Searches with non-LFV channels

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Table of Contents:

1. Rare leptonic decays of charm

- ➢ These decays only proceed at one loop in the SM; GIM is very effective
  - SM rates are expected to be small

★ Rare decays $D \to M\, e^+e^-/\mu^+\mu^-$ and $D \to e^+e^-/\mu^+\mu^-$ are mediated by $c \to u\, ll$

$$\mathcal{L}_{\rm eff}^{\rm SD} = \frac{G_F}{\sqrt{2}} V_{cb}^* V_{ub} \sum_{i=7,9,10} C_i Q_i,$$

$$Q_9 = \frac{e^2}{16\pi^2} \bar{u}_L \gamma_\mu c_L \bar{\ell} \gamma^\mu \ell, \quad Q_{10} = \frac{e^2}{16\pi^2} \bar{u}_L \gamma_\mu c_L \bar{\ell} \gamma^\mu \gamma_5 \ell,$$

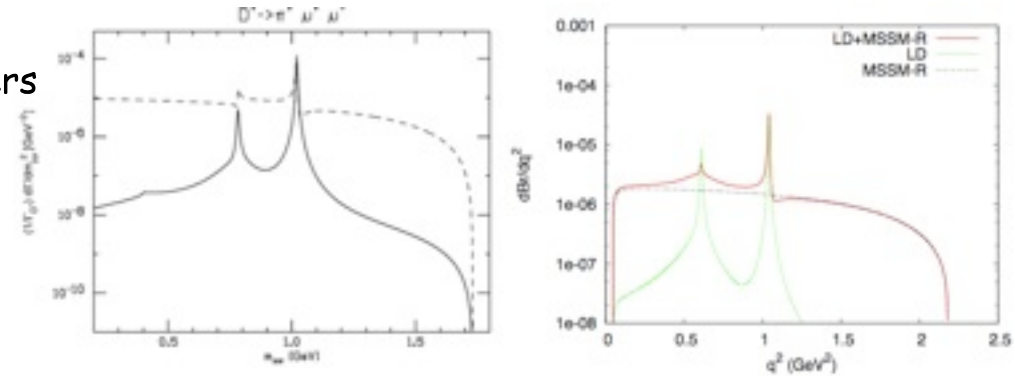
- SM contribution is dominated by LD effects
- could be used to study NP effects

Burdman, Golowich, Hewett, Pakvasa;
Fajfer, Prelovsek, Singer

Mode	LD	Extra heavy q	LD + extra heavy q
$D^+ \to \pi^+ e^+ e^-$	2.0×10^{-6}	1.3×10^{-9}	2.0×10^{-6}
$D^+ \to \pi^+ \mu^+ \mu^-$	2.0×10^{-6}	1.6×10^{-9}	2.0×10^{-6}
Mode	MSSM$\not{R}$	LD + MSSM$\not{R}$	
$D^+ \to \pi^+ e^+ e^-$	2.1×10^{-7}	2.3×10^{-6}	
$D^+ \to \pi^+ \mu^+ \mu^-$	6.5×10^{-6}	8.8×10^{-6}	

★ Example: R-partity-violating SUSY
- operators with the same parameters contribute to D-mixing
- feed results into rare decays

Fajfer, Kosnik, Prelovsek



★ Easiest: $D \to e^+e^-/\mu^+\mu^-$

Standard Model contribution to D → $\mu^+\mu^-$

★ Short distance analysis

$$Q_{10} = \frac{e^2}{16\pi^2}\bar{u}_L\gamma_\mu c_L \bar{\ell}\gamma^\mu\gamma_5\ell,$$

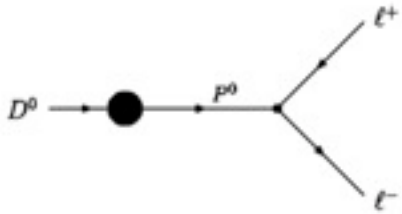
$$B^{(\text{s.d.})}_{D^0\ell^+\ell^-} \simeq \frac{G_F^2 M_W^2 f_D m_\ell}{\pi^2} F\,,$$

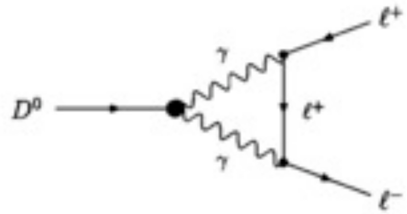
$$F = \sum_{i=d,s,b} V_{ui}V_{ci}^* \left[\frac{x_i}{2} + \frac{\alpha_s}{4\pi}x_i \cdot \left(\ln^2 x_i + \frac{4+\pi^2}{3}\right)\right]$$

- only Q_{10} contribute, SD effects amount to Br ~ 10^{-18}
- single non-perturbative parameter (decay constant)

UKQCD, HPQCD; Jamin, Lange; Penin, Steinhauser; Khodjamirian

★ Long distance analysis





Burdman, Golowich, Hewett, Pakvasa; Fajfer, Prelovsek, Singer

$$B^{(\text{mix})}_{D^0\ell^+\ell^-} = \sum_{P_n} \langle P_n|\mathcal{H}^{(\text{p.c.})}_{wk}|D^0\rangle \frac{1}{M_D^2 - M_{P_n^2}} B_{P_n\ell^+\ell^-}$$

$$\mathcal{I}m\, \mathcal{M}_{D^0\to\ell^+\ell^-} = \frac{1}{2!}\sum_{\lambda_1,\lambda_2}\int \frac{d^3q_1}{2\omega_1(2\pi)^3}\frac{d^3q_2}{2\omega_2(2\pi)^3} \times \mathcal{M}_{D\to\gamma\gamma}\mathcal{M}^*_{\gamma\gamma\to\ell^+\ell^-}(2\pi)^4\delta^{(4)}(p-q_1-q_2)$$

- LD effects amount to Br ~ 10^{-13}

- could be used to study NP effects in correlation with D-mixing

Standard Model contribution to D → μ⁺μ⁻

★ Short distance analysis

$$B^{(\mathrm{s.d.})}_{D^0\ell^+\ell^-} \simeq \frac{G_F^2 M_W^2 f_D m_\ell}{\pi^2} F\,,$$

$$F = \sum_{i=d,s,b} V_{ui} V^*_{ci}\left[\frac{x_i}{2} + \frac{\alpha_s}{4\pi} x_i \cdot \left(\ln^2 x_i + \frac{4+\pi^2}{3}\right)\right]$$

$$Q_{10} = \frac{e^2}{16\pi^2}\bar{u}_L\gamma_\mu c_L \bar{\ell}\gamma^\mu\gamma_5\ell,$$

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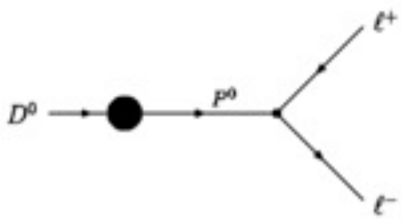
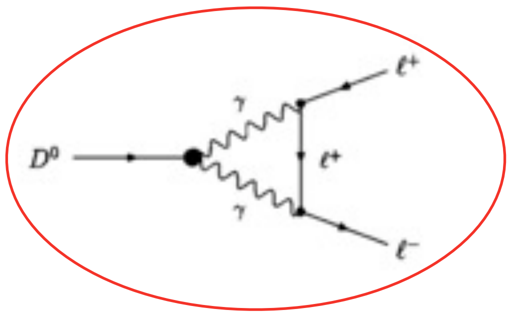
UKQCD, HPQCD; Jamin, Lange; Penin, Steinhauser; Khodjamirian

★ Long distance analysis





Burdman, Golowich, Hewett, Pakvasa; Fajfer, Prelovsek, Singer

$$B^{(\mathrm{mix})}_{D^0\ell^+\ell^-} = \sum_{P_n} \langle P_n|\mathcal{H}^{(\mathrm{p.c.})}_{wk}|D^0\rangle \frac{1}{M_D^2 - M_{P_n}^2} B_{P_n\ell^+\ell^-}$$

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- LD effects amount to Br ~ 10^{-13}

- could be used to study NP effects in correlation with D-mixing

What about D-mixing?

E.Golowich, J. Hewett, S. Pakvasa and A.A.P.
Phys. Rev. D76:095009, 2007

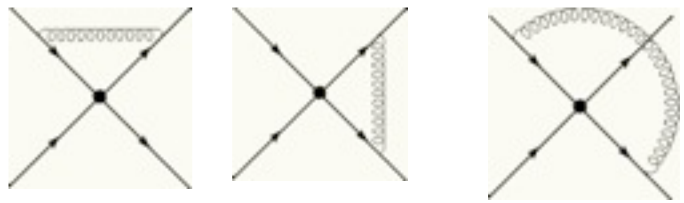
★ Let's write the most general ΔC=2 Hamiltonian

$$\mathcal{H}_{NP}^{\Delta C=2} = \frac{1}{\Lambda_{NP}^2} \sum_{i=1}^{8} C_i(\mu) Q_i$$

$\mu \le 1\, TeV$

... with the following set of 8 independent operators...

$$Q_1 = (\overline{u}_L \gamma_\mu c_L)\,(\overline{u}_L \gamma^\mu c_L)\,, \qquad Q_5 = (\overline{u}_R \sigma_{\mu\nu} c_L)\,(\overline{u}_R \sigma^{\mu\nu} c_L)\,,$$
$$Q_2 = (\overline{u}_L \gamma_\mu c_L)\,(\overline{u}_R \gamma^\mu c_R)\,, \qquad Q_6 = (\overline{u}_R \gamma_\mu c_R)\,(\overline{u}_R \gamma^\mu c_R)\,,$$
$$Q_3 = (\overline{u}_L c_R)\,(\overline{u}_R c_L)\,, \qquad Q_7 = (\overline{u}_L c_R)\,(\overline{u}_L c_R)\,,$$
$$Q_4 = (\overline{u}_R c_L)\,(\overline{u}_R c_L)\,, \qquad Q_8 = (\overline{u}_L \sigma_{\mu\nu} c_R)\,(\overline{u}_L \sigma^{\mu\nu} c_R)\,.$$



$\mu \sim 1\, GeV$

RG-running relate $C_i(m)$ at NP scale to the scale of m ~ 1 GeV, where ME are computed (on the lattice)

$$\frac{d}{d\log\mu}\vec{C}(\mu) = \hat{\gamma}^T(\mu)\vec{C}(\mu)$$

Each model of New Physics provides unique matching condition for $C_i(\Lambda_{NP})$

Generic restrictions on NP

★ Comparing to experimental value of x, obtain constraints on NP models

- assume x is dominated by the New Physics model
- assume no accidental strong cancellations b/w SM and NP

$$\mathcal{H}_{NP}^{\Delta C=2} = \frac{1}{\Lambda_{NP}^2} \sum_{i=1}^{8} z_i(\mu) Q'_i$$

$$\begin{aligned} Q_1^{cu} &= \bar{u}_L^\alpha \gamma_\mu c_L^\alpha \bar{u}_L^\beta \gamma^\mu c_L^\beta, \\ Q_2^{cu} &= \bar{u}_R^\alpha c_L^\alpha \bar{u}_R^\beta c_L^\beta, \\ Q_3^{cu} &= \bar{u}_R^\alpha c_L^\beta \bar{u}_R^\beta c_L^\alpha, \end{aligned} + \left\{ \begin{matrix} L \\ \updownarrow \\ R \end{matrix} \right\} + \begin{aligned} Q_4^{cu} &= \bar{u}_R^\alpha c_L^\alpha \bar{u}_L^\beta c_R^\beta, \\ Q_5^{cu} &= \bar{u}_R^\alpha c_L^\beta \bar{u}_L^\beta c_R^\alpha, \end{aligned}$$

★ ... which are

$$|z_1| \lesssim 5.7 \times 10^{-7} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2,$$

$$|z_2| \lesssim 1.6 \times 10^{-7} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2,$$

$$|z_3| \lesssim 5.8 \times 10^{-7} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2,$$

$$|z_4| \lesssim 5.6 \times 10^{-8} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2,$$

$$|z_5| \lesssim 1.6 \times 10^{-7} \left(\frac{\Lambda_{\rm NP}}{1\ TeV}\right)^2.$$

New Physics is either at a very high scales

tree level: $\Lambda_{NP} \geq (4-10) \times 10^3$ TeV

loop level: $\Lambda_{NP} \geq (1-3) \times 10^2$ TeV

or have highly suppressed couplings to charm!

Gedalia, Grossman, Nir, Perez
arXiv:0906.1879 [hep-ph]

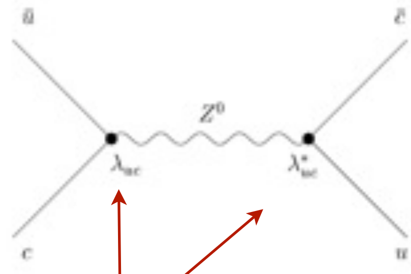
E.Golowich, J. Hewett, S. Pakvasa and A.A.P.
Phys. Rev. D76:095009, 2007

★ Constraints on particular NP models available

Example of a model of New Physics

★ Consider an example: FCNC Z^0-boson

appears in models with
extra vector-like quarks
little Higgs models



$$\lambda_{uc} \equiv -\left(V^*_{ud}V_{cd} + V^*_{us}V_{cs} + V^*_{ub}V_{cb}\right)$$

1. Integrate out Z: for $\mu < M_Z$ get

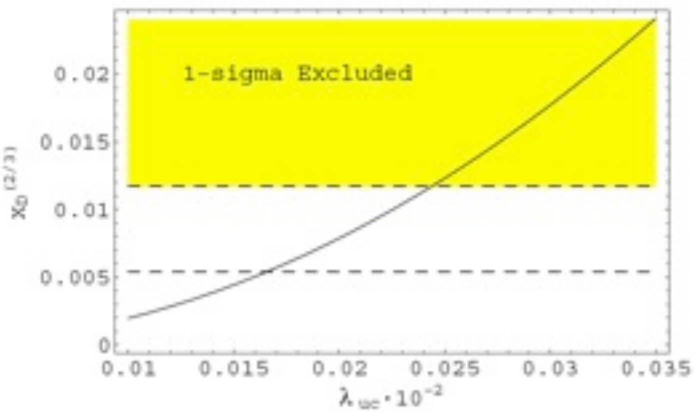
$$\mathcal{H}_{2/3} = \frac{g^2}{8\cos^2\theta_w M_Z^2}\left(\lambda_{uc}\right)^2 \bar{u}_L\gamma_\mu c_L \bar{u}_L\gamma^\mu c_L$$

2. Perform RG running to $\mu \sim m_c$ (in general: operator mixing)

$$\mathcal{H}_{2/3} = \frac{g^2}{8\cos^2\theta_w M_Z^2}\left(\lambda_{uc}\right)^2 r_1(m_c, M_Z) Q_1$$

3. Compute relevant matrix elements and x_D

$$x_D^{(2/3)} = \frac{2G_F f_D^2 M_D}{3\sqrt{2}\Gamma_D} B_D \left(\lambda_{uc}\right)^2 r_1(m_c, M_Z)$$



4. Assume no SM - get an upper bound on NP model parameters/correlate with rare decays!

Generic NP contribution to D → $\mu^+\mu^-$

★ Most general effective Hamiltonian:

$$\langle f|\mathcal{H}_{NP}|i\rangle = G\sum_{i=1} \widetilde{C}_i(\mu)\ \langle f|Q_i|i\rangle(\mu)$$

$$\widetilde{Q}_1 = (\overline{\ell}_L\gamma_\mu\ell_L)\ (\overline{u}_L\gamma^\mu c_L)\ , \qquad \widetilde{Q}_4 = (\overline{\ell}_R\ell_L)\ (\overline{u}_R c_L)\ ,$$

$$\widetilde{Q}_2 = (\overline{\ell}_L\gamma_\mu\ell_L)\ (\overline{u}_R\gamma^\mu c_R)\ , \qquad \widetilde{Q}_5 = (\overline{\ell}_R\sigma_{\mu\nu}\ell_L)\ (\overline{u}_R\sigma^{\mu\nu} c_L)\ ,$$

$$\widetilde{Q}_3 = (\overline{\ell}_L\ell_R)\ (\overline{u}_R c_L)\ ,$$

plus L ↔ R

★ ... thus, the amplitude for D → $e^+e^-/\mu^+\mu^-$ decay is

$$\mathcal{B}_{D^0\to\ell^+\ell^-} = \frac{M_D}{8\pi\Gamma_D}\sqrt{1-\frac{4m_\ell^2}{M_D^2}}\left[\left(1-\frac{4m_\ell^2}{M_D^2}\right)|A|^2+|B|^2\right]\ ,$$

$$\mathcal{B}_{D^0\to\mu^+e^-} = \frac{M_D}{8\pi\Gamma_D}\left(1-\frac{m_\mu^2}{M_D^2}\right)^2\left[|A|^2+|B|^2\right]\ ,$$

$$|A| = G\frac{f_D M_D^2}{4m_c}\left[\widetilde{C}_{3-8}+\widetilde{C}_{4-9}\right]\ ,$$

$$|B| = G\frac{f_D}{4}\left[2m_\ell\left(\widetilde{C}_{1-2}+\widetilde{C}_{6-7}\right)+\frac{M_D^2}{m_c}\left(\widetilde{C}_{4-3}+\widetilde{C}_{9-8}\right)\right],\quad \widetilde{C}_{i-k}\equiv\widetilde{C}_i-\widetilde{C}_k$$

Many NP models give contributions to both D-mixing and D → $e^+e^-/\mu^+\mu^-$ decay: correlate!!!

Mixing vs rare decays: a particular model

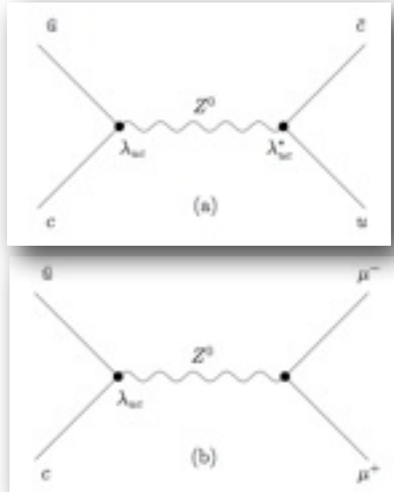
★ Recent experimental constraints

$$\mathcal{B}_{D^0\to\mu^+\mu^-} \leq 1.3\times 10^{-6}, \qquad \mathcal{B}_{D^0\to e^+e^-} \leq 1.2\times 10^{-6},$$

$$\mathcal{B}_{D^0\to\mu^\pm e^\mp} \leq 8.1\times 10^{-7} \quad ,$$

E.Golowich, J. Hewett, S. Pakvasa and A.A.P.
PRD79, 114030 (2009)

★ Relating mixing and rare decay
- consider an example: heavy vector-like quark (Q=+2/3)
  - appears in little Higgs models, etc.



Mixing:

$$\mathcal{H}_{2/3} = \frac{g^2}{8\cos^2\theta_w M_Z^2}\lambda_{uc}^2\, Q_1 \; = \; \frac{G_F\lambda_{uc}^2}{\sqrt{2}}Q_1$$

$$x_{\rm D}^{(+2/3)} = \frac{2G_F\lambda_{uc}^2 f_D^2 M_D B_D r(m_c, M_Z)}{3\sqrt{2}\Gamma_D}$$

Rare decay:

$$A_{D^0\to\ell^+\ell^-} = 0 \qquad B_{D^0\to\ell^+\ell^-} = \lambda_{uc}\frac{G_F f_{\rm D} m_\mu}{2}$$

$$\boxed{\begin{aligned}\mathcal{B}_{D^0\to\mu^+\mu^-} &= \frac{3\sqrt{2}}{64\pi}\,\frac{G_F m_\mu^2 x_{\rm D}}{B_{\rm D} r(m_c, M_Z)}\left[1-\frac{4m_\mu^2}{M_{\rm D}}\right]^{1/2} \\ &\simeq 4.3\times 10^{-9} x_{\rm D} \;\leq\; 4.3\times 10^{-11} \quad .\end{aligned}}$$

Note: a NP parameter-free relation!

Mixing vs rare decays

★ Correlation between mixing/rare decays

- possible for tree-level NP amplitudes

E.Golowich, J. Hewett, S. Pakvasa and A.A.P.
PRD79, 114030 (2009)

Spin-1 intermediate boson: $\mathcal{H}_V = \mathcal{H}_V^{\rm FCNC} + \mathcal{H}_V^{L}$

$$\mathcal{H}_V^{\rm FCNC} = g_{V1}\bar{u}_L\gamma_\mu c_L V^\mu + g_{V2}\bar{u}_R\gamma_\mu c_R V^\mu + g_{V3}\bar{u}_L\sigma_{\mu\nu}c_R V^{\mu\nu} + g_{V4}\bar{u}_R\sigma_{\mu\nu}c_L V^{\mu\nu}$$

$$\mathcal{H}_V^{L} = g'_{V1}\bar{\ell}_L\gamma_\mu\ell_L V^\mu + g'_{V2}\bar{\ell}_R\gamma_\mu\ell_R V^\mu + g'_{V3}\bar{\ell}_L\sigma_{\mu\nu}\ell_R V^{\mu\nu} + g'_{V4}\bar{\ell}_R\sigma_{\mu\nu}\ell_L V^{\mu\nu}.$$

Mixing: $$x_D^{(V)} = \frac{f_D^2 M_D B_D}{2M_V^2\Gamma_D}\left[\frac{2}{3}(C_1(m_c)+C_6(m_c)) - \left[\frac{1}{2}+\frac{\eta}{3}\right]C_2(m_c) + \left[\frac{1}{12}+\frac{\eta}{2}\right]C_3(m_c)\right],$$

$$C_1(m_c) = r(m_c, M_V)g_{V1}^2,$$
$$C_2(m_c) = 2r(m_c, M_V)^{1/2}g_{V1}g_{V2},$$
$$C_3(m_c) = \tfrac{4}{3}[r(m_c, M_V)^{1/2} - r(m_c, M_V)^{-4}]g_{V1}g_{V2},$$
$$C_6(m_c) = r(m_c, M_V)g_{V2}^2.$$

Rare decay: $$\mathcal{B}^{(V)}_{D^0\to\ell^+\ell^-} = \frac{f_D^2 m_\ell^2 M_D}{32\pi M_V^4\Gamma_D}\sqrt{1-\frac{4m_\ell^2}{M_D^2}} \times (g_{V1}-g_{V2})^2(g'_{V1}-g'_{V2})^2.$$

NO contribution from vectors (vector current conservation)

Mixing vs rare decays

★ Correlation between mixing/rare decays
- possible for tree-level NP amplitudes

E.Golowich, J. Hewett, S. Pakvasa and A.A.P. PRD79, 114030 (2009)

Spin-0 intermediate boson: $\mathcal{H}_S = \mathcal{H}_S^{\rm FCNC} + \mathcal{H}_S^{L},$

$$\mathcal{H}_S^{\rm FCNC} = g_{S1}\bar{u}_L c_R S + g_{S2}\bar{u}_R c_L S + g_{S3}\bar{u}_L \gamma_\mu c_L \partial^\mu S + g_{S4}\bar{u}_R \gamma_\mu c_R \partial^\mu S$$

$$\mathcal{H}_S^{L} = g'_{S1}\bar{\ell}_L \ell_R S + g'_{S2}\bar{\ell}_R \ell_L S + g'_{S3}\bar{\ell}_L \gamma_\mu \ell_L \partial^\mu S + g'_{S4}\bar{\ell}_R \gamma_\mu \ell_R \partial^\mu S.$$

Mixing:

$$x_D^{(S)} = -\frac{f_D^2 M_D B_D}{2\Gamma_D M_S^2}\left[\left[\frac{1}{12}+\frac{\eta}{2}\right]C_3(m_c) - \frac{5\eta}{12}(C_4(m_c)+C_7(m_c)) + \eta(C_5(m_c)+C_8(m_c))\right],$$

Rare decay:

$$\mathcal{B}^{(S)}_{D^0\to\ell^+\ell^-} = \frac{f_D^2 M_D^5}{128\pi m_c^2 M_S^4 \Gamma_D}\sqrt{1-\frac{4m_\ell^2}{M_D^2}}(g_{S1}-g_{S2})^2 \times\left[(g'_{S1}+g'_{S2})^2\left(1-\frac{4m_\ell^2}{M_D^2}\right) + (g'_{S1}-g'_{S2})^2\right].$$

NO contribution from scalars

Mixing vs rare decays

★ Correlation between mixing/rare decays
- possible for tree-level NP amplitudes
- some relations possible for loop-dominated transitions

E.Golowich, J. Hewett, S. Pakvasa and A.A.P.
PRD79, 114030 (2009)

★ Consider several popular models

Model	$\mathcal{B}_{D^0\to\mu^+\mu^-}$
Standard Model (SD)	$\sim 10^{-18}$
Standard Model (LD)	$\sim$ several $\times 10^{-13}$
$Q=+2/3$ Vectorlike Singlet	4.3×10^{-11}
$Q=-1/3$ Vectorlike Singlet	$1\times 10^{-11}\ (m_S/500\ \mathrm{GeV})^2$
$Q=-1/3$ Fourth Family	$1\times 10^{-11}\ (m_S/500\ \mathrm{GeV})^2$
Z' Standard Model (LD)	$2.4\times 10^{-12}/(M_{Z'}(\mathrm{TeV}))^2$
Family Symmetry	$0.7\ 10^{-18}$ (Case A)
RPV-SUSY	$1.7\times 10^{-9}\ (500\ \mathrm{GeV}/m_{\tilde{d}_k})^2$

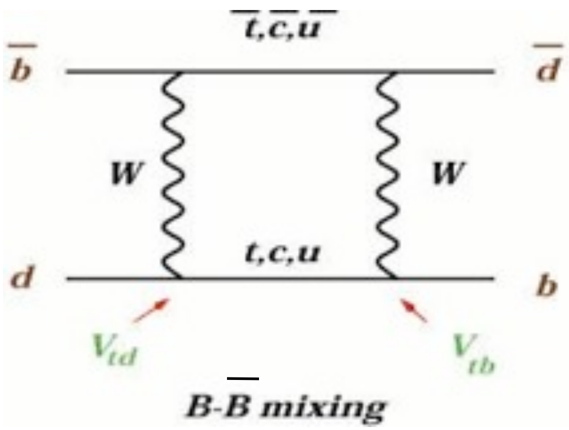
Obtained upper limits on rare decay branching ratios.

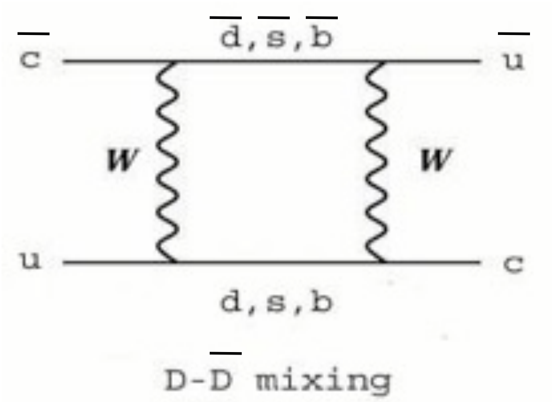
Can we apply the same idea where better data exists?

Same idea can be employed to relate D-mixing to K-mixing

Blum, Grossman, Nir, Perez
arXiv:0903.2118 [hep-ph]

2. D^0-mixing vs B_s-mixing





$\overline{D^0} - D^0$ mixing	$\overline{B^0} - B^0$ mixing
• intermediate down-type quarks • SM: b-quark contribution is negligible due to $V_{cd}V_{ub}^*$ • $rate \propto f(m_s) - f(m_d)$ (zero in the SU(3) limit) Falk, Grossman, Ligeti, and A.A.P. Phys.Rev. D65, 054034, 2002 2nd order effect!!!	• intermediate up-type quarks • SM: t-quark contribution is dominant • $rate \propto m_t^2$ (expected to be large)
1. Sensitive to long distance QCD 2. Small in the SM: New Physics! (must know SM x and y)	1. Computable in QCD (*) 2. Large in the SM: CKM!

(*) up to matrix elements of 4-quark operators

Available experimental data for B_s

- LHCb will probe $B_s \to \mu^+\mu^-$ at the SM level within a year

★ B_s mixing data:

$$\Delta M_{B_s}^{(\text{expt})} = (117.0 \pm 0.8) \times 10^{-13}\ \text{GeV},$$

PDG

E.Golowich, J. Hewett, S. Pakvasa, A.A.P, and G. Yeghiyan PRD83, 114017 (2011)

$$\Delta M_{B_s}^{(\text{SM})} = \frac{(G_{\text{F}} M_{\text{W}} |V_{\text{ts}}^* V_{\text{tb}}|)^2}{6\pi^2} M_{B_s} f_{B_s}^2 \hat{B}_{B_s} \eta_{B_s} S_0(\bar{x}_t) = \left(125.2^{+13.8}_{-12.7}\right) \times 10^{-13}\ \text{GeV}$$

Nierste, Lenz; Buras

$\alpha_s(M_Z) = 0.1184 \pm 0.0007$ [6]	$\lvert V_{ts}\rvert = 0.0403^{+0.0011}_{-0.0007}$ [7]
$\Delta M_{B_s} = (117.0 \pm 0.8) \times 10^{-13}$ GeV [7]	$\Delta\Gamma_{B_s}/\Gamma_{B_s} = 0.092^{+0.051}_{-0.054}$ [7]
$\bar{m}_t(\bar{m}_t) = (163.4 \pm 1.2)$ GeV [8]	$f_{B_s}\sqrt{\hat{B}_{B_s}} = 275 \pm 13$ MeV [9]
$\hat{B}_{B_s} = 1.33 \pm 0.06$ [9]	$f_{B_s} = 0.2388 \pm 0.0095$ GeV [9]

★ Rare decays

$$Br^{(\text{PDG})}_{B_s\to\mu^+\mu^-} < 47 \times 10^{-9} \quad (\text{CL} = 90\%)\ ; \qquad Br^{(\text{CDF})}_{B_s\to\mu^+\mu^-} = \left(18^{+11}_{-9}\right) \times 10^{-9}$$

$$Br^{(\text{LHC})}_{B_s\to\mu^+\mu^-} < 9 \times 10^{-9} \quad (\text{CL} = 90\%)\ ; \qquad Br^{(\text{LHC})}_{B_s\to\mu^+\mu^-} < 11 \times 10^{-9} \quad (\text{CL} = 95\%)$$

$$Br^{(\text{SM})}_{B_s\to\mu^+\mu^-} = \frac{1}{8\pi^5} \cdot \frac{M_{B_s}}{\Gamma_{B_s}} \cdot \left(G_F^2 M_W^2 m_\mu f_{B_s} |V_{\text{ts}}^* V_{\text{tb}}| \eta_Y Y(\bar{x}_t)\right)^2 \left[1 - 4\frac{m_\mu^2}{M_{B_s}^2}\right]^{1/2}$$

$$Br^{(\text{SM})}_{B_s\to\mu^+\mu^-} = \frac{3}{4\pi^3} \cdot \frac{\Delta M_{B_s}^{(\text{Expt})}}{\Gamma_{B_s}} \cdot \frac{(G_F M_W m_\mu \eta_Y Y)^2}{\hat{\eta} \hat{B}_{B_s} S_0(\bar{x}_t)} \left[1 - 4\frac{m_\mu^2}{M_{B_s}^2}\right]^{1/2} = (3.3 \pm 0.2) \times 10^{-9}$$

Buras, Carlucci, Gori, Isidori

New Physics in B_s-mixing

- Relate NP contributions in B_s mixing and rare decays

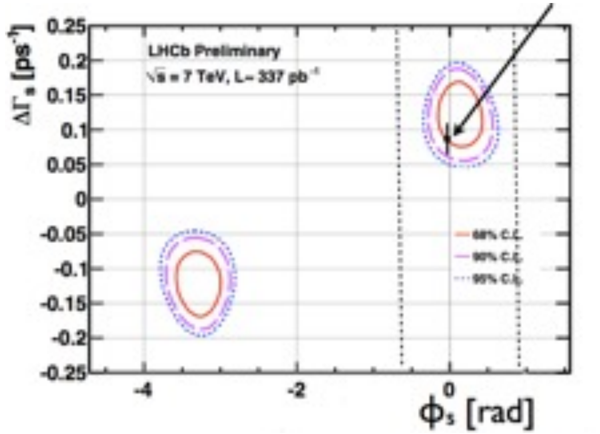
★ B_s mixing data:

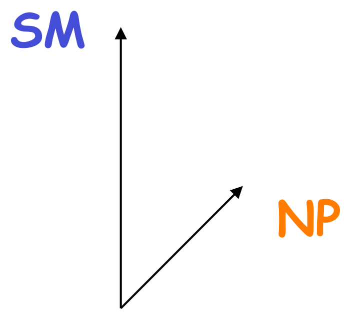
$$\Delta M_{B_s} = \Delta M_{B_s}^{(\mathrm{SM})} + \Delta M_{B_s}^{(\mathrm{NP})} \cos\phi.$$

$$\Delta M_{B_s}^{(\mathrm{Expt})} = \Delta M_{B_s}^{(\mathrm{SM})} + \Delta M_{B_s}^{(\mathrm{NP})}$$

$$\Delta M_{B_s}^{(\mathrm{NP})} = (-20.9 \to +5.6) \times 10^{-13}\ \mathrm{GeV}$$

$$\boxed{|\Delta M_{B_s}^{(\mathrm{NP})}| \leq 20.9 \times 10^{-13}\ \mathrm{GeV}}$$





This characterizes the size of NP "window" still possible in B_s-mixing.
This is what should be related to rare decays (same formulas...)

E.Golowich, J. Hewett, S. Pakvasa, A.A.P, and G. Yeghiyan PRD83, 114017 (2011)

Mixing vs rare decays: some models

- Consider RPV SUSY: $\mathcal{W}_{\not R} = \frac{1}{2}\lambda_{ijk}L_iL_jE_k^c + \lambda'_{ijk}L_iQ_jD_k^c + \frac{1}{2}\lambda''_{ijk}U_i^cD_j^cD_k^c.$

Mixing: $\mathcal{L}_R = -\lambda'_{i23}\tilde{\nu}_{i_L}\bar{b}_R s_L - \lambda'_{i32}\tilde{\nu}_{i_L}\bar{s}_R b_L + \text{H.c.},$

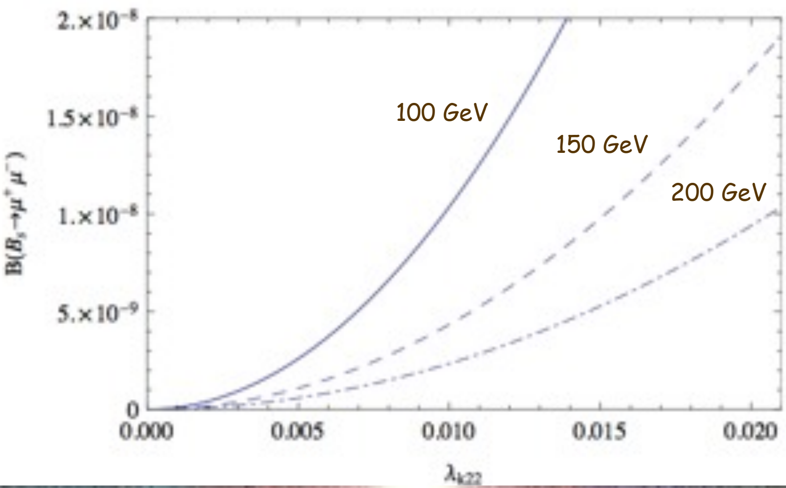
$$\Delta M_{B_s}^{(\not R)} = \frac{5}{24} f_{B_s}^2 M_{B_s} F(C_3, B_3) \sum_i \frac{\lambda'_{i23}\lambda'^*_{i32}}{M_{\tilde{\nu}_i}^2},$$

Rare decay:

$$\mathcal{B}_{B_s\to\mu^+\mu^-}^{(\not R)} = \frac{f_{B_s}^2 M_{B_s}^3}{64\pi\Gamma_{B_s}}\left(\frac{M_{B_s}}{m_b}\right)^2\left(1-\frac{2m_\mu^2}{M_{B_s}^2}\right)\sqrt{1-\frac{4m_\mu^2}{M_{B_s}^2}} \times\left(\left|\sum_i \frac{\lambda^*_{i22}\lambda'_{i32}}{M_{\tilde{\nu}_i}^2}\right|^2 + \left|\sum_i \frac{\lambda_{i22}\lambda'^*_{i23}}{M_{\tilde{\nu}_i}^2}\right|^2\right).$$

$$\mathcal{B}_{B_s\to\mu^+\mu^-}^{(\not R)} = k\frac{f_{B_s}^2 M_{B_s}^3}{64\pi\Gamma_{B_s}}\left(\frac{\lambda_{i22}\lambda'_{i32}}{M_{\tilde{\nu}_i}^2}\right)^2\left(\frac{M_{B_s}}{m_b}\right)^2\left(1-\frac{2m_\mu^2}{M_{B_s}^2}\right) \times\sqrt{1-\frac{4m_\mu^2}{M_{B_s}^2}},$$

...assume that a single sneutrino dominates, neglect possible CP-violation...



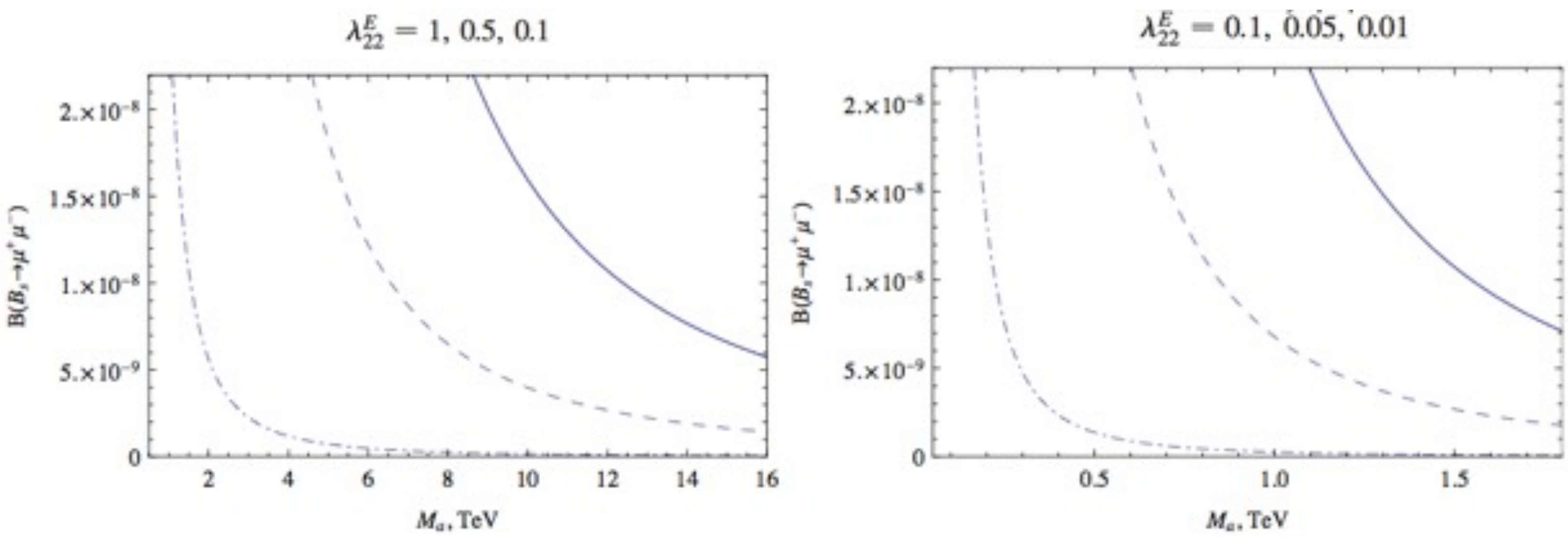
$$\mathcal{B}_{B_s\to\mu^+\mu^-}^{(\not R)} = \frac{3}{20\pi}\frac{M_{B_s}^2}{F(C_3, B_3)}\left(\frac{M_{B_s}}{m_b}\right)^2\left(1-\frac{2m_\mu^2}{M_{B_s}^2}\right) \times\sqrt{1-\frac{4m_\mu^2}{M_{B_s}^2}}\, x_{B_s}^{(\not R)}\frac{\lambda_{k22}^2}{M_{\tilde{\nu}_i}^2}.$$

E.Golowich, J. Hewett, S. Pakvasa, A.A.P, and G. Yeghiyan PRD83, 114017 (2011)

Mixing vs rare decays: some models

- FCNC pseudoscalars:

$$\mathcal{B}^{(a)}_{B_s^0\to\ell^+\ell^-} = \frac{3}{10\pi}\cdot\frac{M_{B_s}^4 x_s^{(a)}}{m_b^2 f_a(\bar{C}_i, m_b)}\left(1-\frac{4m_\ell^2}{M_{B_s}^2}\right)^{1/2}\left(\frac{\lambda_{22}^E}{M_a}\right)^2$$



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Mixing vs rare decays: some models

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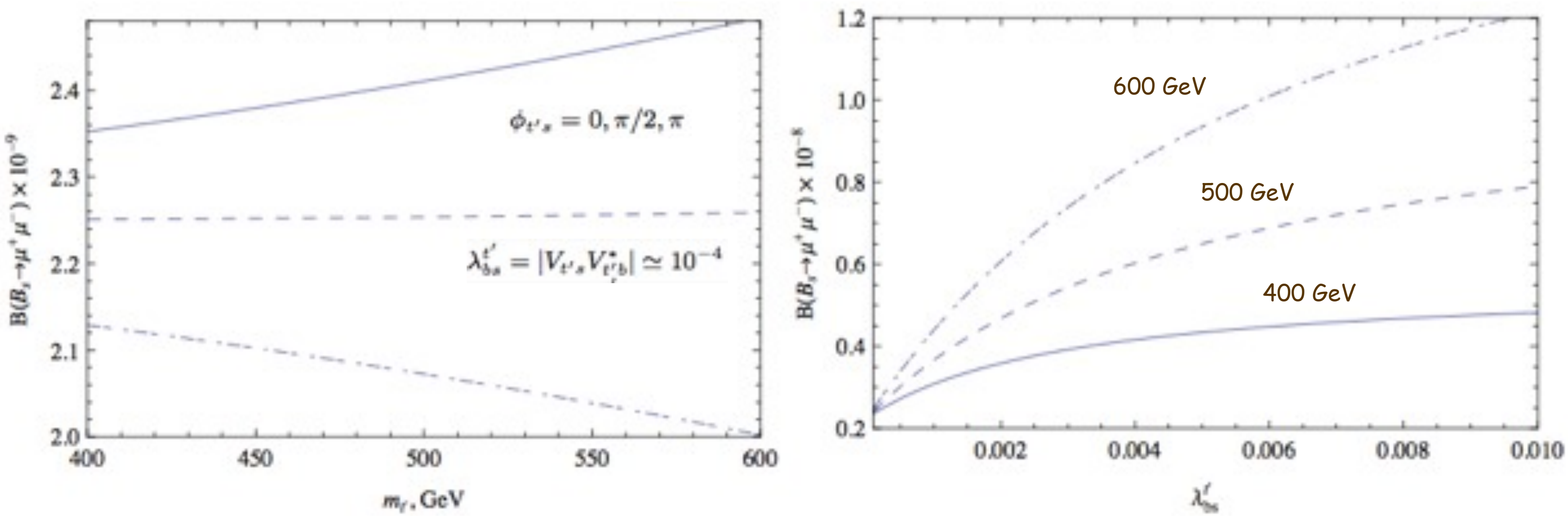
- Sequential 4th generation of quarks:

$$\mathcal{B}_{B_s \to \mu^+\mu^-} = \frac{3\alpha^2 m_\mu^2 x_{B_s}}{8\pi \hat{B}_{B_s} M_W^2} \sqrt{1 - \frac{4m_\mu^2}{m_{B_s}^2}} \frac{|C_{10}^{tot}|^2}{|\Delta'|},$$

$$\Delta' = \eta_t S_0(x_t) + \eta_{t'} R_{t't}^2 S_0(x_{t'}) + 2\eta_{t'} R_{t't} S_0(x_t, x_{t'})$$

Soni et al



Friday, November 11, 11

Things to take home

- Indirect effects of New Physics at flavor factories help to distinguish among models possibly observed at the LHC in the future
  - a combination of bottom/charm sector studies
- Charm provides great opportunities for New Physics studies
  - unique access to up-type quark sector
  - large available statistics/in many cases small SM background
  - contributions from New Physics are still possible
- Can correlate mixing and rare decays with New Physics models
  - signals in D-mixing vs rare decays help differentiate among models
  - similar correlations in B_s studies restrict parameter space of several popular models