Joint LHCb-Belle II global Wilson Coefficient fit to $b \to c\tau^- \overline{\nu}_\tau$ decays.

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Introduction to the R(D)/R(D*) discrepancy

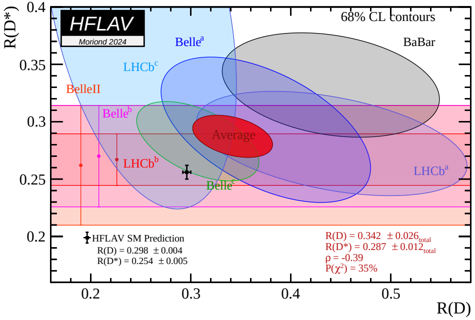
Semileptonic decays can be used to study the **Lepton Flavor Universality (LFU)**.

Motivation

- 3.31σ tension in $R(D)$ and $R(D^*)$ measurement with **Standard Model (SM)** predictions:

$$R(D^*) = \frac{BR(B^0 \to D^* \tau \nu)}{BR(B^0 \to D^* \mu \nu)}$$

- **New Physics (NP)** could effect these ratios:
  - it is possible to **measure dircetly the NP** effects using **Effective Field Theory (EFT)**.

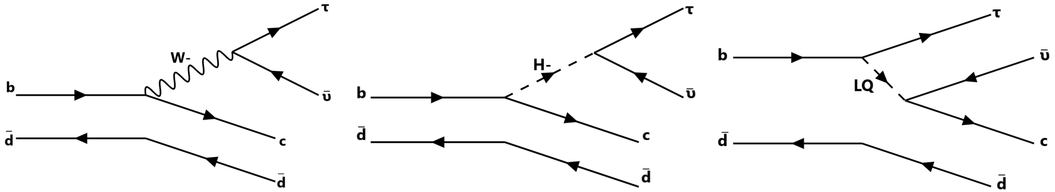


Effective field theory (EFT)

- evaluate model independent NP effects;
- embed NP and SM contributions in the **effective operators** O_i

$$H_{eff} = \frac{G_F}{\sqrt{2}} V_{cb} \sum_i C_i O_i$$

- **Wilson coefficients** describes the magintude of the vertex $C_i = C_i^{SM} + C_i^{NP}$



Hammer: a tool to reweight our templates.

The **Hammer interface** [2002.00020] is used to weight template histograms.

Current	Label	Wilson Coefficient, c_{XY}	Operator
SM	SM	1	$[\bar{c}\gamma^{\mu}P_L b]\,[\bar{\ell}\gamma_{\mu}P_L\nu]$
Vector	V_qLlL	V_{qLlL}	$[\bar{c}\gamma^{\mu}P_L b]\,[\bar{\ell}\gamma_{\mu}P_L\nu]$
	V_qRlL	V_{qRlL}	$[\bar{c}\gamma^{\mu}P_R b]\,[\bar{\ell}\gamma_{\mu}P_L\nu]$
	V_qLlR	V_{qLlR}	$[\bar{c}\gamma^{\mu}P_L b]\,[\bar{\ell}\gamma_{\mu}P_R\nu]$
	V_qRlR	V_{qRlR}	$[\bar{c}\gamma^{\mu}P_R b]\,[\bar{\ell}\gamma_{\mu}P_R\nu]$
Scalar	S_qLlL	S_{qLlL}	$[\bar{c}P_L b]\,[\bar{\ell}P_L\nu]$
	S_qRlL	S_{qRlL}	$[\bar{c}P_R b]\,[\bar{\ell}P_L\nu]$
	S_qLlR	S_{qLlR}	$[\bar{c}P_L b]\,[\bar{\ell}P_R\nu]$
	S_qRlR	S_{qRlR}	$[\bar{c}P_R b]\,[\bar{\ell}P_R\nu]$
Tensor	T_qLlL	T_{qLlL}	$[\bar{c}\sigma^{\mu\nu}P_L b]\,[\bar{\ell}\sigma_{\mu\nu}P_L\nu]$
	T_qRlR	T_{qRlR}	$[\bar{c}\sigma^{\mu\nu}P_R b]\,[\bar{\ell}\sigma_{\mu\nu}P_R\nu]$

It is possible to:

- **change Form Factor** parametrization;
- fit the **Form Factor parameters** for a given parametrization;
- include **NP models** in the templates;
- use it as an interface in the fit to **measure directly the WCs**.

In the following we will closer look to the **NP WCs excluding right-handed neutrinos** (*S_qLlL*, *V_qRlL*, *T_qLlL*).

Analysis strategy (1): introduction

Different channels have different sensitivity to NP operators:

- $B \to D\tau\nu$ are more sensitive to scalar operators;
- $B \to D^*\tau\nu$, $B_c \to J/\psi\tau\nu$ and $\Lambda_b \to \Lambda_c\tau\nu$ are sensitive to vector and tensor operators.

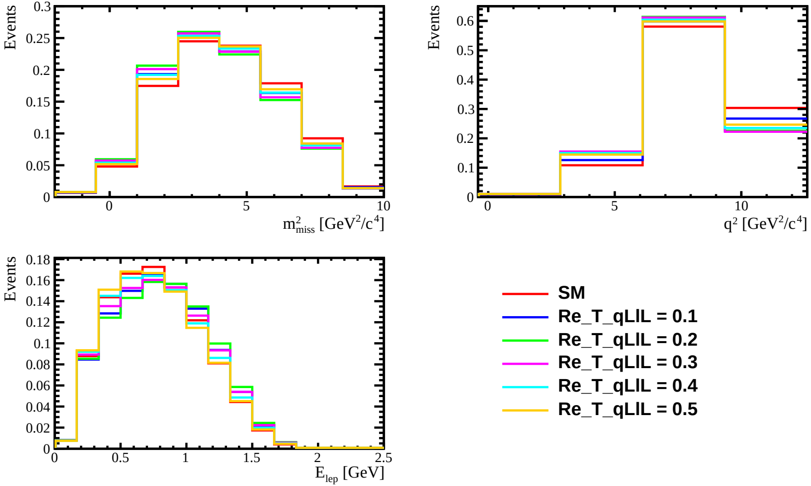
We include different analyses looking at different decay modes:

- Preliminary sensitivity studies:
  - **R(D*) tau-muonic decay**: LHCb-PAPER-2015-025;
  - **R(D*) tau-hadronic decay**: LHCb-PAPER-2022-052;

- We build a **set of templates from the simulations** used in the analyses:
  - Hammer reweighting we can **vary the WCs and the FFs** parameters;
  - we can use them as free parameters in the fit.

Analysis strategy (2): WC template shapes

Example of different values of T_qLlL injected in a $B^0 \to D^*\tau(\to \mu\nu_\mu\nu_\tau)\nu_\tau$ template:



We use Gammacombo to apply a phase-space scans:

- multiple template fits in different phase-space regions.

Profile likelihood method:

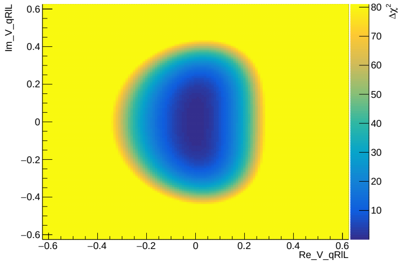
We define:

$$\chi^2(\vec{\alpha}) = -2\ln L(\vec{\alpha})$$

over the $\vec{\alpha}$ phase space.

The confidence interval (Gaussian assumption):

$$1 - \mathrm{CL} = \frac{1}{\sqrt{2}\Gamma(1/2)} \int_{\Delta\chi^2}^{\infty} e^{-1/2} t^{-1/2} \mathrm{d}t$$



Gammacombo combines all the included analysis sharing parameters among each other.

Very time consuming: `runtime` scales with the granularity and N_{dof}.

- Parallelize the different regions of the phase-space.

Model from R(D*) tau-muonic analysis

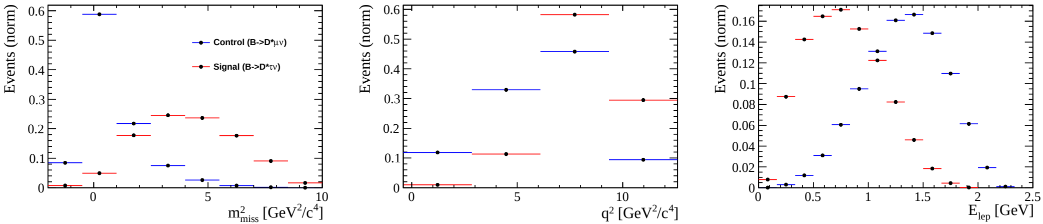
The template is composed by the **weighted simulations** used in the previous analysis.

The **signal mode** ($B^0 \to D^{+*}\tau^-\overline{\nu}_\tau$):

- **Form Factor** weighting: (BD^*, ISGW2) $\to$ (BD^*, BLPRXP).

The **control mode** ($B^0 \to D^{+*}\mu^-\overline{\nu}_\mu$)

- **Form Factor** weighting: (BD^*, BLPR) $\to$ (BD^*, BLPRXP).



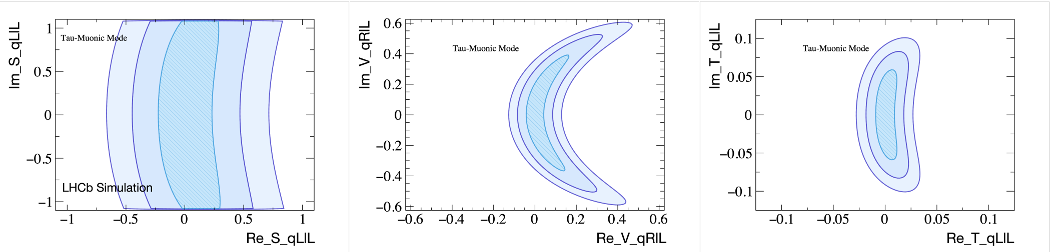
Other background contributions have been excluded in these preliminary studies.

WCs sensitivity of R(D*) tau-muonic analysis

We apply a **Asimov scan** in the signal+control configuration to **study the sensitivity**.

- Each scan **considers 1 of the WCs**;
- the control mode is always considered to be **purely SM**;
- the **SM contribution is shared** among the **signal-control** to parametrize the yields.

	Scalar (qLIL)	Vector (qRIL)	Tensor (qLIL)
Uncertainty on the Real part (1-D)	0.180	0.041	0.008
Uncertainty on the Imaginary part (1-D)	1.104	0.203	0.052



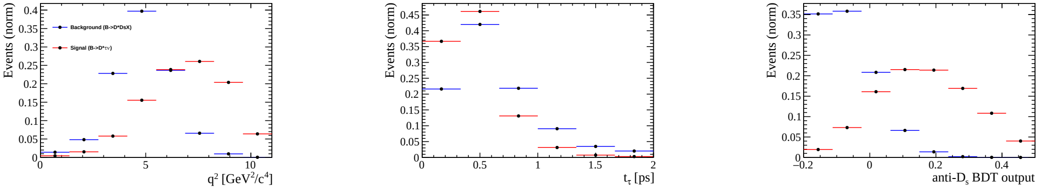
Model from R(D*) tau-hadronic analysis

The signal mode ($B^0 \to D^{+*}\tau^-\overline{\nu}_\tau$):

- **Form Factor** weighting: (BD^*, ISGW2; $\tau\pi\pi\pi$, RCT) $\to$ (BD^*, BLPRXP; $\tau\pi\pi\pi$, RCT).

A proxy background component ($B \to D^* D_s X$):

- is not Hammer weighted (yield is a free parameter).



The signal simulation is produced **using TAUOLA** for the τ^--decay.

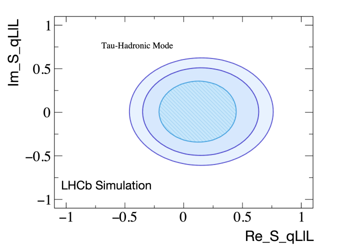
- **TAUOLA is not** the model used in the Hammer **calibration of RCT**;
- **TAUOLA has been validated by compating the kinematic with RCT-nominal model.**

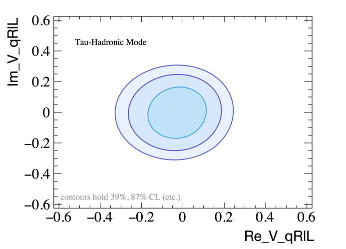
WCs sensitivity of R(D*) tau-hadronic analysis

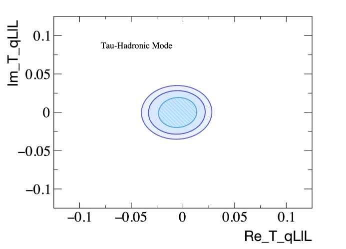
We apply a **Asimov scan** in the signal+background configuration to **study the sensitivity**.

- Each scan **considers 1 of the WCs**;
- We have a good constraint of the **WCs' imaginary part**.

	Scalar (qLlL)	Vector (qRlL)	Tensor (qLlL)
Uncertainty on the Real part (1-D)	0.250	0.154	0.014
Uncertainty on the Imaginary part (1-D)	0.334	0.162	0.018





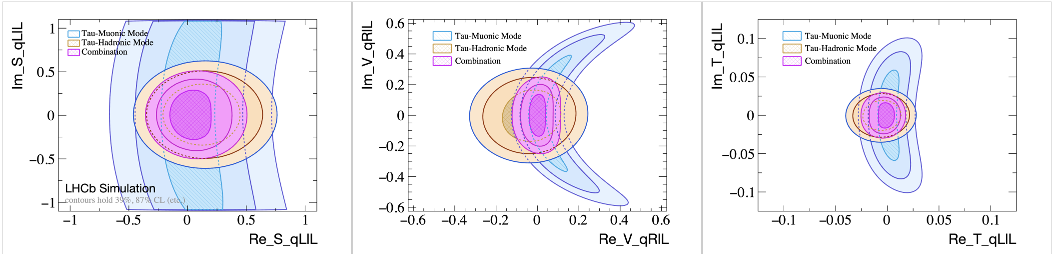


WCs sensitivity of the combination

The two modes give **complementary results**:

- the **NP and SM Wilson Coefficients** are shared among the tow modes;
- the **Muonic mode** constraints the **Real part of the WCs** (higher statistic, ...);
- the **Hadronic mode** constraints the **Imaginary part of the WCs** (τ-vertex weight, ...)

	Scalar (qLlL)	Vector (qRlL)	Tensor (qLlL)
Uncertainty on the Real part (1-D)	0.173	0.039	0.007
Uncertainty on the Imaginary part (1-D)	0.289	0.142	0.016



Conclusions and Outlook

Conclusions

- We are working on a **combined WCs fit** in $b \to c\tau\nu_\tau$ decays using several LHCb + Belle II analyses.
- Currently setting up the **framework and studying sensitivity of the WCs**.
- The framework (GammaCombo + Hammer) allows to **combine multiple analysis**.
- Sensitivity studies have been done using **2 LHCb analysis**:
  - R(D*) measurement with τ-hadronic decay.
  - R(D*) measurement with τ-muonic decay.

Outlook

- **Full description of the background** for the analyses.
- Include other LHCb analysis:
  - we will study the LHCb combination first.
- Setup a **combined measurement with Belle** once all the inputs are confirmed.