Probing new physics in $B_s \to (K, K^*)\tau\nu$ and $B \to \pi\tau\nu$ decays

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- The electroweak interactions mediated via Z^0 and $W^\pm$ bosons are categorized into FCNC and FCCC interactions.

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- There is an upper limit on $\mathcal{B}(B \to \pi\tau\nu) < 2.5 \times 10^{-4}$ from Belle implies $R_\pi < 1.784$.

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Ratio of branching ratio	SM prediction	Experimental prediction
R_D[2]	0.299 ± 0.003	$0.407 \pm 0.039 \pm 0.024$
R_{D^*}[2]	0.258 ± 0.005	$0.304 \pm 0.013 \pm 0.007$
$R_{J/\Psi}$	$[0.20, 0.39]$[3]	$0.71 \pm 0.17 \pm 0.18$[4]
$\mathcal{B}(B \to \tau\nu)$[5]	$(0.84 \pm 0.11) \times 10^{-4}$	$(1.09 \pm 2.4) \times 10^{-4}$
R_π^l	0.566	0.698 ± 0.155
R_π	0.641	< 1.784

- The combined deviation of 3.78σ is observed in R_D and R_{D^*} and around 1.3σ in $R_{J/\Psi}$ from the SM expectations.

[2] HFLAV

[3] JHEP **1809**, 168 (2018)

[4] Phys. Rev. Lett. **115**, no. 11, 111803 (2015)

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- Here, we discuss the NP effects in $B_s \to (K, K^*)\tau\nu$ and $B \to \pi\tau\nu$ semileptonic decays mediated via $b \to u\tau\nu$ charged current interactions.
- We impose 2σ experimental constraints from the measured values of the ratio of branching ratios R_D, R_{D^*}, $R_{J/\Psi}$ and R_π^l

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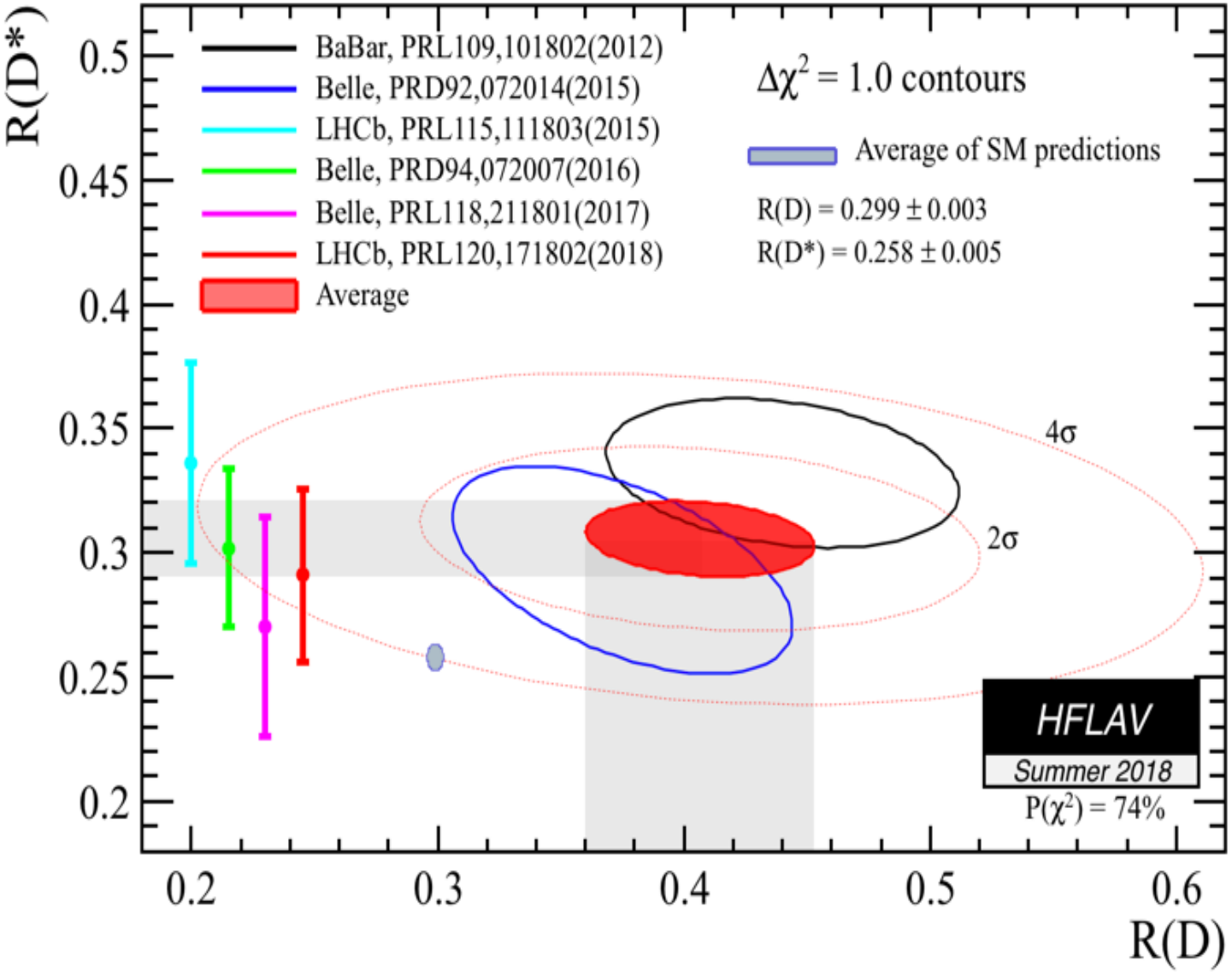

Methodology

- The most general effective Lagrangian in the presence of NP couplings is given by [6],

$$\mathcal{L}_{\text{eff}} = -\frac{4\,G_F}{\sqrt{2}}\,V_{cb}\,\Big\{(1+V_L)\,\bar{l}_L\,\gamma_\mu\,\nu_L\,\bar{c}_L\,\gamma^\mu\,b_L + V_R\,\bar{l}_L\,\gamma_\mu\,\nu_L\,\bar{c}_R\,\gamma^\mu\,b_R$$
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- By considering NP contributions from the vector type NP couplings alone, the effective Lagrangian will take the form as[7]:

$$\mathcal{L}_{eff} = -\frac{G_F}{\sqrt{2}}\,V_{ub}\,\Big\{G_V\,\bar{l}\,\gamma_\mu\,(1-\gamma_5)\,\nu_l\,\bar{u}\,\gamma^\mu\,b - G_A\,\bar{l}\,\gamma_\mu\,(1-\gamma_5)\,\nu_l\,\bar{u}\,\gamma^\mu\,\gamma_5\,b +$$
$$\widetilde{G}_V\,\bar{l}\,\gamma_\mu\,(1+\gamma_5)\,\nu_l\,\bar{u}\,\gamma^\mu\,b - \widetilde{G}_A\,\bar{l}\,\gamma_\mu\,(1+\gamma_5)\,\nu_l\,\bar{u}\,\gamma^\mu\,\gamma_5\,b\Big\} + \text{h.c.},$$

where,

$$G_V = 1 + V_L + V_R\,,\, G_A = 1 + V_L - V_R\,,\, \widetilde{G}_V = \widetilde{V}_L + \widetilde{V}_R\,,\, \widetilde{G}_A = \widetilde{V}_L - \widetilde{V}_R\,.$$

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- The differential decay distribution for the $B \to (P,\ V)\, l\, \nu$ decays

$$\frac{d\Gamma}{dq^2 d\cos\theta} = \frac{G_F^2 |V_{ub}|^2 |\vec{P}_{(P,V)}|}{2^9\, \pi^3\, m_B^2} \left(1 - \frac{m_l^2}{q^2}\right) L_{\mu\nu} H^{\mu\nu}$$

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$$\frac{d\Gamma^P}{dq^2} = \frac{8\, N\, |\vec{P}_P|}{3} \left(G_V^2 + \widetilde{G}_V^2\right) \left\{ H_0^2 \left(1 + \frac{m_l^2}{2\, q^2}\right) + \frac{3\, m_l^2}{2\, q^2} H_t^2 \right\}$$

$$\frac{d\Gamma^V}{dq^2} = \frac{8N|\vec{P}_V|}{3} \left\{ \mathcal{A}_{AV}^2 + \frac{m_l^2}{2q^2} \left[\mathcal{A}_{AV}^2 + 3\mathcal{A}_t^2 (G_A^2 + \widetilde{G}_A^2) + \widetilde{\mathcal{A}}_{AV}^2 \right] + \widetilde{\mathcal{A}}_{AV}^2 \right\}$$

where,

$$N = \frac{G_F^2\, |V_{u\,b}|^2\, q^2}{256\, \pi^3\, m_{B_{(s)}}^2} \left(1 - \frac{m_l^2}{q^2}\right)^2$$

[8] Z. Phys. C **46**, 93 (1990), Eur. Phys. J. C **59**, 27 (2009)

- Helicity amplitudes will look like

$$H_0 = \frac{2\, m_{B_{(s)}}\, |\vec{P}_P|}{\sqrt{q^2}}\, f_+(q^2), \qquad H_t = \frac{m^2_{B_{(s)}} - m^2_P}{\sqrt{q^2}}\, f_0(q^2)$$

$$\mathcal{A}^2_{AV} = \mathcal{A}^2_0 G^2_A + \mathcal{A}^2_{\parallel} G^2_A + \mathcal{A}^2_{\perp} G^2_V, \qquad \widetilde{\mathcal{A}}^2_{AV} = \mathcal{A}^2_0 \widetilde{G}^2_A + \mathcal{A}_{\parallel} \widetilde{G}^2_A + \mathcal{A}^2_{\perp} \widetilde{G}^2_V$$

$$\mathcal{A}_0 = \frac{8 m_{B_s} m_V A_{12}}{\sqrt{q^2}}, \qquad \mathcal{A}_{\parallel} = \frac{2(m_{B_s} + m_V) A_1(q^2)}{\sqrt{2}},$$

$$\mathcal{A}_{\perp} = -\frac{4 m_{B_s} V(q^2) |\vec{P}_V|}{\sqrt{2}(m_{B_s} + m_V)}, \qquad \mathcal{A}_t = \frac{2 m_{B_s} |\vec{P}_V| A_0(q^2)}{\sqrt{2}}, \qquad \mathcal{A}_P = -\frac{2 m_{B_s} |\vec{P}_V| A_0(q^2)}{(m_b(\mu) + m_c(\mu))}$$

[9] Phys. Rev. D **90**, 054506 (2014), Phys. Rev. D **89**, no. 9, 094501 (2014), Phys. Rev. D **92**, no. 1, 014024 (2015)

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- For various meson to meson transition form factors, we use very recent lattice QCD results of Refs.[9].

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q^2 dependent observables

$$\mathrm{DBR}(q^2) = \frac{d\Gamma/dq^2}{\Gamma_{\mathrm{Tot}}}$$

$$R(q^2) = \frac{\mathcal{B}(B_{(s)} \to (P,V)\tau\nu)}{\mathcal{B}(B_{(s)} \to (P,V)\, l\, \nu)}$$

$$A_{FB}^{(P,V)}(q^2) = \frac{\left(\int_{-1}^{0} - \int_{0}^{1}\right) d\cos\theta \frac{d\Gamma^{(P,V)}}{dq^2\, d\cos\theta}}{\frac{d\Gamma^{(P,V)}}{dq^2}}$$

$$P^{l}_{(P,V)}(q^2) = \frac{d\Gamma^{(P,V)}(-)/dq^2 - d\Gamma^{(P,V)}(+)/dq^2}{d\Gamma^{(P,V)}(+)/dq^2 + d\Gamma^{(P,V)}(-)/dq^2}$$

$$C_F^{l^{(P,V)}}(q^2) = \frac{1}{(d\Gamma^{(P,V)}/dq^2)} \frac{d^2}{d(\cos\theta)^2} \left[\frac{d\Gamma^{(P,V)}}{dq^2\, d\cos\theta}\right]$$

where $d\Gamma^{(P,V)}(+)/dq^2$ and $d\Gamma^{(P,V)}(-)/dq^2$ represents differential branching ratio of positive and negative helicity leptons

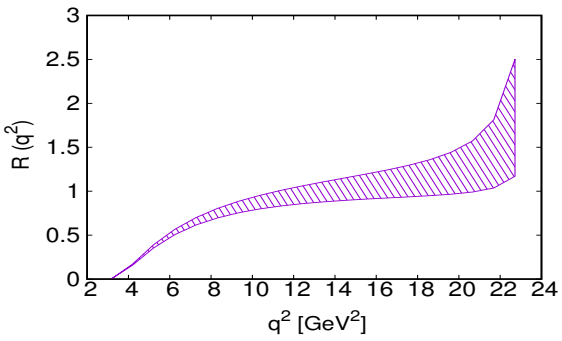
Results and discussion[10]

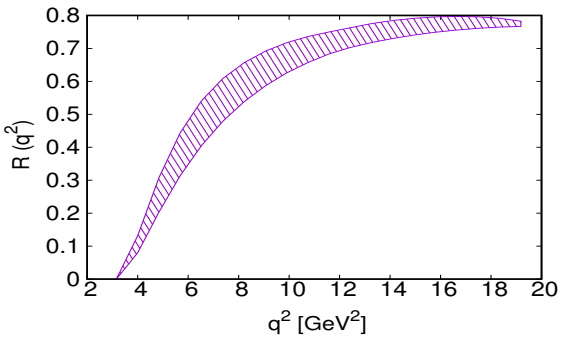
Standard model predictions

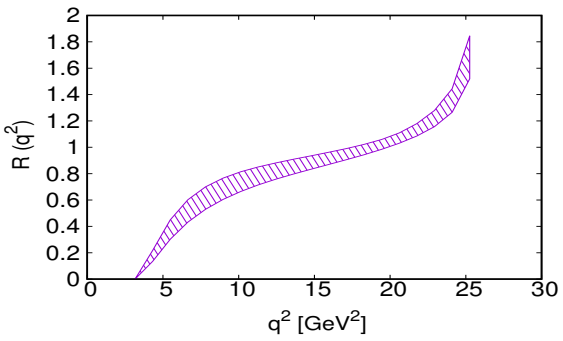
$B_s \to K l \nu$		$BR \times 10^{-4}$	$\langle A^l_{FB} \rangle$	$\langle P^l \rangle$	$\langle C^l_F \rangle$	$R_{B_s K}$
μ mode	Central value	1.520	6.647×10^{-3}	0.982	-1.479	
	1σ range	[1.098, 2.053]	[0.006, 0.007]	[0.979, 0.984]	[-1.482, -1.478]	0.636
τ mode	Central value	0.966	0.284	0.105	-0.607	
	1σ range	[0.649, 1.392]	[0.262, 0.291]	[-0.035, 0.279]	[-0.711, -0.525]	[0.586, 0.688]

$B_s \to K^* l \nu$		$BR \times 10^{-4}$	$\langle A^l_{FB} \rangle$	$\langle P^l \rangle$	$\langle C^l_F \rangle$	$R_{B_s K^*}$
μ mode	Central value	3.259	-0.281	0.993	-0.417	
	1σ range	[2.501, 4.179]	[-0.342, -0.222]	[0.989, 0.995]	[-0.575, -0.247]	0.578
τ mode	Central value	1.884	-0.132	0.539	-0.105	
	1σ range	[1.449, 2.419]	[-0.203, -0.061]	[0.458, 0.603]	[-0.208, -0.007]	[0.539, 0.623]

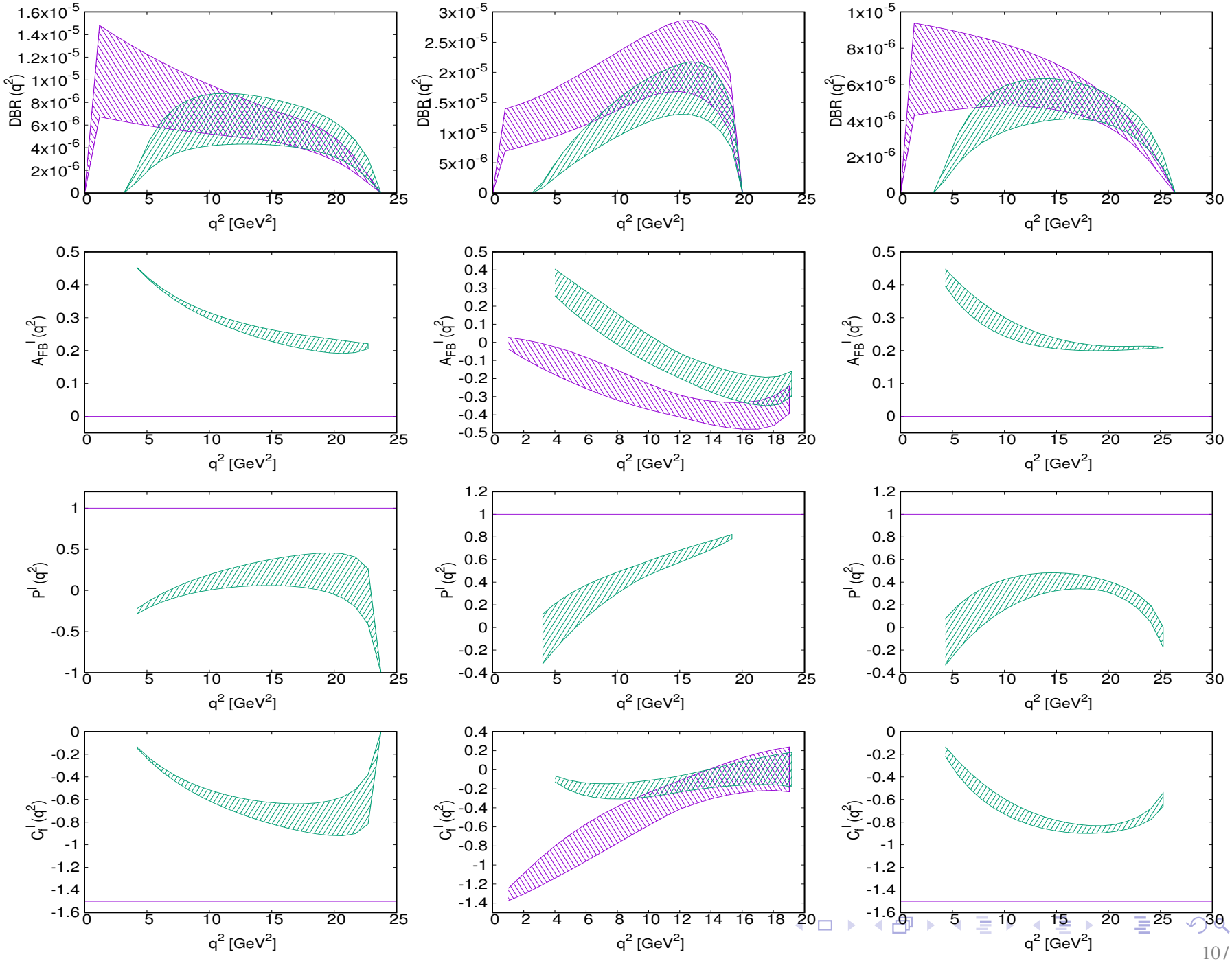
$B \to \pi l \nu$		$BR \times 10^{-4}$	$\langle A^l_{FB} \rangle$	$\langle P^l \rangle$	$\langle C^l_F \rangle$	R_π
μ mode	Central value	1.369	4.678×10^{-3}	0.988	-1.486	
	1σ range	[1.030, 1.786]	[0.004, 0.006]	[0.981, 0.991]	[-1.489, -1.481]	0.641
τ mode	Central value	0.878	0.246	0.298	-0.737	
	1σ range	[0.690, 1.092]	[0.227, 0.262]	[0.195, 0.385]	[-0.781, -0.682]	[0.576, 0.725]



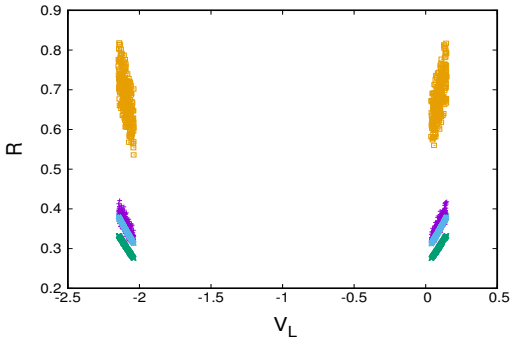


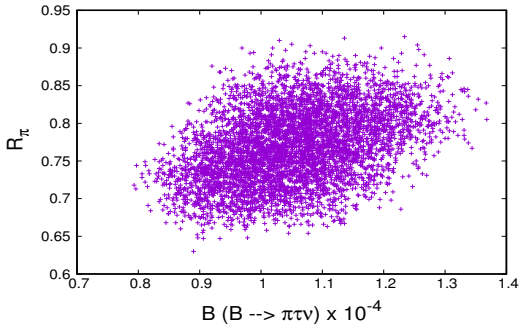


[10] Phys. Rev. D **98**, no. 5, 055024 (2018)

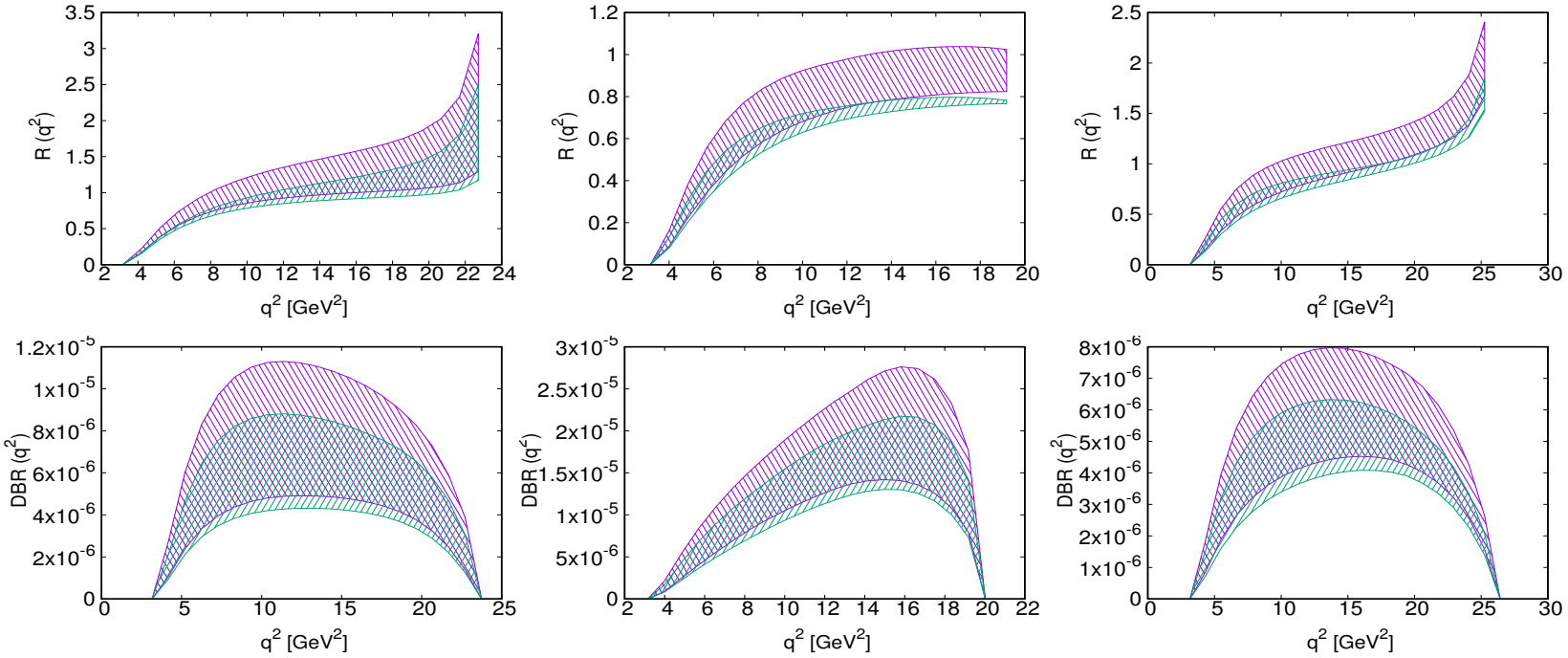

DBR (q^2)
DBR̄ (q^2)
A_FB^l (q^2)
P^l (q^2)
C_f^l (q^2)
q^2 [GeV^2]

New physics predictions in the presence of V_L

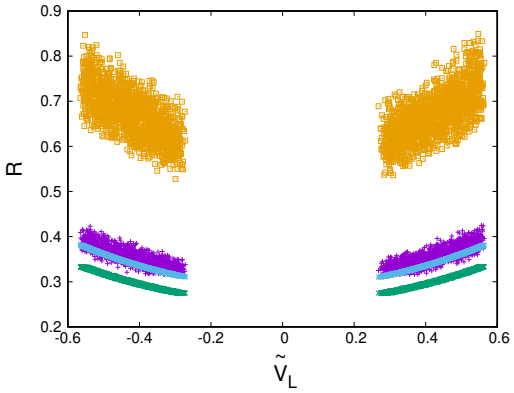


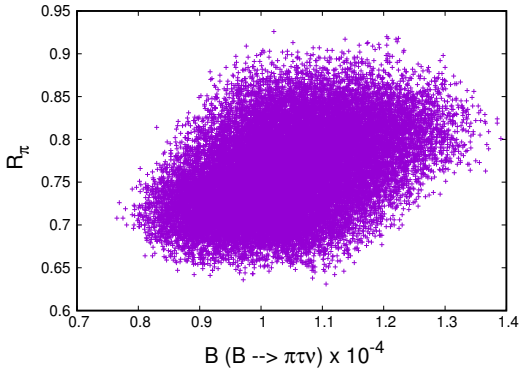


	R	$BR \times 10^{-4}$
$B_s \to K\tau\nu$	$[0.644, 0.891]$	$[0.735, 1.746]$
$B_s \to K^*\tau\nu$	$[0.593, 0.804]$	$[1.684, 2.993]$
$B \to \pi\tau\nu$	$[0.630, 0.915]$	$[0.793, 1.368]$



New physics predictions in the presence of $\widetilde{V}_L$





	R	$BR \times 10^{-4}$	$\langle P^\tau \rangle$
$B_s \to K\tau\nu$	$[0.638, 0.898]$	$[0.731, 1.774]$	$[-0.026, 0.217]$
$B_s \to K^*\tau\nu$	$[0.582, 0.802]$	$[1.579, 3.098]$	$[0.249, 0.513]$
$B \to \pi\tau\nu$	$[0.631, 0.926]$	$[0.765, 1.391]$	$[0.117, 0.315]$

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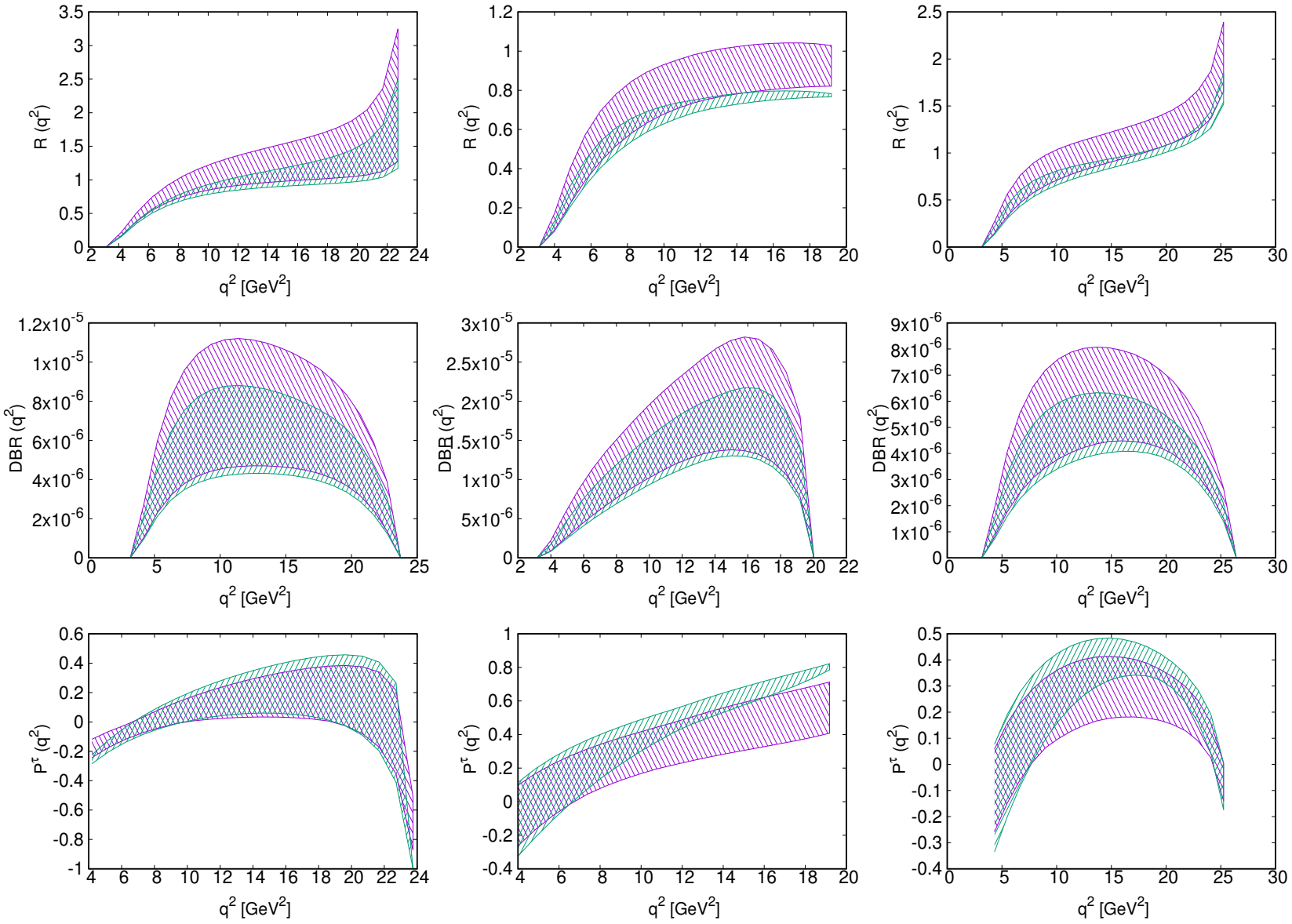

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- It will have the direct consequence on predictions or the measurements of the CKM matrix element $|V_{ub}|$.

...Thank you for your patience...