Constraining Minimal Flavor Violation

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1. New Physics Flavor Problem
   - MFV Hypothesis
2. MFV Signals
   - $\Delta F = 2$ processes
   - $\Delta F = 1$ processes
3. $\Delta F = 1$ analysis
   - Observables & Inputs
   - Strategy
   - Results
4. Charged currents at large $\tan\beta$: $B \to D\tau$
   - Theoretical Status
     - Hadronic uncertainties
   - Sensitivity to New physics
     - Observables

New Physics Flavor Problem

The SM accurately describes high energy physical phenomena up to $\mu_W \gtrsim 100$ GeV.

It is however known to be incomplete – gravity, unification.

But if it is an effective theory, at what scale ($\Lambda < \Lambda_{\mathrm{Planck},GUT}$) does it break down?

$$\mathcal{L}(\mu_W) = \underbrace{\Lambda^2 H^\dagger H}_{\mathrm{EW\ scale}} + \lambda (H^\dagger H)^2 + \mathcal{L}_{SM}^{\mathrm{gauge}} + \mathcal{L}_{SM}^{\mathrm{Yukawa}} + \underbrace{\frac{\mathcal{L}_5}{\Lambda} + \frac{\mathcal{L}_6}{\Lambda^2} + \ldots}_{\mathrm{FCNC,\ CPV,\ etc.}}$$

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EW hierarchy problem suggests: $\Lambda \lesssim 1$ TeV
Flavor bounds on generic NP operators:

$s \to d$:	$\Lambda \gtrsim 2 \times 10^5$ TeV	from ϵ_K
$b \to d$:	$\Lambda \gtrsim 2 \times 10^3$ TeV	from $A_{CP}(B_d \to \Psi K_s)$, Δm_d
$b \to s$:	$\Lambda \gtrsim 40$ TeV	from $Br(B \to X_s \gamma)$

recent analysis
UT*fit* '07

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EW hierarchy problem suggests: $\Lambda \lesssim 1$ TeV
Flavor bounds on generic NP operators: $\Lambda \sim 10^2 - 10^5$ TeV

Tension between these estimates of expected NP scales.

MFV Hypothesis

D'Ambrosio et al. hep-ph/0207036

All flavor symmetry breaking in and beyond the SM is proportional to the SM Yukawas:

- CKM is the only source of flavor mixing even beyond SM
- All (non-helicity suppressed) tree level and CP violating processes are constrained to their SM values
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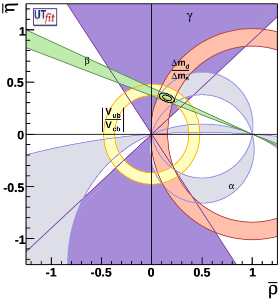

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- NP FCNCs in the down quark sector are driven by the large top Yukawa (λ_t)
- SM operator basis in the effective weak Hamiltonian is complete

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Large $\tan\beta$

- bottom Yukawa contributions become important as $\lambda_b(\sim m_b \tan\beta/v_u) \sim \lambda_t$
- partial lifting of helicity suppression in the down sector
- new density operators contribute to the effective weak Hamiltonian

MFV Signals

$\Delta F = 2$

- box loop mediated in the SM, few operators contributing
- moderate sensitivity to large $\tan\beta$ scenario
- K, B_q oscillation observables

recent UT*fit* analysis (0707.0636 [hep-ph])

$\Delta F = 1$

- penguin loop mediated in the SM, many operators contributing (orthogonal to $\Delta F = 2$)
- interesting role of large $\tan\beta$ scenario
- radiative, (semi)leptonic decays

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At large $\tan\beta$ also charged current processes become interesting!

$\Delta F = 2$ processes

$$\mathcal{H}_{\text{eff}}^{\Delta F=2} = \frac{G_F^2 m_W^2}{8\pi^2} |V_{ti}^* V_{tj}|^2 C_0 \left[\bar{d}_i \gamma_\mu (1-\gamma_5) d_j\right]^2$$

$$C_0(\mu_W) \to C_0(\mu_W)^{SM} (= S_0(x_t)/2) + \delta C_0$$

The shift can than we translated in terms of the tested energy scale ($\Lambda_0 = \lambda_t \sin^2(\theta_W) m_W / \alpha_{em} \sim 2.4$ TeV)

$$\delta C_0 = 2a \frac{\Lambda_0^2}{\Lambda^2}$$

where $a \sim 1$ for tree level NP contributions and $a \sim 1/16\pi^2$ for loop suppressed NP contributions

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small $\tan\beta$

NP shift δC_0 is a universal factor for K and B_q mixing:

$$\Lambda > 5.5 \text{ TeV @95\% Prob.}$$

large $\tan\beta$

$\lambda_b \tan\beta$ contributions break NP universality between Kaon and B sectors:

$$\Lambda > 5.1 \text{ TeV @95\% Prob.}$$

At very large $\tan\beta$

new operator contributes due to Higgs exchange in loop

$$\frac{a'}{\Lambda^2}\lambda_i\lambda_j \left[\bar{d}_i(1-\gamma_5)d_j\right]\left[\bar{d}_i(1+\gamma_5)d_j\right]$$

with a' being the $\tan\beta$ enhanced loop factor – relevant contributions to B_s mixing: bound on the charged Higgs mass

$$m_H^+ > 5\sqrt{a'}(\tan\beta/50) \text{ TeV @95\% Prob.}$$

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Independent NP contributions to the various operators: $C_i = C_i^{SM} + \delta C_i$

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EM and QCD dipole operators

$$\mathcal{Q}_{7\gamma} = \frac{2}{g^2} m_j \bar{d}_{iL} \sigma_{\mu\nu} d_{jR} (e F_{\mu\nu}) \qquad \mathcal{Q}_{8G} = \frac{2}{g^2} m_j \bar{d}_{iL} \sigma_{\mu\nu} T^a d_{jR} (g_s G^a_{\mu\nu})$$

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density operator at large $\tan\beta$

$$\mathcal{Q}_{S-P} = 4(\bar{d}_{iL} d_{jR})(\bar{\ell}_R \ell_L)$$

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NP contributions in QCD penguin operators neglected.

Observables

Theoretically most clean observables used to bound NP contributions:

- **$\mathbf{Br(B \to X_s \ell^+ \ell^-)}$** measured in 4 bins. We ommit the charmonium resonance region.

  Operators contributing: $\mathcal{Q}_{7\gamma}$, $\mathcal{Q}_{8G}$, $\mathcal{Q}_{9V}$, $\mathcal{Q}_{10A}$, $\mathcal{Q}_{S-P}$

  We use partial NNLO result including all NP contributions and rescale the expressions so that our SM prediction agrees with the full NNLO EM corrected result (only needed for the high q^2 region).

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- **$\mathbf{Br(K^+ \to \pi^+ \nu \bar{\nu})}$** hints.

  Operator contributing: $\mathcal{Q}_{\nu\bar{\nu}}$

  Theoretically clean by combining $K\ell 3$ experimental data.

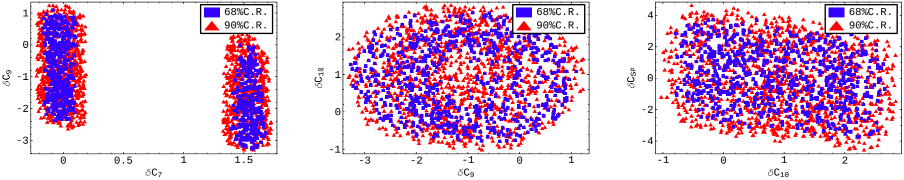
Inputs and Strategy

- CKM Inputs:
  - Use UUT fit correlated results from tree level observables and CKM phase.
- Known NP Correlations:
  - $C_{7\gamma}$ and C_{8G} always appear in the same quadratic combination – form degenerate ellipses in the parameter plane. We omit δC_{8G} from the fit.
  - $C_{\nu\bar{\nu}}$ contributes only to $K^+ \to \pi^+ \nu\bar{\nu}$. Perform a separate fit.
- Fit procedure:
  - MC sampling of input parameter space. Combined fit of all correlated observables (minimal χ^2/d.o.f $\simeq 0.5$, SM χ^2/d.o.f $\simeq 1$).

Results

Discrete ambiguities and correlations

- $\delta C_{7\gamma}$ is bounded up to a single discrete ambiguity from $B \to X_s\gamma$.
- δC_{10A} and δC_{9V} contribute comparably in the higher q^2 regions of $B \to X_s\ell^+\ell^-$ resulting in a bound on their quadratic combination (ellipse).
- δC_{S-P} is then mostly bounded by $B_s \to \mu^+\mu^-$
- A slight correlation develops between $\delta C_{7\gamma}$ and δC_{9V} due to their interference term, dominating the low q^2 region in $B \to X_s\ell^+\ell^-$.
- Small correlation also between δC_{10A} and δC_{S-P} due to their interference in $B_s \to \mu^+\mu^-$.



Limits

Conservative estimate

Taking into account all correlations and discrete ambiguities (allowing for fine-tuned solutions).

$\delta C_{7\gamma}$	$\Lambda > 1.6$ TeV @ 95% Prob.
δC_{8G}	$\Lambda > 1.2$ TeV @ 95% Prob.
δC_{9V}	$\Lambda > 1.4$ TeV @ 95% Prob.
δC_{10A}	$\Lambda > 1.5$ TeV @ 95% Prob.
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$\delta C_{\nu\bar{\nu}}$	$\Lambda > 1.5$ TeV @ 95% Prob.

Bounds are convention dependent. Compared to previous analysis (D'Ambrosio et al. hep-ph/0207036):

- Factor of $1/\sqrt{2}$ for penguin operators.
- Factor of e, g_s for $\delta C_{7\gamma,8G}$

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Individual couplings

Due to the small correlations, the bounds do not improve dramatically. Exceptions are $\delta C_{7\gamma,8G}$ and δC_{9V}. Especially if we discard the fine-tuned solution for the former.

$\delta C_{7\gamma}$	$\Lambda > 2.0(5.3)$ TeV @ 95% Prob.
δC_{8G}	$\Lambda > 1.4(3.1)$ TeV @ 95% Prob.
δC_{9V}	$\Lambda > 1.6$ TeV @ 95% Prob.

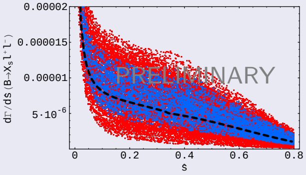
Window for new physics in other observables

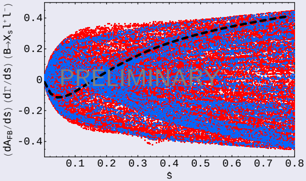
Using NP parameter combinations within the 95% C.L. regions of our fit, we make predictions for other observables.

Observables to discriminate between SM and MFV NP

- **$dA_{FB}(B \to X_s \ell^+ \ell^-)/dq^2$ and its zero:**

  Present bounds still allow for the full range of possible predictions for both the integrated A_{FB} as well as for the position or absence of the zero of $(dA_{FB}/dq^2)/(d\Gamma/dq^2)$.





- Similar results for the exclusive channel $B \to K^* \ell^+ \ell^-$.

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Observables to invalidate MFV and probe large $\tan\beta$

- $(\mathbf{d\Gamma(B \to K\mu^+\mu^-)/dq^2})/(\mathbf{d\Gamma(B \to Ke^+e^-)/dq^2})$:
  In the SM this ratio is close to 1. In MFV with large $\tan\beta$ up to $\mathcal{O}(10\%)$ deviations in the high q^2 region are still allowed.

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- $\mathbf{Br(B_d \to \mu^+\mu^-) < 1.2 \times 10^{-9}}$
  Similar suppression for other $b \to d$ transitions.

Summary of Part 1

- Model independent bounds can be set on the complete set of MFV NP contributions (also in the limit of large $\tan\beta$).
  - Bounds on NP contributions in $\Delta F = 2$ processes very constraining
  - In $\Delta F = 1$ processes, presently only $\delta C_{7\gamma}$ (δC_{8G}) bounds of comparable strength
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  - Possibilities to invalidate MFV: $|V_{td}/V_{ts}|^2 \sim 4\%$ $B_d \to \mu^+\mu^-$, $B \to X_d \gamma$, $B \to X_d \ell^+ \ell^-$, etc. should be suppressed.
  - Distinctive new signals of large $\tan\beta$: $d\Gamma(B \to K\mu^+\mu^-)/dq^2)/(d\Gamma(B \to Ke^+e^-)/dq^2)$

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    $B_d \to \mu^+\mu^-$, $B \to X_d \gamma$, $B \to X_d \ell^+ \ell^-$, etc. should be suppressed.
  - Distinctive new signals of large $\tan\beta$:
    $d\Gamma(B \to K\mu^+\mu^-)/dq^2)/(d\Gamma(B \to Ke^+e^-)/dq^2)$
- Also these bounds are consistent with new degrees of freedom being found at the LHC

Tree level NP d.o.f. exchange:	$\Lambda \gtrsim 1$ TeV
Loop NP d.o.f. exchange:	$\Lambda \gtrsim 100$ GeV

MFV at large $\tan\beta$ and charged currents:
$B \to D\tau\nu$

Status of $b \to c$ transitions

V_{cb} is determined precisely

- From combined fit to inclusive $B \to X_c \ell\nu$ and $B \to X_s\gamma$ decays using theoretical HQ OPE inputs:

$$|V_{cb}|_{\rm 1S} = (41.78 \pm 0.30({\rm fit}) \pm 0.08(\tau_B)) \times 10^{-3}$$

HFAG, LP07

- From a fit to exclusive $B \to D^*\ell\nu$ differential decay rate, using theoretical form factor inputs from HQET, dispersion relations and lattice QCD:

$$|V_{cb}|_{\rm excl.} = (38.84 \pm 0.61({\rm exp}) \pm 0.96({\rm theo})) \times 10^{-3}$$

M. Rotondo, Heidelberg '07

Status of $b \to c$ transitions

Possibility to probe "subleading" phenomenology

- $B \to D\ell\nu$: probe theoretical approaches to form factor calculations and HQET $1/m_Q$ power corrections
- $B \to D\tau\nu$:
  - Motivation related to pure leptonic decays: $K \to \mu\nu$, $D_{(s)} \to \mu\nu$, $B_u \to \tau\nu$
    - Lepton flavor universality tests
    - Large lepton mass enables probing helicity suppressed contributions

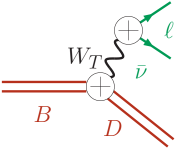
    } Possible windows to new physics (Charged Higgs, LFV SUSY,. . .)
  - More involved due to the interference with the non helicity suppressed amplitude.
  - Same information more diluted in $B \to D^*\tau\nu$ or $B \to X_c\tau\nu$.
- $B \to D^{**}\ell\nu$ puzzle, . . .

Theoretical Status of $B \to D\ell\nu$ transitions (in the SM)

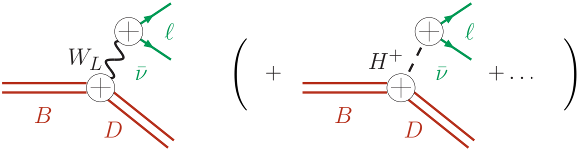
The differential decay rate ($w = v_B \cdot v_D$, $\ell = e, \mu, \tau$) factorizes:

$$\frac{d\Gamma(B \to D\ell\overline{\nu})}{dw} = \frac{G_F^2 |V_{cb}|^2 m_B^5}{192\pi^3} \underbrace{\rho_V(w)}\left[1 - \underbrace{\frac{m_\ell^2}{m_B^2}\rho_S(w)}\right],$$

Transverse vector contribution



Relative longitudinal vector (and scalar) contributions



Theoretical Status of $B \to D\ell\nu$ transitions (in the SM)

The differential decay rate ($w = v_B \cdot v_D$, $\ell = e, \mu, \tau$) factorizes:

$$\frac{d\Gamma(B \to D\ell\overline{\nu})}{dw} = \frac{G_F^2 |V_{cb}|^2 m_B^5}{192\pi^3} \rho_V(w) \left[1 - \frac{m_\ell^2}{m_B^2} \rho_S(w)\right],$$

Helicity amplitudes ($t(w) = m_B^2 + m_D^2 - 2wm_D m_B$):

$$\rho_V(w) = 4\left(1 + \frac{m_D}{m_B}\right)^2 \left(\frac{m_D}{m_B}\right)^3 \left(w^2 - 1\right)^{\frac{3}{2}} \left(1 - \frac{m_\ell^2}{t(w)}\right)^2 \left(1 + \frac{m_\ell^2}{2t(w)}\right) G(w)^2,$$

$$\rho_S(w) = \frac{3}{2}\frac{m_B^2}{t(w)} \left(1 + \frac{m_\ell^2}{2t(w)}\right)^{-1} \frac{1+w}{1-w} \Delta(w)^2,$$

Nonperturbative QCD dynamics encoded in the two form factors.

Determining $G(w)$

- Contributes only to helicity 1 amplitude (proportional to $F_1(t)$) – enough to describe $B \to De(\mu)\nu$
- Equal to the universal Isgur-Wise function $\xi(w)$ in the heavy quark limit
- QCD and $1/m_Q$ power corrections can be systematically evaluated at zero recoil ($w = 1$) point:

$$G(1) = \eta_v - \frac{m_B - m_D}{m_B + m_D}(\delta_{\rm rad} + \delta_{1/m_Q}) + \mathcal{O}(\alpha_s^2, 1/m_Q^2) = 1.05(8)$$

Nierste et al. arXiv:0801.4938

- Same kinematical point is accessible on the lattice
  - Double correlator ratios and heavy quark symmetry reduce sources of discretization, renormalization as well as statistical errors
  - First unquenched results available

$$G(1) = 1.074(18)(16)$$

Okamoto et al. hep-lat/0409116

Determining $G(w)$ away from zero recoil

- Values away from zero recoil are needed in order to evaluate differential and (partially) integrated decay rates and asymmetries.
- A parameterization can be used (several on the market)
  - Simple Taylor expansion: $G(w) = G(1) \times (1 + \rho^2(w-1) + \ldots)$,
  - Based on general analyticity and crossing symmetry arguments

$$G(t(w)) = \frac{1}{P(t)\phi(t,t_0)} \sum_{k=0}^{\infty} a_k(t_0) z(t,t_0)^k \,,$$

    Expansion series can be made well behaved using unitarity (choice of ϕ) and known positions of subtreshold poles (zeros of P).

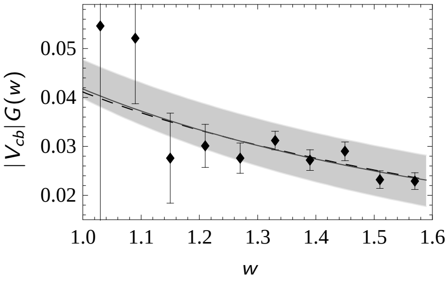
    Hill hep-ph/0606023
  - Using in heavy quark symmetry relations (up to $1/m_Q^2$ corrections) and dispersion relations, similarly
    $G(w) = G(1) \times [1 - 8\rho^2 z(w) + (51\rho^2 - 10) z(w)^2 - (252\rho^2 - 84) z(w)^3]$,

    Caprini et al. hep-ph/9712417

Determining $G(w)$ away from zero recoil

- Extrapolation parameters can be extracted from measured $B \to De\nu$ decay spectra
- Poor handle on parameters near zero recoil due to small statistics
- Presently, data do not distinguish between the parameterizations

Belle hep-ex/0111082



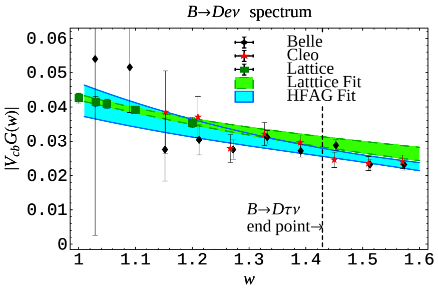
Nierste et al. arXiv:0801.4938

Determining $G(w)$ away from zero recoil

- First (quenched) lattice studies of $G(w)$ at $w \geq 1$

  Divitiis et al. arXiv:0707.0582

- Limited kinematical range currently accessible $w \in [1, 1.2]$
- Complementary to experimental data – possible to compare extrapolations



J.F.K. & F. Mescia arXiv:0802.3790

Determining $\Delta(w)$

- Contributes only to helicity 0 amplitude (proportional to $F_0(t)/F_1(t)$) – contributions suppressed by m_ℓ/m_B in the SM
- Essential for describing $B \to D\tau\nu$, sensitive to scalar NP contributions
- At leading order is constant over the kinematical phase-space:

$$\Delta(w) = \frac{m_B - m_D}{m_B + m_D} + \mathcal{O}(1/m_Q)$$

- Dimensionless variable, leading order value fixed by symmetry & kinematics ($\Delta_{l.o.} = 0.477$) – very good precision attainable on the lattice
- First estimate consistent with a constant value over the presently accessible range $w \in [1, 1.2]$

$$\Delta(w) = 0.46(1)$$

Divitiis et al. arXiv:0707.0582,

New physics and $B \to D\tau\nu$

We are interested in (pseudo)scalar contributions to the effective $\Delta F = 1$ Hamiltonian governing charged current transitions involving b quarks

$$\mathcal{H}_{eff}^{b\to q} = \frac{G_F}{\sqrt{2}} V_{qb} \sum_{\ell=e,\mu,\tau} \Big[(\bar{q}\gamma_\mu(1-\gamma_5)b)(\bar{\ell}\gamma^\mu(1-\gamma_5)\nu) + C_{NP}^{\ell}(\bar{q}(1+\gamma_5)b)(\bar{\ell}(1-\gamma_5)\nu_\ell) \Big] + \text{h.c.}$$

- Minimal Flavor Violating NP with two Higgs doublets and large $v_u/v_d = \tan\beta$ (THDM, MFV MSSM)

$$C_{NP}^{\ell} = -\frac{m_b m_\ell}{m_{H^+}^2} \frac{\tan^2\beta}{1+\epsilon_0 \tan\beta}$$

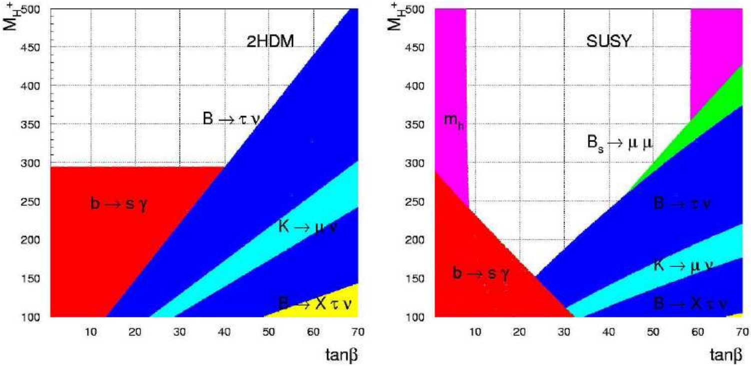
($\epsilon_0 \sim 0.01$ parametrizes loop corrections in MSSM, becomes important at very large $\tan\beta$)

- Other relevant scenarios: R Parity Violating MSSM, Lepton Flavor Violating MSSM,...

New physics and $B \to D\tau\nu$

Several NP models predict links to other phenomenology

- Charged currents among different flavors: $b \to c$, $b \to u$, $s \to u$
- Flavor changing neutral currents: $b \to s\gamma$, $B_s \to \mu\mu$
- Flavor conserving observables: direct searches, R_b,...

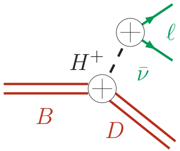


P. Paradisi, Perugia '08

New physics and $B \to D\tau\nu$

New physics effects on the $B \to D\tau\nu$ differential decay rate

$$\frac{d\Gamma(B \to D\tau\nu)}{dw} = \frac{G_F^2 |V_{cb}|^2 m_B^5}{192\pi^3} \rho_V(w) \left[1 - \frac{m_\tau^2}{m_B^2} \left| 1 + \underbrace{\frac{t(w)}{(m_b - m_c) m_\tau}} C_{NP}^\tau \right|^2 \rho_S(w) \right]$$

$+$  $+ \ldots$

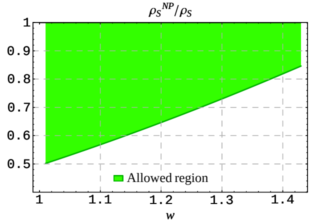
Comparison with $B_{u,c} \to \tau\nu$:

$$Br(B_q \to \tau\nu) = \frac{G_F^2 |V_{qb}|^2}{8\pi} m_\tau^2 f_{B_q}^2 m_{B_q} \tau_{B_q} \left(1 - \frac{m_\tau^2}{m_{B_q}^2} \right)^2 \left| 1 + \frac{m_{B_q}^2}{(m_b + m_q) m_\tau} C_{NP}^\tau \right|^2$$

New physics and $B \to D\tau\nu$

New physics effects on the $B \to D\tau\nu$ differential decay rate

$$\frac{d\Gamma(B \to D\tau\nu)}{dw} = \frac{G_F^2 |V_{cb}|^2 m_B^5}{192\pi^3} \rho_V(w) \left[1 - \frac{m_\tau^2}{m_B^2} \left| 1 + \underbrace{\frac{t(w)}{(m_b - m_c) m_\tau} C_{NP}^\tau} \right|^2 \rho_S(w) \right]$$



Taking into account existing bounds from $B_u \to \tau\nu$ and $K \to \mu\nu$ (within MFV models), there is room for large deviations in $B \to D\tau\nu$ zero helicity amplitude!

Observables – Presently Accessible

Fully integrated branching ratio $Br(B \to D\tau\nu) = \tau_B \int_w d\Gamma(B \to D\tau\nu)$

Theoretical uncertainties:

- $G(1)$ normalization (2%), $|V_{cb}|$ (1%) – relevant product in principle extractible from $B \to De\nu$ but inefficient (11%),
- B meson lifetime τ_B (1%),
- $G(w)$ parametrization – ρ^2 (15%),
- scalar form factor Δ (2%)

Experimentally a "derived" quantity ($B \to D\tau\nu$ rate is normalized by $B \to De\nu$)

Observables – Presently Accessible

Ratio $Br(B \to D\tau\nu)/Br(B \to De\nu)$

- Only the last two theoretical inputs remain relevant ("ρ^2", Δ)
- Normalization to $Br(B \to De\nu)$ requires large extrapolation – large parametrization effects

$$\left.\frac{Br(B \to D\tau\nu)}{Br(B \to De\nu)}\right|_{th} = (0.28 \pm 0.02) \times \left[1 + 1.38(3) Re(C^\tau_{NP}) + 0.88(2) |C^\tau_{NP}|^2\right] .$$

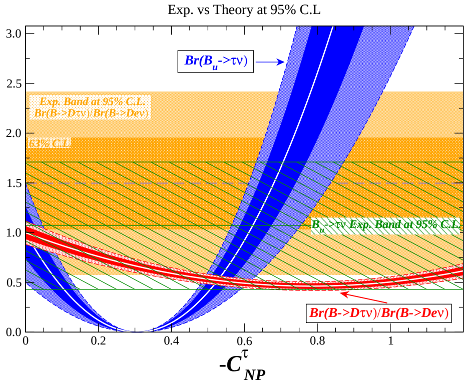
- Experimentally measured:
  $Br(B \to D\tau\nu)/Br(B \to De\nu)_{exp} = (40.7 \pm 12.0 \pm 4.9)\%$

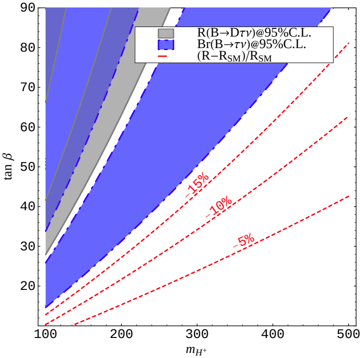
BaBar arXiv:0707.2758

- Already allows to constrain NP contributions to
  $(-2.25 < C^\tau_{NP} < -1.04) \bigcup (-0.52 < C^\tau_{NP} < 0.69)$ at 95% C.L.

Observables – Presently Accessible

Comparison of bounds from $B \to D\tau\nu$ and $B_u \to \tau\nu$ (in MFV)





J.F.K. & F. Mescia arXiv:0802.3790

Observables – Presently Accessible

Ratio $Br(B \to D\tau\nu)/Br(B \to De\nu)|_{w<1.43}$

- Theoretical uncertainties reduced by smaller extrapolation region

$$\left.\frac{Br(B \to D\tau\nu)}{Br(B \to De\nu)}\right|_{w<1.43,th} = (0.56 \pm 0.02) \times \left[1 + 1.38(3) Re(C^{\tau}_{NP}) + 0.88(2)|C^{\tau}_{NP}|^2\right]$$

  - Only the overall factor affected.
  - Relative NP contributions only sensitive to Δ.
- Experimentally, full $B \to D\tau\nu$ statistics can be retained with such kinematical cut.
- Tightening the cut closer to the region directly accessible to lattice simulations ($w < 1.2$) can further reduce theoretical uncertainties due to extrapolation at the expense of experimental statistics.

Observables – Prospective

Binned, partially integrated differential rates, normalized to the $B \longrightarrow De\nu$

$$\frac{d\Gamma(B \to D\tau\nu)/dw}{d\Gamma(B \to De\nu)/dw} = \left(1 - \frac{m_\ell^2}{t(w)}\right)^2 \left(1 + \frac{m_\ell^2}{2t(w)}\right) \times \left[1 - \frac{m_\tau^2}{m_B^2}\left|1 + \frac{t(w)}{(m_b - m_c)m_\tau} C_{NP}^\tau\right|^2 \rho_S(w)\right]$$

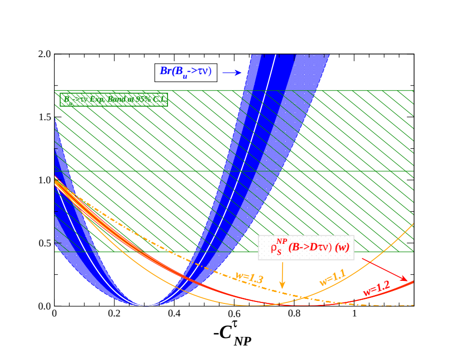
K. Kiers & A. Soni hep-ph/9706337

- Theoretical uncertainties related to vector form factor normalization and shape are reduced
- All emphasis theoretically is here on the determination of Δ
- With constant or mildly varying Δ, NP contribution has a distinctive kinematic $t(w)$ dependence compared to the SM
- Comparison with binned experimentally determined distributions still requires interpolations of $G(w)$ over finite binned energy range.

Observables – Prospective

Binned, partially integrated differential rates, normalized to the $B \to De\nu$

- Sensitivity to NP contributions varies within the kinematical range



J.F.K. & F. Mescia arXiv:0802.3790

Observables – Prospective

Other distributions & tau polarization observables

The transverse polarization of the tau ($\mathbf{S}_\tau$ is the spin of the tau):

$$p_T^\tau = \frac{\mathbf{S}_\tau \cdot (\mathbf{p}_\tau \times \mathbf{p}_D)}{|\mathbf{p}_\tau \times \mathbf{p}_D|}$$

Atwood et al. hep-ph/9303268,

Grossman & Ligeti hep-ph/9403376

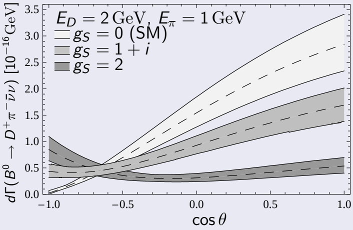
- vanishes in the SM
- very clean observable, applicable to all exclusive modes as well as the inclusive $B \to X_c \tau \nu$ transition
- very sensitive to the presence of a CP-odd phase in scalar interactions

Observables – Prospective

Other distributions & tau polarization observables

Decay chain $B \to D\nu\tau[\to \pi\nu]$ differential distribution with respect to the angle between three-momenta $\mathbf{p}_D$ and $\mathbf{p}_\pi$ (in B rest-frame)

- In conjunction with $B \to \tau\nu$ measurement sensitive to the weak phase of the NP contribution



$(g_S = -C^\tau_{NP} m_B^2 / m_b m_\tau)$

Nierste et al. arXiv:0801.4938

- Only experimentally accessible at the Super Flavor Factory

Conclusions Part II

$B \to D\tau\nu$ decay theoretically well under control

- Using judiciously constructed observables many uncertainties can be reduced
- Irreducible uncertainties: $\Delta(w)$ form factor – well suited for lattice studies
- Partially reducible uncertainties: extrapolation parameters – can be constrained and eliminated combining lattice results and experimental $B \to De\nu$ data
- $B_s \to D_s$ transitions are much better suited for lattice studies: large uncertainties related to chiral extrapolation of valence quark masses are reduced

Conclusions Part II

Sensitivity to scalar NP contributions

- Even in presence of existing bounds from other observables large room remains
- Improvements in precision possible at hadronic machines (unlike e.g. $B \to \tau\nu$)
- With progressive experimental precision, progressively more sensitive observables can be sought
  - Branching ratios w/o kinematic cuts – good for constraining NP
  - Binned differential decay distributions – can probe NP couplings
  - Other distributions and tau polarization observables – sensitive to new NP phases