Study of semileptonic decays of $D_s$ meson within R-parity violating supersymmetric model.

Farida Tahir*, Azeem Mir†

(*Physics Department, COMSATS Institute of Information Technology, Islamabad, †Physics Department, COMSATS Institute of Information Technology, Lahore)

Abstract

We present the comparative study of semileptonic and leptonic decays of $D_s$, $D^\pm$ and $D^0$ meson ($D \to M l^\alpha l^\beta \nu; \alpha, \beta = e, \mu$) within the framework of R-parity violating ($R_p$) Minimal Supersymmetric Standard Model (MSSM). The comparison shows that combination and product couplings ($\lambda^\beta_{ijq} \lambda^*_{jkq}$ or $\lambda^\beta_{ijk} \lambda^*_{ijk}$) contribution to the branching fractions of the said processes processes(under consideration) is consistent or comparable to the experimental measurements in most of the cases. However, there exists some cases, where these contributions are suppressed but still comparable to that of standard model.

1 Introduction

Flavor changing neutral current (FCNC) involving decays of charm mesons have played a leading role in flavor physics as well as in search for new physics[1]. These processes involve neutral meson oscillations, radiative decays and leptonic and semileptonic (Lepton flavor and number conserving) decays. Lepton flavor and number violating (LFV) processes are also important in this regard and have been explored for signs of new physics. They are allowed in the SM through higher order diagrams similar to FCNC but assuming oscillation in the virtual neutrino loop. These diagrams are doubly cabibbo suppressed, furthermore LFV are not allowed in SM. Therefore such processes provide the golden charmed physics beyond the SM. Neutral meson oscillations like $D^0 - \bar{D}^0$ mixing and coherent double-flavor oscillations is an exciting new way to search for CP-violation in the charm sector[2]. Radiative decays of charm mesons have been studied upto

*neutrino79@hotmail.com
†farida_tahir@comsats.edu.pk, ftahir@ku.edu
one loop order \[3\]. Processes involving \( D \) meson have proven to be an excellent laboratory for studying QCD since charm meson masses, \( O(2 \text{ GeV}) \), are placed in the middle of the region of non-perturbative hadronic physics[4].

New physics models, which are currently being explored in the charm sector include Higgs models like 2HDM and Little Higgs model with T-parity[5]. R-parity violating MSSM Yukawa couplings have been used to study anomaly in the branching fraction of leptonic decays of \( D_s \) meson, its correlation with the branching fraction of \( \tau \) LFV decays[6]. The possibility of detecting signals of light sparticles using R parity Yukawa couplings derived from the leptonic decays of \( D_S \) meson has also been explored[6]. Unparticle physics has also been explored in the sector of charm mesons[7].

Charm mesons(\( D, D^\pm, D_s \)) have been studied at facilities namely \( E687, E831 \) (Fermilab), \( BES III \) (Beijing Spectrometer III), \( CDF \) and the \( CLEO \) collaboration[8, 9, 10]. Leptonic and semileptonic decays of \( D_s \) meson have also been studied in Belle and BaBar[11].

The aim of this paper is to analyze FCNC processes involving leptonic and semileptonic decays and compare them with current experimental limits. The comparison is also made with the other decay processes of charm mesons having the same quark subprocess. For example (\( D^\pm_s \rightarrow K^\pm l^+_\alpha l^-_\beta \), \( D^0 \rightarrow l^+_\alpha l^-_\beta \), \( D^\pm \rightarrow \pi^\pm l^+_\alpha l^-_\beta \)) have the same subquark process (\( c \rightarrow ul^+_\alpha l^-_\beta \)) while (\( D^0 \rightarrow \pi^- l^+_\alpha v_\beta \), \( D^+ \rightarrow l^+_\alpha v_\beta \)) have the same subquark process (\( c \rightarrow dl^+_\alpha v_\beta \)). Spectator quark model[12] is used to calculate branching fraction of above mentioned processes.

FCNC proceed through box and penguin diagrams[10] within the standard model(SM) and are highly suppressed[11, 13]. Since they are allowed at tree level within R-parity violating MSSM[6] any significant deviation from the SM prediction will hint at new physics. This fact motivates us to study leptonic and semileptonic decays of charm mesons within R-parity violating MSSM.

The Minimal Supersymmetric Standard Model (\( MSSM \)) [14] was introduced by keeping in view the phenomenological implication of \( SUSY \). It contains the minimum number of particles and fields. It is also the minimal extension of \( SM \) having \( N=1 \) generators[14].

MSSM allows processes that violate baryon and lepton number. It also allows LFV processes. R-parity, a discrete symmetry is imposed to prevent baryon number, lepton number and flavor violating processes. It is defined as \( R_p = (-1)^{3B+L+2S} \)[15]. R-parity conservation is phenomenologically motivated and if relaxed carefully allows one to analyze rare and forbidden decays while maintaining the stability of matter[16]. The R-parity violating gauge invariant and renormalizable superpotential is[15]

\[
W_{R_p} = \frac{1}{2} \lambda_{ijk} L_i L_j E_k^c + \tilde{\lambda}_{ijk} L_i Q_j D_k^c + \frac{1}{2} \lambda''_{ijk} U_i^c D_j^C D_k^C + \mu_i H_u L_i, 
\]

where \( i, j, k \) are generation indices, \( L_i \) and \( Q_i \) are the lepton and quark left-handed \( SU(2)_L \) doublets and
$E^c$, $D^c$ are the charge conjugates of the right-handed leptons and quark singlets, respectively. $\lambda_{ijk}$, $\lambda'_{ijk}$ and $\lambda''_{ijk}$ are Yukawa couplings. The term proportional to $\lambda_{ijk}$ is antisymmetric in first two indices $[i, j]$ and $\lambda''_{ijk}$ is antisymmetric in last two indices $[j, k]$, implying $9(\lambda_{ijk}) + 27(\lambda'_{ijk}) + 9 (\lambda''_{ijk}) = 45$ independent coupling constants among which 36 are related to the lepton flavor violation (9 from $LLE^c$ and 27 from $LQD^c$). We can rotate the last term away without affecting things of our interest.

2 $\ (D^+, D_s) \rightarrow l^+_\alpha \nu_\beta \ \text{In Ir} \ \tilde{R}_P$ SUSY

The effective Lagrangian for the decay of $(D^+, D_s) \rightarrow l^+_\alpha + \nu_\beta$ in the quark mass basis is given as

$$L_{R,P}^{\text{eff}} (c \rightarrow q + l^+_\alpha + \nu_\beta) = \frac{4G_F V_{cq}}{\sqrt{2}} \left[ A_{\alpha\beta}^{cq} (\bar{c} \gamma^\mu P_L q) (\bar{l}_\alpha \gamma_\mu P_L \nu_\beta) - B_{\alpha\beta}^{cq} (\bar{c} P_R q) (\bar{l}_\alpha P_L \nu_\beta) \right],$$

(2)

where $\alpha, \beta = e, \mu$ and $q = d, s$. The dimensionless coupling constants $A_{\alpha\beta}^{cq}$ and $B_{\alpha\beta}^{cq}$ are given as,

$$A_{\alpha\beta}^{cq} = \frac{\sqrt{2}}{4G_F V_{cq}} \sum_{j,k=1}^{3} \frac{1}{2m^2_{\tilde{d}_k}} V_{ij} \lambda'_{\beta qj} \lambda'_{\alpha ik}$$

$$B_{\alpha\beta}^{cq} = \frac{\sqrt{2}}{4G_F V_{cq}} \sum_{i,j=1}^{3} \frac{2}{m^2_{\tilde{l}_i}} V_{ij} \lambda_{\beta i \alpha} \lambda'_{\alpha jq}$$

(3)

Thus the decay rate of the flavor conserving process $D^+ \rightarrow l^+_\alpha \nu_\alpha$ is given by

$$\Gamma (M^- \rightarrow l_\alpha \nu_\alpha) = \frac{1}{8\pi} G_F^2 |V_{cq}|^2 f^2_D M^2_D (1 - \eta_\alpha^2)^2 \left[ 1 + A_{\alpha\alpha}^{cq} \right] \eta_\alpha - \left( \frac{M_D}{m_c + m_{d,s}} \right) B_{\alpha\alpha}^{cq},$$

(4)

where $\eta_\alpha = \frac{m_\alpha}{M_D}$ is mass of charged lepton $l$, $M_D$ is the mass of charm meson, where $f_M$ is pseudoscalar meson decay constant. Here, following PCAC (partial conservation of axial-vector current) relations have been used:

$$< 0 | \bar{q}_c \gamma^\mu \gamma_5 q_q | M(p) > = if_M p_M^\mu$$

$$< 0 | \bar{q}_c \gamma_5 q_q | M(p) > = if_M \frac{M^2_M}{m_{q_c} + m_{q_q}}$$

(5)

The general decay rate including SM and R-parity violating contribution is given by

$$\Gamma = \Gamma_{SM}(1 + \alpha).$$

(6)
Where $\alpha$ is New Physics parameter (NP) given by

$$\alpha = \left| A_{\alpha\beta}^{cq} \right|^2 + \frac{1}{\eta_{\alpha}} \left( \frac{M_D}{m_c + m_d,s} \right)^2 \left| B_{\alpha\beta}^{cq} \right|^2 \quad (7)$$

The sneutrino Yukawa coupling products enhances SM contribution to the branching fraction of leptonic decays ($D \rightarrow l^+_{\alpha} v_{\alpha}$) many times ($\frac{1}{\eta_{\alpha}}$ in eq. (7)). So we do not include this factor to measure the NP.

$$\alpha = \left| A_{\alpha\beta}^{cq} \right|^2 \quad (8)$$

3  $D \rightarrow (\pi, K) l^+_{\alpha} \nu_{\beta}$ decay in $R_p$ SUSY

The effective Lagrangian for the decay of $D \rightarrow (\pi, K) l^+_{\alpha} + \nu_{\beta}$ in the quark mass basis is given as

$$L_{R_p}^{eff} \left( c \rightarrow q + l^+_{\alpha} + \nu_{\beta} \right) = \frac{4 G_F V_{cq}}{\sqrt{2}} \left[ \begin{array}{c}
A_{\alpha\beta}^{cq} (\bar{c} \gamma^\mu P_L l_{\gamma}^\mu \nu_{\beta}) \\
- B_{\alpha\beta}^{cq} (\bar{c} P_{Lq} l_{\alpha}^\mu \nu_{\beta})
\end{array} \right], \quad (9)$$

where $\alpha, \beta = e, \mu$ and $q = d, s$. The dimensionless coupling constants $A_{\alpha\beta}^{cq}$ and $B_{\alpha\beta}^{cq}$ are given as,

$$A_{\alpha\beta}^{cq} = \frac{\sqrt{2}}{4 G_F V_{cq}} \sum_{j,k=1}^{3} \frac{1}{2 m_{d,s}^2} V_{cj} \lambda_{jk}^\prime \lambda_{\alpha jk}^*$$

$$B_{\alpha\beta}^{cq} = \frac{\sqrt{2}}{4 G_F V_{cq}} \sum_{i,j=1}^{3} \frac{2}{m_{d,s}^2} V_{cj} \lambda_{i\alpha}^\prime \lambda_{ijq}^* \quad (10)$$

Thus the decay rate of $D \rightarrow K l^+_{\alpha} \nu_{\beta}$ induced by is given by

$$\Gamma \left[ c \rightarrow q l^+_{\alpha} \nu_{\beta} \right] = \frac{m_D^5}{192 \pi^3 G_F^2} V_{cq}^2 \left( \left| A_{\alpha\beta}^{cq} \right|^2 \left( \left| B_{\alpha\beta}^{cq} \right|^2 \right) \right). \quad (11)$$

4  $D^0 \rightarrow l^\pm_{\alpha} l^\mp_{\beta}$ In $R_p$ SUSY

The effective Lagrangian for the decay of $D^0 \rightarrow l^\pm_{\alpha} l^\mp_{\beta}$ in the quark mass basis is given as

$$L_{R_p}^{eff} \left( c \rightarrow u + l^\pm_{\alpha} + l^\mp_{\beta} \right) = \frac{4 G_F}{\sqrt{2}} \left[ A_{\alpha\beta}^{cu} (\bar{c} \gamma^\mu P_L l_{\gamma}^\mu \nu_{\beta}) \right], \quad (12)$$

where $\alpha, \beta = e, \mu$. The dimensionless coupling constants $A_{\alpha\beta}^{cu}$ is given by

$$A_{\alpha\beta}^{cu} = \frac{\sqrt{2}}{4 G_F} \sum_{i=1}^{3} \frac{V_{ni}^* V_{im}^*}{2 m_{d,s}^2} \lambda_{\alpha i}^\prime \lambda_{\alpha m}^* \quad (13)$$
The decay rate of the processes \( M \to l^\pm_\alpha l^\mp_\beta \) is given by

\[
\Gamma \left[ M \to l^\pm_\alpha l^\mp_\beta \right] = \frac{1}{8\pi} f_M^2 f_M^3 \left[ 1 + \left( \frac{m_\alpha}{M} \right)^2 \right] - 2 \left( \eta_\alpha^2 + \eta_\beta^2 \right) \left( A_{\alpha\beta}^c \right)^2 \left[ \frac{m_\beta}{M} \right] \left( \eta_\alpha^2 - \eta_\beta^2 \right)^2 (14)
\]

where \( \eta_\alpha \equiv \frac{m_\alpha}{M} \), \( m_\alpha \) is mass of lepton, \( M \) is the mass of meson, \( f_M \) is the pseudoscalar meson decay constant which are extracted from the leptonic decay of each pseudoscalar meson.

5 \( D_s \to Kl^-l^+ \) decay in \( \mathcal{R}_p \) SUSY

In MSSM the relevant effective Lagrangian for the decay process \( D_s \to Kl^-l^+ \) is given by

\[
L^{eff}_{\mathcal{R}_p} \left( c \to u + l^-_\alpha + l^+_\beta \right) = \frac{4G_F}{\sqrt{2}} \left[ A_{\alpha\beta}^c \left( \bar{\nu}_\alpha \gamma^\mu P_L l_\beta \right) \left( \bar{\nu}_\gamma P_R c \right) \right]. (15)
\]

Where \( \alpha, \beta = e, \mu \). The first term in eq. (2) comes from the up quark exchange (where \( c \) and \( u \) are up type quarks). The dimensionless coupling constant \( A_{\alpha\beta}^c \) is given by

\[
A_{\alpha\beta}^c = \frac{\sqrt{2}}{4G_F} \sum_{m,n,i=1}^3 \frac{V_{mj}^\dagger V_{im}^m}{2m^2_\beta} \lambda^\alpha_{\beta n1} \lambda^\alpha_{\alpha m2}. (16)
\]

The inclusive decay rate of the process is given by

\[
\Gamma \left[ c \to u l^-_\alpha l^+_\beta \right] = \frac{m^5_D}{192\pi} G_F^2 \left| A_{\alpha\beta}^c \right|^2. (17)
\]

6 Results and Discussions

We have plotted Figs.(4-13) using data\[19\]. Table 1,2 and 3 summarizes new bounds on the branching fraction of the given decay processes. We have used the bounds on the Yukawa coupling products from [16, 20]. In table 2 and 3, we have calculated our results on branching fraction and Yukawa coupling bounds within 1\( \sigma \) error. Fig.(4) shows a comparison between \( D^\pm \to \pi^\pm e^+ e^- \) and \( D^0 \to e^+ e^- \). This comparison shows that \( \mathcal{R}_p \) MSSM contribution to \( D^0 \to e^+ e^- \) is suppressed as compared to the current experimental limits. While a comparison between \( D^\pm \to \pi^\pm e^+ e^- \) and \( D_s^\pm \to K^\pm e^+ e^- \) shows that \( \mathcal{R}_p \) MSSM contribution to \( D_s^\pm \to K^\pm e^+ e^- \) is 10^2 times smaller than the current experimental limits. So the experimental limits on \( D_s^\pm \to K^\pm e^+ e^- \) is expected to get lower.
Fig.(5) shows a comparison between $D^\pm \to \pi^\pm \mu^+\mu^-$ and $D^0 \to \mu^+\mu^-$. This comparison shows that $R_p$ MSSM contribution to $D^0 \to \mu^+\mu^-$ is 10^2 times smaller than the current experimental limits. However, this is significantly much better than the case of $D^0 \to e^+e^-$. This is because the branching fraction of the pure leptonic decay depends directly to the square of lepton to meson mass ratio. A comparison between $D^\pm \to \pi^\pm \mu^+\mu^-$ and $D_s^\pm \to K^\pm \mu^+\mu^-$ shows that $R_p$ MSSM contribution to $D_s^\pm \to K^\pm \mu^+\mu^-$ is comparable to the experimental limits. So this is one decay process to be explored at Fermilab and CLEO.

Fig.(6) shows a comparison between $D^\pm \to \pi^\pm e^+\mu^-$ and $D_s^\pm \to K^\pm e^+\mu^-$. This comparison shows that $R_p$ MSSM contribution to $D_s^\pm \to K^\pm e^+\mu^-$ is similar to the current experimental limits. Therefore, it is also a promising process to be explored at Fermilab and CLEO.

Fig.(7) shows a comparison between $D^0 \to \pi^- e^+v_\mu$ and $D^+ \to e^+v_\mu$. This comparison shows that $R_p$ MSSM contribution to $D^0 \to \pi^- e^+v_\mu$ is solely by squark exchange Yukawa couplings ($\lambda_{\beta\betaqk}^i \lambda_{\alpha jk}^{*i}$) while $R_p$ MSSM contribution to $D^+ \to e^+v_\mu$ is mostly by sneutrino exchange Yukawa couplings ($\lambda_{\beta\betaqk}^i \lambda_{\alpha jk}^{*i}$). The contribution to $\text{Br}(D^+ \to e^+v_\mu)$ from squark exchange Yukawa coupling products ($\lambda_{\beta\betaqk}^i \lambda_{\alpha jk}^{*i}$) is comparable with SM contribution ($\alpha \leq 15\%$, see Fig.(12)) but negligible as compared to existing bounds. $D^+ \to \pi^0 e^+v_\mu$ displays the same behavior similar to $D^0 \to \pi^- e^+v_\mu$ as shown in Fig. (8).

Fig.(9) displays a comparison between $D^0 \to \pi^- \mu^+v_\mu$ and $D^+ \to \mu^+v_\mu$. This comparison shows that $R_p$ MSSM contribution to $D^0 \to \pi^- \mu^+v_\mu$ is dominated by squark exchange The contribution to $\text{Br}(D^+ \to e^+v_\mu)$ from squark Yukawa couplings ($\lambda_{\beta\betaqk}^i \lambda_{\alpha jk}^{*i}$) is comparable with SM ($\alpha \leq 14\%$, see Fig.(13)) while slepton exchange Yukawa couplings ($\lambda_{\beta\betaqk}^i \lambda_{\alpha jk}^{*i}$) exchange Yukawa terms also contributes to $D^+ \to \mu^+v_\mu$.

Fig.(10) displays a comparison between $D^0 \to K^- \mu^+v_\mu$ and $D_s^+ \to \mu^+v_\mu$. This comparison shows that $R_p$ MSSM contribution to $D^0 \to K^- \mu^+v_\mu$ and $D_s^+ \to \mu^+v_\mu$ is consistent with available experimental data. The contribution to $\text{Br}(D^+ \to \mu^+v_\mu)$ to from squark Yukawa coupling products to is comparable with SM ($\alpha \leq 1.4\%$, see Fig.(13)).

Fig.(11) displays a comparison between $D^0 \to K^- e^+v_\mu$ and $D_s^+ \to e^+v_\mu$. This comparison shows that $R_p$ MSSM contribution to $D^0 \to K^- e^+v_\mu$ is solely by squark exchange Yukawa couplings ($\lambda_{\beta\betaqk}^i \lambda_{\alpha jk}^{*i}$) while $R_p$ MSSM contribution to $D_s^+ \to e^+v_\mu$ is by slepton exchange Yukawa couplings ($\lambda_{\beta\betaqk}^i \lambda_{\alpha jk}^{*i}$). Table 3 also shows that the contribution made by squark exchange Yukawa terms to the branching fraction of $(D_s^+ \to e^+v_\mu)$ is suppressed but is consistent with SM ($\alpha \leq 10\%$, see Fig.(13)).

Fig. (12-13) shows the variation of NP parameter $\alpha$ (see eq.7). The CKM factor $V_{cq}(q = d, s)$ is responsible for the higher and lower value of $\alpha$.

$$1.4 \leq \alpha(\%) \leq 15.$$
The comparison in Table (1) shows that the branching fraction of some decay processes like \((D^0 \to e^+e^-, D^0 \to \mu^+\mu^-, D_s^\pm \to K^\pm e^+e^-)\) receives contribution from \(R_p\) MSSM that is smaller than the current experimental limits. While the decay processes \((D^0 \to e^+\mu^-, D_s^\pm \to K^\pm e^+\mu^-, D_s^\pm \to K^\pm \mu^+\mu^-)\) receive sizeable contribution from \(R_p\) MSSM that is comparable to the current experimental limits. These processes are thus the most important ones in the future searches of new physics in decays of charm meson.

This comparison in Table (2) and Table (3) also shows that for the decay processes \((D^0 \to (\pi, K^-) l^+_{\alpha} v_{\beta}, D^+ \to l^+_{\alpha} v_{\beta}, D_s \to l^+_{\alpha} v_{\beta})\), slepton exchange terms contribute the branching fraction of leptonic decays only. The contribution made by squark exchange terms to branching fraction of both leptonic and semileptonic decays is consistent with experimental measurements in most of the cases. Table (2) also shows that \((D^0 \to \pi^- e^+ v_{e}, D^+ \to \pi^0 e^+ v_{e}, D^0 \to \pi^- \mu^+ v_{\mu}, D^+ \to \mu^+ v_{\mu})\) are also very important ones in the future searches of new physics in decays of charm meson.

Summarizing, we have analyzed decay processes \((D_s^\pm \to K^\pm l^+_{\alpha} l^-_{\beta}(v_{\alpha}), D^0 \to l^+_{\alpha} l^-_{\beta}, D^\pm \to \pi^\pm l^+_{\alpha} l^-_{\beta}(v_{\alpha}))\) and compared their branching fractions against a common parameter \(\lambda^\prime_{\beta n} \lambda^{\ast}_{\alpha m}\). The analysis shows that \(D_s^\pm \to K^\pm \mu^+\mu^-\) is the most favorable process within SM for study at Fermilab and CLEO detector\[^9\,^10\]. While \(D_s^\pm \to K^\pm e^+\mu^-\) is the favorable process, not allowed by SM to be searched for at these sites.

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| Process                  | Subquark Process | Branching Fraction | $R_p$ couplings | Branching Fraction |
|-------------------------|------------------|--------------------|----------------|--------------------|
| $D^0 \to e^+e^-$        |                  | $< 1.2 \times 10^{-6}$ | $|\lambda'_{31}^{13} \lambda'_{132}|$ | $< 2.8 \times 10^{-12}$ (Weak) |
| $D^0_\pm \to K^{\pm}e^+e^-$ | $c \to u e^+e^-$ | $< 1.6 \times 10^{-3}$ | $< 1.98 \times 10^{-3}$ | $< 7.4 \times 10^{-6}$ Consistent |
| $D^0 \to \mu^+\mu^-$   |                  | $< 1.3 \times 10^{-6}$ | $|\lambda'_{231}^{13} \lambda'_{232}|$ | $< 6 \times 10^{-8}$ (Weak) |
| $D^0_\pm \to K^{\pm}\mu^+\mu^-$ | $c \to u \mu^+\mu^-$ | $< 3.6 \times 10^{-5}$ | $< 1.44 \times 10^{-3}$ | $< 3.9 \times 10^{-6}$ Consistent |
| $D^0 \to e^+\mu^-$     |                  | $< 8.1 \times 10^{-7}$ | $|\lambda'_{231}^{13} \lambda'_{232}|$ | $< 4 \times 10^{-7}$ (Comparable) |
| $D^0_\pm \to K^{\pm}e^+\mu^-$ | $c \to u e^+\mu^-$ | $< 6.3 \times 10^{-4}$ | $< 2.1 \times 10^{-4}$ (Comparable) | |
| $D^0_\pm \to \pi^{\pm}e^+\mu^-$ |                  | $< 3.4 \times 10^{-5}$ | $< 4.24 \times 10^{-3}$ | $< 3.4 \times 10^{-5}$ Consistent |

Table 1: A table showing comparison between branching fraction of decay processes of charmed mesons ($D_s$, $D^0$, $D^\pm$). Yukawa couplings are normalized to $1/(m_{\tilde{d}}/100GeV)^2$
Table 2: A table showing comparison between branching fraction of decay processes of charmed mesons ($D_s$, $D^0$, $D^\pm$). (*) indicates that R-parity contribution is consistent with the experimental measurements. Squark Yukawa couplings products are normalized as $1/(m_{\tilde{s}}/100GeV)^2$. 

| Processes | $Subquark$ Process | Branching Fraction | $R_p$ couplings | Branching Fraction |
|-----------|-------------------|--------------------|----------------|-------------------|
|           |                   | (Experimental)     | $\lambda^{'}_{113}\lambda_{3j3}$ | (Experimental) |
|           |                   | (Standard Model)   | ($-3.26 \pm 1.74) \times 10^{-2}$ | ($-3.26 \pm 1.74) \times 10^{-2}$ |
| $D^0 \rightarrow \pi^- e^+\nu_e$ | ($c \rightarrow u e^+\nu_e$) | $(2.83 \pm 0.17) \times 10^{-3}$ | $\lambda_{213}\lambda_{3j3}$ | $-(6.2 \pm 0.18) \times 10^{-2}$ |
| $D^+ \rightarrow e^+\nu_e$ | ($c \rightarrow d e^+\nu_e$) | < $2.4 \times 10^{-5}$ | $\lambda_{113}\lambda_{3j3}$ | $-(6.2 \pm 0.18) \times 10^{-2}$ |
| $D^0 \rightarrow \pi^0 e^+\nu_e$ | $\lambda_{113}\lambda_{3j3}$ | $(4.4 \pm 0.7) \times 10^{-3}$ | $\alpha \leq 15\%$ | $(7.6 \pm 0.2) \times 10^{-4}$ |
| $D^0 \rightarrow \mu^+\nu\mu$ | ($c \rightarrow d \mu^+\nu\mu$) | $(2.37 \pm 0.24) \times 10^{-3}$ | $\lambda_{113}\lambda_{3j3}$ | $-(6.2 \pm 0.18) \times 10^{-2}$ |
| $D^+ \rightarrow \mu^+\nu$ | ($c \rightarrow d \mu^+\nu$) | $(4.4 \pm 0.7) \times 10^{-4}$ | $\alpha \leq 14\%$ | $(7.6 \pm 0.2) \times 10^{-4}$ |
| $D^0 \rightarrow K^- e^+\nu_e$ | ($c \rightarrow s e^+\nu_e$) | $(3.58 \pm 0.06)\%$ | $\lambda_{113}\lambda_{3j3}$ | $-(6.2 \pm 0.18) \times 10^{-2}$ |
| $D^0 \rightarrow K^- \mu^+\nu$ | ($c \rightarrow s \mu^+\nu$) | $(3.58 \pm 0.06)\%$ | $\alpha \leq 15\%$ | $(7.6 \pm 0.2) \times 10^{-4}$ |
| $D^+ \rightarrow e^+\nu_e$ | ($c \rightarrow u e^+\nu_e$) | < $1.3 \times 10^{-4}$ | $\alpha \leq 10\%$ | $(7.6 \pm 0.2) \times 10^{-4}$ |
| $D^0 \rightarrow K^- \mu^+\nu$ | ($c \rightarrow s \mu^+\nu$) | $(3.31 \pm 0.13)\%$ | $\alpha \leq 10\%$ | $(7.6 \pm 0.2) \times 10^{-4}$ |
| $D^+ \rightarrow \mu^+\nu$ | ($c \rightarrow u \mu^+\nu$) | $(6.2 \pm 0.6) \times 10^{-3}$ | $\lambda_{113}\lambda_{3j3}$ | $-(6.2 \pm 0.18) \times 10^{-2}$ |
| $D_s^+ \rightarrow \mu^+\nu$ | ($c \rightarrow u \mu^+\nu$) | $(6.2 \pm 0.6) \times 10^{-3}$ | $\alpha \leq 1.4\%$ | $(7.6 \pm 0.2) \times 10^{-4}$ |
| Processes | Subquark Process | Branching Fraction | $R_p$ couplings | Branching Fraction |
|-----------|-----------------|--------------------|-----------------|-------------------|
| $D^0 \rightarrow \pi^- e^+ v_e$ | $c\rightarrow u e^+ v_e$ | $(2.83 \pm 0.17) \times 10^{-3}$ | $\left| \lambda^{\prime}_{3j1} \lambda_{131} \right|$ | $< 1.51 \times 10^{-6}$ (Weak) |
| $D^+ \rightarrow e^+ v_e$ | $c\rightarrow u e^+ v_e$ | $< 2.4 \times 10^{-5}$ | $< 7.16 \times 10^{-4}$ | $< 2.4 \times 10^{-5}$ (Consistent) |
| $D^+ \rightarrow \pi^0 e^+ v_e$ | | $(4.4 \pm 0.7) \times 10^{-3}$ | $< 3.88 \times 10^{-6}$ (Weak) | |
| $D^0 \rightarrow \pi^- \mu^+ v_\mu$ | $c\rightarrow u \mu^+ v_\mu$ | $(2.37 \pm 0.24) \times 10^{-3}$ | $\left| \lambda^{\prime}_{3j1} \lambda_{232} \right|$ | $< (2.53 \pm 0.44) \times 10^{-4}$ (weak an order less) |
| $D^+ \rightarrow \mu^+ v_\mu$ | | $(4.4 \pm 0.7) \times 10^{-4}$ | $< (9.24 \pm 0.81) \times 10^{-3}$ | $< (4.4 \pm 0.7) \times 10^{-4}$ (Consistent) |
| $D^0 \rightarrow K^- e^+ v_e$ | $c\rightarrow s e^+ v_e$ | $(3.58 \pm 0.06)\%$ | $\left| \lambda^{\prime}_{3j2} \lambda_{131} \right|$ | $< 9.79 \times 10^{-6}$ (Weak) |
| $D_s^+ \rightarrow e^+ v_e$ | | $< 1.3 \times 10^{-4}$ | $< 1.82 \times 10^{-3}$ | $< 1.3 \times 10^{-4}$ (Consistent) |
| $D^0 \rightarrow K^- \mu^+ v_\mu$ | $c\rightarrow s \mu^+ v_\mu$ | $(3.31 \pm 0.13)\%$ | $\left| \lambda^{\prime}_{3j2} \lambda_{232} \right|$ | $< 4.67 \times 10^{-3}$ (weak an order less) |
| $D_s^+ \rightarrow \mu^+ v_\mu$ | | $(6.2 \pm 0.6) \times 10^{-3}$ | $< (3.78 \pm 0.21) \times 10^{-2}$ | $< (6.2 \pm 0.6) \times 10^{-3}$ (Consistent) |

Table 3: A table showing comparison between branching fraction of decay processes of charmed mesons ($D_s$, $D^0$, $D^\pm$). (*) indicates that R-parity contribution is consistent with the experimental measurements. Slepton Yukawa couplings products are normalized as $1/(m_{\tilde{e}}/100GeV)^2$. 
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