Search for New Physics in semileptonic B decays

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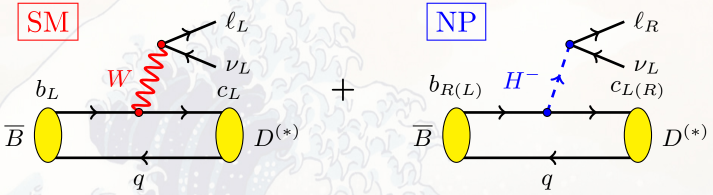
Outline

1. Introduction and motivation
2. Test of some New Physics models
3. Probing New Physics in angular distributions
4. Conclusions



- Tree-level (TL) process. Large $\mathcal{B}^{(\mathrm{SM})} \sim (1-2)\%$.
- TL processes can be sensitive to NP as well as FCNCs.
  - e.g. sensitive to the charged Higgs (2HDM).
- B-decays with τ in the final state offer possibilities to study NP effects not present in processes with light leptons.
- Hadronic uncertainties better controlled (or can be!).
- Popular NP test via

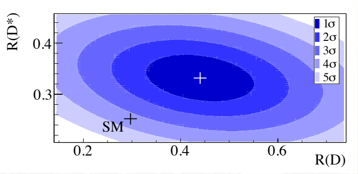
$$R(D) = \frac{\mathcal{B}(B \to D\tau\overline{\nu}_\tau)}{\mathcal{B}(B \to D\ell\overline{\nu}_\ell)}, \quad R(D^*) = \frac{\mathcal{B}(B \to D^*\tau\overline{\nu}_\tau)}{\mathcal{B}(B \to D^*\ell\overline{\nu}_\ell)} \quad (\ell = e, \mu)$$

in order to cancel/reduce theoretical uncertainties in V_{cb}/FFs.

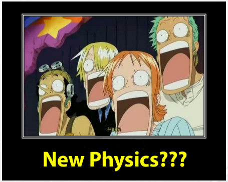
The *BABAR* results [arXiv:1205.5442],

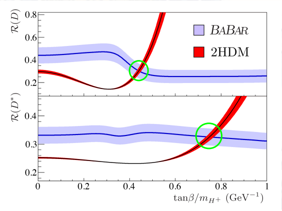
$$R(D)^{\text{exp}} = 0.440 \pm 0.058 \pm 0.042\,, \qquad R(D)^{\text{SM}} = 0.297 \pm 0.017\,,$$
$$R(D^*)^{\text{exp}} = 0.332 \pm 0.024 \pm 0.018\,, \qquad R(D^*)^{\text{SM}} = 0.252 \pm 0.003\,,$$

disagree with the SM at the 3.4 σ level (combining with Belle result, we obtain 3.5 σ).



[*BABAR*('13), arXiv:1303.0571]





2HDM-II EXCLUDED at 99.8% C.L. © BABAR →

- (A)2HDM[III] ?
- Leptoquarks ?
- $\not R$ MSSM ?
- smth else ?

“Model independent” approach

- We assume that there is NO right-handed neutrino.

$\mathcal{H}_{\rm eff}$ describing the $b \to c\tau\overline{\nu}$ process

$$\mathcal{H}_{\rm eff} = \frac{4G_F}{\sqrt{2}} V_{cb} \Big[(\underbrace{1}_{\rm SM} + \underbrace{C_{V_1}) \mathcal{O}_{V_1} + C_{V_2} \mathcal{O}_{V_2} + C_{S_1} \mathcal{O}_{S_1} + C_{S_2} \mathcal{O}_{S_2} + C_T \mathcal{O}_T}_{\rm NP} \Big]$$

$$\mathcal{O}_{V_1} = (\bar{c}_L \gamma^\mu b_L)(\bar{\tau}_L \gamma_\mu \nu_L)\,, \quad \mathcal{O}_{V_2} = (\bar{c}_R \gamma^\mu b_R)(\bar{\tau}_L \gamma_\mu \nu_L)\,,$$
$$\mathcal{O}_{S_1} = (\bar{c}_L b_R)(\bar{\tau}_R \nu_L)\,, \quad \mathcal{O}_{S_2} = (\bar{c}_R b_L)(\bar{\tau}_R \nu_L)\,,$$
$$\mathcal{O}_T = (\bar{c}_R \sigma^{\mu\nu} b_L)(\bar{\tau}_R \sigma_{\mu\nu} \nu_L)\,.$$

- E.g. in the 2HDM-II

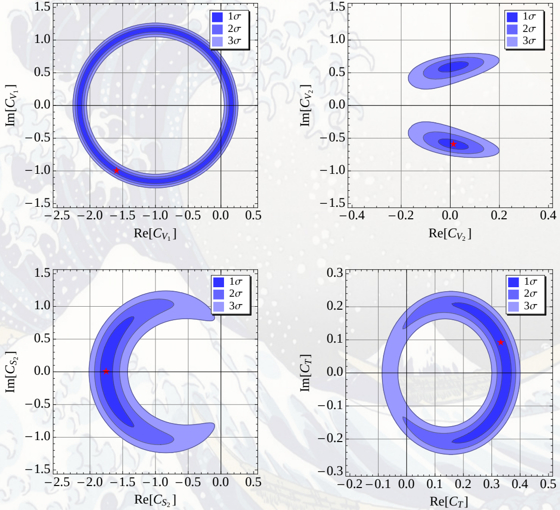
$$C_{S_1} = -\frac{m_b m_\tau}{m_{H^\pm}^2} \tan^2\beta$$

which is excluded by *BABAR* $\forall$ $\tan\beta / m_{H^\pm}$ $\Rightarrow$ the S_1 scenario is discarded!

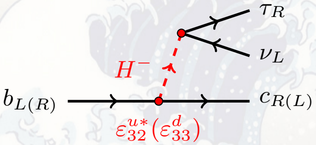
NB: the pseudotensor operator is not independent of $\mathcal{O}_T$ due to the relation $\bar{c}\sigma_{\mu\nu}\gamma_5 b = -\frac{i}{2}\epsilon_{\mu\nu\alpha\beta}\bar{c}\sigma^{\alpha\beta} b$.

Constraints on NP from $R(D)\&R(D^*)$

Assuming the presence of only one NP type, we do χ^2 fit of the combined *BABAR*+Belle result on $R(D)\&R(D^*)$ and obtain the constraints on the NP Wilson coefficients:



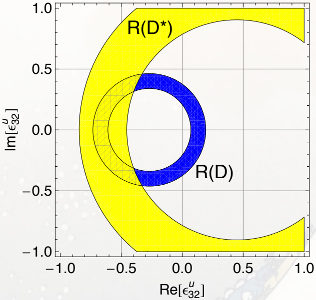
$$\mathcal{L}_{\rm Y} = \overline{Q}^a_{fL}[Y^d_{fi}\epsilon_{ab}H^{b*}_d - \varepsilon^d_{fi}H^a_u]d_{iR} - \overline{Q}^a_{fL}[Y^u_{fi}\epsilon_{ab}H^{b*}_u + \varepsilon^u_{fi}H^a_u]u_{iR} + \text{h.c.}$$



$$C_{S_1} \simeq \frac{1}{2\sqrt{2}G_F}\frac{m_\tau}{v}\varepsilon^d_{33}\frac{\sin\beta\tan^2\beta}{M^2_{H^\pm}}$$

-disfavoured by *BABAR*!

$$C_{S_2} \simeq \frac{1}{2\sqrt{2}G_F V_{cb}}\frac{m_\tau}{v}\varepsilon^{u*}_{32}\frac{\sin\beta\tan\beta}{M^2_{H^\pm}}$$



Allowed 1σ regions for $\tan\beta = 50$ and $M_H = 500$ GeV

[Crivellin at al.('12), arXiv:1206.2634]

2HDM-III can explain $R(D)$ and $R(D^*)$ simultaneously using a single free parameter ε^u_{32}.

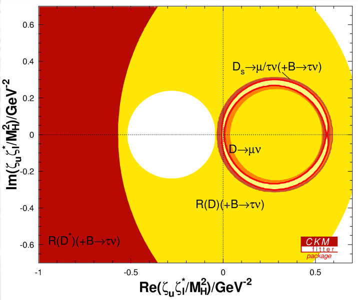
[see the talk of A. Crivellin]

$$\mathcal{L}_{\rm Y}^{H^\pm} = -\frac{\sqrt{2}}{v}[\overline{u}\varsigma_d V_{\rm CKM} M_d P_R d - \overline{u}\varsigma_u M_u V_{\rm CKM} P_L d + \varsigma_\ell \overline{\nu} M_\ell P_R \ell] H^+ + \text{h.c.}$$

$$C_{S_1} = -\varsigma_d \varsigma_\ell^* \frac{m_b m_\tau}{M_{H^\pm}^2}$$

$$\boxed{C_{S_2} = \varsigma_u \varsigma_\ell^* \frac{m_c m_\tau}{M_{H^\pm}^2}}$$

-tension between $D_{(s)}$ leptonic decays and $R(D^*)$ and $B \to \tau\overline{\nu}$.



[Celis at al.('13), arXiv:1210.8443]

A2HDM can explain $R(D^{(*)})$ and $B \to \tau\overline{\nu}$ simultaneously. However, the resulting parameter ranges are in conflict with the constraints from leptonic charm decays.

[see the talk of A. Celis]

Leptoquark models

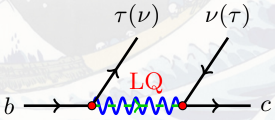
$\mathcal{L}_{\text{eff}}$ with generic dimensionless $SU(3) \times SU(2) \times U(1)$ invariant *non-diagonal* couplings of scalar and vector LQs (6 models)

$$\mathcal{L}^{\text{LQ}}_{F=0} = \left(h^{ij}_{1L}\,\overline{Q}_{iL}\gamma^\mu L_{jL} + h^{ij}_{1R}\,\overline{d}_{iR}\gamma^\mu \ell_{jR}\right) U_{1\mu} + h^{ij}_{3L}\,\overline{Q}_{iL}\boldsymbol{\sigma}\gamma^\mu L_{jL}\boldsymbol{U}_{3\mu}$$
$$+ \left(h^{ij}_{2L}\,\overline{u}_{iR}L_{jL} + h^{ij}_{2R}\,\overline{Q}_{iL}i\sigma_2\ell_{jR}\right) R_2$$
$$\mathcal{L}^{\text{LQ}}_{F=-2} = \left(g^{ij}_{1L}\,\overline{Q}^c_{iL}i\sigma_2 L_{jL} + g^{ij}_{1R}\,\overline{u}^c_{iR}\ell_{jR}\right) S_1 + g^{ij}_{3L}\,\overline{Q}^c_{iL}i\sigma_2\boldsymbol{\sigma}L_{jL}\boldsymbol{S}_3$$
$$+ \left(g^{ij}_{2L}\,\overline{d}^c_{iR}\gamma^\mu L_{jL} + g^{ij}_{2R}\,\overline{Q}^c_{iL}\gamma^\mu \ell_{jR}\right) V_{2\mu}$$

[Buchmüller et al.('87), Phys.Lett.B191]

Quantum numbers

	S_1	S_3	V_2	R_2	U_1	U_3
spin	0	0	1	0	1	1
$F = 3B + L$	-2	-2	-2	0	0	0
$SU(3)_c$	3^*	3^*	3^*	3	3	3
$SU(2)$	1	3	2	2	1	3
$U(1)_{Y=Q-T_3}$	1/3	1/3	5/6	7/6	2/3	2/3



$\text{LQ} = R_2^{2/3},\ U_{1\mu}^{2/3},\ U_{3\mu}^{2/3}$
$(S_1^{1/3},\ S_3^{1/3},\ V_{2\mu}^{1/3})$

Leptoquark models

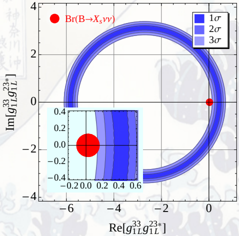
General Wilson coefficients (at $M_{\rm LQ}$ scale) for *all possible types of LQs contributing to the* $b \to c\tau\bar{\nu}$ *process* :

$$
\begin{aligned}
C_{V_1} &\simeq \frac{1}{2\sqrt{2}G_F V_{cb}} \left[\frac{g_{1L}^{33} g_{1L}^{23*}}{2M_{S_1}^2} - \frac{g_{3L}^{33} g_{3L}^{23*}}{2M_{S_3}^2} + \frac{h_{1L}^{23} h_{1L}^{33*}}{M_{U_1}^2} - \frac{h_{3L}^{23} h_{3L}^{33*}}{M_{U_3}^2} \right] \\
C_{V_2} &= 0 \\
C_{S_1} &\simeq \frac{1}{2\sqrt{2}G_F V_{cb}} \left[-\frac{2g_{2L}^{33} g_{2R}^{23*}}{M_{V_2}^2} - \frac{2h_{1L}^{23} h_{1R}^{33*}}{M_{U_1}^2} \right] \\
C_{S_2} &\simeq \frac{1}{2\sqrt{2}G_F V_{cb}} \left[-\frac{g_{1L}^{33} g_{1R}^{23*}}{2M_{S_1}^2} - \frac{h_{2L}^{23} h_{2R}^{33*}}{2M_{R_2}^2} \right] \\
C_T &\simeq \frac{1}{2\sqrt{2}G_F V_{cb}} \left[\frac{g_{1L}^{33} g_{1R}^{23*}}{8M_{S_1}^2} - \frac{h_{2L}^{23} h_{2R}^{33*}}{8M_{R_2}^2} \right]
\end{aligned}
$$

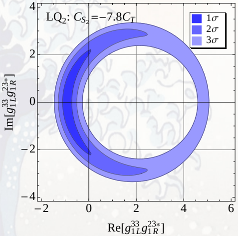
- We neglect $\mathcal{O}(\lambda^2)$ terms and keep only the leading terms proportional to V_{tb}.
- In the simplified scenario with only $R_2^{2/3}$ **or** $S_1^{1/3}$ LQ contribution, $C_{S_2}(M_{\rm LQ}) = \pm 4 C_T(M_{\rm LQ}) \Rightarrow$ for $M_{\rm LQ} \sim 1$ TeV, $C_{S_2}(\mu_b) \simeq \pm 7.8 C_T(\mu_b)$

[Sakaki,Tanaka,AT,Watanabe('13), arXiv:1309.0301]

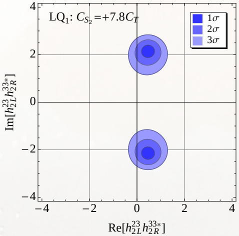
S_1 with only L couplings



S_1 with L, R couplings



R_2 with L, R couplings

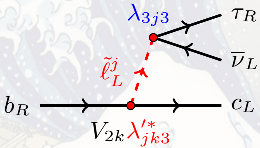


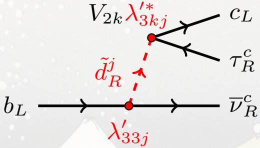
- The constraints on $g^{33}_{1(3)L}g^{23*}_{1(3)L}$ $(S_{1,3})$ from $R(D)\&R(D^*)$ and $\mathcal{B}(B \to X_s\nu\bar{\nu})$ are consistent only at 3σ level and force the couplings to be rather small.
- The U_3 LQ scenario with $h^{23}_{3L}h^{33*}_{3L}$ is excluded by $R(D)\&R(D^*)$ and $\mathcal{B}(B \to X_s\nu\bar{\nu})$.
- $h^{23}_{1L}h^{33*}_{1L}$ (U_1) remain unconstrained from $\mathcal{B}(B \to X_s\nu\bar{\nu})$ and the magnitude of $\mathcal{O}(1)$ can be sufficient to explain the data.
- For $M_{S_1,R_2} \sim 1$ TeV, one can have $g^{33}_{1L}g^{23*}_{1R}$, $h^{23}_{2L}h^{33*}_{2R} \sim \mathcal{O}(1)$.
- The other V_2 and U_1 LQ scenarios with L, R couplings are disfavoured as in the 2HDM-II.

$$W_{\rm RPV} = \frac{1}{2}\lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c$$

$$\mathcal{L}_{\rm eff}^{\rm RPV} = -\sum_{j,k=1}^{3} V_{2k}\left[\frac{\lambda_{3j3}\lambda'^{*}_{jk3}}{m^2_{\tilde{\ell}^j_L}}(\bar{c}_L b_R)(\bar{\tau}_R \nu_L) + \frac{\lambda'_{33j}\lambda'^{*}_{3kj}}{m^2_{\tilde{d}^j_R}}(\bar{c}_L \tau^c_R)(\overline{\nu}^c_R b_L)\right]$$

$$= -\sum_{j,k=1}^{3} V_{2k}\left[\frac{\lambda_{3j3}\lambda'^{*}_{jk3}}{m^2_{\tilde{\ell}^j_L}}\underbrace{(\bar{c}_L b_R)(\bar{\tau}_R \nu_L)}_{\mathcal{O}_{S_1}} + \frac{\lambda'_{33j}\lambda'^{*}_{3kj}}{2m^2_{\tilde{d}^j_R}}\underbrace{(\bar{c}_L \gamma^\mu b_L)(\bar{\tau}_L \gamma_\mu \nu_L)}_{\mathcal{O}_{V_1}}\right]$$





The corresponding Wilson coefficients are

$$C_{S_1} = \frac{1}{2\sqrt{2}G_F V_{cb}}\sum_{j,k=1}^{3} V_{2k}\frac{\lambda_{3j3}\lambda'^{*}_{jk3}}{2m^2_{\tilde{\ell}^j_L}}, \qquad \boxed{C_{V_1} = \frac{1}{2\sqrt{2}G_F V_{cb}}\sum_{j,k=1}^{3} V_{2k}\frac{\lambda'_{33j}\lambda'^{*}_{3kj}}{2m^2_{\tilde{d}^j_R}}}$$

[Tanaka,Watanabe('12), arXiv:1212.1878]

MSSM with $\not R$-parity violation

The largest effect on $R(D^{(*)})$ is obtained for $\not R$PV couplings for $k = 2$:

$$C_{V_1}^{\not R\text{MSSM}} \simeq \frac{1}{2\sqrt{2}G_F V_{cb}} \sum_{j=1}^{3} \frac{\lambda'_{33j}\lambda'^{*}_{32j}}{2m^2_{\tilde{d}^j_R}}$$

The same $\not R$PV couplings appear also in the NP contribution to $b \to s\nu\bar{\nu}$:

$$\mathcal{H}_{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^{*} \left[C_L^{(\text{SM})} + C_L\right] \mathcal{O}_L$$

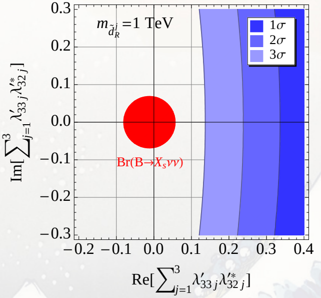
$$\mathcal{O}_L = (\bar{s}_L\gamma^\mu b_L)(\bar{\nu}_L\gamma_\mu\nu_L)$$

$$C_L^{\not R\text{MSSM}} \simeq \frac{1}{2\sqrt{2}G_F V_{tb}V_{ts}^{*}} \sum_{j=1}^{3} \frac{\lambda'_{33j}\lambda'^{*}_{32j}}{m^2_{\tilde{d}^j_R}}$$

[Tanaka,Watanabe('12), arXiv:1212.1878]

$$\mathcal{B}^{\text{exp}}(B \to X_s\nu\bar{\nu}) < 6.4 \times 10^{-4}$$

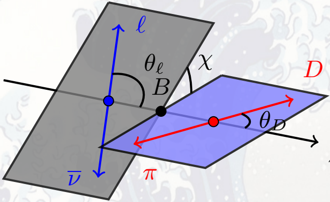
[ALEPH('00), arXiv:0010022]



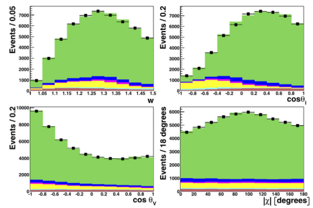
- MSSM with $\not R$PV is inconsistent with both $B \to D^{(*)}\tau\bar{\nu}$ and $B \to X_s\nu\bar{\nu}$ at the same time.
- $\mathcal{L}_{\text{eff}}^{RPV}$ involves the interaction which induces LFV $\Rightarrow$ one can have ν with flavour different from τ. In this case the conclusion remains same.

Angular distributions

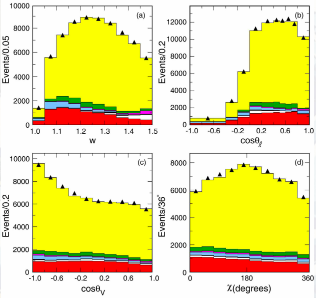
Study full angular distributions and find quantities that are (a) sensitive to NP and (b) partially or completely complementary to $d\Gamma/dq^2$.



[Belle('10), arXiv:1010.5620]



[BABAR('08), arXiv:0705.4008]



Belle and *BABAR* had already studied 4 **separate 1D** distributions in q^2, $\cos\theta_\ell$, $\cos\theta_D$ and χ of *light lepton mode* from which the hadronic FF$\times V_{cb}$ were extracted. However,

- Only SM contribution was assumed!
- $\Rightarrow$ Some terms were omitted, as in [Körner,Schuler('90), Z.Phys.C46].
- $\Rightarrow$ Redo the *full angular* analysis w/o assuming validity of the SM.

NP in azimuthal observables and CPV triple products

The full angular analysis of $B \to D^* \tau \overline{\nu}$ has been recently done in [Duraisamy,Datta('13), arXiv:1302.7031], [Duraisamy et al.('14), arXiv:1405.3719]. For comparison with our operator basis on p.6 please note

$$g_{V,A} = C_{V_2} \pm C_{V_1} \,, \quad g_{S,P} = C_{S_1} \pm C_{S_2} \,, \quad T_L = C_T$$

Some of the conclusions from arXiv:1405.3719, 1405.3719

- 2 of 3 CPV triple products are only sensitive to vector/axial vector NP and do not depend on pseudoscalar NP.
- One can use the triple products to search even in e and μ modes.
- Azimuthal asymmetries, integrated over q^2, have different sensitivities to different NP structures hence becoming powerful probes of the nature of NP.
- In particular, these observables turn out to be very efficient in discriminating between the two LQ models.

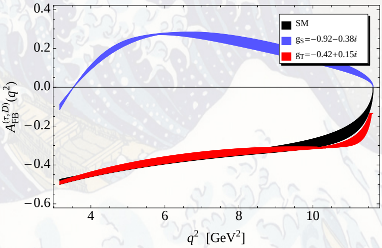
Using the operators of higher dimension, the process $b \to c\ell\overline{\nu}_\ell$ can be described by the general effective Hamiltonian:

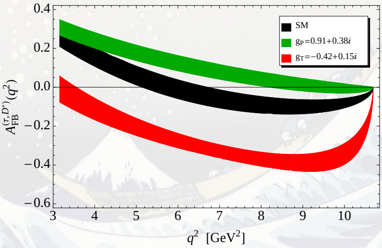
$$\mathcal{H}_{\rm eff} = \frac{G_F}{\sqrt{2}} V_{cb} \big[(1 + g_V) \bar{c}\gamma_\mu b + (-1 + g_A) \bar{c}\gamma_\mu\gamma_5 b + g_S\, i\partial_\mu(\bar{c}b) + g_P\, i\partial_\mu(\bar{c}\gamma_5 b) + g_T\, i\partial_\nu(\bar{c}i\sigma_{\mu\nu}b) + g_{T5}\, i\partial_\nu(\bar{c}i\sigma_{\mu\nu}\gamma_5 b) \big] (\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell)$$

$$g_{V,A} \sim \mathcal{O}\left(\frac{v^2}{\Lambda^2_{\rm NP}}\right), \quad g_{S,P,T,T5} \sim \frac{1}{v}\mathcal{O}\left(\frac{v^2}{\Lambda^2_{\rm NP}}\right)$$

$$\frac{d^2\Gamma}{dq^2 d\cos\theta_\ell} = a_{\theta_\ell}(q^2) + b_{\theta_\ell}(q^2)\cos\theta_\ell + c_{\theta_\ell}(q^2)\cos^2\theta_\ell$$

$$\mathcal{A}_{FB}^{(\ell)}(q^2) = \frac{\int_0^1 \frac{d^2\Gamma}{dq^2 d\cos\theta_\ell} d\cos\theta_\ell - \int_{-1}^0 \frac{d^2\Gamma}{dq^2 d\cos\theta_\ell} d\cos\theta_\ell}{\int_{-1}^1 \frac{d^2\Gamma}{dq^2 d\cos\theta_\ell} d\cos\theta_\ell} = \frac{b_{\theta_\ell}(q^2)}{d\Gamma/dq^2}$$





[Bečirević,Fajfer,Nišandžić,AT, in preparation]

$B \to D^*(\to D\pi)\ell\overline{\nu}_\ell$: full angular distribution

The full angular distribution is given by

$$\frac{d^4\Gamma}{dq^2 d\cos\theta_\ell d\cos\theta_D d\chi} = \frac{3G_F^2|V_{cb}|^2}{256(2\pi)^4 m_B^3} q^2 \left(1-\frac{m_\ell^2}{q^2}\right)^2 \sqrt{\lambda_{D^*}(q^2)} \times \mathcal{B}(D^* \to D\pi) \times \Bigg\{$$

$$[|H_+|^2+|H_-|^2]\left(1+\cos^2\theta_\ell + \frac{m_\ell^2}{q^2}\sin^2\theta_\ell\right)\sin^2\theta_D + 2[|H_+|^2-|H_-|^2]\cos\theta_\ell\sin^2\theta_D$$

$$+4|H_0|^2\left(\sin^2\theta_\ell + \frac{m_\ell^2}{q^2}\cos^2\theta_\ell\right)\cos^2\theta_D + 4|H_t|^2\frac{m_\ell^2}{q^2}\cos^2\theta_D$$

$$-2\beta_\ell^2\left(\mathcal{R}e[H_+H_-^*]\cos 2\chi + \mathcal{I}m[H_+H_-^*]\sin 2\chi\right)\sin^2\theta_\ell\sin^2\theta_D$$

$$-\beta_\ell^2\left(\mathcal{R}e[H_+H_0^* + H_-H_0^*]\cos\chi + \mathcal{I}m[H_+H_0^* - H_-H_0^*]\sin\chi\right)\sin 2\theta_\ell\sin 2\theta_D$$

$$-2\mathcal{R}e\left[H_+H_0^* - H_-H_0^* - \frac{m_\ell^2}{q^2}\left(H_+H_t^* + H_-H_t^*\right)\right]\cos\chi\sin\theta_\ell\sin 2\theta_D$$

$$-2\mathcal{I}m\left[H_+H_0^* + H_-H_0^* - \frac{m_\ell^2}{q^2}\left(H_+H_t^* - H_-H_t^*\right)\right]\sin\chi\sin\theta_\ell\sin 2\theta_D$$

$$+8\mathcal{R}e[H_0H_t^*]\frac{m_\ell^2}{q^2}\cos\theta_\ell\cos^2\theta_D\Bigg\}, \quad \beta_\ell(q^2) = \sqrt{1-\frac{m_\ell^2}{q^2}}, \quad H(q^2) = \tilde{\varepsilon}^{\mu *}\langle D^*(\varepsilon)|J_\mu|\overline{B}\rangle$$

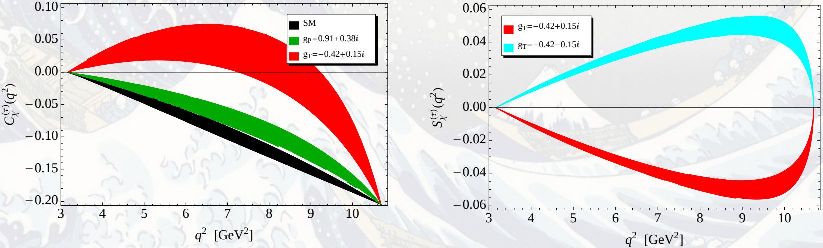
In the SM, the $\mathcal{I}m$-terms $=0$ and therefore were omitted in the analyses of Belle and *BABAR*. But if there are NP complex phases, these terms could be important and interesting to study.

[Bečirević,Fajfer,Nišandžić,AT, in preparation]

$$\frac{d^2\Gamma}{dq^2 d\chi} = a_\chi(q^2) + b^c_\chi(q^2)\cos\chi + b^s_\chi(q^2)\sin\chi + c^c_\chi(q^2)\cos 2\chi + c^s_\chi(q^2)\sin 2\chi$$

- $b^{c,s}_\chi(q^2) = 0$ unless there is interference with $(D\pi)_S$ amplitude.
- $c^s_\chi(q^2) \equiv 0$ in the SM $\Rightarrow$ $c^s_\chi(q^2) \neq 0$ would be a clear signal of NP!
- 2 NEW NP-sensitive observables (independent of pseudoscalar NP!)

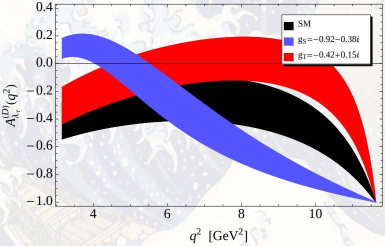
$$C^{(\ell)}_\chi(q^2) = \frac{c^c_\chi(q^2)}{a_\chi(q^2)}, \qquad S^{(\ell)}_\chi(q^2) = \frac{c^s_\chi(q^2)}{a_\chi(q^2)}$$

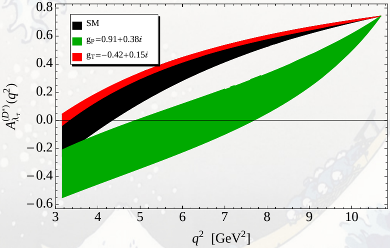


[Bečirević,Fajfer,Nišandžić,AT, in preparation]

3. Lepton spin asymmetry

$$\mathcal{A}_{\lambda_\tau}(q^2) = \frac{d\Gamma/dq^2(\lambda_\tau = -1/2) - d\Gamma/dq^2(\lambda_\tau = 1/2)}{d\Gamma/dq^2}$$





[Bečirević,Fajfer,Nišandžić,AT, in preparation]

Sensitivity summary

$B \to D\ell\overline{\nu}_\ell$

observable	g_V	g_S	g_T
$\mathcal{B}^{(\mu)}$	⋆⋆	–	⋆⋆
$\mathcal{B}^{(\tau)}$	⋆	⋆⋆⋆	⋆
$R(D)$	–	⋆⋆⋆	–
$\mathcal{A}_{FB}^{(\mu)}$	–	⋆	–
$\mathcal{A}_{FB}^{(\tau)}$	–	⋆⋆⋆	–
$\mathcal{A}_{\lambda}^{(\tau)}$	–	⋆⋆	–

$B \to D^*\ell\overline{\nu}_\ell$

observable	g_V	g_A	g_P	g_T
$\mathcal{B}^{(\mu)}$	⋆	⋆⋆	–	⋆⋆⋆⋆
$\mathcal{B}^{(\tau)}$	–	⋆	⋆	⋆⋆⋆
$R(D^*)$	⋆	–	⋆	⋆⋆
$\mathcal{A}_{FB}^{(\mu)}$	⋆⋆⋆	⋆⋆⋆	–	⋆⋆⋆
$\mathcal{A}_{FB}^{(\tau)}$	⋆⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆⋆
$\mathcal{A}_{\lambda}^{(\tau)}$	–	–	⋆⋆⋆	–
$c_\chi^{c(\mu)}/a_\chi^{(\mu)}$	–	–	–	⋆
$c_\chi^{c(\tau)}/a_\chi^{(\tau)}$	–	–	⋆⋆	⋆
$c_\chi^{s(\mu)}/a_\chi^{(\mu)}$	⋆⋆⋆	⋆⋆⋆	–	⋆⋆⋆
$c_\chi^{s(\tau)}/a_\chi^{(\tau)}$	⋆⋆⋆	⋆⋆⋆	–	⋆⋆⋆⋆

The number of $\star$ in the tables represent

- the strength of the constraints obtained from the $\mathcal{B}$'s and R's measurements,
- the sensitivity of asymmetries and angular observables to particular couplings.

Conclusions

1. Not only FCNC loop processes can provide a window to NP search. Tree-level decays are as good and often even more interesting, especially when the hadronic uncertainties are well controlled.
2. Excess in $\overline{B} \to D\tau\overline{\nu}$ and $\overline{B} \to D^*\tau\overline{\nu}$, observed by *BABAR* and Belle, helped discarding 2HDM-II.
3. Some of the leptoquark models can explain the observed discrepancy in $R(D)$ and $R(D^*)$ and can provide quite good constraints on leptoquark couplings which are allowed to be $\sim \mathcal{O}(1)$.
4. More precise data that will be given in a future Belle II experiment will allow us to identify the relevant NP operator(s) and test some particular NP models if the deviation from the SM persists. Various angular distributions and asymmetries could be very helpful for testing NP signals.

BACKUP SLIDES

How to distinguish between NP scenarios : various observables

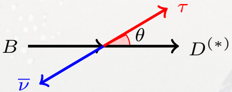
- R ratios (to be improved at Belle II)

$$R(D^{(*)}) = \frac{\mathcal{B}(B\to D^{(*)}\tau\overline{\nu})}{\mathcal{B}(B\to D^{(*)}\ell\overline{\nu})}$$

- τ forward-backward asymmetry,

$$\mathcal{A}_{\rm FB} = \frac{\int_0^1 \frac{d\Gamma}{d\cos\theta}d\cos\theta - \int_{-1}^0 \frac{d\Gamma}{d\cos\theta}d\cos\theta}{\int_{-1}^1 \frac{d\Gamma}{d\cos\theta}d\cos\theta} = \frac{\int b_\theta(q^2)dq^2}{\Gamma}$$

$$\frac{d^2\Gamma}{dq^2 d\cos\theta} = a_\theta(q^2) + b_\theta(q^2)\cos\theta + c_\theta(q^2)\cos^2\theta$$



- τ polarization parameter by studying further τ decays,

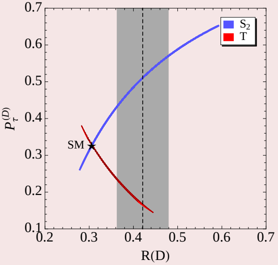
$$P_\tau = \frac{\Gamma(\lambda_\tau=1/2)-\Gamma(\lambda_\tau=-1/2)}{\Gamma(\lambda_\tau=1/2)+\Gamma(\lambda_\tau=-1/2)}$$

- D^* longitudinal polarization using the $D^* \to D\pi$ decay,

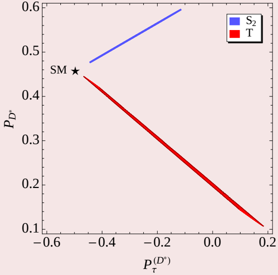
$$P_{D^*} = \frac{\Gamma(\lambda_{D^*}=0)}{\Gamma(\lambda_{D^*}=0)+\Gamma(\lambda_{D^*}=1)+\Gamma(\lambda_{D^*}=-1)}$$

Applying the constraints on C_{S_2} or C_T from the χ^2 fit of $R(D)\&R(D^*)$ at 3σ level,

τ polarization



D^* polarization



[Sakaki,Tanaka,AT,Watanabe('13), arXiv:1309.0301]

Measurements of these observables in addition to more precise determination of $R(D^{(*)})$ are the key issue in order to identify the origin of the present excess of $\overline{B} \to D^{(*)}\tau\overline{\nu}$.

BUT this is NOT an easy experimental task ☹

Exploring the q^2 dependence for the NP search

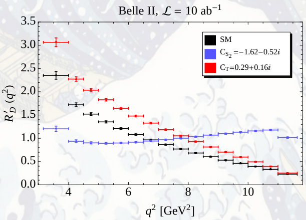
- To reduce the FF uncertainties, one can explore the q^2-dependent ratio

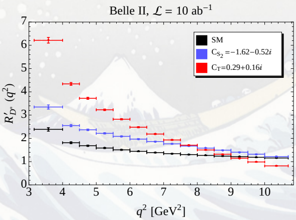
$$R_{D^{(*)}}(q^2) \equiv \frac{d\mathcal{B}(\overline{B} \to D^{(*)}\tau\overline{\nu})/dq^2}{d\mathcal{B}(\overline{B} \to D^{(*)}\ell\overline{\nu})/dq^2}$$

- For our convenience, we introduce

$$R'_D(q^2) \equiv R_D(q^2) \times \frac{\lambda_D(q^2)}{(m_B^2 - m_D^2)^2} \times \left(1 - \frac{m_\tau^2}{q^2}\right)^{-2}$$

$$R'_{D^*}(q^2) \equiv R_{D^*}(q^2) \times \left(1 - \frac{m_\tau^2}{q^2}\right)^{-2}$$





[Sakaki,Tanaka,AT,Watanabe, in preparation]