New Physics in $b \to s\tau^+\tau^-$ Processes: An (SM)EFT Analysis

Based on 2605.21291 and 2609.40072 with A. Crivellin, R. Escribano, J. Matias and M. Novoa-Brunet

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10th Symposium on Prospects in the Physics of Discrete Symmetries

Introduction

Anomalies in semileptonic B-decays

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$b \to s\ell^+\ell^-$ (FCNC):

- Global fits with more than 200 observables.
  - $\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)$ and $\mathcal{B}(B_s \to \phi\mu^+\mu^-)$
  - Angular observables in $B \to K^*\mu^+\mu^-$ and $B_s \to \phi\mu^+\mu^-$
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Deviations from the SM (significance above 5σ level)

$\hookrightarrow$ Lepton Flavour Universal NP for the first two generations.

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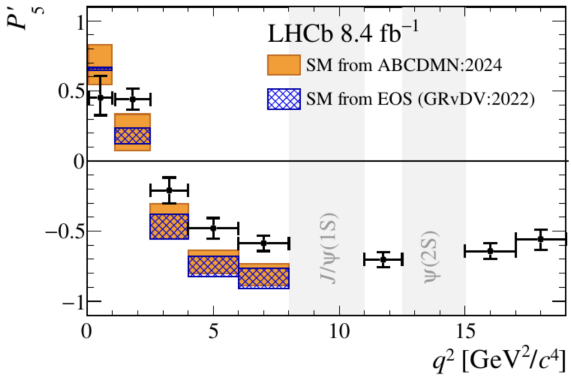
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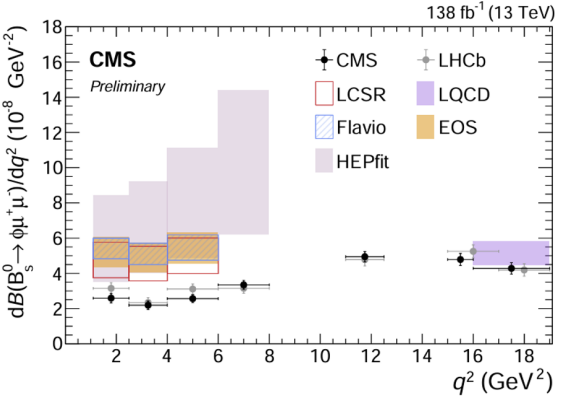
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CMS collab., CMS-PAS-BPH-23-003 (2026)

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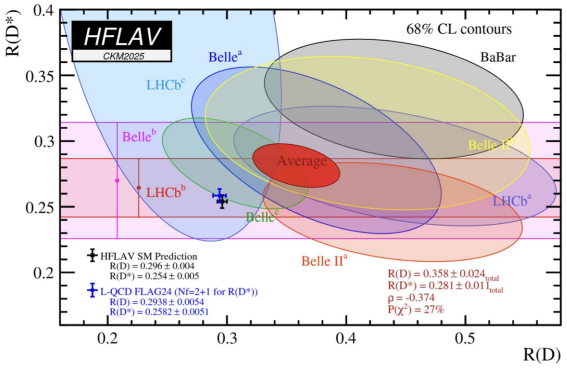
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(without including the unpublished last result of BaBar in the average)

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- $R^{\nu,\,\mathrm{exp}}_{K} = 2.9 \pm 0.9$
- $R^{\nu,\,\mathrm{exp}}_{K^*} < 2.7$ (90 % CL)

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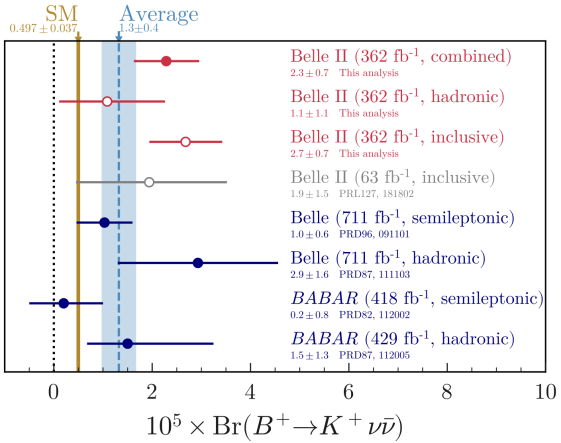
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More difficult to measure due to missing energy from νs

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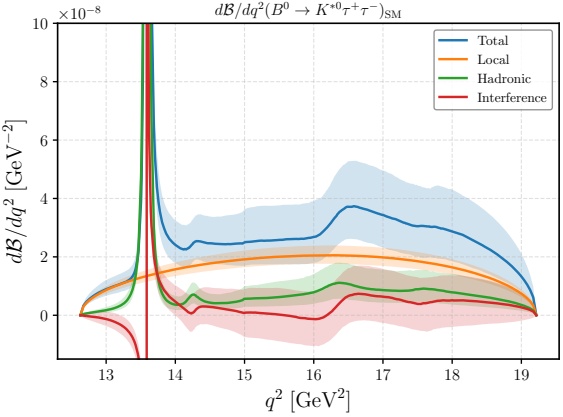
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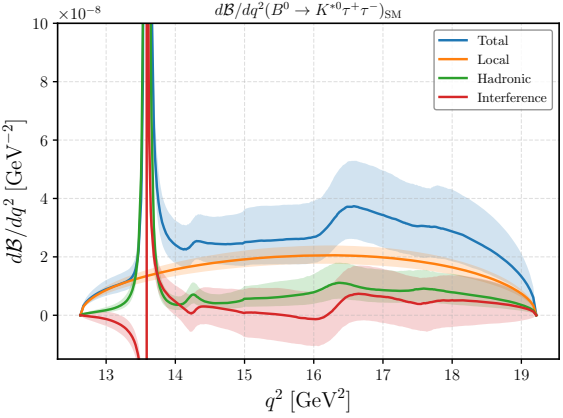
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More difficult to measure due to missing energy from νs

Data-driven predictions:

$$\mathcal{B}(B^+ \to K^+\tau^+\tau^-)_{\rm SM}^{[4m_\tau^2, q^2_{K,\rm max}]} = 1.86^{+0.17}_{-0.16} \times 10^{-6}$$

$$\mathcal{B}(B \to K^*\tau^+\tau^-)_{\rm SM}^{[4m_\tau^2, q^2_{K^*,\rm max}]} = 1.50^{+0.23}_{-0.22} \times 10^{-6}$$

$$\mathcal{B}(B^+ \to K^+\tau^+\tau^-)_{\rm SM}^{[14.18, q^2_{K,\rm max}]} = 1.54^{+0.16}_{-0.13} \times 10^{-7}$$

$$\mathcal{B}(B \to K^*\tau^+\tau^-)_{\rm SM}^{[14.18, q^2_{K^*,\rm max}]} = 1.36^{+0.61}_{-0.40} \times 10^{-7}$$

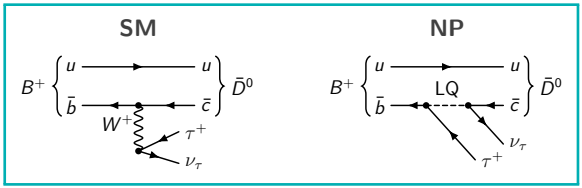
Integrating over the **full phase space** from $4m_\tau^2$ is necessary for comparisons with LHCb/CMS.

SMEFT analysis

SMEFT link: manifest $SU(2)_L$ gauge invariance correlates the left-handed $bc\tau\nu$ current with $b \to s\tau^+\tau^-$ and $b \to s\nu\bar{\nu}$ transitions.

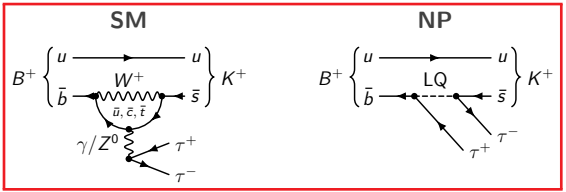
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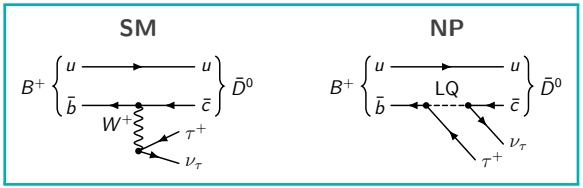
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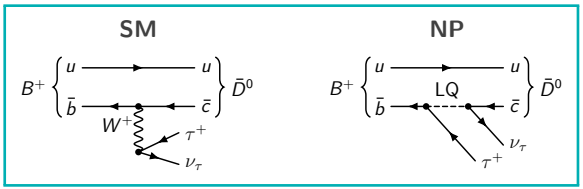


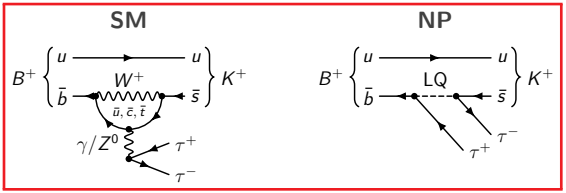


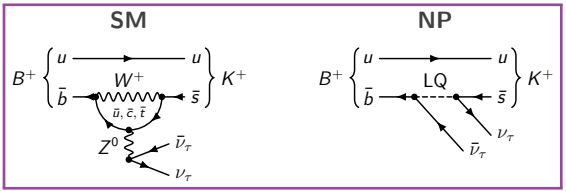
NP enhancements of $b \to s\tau^+\tau^-$ up to some **orders of magnitude** are predicted.

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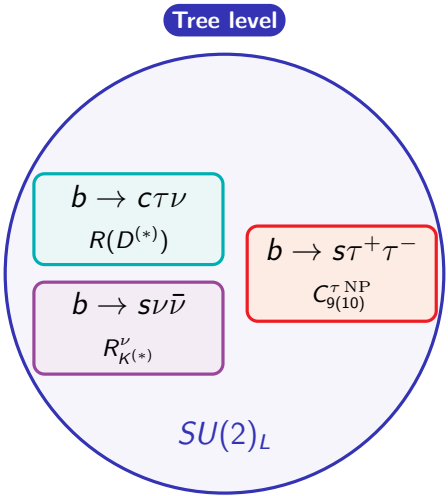




NP enhancements of $b \to s\tau^+\tau^-$ up to some **orders of magnitude** are predicted.

Current measurements of $b \to s\nu\bar{\nu}$ should be accommodated.

SMEFT analysis



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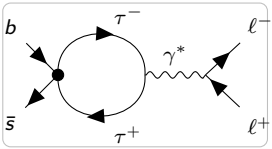
Tree level → **Loop level**

$b \to c\tau\nu$
$R(D^{(*)})$

$b \to s\tau^+\tau^-$
$C_{9(10)}^{\tau\,\mathrm{NP}}$

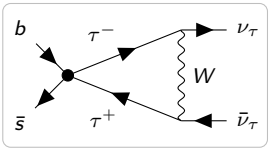
$b \to s\nu\bar{\nu}$
$R_{K^{(*)}}^{\nu}$

$SU(2)_L$



off-shell photon penguin

$b \to s\ell^+\ell^-$
LFU NP: C_9^{U}



W vertex correction

$b \to s\nu\bar{\nu}$
$C_L^{\nu_\tau\,\mathrm{W}}$

SMEFT analysis

Dimension-six SMEFT:

$$\mathcal{L}^{(6)}_{\rm SMEFT} \supset \sum_i \frac{\tilde{C}_i}{\Lambda^2}\mathcal{O}_i = \sum_i C_i\,\mathcal{O}_i$$

Relevant four-fermion operators:

$$\begin{aligned}
\mathcal{O}^{(1)}_{23} &= \left[\bar{Q}_2\gamma_\mu Q_3\right]\left[\bar{L}_3\gamma^\mu L_3\right], \\
\mathcal{O}^{(3)}_{23} &= \left[\bar{Q}_2\gamma_\mu \sigma^I Q_3\right]\left[\bar{L}_3\gamma^\mu \sigma^I L_3\right], \\
\mathcal{O}^{\ell d}_{23} &= \left[\bar{d}_{2R}\gamma_\mu d_{3R}\right]\left[\bar{L}_3\gamma^\mu L_3\right],
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SMEFT coefficients

$C^{(1)}_{23} \Rightarrow$ LHC

$C^{(3)}_{23} \Rightarrow$ LHC

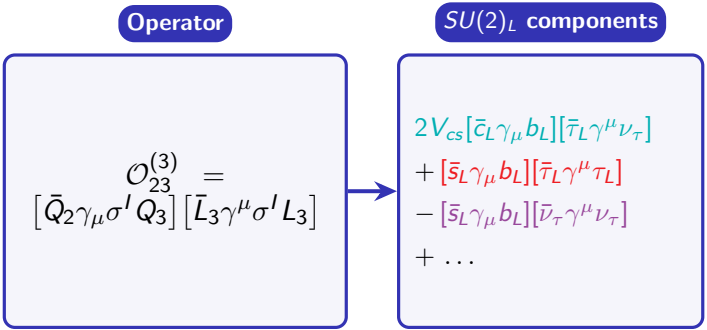
$C^{\ell d}_{23} \Rightarrow$ RHC

SMEFT analysis

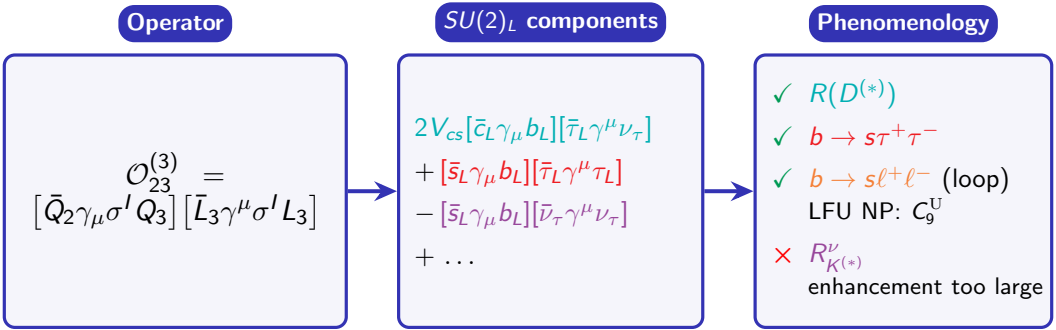
Operator

$$\mathcal{O}_{23}^{(3)} = \left[\bar{Q}_2 \gamma_\mu \sigma^I Q_3\right]\left[\bar{L}_3 \gamma^\mu \sigma^I L_3\right]$$

SMEFT analysis



SMEFT analysis



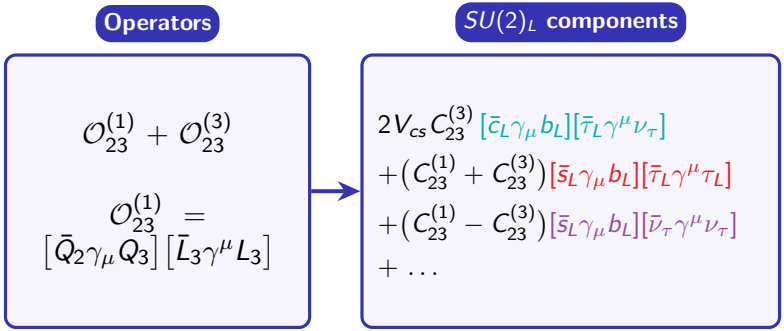
SMEFT analysis

Operators

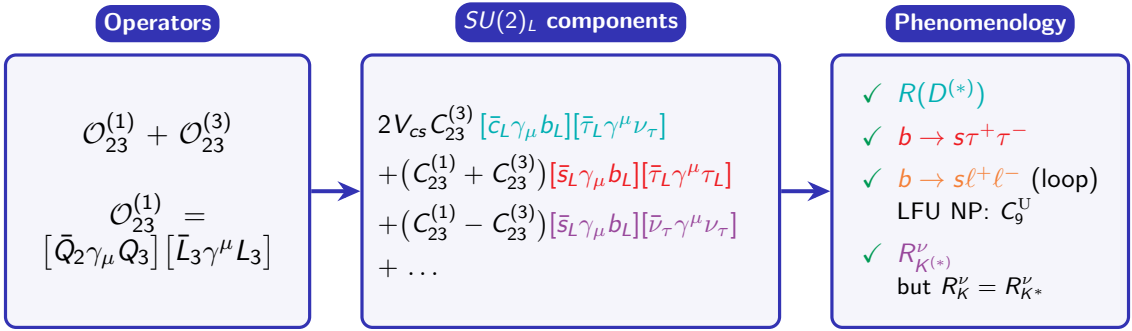
$$\mathcal{O}_{23}^{(1)} + \mathcal{O}_{23}^{(3)}$$

$$\mathcal{O}_{23}^{(1)} = \left[\bar{Q}_2 \gamma_\mu Q_3\right]\left[\bar{L}_3 \gamma^\mu L_3\right]$$

SMEFT analysis



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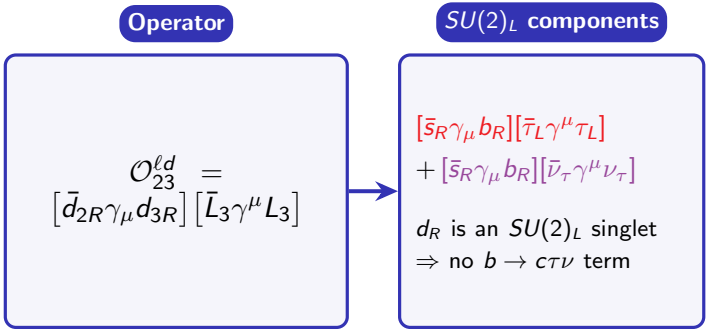


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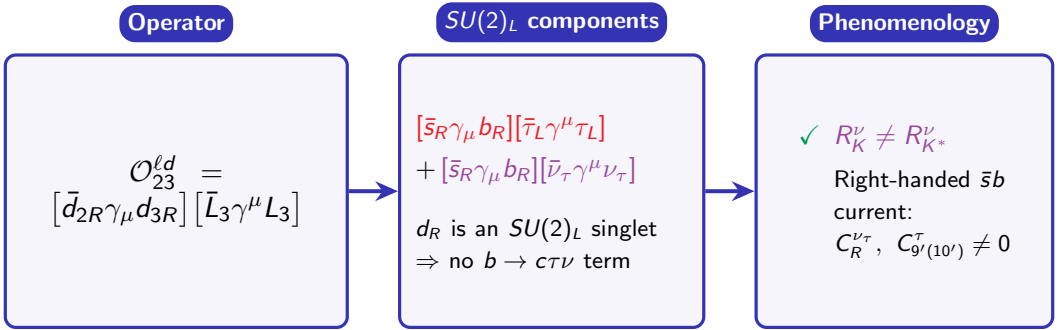
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$$\begin{aligned}\mathcal{L}_{\text{eff}}^{\text{NP}} &= 2V_{cs}C_{23}^{(3)}\,(\bar{c}_L\gamma_\mu b_L)(\bar{\tau}_L\gamma^\mu\nu_{L\tau}) \\ &+ \left(C_{23}^{(1)} + C_{23}^{(3)}\right)(\bar{s}_L\gamma_\mu b_L)(\bar{\tau}_L\gamma^\mu\tau_L) \\ &+ \left(C_{23}^{(1)} - C_{23}^{(3)}\right)(\bar{s}_L\gamma_\mu b_L)(\bar{\nu}_{L\tau}\gamma^\mu\nu_{L\tau}) \\ &+ C_{23}^{\ell d}\left[(\bar{s}_R\gamma_\mu b_R)(\bar{\nu}_{L\tau}\gamma^\mu\nu_{L\tau}) + (\bar{s}_R\gamma_\mu b_R)(\bar{\tau}_L\gamma^\mu\tau_L)\right] + \text{h.c.}\end{aligned}$$

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Scenario I

$$C_{23}^{(1)} = C_{23}^{(3)}$$
$$C_{23}^{\ell d} = 0$$

$b \to s\nu\bar{\nu}$ only at loop level

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Scenario I

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$b \to s\nu\bar{\nu}$ only at loop level

Scenario II

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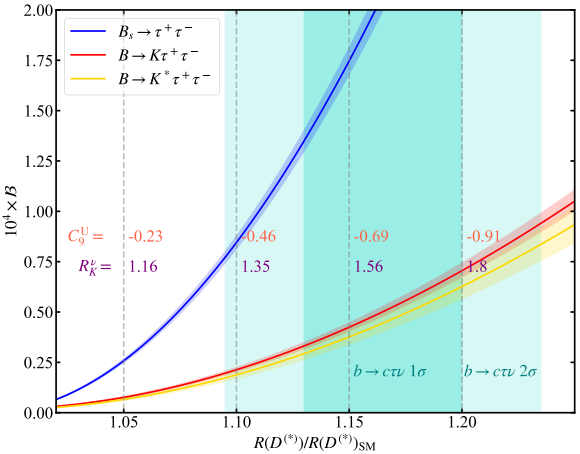
Scenario III

$C_{23}^{(1)} \neq C_{23}^{(3)}$

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Right-handed currents: $R_K^\nu \neq R_{K^*}^\nu$

Phenomenology



Scenario I: 1 solution

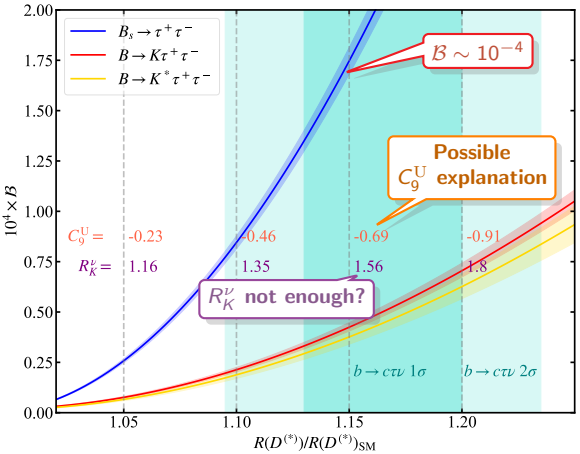
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NP scale $\Lambda = 5$ TeV

Phenomenology



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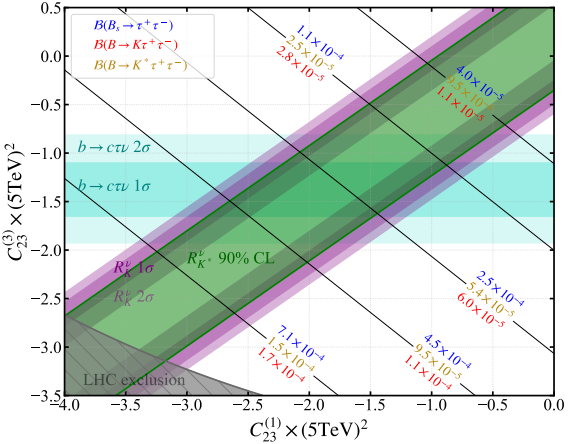
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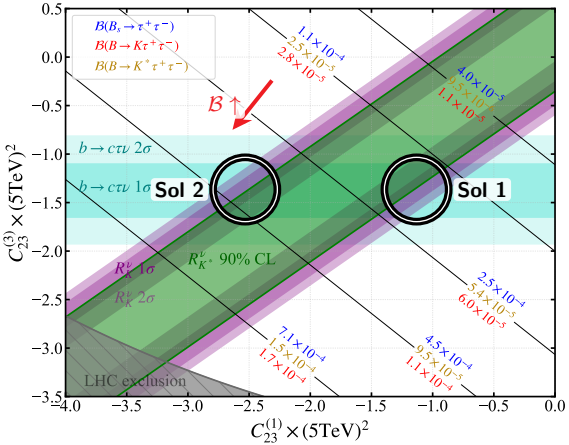
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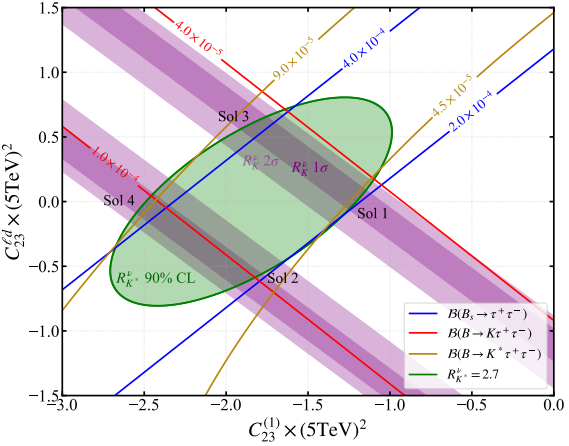
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Phenomenology



Scenario III: 4 solutions

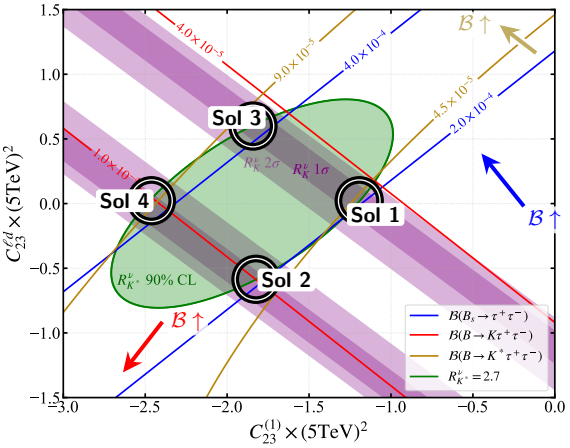
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NP scale $\Lambda = 5\,\mathrm{TeV}$

$$C_{23}^{(3)} = -1.4/(5\,\mathrm{TeV})^2$$
$$(R(D^{(*)})/R(D^{(*)})_{\mathrm{SM}} = 1.17)$$

Phenomenology



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- Tauonic FCNC modes can resolve NP scenarios that remain degenerate in $B \to K^{(*)}\nu\bar{\nu}$ observables.
- $b \to s\tau^+\tau^-$ decays provide a powerful and experimentally accessible probe of NP in the third-generation flavour sector.

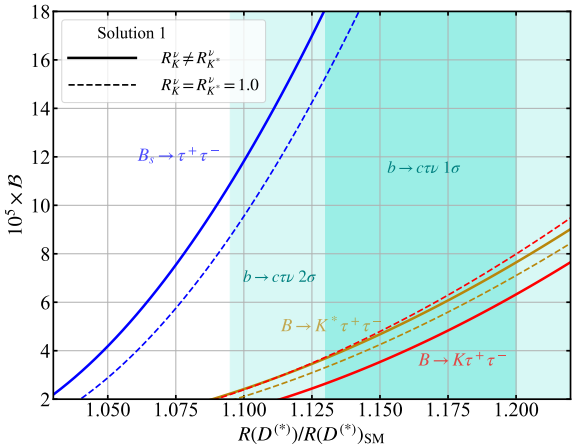
Thank you!

Questions?

Back-up slides

Phenomenology

Scenario III, solution 1: $\mathcal{B}$ vs $R(D^{(*)})/R(D^{(*)})_{\rm SM}$

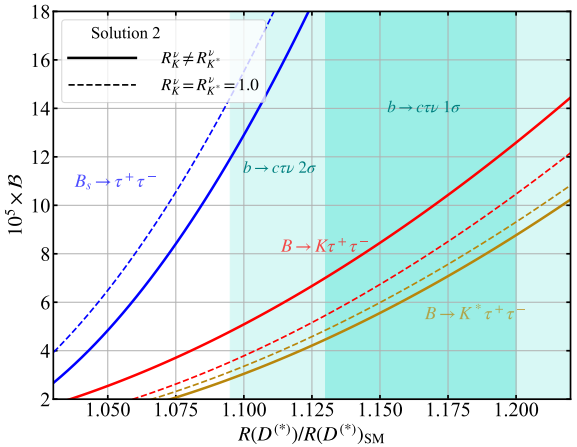


$\mathcal{B}(B_s \to \tau^+\tau^-)$ (blue), $\mathcal{B}(B \to K\tau^+\tau^-)$ (red) and $\mathcal{B}(B \to K^*\tau^+\tau^-)$ (yellow) as a function of $R(D^{(*)})/R(D^{(*)})_{\rm SM}$.

- Light-blue region: preferred by the $b \to c\tau\nu$ measurements.
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Phenomenology

Scenario III, solution 2: $\mathcal{B}$ vs $R(D^{(*)})/R(D^{(*)})_{\rm SM}$

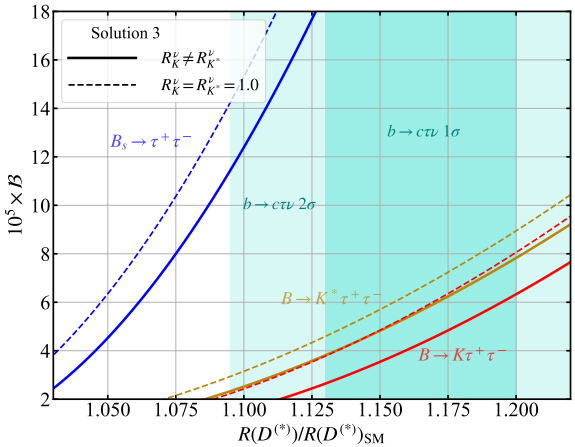


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Phenomenology

Scenario III, solution 3: $\mathcal{B}$ vs $R(D^{(*)})/R(D^{(*)})_{\rm SM}$

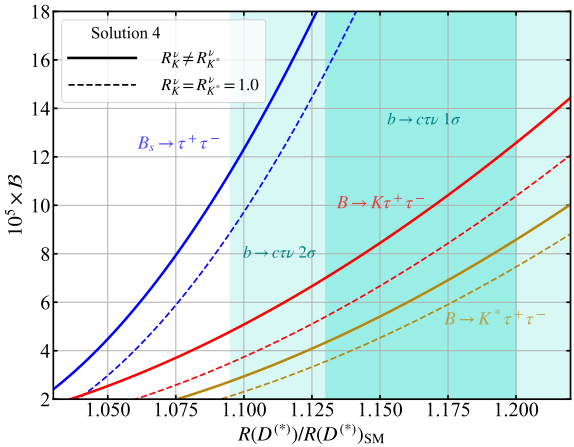


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Phenomenology

Scenario III, solution 4: $\mathcal{B}$ vs $R(D^{(*)})/R(D^{(*)})_{\rm SM}$



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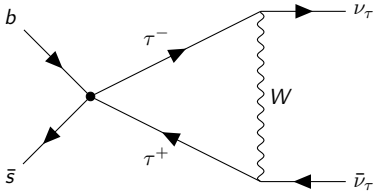
$b \to s\tau^+\tau^-$ searches can help to disentangle the four solutions, probing NP in the neutrino mode.

SMEFT framework

Matching relations: W vertex correction

We include a W vertex correction:

- One-loop mixing of $\mathcal{O}_9^\tau$ into $\mathcal{O}_L^{\nu_\tau \nu_\tau}$.
- Generates an effect in $b \to s\nu\bar{\nu}$ processes even for $C_{23}^{(1)} = C_{23}^{(3)}$.

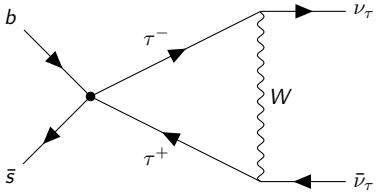


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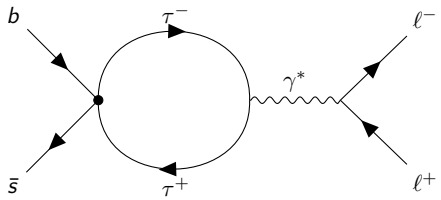


$$C_L^{\nu_\tau \mathrm{W}} = \frac{3}{4\sqrt{2} G_F \sin^2\theta_W} \frac{1}{V_{tb} V_{ts}^*} \log\left(\frac{m_W^2}{\Lambda^2}\right) \left(C_{23}^{(1)} + C_{23}^{(3)}\right)$$

SMEFT framework

Loop effects in $b \to s\ell^+\ell^-$

A large Wilson coefficient $C_9^{\tau\,\mathrm{NP}}$ has important loop effects relevant for $b \to s\ell^+\ell^-$ transitions with light leptons.



Tau-loop off-shell photon penguin with the photon coupling to $\ell^+\ell^-$, generating a mixing of $\mathcal{O}_9^\tau$ into $\mathcal{O}_9^{\mathrm{U}}$.

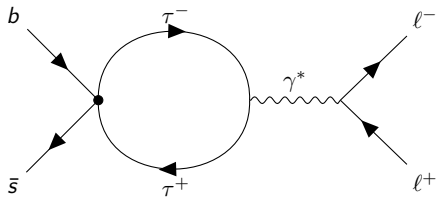
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$$C_9^{\mathrm{U}} = -\frac{\alpha}{3\pi} \log\left(\frac{\Lambda^2}{\mu_b^2}\right) C_9^{\tau\,\mathrm{NP}}$$

where we identify $C_9^{\mathrm{U}} \equiv C_9^{\mu\,\mathrm{NP}} = C_9^{e\,\mathrm{NP}}$.



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Matching conditions:

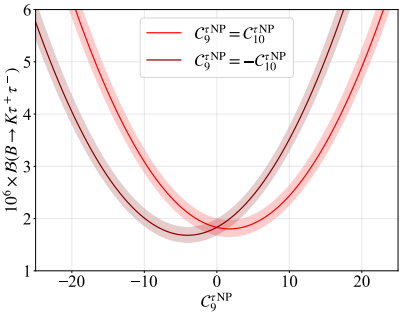
$$C_{9(10)}^{\tau} = C_{9(10)}^{\text{SM}} + (-)\frac{1}{2\mathcal{N}}\left(C_{23}^{(1)} + C_{23}^{(3)}\right), \qquad C_{9'(10')}^{\tau} = +(-)\frac{1}{2\mathcal{N}}C_{23}^{\ell d},$$

$$C_L^{\nu_\tau} = C_L^{\text{SM}} + C_L^{\nu_\tau\,\text{W}} + \frac{1}{2\mathcal{N}}\left(C_{23}^{(1)} - C_{23}^{(3)}\right), \qquad C_R^{\nu_\tau} = \frac{1}{2\mathcal{N}}C_{23}^{\ell d},$$

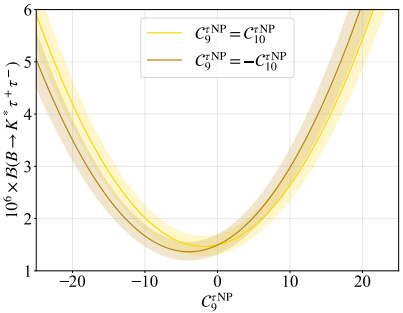
$$\epsilon_L = -\frac{1}{\sqrt{2}G_F}\left(\frac{V_{cs}}{V_{cb}}C_{23}^{(3)} + C_{33}^{(3)}\right), \qquad \text{with} \quad \mathcal{N} \propto G_F V_{tb}V_{ts}^*\,\alpha\,.$$

$b \to s\tau^+\tau^-$

NP enhancement



$B \to K\tau^+\tau^-$



$B \to K^*\tau^+\tau^-$

- $C_9^{\tau\,\mathrm{NP}} = -C_{10}^{\tau\,\mathrm{NP}}$ $(U_1,\ S_1 + S_3) \Rightarrow$ can explain C_9^{U} via off-shell photon penguin and $R(D^{(*)})$
- $C_9^{\tau\,\mathrm{NP}} = +C_{10}^{\tau\,\mathrm{NP}}$ $(R_2) \Rightarrow$ only C_9^{U} via off-shell photon penguin

$b \to s\nu\bar{\nu}$ and $b \to c\tau\nu$

$b \to s\nu\bar{\nu}$ and $b \to c\tau\nu$

$b \to s\nu\bar{\nu}$ (WET):

$$\mathcal{L}_{\text{eff}}^{b\to s\nu\bar{\nu}} = \frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \left(C_L^{\nu_\tau} \mathcal{O}_L^{\nu_\tau} + C_R^{\nu_\tau} \mathcal{O}_R^{\nu_\tau} \right) + \text{h.c.}$$

$$\mathcal{O}_L^{\nu_\tau} = \frac{e^2}{(4\pi)^2} (\bar{s}_L \gamma_\mu b_L)(\bar{\nu}_\tau \gamma^\mu (1-\gamma_5)\nu_\tau)\,,$$

$$\mathcal{O}_R^{\nu_\tau} = \frac{e^2}{(4\pi)^2} (\bar{s}_R \gamma_\mu b_R)(\bar{\nu}_\tau \gamma^\mu (1-\gamma_5)\nu_\tau)\,.$$

$$R_{K^{(*)}}^{\nu} \equiv \frac{\mathcal{B}(B\to K^{(*)}\nu\bar{\nu})}{\mathcal{B}_{\text{SM}}(B\to K^{(*)}\nu\bar{\nu})} = 1 + \delta\mathcal{B}_{K^{(*)}}^{\nu_\tau}$$

$b \to s\nu\bar{\nu}$ and $b \to c\tau\nu$

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$b \to c\tau\nu$ (effective Lagrangian):

$$\mathcal{L}_{\text{eff}} = -\frac{4G_F V_{cb}}{\sqrt{2}}(1+\epsilon_L) \times (\bar{\tau}\gamma_\mu P_L\nu_\tau)(\bar{c}\gamma^\mu P_L b) + \text{h.c.}$$

The relative effect w.r.t. the SM in tauonic B decays is given by

$$\frac{R(D^{(*)})}{R(D^{(*)})_{\text{SM}}} = \frac{R(J/\psi)}{R(J/\psi)_{\text{SM}}} = |1+\epsilon_L|^2$$

$b \to s\tau^+\tau^-$

SM predictions

Experimentally (90 % *CL*):

- $\mathcal{B}(B_s \to \tau^+\tau^-)_{\rm exp} \leq 5.2 \times 10^{-3}$
- $\mathcal{B}(B \to K\tau^+\tau^-)_{\rm exp} \leq 5.6 \times 10^{-4}$
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Theoretically (WET):

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum_i C_i\,\mathcal{O}_i$$

$$\mathcal{O}^\tau_{9(10)} = \tfrac{\alpha}{4\pi}[\bar{s}_L\gamma^\mu b_L][\bar{\tau}\gamma_\mu(\gamma_5)\tau]$$

$$\mathcal{O}^\tau_{9'(10')} = \tfrac{\alpha}{4\pi}[\bar{s}_R\gamma^\mu b_R][\bar{\tau}\gamma_\mu(\gamma_5)\tau]$$

$$C_i = C^\tau_9\,,\, C^\tau_{10}\,,\, C^\tau_{9'}\,,\, C^\tau_{10'}$$

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$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i \mathcal{O}_i$$

$$\mathcal{O}^\tau_{9(10)} = \tfrac{\alpha}{4\pi}[\bar{s}_L\gamma^\mu b_L][\bar{\tau}\gamma_\mu(\gamma_5)\tau]$$

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$$C_i = C_9^\tau\,,\, C_{10}^\tau\,,\, C_{9'}^\tau\,,\, C_{10'}^\tau$$

SM predictions:

$$\mathcal{B}(B^+ \to K^+\tau^+\tau^-)_{\text{SM}}^{[4m_\tau^2, q^2_{K,\max}]} = 1.86^{+0.17}_{-0.16} \times 10^{-6}$$

$$\mathcal{B}(B^+ \to K^+\tau^+\tau^-)_{\text{SM}}^{[14.18, q^2_{K,\max}]} = 1.54^{+0.16}_{-0.13} \times 10^{-7}$$

$$\mathcal{B}(B \to K^*\tau^+\tau^-)_{\text{SM}}^{[4m_\tau^2, q^2_{K^*,\max}]} = 1.50^{+0.23}_{-0.22} \times 10^{-6}$$

$$\mathcal{B}(B \to K^*\tau^+\tau^-)_{\text{SM}}^{[14.18, q^2_{K^*,\max}]} = 1.36^{+0.61}_{-0.40} \times 10^{-7}$$

$b \to s\tau^+\tau^-$

SM predictions

$b \to s\tau^+\tau^-$ measurements (90 % CL):

- $\mathcal{B}(B_s \to \tau^+\tau^-)_{\rm exp} \leq 5.2 \times 10^{-3}$
- $\mathcal{B}(B \to K\tau^+\tau^-)_{\rm exp} \leq 5.6 \times 10^{-4}$
- $\mathcal{B}(B \to K^*\tau^+\tau^-)_{\rm exp} \leq 2.5 \times 10^{-4}$
- $\mathcal{B}\,(B_s \to \phi\tau^+\tau^-)_{\rm exp} \leq 4.1 \times 10^{-4}$

More difficult to measure due to missing energy from νs

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SMEFT analysis

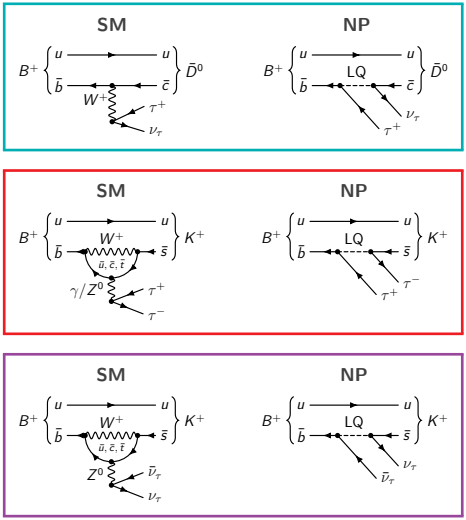
SMEFT link: manifest $SU(2)_L$ gauge invariance correlates the left-handed $bc\tau\nu$ current with $b \to s\tau^+\tau^-$ and $b \to s\nu\bar{\nu}$ transitions.

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$$\mathcal{O}^{(3)}_{2333} = [\bar{Q}_2\gamma_\mu\sigma^I Q_3][\bar{L}_3\gamma^\mu\sigma^I L_3]$$
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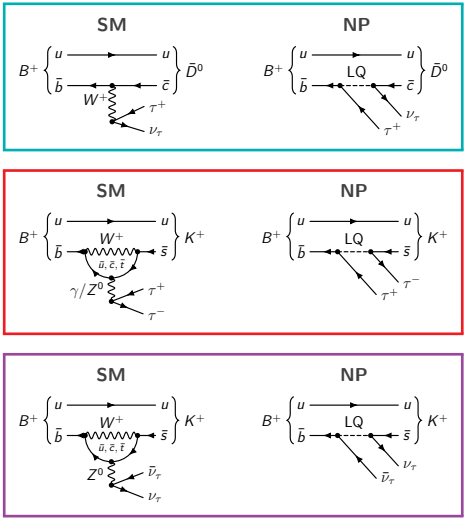


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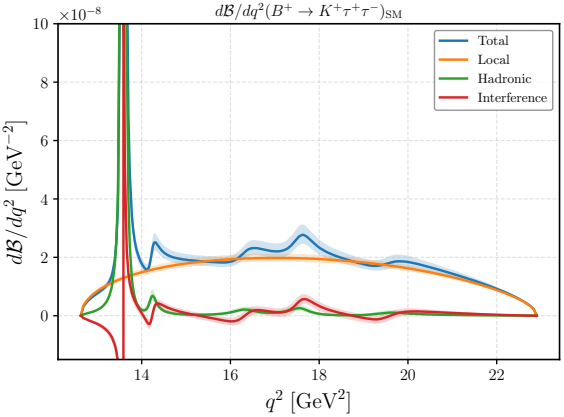


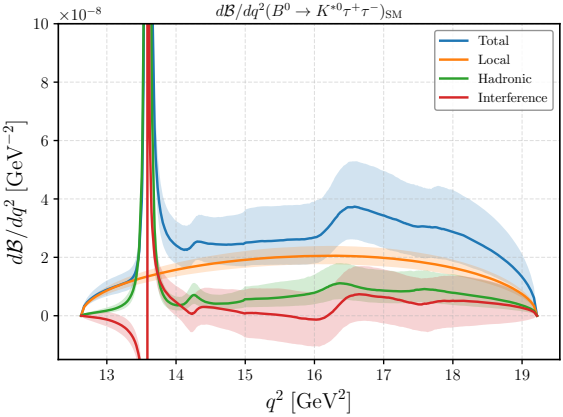
NP enhancements of $b \to s\tau^+\tau^-$ up to some **orders of magnitude** are predicted.

$b \to s\tau^+\tau^-$

SM predictions

Description of the spectrum:





$b \to s\tau^+\tau^-$

NP enhancement

Description of the spectrum:

