D - physics

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Outline

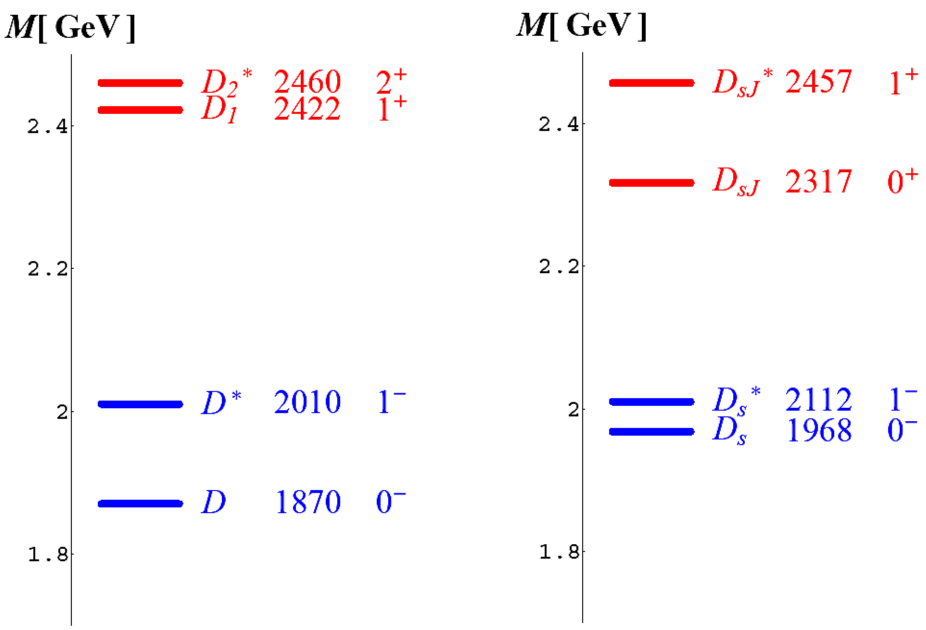
• Strong decays

impact of open charm mesons

• Semileptonic decays

• Search for new physics in rare D decays

This talk does not include: D^0 - $\bar{D}^0$ mixing, electromagnetic decays, weak hadronic decays, leptonic charm decays...



Mass spectrum of open charm mesons

Question: what is their impact on strong and weak charm meson decays?

Strong decays of positive and negative parity charmed mesons

Meson	J^P	Mass [GeV]	Width [GeV]	$Br.$ [%] (final states)
D^{*+}	1^-	2.010	$(9.6 \pm 2.2) \times 10^{-5}$	67.7 ± 0.5 $(D^0\pi^+)$, 30.7 ± 0.5 $(D^+\pi^0)$
D^{*+}	1^-	2.007	< 0.0021	61.9 ± 2.9 $(D^0\pi^0)$
D_0^{*+}	0^+	$2.403 \pm 0.014 \pm 0.035$	$0.283 \pm 0.024 \pm 0.034$	$(D^0\pi^+)^a$
D_0^{*0}	0^+	2.350 ± 0.027^b	0.262 ± 0.051^b	$(D^+\pi^-)^a$
$D_1^{\prime 0}$	1^+	2.438 ± 0.030^c	0.329 ± 0.084^c	$(D^{*+}\pi^-)^a$

a) average of Belle and Focus values;
b) average of Belle and CLEO values;

There are many studies : quark models, QCD sum rules, HMChPT, lattice...

S.F. and J. Kamenik hep-ph/0606278 (Phys. Rev D):

Strong couplings are investigated including chiral loop corrections within Heavy meson chiral perturbation theory (I.W. Stewart, NP B529, 62 (1998), T. Mehen and R. Springer, PRD 72, 034006 (2005).

Framework

The leading order of HMChPT in chiral and heavy quark expansion

$$H = 1/2(1+\not{v})[P^*_\mu \gamma^\mu - P\gamma_5]$$

$$S = 1/2(1+\not{v})[P^*_{1\mu}\gamma^\mu\gamma_5 - P_0]$$

$$\mathcal{L} = \mathcal{L}_\chi + \mathcal{L}_{\frac{1}{2}^-} + \mathcal{L}_{\frac{1}{2}^+} + \mathcal{L}_{\text{mix}},$$

$$\mathcal{L}_\chi = \frac{f^2}{8}\partial_\mu \Sigma_{ab}\partial^\mu \Sigma^\dagger_{ba},$$

$$\mathcal{L}_{\frac{1}{2}^-} = -\text{Tr}\left[\bar{H}_a(iv\cdot\mathcal{D}_{ab} - \delta_{ab}\Delta_H)H_b\right] + g\text{Tr}\left[\bar{H}_b H_a \not{\mathcal{A}}_{ab}\gamma_5\right],$$

$$\mathcal{L}_{\frac{1}{2}^+} = \text{Tr}\left[\bar{S}_a(iv\cdot\mathcal{D}_{ab} - \delta_{ab}\Delta_S)S_b\right] + \tilde{g}\text{Tr}\left[\bar{S}_b S_a \not{\mathcal{A}}_{ab}\gamma_5\right],$$

$$\mathcal{L}_{\text{mix}} = h\text{Tr}\left[\bar{H}_b S_a \not{\mathcal{A}}_{ab}\gamma_5\right] + \text{h.c.}.$$

These three couplings are Being discussed within this study

$$\pi^i\lambda^i = \begin{pmatrix} \frac{1}{\sqrt{6}}\eta + \frac{1}{\sqrt{2}}\pi^0 & \pi^+ & K^+ \\ \pi^- & \frac{1}{\sqrt{6}}\eta - \frac{1}{\sqrt{2}}\pi^0 & K^0 \\ K^- & \bar{K}^0 & -\sqrt{\frac{2}{3}}\eta \end{pmatrix}$$

$$\mathcal{D}^\mu_{ab} = \delta_{ab}\partial^\mu - \mathcal{V}^\mu_{ab}$$

$$\mathcal{V}_\mu = 1/2(\xi^\dagger\partial_\mu\xi + \xi\partial_\mu\xi^\dagger)$$

$$\mathcal{A}_\mu = i/2(\xi^\dagger\partial_\mu\xi - \xi\partial_\mu\xi^\dagger)$$

$$\Sigma = \xi^2 = \exp(2i\pi^i\lambda^i/f)$$

One is free to set $\Delta_H = 0$

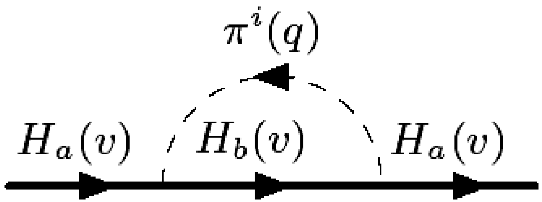
But, in the loop calculations enter:

$$\Delta_{SH} = \Delta_S - \Delta_H$$

Note, that previous calculations extracted g coupling without positive parity states and h only at tree level.

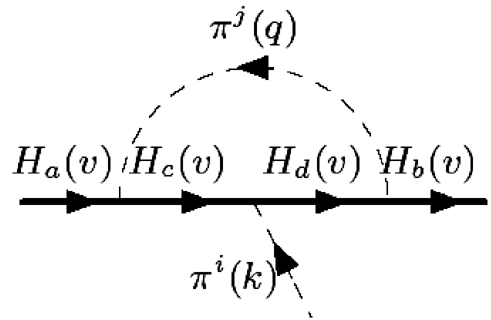
Extraction of bare couplings

Wave function renormalization



$$Z_{2H} = 1 - \frac{1}{2} \frac{\partial \Pi(v \cdot p)}{\partial v \cdot p} \Big|_{\mathrm{on\ mass-shell}},$$

Vertex corrections



$$v \cdot k_\pi = \Delta_{fi} = \Delta_f - \Delta_i$$

residual masses of the final and inital states

$$g^{\mathrm{eff.}}_{P_a^* P_b \pi^i} = g \frac{\sqrt{Z_{2P_a}} \sqrt{Z_{2P_b^*}} \sqrt{Z_{2\pi^i}}}{\sqrt{Z_{1 P_a P_b^* \pi^i}}} = g Z^g_{P_a^* P_b \pi^i}$$

$$\Gamma(P_a^* \to \pi^i P_b) = \frac{|g^{\mathrm{eff.}}_{P_a^* P_b \pi^i}|^2}{6\pi f^2} |\vec{k}_{\pi^i}|^3$$

Scale dependence of the loops cancelled by the counterterms. However, many new parameters appear in counterterms which cannot be fixed by existing data.

Wave function renormalisation

$$Z_{2P_{0a}} = 1 - \frac{\lambda^i_{ab}\lambda^i_{ba}}{16\pi^2 f^2} \times \left[3\tilde{g}^2 C_1'\left(\frac{\tilde{\Delta}_{ba}}{m_i}, m_i\right) - h^2 C'\left(\frac{\Delta_{b\tilde{a}} - \Delta_{SH}}{m_i}, m_i\right)\right]$$

$$Z_{2P_a} = 1 - \frac{\lambda^i_{ab}\lambda^i_{ba}}{16\pi^2 f^2} \times \left[3g^2 C_1'\left(\frac{\Delta_{ba}}{m_i}, m_i\right) - h^2 C'\left(\frac{\Delta_{\tilde{b}a} + \Delta_{SH}}{m_i}, m_i\right)\right]$$

$\mathcal{O}(p^2)$

Vertex corrections

$\mathcal{O}(p^3)$

$$Z_{1P^*_a P_b \pi^i} = 1 - \frac{\lambda^j_{ac}\lambda^i_{cd}\lambda^j_{db}}{\lambda^i_{ab} 16\pi^2 f^2} \times \left\{ g^2 C_1'\left(\frac{\Delta_{ca}}{m_j}, \frac{\Delta_{db}}{m_j}, m_j\right) + \frac{h^2\tilde{g}}{g} C'\left(\frac{\Delta_{\tilde{c}a} + \Delta_{SH}}{m_j}, \frac{\Delta_{\tilde{d}b} + \Delta_{SH}}{m_j}, m_j\right)\right\} + \frac{\lambda^i_{ac}(m_q)_{cb}}{\Lambda_\chi \lambda^i_{ab}}(\kappa_9 + \delta^{ab}\kappa_5) - \frac{\Delta_{ba}}{\Lambda_\chi}\frac{\delta_2 + \delta_3}{g}.$$

$$Z_{1P^*_{1a} P_{0b} \pi^i} = 1 - \frac{\lambda^j_{ac}\lambda^i_{cd}\lambda^j_{db}}{\lambda^i_{ab} 16\pi^2 f^2} \times \left\{ \tilde{g}^2 C_1'\left(\frac{\tilde{\Delta}_{ca}}{m_j}, \frac{\tilde{\Delta}_{db}}{m_j}, m_j\right) + \frac{h^2 g}{\tilde{g}} C'\left(\frac{\Delta_{c\tilde{a}} - \Delta_{SH}}{m_j}, \frac{\Delta_{d\tilde{b}} - \Delta_{SH}}{m_j}, m_j\right)\right\} + \frac{\lambda^i_{ac}(m_q)_{cb}}{\Lambda_\chi \lambda^i_{ab}}(\tilde{\kappa}_9 + \delta^{ab}\tilde{\kappa}_5) - \frac{\tilde{\Delta}_{ba}}{\Lambda_\chi}\frac{\tilde{\delta}_2 + \tilde{\delta}_3}{\tilde{g}}.$$

$$Z_{1P_{0a} P_b \pi^i} = 1 - \frac{\lambda^j_{ac}\lambda^i_{cd}\lambda^j_{db}}{\lambda^i_{ab} 16\pi^2 f^2} \times \left\{ 3g\tilde{g} C_1'\left(\frac{\tilde{\Delta}_{ca}}{m_j}, \frac{\Delta_{db}}{m_j}, m_j\right) - h^2 C'\left(\frac{\Delta_{c\tilde{a}} - \Delta_{SH}}{m_j}, \frac{\Delta_{\tilde{d}b} + \Delta_{SH}}{m_j}, m_j\right)\right\} + \frac{\lambda^i_{ac}(m_q)_{cb}}{\Lambda_\chi \lambda^i_{ab}}(\kappa_9' + \delta^{ab}\kappa_5') - \frac{\Delta_{b\tilde{a}} - \Delta_{SH}}{\Lambda_\chi}\frac{\delta_2' + \delta_3'}{h}.$$

We assume: $g \in [0,1]$ $|h| \in [0,1]$ $\tilde{g} \in [-1,1]$

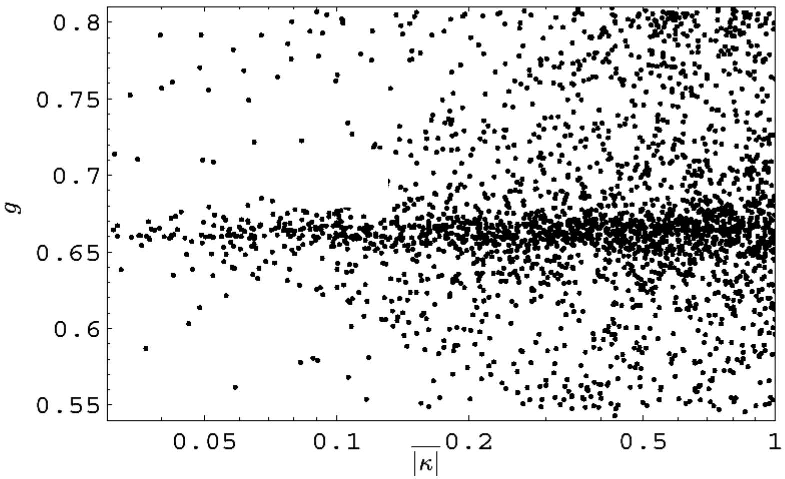
Then Monte -Carlo randomized least –square fit for all three couplings is performed using experimental values for the decay rates to comput χ^2 . It is found that g =0.66, |h|=0.47 and $\tilde{g} = -0.06$ at $\chi^2 = 3.9$.

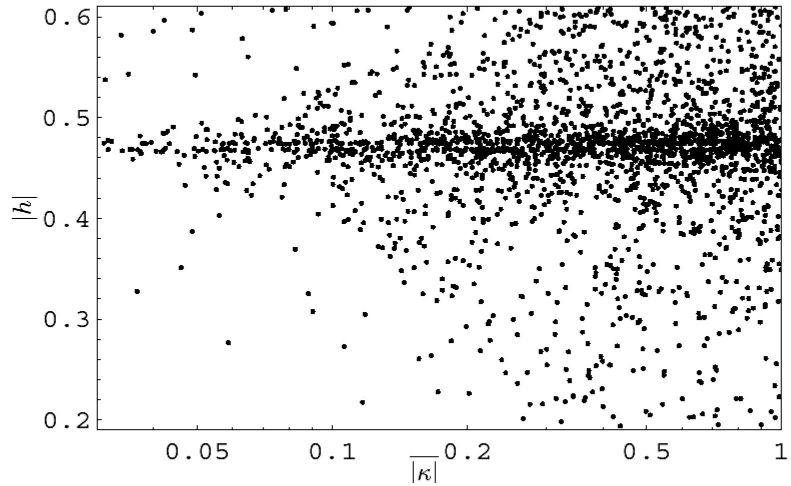
Next we study effects of counterterms

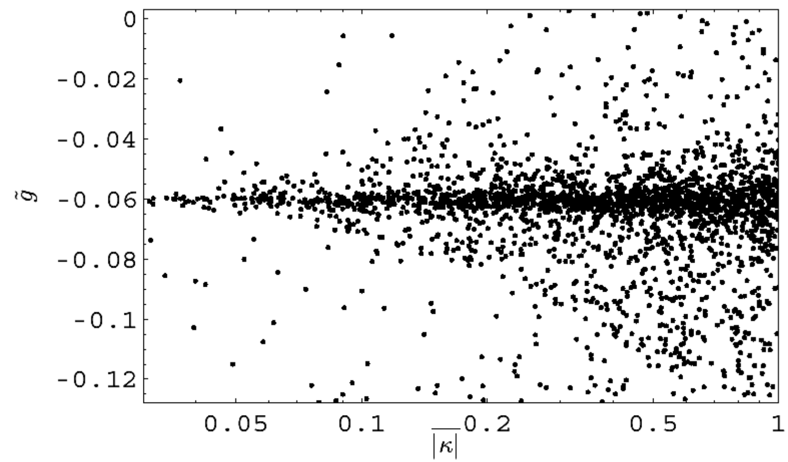
$$\kappa_5,\ \kappa'_5,\ \kappa_{19},\ \kappa'_{19},\ \delta_2 + \delta_3 \text{ and } \delta'_2 + \delta'_3$$

We take counterterm couplings entering our decay modes to be randomly distributed at $\mu \simeq 1$ GeV in the interval $[-1,1]$ and 5000 values of g, $|h|$ and $\tilde{g}$ are generated near original fitted solution by minimizing χ^2 at each counterterm sample.

For each solution the average absolute value of the randomized couterterm couplings $(\overline{|\kappa|})$ is computed. It is assumed that counterterm contributions do not exceed values of the order $\mathcal{O}(1)$.







The inclusion of counterterms spreads the fitted values of the tree couplings.

Extracted bare couplings:

$$g = 0.66^{+0.08}_{-0.06},\ |h| = 0.47^{+0.07}_{-0.04} \text{ and } \tilde{g} = -0.06^{+0.03}_{-0.04}$$

Calculation scheme	g	$\|h\|$	$\tilde{g}$
Leading order	0.61 [40]	0.52	-0.15^a
One-loop without positive parity states	0.53		
One-loop with positive parity states	0.66	0.47	-0.06

[a] Effective tree level coupling value derived from one loop calculation for the case $D_1'^0 \to D_0^{*+}\pi^-$.

at $\mu \simeq 1$ GeV

• We could not include $(1/m_H)$ terms due to very large number of new parameters, however lattice studies indicate that they do not contribute significantly;

• The result is in a way complementary to the study of renormalization scale dependence. Both are important since although it is possible to trade the counteterms contributions for a specific choice of the renormalization scale, the latter will be different for different amplitudes where the combination of counterterms will be different.

Chiral extrapolation

Lattice QCD performs calculations using large light quark masses and then makes chiral limit.

The inclusion of heavy excited mesons in the chiral loops introduces large scale dependence into the renormalization of the coupling constants. It looks as excited states dominates loop contributions.

Note that pions in the loops can be real, what introduces uncontrollable FSI.

The loop integral depends on two scales:

• the mass of pseudogoldstone boson (its value can be as large as 1 GeV in the lattice calculation, small in CHPT);

• the scale Δ contains the splitting and it is not protected either by heavy quark or chiral symmetry to be small;

$1/\left(v \cdot q - \Delta\right)$

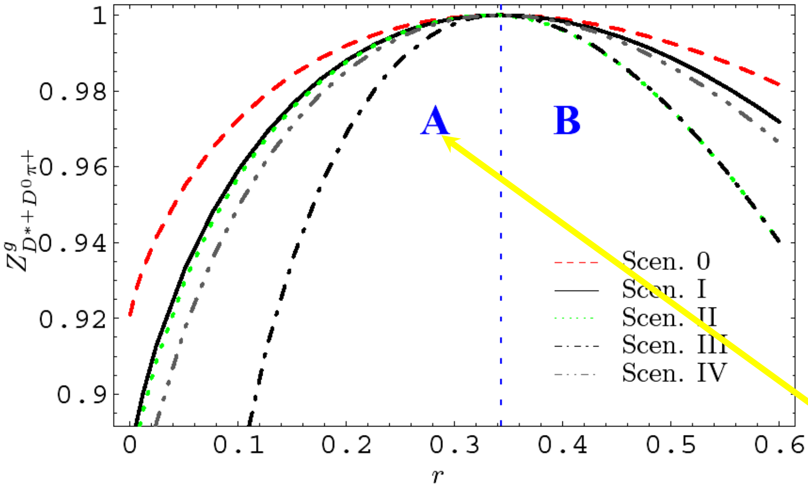
$$I_1^{\mu\nu}(m,\Delta)|_{\Delta=\text{large}} =$$
$$= \frac{\mu^{4-D}}{(2\pi)^D}\int \mathrm{d}^D q \frac{q^\mu q^\nu}{q^2 - m^2 - i\varepsilon} \frac{-1}{\Delta}\left(1 + \frac{q\cdot v}{\Delta} + \ldots\right),$$

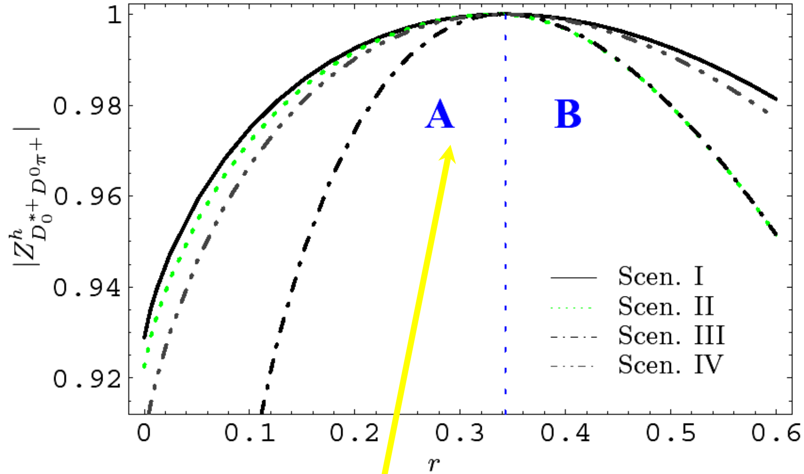
It is important to stress that the relevant ratio for the validity of this approach is $\Delta/E_\pi \gg 1$ as we are expanding in powers of loop momentum, not pseudo-Goldstone masses.

$$\frac{1}{m_j^2}\frac{\mathrm{d}g^{\mathrm{eff.}}_{P_a^* P_b \pi^i}}{\mathrm{d}\log m_j^2} = \frac{g}{(4\pi f)^2} \times \left\{ \frac{\lambda^j_{ac}\lambda^j_{ca} + \lambda^j_{bc}\lambda^j_{cb}}{2}\left[-3g^2 - h^2\left(1 - \frac{6\Delta^2_{SH}}{m_j^2}\right)\right] + \frac{\lambda^j_{ac}\lambda^i_{cd}\lambda^j_{db}}{\lambda^i_{ab}}\left[g^2 - h^2\frac{\tilde{g}}{g}\left(1 - \frac{6\Delta^2_{SH}}{m_j^2}\right)\right]\right\}. \quad (16)$$

These contribution dominate the chiral limit

If we instead use the loop integral expansion we effectively replace $1 - 6\Delta^2_{SH}/m_j^2$ by $m^2/4\Delta^2_{SH}$. Furthermore, these terms then become of the order $m^4 \log m^2$ and formally contribute only to next-to-leading chiral log running.





: The g coupling renormalization in $D^{*+} \to D^0\pi^+$.

Chiral extrapolation of the h coupling renormaliz tion in $D_0^{*+} \to D^0\pi^+$.

omparison of chiral extrapolation with $g = 0.66$, $|h| =$ 47, $\tilde{g} = -0.06$ and (I) loop integral expansion (black, solid), I) Δ_{SH} "freeze out" (green, dotted), (III) complete log con- ibution (dark gray, dash-dotted), (IV) the degenerate limit ght gray, dash-double dotted), and (0) without positive par- y doublets included in the loops ($g = 0.53$, $|h| = 0$) (red, ished line) as explained in the text.

region where $1/\Delta$ expansion is valid

$$r = m_{u,d}/m_s$$

$$_\pi^2 = \frac{8\lambda_0 m_s}{f^2} r, \qquad m_K^2 = \frac{8\lambda_0 m_s}{f^2}\frac{r+1}{2}, \quad 8\lambda_0 m_s/f^2 = 2m_K^2 - m_\pi^2 = 0.468\ \mathrm{GeV}^2$$

$$_\eta^2 = \frac{8\lambda_0 m_s}{f^2}\frac{r+2}{3},$$

• Since we consider only pions in the final state we do not expect large counterterms contributions;

• Due to large number of parameters (Mehen&Springer) in 1/M corrections and chiral loop corrections it is not possible to determine them all;

• We found that for the chiral extrapolation of the coupling g full loop contributions give sizable effects in modifying slope and curvature in the case when $m_\pi \to 0$.

• If we instead use $1/\Delta_{SH}$ expansion the effect is reduced; h coupling contributions are reduced to be of the order 5%.

D meson semileptonic weak decays

$$\langle P(p_P)|(V-A)^\mu|H(p_H)\rangle$$
$$= F_+(q^2)\left((p_H+p_P)^\mu - \frac{m_H^2-m_P^2}{q^2}q^\mu\right)$$
$$+F_0(q^2)\frac{m_H^2-m_P^2}{q^2}q^\mu,$$

$$F_+(0)=F_0(0)$$

$$\langle V(\epsilon_V,p_V)|\bar{q}\gamma^\mu Q|H(p_H)\rangle = -\frac{2V(q^2)}{m_H+m_V}\epsilon^{\mu\nu\alpha\beta}\epsilon^*_{V\nu}p_{H\alpha}p_{V\beta},$$

$$\langle V(\epsilon_V,p_V)|\bar{q}\gamma^\mu\gamma^5 Q|H(p_H)\rangle = i\epsilon^*_V\cdot q\frac{2m_V}{q^2}q^\mu A_0(q^2) - i(m_H+m_V)\left[\epsilon^{*\mu}_V - \frac{\epsilon^*_V\cdot q}{q^2}q^\mu\right]A_1(q^2$$
$$+i\frac{\epsilon^*_V\cdot q}{(m_H+m_V)}\left[(p_H+p_V)^\mu - \frac{m_H^2-m_V^2}{q^2}q^\mu\right]A_2(q^2),$$

S.F. and J. Kamenik
Phys. Rev. D 71, 014020 (2005),
Phys. Rev. D72, 034029 (2005),
Phys. Rev. D 73, 057503 (2006).

$$A_0(0)+\frac{m_H+m_V}{2m_V}A_1(0)-\frac{m_H-m_V}{2m_V}A_2(0)=0$$

Experimental results on D meson semiletponic form factors

There are new experimental results on D semileptonic decays (FOCUS, CLEO and Belle collaboration):

FOCUS: hep-ex/ 0410037; Phys Lett. B607, 233 (2005)
CLEO: hep-ex/0407035; Phys. Rev. Lett. 94, 011802 (2005)
BELLE: hep-ex/0510003;
BaBar:hep-ex/0607077

They investigated form factors in $D^0 \to \pi^- \ell^+ \nu$ and $D^0 \to K^- \ell^+ \nu$

Usually in D semileptonic decays a simple pole parametrization has been used in the past.

$$f_+(q^2) = \frac{f_+(0)}{(1 - q^2/m^2_{\text{pole}})}$$

In the case of K meson in the final state the pole masses are inconsistent with physical masses of the vector meson resonances.

These experimental results suggest the existence of contributions beyond the lowest lying charm meson resonances!

A fit to modified pole is done using:

$$f_+(q^2) = \frac{f_+(0)}{(1 - q^2/m^2_{\rm pole})(1 - \alpha_p q^2/m^2_{\rm pole})}$$

Becirevic – Kaidalov parametrization

$$\alpha_p(D^0 \to K^- e^+ \nu) = 0.40 \pm 0.12 \pm 0.09$$
$$\alpha_p(D^0 \to K^- \mu^+ \nu) = 0.66 \pm 0.11 \pm 0.09$$
$$\alpha_p(D^0 \to \pi^- e^+ \nu) = 0.03 \pm 0.27 \pm 0.13$$
$$\alpha_p(D^0 \to \pi^- \mu^+ \nu) = 0.19 \pm 0.32 \pm 0.16$$

(here are given results of Belle collaboration; CLEO and FOCUS results are rather close to these)

These results show that in the case of $K\ell\nu$ decay mode there is significant deviation from the prediction of simple pole.

FOCUS (hep-ex/0509027) presented the first measurements of the helicity basis form factors free from the assumption of spectroscopic pole dominance in the case of ,

$$D^+ \to \overline{K}^{*0} \mu^+ \nu$$

BaBar recent study (hep-ex/0607085) still has single pole dependence for form factors in

$$D_s^+ \to \phi e^+ \nu_e$$

In static limit of HQET

$$\lim_{m_H \to \infty} \frac{1}{\sqrt{m_H}} |H(p_H)\rangle_{QCD} = |H(v)\rangle_{HQET}.$$

$$\langle P(p_P)|(V-A)^\mu|H(v)\rangle_{\rm HQET}$$
$$= [p_P^\mu - (v\cdot p_P)v^\mu]\, f_p(v\cdot p_P)$$
$$+ v^\mu f_v(v\cdot p_P),$$

$$v\cdot p_P = \frac{m_H^2 + m_P^2 - q^2}{2m_H}$$

Becirevic – Kaidalov parametrization: includes all HQET and QCD sum rules, as well SCET limits

$$F_+(q^2) = c_B\left(\frac{1}{1-x} - \frac{a}{1-x/\gamma}\right)$$
$$F_0(q^2) = \frac{c_B(1-a)}{1-bx},$$

S.F and J. Kamenik Phys. Rev. D followed this ideas for H -> V semileptonic deca

$$\langle V(\epsilon_V,p_V)|\bar q\gamma^\mu Q_v|H(v)\rangle = -f_v\epsilon^{\mu\nu\alpha\beta}\epsilon^*_{V\nu}v_\alpha p_{V\beta},$$
$$\langle V(\epsilon_V,p_V)|\bar q\gamma^\mu\gamma^5 Q_v|H(v)\rangle = -ia_2(\epsilon_V^*\cdot v)\,[p_V^\mu - (v\cdot p_V)v^\mu]$$
$$-ia_1\,[\epsilon_V^{*\mu} - (v\cdot\epsilon_V^*)v^\mu]$$
$$+ia_0(v\cdot\epsilon_V^*)v^\mu,$$

HQET limit

SCET limit

$$V(q^2)|_{q^2\approx 0} = \frac{m_H+m_V}{m_H}\xi_\perp(E_V),$$

$$A_1(q^2)|_{q^2\approx 0} = \frac{2E_V}{m_H+m_V}\xi_\perp(E_V),$$

$$A_2(q^2)|_{q^2\approx 0} = \frac{m_H+m_V}{m_H}\left[\xi_\perp(E_V) - \frac{m}{E}\xi_\parallel(E_V)\right],$$

$$A_0(q^2)|_{q^2\approx 0} = \left(1-\frac{m_V^2}{2E_V m_H}\right)\xi_\parallel(E_V) \approx \xi_\parallel(E_V),$$

$$\left[V(q^2)/A_1(q^2)\right]|_{q^2\approx 0} = \frac{(m_H+m_V)^2}{2E_V m_H}$$

Both limits impose parametrization:

$$V(q^2) = c_H \frac{1-\alpha'}{(1-x)(1-\alpha' x)}$$

$$A_1(q^2) = c_H \xi \frac{1-\alpha'}{1-\beta' x} \qquad A_0(q^2) = c'_H \frac{1-\alpha''}{(1-y)(1-\alpha'' y)},$$

$$A_2(q^2) = \frac{(m_H+m_V)\xi c_H(1-\alpha') + 2m_V c'_H(1-\alpha'')}{(m_H-m_V)(1-\beta' x)(1-\beta'' x)}$$

$x = q^2/m_{H^*}^2$

$y = q^2/m_H^2$ ensures the physical 0^- pole

Framework for light vector mesons

$$\mathcal{L}_{\rm int} = -i\beta\langle H_b v_\mu \hat{\rho}^\mu_{ba} \bar{H}_a\rangle + i\lambda\langle H_b \sigma^{\mu\nu} F_{\mu\nu}(\hat{\rho})_{ba} \bar{H}_a\rangle$$

$$\hat{\rho}_\mu = i\frac{g_V}{\sqrt{2}}\rho_\mu$$

$$F_{\mu\nu}(\hat{\rho}) = \partial_\mu \hat{\rho}_\nu - \partial_\nu \hat{\rho}_\mu + [\hat{\rho}_\mu, \hat{\rho}_\nu]$$

$$\rho_\mu = \begin{pmatrix} \frac{1}{\sqrt{2}}(\omega_\mu + \rho^0_\mu) & \rho^+_\mu & K^{*+}_\mu \\ \rho^-_\mu & \frac{1}{\sqrt{2}}(\omega_\mu - \rho^0_\mu) & K^{*0}_\mu \\ K^{*-}_\mu & \bar{K}^{*0}_\mu & \phi_\mu \end{pmatrix}$$

$$\begin{aligned} \mathcal{L}'_{\rm int} &= -i\zeta\langle H_b v_\mu \hat{\rho}^\mu_{ba} \bar{G}_a\rangle + \text{h.c.} \\ &\quad + i\mu\langle H_b \sigma^{\mu\nu} F_{\mu\nu}(\hat{\rho})_{ba} \bar{G}_a\rangle + \text{h.c.}. \end{aligned}$$

leading order interaction for heavy even and odd parity fields and light vector fields

Weak interactions

$$\begin{aligned} J^\mu_a &= \frac{1}{2} i\alpha\langle\gamma^\mu(1-\gamma^5)H_a\rangle \\ &\quad + \alpha_1\langle\gamma^5 H_b \hat{\rho}^\mu_{ba}\rangle + \alpha_2\langle\gamma^\mu\gamma^5 H_b v_\alpha \hat{\rho}^\alpha_{ba}\rangle \end{aligned}$$

$$J'^\mu_a = \frac{1}{2} i\alpha'\langle\gamma^\mu(1-\gamma^5)G_a\rangle;$$

$$\tilde{J}^\mu_a = \frac{1}{2} i\tilde{\alpha}\langle\gamma^\mu(1-\gamma^5)H'_a\rangle$$

We include also another odd parity heavy meson multiplet field H'.

Results D semileptonic decays

$$F_0(q^2_{\rm max}) = -\frac{\alpha}{\sqrt{m_H}f} + \frac{\alpha'}{\sqrt{m_H}f} h \frac{m_P}{m_P + \Delta_{H_S}} - \frac{\tilde{\alpha}}{2\sqrt{m_H}f}\tilde{g}\frac{m_H}{m_P + \Delta_{H'^*}}$$

$$F_+(q^2_{\rm max}) = -\frac{\alpha}{2\sqrt{m_H}f} g \frac{m_H}{m_P + \Delta_{H^*}}$$

our model

$$F_+(q^2) = c_B\left(\frac{1}{1-x} - \frac{a}{1-x/\gamma}\right)$$

$$F_0(q^2) = \frac{c_B(1-a)}{1-bx},$$

We fix the parameters a and b by the next-to-nearest resonances and we use physical pole masses of excited charmed mesons

by fitting PDG data on branching ratios

$$\Gamma = \frac{G_F^2 m_H^2 |K_{HP}|^2}{24\pi^3}\int_0^{y_m} dy |F_+(m_H^2 y)|^2 |\vec{p}_P(y)|^3$$

$$y = q^2/m_H^2$$

we determine $\tilde{\alpha}\tilde{g} = -0.0050 \text{ GeV}^{3/2}$ $\alpha' = -0.47 \text{ GeV}^{3/2}$

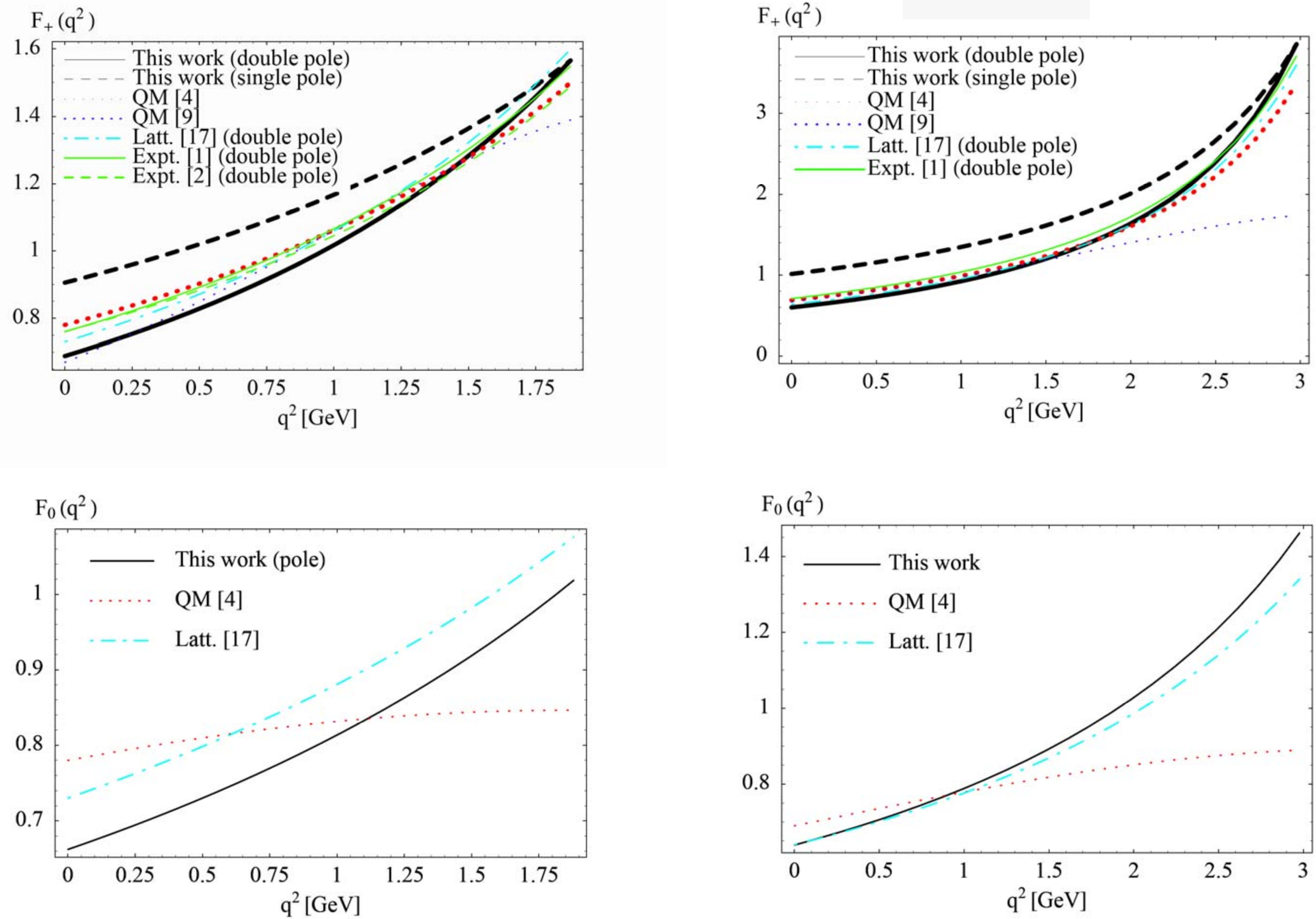
1/MD corrections might be important!)

We use tree level values for g and h.

Two pole behaviour of the relevant form factor agrees well with recent experimental result and the branching ratio are very close to the measured once.

$D \to K$

$D^0 \to \pi^-$



F+ (q2)
This work (double pole)
This work (single pole)
QM [4]
QM [9]
Latt. [17] (double pole)
Expt. [1] (double pole)
Expt. [2] (double pole)
q2 [GeV]
F+ (q2)
This work (double pole)
This work (single pole)
QM [4]
QM [9]
Latt. [17] (double pole)
Expt. [1] (double pole)
q2 [GeV]
F0 (q2)
This work (pole)
QM [4]
Latt. [17]
q2 [GeV]
F0 (q2)
This work
QM [4]
Latt. [17]
q2 [GeV]

Vector and axial form factors within HMChL

$$
\begin{aligned}
V(q^2)|_{q^2\approx q_{\max}} &= \frac{g_V}{\sqrt{2}}\alpha m_H\sqrt{m_H}\frac{\lambda}{v\cdot p_V+\Delta_{H^*}} \\
&+\frac{g_V}{\sqrt{2}}\tilde{\alpha} m_H\sqrt{m_H}\frac{\tilde{\mu}}{v\cdot p_V+\Delta_{H'^*}} \\
A_1(q^2)|_{q^2\approx q_{\max}} &= \frac{g_V}{\sqrt{2}}\alpha'\frac{\sqrt{m_H}}{m_H+m_V}\frac{\zeta-2\mu v\cdot p_V}{v\cdot p_V+\Delta_{H_A}} \\
&-\sqrt{2}g_V\alpha_1\frac{\sqrt{m_H}}{m_H+m_V} \\
A_2(q^2)|_{q^2\approx q_{\max}} &= \frac{g_V}{\sqrt{2}}\alpha'\frac{m_H+m_V}{\sqrt{m_H}}\frac{\mu}{v\cdot p_V+\Delta_{H_A}} \\
A_0(q^2)|_{q^2\approx q_{\max}} &= \frac{g_V}{2\sqrt{2}}\frac{\sqrt{m_H}}{m_V}\Big(2\alpha_1-2\alpha_2 \\
&+\alpha\frac{\beta}{v\cdot p_V+\Delta_{H_P}}+\tilde{\alpha}\frac{\tilde{\zeta}}{v\cdot p_V+\Delta_{H'_P}}\Big)
\end{aligned}
$$

$$
\begin{aligned}
H_{\pm}(y) &= +(m_H + m_V)A_1(m_H^2 y) \mp \frac{2m_H|\vec{p}_V(y)|}{m_H + m_V}V(m_H^2 y) \\
H_0(y) &= +\frac{m_H + m_V}{2m_H m_V\sqrt{y}}[m_H^2(1-y) - m_V^2]A_1(m_H^2 y) \\
&\quad -\frac{2m_H|\vec{p}_V(y)|}{m_V(m_H + m_V)\sqrt{y}}A_2(m_H^2 y) \qquad (2)
\end{aligned}
$$

helicity amplitudes

$$
\Gamma_a = \frac{G_F^2 m_H^2 |K_{HV}|^2}{96\pi^3}\int_0^{y_m^V} y\mathrm{d}y|H_a(y)|^2|\vec{p}_V(y)|
$$

$$
y_m^V = \left(1 - \frac{m_V}{m_H}\right)^2.
$$

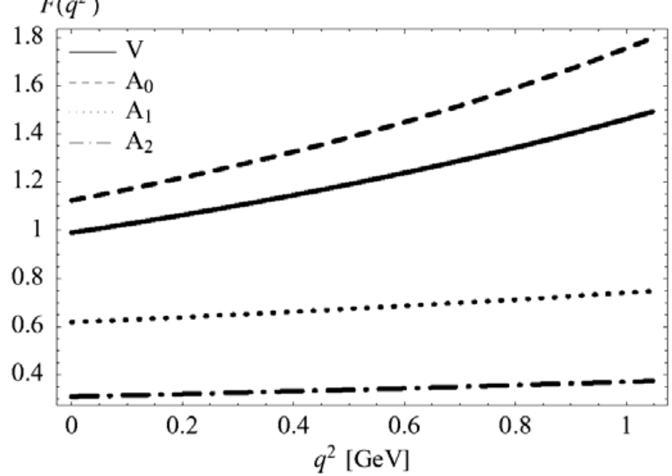
$$
\begin{aligned}
\Gamma_T &= \Gamma_+ + \Gamma_-, \\
\Gamma_L &= \Gamma_0, \\
\Gamma &= \Gamma_T + \Gamma_L.
\end{aligned}
$$

Decay	$\mathcal{B}$ (model) [%]	$\mathcal{B}$ (Exp.) [%]	Γ_L/Γ_T (model)	Γ_L/Γ_T (Exp.)	Γ_+/Γ_- (model)	Γ_+/Γ_- (Exp.)
$D^0 \to K^{-*}$	2.2	2.15 ± 0.35 [50][a]	1.14		0.22	
$D^0 \to \rho^-$	0.20	$0.194 \pm 0.039 \pm 0.013$ [63]	1.10		0.13	
$D^+ \to K^{0*}$	5.6	5.73 ± 0.35 [50][a]	1.13	1.13 ± 0.08 [50][a]	0.22	0.22 ± 0.06 [50][a]
$D^+ \to \rho^0$	0.25	0.25 ± 0.08 [50][a]	1.10		0.13	
$D^+ \to \omega$	0.25	$0.17 \pm 0.06 \pm 0.01$ [63]	1.10		0.13	
$D_s \to \phi$	2.4	2.0 ± 0.5 [50][a]	1.08		0.21	
$D_s \to K^{0*}$	0.22		1.03		0.13	

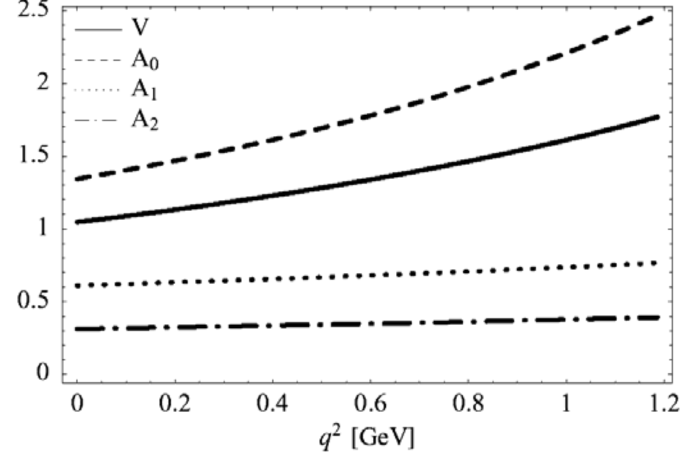
[a] Values used in the fit of our model parameters

[50] S. Eidelman et al. (Particle Data Group), Phys. Lett. **B592**, 1 (2004).
[63] S. Blusk (the CLEO) (2005), hep-ex/0505035.

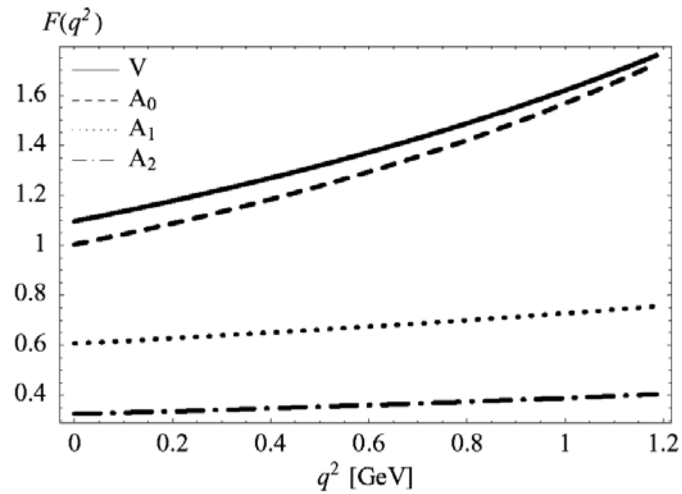
$$\tilde{\alpha}\tilde{\mu} = 0.090\ \mathrm{GeV}^{1/2}$$
$$\alpha'\zeta = 0.038\ \mathrm{GeV}^{3/2}$$
$$\alpha'\mu = -0.066\ \mathrm{GeV}^{1/2}$$
$$\alpha_1 = -0.128\ \mathrm{GeV}^{1/2}$$



Our model predictions for the q^2 dependence of the form factors $V(q^2)$ (solid line), $A_0(q^2)$ (dashed line), $A_1(q^2)$ (dotted line) and $A_2(q^2)$ (dash-dotted line) in $D^0 \to K^{-*}$ transition.



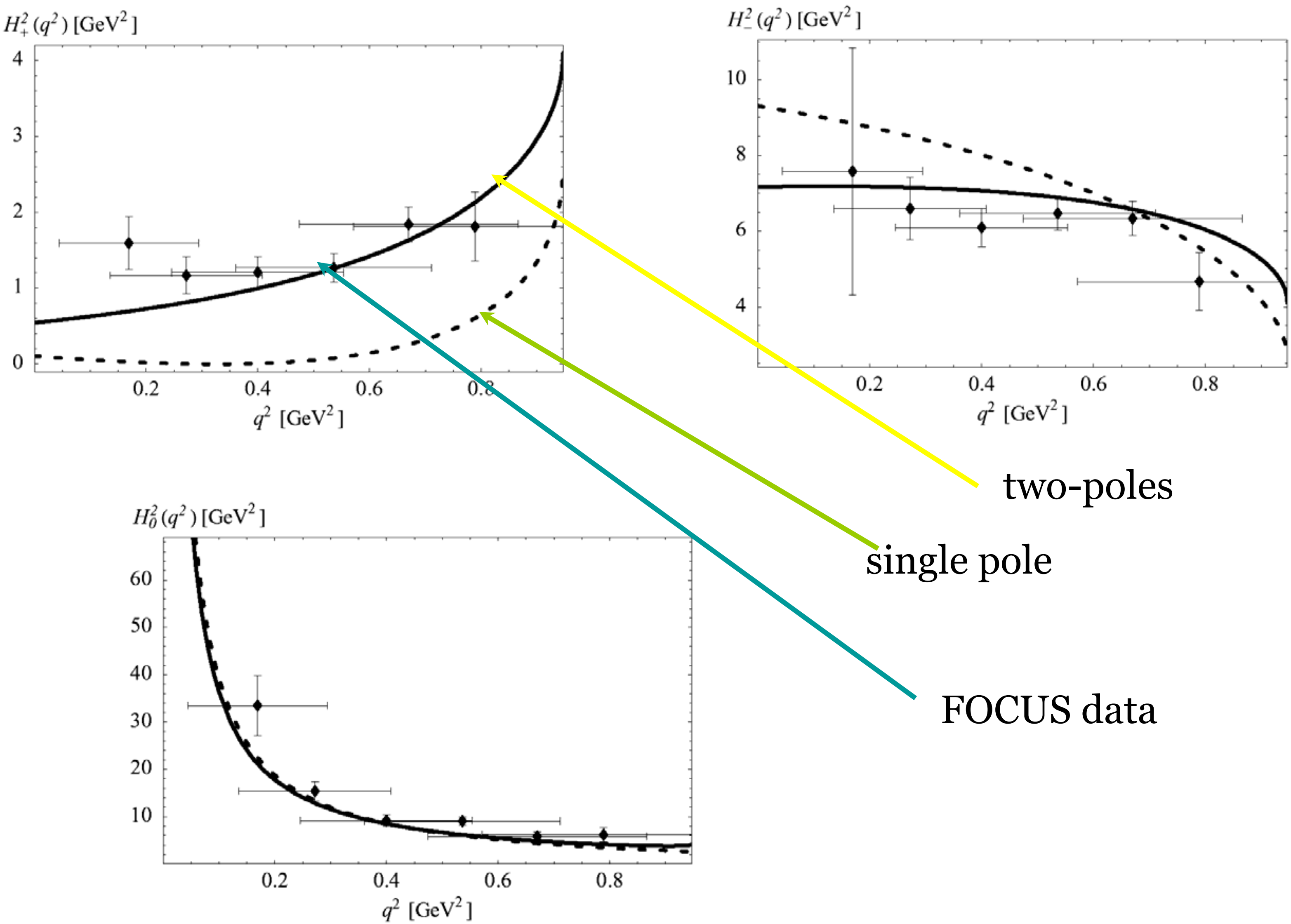
Our model predictions for the q^2 dependence of the form factors $V(q^2)$ (solid line), $A_0(q^2)$ (dashed line), $A_1(q^2)$ (dotted line) and $A_2(q^2)$ (dash-dotted line) in $D^0 \to \rho^-$ transition.



Our model predictions for the q^2 dependence of the form factors $V(q^2)$ (solid line), $A_0(q^2)$ (dashed line), $A_1(q^2)$ (dotted line) and $A_2(q^2)$ (dash-dotted line) in $D_s \to \phi$ transition.

$D^+ \to K^{*0}$ semileptonic decay

Helicity amplitudes



Search for new physics in rare D decays

Search for new physics in the up-like sector is not very attractive due to:
- FCNC at loop level in SM suffer from GIM cancellation;
- most of charm processes , where $c \to u$ and $c\bar{u} \leftrightarrow \bar{c}u$ transitions occur are dominated by the SM long-distance contributions.

1) $\mathrm{c} \to \mathrm{u}\gamma$

Experimentally is only seen $BR(D \to \phi\gamma) = 2.6^{+0.7}_{-0.6} \times 10^{-5}$

QCD corrected SM gives $\mathrm{BR}(\mathrm{c} \to \mathrm{u}\gamma) \simeq 3 \times 10^{-8}$

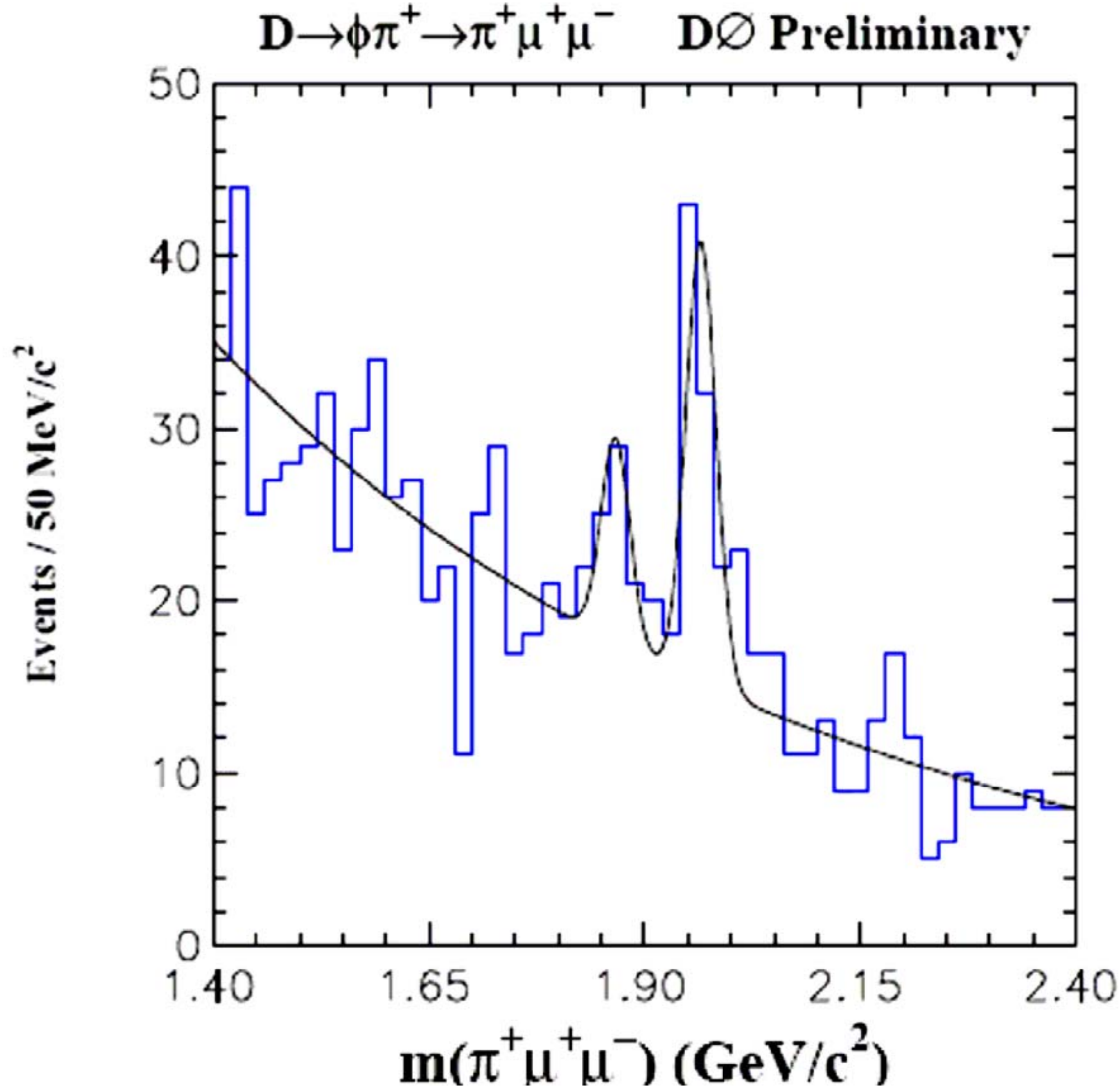
MSSM (gluino exchange diagram) $\dfrac{\mathrm{BR}(\mathrm{c} \to \mathrm{u}\gamma)_{\mathrm{MSSM}}}{\mathrm{BR}(\mathrm{c} \to \mathrm{u}\gamma)_{\mathrm{SM}}} \simeq 10^2$

2) $c \to u l^+ l^-$

QCD corrected SM gives $\Gamma(c \to u e^+ e^-)/\Gamma_{D^0} = 2.4 \times 10^{-10}$

$\mu^+\mu^-$ 0.5×10^{-10}

New physics effects investigated by authors:
G. Burdman et al., PRD 66, 014009 (2002),
S.F., S. Prelovsek, P. Singer, PRD 64, 114009 (2001), S.F. S.P. PRD 73 054026 (2006)



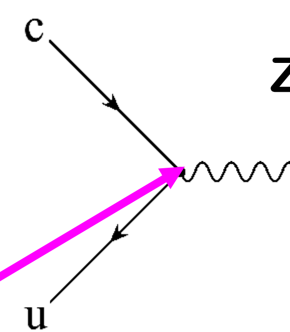
D→φπ⁺→π⁺μ⁺μ⁻ DØ Preliminary
Events / 50 MeV/c²
m(π⁺μ⁺μ⁻) (GeV/c²)
0
10
20
30
40
50
1.40
1.65
1.90
2.15
2.40

FCNC and new physics coming from an extra up-like quark singlet

S.F. and S. Prelovsek, ICHEP 2006, hep-ph/0610032,
Littlest Higgs Model in Phys. Rev. D 73 054026 (2006)

$$\mathcal{L}_{NC} = \frac{g}{cos\theta_W} Z_\mu (J^\mu_{W^3} - sin^2\theta_W J^\mu_{EM})$$

With an additional up-like quark there is a tree level FCNC for the up-like sector



$$J^\mu_{W^3} = \frac{1}{2} \bar{U}^m_L \gamma^\mu \Omega U^m_L - \frac{1}{2} \bar{D}^m_L \gamma^\mu D^m_L$$

extended CKM

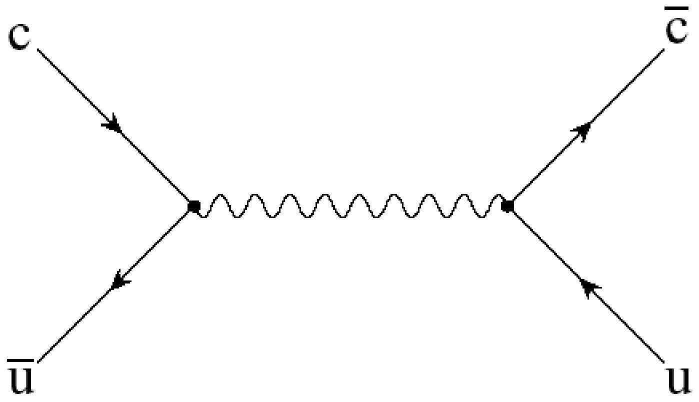
$$ig\Omega_{uc}/(2\cos\theta_W)\ \bar{u}_L \gamma^\mu c_L Z^\mu$$

Using unitarity limit one gets

$$\Omega_{uc} = |\Theta_u||\Theta_c| < 0.0028$$

(we use the lowest value of CKM as given in PDG to get maximal effects)

The stringent limit comes from $D^0 - \bar{D}^0$ mixing



$$(\Delta m_D)^Z \approx 2 \times 10^{-7} \times |\Omega_{uc}|^2 \text{ GeV}$$

Exp. Result (PDG):

$$\left| m_{D_1^0} - m_{D_2^0} \right| < 7 \times 10^{10} \hbar \text{ s}^{-1}$$

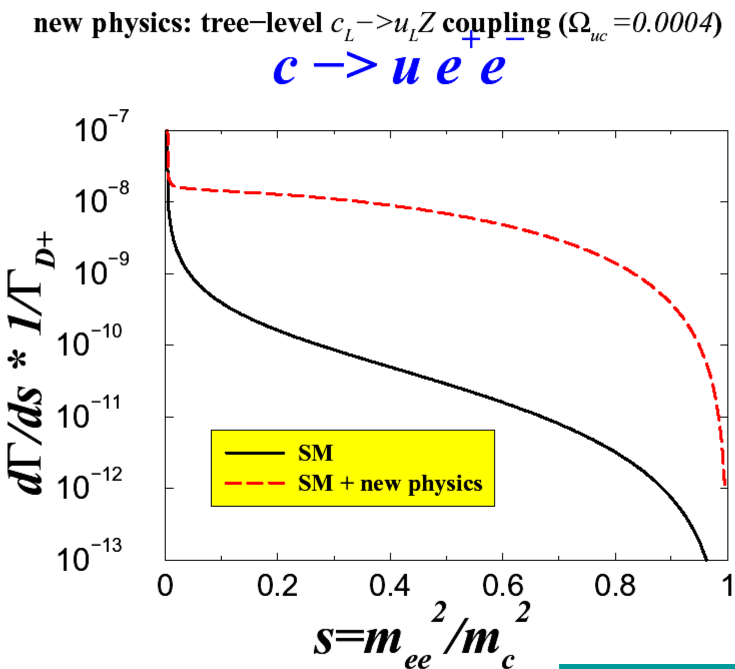
Maximal value is $|\Omega_{uc}| = 0.0004$

This corresponds to the maximal effect that any new physics possibly have on rare D decays given by model independent constraints on Z mediated flavor changing currents.

New Physics model modifies Wilson coefficients:

$$V_{cb}^{*}V_{ub}\ \delta C_9^{NP} = \frac{8\pi}{\alpha}\Omega_{uc} g_V^l, \quad V_{cb}^{*}V_{ub}\ \delta C_{10}^{NP} = -\frac{8\pi}{\alpha}\Omega_{uc} g_A^l$$

$$g_V^l = -1/2 + 2\sin^2\theta_W \ \text{and} \ g_A^l = -1/2$$



for inclusive decays

$$\frac{\Gamma^{NP}(c \to u e^+ e^-)}{\Gamma_{D^+}} \simeq \frac{\Gamma^{NP}(c \to u \mu^+ \mu^-)}{\Gamma_{D^+}} = 6.3 \times 10^{-9}$$

Effects on $D^+ \to \pi^+ l^+ l^-$ decay

CLEO's and FOCUS upper upper bounds

$$Br^{exp}(D^+ \to \pi^+ e^+ e^-) < 7.4 \times 10^{-6} \ , \quad Br^{exp}(D^+ \to \pi^+ \mu^+ \mu^-) < 8.8 \times 10^{-6}$$

$$Br^{exp}(D^+ \to \pi^+ \phi \to \pi^+ e^+ e^-) = (2.8 \pm 1.9 \pm 0.2) \times 10^{-6}$$

This is consistent with

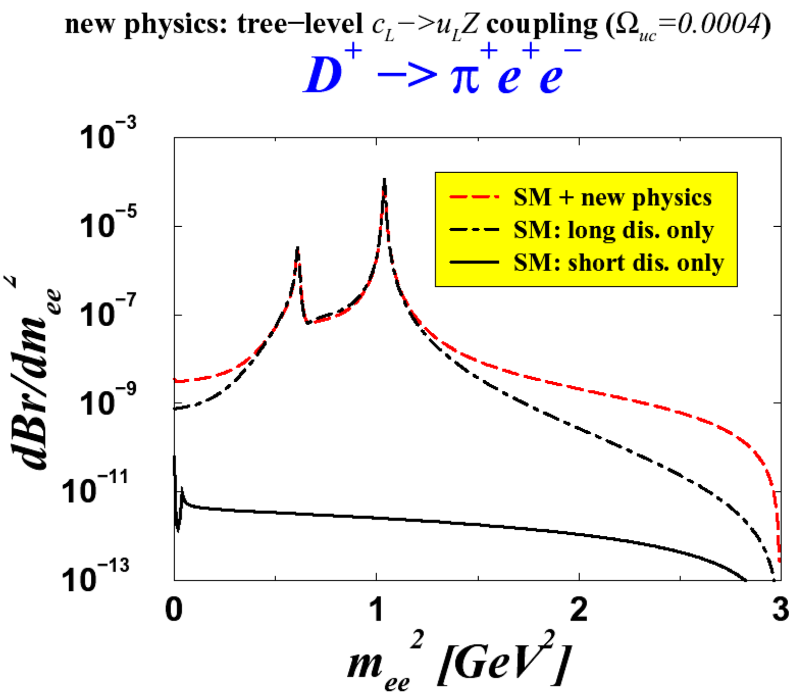
$$Br(D^+ \to \phi\pi^+ \to \pi^+ e^+ e^-) =$$

$$Br(D^+ \to \phi\pi^+) \times Br(\phi \to e^+ e^-) = (1.9 \pm 0.2) \times 10^{-6}$$

It already indicates that resonant decay channels $D^+ \to \pi^+ V_0 \to \pi^+ l^+ l^-$ with intermediate resonances $V_0 = \rho^0, \omega, \phi$ constitute an important long-distance contribution to the charmed meson decay, which may shadow contribution induced by $c \to u l^+ l^-$.

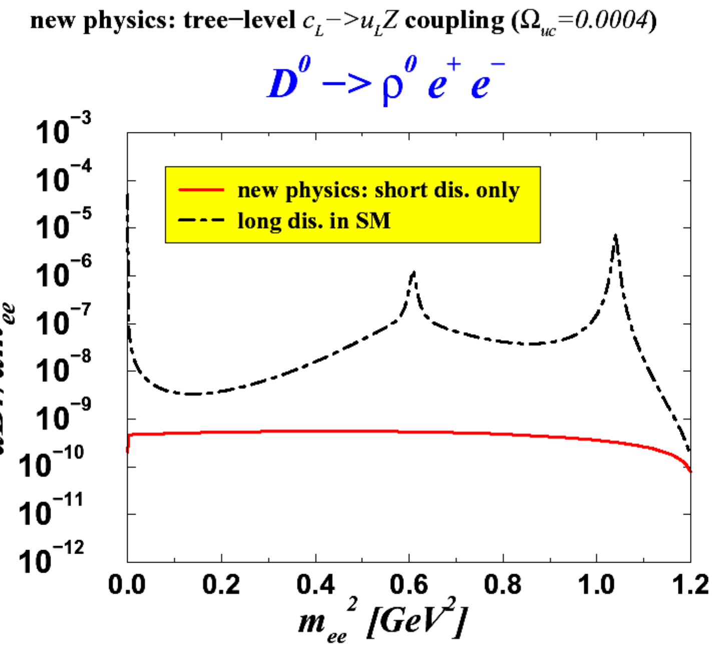
Instead of using theoretical model we take full advantage of the experimental input that is available to determine long distance contribution. The dominant contribution is:

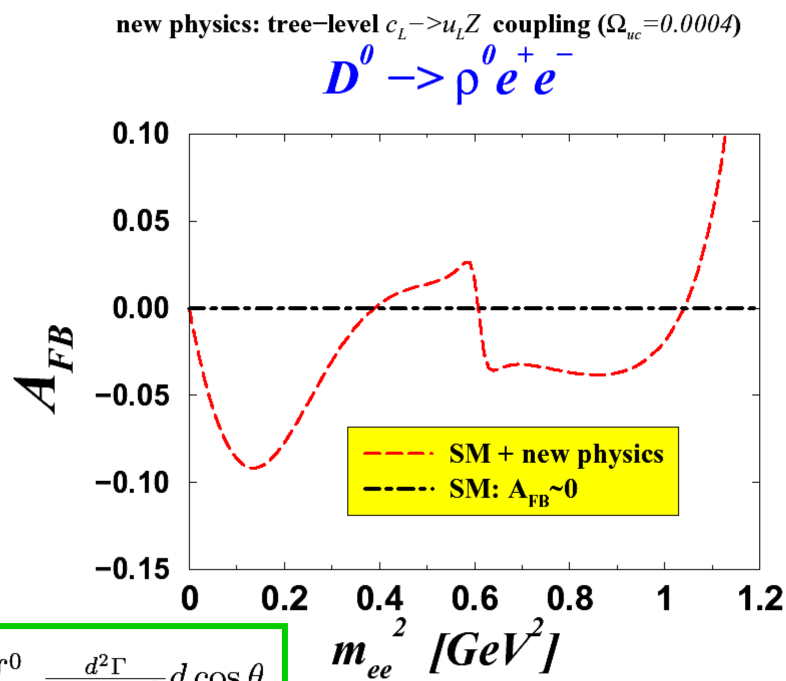
$$\frac{d\Gamma_{D\to\pi V_0\to\pi l^+l^-}}{dq^2} = \Gamma_{D\to\pi V_0}(q^2)\frac{1}{\pi}\frac{\sqrt{q^2}}{(m_{V_0}^2 - q^2)^2 + m_{V_0}^2\Gamma_{V_0}^2}\Gamma_{V_0\to l^+l^-}(q^2)$$



Effects on $D^0 \to \rho^0 l^+ l^-$ decay

Due to the lack of experimental data we are forced to use a model:(we use heavy quark symmetries for D and D* and chiral
symmetry for light pseudoscalar and vector mesons)





The dilepton mass distribution and the forward-backward asymmetry

in SM it is 0!

$$A_{FB}(m_{ll}^2) = \frac{\int_0^1 \frac{d^2\Gamma}{d\cos\theta\, dm_{ll}^2} d\cos\theta - \int_{-1}^0 \frac{d^2\Gamma}{d\cos\theta\, dm_{ll}^2} d\cos\theta}{\frac{d\Gamma}{dm_{ll}^2}}$$

New physics produces nonzero forward-backward asymmetry!

Br	short distance contribution only		total rate $\simeq$ long distance contr.	experiment
	SM	SM + NP		
$D^+ \to \pi^+ e^+ e^-$	6×10^{-12}	5.5×10^{-9}	1.9×10^{-6}	$< 7.4 \times 10^{-6}$
$D^+ \to \pi^+ \mu^+ \mu^-$	6×10^{-12}	5.5×10^{-9}	1.9×10^{-6}	$< 8.8 \times 10^{-6}$
$D^0 \to \rho^0 e^+ e^-$	negligible	5.3×10^{-10}	1.6×10^{-7}	$< 1.0 \times 10^{-4}$
$D^0 \to \rho^0 \mu^+ \mu^-$	negligible	5.1×10^{-10}	1.5×10^{-7}	$< 2.2 \times 10^{-5}$

Table 1: Branching ratios for the hadronic decays, which are most suitable to probe $c \to u l^+ l^-$ transition experimentally. The total rates in Standard and New Physics models are completely dominated by the resonant long-distance contribution of D decays . We also provide the short-distance contribution in SM together with its maximal modification in NP model . The SM short distance contribution is not shown since it is completely negligible in comparison to the long distance contribution.

Summary

• contributions of positive and negative parities charm mesons are very important in understanding of their strong decay dynamics ;

• form factors describing semileptonic decays have to contain contributions of open charm mesons;

• there is still tiny chance to see presence of new physics in rare charm meson decays.

Appendix

Counterterms

$$
\begin{aligned}
\mathcal{L}^{\mathrm{ct}} &= \mathcal{L}_\chi^{\mathrm{ct}} + \mathcal{L}_{\frac{1}{2}^-}^{\mathrm{ct}} + \mathcal{L}_{\frac{1}{2}^+}^{\mathrm{ct}} + \mathcal{L}_{\mathrm{mix}}^{\mathrm{ct}}, \\
\mathcal{L}_\chi^{\mathrm{ct}} &= \lambda_0 \left[(m_q)_{ab}\Sigma_{ba} + (m_q)_{ab}\Sigma_{ba}^\dagger \right], \\
\mathcal{L}_{\frac{1}{2}^-}^{\mathrm{ct}} &= \lambda_1 \mathrm{Tr}\left[\bar{H}_b H_a (m_q^\xi)_{ba}\right] + \lambda_1' \mathrm{Tr}\left[\bar{H}_a H_a (m_q^\xi)_{bb}\right] \\
&+ \frac{g\kappa_1}{\Lambda_\chi^2}\mathrm{Tr}\left[(\bar{H}H\mathcal{A}\!\!\!/\gamma_5)_{ab}(m_q^\xi)_{ba}\right] + \frac{g\kappa_3}{\Lambda_\chi^2}\mathrm{Tr}\left[(\bar{H}H\mathcal{A}\!\!\!/\gamma_5)_{aa}(m_q^\xi)_{bb}\right] \\
&+ \frac{g\kappa_5}{\Lambda_\chi^2}\mathrm{Tr}\left[\bar{H}_a H_a \mathcal{A}\!\!\!/_{bc}\gamma_5 (m_q^\xi)_{cb}\right] + \frac{g\kappa_9}{\Lambda_\chi^2}\mathrm{Tr}\left[\bar{H}_c H_a (m_q^\xi)_{ab}\mathcal{A}\!\!\!/_{bc}\gamma_5\right] \\
&+ \frac{\delta_2}{\Lambda_\chi}\mathrm{Tr}\left[\bar{H}_a H_b iv\cdot\mathcal{D}_{bc}\mathcal{A}\!\!\!/_{ca}\gamma_5\right] + \frac{\delta_3}{\Lambda_\chi}\mathrm{Tr}\left[\bar{H}_a H_b i\mathcal{D}\!\!\!/_{bc} v\cdot\mathcal{A}_{ca}\gamma_5\right] \\
&+ \ldots, \\
\mathcal{L}_{\frac{1}{2}^+}^{\mathrm{ct}} &= -\tilde{\lambda}_1 \mathrm{Tr}\left[S_a \bar{S}_b (m_q^\xi)_{ba}\right] - \tilde{\lambda}_1' \mathrm{Tr}\left[S_a \bar{S}_a (m_q^\xi)_{bb}\right] \\
&+ \frac{\tilde{g}\tilde{\kappa}_1}{\Lambda_\chi^2}\mathrm{Tr}\left[(\bar{S}S\mathcal{A}\!\!\!/\gamma_5)_{ab}(m_q^\xi)_{ba}\right] + \frac{\tilde{g}\tilde{\kappa}_3}{\Lambda_\chi^2}\mathrm{Tr}\left[(\bar{S}S\mathcal{A}\!\!\!/\gamma_5)_{aa}(m_q^\xi)_{bb}\right] \\
&+ \frac{\tilde{g}\tilde{\kappa}_5}{\Lambda_\chi^2}\mathrm{Tr}\left[\bar{S}_a S_a \mathcal{A}\!\!\!/_{bc}\gamma_5 (m_q^\xi)_{cb}\right] + \frac{\tilde{g}\tilde{\kappa}_9}{\Lambda_\chi^2}\mathrm{Tr}\left[\bar{S}_c S_a (m_q^\xi)_{ab}\mathcal{A}\!\!\!/_{bc}\gamma_5\right] \\
&+ \frac{\tilde{\delta}_2}{\Lambda_\chi}\mathrm{Tr}\left[\bar{S}_a S_b iv\cdot\mathcal{D}_{bc}\mathcal{A}\!\!\!/_{ca}\gamma_5\right] + \frac{\tilde{\delta}_3}{\Lambda_\chi}\mathrm{Tr}\left[\bar{S}_a S_b i\mathcal{D}\!\!\!/_{bc} v\cdot\mathcal{A}_{ca}\gamma_5\right] \\
&+ \ldots,
\end{aligned}
$$

and $\Lambda_\chi = 4\pi f$. Ellipses denote terms contributing only to precesses with more then one pseudo-Goldstone boson as well as terms with $(iv\cdot\mathcal{D})$ acting on H or S, which do not contribute at this order [25]. The matrix $m_q = \mathrm{diag}(m_u, m_d, m_s)$ induces masses of the pseudo-Goldstone mesons $m_{ab}^2 = 4\lambda_0(m_a + m_b)/f^2$, where a, b are the light quark flavor indices while $m_q^\xi = (\xi m_q \xi + \xi^\dagger m_q \xi^\dagger)$. Thus, in our power counting $(m_q \sim p^2)$ all the λ terms in $\mathcal{L}^{\mathrm{ct}}$ are of the order $\mathcal{O}(p^2)$ while the δ and κ terms are of the order $\mathcal{O}(p^3)$. Parameters λ_1' and $\tilde{\lambda}_1'$ can be absorbed into the definition of heavy meson masses by a phase redefinition of H and S, while λ_1 and $\tilde{\lambda}_1$ split the masses of $SU(3)$ flavor triplets of H_a and S_a, inducing residual mass terms in heavy meson propagators: $\Delta_a = 2\lambda_1 m_a$ and $\tilde{\Delta}_a = 2\tilde{\lambda}_1 m_a$ respectively [25]. As with $\Delta_{H(S)}$, only differences between these $\mathcal{O}(p^2)$ residual mass terms enter our expressions. We denote them as $\Delta_{ba} = \Delta_b - \Delta_a$, $\Delta_{\tilde{b}a} = \tilde{\Delta}_b - \Delta_a$ and $\tilde{\Delta}_{ba} = \tilde{\Delta}_b - \tilde{\Delta}_a$ and fix them from phenomenological mass splittings between heavy mesons of different $SU(3)$ flavor. Assuming exact isospin and heavy quark spin symmetry, the only nonvanishing splittings are then $\Delta_{3a} \approx \Delta_{\tilde{3}a} \approx \Delta_{3\tilde{a}} \approx \tilde{\Delta}_{3a} \approx 100$ MeV, where here $a = 1, 2$. For the κ_1 and κ_9 terms only the combination $\kappa_{19} = \kappa_1 + \kappa_9$ will enter in an isospin conserving manner here [25] (the $\kappa_1 - \kappa_9$ combination contributes to isospin violating $D_s^* \to D_s\pi^0$ decay, which we do not consider in this paper). In the same manner we only consider contributions of $\kappa_{19}' = \kappa_1' + \kappa_9'$ and $\tilde{\kappa}_{19} = \tilde{\kappa}_1 + \tilde{\kappa}_9$. At any fixed value of m_q, the finite parts of κ_3, $\tilde{\kappa}_3$ and κ_3' can be absorbed into the definitions of g, $\tilde{g}$ and h

$$
\begin{aligned}
\mathcal{L}^{\rm ct}_{\rm mix} \;=\; & \frac{h\kappa_1'}{\Lambda_\chi^2}\mathrm{Tr}\left[(\bar{H}S\not{\mathcal{A}}\gamma_5)_{ab}(m_q^\xi)_{ba}\right] \\
& + \frac{h\kappa_3'}{\Lambda_\chi^2}\mathrm{Tr}\left[(\bar{H}S\not{\mathcal{A}}\gamma_5)_{aa}(m_q^\xi)_{bb}\right] \\
& + \frac{h\kappa_5'}{\Lambda_\chi^2}\mathrm{Tr}\left[\bar{H}_a S_a \not{\mathcal{A}}_{bc}\gamma_5 (m_q^\xi)_{cb}\right] + \frac{h\kappa_9'}{\Lambda_\chi^2}\mathrm{Tr}\left[\bar{H}_c S_a (m_q^\xi)_{ab}\not{\mathcal{A}}_{bc}\gamma_5\right] \\
& + \frac{\delta_2'}{\Lambda_\chi}\mathrm{Tr}\left[\bar{H}_a S_b i v\cdot\mathcal{D}_{bc}\not{\mathcal{A}}_{ca}\gamma_5\right] + \frac{\delta_3'}{\Lambda_\chi}\mathrm{Tr}\left[\bar{H}_a S_b i \not{\mathcal{D}}_{bc} v\cdot\mathcal{A}_{ca}\gamma_5\right] \\
& + \mathrm{h.c.} \; + \ldots .
\end{aligned}
$$

$$I_0(m) = \mu^{(4-D)} \int \frac{\mathrm{d}^D q}{(2\pi)^D} \frac{1}{(q^2 - m^2)} = -\frac{i}{16\pi^2} m^2 \log\left(\frac{m^2}{\mu^2}\right),$$

$$I_1^{\mu\nu}(m,\Delta) = \mu^{(4-D)} \int \frac{\mathrm{d}^D q}{(2\pi)^D} \frac{q^\mu q^\nu}{(q^2 - m^2)(v \cdot q - \Delta)} = \frac{i}{16\pi^2} \left[C_1\left(\frac{\Delta}{m}, m\right) g^{\mu\nu} + C_2\left(\frac{\Delta}{m}, m\right) v^\mu v^\nu\right],$$

$$I_2^{\mu}(m,\Delta) = \mu^{(4-D)} \int \frac{\mathrm{d}^D q}{(2\pi)^D} \frac{q^\mu}{(q^2 - m^2)(v \cdot q - \Delta)} = \frac{i}{16\pi^2} C\left(\frac{\Delta}{m}, m\right) \frac{v^\mu}{\Delta},$$

$$\begin{aligned} I_3^{\mu\nu}(m,\Delta_1,\Delta_2) &= \mu^{(4-D)} \int \frac{\mathrm{d}^D q}{(2\pi)^D} \frac{q^\mu q^\nu}{(q^2 - m^2)(v \cdot q - \Delta_1)(v \cdot q - \Delta_2)} \\ &= \frac{1}{\Delta_1 - \Delta_2} \left[I_1^{\mu\nu}(m,\Delta_1) - I_1^{\mu\nu}(m,\Delta_2)\right], \end{aligned}$$

where

$$I_3^{\mu\nu}(m,\Delta,\Delta) = \frac{\mathrm{d}}{\mathrm{d}\Delta} I_1^{\mu\nu}(m,\Delta).$$

In the text we then make use of the following expressions

$$C(x,m) = \frac{m^3}{9}\left[-18x^3 + (18x^3 - 9x)\log\left(\frac{m^2}{\mu^2}\right) + 36x^3 F\left(\frac{1}{x}\right)\right],$$

$$C_1(x,m) = \frac{m^3}{9}\left[-12x + 10x^3 + (9x - 6x^3)\log\left(\frac{m^2}{\mu^2}\right) - 12x(x-1)F\left(\frac{1}{x}\right)\right],$$

$$C_2(x,m) = C(x,m) - C_1(x,m),$$

with

$$C'_{1,2}(x,y,m) = \frac{1}{m}\frac{1}{x-y}[C_{1,2}(y,m) - C_{1,2}(x,m)],$$

$$C'_{1,2}(x,m) = C'_{1,2}(x,x,m) = \frac{1}{m}\frac{\mathrm{d}}{\mathrm{d}x}C_{1,2}(x,m).$$

The function $F(x)$ was calculated in Ref. [25]

$$F\left(\frac{1}{x}\right) = \begin{cases} \frac{\sqrt{x^2-1}}{x}\log\left(x + \sqrt{x^2-1}\right), & |x| \geq 1, \\ -\frac{\sqrt{1-x^2}}{x}\left[\frac{\pi}{2} - \tan^{-1}\left(\frac{x}{\sqrt{1-x^2}}\right)\right], & |x| \leq 1. \end{cases}$$

TABLE II: The branching ratios for the $D \to P$ semileptonic decays. Comparison of different model predictions with experiment as explained in the text.

Decay	$\mathcal{B}[\%]$	Reference
$D^0 \to K^-$	3.4	This work (double pole)
	4.9	This work (single pole)
	3.75 ± 1.16	QM [8]
	4.0	QM [4]
	3.9 ± 1.2	QM [9]
	2.7 ± 0.6	SR [10]
	$3.4^{+1.2}_{-1.0}$	SR [12]
	3.7 ± 1.4	SR [15]
	3.43 ± 0.14	Expt.
$D^0 \to \pi^-$	0.27	This work (double pole)
	0.56	This work (single pole)
	0.236 ± 0.034	QM [8]
	0.39	QM [4]
	0.30 ± 0.09	QM [9]
	0.16 ± 0.3	SR [11]
	$0.28^{+0.09}_{-0.08}$	SR [12]
	0.27 ± 0.10	SR [15]
	0.36 ± 0.06	Expt.
$D_s^+ \to \eta$	1.7	This work (double pole)
	2.5	This work (single pole)
	1.8 ± 0.6	QM [8]
	2.45	QM [4]
	2.5 ± 0.7	Expt.

TABLE II: The branching ratios for the $D \to P$ semileptonic decays. Comparison of different model predictions with experiment as explained in the text.

Decay	$\mathcal{B}[\%]$	Reference
$D_s^+ \to \eta'$	0.61	This work (double pole)
	0.74	This work (single pole)
	0.93 ± 0.29	QM [8]
	0.95	QM [4]
	0.89 ± 0.33	Expt.
$D^+ \to \bar{K}^0$	8.4	This work (double pole)
	12.4	This work (single pole)
	6.8 ± 0.8	Expt.
$D^+ \to \pi^0$	0.33	This work (double pole)
	0.70	This work (single pole)
	0.31 ± 0.15	Expt.
$D^+ \to \eta$	0.10	This work (double pole)
	0.15	This work (single pole)
	< 0.5	Expt.
$D^+ \to \eta'$	0.016	This work (double pole)
	0.019	This work (single pole)
	< 1.1	Expt.
$D_s^+ \to K^0$	0.20	This work (double pole)
	0.32	This work (single pole)
	0.3	QM [4]

FCNC in Littlest Higgs model

• rather simple solution to the gauge hierarchy problem;

• new massive gauge bosons and new heavy quark states;

the quadratic divergences

- the spin ½ contribution of the top quark is cancelled by the new fermion;
- the spin 1 contributions are cancelled by new gauge bosons;
- the spin 0 quadratically divergent contributions are vanishing due to

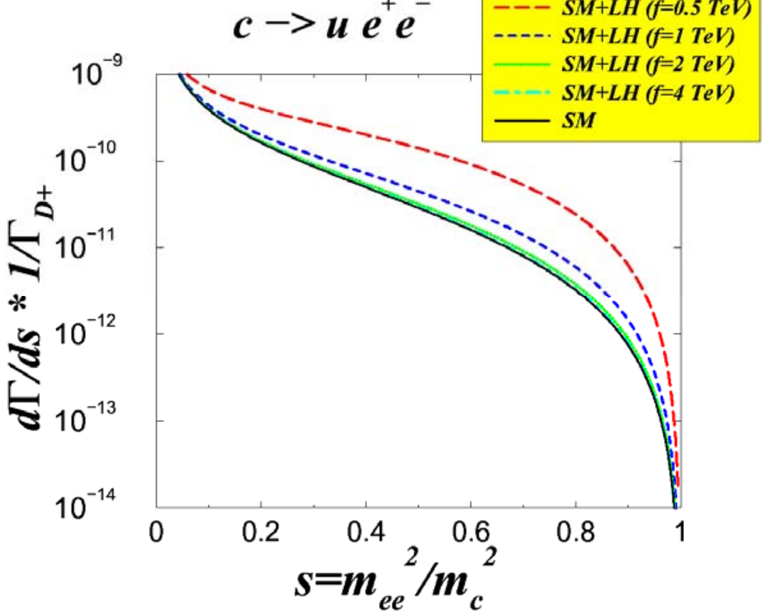
the fact that all scalars in the model are Goldstone bosons at tree level.

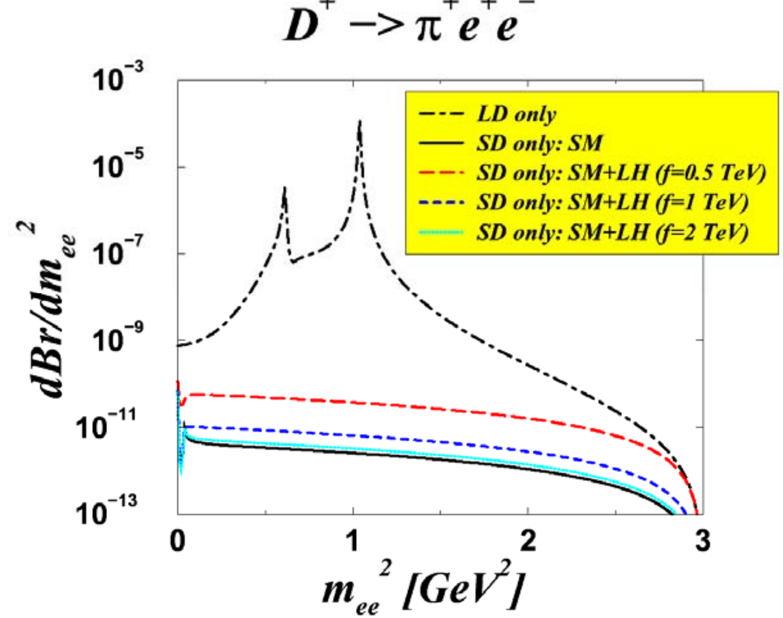
• model Lae Yong Lee, JHEP 0412 (2004) 065, hep-ph/0408362;
(there is an extra vector –like heavy quark, which is a single of SU(2) group and which mixes with the third generation) ;

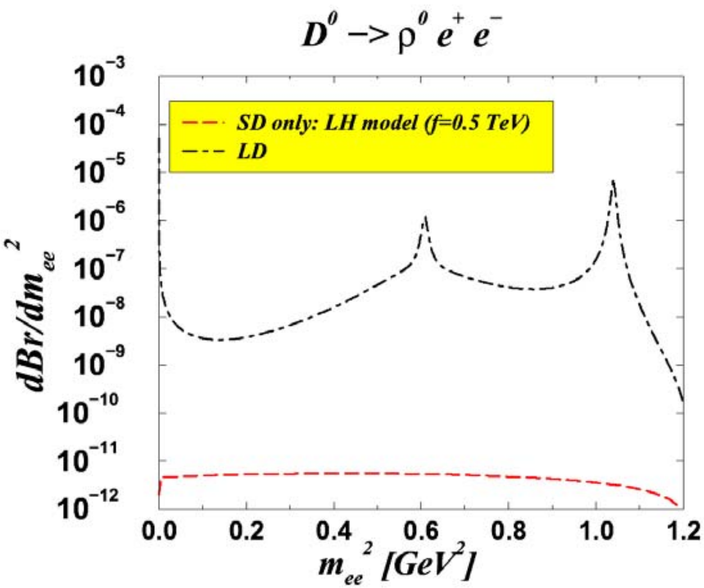
• this mixing induces new tree level flavor changing charged and neutral currents in which parameters are:

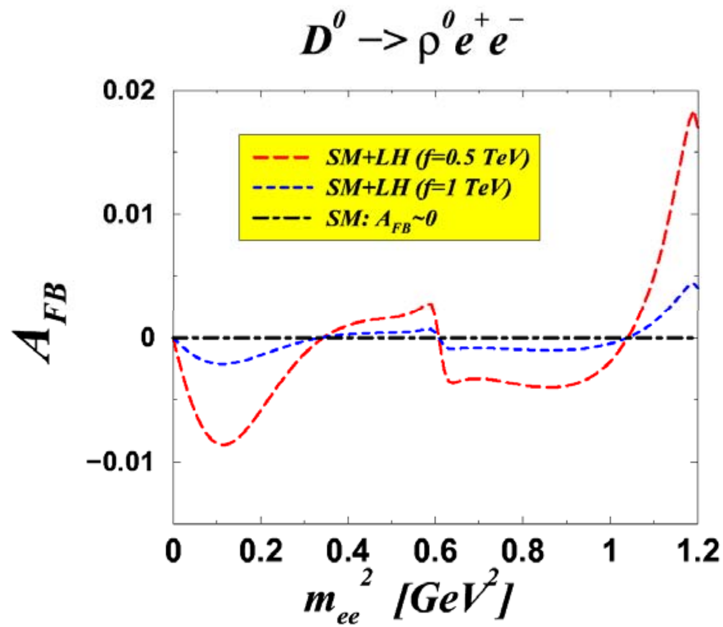
$$|\Omega_{uc}| \simeq |V_{ub}||V_{cb}|\frac{v^2}{f^2} \simeq 10^{-5}\left(\frac{1\ \text{TeV}}{f}\right)^2$$

$$0.5\ \text{TeV} \leq f \leq 4\ \text{TeV}$$


c -> u e+ e−
SM+LH (f=0.5 TeV)
SM+LH (f=1 TeV)
SM+LH (f=2 TeV)
SM+LH (f=4 TeV)
SM
dΓ/ds * 1/Γ_D+
s=m_ee^2/m_c^2

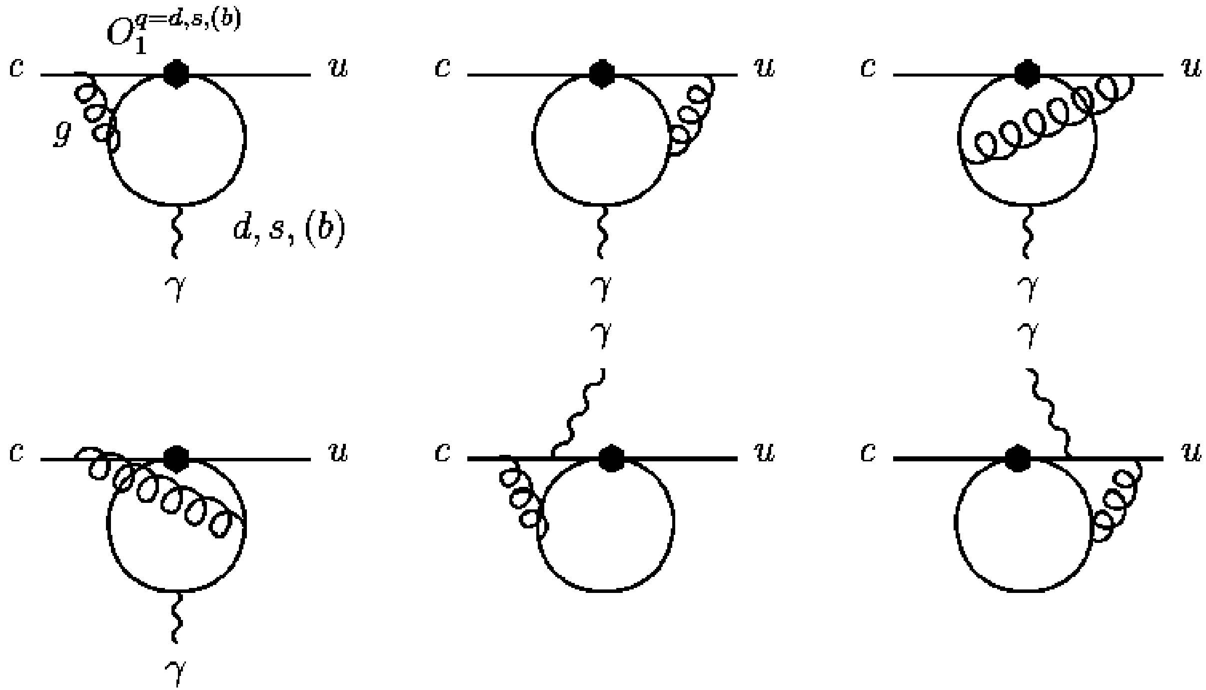

D+ -> π+ e+ e−
LD only
SD only: SM
SD only: SM+LH (f=0.5 TeV)
SD only: SM+LH (f=1 TeV)
SD only: SM+LH (f=2 TeV)
dBr/dm_ee^2
m_ee^2 [GeV^2]


D0 -> ρ0 e+ e−
SD only: LH model (f=0.5 TeV)
LD
dBr/dm_ee^2
m_ee^2 [GeV^2]


D0 -> ρ0 e+ e−
SM+LH (f=0.5 TeV)
SM+LH (f=1 TeV)
SM: A_FB~0
A_FB
m_ee^2 [GeV^2]

Additional slides

• c → u γ transition in SM



$$\mathcal{L} = -A\, C_{7\gamma}^{\rm eff} \frac{e}{4\pi^2} F_{\mu\nu} \left[\bar{u}\sigma^{\mu\nu} \tfrac{1}{2}(1+\gamma_5)c\right]$$

GIM cancellation at one loop level and QCD enhancement

$$V_{cb}^* V_{ub} \hat{C}_7^{eff} = V_{cs}^* V_{us} (0.007 \pm 0.020i)(1 \pm 0.2)$$

C.Greub, T.Hurth, M.Misiak, D. Wyler, Phys. Lett. B 382 (1996) 415

Theoretical framework

$$\mathcal{L}_{\rm eff} = -\frac{G_F}{\sqrt{2}}\left[V_{cd}^* V_{ud} \sum_{i=1,2} C_i Q_i^d + V_{cs}^* V_{us} \sum_{i=1,2} C_i Q_i^s - V_{cb}^* V_{ub} \sum_{i=3,\ldots,10} C_i Q_i\right]$$

$$Q_1^q = (\bar{u}^\alpha q^\beta)_{V-A}(\bar{q}^\beta c^\alpha)_{V-A}, \qquad Q_2^q = (\bar{u}q)_{V-A}(\bar{q}c)_{V-A},$$

$$Q_3 = (\bar{u}c)_{V-A}\sum_q(\bar{q}q)_{V-A}, \qquad Q_4 = (\bar{u}^\alpha c^\beta)_{V-A}\sum_q(\bar{q}^\beta q^\alpha)_{V-A},$$

$$Q_5 = (\bar{u}c)_{V-A}\sum_q(\bar{q}q)_{V+A}, \qquad Q_6 = (\bar{u}^\alpha c^\beta)_{V-A}\sum_q(\bar{q}^\beta q^\alpha)_{V+A},$$

$$Q_7 = \frac{e}{4\pi^2} m_c F_{\mu\nu}\bar{u}\sigma^{\mu\nu}P_R c, \qquad Q_8 = \frac{g_s}{4\pi^2} m_c G^a_{\mu\nu}\bar{u}\sigma^{\mu\nu}T^a P_R c,$$

$$Q_9 = \frac{e^2}{16\pi^2}(\bar{u}_L\gamma^\mu c_L)(\bar{l}\gamma_\mu l), \qquad Q_{10} = \frac{e^2}{16\pi^2}(\bar{u}_L\gamma^\mu c_L)(\bar{l}\gamma_\mu\gamma_5 l),$$

-	μ(GeV)	C_1	C_2	C_3	C_4	C_5	C_6	C_9
LO	1.0	-0.64	1.34	0.016	-0.036	0.010	-0.046	-0.07
NLO	1.0	-0.49	1.26	0.024	-0.060	0.015	-0.060	-0.60
NLO	1.5	-0.37	1.18	0.013	-0.036	0.012	-0.033	-0.13
NLO	2.0	-0.30	1.14	0.009	-0.025	0.009	-0.021	-0.13

Values of Wilson coefficients at scales $\mu = 1.0$ GeV, 1.5 GeV, 2.0 GeV, calculated at next-to-leading order

$c \to u l^+ l^-$

$$V_{cb}^* V_{ub} \hat{C}_9^{\text{eff}} = 2 V_{cs}^* V_{us} \left(h(z_s, \hat{s}) - h(z_d, \hat{s}) \right) \left(3 C_1(m_c) + C_2(m_c) \right)$$

Dominated by the 1-loop insertion of the $Q_{1,2}^q$ $V_{cb}^* V_{ub} C_9(\mu) \sim 10^{-4}$;

with $z_q = m_q/m_c$, $\hat{s} = (m_{l^+l^-}/m_c)^2$ and $m_{l^+l^-}$ the mass of the lepton pair, while

$$h(z,s) = -\frac{8}{9}\ln z + \frac{8}{27} + \frac{4}{9}x - \frac{2}{9}(2+x)\sqrt{|1-x|} \begin{cases} \ln\left|\frac{\sqrt{1-x}+1}{\sqrt{1-x}-1}\right| - i\pi, & \text{for } x < 1, \\ 2\,\text{Arctan}\left(\frac{1}{\sqrt{x-1}}\right), & \text{for } x \geq 1, \end{cases}$$

where $x = 4z^2/s$

$$\lim_{\hat{s}\to 0} \left(h(z_s, \hat{s}) - h(z_d, \hat{s}) \right) \to -\frac{8}{9} \ln\left(\frac{m_s}{m_d}\right)$$

Inami Lim result recovered

We fix the parameters a and b by the next-to-nearest resonances and we use physical pole masses of excited charmed mesons

$$F_+(q^2) = c_B\left(\frac{1}{1-x} - \frac{a}{1-x/\gamma}\right)$$
$$F_0(q^2) = \frac{c_B(1-a)}{1-bx},$$

$a = 1/\gamma$ → $m^2_{H'^*}/m^2_{H^*}$

b → $m^2_{H^*}/m^2_{H_S}$

- dubious Selex results!

$m_{D^+_{sJ}(2632)} = 2.632$ GeV

we use for scalar resonance

$m_{D_{sJ}(2317)^+} = 2.317$ GeV

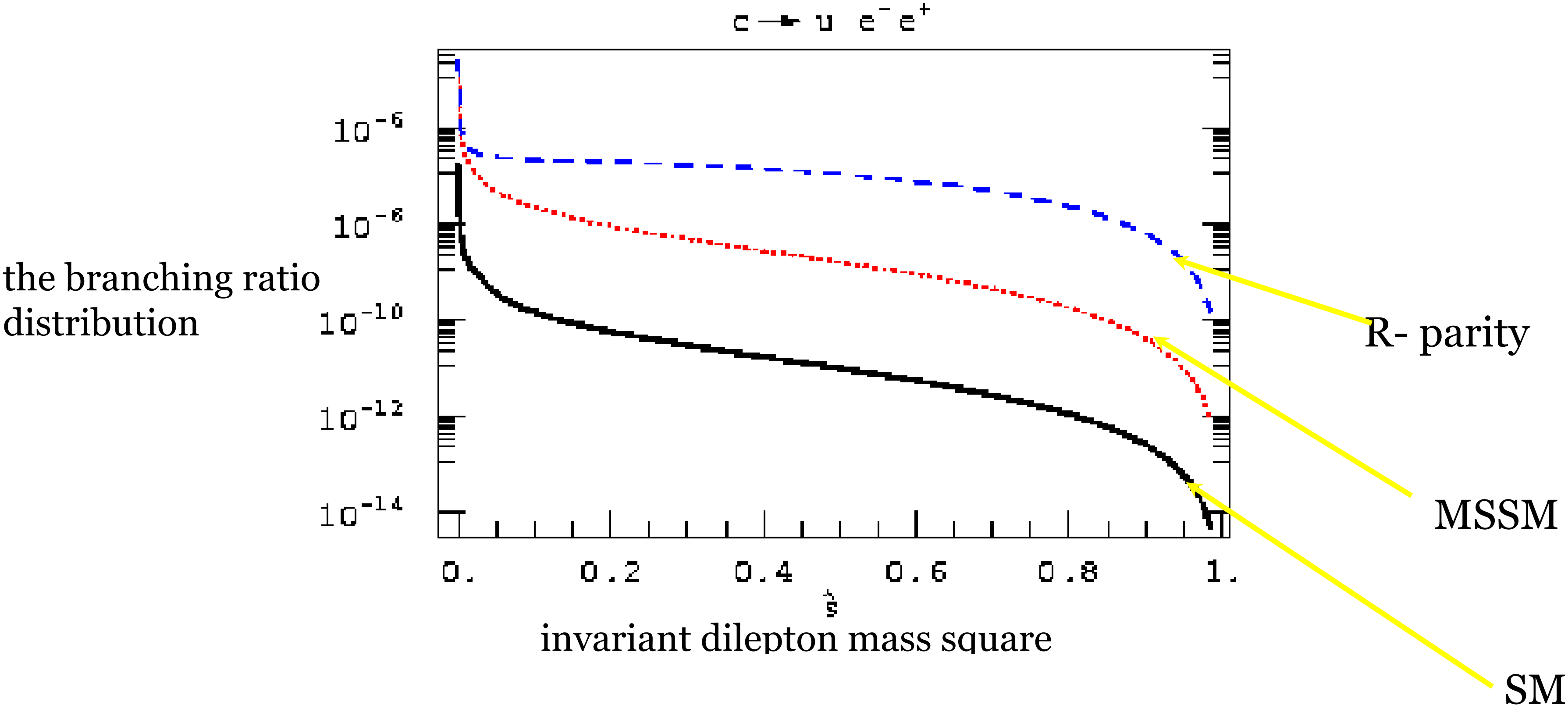
instead we used theoretical prediction $m_{D'^*} \simeq 2.7$ GeV and $m_{D'^*_s} \simeq 2.8$ GeV

(M. Di Pierro and E. Eichten, Phys. Rev. **D64**, 114004 (2001), hep-ph/0104208)

We use $\alpha = f_H\sqrt{m_H}$ $g = 0.59$ $h = -0.6$

from the lattice QCD value of $f_D = 0.225$ GeV

for the $\eta-\eta'$ mixing angle we use the value of $\phi \simeq 40°$



FSZ EPJ C27 (2003) 201, BGHP, PRD66 (2002) 014009, FPS PRD 64 (2001) 010633

Intensive searches of exclusive rare D decays at CLEO and FERMILAB;

References for extra up-like quark

- for a general framework:
V. Barger, M.S. Berger and R. J. N. Phillips, PRD 52 (1995);
P. Langacker and D. London, PRD 38 (1988) 886;
J. A. Aguilar-Saavedra, PLB 625 (2005) 234;
K. Higuchi and K. Yamamoto, PRD 62 (2000) 073005;
J. Alwal et al, hep-ph/0607115.

- **GUT** approaches: R. Barbieri and L. Hall, NPB 319 (1989) 1;
E. Ma PLB 322 (1994) 363

-up-like quark from extra dimension:
F.del Aguila and J. Santiago, JHEP 03 (2002) 010

-intersecting brane models
S.A. Abel et al., JHEP 04 (2003) 057

-Little Higgs Model
-Jae Yong Lee , JHEP 04 (2004) 065

The SM short distance contribution is dominated by the

$$\mathcal{A}^{SD}[D(p)\to\pi(p-q)l^+l^-] = i\,\frac{G_F}{\sqrt{2}}e^2V_{cb}^*V_{ub}\Big[\frac{C_{10}}{16\pi^2}f_+(q^2)\;\bar{u}(p_-)\not{p}\gamma_5 v(p_+) + \{\frac{C_7}{2\pi^2}m_c s(q^2)+\frac{C_9}{16\pi^2}f_+(q^2)\}\bar{u}(p_-)\not{p}v(p_+)\Big]$$

where $q^2 = m_{ll}^2$ and form factors $f_+(q^2)$ and $s(q^2)$ are defined by

$$\langle\pi(p_\pi)|\bar{u}\gamma^\mu(1-\gamma_5)c|D(p)\rangle = (p+p_\pi)^\mu f_+(q^2) + (p-p_\pi)^\mu f_-(q^2)\ ,$$

$$\langle\pi(p_\pi)|\bar{u}\sigma^{\mu\nu}(1\pm\gamma_5)c|D(p)\rangle = is(q^2)\big[(p+p_\pi)^\mu q^\nu - q^\mu(p+p_\pi)^\nu \pm i\epsilon^{\mu\nu\lambda\sigma}(p+p_\pi)_\lambda q_\sigma$$

We use experimental information on $D\to\pi$

$f_+(0) = 0.73\pm0.14\pm0.06$ and D* pole dominance of the form factor

$s(q^2) = f_+(q^2)/m_D$ (this holds strictly in the heavy quark limit!)

The success of narrow width approximation allows to write

$$Br(D \to \pi V_0 \to \pi l^+ l^-) = Br(D \to \pi V_0) Br(V_0 \to l^+ l^-)$$

That indicates that the amplitude for a cascade via resonances can be written as

$$\mathcal{A}^{LD}\left[D(p) \to \pi V_0 \to \pi(p-q) l^+ l^-\right] = e^{i\varphi_{V_0}} a_{V_0} \frac{1}{q^2 - m_{V_0}^2 + i m_{V_0} \Gamma_{V_0}} \bar{u}(p_-) \not{p} v(p_+)$$

overall phase is unknown

comes from the experimental data

$$a_\rho = 2.9 \times 10^{-9}\ \mathrm{GeV}^{-2} \text{ and } a_\phi = 4.2 \times 10^{-9}\ \mathrm{GeV}^{-2}$$

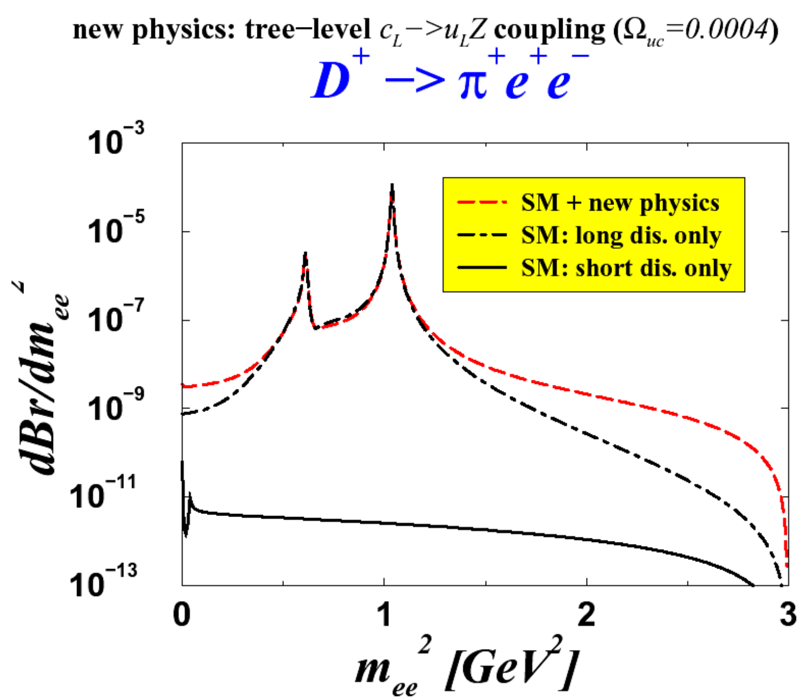
$$Br(D \to \pi V_0)$$

$$\mathcal{A}^{LD}[D(p) \to \pi(p-q)l^+l^-]$$
$$= e^{i\varphi}\left[a_\rho\left(\frac{1}{q^2 - m_\rho^2 + im_\rho\Gamma_\rho} - \frac{1}{3}\,\frac{1}{q^2 - m_\omega^2 + im_\omega\Gamma_\omega}\right) - a_\phi \frac{1}{q^2 - m_\phi^2 + im_\phi\Gamma_\phi}\right]\bar{u}(p_-)\not{p}v(p_+)$$

We argue that the relative sign of ω/ρ^0 amplitudes can be determined by considering the cascade decays (using vector meson dominance of the electromagnetic current).

The remaining part of the difference I s due to the weak transition $D^+ \to \pi^+ V^0$ which is induced by the operators $Q_{1,2}^{d,s}$ and can proceed via three ways (detail in appendix)

$$A(\omega)/A(\rho^0) = -1/3$$
$$|A(\phi)/A(\rho^0)| = a_\phi/a_\rho$$



The long distance contributions in $D \to P\ (V)\ \gamma^*$