$B \to D^{(*)}\tau\nu$ Decays in the 2HDM

Alejandro Celis
IFIC CSIC-Universitat de València

In collaboration with: Martin Jung, Xin-Qiang Li and Antonio Pich.

IV CPAN Days, November 26 (2012)

Some remarks

I want you to get from this talk:

- What is the Two-Higgs doublet Model?
- Why $B \to D^{(*)}\tau\nu$ decays are interesting?
- $B \to D^{(*)}\tau\nu$ have many special features that make it an ideal place to look for NP

not an historical review on the subject
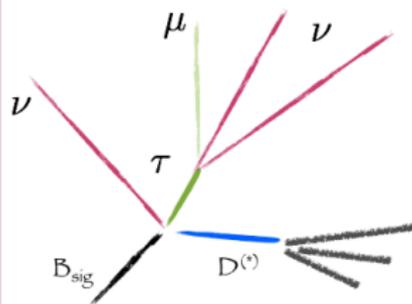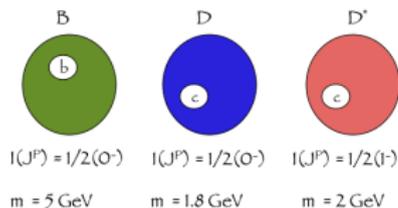
not an overview of the current situation

apologies when not providing references

What can we learn from $B \to D^{(*)} \tau \nu$ Decays?

$$\mathcal{L}_Y = \bar{Q}_L(Y_d\,H)d_R \to \frac{M_d}{v}\bar{Q}_L\,H d_R$$

$$\mathcal{L}_W \to \frac{g}{\sqrt{2}}\left[W_\mu^+\,\bar{u}_L\,V_{CKM}\,\gamma^\mu\,d_L\right]$$

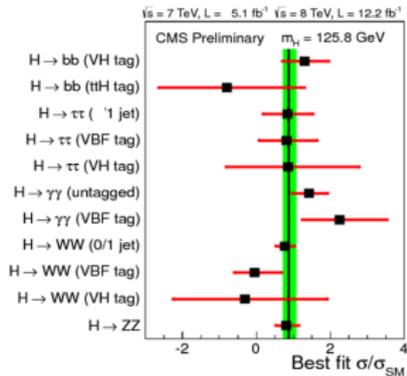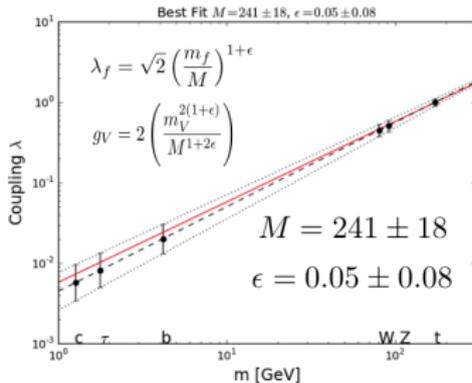# What can we learn from $B \to D^{(*)}\tau\nu$ Decays?

Best–fit Higgs mass m_H :
126.0 ± 0.4 (stat) ± 0.4 (syst) GeV

- M=125.8 ± 0.4 (stat) ± 0.4 (syst) GeV
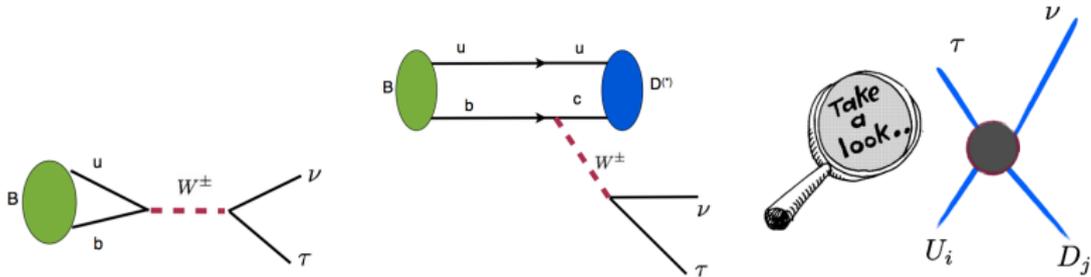
- σ/σ_{SM}=0.88±0.21

$$\lambda_f = \sqrt{2}\left(\frac{m_f}{M}\right)^{1+\epsilon}$$

$$g_V = 2\left(\frac{m_V^{2(1+\epsilon)}}{M^{1+2\epsilon}}\right)$$

$$M = 241 \pm 18$$
$$\epsilon = 0.05 \pm 0.08$$
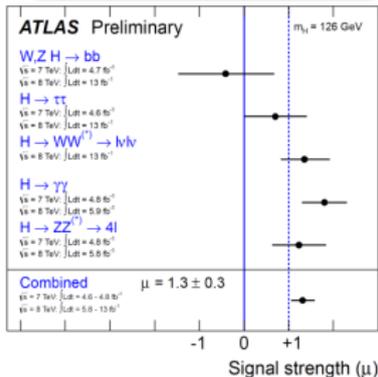
J. Ellis & T. You
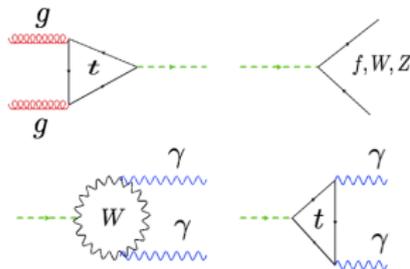
What can we learn from $B \to D^{(*)}\tau\nu$ Decays?

a second Higgs doublet $\to$ 8 real fields

$$\phi_k = \begin{pmatrix} \phi_k{}^+ \\ \phi_k{}^0 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi_k^1 + i\phi_k^2 \\ \phi_k^3 + i\phi_k^4 \end{pmatrix}.$$

3 Goldstone bosons: $\mathbf{M_{W^\pm}, M_Z}$
3 neutral Higgs bosons: $\mathbf{h, H, A}$
2 charged Higgs: $\mathbf{H^\pm}$

What can we learn from $B \to D^{(*)}\tau\nu$ Decays?

$$\mathcal{L}_Y = -\frac{\sqrt{2}}{v}\bar{Q}_L(M_d\,\phi_1 + Y_d\,\phi_2)d_R$$

$Y_f = \varsigma_f\,M_f$ **Yukawa Alignment** [Pich, Tuzon (2009)]

$\varsigma_u = \cot\beta\,, \qquad \varsigma_d = \varsigma_l = -\tan\beta$ Type II 2HDM

$$H^+(x)\left\{\bar{u}(x)\left[\varsigma_d\,VM_d\mathcal{P}_R - \varsigma_u\,M_u^\dagger V\mathcal{P}_L\right]d(x) + \varsigma_l\,\bar{\nu}(x)M_l\mathcal{P}_R l(x)\right\}$$

$B \to D^{(*)}\tau\nu$ decays are an excellent laboratory to look for NP effects related to EWSB

What can we learn from $B \to D^{(*)}\tau\nu$ Decays?

$$q^2 = (p_B - p_{D^{(*)}})^2$$
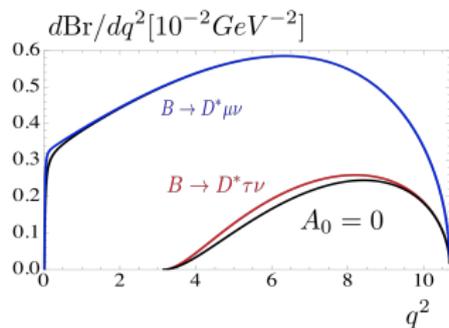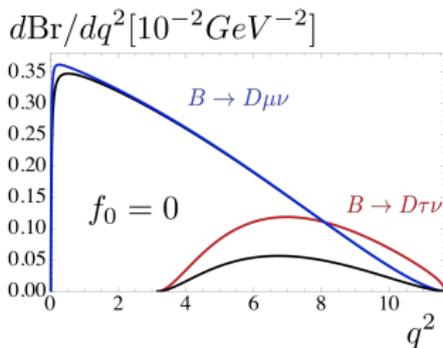
$$B \to D \qquad\qquad B \to D^*$$

$$f_0(q^2), f_+(q^2) \qquad\qquad A_0(q^2), V(q^2), A_1(q^2), A_2(q^2)$$

[Caprini, Lellouch, Neubert, Isgur, Wise]

$$\tilde{f}_0(q^2) = f_0(q^2) \left[1 + \frac{q^2}{m_{H^\pm}^2} \left(\frac{m_c \varsigma_u \varsigma_l^* - m_b \varsigma_d \varsigma_l^*}{m_b - m_c} \right) \right]$$

$$\tilde{A}_0(q^2) = A_0(q^2) \left[1 - \frac{q^2}{m_{H^\pm}^2} \left(\frac{m_c \varsigma_u \varsigma_l^* + m_b \varsigma_d \varsigma_l^*}{m_b + m_c} \right) \right]$$

$R(D)$ and $R(D^*)$ in the 2HDM

$B \to \tau\nu$, $D_{(s)} \to \mu\nu$, $D_s \to \tau\nu$
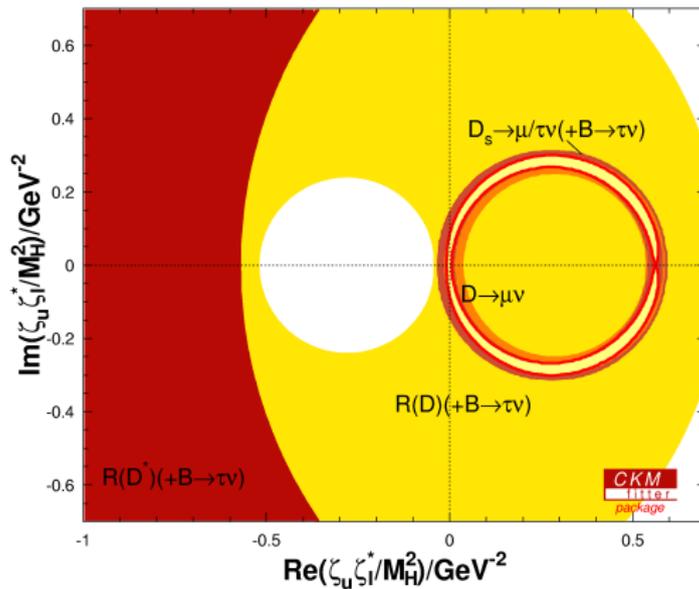
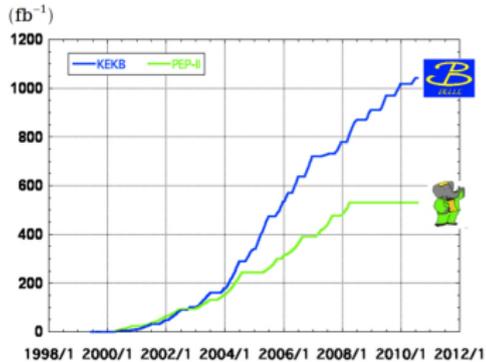

Departure from family Universality of Yukawa couplings

$$Y_q = \varsigma_q \, M_q$$

[A.C., M. Jung, X. Li, A. Pich. (2012)]
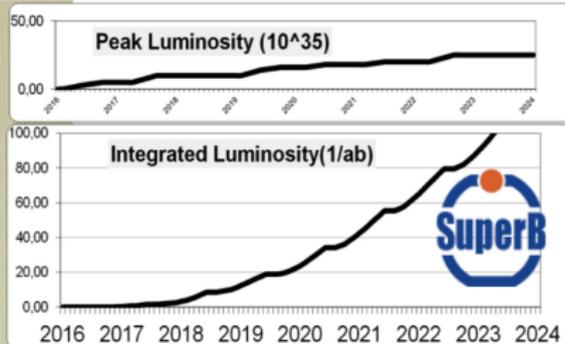
$B \to D^{(*)}\tau\nu$ at future Super-Flavor Factories

Integrated luminosity of B factories

> 1 ab^{-1}
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 25 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

Exiting future for precision flavor physics!
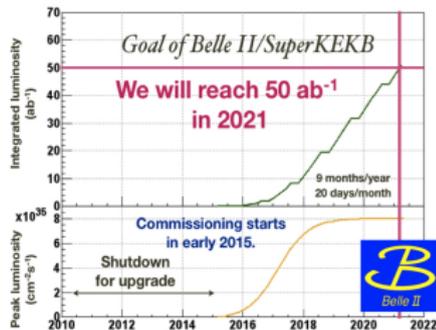
Conclusions

- $B \to D^{(*)}\tau\nu$ decays are an excellent laboratory to test the mechanism of electroweak symmetry breaking (c, b, τ, ν_τ). NP at tree level. Rich three-body kinematics. All the ingredients to look for new physics "and determine its nature".

- What are the prospects for future Super Flavor Factories?

- Experimentally very challenging process... I hope to have convinced you that it worths the effort.

- Expected new measurement from Belle, update from BaBar. Will LHCb surprise us?

Conclusions

Not covered in this talk: Recent progress on the theoretical determination of the form-factors
Fermilab Lattice and MILC Collaborations (2012)
Becirevic, Kosnik, Tayduganov.(2012)

Other recent works on $B \to D^{(*)} \tau \nu$ in light of the reported BaBar excess:
Y. Sakaki, H. Tanaka (2012)
S. Fajfer, J. F. Kamenik, I. Nisandzic, J. Zupan (2012)
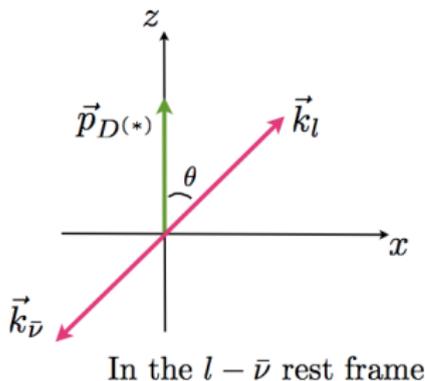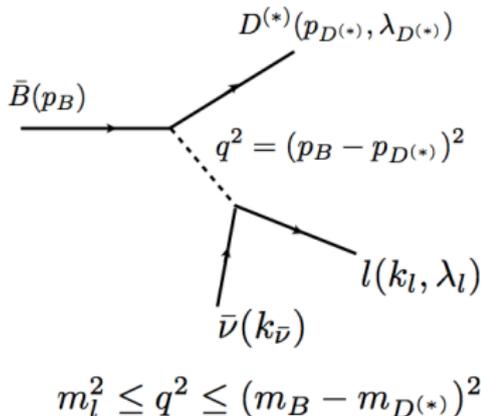A. Crivellin, C. Greub, A. Kokulu (2012)
Xiao-Gang He, G. Valencia (2012)
N.G. Deshpande, A. Menon (2012)
A. Datta, M. Duraisamy, D. Ghosh (2012)
D. Choudhury, D. Ghosh, A. Kundu (2012)

$\bar{B} \to D^{(*)} l \bar{\nu}$ Decays

$$m_l^2 \leq q^2 \leq (m_B - m_{D^{(*)}})^2$$

In the $l - \bar{\nu}$ rest frame

$$\left| \mathcal{M}(\bar{B} \to D^{(*)} l \bar{\nu}) \right|^2 = \left| \langle D^{(*)} l \bar{\nu} | \mathcal{L}_{eff} | \bar{B} \rangle \right|^2 = L_{\mu\nu} H^{\mu\nu}$$

$$\frac{d^2 \Gamma_l}{dq^2 d\cos\theta} = \frac{G_F^2 |V_{cb}|^2}{(2\pi)^3} \frac{|\vec{p}_B|}{2m_B^2} \left(1 - \frac{m_l^2}{q^2} \right) L_{\mu\nu} H^{\mu\nu}$$
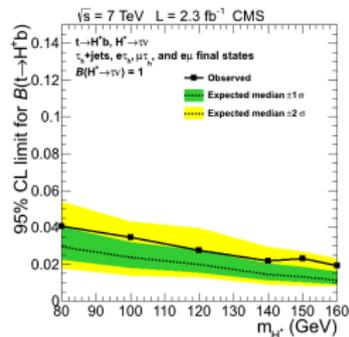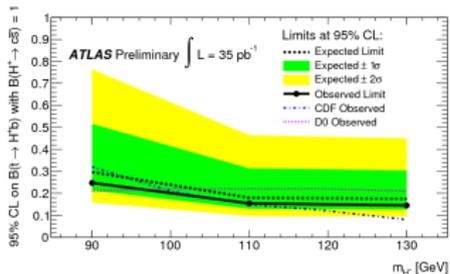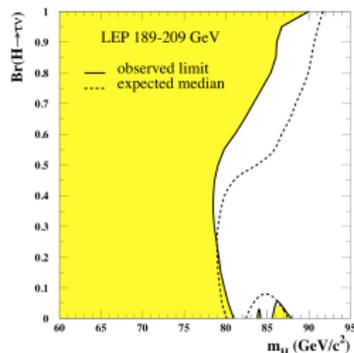
$\bar{B} \to D l \bar{\nu}$ Decays

- $\langle D(p_D)|\bar{c}\gamma^{\mu}b|\bar{B}(p_B)\rangle = f_+(q^2)\left[(p_B + p_D)^{\mu} - \dfrac{m_B^2 - m_D^2}{q^2}q^{\mu}\right]$

  $+ f_0(q^2)\dfrac{m_B^2 - m_D^2}{q^2}q^{\mu}$

- $\langle D(p_D)|\bar{c}\,\gamma^{\mu}\gamma_5 b|\bar{B}(p_B)\rangle = 0$

$\bar{B} \to D^* l \bar{\nu}$ **Decays**

- $\langle D^*(p_{D^*}, \epsilon^*)|\bar{c}\gamma_\mu b|\bar{B}(p_B)\rangle \;=\; \dfrac{2iV(q^2)}{m_B + m_{D^*}} \, \epsilon_{\mu\nu\alpha\beta} \, \epsilon^{*\nu} p_B^\alpha p_{D^*}^\beta \,,$

- $\langle D^*(p_{D^*}, \epsilon^*)|\bar{c}\gamma_\mu \gamma_5 b|\bar{B}(p_B)\rangle \;=\; 2m_{D^*} \, A_0(q^2) \, \dfrac{\epsilon^* \cdot q}{q^2} \, q_\mu$

  $+ \, (m_B + m_{D^*}) \, A_1(q^2) \left(\epsilon_\mu^* - \dfrac{\epsilon^* \cdot q}{q^2} \, q_\mu \right)$

  $- \, A_2(q^2) \, \dfrac{\epsilon^* \cdot q}{m_B + m_{D^*}} \left[(p_B + p_{D^*})_\mu - \dfrac{m_B^2 - m_{D^*}^2}{q^2} \, q_\mu \right] \,,$

Interplay between flavor and LHC physics.

LEP upper limit on the charged Higgs mass $e^+e^- \to H^+H^-$

Charged Higgs coupling with the top quark

LHC searches for a charged Higgs $t \to W^+(H^+)b$

Loop induced processes: $Z \to b\bar{b}$, Kaon mixing, B mixing.