Flavor models for $B \rightarrow D^{(*)} \tau \bar{\nu}$

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Implications of LHCb Measurements and Future Prospects
CERN, Nov 3–5, 2015

The most significant deviation from the SM

- Belle & LHCb results on the anomaly seen by BaBar in

\[ R(X) \equiv \frac{\Gamma(B \to X\tau\bar{\nu})}{\Gamma(B \to X(e/\mu)\bar{\nu})} \]

<table>
<thead>
<tr>
<th></th>
<th>( R(D) )</th>
<th>( R(D^*) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaBar</td>
<td>0.440 ± 0.058 ± 0.042</td>
<td>0.332 ± 0.024 ± 0.018</td>
</tr>
<tr>
<td>Belle</td>
<td>0.375 ± 0.064 ± 0.026</td>
<td>0.293 ± 0.038 ± 0.015</td>
</tr>
<tr>
<td>LHCb</td>
<td></td>
<td>0.336 ± 0.027 ± 0.030</td>
</tr>
<tr>
<td>Average</td>
<td>0.391 ± 0.050</td>
<td>0.322 ± 0.022</td>
</tr>
<tr>
<td>my SM expectation</td>
<td>0.300 ± 0.010</td>
<td>0.252 ± 0.005</td>
</tr>
<tr>
<td>Belle II, 50/ab</td>
<td>±0.010</td>
<td>±0.005</td>
</tr>
</tbody>
</table>

SM predictions fairly robust: heavy quark symmetry + lattice QCD, only \( R(D) \) \cite{[1503.07237, 1505.03925]}

- Need NP at fairly low scales (leptoquarks, \( W' \), etc.), likely visible in LHC Run 2
- Next: LHCb result for \( R(D) \) ? Using more \( \tau \) decays? Measure \( \Lambda_b \to \Lambda_c^{(*)}\tau\nu \)?
- Question we asked: can the new physics explaining \( R(D^{(*)}) \) be MFV?
**B → D(∗)eν vs. B → D(∗)µν**

- How well is the difference of the $e$ and $µ$ rates constrained?

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$D_e$ sample</th>
<th>$D_µ$ sample</th>
<th>combined result</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ρ_D^2$</td>
<td>1.22 ± 0.05 ± 0.10</td>
<td>1.10 ± 0.07 ± 0.10</td>
<td>1.16 ± 0.04 ± 0.08</td>
</tr>
<tr>
<td>$ρ_{D^*}^2$</td>
<td>1.34 ± 0.05 ± 0.09</td>
<td>1.33 ± 0.06 ± 0.09</td>
<td>1.33 ± 0.04 ± 0.09</td>
</tr>
<tr>
<td>$R_1$</td>
<td>1.59 ± 0.09 ± 0.15</td>
<td>1.53 ± 0.10 ± 0.17</td>
<td>1.56 ± 0.07 ± 0.15</td>
</tr>
<tr>
<td>$R_2$</td>
<td>0.67 ± 0.07 ± 0.10</td>
<td>0.68 ± 0.08 ± 0.10</td>
<td>0.66 ± 0.05 ± 0.09</td>
</tr>
<tr>
<td>$B(D^0_e ν)(%)$</td>
<td>2.38 ± 0.04 ± 0.15</td>
<td>2.25 ± 0.04 ± 0.17</td>
<td>2.32 ± 0.03 ± 0.13</td>
</tr>
<tr>
<td>$B(D^{*0}_e ν)(%)$</td>
<td>5.50 ± 0.05 ± 0.23</td>
<td>5.34 ± 0.06 ± 0.37</td>
<td>5.48 ± 0.04 ± 0.22</td>
</tr>
<tr>
<td>$χ^2$/n.d.f. (probability)</td>
<td>416/468 (0.96)</td>
<td>488/464 (0.21)</td>
<td>2.0/6 (0.92)</td>
</tr>
</tbody>
</table>

[BaBar, 0809.0828 — similar results in Belle, 1010.5620]

Individual rates appear to be systematics limited

- We assumed $e/µ$ universality, not a necessity

- Can difference be constrained better? How much better?

Reaching the 1% level on ratio might be possible (but tough) even at Belle II
SM predictions fairly robust

- Measurements + heavy quark symmetry + lattice QCD calculations

![Graph showing the measured $w$ dependence of $F(w)|V_{cb}|$ compared to the theoretical function with fitted parameters. The experimental uncertainties are too small to be visible.](BaBar, 0705.4008)
Tension with SM is model independent

- Use an OPE-based analysis to constrain SM allowed range as much as possible

- Learn from inclusive = ∑ exclusive

\[ R(X_c) = 0.222 \pm 0.003 \]

\[ \mathcal{B}(B^- \to X_c \ell \bar{\nu}) = (10.92 \pm 0.16)\% \]

\[ \Rightarrow \mathcal{B}(B^- \to X_c \tau \bar{\nu}) = (2.42 \pm 0.05)\% \]

[LEP: \( \mathcal{B}(b \to X \tau^+ \nu) = (2.41 \pm 0.23)\% \)]

- The \( R(D^{(*)}) \) data imply: \( \mathcal{B}(\bar{B} \to D^* \tau \bar{\nu}) + \mathcal{B}(\bar{B} \to D \tau \bar{\nu}) = (2.78 \pm 0.25)\% \)

- Estimate \( \mathcal{B}(B \to D^{**} \tau \bar{\nu}) \gtrsim 0.2\% \) in the SM (the four \( 1P \) states)

- Tension \( \gtrsim 2\sigma \), based on inclusive calculation + minimal assumptions

Complementary to SM calculation of \( R(D^{(*)}) \) and LEP data
No measurements since LEP, Belle analysis in progress (ε theory work in last ~ 15 yrs) Papers in '90s used $m_b^{\text{pole}}$, no study of spectra (exp. needed) & uncertainties — big $1/m^2$ terms

[ZL & Tackmann, 1406.7013]
Consider all $\tau$ modes... $b \rightarrow u\tau\bar{\nu}$?

- If deviation clearly established, huge motivation to study all decay modes with $\tau$

  If LEP could measure $B \rightarrow X_c\tau\bar{\nu}$ with a few $\times 10^6$ $B - \bar{B}$ pairs...

  ... “surely” Belle II can measure $B \rightarrow X_u\tau\bar{\nu}$ with $5 \times 10^{10}$ $B - \bar{B}$ pairs...

- The inclusive calculation is unavailable for any distribution

  $m_\tau \neq 0$ complicates things in an interesting way

  $1.8 \text{ GeV} < E_\tau < 2.9 \text{ GeV}$ — Subtleties with shape function; full rate in SF region?

- Phase space suppression is smaller in $b \rightarrow u$:

  \[
  \frac{\Gamma(B \rightarrow X_u\ell\bar{\nu})}{\Gamma(B \rightarrow X_u\tau\bar{\nu})} \simeq 3.0 \quad \quad \frac{\Gamma(B \rightarrow X_c\ell\bar{\nu})}{\Gamma(B \rightarrow X_c\tau\bar{\nu})} \simeq 4.5
  \]

- Can LHCb measure $b \rightarrow u\tau\bar{\nu}$ decay modes? Ratios of $\tau/\mu$ or/and $c/u$?

  $\Lambda_b \rightarrow \Lambda\tau\bar{\nu}$? $B \rightarrow \pi\tau\bar{\nu}$? $B \rightarrow \rho\tau\bar{\nu}$?

  [See also P. Owen’s talk]
Operator analysis
BaBar statements from $q^2$ spectrum results

- BaBar studied consistency of rates with 2HDM, and $d\Gamma/dq^2$ with several models

- Found that type-II 2HDM gave nearly as bad fit to the data as the SM

- $d\Gamma/dq^2$ has additional discriminating power (no other distribution measured yet)

- Not enough public info to do real fit, eyeball which solutions are disfavored

**Consider redundant set of operators**

- **Fits to different fermion orderings convenient to understand allowed mediators**

Usually only the first 5 operators considered, related by Fierz from dim-6 terms, others from dim-8 only

<table>
<thead>
<tr>
<th>Operator</th>
<th>Fierz identity</th>
<th>Allowed Current</th>
<th>$\delta L_{\text{INT}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$O_{V_L}$ $(\bar{c}\gamma_{\mu}P_Lb)$ $(\bar{\tau}\gamma^{\mu}P_L\nu)$</td>
<td>$O_{V_L}$</td>
<td>$(1, 3)_0$</td>
<td>$(g_\ell \bar{q}<em>L \tau \gamma^\mu q_L + g</em>\ell \bar{\ell}<em>L \tau \gamma^\mu \ell_L)W^\mu</em>{\mu}$</td>
</tr>
<tr>
<td>$O_{V_R}$ $(\bar{c}\gamma_{\mu}P_Rb)$ $(\bar{\tau}\gamma^{\mu}P_L\nu)$</td>
<td>$-2O_{V_R}$</td>
<td>$\left{(1, 2)_{1/2}\right}$</td>
<td>$\left(\lambda_d \bar{q}_L d_R \phi + \lambda_u \bar{q}<em>L u_R i\tau_2 \phi + \lambda</em>\ell \bar{\ell}_L e_R \phi\right)$</td>
</tr>
<tr>
<td>$O_{S_R}$ $(\bar{c}P_Rb)$ $(\bar{\tau}P_L\nu)$</td>
<td>$-\frac{1}{2}O_{V_R}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_{S_L}$ $(\bar{c}P_Lb)$ $(\bar{\tau}P_L\nu)$</td>
<td>$-\frac{1}{2}O_{S_L} - \frac{1}{8}O_T$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_T$ $(\bar{c}\sigma^{\mu\nu}P_Lb)$ $(\bar{\tau}\sigma_{\mu\nu}P_L\nu)$</td>
<td>$-6O_{S_L} + \frac{1}{2}O_T$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O'<em>{V_L}$ $(\bar{\tau}\gamma</em>{\mu}P_Lb)$ $(\bar{\tau}\gamma^{\mu}P_L\nu)$</td>
<td>$\left{O_{V_L}\right}$</td>
<td>$(3, 3)_{2/3}$</td>
<td>$\lambda \bar{q}<em>L \tau \gamma</em>{\mu} \ell_L U^\mu$</td>
</tr>
<tr>
<td>$O'<em>{V_R}$ $(\bar{c}\gamma</em>{\mu}P_Rb)$ $(\bar{\tau}\gamma^{\mu}P_L\nu)$</td>
<td>$-2O_{S_R}$</td>
<td>$(3, 1)_{2/3}$</td>
<td>$(\lambda \bar{q}<em>L \gamma</em>{\mu} \ell_L + \tilde{\lambda}<em>d \gamma</em>{\mu} \gamma_{\nu} \epsilon_R)U^\mu$</td>
</tr>
<tr>
<td>$O'_{S_R}$ $(\bar{\tau}P_Rb)$ $(\bar{\tau}P_L\nu)$</td>
<td>$-\frac{1}{2}O_{S_L} - \frac{1}{8}O_T$</td>
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<td>$-\frac{1}{2}O_{S_L} + \frac{1}{8}O_T$</td>
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<tr>
<td>$O''<em>{V_L}$ $(\bar{\tau}\gamma</em>{\mu}PL\epsilon^c)$ $(\bar{\tau}\gamma_{\mu}P_L\nu)$</td>
<td>$-\frac{1}{2}O_{V_L}$</td>
<td>$(3, 3)_{5/3}$</td>
<td>$(\lambda \tilde{d}<em>R \gamma</em>{\mu} \ell_L + \bar{\tilde{\lambda}} \bar{q}<em>L \gamma</em>{\mu} \gamma_{\nu} \epsilon_R)V^\mu$</td>
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<tr>
<td>$O''<em>{V_R}$ $(\bar{\tau}\gamma</em>{\mu}PR\epsilon^c)$ $(\bar{\tau}\gamma_{\mu}P_L\nu)$</td>
<td>$-2O_{S_R}$</td>
<td>$(3, 3)_{1/3}$</td>
<td>$\lambda \bar{q}_L i\tau_2 \ell_L S$</td>
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<tr>
<td>$O''_{S_R}$ $(\bar{\tau}P_R\epsilon^c)$ $(\bar{\tau}P_L\nu)$</td>
<td>$\frac{1}{2}O_{V_L}$</td>
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<td>$(3, 1)_{1/3}$</td>
<td>$(\lambda \bar{q}_L i\tau_2 \ell_L + \tilde{\lambda} \bar{u}_R \epsilon_R)S$</td>
</tr>
<tr>
<td>$O''<em>{T}$ $(\bar{\tau}\sigma^{\mu\nu}PL\epsilon^c)$ $(\bar{\tau}\sigma</em>{\mu\nu}P_L\nu)$</td>
<td>$-6O_{S_L} - \frac{1}{2}O_T$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fits to a single operator

The 5 “standard” operators

\( (\bar{q}q)(\bar{H}H) \)

\( (\bar{l}q)(ql) \)

Solution marked \( \times \) ruled out by the \( q^2 \) spectrum

- We rederived all rates from scratch

Agree with the “classic” paper (up to a minor typo)

[BaBar, 1303.0571]

[Goldberger, hep-ph/9902311]
Fits to two operators

Operator coefficients

\begin{align*}
C'_{V_L} &= 0.24 & C'_V &= 1.10 \\
C'_{V_R} &= 0.18 & C'_{V_R} &= -0.01 \\
C''_S &= 0.96 & C''_S &= 2.41
\end{align*}

[BaBar, 1303.0571]
Flavor symmetries for $b \rightarrow c\tau\bar{\nu}$
Several viable mediators

- Good fits for several mediators: scalar, “Higgs-like” \((1, 2)_{1/2}\)
  - vector, “\(W’\)-like” \((1, 3)_0\)
  - “scalar leptoquark” \((\overline{3}, 1)_{1/3}\) or \((\overline{3}, 3)_{1/3}\)
  - “vector leptoquark” \((3, 1)_{2/3}\) or \((3, 3)_{2/3}\)

- If there is NP within reach, its flavor structure must be highly non-generic
  - Surprising if only BSM operator had \((\overline{b}c)(\overline{\tau}\nu)\) structure

- MFV probably a useful organizing principle / starting point
  - Global \(U(3)_Q \times U(3)_u \times U(3)_d\) flavor sym.; \(Y_u \sim (3, \overline{3}, 1),\ Y_d \sim (3, 1, \overline{3})\)

- Which BSM scenarios can be MFV?
  - Bounds: \(b \rightarrow s\nu\overline{\nu},\ D^0 \& K^0\) mixing, \(Z \rightarrow \tau^+\tau^-\), LHC contact int., \(pp \rightarrow \tau^+\tau^-\), etc.

- If central values & patterns change, more “conventional” models may fit
Excluding MFV scalars and vectors

- **Scalars:** Need comparable values of $C_{SL}$ and $C_{SR}$

  If $H^\pm$ flavor singlet, $C_{SL} \propto y_c$, so cannot fit $R(D^*)$ keeping $y_t$ perturbative

  If $H^\pm$ is charged under flavor (combination of $Y$-s, to couple to quarks & leptons), to generate $C_{SL} \sim C_{SR}$, some $O(1)$ coupling to 1st generation quarks unavoidable

  Bounds on $4q$ or $2q2\ell$ operators exclude it

- **Vectors:** Rescaling the SM operator ($O_{VL}$) gives good fit to the data

  Flavor singlet w/ $W$-like couplings: $m_{W'} \gtrsim 1.8$ TeV $\iff 0.2 \sim g^2 |V_{cb}| (1$ TeV$/m_{W'})^2$

  Couplings to $u, d$ suppressed for $(\bar{3}, 3, 1)$ and $(\bar{3}, 1, 3)$ under $U(3)_Q \times U(3)_u \times U(3)_d$

  $(\bar{3}, 3, 1)$: $b \rightarrow c$ transitions suppressed by $y_c$, too small

  $(\bar{3}, 1, 3)$: can fit data if $y_b = O(1)$, but excluded by tree-level FCNC via $W'^0$

  (If dynamics allows $W'\bar{Q}^3_L Q^3_L$, but not $W'\bar{Q}^i_L Q^i_L$, viable models exist; beyond MFV [Greljo, Isidori, Marzocca, 1506.0170])

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ZL – p. 12
MFV leptoquarks

- Assign charges under flavor sym.: 
  \[ U(3)_Q \times U(3)_u \times U(3)_d \]

- Simplest choices — leptoquarks could be electroweak \( SU(2)_L \) singlets or triplets:
  - scalars: \( S \sim (\bar{3}, 1, 1), \ (1, \bar{3}, 1), \ (1, 1, \bar{3}) \)
  - vectors: \( U_\mu \sim (3, 1, 1), \ (1, 3, 1), \ (1, 1, 3) \)

- \( S(\bar{3}, 1, 1) \) and \( U_\mu(3, 1, 1) \) give large \( pp \rightarrow \tau^+\tau^- \), excluded by \( Z' \) searches

- \( S(1, \bar{3}, 1) \) and \( U_\mu(1, 3, 1) \) give \( y_c \) suppressed \( B \rightarrow D^{(*)}\tau\bar{\nu} \) contributions
  \( \Rightarrow \) too large couplings, or too light leptoquarks

- Possibly viable: \( S(1, 1, \bar{3}) \) and \( U_\mu(1, 1, 3) \) \( \Rightarrow \) consider in more detail
  Both can be electroweak singlets or triplets

[viable MFV LQs: Freytsis, ZL, Ruderman]
The $S(1, 1, \bar{3})$ scalar LQ

- Interactions terms for electroweak singlet:

$$\mathcal{L} = S(\lambda Y_d^\dagger q_L i\tau_2 \ell_L + \tilde{\lambda} Y_u^\dagger \bar{u}_R e_R)$$

$$= S_i(\lambda y_{d_i} V_{ji}^* \bar{u}^c_{Lj} e_L - \lambda y_{d_i} d^c_{Li} \nu_L + \tilde{\lambda} y_{d_i} y_{u_j} V_{ji}^* \bar{u}^c_{Rj} e_R)$$

Integrating out $S$, contribution to $R(X_c)$ via:

$$(m_{S_3} \neq m_{S_1} = m_{S_2})$$

$$- \frac{V_{cb}^*}{m^2_{S_3}} \left( \lambda^2 y_b^2 \mathcal{O}''_{S_R} + \lambda \tilde{\lambda} y_c y_b^2 \mathcal{O}''_{S_L} \right)$$

[electroweak triplet has no $\tilde{\lambda}$ term]

- Can fit $R(D(\ast))$ data if $y_b = \mathcal{O}(1)$

Check $Z\tau^+\tau^-$ constraints, etc.

- Leptons:
  (i) $\tau$ alignment, charge LQ and 3rd gen. leptons opposite under $U(1)_\tau$

  (ii) lepton MFV, $(1, \bar{3})$ under $U(3)_L \times U(3)_e$ [constraints differ]

- LHC Run 1 bounds on pair-produced LQ decaying to $t\tau$ or $b\nu$, $m_{S_3} \gtrsim 560$ GeV

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ZL – p. 14
With three Yukawa spurion insertions, one can write:

\[ \delta \mathcal{L}' = \lambda' S Y_d^\dagger Y_u Y_u^\dagger \bar{q}^c_L i \tau_2 \ell_L \]

Generates four-fermion operator:

\[ \frac{V^*_{tb} V_{ts}}{2m^2_{S_3}} y_t y_b \lambda' \lambda (\bar{b}_L \gamma^\mu s_L \bar{\nu}_L \gamma_\mu \nu_L) \]

Current limits on \( B \rightarrow K \nu \bar{\nu} \) imply: \( \lambda'/\lambda \lesssim 0.1 \) — some suppression of \( \lambda' \) required

Electroweak singlet vector LQ is the only one of the four models w/o this constraint (E.g., vector triplet has \( \lambda' \bar{q}_L Y_u Y_u^\dagger Y_d \sigma \gamma_\mu \ell_L U^\mu \) term)
The $U^\mu(1,1,3)$ vector LQ

- Interactions terms for electroweak singlet:

$$\mathcal{L} = (\lambda \bar{q}_L Y_q \gamma_\mu \ell_L + \tilde{\lambda} \bar{d}_R \gamma_\mu e_R) U^\mu$$

$$= (\lambda y_d V_{ji} \bar{u}_L j \gamma_\mu \nu_L + \lambda y_d \bar{d}_L \gamma_\mu \tau_L + \tilde{\lambda} \bar{d}_R \gamma_\mu \tau_R) U^\mu_i$$

As before, contribution to $R(X_c)$ via: $(m_{U_3} \neq m_{U_1} = m_{U_2})$

$$\frac{C'_{VL}}{\Lambda^2} = \frac{V_{cb}}{m^2_{U_3}} \lambda^2 y^2_b$$

- Can fit data if $y_b = \mathcal{O}(1)$; good fit for $\lambda y_b / m_{U_3} = (2.2 \pm 0.4) / \text{TeV}$

- Only $\tau$ alignment seems viable (lepton MFV not)

[NB: vector leptoquarks are hard to make sense of as a low energy effective theory, without knowing the UV completion — divergences]
The $\tilde{\lambda}$ term for electroweak singlet vector leptoquark gives unsuppressed coupling to 1st generation

$\Rightarrow$ constraints from $t$-channel exchange in $pp \rightarrow \tau^+\tau^- \Rightarrow \tilde{\lambda} \lesssim 0.15 \lambda$

Limits on $m_{U_3}$ from direct leptoquark search ($b\tau$) or recasting stop ($t\nu$) searches

LQ direct production rate is higher than that of stops, data up to the leptoquark exclusion limit is not available

Show conservative extrapolation

Ambiguities related to possible “dipole” term:

$-i g_s \kappa U^{i\mu}_\mu t^{a}_{ij} U^j_\nu G^{\mu\nu}_a$

Obtain: $m_{U_3} \gtrsim 750$ GeV
BUCKLE UP

IT COULD SAVE YOUR LIFE
How strange models can be viable?

- All papers enhance the $\tau$ mode compared to the SM
  Can we suppress the $e$ and $\mu$ modes instead? [Freytsis, ZL, Ruderman, to appear]

  Good fit with: $V_{cb}^{(\text{exp})} \sim V_{cb}^{(\text{SM})} \times 0.9 \quad V_{ub}^{(\text{exp})} \sim V_{ub}^{(\text{SM})} \times 0.9$

- Strongest constraint is from $\epsilon_K$

  $$|\epsilon_K| = \frac{G_F^2 m_W^2 m_K f_K^2 \hat{B}_K \kappa_\epsilon |V_{cb}|^2 \lambda^2 \eta}{6 \sqrt{2} \pi^2 \Delta m_K} \left[ |V_{cb}|^2 (1 - \bar{\rho}) \eta_{tt} S_0(x_t) + \eta_{ct} S_0(x_c, x_t) - \eta_{cc} x_c \right]$$

  - Current central values cannot be accommodated by such models
  - If $R(D^{(*)})$ excess shrinks to $\sim$ half of present size, such models become viable
  - Or make cocktails...

- Even an enhancement much smaller than today can become $5\sigma$ in the future
Final comments
Many signals, tests, consequences

- LHC: several extensions to current searches would be interesting
  - Searches for $t\tau$ and $b\tau$ resonances
  - Extensions of stop/sbottom searches to higher prod. cross sections ($t\nu$ and $b\nu$)
  - Searches for states appearing on-shell in $t$- but not in $s$-channel in $pp$ collisions
  - Enhanced $h \rightarrow \tau^+\tau^-$ rate (and $t \rightarrow b\tau\bar{\nu}$ and/or $t \rightarrow c\tau^+\tau^-$)

- Low energy probes:
  - Firm up $B \rightarrow D(*)\tau\bar{\nu}$ rate and kinematic distributions; Cross checks w/ inclusive
  - Smaller theor. error in $[d\Gamma(B \rightarrow D(*)\tau\bar{\nu})/dq^2]/[d\Gamma(B \rightarrow D(*)l\bar{\nu})/dq^2]$ at same $q^2$
  - Improve bounds on $B(B \rightarrow K(*)\nu\bar{\nu})$
  - $B(D \rightarrow \pi\nu\bar{\nu}) \sim 10^{-5}$ possible, maybe BES III; enhanced $B(D \rightarrow \mu^+\mu^-)$
  - $B(B_s \rightarrow \tau^+\tau^-) \sim 10^{-3}$ possible

ZL – p. 19
Conclusions

• Amusing if NP shows up in an operator without much CKM and loop suppression

• There are (somewhat) sensible MFV models for $B \rightarrow D(*)\tau\bar{\nu}$ excesses, not requiring ad-hoc flavor assignments

• Several simple extensions to current LHC searches could cover much of this parameter space (see anomalies or rule out models)

• Measurements of $b \rightarrow c\tau\bar{\nu}$ will improve in the next decade by order of magnitude (Even if central values change, plenty of room for significant deviations from SM)