# New physics in $B \to D^* \tau \nu_\tau$ decay

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QCD@work, Lecce, 18-21 June 2012

# Outline

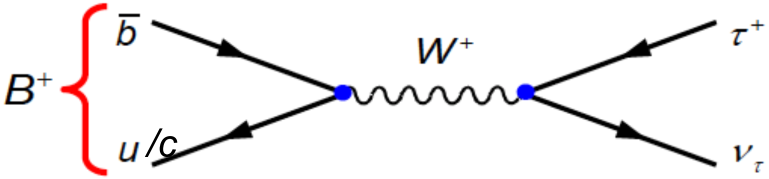
1. Why B decay modes with $\tau\ \nu_\tau$ in the final state are interesting?
2. Belle and BaBar experimental results;
3. SM + NP in exclusive channels for $b \to u\tau\nu_\tau$ and $b \to c\tau\nu_\tau$ transitions;
4. NP searches in $B \to D^*\tau\nu_\tau$.
5. Summary and outlook

Based on:

S.F. J.F. Kamenik, I. Nišandžić, J. Zupan, **1206.1872**
S.F. J.F. Kamenik, I. Nišandžić, **1203.2654**

## SM in $b \to c(u)\tau\nu_\tau$

$$\mathcal{H}_{\rm eff}^{b\to q} = \frac{G_F}{\sqrt{2}} V_{qb} \sum_{l=e,\mu,\tau} [(\bar{q}\gamma_\mu(1-\gamma_5)b)(\bar{l}\gamma^\mu(1-\gamma_5)\nu)$$




Why important?

$$B \to \tau\nu_\tau$$
$$B \to X_c\tau\nu_\tau$$
$$B \to \pi(\rho)\tau\nu_\tau$$
$$B \to D(D^*)\tau\nu_\tau$$

i) Precise knowledge of $V_{cb}$ and $V_{ub}$ CKM

ii) learn about SM – decay constants & form-factors;

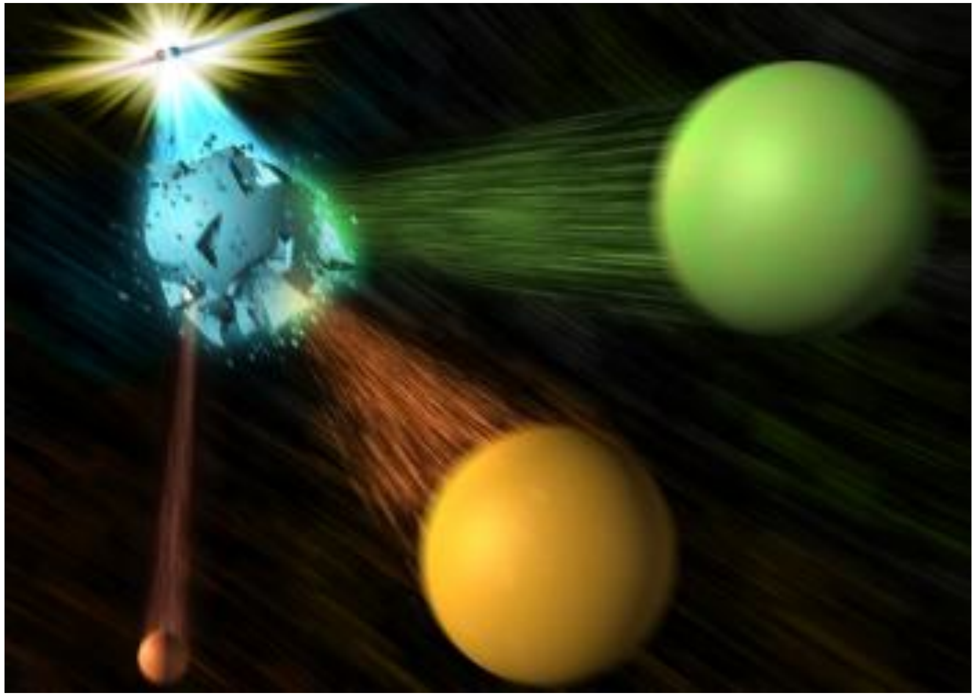
iii) form-factors which cannot be accessed in other semileptonic decays;

iv) NP at tree level;

v) possible tests of lepton universality.

https://news.slac.stanford.edu/

BaBar Data Hint at Cracks in the Standard Model



Jun 18, 2012

Recently analyzed data from the BaBar experiment may suggest possible flaws in the Standard Model of particle physics, the reigning description of how the universe works on subatomic scales. The data from BaBar, a high-energy physics experiment based at the U.S. Department of Energy's (DOE) SLAC National Accelerator Laboratory, show that a particular type of particle decay called "B to D-star-tau-nu" happens more often than the Standard Model says it should.

## B decays to $\tau \nu_\tau$

Experimental results

$$\mathcal{R}^*_{\tau/\ell} \equiv \frac{\mathcal{B}(B \to D^* \tau \nu)}{\mathcal{B}(B \to D^* \ell \nu)} = 0.332 \pm 0.030$$

$$\mathcal{R}_{\tau/\ell} \equiv \frac{\mathcal{B}(B \to D \tau \nu)}{\mathcal{B}(B \to D \ell \nu)} = 0.440 \pm 0.072$$

BaBar: 1205.5442
Belle: 0706.4429

$$\mathcal{R}^{*,\mathrm{SM}}_{\tau/\ell} = 0.252(3)$$

$$\mathcal{R}^{\mathrm{SM}}_{\tau/\ell} = 0.296(16)$$

combined 3.4σ larger than SM

$$Br(B^+ \to \bar{D}^0 \tau^+ \nu_\tau)_{\mathrm{exp}} = (0.77 \pm 0.25)\%\,,$$

$$Br(B^+ \to \bar{D}^0 \ell^+ \nu_\ell)_{\mathrm{exp}} = (2.23 \pm 0.11)\%\,, \quad \text{for } \ell = e, \mu\,,$$

PDG values

$$Br(B^+ \to \bar{D}^0 \tau^+ \nu_\tau)_{\mathrm{SM}} = (0.66 \pm 0.05)\%$$

$$Br(B^0 \to D^- \tau^+ \nu_\tau)_{\mathrm{SM}} = (0.64 \pm 0.05)\%$$

without NP

$$BR(B \to \tau \nu_\tau) = (16.8 \pm 3.1) \times 10^{-5}$$

Belle:hep-ex/0604018; 1006.4201
BaBar:arXiv:0708.2260 [hep-ex];
PRDD 81, 051101 (2010);

2.9 σ disagreement with SM prediction (global fit CKM fitter)

## Standard Model or New Physics?

Can observed effects be explained within SM?

Maybe! New form-factors show up in $B \to D^{(*)} \tau \nu_\tau$

How well do we know all new/old form-factors?

HQ - Isgur-Wise "paradigm"?

Lattice improvements?

Indication on LFU in both processes? $\left\{ \begin{array}{l} b \to c \\ b \to u \end{array} \right.$

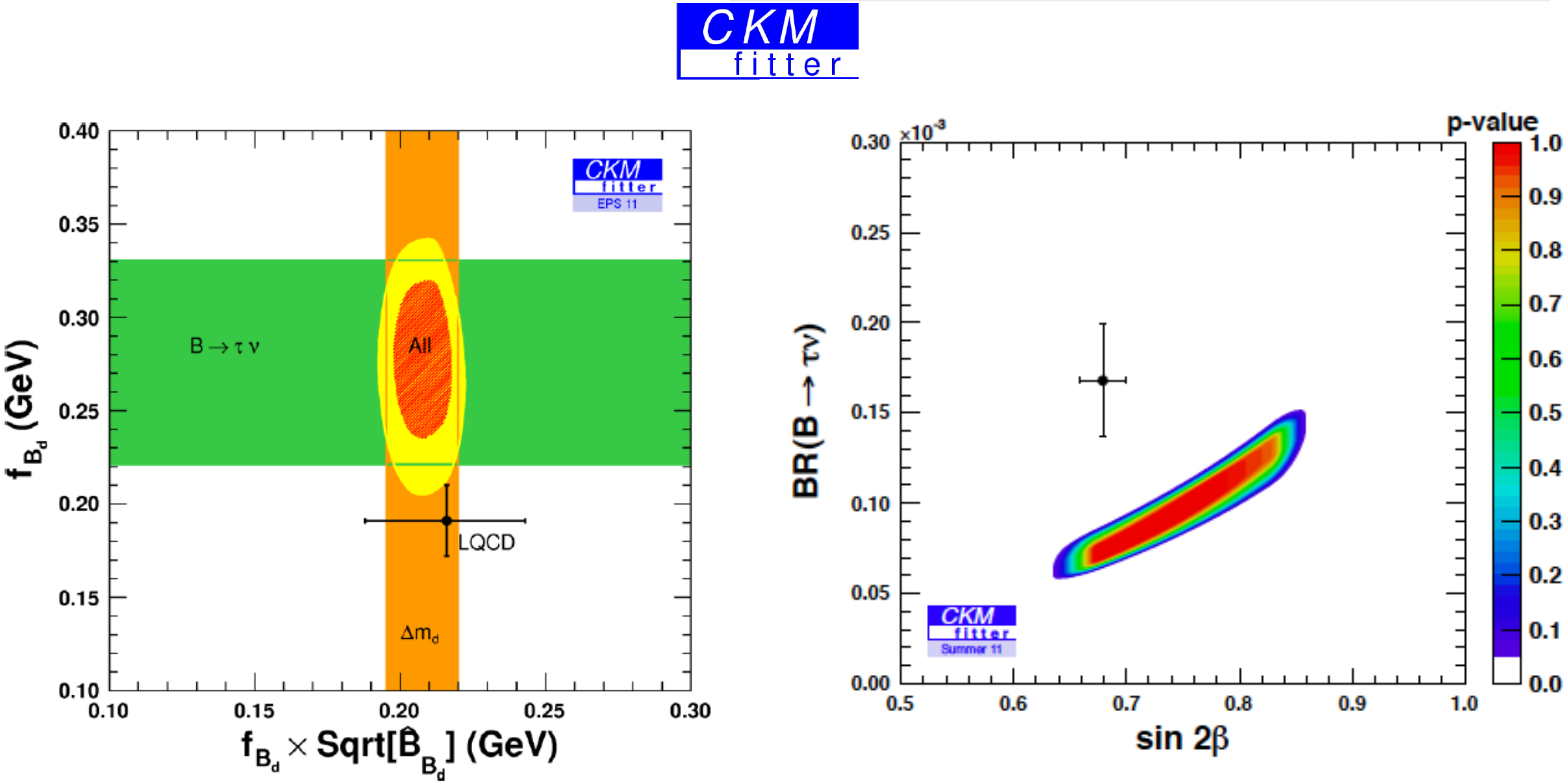
S.F. J.F. Kamenik, I. Nišandžić, J. Zupan, **1206.1872**

π and K physics: Tests of LFU conservation holds up to 1 percent level for all three lepton generations. Experiment and SM expectations – excellent agreement!

# SM or NP in $B \to \tau\nu_\tau$?

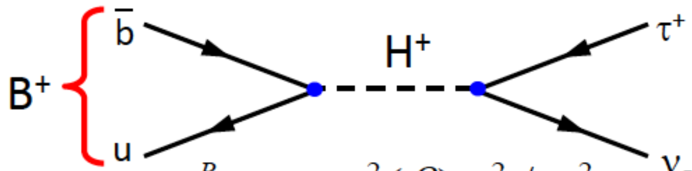
helicity suppressed $\sim f_B V_{ub}$

$$BR(B^+ \to \tau^+\nu) = \frac{G_F^2 m_B \tau_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_{B_d}^2 |V_{ub}|^2$$



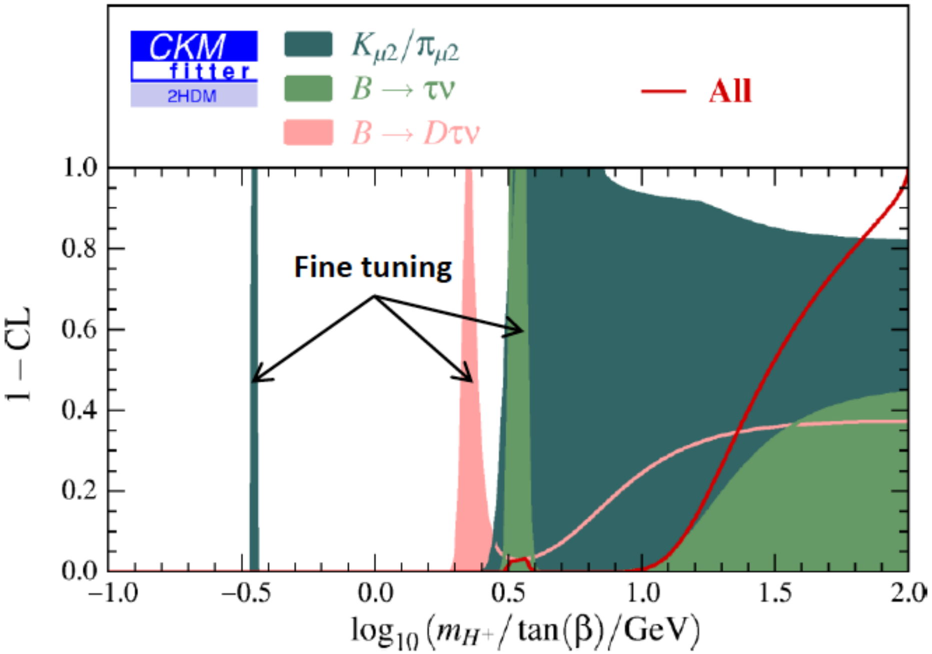

Tension: within the SM is not possible to fit the both:
either $BR(B \to \tau\nu_\tau)$ is too high, or $\beta_{cc}$ too low!

## New Physics: 2HDM Type II




$$r_H^B \approx -\tan^2(\beta) m_B^2 / m_{H^+}^2$$

$$BR(B^+ \to \tau^+\nu) = \frac{G_F^2 m_B \tau_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_{B_d}^2 |V_{ub}|^2 \times (1+r_H^B)^2$$




No indication for 2HDM II!

## NP in $B \to D\tau\nu_\tau$

The simplest extension of SM

$$\mathcal{H}_{\text{eff}}^{b\to q} = C^l_{\text{NP}}(\bar{q}(1+\gamma_5)b)(\bar{l}(1-\gamma_5)\nu_l)] + \text{H.c.}$$

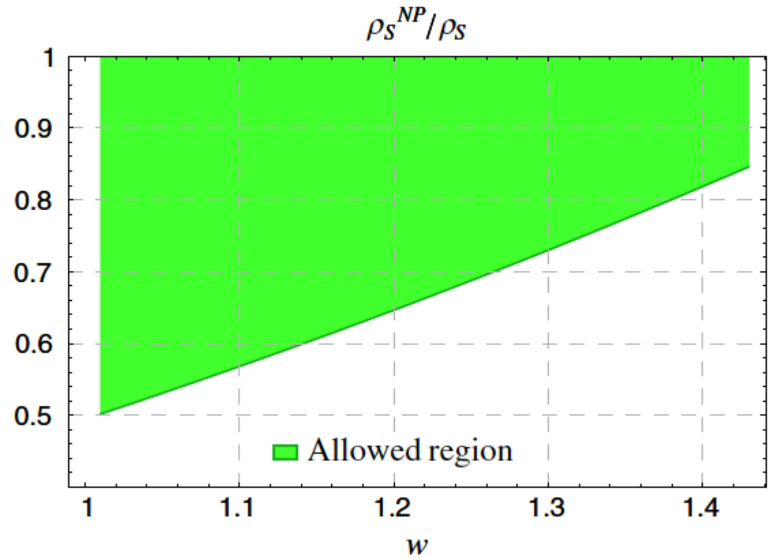
$$C^l_{\text{NP}} = -\frac{m_b m_l}{m^2_{H^+}}\frac{\tan^2\beta}{1+\epsilon_0\tan\beta}$$

Many authors:
Kirs&Sony, (1997)
Nierste et al. 0801.4938…

NP – additional Higgs doublet

Kamenik & Mescia 2008

$$\frac{d\Gamma(B\to Dl\bar{\nu})}{dw} = \frac{G_F^2|V_{cb}|^2 m_B^5}{192\pi^3}\rho_V(w)\left[1-\frac{m_l^2}{m_B^2}\right.$$
$$\times\left|1+\frac{t(w)}{(m_b-m_c)m_l}C^l_{\text{NP}}\right|^2\rho_S(w$$




$w = v_B \cdot v_D$

# Effective Lagrangian approach

NP generated at a scale Λ higher than the electroweak scale

$$v = (\sqrt{2}/4G_F)^{1/2} \simeq 174 \text{ GeV}$$

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_a \frac{z_a}{\Lambda^{d_a-4}} \mathcal{Q}_i + \text{h.c.}$$

NP contribution

$$c_a = z_a (\Lambda/v)^{d_a-4}$$

the lowest dimensional operators $d_i \leq 8$ are:

Assumptions:

a) no down – type FCNCs;
b) no LFU in pion and kaon sector

$$\mathcal{Q}_L = (\bar{q}_3 \gamma_\mu \tau^a q_3) \mathcal{J}^\mu_{3,a} \,,$$

$$\mathcal{Q}^i_R = (\bar{u}_{R,i} \gamma_\mu b_R)(H^\dagger \tau^a \tilde{H}) \mathcal{J}^\mu_{3,a} \,,$$

$$\tau_a = \sigma_a/2, \; \mathcal{J}^\mu_{j,a} = (\bar{l}_j \gamma^\mu \tau_a l_j), \; \tilde{H} \equiv i\sigma_2 H^*$$

$$\mathcal{Q}_{LR} = i\partial_\mu (\bar{q}_3 \tau^a H b_R) \sum_j \mathcal{J}^\mu_{j,a} \,,$$

$$\mathcal{Q}^i_{RL} = i\partial_\mu (\bar{u}_{R,i} \tilde{H}^\dagger \tau^a q_3) \sum_j \mathcal{J}^\mu_{j,a} \,,$$

i,j are generational indices

down quark basis $q_i = (V^{ji*}_{CKM} u_{L,j}, d_{L,i})^T$

and charged lepton basis $l_i = (V^{ji*}_{PMNS} \nu_{L,j}, e_{L,i})^T$

a new light invisible fermion ψ could mimic the missing energy of SM neutrinos

$$\mathcal{Q}^i_\psi = (\bar{q}_i b_R)(\bar{l}_3 \psi_R)$$

In our study we use:

$$\mathcal{R}^*_{\tau/\ell} \equiv \frac{\mathcal{B}(B\to D^*\tau\nu)}{\mathcal{B}(B\to D^*\ell\nu)} = 0.332 \pm 0.030$$

$$\mathcal{R}_{\tau/\ell} \equiv \frac{\mathcal{B}(B\to D\tau\nu)}{\mathcal{B}(B\to D\ell\nu)} = 0.440 \pm 0.072\,,$$

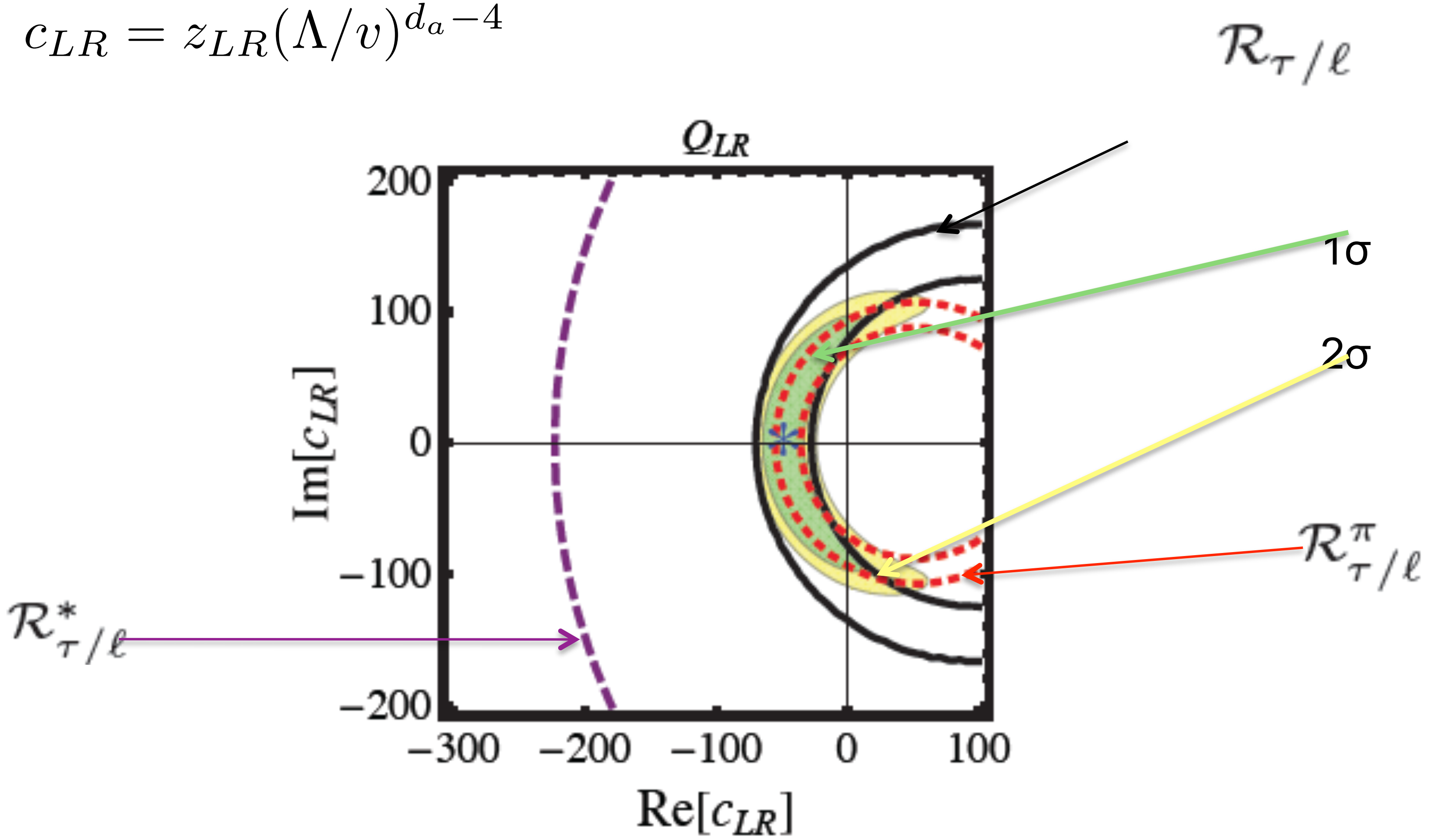
$$\mathcal{R}^{\pi}_{\tau/\ell} \equiv \frac{\tau(B^0)}{\tau(B^-)} \frac{\mathcal{B}(B^- \to \tau^-\bar{\nu})}{\mathcal{B}(\bar{B}^0 \to \pi^+\ell^-\bar{\nu})} = 1.07 \pm 0.20$$

$B \to \pi$ form-factors from recent lattice QCD (Laiho, 0910.2928)

left-right operator

$$\mathcal{Q}_{LR} \longrightarrow \begin{cases} \mathcal{R}^{\pi,\mathrm{LR}}_{\tau/\ell}/\mathcal{R}^{\pi,\mathrm{SM}}_{\tau/\ell} = 1 - 0.038\,\mathrm{Re}(c_{LR}) + 3.6\ 10^{-4}|c_{LR}|^2\ , \\ \mathcal{R}^{\mathrm{LR}}_{\tau/\ell}/\mathcal{R}^{\mathrm{SM}}_{\tau/\ell} = 1 - 0.0076\,\mathrm{Re}(c_{LR}) + 2.6\ 10^{-5}|c_{LR}|^2\ , \\ \mathcal{R}^{*,\mathrm{LR}}_{\tau/\ell}/\mathcal{R}^{*,\mathrm{SM}}_{\tau/\ell} = 1 - 6.2\ 10^{-4}\,\mathrm{Re}(c_{LR}) + 1.2\ 10^{-6}|c_{LR}|^2\ , \end{cases}$$

$$c_{LR} = z_{LR}(\Lambda/v)^{d_a-4}$$




LR operator

Tension between observables for LR operator!

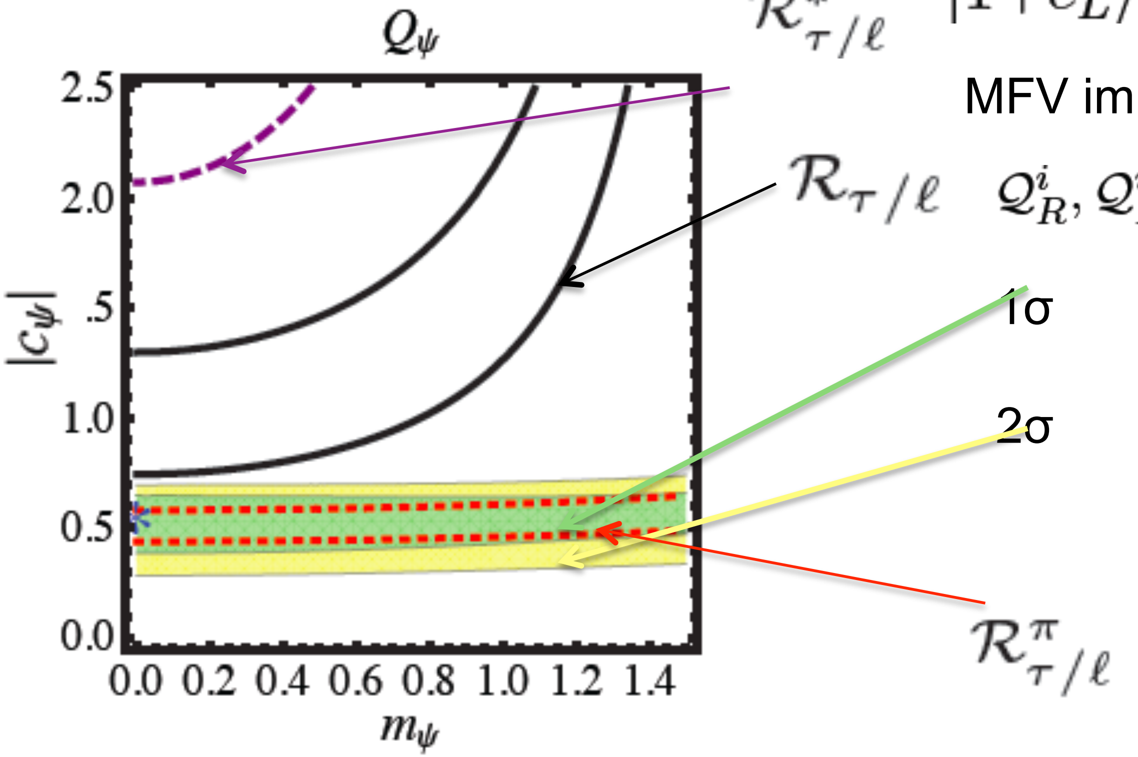
MFV

requirement no tree-level FCNC in down sector
charged currents are proportional to the same CKM elements

$\mathcal{Q}_L$ contributions are rescaled by $|1+c_L/2|^2$ $\quad c_L = z_L'(v/\Lambda)^2$

$\mathcal{R}^{\pi}_{\tau/\ell}$ $\mathcal{R}_{\tau/\ell}$ and $\mathcal{R}^{*}_{\tau/\ell}$ well accommodated tension above 2σ level

$\mathcal{R}^{*}_{\tau/\ell}$ $\quad |1+c_L/2| \simeq 1.18$




MFV implies for the right handed operators

$\mathcal{Q}^i_R, \mathcal{Q}^i_{RL}$ or $\mathcal{Q}^i_\psi$ $\longrightarrow$ $z^i_{R,RL} \propto m_{u_i}$

best fit value
tension remains

$c_\psi \simeq 0.54$ and $m_\psi = 0$

## Generic flavor structure

More general flavor violation: NP in $\mathcal{R}^{\pi}_{\tau/\ell}$ is not related to $\mathcal{R}^{(*)}_{\tau/\ell}$

SM values for $\mathcal{R}_{\tau/\ell}$ are modified by $|1 - c_R/2V_{cb}|^2$

$\mathcal{R}^{\pi}_{\tau/\ell}$ by $|1 + \epsilon_R c_R/2V_{ub}|^2$

$\mathcal{Q}^i_R$ contributions

$$\mathcal{R}^{*,R(\mathrm{MFV})}_{\tau/\ell}/\mathcal{R}^{*,\mathrm{SM}}_{\tau/\ell} = 1 - 0.88\,\mathrm{Re}(c_R/V_{cb}) + 0.25|c_R/V_{cb}|^2.$$

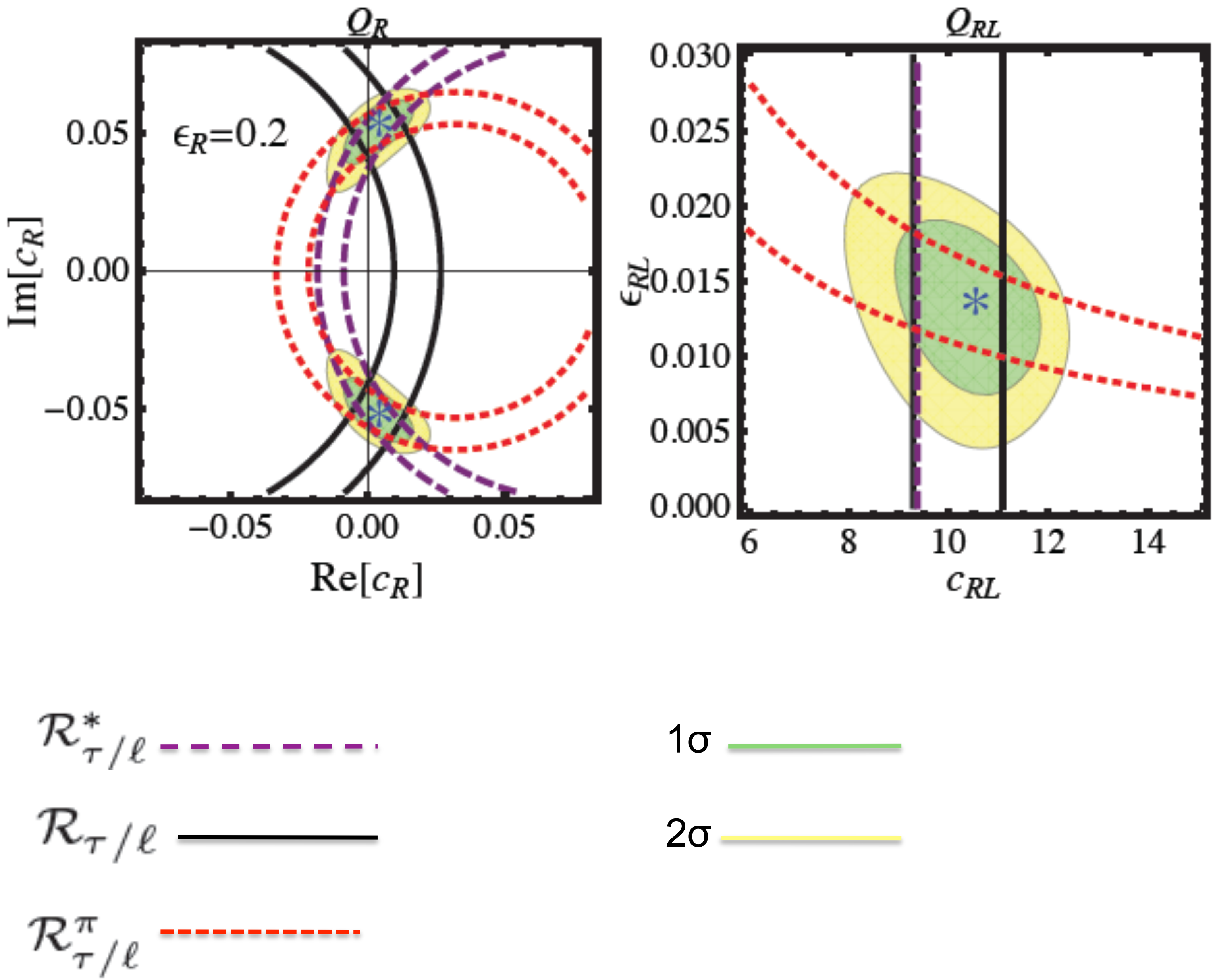
presence of large ~~CP~~

$$c_R \simeq -0.0039 \pm 0.053i \text{ and } \epsilon_R \simeq 0.20 \qquad v|\mathrm{Im}(c_R)|^{-1/4} \simeq 0.36 \text{ TeV}$$

$\mathcal{Q}^i_{RL}$ contributions

$$c_{RL} \simeq 11 \text{ and } \epsilon_{RL} \simeq 0.013 \qquad v|c_{RL}|^{-1/4} \simeq 97 \text{ GeV}$$

low NP scale!



$Q_R$
$\epsilon_R$=0.2
Im[$c_R$]
Re[$c_R$]
0.05
0.00
−0.05
−0.05
0.00
0.05
$Q_{RL}$
$\epsilon_{RL}$
$c_{RL}$
0.030
0.025
0.020
0.015
0.010
0.005
0.000
6
8
10
12
14
$\mathcal{R}^*_{\tau/\ell}$
$\mathcal{R}_{\tau/\ell}$
$\mathcal{R}^\pi_{\tau/\ell}$
1σ
2σ

# Explicit models

## 2HDM

There are varieties of 2HDM: Type I, Type II, "lepton specific", and "flipped" (see e.g. Branco et al. 1106.0034)

$$c_{LR} = (2m_b v/m^2_{H+})\{\mathrm{ctg}^2\beta, \mathrm{tg}^2\beta, -1, -1\}$$
$$c^i_{RL} = (2m^i_u v/m^2_{H+})\{\mathrm{ctg}^2\beta, -1, -1, \mathrm{ctg}^2\beta\}$$

for $m_{H+} \gtrsim 80~\mathrm{GeV}$ LEP constraints

$\mathcal{O}(1) \leq tg\beta \leq \mathcal{O}(100)$ (Yukawas are perturbative)

None of the natural flavor conservation 2HDMs can simultaneously account for the three LFU ratios!

## 2HDM with the more general flavor structure

Limit: only one Higgs doublet obtains vev

$$\mathcal{L} \supset \kappa^{i}_{RL}\bar{q}_3 u^{i}_{R}\bar{H} + \kappa^{i}_{LR}\bar{b}_R\bar{H}^{\dagger}q_i + \kappa^{\tau}\bar{\tau}_R l_3\bar{H} + \mathrm{h.c}$$

$$c^{i\tau}_{RL} = -\kappa^{i*}_{RL}(\kappa^{\tau}v/m_{\tau})(v/m_{H^+})^2$$
$$c^{i\tau}_{LR} = -\kappa^{i*}_{LR}(\kappa^{\tau}v/m_{\tau})(v/m_{H^+})^2$$

The best fit regions $(\kappa^{u}_{LR} - \kappa^{u}_{RL})\kappa^{\tau} \simeq \{1.5, -5\}\cdot 10^{-3}(m_{H^+}/v)^2,$

$$(\kappa^{c}_{RL}\kappa^{\tau}, \kappa^{c}_{LR}\kappa^{\tau}) \simeq \{(-6, 8), (-12, 1)\}\cdot 10^{-2}(m_{H^+}/v)^2$$

$\kappa^{c(u)}_{RL}\kappa^{\tau}$ is about 3(4) times larger than Yukawas $(m_{c(u)}/v)(m_{\tau}/v)$

FCNC bounds from D, B, $B_s$ require an order of magnitude cancellation

$\kappa^{\tau} = 1$ ($\kappa^{i}_{LR} = 0$, for $B_s$)

## LHC signatures

1) Higgs lighter than top the signal $t \to bH^+$

existing searches at ATLAS and CMS

$$|\kappa^t_{RL,LR}| \lesssim \mathcal{O}(0.2 - 0.4)$$ for 80 GeV < $m_{H-}$ < 160 GeV

2) Heavier Higgs $m_{H^-} = 200\ \mathrm{GeV}$

dominant signal $gb \to H^- t$

LHC: at 8 TeV $\sigma_{pp} = 1.4\ \ pb(|\kappa^t_{RL}|^2 + |\kappa^t_{LR}|^2)$

## Leptoquarks

Quantum numbers assignment $SU(3)_c \times SU(2)_L \times U(1)_Y$

possible cases $(3, 3, -1/3), \ (\bar{3}, 2, -7/6), \ (3, 1, -1/3)$

e.g. $$\mathcal{L}^{\rm int}_{S_3} = Y_{S_3} \overline{q^c_3} i\sigma_2 \tau^a S^{a*}_3 l_3 + \text{h.c.}$$

contribution to $\mathcal{Q}_L$ with $c_L = (|Y_{S_3}|^2/4)(v/m_{S_3})^2$

$$|Y_{S_3}|/m_{S_3} \simeq 1/150 \ \text{GeV}$$

In conflict with electroweak precision tests $|Y_{S_3}|/m_{S_3} \leq 1/450 \ \text{GeV}$

CMS search for the third generation LQ from $S_3 \to b\nu$

$$m_{S_3} \gtrsim 280 \ \text{GeV}$$

## Composite III generation of fermions

contribution of $\mathcal{Q}_{L,R}$

$$\frac{z_L}{\Lambda^2} \sim \frac{g_\rho^2}{m_\rho^2}[f_3^q]^2[f_3^l]^2 , \quad \frac{z_R^{u(c)}}{\Lambda^4} \sim \frac{g_\rho^2}{m_\rho^2} \frac{y_3^{Qd} y_{1(2)}^{Qu}}{m_Q^2}[f_3^l]^2$$

$g_\rho \lesssim \sqrt{4\pi} \quad m_\rho \sim \mathcal{O}(\mathrm{TeV})$ — vector resonance

$(\mathbf{3}, \mathbf{2}, 1/6) \quad m_Q \lesssim \mathcal{O}(\mathrm{TeV})$ — strong sector fermion resonance

$f_i^{q,l} \in [0, 1]$ compositeness fractions

$y_i^{Qd,Qu}$ $u_R$ and $d_R$ couplings to composite Higgs and Q fermion

$$\mathcal{L} \sim y_i^{Q_d} \bar{Q} H d_R^i + y_i^{Q_u} \bar{Q} \tilde{H} u_R^i + h.c.$$

we fix $f_3^l = f_3^q = 1$ $\quad g_\rho = \sqrt{4\pi}$

$$\epsilon_{32} \equiv y_3^{Qd} y_2^{Qu} v^2/m_Q^2$$

$$\epsilon_{31} \equiv y_3^{Qd} y_1^{Qu} v^2/m_Q^2$$

$$m_\rho \simeq 1 \text{ TeV}$$

$\epsilon_{32} \simeq 0$ and $\epsilon_{31} \simeq -0.01$

$\epsilon_{32} \simeq 0.01$ and $\epsilon_{31} \simeq 0.05$

## Prospect to check LFU in B physics

$$[\mathcal{B}(B \to \pi\tau\nu)/\mathcal{B}(B \to \pi\ell\nu)]^{\mathrm{SM}} = 0.68 \pm 0.03$$

- measurements of $BR(B \to \pi\tau\nu_\tau)$ $BR(B_c \to \tau\nu_\tau)$

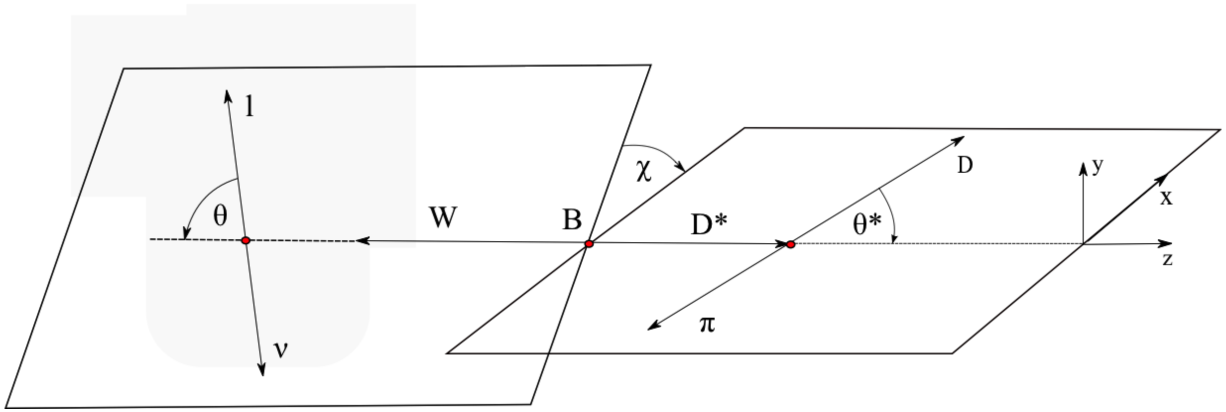
- lattice improvements of the scalar form-factor

## Impact on LHC

- search for charged Higgs, LQ
- all models predict $h + \tau + MET$ (MET – missing transverse energy)
- models with $\mathcal{Q}_R^i$, $\mathcal{Q}_{LR}$ and $\mathcal{Q}_{RL}^i$ $t + MET$

$$(t+)\tau + MET$$

# How to identify NP in $B \to D^* \tau \nu_\tau$




helicity amplitudes

$$\frac{d^2\Gamma_\tau}{dq^2 d\cos\theta} = \frac{G_F^2 |V_{cb}|^2 |\mathbf{p}| q^2}{256\pi^3 m_B^2} \left(1 - \frac{m_\tau^2}{q^2}\right)^2 \times$$

$$\left[ (1-\cos\theta)^2 |H_{++}|^2 + (1+\cos\theta)^2 |H_{--}|^2 + 2\sin^2\theta |H_{00}|^2 + \right.$$

$$\left. \frac{m_\tau^2}{q^2} \left( (\sin^2\theta (|H_{++}|^2 + |H_{--}|^2) + 2|H_{0t} - H_{00}\cos\theta|^2 \right) \right],$$

$\theta$ the angle between D* and τ

S.F. , Nisanndzic, J.F.Kamenik, 1203.2654

Körner& Schuller, ZPC 38 (1988) 511

$$H^{\rm SM}_{\pm\pm}(q^2) = (m_B + m_{D^*})A_1(q^2) \mp \frac{2m_B}{m_B + m_{D^*}}|\mathbf{p}|V(q^2),$$

$$H^{\rm SM}_{00}(q^2) = \frac{1}{2m_{D^*}\sqrt{q^2}}\left[(m_B^2 - m_{D^*}^2 - q^2)(m_B + m_{D^*})A_1(q^2) - \frac{4m_B^2|\mathbf{p}|^2}{m_B + m_{D^*}}A_2(q^2)\right]$$

$$H^{\rm SM}_{0t}(q^2) = \frac{2m_B|\mathbf{p}|}{\sqrt{q^2}}A_0(q^2).$$

Heavy Quark limit for b and c quarks ⟶ only one form-factor!

$$A_0(q^2) = \frac{R_0(w)}{R_{D^*}}h_{A_1}(w)$$

$$A_2(q^2) = \frac{R_2(w)}{R_{D^*}}h_{A_1}(w)$$

$$V(q^2) = \frac{R_1(w)}{R_{D^*}}h_{A_1}(w)$$

$$h_{A_1}(w) = A_1(q^2)\frac{1}{R_{D^*}}\frac{2}{w+1}$$

$$w \equiv v_B \cdot v_{D^*} = \frac{m_B^2 + m_{D*}^2 - q^2}{2m_B m_{D*}}$$

Caprini et al., hep-ph/9712417

recent work form-factors: Gambino et a.l, **1206.2296**

## NP signatures in $B \to D^* \tau \nu_\tau$

effective hamiltonian

$$\mathcal{H}_{\rm eff} = \frac{4 G_F V_{cb}}{\sqrt{2}} J_{bc,\mu} \sum_{\ell = e,\mu,\tau} (\bar{\ell} \gamma^\mu P_L \nu_\ell) + \text{h.c.}$$

$$J^\mu_{bc} = \bar{c} \gamma^\mu P_L b + g_{SL} i \partial^\mu (\bar{c} P_L b) + g_{SR} i \partial^\mu (\bar{c} P_R b)$$

$$B \to D \tau \nu_\tau$$

$$R/R_{\rm SM} = 1 + 1.5 {\rm Re}[m_\tau (g_{SR} + g_{SL})] + 1.0 |m_\tau (g_{SR} + g_{SL})|^2$$

modification of new physics

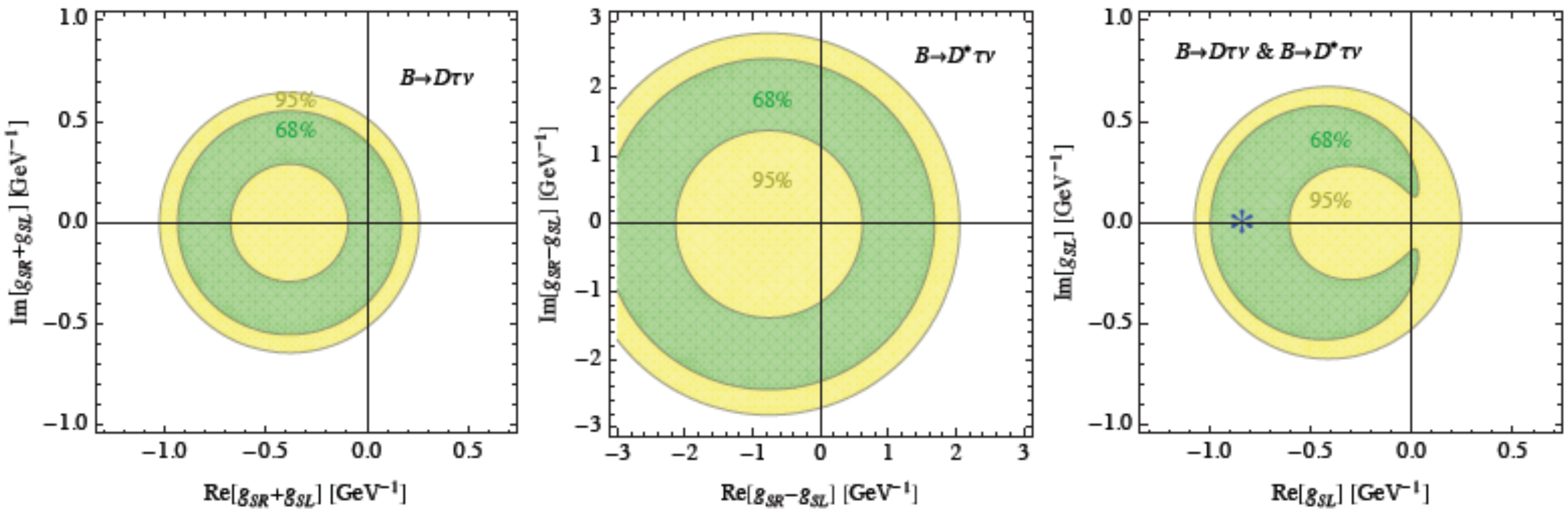
using form-factor shapes
from HFAG and PDG parameters

$$\frac{d\Gamma_\tau}{dq^2} = \frac{G_F^2 |V_{cb}|^2 |\mathbf{p}| q^2}{96\pi^3 m_B^2} \left(1 - \frac{m_\tau^2}{q^2}\right)^2 \left[ \left(|H_{++}|^2 + |H_{--}|^2 + |H_{00}|^2\right) \left(1 + \frac{m_\tau^2}{2q^2}\right) + \frac{3}{2}\frac{m_\tau^2}{q^2} |H_{0t}|^2 \right]$$

NP modifies

$$H_{0t} = H_{0t}^{\rm SM} \left[1 + (g_{SR} - g_{SL}) \frac{q^2}{m_b + m_c}\right]$$

In order to reduce theoretical uncertainties it is better to look $R^* \equiv \dfrac{Br(B \to D^* \tau \bar{\nu}_\tau)}{Br(B \to D^* e \bar{\nu}_e)}$




$$R^* = R^*_{\rm SM} \left\{1 + 0.12 {\rm Re}[m_\tau (g_{SR} - g_{SL})] + 0.05 |m_\tau (g_{SR} - g_{SL})|^2\right\}$$

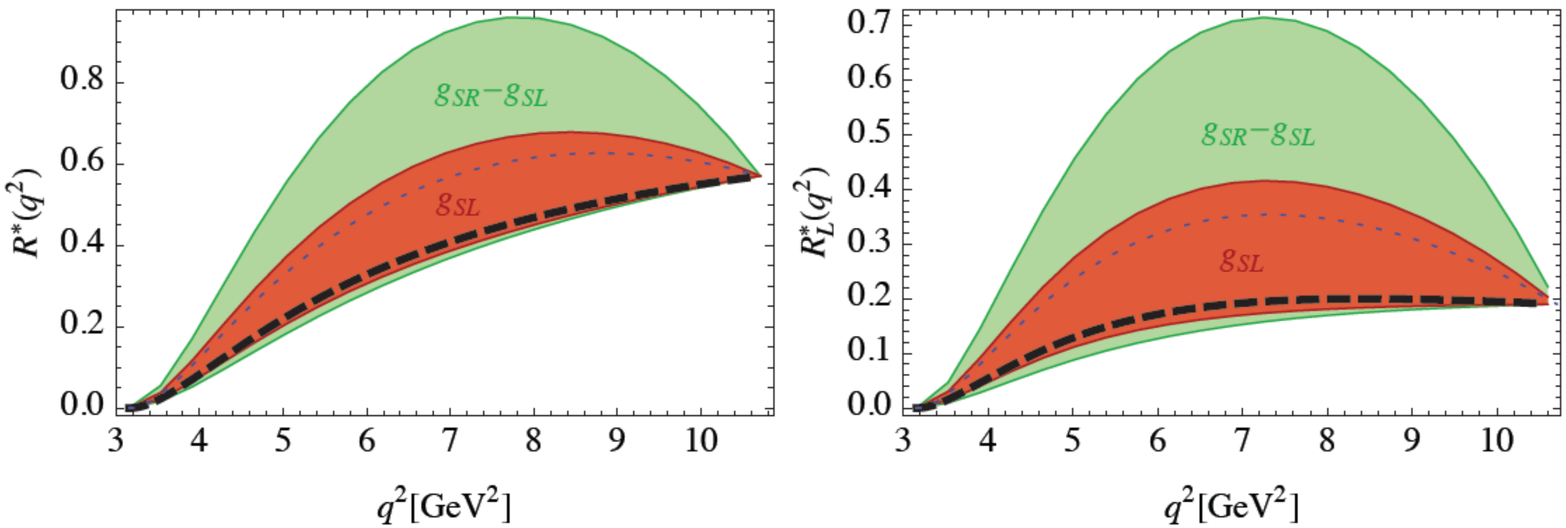
Possible variables:

$$R^*(q^2) = \frac{d\Gamma_\tau/dq^2}{d\Gamma_\ell/dq^2} = \left(1 - \frac{m_\tau^2}{q^2}\right)^2 \left[\left(1 + \frac{m_\tau^2}{2q^2}\right) + \frac{3}{2}\frac{m_\tau^2}{q^2}\frac{|H_{0t}|^2}{|H_{++}|^2 + |H_{--}|^2 + |H_{00}|^2}\right]$$

sensitivity on $H_{0t}$

NP contributes only to longitudinally polarized D* (information comes from the Study of angular distribution of D π)

$$R_L^* \equiv \frac{Br(B \to D_L^* \tau \bar{\nu}_\tau)}{Br(B \to D^* e \bar{\nu}_\tau)} = 0.115(2)\left\{1 + 0.27\mathrm{Re}[m_\tau(g_{SR} - g_{SL})] + 0.10|m_\tau(g_{SR} - g_{SL})|^2\right\}$$



Opening angle asymmetry

$$A_\theta(q^2) \equiv \frac{\int_{-1}^{0} d\cos\theta (d^2\Gamma_\tau/dq^2 d\cos\theta) - \int_0^1 d\cos\theta (d^2\Gamma_\tau/dq^2 d\cos\theta)}{d\Gamma_\tau/dq^2}$$

$$= \frac{3}{4} \frac{|H_{++}|^2 - |H_{--}|^2 + 2\frac{m_\tau^2}{q^2}\mathrm{Re}(H_{00}H_{0t})}{\left[(|H_{++}|^2 + |H_{--}|^2 + |H_{00}|^2)\left(1 + \frac{m_\tau^2}{2q^2}\right) + \frac{3}{2}\frac{m_\tau^2}{q^2}|H_{0t}|^2\right]}.$$

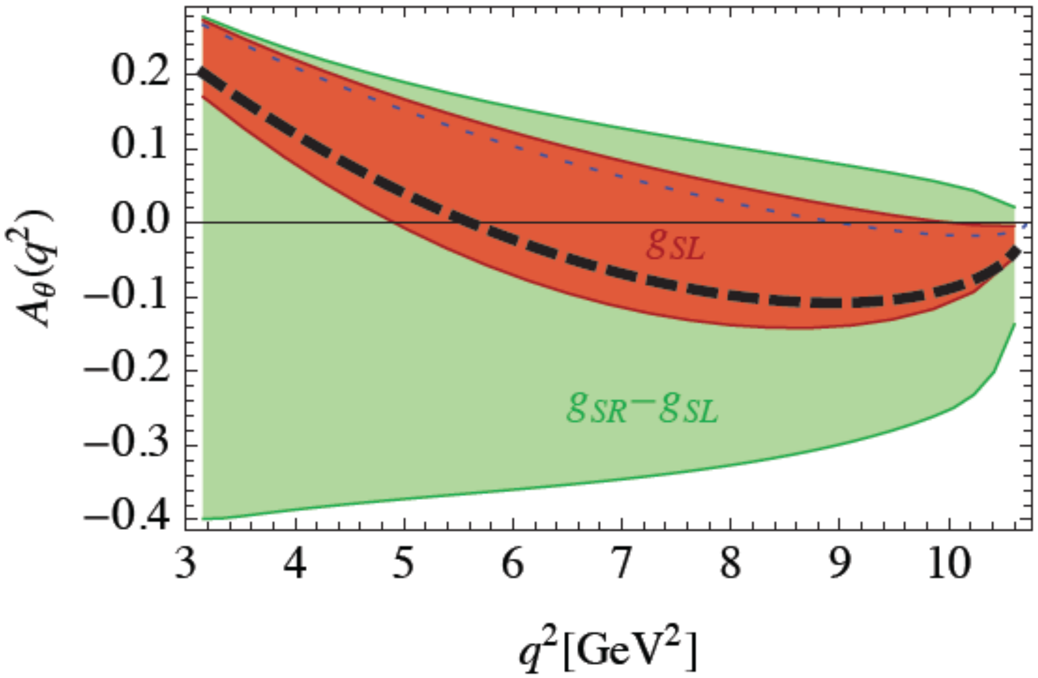
SM: $A_\theta = 0$ for $q_0^2 \simeq 5.6\ \mathrm{GeV}^2$

integrated

$$A_{\theta,SM} = -6.0(8)\%$$

SM + NP: $A_{\theta,NP}$

for benchmark points 3.4%, being even -30%



## Using τ helicity

$$\frac{d\Gamma_\tau}{dq^2}(\lambda_\tau = -1/2) = \frac{G_F^2|V_{cb}|^2|\mathbf{p}|q^2}{96\pi^3 m_B^2}\left(1-\frac{m_\tau^2}{q^2}\right)^2 (H_{--}^2 + H_{++}^2 + H_{00}^2) \ ,$$

$$\frac{d\Gamma_\tau}{dq^2}(\lambda_\tau = 1/2) = \frac{G_F^2|V_{cb}|^2|\mathbf{p}|q^2}{96\pi^3 m_B^2}\left(1-\frac{m_\tau^2}{q^2}\right)^2 \frac{m_\tau^2}{2q^2}(H_{--}^2 + H_{++}^2 + H_{00}^2 + 3H_{0t}^2)$$

$$A_\lambda(q^2) = \frac{d\Gamma_\tau/dq^2(\lambda_\tau = -1/2) - d\Gamma_\tau/dq^2(\lambda_\tau = 1/2)}{d\Gamma_\tau/dq^2}$$

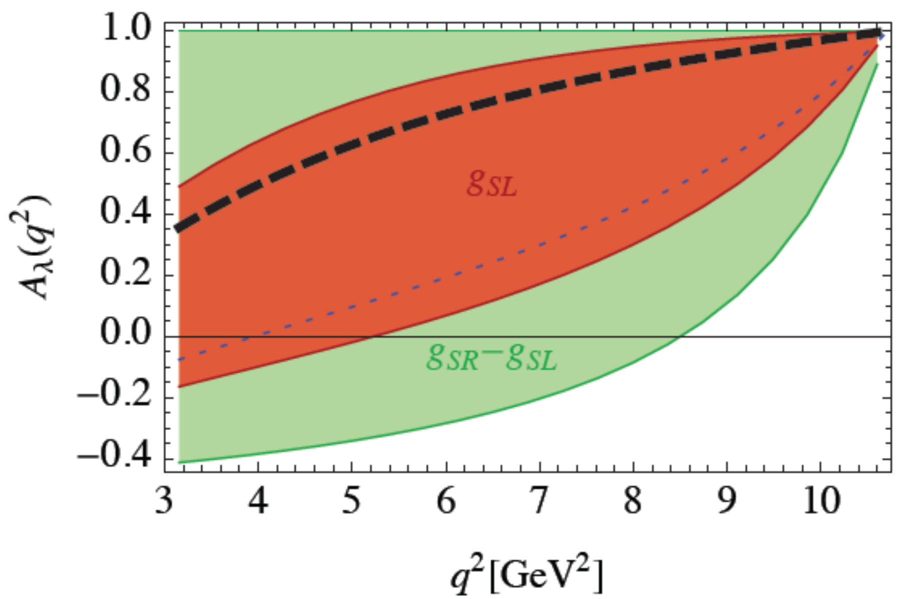
$$A_\lambda(q^2) = 1 - \frac{6|H_{0t}|^2 m_\tau^2}{(2q^2+m_\tau^2)(|H_{--}|^2 + |H_{00}|^2 + |H_{++}|^2) + 3|H_{0t}|^2 m_\tau^2}$$

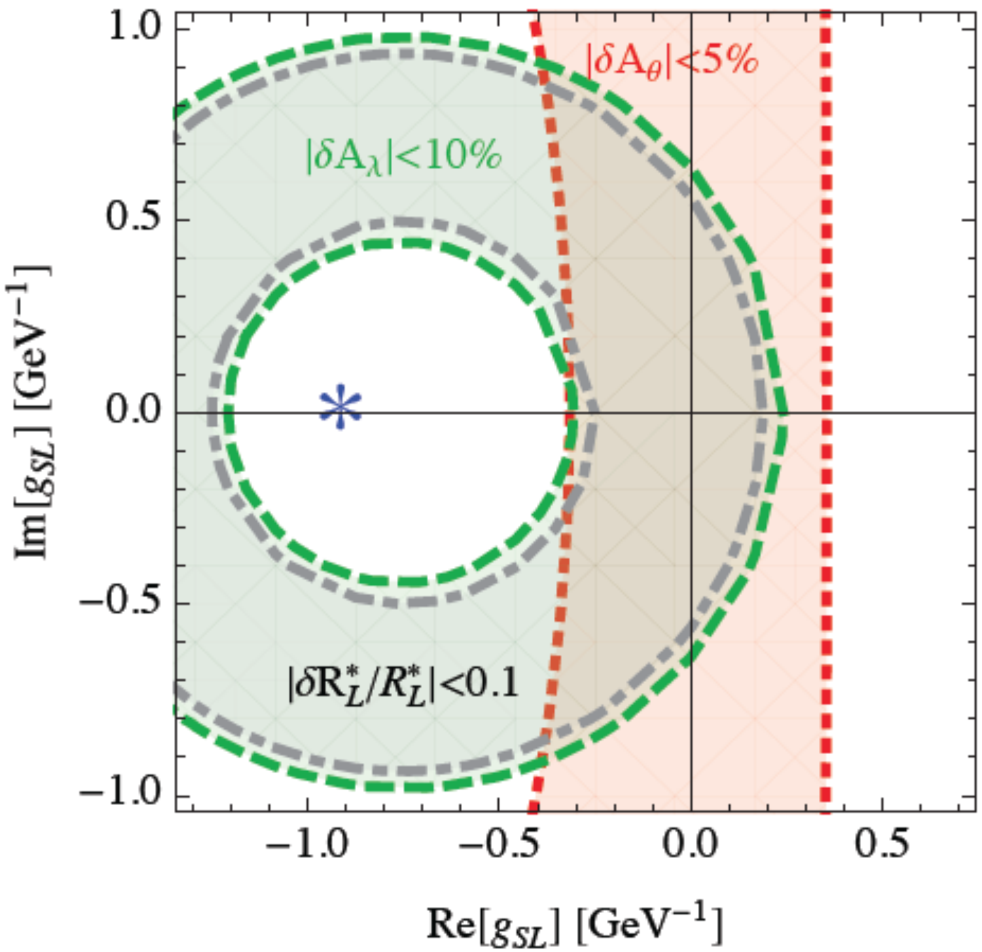
SM only:

$$A_{\lambda,SM} = 0.829(15)$$

SM+NP (benchmark point):

$$A_{\lambda,NP} = 0.36$$





1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
|δA_λ|<10%
|δA_θ|<5%
|δR*_L/R*_L|<0.1
Im[g_SL] [GeV^−1]
Re[g_SL] [GeV^−1]

# Summary and outlook

- disagreement exp. SM in $b \to u\tau\nu_\tau$ and $b \to c\tau\nu_\tau$;

- SM form factor knowledge can be improved;

- NP models can be constraint:

- MFV disfavored; 2HDM Type I, Type II, "lepton specific", and "flipped" can not account new $\tau\upsilon_\tau$ final states observables;
- 2HDM with general FV LQ, composite fermions, …
are able to account $\tau\upsilon$ observables;

- NP possible to constrain better in a number of new observables in $B \to D^* \tau\nu_\tau$

- measurements of $BR(B \to \pi\tau\nu_\tau)$ $BR(B_c \to \tau\nu_\tau)$
would give additional check of possible ~~LFU~~ ;
possible LHC signatures!

# 2HDM

$$\mathcal{L} = \bar{Q}_L \eta_1^U U_R \tilde{\Phi}_1 + \bar{Q}_L \eta_1^D D_R \Phi_1 + \bar{Q}_L \eta_2^U U_R \tilde{\Phi}_2 + \bar{Q}_L \eta_2^D D_R \Phi_2 + \bar{L}_L \eta_1^E E_R \Phi_1 + \bar{L}_L \eta_2^E E_R \Phi_2 + h.c.,$$

$$M^F = \frac{v}{\sqrt{2}}(\eta_1^F \cos\beta + \eta_2^F \sin\beta),$$

$$v_1 = v\cos\beta,\ v_2 = v\sin\beta \text{ with } v = 246 \text{ GeV}$$

Higgs doublet

$$\Phi_j = \begin{pmatrix} \phi_j^+ \\ (v_j + \rho_j + i\eta_j)/\sqrt{2} \end{pmatrix}.$$

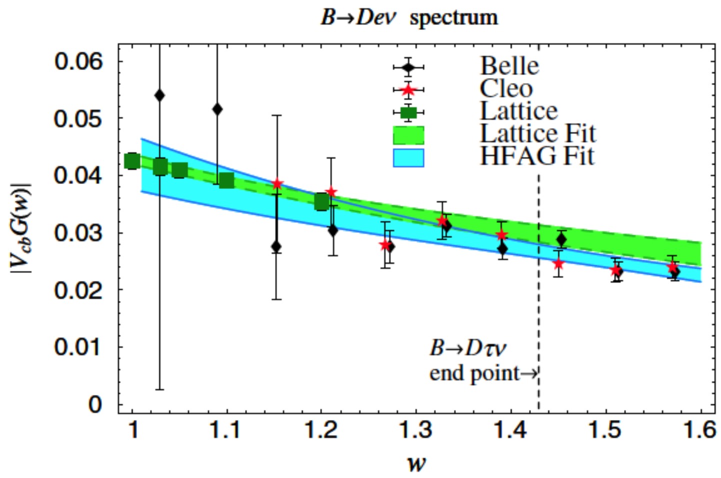
physical Higgses

$$\begin{aligned} h &= \rho_1 \sin\alpha - \rho_2 \cos\alpha, \\ H &= -\rho_1 \cos\alpha - \rho_2 \sin\alpha, \\ A &= \eta_1 \sin\beta - \eta_2 \cos\beta, \\ G^0 &= \eta_1 \cos\beta + \eta_2 \sin\beta \end{aligned}$$

assumption:
$\eta_i$ are diagonal
in the same basis as $M_F$.

$$c_{LR} = 4\left(\frac{v}{m_{H^+}}\right)^2 \left(\cot\beta \frac{\sqrt{2}m^D}{v} - \frac{\eta_1^D}{\sin\beta}\right)\cot\beta,$$

$$c_{RL} = 4\left(\frac{v}{m_{H^+}}\right)^2 \left(\cot\beta \frac{\sqrt{2}m^U}{v} - \frac{\eta_1^U}{\sin\beta}\right)\cot\beta,$$




$$\frac{\text{Br}(B \to D\tau\nu)}{\text{Br}(B \to De\nu)} = (0.28 \pm 0.03) \times [1 + 1.38(6)\,\text{Re}(C^{\tau}_{\text{NP}}) + 0.88(4)|C^{\tau}_{\text{NP}}|^2]$$