Novel Observables for $b \to c\tau\bar{\nu}_\tau$ Decays

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LFV and LUV in Meson and Baryon Decays

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Outline of Talk

- Motivation is the deviation in $\bar{B} \to D^+\tau^-\bar{\nu}_\tau$ and $\bar{B} \to D^{*+}\tau^-\bar{\nu}_\tau$ decays : $R(D^{(*)})$ puzzle.
- Rates themselves has limited information on the nature of New Physics.
- In joint explanations of the NC $b \to s\ell^+\ell^-$ and CC $b \to c\tau^-\bar{\nu}$ anomalies deviations may be small in rates.
- Explore angular distributions. In particular CP violating ones which are largely free from hadronic uncertainties.
- Consider other decays $\Lambda_b \to \Lambda_c\tau\bar{\nu}_\tau$, $B \to X\tau\bar{\nu}_\tau$ since the underlying transition in both baryon and meson decays is $b \to c\tau^-\bar{\nu}_\tau$.

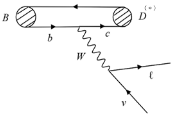
$R(D^{(*)})$ puzzle

$R(D^{(*)})$ puzzle: Violation of Lepton Universality in charged current Decays.

Anomalies

$$R(D^{(*)}) \equiv \frac{BR(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)}{BR(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell)};\ \ell = e, \mu$$

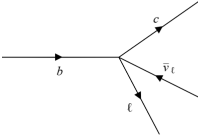
The quark-level transition is



Integrating out the boson, the effective Hamiltonian for this transition becomes:

$$\mathscr{H}_{eff} = \frac{G_F V_{cb}}{\sqrt{2}} [\bar{c}\gamma_\mu(1-\gamma_5)b][\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell]$$

Four Fermion operator



After taking into account the hadronic effects

$$\mathscr{M} = \frac{G_F V_{cb}}{\sqrt{2}} [< D^{(*)} \left| \bar{c}\gamma_\mu(1-\gamma_5)b \right| B >][\bar{\ell}\gamma^\mu(1-\gamma_5)\nu_\ell]$$

Model independent NP analysis

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

$$\mathcal{H}_{eff} = \frac{4 G_F V_{cb}}{\sqrt{2}} \Big[(1+g_L) [\bar{c}\gamma_\mu P_L b] [\bar{l}\gamma^\mu P_L \nu_l] + g_R [\bar{c}\gamma^\mu P_R b] [\bar{l}\gamma_\mu P_L \nu_l]$$
$$+ g_s [\bar{c} b] [\bar{l} P_L \nu_l] + g_p [\bar{c}\gamma_5 b] [\bar{l} P_L \nu_l] + g_T [\bar{c}\sigma^{\mu\nu} P_L b] [\bar{l}\sigma_{\mu\nu} P_L \nu_l] \Big]$$

Define $g_{V,A} = g_R \pm g_L$.

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

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

Specific NP models

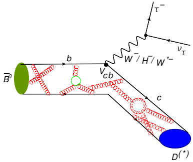
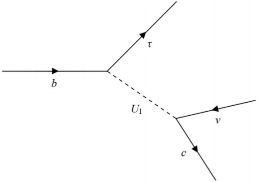


Figure: New Physics can be an extra W' or new charged Higgs ($H^{\pm}$).

Leptoquark Models

- Leptoquarks emerge in some extensions of the SM
- LQs can couple to both leptons and quarks



The leptoquarks that contribute are:

$$
\begin{aligned}
\mathcal{L}^{\mathrm{LQ}} &= \mathcal{L}^{\mathrm{LQ}}_{F=0} + \mathcal{L}^{\mathrm{LQ}}_{F=-2}\,, \\
\mathcal{L}^{\mathrm{LQ}}_{F=0} &= (h^{ij}_{1L}\bar{Q}_{iL}\gamma^\mu L_{jL} + h^{ij}_{1R}\bar{d}_{iR}\gamma^\mu \ell_{jR})U_{1\mu} + h^{ij}_{3L}\bar{Q}_{iL}\vec{\sigma}\gamma^\mu L_{jL}\cdot\vec{U}_{3\mu} \\
&\quad + (h^{ij}_{2L}\bar{u}_{iR}L_{jL} + h^{ij}_{2R}\bar{Q}_{iL}i\sigma_2\ell_{jR})R_2 + h.c., \\
\mathcal{L}^{\mathrm{LQ}}_{F=-2} &= (g^{ij}_{1L}\bar{Q}^c_{iL}i\sigma_2 L_{jL} + g^{ij}_{1R}\bar{u}^c_{iR}\ell_{jR})S_1 + (g^{ij}_{3L}\bar{Q}^c_{iL}i\sigma_2\vec{\sigma}L_{jL})\cdot\vec{S}_3 \\
&\quad + (g^{ij}_{2L}\bar{d}^c_{iR}\gamma_\mu L_{jL} + g^{ij}_{2R}\bar{Q}^c_{iL}\gamma_\mu\ell_{jR})V^\mu_2 + h.c.
\end{aligned}
$$

Specific NP model- Leptoquark

Leptoquark Couplings.

Leptoquark Models

After integrating out the LQs:

$$
\begin{aligned}
g_S(\mu_b) &= \frac{\sqrt{2}}{4G_F V_{cb}}\left(C_{\mathcal{S}_1}(\mu_b) + C_{\mathcal{S}_2}(\mu_b)\right), \\
g_P(\mu_b) &= \frac{\sqrt{2}}{4G_F V_{cb}}\left(C_{\mathcal{S}_1}(\mu_b) - C_{\mathcal{S}_2}(\mu_b)\right), \\
g_L &= \frac{\sqrt{2}}{4G_F V_{cb}} C^l_{\mathcal{V}_1}, \\
g_R &= \frac{\sqrt{2}}{4G_F V_{cb}} C^l_{\mathcal{V}_2}, \\
g_T(\mu_b) &= \frac{\sqrt{2}}{4G_F V_{cb}} C_{\mathcal{T}}(\mu_b),
\end{aligned}
$$

$$
\begin{aligned}
C_{\mathrm{SM}} &= 2\sqrt{2} G_F V_{cb}\,, \\
C^l_{\mathcal{V}_1} &= \sum_{k=1}^{3} V_{k3}\left[\frac{g^{kl}_{1L} g^{23*}_{1L}}{2M^2_{S_1}} - \frac{g^{kl}_{3L} g^{23*}_{3L}}{2M^2_{\mathbf{S}_3}} + \frac{h^{2l}_{1L} h^{k3*}_{1L}}{M^2_{U_1}} - \frac{h^{2l}_{3L} h^{k3*}_{3L}}{M^2_{\mathbf{U}_3}}\right], \\
C^l_{\mathcal{V}_2} &= 0\,, \\
C^l_{\mathcal{S}_1} &= \sum_{k=1}^{3} V_{k3}\left[-\frac{2 g^{kl}_{2L} g^{23*}_{2R}}{M^2_{V_2}} - \frac{2 h^{2l}_{1L} h^{k3*}_{1R}}{M^2_{U_1}}\right], \\
C^l_{\mathcal{S}_2} &= \sum_{k=1}^{3} V_{k3}\left[-\frac{g^{kl}_{1L} g^{23*}_{1R}}{2M^2_{S_1}} - \frac{h^{2l}_{2L} h^{k3*}_{2R}}{2M^2_{R_2}}\right], \\
C^l_{\mathcal{T}} &= \sum_{k=1}^{3} V_{k3}\left[\frac{g^{kl}_{1L} g^{23*}_{1R}}{8M^2_{S_1}} - \frac{h^{2l}_{2L} h^{k3*}_{2R}}{8M^2_{R_2}}\right].
\end{aligned}
$$

A single Leptoquark Model can contribute to several effective couplings.

Angular Distribution-Helicity Amplitudes

The Angular Distribution is written in terms of Helicity Amplitudes

Angular Distribution

1- SM: Decay is interpreted as

Defining the helicity amplitudes as: $\mathcal{M}_{(m;n)}(B \to D^* W^*) = \epsilon^{*\mu}_{D^*}(m) M_{\mu\nu} \epsilon^{*\nu}_{W^*}(n)$

- has three polarizations:
- has 4 polarization:

Of the 12 combinations of and polarizations only 4 are allowed from angular momentum conservation:

$$
\begin{aligned}
\mathcal{M}_{(+;+)}(B \to D^* W^*) &= \mathcal{A}_+ \ , \\
\mathcal{M}_{(-;-)}(B \to D^* W^*) &= \mathcal{A}_- \ , \\
\mathcal{M}_{(0;0)}(B \to D^* W^*) &= \mathcal{A}_0 \ , \\
\mathcal{M}_{(0;t)}(B \to D^* W^*) &= \mathcal{A}_t \ .
\end{aligned}
$$

SM+NP Helicity Amplitudes

With NP we have to add new Helicity Amplitudes.

Angular Distribution

In the VA case we had $\mathcal{A}_0,\ \mathcal{A}_t,\ \mathcal{A}_+,\ \mathcal{A}_-$

With NP 4 more are added $\mathcal{A}_{SP},\ \mathcal{A}_{0,T},\ \mathcal{A}_{+,T},\ \mathcal{A}_{-,T}$

With SM+NP contributions we have

$$d\Gamma \propto \left|\mathcal{M}(\bar{B}^0 \to D^{*+}(\to D^0\pi^+)\mu^-\bar{\nu}_\mu)\right|^2 = \left|\mathcal{M}^{SP} + \mathcal{M}^{VA} + \mathcal{M}^{T}\right|^2$$

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

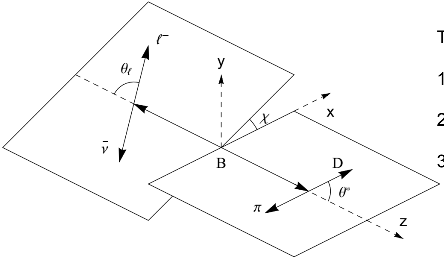
Decay Distribution described by Helicity Amplitudes

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

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

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

Angular Distribution



Types of terms that appear in

1- $|\mathcal{A}_i|^2 S_i(\mathrm{angles})$

2- $\mathrm{Re}[\mathcal{A}_i\mathcal{A}_j^*]R_{ij}(\mathrm{angles})$

3- $\mathrm{Im}[\mathcal{A}_i\mathcal{A}_j^*]I_{ij}(\mathrm{angles})$ $\longrightarrow$ sensitive to phase differences

$\mathrm{Im}[\mathcal{A}_i\mathcal{A}_j^*]$volves only weak phases. These terms are signals of CP violation

$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_\ell\, d\cos\theta^*\, d\chi} \propto \left(N_1 + \frac{m_\ell}{\sqrt{q^2}}N_2 + \frac{m_\ell^2}{q^2}N_3\right)$$

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Triple Product Correlations in B decays - G. Valencia, Datta and London

- In the B rest frame we can construct T.P

$$T.P = \vec{v_1}.(\vec{v_2} \times \vec{v_3}).$$

- We can define a T-odd asymmetry

$$A_T = \frac{\Gamma[T.P > 0] - \Gamma[T.P < 0]}{\Gamma[T.P > 0] + \Gamma[T.P < 0]}.$$

- For true CP violation, we need to compare A_T and $\bar{A}_T$

$$A^{true}_{T.P} = A_T + \bar{A}_T \propto \sin\Delta\phi \cos\Delta\delta,$$
$$A^{fake}_{T.P} = A_T - \bar{A}_T \propto \cos\Delta\phi \sin\Delta\delta.$$

- If the strong phase is small:

$$A^{true}_{T.P} \sim 2A_T \propto \sin\Delta\phi,$$

$$A^{fake}_{T.P} = A_T - \bar{A}_T \propto \cos\Delta\phi \sin\Delta\delta \sim 0.$$

TP in $\bar{B} \to D^{*+}\tau^-\bar{\nu}_\tau$- Datta and Duraisamy 2013

The TP in $\bar{B} \to D^{*+}\tau^-\bar{\nu}_\tau$ is proportional to $(\hat{n}_D \times \hat{n}_l) \cdot \hat{n}_z$ in its rest frame, where the unit vectors are given in terms of the momenta of the final-state particles as

$$\hat{n}_D = \frac{\hat{p}_D \times \hat{p}_\pi}{|\hat{p}_D \times \hat{p}_\pi|}, \quad \hat{n}_z = \frac{\hat{p}_D + \hat{p}_\pi}{|\hat{p}_D + \hat{p}_\pi|} = \{0,0,1\}, \quad \hat{n}_l = \frac{\hat{p}_{l^-} \times \hat{p}_{\bar{\nu}_\tau}}{|\hat{p}_{l^-} \times \hat{p}_{\bar{\nu}_\tau}|} .$$

The vectors $\hat{n}_D$ and $\hat{n}_l$ are perpendicular to the decay planes of the D^* and the virtual vector boson. In terms of the azimuthal angle χ, one gets

$$\cos\chi = \hat{n}_D \cdot \hat{n}_l , \quad \sin\chi = (\hat{n}_D \times \hat{n}_l) \cdot \hat{n}_z ,$$

and hence the quantities that are coefficients of $\sin\chi$ (or of $\sin 2\chi = 2\sin\chi\cos\chi$) are the TPs.

Direct CPV may be possible with charm resonances - 1806.04146

TP in $\bar{B} \to D^{*+}\tau^-\bar{\nu}_\tau$-

- In the SM $\bar{B} \to D^{*+}\tau^-\bar{\nu}_\tau$ proceeds through the W exchange diagram and so there is one amplitude with the weak phase comes V_{cb} and there is no weak phase difference and so T.P.A=0.

- Any non zero measurement of TPA is a smoking gun signal of NP independent of any hadronic inout.

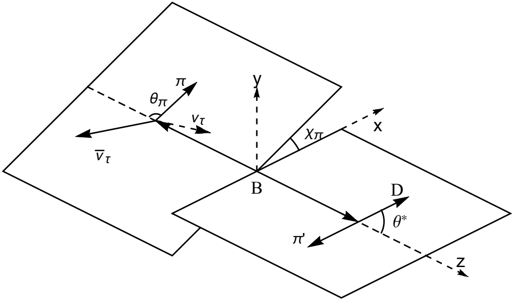
- One can measure the T.P.A from the azimuthal angular distributions:

$$\frac{d^2\Gamma}{dq^2 d\chi} = \frac{1}{2\pi}\frac{d\Gamma}{dq^2}\left[1 + \left(A_C^{(1)}\cos 2\chi + A_T^{(1)}\sin 2\chi\right)\right].$$

- Main issue is that the direction of the τ lepton is not known precisely because of two neutrinos in the final state - ok for $B \to D^*\mu\nu_\mu$: See 1903.02567.

Making the τ Decay: 2005.03032, JHEP

We consider the decay $\tau \to \pi \nu_\tau$



$$\cos\theta_\pi = -\frac{\vec{p}_{D^*} \cdot \vec{p}_\pi}{|\vec{p}_{D^*}||\vec{p}_\pi|} ,$$

while χ_π is defined using three-momenta evaluated in the B rest frame,

$$\sin\chi_\pi = \frac{[(\vec{p}_{\pi'} \times \vec{p}_D) \times (\vec{p}_{D^*} \times \vec{p}_\pi)] \cdot \vec{p}_{D^*}}{|\vec{p}_{\pi'} \times \vec{p}_D||\vec{p}_{D^*} \times \vec{p}_\pi||\vec{p}_{D^*}|} .$$

Angular Distribution

$$
\begin{aligned}
d^5\Gamma &\propto \sum_{i,j} \left(\mathcal{N}_i^S \, |\mathcal{A}_i|^2 + \mathcal{N}_{i,j}^R \, \mathrm{Re}[\mathcal{A}_i \mathcal{A}_j^*] + \mathcal{N}_{i,j}^I \, \mathrm{Im}[\mathcal{A}_i \mathcal{A}_j^*] \right) d\Omega \\
d\Omega &= dq^2 \, dE_\pi \, d\cos\theta^* \, d\cos\theta_\pi \, d\chi_\pi
\end{aligned}
$$

$$
d^5\Gamma \propto \left[\sum_{i=1}^{9} f_i^R(q^2, E_\pi) \Omega_i^R(\theta^*, \theta_\pi, \chi_\pi) + \sum_{i=1}^{3} f_i^I(q^2, E_\pi) \Omega_i^I(\theta^*, \theta_\pi, \chi_\pi) \right] d\Omega
$$

$$
E_\tau \to \frac{q^2 + m_\tau^2}{2\sqrt{q^2}} \quad , \quad |\vec{p}_\tau| \to \frac{q^2 - m_\tau^2}{2\sqrt{q^2}} \quad , \quad \cos\theta_{\tau\pi} \to \frac{2E_\tau E_\pi - m_\tau^2 - m_\pi^2}{2|\vec{p}_\tau||\vec{p}_\pi|} \, .
$$

TPA

Coefficient $f_i^I(q^2, E_\pi)$	Angular Function $\Omega_i^I(\theta^*, \theta_\pi, \chi_\pi)$
$\mathcal{I}m[\mathcal{A}_t\mathcal{A}_\perp^*], \mathcal{I}m[\mathcal{A}_{\parallel,T}\mathcal{A}_0^*], \mathcal{I}m[\mathcal{A}_{SP}\mathcal{A}_\perp^*]$ $\mathcal{I}m[\mathcal{A}_{SP}\mathcal{A}_{\perp,T}^*], \mathcal{I}m[\mathcal{A}_{0,T}\mathcal{A}_\parallel^*], \mathcal{I}m[\mathcal{A}_{\perp,T}\mathcal{A}_t^*]$	$\propto \sin\chi_\pi$
$\mathcal{I}m[\mathcal{A}_0\mathcal{A}_\perp^*], \mathcal{I}m[\mathcal{A}_{0,T}\mathcal{A}_\perp^*], \mathcal{I}m[\mathcal{A}_{\perp,T}\mathcal{A}_0^*]$	$\propto \sin\chi_\pi$
$\mathcal{I}m[\mathcal{A}_\parallel\mathcal{A}_\perp^*], \mathcal{I}m[\mathcal{A}_{\perp,T}\mathcal{A}_\parallel^*], \mathcal{I}m[\mathcal{A}_{\parallel,T}\mathcal{A}_\perp^*]$	$\propto \sin 2\chi_\pi$

Helicity Amplitude	Coupling
$\mathcal{A}_0,\ \mathcal{A}_\parallel,\ \mathcal{A}_t$	$1 + g_L - g_R$
$\mathcal{A}_\perp$	$1 + g_L + g_R$
$\mathcal{A}_{SP}$	g_P
$\mathcal{A}_{0,T},\ \mathcal{A}_{\parallel,T},\ \mathcal{A}_{\perp,T}$	g_T

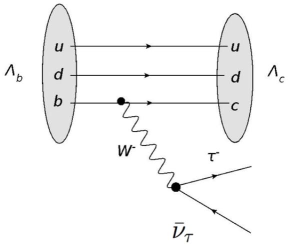
TPA are kinematical effects which means it is nonzero when there is interference between different Lorentz structures.

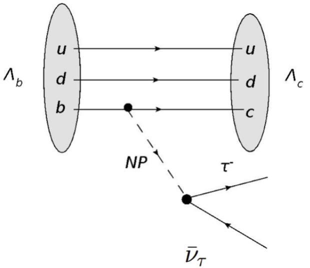
Analyzing NP

- Angular distributions with different τ models have to be worked out. Eg. $\tau \to \rho\nu_\tau, \tau \to 3\pi\nu_\tau$. See 1403.5892]
- There may be new correlations among the helicity amplitudes. See
- Explore how TPA can probe New physics. As an example the U_1 LQ produces only g_L and hence the measurement of non-zero TPA will rule out the single U_1 LQ solution.

Other Decays

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





Observables

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

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

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

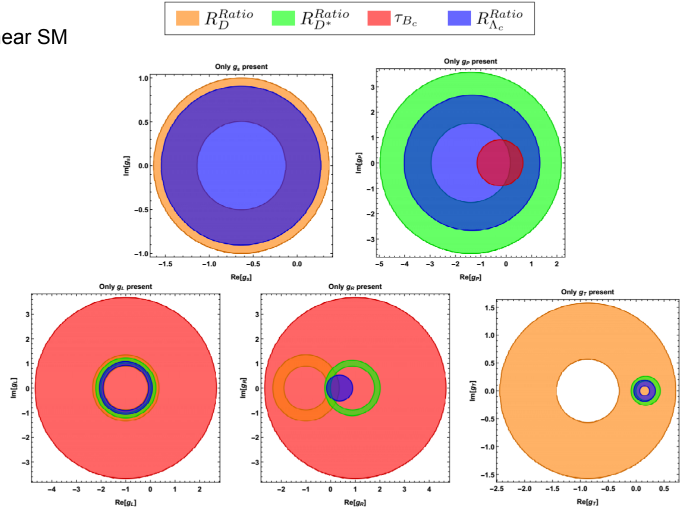
- These ratios can be calculated in SM and NP using $\Lambda_b \to \Lambda_c$ form factors are calculated from lattice QCD (Detmold:2015aaa, Datta:2017aue).

$R_{\Lambda_c}^{Ratio} = 1.0 \pm 3 \times 0.05$

Consider two cases: 1- near SM

$R_{\Lambda_c}^{Ratio} = 1 \pm 3 \times 0.05$

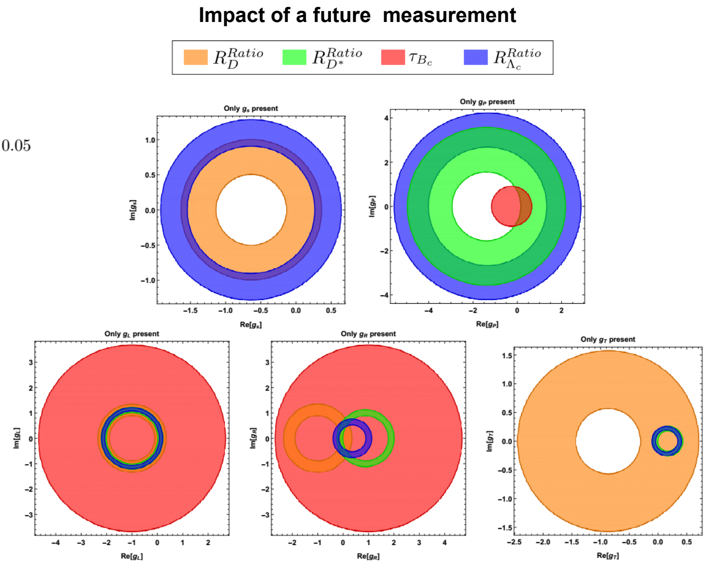
Impact of a future measurement



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

2- far from SM

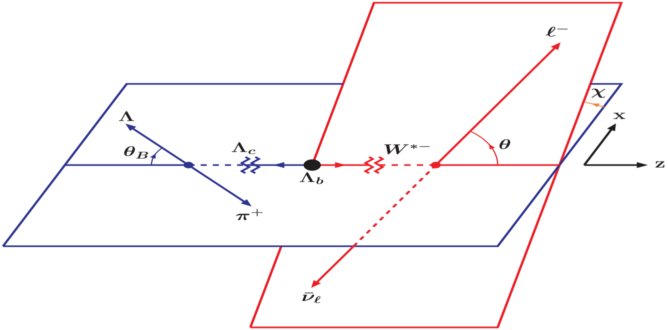
$$R_{\Lambda_c}^{Ratio} = 1.3 \pm 3 \times 0.05$$



Angular Distribution

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)

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



Helicity Amplitudes

SM+NP Helicity Amplitudes.

With New Physics

$$\eta_\lambda = (+1, -1, -1, -1)$$

With the same method we can calculate New-Physics contributions to the decay amplitude.

Considering the spin states of the and , we can write the whole amplitude as:

$$\mathcal{M}^{\lambda_\tau}_{\lambda_{\Lambda_c}} = H^{SP}_{\lambda_{\Lambda_c}} L^{\lambda_\tau} + \sum_\lambda \eta_\lambda H^{VA}_{\lambda_{\Lambda_c},\lambda} L^{\lambda_\tau}_\lambda + \sum_{\lambda,\lambda'} \eta_\lambda \eta_{\lambda'} H^{(T)\lambda_{\Lambda_b}}_{\lambda_{\Lambda_c},\lambda,\lambda'} L^{\lambda_\tau}_{\lambda,\lambda'}$$

Scalar

$$\begin{aligned} H^{SP}_{\lambda_{\Lambda_c},\lambda=0} &= H^{S}_{\lambda_{\Lambda_c},\lambda=0} + H^{P}_{\lambda_{\Lambda_c},\lambda=0}, \\ H^{S}_{\lambda_{\Lambda_c},\lambda=0} &= g_S \langle \Lambda_c | \bar{c} b | \Lambda_b \rangle, \\ H^{P}_{\lambda_{\Lambda_c},\lambda=0} &= g_P \langle \Lambda_c | \bar{c} \gamma_5 b | \Lambda_b \rangle, \end{aligned}$$

$$L^{\lambda_\tau} = \langle \tau \bar{\nu}_\tau | \bar{\tau}(1-\gamma_5)\nu_\tau | 0 \rangle$$

Vector

$$\begin{aligned} H^{VA}_{\lambda_{\Lambda_c},\lambda} &= H^{V}_{\lambda_{\Lambda_c},\lambda} - H^{A}_{\lambda_{\Lambda_c},\lambda}, \\ H^{V}_{\lambda_{\Lambda_c},\lambda} &= (1+g_L+g_R)\,\epsilon^{*\mu}(\lambda) \langle \Lambda_c | \bar{c}\gamma_\mu b | \Lambda_b \rangle, \\ H^{A}_{\lambda_{\Lambda_c},\lambda} &= (1+g_L-g_R)\,\epsilon^{*\mu}(\lambda) \langle \Lambda_c | \bar{c}\gamma_\mu\gamma_5 b | \Lambda_b \rangle, \end{aligned}$$

$$L^{\lambda_\tau}_\lambda = \epsilon^\mu(\lambda) \langle \tau \bar{\nu}_\tau | \bar{\tau}\gamma_\mu(1-\gamma_5)\nu_\tau | 0 \rangle$$

Tensor

$$\begin{aligned} H^{(T)\lambda_{\Lambda_b}}_{\lambda_{\Lambda_c},\lambda,\lambda'} &= H^{(T1)\lambda_{\Lambda_b}}_{\lambda_{\Lambda_c},\lambda,\lambda'} - H^{(T2)\lambda_{\Lambda_b}}_{\lambda_{\Lambda_c},\lambda,\lambda'}, \\ H^{(T1)\lambda_{\Lambda_b}}_{\lambda_{\Lambda_c},\lambda,\lambda'} &= g_T\, \epsilon^{*\mu}(\lambda)\epsilon^{*\nu}(\lambda') \langle \Lambda_c | \bar{c} i\sigma_{\mu\nu} b | \Lambda_b \rangle, \\ H^{(T2)\lambda_{\Lambda_b}}_{\lambda_{\Lambda_c},\lambda,\lambda'} &= g_T\, \epsilon^{*\mu}(\lambda)\epsilon^{*\nu}(\lambda') \langle \Lambda_c | \bar{c} i\sigma_{\mu\nu}\gamma_5 b | \Lambda_b \rangle. \end{aligned}$$

$$L^{\lambda_\tau}_{\lambda,\lambda'} = -i\epsilon^\mu(\lambda)\epsilon^\nu(\lambda') \langle \tau \bar{\nu}_\tau | \bar{\tau}\sigma_{\mu\nu}(1-\gamma_5)\nu_\tau | 0 \rangle$$

Distributions: Analyzer of New Physics

The differential decay rate for this process can be represented as

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

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

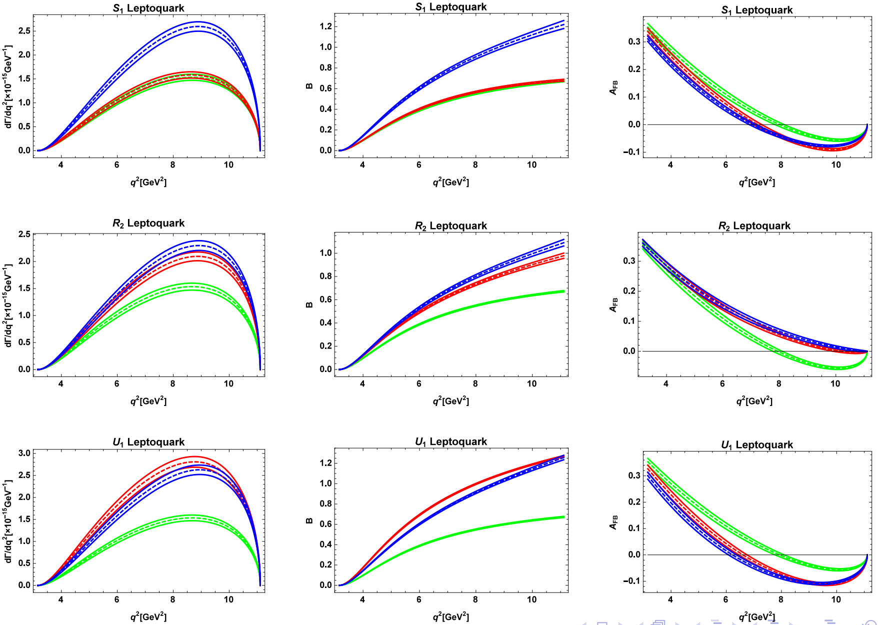
where ℓ represents μ or e. We also consider the forward-backward asymmetry

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

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

With the Full distribution we can also study T.P.A.

Probing Leptoquark Models: Datta:2017aue



Conclusions

- If the $R(D^{(*)})$ measurements are real deviations from the SM then new probes of NP are necessary.
- This NP parameters may be complex and so we should expect CP violation in Triple product Asymmetries.
- Measurement with other decays with the same underlying quark transitionn like $\Lambda_b \to \Lambda_c \tau \bar{\nu}_\tau$ can also be useful to establish NP. and find its nature.