

Rare Charm Decays

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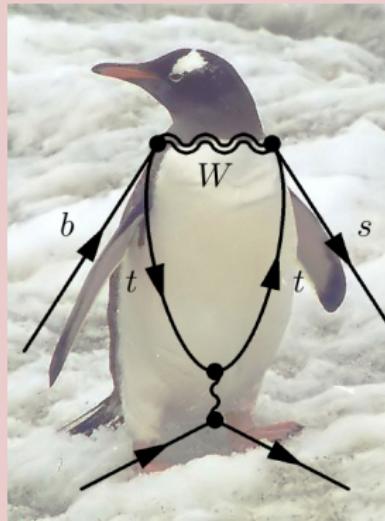
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EFT at the charm scale

de Boer, (2017), PhD thesis, TU Dortmund

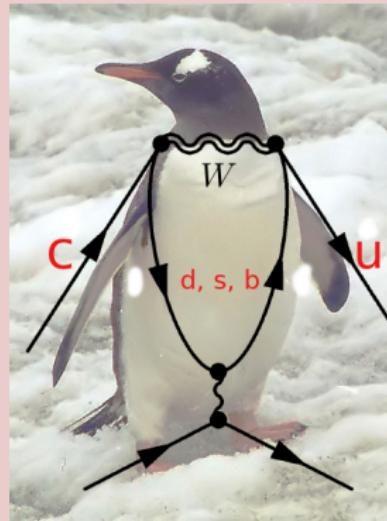
What is the difference between $b \rightarrow s$ and $c \rightarrow u$ penguins?



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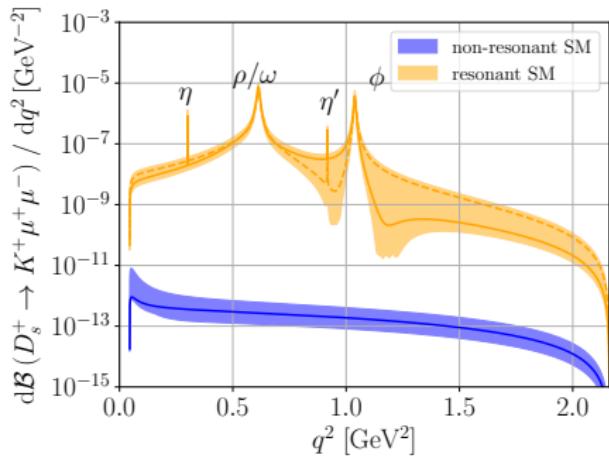
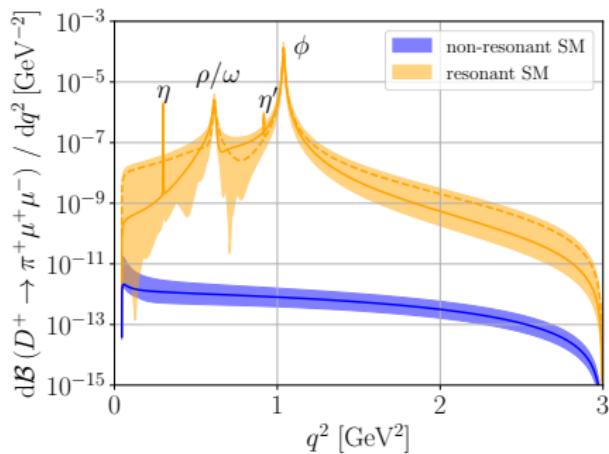
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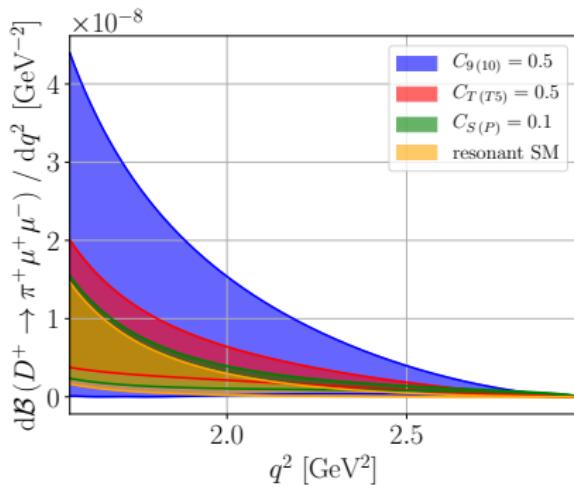
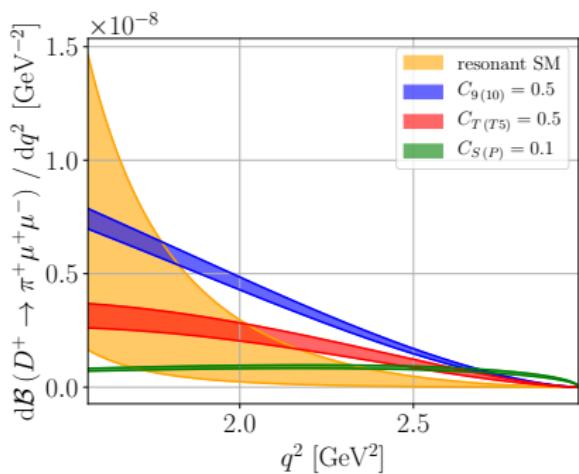
- ▶ Light quark masses need to be set to zero at μ_W
- ▶ Effective GIM-mechanism kills $C_{7,9,10}$ at μ_W
- ▶ $C_{7,9}$ are induced by RG running to μ_c
- ▶ $C_{10}(\mu_c) = 0$

$D_{(s)} \rightarrow \pi(K)\ell\ell$ Decays Bause, MG, Hiller, Tayduganov, (1909.11108)



► $C_9^{\text{SM}} = C_9^{\text{eff}} + C_9^{\text{resonant}} \simeq C_9^{\text{resonant}}$

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- ▶ $C_9^{\text{SM}} = C_9^{\text{eff}} + C_9^{\text{resonant}} \simeq C_9^{\text{resonant}}$
- ▶ NP searches in branching ratios hard even at high q^2 .

Null test observables

Null tests are based on

- ▶ appr. CP-symmetry $\Rightarrow A_{\text{CP}}(q^2)$
- ▶ angular observables \Rightarrow lepton forward-backward asymmetry $A_{\text{FB}}(q^2)$, flat-term $F_H(q^2)$
- ▶ Lepton universality $\Rightarrow R_\pi^D, R_K^{D_s}$
- ▶ Lepton flavor conservation $\Rightarrow \mathcal{B}(D_{(s)} \rightarrow \pi(K)e\mu)$ (LFV)

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Parts of these will be discussed in this talk.

LFU tests

$$R_P^D = \frac{\int_{q_{\min}^2}^{q_{\max}^2} \frac{d\mathcal{B}(D \rightarrow P \mu^+ \mu^-)}{dq^2} dq^2}{\int_{q_{\min}^2}^{q_{\max}^2} \frac{d\mathcal{B}(D \rightarrow P e^+ e^-)}{dq^2} dq^2}$$

Same cuts for electrons and muons necessary.

$D \rightarrow \pi$	SM	$ C_9 = 0.5$	$ C_{10} = 0.5$	$ C_9 = \pm C_{10} = 0.5$
full q^2	$1.00 \pm \mathcal{O}(\%)$	SM-like	SM-like	SM-like
low q^2	$0.95 \pm \mathcal{O}(\%)$	$\mathcal{O}(100)$	$\mathcal{O}(100)$	$\mathcal{O}(100)$
high q^2	$1.00 \pm \mathcal{O}(\%)$	$0.2 \dots 11$	$3 \dots 7$	$2 \dots 17$

$D_s \rightarrow K$	SM	$ C_9 = 0.5$	$ C_{10} = 0.5$	$ C_9 = \pm C_{10} = 0.5$
full q^2	$1.00 \pm \mathcal{O}(\%)$	SM-like	SM-like	SM-like
low q^2	$0.94 \pm \mathcal{O}(\%)$	$0.1 \dots 3.0$	$1.3 \dots 1.5$	$0.5 \dots 3.6$
high q^2	$1.00 \pm \mathcal{O}(\%)$	$0.2 \dots 16$	$3 \dots 11$	$2 \dots 26$

$$D \rightarrow P_1 P_2 \ell^+ \ell^- \quad \text{de Boer, Hiller, (1805.08516)}$$

$$R_{P_1 P_2}^D = \frac{\int_{q_{\min}^2}^{q_{\max}^2} \frac{d\mathcal{B}(D \rightarrow P_1 P_2 \mu^+ \mu^-)}{dq^2} dq^2}{\int_{q_{\min}^2}^{q_{\max}^2} \frac{d\mathcal{B}(D \rightarrow P_1 P_2 e^+ e^-)}{dq^2} dq^2}$$

For order one BSM effects, or specific LQ model.

$D \rightarrow \pi\pi$	SM	BSM	LQ
full q^2	$1.00 \pm \mathcal{O}(\%)$	$0.85 \dots 0.99$	SM-like
high q^2	$1.00 \pm \mathcal{O}(\%)$		0.7 ... 4.4

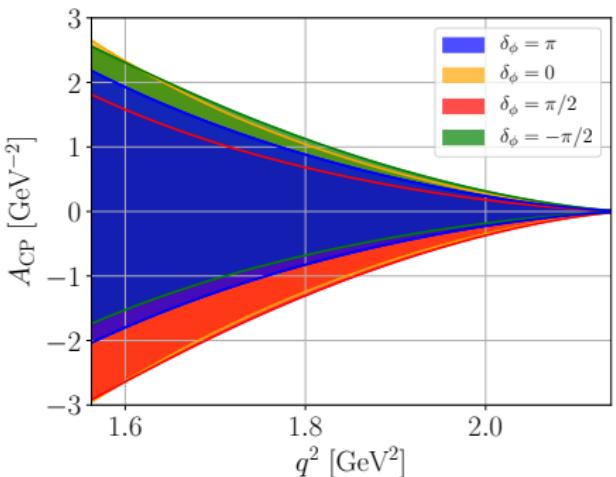
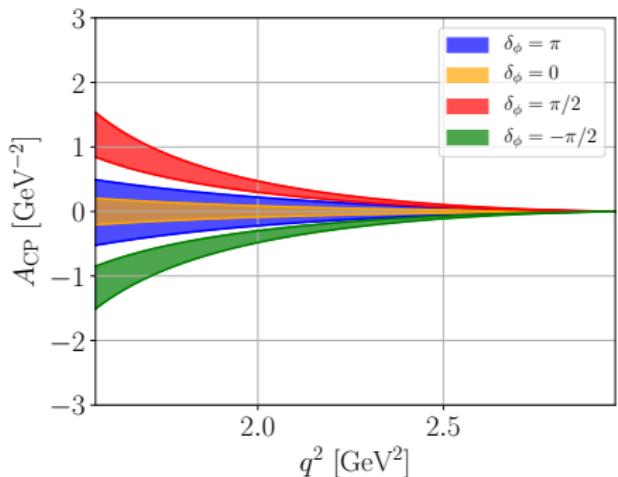
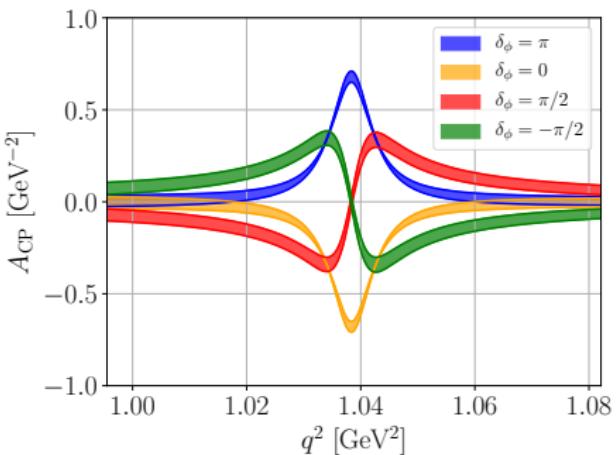
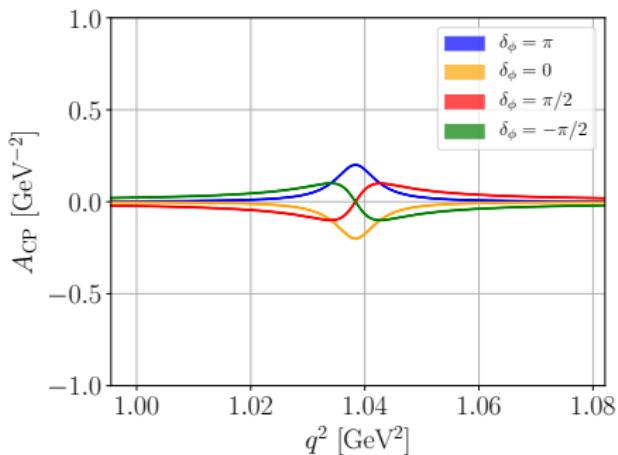
$D \rightarrow KK$	SM	BSM	LQ
full q^2	$1.00 \pm \mathcal{O}(\%)$	SM-like	SM-like
low q^2	$0.83 \pm \mathcal{O}(\%)$	$0.60 \dots 0.87$	

CP-asymmetries

$$A_{\text{CP}}(q^2) = \frac{1}{\Gamma + \bar{\Gamma}} \left(\frac{d\Gamma}{dq^2} - \frac{d\bar{\Gamma}}{dq^2} \right)$$

$$\text{with } \Gamma = \int_{q_{\min}^2}^{q_{\max}^2} \frac{d\Gamma}{dq^2} dq^2$$

- ▶ Strong phase from resonances needed \Rightarrow measurement around the ϕ resonance, or in the high q^2 region.
- ▶ NP phase needed. \Rightarrow benchmark $C_9 = 0.1 \exp(i\pi/4)$.
- ▶ Binning necessary.



$D \rightarrow K_1(\rightarrow K\pi\pi)\gamma$ Adolph, Hiller, Tayduganov, (1812.04679) $D \rightarrow V\gamma$ de Boer, Hiller, (1802.02769)

- ▶ Investigations of radiative decays are complementary to leptonic modes.
- ▶ measurements of the photon polarization are possible.
- ▶ Sensitive to differences in C_7 vs. C'_7 .
- ▶ In $D \rightarrow P\ell\ell$ only $C_7 + C'_7$ enters.

Conclusions

- ▶ The charm quark offers the unique possibility to test the flavor structure of the SM in the up-type sector.
- ▶ Null test observables can be probed and allow for large NP contributions.
- ▶ Theory uncertainties shrink with improved measurements of $\mathcal{B}(D_{(s)} \rightarrow \pi(K)M)$ and $\mathcal{B}(M \rightarrow \ell\ell)$ with $M = \rho, \omega, \phi, \eta, \eta'$.
- ▶ Main source of theoretical uncertainties are unknown strong phases.
- ▶ Rare semileptonic and radiative decays are complementary.
- ▶ BSM models were not discussed in this talk \Rightarrow Leptoquarks, Susy, $U(1)'$ extensions.

BACKUP

$$\mathcal{H}_{\rm eff} \supset -\frac{4G_F}{\sqrt{2}}\frac{\alpha_e}{4\pi}\bigg[\sum_{i=7,9,10,S,P}(C_iO_i+C'_iO'_i)+\sum_{i=T,T5}C_iO_i\bigg]\,,$$

$$O_7=\frac{m_c}{e}(\overline{u}_L\sigma_{\mu\nu}c_R)F^{\mu\nu}\,,$$

$$O_9=(\overline{u}_L\gamma_\mu c_L)(\bar{\ell}\gamma^\mu\ell)\,,$$

$$O_{10}=(\overline{u}_L\gamma_\mu c_L)(\bar{\ell}\gamma^\mu\gamma_5\ell)\,,$$

$$O_S=(\overline{u}_Lc_R)(\bar{\ell}\ell)\,,$$

$$O_P=(\overline{u}_Lc_R)(\bar{\ell}\gamma_5\ell)\,,$$

$$O_T=\frac{1}{2}(\overline{u}\sigma_{\mu\nu}c)(\bar{\ell}\sigma^{\mu\nu}\ell)\,,$$

$$O_{T5}=\frac{1}{2}(\overline{u}\sigma_{\mu\nu}c)(\bar{\ell}\sigma^{\mu\nu}\gamma_5\ell)\,.$$

$$O_1^q = (\overline{u}_L\gamma_\mu T^a q_L)(\overline{q}_L\gamma^\mu T^a c_L)\,, \quad O_2^q = (\overline{u}_L\gamma_\mu q_L)(\overline{q}_L\gamma^\mu c_L)\,, \quad q=d,\,s$$

Table: Integrated branching fractions in the high q^2 -bin ($\sqrt{q^2} \geq 1.25$ GeV) in the SM and in the NP benchmark scenarios.

$\frac{\mathcal{B} _{\text{high } q^2} \times 10^9}{D^+ \rightarrow \pi^+ \mu^+ \mu^-}$	SM	$C_{9(10)} = 0.5$	$C_{S(P)} = 0.1$
$D_s^+ \rightarrow K^+ \mu^+ \mu^-$	0.03 ... 0.3	1.9 ± 0.1	0.48 ± 0.04
		3.5 ± 3.5	1.4 ± 0.8
$D_s^+ \rightarrow K^+ \mu^+ \mu^-$	0.03 ... 0.3	0.40 ± 0.05	0.15 ± 0.07
		0.8 ± 0.7	0.3 ± 0.2

$\frac{\mathcal{B} _{\text{high } q^2} \times 10^9}{D^+ \rightarrow \pi^+ \mu^+ \mu^-}$	$C_{T(T5)} = 0.5$	$C_9 = \pm C_{10} = 0.5$
$D_s^+ \rightarrow K^+ \mu^+ \mu^-$	1.1 ± 0.2	3.9 ± 0.2
	2.3 ± 1.5	5.6 ± 3.6
$D_s^+ \rightarrow K^+ \mu^+ \mu^-$	0.15 ± 0.05	0.8 ± 0.1
	0.4 ± 0.3	1.2 ± 0.8

