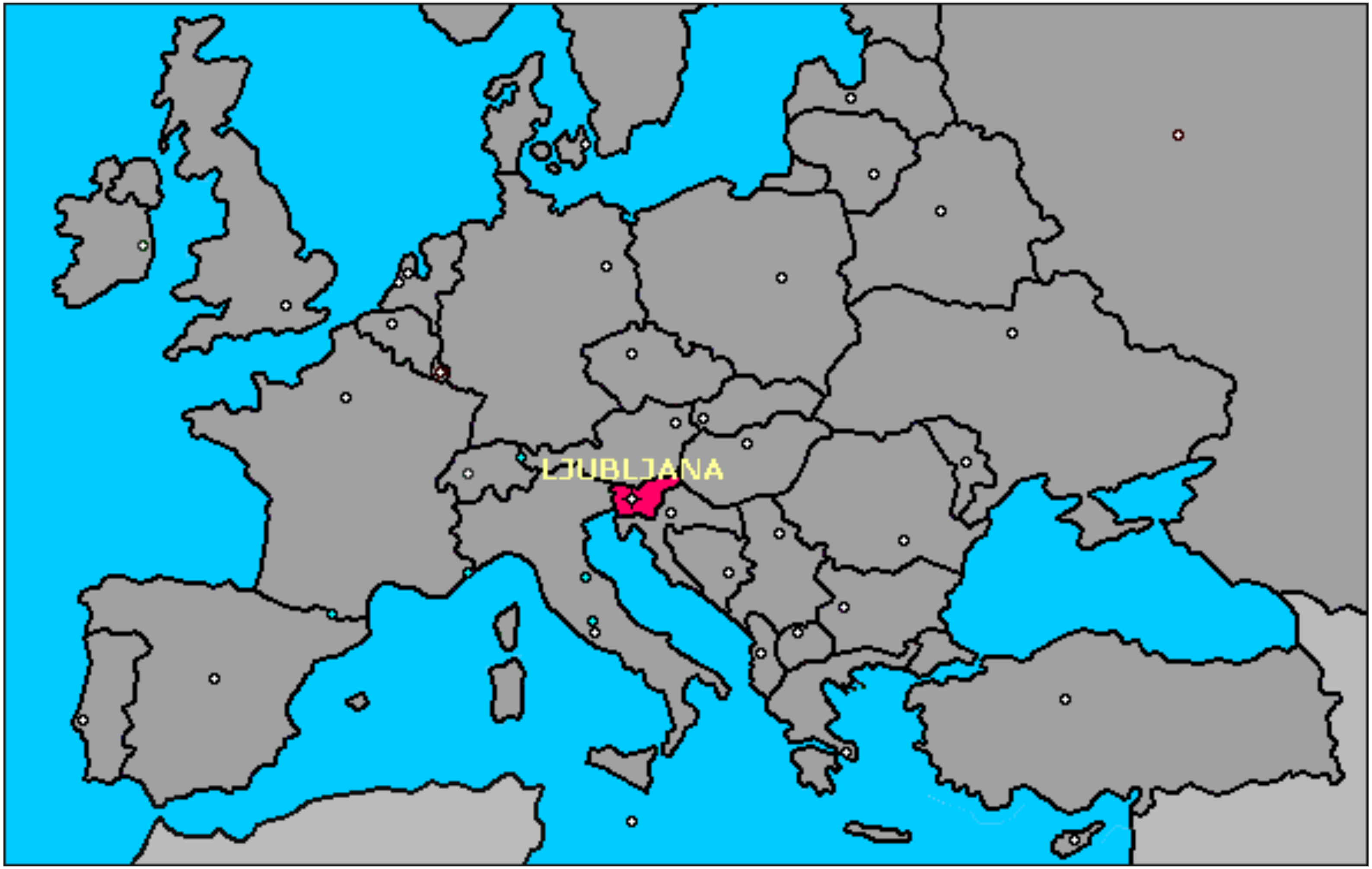
a) Lattice calculations of form factors in $D \to P$ and $D \to V$;
b) High precision experimental studies of all observables.

-

b) Prospect of NP in FCNC D decays

- Effective Lagrangian approach used to described NP effects: NP can appear in as in SM in C_7, C_9, C_{10} or in C_S, C_P, C_T, C_7',C_9', C_{10}', C_S', C_P', CT_5;
- All these Wilson coefficents can be bounded by LHCb results on nonresonant background in $D^+ \to \pi^+ \mu^+ \mu^-$;
- Models of NP : Spin-1 weak triplet, Scalar leptoquark (3,2,7/6),Vector leptoquark (3,1,5/3) , Two Higgs doublet model type III , Z' model might contribute to Wilson coefficients;
- Suggestion: to check of LFU violation.

Thanks!

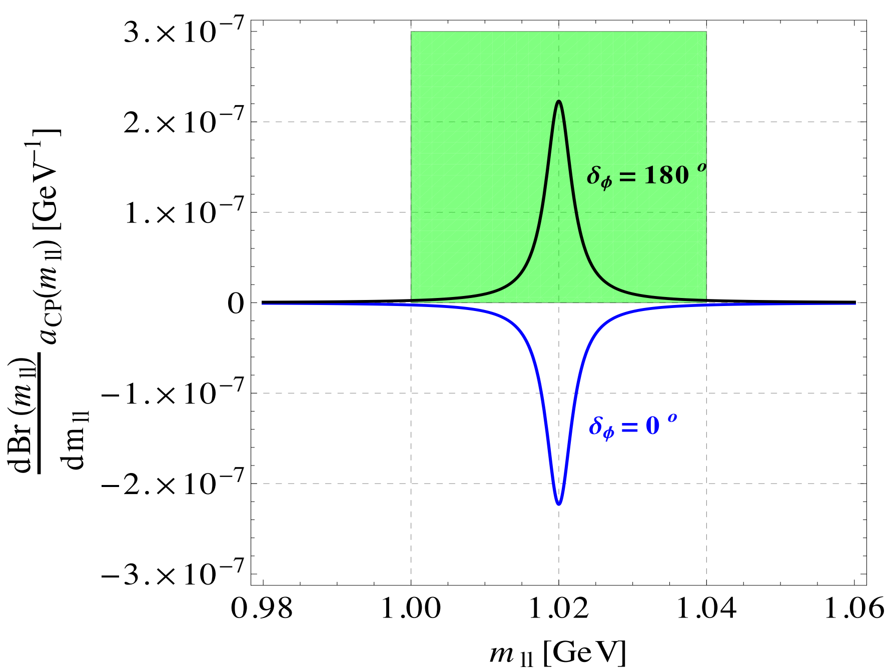


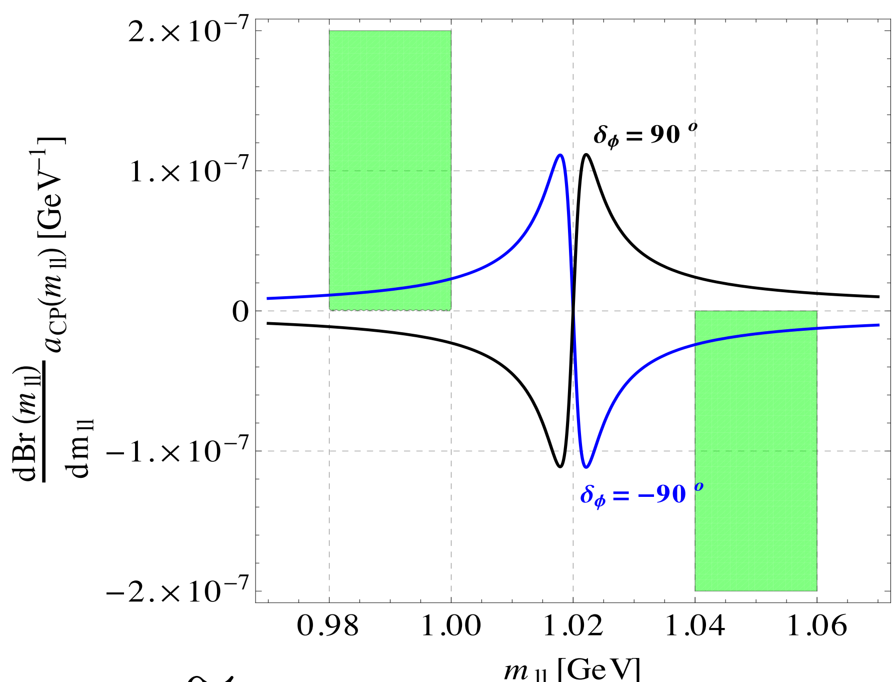
$$a_{CP}(\sqrt{q^2}) \equiv \frac{|\mathcal{A}|^2 - |\overline{\mathcal{A}}|^2}{|\mathcal{A}|^2 + |\overline{\mathcal{A}}|^2}$$

$$= \frac{-3}{2\pi^2}\frac{f_T(q^2)}{a_\phi}\frac{m_c}{m_D + m_\pi}\mathrm{Im}\left[\frac{\lambda_b}{\lambda_s}C_7\right]\left[\cos\delta_\phi - \frac{q^2 - m_\phi^2}{m_\phi\Gamma_\phi}\sin\delta_\phi\right]$$

G. Isidori et al, PLB 711, (2012) 46 $|\mathrm{Im}[\mathrm{C_7(m_c)}]| \simeq |\mathrm{Im}[\mathrm{C_8^{NP}(m_c)}]|$

at scale M≈ 1TeV $|\mathrm{Im}[\lambda_b \mathrm{C_7(m_c)}]| \simeq (0.1 - 0.4) \times 10^{-2}$





$$a_{CP} \sim 1\%$$

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

Relevant matrix elements

$$\langle \pi(k)\,|\,\bar{u}\gamma^\mu(1\pm\gamma_5)c\,|\,D(p)\rangle = f_+(q^2)\left[(p+k)^\mu - \frac{m_D^2-m_\pi^2}{q^2}q^\mu\right] + f_0(q^2)\frac{m_D^2-m_\pi^2}{q^2}q^\mu$$

$$\langle \pi(k)\,|\,\bar{u}\sigma^{\mu\nu}(1\pm\gamma_5)c\,|\,D(p)\rangle = i\frac{f_T(q^2)}{m_D+m_\pi}\left[(p+k)^\mu q^\nu - (p+k)^\nu q^\mu \pm i\epsilon^{\mu\nu\alpha\beta}(p+k)_\alpha q_\beta\right]$$

Most general parametrisation of the amplitude with NP contributions:

$$\mathcal{A}_{\rm SD}(D^+(p)\to\pi^+(p')\mu^+(k_+)\mu^-(k_-)) =$$
$$= \frac{iG_F\lambda_b\alpha}{\sqrt{2}\pi}\left[V\,\bar{u}\not{p}v + A\,\bar{u}\not{p}\gamma_5 v + (S+T\cos\theta)\bar{u}v + (P+T_5\cos\theta)\bar{u}\gamma_5 v\right]$$

NP enters through such combinations:

$$
\begin{aligned}
V &= \frac{2m_c f_T(q^2)}{m_D + m_\pi}(C_7 + C_7') + f_+(q^2)(C_9 + C_9') + \frac{8 f_T(q^2) m_\ell}{m_D + m_\pi} C_T \,, \\
A &= f_+(q^2)(C_{10} + C_{10}') \,, \\
S &= \frac{m_D^2 - m_\pi^2}{2m_c} f_0(q^2)(C_S + C_S') \,, \\
P &= \frac{m_D^2 - m_\pi^2}{2m_c} f_0(q^2)(C_P + C_P') - m_\ell \left[f_+(q^2) - \frac{m_D^2 - m_\pi^2}{q^2} \big(f_0(q^2) - f_+(q^2) \big) \right] (C_{10} + C_{10}') \,, \\
T &= \frac{2 f_T(q^2) \beta_\ell \lambda^{1/2}}{m_D + m_\pi} C_T \,, \\
T_5 &= \frac{2 f_T(q^2) \beta_\ell \lambda^{1/2}}{m_D + m_\pi} C_{T5} \,.
\end{aligned}
$$

V, A, S, P, T, T_5 are functions of the appropriate Wilson coefficients.