SEARCH FOR NEW PHYSICS IN RARE D DECAYS

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In many extensions of the standard model an additional up-like heavy quark appears. Its appearance induces flavour changing neutral current transition in the up-quark region at the tree level. We investigate possible effects of these models in the $c \to ul^+l^-$ transitions. First we determine impact of new physics on the relevant Wilson coefficients and then we reevaluate the standard model long-distance contributions. We calculate differential branching ratio for the $D^+ \to \pi^+l^+l^-$ and $D^0 \to \rho l^+l^-$ decays. Among all D decay modes these two are the simplest ones for the experimental studies. We also determine the forward-backward asymmetry for the $D^0 \to \rho l^+l^-$ decay and we comment on the effects of the Littlest Higgs model in both decay modes.

Keywords: D decays, FCNC, heavy up-like quark.

At low-energies new physics is usually expected in the down-like quark sector. Numerous studies of new physics effects were performed in the $s \to d$, $b \to s(d)$, $s\bar{d} \leftrightarrow s \bar{s}$, $b\bar{d} \leftrightarrow d \bar{b}$ and $bs \leftrightarrow sb$ transitions.

However, searches for new physics in the up-like quark sector at low energies were not so attractive. Reasons are following: a) flavour changing neutral current processes are suppressed by the GIM cancellation leading to very small effects in the $c \to u$ transitions. The GIM mechanism acts in many extensions of the standard model too, making contributions of new physics insignificant. b) Most of the charm meson processes, where $c \to u$ and $c\bar{u} \leftrightarrow \bar{c}u$ transitions might occur are dominated by the standard model long-distance contributions $^1$ - $^9$.

On the experimental side there are many studies of rare charm meson decays. The first observed rare $D$ meson decay was the radiative weak decay $D \to \phi \gamma$. Its rate $BR(D \to \phi \gamma) = 2.6^{+0.7}_{-0.6} \times 10^{-5}$ has been measured by Belle collaboration $^{10}$ and hopefully other radiative weak charm decays will be observed soon$^{11}$.

In the standard model (SM) $^1$ the contribution coming from the penguin diagrams in $c \to u\gamma$ transition gives branching ratio of order $10^{-18}$. The QCD corrected effective Lagrangian $^{12}$ gives $BR(c \to u\gamma) \sim 3 \times 10^{-8}$. A variety of models beyond SM were investigated and it was found that the gluino exchange diagrams $^{13}$ within general minimal supersymmetric SM (MSSM) might lead to the enhancement

$$\frac{BR(c \to u\gamma)_{\text{MSSM}}}{BR(c \to u\gamma)_{\text{SM}}} \approx 10^2.$$ (1)

The inclusive $c \to ul^+l^-$ calculated at one-loop level in SM $^7$ was found to be suppressed by QCD corrections $^2$. The inclusion of the renormalization group equations for the Wilson coefficients gave an additional significant suppression $^8$ leading to the rates $\Gamma(c \to uc^+e^-)/\Gamma_{D^0} = 2.4 \times 10^{-10}$ and $\Gamma(c \to um^+\mu^-)/\Gamma_{D^0} = 0.5 \times 10^{-10}$. These transitions are largely driven by virtual photon at low dilepton mass $m_{\ell\ell}$.

The leading contribution to $c \to ul^+l^-$ in general MSSM with conserved R parity
comes from the one-loop diagram with gluino and squarks in the loop. It proceeds via virtual photon and significantly enhances the $c \to u l^+ l^-$ spectrum at small dilepton mass $m_{ll}$. The authors of Ref. 2 have investigated supersymmetric (SUSY) extension of the SM with R parity breaking and they found that it can modify the rate. Using most recent CLEO results for the $D^+ \to \pi^+ \mu^+ \mu^-$ one can set the bound for the product of the relevant parameters entering the R parity violating $\tilde{\lambda}_{2k} \tilde{\lambda}_{21k} \simeq 0.001$ (assuming that the mass of squark $M_{\tilde{d}_k} \simeq 100$ GeV). This bound gives the rates $BR_R(c \to u e^+ e^-) \simeq 1.6 \times 10^{-8}$ and $BR_R(c \to u \mu^+ \mu^-) \simeq 1.8 \times 10^{-8}$.

Some of models of new physics (NP) contain an extra up-like heavy quark inducing the flavour changing neutral currents at tree level for the up-quark sector. The isospin component of the weak neutral current is given as

$$J_{\mu W3}^n = \frac{1}{2} U_L^T \gamma^\mu \Omega U_L - \frac{1}{2} D_L^T \gamma^\mu D_L$$

with $L = \frac{1}{2}(1 - \gamma_5)$ and mass eigenstates $U_L^m = (u_L, c_L, t_L, T_L)^T$, $D_L^m = (d_L, s_L, b_L)^T$. The neutral current for the down-like quarks is the same as in the SM, while there are tree-level flavour changing transitions between up-quarks if $\Omega \neq I$. The elements of $4 \times 4$ matrix $\Omega$ can be constrained by CKM unitarity violations currently allowed by experimental data. Even more stringent bound on $cuZ$ coupling $\Omega_{uc}$ comes from the present bound on $\Delta m$ in $D^0 - \bar{D}^0$ transition. It gives $|\Omega_{uc}| \leq 0.0004$ and we use the upper bound to determine the maximal effect on rare $D$ decays in what follows. In this case the dilepton mass distribution of the $c \to u l^+ l^-$ differential branching ratio can be enhanced by two orders of magnitude in comparison with SM (see Fig.1).

A particular version of the model with tree-level up-quark FCNC transitions is the Littlest Higgs model. In this case the magnitude of the relevant $c \to u Z$ coupling $\Omega_{cu} = |V_{ub}| |V_{cb}| |u|^2/f^2 \leq 10^{-5}$ is even further constrained via the scale $f \geq \mathcal{O}(1 \text{ TeV})$ by the precision electro-weak data. The smallness of $\Omega_{uc}$ implies that the effect of this particular model on $c \to u l^+ l^-$ decay and relevant rare $D$ decays is insignificant.

The study of exclusive $D$ meson rare decay modes is very difficult due to the dominance of the long distance effects. The inclusive $c \to u l^+ l^-$ can be tested in the rare decays $D \rightarrow \mu^+ \mu^-$, $D \rightarrow P(V)l^+ l^-$. The branching ratio for the rare decay $D \rightarrow \mu^+ \mu^-$ is very small in the SM. The detailed treatment of this decay rate gives $Br(D \rightarrow \mu^+ \mu^-) \simeq 3 \times 10^{-13}$.

The branching ratio for the rare decay $D \rightarrow P(V)l^+ l^-$ decays offer another possibility to study the $c \to u l^+ l^-$ transition in charm sector. The most appropriate decay modes for the experimental searches are $D^+ \rightarrow \pi^+ l^+ l^-$ and $D^0 \rightarrow \rho^0 e^+ e^-$. In the following we present the possible maximal effect on these decays coming from general model with tree level $cuZ$ coupling at its upper bound $|\Omega_{uc}| = 0.0004$. We already pointed out that in Littlest Higgs model, which is a particular version of these models, the coupling $\Omega_{uc}$ is constrained to be smaller and the effects on rare $D$ decays are insignificant.

The calculations of the long distance contributions in the decays $D^+ \rightarrow \pi^+ l^+ l^-$ and $D^0 \rightarrow \rho^0 l^+ l^-$ are presented in Refs. 14,6,7. The contributions of the intermediate vector resonances $V_0 = \rho^0, \omega, \phi$ with $V_0 \rightarrow l^+ l^-$ constitute an important long-distance contribution to the hadronic decay, which may shadow interesting short-distance contribution induced by $c \to u l^+ l^-$ transition.

Our determination of short and long dis-
tance contributions to $D^+ \to \pi^+ l^+ l^-$ takes advantage of the available experimental data \(^{14}\). This is a fortunate circumstance for this particular decay since the analogous experimental input is not available for determination of the other $D \to X l^+ l^-$ rates in a similar way. The rate resulting from the amplitudes (14) and (19) of $|\Omega_{ac}| = 0.0004$ are given in Figure 2 and Table 1.

We are unable to determine the amplitude of the long-distance contribution to $D^0 \to \rho^0 V_0 \to \rho^0 l^+ l^-$ using the measured rates for $D^0 \to \rho^0 V_0$ since only the rate of $D^0 \to \rho^0 \phi$ is known experimentally. We are forced to use a model \(^{6}\), developed to describe all $D \to V l^+ l^-$ and $D \to V \gamma$ decays, and the resulting rates are presented in Figure 3 and Table 1.

Therefore, the total rates for $D \to X l^+ l^-$ are dominated by the long distance resonant contributions at dilepton mass $m_{ll} = m_{\rho}$, $m_{\omega}$, $m_{\phi}$ and even the largest contributions from new physics are not expected to affect the total rate significantly \(^{2,7}\). New physics could only modify the SM dilepton mass distribution at low $m_{ll}$ below $\rho$ or spectrum at high $m_{ll}$ above $\phi$. In the case of $D \to \pi^+ l^- l^-$ differential decay distribution there is a broad region at high $m_{ll}$ (see Fig. 2), which presents a unique possibility to study $c \to u l^+ l^-$ transition \(^{7,14}\).

The non-zero forward-backward asymmetry in $D \to \rho l^+ l^-$ decay arises only when $C_{10} \neq 0$ (assuming $m_t \to 0$). The enhancement of the $C_{10}$ in the NP models \(^{14}\) is due to the tree-level $u_L \gamma_\mu c_L \bar{Z}^\mu$ coupling and leads to nonzero asymmetry $A_{FB}(m_{ll}^2)$ shown in Fig. 4. The forward-backward asymmetry for $D^0 \to \rho^0 l^+ l^-$ vanishes in SM ($C_{10} \simeq 0$), while it is reaching $\mathcal{O}(10^{-2})$ in NP model with the extra up-like quark as shown in Fig. 4. Such asymmetry is still small and difficult to be seen in the present or planned experiments given that the rate itself is already small.

We have investigated impact of the tree-level flavor changing neutral transition $c \to u Z$ on the rare $D$ meson decay observables. However, the most suitable $D^+ \to \pi^+ l^+ l^-$ and $D^0 \to \rho^0 l^+ l^-$ decays are found to be dominated by the SM long distance contributions. Only small enhancement of the differential mass distribution can be seen in the case of $D^+ \to \pi^+ l^+ l^-$ decay at high dilepton mass and tiny forward backward asymmetry can be induced by new physics in $D^0 \to \rho^0 l^+ l^-$ decay.

We conclude that the new physics scenarios which contain an extra singlet heavy

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Fig. 1. The dilepton mass distribution $dBr/dm_{ll}^2$ for the inclusive decay $c \to u l^+ l^-$ as a function of the dilepton mass square $m_{ll}^2 = (p_+ + p_-)^2$.

Fig. 2. The dilepton mass distribution $dBr/dm_{ee}^2$ for $D^+ \to \pi^+ e^+ e^-$. 
Table 1. Branching ratios for decays in which $c \to u\ell^+\ell^-$ transition can be probed.

| Br $\to$ | short distance | total rate $\simeq$ | experiment $\simeq$ |
|----------|----------------|------------------|------------------|
| $D^+ \to \pi^+ e^+ e^-$ | $6 \times 10^{-12}$ | $1.9 \times 10^{-6}$ | $< 7.4 \times 10^{-6}$ |
| $D^+ \to \pi^+ \mu^+ \mu^-$ | $6 \times 10^{-12}$ | $1.9 \times 10^{-6}$ | $< 8.8 \times 10^{-6}$ |
| $D^0 \to \rho^0 e^+ e^-$ | negligible | $5 \times 10^{-10}$ | $1.6 \times 10^{-7}$ | $< 1.0 \times 10^{-4}$ |
| $D^0 \to \rho^0 \mu^+ \mu^-$ | negligible | $5 \times 10^{-10}$ | $1.5 \times 10^{-7}$ | $< 2.2 \times 10^{-5}$ |

up-like quark, have rather small effects on the charm meson observables.

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