R_{Λ_c}: New physics in baryonic $b \to c$ modes

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Outline of Talk

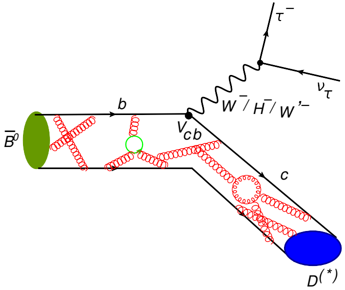
- Hints of deviation in $\bar{B} \to D^+\tau^-\bar{\nu}_\tau$ and $\bar{B} \to D^{*+}\tau^-\bar{\nu}_\tau$: $R(D^{(*)})$ puzzle.

- Implication of these deviations in $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$ decays since the underlying transition in both baryon and meson decays is $b \to c\tau^-\bar{\nu}_\tau$. (arXiv:1502.07230 [New Physics], arXiv:1502.04864 [SM], e-Print: arXiv:1702.02243 with lattice form factors)

- Given $R(D^{(*)})$ measurements how large can the NP effects be in $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$.

- How can measurement in $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$ constrain NP models. How can these measurements distinguish different NP models.

$R(D^{(*)})$ puzzle



$$A_{SM} \;=\; \frac{G_F}{\sqrt{2}} V_{cb} \left[\langle D^{(*)}(p') | \bar{c}\gamma^{\mu}(1-\gamma_5) b | \bar{B}(p) \rangle \right] \bar{\tau}\gamma_{\mu}(1-\gamma_5)\nu_{\tau}$$

$$R(D) \;\equiv\; \frac{\mathcal{B}(\bar{B} \to D^{+}\tau^{-}\bar{\nu}_{\tau})}{\mathcal{B}(\bar{B} \to D^{+}\ell^{-}\bar{\nu}_{\ell})} \qquad R(D^{*}) \equiv \frac{\mathcal{B}(\bar{B} \to D^{*+}\tau^{-}\bar{\nu}_{\tau})}{\mathcal{B}(\bar{B} \to D^{*+}\ell^{-}\bar{\nu}_{\ell})}.$$

Experiments: $R(D^{(*)})$ puzzle

Recently, the BaBar, Belle and LHCb have reported the following measurements :

$$\begin{aligned} R(D) &\equiv \frac{\mathcal{B}(\bar{B} \to D^+ \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^+ \ell^- \bar{\nu}_\ell)} = 0.440 \pm 0.058 \pm 0.042 \, , \\ R(D^*) &\equiv \frac{\mathcal{B}(\bar{B} \to D^{*+} \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{*+} \ell^- \bar{\nu}_\ell)} = 0.332 \pm 0.024 \pm 0.018 \, . \end{aligned} \quad (1)$$

Belle

$$\begin{aligned} R(D) &\equiv 0.375 \pm 0.064 \pm 0.026 \, , \\ R(D^*) &\equiv 0.293 \pm 0.038 \pm 0.015 \, , 0.302 \pm 0.030 \pm 0.011 \, . \end{aligned} \quad (2)$$

LHCb

$$\begin{aligned} R(D^*) &\equiv 0.336 \pm 0.027 \pm 0.030 \, . \\ R(D^*) &\equiv 0.306 \pm 0.016 \pm 0.010 \, . \end{aligned} \quad (3)$$

Average HFAG

$$\begin{aligned} R(D) &= 0.407 \pm 0.039 \pm 0.024, \\ R(D^*) &= 0.304 \pm 0.013 \pm 0.007, \end{aligned}$$

Theory

$$\begin{aligned} R(D) &\equiv 0.299 \pm 0.011(FNAL/MILC), 0.300 \pm 0.008(HPQCD) \\ &\equiv 0.299 \pm 0.003(arXiv:1703.05330) \\ R(D^*) &\equiv 0.257 \pm 0.003(arXiv:1703.05330)\ . \end{aligned} \tag{4}$$

$R(D^*)$ and $R(D)$ exceed the SM predictions by 3.4σ and $2.3\ \sigma$, respectively. The combined analysis of $R(D^*)$ and $R(D)$, taking into account measurement correlations, finds that the deviation is 4.1σ from the SM prediction.

Model independent NP analysis (See for example: Datta, Duraisamy, Ghosh)

- Effective Hamiltonian for $b \to c l^- \bar{\nu}_l$ with Non-SM couplings. The NP has to be LUV.

$$\mathcal{H}_{eff} = \frac{4 G_F V_{cb}}{\sqrt{2}} \Big[(1 + V_L) \left[\bar{c}\gamma_\mu P_L b\right] \left[\bar{l}\gamma^\mu P_L \nu_l\right] + V_R \left[\bar{c}\gamma^\mu P_R b\right] \left[\bar{l}\gamma_\mu P_L \nu_l\right]$$

$$+ S_L \left[\bar{c} P_L b\right] \left[\bar{l} P_L \nu_l\right] + S_R \left[\bar{c} P_R b\right] \left[\bar{l} P_L \nu_l\right] + T_L \left[\bar{c}\sigma^{\mu\nu} P_L b\right] \left[\bar{l}\sigma_{\mu\nu} P_L \nu_l\right] \Big]$$

$R(D^{(*)})$ measurements constrains the NP couplings.

The NP can be further probed via distributions and other related decays.

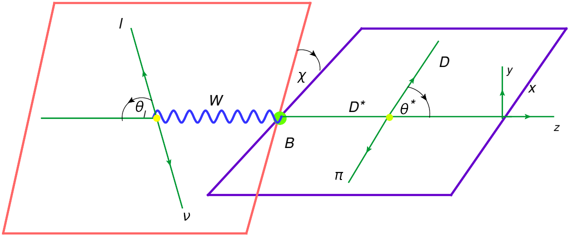
$B \to D^{(*)}\tau\nu_\tau$ in SM + NP, Helicity Amplitudes

Decay Distribution described by Helicity Amplitudes

$$
\begin{aligned}
\mathcal{H}_0 &= \frac{1}{2m_{D^*}\sqrt{q^2}}\Big[(m_B^2 - m_{D^*}^2 - q^2)(m_B + m_{D^*})A_1(q^2) \\
&\quad - \frac{4m_B^2|p_{D^*}|^2}{m_B + m_{D^*}}A_2(q^2)\Big](1 - g_A)\,, \\
\mathcal{H}_{\parallel} &= \sqrt{2}(m_B + m_{D^*})A_1(q^2)(1 - g_A)\,, \\
\mathcal{H}_{\perp} &= -\sqrt{2}\frac{2m_B V(q^2)}{(m_B + m_{D^*})}|p_{D^*}|(1 + g_V)\,, \\
\mathcal{H}_t &= \frac{2m_B|p_{D^*}|A_0(q^2)}{\sqrt{q^2}}(1 - g_A)\,, \\
\mathcal{H}_P &= -\frac{2m_B|p_{D^*}|A_0(q^2)}{(m_b(\mu) + m_c(\mu))}g_P\,.
\end{aligned}
$$

$B \to D^{(*)}\tau\nu_\tau$ in SM

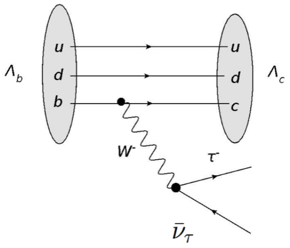
The helicity amplitudes and consequently the NP couplings can be extracted from an angular distribution and compared with models.

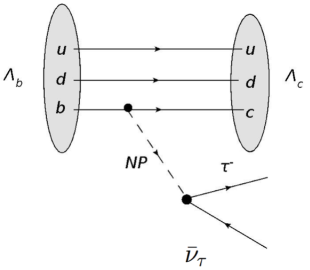


Distribution includes CPV terms which are clean probes of NP without form factor issues. If we observe τ decay then we can measure τ polarization and CPV.

Other Decays

- NP can be constrained from other decays have the same quark transition as $R(D^{(*)})$: $B_c \to \tau^- \bar{\nu}_\tau$(Alonso, Grinstein, Camalich) , $B_c \to J/\psi \tau^- \bar{\nu}_\tau$, $b \to \tau \nu X$(LEP), $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$.





Λ_b Rates

- Semileptonic Λ_b rates are of the same size as B semileptonic Decays.
- $\Lambda_b \to \Lambda_c l^- \bar{\nu}_l X$ is 10.7 ± 2.2 %, $B^0 \to X_c e^+ \nu = 10.1 \pm 0.4$ %
- $\Lambda_b \to \Lambda_c l \bar{\nu}_l$ is $6.2^{+1.4}_{-1.2}$ %.
- Hadron machines can measure Λ_b Decays. Better measurements of $\Lambda_b \to \Lambda_c l \bar{\nu}_l$ and $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$ with the differential distribution is desirable.
- Note effects in $R(D^{(*)})$ are large so effects in Λ_b decays can be large enough and go beyond form factor uncertainties.
- Measurement of $R(D^{(*)})$ is larger than the SM value. Can the corresponding ratio for Λ_b decay be less than the SM value for some new physics?

Observables

- Measurements in $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$ that can further constrain the NP parameter space.

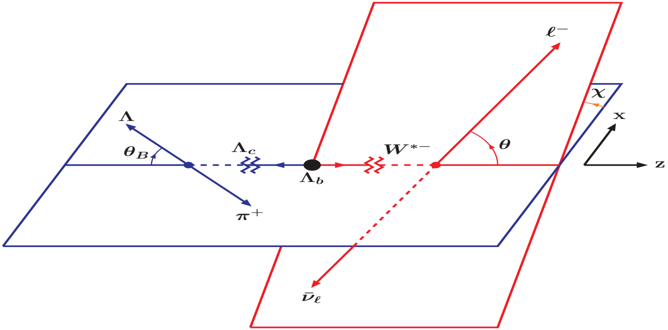
$$R(\Lambda_c) = \frac{\mathcal{B}[\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau]}{\mathcal{B}[\Lambda_b \to \Lambda_c \ell \bar{\nu}_\ell]}$$

$$R^{Ratio}_{\Lambda_c} = \frac{R(\Lambda_c)^{SM+NP}}{R(\Lambda_c)^{SM}}.$$

- These ratios can be calculated in SM and NP using$\Lambda_b \to \Lambda_c$ form factors are calculated from lattice QCD (Datta:2017aue, Detmold:2015aaa).

The decay and helicity angles for $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$ and $\Lambda_b \to \Lambda_c \ell \bar{\nu}_\ell$ are(See 1502.04864)

$$\Lambda_b \to \Lambda_c (\to \Lambda \pi) W^{*-} (\to \ell^- \bar{\nu}_\ell)$$



Decay Process

The process under consideration is

$$\Lambda_b(p_{\Lambda_b}) \to \tau^-(p_1) + \bar{\nu_\tau}(p_2) + \Lambda_c(p_{\Lambda_c})$$

In the SM the amplitude for this process is

$$M_{SM} = \frac{G_F V_{cb}}{\sqrt{2}} L^\mu H_\mu,$$

where the leptonic and hadronic currents are,

$$\begin{aligned} L^\mu &= \bar{u}_\tau(p_1)\gamma^\mu(1-\gamma_5)v_{\nu_\tau}(p_2), \\ H_\mu &= \langle\Lambda_c|\, \bar{c}\gamma_\mu(1-\gamma_5)b\, |\Lambda_b\rangle\,. \end{aligned}$$

The hadronic current is expressed in terms of six form factors,

$$\begin{aligned} \langle\Lambda_c|\, \bar{c}\gamma_\mu b\, |\Lambda_b\rangle &= \bar{u}_{\Lambda_c}(f_1\gamma_\mu + if_2\sigma_{\mu\nu}q^\nu + f_3 q_\mu)u_{\Lambda_b}, \\ \langle\Lambda_c|\, \bar{c}\gamma_\mu\gamma_5 b|\, |\Lambda_b\rangle &= \bar{u}_{\Lambda_c}(g_1\gamma_\mu\gamma_5 + ig_2\sigma_{\mu\nu}q^\nu\gamma_5 + g_3 q_\mu\gamma_5)u_{\Lambda_b}. \end{aligned}$$

Here $q = p_{\Lambda_b} - p_{\Lambda_c}$ is the momentum transfer and the form factors are functions of q^2.

Heavy Quarks and form Factors

- In the heavy quark limit, $m_{b,c} \to \infty$ there is only one independent form factor.

- $f_1 = g_1$, $f_2 = g_2 = f_3 = g_3 = 0$.

- In the "light" charm case, $m_b \to \infty$ and m_c finite there are only two independent form factors.

- $g_1 = f_1$, $g_2 = f_2$ and $f_3 = g_3 = f_2$.

- Form factors have been calculated in lattice QCD [Detmold:2015aaa].

When considering NP operators Scalars and Tensors operators arise.

$$\begin{aligned}\langle\Lambda_c|\,\bar{c}b\,|\Lambda_b\rangle &= \bar{u}_{\Lambda_c}(f_1\frac{\not{q}}{m_b-m_c}+f_3\frac{q^2}{m_b-m_c})u_{\Lambda_b},\\ \langle\Lambda_c|\,\bar{c}\gamma_5 b\,|\Lambda_b\rangle &= \bar{u}_{\Lambda_c}(-g_1\frac{\not{q}\gamma_5}{m_b+m_c}-g_3\frac{q^2\gamma_5}{m_b+m_c})u_{\Lambda_b}.\end{aligned}$$

The matrix elements of the tensor currents can be written in terms of four form factors h_+, $h_\perp$, $\widetilde{h}_+$, $\widetilde{h}_\perp$,

$$\begin{aligned}&\langle\Lambda_c|\,\bar{c}i\sigma^{\mu\nu}b\,|\Lambda_b\rangle = \bar{u}_{\Lambda_c}\Big[2h_+(q^2)\frac{p^\mu_{\Lambda_b}p^\nu_{\Lambda_c}-p^\nu_{\Lambda_b}p^\mu_{\Lambda_c}}{Q_+}\\ &+h_\perp(q^2)\Big(\frac{m_{\Lambda_b}+m_{\Lambda_c}}{q^2}(q^\mu\gamma^\nu-q^\nu\gamma^\mu)-2(\frac{1}{q^2}+\frac{1}{Q_+})(p^\mu_{\Lambda_b}p^\nu_{\Lambda_c}-p^\nu_{\Lambda_b}p^\mu_{\Lambda_c})\Big)\\ &+\widetilde{h}_+(q^2)\Big(i\sigma^{\mu\nu}-\frac{2}{Q_-}(m_{\Lambda_b}(p^\mu_{\Lambda_c}\gamma^\nu-p^\nu_{\Lambda_c}\gamma^\mu)\\ &-m_{\Lambda_c}(p^\mu_{\Lambda_b}\gamma^\nu-p^\nu_{\Lambda_b}\gamma^\mu)+p^\mu_{\Lambda_b}p^\nu_{\Lambda_c}-p^\nu_{\Lambda_b}p^\mu_{\Lambda_c})\Big)\\ &+\widetilde{h}_\perp(q^2)\frac{m_{\Lambda_b}-m_{\Lambda_c}}{q^2Q_-}\Big((m^2_{\Lambda_b}-m^2_{\Lambda_c}-q^2)(\gamma^\mu p^\nu_{\Lambda_b}-\gamma^\nu p^\mu_{\Lambda_b})\end{aligned}$$

Helicity Amplitudes

$$
\begin{aligned}
H_{\lambda_{\Lambda_c},\lambda_w} &= H^V_{\lambda_{\Lambda_c},\lambda_w} - H^A_{\lambda_{\Lambda_c},\lambda_w}, \\
H^V_{\frac{1}{2}0} &= (1+g_L+g_R)\frac{\sqrt{Q_-}}{\sqrt{q^2}}\Big((M_1+M_2)f_1 - q^2 f_2\Big), \\
H^A_{\frac{1}{2}0} &= (1+g_L-g_R)\frac{\sqrt{Q_+}}{\sqrt{q^2}}\Big((M_1-M_2)g_1 + q^2 g_2\Big), \\
H^V_{\frac{1}{2}1} &= (1+g_L+g_R)\sqrt{2Q_-}\Big(f_1 - (M_1+M_2)f_2\Big), \\
H^A_{\frac{1}{2}1} &= (1+g_L-g_R)\sqrt{2Q_+}\Big(g_1 + (M_1-M_2)g_2\Big), \\
H^V_{\frac{1}{2}t} &= (1+g_L+g_R)\frac{\sqrt{Q_+}}{\sqrt{q^2}}\Big((M_1-M_2)f_1 + q^2 f_3\Big), \\
H^A_{\frac{1}{2}t} &= (1+g_L-g_R)\frac{\sqrt{Q_-}}{\sqrt{q^2}}\Big((M_1+M_2)g_1 - q^2 g_3\Big), \qquad (5)
\end{aligned}
$$

The scalar and pseudo-scalar helicities associated with the new physics scalar and pseudo-scalar interactions are

$$\begin{aligned} {H^{SP}}_{1/2,0} &= {H^{P}}_{1/2,0} + {H^{S}}_{1/2,0}, \\ {H^{S}}_{1/2,0} &= g_S \frac{\sqrt{Q_+}}{m_b - m_c}\Big((M_1 - M_2)f_1 + q^2 f_3\Big), \\ {H^{P}}_{1/2,0} &= -g_P \frac{\sqrt{Q_-}}{m_b + m_c}\Big((M_1 + M_2)g_1 - q^2 g_3\Big). \end{aligned}$$

The parity related amplitudes are,

$$\begin{aligned} {H^{S}}_{\lambda_{\Lambda_c},\lambda_{NP}} &= {H^{S}}_{-\lambda_{\Lambda_c},-\lambda_{NP}}, \\ {H^{P}}_{\lambda_{\Lambda_c},\lambda_{NP}} &= -{H^{P}}_{-\lambda_{\Lambda_c},-\lambda_{NP}}. \end{aligned}$$

The tensor helicity amplitudes are

$$H^{(T)-1/2}_{-1/2,t,0} = -g_T\left[-h_+\sqrt{Q_-}+\widetilde{h}_+\sqrt{Q_+}\right],$$

$$H^{(T)+1/2}_{+1/2,t,0} = g_T\left[h_+\sqrt{Q_-}+\widetilde{h}_+\sqrt{Q_+}\right],$$

$$H^{(T)-1/2}_{+1/2,t,+1} = -g_T\frac{\sqrt{2}}{\sqrt{q^2}}\left[h_\perp(m_{\Lambda_b}+m_{\Lambda_c})\sqrt{Q_-}+\widetilde{h}_\perp(m_{\Lambda_b}-m_{\Lambda_c})\sqrt{Q_+}\right],$$

$$H^{(T)+1/2}_{-1/2,t,-1} = -g_T\frac{\sqrt{2}}{\sqrt{q^2}}\left[h_\perp(m_{\Lambda_b}+m_{\Lambda_c})\sqrt{Q_-}-\widetilde{h}_\perp(m_{\Lambda_b}-m_{\Lambda_c})\sqrt{Q_+}\right],$$

$$H^{(T)-1/2}_{+1/2,0,+1} = -g_T\frac{\sqrt{2}}{\sqrt{q^2}}\left[h_\perp(m_{\Lambda_b}+m_{\Lambda_c})\sqrt{Q_-}+\widetilde{h}_\perp(m_{\Lambda_b}-m_{\Lambda_c})\sqrt{Q_+}\right],$$

$$H^{(T)+1/2}_{-1/2,0,-1} = g_T\frac{\sqrt{2}}{\sqrt{q^2}}\left[h_\perp(m_{\Lambda_b}+m_{\Lambda_c})\sqrt{Q_-}-\widetilde{h}_\perp(m_{\Lambda_b}-m_{\Lambda_c})\sqrt{Q_+}\right],$$

In the physical limit (zero lattice spacing and physical quark masses), the nominal fit function for a form factor f reduces to the form

$$f(q^2) = \frac{1}{1 - q^2/(m_{\rm pole}^f)^2}\left[a_0^f + a_1^f\, z^f(q^2)\right], \tag{7}$$

while the higher-order fit function is given by

$$f_{\rm HO}(q^2) = \frac{1}{1 - q^2/(m_{\rm pole}^f)^2}\left[a_{0,\rm HO}^f + a_{1,\rm HO}^f\, z^f(q^2) + a_{2,\rm HO}^f\, [z^f(q^2)]^2\right]. \tag{8}$$

The kinematic variables z^f are defined as

$$z^f(q^2) = \frac{\sqrt{t_+^f - q^2} - \sqrt{t_+^f - t_0}}{\sqrt{t_+^f - q^2} + \sqrt{t_+^f - t_0}}, \tag{9}$$

$$t_0 = (m_{\Lambda_b} - m_{\Lambda_c})^2, \tag{10}$$

$$t_+^f = (m_{\rm pole}^f)^2. \tag{11}$$

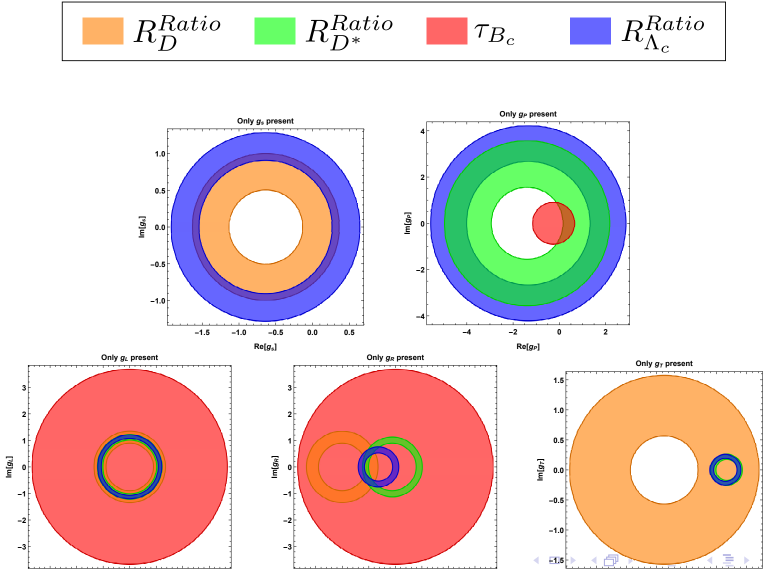
$R^{Ratio}_{\Lambda_c}$ Predictions

Given constraints from $R(D^{(*)})$, $R^{Ratio}_{\Lambda_c}$ predictions are:

Coupling	$R(\Lambda_c)_{max}$	$R^{Ratio}_{\Lambda_c,max}$	coupling value	$R(\Lambda_c)_{min}$	$R^{Ratio}_{\Lambda_c,min}$	co
g_S only	0.405	1.217	0.363	0.314	0.942	
g_P only	0.354	1.062	0.658	0.337	1.014	
g_L only	0.495	1.486	$0.094 + 0.538i$	0.340	1.022	$-0.$
g_R only	0.525	1.576	$0.085 + 0.793i$	0.336	1.009	
g_T only	0.526	1.581	0.428	0.338	1.015	

Table: The maximum and minimum values of $R(\Lambda_c)$ and $R^{Ratio}_{\Lambda_c}$ allowed by the mesonic constraints for each new-physics coupling, and the coupling values at which these extrema are reached.

$R_{\Lambda_c}^{Ratio} = 1.3 \pm 3 \times 0.05$



Specific Models: Leptoquarks

Model independent: One operator at a time. Generally not true in specific models:

In Ref.[Dumont:2016xpj], there is a list several leptoquark models that generate scalar, vector, and tensor operators. We can group the leptoquarks as vector or scalar leptoquarks. These leptoquarks can in turn be $SU(2)$ singlets, doublets, or triplets.

	spin	$SU(3)_c$	$SU(2)_L$	$U(1)_{Y=Q-T_3}$
S_1	0	3^*	1	$1/3$
$\mathbf{S}_3$	0	3^*	3	$1/3$
R_2	0	3	2	$7/6$
V_2	1	3^*	2	$5/6$
U_1	1	3	1	$2/3$
$\mathbf{U}_3$	1	3	3	$2/3$

Table: Quantum numbers of scalar and vector leptoquarks.

The Lagrangians for the various leptoquarks are

$$\mathcal{L}^{\mathrm{LQ}} = \mathcal{L}_V^{\mathrm{LQ}} + \mathcal{L}_S^{\mathrm{LQ}}\,, \tag{12}$$

$$\begin{aligned}\mathcal{L}_V^{\mathrm{LQ}} &= \left(h_{1L}^{ij}\,\bar{Q}_L^i\gamma_\mu L_L^j + h_{1R}^{ij}\,\bar{d}_R^i\gamma_\mu\ell_R^j\right)U_1^\mu + h_{3L}^{ij}\,\bar{Q}_L^i\sigma\gamma_\mu L_L^j\mathbf{U}_3^\mu \\ &+ \left(g_{2L}^{ij}\,\bar{d}_R^{c,i}\gamma_\mu L_L^j + g_{2R}^{ij}\,\bar{Q}_L^{c,i}\gamma_\mu\ell_R^j\right)V_2^\mu + \text{h.c.}\end{aligned} \tag{13}$$

$$\begin{aligned}\mathcal{L}_S^{\mathrm{LQ}} &= \left(g_{1L}^{ij}\,\bar{Q}_L^{c,j}i\sigma_2 L_L^j + g_{1R}^{ij}\,\bar{u}_R^{c,i}\ell_R^j\right)S_1 + g_{3L}^{ij}\,\bar{Q}_L^{c,i}i\sigma_2\sigma L_L^j\mathbf{S}_3 \\ &+ \left(h_{2L}^{ij}\,\bar{u}_R^i L_L^j + h_{2R}^{ij}\,\bar{Q}_L^i i\sigma_2\ell_R^j\right)R_2 + \text{h.c.},\end{aligned} \tag{14}$$

where h^{ij} and g^{ij} are dimensionless couplings, S_1, $\mathbf{S}_3$, and R_2 are the scalar leptoquark bosons, U_1^μ, $\mathbf{U}_3^\mu$, and V_2^μ are the vector leptoquark bosons, and the index i (j) indicates the generation of quarks (leptons).

The different leptoquarks produce different effective operators as summarized below:

- The S_1 leptoquark with nonzero (g_{1L}, g_{1R}^*) generates $C_{\mathcal{V}_1}^l$, $C_{\mathcal{S}_2}^l$, and $C_{\mathcal{T}}^l$, with the relation $C_{\mathcal{S}_2}^l = -4C_{\mathcal{T}}^l$.
- The R_2 leptoquark with (h_{2L}, h_{2R}^*) generates $C_{\mathcal{S}_2}^l$ and $C_{\mathcal{T}}^l$ with the relation $C_{\mathcal{S}_2}^l = 4C_{\mathcal{T}}^l$.
- The V_2 leptoquark generates $C_{\mathcal{S}_1}^l$ and is tightly constrained, so we do not consider this model.
- The U_1 leptoquark with nonzero (g_{2L}, g_{2R}^*) generates $C_{\mathcal{S}_1}^l$ and $C_{\mathcal{V}_1}^l$.
- The $\mathbf{S}_3$ and $\mathbf{U}_3$ leptoquarks with nonzero values of (g_{3L}, g_{3L}^*) and (h_{3L}, h_{3L}^*) generate $C_{\mathcal{V}_1}^l$.

Model	Case	$R(\Lambda_c)$	$R_{\Lambda_c}^{Ratio}$
S_1	1	0.343 ± 0.011	1.032 ± 0.004
S_1	2	0.549 ± 0.020	1.648 ± 0.025
R_2	1	0.445 ± 0.016	1.337 ± 0.016
R_2	2	0.485 ± 0.018	1.455 ± 0.025
U_1	1	0.605 ± 0.019	1.818 ± 0.008
U_1	2	0.553 ± 0.018	1.663 ± 0.005
$\mathbf{S}_3$	1	0.342 ± 0.010	1.027
$\mathbf{S}_3$	2	0.345 ± 0.011	1.037
$\mathbf{U}_3$	1	0.349 ± 0.011	1.047
$\mathbf{U}_3$	2	0.340 ± 0.010	1.022

Distributions:

The differential decay rate for this process can be represented as

$$\frac{d\Gamma}{dq^2 d\cos\theta_\tau} = \frac{G_F^2 |V_{cb}|^2}{2048\pi^3}\left(1-\frac{m_\tau^2}{q^2}\right)\frac{\sqrt{Q_+ Q_-}}{m_{\Lambda_b}^3}\sum_{\lambda_{\Lambda_c}}\sum_{\lambda_\tau}|\mathcal{M}^{\lambda_\tau}_{\lambda_{\Lambda_c}}|^2.$$

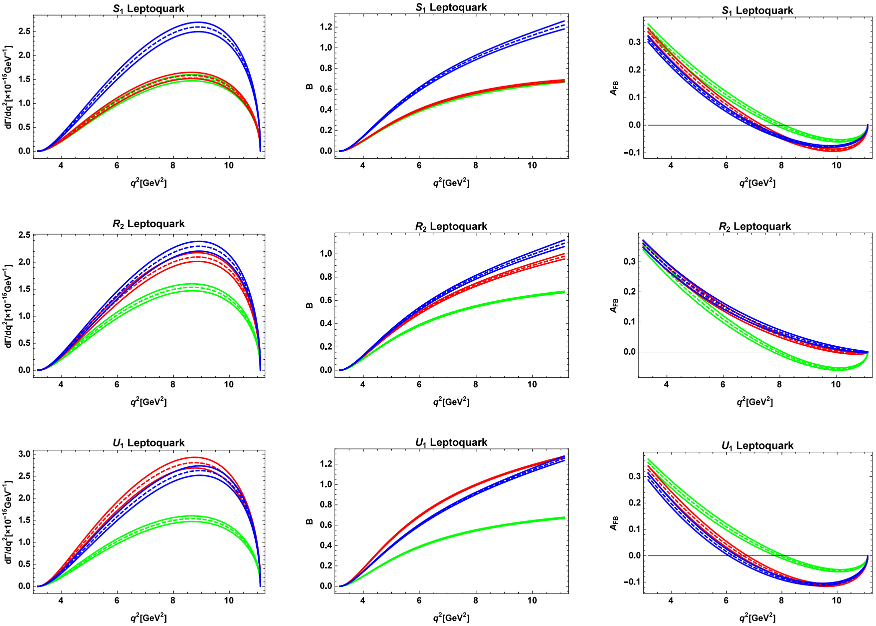
$$B_{\Lambda_c}(q^2) = \frac{\frac{d\Gamma[\Lambda_b\to\Lambda_c\tau\bar{\nu}_\tau]}{dq^2}}{\frac{d\Gamma[\Lambda_b\to\Lambda_c\ell\bar{\nu}_\ell]}{dq^2}},$$

where ℓ represents μ or e.

We also consider the forward-backward asymmetry

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

where θ_τ is the angle between the momenta of the τ lepton and Λ_c baryon in the dilepton rest frame.


S_1 Leptoquark
$d\Gamma/dq^2[\times10^{-15}GeV^{-1}]$
$q^2[GeV^2]$
S_1 Leptoquark
B
$q^2[GeV^2]$
S_1 Leptoquark
A_{FB}
$q^2[GeV^2]$
R_2 Leptoquark
$d\Gamma/dq^2[\times10^{-15}GeV^{-1}]$
$q^2[GeV^2]$
R_2 Leptoquark
B
$q^2[GeV^2]$
R_2 Leptoquark
A_{FB}
$q^2[GeV^2]$
U_1 Leptoquark
$d\Gamma/dq^2[\times10^{-15}GeV^{-1}]$
$q^2[GeV^2]$
U_1 Leptoquark
B
$q^2[GeV^2]$
U_1 Leptoquark
A_{FB}
$q^2[GeV^2]$

Conclusions and Outlook

- Evidence of new physics in $\bar{B} \to D^{*+}\tau^-\bar{\nu}_\tau$ and $\bar{B} \to D^+\tau^-\bar{\nu}_\tau$.
- Another mode to look for these effects are in $\Lambda_b \to \Lambda_c\tau\bar{\nu}_\tau$ decays as the quark level transition is the same.
- Large deviations from the SM are possible in $R_{\Lambda_b} = \frac{BR[\Lambda_b\to\Lambda_c\tau\bar{\nu}_\tau]}{BR[\Lambda_b\to\Lambda_c\ell\bar{\nu}_\ell]}$ Effects are beyond form factor uncertainties.
- Additional observables in distributions such as $B_{\Lambda_b}(q^2) = \frac{\frac{d\Gamma[\Lambda_b\to\Lambda_c\tau\bar{\nu}_\tau]}{dq^2}}{\frac{d\Gamma[\Lambda_b\to\Lambda_c\ell\bar{\nu}_\ell]}{dq^2}}$ and A_{FB} can point to the right NP models
- Experimental measurements of the rates and differential distribution for $\Lambda_b \to \Lambda_c\ell\bar{\nu}_\ell$ and $\Lambda_b \to \Lambda_c\tau\bar{\nu}_\tau$ are desirable.