LFU tests in the angular observables of $B \to D^{(*)}\ell\nu$

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based on arXiv:190x.xxxxx in collaboration with:

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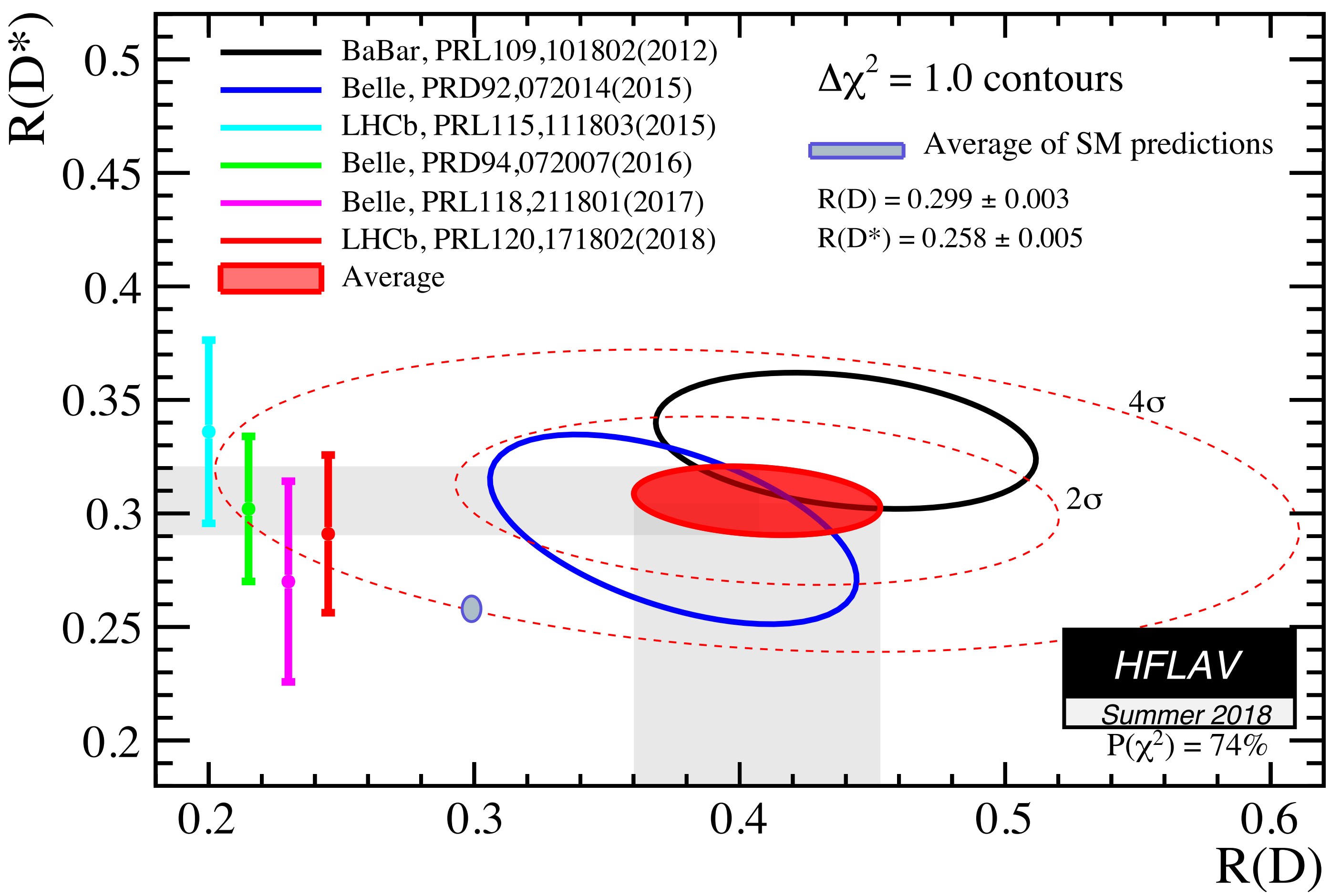
Introduction

- Tree level processes with large Br (~ few %)
- Theoretically cleaner (w.r.t FCNC b→s transitions)
- Sensitive to NP via LFUV tests

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



Experimental average (HFLAV):

$$R(D) = 0.407 \pm 0.039 \pm 0.024$$
$$R(D^*) = 0.306 \pm 0.013 \pm 0.007$$

SM predictions:

$$R(D) = 0.299 \pm 0.003$$
$$R(D^*) = 0.258 \pm 0.005$$

Comb. discrepancy at 3.8σ level

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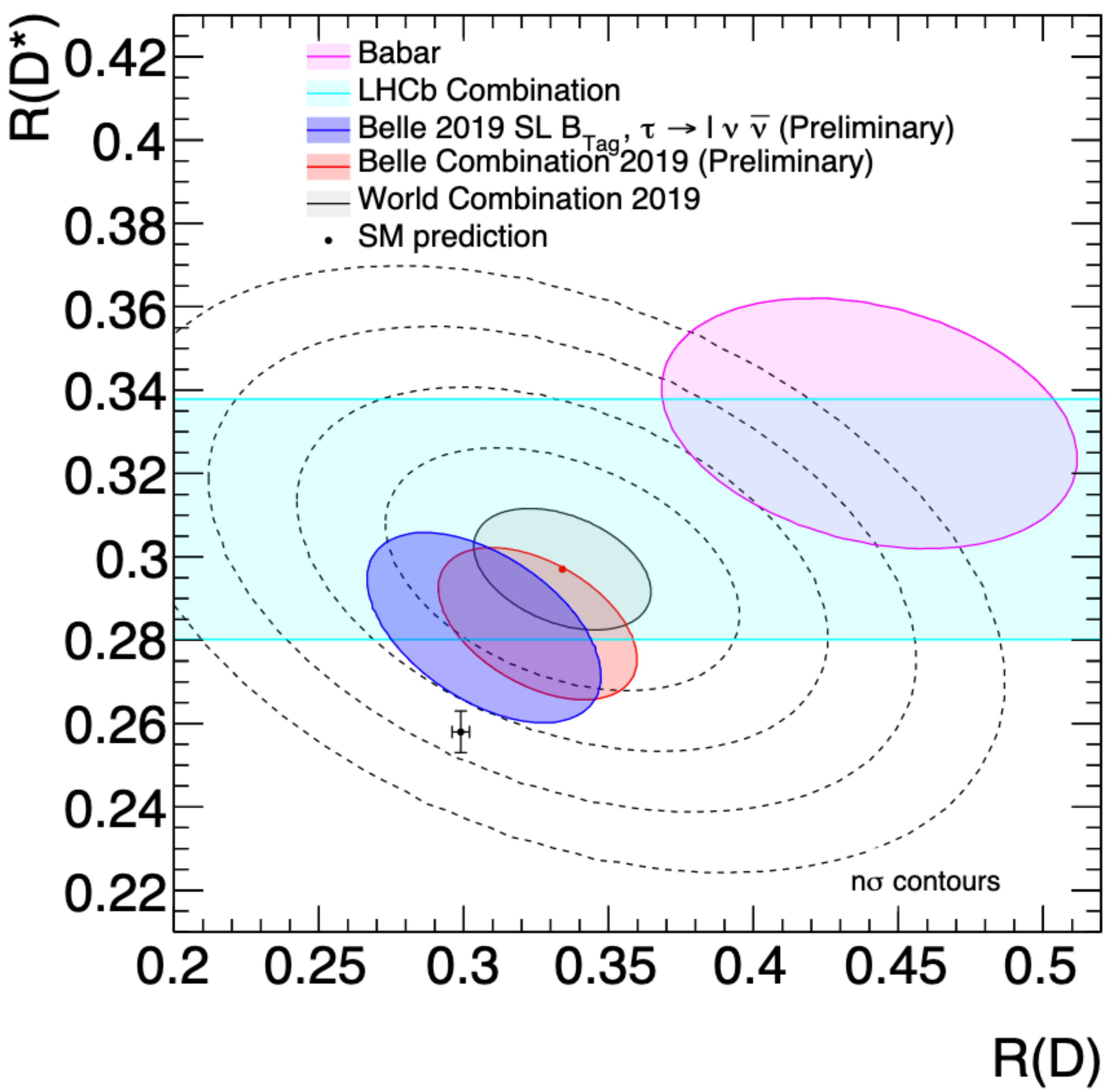


(My) Experimental average (PlotDig.):

$$R(D) = 0.334 \pm 0.029$$
$$R(D^*) = 0.297 \pm 0.014$$

SM predictions:

$$R(D) = 0.299 \pm 0.003$$
$$R(D^*) = 0.258 \pm 0.005$$

Comb. discrepancy at 3.1σ level

Goal of my talk

- These measurements, if indeed confirmed, point unequivocally to the presence of NP effects in $b \to c$ transitions

- Can we build more observables, complementary to $R(D^{(*)})$, in order to further probe NP effects?

- Can these new observable distinguish between different Lorentz structure? (Presently, several different solutions allowed)

Assumptions of my talk

- I will assume NP effects affecting only the τ channel, with SM behaviour assumed for the e and μ channel, using an effective Hamiltonian

- I will study the effects obtained considering only one NP WC at a time

- I will assume complex values for all WC

NP analysis

It is possible to describe the process b→c$\ell\nu$ by means of the effective Hamiltonian

$$\mathcal{H}_{\rm eff} = \sqrt{2} G_F V_{cb} \Big\{ \Big[(1 + g_V)\, \bar{c}\gamma_\mu b + (-1 + g_A)\, \bar{c}\gamma_\mu\gamma_5 b \Big] \bar{\ell}_L \gamma^\mu \nu_L$$

$$+ \Big[g_S\, \bar{c} b + g_P\, \bar{c}\gamma_5 b \Big] \bar{\ell}_R \nu_L$$

$$+ \Big[g_T\, \bar{c}\sigma_{\mu\nu} b + g_{T5}\, \bar{c}\sigma_{\mu\nu}\gamma_5 b \Big] \bar{\ell}_R \sigma^{\mu\nu} \nu_L \Big\} + \text{h.c.}$$

Only left-handed neutrinos!

$$g_i \sim \mathcal{O}\left(\frac{v^2}{\Lambda^2_{\rm NP}}\right), \qquad g_i^{\rm (SM)} = 0$$

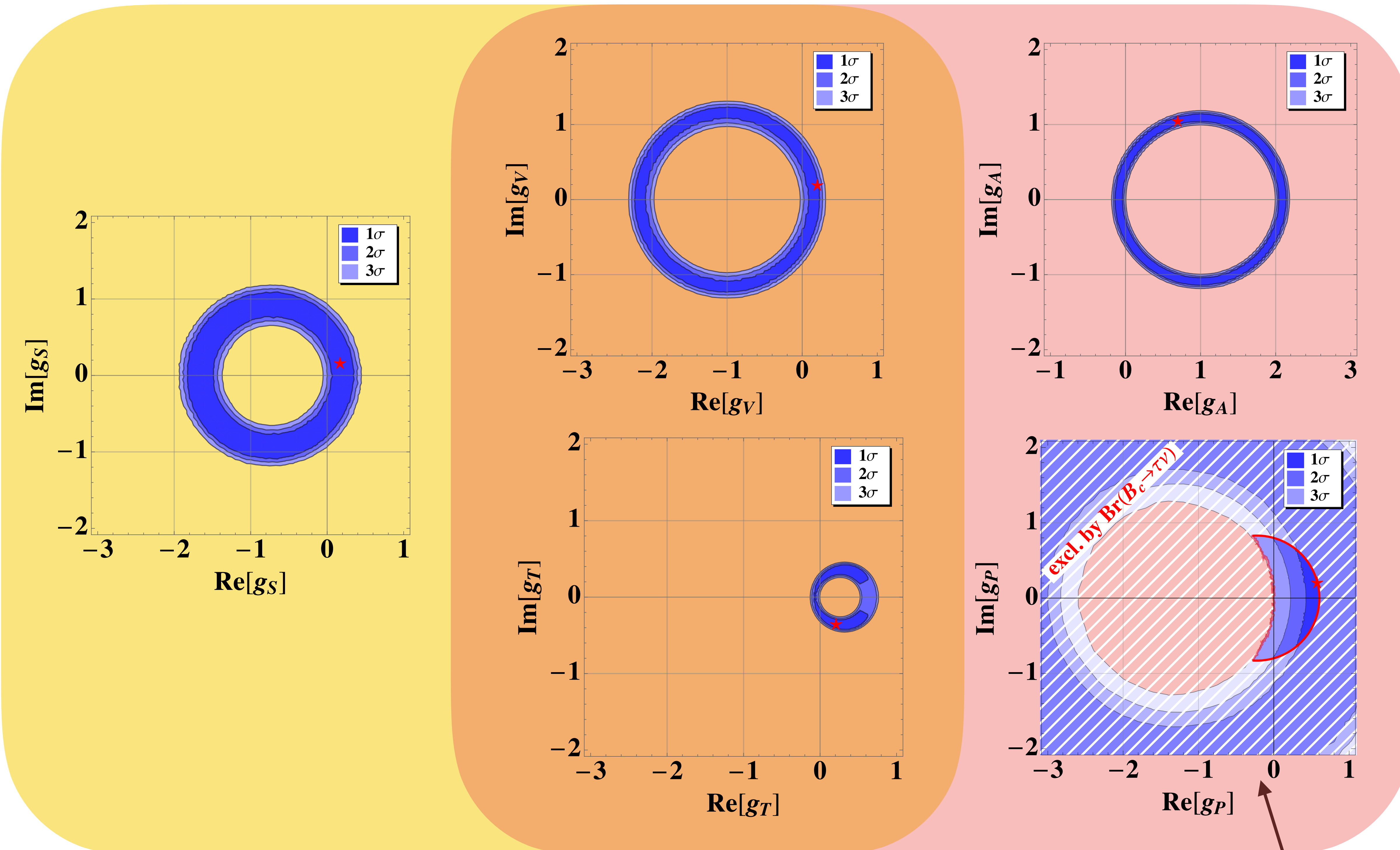
Tensor couplings are actually not independent, due to the relation $\sigma_{\mu\nu}\gamma_5 = (i/2)\epsilon_{\mu\nu\alpha\beta}\sigma^{\alpha\beta}$

As a first step, let's start by fitting present data and constraining each WC

NP analysis

$R(D)$

$R(D^*)$



Only one WC at a time!

$Br(B_c \to \tau\nu) < 30\%$

NP analysis - chiral basis

Alternatively, it is possible to use the effective chiral Hamiltonian

$$\mathcal{H}_{\rm eff} = \sqrt{2} G_F V_{cb} \Big\{ \Big[(1 + g_{V_L}) \, \bar{c}_L \gamma_\mu b_L + g_{V_R} \, \bar{c}_R \gamma_\mu b_R \Big] \bar{\ell}_L \gamma^\mu \nu_L + \Big[g_{S_L} \, \bar{c}_R b_L + g_{S_R} \, \bar{c}_L b_R \Big] \bar{\ell}_R \nu_L + g_{T_L} \, (\bar{c}_R \sigma_{\mu\nu} b_L)(\bar{\ell}_R \sigma^{\mu\nu} \nu_L) \Big\} + \text{h.c.}$$

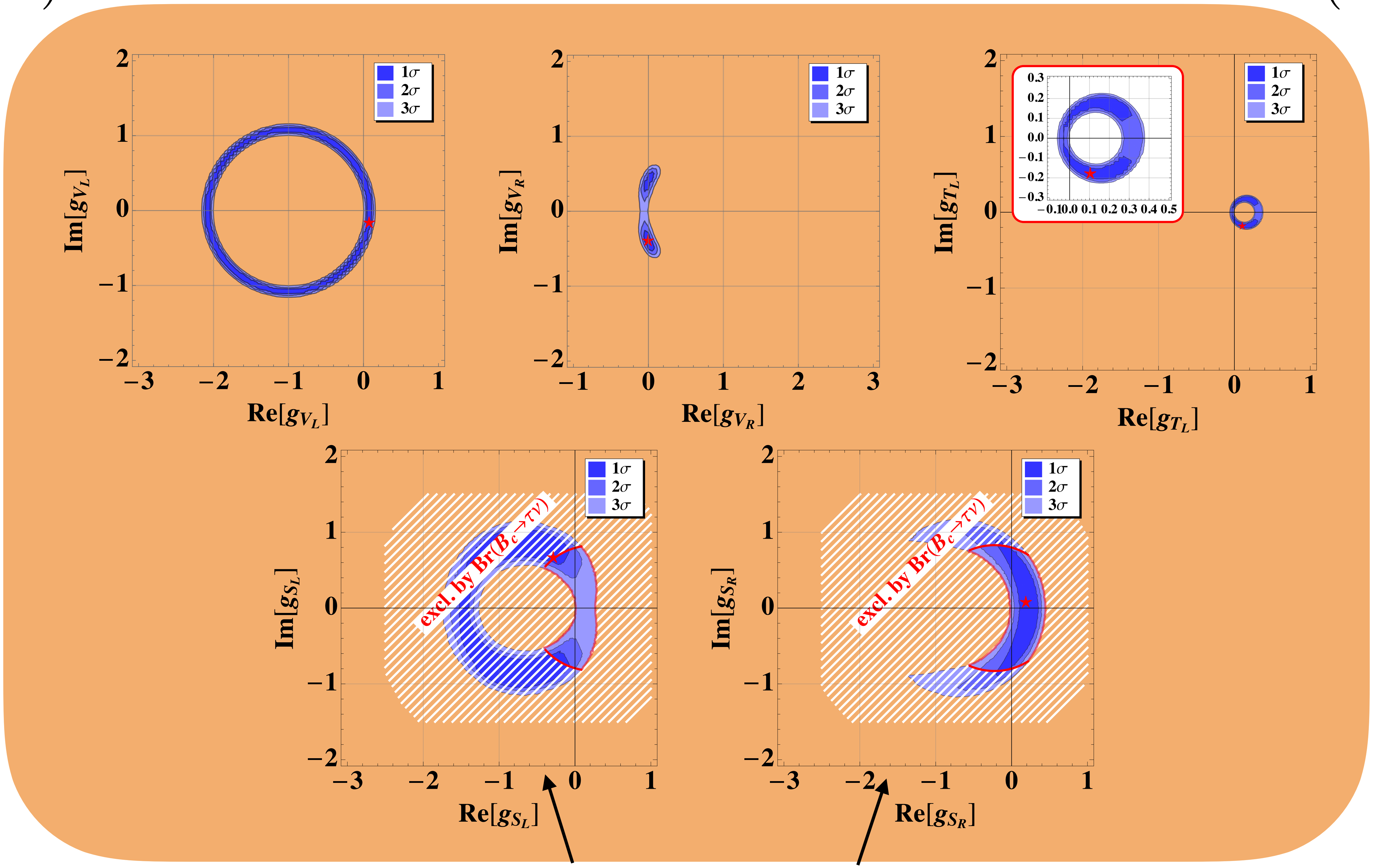
Only left-handed neutrinos!

$$g_{V,\,A} = g_{V_R} \pm g_{V_L} \,, \quad g_{S,\,P} = g_{S_R} \pm g_{S_L} \,, \quad g_T = -g_{T5} = g_{T_L}$$

R-handed tensor operator identically vanishes due to Fierz

NP analysis - chiral basis

$R(D)$ $R(D^*)$



$Br(B_c \to \tau\nu) < 30\%$

Only one WC at a time!

Angular distributions

The B → $D^{(*)}\ell\nu$ is a 3 (4) bodies decay, hence allowing for the experimental study of its angular distribution.

The aim is the definition of observables that are:

- Theoretically clean
- Sensitive to NP effects
- Complementary to Br measurements

Some of these observables, if properly built, could show hint of NP evidence even if the anomaly in the Br would disappear in the future (similarly to P'_5 for B → $K^*\mu\mu$)

B → D$\ell\nu$

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

$$a_{\theta_\ell}(q^2) = \frac{G_F^2|V_{cb}|^2}{256\pi^3 m_B^3} q^2 \sqrt{\lambda_{BD}(q^2)} \left(1 - \frac{m_\ell^2}{q^2}\right)^2 \left[|\tilde{h}_0^-|^2 + \frac{m_\ell^2}{q^2}|\tilde{h}_t|^2\right]$$

$$b_{\theta_\ell}(q^2) = \frac{G_F^2|V_{cb}|^2}{128\pi^3 m_B^3} q^2 \sqrt{\lambda_{BD}(q^2)} \left(1 - \frac{m_\ell^2}{q^2}\right)^2 \frac{m_\ell^2}{q^2}\mathrm{Re}[\tilde{h}_0^+ \tilde{h}_t^*]$$

$$c_{\theta_\ell}(q^2) = -\frac{G_F^2|V_{cb}|^2}{256\pi^3 m_B^3} q^2 \sqrt{\lambda_{BD}(q^2)} \left(1 - \frac{m_\ell^2}{q^2}\right)^2 \left[|\tilde{h}_0^-|^2 - \frac{m_\ell^2}{q^2}|\tilde{h}_0^+|^2\right]$$

$$\boxed{\frac{d\Gamma}{dq^2} = 2a_{\theta_\ell}(q^2) + \frac{2}{3}c_{\theta_\ell}(q^2)}$$

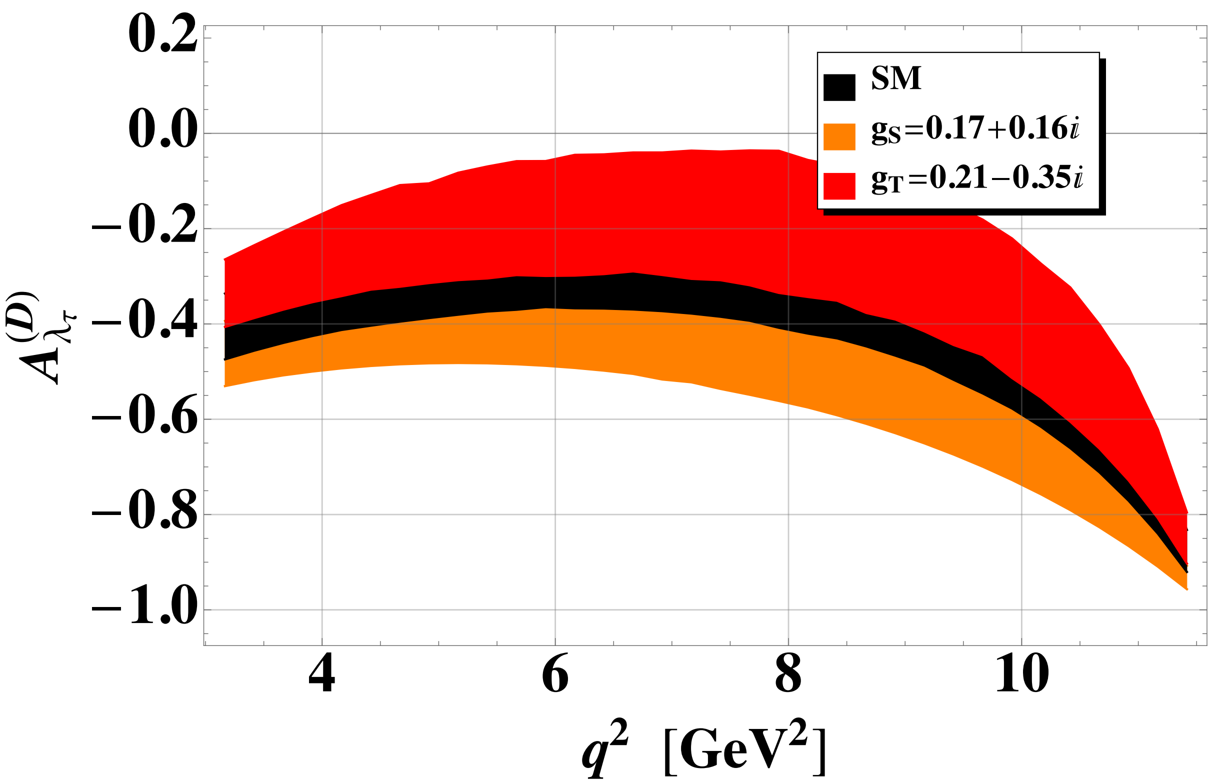
Room for 2 more!

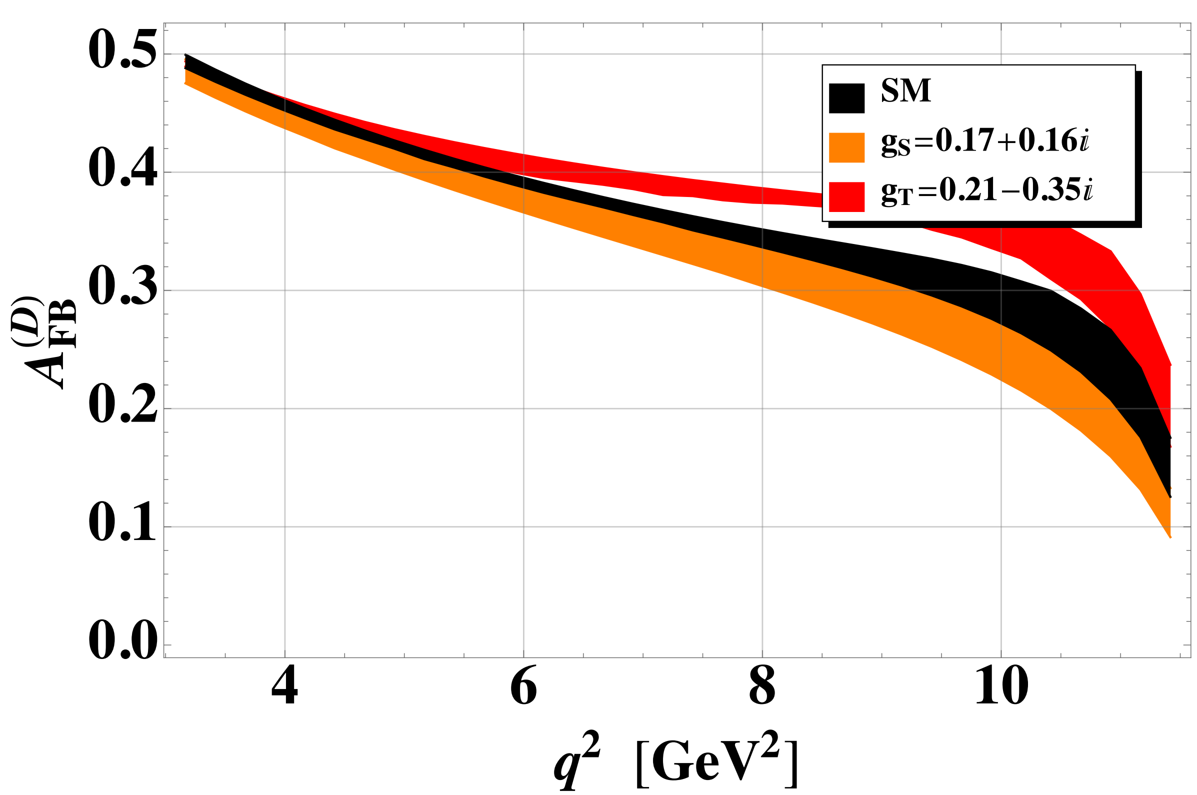
$B \to D\ell\nu$ - $A_{\lambda\ell}$ & A_{FB}

$$A_{\lambda_\ell}(q^2) = \frac{d\Gamma^{\lambda_\ell=-1/2}/dq^2 - d\Gamma^{\lambda_\ell=+1/2}/dq^2}{d\Gamma/dq^2}$$

function of $a_{\theta_\ell}(q^2)$, $c_{\theta_\ell}(q^2)$

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





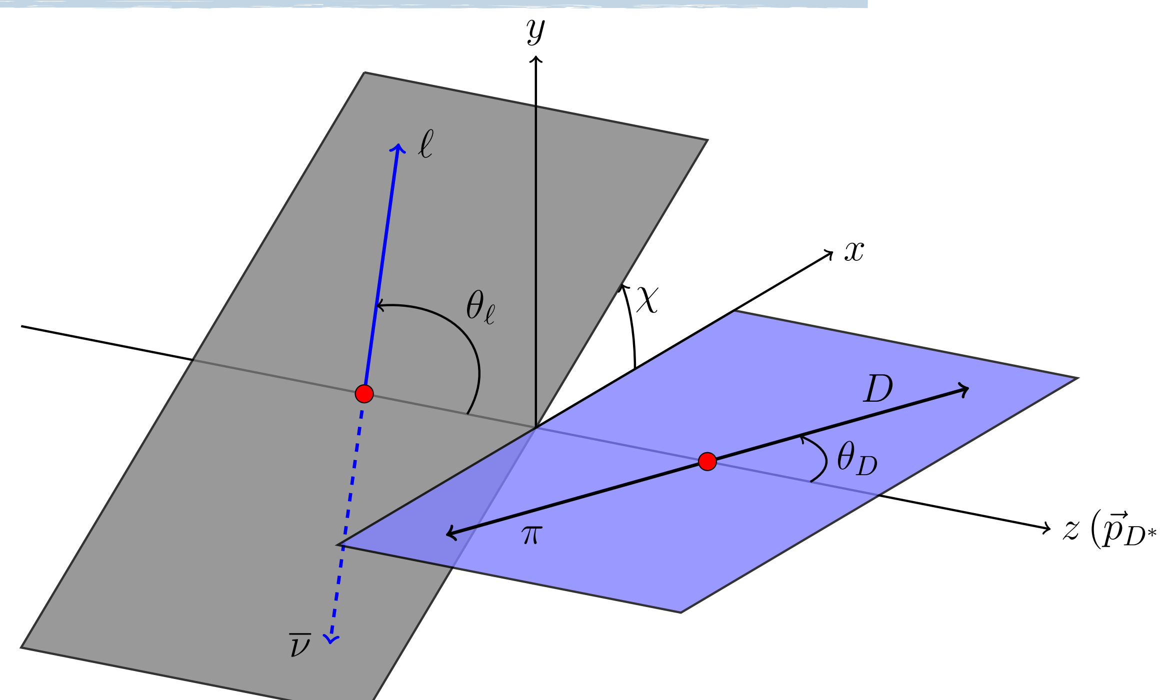
$B \to D^* \ell \nu$

$$
\begin{aligned}
\frac{d^4\Gamma}{dq^2 d\cos\theta_D d\cos\theta_\ell d\chi} = \frac{9}{32\pi} \Big\{ \\
& I_{1c}\cos^2\theta_D + I_{1s}\sin^2\theta_D \\
& + \left[I_{2c}\cos^2\theta_D + I_{2s}\sin^2\theta_D\right]\cos 2\theta_\ell \\
& + \left[I_{6c}\cos^2\theta_D + I_{6s}\sin^2\theta_D\right]\cos\theta_\ell \\
& + \left[I_3\cos 2\chi + I_9\sin 2\chi\right]\sin^2\theta_\ell\sin^2\theta_D \\
& + \left[I_4\cos\chi + I_8\sin\chi\right]\sin 2\theta_\ell\sin 2\theta_D \\
& + \left[I_5\cos\chi + I_7\sin\chi\right]\sin\theta_\ell\sin 2\theta_D \Big\}
\end{aligned}
$$

- 12 independent angular coefficients

$$\Downarrow$$

- 12 independent angular observables!



$B \to D^* \ell \nu$ - building the amplitudes

As a first step, we define the "tilde" helicity amplitudes as functions of the "usual" helicity ones, in order to simplify the following expressions

$$\boxed{\begin{aligned} \tilde{H}^+_{\pm}(q^2) &\equiv H_{\pm}(q^2) - 2\frac{\sqrt{q^2}}{m_\ell} H_{T,\pm}(q^2) \\ \tilde{H}^+_{0}(q^2) &\equiv H_{0}(q^2) - 2\frac{\sqrt{q^2}}{m_\ell} H_{T,0}(q^2) \end{aligned}}$$

$$\boxed{\begin{aligned} \tilde{H}^-_{\pm}(q^2) &\equiv H_{\pm}(q^2) - 2\frac{m_\ell}{\sqrt{q^2}} H_{T,\pm}(q^2) \\ \tilde{H}^-_{0}(q^2) &\equiv H_{0}(q^2) - 2\frac{m_\ell}{\sqrt{q^2}} H_{T,0}(q^2) \end{aligned}}$$

$$\boxed{\tilde{H}_t(q^2) \equiv H_t(q^2) + \frac{\sqrt{q^2}}{m_\ell^2} H_P(q^2)}$$

B → D*$\ell\nu$ - angular coeffs I

$$I_{1c} = 2N\left[|\tilde{H}_0^-|^2 + \frac{m_\ell^2}{q^2}|\tilde{H}_0^+|^2 + 2\frac{m_\ell^2}{q^2}|\tilde{H}_t|^2\right]$$

$$I_{1s} = \frac{N}{2}\left[3\big(|\tilde{H}_+^-|^2 + |\tilde{H}_-^-|^2\big) + \frac{m_\ell^2}{q^2}\big(|\tilde{H}_+^+|^2 + \tilde{H}_-^+|^2\big)\right]$$

$$I_{2c} = 2N\left[-|\tilde{H}_0^-|^2 + \frac{m_\ell^2}{q^2}|\tilde{H}_0^+|^2\right]$$

$$I_{2s} = \frac{N}{2}\left[|\tilde{H}_+^-|^2 + |\tilde{H}_-^-|^2 - \frac{m_\ell^2}{q^2}\big(|\tilde{H}_+^+|^2 + |\tilde{H}_-^+|^2\big)\right]$$

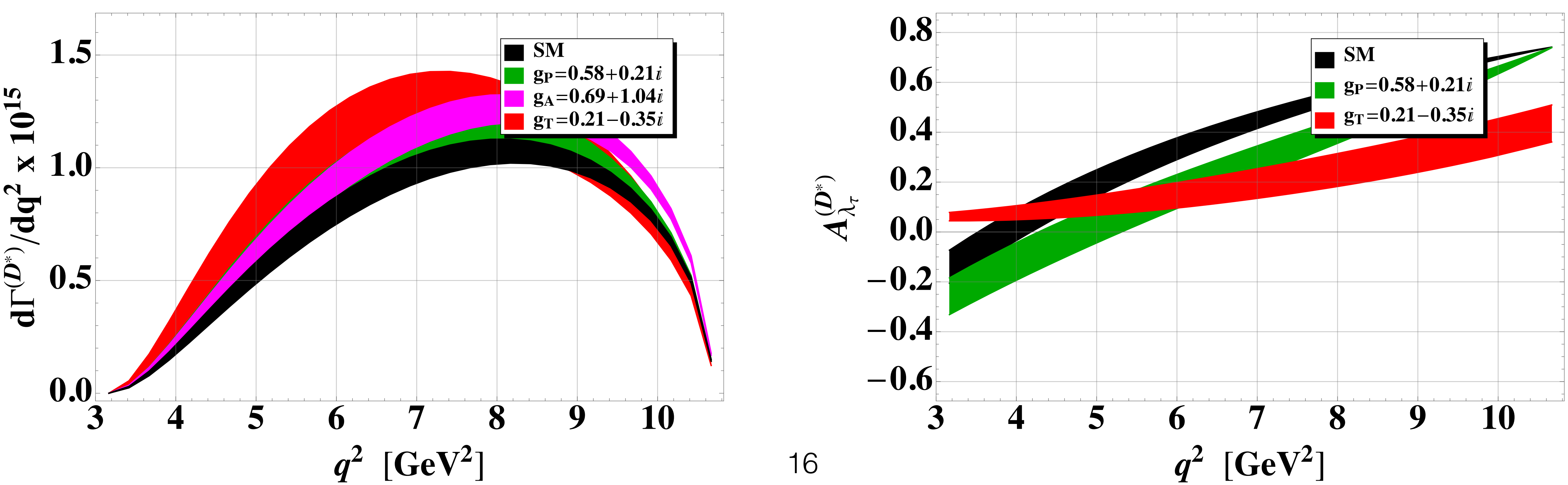
- They all involve Absolute values of the helicity amplitudes
- Can be used to build 4 Obs.

$$N(q^2) = \mathcal{B}(D^* \to D\pi)\frac{G_F^2|V_{cb}|^2}{48(2\pi)^3 m_B^3}q^2\sqrt{\lambda_{BD^*}(q^2)}\left(1 - \frac{m_\ell^2}{q^2}\right)^2$$

$B \to D^*\ell\nu$ - BR & $A_{\lambda\ell}$

$$\boxed{\frac{d^4\Gamma}{dq^2} = \frac{1}{4}(3I_{1c} + 6I_{1s} - I_{2c} - 2I_{1s})}$$

$$\boxed{A_{\lambda_\ell}(q^2) = \frac{d\Gamma^{\lambda_\ell=-1/2}/dq^2 - d\Gamma^{\lambda_\ell=+1/2}/dq^2}{d\Gamma/dq^2}}$$



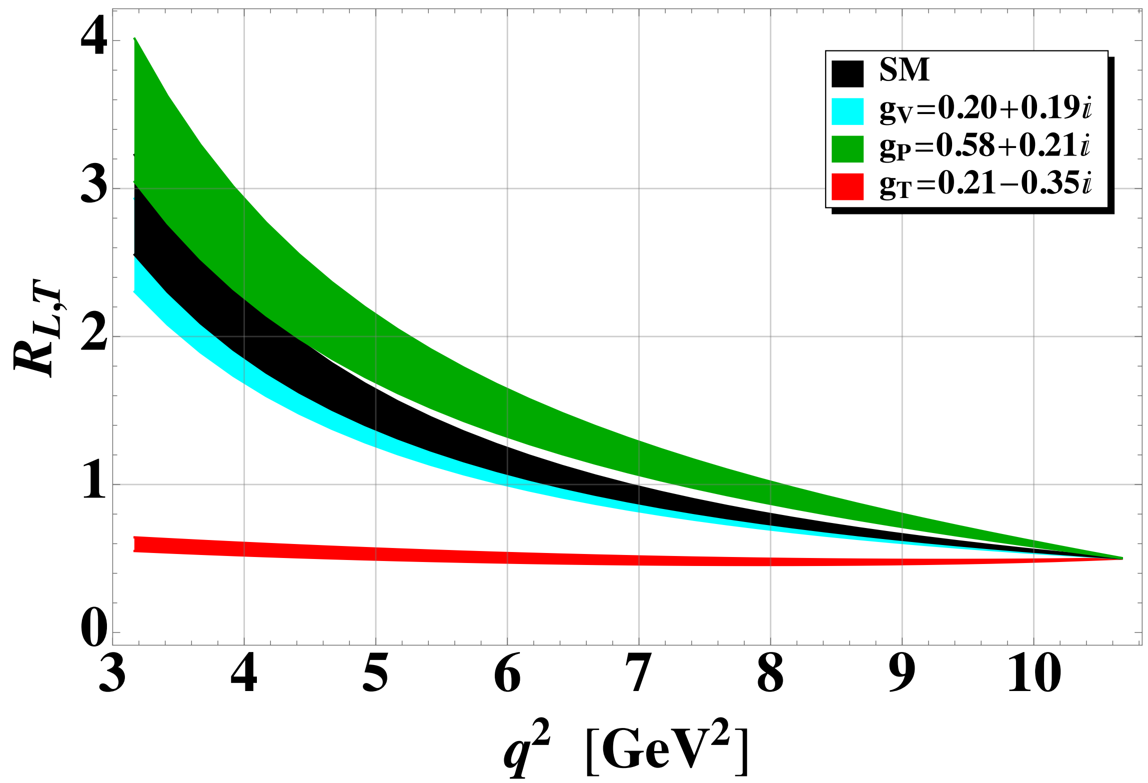
$B \to D^* \ell \nu$ - R_{LT} & R_{AB}

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

$$\frac{d\Gamma_L}{dq^2} = \frac{2a_{\theta_D} + 2c_{\theta_D}}{3} = \frac{3I_{1c} - I_{2c}}{4}$$

$$\frac{d\Gamma_T}{dq^2} = \frac{4}{3}a_{\theta_D} = \frac{3I_{1s} - I_{2s}}{2}$$

$$\boxed{R_{L,T}(q^2) = \frac{d\Gamma_L/dq^2}{d\Gamma_T/dq^2}}$$

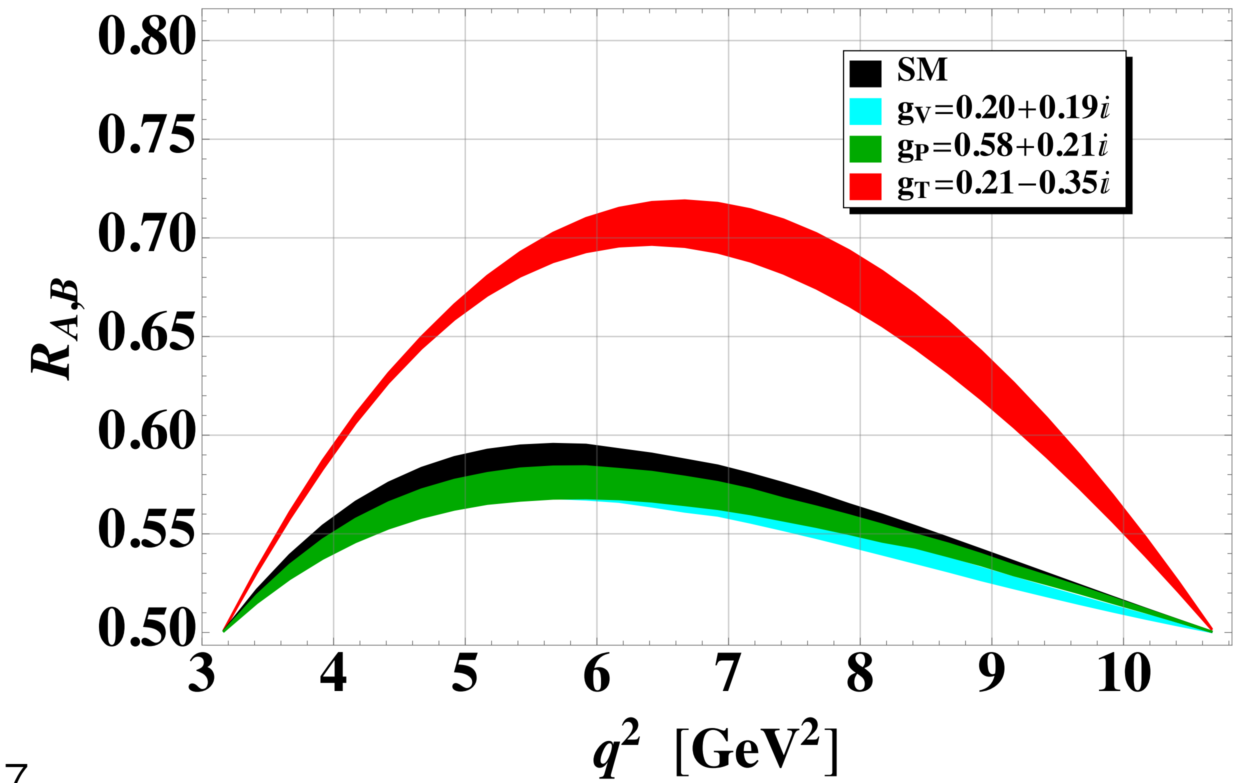


$$\frac{d^2\Gamma}{dq^2 d\cos\theta_l} = a_{\theta_l}(q^2) + b_{\theta_l}(q^2)\cos\theta_l + c_{\theta_l}(q^2)\cos^2\theta_l$$

$$\frac{d\Gamma_A}{dq^2} = \frac{2a_{\theta_l} - 2c_{\theta_l}}{3} = \frac{I_{1c} + 2I_{1s} - 3I_{2c} - 6I_{2s}}{4}$$

$$\frac{d\Gamma_B}{dq^2} = \frac{4a_{\theta_l} + 4c_{\theta_l}}{3} = \frac{I_{1c} + 2I_{1s} + I_{2c} + 2I_{2s}}{2}$$

$$\boxed{R_{A,B}(q^2) = \frac{d\Gamma_A/dq^2}{d\Gamma_B/dq^2}}$$



B → D*$\ell\nu$ - angular coeffs II

$$I_3 = -2N\,\mathrm{Re}\left[\tilde{H}_+^-\tilde{H}_-^{-*} - \frac{m_\ell^2}{q^2}\tilde{H}_+^+\tilde{H}_-^{+*}\right]$$

$$I_4 = N\,\mathrm{Re}\left[(\tilde{H}_+^- + \tilde{H}_-^-)\tilde{H}_0^{-*} - \frac{m_\ell^2}{q^2}(\tilde{H}_+^+ + \tilde{H}_-^+)\tilde{H}_0^{+*}\right]$$

$$I_5 = 2N\,\mathrm{Re}\left[(\tilde{H}_+^- - \tilde{H}_-^-)\tilde{H}_0^{-*} - \frac{m_\ell^2}{q^2}(\tilde{H}_+^+ + \tilde{H}_-^+)\tilde{H}_t^*\right]$$

$$I_7 = 2N\,\mathrm{Im}\left[(\tilde{H}_+^- + \tilde{H}_-^-)\tilde{H}_0^{-*} - \frac{m_\ell^2}{q^2}(\tilde{H}_+^+ - \tilde{H}_-^+)\tilde{H}_t^*\right]$$

$$I_8 = N\,\mathrm{Im}\left[(\tilde{H}_+^- - \tilde{H}_-^-)\tilde{H}_0^{-*} - \frac{m_\ell^2}{q^2}(\tilde{H}_+^+ - \tilde{H}_-^+)\tilde{H}_0^{+*}\right]$$

$$I_9 = -2N\,\mathrm{Im}\left[\tilde{H}_+^-\tilde{H}_-^{-*} - \frac{m_\ell^2}{q^2}\tilde{H}_+^+\tilde{H}_-^{+*}\right]$$

- They all involve Re/Im parts of the amplitude, and can be studied in pairs
- The ones involving Im part are null tests in the SM, but sensitive to NP phases!
- Can be used to build 6 Obs.

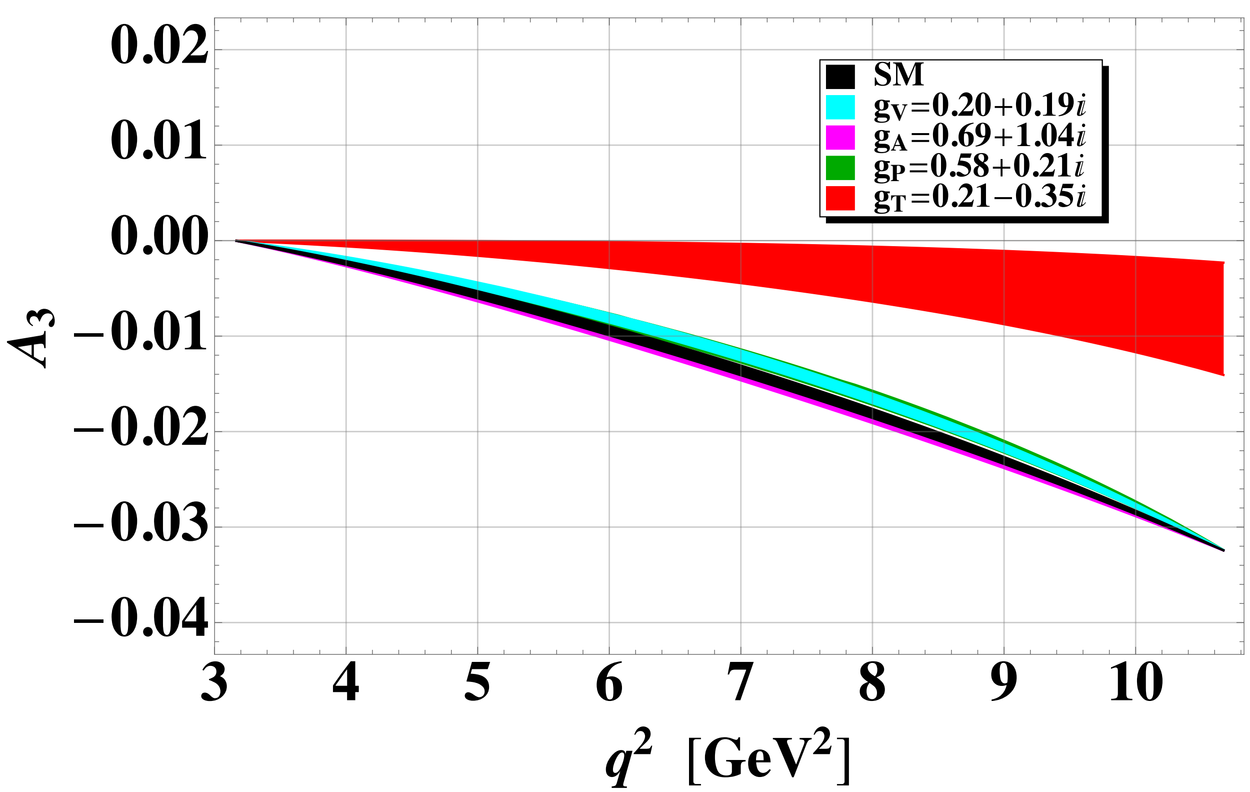
$B \to D^*\ell\nu$ - A_3 & A_9

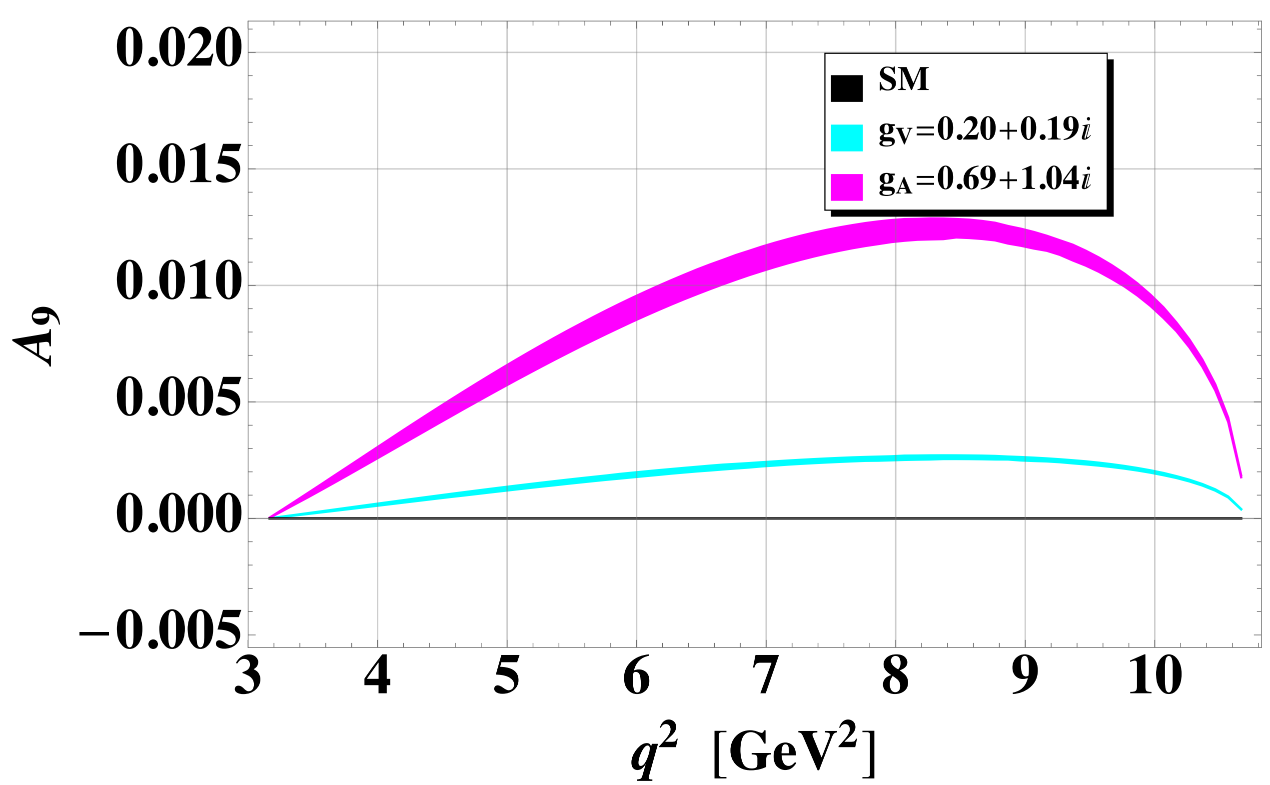
$$\frac{d^2\Gamma}{dq^2 d\chi} = a_\chi(q^2) + c_\chi^c(q^2)\cos 2\chi + c_\chi^s(q^2)\sin 2\chi$$

$$A_3(q^2) = \frac{c_\chi^c(q^2)}{d\Gamma/dq^2} = \frac{1}{2\pi}\frac{I_3}{d\Gamma/dq^2}$$

$$A_9(q^2) = \frac{c_\chi^s(q^2)}{d\Gamma/dq^2} = \frac{1}{2\pi}\frac{I_9}{d\Gamma/dq^2}$$

Sensitive to NP phase!





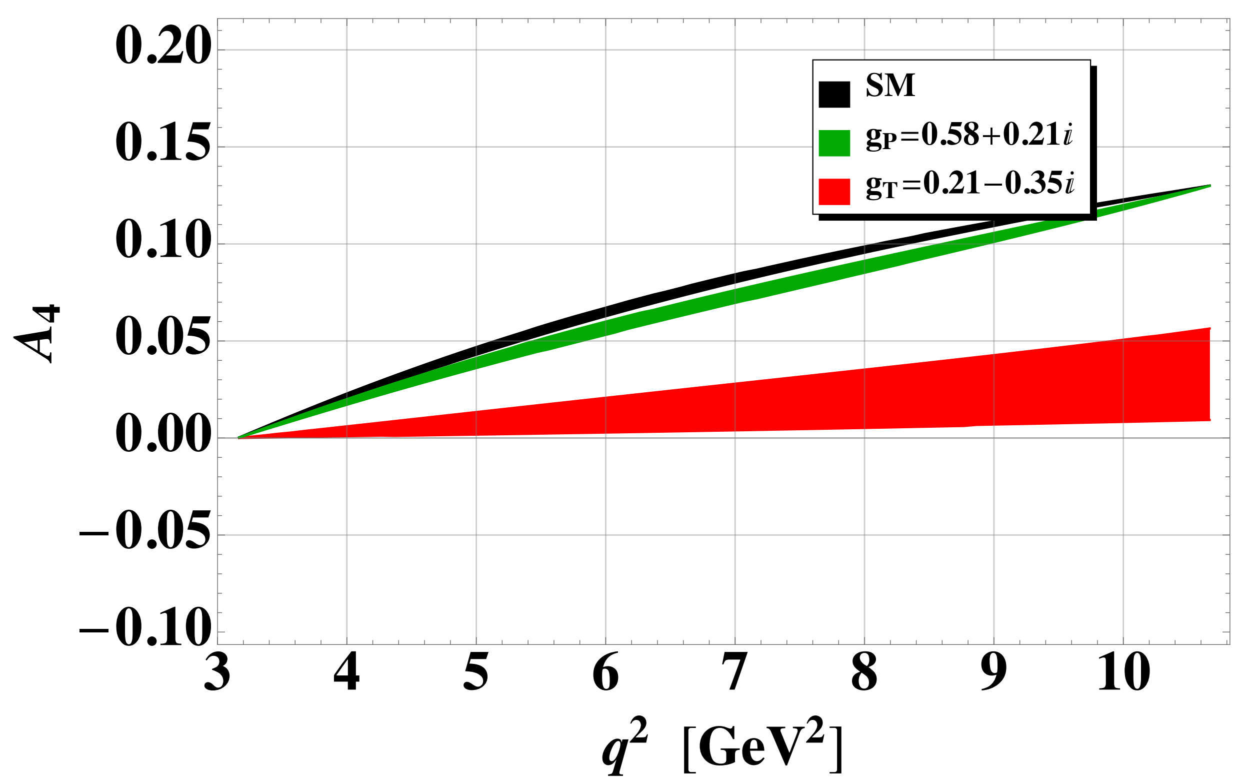
$B \to D^* \ell \nu$ - A_4 & A_8

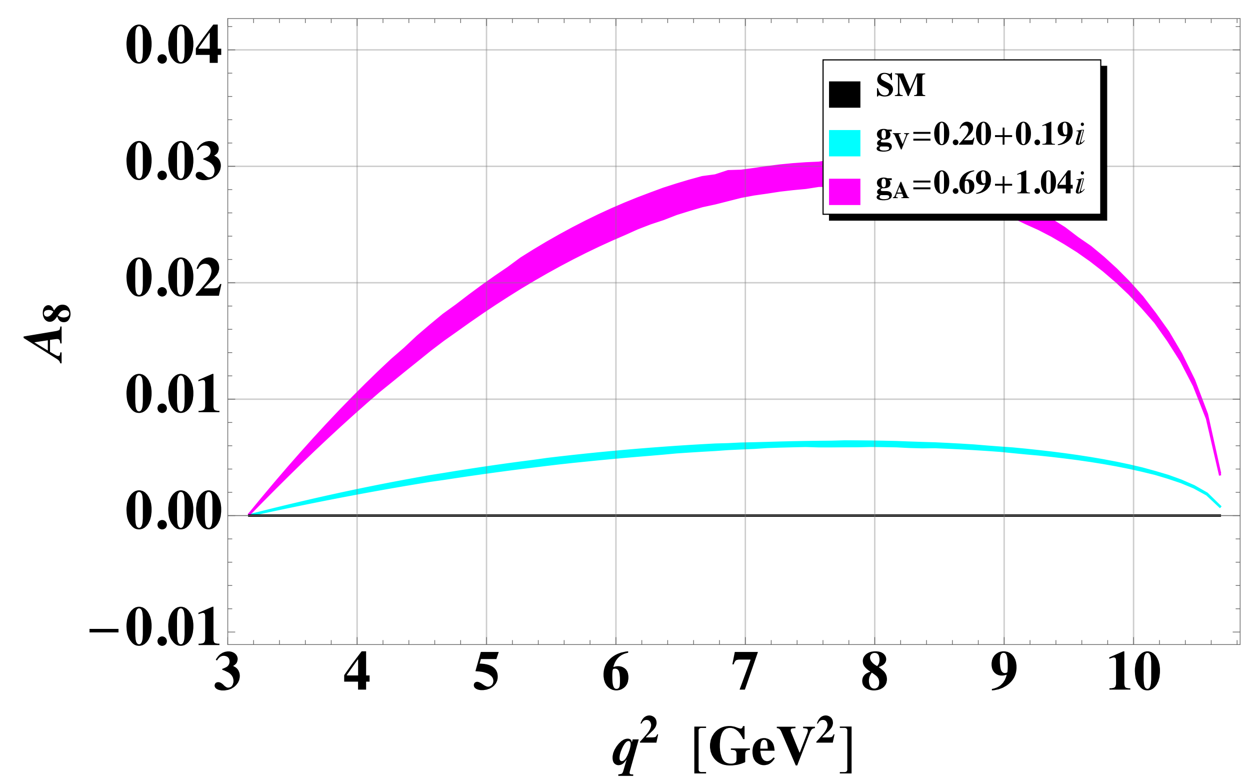
$$\Phi_{48}(q^2,\chi) = \left[\int_{-1}^{0} - \int_{0}^{1}\right]\left\{\left[\int_{-1}^{0} - \int_{0}^{1}\right] \frac{d^4\Gamma}{dq^2 d\chi d\cos\theta_\ell d\cos\theta_D}\, d\cos\theta_D\right\} d\cos\theta_\ell$$

$$\boxed{A_4(q^2) = \frac{\left[\int_{\pi/2}^{3\pi/2} - \int_{0}^{\pi/2} - \int_{3\pi/2}^{2\pi}\right] \Phi_{48}(q^2,\chi)\ d\chi}{d\Gamma/dq^2} = -\frac{2}{\pi}\frac{I_4}{d\Gamma/dq^2}}$$

$$\boxed{A_8(q^2) = \frac{\left[\int_{0}^{\pi} - \int_{\pi}^{2\pi}\right] \Phi_{48}(q^2,\chi)\ d\chi}{d\Gamma/dq^2} = \frac{2}{\pi}\frac{I_8}{d\Gamma/dq^2}}$$

Sensitive to NP phase!





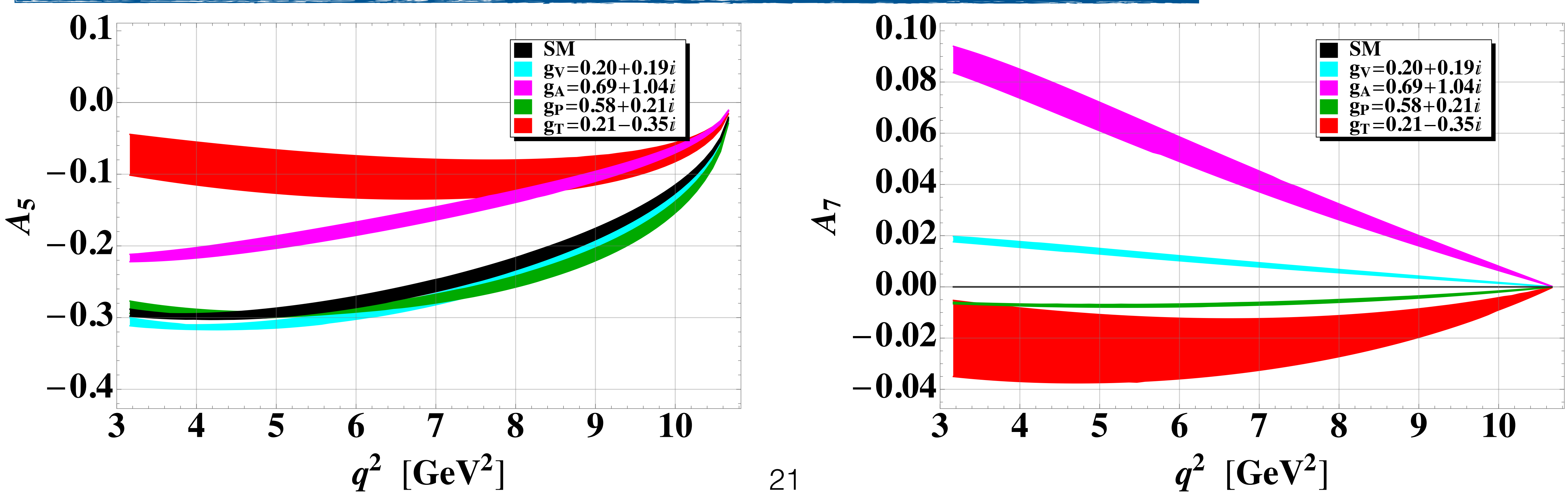
$B \to D^* \ell \nu$ - A_5 & A_7

$$\Phi_{57}(q^2,\chi) = \left[\int_{-1}^{0} - \int_{0}^{1}\right] \frac{d^3\Gamma}{dq^2 d\chi d\cos\theta_D}\, d\cos\theta_D$$

$$\boxed{A_5(q^2) = -\frac{\left[\int_{\pi/2}^{3\pi/2} - \int_0^{\pi/2} - \int_{3\pi/2}^{2\pi}\right]\Phi_{57}(q^2,\chi)\, d\chi}{d\Gamma/dq^2} = -\frac{3}{4}\frac{I_5}{d\Gamma/dq^2}}$$

$$\boxed{A_7(q^2) = \frac{\left[\int_0^{\pi} - \int_{\pi}^{2\pi}\right]\Phi_{57}(q^2,\chi)\, d\chi}{d\Gamma/dq^2} = -\frac{3}{4}\frac{I_7}{d\Gamma/dq^2}}$$

Sensitive to NP phase!



B → D*$\ell\nu$ - angular coeffs III

$$I_{6c} = 8N\frac{m_\ell^2}{q^2}\,\mathrm{Re}\big[\tilde{H}_0^{+}\tilde{H}_t^{*}\big]$$

$$I_{6s} = 2N\big(|\tilde{H}_{+}^{-}|^2 - |\tilde{H}_{-}^{-}|^2\big)$$

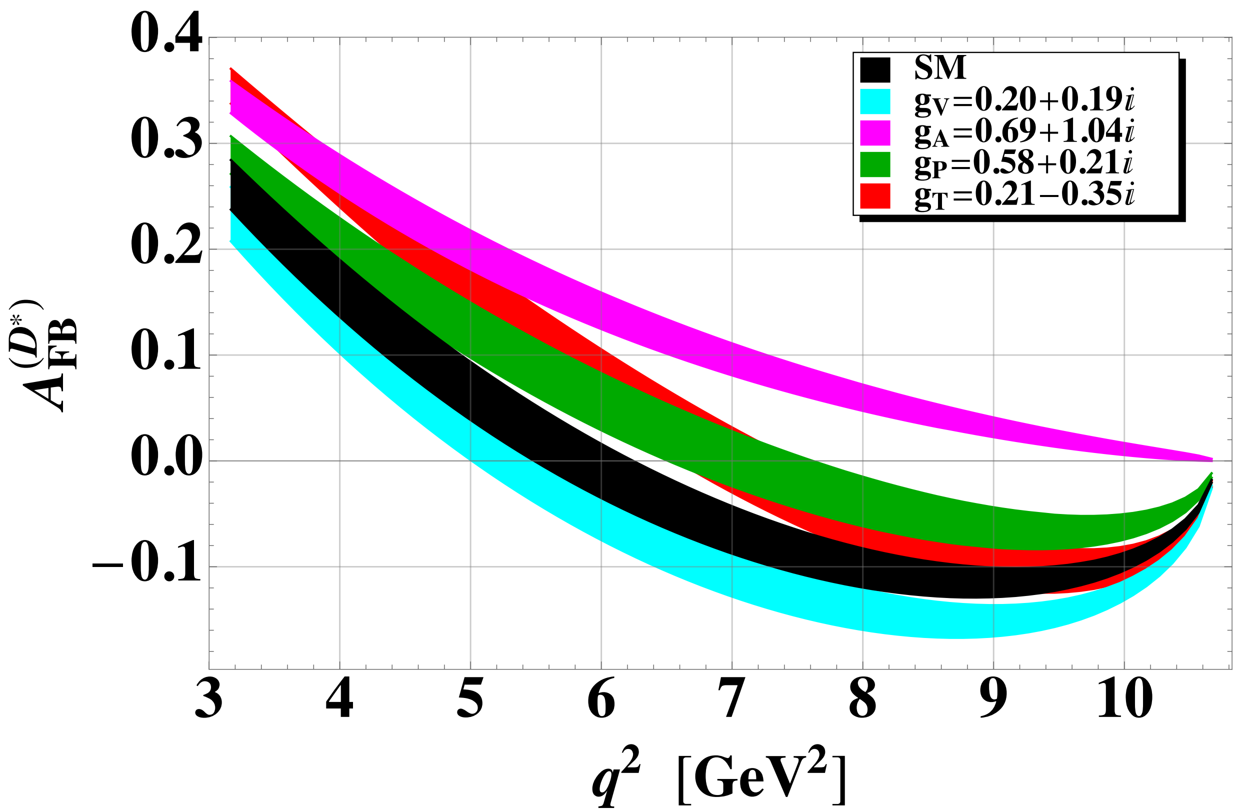
- Can be used to build 2 Obs.

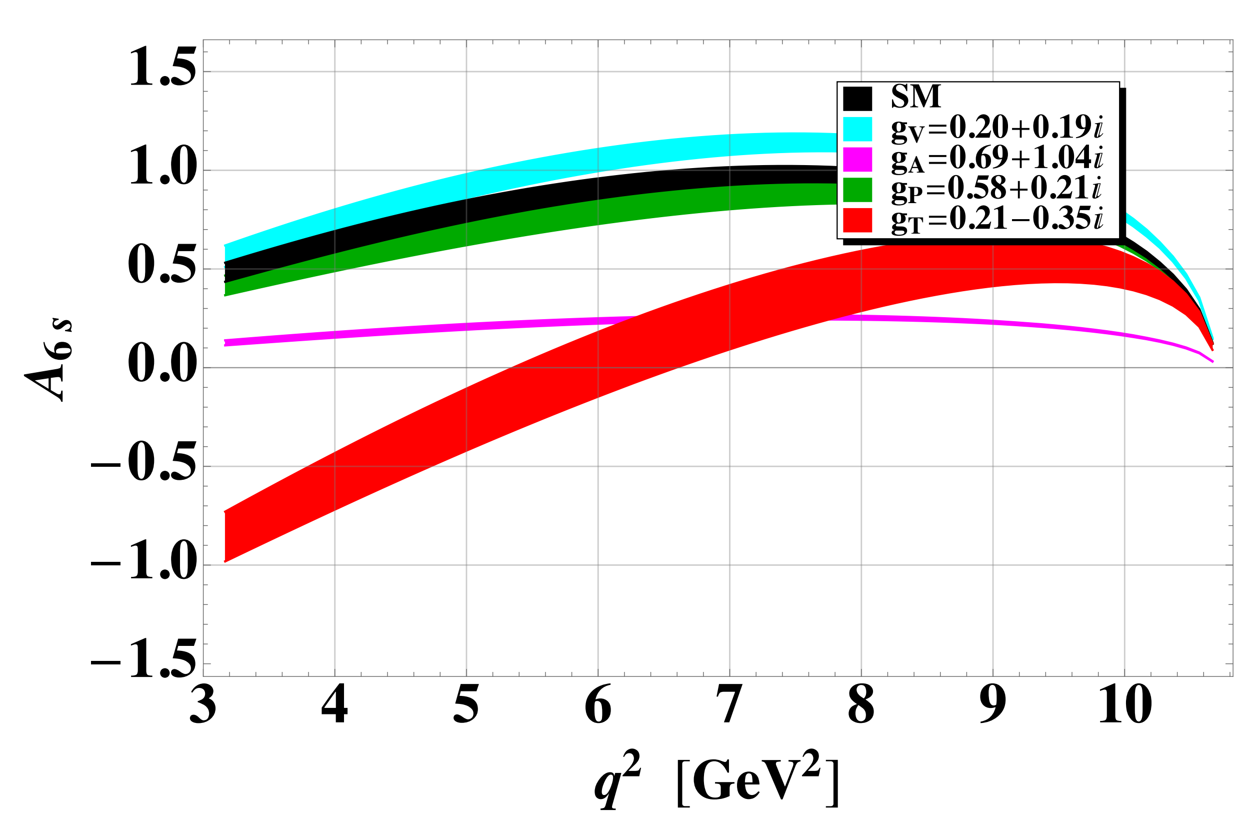
$B \to D^* \ell \nu$ - A_{FB} & A_{6s}

$$\boxed{A_{FB}(q^2) = \frac{b_{\theta_\ell}}{d\Gamma/dq^2} = \frac{3}{8}\frac{(I_{6c} + 2I_{6s})}{d\Gamma/dq^2}}$$

$$\Phi_6(q^2, \theta_D) = \left[\int_{-1}^{0} - \int_{0}^{1}\right] \frac{d^3\Gamma}{dq^2 d\cos\theta_D d\cos\theta_\ell} \; d\cos\theta_\ell$$

$$\boxed{A_{6s}(q^2) = \frac{\left[7\int_{-1/2}^{1/2} - \int_{1/2}^{1} - \int_{-1}^{-1/2}\right] \Phi_6(q^2, \theta_D) \; d\cos\theta_D}{d\Gamma/dq^2} = -\frac{27}{8}\frac{I_{6s}}{d\Gamma/dq^2}}$$





LFUV Observables

For most of the other angular observables, we define the LFUV observables as ratios

$$R(O_i) \equiv \frac{\langle O_i^\tau \rangle}{\frac{1}{2}\left(\langle O_i^e \rangle + \langle O_i^\mu \rangle\right)}$$

Since $I_{7,8,9}^{e,\mu} = I_{7,8,9}^{e,\mu\ (\mathrm{SM})} = 0$, we define the last three LFUV observables as differences

$$D(A_{7,8,9}) \equiv \langle A_{7,8,9}^\tau \rangle - \frac{1}{2}\left(\langle A_{7,8,9}^e \rangle + \langle A_{7,8,9}^\mu \rangle\right)$$

Each angular observable is integrated over the q² spectrum

$$O_i^\ell = \frac{\mathcal{N}_i^\ell(q^2)}{\mathcal{D}_i^\ell(q^2)} \quad \Rightarrow \quad \langle O_i^\ell \rangle = \frac{\int_{m_\ell^2}^{q^2_{\max}} \mathcal{N}_i^\ell(q^2)\ dq^2}{\int_{m_\ell^2}^{q^2_{\max}} \mathcal{D}_i^\ell(q^2)\ dq^2}$$

LFUV Observables predictions

~ 2σ, 3σ, 4σ difference from the SM value

Obs.	SM	g_V	g_A	g_S	g_P	g_T
$R(A_{FB}^D)$	0.077 ± 0.004	0.074 ± 0.003	–	$[-0.058, 0.074]$	–	0.082 ± 0.004
$R(A_{\lambda_\ell}^D)$	-0.332 ± 0.003	-0.331 ± 0.003	–	-0.48 ± 0.05	–	-0.25 ± 0.05
$R(A_{\lambda_\ell}^{D^*})$	0.47 ± 0.02	0.48 ± 0.04	0.48 ± 0.02	–	0.36 ± 0.04	0.18 ± 0.14
$R(R_{L,T})$	0.79 ± 0.02	0.78 ± 0.02	0.80 ± 0.02	–	0.95 ± 0.05	0.42 ± 0.14
$R(R_{A,B})$	0.520 ± 0.004	0.514 ± 0.005	0.524 ± 0.004	–	0.516 ± 0.004	0.64 ± 0.07
$R(A_{FB}^{D^*})$	0.23 ± 0.04	$[-1.52, 0.40]$	$[-1.38, 0.20]$	–	0.00 ± 0.06	-0.02 ± 0.06
$R(A_3)$	0.62 ± 0.01	0.58 ± 0.01	0.63 ± 0.02	–	0.56 ± 0.02	0.11 ± 0.23
$R(A_4)$	0.46 ± 0.01	0.45 ± 0.01	0.46 ± 0.01	–	0.42 ± 0.01	0.06 ± 0.18
$R(A_5)$	1.15 ± 0.02	$[-0.26, 1.28]$	$[-0.09, 1.12]$	–	1.24 ± 0.05	0.42 ± 0.30
$R(A_6)$	0.79 ± 0.01	$[-0.96, 0.96]$	$[-0.76, 0.76]$	–	0.72 ± 0.02	0.15 ± 0.25
$D(A_7)$	0	$[-0.05, 0.05]$	$[-0.04, 0.04]$	–	0.00 ± 0.01	0.00 ± 0.02
$D(A_8)$	0	$[-0.03, 0.03]$	$[-0.03, 0.03]$	–	0	0
$D(A_9)$	0	$[-0.09, 0.09]$	$[-0.07, 0.07]$	–	0	0

Complex g_i are varied as free parameter according to p.d.f. obtained from the fit of $R(D^{(*)})$

LFUV Observables predictions

~ 2σ, 3σ, 4σ difference from the SM value

Allowed 2σ region

Obs.	SM	g_V	g_A	g_S	g_P	g_T
$R(A_{FB}^D)$	0.077 ± 0.004	0.074 ± 0.003	$-$	$[-0.058, 0.074]$	$-$	0.082 ± 0.004
$R(A_{\lambda_\ell}^D)$	-0.332 ± 0.003	-0.331 ± 0.003	$-$	-0.48 ± 0.05	$-$	-0.25 ± 0.05
$R(A_{\lambda_\ell}^{D^*})$	0.47 ± 0.02	0.48 ± 0.04	0.48 ± 0.02	$-$	0.36 ± 0.04	0.18 ± 0.14
$R(R_{L,T})$	0.79 ± 0.02	0.78 ± 0.02	0.80 ± 0.02	$-$	0.95 ± 0.05	0.42 ± 0.14
$R(R_{A,B})$	0.520 ± 0.004	0.514 ± 0.005	0.524 ± 0.004	$-$	0.516 ± 0.004	0.64 ± 0.07
$R(A_{FB}^{D^*})$	0.23 ± 0.04	$[-1.52, 0.40]$	$[-1.38, 0.20]$	$-$	0.00 ± 0.06	-0.02 ± 0.06
$R(A_3)$	0.62 ± 0.01	0.58 ± 0.01	0.63 ± 0.02	$-$	0.56 ± 0.02	0.11 ± 0.23
$R(A_4)$	0.46 ± 0.01	0.45 ± 0.01	0.46 ± 0.01	$-$	0.42 ± 0.01	0.06 ± 0.18
$R(A_5)$	1.15 ± 0.02	$[-0.26, 1.28]$	$[-0.09, 1.12]$	$-$	1.24 ± 0.05	0.42 ± 0.30
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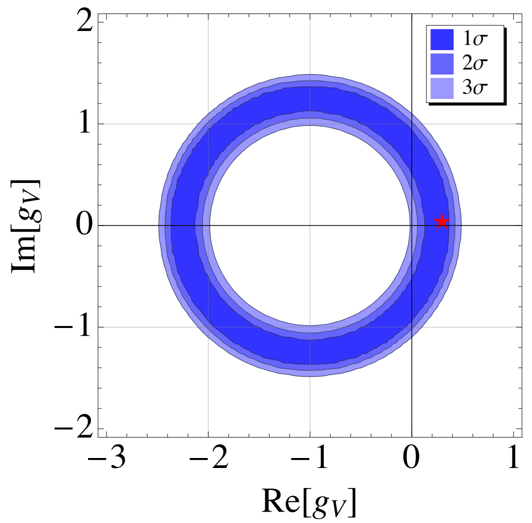
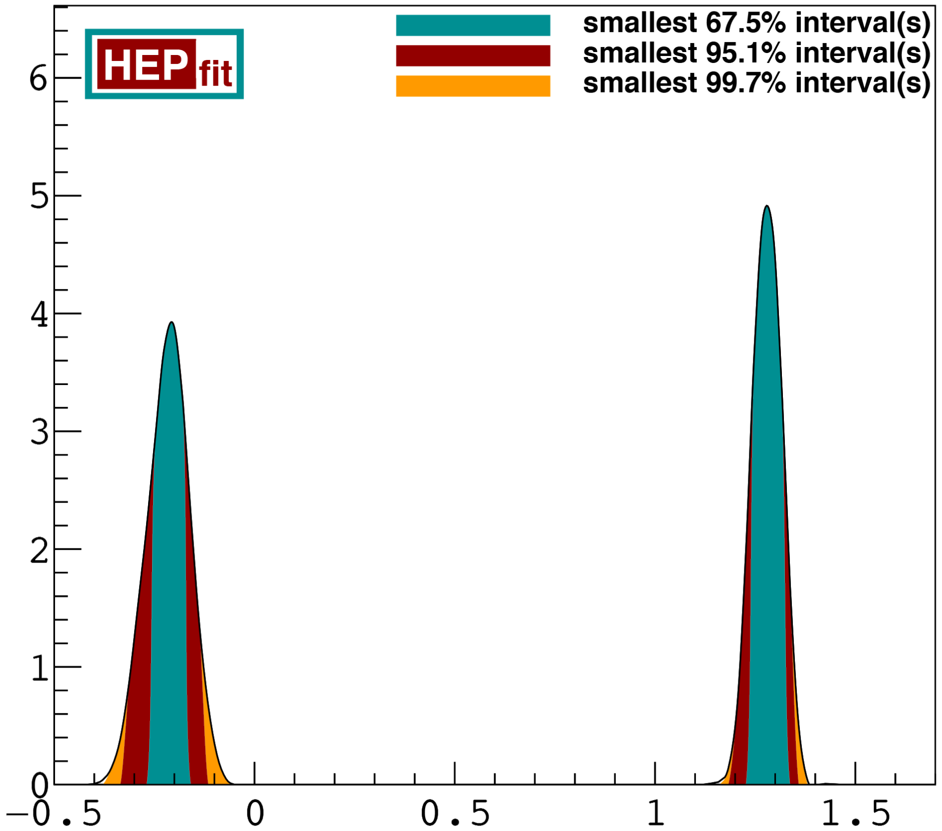
$D(A_7)$	0	$[-0.05, 0.05]$	$[-0.04, 0.04]$	$-$	0.00 ± 0.01	0.00 ± 0.02
$D(A_8)$	0	$[-0.03, 0.03]$	$[-0.03, 0.03]$	$-$	0	0
$D(A_9)$	0	$[-0.09, 0.09]$	$[-0.07, 0.07]$	$-$	0	0

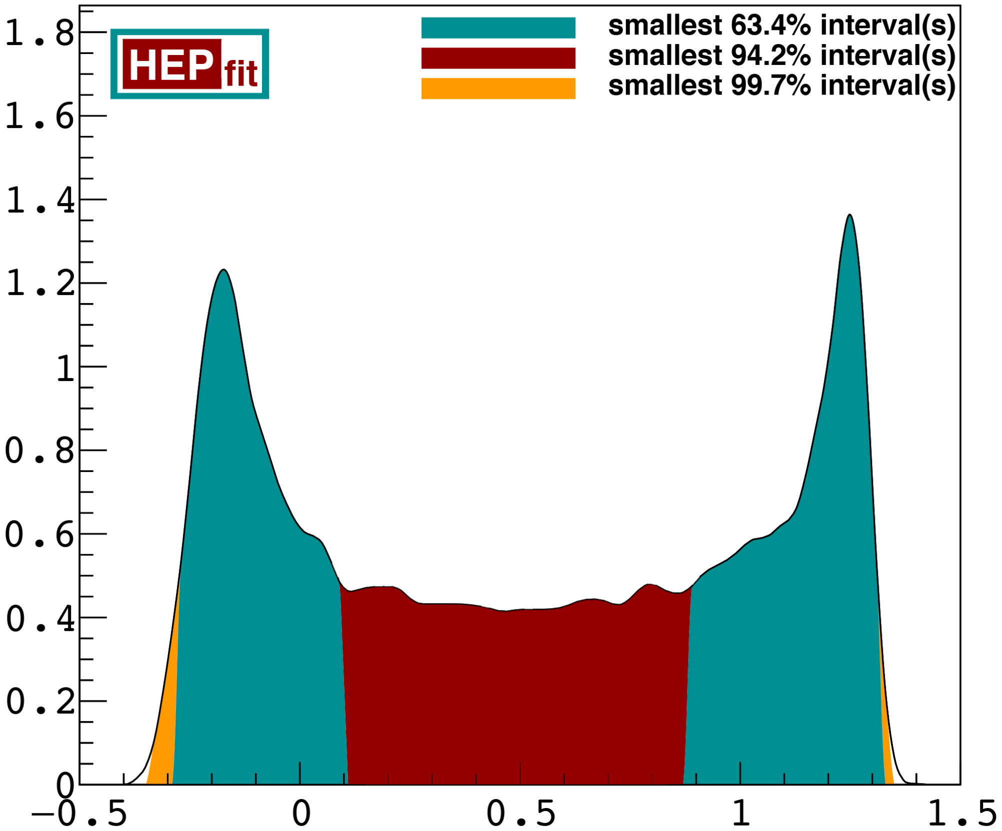
Complex g_i are varied as free parameter according to p.d.f. obtained from the fit of $R(D^{(*)})$

LFUV Observables predictions



- R(A_5) is sensitive to $\mathrm{Re}(g_V)$
- Assuming a real coupling, 2 solutions (left plot)
- Allowing for a complex coupling, we obtain a continuum due to the interplay between real and imaginary parts (right plot)





Measuring e.g. R(A_5) would correspond to a vertical band in the $\mathrm{Re}(g_V)$-$\mathrm{Im}(g_V)$ plane, sensibly reducing the allowed region!

LFUV Observables predictions

~ 2σ, 3σ, 4σ difference from the SM value

Allowed 2σ region

Obs.	SM	g_V	g_A	g_S	g_P	g_T
$R(A_{FB}^D)$	0.077 ± 0.004	0.074 ± 0.003	$-$	$[-0.058, 0.074]$	$-$	0.082 ± 0.004
$R(A_{\lambda_\ell}^D)$	-0.332 ± 0.003	-0.331 ± 0.003	$-$	-0.48 ± 0.05	$-$	-0.25 ± 0.05
$R(A_{\lambda_\ell}^{D^*})$	0.47 ± 0.02	0.48 ± 0.04	0.48 ± 0.02	$-$	0.36 ± 0.04	0.18 ± 0.14
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$D(A_8)$	0	$[-0.03, 0.03]$	$[-0.03, 0.03]$	$-$	0	0
$D(A_9)$	0	$[-0.09, 0.09]$	$[-0.07, 0.07]$	$-$	0	0

Moreover, we obtain similar results is we assume $R(D^{(*)})_{\rm exp} = R(D^{(*)})_{\rm SM} \pm 10\%$

Conclusions

- We have constructed 2(11) angular observables when considering the decay to a pseudoscalar(vector) meson

- We have combined these observable in order to build LFUV tests, complementary to $R(D^{(*)})$, and made predictions for SM & NP scenarios

- These quantities can be of great help when studying NP effects in $b \to c$ transitions (in particular concerning its Lorentz structure), since many NP predictions differ from the SM at $\sim 3{,}4\sigma$ level

- These observable would still be of interest even if the Br anomalies would disappear, since they involve different pieces of the amplitudes

- The above description is totally general, and equally applicable to all the various semileptonic pseudoscalar $\to$ pseudoscalar/vector decay

Back-up

Form Factors treatment

B → D$\ell\nu$: All FF from Lattice (Bailey et al., ’15)

B → D*$\ell\nu$:

- All FF from Constituent quark Model (Melikhov, Stech, ’00)

  or

- V, $A_{1,2}$ from either CLN parametrization (Caprini, Lelouch, Neubert, ’97) or BGL (Bigi, Gambino, Schacht, ’17)

- $A_0, T_{1,2,3}$ from HQET@NLO in $1/m_{c,b}$ (Bernolochner et al., ’17) but with more generous err.

All the obtained results are in good agreement for different methods and parameterizations!