Can FCNC transition $c \rightarrow ul^+l^-$ be seen in $D \rightarrow Vl^+l^-$ decays?

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The decays $D \rightarrow Vl^+l^-$ present in principle the opportunity to observe the short distance FCNC transition $c \rightarrow ul^+l^-$, which is sensitive to the physics beyond the Standard Model. We analyze the $D \rightarrow Vl^+l^-$ decays within the Standard Model, where in addition to the short distance dynamics also the long distance dynamics is present. The short distance contribution due to $c \rightarrow ul^+l^-$ transition, which is present only in the Cabibbo suppressed decays, is found to be three orders of magnitude smaller than the long distance contribution. The branching ratios well above $10^{-7}$ for Cabibbo suppressed decays could signal new physics. The most frequent decays are the Cabibbo allowed decays $D_s^+ \rightarrow \rho^+\mu^+\mu^-$ and $D^0 \rightarrow \bar{K}^0\mu^+\mu^-$, which are expected at the branching ratios of $3 \cdot 10^{-5}$ and $1.7 \cdot 10^{-6}$, respectively. These rates are not much lower than the present experimental upper limit.

In the charm sector the phenomena like $D^0 - \bar{D}^0$ mixing, CP-violation and rare decay probabilities are small, which makes them good candidates as probes for New physics with small background from the Standard Model. The smallness of the short-distance (SD) $c \rightarrow ul^+l^-$ rate within the Standard Model suggests that the decays $D \rightarrow Vl^+l^-$ ($V$ is light vector meson) could serve as a possible good window to non-standard contributions to the flavour-changing neutral transition $c \rightarrow ul^+l^-$. We analyse all $D \rightarrow Vl^+l^-$ decays within the Standard Model, where except for the short distance dynamics also the long distance (LD) dynamics is present. We calculate the SD and LD contributions using the hybrid model, which combines heavy quark and chiral perturbation theory. The SD contribution due to $c \rightarrow ul^+l^-$ is present only in the Cabibbo suppressed decays $D^0 \rightarrow \rho^0l^+l^-$, $D^0 \rightarrow \omega l^+l^-$ $D^0 \rightarrow \phi l^+l^-$, $D^+ \rightarrow \rho^+l^+l^-$ and $D_s^+ \rightarrow K^*l^+l^-$. In this decays our motivation is to determine the relative magnitude of SD and LD contribution. Our results should provide the appropriate theoretical background against which possible signals of new physics are searched for. Motivated by the experimental searches, we analyze also the Cabibbo allowed decays ($D^0 \rightarrow K^{*0}l^+l^-$ and $D_s^+ \rightarrow \rho^*l^+l^-$), which are the best candidates for their early detection, and the doubly Cabibbo suppressed decays ($D^+ \rightarrow K^{*+}l^+l^-$ and $D^0 \rightarrow K^{*0}l^+l^-$). Here the signals from new physics are not expected from the theoretical models usually considered.

On the experimental side, so far there are only upper bounds on decays $D \rightarrow Vl^+l^-$ from E653 and CLEO, in the range $10^{-3}-10^{-4}$, but these are expected to improve in the future.

This work has been presented in detail in [4].

The long distance contribution in $D \rightarrow Vl^+l^-$ decays is due to the effective nonleptonic weak Lagrangian, which induces the weak transition between the initial and final hadronic state. The weak transition has to be accompanied by the emission of a virtual photon, which finally decays into a lepton antilepton pair. The effective nonleptonic weak Lagrangian responsible for charm meson decays is

$$
\mathcal{L}_{LD} = \frac{G_F}{\sqrt{2}} V_{uq} V_{cq}^* \left[ a_1 (\bar{u}_q\gamma_\mu q_c)^\mu \right]
+ a_2 (\bar{u}_c)^\mu (\bar{q}_j q_i)_\mu ,
$$

where $(\bar{u}_q\psi_2)^\mu \equiv \bar{u}_q\gamma_\mu(1 - \gamma^5)\psi_2$ and $q_{i,j}$ represent the fields of $d$ or $s$ quarks. There are two kinds of LD contribution: in the resonant mechanism, apart from the final vector meson $V$, an additional neutral vector meson $V_0$ is produced,
which converts to a photon through vector meson dominance \((D \to VV_0 \to V\gamma \to Vl^+l^-); V^0\) is \(\rho, \omega\) or \(\phi\); in the nonresonant mechanism the photon is emitted directly from the initial \(D\) or final \(V\) meson state. To calculate the amplitudes we use the factorization approximation and the hybrid model, which combines heavy quark effective theory and chiral perturbation theory \([4]\).

The details of this framework and its previous application is given in \([3]\). The relevant degrees of freedom are heavy pseudoscalar \((D)\) and vector \((D^*)\) meson fields and light pseudoscalar \((P)\) and vector \((V)\) meson fields. Within this approach, the diagrams that contribute to the process under study are given in Fig. 1. The diagrams are divided in three different types according to the factorization: Figs. 1a and 1b represent two types of spectator contributions, while Fig. 1c represents the weak annihilation contribution. The square in each diagram denotes the weak transition due to the effective Lagrangian \(L_{LD}\) \([1]\). This Lagrangian contains a product of two left handed quark currents \((\bar{q}_L q_L)^\mu\), each denoted by a dot. The diagrams \(II\) and \(IV\) represent nonresonant contribution, while all the remaining diagrams represent the resonant contribution. The vertices are evaluated using the hybrid model \([\mathbb{I}]\).

The short distance contribution due to FCNC \(c \to ul^+l^-\) is present only in the Cabibbo suppressed \(D \to Vl^+l^-\) decays. The effective Lagrangian for \(c \to ul^+l^-\) arises from WW exchange box diagrams and \(Z\) and \(\gamma^*\) penguin operators \([\mathbb{I}], [\mathbb{I}]\). The main contribution comes from the intermediate \(d\) and \(s\) quarks exchange and by using \(m_d^2 \ll m_W^2\) and \(m_s^2 \ll m_W^2\) one obtains

\[
\mathcal{L}_{SD} = \frac{G_F e^2}{\sqrt{2}} \sum_{i=d,s,b} V^*_{ei}V_{ut}A_i \frac{(\bar{u}c)^\mu}{8\pi^2\sin^2\theta_W} \bar{l}_\mu l,
\]

where the Willson coefficient \(A_i\) is given in \([\mathbb{I}]\). This gives the branching ratio for inclusive \(c \to ul^+l^-\) process \(\Gamma(c \to ul^+l^-)/\Gamma(D^0) = 2.9 \times 10^{-9}\), while for the exclusive processes \(D \to Vl^+l^-\) we evaluate \((V|\bar{u}c)^\mu|D\) using the hybrid model.

The predicted branching ratios \([\mathbb{I}]\) containing LD and SD contributions and experimental upper bounds \([\mathbb{I}]\) are given in Table 1. Apart from the Cabibbo structure, the branching ratios depend mainly on whether the initial state is charged or neutral, with bigger branching ratio in the former case. The Cabibbo allowed decays \(D^0 \to K^0\mu^+\mu^-\) and \(D_s^+ \to \rho^+\mu^+\mu^-\) have the best probability for their early detection. Note that their predicted branching ratios are not far below the present experimental upper bound.

In the Cabibbo suppressed decays the branching ratios due to SD contribution are three orders of magnitude smaller than the LD contribution: \(9.5 \times 10^{-10}\) for \(D^0 \to \rho^0(\omega)\mu^+\mu^-\), \(4.8 \times 10^{-9}\) for \(D^+ \to \rho^+\mu^+\mu^-\), \(1.6 \times 10^{-9}\) for \(D_s^+ \to K^{*+}\mu^+\mu^-\) and 0 for \(D^0 \to \phi\mu^+\mu^-\). We show the distributions \((1/\Gamma_D)d\Gamma(D \to V\mu^+\mu^-)/dq_\mu^2\) for the most frequent decay \(D_s^+ \to \rho^+\mu^+\mu^-\) and for the Cabibbo suppressed decay \(D^0 \to \rho^0\mu^+\mu^-\) in Fig. 2, where we separate SD, nonresonant LD and the total branching ratio. The rates are obviously dominated by the resonant LD part. It is interesting to remark however, that the SD part is comparable to nonresonant LD part in \(D^0 \to \rho^0(\omega)\mu^+\mu^-\) decays.

We have analyzed SD and LD contributions to \(D \to Vl^+l^-\) decays within the Standard Model. The predicted branching ratios for Cabibbo allowed decays are not much lower than the present experimental upper bound. In Cabibbo suppressed decays, the SD contributions are smaller than LD ones by three orders of magnitude. Still, the new physics could greatly enhance SD rates and branching ratios well above \(10^{-7}\) for Cabibbo suppressed decays could signal new physics. As the present experimental upper bounds for Cabibbo suppressed decays are much higher, they provide a large discovery window.

**REFERENCES**

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Table 1

| $D \rightarrow V\mu^+\mu^-$ | theory $Br(LD + SD)$ | exp $Br$ |
|------------------------|-----------------|--------|
| $D^0 \rightarrow K^{*0}$ | $1.6 - 1.9 \times 10^{-6}$ | $< 1.18 \times 10^{-3}$ |
| $D_s^+ \rightarrow \rho^+$ | $3.0 - 3.3 \times 10^{-7}$ | |
| $D^0 \rightarrow \rho^0$ | $3.5 - 4.7 \times 10^{-6}$ | $< 2.3 \times 10^{-4}$ |
| $D^0 \rightarrow \omega$ | $3.3 - 4.5 \times 10^{-6}$ | $< 8.3 \times 10^{-4}$ |
| $D^0 \rightarrow \phi$ | $6.5 - 9.0 \times 10^{-8}$ | $< 4.1 \times 10^{-4}$ |
| $D^+ \rightarrow \rho^+$ | $1.5 - 1.8 \times 10^{-6}$ | $< 5.6 \times 10^{-4}$ |
| $D_s^+ \rightarrow K^{*+}$ | $5.0 - 7.0 \times 10^{-7}$ | $< 1.4 \times 10^{-3}$ |
| $D^+ \rightarrow K^{*+}$ | $3.1 - 3.7 \times 10^{-8}$ | $< 8.5 \times 10^{-4}$ |
| $D^0 \rightarrow K^{*0}$ | $4.4 - 5.1 \times 10^{-9}$ | |

The predicted branching ratios (second column), which contain LD and SD contributions, and experimental upper bounds (for Cabibbo allowed, suppressed and doubly suppressed $D \rightarrow V\mu^+\mu^-$ decays.

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**Figure Captions:**

**Fig. 1:** Skeleton diagrams of various long distance contributions to the decay $D \rightarrow Vl^+l^-$ resulting from $\mathcal{L}_{LD}$.

**Fig. 2:** The predicted differential branching ratios $(1/\Gamma_D)d\Gamma(D_s^+ \rightarrow \rho^+\mu^+\mu^-)/dq^2$ (Fig. 2a) and $(1/\Gamma_D)d\Gamma(D^0 \rightarrow \rho^0\mu^+\mu^-)/dq^2$ (Fig. 2b) as a function of $q^2$ ($q^2$ the invariant $\mu^+\mu^-$ mass). The full line represents the total branching ratio, the dot-dashed line represents the short distance part, while the dashed line represents the nonresonant long distance part.
Fig. 1a

Fig. 1b

Fig. 1c

Fig. 1
\[
\frac{d\Gamma(D_s^+ \rightarrow \rho^+ \mu^- \bar{\nu}_\mu)}{\Gamma_{D_s} dq^2}
\]
Fig. 2b