Lepton flavor violation and lepton universality violation tests in rare charm decays

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Based on 2007.05001, 1909.11108, 1805.08516.

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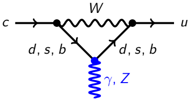
Charm physics is exceptional

1. **Unique window to explore FCNCs in the up-sector!**

2. **Non-perturbative dynamics** $\to$ **"Null tests" observables $\mathcal{O} \pm \delta\,\mathcal{O}$**

   Bird's-eye view of the playground:[1]
   - SM symmetries: $\mathcal{O}_{\rm SM} = \mathbf{0}$.
   - Small uncertainties: $\mathcal{O}_{\rm SM} \gg \delta\,\mathcal{O}_{\rm SM}$.
   - Large hadronic effects to enhance small NP contributions.
   - Sensitive to specific NP.

3. **Very efficient GIM mechanism:** $\sum_i \lambda_i = 0$ with $\lambda_i \equiv V_{ci}^* V_{ui}$.



$$= \sum_{i=d,s,b} \lambda_i\, f_i \;=\; \lambda_s \left[(f_s - f_d) + \frac{\lambda_b}{\lambda_s}\,(f_b - f_d) \right]$$

$f_i \sim \frac{m_i^2}{(4\pi)^2 M_W^2}$, ${\rm Im}(\lambda_b/\lambda_s) \sim 10^{-3}$

BRs ($A_{\rm CP}$) are loop-(CKM-) suppressed!

Formidable place to search for BSM physics!

[1] 1510.00311, 1701.06392, 1802.02769, 1805.08516, 1812.04679, 1909.11108, 2004.01206, 2007.05001,...

EFT approach to charm physics de Boer, (2017), PhD thesis, TU Dortmund

1. Dynamical fields ϕ_i at μ_{EW}: $\phi_i^{\text{SM}} = q_i, \ell_i, g, \ldots$
2. Symmetries to build all $O_j(\phi_i)$ up to $(p^2/\mu_{\text{EW}}^2)^n$, $\mathcal{H}_{\text{eff}} = \sum_i C_i\, O_i$

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

$$O_7^{(\prime)} = \frac{m_c}{e}(\overline{u}_{L\,(R)}\, \sigma_{\mu\nu}\, c_{R\,(L)})\, F^{\mu\nu}\,, \;\; O_{9\,(10)}^{(\prime)} = (\overline{u}_{L\,(R)} \gamma_\mu c_{L\,(R)})(\overline{\ell}\, \gamma^\mu (\gamma_5)\, \ell)\,,$$

$$O_{S\,(P)}^{(\prime)} = (\overline{u}_{L\,(R)} c_{R\,(L)})(\overline{\ell}\, (\gamma_5)\, \ell)\,, \;\; O_{T\,(T5)} = \frac{1}{2}(\overline{u}\, \sigma_{\mu\nu}\, c)(\overline{\ell}\, \sigma^{\mu\nu}\, (\gamma_5)\, \ell)\,.$$

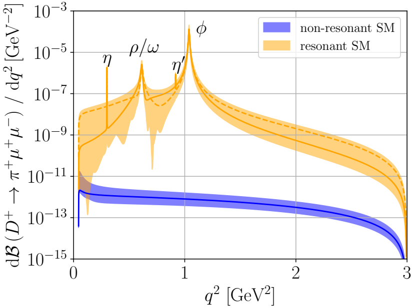
3. Compute $C_i(\mu_{\text{EW}})$ to avoid large $\alpha_s(\mu_{\text{low}}) \log(\mu_{\text{low}}^2/\mu_{\text{EW}}^2)$.

$$m_{q_{\text{light}}} = 0 + \text{GIM mechanism} \implies \boxed{C_{7,9,10}^{\text{SM}}(\mu_{\text{EW}}) = 0!}$$

4. RGEs to go down $\mu_{\text{low}} \approx m_c$ (2-step matching at μ_{EW} and m_b).
   - Penguins generated at $\mu = m_b$.
   - $O_{7,9}$ mix with $O_{1,2}$, but O_{10} not $\Rightarrow$ $\boxed{C_{7,9}^{\text{SM}}(\mu_c) \neq 0 \,\&\, C_{10}^{\text{SM}}(\mu_c) = 0}$
5. $\langle O_i(\mu_{\text{low}}) \rangle$ from non-perturbative techniques (Lattice, LCSR, ...)
6. Include resonances: Breit–Wigner distributions + exp. data.

Rare semileptonic charm $c \to u\,\ell^+\ell^-$ decays

e.g. $D^+ \to \pi^+\mu^+\mu^-$



- 1909.11108 ($D \to P\,\ell\ell$)
- 1805.08516 ($D \to P_1 P_2\,\ell\ell$)

- **Dominated by resonances from $D \to \pi M(\to \ell\ell)$,**
  $$C_9^{\text{eff}} \ll C_9^{\text{R}} \to C_9^{\text{SM}} \approx C_9^{\text{R}}$$
- **Current data still allows for large NP effects at large q^2.**[a]
  $$\mathcal{B}_{D^+\to\pi^+\mu^+\mu^-} < 6.7 \cdot 10^{-8},\ 90\%\ \text{C.L.}$$
- **Exp. close to R curves, NP searches in BRs are difficult (NP$\times$R increase $\delta\mathcal{B}_{\text{theo}}$)**
- **No NP$\to$ QCD tests!**

[a] LHCb talk of Dominik Mitzel at FPCP 2020.

$\mathcal{B}\vert_{\text{high } q^2} \times 10^9$	SM	$C_{9\,(10)} = 0.5$	$C_{S\,(P)} = 0.1$	$C_{T\,(T5)} = 0.5$	$C_9 = \pm C_{10} = 0.5$
$D^+ \to \pi^+\mu^+\mu^-$	$0.1\dots1.7$	1.9 ± 0.1	0.48 ± 0.04	1.1 ± 0.2	3.9 ± 0.2
		3.5 ± 3.5	1.4 ± 0.8	2.3 ± 1.5	5.6 ± 3.6
$D_s^+ \to K^+\mu^+\mu^-$	$0.03\dots0.3$	0.40 ± 0.05	0.15 ± 0.07	0.15 ± 0.05	0.8 ± 0.1
		0.8 ± 0.7	0.3 ± 0.2	0.4 ± 0.3	1.2 ± 0.8

Testing lepton universality with $c \to u\,\ell^+\ell^-$ decays

- **LU can be probed in $c \to u\,\ell^+\ell^-$ (same as B decays)**

$$R_P^D = \frac{\displaystyle\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{d\mathcal{B}(D \to P\mu^+\mu^-)}{dq^2} dq^2}{\displaystyle\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{d\mathcal{B}(D \to Pe^+e^-)}{dq^2} dq^2}$$

- **Same kinematical limits $\to$ Cancellation of had. uncertainties!**
- **Well control of SM prediction:** $\boxed{R_P^D|_{\rm SM} \approx 1}$
- **e.g. $D^+ \to \pi^+\,\ell^+\ell^-$ 1909.11108, see 1805.08516 ($D \to P_1P_2\,\ell^+\ell^-$)**
  - **full q^2:** insensitive to NP.
  - **low q^2:** poor knowledge of resonances $\to$ sizable uncertainties.
  - **high q^2:** induce significant NP effects.

NP effects at low q^2 are huge. With more exp. data, uncertainties could be reduced studying resonance effects.

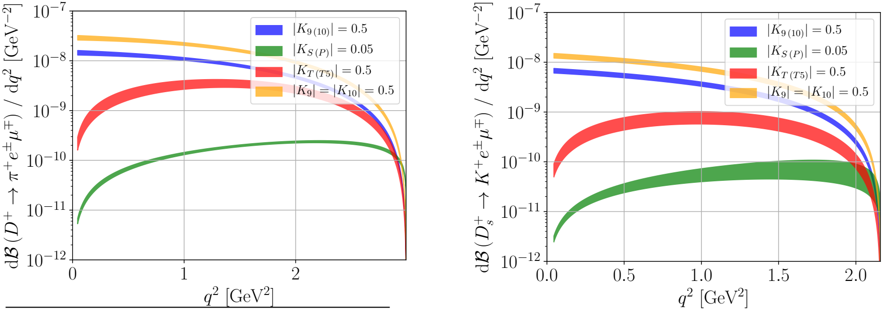
	SM	$\lvert C_9\rvert = 0.5$	$\lvert C_{10}\rvert = 0.5$	$\lvert C_9\rvert = \pm\lvert C_{10}\rvert = 0.5$	$\lvert C_{S(P)}\rvert = 0.1$	$\lvert C_T\rvert = 0.5$	$\lvert C_{T5}\rvert = 0.5$
full q^2	$1.00 \pm \mathcal{O}(10^{-2})$	SM-like	SM-like	SM-like	SM-like	SM-like	SM-like
low q^2	$0.95 \pm \mathcal{O}(10^{-2})$	$\mathcal{O}(100)$	$\mathcal{O}(100)$	$\mathcal{O}(100)$	$0.9 \ldots 1.4$	$\mathcal{O}(10)$	$1.0 \ldots 5.9$
high q^2	$1.00 \pm \mathcal{O}(10^{-2})$	$0.2 \ldots 11$	$3 \ldots 7$	$2 \ldots 17$	$1 \ldots 2$	$1 \ldots 5$	$2 \ldots 4$

Testing lepton flavor violation with $c \to u\,\ell^+\ell'^-$ $(\ell \neq \ell')$ decays

- **Forbidden in SM! Any signal would cleanly signal LFV!**
- **Extend LFC EFT via $\bar{\ell}\, A_{\text{Dirac}}\, \ell \to \bar{\ell}\, A_{\text{Dirac}}\, \ell'$.**
- **Experimental bounds:**[2]

$$\mathcal{B}(D^+ \to \pi^+ e^- \mu^+) < 2.2 \cdot 10^{-7},\ 90\%\ \text{C.L.}$$
$$\mathcal{B}(D_s^+ \to K^+ e^- \mu^+) < 9.4 \cdot 10^{-7},\ 90\%\ \text{C.L.}$$

1909.11108



[2] LHCb talk of Dominik Mitzel at FPCP 2020.

Rare charm dineutrino modes $c \to u\,\nu\bar{\nu}$

- $c \to u\,\nu\bar{\nu}$ are GIM-suppressed in the SM:[3]

Any observation would cleanly signal NP!

- **Well-suited for e^+e^-–colliders** such as **Belle II** and future **FCC-ee**.

- **What is the new physics reach?**

⋆ Fragmentation fractions $f(c \to h_c)$, 1509.01061

⋆ Number of $c\bar{c}$: Abada:2019lih

- $N(c\bar{c})_{\text{Belle II}} = 65 \cdot 10^9$ for $50\,\text{ab}^{-1}$.
- $N(c\bar{c})_{\text{FCC-ee}} = 550 \cdot 10^9$.

⋆ $N(h_c) = 2\,f(c \to h_c)\,N(c\bar{c})$.

h_c	$f(c \to h_c)$	$N(h_c)_{\text{FCC-ee}}$	$N(h_c)_{\text{Belle II}}$
D^0	0.59	$6 \cdot 10^{11}$	$8 \cdot 10^{10}$
D^+	0.24	$3 \cdot 10^{11}$	$3 \cdot 10^{10}$
D_s^+	0.10	$1 \cdot 10^{11}$	$1 \cdot 10^{10}$
Λ_c^+	0.06	$7 \cdot 10^{10}$	$8 \cdot 10^{9}$

$\Downarrow$

$$N(h_c) \sim 10^{11}!$$

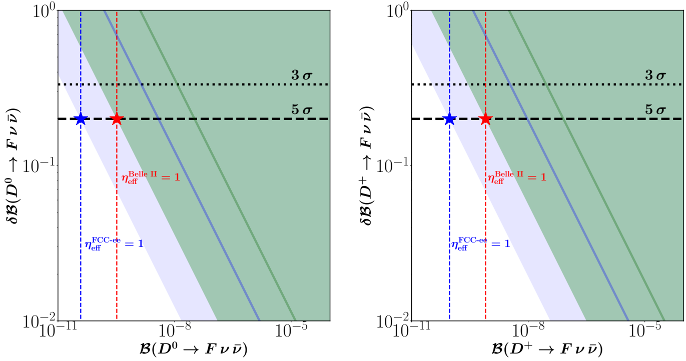
[3] hep-ph/0112235, 0908.1174

Experimental projections: $\delta\mathcal{B}$ vs $\mathcal{B}$ for D^0 and D^+

SM contribution can't be seen in plot, it is well below 10^{-10}!

Any signal is NP: model independently LQs, Z',...

$$\delta\mathcal{B}(h_c \to F\,\nu\,\bar\nu) = 1/\sqrt{N_F^{\rm exp}} \text{ with } N_F^{\rm exp} = \eta_{\rm eff}\, N(h_c)\, \mathcal{B}(h_c \to F\,\nu\,\bar\nu).$$

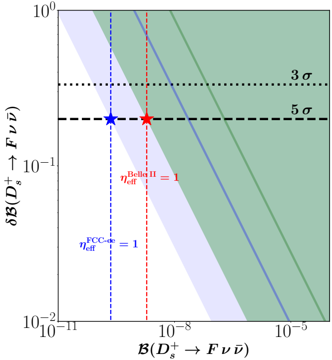


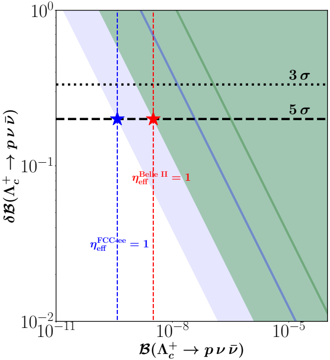
$\downarrow$ $\downarrow$ $\eta_{\rm eff}$**?** e.g. solid lines $\eta_{\rm eff} = 10^{-2}$

$\mathcal{B}_{5\sigma}(D^0 \to F\nu\bar\nu)/\eta_{\rm eff} \approx 3 \cdot 10^{-10}$ $(4 \cdot 10^{-11})$

$\mathcal{B}_{5\sigma}(D^+ \to F\nu\bar\nu)/\eta_{\rm eff} \approx 8 \cdot 10^{-10}$ $(9 \cdot 10^{-11})$

Further opportunities with D_s^+ and Λ_c^+





$\downarrow$ $\quad$ $\downarrow$ $\eta_{\rm eff}$**?** e.g. solid lines $\eta_{\rm eff} = 10^{-2}$

$\mathcal{B}_{5\sigma}(D_s^+ \to F\nu\bar\nu)/\eta_{\rm eff} \approx 2\cdot 10^{-9}\ (2\cdot 10^{-10})$

$\mathcal{B}_{5\sigma}(\Lambda_c^+ \to p\nu\bar\nu)/\eta_{\rm eff} \approx 3\cdot 10^{-9}\ (4\cdot 10^{-10})$

If no loss of information, Belle II & FCC-ee can reach BRs $\sim 10^{-10}$!

Are there any model-independent upper limits?

$c \to u\,\ell\ell$ $\xrightarrow{?}$ $c \to u\,\nu\bar{\nu}$

$|\Delta c| = |\Delta u| = 1$ Low energy descriptions:

- **Dineutrino transitions:**

$$\mathcal{H}_{\text{eff}}^{c\to u\,\nu_i\bar{\nu}_j} = -\frac{4\,G_F}{\sqrt{2}}\frac{\alpha}{4\pi}\left(\mathcal{C}_L^{Uij}\,Q_L^{ij} + \mathcal{C}_R^{Uij}\,Q_R^{ij}\right) + \text{h.c.}\,,$$

$Q^{ij}_{\mathrm{L\,(R)}} = (\bar{u}_{L\,(R)}\gamma_\mu c_{L\,(R)})\,(\bar{\nu}_{j\,L}\gamma^\mu \nu_{i\,L})$, Only two operators (no RH neutrinos like SM)

- **Charged dilepton transitions:**

$$\mathcal{H}_{\text{eff}}^{c\to u\,\ell\ell'} = -\frac{4\,G_F}{\sqrt{2}}\frac{\alpha}{4\pi}\left(\mathcal{K}_L^{U\ell\ell'}\,O_L^{\ell\ell'} + \mathcal{K}_R^{U\ell\ell'}\,O_R^{\ell\ell'} + \ldots\right) + \text{h.c.}\,,$$

$O^{\ell\ell'}_{\mathrm{L\,(R)}} = (\bar{u}_{L\,(R)}\gamma_\mu c_{L\,(R)})\,(\bar{\ell}'_L\gamma^\mu \ell_L)$, Further operators non-connected

Dineutrino BR is obtained via an incoherent neutrino flavor sum:

$$\mathcal{B}\,(c \to u\,\nu\bar{\nu}) = \sum_{i,j}\mathcal{B}\,(c \to u\,\nu_i\bar{\nu}_j) \propto x = \sum_{i,j}\left(|\mathcal{C}_L^{Uij}|^2 + |\mathcal{C}_R^{Uij}|^2\right)$$

Is it possible to translate x in terms of $\mathcal{K}$? ($\mathcal{C}$ and $\mathcal{K}$ in the mass basis)

Correlate neutrinos and charged leptons with SU(2)

1. **$SU(2)_L \times U(1)_Y$–invariant effective theory:**[4]

$$\mathcal{L}^{\rm LO}_{\rm SMEFT} \supset \frac{C^{(1)}_{\ell q}}{v^2}\bar{Q}\gamma_\mu Q\,\bar{L}\gamma^\mu L + \frac{C^{(3)}_{\ell q}}{v^2}\bar{Q}\gamma_\mu\tau^a Q\,\bar{L}\gamma^\mu\tau^a L + \frac{C_{\ell u}}{v^2}\bar{U}\gamma_\mu U\,\bar{L}\gamma^\mu L + \frac{C_{\ell d}}{v^2}\bar{D}\gamma_\mu D\,\bar{L}\gamma^\mu L$$

2. **Writing in $SU(2)_L$-components:** ($C \to$ dineutrinos and $K \to$ dileptons in the gauge basis)

$$C_L^U = K_L^D = C^{(1)}_{\ell q} + C^{(3)}_{\ell q}\,, \qquad C_R^U = K_R^U = C_{\ell u}\,,$$
$$C_L^D = K_L^U = C^{(1)}_{\ell q} - C^{(3)}_{\ell q}\,, \qquad C_R^D = K_R^D = C_{\ell d}\,.$$

3. **$C_R^{U,D} = K_R^{U,D}$ holds model independently! But, $C_L^{U,D} = K_L^{D,U}$!**
4. In terms of mass eigenstates, $Q_\alpha = (u_{L\alpha}, V_{\alpha\beta}\, d_{L\beta})$, $L_i = (\nu_{Li}, W^*_{ki}\,\ell_{Lk})$

$$\boxed{\mathcal{C}_L^U = W^\dagger \mathcal{K}_L^D W + \mathcal{O}(\lambda), \qquad \mathcal{C}_R^U = W^\dagger \mathcal{K}_R^U W\ ,}$$

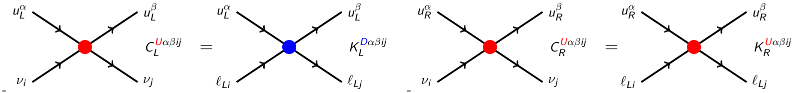
[4] 1008.4884

Connection via "trace identities" in the mass basis

$$\mathcal{B} \propto \sum_{\nu=i,j} \left(|\mathcal{C}_L^{Uij}|^2 + |\mathcal{C}_R^{Uij}|^2 \right) = \mathrm{Tr}\left[\mathcal{C}_L^U \, \mathcal{C}_L^{U\dagger} + \mathcal{C}_R^U \, \mathcal{C}_R^{U\dagger} \right]$$

$$= \mathrm{Tr}\left[\mathcal{K}_L^D \mathcal{K}_L^{D\dagger} + \mathcal{K}_R^U \mathcal{K}_R^{U\dagger} \right] + \mathcal{O}(\lambda) = \sum_{\ell=i,j} \left(|\mathcal{K}_L^{Dij}|^2 + |\mathcal{K}_R^{Uij}|^2 \right) + \mathcal{O}(\lambda)$$

1. **SU(2) relates up, down, neutrinos and charged leptons.**



2. **Mass basis:** $\mathcal{C}_L^U = W^\dagger \, \mathcal{K}_L^D \, W + \mathcal{O}(\lambda), \quad \mathcal{C}_R^U = W^\dagger \, \mathcal{K}_R^U \, W$

3. **Unitarity** $\boldsymbol{WW^\dagger = W^\dagger W = I}$

$c \to u\,\ell\ell$ ⟶ $c \to u\,\nu\bar{\nu}$ ⟵ $d \to s\,\ell\ell$

⋆ **Independent of PMNS matrix and subleading $\mathcal{O}(\lambda)$ corrections!**

⋆ **Prediction of dineutrino rates for different leptonic flavor structures $\mathcal{K}_{L,R}^{ij}$ can be probed with lepton-specific measurements!**

Possible leptonic flavor structures for $\mathcal{K}_{L,R}^{ij}$

i) ***Lepton-universality*** **(LU).**

$$\begin{pmatrix} k & 0 & 0 \\ 0 & k & 0 \\ 0 & 0 & k \end{pmatrix}$$

ii) ***Charged lepton flavor conservation*** **(cLFC).**

$$\begin{pmatrix} k_{11} & 0 & 0 \\ 0 & k_{22} & 0 \\ 0 & 0 & k_{33} \end{pmatrix}$$

iii) $\mathcal{K}_{L,R}^{ij}$ **arbitrary.**

$$\begin{pmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ k_{31} & k_{32} & k_{33} \end{pmatrix}$$

Upper limits on dineutrino modes can probe lepton unversality!

- **Bounds on lepton specific WCs for $\ell, \ell' = e, \mu, \tau$.**[5]

	$\lvert\mathcal{K}_A^{P\ell\ell'}\rvert$	ee	$\mu\mu$	$\tau\tau$	$e\mu$	$e\tau$	$\mu\tau$
$s \to d$	$\lvert\mathcal{K}_L^{D\ell\ell'}\rvert$	3.5	1.9	6.7	2.0	6.1	6.6
$c \to u$	$\lvert\mathcal{K}_R^{U\ell\ell'}\rvert$	2.9	1.6	5.6	1.6	4.7	5.1

- $x = \sum_{\ell,\ell'} \left(\lvert\mathcal{K}_L^{D\ell\ell'}\rvert^2 + \lvert\mathcal{K}_R^{U\ell\ell'}\rvert^2\right) + \mathcal{O}(\lambda) = \sum_{\ell,\ell'} R^{\ell\ell'} + \mathcal{O}(\lambda)$

  $x = 3\,R^{\mu\mu} \lesssim 18\,,$ **(Lepton Universality)**

  $x = R^{ee} + R^{\mu\mu} + R^{\tau\tau} \lesssim 103\,,$ **(charged Lepton Flavor Conservation)**

  $x = R^{ee} + R^{\mu\mu} + R^{\tau\tau} + 2\left(R^{e\mu} + R^{e\tau} + R^{\mu\tau}\right) \lesssim 375.$

  LU is fixed by the most stringent bound (muons).

[5] From high-p_T bounds: 2003.12421, 2002.05684

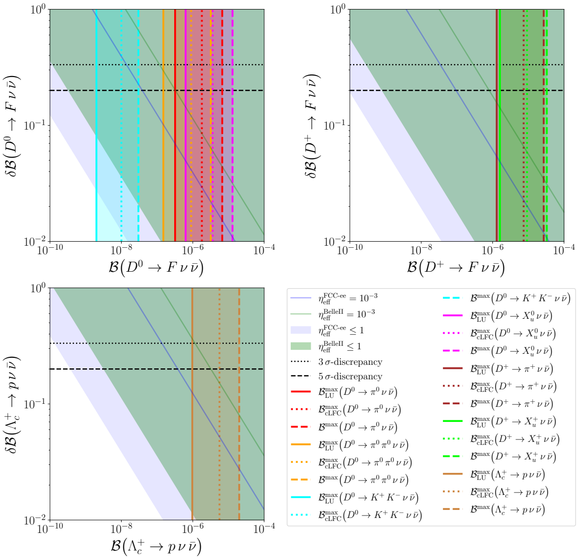
Dineutrino branching ratios upper limits

$$\mathcal{B}(h_c \to F\,\nu\bar{\nu}) = A_+^{h_c F}\, x_+ + A_-^{h_c F}\, x_-\,, \quad x_\pm = \sum_{i,j} |\mathcal{C}_L^{Uij} \pm \mathcal{C}_R^{Uij}|^2 < 2\,x\,.$$

$N_i = \eta_{\text{eff}}\, \mathcal{B}_i\, N(h_c)$, $N(c\bar{c})_{\text{Belle II}} = 65 \cdot 10^9$ for $50\,\text{ab}^{-1}$, $N(c\bar{c})_{\text{FCC-ee}} = 550 \cdot 10^9$.

$h_c \to F$	$\mathcal{B}^{\max}_{\text{LU}}$ $[10^{-7}]$	$\mathcal{B}^{\max}_{\text{cLFC}}$ $[10^{-7}]$	$\mathcal{B}^{\max}$ $[10^{-7}]$	$N_{\text{LU}}/\eta_{\text{eff}}$	$N_{\text{cLFC}}/\eta_{\text{eff}}$	$N_{\max}/\eta_{\text{eff}}$
$D^0 \to \pi^0$	3.2	18	67	25 k (210 k)	138 k (1.2 M)	514 k (4.3 M)
$D^+ \to \pi^+$	13	74	270	41 k (340 k)	230 k (2.0 M)	840 k (7.1 M)
$D_s^+ \to K^+$	2.4	14	50	3 k (26 k)	18 k (150 k)	65 k (550 k)
$D^0 \to \pi^0\pi^0$	1.5	9	32	12 k (97 k)	69 k (580 k)	250 k (2.1 M)
$D^0 \to \pi^+\pi^-$	1.5	9	31	12 k (97 k)	69 k (580 k)	240 k (2.0 M)
$D^0 \to K^+K^-$	0.02	0.1	0.3	150 (1 k)	770 (6 k)	2 k (19 k)
$\Lambda_c^+ \to p^+$	9.7	56	200	8 k (64 k)	44 k (370 k)	160 k (1.3 M)
$\Xi_c^+ \to \Sigma^+$	19	110	400	14 k (130 k)	86 k (730 k)	310 k (2.6 M)
$D^0 \to X_u$	6.3	36	130	48 k (410 k)	280 k (2.3 M)	1.0 M (8.4 M)
$D^+ \to X_u$	16	92	330	49 k (420 k)	290 k (2.4 M)	1.0 M (8.7 M)
$D_s^+ \to X_u$	7.7	44	160	10 k (85 k)	57 k (480 k)	210 k (1.8 M)
	$\sim 10^{-6}$	$\sim 10^{-5}$	$\sim 10^{-5}$	~ 10 k (100 k)	~ 100 k (1 M)	~ 100 k (1 M)

$\delta\mathcal{B}$ vs $\mathcal{B}$: exp. projections and theo. predictions



Final remarks

- ⋆ **Plenty of opportunities to probe LFV and universality with charm decays.**

- ⋆ **New ideas presented: probes with $\mathcal{B}(c \to u\nu\bar{\nu})$.**

$$\boxed{c \to u\,\ell\ell} \longrightarrow \boxed{c \to u\,\nu\bar{\nu}} \longleftarrow \boxed{d \to s\,\ell\ell}$$

- ⋆ **Large event rates for Belle II and FCC-ee, complementarity to LHCb tests.**

Thank you for your attention!

BACKUP

Correlations between different dineutrino modes

- The **excellent complementarity between different dineutrino modes** provides a **formidable environment for NP searches!**

$$\mathcal{B}(h_c \to F\,\nu\bar{\nu}) = A_+^{h_cF}\,x_+ + A_-^{h_cF}\,x_-\,, \qquad x_\pm \;=\; x\,(1 \pm z)\;.$$

1. $A_-^{h_cF} \approx 0$ in $D \to P\,\nu\bar{\nu}$,
2. $A_+^{h_cF} \approx 0$ in $D \to P_1 P_2\,\nu\bar{\nu}$,
3. $\mathcal{O}(A_-^{h_cF}) \sim \mathcal{O}(A_+^{h_cF})$ in baryonic charm decays,
4. $A_-^{h_cF} = A_+^{h_cF}$ in inclusive D decays,

- **Correlations test the completeness of EFT:**

$$\boxed{\mathcal{B}(h_c \to F\,\nu\,\bar{\nu}) \;=\; r_+^{h_cF}\,\mathcal{B}(D \to P\nu\bar{\nu}) + \,r_-^{h_cF}\,\mathcal{B}(D' \to P_1\,P_2\,\nu\,\bar{\nu})}$$

where $r_+^{h_cF} = A_+^{h_cF}/A_+^{DP}$ and $r_-^{h_cF} = A_-^{h_cF}/A_-^{DP_1P_2}$.

- **$x_\pm$–independent! Model independent correlations!**

- **All dineutrino BRs from two experimental measurements.**

- **Measurements of *a priori* disconnected modes could provide hints on missing information in the EFT,** *i.e.* light fields.