Opportunities with (semi)leptonic rare charm decays

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based on works with Gudrun Hiller, arXiv:1510.00311 [hep-ph]

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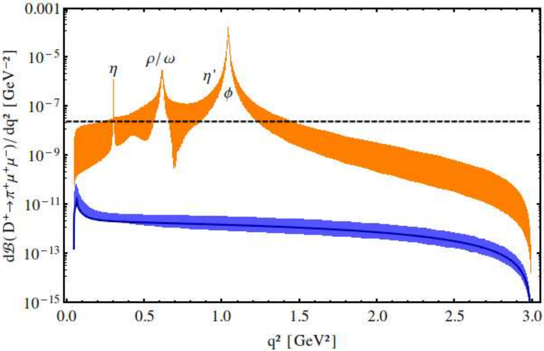
DFG

(Semi)leptonic rare charm decays

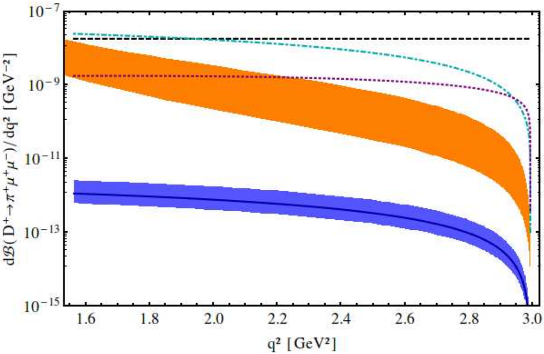
- Rare in the SM due to an effective GIM mechanism, e.g.
  $\mathcal{B}^{\text{nr}}(D^+ \to \pi^+ \mu^+ \mu^-) < 7.3 \times 10^{-8}$ @CL=90% [LHCb 2013],
  thus sensitive to BSM physics.
- Convergence of calculations by means of α_s and Λ_{QCD}/m_c?
- Unique up-type quark FCNC, complementary to K/B physics.
- SM null test, e.g.
  $\mathcal{B}(D^0 \to e^\pm \mu^\mp) < 1.3 \times 10^{-8}$ @CL=90% [LHCb 2015].

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



q^2 is dilepton mass squared and dashed black line shows 90% CL experimental upper limit. Solid blue curve is non-resonant SM (N)NLO QCD prediction within OPE at $\mu_c = m_c$ and lighter blue band its μ_c-uncertainty. Orange band represents resonant modes modeled via Breit-Wigner shape to fit data and varying relative strong phases.

$D^+ \to \pi^+\mu^+\mu^-$ branching ratio at high q^2



Additional two (dot-dashed cyan and dotted purple) curves are $D^0 \to \mu^+\mu^-$-consistent model-independent BSM cases.

Angular observables, LFV and dineutrino decays

Approximate SM null tests, model-independently at high q^2

$$|A_{\rm FB}(D^+ \to \pi^+\mu^+\mu^-)| \lesssim 0.6\,,$$
$$F_H(D^+ \to \pi^+\mu^+\mu^-) \lesssim 1.5\,.$$

$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta} = \frac{3}{4}(1-F_H)(1-\cos^2\theta) + A_{FB}\cos\theta + \frac{1}{2}F_H$

($\theta = \measuredangle(l^-, D^+)$ in dilepton center-of-mass frame).

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LFV and dineutrino modes may be close to experimental limits

$\mathcal{B}(D^+ \to \pi^+ e^\pm \mu^\mp) \lesssim 3\cdot 10^{-6}$ @CL=90% [BaBar 2011],

$\mathcal{B}(D^+ \to \pi^+\nu\bar{\nu}) \sim 10^{-5}$ sensitivity at BESIII.

Leptoquark models and flavor patterns

- May generate LNU in $R(K)$ and $R(D^*)$ [Alonso et al. 2015], [Bauer et al. 2015], [Fajfer et al. 2015], talk by Nejc Kosnik.
- May induce the 750 GeV diphoton decay [Bauer et al. 2015], [Murphy 2015].
- Couple quark singlets (case 1) or doublets (case 2).
- Constrained by collider experiments and $\mu \to e\gamma$, $\mu - e$ conversion in nuclei and K physics ...

Scalar LQ	Vector LQ
$S_1(3, 1, -1/3)$	$\tilde{V}_1(3, 1, -5/3)$
$S_2(3, 2, -7/6)$	$V_2(3, 2, -5/6)$
$S_3(3, 3, -1/3)$	$\tilde{V}_2(3, 2, 1/6)$
	$V_3(3, 3, -2/3)$

$(SU(3)_C, SU(2)_L, Y)$

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Couplings via flavor patterns inspired by Frogatt-Nielsen $U(1)$ (quarks, rows) and A_4 (leptons, columns) symmetries, e.g. [de Medeiros Varzielas et al. 2015]

$$\lambda_{\mathrm{i,ii,iii}} \sim \begin{pmatrix} \rho_d\kappa & \rho_d & \rho_d \\ \rho\kappa & \rho & \rho \\ \kappa & 1 & 1 \end{pmatrix}, \quad \begin{pmatrix} 0 & * & 0 \\ 0 & * & 0 \\ 0 & * & 0 \end{pmatrix}, \quad \begin{pmatrix} * & 0 & 0 \\ 0 & * & 0 \\ 0 & * & 0 \end{pmatrix}$$

Leptoquark models and branching ratios

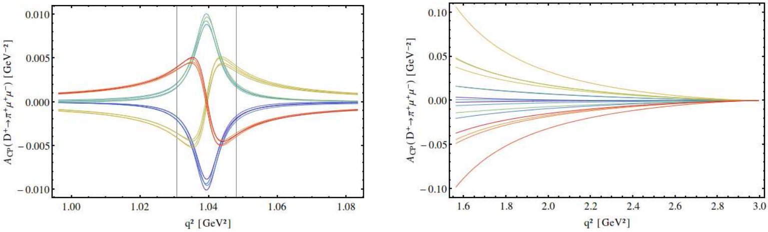
	$\mathcal{B}(D^+ \to \pi^+\mu^+\mu^-)$	$\mathcal{B}(D^0 \to \mu^+\mu^-)$
ii.1)	$\lesssim 7 \cdot 10^{-8}$ $(2 \cdot 10^{-8})$	$\lesssim 3 \cdot 10^{-9}$
iii.1)	SM-like	SM-like
exp.	$< 7.3 \cdot 10^{-8}$ $(2.6 \cdot 10^{-8})$	$< 6.2 \cdot 10^{-9}$ [LHCb 2013]

Full q^2-bin (high q^2-bin) for two classes of leptoquark couplings.

	$\mathcal{B}(D^+ \to \pi^+ e^\pm \mu^\mp)$	$\mathcal{B}(D^0 \to \mu^\pm e^\mp)$	$\mathcal{B}(D^+ \to \pi^+ \nu\bar{\nu})$
ii.1)	0	0	$\lesssim 8 \cdot 10^{-8}$
iii.1)	$\lesssim 2 \cdot 10^{-6}$	$\lesssim 4 \cdot 10^{-8}$	$\lesssim 2 \cdot 10^{-6}$
exp.	$\lesssim 3 \cdot 10^{-6}$	$< \mathbf{1.3 \cdot 10^{-8}}$	$\sim 10^{-5}$

The $c \to u e^+ e^-$ branching ratios are SM-like, thus LNU in charm decays may be generated.

Leptoquark models and CP asymmetries



Normalized to shown bins for case ii.2) around ϕ (left plot) and at high q^2 (right plot). From yellow (upper curves above ϕ) to red (lower curves above ϕ) each bunch represents $\delta_\phi = \pi/2, \pi, 0, 3/2\pi$.

Probes $Q_9 = (\bar{u}_L\gamma_\mu c_L)(\bar{l}\gamma^\mu l)$ independent of strong phases around ϕ and small C_9 as linked to K/B physics at high q^2.

Conclusion

BSM opportunities with (semi)leptonic rare charm decays via

- $\mathcal{B}(D^+ \to \pi^+\mu^+\mu^-)$ above the resonances.
- Angular observables and CP asymmetries.
- LFV and dineutrino decays.

Leptoquark models link charm and K/B physics (LNU).

BSM physics depend on flavor patterns and vice versa.