Charm Weak Decays in the SM and Beyond

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Outline

- Semileptonic Charm Decays: The impact of precision measurements in exclusive semileptonic D decays.
- $D^0 - \bar{D}^0$ Mixing: How close is the Long Distance wall?
- Rare Charm Decays in the Standard Model:
  - Radiative Decays: $D \to X\gamma$.
  - Semileptonic Modes: $D \to \pi\ell^+\ell^-$, $D\rho\pi\ell^+\ell^-$,...
- New Physics: Effects of Supersymmetry.
  - Non-universal soft term in SUSY with R_P conservation.
  - Effects of R_P violation.
- Conclusions

D Semileptonic Decays

- Why do we need precision measurements of exclusive semileptonic decays? $D \to K^{(*)}\ell\nu$ and $D \to \pi(\rho)\ell\nu$.
- Study of hadronic physics at m_c. Form-factor normalization and q^2 dependence.
- Impact on B physics I: Comparison with $B \to \pi\ell\nu$ and $B \to \rho\ell\nu$. Test of $HQET$: are $1/M_Q$ large? V_{ub} ? New Physics: same form-factors for rare decays $B \to K^*\ell^+\ell^-$,
- Impact on B physics II: Are the $SU(3)$ corrections under control?
- Impact on B physics III: Precision SL and Leptonic decays of charm will test Lattice calculations => Lattice predictions of $B \to \pi\ell\nu$, $B \to K^*\ell^+\ell^-$, etc.
- $|V_{cd}|$.

Heavy Quark Symmetry (*Isgur-Wise '89*)

In the $m_Q \to \infty$ limit ($m_Q \gg \Lambda_{\rm QCD}$),

- *Flavor Symmetry*: Light degrees of freedom can't tell the heavy flavor.
  => $b \longleftrightarrow c$. Applications: extraction of $|V_{cb}|$ from inclusive and exclusive semileptonic $b \to c\ell\nu$ decays. Works best at low recoil (Luke's Theorem at zero recoil).

- *Spin Symmetry*: Spin decouples in the $m_Q \to \infty$ limit. E.g.: $\Delta m_B \equiv m_{B^*} - m_B \longrightarrow 0$.

But for Heavy $\longrightarrow$ Light decays applications are more limited:

$$
\begin{array}{ccccc}
 & D & \longrightarrow & K^*\ell\nu & \\
SU(2)_F & \updownarrow & & \updownarrow & SU(3) \\
 & B & \longrightarrow & \rho\ell\nu &
\end{array}
$$

Heavy Quark Symmetry and $H \to \pi \ell \nu$

- One form-factor:

$$\langle \pi(k)|(\bar{q}\gamma_\mu c)|D(p)\rangle = f_+(q^2)(P+k)_\mu + f_-(q^2)(P-k)_\mu$$

But if $m_\ell \to 0$

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3}|V_{cd}|^2\, k^3\, |f_+(q^2)|^2$$

=> precision measurement of $d\Gamma/dq^2$ in $D \to \pi \ell \nu$ gives $f_+(q^2)$.

- B Physics Impact: Heavy Quark Symmetry => $B \to \pi \ell \nu$ given by same f_+ up to heavy mass scaling:

$$\frac{f_+^{B\to\pi}(v.k)}{f_+^{D\to\pi}(v.k)} = \left(\frac{\alpha_s(m_b)}{\alpha_s(m_c)}\right)^{-6/25}\sqrt{\frac{m_B}{m_D}} \times \left\{1 + C\left(\frac{1}{m_b} - \frac{1}{m_c}\right) + \ldots\right\}$$

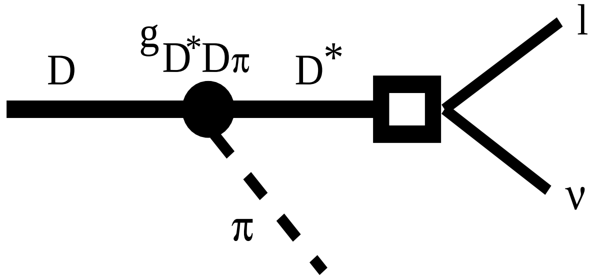
with $v.k = E_\pi$ in the heavy meson rest frame.

$$=> E_\pi < 1 \text{ GeV}$$

Chiral Symmetry helps at low recoil (*M. Wise; G.B. and J. Donoghue '92*) • Chiral Perturbation Theory for Heavy Hadrons (ChPTHH) predicts $f_+(v.p_\pi)$ at low p_π to be

$$f_+(v.p_\pi) \quad = \quad \frac{g_{D^*D\pi} f_{D^*}}{2f_\pi}\left(\frac{m_D - v.p_\pi}{v.p_\pi + \Delta}\right) + \frac{f_D}{2f_\pi}$$

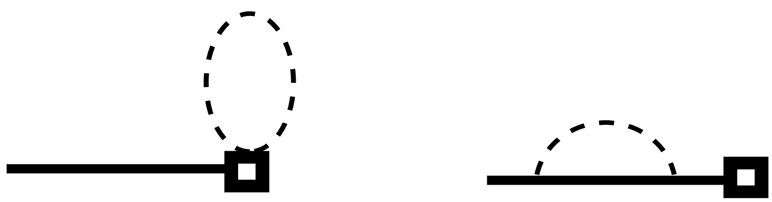
with $\Delta_D \equiv m_{D^*} - m_D$. This is dominated by the D^* pole contribution.



This is valid to Next-to-Leading Order in the $1/M$ expansion. (*G.B., Z. Ligeti, M. Neubert and Y. Nir '93*)

SU(3) Breaking

- How large is $SU(3)$ breaking in semileptonic form-actors?
  Relevant e.g . for $B \to \pi \ell \nu \leftrightarrow B \to K \ell^+ \ell^-$.
- Compare $D \to \pi \ell \nu$ to $D \to K \ell \nu$. What can we expect? The lesson from decay constants:



$$\frac{f_{D_s}}{f_D} - 1 \simeq \frac{(1+3g^2_{D^*D\pi})}{32\pi^2 f_\pi^2} \left\{ m_K^2 \log\left(\frac{m_K^2}{\mu^2}\right) + m_\eta^2 \log\left(\frac{m_\eta^2}{\mu^2}\right) \right\}$$

Which gives $f_{D_s}/f_D \simeq 1.10$. (*B. Grinstein, E. Jenkins, A. Manohar and M. Wise '92*)

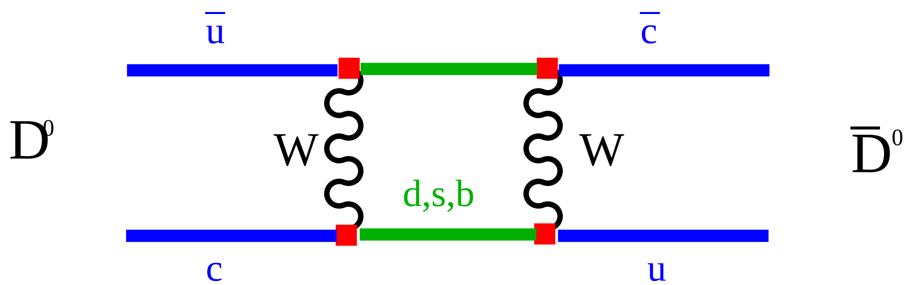
- For the semileptonic decays, the $SU(3)$ breaking coming from the chiral logarithms is around $20-30\%$, strongly depending on the value of $g_{D^* D\pi}$. (*A. Falk and B. Grinstein '93*)
- But these are not the only terms. How large are the counter-term contributions? The data will tell us.

D^0-$\bar{D}^0$ Mixing

The mixing rate is

$$r_D \equiv \frac{\Gamma(D^0 \to \ell^- X)}{\Gamma(D^0 \to \ell^+ X)} \simeq \frac{1}{2}\left[x^2 + y^2\right]$$

with $x \equiv \Delta m/\Gamma$ and $y \equiv \Delta\Gamma/2\Gamma$.



Theoretical Expectations

- Short distance in the SM: Box + Penguin diagrams give $x \lesssim 10^{-4}$.
- But potentilly large contributions from higher dimensional operators could give $x \simeq 10^{-3}$. (With very large uncertainties). This typically signals large long distance contributions!
- Long Distance effects in x and y from real intermediate states => expect

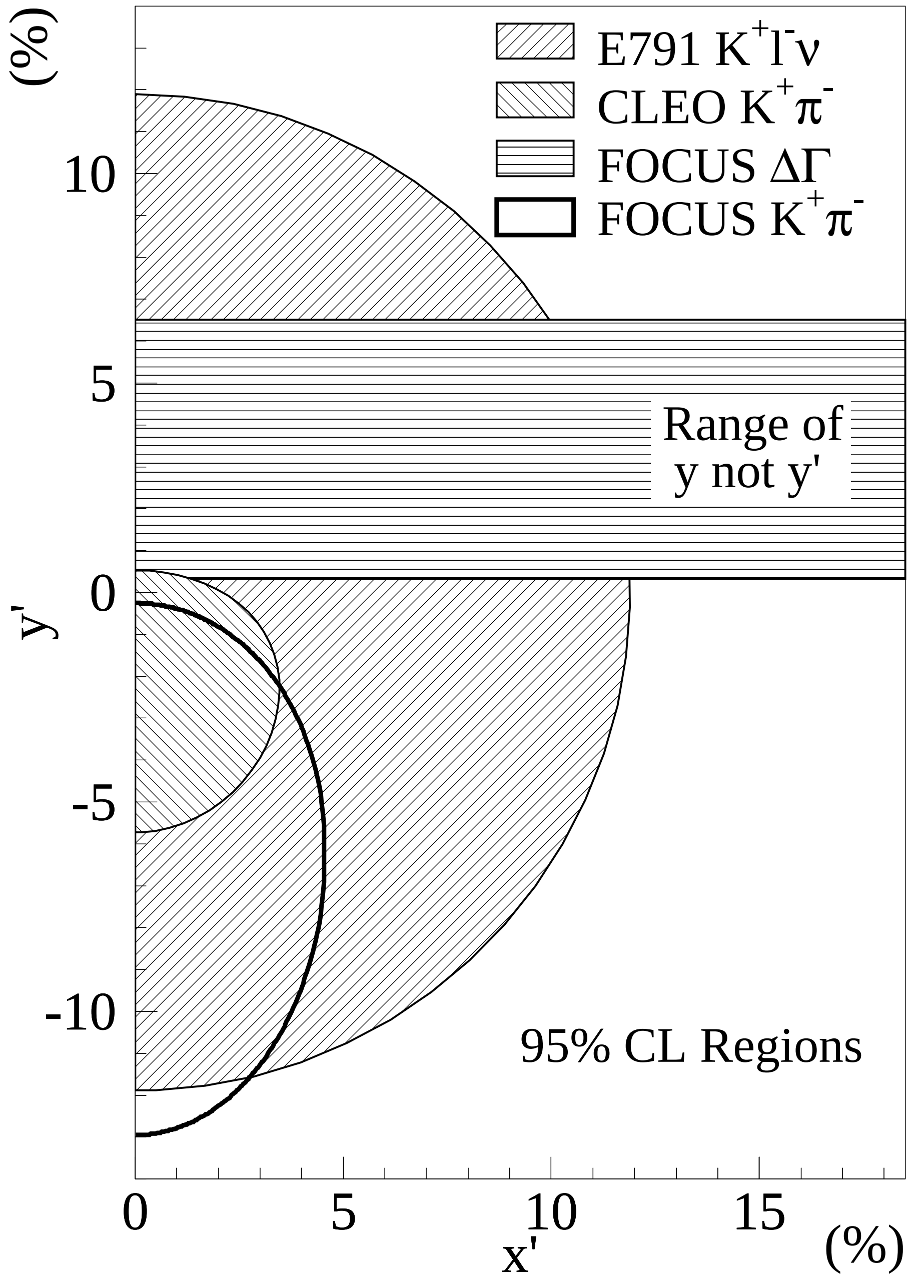
$$x_{\rm LD} \simeq y \lesssim 10^{-3}$$

- Relative strong phase δ, between CF and DCS amplitudes rotates x, y to

$$\begin{aligned} x' &= x\cos\delta + y\sin\delta \\ y' &= y\cos\delta - x\sin\delta \end{aligned}$$

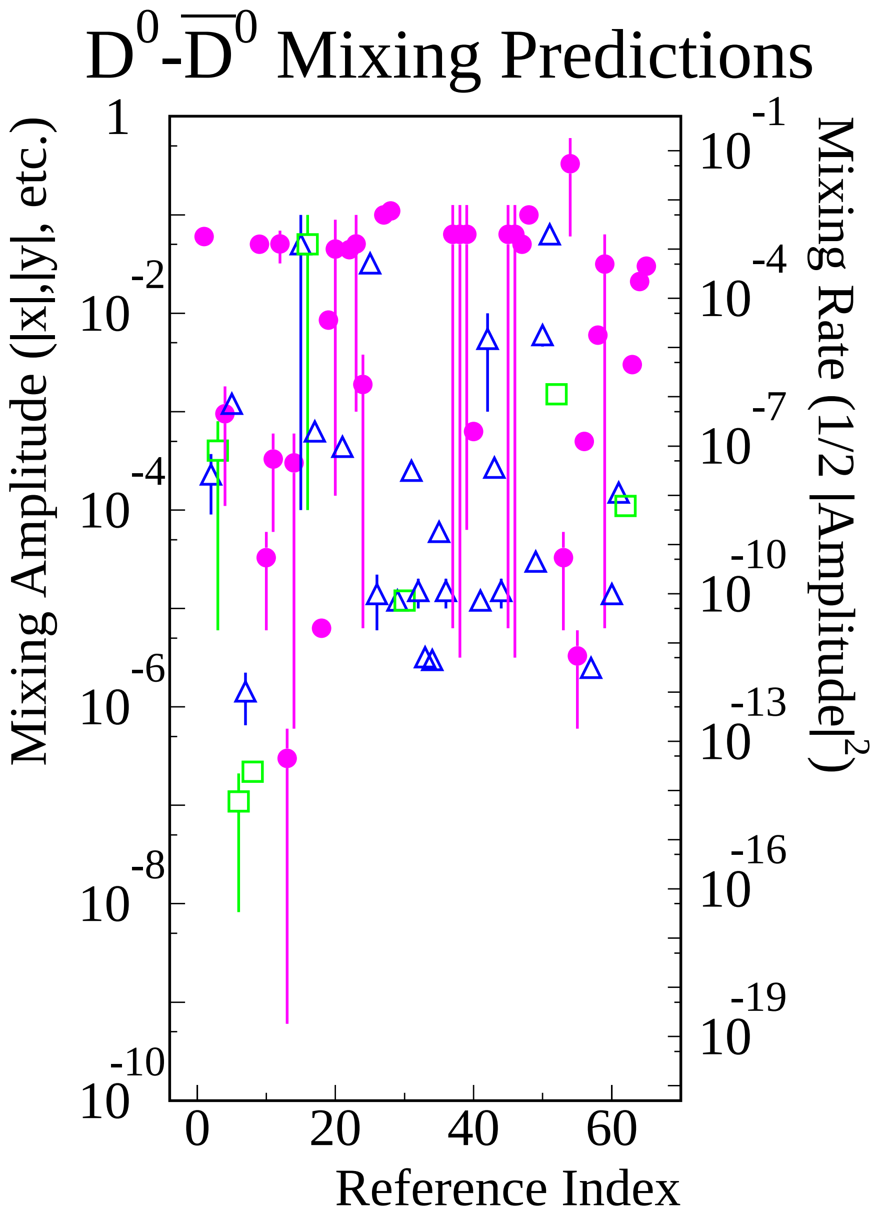
- Data seems to suggest δ not small.

D^0-$\bar{D}^0$ Mixing
Experimental Situation



Is there room for New Physics beyond the SM ?

(*H. Nelson '99*)



Rare Charm Decays

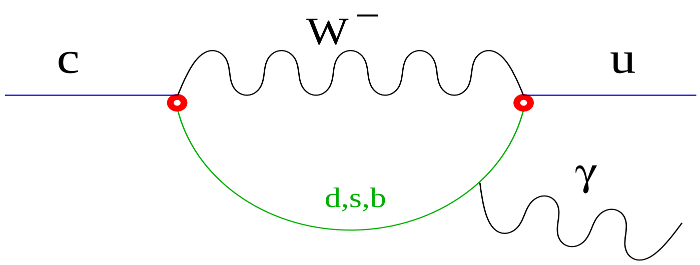
Q:

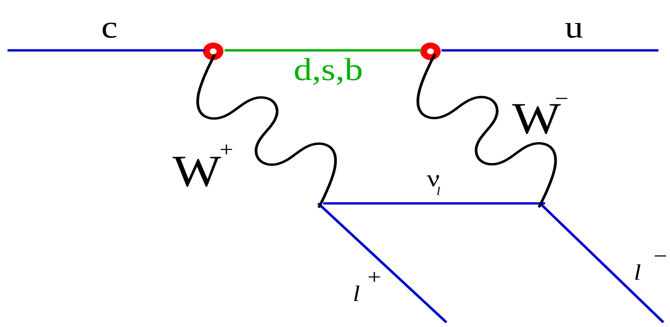
- $D \to X\gamma$, $D \to X\ell^+\ell^-$, ...
  Can Rare Charm Decays test the SM ?
- Short distance SM very suppressed.
- Long distance (e.g. resonances) dominate rates.
- Is there room to see new physics ?

A:

- $D \to X\gamma$, $D^0 \to \gamma\gamma$: Dominated by large long distance contributions.
- $D \to X\ell^+\ell^-$: Long distance dominates the rates but maybe room for short distance away from the resonances.
- Other modes: $D^0 \to \ell^+\ell^-$, $D \to X\nu\bar{\nu}$, etc. Very small short and long distance => only large new physics effects.

Rare Charm Decays





so

	i	$F(x_i)$	$\lambda_i F(x_i)$
$c \to u\gamma$	d	1.6×10^{-9}	3.4×10^{-10}
	s	2.9×10^{-7}	6.3×10^{-8}
	b	3.3×10^{-4}	3.2×10^{-8}
$b \to s\gamma$	u	2.3×10^{-9}	1.3×10^{-12}
	c	2.0×10^{-4}	7.3×10^{-6}
	t	0.4	1.6×10^{-2}

Factorization of Short Distance Physics in $c \to u$ Transitions

Effective Hamiltonian at low energies:

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} \sum_{i=1}^{10} C_i(\mu)\, \mathcal{O}_i(\mu)$$

Integrating out heavy particles.

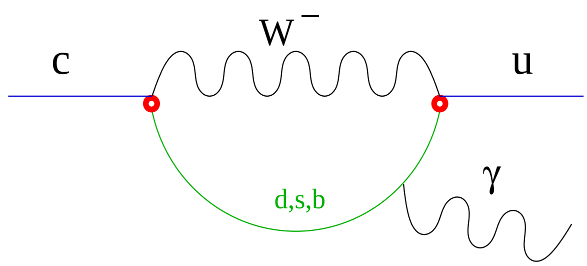
- C_i: Wilson coefficients. Content of the short distance physics, e.g. the stuff inside the loop.
- $\mathcal{O}_i$: Operator basis. All possible (Lorentz invariant, etc.) giving $c \to u$. Matrix elements contain long distance physics.

New Physics will affect matching conditions on the C_i at $\mu = M$.
E.g. in the SM $M \simeq M_W$.

Radiative Decays

(*G.B., E. Golowich, J. Hewett and S. Pakvasa '95; B. Bajc et al. '95; C. Greub et al.'96*)

- $c \to u\gamma$: Short distance determined by $C_7(\mu)$ corresponding to the photon penguin diagram



and to the operator

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_c (\bar{u}_L \sigma_{\mu\nu} c_R)\, F^{\mu\nu}$$

The branching ratio is

$$Br(D \to X_u\gamma) = ...|C_7(m_c)|^2$$

which is $\mathcal{O}(10^{-17})$.

- Operator mixing, mainly with $O_2 = (\bar{u}_L \gamma_\mu q_L)(\bar{q}_L \gamma^\mu c_L)$, plus large QCD corrections, result in

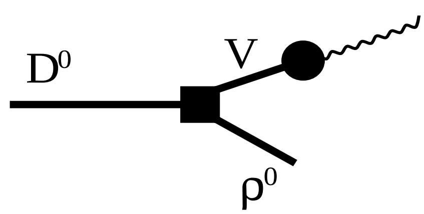
$$C_7(m_c) \longrightarrow C_7^{\rm eff.}(m_c)$$

which give $\mathrm{Br}(c \to u\gamma) \simeq \mathcal{O}(10^{-8})$.

- Long Distance contributions to $D \to X\gamma$: Take one example: $D^0 \to \rho^0\gamma$. Two types of LD diagrams:

Pole diagrams:

Vector Meson Dominance:



Mode	$\mathcal{A}$ (in GeV^{-1})			$B_{D\to M\gamma}$ (10^{-5})
	P-I	P-II	VMD <	
$D_s^+ \to \rho^+\gamma$	8.2	-1.9	± 6.0	$6 - 38$
$D^0 \to \bar{K}^{*0}\gamma$	5.6	-5.9	± 10	$7 - 12$
$D_s^+ \to b_1^+\gamma$	7.2	—	—	~ 6.3
$D_s^+ \to a_1^+\gamma$	1.2	—	—	~ 0.2
$D_s^+ \to a_2^+\gamma$	2.1	—	—	~ 0.01
$D^+ \to \rho^+\gamma$	1.3	-0.4	± 3.5	$2 - 6$
$D^+ \to b_1^+\gamma$	1.2	—	—	~ 3.5
$D^+ \to a_1^+\gamma$	0.5	—	—	~ 0.04
$D^+ \to a_2^+\gamma$	3.4	—	—	~ 0.03
$D_s^+ \to K^{*+}\gamma$	2.8	-0.5	± 1.9	$0.8 - 3$
$D_s^+ K_2^{*+}\gamma$	6.0	—	—	~ 0.2
$D^0 \to \rho^0\gamma$	0.5	-0.5	± 2	$0.1 - 0.5$
$D^0 \to \omega^0\gamma$	0.6	-0.7	± 1.3	$\simeq 0.2$
$D^0 \to \phi^0\gamma$	0.7	-1.6	± 5	$0.1 - 3.4$
$D^+ \to K^{*+}\gamma$	0.4	-0.1	± 0.8	$0.1 - 0.3$
$D^0 \to K^{*0}\gamma$	0.2	-0.3	± 0.4	$\simeq 0.01$

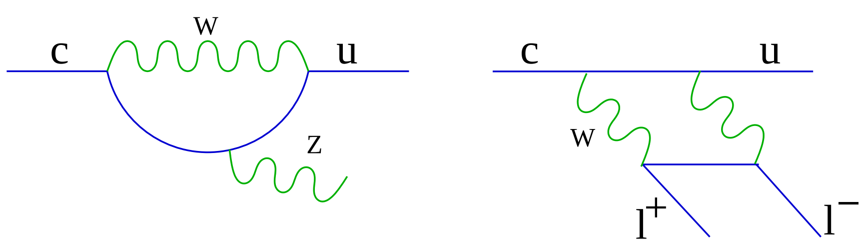
These contributions overwhelm ("irreducibly") the short distance physics.

Dilepton Modes

(*G.B., E. Golowich, J. Hewett and S. Pakvasa '01, also Fajfer, Prelovsekk and Singer '01*)

$D \to X\ell^+\ell^-$

- In addition to the photon penguin, now we also have



Then, the short distance is given by O_7 plus

$$O_9 = \frac{e^2}{16\pi^2}(\bar{u}_L\gamma_\mu c_L)(\bar{\ell}\gamma^\mu\ell) \ ,$$

$$O_{10} = \frac{e^2}{16\pi^2}(\bar{u}_L\gamma_\mu c_L)(\bar{\ell}\gamma^\mu\gamma_5\ell) \ .$$

- Compute C_7, C_9 and C_{10}. When QCD is added, mixing with other operators. In the SM we have

$$\mathcal{B}r^{(\mathrm{sd})}_{D^+\to X_u^+ e^+e^-} \simeq 2\times 10^{-8}$$

$$\mathcal{B}r^{(\mathrm{sd})}_{D^0\to X_u^0 e^+e^-} \simeq 8\times 10^{-9}$$

- Long Distance contributions: Dominated by intermediate vector meson states: $D \to PV^0 \to P\ell^+\ell^-$. For instance, in $D^+ \to \pi^+\ell^+\ell^-$, ϕ dominates.

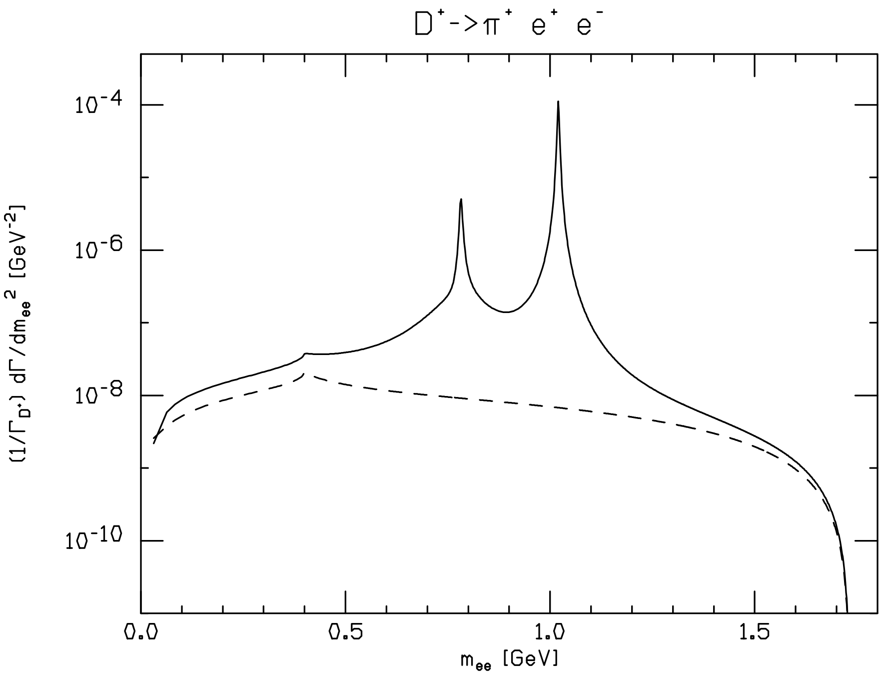
Mode	$\mathcal{B}r^{(\text{pole})}$	$\mathcal{B}r^{(\text{exp.})}$
$D^+ \to \pi^+\phi \to \pi^+e^+e^-$	$1.8 \cdot 10^{-6}$	$< 6.6 \cdot 10^{-5}$
$D^+ \to \pi^+\phi \to \pi^+\mu^+\mu^-$	$1.5 \cdot 10^{-6}$	$< 1.8 \cdot 10^{-5}$
$D_s^+ \to \pi^+\phi \to \pi^+e^+e^-$	$1.1 \cdot 10^{-5}$	$---$
$D_s^+ \to \pi^+\phi \to \pi^+\mu^+\mu^-$	$0.9 \cdot 10^{-5}$	$< 4.3 \cdot 10^{-4}$

- They affect the vector couplings of leptons. => the off-resonance effects can be included as

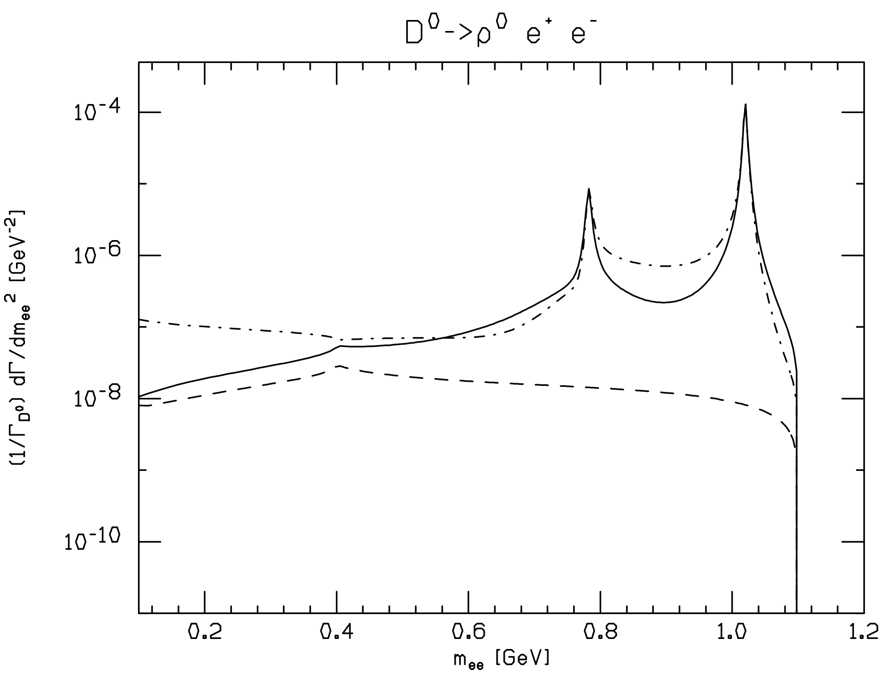
$$C_9 \to C_9 + \frac{3\pi}{\alpha^2}\sum_i \kappa_i \frac{m_{V_i}\Gamma_{V_i\to\ell^+\ell^-}}{m_{V_i}^2 - s - i m_{V_i}\Gamma_{V_i}} \;,$$

with the κ_i's fit to $D^+ \to \pi^+ V_i$ data.

Finally, using semileptonic form-factors gives predictions for $D^+ \to \pi^+ \ell^+ \ell^-$,



and $D^0 \to \rho^0 \ell^+ \ell^-$:

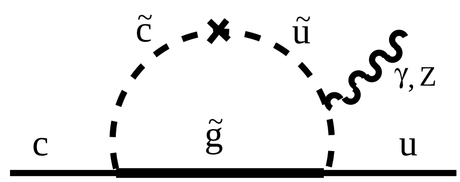


Rare D Decays in the MSSM

- Non-universal soft breaking terms:

$$\mathcal{L}_{\rm soft}^{\rm n.u.} = -Q^{i\dagger}(M_Q^2)^{ij}Q^j - D^{i\dagger}(M_D^2)^{ij}D^j$$
$$-U^{i\dagger}(M_U^2)^{ij}U^j + \cdots$$
$$+({A_D}^{ij}H^1Q^iD^j + {A_U}^{ij}H^2Q^iU^j + \cdots)$$

- Stability bounds apply to trilinear terms A^{ij}.
- Bounds on off-diagonal M_Q, etc. from FCNC.



=> bounds on

$$(\delta_{ij}^u)_{AB} \equiv \frac{(M_{ij}^U)_{AB}^2}{M_{\tilde{q}}^2}$$

and $A, B = L, R$.

Effects of squark-gluino in Wilson coefficients:

- The operators O_7 and O_9 get

$$C_7^{\tilde{g}} = -\frac{16}{9}\left(\frac{v}{M_{\tilde{q}}}\right)^2 \pi\alpha_s \left\{(\delta_{12}^u)_{LL}\frac{P_{132}(u)}{4} + (\delta_{12}^u)_{RL} P_{122}(u)\frac{M_{\tilde{g}}}{m_c}\right\}$$

$$C_9^{\tilde{g}} = -\frac{16}{27}\left(\frac{v}{M_{\tilde{q}}}\right)^2 \pi\alpha_s\,(\delta_{12}^u)_{LL} P_{042}(u)$$

- C_{10} requires *two* mass insertions

$$C_{10}^{\tilde{g}} = -\frac{1}{9}\frac{\alpha_s}{\alpha}(\delta_{22}^u)_{RL}(\delta_{12}^u)_{LR} P_{032}(u)$$

$u \equiv \left(\frac{M_{\tilde{g}}}{M_{\tilde{q}}}\right)^2$

- Operator basis is extended to include:

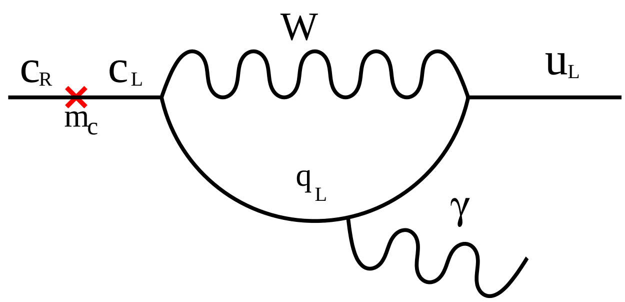
$$
\begin{aligned}
O_7' &= \frac{e}{16\pi^2} m_c (\bar{u}_R \sigma_{\mu\nu} c_L)\, F^{\mu\nu} \\
O_9' &= \frac{e^2}{16\pi^2} (\bar{u}_R \gamma_\mu c_R)(\bar{\ell}\gamma^\mu \ell) \\
O_{10}' &= \frac{e^2}{16\pi^2} (\bar{u}_R \gamma_\mu c_R)(\bar{\ell}\gamma^\mu \gamma_5 \ell)
\end{aligned}
$$

- These get

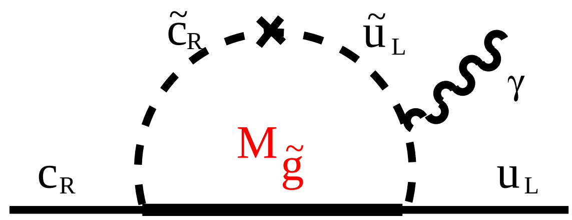
$$
\begin{aligned}
C_7'^{\tilde{g}} &= -\frac{16}{9}\left(\frac{v}{M_{\tilde{q}}}\right)^2 \pi\alpha_s \left\{ (\delta_{12}^u)_{RR} \frac{P_{132}(u)}{4} \right. \\
&\quad \left. + (\delta_{12}^u)_{LR} P_{122}(u) \frac{M_{\tilde{g}}}{m_c} \right\} \\
C_9'^{\tilde{g}} &= -\frac{16}{27}\left(\frac{v}{M_{\tilde{q}}}\right)^2 \pi\alpha_s\, (\delta_{12}^u)_{RR} P_{042}(u) \\
C_{10}'^{\tilde{g}} &= -\frac{1}{9}\,\frac{\alpha_s}{\alpha}\, (\delta_{22}^u)_{LR} (\delta_{12}^u)_{LR} P_{032}(u)
\end{aligned}
$$

$M_{\tilde{g}}$ enhancement

- In the SM $O_7 = \frac{e}{16\pi^2} m_c (\bar{u}_L \sigma_{\mu\nu} c_R) \, F^{\mu\nu}$ requires m_c insertion



- But here the flip is done in the gluino line



=> C_7 (and C_7') pick up a factor of $M_{\tilde{g}}/m_c$.

Bounds on the $(\delta^u_{ij})_{AB}$

- Best limits on $(\delta^u)_{AB}$ come from $D^0 - \bar{D}^0$ mixing (CLEO, FOCUS)

$$\frac{1}{2}\left\{\left(\frac{\Delta m_D}{\Gamma_{D^0}}\right)^2 \cos\delta + \left(\frac{\Delta\Gamma_D}{2\Gamma_{D^0}}\right)^2 \sin\delta\right\} < 0.04\%$$

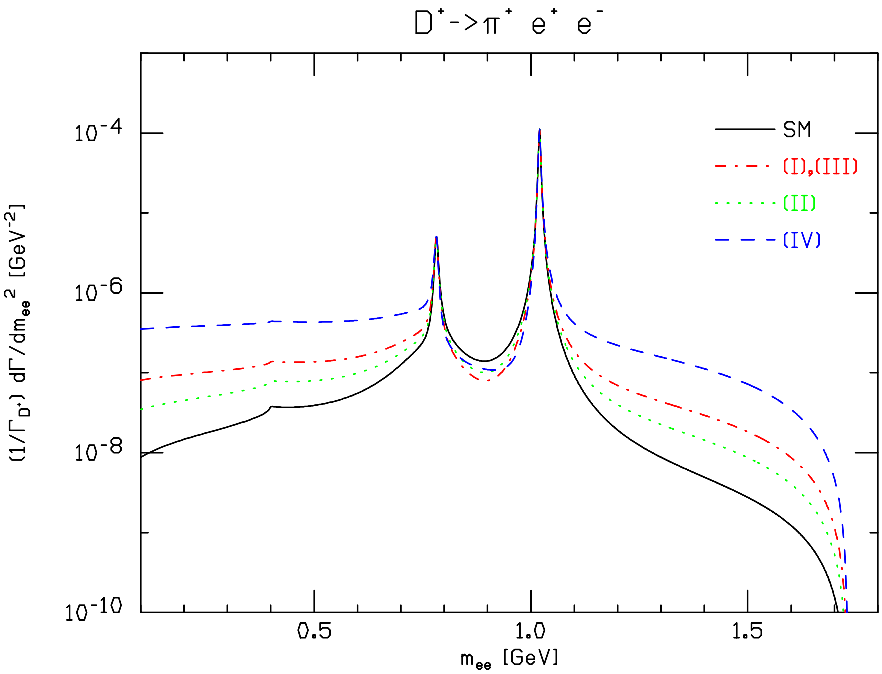
with δ relative strong phase between $D^0 \to K^-\pi^+$ and $D^0 \to K^+\pi^-$.

- Assuming δ is negligible

$M^2_{\tilde{g}}/M^2_{\tilde{q}}$	$(\delta^u_{12})_{LL}$	$(\delta^u_{12})_{LR}$
0.3	0.03	0.04
1.0	0.06	0.02
4.0	0.14	0.02

$\times M_{\tilde{q}}/500$ GeV.

The effects in $D \to \pi \ell^+ \ell^-$ moderately constraining



with

(I) : $M_{\tilde{g}} = M_{\tilde{q}} = 250$ GeV

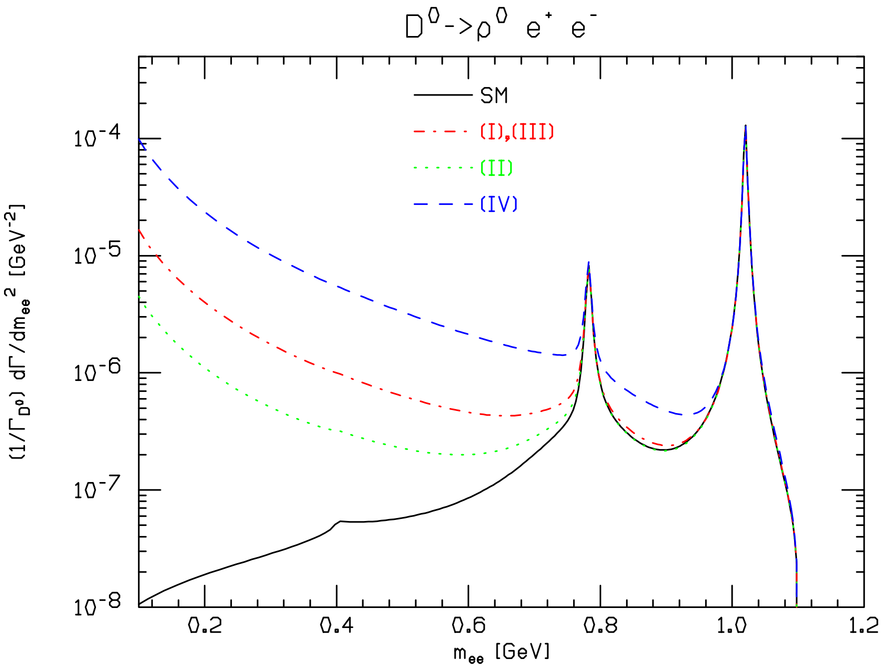
(II) : $M_{\tilde{g}} = 2\, M_{\tilde{q}} = 500$ GeV

(III): $M_{\tilde{g}} = M_{\tilde{q}} = 1000$ GeV

(IV): $M_{\tilde{g}} = (1/2)\, M_{\tilde{q}} = 250$ GeV.

and we take $(\delta^u_{12})_{RR} = 0$ and $(\delta^u_{12})_{RL} = (\delta^u_{12})_{LR}$.

Potentially large effects in the $D \to \rho\ell^+\ell^-$ channels



- Low $q^2 = m_{ee}^2$ enhancement due to photon propagator in C_7 term. In $D \to \pi\ell^+\ell^-$ this is cancelled by matrix element giving $(q^2\gamma_\mu - q_\mu \not{q})$.
- $Br(D^0 \to \rho^0 e^+ e^-) \simeq 1.3 \times 10^{-5} \simeq$ 5 SM.
  $Br^{\text{exp.}}(D^0 \to \rho^0 e^+ e^-) < 1.2 \times 10^{-4}$.

R Parity Violation in SUSY

- Large violation of R parity is possible if other symmetries invoked to avoid proton decay. RPV superpotential

$$\mathcal{W}_{R_p} = \epsilon_{ab}\tilde{\lambda}'_{ijk} L_i^a Q_j^b \bar{D}_k + \cdots$$

- In the mass eigenbasis we get

$$\mathcal{W}_{R_p} = \lambda'_{ijk}\left[N_i V_{jl} D_l - E_i U_j\right]\bar{D}_k + \cdots$$

with

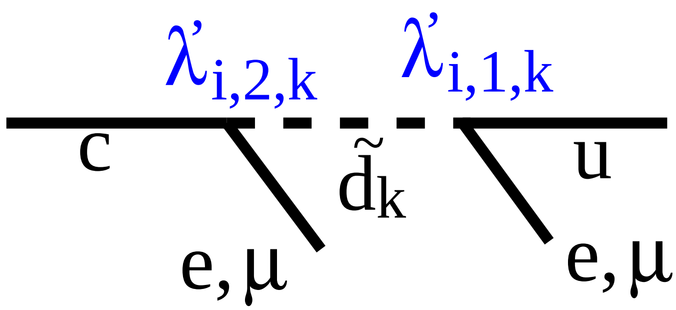
$$\lambda'_{ijk} \equiv \tilde{\lambda}'_{irs}\mathcal{U}^L_{rj}\mathcal{D}^{*R}_{sk}$$

and $\mathcal{U}$, $\mathcal{D}$ rotate quarks to mass basis.

The interesting part of the super-potential gives (expanded in components in the mass basis)

$$\mathcal{W}_{\lambda'} = \lambda'_{ijk}\Big\{V_{jl}[\tilde{\nu}^i_L \bar{d}^k_R d^l_L + \tilde{d}^l_L \bar{d}^k_R \nu^i_L + (\tilde{d}^k_R)^* \overline{(\nu^i_L)}^c d^l_L] \\ -\tilde{e}^i_L \bar{d}^k_R u^j_L - \tilde{u}^j_L \bar{d}^k_R e^i_L - (\tilde{d}^k_R)^* \overline{(e^i_L)}^c u^j_L \Big\}$$

Two insertions of last term => $c \to u\ell\ell'$ transitions.



This induces

$$\delta\mathcal{H}_{\rm eff.} = -\frac{\lambda'_{i2k}\lambda'_{i1k}}{2m^2_{\tilde{d}^k_R}}\,(\bar{u}_L\gamma_\mu c_L)(\bar{\ell}_L\gamma^\mu\ell_L)$$

leading to

$$\delta C_9 = -\delta C_{10} = \frac{s^2\theta_W}{2\alpha^2}\left(\frac{M_W}{m_{\tilde{d}^k_R}}\right)^2\ \lambda'_{i2k}\lambda'_{i1k}$$

(More) model-independent bounds give -in units of $\times(m_{\tilde{d}^k_R}/100)$ GeV-

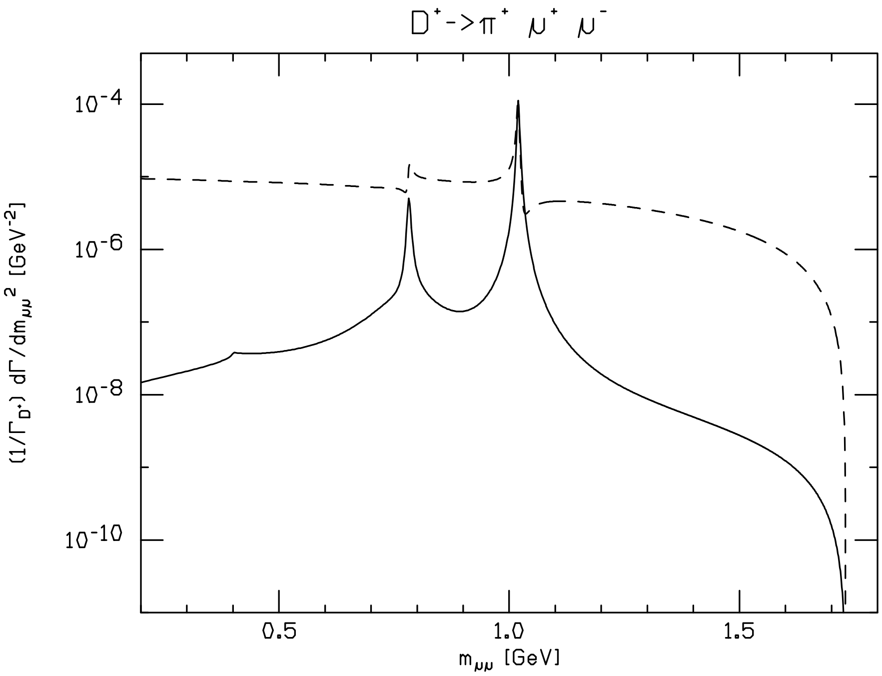
λ'_{11k}	λ'_{12k}	λ'_{21k}	λ'_{22k}
0.02[a)]	0.04[a)]	0.06[b)]	0.21[c)]

a) Charged current universality.

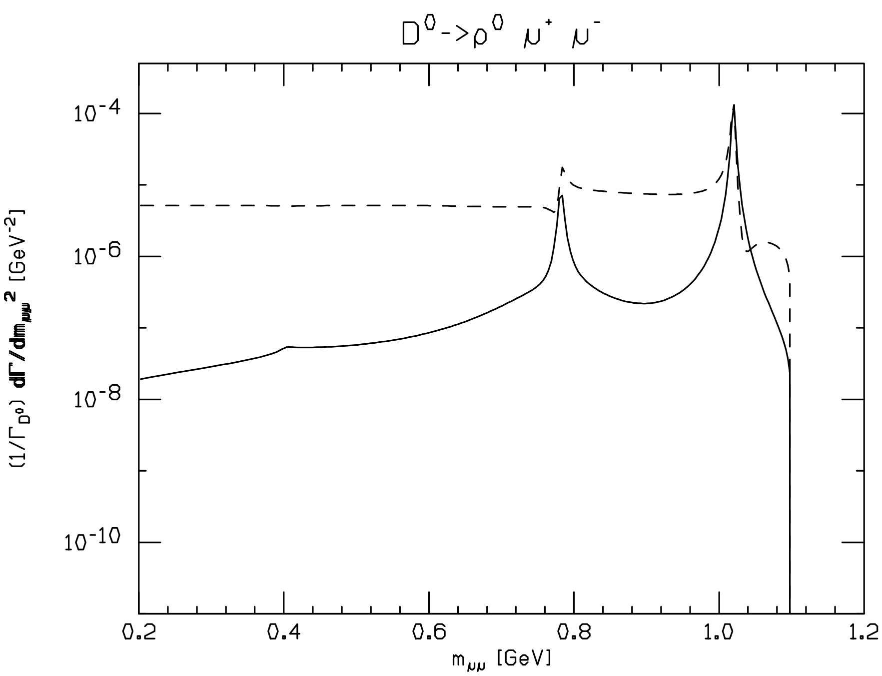
b) $R_\pi = \Gamma(\pi\to e\nu)/\Gamma(\pi\to\mu\nu)$.

c) $D\to K\ell\nu$.

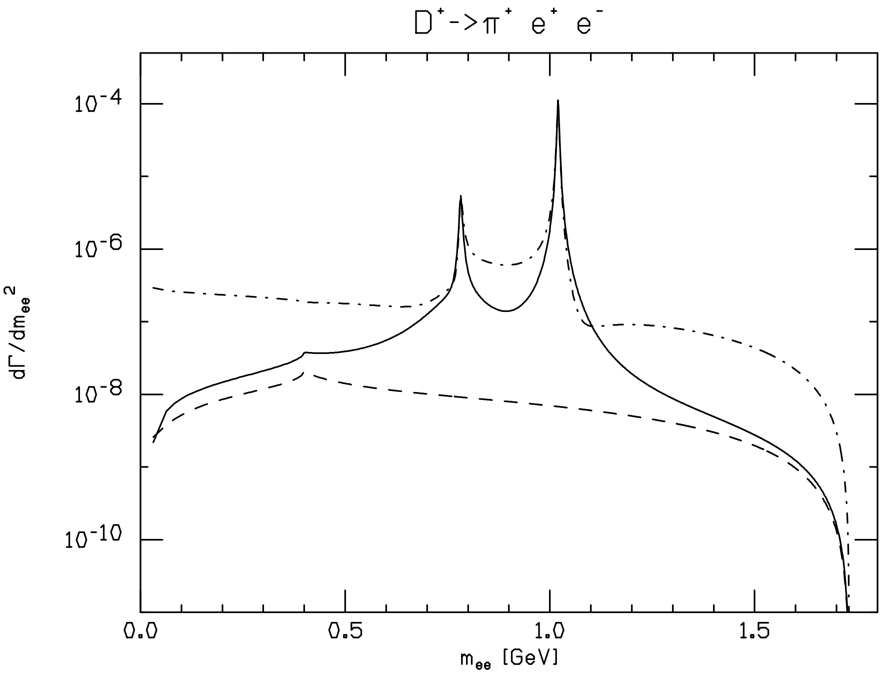
Large effects in the $\mu^+\mu^-$ channel.

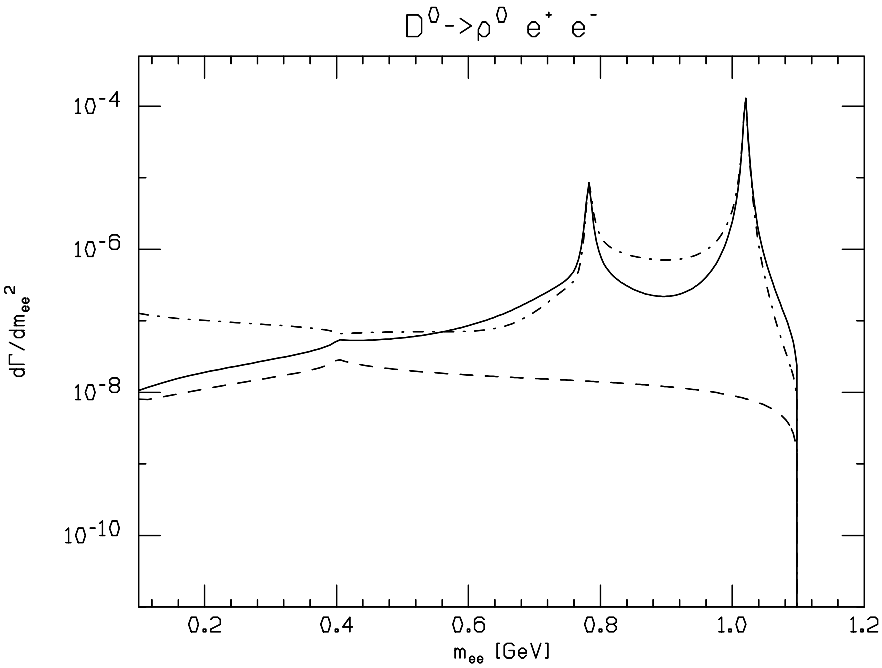


This actually => $\lambda'_{22k}\,\lambda'_{21k} < 0.004$ and gives



Effects in the e^+e^- channel.



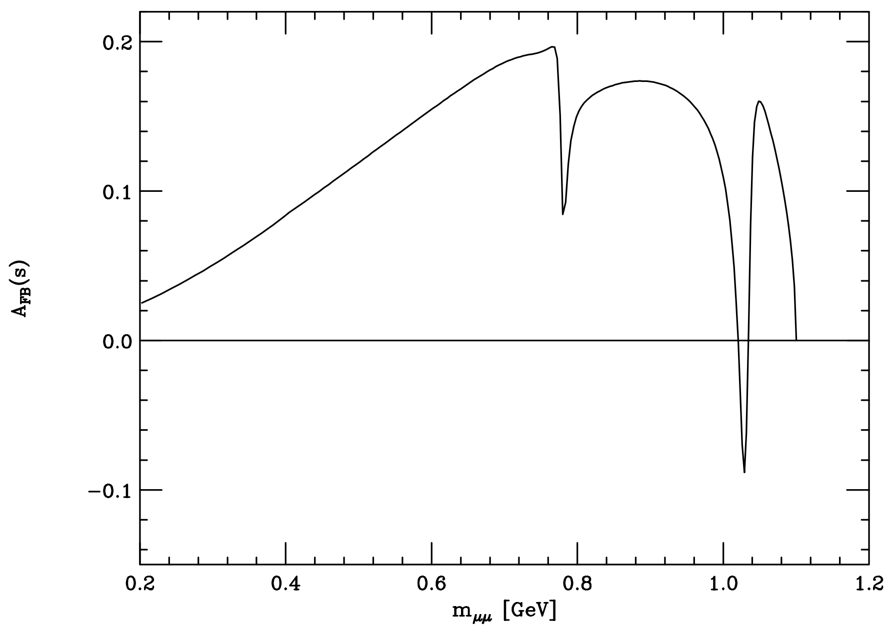


Forward-Backward Asymmetry in $D \to \rho \ell^+ \ell^-$

FB Asymmetry for leptons

$$A_{FB}(q^2) = \frac{\int_0^1 \frac{d^2\Gamma}{dx dq^2} dx - \int_{-1}^0 \frac{d^2\Gamma}{dx dq^2} dx}{\frac{d\Gamma}{dq^2}}$$

with $x = \cos\theta$. It's negligible in the SM! But if $C_{10} \simeq C_9$ it could be observable:



$A_{FB}^{\mathrm{tot.}} \lesssim 0.15$ for $\mu^+\mu^-$.
$A_{FB}^{\mathrm{tot.}} \lesssim 0.08$ for e^+e^-.

Decay Mode	SM	$\not R_p$	Exp. Limit.
$D^+ \to \pi^+ e^+ e^-$	2.0×10^{-6}	2.3×10^{-6}	5.2×10^{-5}
$D^0 \to \rho^0 e^+ e^-$	2.5×10^{-6}	5.1×10^{-6}	1.2×10^{-4}
$D^+ \to \pi^+ \mu^+ \mu^-$	1.9×10^{-6}	1.5×10^{-5}	1.5×10^{-5}
$D^0 \to \rho^0 \mu^+ \mu^-$	4.5×10^{-6}	8.7×10^{-6}	2.2×10^{-5}
$D^0 \to \mu^+ \mu^-$	3.0×10^{-15}	3.5×10^{-6}	5.2×10^{-6}
$D^0 \to e^+ e^-$	few 10^{-24}	1.0×10^{-10}	6.2×10^{-6}
$D^0 \to \mu^+ e^-$	0	1.0×10^{-6}	8.1×10^{-6}
$D^+ \to \pi^+ \mu^+ e^-$	0	3.0×10^{-5}	3.4×10^{-5}
$D^0 \to \rho^0 \mu^+ e^-$	0	1.4×10^{-5}	6.6×10^{-5}

Conclusions

- Semileptonic Decays: Precision measurements of $D \to (\pi, \rho)\ell\nu$, $D \to K^{(*)}\ell\nu$ => Tests of HQET, $SU(3)$, Lattice calculations. Impact on B physics: V_{ub}, predictions for exclusive rare B decays ($B \to K^{(*)}\ell^+\ell^-$).
- $D^0 - \bar{D}^0$ Mixing: theoretical limitation, need to understand long distance constributions.
- Charm decays induced by FCNC are sensitive to short distance physics if one stays away from resonances: e.g. this is possible in $D \to \pi\ell^+\ell^-$ and $D \to \rho\ell^+\ell^-$
- $D \to \pi\ell^+\ell^-$ and *especially* $D \to \rho\ell^+\ell^-$, are sensitive to non-universal effects in the MSSM scalar sector if sensitivities around (10^{-6}-10^{-7}) are achieved.
- With current sensitivity around 10^{-5} these modes are already constraining R-parity violating couplings.