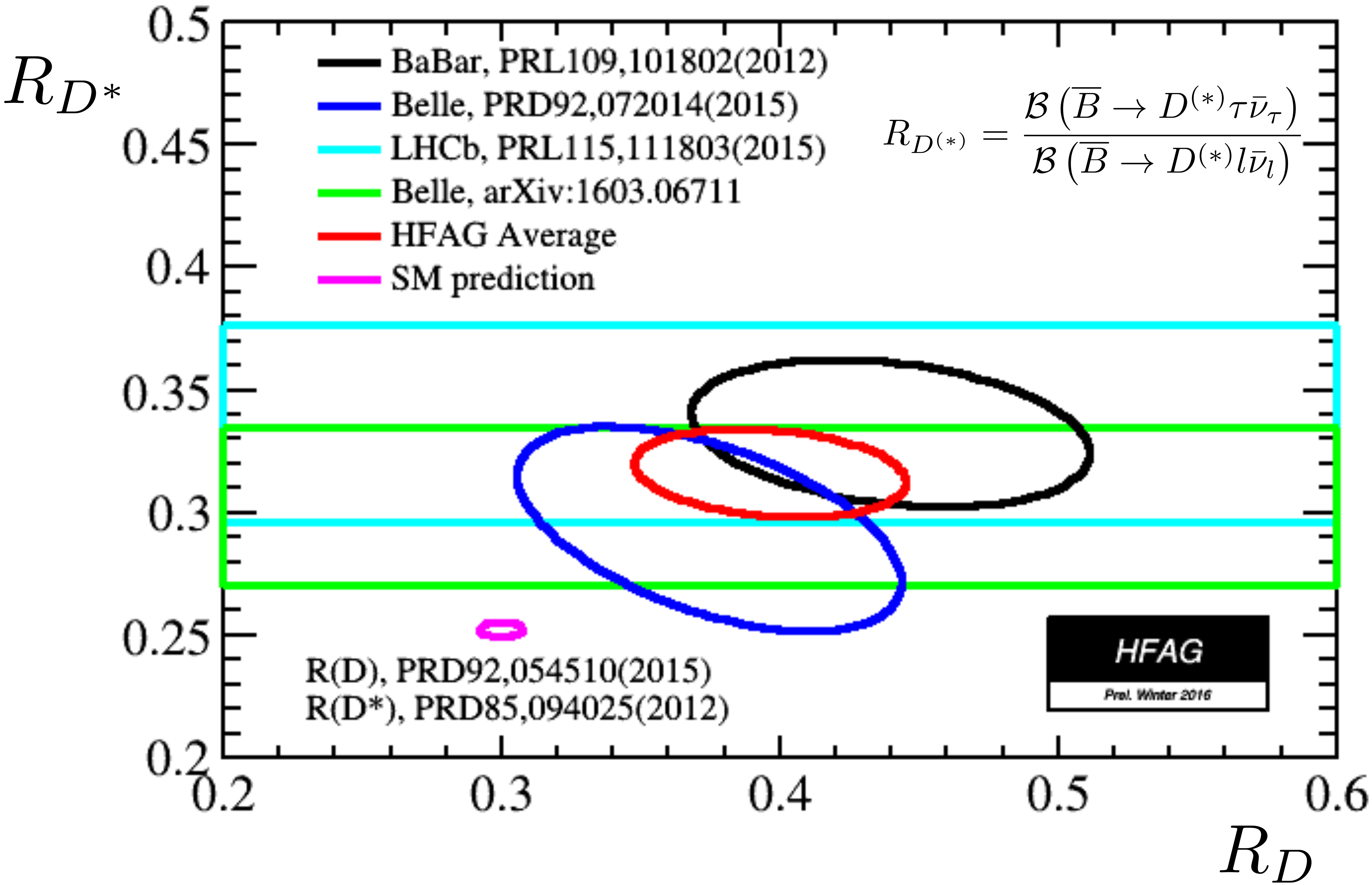
A closer look at the R_D and R_{D^*} anomalies

Diptimoy Ghosh
Weizmann Institute of Science

Based on arXiv:1610.03038 / JHEP 1701 (2017) 125
in collaboration with
Debjyoti Bardhan and Pritibhajan Byakti

Motivation



Deviation from the SM is at the 4σ level

Experimental strategies

B-factories :

- Multiple neutrinos prevent to fully determine the kinematics

- Exploit unique experimental set-up: knowledge of initial state and known production process

$$e^+e^- \to \Upsilon(4S) \to B_{\rm comp}\overline{B}_{\rm sig}$$

The companion *B* meson reconstruction

- **Hadronic**: *sum of exclusive hadronic decays*

  $$B \to \overline{D}^{(*)}n\pi,\ \overline{D}^{(*)}D^{(*)}K,\ \overline{D}_s^{(*)}D^{(*)},\ J/\psi K n\pi$$

- **Semi-leptonic**: *sum of exclusive semi-leptonic decays*

  $$B \to \overline{D}^{(*)}\ell\nu_\ell$$

- ***Untagged/Inclusive***: *sum all tracks/clusters not used for B_{sig} reconstruction*

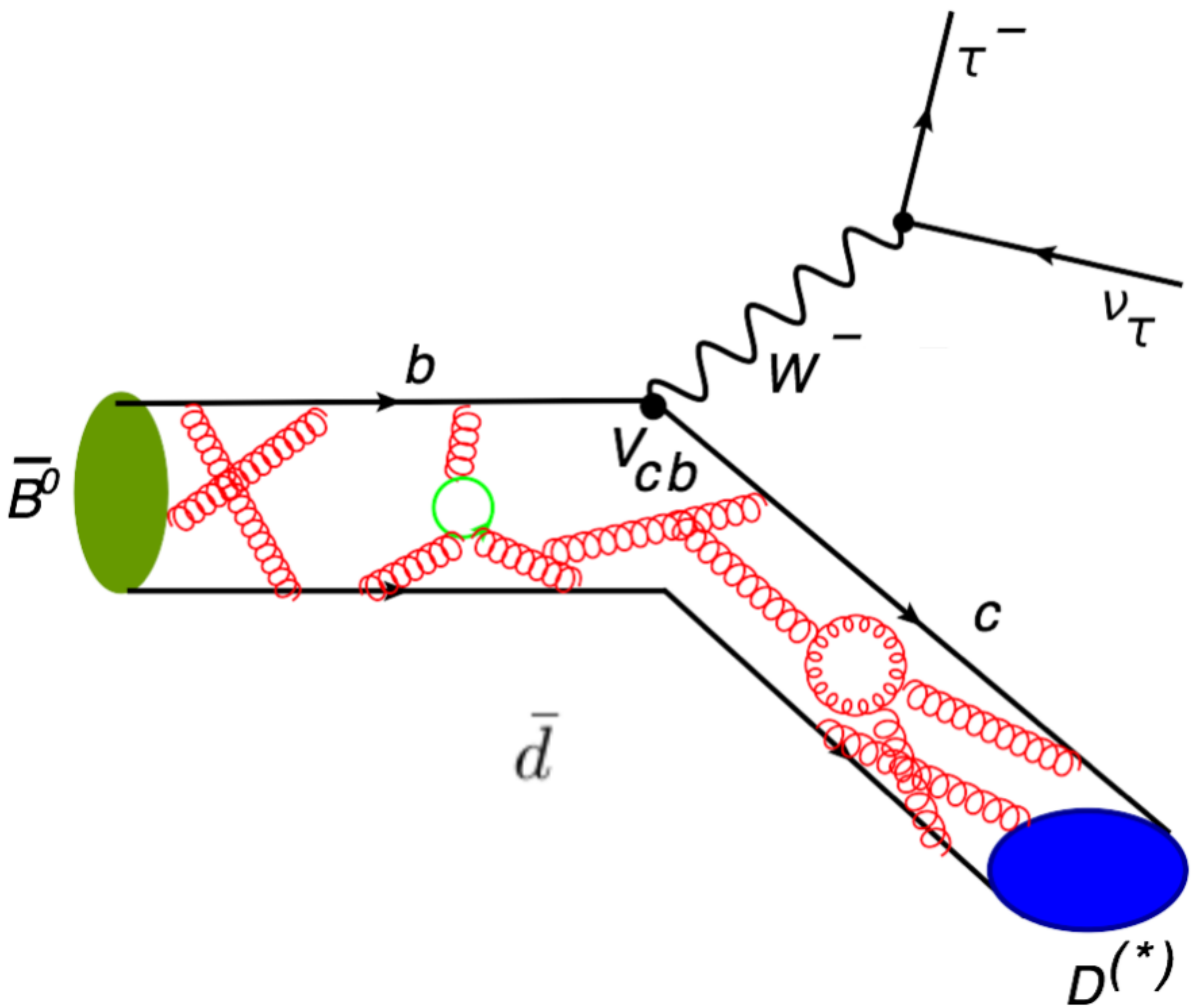
Slide taken from a talk by Anže Zupanc

Experimental status

Experiment	Mode	Technique	Observables
BaBar [PRL109, 101802; PRD88, 072012]	$B \to \overline{D}^{(*)}\tau\nu_\tau$ $\tau \to \ell\overline{\nu}_\ell\nu_\tau$	Hadronic	R(D), R(D*), q^2
Belle [PRL99,191807; PRD82,072005;]	$B \to \overline{D}^{(*)}\tau\nu_\tau$ $\tau \to \ell\overline{\nu}_\ell\nu_\tau$	Inclusive	Br
Belle [PRD92,072014]	$B \to \overline{D}^{(*)}\tau\nu_\tau$ $\tau \to \ell\overline{\nu}_\ell\nu_\tau$	Hadronic	R(D), R(D*), q^2, $\|p_l^*\|$
Belle [PRD94, 072007]	$B^0 \to D^{*-}\tau\nu_\tau$ $\tau \to \ell\overline{\nu}_\ell\nu_\tau$	Semi-leptonic	R(D*), $\|p^*_l\|$, $\|p^*_{D^*}\|$
Belle [arXiv:1608.06391]	$B \to \overline{D}^{*}\tau\nu_\tau$ $\tau \to \pi\nu_\tau,\ \rho\nu_\tau$	Hadronic	R(D*), P_τ
LHCb [PRL115,111803]	$B^0 \to D^{*-}\tau\nu_\tau$ $\tau \to \mu\overline{\nu}_\mu\nu_\tau$		R(D*)

Slide taken from a talk by Anže Zupanc

$$\overline{B} \to D^{(*)} \tau \bar{\nu}_\tau$$



$$q = p_\tau + p_{\nu_\tau}$$
$$= p_{\bar{B}^0} - p_{D^{(*)}}$$

$\overline{B} \to D$ Form Factors

$$\langle D(p_D, M_D)|\bar{c}\gamma^\mu b|\bar{B}(p_B, M_B)\rangle = F_+(q^2)\left[(p_B + p_D)^\mu - \frac{M_B^2 - M_D^2}{q^2} q^\mu\right] + F_0(q^2)\frac{M_B^2 - M_D^2}{q^2} q^\mu$$

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

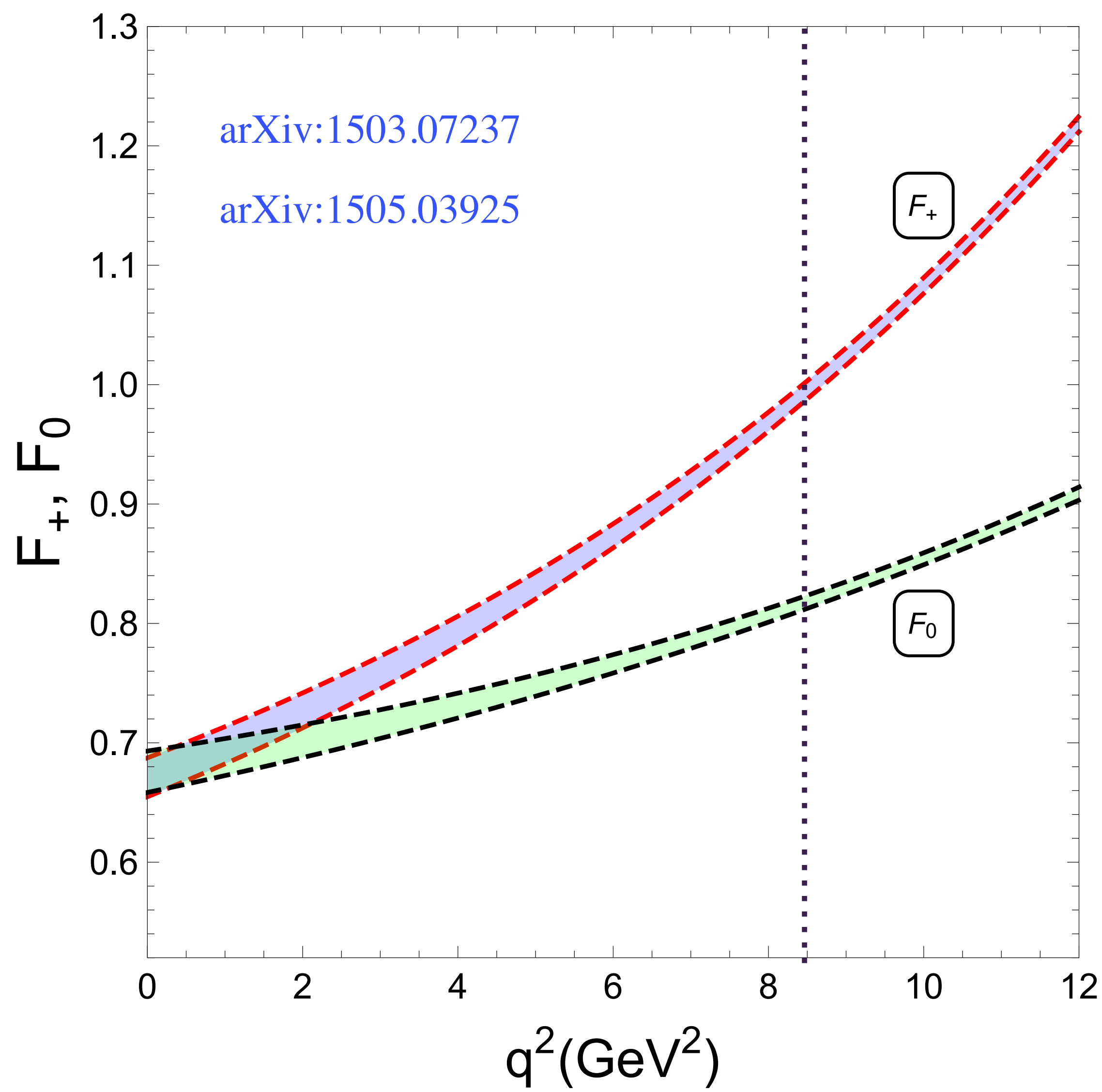
$$\langle D(p_D, M_D)|\bar{c}b|\bar{B}(p_B, M_B)\rangle = F_0(q^2)\frac{M_B^2 - M_D^2}{m_b - m_c}$$

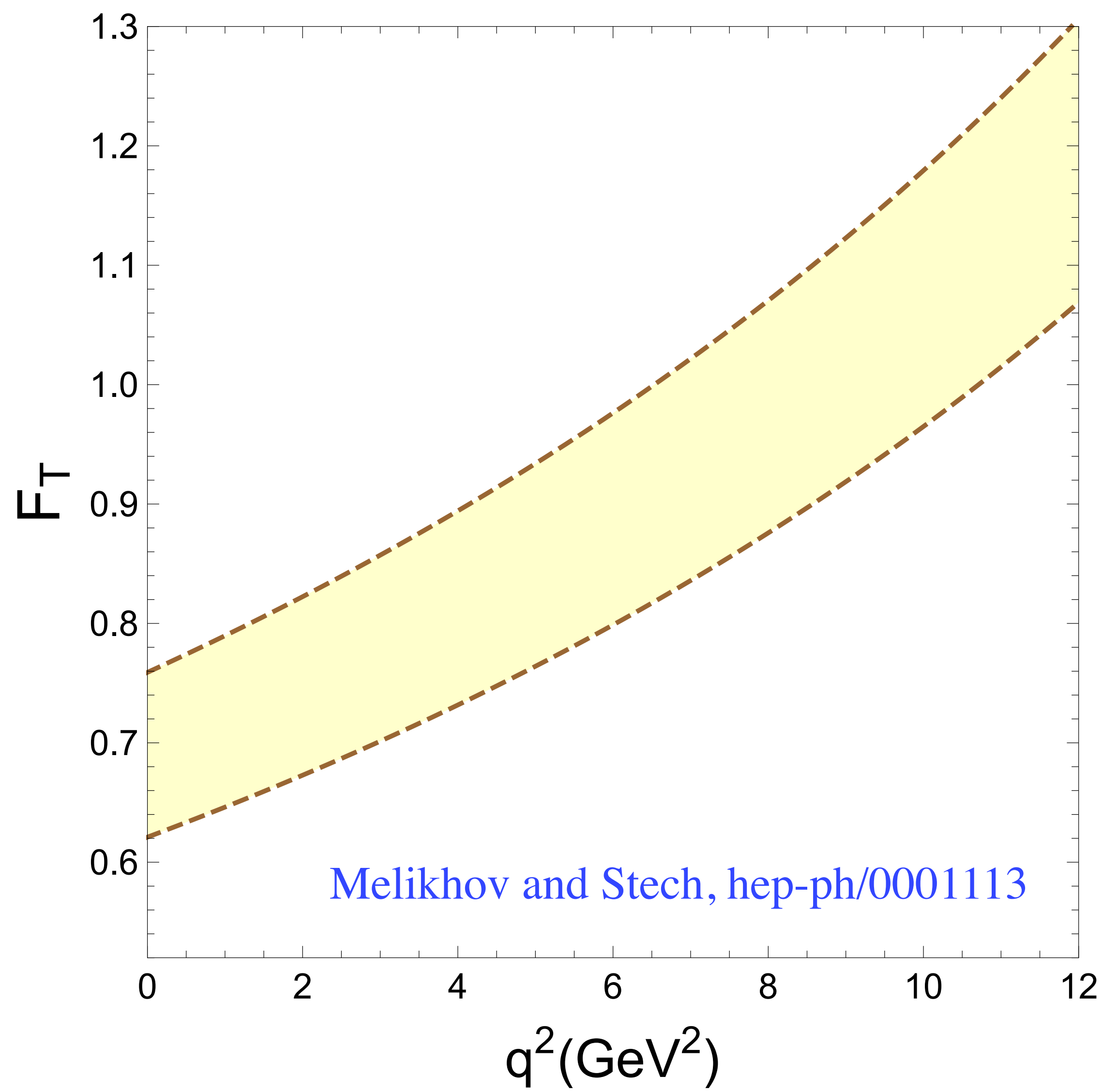
$$\langle D(p_D, M_D)|\bar{c}\gamma_5 b|\bar{B}(p_B, M_B)\rangle = 0$$

$$\langle D(p_D, M_D)|\bar{c}\sigma^{\mu\nu} b|\bar{B}(p_B, M_B)\rangle = -i(p_B^\mu p_D^\nu - p_B^\nu p_D^\mu)\frac{2F_T(q^2)}{M_B + M_D}$$

$$\langle D(p_D, M_D)|\bar{c}\sigma^{\mu\nu}\gamma_5 b|\bar{B}(p_B, M_B)\rangle = \varepsilon^{\mu\nu\rho\sigma} p_{B\rho} p_{D\sigma}\frac{2F_T(q^2)}{M_B + M_D}$$

$\overline{B} \to D$ Form Factors





$\overline{B} \to D^*$ Form Factors

$$\langle D^*(p_{D^*}, M_{D^*})|\bar{c}\gamma_\mu b|\bar{B}(p_B, M_B)\rangle = i\varepsilon_{\mu\nu\rho\sigma}\epsilon^{\nu *}p_B^\rho p_{D^*}^\sigma \frac{2V(q^2)}{M_B + M_{D^*}}$$

$$\langle D^*(p_{D^*}, M_{D^*})|\bar{c}\gamma_\mu\gamma_5 b|\bar{B}(p_B, M_B)\rangle = 2M_{D^*}\frac{\epsilon^*.q}{q^2}q_\mu A_0(q^2) + (M_B + M_{D^*})\left[\epsilon_\mu^* - \frac{\epsilon^*.q}{q^2}q_\mu\right]A_1(q^2) - \frac{\epsilon^*.q}{M_B + M_{D^*}}\left[(p_B + p_{D^*})_\mu - \frac{M_B^2 - M_{D^*}^2}{q^2}q_\mu\right]A_2(q^2)$$

$$\langle D^*(p_{D^*}, M_{D^*})|\bar{c}b|\bar{B}(p_B, M_B)\rangle = 0$$

$$\langle D^*(p_{D^*}, M_{D^*})|\bar{c}\gamma_5 b|\bar{B}(p_B, M_B)\rangle = -\epsilon^*.q\,\frac{2M_{D^*}}{m_b + m_c}A_0(q^2)$$

$$\langle D^*(p_{D^*}, M_{D^*})|\bar{c}\sigma_{\mu\nu} b|\bar{B}(p_B, M_B)\rangle = -\varepsilon_{\mu\nu\alpha\beta}\Big[- \epsilon^{\alpha *}(p_{D^*} + p_B)^\beta T_1(q^2) + \frac{M_B^2 - M_{D^*}^2}{q^2}\epsilon^{*\alpha}q^\beta\left(T_1(q^2) - T_2(q^2)\right) + 2\frac{\epsilon^*.q}{q^2}p_B^\alpha p_{D^*}^\beta\left(T_1(q^2) - T_2(q^2) - \frac{q^2}{M_B^2 - M_{D^*}^2}T_3(q^2)\right)\Big]$$

$$\langle D^*(p_{D^*}, M_{D^*})|\bar{c}\sigma_{\mu\nu}q^\nu b|\bar{B}(p_B, M_B)\rangle = -2\varepsilon_{\mu\nu\rho\sigma}\epsilon^{*\nu}p_B^\rho p_{D^*}^\sigma T_1(q^2)$$

Summary of experimental measurements

List of Observables			
Observable	Experimental Results		SM Prediction
	Experiment	Measured value	
R_D	Belle	$0.375 \pm 0.064 \pm 0.026$	0.299 ± 0.011
	BaBar	$0.440 \pm 0.058 \pm 0.042$	0.300 ± 0.008
	HFAG average	$0.397 \pm 0.040 \pm 0.028$	$\mathbf{0.300^{+0.012}_{-0.011}}$
R_{D^*}	Belle	$0.293 \pm 0.038 \pm 0.015$	
	Belle	$0.302 \pm 0.030 \pm 0.011$	
	BaBar	$0.332 \pm 0.024 \pm 0.018$	
	LHCb	$0.336 \pm 0.027 \pm 0.030$	0.252 ± 0.003
	HFAG average	$0.316 \pm 0.016 \pm 0.010$	$\mathbf{0.254 \pm 0.004}$
	Belle	$0.276 \pm 0.034\ ^{+0.029}_{-0.026}$	
	Our average	0.310 ± 0.017	
$\mathcal{B}\left(\overline{B} \to D\tau\bar{\nu}_\tau\right)$	BaBar	$1.02 \pm 0.13 \pm 0.11$ %	$\mathbf{0.633 \pm 0.016}$ %
$\mathcal{B}\left(\overline{B} \to D^*\tau\bar{\nu}_\tau\right)$	BaBar	$1.76 \pm 0.13 \pm 0.12$ %	$\mathbf{1.27 \pm 0.09}$ %
$\mathcal{B}\left(\overline{B} \to Dl\bar{\nu}_l\right)$	HFAG average	$2.13 \pm 0.03 \pm 0.09$ %	$\mathbf{2.11^{+0.09}_{-0.11}}$ %
$\mathcal{B}\left(\overline{B} \to D^*l\bar{\nu}_l\right)$	HFAG average	$4.93 \pm 0.01 \pm 0.11$ %	$\mathbf{5.04^{+0.44}_{-0.35}}$ %
$P_\tau\left(\overline{B} \to D\tau\bar{\nu}_\tau\right)$			0.325 ± 0.009 $\mathbf{0.325^{+0.013}_{-0.014}}$
$P_\tau\left(\overline{B} \to D^*\tau\bar{\nu}_\tau\right)$	Belle	$-0.44 \pm 0.47\ ^{+0.20}_{-0.17}$	-0.497 ± 0.013 $\mathbf{-0.497 \pm 0.008}$
$\mathcal{A}_{FB}^{D}$			$\mathbf{-0.360^{+0.002}_{-0.001}}$
$\mathcal{A}_{FB}^{D^*}$			$\mathbf{0.064 \pm 0.014}$

Operator basis

$$\mathcal{L}_{\rm eff}^{b\to c\,\ell\,\nu} = \frac{2G_F V_{cb}}{\sqrt{2}} \Big(C_9^{cb\ell}\,\mathcal{O}_9^{cb\ell} + C_9^{cb\ell\,\prime}\,\mathcal{O}_9^{cb\ell\,\prime} + C_{10}^{cb\ell}\,\mathcal{O}_{10}^{cb\ell} + C_{10}^{cb\ell\,\prime}\,\mathcal{O}_{10}^{cb\ell\,\prime}$$
$$+ \; C_s^{cb\ell}\,\mathcal{O}_s^{cb\ell} + C_s^{cb\ell\,\prime}\,\mathcal{O}_s^{cb\ell\,\prime} + C_p^{cb\ell}\,\mathcal{O}_p^{cb\ell} + C_p^{cb\ell\,\prime}\,\mathcal{O}_p^{cb\ell\,\prime}$$
$$+ \; C_T^{cb\ell}\,\mathcal{O}_T^{cb\ell} + C_{T5}^{cb\ell}\,\mathcal{O}_{T5}^{cb\ell} \Big)$$

$$\mathcal{O}_9^{cb\ell} = [\bar c\,\gamma^\mu\,\mathrm{P}_L\,b][\bar\ell\,\gamma_\mu\,\nu] \qquad \mathcal{O}_9^{cb\ell\,\prime} = [\bar c\,\gamma^\mu\,\mathrm{P}_R\,b][\bar\ell\,\gamma_\mu\,\nu]$$
$$\mathcal{O}_{10}^{cb\ell} = [\bar c\,\gamma^\mu\,\mathrm{P}_L\,b][\bar\ell\,\gamma_\mu\gamma_5\,\nu] \qquad \mathcal{O}_{10}^{cb\ell\,\prime} = [\bar c\,\gamma^\mu\,\mathrm{P}_R\,b][\bar\ell\,\gamma_\mu\gamma_5\,\nu]$$
$$\mathcal{O}_s^{cb\ell} = [\bar c\,\mathrm{P}_L\,b][\bar\ell\,\nu] \qquad \mathcal{O}_s^{cb\ell\,\prime} = [\bar c\,\mathrm{P}_R\,b][\bar\ell\,\nu]$$
$$\mathcal{O}_p^{cb\ell} = [\bar c\,\mathrm{P}_L\,b][[\bar\ell\,\gamma_5\,\nu] \qquad \mathcal{O}_p^{cb\ell\,\prime} = [\bar c\,\mathrm{P}_R\,b][[\bar\ell\,\gamma_5\,\nu]$$
$$\mathcal{O}_T^{cb\ell} = [\bar c\,\sigma^{\mu\nu}\,b][\bar\ell\,\sigma_{\mu\nu}\,\nu] \qquad \mathcal{O}_{T5}^{cb\ell} = [\bar c\,\sigma^{\mu\nu}\,b][\bar\ell\,\sigma_{\mu\nu}\gamma_5\,\nu]$$

$$\begin{aligned} \epsilon_{\mu\nu\alpha\beta}[\bar c\,\sigma^{\mu\nu}\,b][\bar\ell\,\sigma^{\alpha\beta}\,\nu] &= -2i\mathcal{O}_{T5}^{cb\ell} \\ [\bar c\,\sigma^{\mu\nu}\gamma_5\,b][\bar\ell\,\sigma_{\mu\nu}\gamma_5\,\nu] &= \mathcal{O}_T^{cb\ell} \\ [\bar c\,\sigma^{\mu\nu}\gamma_5\,b][\bar\ell\,\sigma_{\mu\nu}\,\nu] &= \mathcal{O}_{T5}^{cb\ell}\,. \end{aligned}$$

Operator basis

$$\mathcal{O}^{cb\ell}_{\rm VL} = [\bar{c}\,\gamma^{\mu}\,b][\bar{\ell}\,\gamma_{\mu}\,P_L\,\nu] \qquad \mathcal{O}^{cb\ell}_{\rm VR} = [\bar{c}\,\gamma^{\mu}\,b][\bar{\ell}\,\gamma_{\mu}\,P_R\,\nu]$$

$$\mathcal{O}^{cb\ell}_{\rm AL} = [\bar{c}\,\gamma^{\mu}\,\gamma_5\,b][\bar{\ell}\,\gamma_{\mu}\,P_L\,\nu] \qquad \mathcal{O}^{cb\ell}_{\rm AR} = [\bar{c}\,\gamma^{\mu}\,\gamma_5\,b][\bar{\ell}\,\gamma_{\mu}\,P_R\,\nu]$$

$$\mathcal{O}^{cb\ell}_{\rm SL} = [\bar{c}\,b][\bar{\ell}\,P_L\,\nu] \qquad \mathcal{O}^{cb\ell}_{\rm SR} = [\bar{c}\,b][\bar{\ell}\,P_R\,\nu]$$

$$\mathcal{O}^{cb\ell}_{\rm PL} = [\bar{c}\,\gamma_5\,b][[\bar{\ell}\,P_L\,\nu] \qquad \mathcal{O}^{cb\ell}_{\rm PR} = [\bar{c}\,\gamma_5\,b][[\bar{\ell}\,P_R\,\nu]$$

$$\mathcal{O}^{cb\ell}_{\rm TL} = [\bar{c}\,\sigma^{\mu\nu}\,b][\bar{\ell}\,\sigma_{\mu\nu}\,P_L\,\nu] \qquad \mathcal{O}^{cb\ell}_{\rm TR} = [\bar{c}\,\sigma^{\mu\nu}\,b][\bar{\ell}\,\sigma_{\mu\nu}\,P_R\,\nu]$$

SM: $C^{cb\ell}_{\rm VL} = 1, C^{cb\ell}_{\rm AL} = -1$

$$C^{cb\ell}_{\rm VL} = \frac{1}{2}\left(C^{cb\ell}_9 - C^{cb\ell}_{10} + C^{cb\ell\,\prime}_9 - C^{cb\ell\,\prime}_{10}\right) \qquad C^{cb\ell}_{\rm SR} = \frac{1}{2}\left(C^{cb\ell}_s + C^{cb\ell}_p + C^{cb\ell\,\prime}_s + C^{cb\ell\,\prime}_p\right)$$

$$C^{cb\ell}_{\rm AL} = \frac{1}{2}\left(-C^{cb\ell}_9 + C^{cb\ell}_{10} + C^{cb\ell\,\prime}_9 - C^{cb\ell\,\prime}_{10}\right) \qquad C^{cb\ell}_{\rm PR} = \frac{1}{2}\left(-C^{cb\ell}_s - C^{cb\ell}_p + C^{cb\ell\,\prime}_s + C^{cb\ell\,\prime}_p\right)$$

$$C^{cb\ell}_{\rm SL} = \frac{1}{2}\left(C^{cb\ell}_s - C^{cb\ell}_p + C^{cb\ell\,\prime}_s - C^{cb\ell\,\prime}_p\right) \qquad C^{cb\ell}_{\rm VR} = \frac{1}{2}\left(C^{cb\ell}_9 + C^{cb\ell}_{10} + C^{cb\ell\,\prime}_9 + C^{cb\ell\,\prime}_{10}\right)$$

$$C^{cb\ell}_{\rm PL} = \frac{1}{2}\left(-C^{cb\ell}_s + C^{cb\ell}_p + C^{cb\ell\,\prime}_s - C^{cb\ell\,\prime}_p\right) \qquad C^{cb\ell}_{\rm AR} = \frac{1}{2}\left(-C^{cb\ell}_9 - C^{cb\ell}_{10} + C^{cb\ell\,\prime}_9 + C^{cb\ell\,\prime}_{10}\right)$$

$$C^{cb\ell}_{\rm TL} = \left(C^{cb\ell}_T - C^{cb\ell}_{T5}\right) \qquad C^{cb\ell}_{\rm TR} = \left(C^{cb\ell}_T + C^{cb\ell}_{T5}\right)$$

We provide analytical expressions for all the operators, for the first time in the literature!

Operators → Amplitudes

Operators	Amplitudes
$\mathcal{O}_{\rm VL}^{cb\ell} = [\bar{c}\,\gamma^{\mu}\,b][\bar{\ell}\,\gamma_{\mu}\,P_L\,\nu]$	$\overline{B} \to D^{(*)}\tau\bar{\nu}_{\tau}$
$\mathcal{O}_{\rm AL}^{cb\ell} = [\bar{c}\,\gamma^{\mu}\,\gamma_5\,b][\bar{\ell}\,\gamma_{\mu}\,P_L\,\nu]$	$\overline{B} \to D^{*}\tau\bar{\nu}_{\tau}$
$\mathcal{O}_{\rm SL}^{cb\ell} = [\bar{c}\,b][\bar{\ell}\,P_L\,\nu]$	$\overline{B} \to D\tau\bar{\nu}_{\tau}$
$\mathcal{O}_{\rm PL}^{cb\ell} = [\bar{c}\,\gamma_5\,b][[\bar{\ell}\,P_L\,\nu]$	$\overline{B} \to D^{*}\tau\bar{\nu}_{\tau}$
$\mathcal{O}_{\rm TL}^{cb\ell} = [\bar{c}\,\sigma^{\mu\nu}\,b][\bar{\ell}\,\sigma_{\mu\nu}\,P_L\,\nu]$	$\overline{B} \to D^{(*)}\tau\bar{\nu}_{\tau}$

→ The two decays $\overline{B} \to D^{*}\tau\bar{\nu}_{\tau}$ and $\overline{B} \to D\tau\bar{\nu}_{\tau}$ are in general theoretically independent

Observables

$$\frac{d^2\mathcal{B}_\ell^{D^{(*)}}}{dq^2\,d(\cos\theta)} = \mathcal{N}\,|p_{D^{(*)}}|\left(a_\ell^{D^{(*)}} + b_\ell^{D^{(*)}}\cos\theta + c_\ell^{D^{(*)}}\cos^2\theta\right)$$

$$\mathcal{B}_\ell^{D^{(*)}} = \int \mathcal{N}\,|p_{D^{(*)}}|\left(2a_\ell^{D^{(*)}} + \frac{2}{3}c_\ell^{D^{(*)}}\right)dq^2$$

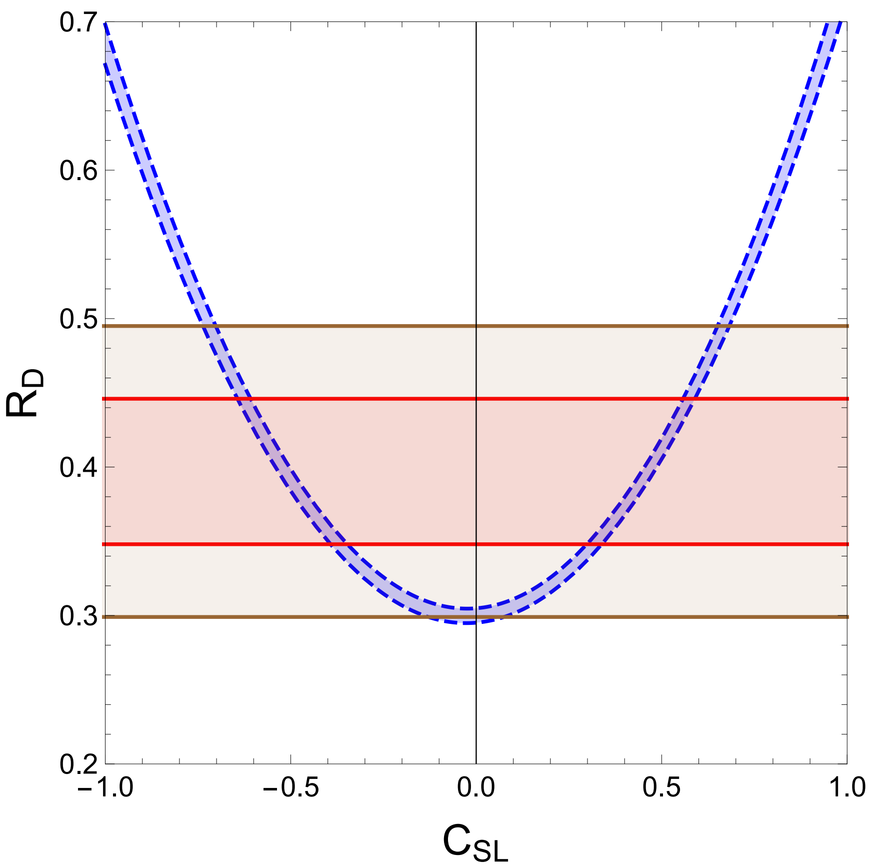
$$R_{D^{(*)}} = \frac{\mathcal{B}\left(\overline{B}\to D^{(*)}\tau\bar{\nu}_\tau\right)}{\mathcal{B}\left(\overline{B}\to D^{(*)}l\bar{\nu}_l\right)}$$

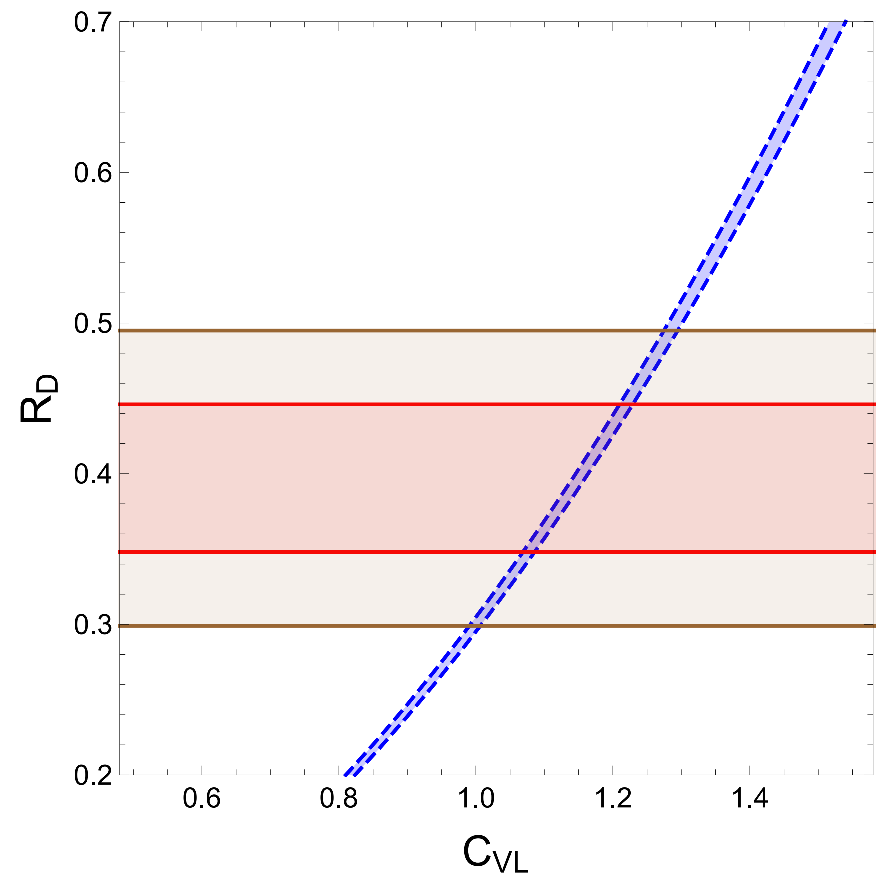
$$R_{D^{(*)}}[q^2\ \mathrm{bin}] = \frac{\mathcal{B}_\tau^{D^{(*)}}[q^2\ \mathrm{bin}]}{\mathcal{B}_l^{D^{(*)}}[q^2\ \mathrm{bin}]}$$

$$P_\tau(D^{(*)}) = \frac{\Gamma_\tau^{D^{(*)}}(+) - \Gamma_\tau^{D^{(*)}}(-)}{\Gamma_\tau^{D^{(*)}}(+) + \Gamma_\tau^{D^{(*)}}(-)}$$

$$\mathcal{A}_{FB}^{D^{(*)}} = \frac{\int b_\tau^{D^{(*)}}(q^2)dq^2}{\Gamma^{D^{(*)}}}$$

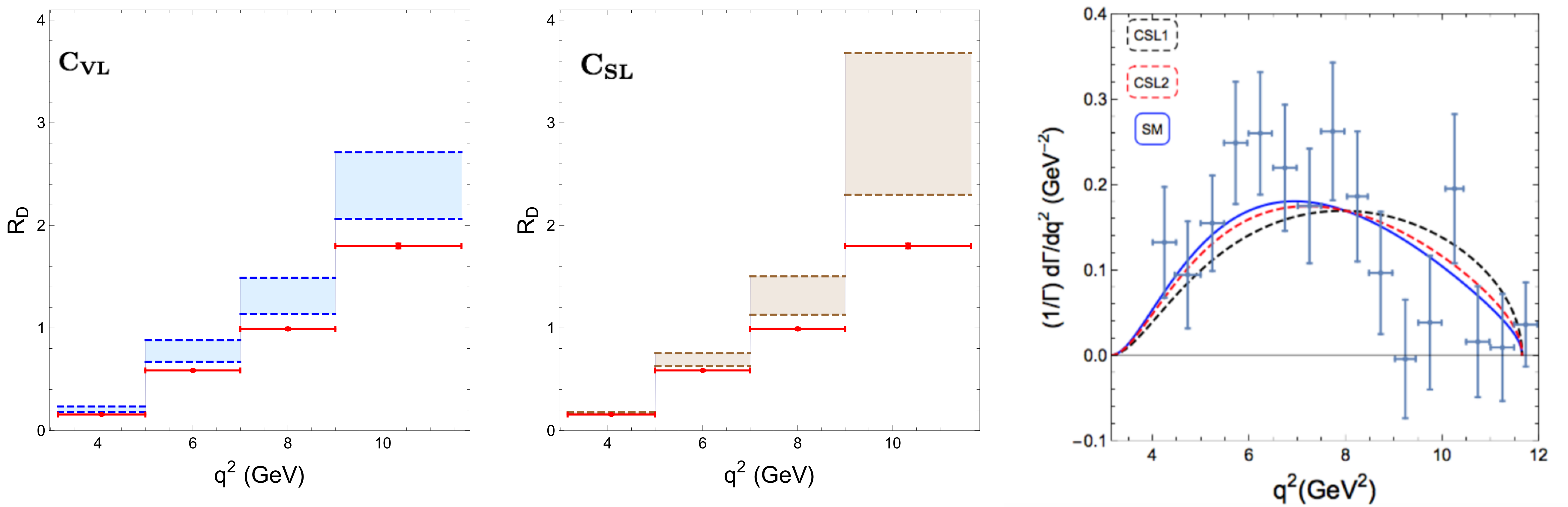
Explaining R_D



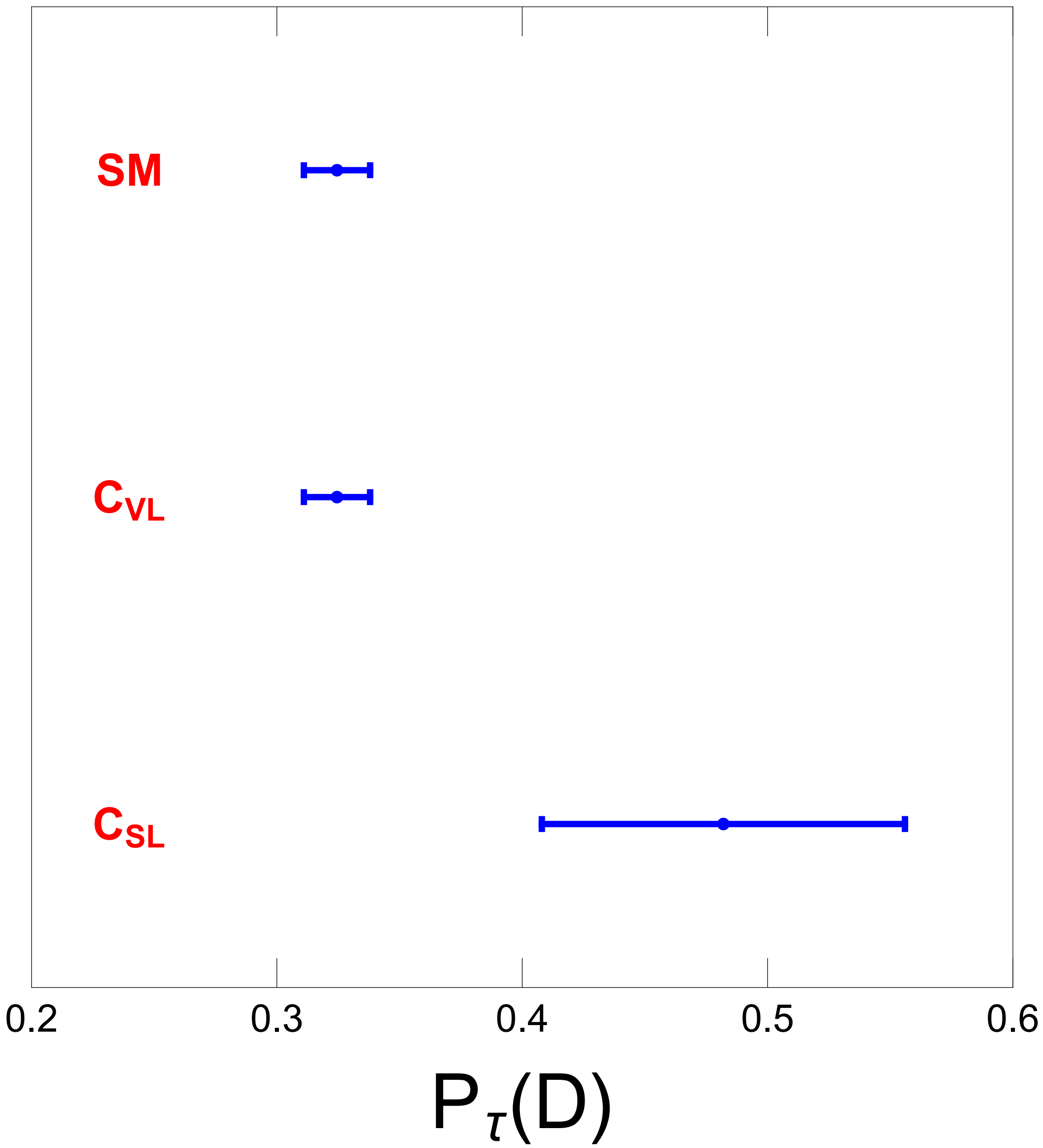


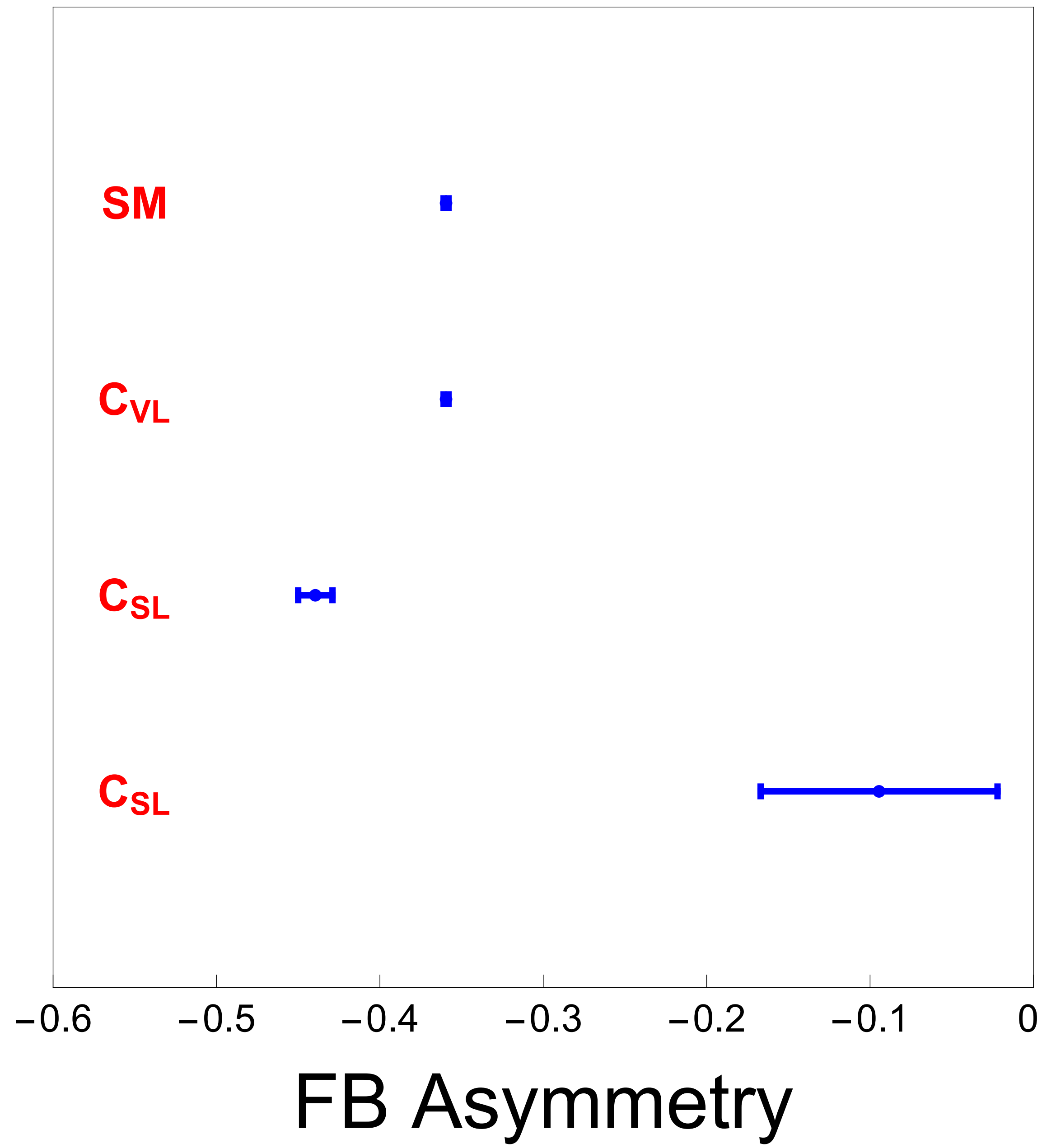
		SM	$\mathbf{C_{VL}}$ ($\mathbf{C_{SL}} = 0$)	$\mathbf{C_{SL}}$ ($\mathbf{C_{VL}} = 1$)
	1σ range of the WC		[1.073, 1.222]	[−0.656, −0.342] [0.296, 0.596]
	$P_\tau(D)$	[0.313, 0.336]	[0.313, 0.336]	[0.408, 0.556]
	$\mathcal{A}_{FB}^D$	[−0.361, −0.358]	[−0.361, −0.358]	[−0.168, −0.022] [−0.450, −0.428]
R_D [bin]	$[m_\tau^2 - 5]$ GeV^2	[0.154, 0.158]	[0.178, 0.236]	[0.161, 0.181]
	$[5 - 7]$ GeV^2	[0.578, 0.593]	[0.665, 0.888]	[0.626, 0.752]
	$[7 - 9]$ GeV^2	[0.980, 1.003]	[1.127, 1.505]	[1.125, 1.502]
	$[9 - (M_B - M_D)^2]$ GeV^2	[1.776, 1.823]	[2.049, 2.741]	[2.294, 3.669]

Explaining R_D

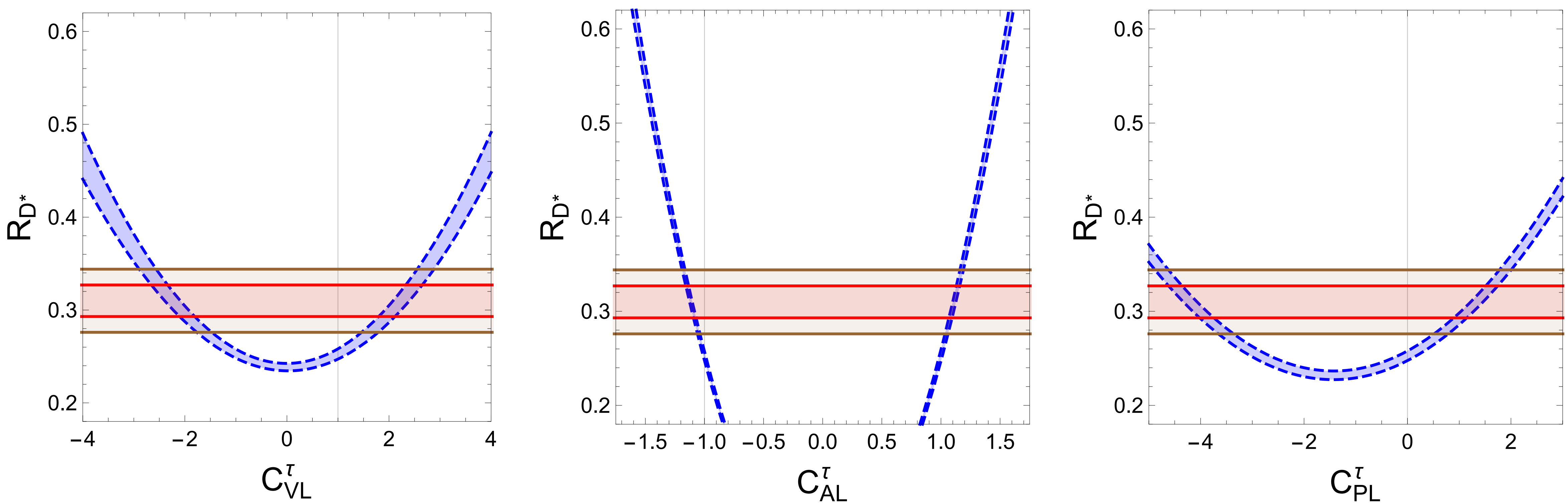


Explaining R_D



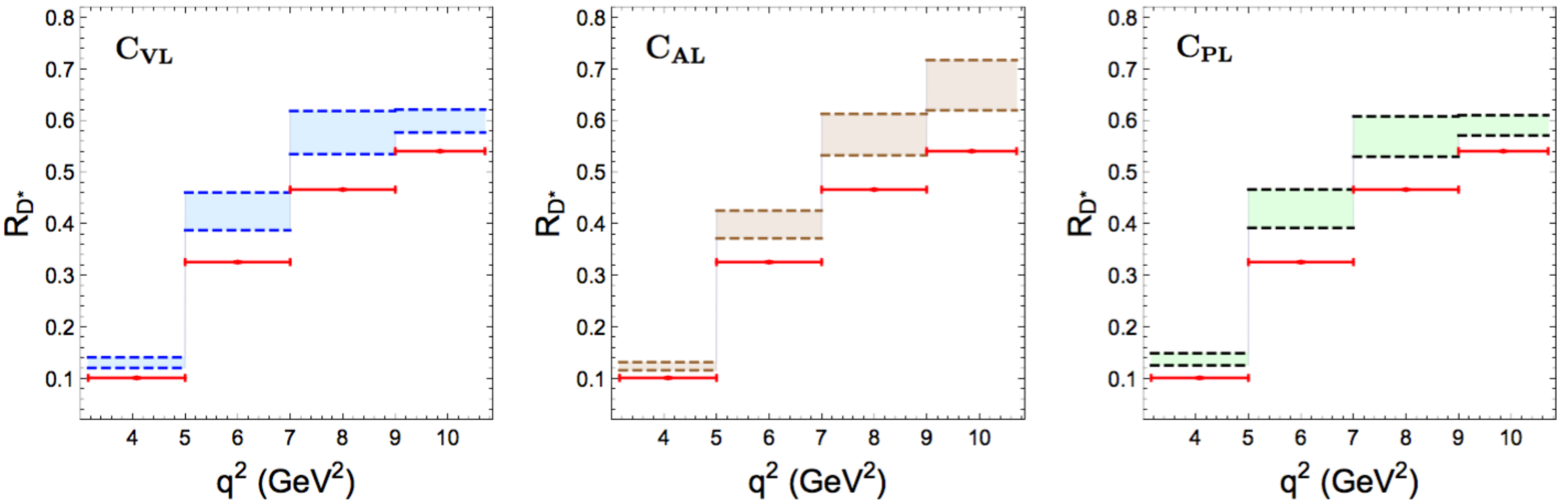


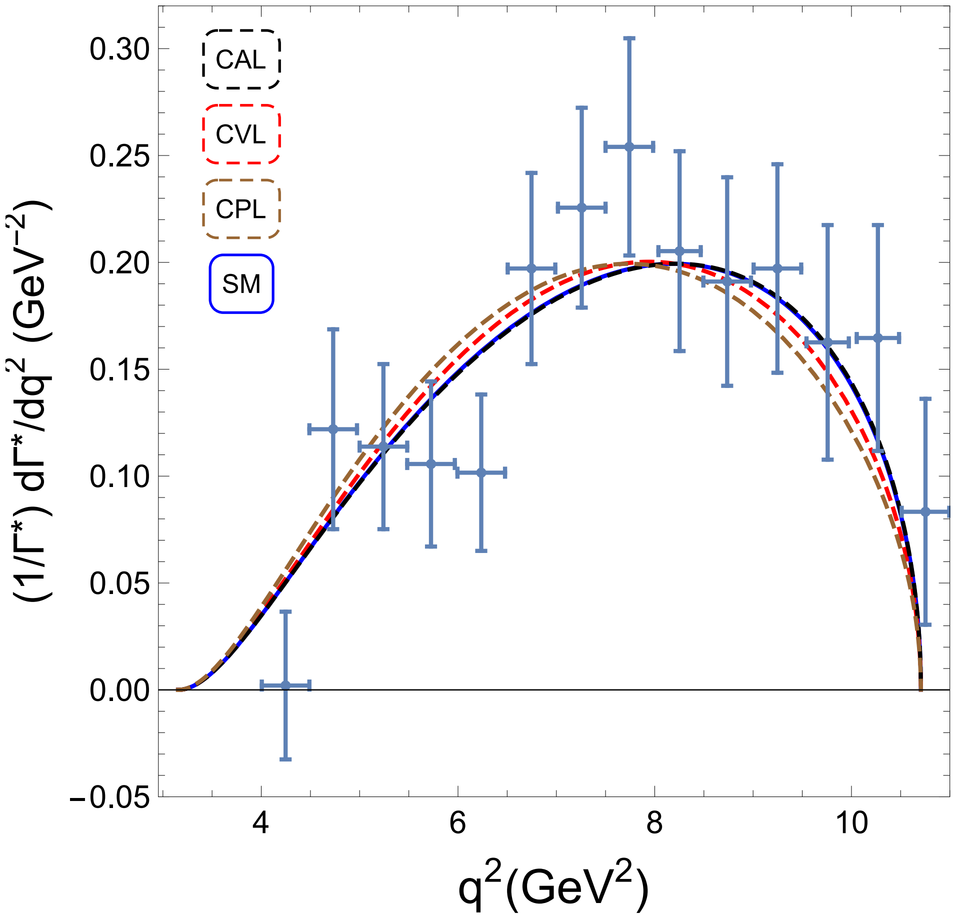
Explaining R_{D^*}



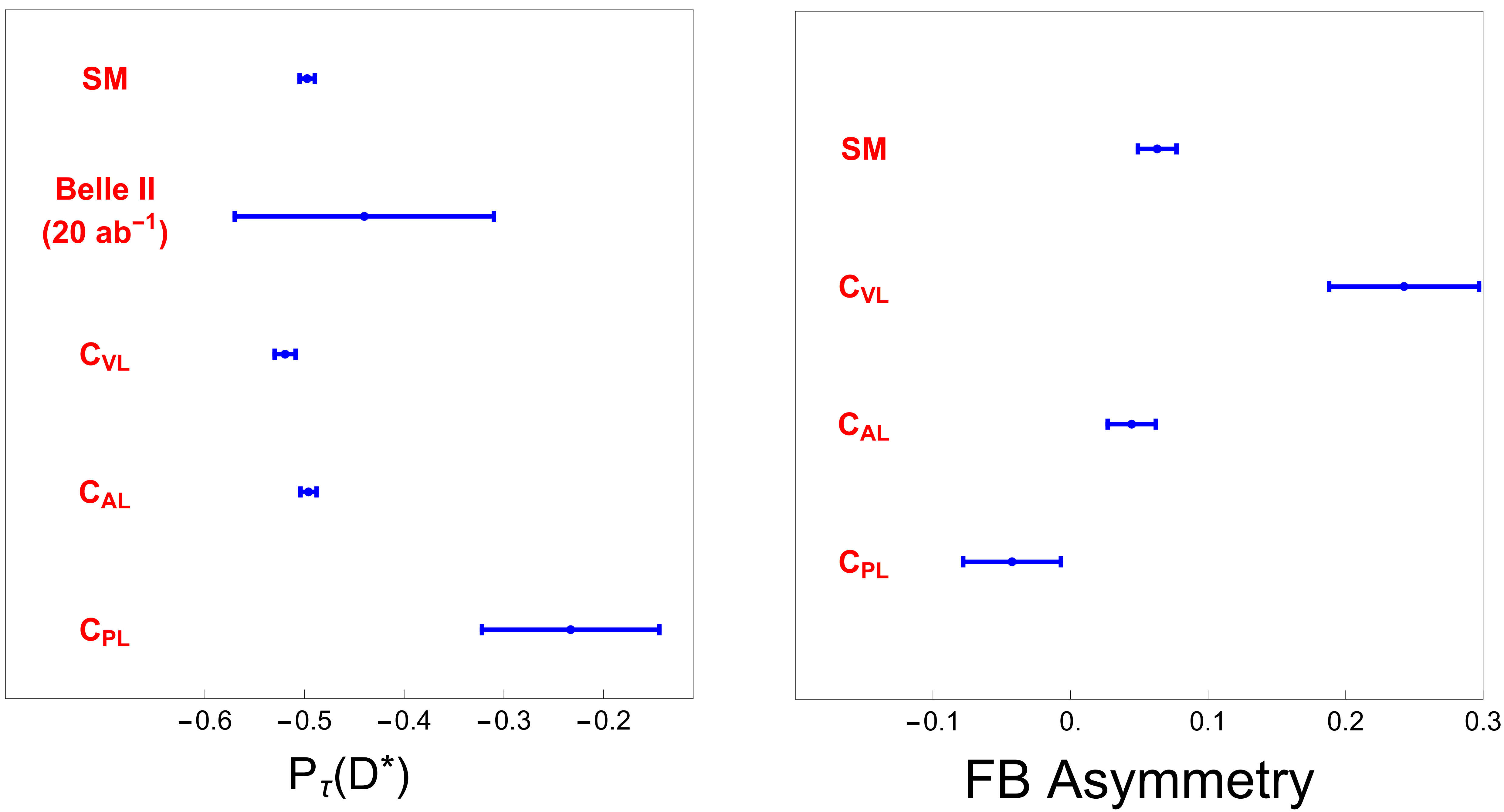
		SM	$\mathbf{C_{VL}}$ $\mathbf{C_{AL,PL}} = -1, 0$	$\mathbf{C_{AL}}$ $\mathbf{C_{VL,PL}} = 1, 0$	$\mathbf{C_{PL}}$ $\mathbf{C_{VL,AL}} = 1, -1$
	Range in WC		[1.856, 2.569]	[−1.149, −1.073]	[0.890, 1.583]
	$P_\tau(D^*)$	[−0.505, −0.490]	[−0.530, −0.509]	[−0.505, −0.488]	[−0.322, −0.144]
	$\mathcal{A}_{FB}^{D^*}$	[0.050, 0.078]	[0.191, 0.297]	[0.028, 0.062]	[−0.078, −0.007]
R_{D^*} [bin]	$[m_\tau^2 - 5]$ GeV^2	[0.103, 0.105]	[0.120, 0.140]	[0.116, 0.132]	[0.124, 0.148]
	$[5-7]$ GeV^2	[0.331, 0.336]	[0.387, 0.457]	[0.373, 0.425]	[0.390, 0.465]
	$[7-9]$ GeV^2	[0.475, 0.479]	[0.535, 0.613]	[0.535, 0.613]	[0.534, 0.610]
	$[9-(M_B - M_{D^*})^2]$ GeV^2	[0.554, 0.556]	[0.577, 0.619]	[0.621, 0.710]	[0.571, 0.611]

Explaining R_{D^*}

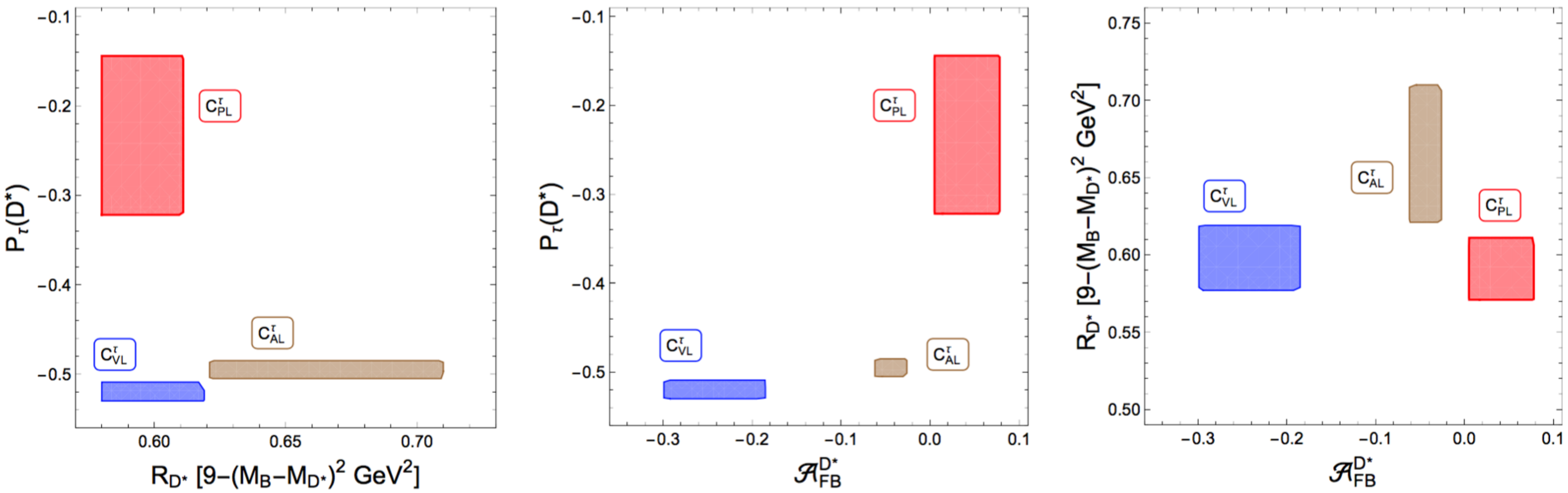




Distinguishing the various operators



Distinguishing the various operators



Explaining R_D and R_D^* together

$\mathcal{O}^{cb\ell}_{\rm VL} = [\bar{c}\,\gamma^\mu\, b][\bar{\ell}\,\gamma_\mu\, P_L\,\nu]$ $\qquad \overline{B} \to D^{(*)}\tau\bar{\nu}_\tau$

$\mathcal{O}^{cb\ell}_{\rm AL} = [\bar{c}\,\gamma^\mu\,\gamma_5\, b][\bar{\ell}\,\gamma_\mu\, P_L\,\nu]$ $\qquad \overline{B} \to D^{*}\tau\bar{\nu}_\tau$

$\mathcal{O}^{cb\ell}_{\rm SL} = [\bar{c}\, b][\bar{\ell}\, P_L\,\nu]$ $\qquad \overline{B} \to D\tau\bar{\nu}_\tau$

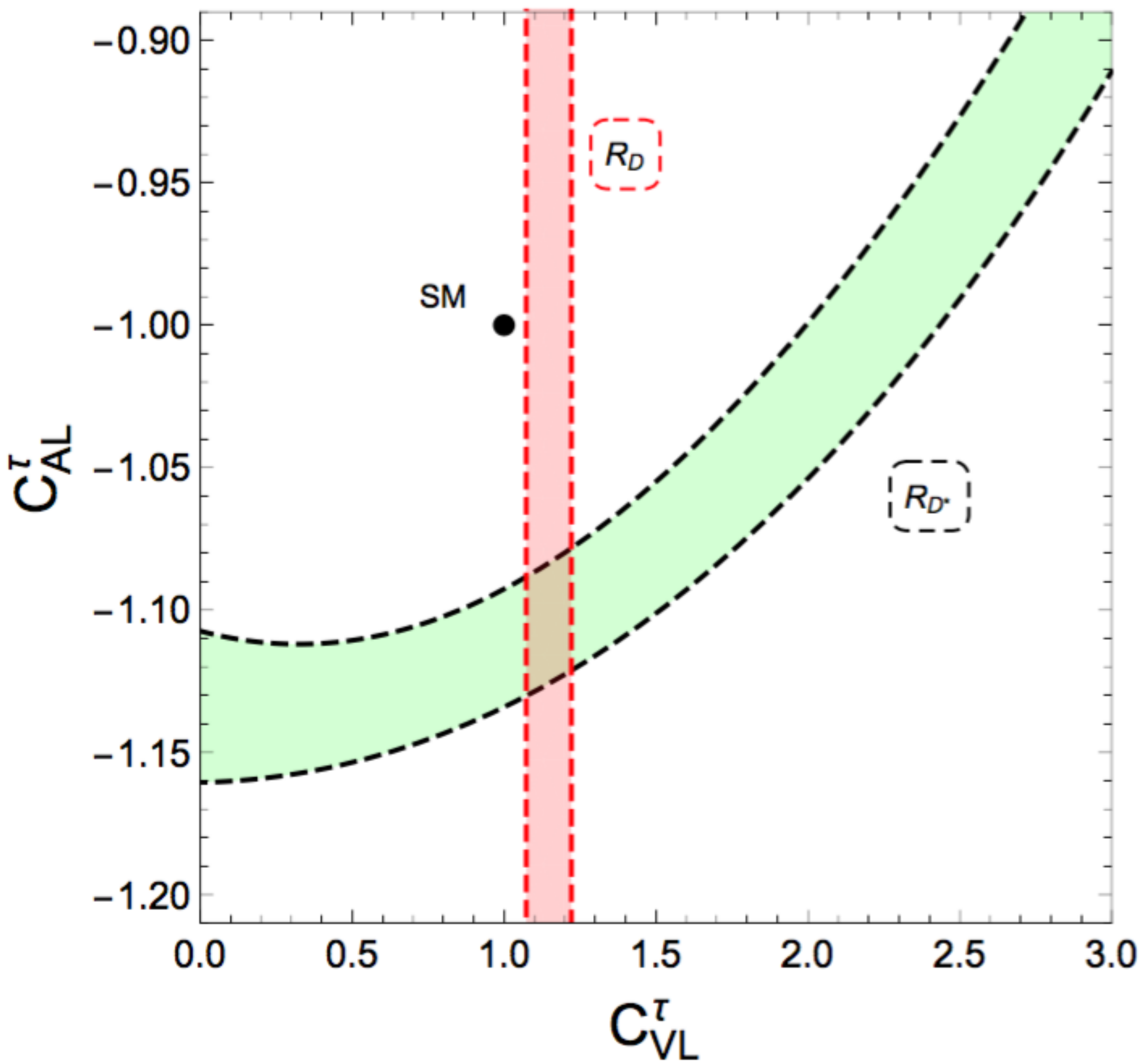
$\mathcal{O}^{cb\ell}_{\rm PL} = [\bar{c}\,\gamma_5\, b][[\bar{\ell}\, P_L\,\nu]$ $\qquad \overline{B} \to D^{*}\tau\bar{\nu}_\tau$

$\mathcal{O}^{cb\ell}_{\rm TL} = [\bar{c}\,\sigma^{\mu\nu}\, b][\bar{\ell}\,\sigma_{\mu\nu}\, P_L\,\nu]$ $\qquad \overline{B} \to D^{(*)}\tau\bar{\nu}_\tau$

$\mathbf{C_{SL}}$: [-0.656, -0.342]
[0.296, 0.596]

$\mathbf{C_{PL}}$: [0.937, 1.710]

Explaining R_D and R_D^* together



C^τ_{VL} $\in$ [1.073, 1.222]	$P_\tau(D^*)$ $\in$ [-0.507, -0.489]	R_{D^*} [bin]			
		$[m_\tau^2 - 5]$ GeV^2	$[5-7]$ GeV^2	$[7-9]$ GeV^2	$[9-(M_B - M_{D^*})^2]$ GeV^2
C^τ_{AL} $\in$ [-1.144, -1.067]	$\mathcal{A}_{FB}^{D^*}$ $\in$ [0.055, 0.092]	[0.116, 0.131]	[0.373, 0.426]	[0.535, 0.609]	[0.616, 0.706]

Explaining R_D and R_D^* together

A minimum value of $C^{\tau}_{VL} \approx -C^{\tau}_{AL} \approx 1.07$ can explain both R_D and R_{D^*}

$$\rightarrow \quad \frac{g^2_{NP}}{\Lambda^2}\,[\bar{c}\gamma^{\mu}\mathrm{P}_L b]\,[\bar{\ell}\,\gamma_{\mu}\mathrm{P}_L\,\nu]$$

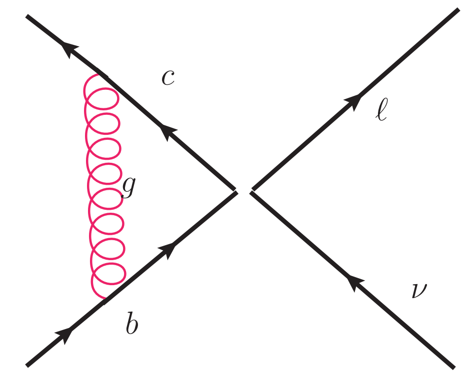
$$\rightarrow \quad \Lambda \approx g_{\mathrm{NP}}\, 2.25\ \mathrm{TeV}$$

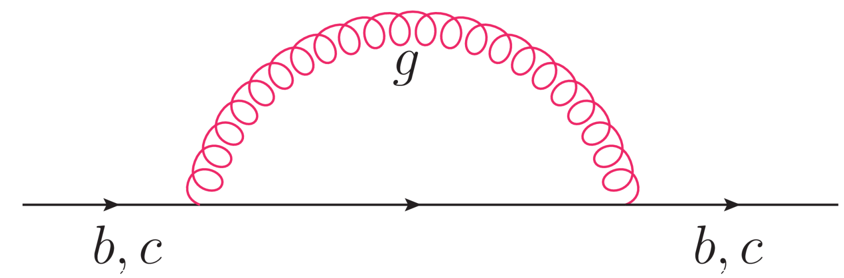
RG running

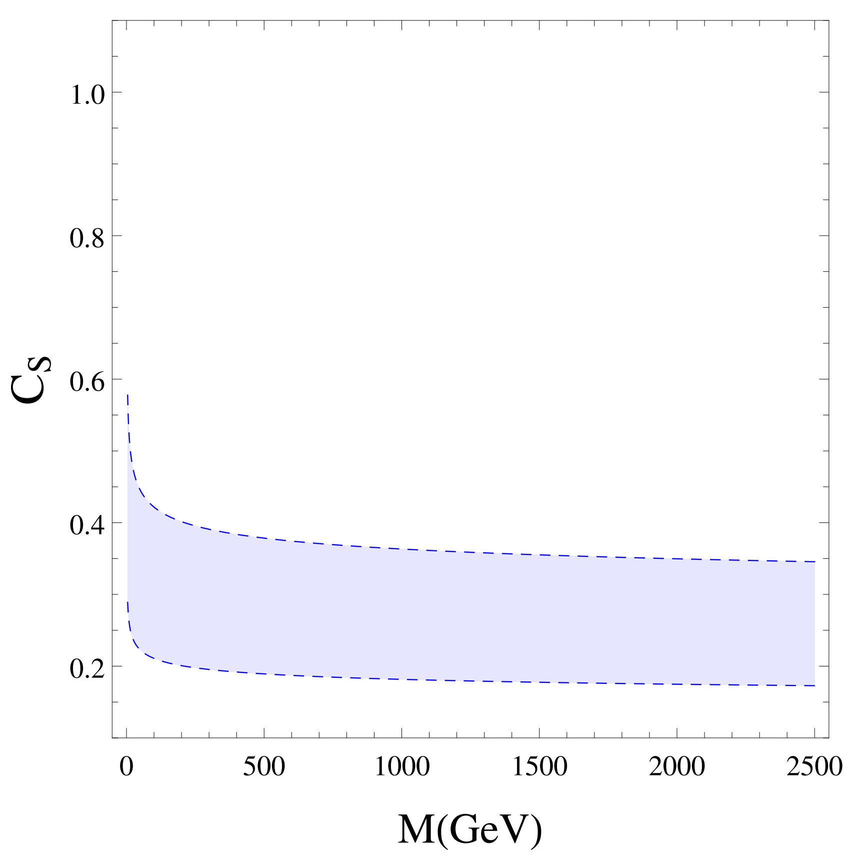
$$C_S(M) = \left[\frac{\alpha_s(m_t)}{\alpha_s(m_b)}\right]^{-\frac{\gamma_S}{2\beta_0^{(5)}}} \left[\frac{\alpha_s(M)}{\alpha_s(m_t)}\right]^{-\frac{\gamma_S}{2\beta_0^{(6)}}} C_S(m_b)$$

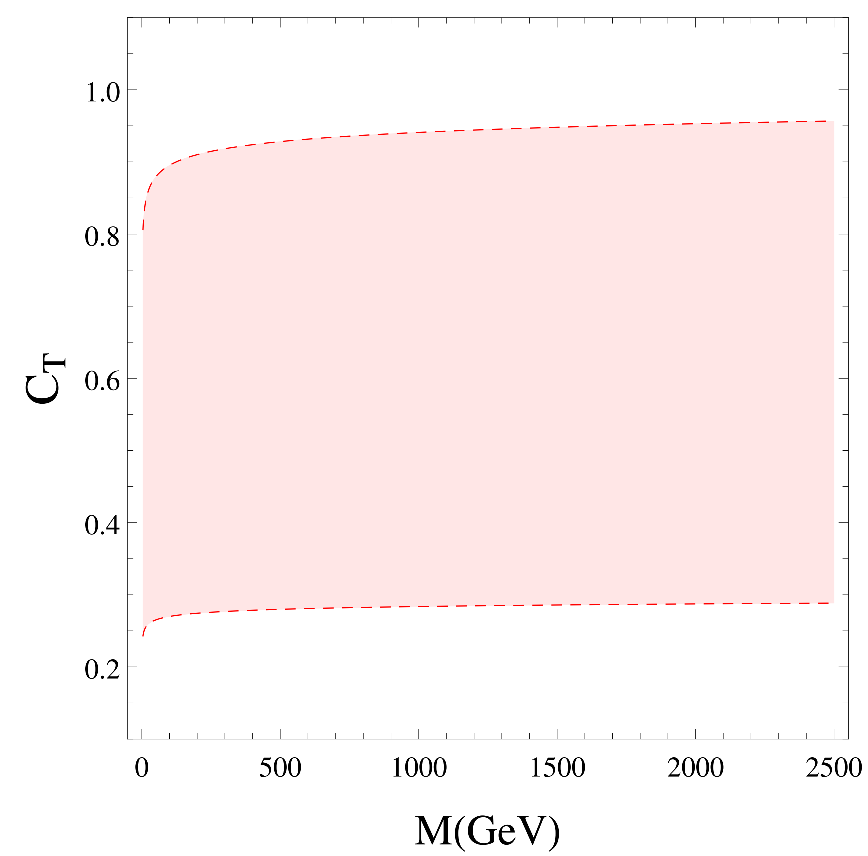
$$C_T(M) = \left[\frac{\alpha_s(m_t)}{\alpha_s(m_b)}\right]^{-\frac{\gamma_T}{2\beta_0^{(5)}}} \left[\frac{\alpha_s(M)}{\alpha_s(m_t)}\right]^{-\frac{\gamma_T}{2\beta_0^{(6)}}} C_T(m_b)$$

$$\gamma_S = -8 \qquad \gamma_T = \frac{8}{3}$$









Belle II Prospect

- 5 ab^{-1}: 6% (stat.) ± 3.9% (syst.)
- 50 ab^{-1}: 2% (stat.) ± 2.5% (syst.)

$R(D)$

- 5 ab^{-1}: 3% (stat.) ± 2.5% (syst.)
- 50 ab^{-1}: 1% (stat.) ± 2.0% (syst.)

$R(D^*)$

- 5 ab^{-1}: 0.18 (stat.) ± 0.08 (syst.)
- 50 ab^{-1}: 0.06 (stat.) ± 0.04 (syst.)

P_τ