

New Physics effects in $\Lambda_b \rightarrow \Lambda_c^{(*)}$ semileptonic decays.

Neus Penalva^a,
E. Hernández^b and J. Nieves^a

^aInstitut de Física Corpuscular (CSIC-UV)

^bUniversidad de Salamanca

October 25th, 2022

Talk partially based on:

JHEP 04 (2022) 026 and Phys. Rev. D 106 (2022) 5, 055039

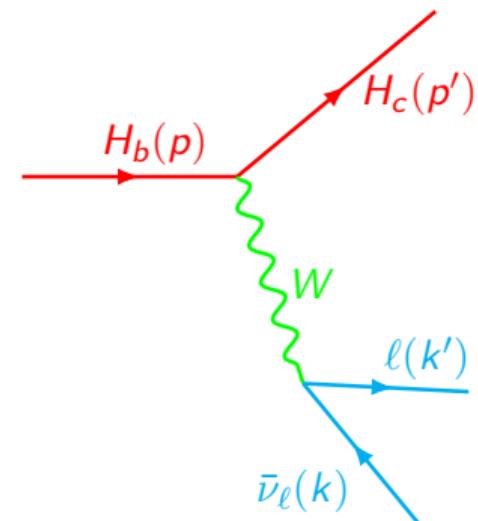


Motivation: LFUV in $b \rightarrow c$ decays?

\mathcal{R}_{Λ_c} latest result from LHCb* + other observables measured**:

$$\mathcal{R}_{H_c} = \frac{\Gamma(H_b \rightarrow H_c \tau \bar{\nu}_\tau)}{\Gamma(H_b \rightarrow H_c \ell \bar{\nu}_\ell)}, P_\tau(D^*), F_L^{D^*}.$$

⇒ NP affecting 3th quark and lepton generations.



* LHCb collab. Phys.Rev.Lett. 128, 191803

** Results from BaBar, Belle and LHCb combined in:

HFLAV group. Eur.Phys.J.C 81(2021) 3, 226

$b \rightarrow c$ decays

NP effects introduced using a effective Hamiltonian:

$$H_{\text{eff}} = \frac{4G_F V_{cb}}{\sqrt{2}} \left[\underbrace{(1 + C_{LL}^V) \mathcal{O}_{LL}^V + C_{RL}^V \mathcal{O}_{RL}^V}_{\text{(axial-)vector}} + \underbrace{C_{LL}^S \mathcal{O}_{LL}^S + C_{RL}^S \mathcal{O}_{RL}^S}_{\text{(pseudo-)scalar}} + \underbrace{C_{LL}^T \mathcal{O}_{LL}^T}_{\text{tensor}} \right. \\ \left. + \underbrace{C_{LR}^V \mathcal{O}_{LR}^V + C_{RR}^V \mathcal{O}_{RR}^V + C_{LR}^S \mathcal{O}_{LR}^S + C_{RR}^S \mathcal{O}_{RR}^S + C_{RR}^T \mathcal{O}_{RR}^T}_{\text{right-handed neutrinos}} \right] + h.c.,$$

Wilson coeff. are fitted to experimental data. \rightarrow Different models give same results for \mathcal{R}_{H_c} .

We will use:

- Fit 6 and 7 from [Murgui et al. JHEP 09 \(2019\) 103](#)
- S7a from [Mandal et al. JHEP 08 \(2020\) 08, 022](#)

We will present results for:

- $\Lambda_b \rightarrow \Lambda_c$ in all ω range
- $\Lambda_b \rightarrow \Lambda_c^*$ only for $\omega = [1, 1.1]$

Available information

All the physics is encoded in 10 independent functions of ω and the Wilson coefficients.

	observables
unpolarized τ^-	n_0, A_{FB}, A_Q
polarized τ^-	$\langle P_L^{\text{CM}} \rangle, \langle P_T^{\text{CM}} \rangle, Z_L, Z_Q, Z_\perp$
complex WC's	$\langle P_{TT} \rangle, Z_T$

n_0 : contains all the dynamical effects $\left(\frac{d\Gamma_{\text{SL}}}{d\omega} \propto n_0 \right)$ $\langle P_{L,T,TT}^{\text{CM}} \rangle$: τ spin asymmetries

$A_{\text{FB},Q}$: τ angular asymmetries

$Z_{L,T,\perp}$: τ angular-spin asymmetries

Approach

* LHCb collab. Phys.Rev.Lett. 128, 191803

PROBLEM: The τ^- particle decays very fast and has to be reconstructed.

- τ^- decay modes: $\left\{ \begin{array}{l} \triangleright \mu^- \bar{\nu}_\mu \nu_\tau \\ \triangleright \pi^- \nu_\tau \\ \triangleright \rho^- \nu_\tau \\ \triangleright \pi^- \pi^+ \pi^- (\pi^0) \nu_\tau \rightarrow \text{used for the LHCb result*} \\ \triangleright \dots \end{array} \right.$

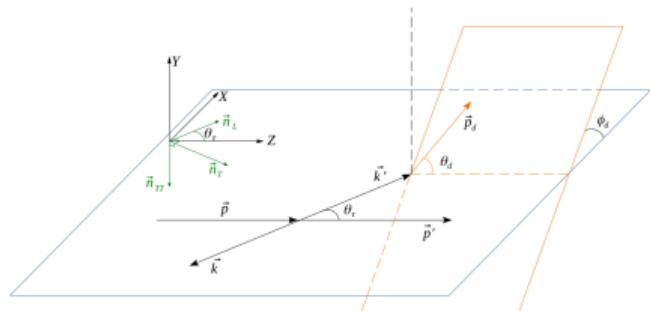


Figure: Kinematics in the $\tau \bar{\nu}_\tau$ CM reference system.

In the decay, neutrinos are always involved.
Solution: Using variables that are related to the visible decay products instead of the τ^- energy or direction.

Starting point

Asadi et al. Phys.Rev.D 102 (2020) 9, 095028

N.P. et al. JHEP 10 (2021) 122

The $H_b \rightarrow H_c \tau (\rightarrow d\nu_\tau) \bar{\nu}_\tau$ differential decay rate:

$$\frac{d^3\Gamma_d}{d\omega d\xi_d d \cos \theta_d} = \mathcal{B}_d \frac{d\Gamma_{\text{SL}}}{d\omega} \left\{ F_0^d(\omega, \xi_d) + F_1^d(\omega, \xi_d) \cos \theta_d + F_2^d(\omega, \xi_d) P_2(\cos \theta_d) \right\},$$

where

$$\begin{aligned} F_0(\omega, \xi_d) &= C_n(\omega, \xi_d) + C_{P_L}(\omega, \xi_d) \langle P_L^{\text{CM}} \rangle \\ F_1(\omega, \xi_d) &= C_{A_{FB}}(\omega, \xi_d) A_{FB} + C_{Z_L}(\omega, \xi_d) Z_L + C_{P_T}(\omega, \xi_d) \langle P_T^{\text{CM}} \rangle \\ F_2(\omega, \xi_d) &= C_{A_Q}(\omega, \xi_d) A_Q + C_{Z_Q}(\omega, \xi_d) Z_Q + C_{Z_\perp}(\omega, \xi_d) Z_\perp. \end{aligned}$$

The C_i functions are kinematical factors that depend on the tau decay mode (π , ρ or $\mu\bar{\nu}_\mu$).

The CP-violating contributions disappear after integrating over the azimuthal angle (ϕ_d).

ω distribution

We can follow different paths:

The diagram illustrates four different mathematical paths to express the differential decay rate $d\Gamma_d/d\omega$:

- Path 1 (Orange):** $\frac{d^3\Gamma_d}{d\omega d\xi_d d \cos \theta_d} \rightarrow \frac{d^2\Gamma_d}{d\omega d \cos \theta_d} \rightarrow \frac{d\Gamma_d}{d \cos \theta_d}$
- Path 2 (Blue):** $\frac{d^3\Gamma_d}{d\omega d\xi_d d \cos \theta_d} \rightarrow \frac{d^2\Gamma_d}{d\omega d \xi_d} \rightarrow \frac{d\Gamma_d}{dE_d}$
- Path 3 (Black):** $\frac{d^3\Gamma_d}{d\omega d\xi_d d \cos \theta_d} \rightarrow \frac{d^2\Gamma_d}{d\omega d \cos \theta_d} \rightarrow \frac{d\Gamma_d}{d\omega} = \mathcal{B}_d \frac{d\Gamma_{SL}}{d\omega}$

- * We make the change of variables $\xi_d = E_d/(\gamma m_\tau)$.

N.P. et al. JHEP 04 (2022) 026

The $d^2\Gamma/(d\omega d \cos \theta_d)$ distribution

$$\frac{d^3\Gamma_d}{d\omega d\xi_d d \cos \theta_d} \xrightarrow{\quad} \frac{d^2\Gamma_d}{d\omega d \cos \theta_d}$$

We get,

$$\frac{d^2\Gamma_d}{d\omega d \cos \theta_d} = \mathcal{B}_d \frac{d\Gamma_{\text{SL}}}{d\omega} \left[\tilde{F}_0^d(\omega) + \tilde{F}_1^d(\omega) \cos \theta_d + \tilde{F}_2^d(\omega) P_2(\cos \theta_d) \right],$$

For all τ decay modes:

We loose information on $\langle P_L^{\text{CM}} \rangle$

$$\tilde{F}_0(\omega) = \underbrace{\int_{\xi_1}^{\xi_2} C_n(\omega, \xi_d) d\xi_d}_{1/2} + \cancel{\langle P_L^{\text{CM}} \rangle(\omega)} \underbrace{\int_{\xi_1}^{\xi_2} C_{P_L}(\omega, \xi_d) d\xi_d}_{0}$$

The $d^2\Gamma/(d\omega d \cos \theta_d)$ distribution (II)

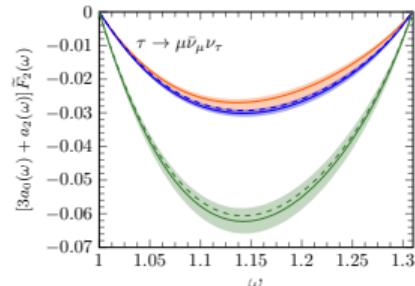
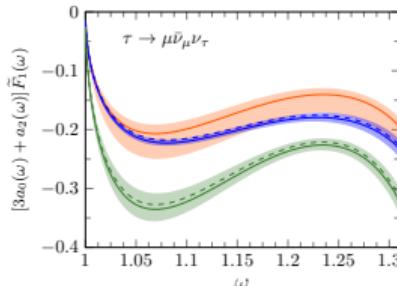
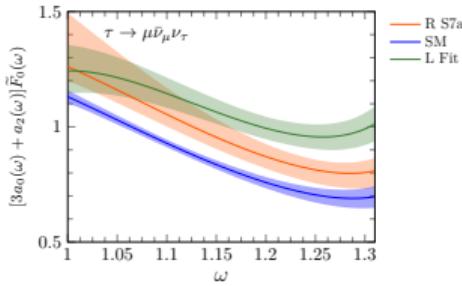
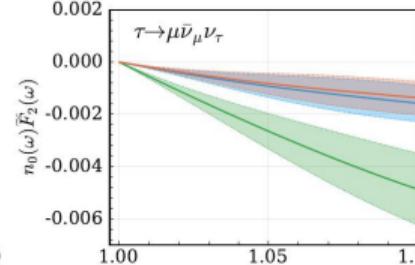
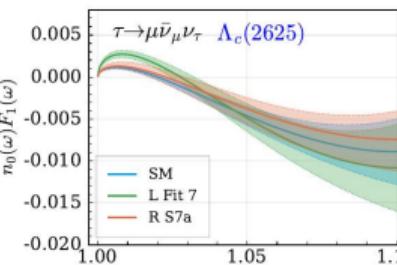
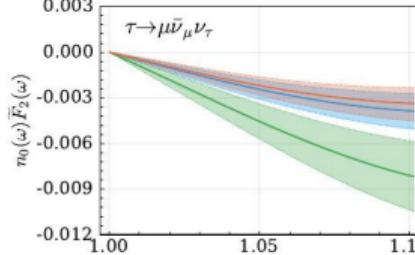
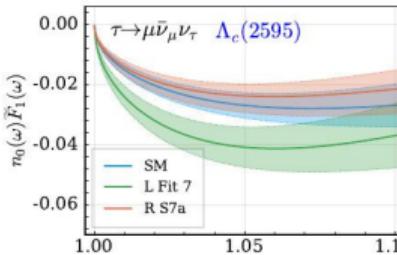


Figure: $n_0 \tilde{F}_{0,1,2}^{\mu\bar{\nu}_\mu}(\omega)$ for $\Lambda_b \rightarrow \Lambda_c^{(*)}$ decays in SM and different NP fits.



The limit $y = \frac{m_d}{m_\tau} = 0$ works fine for $\tau \rightarrow \mu\bar{\nu}_\mu\nu_\tau$.

$\Lambda_b \rightarrow \Lambda_c^{*}$ results in
Du et al. Phys.Rev.D 106 (2022) 5, 055039

The $d^2\Gamma/(d\omega d \cos \theta_d)$ distribution (III)

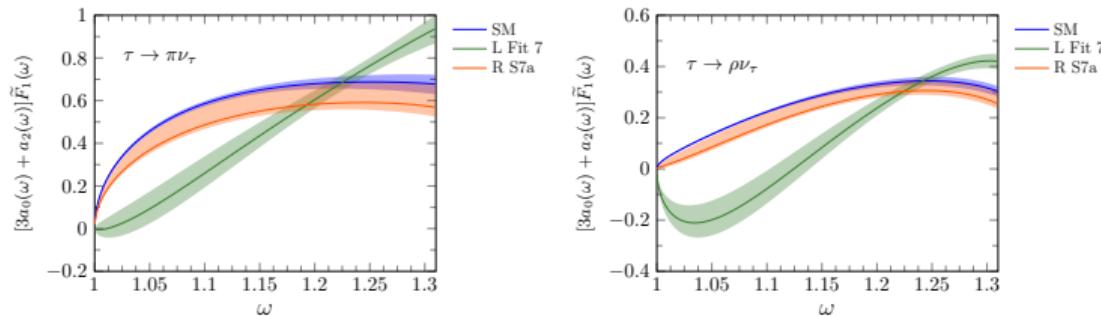


Figure: $n_0 \tilde{F}_1^{\pi(\rho)}(\omega)$ for $\Lambda_b \rightarrow \Lambda_c$ decays .

Moreover, for $\tau \rightarrow \pi \nu_\tau$, where the limit is also good:

$$C_{A_{FB}, A_Q}^\pi(\omega) = C_{A_{FB}, A_Q}^{\mu \bar{\nu}_\mu}(\omega) + \mathcal{O}(y^2),$$

$$C_{P_T, Z_L, Z_Q, Z_\perp}^\pi(\omega) = -3 C_{P_T, Z_L, Z_Q, Z_\perp}^{\mu \bar{\nu}_\mu}(\omega) + \mathcal{O}(y^2)$$

More discriminating power for
 $\tau \rightarrow \pi \nu_\tau$

Analytical expressions for $C_i(\omega)$ in
N.P. et al. JHEP 04 (2022) 026

The $d\Gamma/(d \cos \theta_d)$ distribution

$$\frac{d^3\Gamma_d}{d\omega d\xi_d d \cos \theta_d} \xrightarrow{} \frac{d^2\Gamma_d}{d\omega d \cos \theta_d} \xrightarrow{} \frac{d\Gamma_d}{d \cos \theta_d}$$

And we get,

$$\frac{d\Gamma_d}{d \cos \theta_d} = \mathcal{B}_d \Gamma_{\text{SL}} \left[\frac{1}{2} + \hat{F}_1^d \cos \theta_d + \hat{F}_2^d P_2(\cos \theta_d) \right].$$

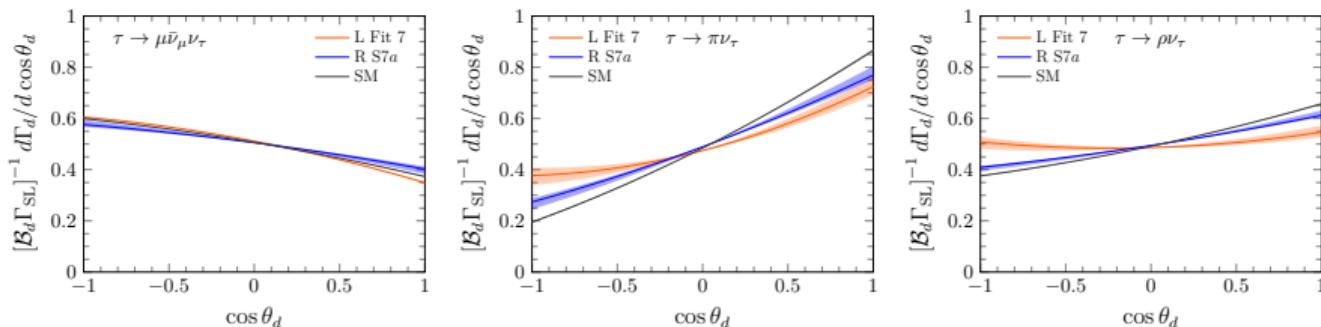


Figure: Angular $d\Gamma/d \cos \theta_d$ distribution for the $\Lambda_b \rightarrow \Lambda_c$ decays. Same NP scenarios as before.

The $d\Gamma/(d\omega d\xi_d)$ distribution

$$\boxed{\frac{d^3\Gamma_d}{d\omega d\xi_d d \cos \theta_d} \xrightarrow{\text{blue arrow}} \frac{d^2\Gamma_d}{d\omega d\xi_d}}$$

The $F_1(\omega, \xi_d)$ and $F_2(\omega, \xi_d)$ contributions disappear.

The distribution looks like:

$$\frac{d^2\Gamma_d}{d\omega d\xi_d} = 2\mathcal{B}_d \frac{d\Gamma_{\text{SL}}}{d\omega} \left(C_n^d(\omega, \xi_d) + C_{P_L}^d(\omega, \xi_d) \langle P_L^{\text{CM}} \rangle(\omega) \right)$$

As C_n^d and $C_{P_L}^d$ are known, $\langle P_L^{\text{CM}} \rangle(\omega)$ can be extracted.

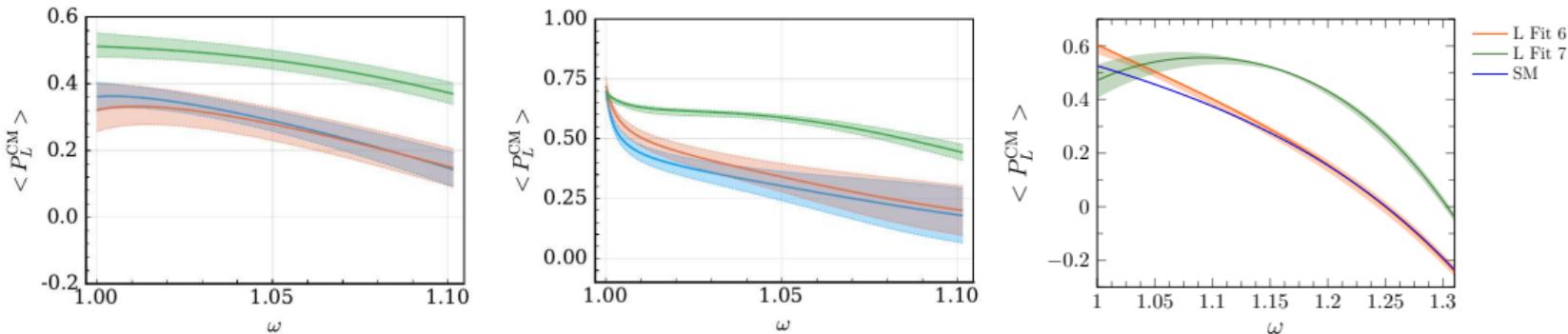


Figure: $\langle P_L^{\text{CM}} \rangle$ for the $\Lambda_b \rightarrow \Lambda_c^*(2595)$, $\Lambda_b \rightarrow \Lambda_c^*(2625)$ and $\Lambda_b \rightarrow \Lambda_c$ decays.

Using that result:

$$\mathcal{P}_\tau = \frac{-1}{\Gamma_{\text{SL}}} \int d\omega \frac{d\Gamma_{\text{SL}}}{d\omega} \langle P_L^{\text{CM}} \rangle(\omega)$$



Already measured in $B \rightarrow D^*$ decays. [S. Hirose et al. \(Belle\)](#)

[Phys. Rev. Lett. 118, 211801 \(2017\)](#)

The $d\Gamma/(dE_d)$ distribution

$$\boxed{\frac{d^3\Gamma_d}{d\omega d\xi_d d \cos \theta_d} \xrightarrow{\quad} \frac{d^2\Gamma_d}{d\omega d\xi_d} \xrightarrow{\quad} \frac{d\Gamma_d}{dE_d}}$$

$$\hat{F}_0^d(E_d) = \frac{1}{\Gamma_{\text{SL}}} \int_1^{\omega_{\text{sup}}(E_d)} \frac{1}{\gamma} \frac{d\Gamma_{\text{SL}}}{d\omega} \left\{ C_n^d(\omega, E_d) + C_{P_L}^d(\omega, E_d) \langle P_L^{\text{CM}} \rangle(\omega) \right\} d\omega,$$

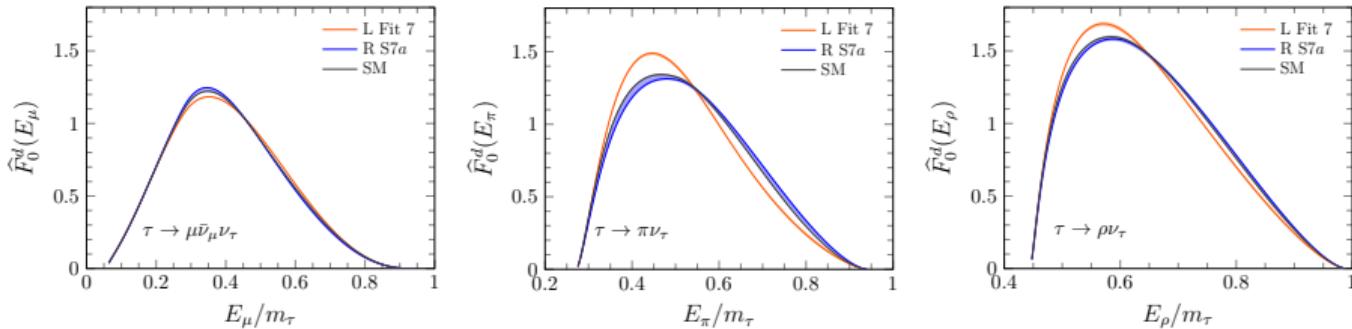


Figure: $\hat{F}_0^d(E_d)$ for the $\Lambda_b \rightarrow \Lambda_c$ decays.

Conclusions

- Using visible final-state kinematics helps to avoid using τ variables that are difficult to reconstruct.

$$\frac{d^3\Gamma}{d\omega d\xi_d d \cos\theta_d} \rightarrow n_0, A_{FB,Q}, Z_{L,Q,\perp}, \langle P_L^{\text{CM}} \rangle, \langle P_T^{\text{CM}} \rangle$$

- One can increase statistics by integrating in some of the variables.

$$\frac{d^2\Gamma}{d\omega d\xi_d} \rightarrow \langle P_L^{\text{CM}} \rangle, \quad \frac{d^2\Gamma}{d\omega d \cos\theta_d} \rightarrow \text{all other angular - spin asymmetries}$$

- $\frac{d\Gamma}{d \cos\theta_d}$, $\frac{d\Gamma}{d E_d}$ and $\frac{d\Gamma}{d\omega}$ are also useful.
- In general, the hadronic τ -decay modes have more discriminating power.