(Charm) decays and mixing

Alexey A. Petrov
Wayne State University
Michigan Center for Theoretical Physics

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Thursday, October 13, 11

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 $D \to M\, e^+e^-/\mu^+\mu^-/\tau^+\tau^-$ mediated by $c \to u\, ll$

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

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

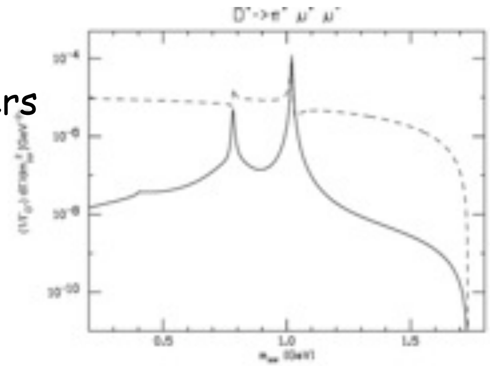
$$Q_9 = \frac{e^2}{16\pi^2} \bar{u}_L \gamma_\mu c_L \bar{\ell}\gamma^\mu \ell, \quad Q_{10} = \frac{e^2}{16\pi^2} \bar{u}_L \gamma_\mu c_L \bar{\ell}\gamma^\mu \gamma_5 \ell,$$

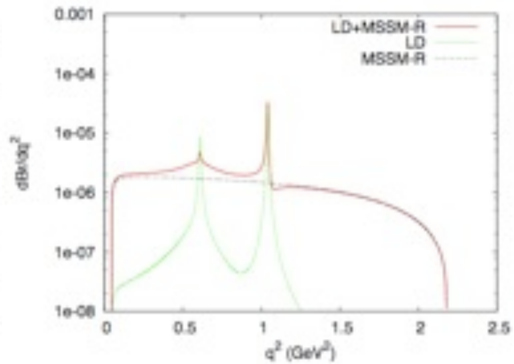
Mode	LD	Extra heavy q	LD + extra heavy q
$D^+ \to \pi^+ e^+ e^-$	2.0×10^{-6}	1.3×10^{-9}	2.0×10^{-6}
$D^+ \to \pi^+ \mu^+ \mu^-$	2.0×10^{-6}	1.6×10^{-9}	2.0×10^{-6}
Mode	MSSM$\not{R}$	LD + MSSM$\not{R}$	
$D^+ \to \pi^+ e^+ e^-$	2.1×10^{-7}	2.3×10^{-6}	
$D^+ \to \pi^+ \mu^+ \mu^-$	6.5×10^{-6}	8.8×10^{-6}	

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

Fajfer, Kosnik, Prelovsek

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





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

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

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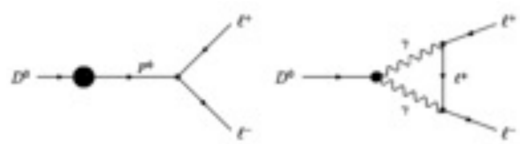


- only Q_{10} contribute, but SM contribution is dominated by LD effects ($Br \sim 10^{-18}$-10^{-13})
- single non-perturbative parameter (decay constant)
- could be used to study NP effects in correlation with D-mixing

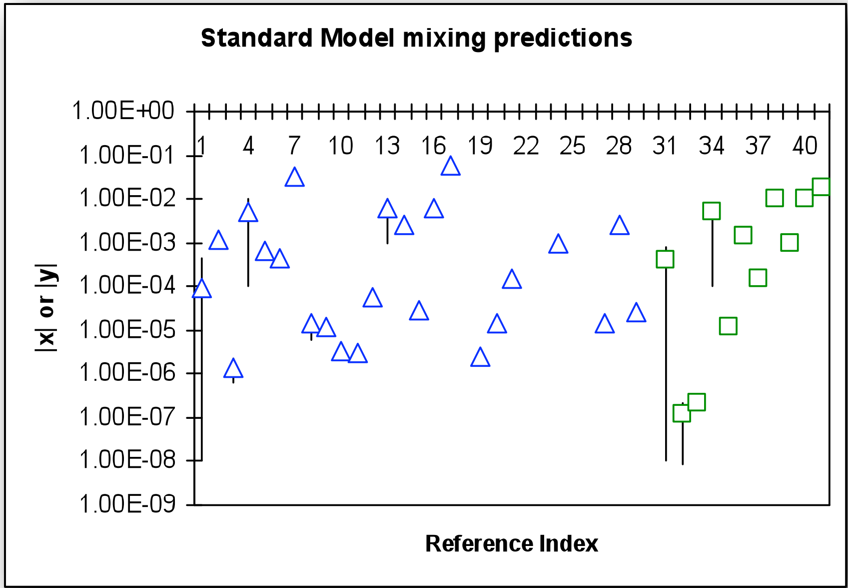
UKQCD, HPQCD; Jamin, Lange; Penin, Steinhauser; Khodjamirian

Mixing: Standard Model predictions

$x = 0.63^{+0.19}_{-0.20}\%$
$y = 0.75 \pm 0.12\ \%$

HFAG 2011

*



* Not an actual representation of theoretical uncertainties. Objects might be bigger then what they appear to be...

★ Predictions of x and y in the SM are complicated
- -second order in flavor SU(3) breaking
- $-m_c$ is not quite large enough for OPE
  - -x, y << 10^{-3} ("short-distance")
  - -x, y ~ 10^{-2} ("long-distance")

★ Short distance:
- -assume m_c is large
  - -combined m_s, $1/m_c$, a_s expansions
  - -leading order: m_s^2, $1/m_c^6$!

H. Georgi; T. Ohl, …
I. Bigi, N. Uraltsev;

M. Bobrowski et al

★ Long distance:
- -assume m_c is NOT large
  - -sum of large numbers with alternating signs, SU(3) forces zero!
  - -multiparticle intermediate states dominate

J. Donoghue et. al.
P. Colangelo et. al.

Resume: a contribution to x and y of the order of 1% is natural in the SM but for the correlation studies assume that ΔM is dominated by NP!

Falk, Grossman, Ligeti, Nir. A.A.P. Phys.Rev. D69, 114021, 2004
Falk, Grossman, Ligeti, and A.A.P. Phys.Rev. D65, 054034, 2002

Global Analysis of New Physics in 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

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

$\mu \leq 1\,TeV$

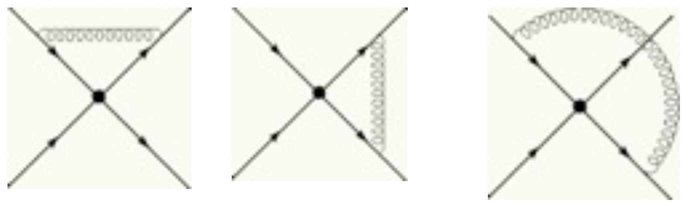
… with the following set of 8 independent operators…

$$Q_1 = (\overline{u}_L \gamma_\mu c_L)\,(\overline{u}_L \gamma^\mu c_L)\,, \qquad Q_5 = (\overline{u}_R \sigma_{\mu\nu} c_L)\,(\overline{u}_R \sigma^{\mu\nu} c_L)\,,$$

$$Q_2 = (\overline{u}_L \gamma_\mu c_L)\,(\overline{u}_R \gamma^\mu c_R)\,, \qquad Q_6 = (\overline{u}_R \gamma_\mu c_R)\,(\overline{u}_R \gamma^\mu c_R)\,,$$

$$Q_3 = (\overline{u}_L c_R)\,(\overline{u}_R c_L)\,, \qquad Q_7 = (\overline{u}_L c_R)\,(\overline{u}_L c_R)\,,$$

$$Q_4 = (\overline{u}_R c_L)\,(\overline{u}_R c_L)\,, \qquad Q_8 = (\overline{u}_L \sigma_{\mu\nu} c_R)\,(\overline{u}_L \sigma^{\mu\nu} c_R)\,.$$



$\mu : 1\,GeV$

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

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

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

★ ... which are

$$|z_1| \lesssim 5.7 \times 10^{-7} \left(\frac{\Lambda_{NP}}{1\ TeV}\right)^2,$$
$$|z_2| \lesssim 1.6 \times 10^{-7} \left(\frac{\Lambda_{NP}}{1\ TeV}\right)^2,$$
$$|z_3| \lesssim 5.8 \times 10^{-7} \left(\frac{\Lambda_{NP}}{1\ TeV}\right)^2,$$
$$|z_4| \lesssim 5.6 \times 10^{-8} \left(\frac{\Lambda_{NP}}{1\ TeV}\right)^2,$$
$$|z_5| \lesssim 1.6 \times 10^{-7} \left(\frac{\Lambda_{NP}}{1\ TeV}\right)^2.$$

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]

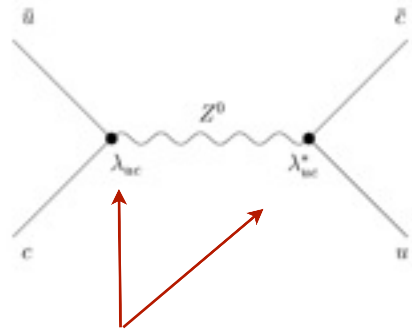
E.Golowich, J. Hewett, S. Pakvasa and A.A.P.
Phys. Rev. D76:095009, 2007

★ 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



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

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

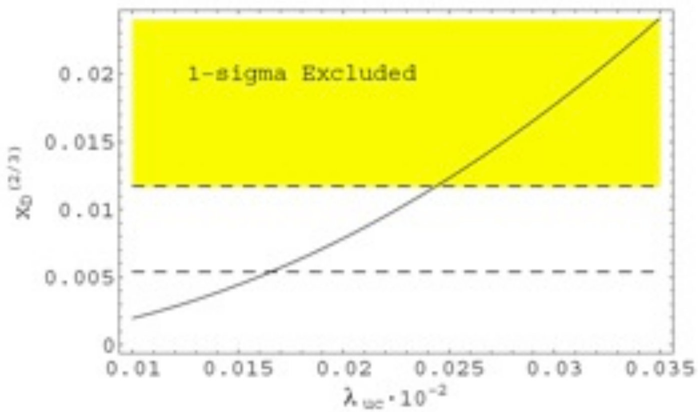
$$\mathcal{H}_{2/3} = \frac{g^2}{8\cos^2\theta_w M_Z^2}(\lambda_{uc})^2\,\bar{u}_L\gamma_\mu c_L \bar{u}_L\gamma^\mu c_L$$

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

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

3. Compute relevant matrix elements and x_D

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



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

Rare decays

★ Most general effective Hamiltonian:

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

$$\tilde{Q}_1 = (\bar{\ell}_L\gamma_\mu\ell_L)\ (\bar{u}_L\gamma^\mu c_L)\ , \qquad \tilde{Q}_4 = (\bar{\ell}_R\ell_L)\ (\bar{u}_R c_L)\ ,$$
$$\tilde{Q}_2 = (\bar{\ell}_L\gamma_\mu\ell_L)\ (\bar{u}_R\gamma^\mu c_R)\ , \qquad \tilde{Q}_5 = (\bar{\ell}_R\sigma_{\mu\nu}\ell_L)\ (\bar{u}_R\sigma^{\mu\nu} c_L)\ ,$$
$$\tilde{Q}_3 = (\bar{\ell}_L\ell_R)\ (\bar{u}_R c_L)\ ,$$

plus L ↔ R

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

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

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

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

$$|B| = G\frac{f_D}{4}\left[2m_\ell\left(\tilde{C}_{1-2}+\tilde{C}_{6-7}\right)+\frac{M_D^2}{m_c}\left(\tilde{C}_{4-3}+\tilde{C}_{9-8}\right)\right]$$

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

Mixing vs rare decays: a particular model

★ Recent experimental constraints

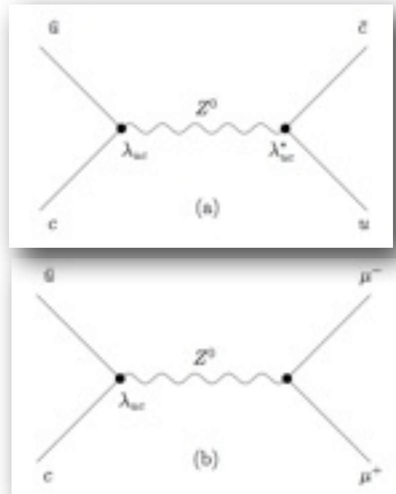
$$\mathcal{B}_{D^0\to\mu^+\mu^-} \leq 1.3\times 10^{-6}, \qquad \mathcal{B}_{D^0\to e^+e^-} \leq 1.2\times 10^{-6},$$

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

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:

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

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

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	$1.7\times 10^{-9}\ (500\ \mathrm{GeV}/m_{\tilde{d}_k})^2$

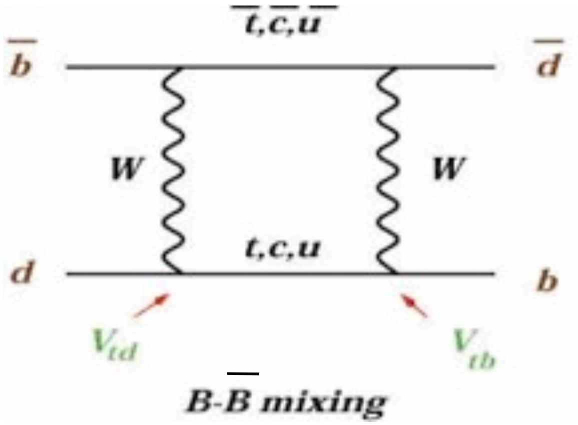
Obtained upper limits on rare decay branching ratios.

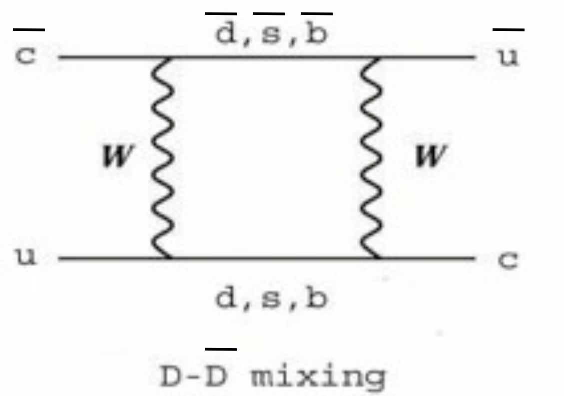
Can we apply the same idea where better data exists?

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

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

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

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

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

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

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

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

Buras

New Physics in B_s-mixing

➢ Relate NP contributions in B_s mixing and rare decays

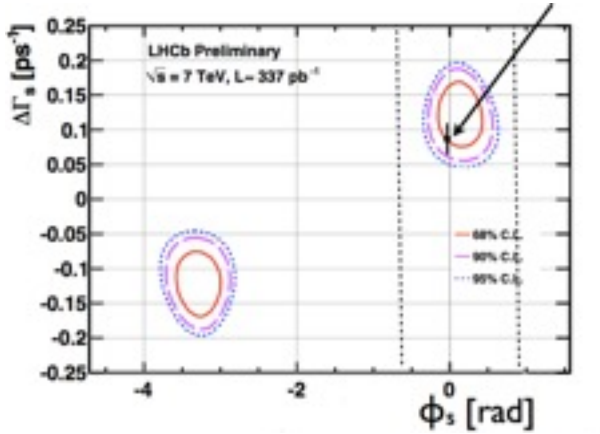
★ B_s mixing data:

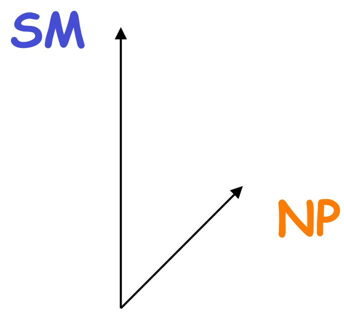
$$\Delta M_{B_s} = \Delta M_{B_s}^{(\mathrm{SM})} + \Delta M_{B_s}^{(\mathrm{NP})} \cos\phi.$$

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

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

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





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

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Mixing vs rare decays: some models

- Consider RPV SUSY: $\mathcal{W}_{\not R} = \frac{1}{2}\lambda_{ijk}L_iL_jE^c_k + \lambda'_{ijk}L_iQ_jD^c_k + \frac{1}{2}\lambda''_{ijk}U^c_iD^c_jD^c_k.$

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

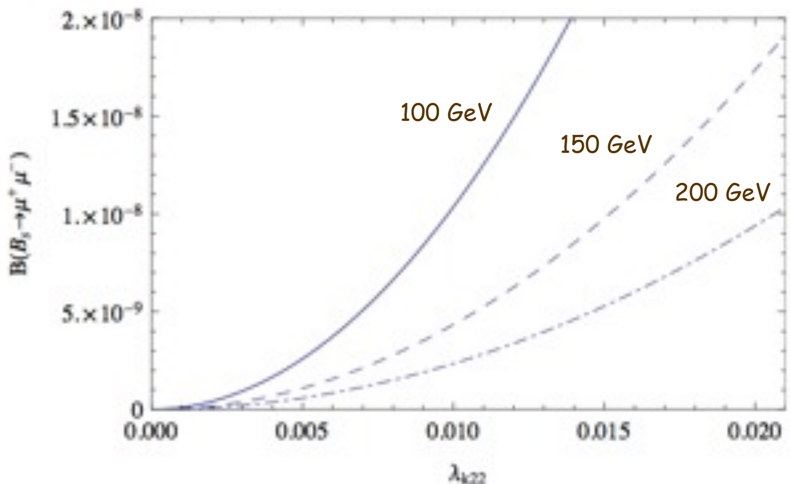
$$\Delta M^{(\not R)}_{B_s} = \frac{5}{24} f^2_{B_s} M_{B_s} F(C_3, B_3) \sum_i \frac{\lambda'_{i23}\lambda'^*_{i32}}{M^2_{\tilde{\nu}_i}},$$

Rare decay:

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

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

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



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

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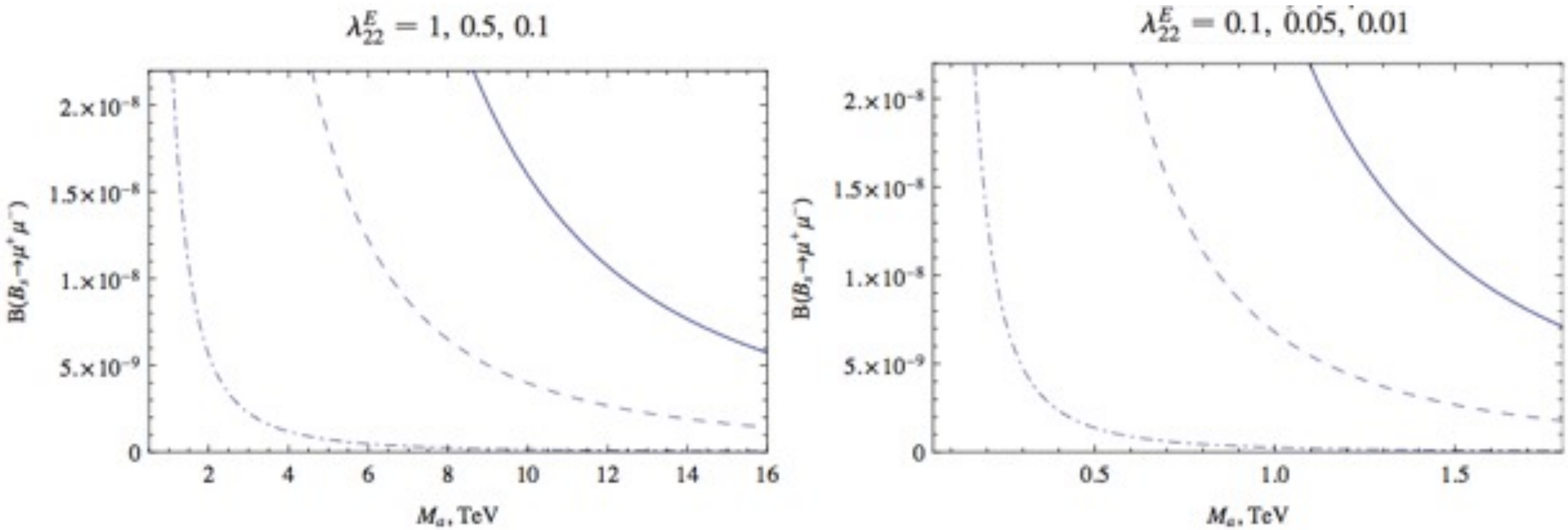
Mixing vs rare decays: some models

- 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:

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

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

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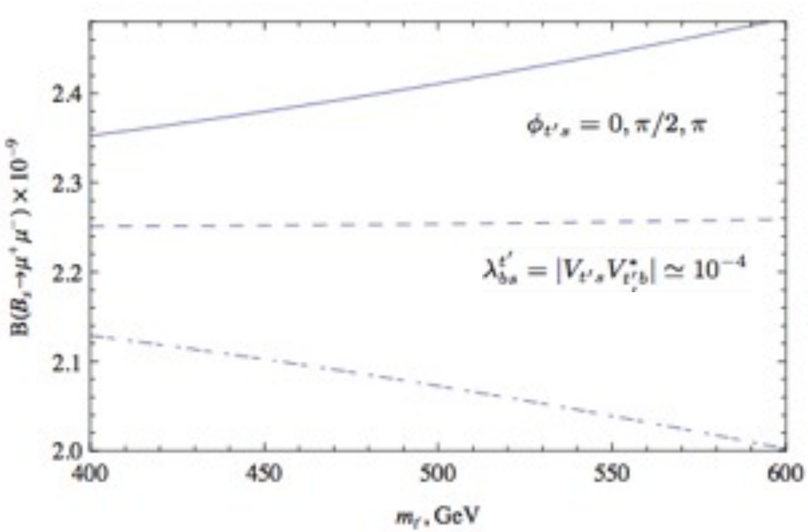

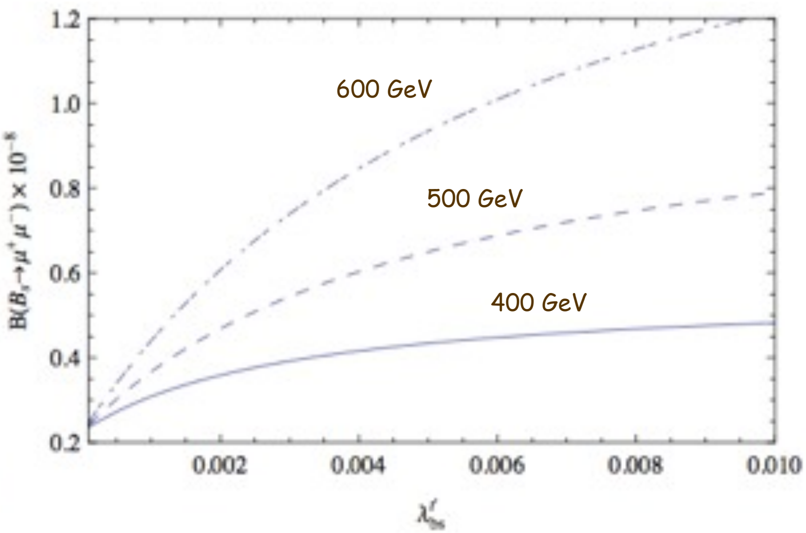

Things to take home

- 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
  - don't forget measurements unique to tau-charm factories
- Charm provides great opportunities for New Physics studies
  - unique access to up-type quark sector
  - large available statistics/in many cases small SM background
  - D-mixing is a second order effect in SU(3) breaking ($x,y \sim 1\%$ in the SM)
  - 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
- Happy Birthday, Alexander!!!