Universitat de València
Institut de Física Corpuscular

Flavor anomalies: Short-distance Origins and Outlook

Ben Stefanek
IFIC Valencia

BFA Workshop 2026
Santiago de Compostela
April 17th, 2026

Generalitat Valenciana
Conselleria de Educación, Cultura, Universidades y Empleo
CSIC
Consejo Superior de Investigaciones Científicas

Belle II and Theory Workshop: July 1-3, 2026

We will host a Belle II & Theory Workshop in Vienna from **July 1st - 3rd 2026 in Vienna**

Scope: bring together members from theory and Belle II community to discuss **full breadth** of physics program

LHCb members welcome :)

https://indico.belle2.org/event/17871/

Workshop

Belle II & Theory

1st - 3rd July 2026

Vienna University of Technology, Austria

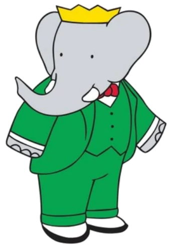
The Belle II & Theory workshop intends to bring together members of the Belle II experiment with the theory community at large. The program is organized jointly and covers all aspects of the Belle II physics reach. Belle II will soon enter its inverse attobarn era, pushing beyond the sensitivities of the predecessor e+e- B factory experiments.

Organisation: LOC, Soeren Prell, Florian Bernlochner

$b \to c\tau\nu$ Anomalies

- There was an excellent overview in *Antonio Romero's talk*

[Thanks to Martin Novoa + Copilot :)]

*If we kick out the  in the room (for illustrative purposes only)

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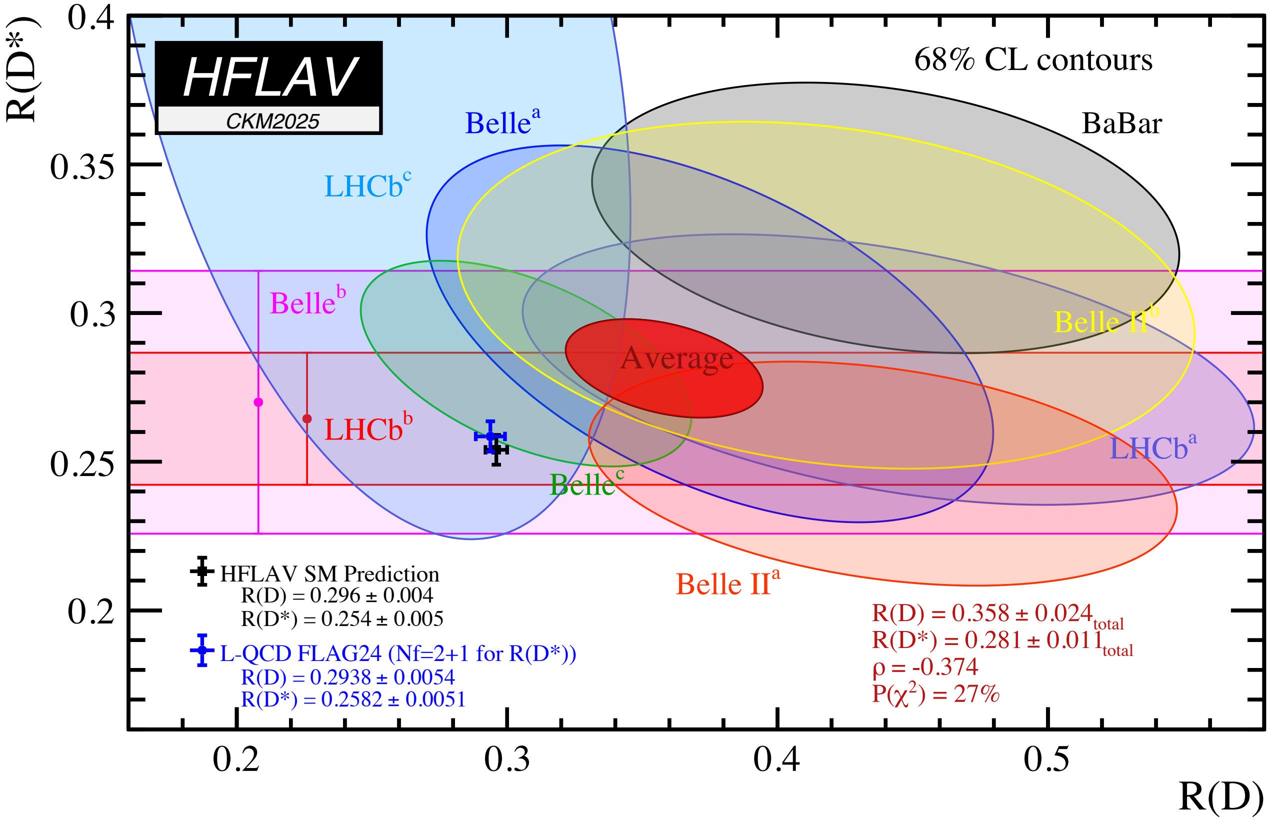
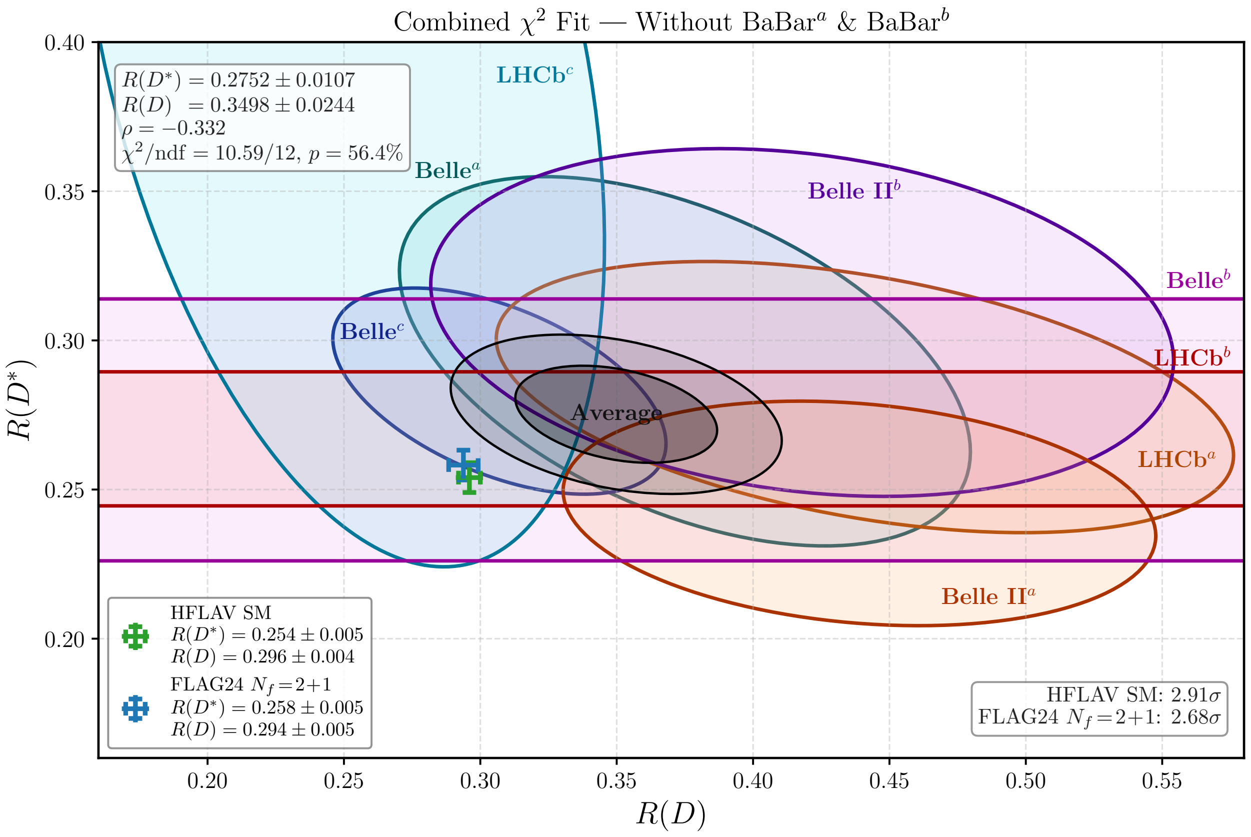




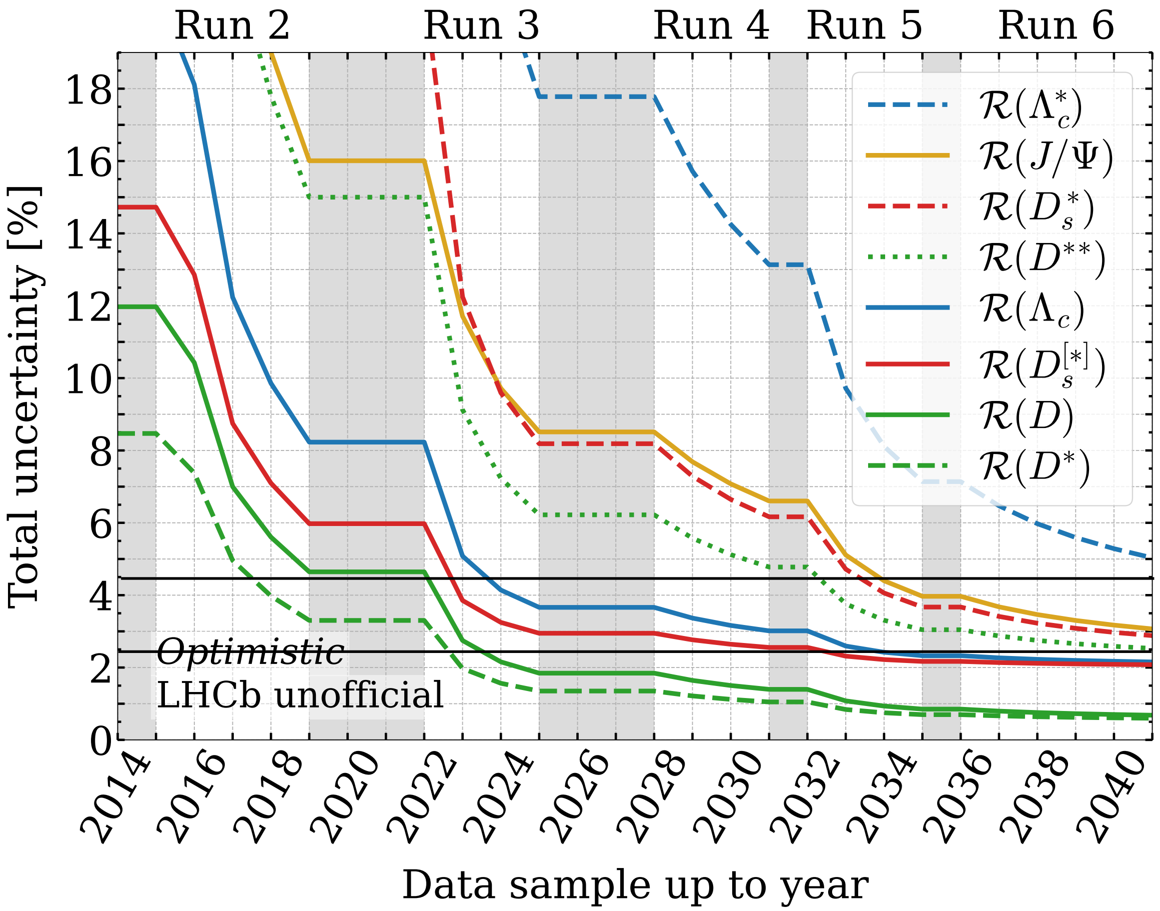
In either case, current error on the averages: $R_D \sim 7\,\%$, $R_{D^*} \sim 4\,\%$

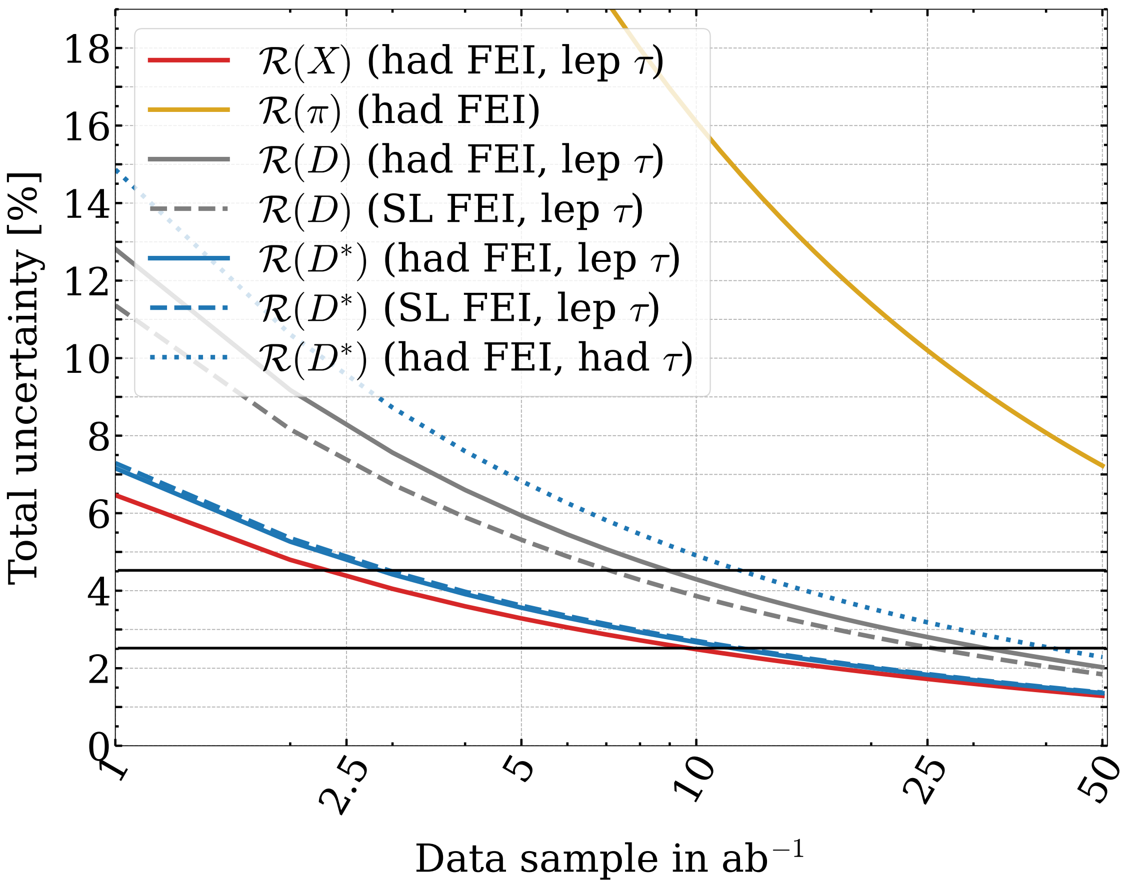
Tension: 3.8σ

Tension: 2.9σ

$b \to c\tau\nu$ Anomalies

- For more: *See Antonio Romero’s talk*





For fun, let’s assume central values stay but errors reduced by a factor ~1.5: R_D around 4.5%, R_{D*} around 2.5%

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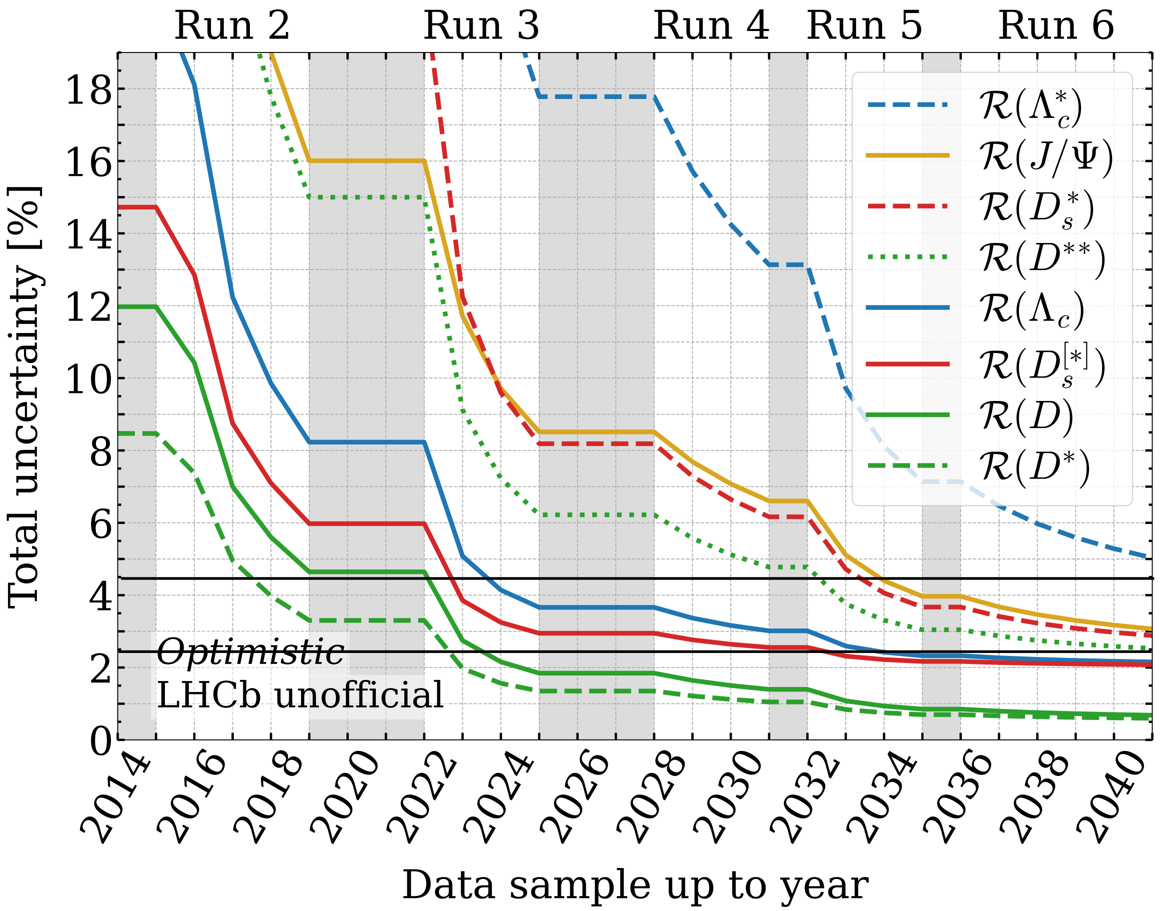
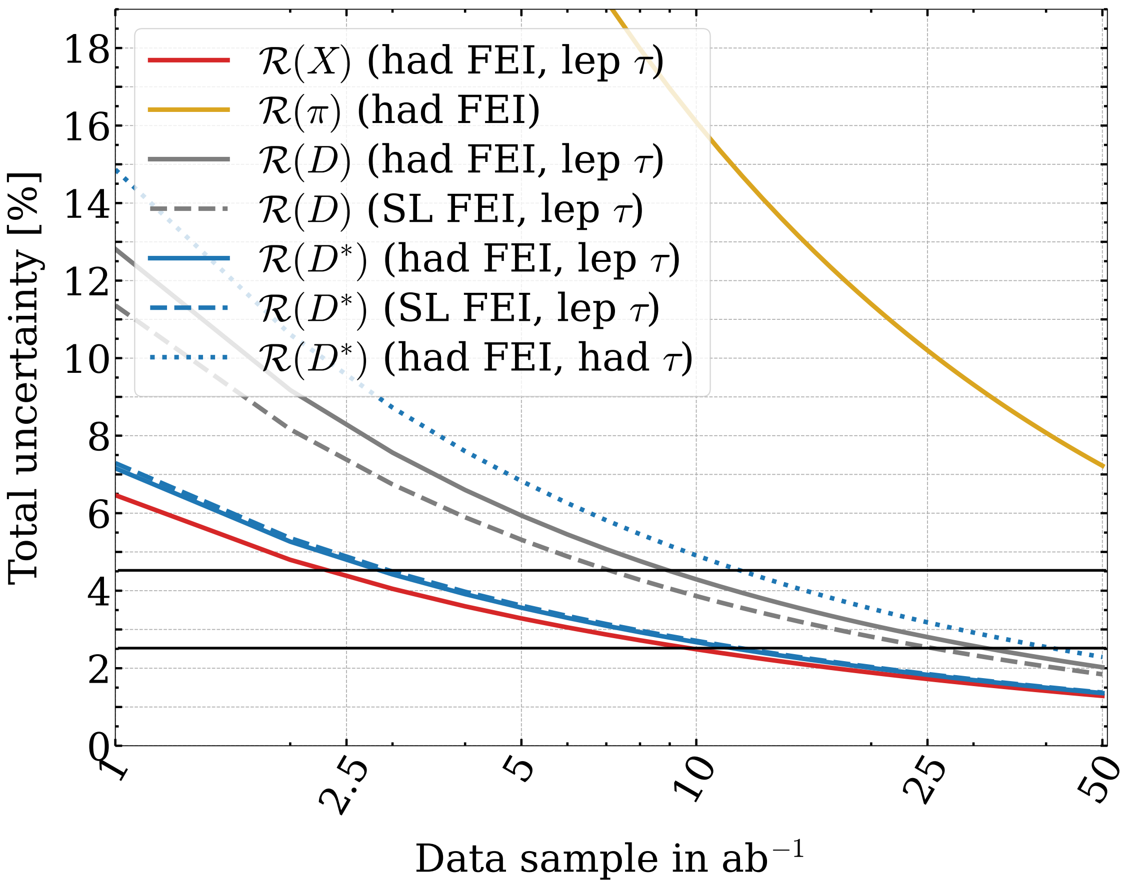




For fun, let's assume central values stay but errors reduced by a factor ~1.5: R_D around 4.5%, R_{D*} around 2.5%

HFLAV '25 tension w/ SM → 5.5σ

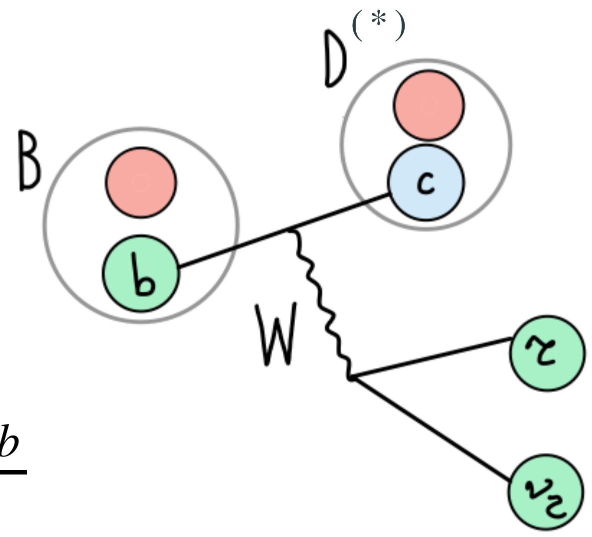
HFLAV '25 tension w/ SM (no BaBar) → 4.3σ

New physics in $b \to c\tau\nu$ transitions

$$\delta R_{D^{(*)}} = R_{D^{(*)}}/R^{\mathrm{SM}}_{D^{(*)}} - 1$$

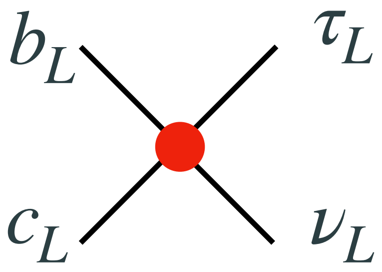
- We need ~10% of a tree-level SM process due to NP. Heavy NP should therefore also be tree-level to compete. Consider Fermi-like LH NP:

SM process



$$\mathscr{A}_{\mathrm{SM}} \sim \frac{g_L^2 V_{cb}}{2M_W^2} = \frac{2V_{cb}}{v^2}$$

Heavy new physics



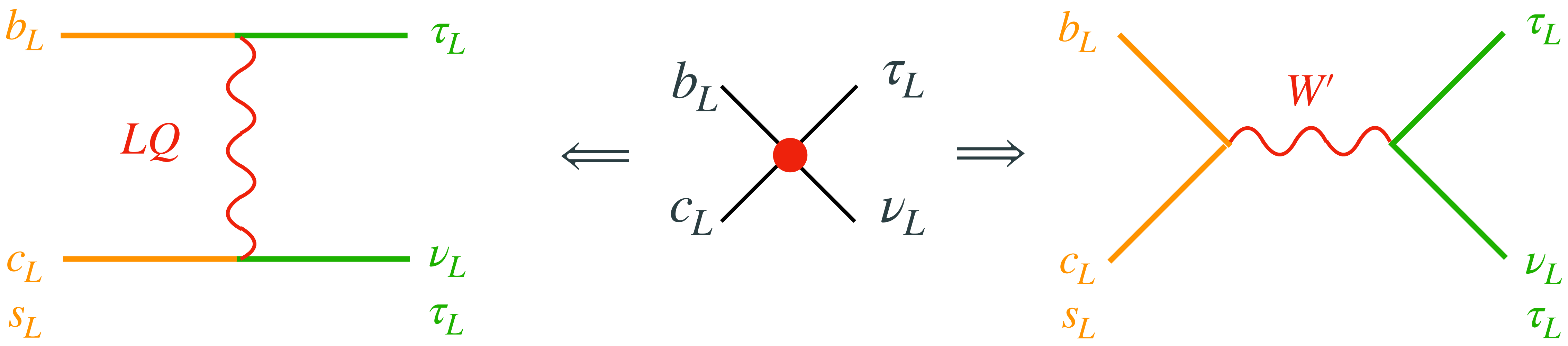
$$\mathscr{A}_{\mathrm{NP}} \sim \frac{1}{\Lambda_{\mathrm{NP}}^2}$$

- The charged current *B*-anomalies are calling for a low NP scale!

$$2\frac{\mathscr{A}_{\mathrm{NP}}}{\mathscr{A}_{\mathrm{SM}}} = \frac{v^2}{V_{cb}\Lambda_{\mathrm{NP}}^2} \approx \delta R_{D*} \implies \Lambda_{\mathrm{NP}} \approx \frac{v}{\sqrt{V_{cb}\,\delta R_{D*}}} \approx 3.6\ \mathrm{TeV}\left(\frac{0.12}{\delta R_{D*}}\right)^{1/2}$$

**Low NP scale for CC anomaly drives connection to high-p_T !*

What kind of new particles could we have?

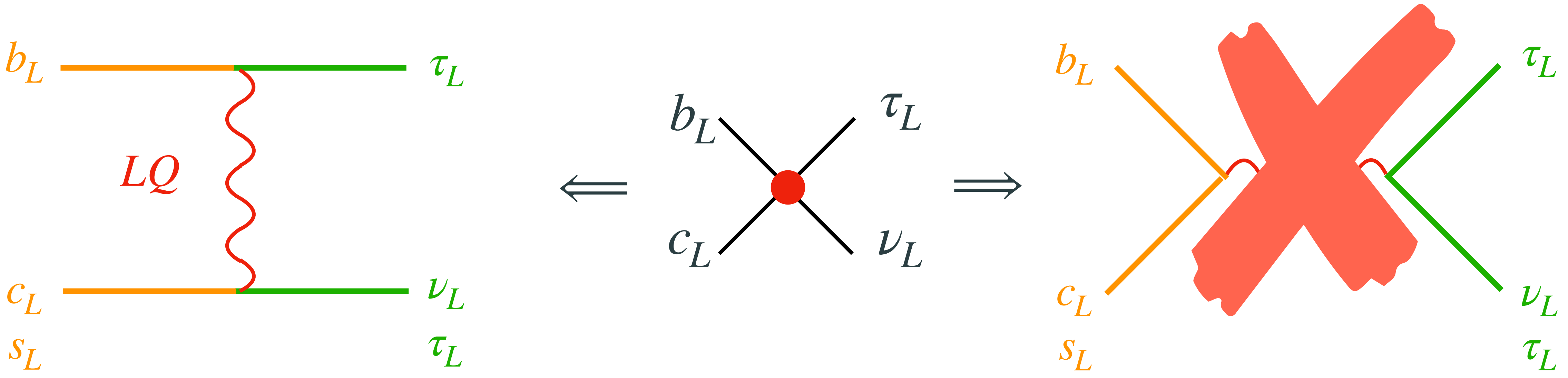


- LH NP $\Longrightarrow$ $b \to s\tau\tau(\nu\nu)$ couplings. LQ's have two important advantages

1. $\Delta F = 2:$

2. **Direct searches:** t-channel versus resonant s-channel production

What kind of new particles could we have?



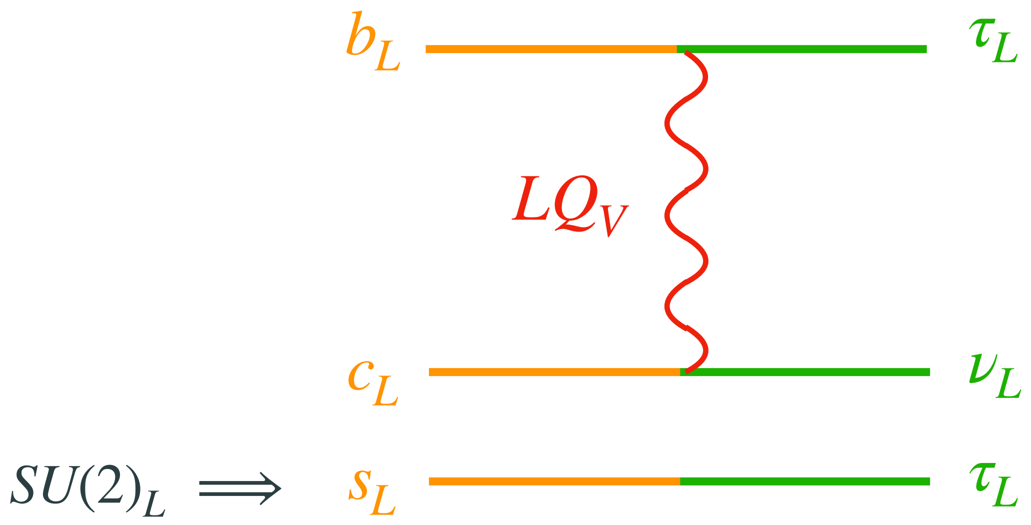
- LH NP $\Longrightarrow$ $b \to s\tau\tau(\nu\nu)$ couplings. LQ's have two important advantages

1. $\Delta F = 2:$

2. **Direct searches:** t-channel versus resonant s-channel production

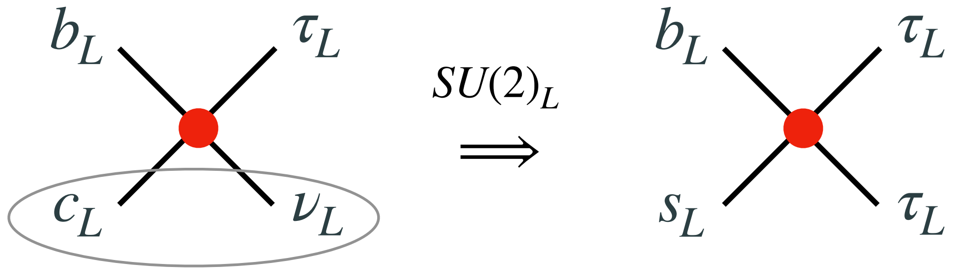
Which leptoquark?

- Focus here on two possible options: U_1 vector LQ and S_1 scalar LQ.



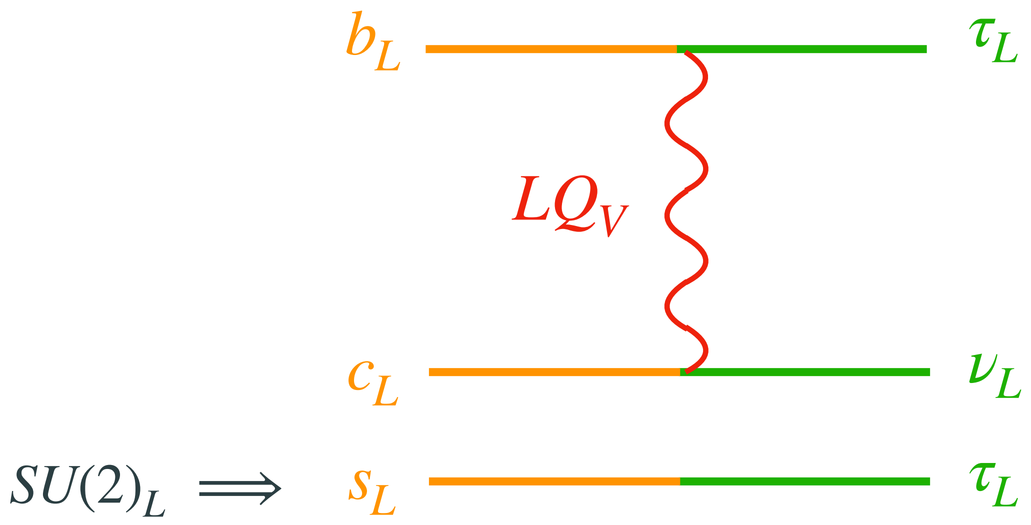
$$U_1 \sim (3,1,2/3)$$

- Vector LQ
- Tree level: $b \to c\tau\nu + b \to s\tau\tau$

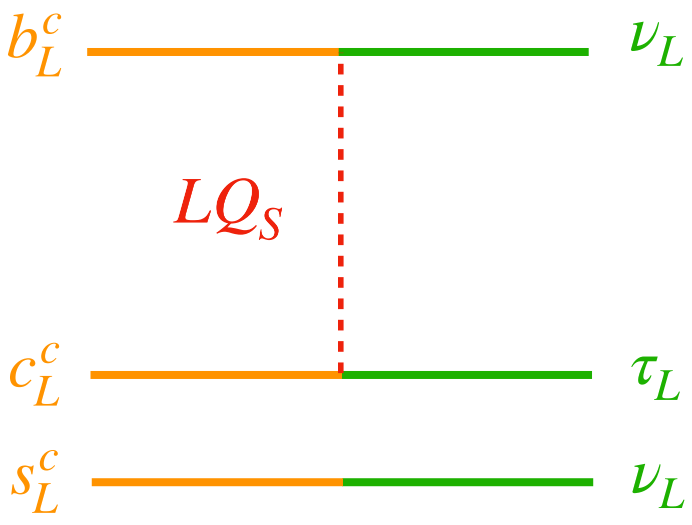


Which leptoquark?

- Focus here on two possible options: U_1 vector LQ and S_1 scalar LQ.

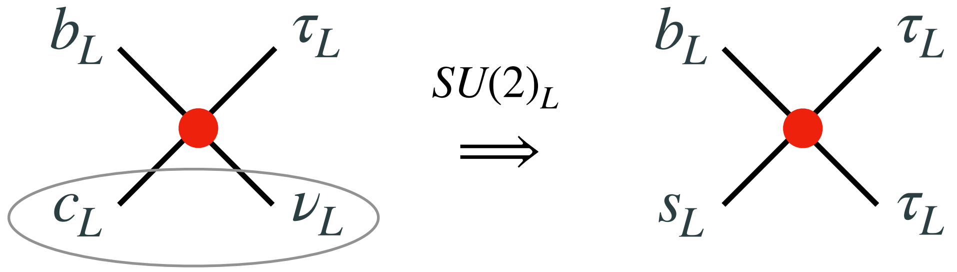


$$U_1 \sim (3,1,2/3)$$

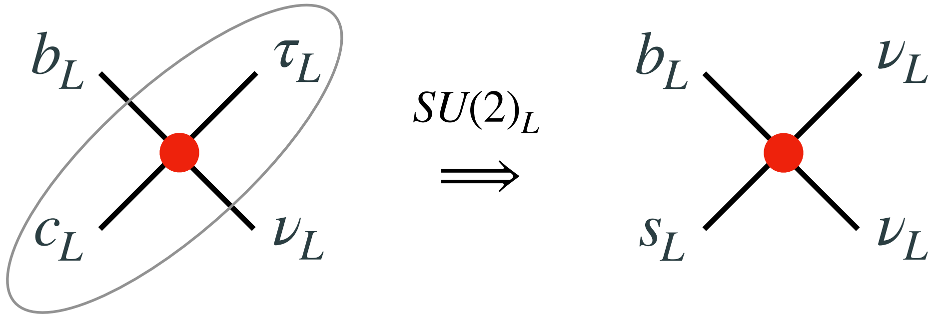


$$S_1 \sim (\bar{3},1,1/3)$$

- Vector LQ
- Tree level: $b \to c\tau\nu + b \to s\tau\tau$



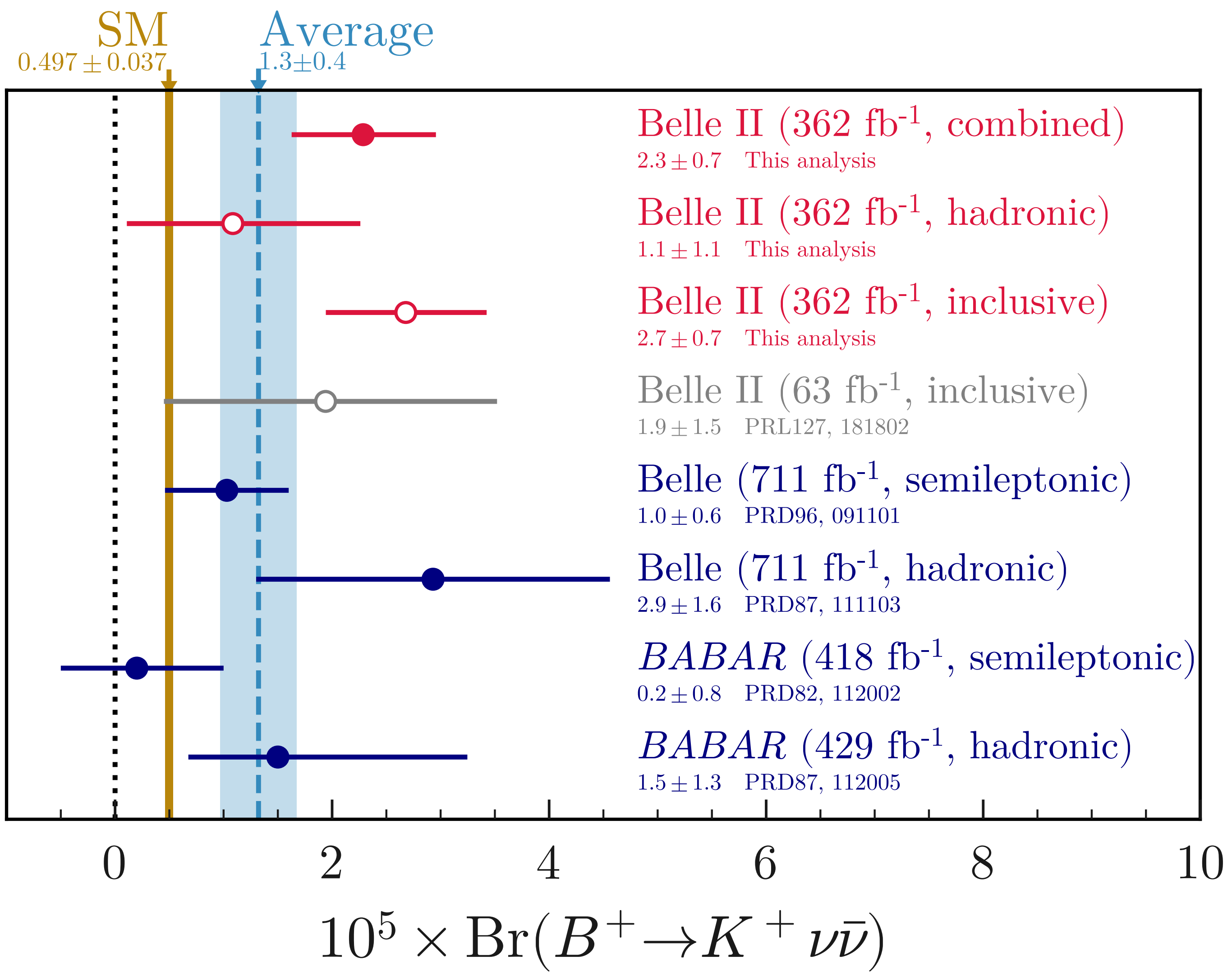
- Scalar LQ
- Tree level: $b \to c\tau\nu + b \to s\nu_\tau\nu_\tau$



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

$B^+ \to K^+\nu\bar{\nu}$ measurement from Belle II

- Belle II has updated the measurement of $\mathscr{B}(B^+ \to K^+\nu\bar{\nu})$ with 362/fb of data. For details of the analysis: See Sally's talk



[Belle II Collaboration, 2311.14647]

$$R^{\nu}_{K^{(*)}} = \frac{\mathscr{B}(B \to K^{(*)}\nu\bar{\nu})}{\mathscr{B}(B^+ \to K^{(*)}\nu\bar{\nu})_{\mathrm{SM}}}$$

Belle II (362/fb combined):

$$R^{\nu}_{K^+} = 4.6 \pm 1.4$$

Average of measurements:

$$R^{\nu}_{K^+} = 2.6 \pm 0.8$$

Belle II combination is 2.6σ above the SM, while the average is 2σ above.

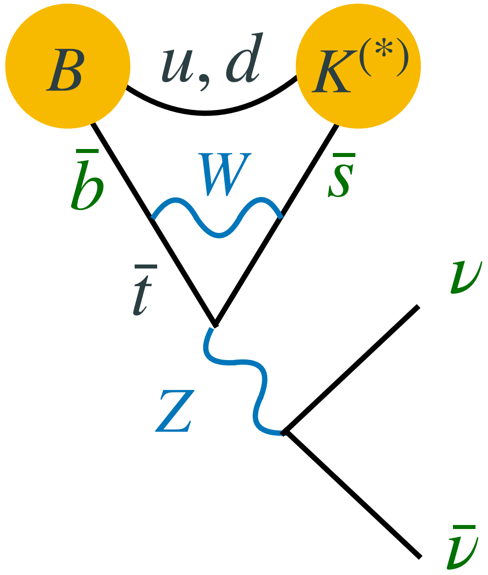
New physics in $b \to s\nu\bar{\nu}$ decays

- We need 2-3x a SM loop process due to NP. Large effect means heavy NP likely tree-level to compete. Consider Fermi-like LH NP:

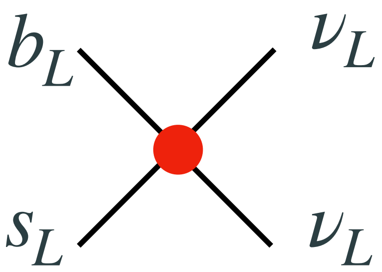
SM process

$$C_\nu^{\mathrm{SM}} \approx -1.47$$

$$\mathscr{A}_{\mathrm{SM}} \sim \frac{\alpha_L}{\pi v^2} V_{tb} V_{ts}^* \, C_\nu^{\mathrm{SM}}$$



Heavy new physics



$$\mathscr{A}_{\mathrm{NP}} \sim \frac{1}{\Lambda_{\mathrm{NP}}^2}$$

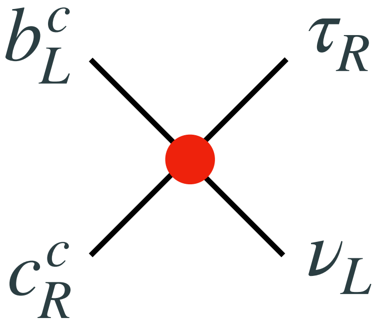
- If we assume a new physics effect ONLY in tau neutrinos:

$$R^\nu_{K^{(*)}} = \frac{2}{3} + \frac{1}{3}\left|1 + \frac{\mathscr{A}_{\mathrm{NP}}}{\mathscr{A}_{\mathrm{SM}}}\right|^2 \implies \Lambda_{\mathrm{NP}} \approx 8.1 \ \mathrm{TeV} \qquad (R^\nu_{K^{(*)}} = 2.6)$$

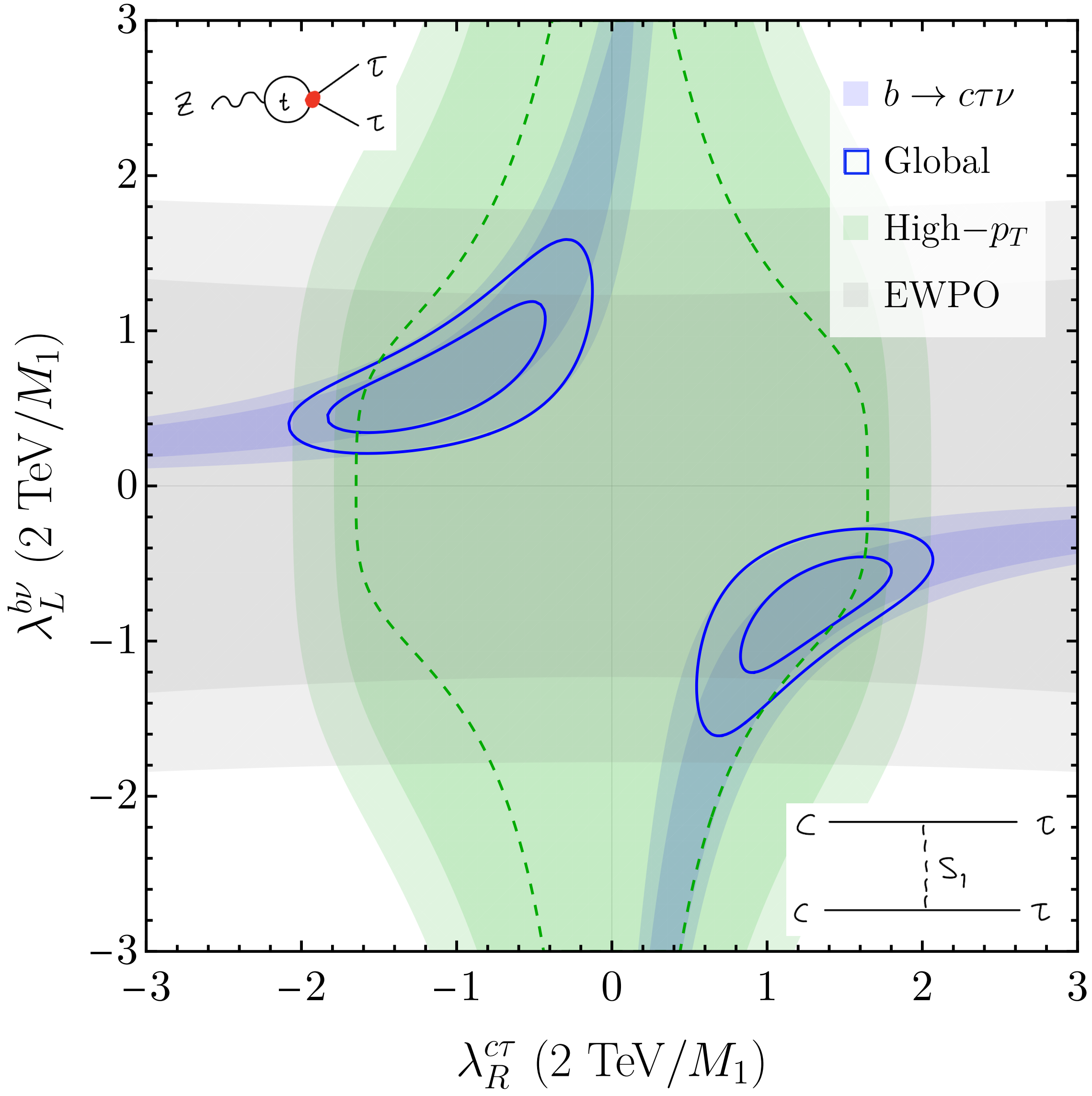
$\Lambda_{\mathrm{NP}} \approx 650$ GeV (loop)

Simplified S_1 scalar LQ model and fit

$$C_{V_L},\, C_{S_L} = -4C_T$$



$$\mathcal{L} \supset \overbrace{\underbrace{\lambda_L^{b\nu}\,\bar q_L^{c3}\epsilon\ell_L^3\, S_1 + \lambda_L^{s\nu}}_{B \to K\nu\bar\nu}\,\bar q_L^{c2}\epsilon\ell_L^3\, S_1 + \lambda_R^{c\tau}}^{b \to c\tau\nu}\,\bar c_R^c\tau_R\, S_1$$



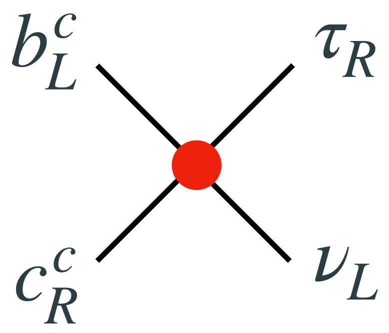
*This model can contribute to $B_{d,s} \to K^{(*)}\bar K^{(*)}$: [Lizana, Matias, BAS, 2306.09178]

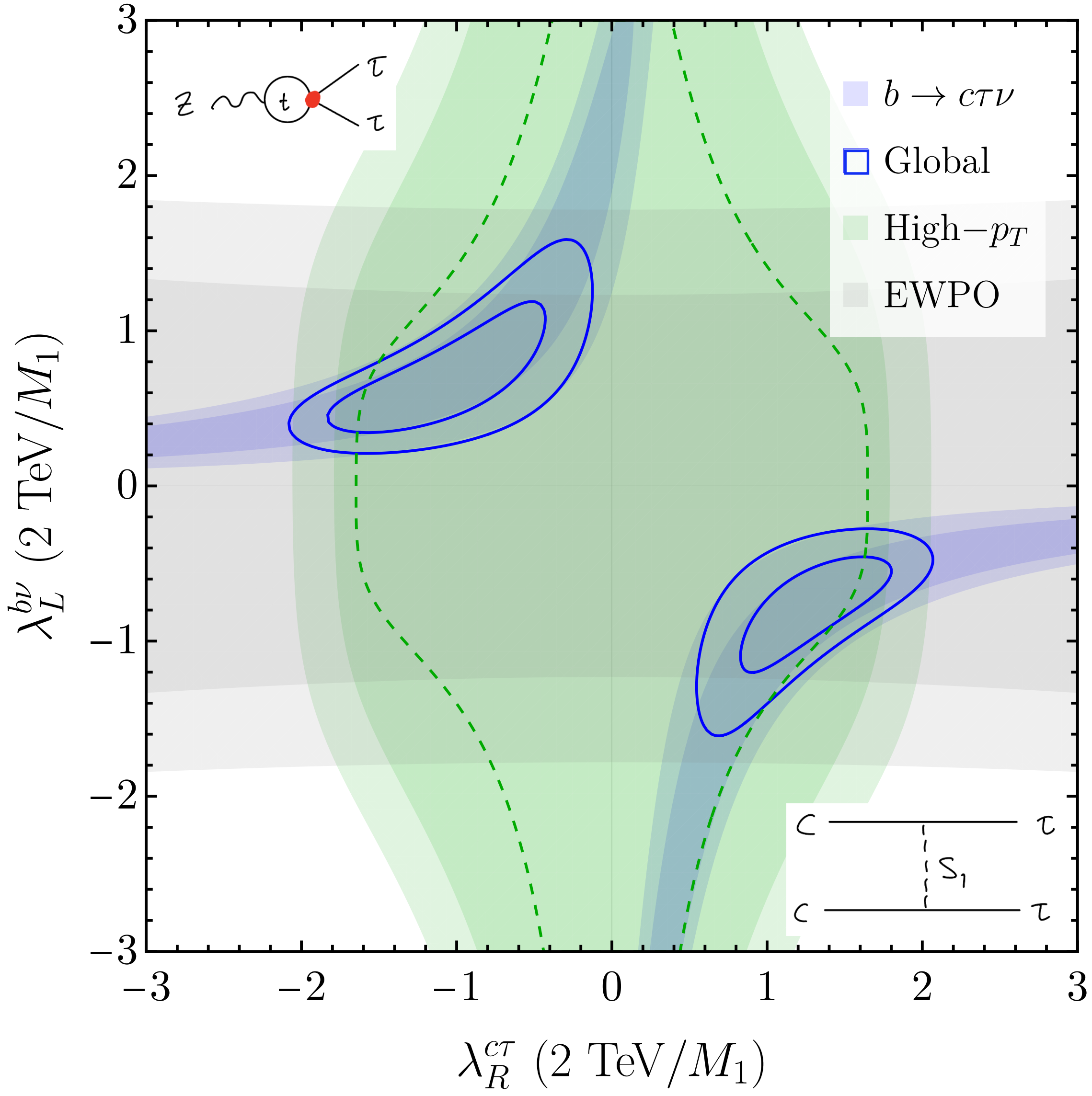
See Davide's talk

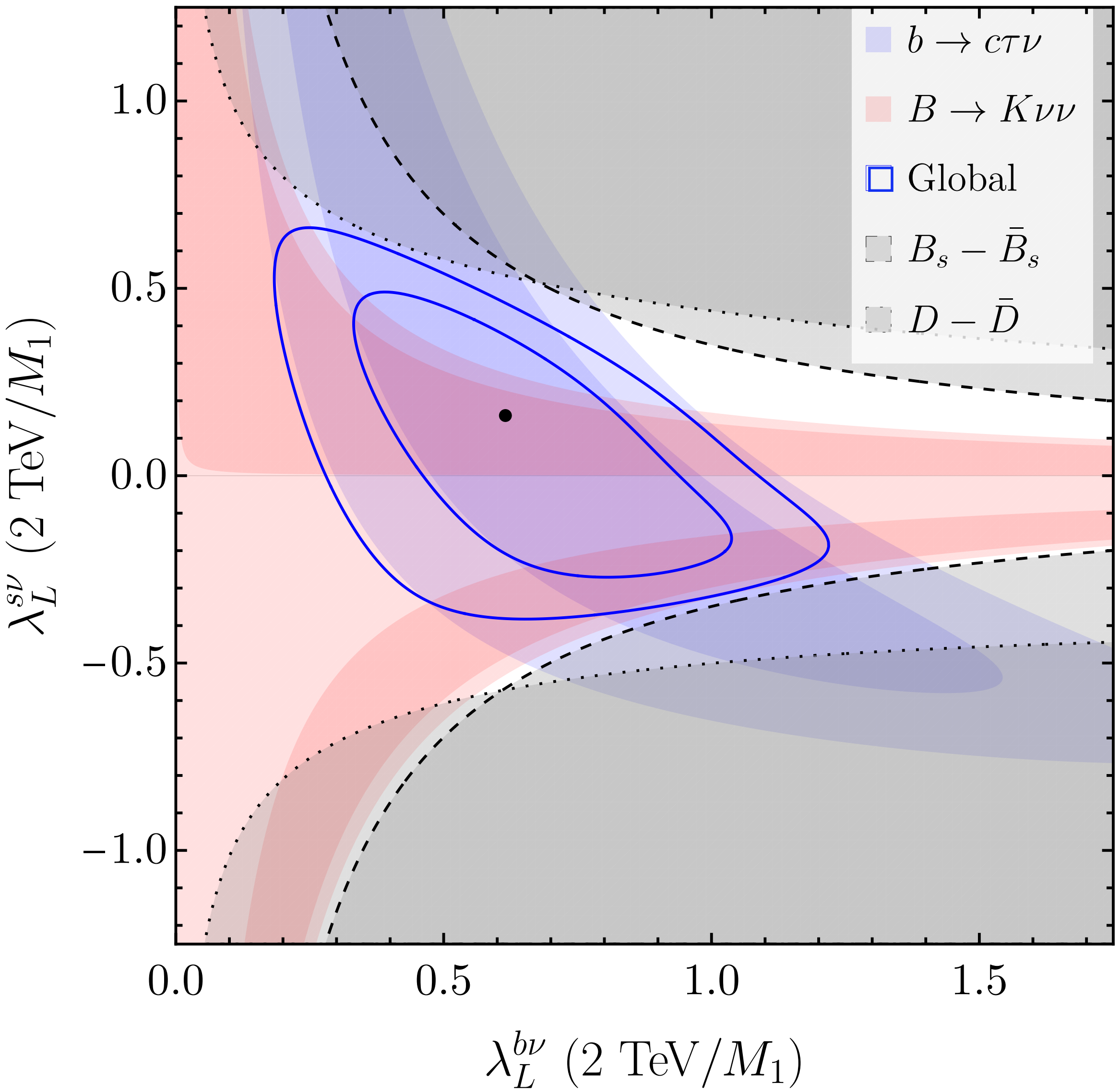
Simplified S_1 scalar LQ model and fit

$C_{V_L}, C_{S_L} = -4C_T$

$$\mathscr{L} \supset \overbrace{\underbrace{\lambda_L^{b\nu}\,\bar q_L^{c3}\epsilon\ell_L^3 S_1 + \lambda_L^{s\nu}}_{B\to K\nu\bar\nu}\,\bar q_L^{c2}\epsilon\ell_L^3 S_1 + \lambda_R^{c\tau}}^{b\to c\tau\nu}\,\bar c_R^c\tau_R S_1$$







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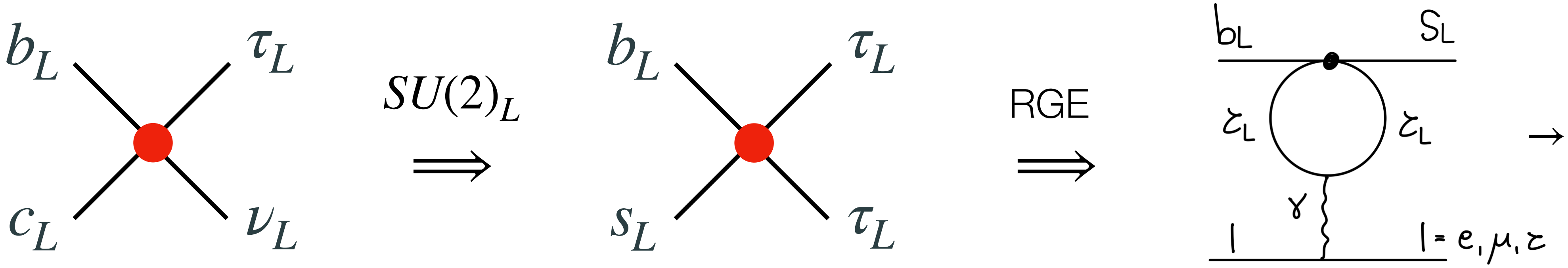
See Davide's talk

Connecting $b \to c\tau\nu$ and $b \to s\ell\ell$

Connection: $b \to c\tau\nu$ and $b \to s\mu\mu$

- Some mediators that explain the charged-current anomalies give a *flavor-universal* effect in $b \to s\ell\ell$ via RGE. *Discussed also in Mauro's talk*



$$\to \Delta C_9^U = C_9^U - C_9^{\rm SM}$$

$$\mathscr{L}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i C_i^\ell O_i^\ell \qquad O_9^\ell = (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \ell)$$

- Leading-log running gives

$$\Delta C_9^U = \frac{v_{\rm EW}^2}{3V_{tb}V_{ts}^*}\left([C_{lq}^{(3)}]_{3323} + [C_{lq}^{(1)}]_{3323}\right)\log\left(\frac{m_b^2}{M^2}\right)$$

[Bobeth, Haisch, 1109.1826; Crivellin et al., 1807.02068; Algueró et al., 1809.08447]

Connection: $b \to c\tau\nu$ and $b \to s\mu\mu$

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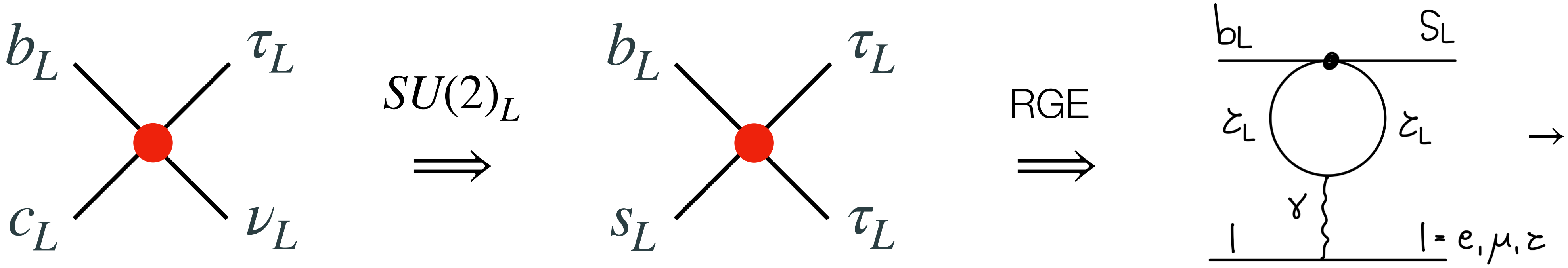

$\to \Delta C_9^U = C_9^U - C_9^{\mathrm{SM}}$

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U_1 ✓	S_1 ✗
$C_{lq}^{(3)} = C_{lq}^{(1)}$	$C_{lq}^{(3)} = -C_{lq}^{(1)}$

[Bobeth, Haisch, 1109.1826; Crivellin et al., 1807.02068; Algueró et al., 1809.08447]

Simplified model for U_1 leptoquark

$U_1 \sim (\mathbf{3}, \mathbf{1}, 2/3)$

$$\mathscr{L} \supset \frac{g_U}{\sqrt{2}} U_1^\mu \left[(\bar{q}_L^3 \gamma_\mu \ell_L^3) + \underset{\uparrow}{\beta_L^{s\tau}} (\bar{q}_L^2 \gamma_\mu \ell_L^3) + \beta_R^{b\tau} (\bar{b}_R \gamma_\mu \tau_R) \right] + \mathrm{h.c.}$$

$U(2)_q$-breaking $\sim O(V_{cb})$

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Integrate out the U_1 LQ: $\frac{1}{\Lambda_{\mathrm{NP}}^2} = \frac{g_U^2}{2M_U^2}$

RUNNING to EW SCALE + MATCHING

$$\mathcal{L}_{b\to c\tau\bar{\nu}} = -\frac{2}{v^2} V_{cb} \left[\left(1 + C_{LL}^c\right) (\bar{c}_L \gamma_\mu b_L)(\bar{\tau}_L \gamma^\mu \nu_L) - 2\, C_{LR}^c\, (\bar{c}_L b_R)(\bar{\tau}_R \nu_L) \right]$$

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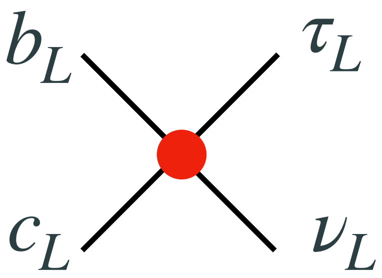
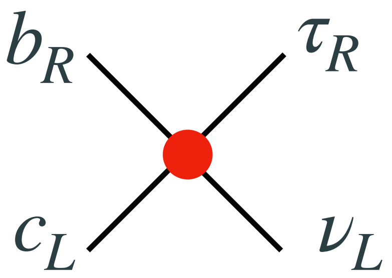
Contact interaction:



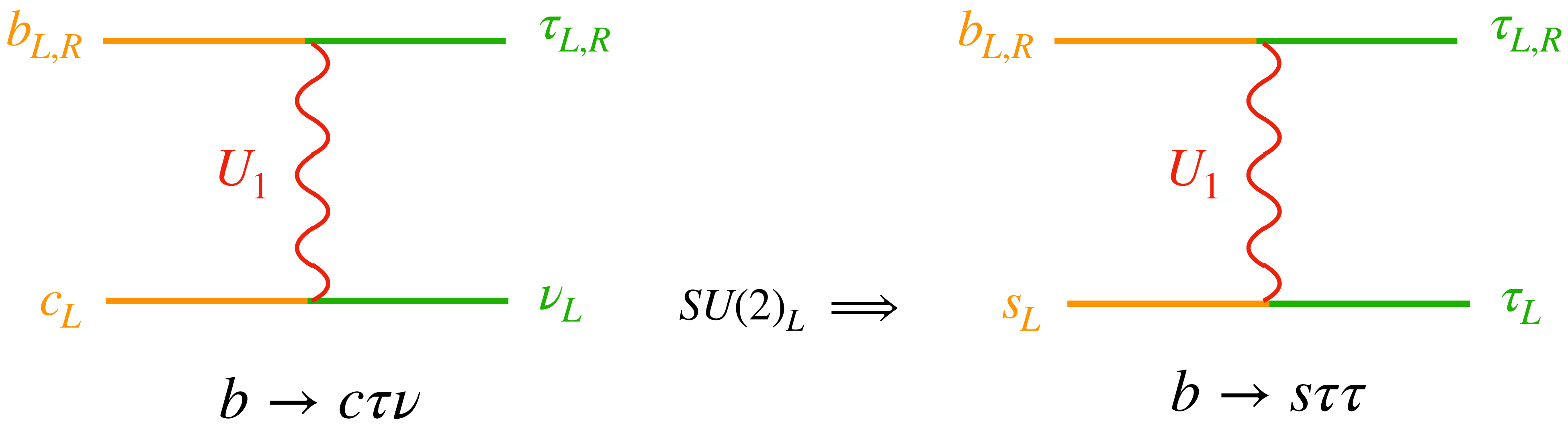


Low-energy WC's ↔ Model parameters:

$$C_{LL}^c = \frac{g_U^2 v^2}{4M_U^2} \left(1 + \frac{V_{cs}}{V_{cb}} \beta_L^{s\tau}\right), \qquad C_{LR}^c = \beta_R^{b\tau*} C_{LL}^c$$

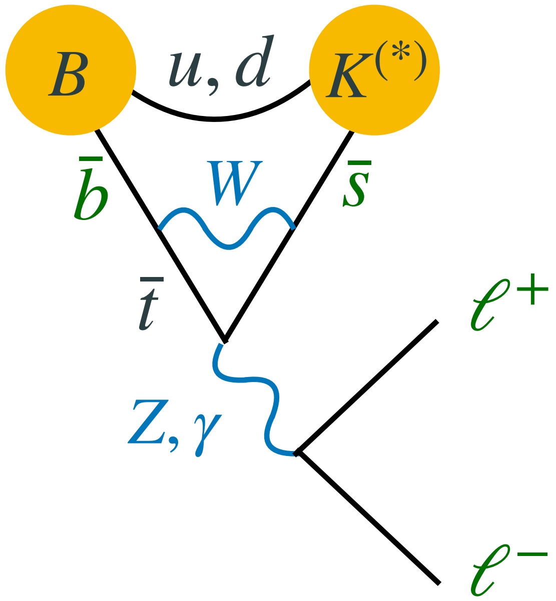
U_1 connects $R_{D^{(*)}}$ to $b \to s\tau\tau$ observables

- We have tree-level effects in $b \to s\tau\tau$ connected to the size of $R_{D^{(*)}}$



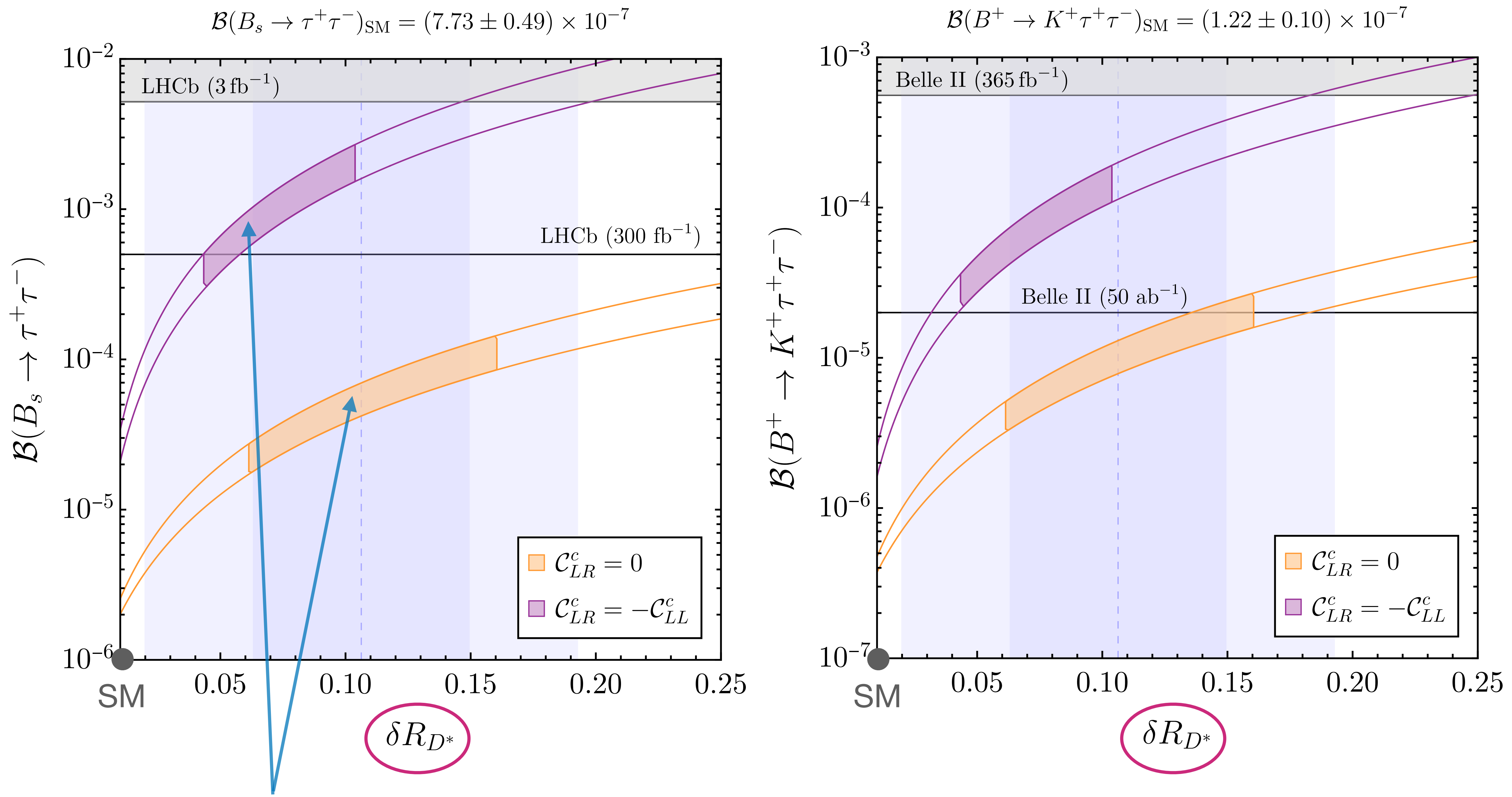
- Since $b \to s\tau\tau$ is a FCNC, it is a 1-loop process in the SM. We therefore expect a huge NP enhancement in $b \to s\tau\tau$!

$$\frac{\mathscr{B}(B \to K^{(*)}\tau\tau)}{\mathscr{B}(B \to K^{(*)}\tau\tau)_{\mathrm{SM}}} \sim 16\pi^2 \frac{R_{D^{(*)}}}{R_{D^{(*)}}^{\mathrm{SM}}}$$



U_1 connects $R_{D^{(*)}}$ to $b \to s\tau\tau$ observables

- For the latest experimental results, see the *talk by Hanae and Stefano* 👁

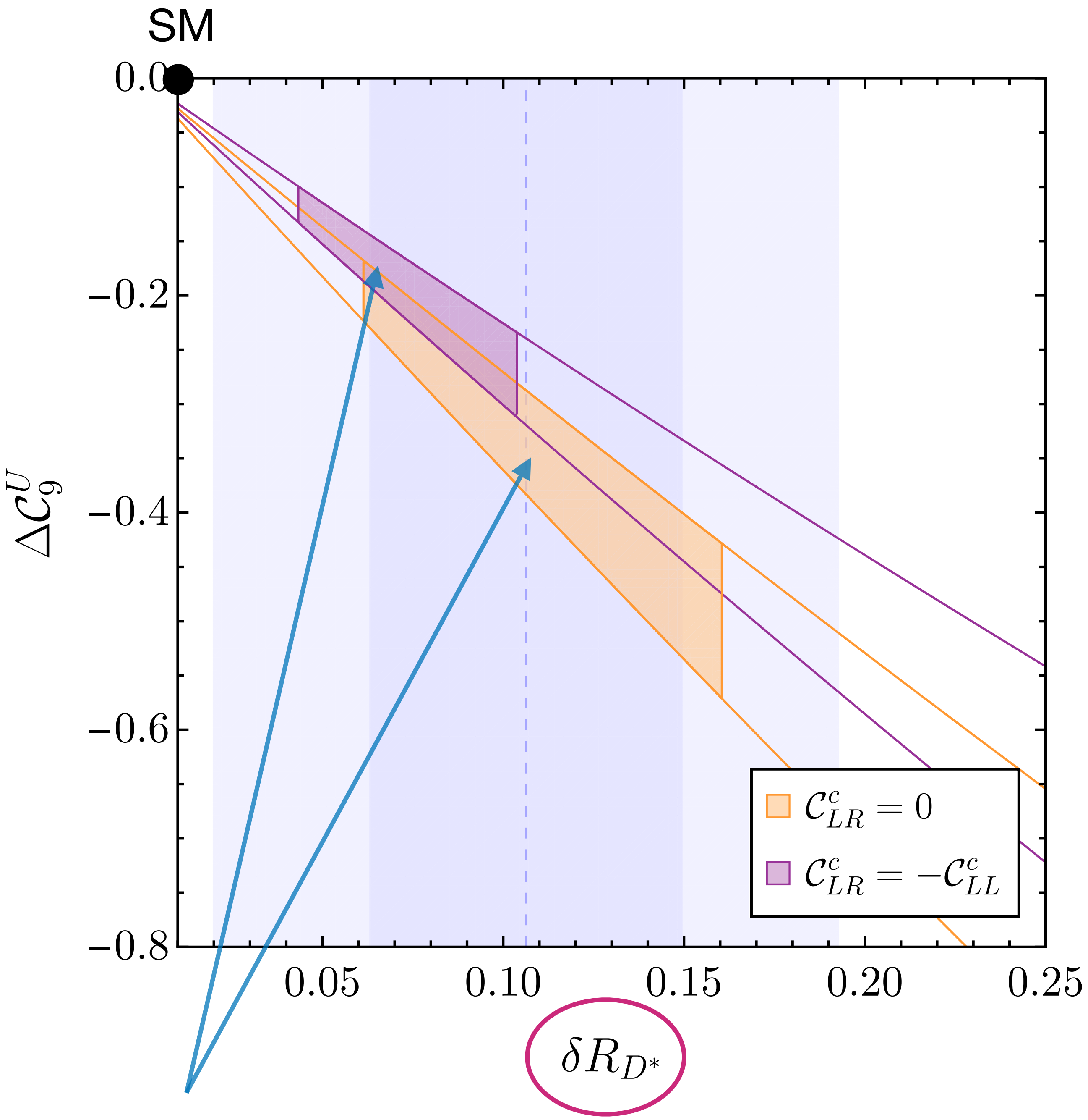


HFLAV ’25 updated 90% CL region preferred by low-energy $b \to c\tau\nu$ data

[J. Aebischer, G. Isidori, M. Pesut, BAS, F. Wilsch, 2210.13422]

U_1 connects $R_{D^{(*)}}$ to universal $b \to s\ell\ell$ observables

- Large $b \to s\tau\tau$ implies a sizable *flavor-universal* loop effect in $b \to s\ell\ell$!

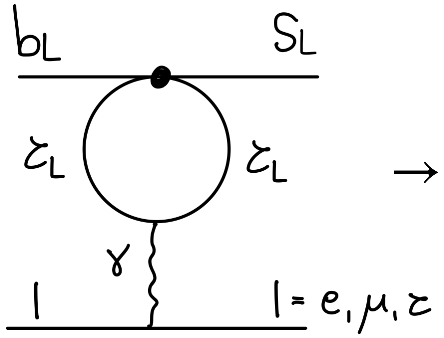


HFLAV ’25 updated 90% CL region preferred by low-energy $b \to c\tau\nu$ data

$$\mathscr{L}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \frac{\alpha}{4\pi} \sum_i C_i^\ell O_i^\ell$$

$$O_9^\ell = (\bar{s}_L \gamma_\mu b_L)(\bar{\ell} \gamma^\mu \ell)$$

RGE $\Longrightarrow$



$\to \Delta C_9^U = C_9^U - C_9^{\text{SM}}$

Global Fits to $b \to s\ell^+\ell^-$ data:
$\Delta C_9^U \sim -C_9^{\text{SM}}/4$

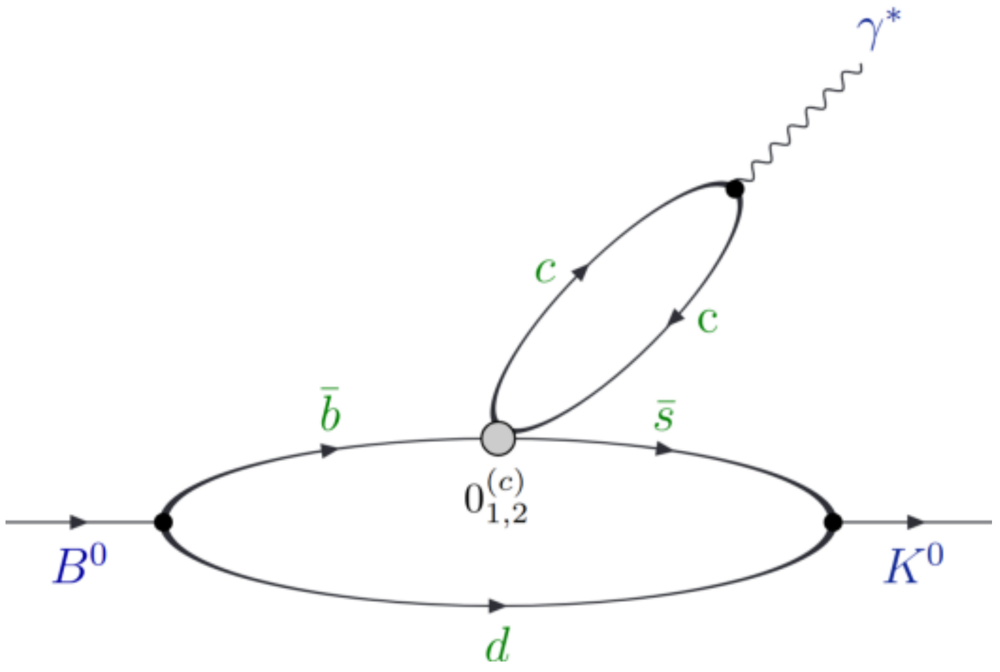
**For more, see Mauro’s talk*

[J. Aebischer, G. Isidori, M. Pesut, BAS, F. Wilsch, 2210.13422]

Resolving the $b \to s\mu\mu$ anomalies

- Excellent talks by *Enrico and Luca* 👁. Seems we have both theoretical and experimental paths to resolve these anomalies:

Charming Penguins on the Lattice



- *Theoretical framework that allows, in principle, to evaluate the long-distance contributions on the lattice.*
- *Proof of principle calculation of a single charming-penguin diagram, for now in an unphysical setup. But gives encouraging results in the large-q^2 region.*

[Frezzotti et. al, 2508.03655]

Inclusive $B \to X_s \ell\ell$ Measurements

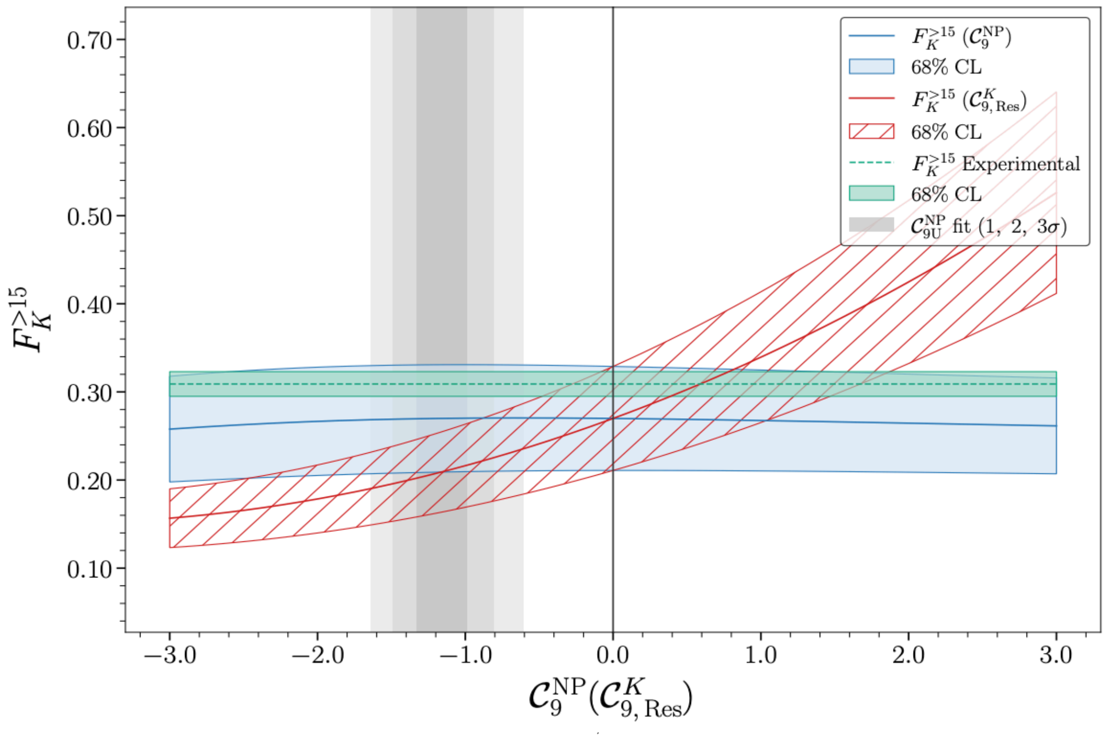
- The inclusive calculations that we need for current phenomenology are:

$$\mathcal{B}[1,6]_{\ell\ell} = (17.4 \pm 1.3) \times 10^{-7} \qquad [7.4\%]$$

$$\mathcal{B}[>15]_{\text{no QED}} = (2.59 \pm 0.68) \times 10^{-7} \qquad [26\%]$$

$$\mathcal{R}(15)_{\text{no QED}} = (17.00 \pm 1.9) \times 10^{-4} \qquad [7.2\%]$$

- In order to use $\mathcal{R}(15)$ we need the $B \to X_u \ell\nu$ normalization:



$$[\mathcal{F}_K^{>15}]_{\rm exp} = \left[1 + \frac{\mathcal{B}(K^*\mu\mu) + \mathcal{B}((K\pi)_S\mu\mu) + \mathcal{B}(B \to K\pi\pi\mu\mu)}{\mathcal{B}(K\mu\mu)}\right]^{-1}$$

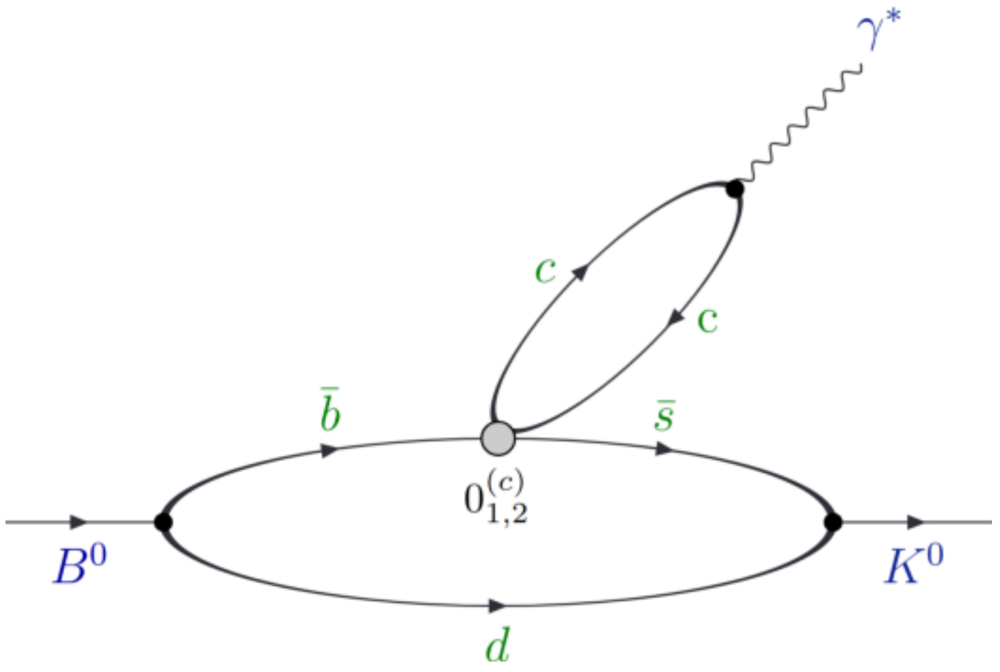
$$= 0.309 \pm 0.015$$

[LHCb, CMS]

Resolving the $b \to s\mu\mu$ anomalies

- Excellent talks by *Enrico and Luca* 👁. Seems we have both theoretical and experimental paths to resolve these anomalies:

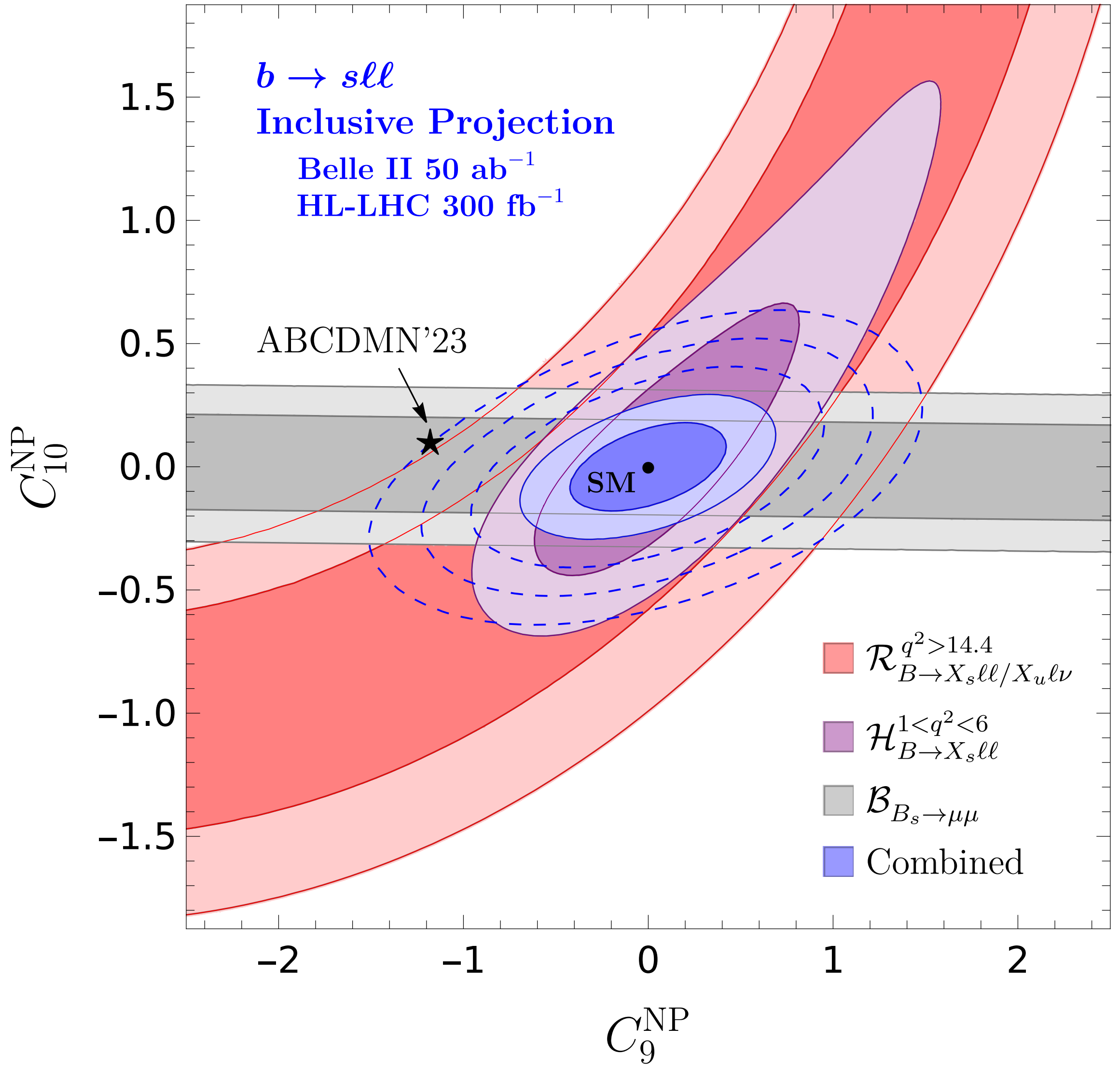
Charming Penguins on the Lattice



- *Theoretical framework that allows, in principle, to evaluate the long-distance contributions on the lattice.*
- *Proof of principle calculation of a single charming-penguin diagram, for now in an unphysical setup. But gives encouraging results in the large-q^2 region.*

[Frezzotti et. al, 2508.03655]

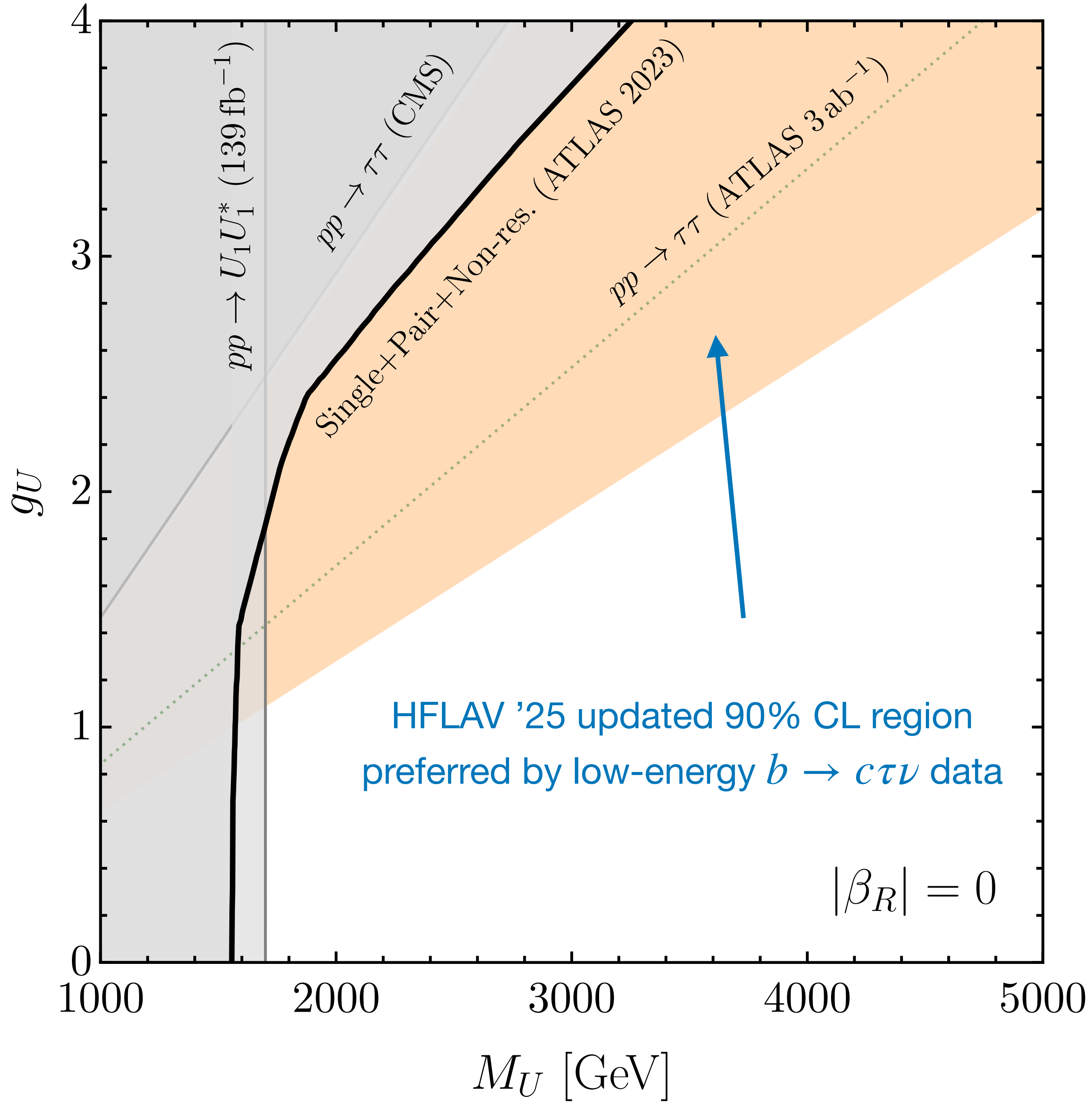
Inclusive $B \to X_s \ell\ell$ Measurements



[Huber, Hurth, Jenkins, Lunghi, Qin, 2404.03517]

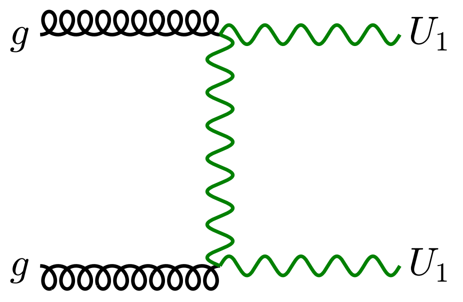
High-energy searches: U_1 leptoquark model (LH)

- Of course, eventually we need to see something at high-pT. The LHC is already probing relevant parameter space.



HFLAV '25 updated 90% CL region preferred by low-energy $b \to c\tau\nu$ data

U_1 pair production

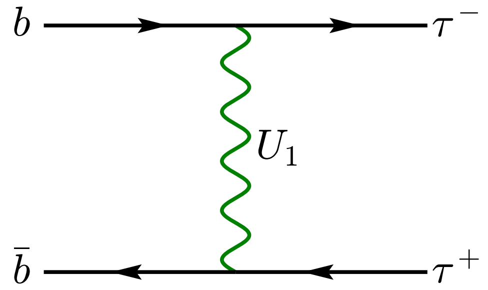


$U_1 \to b\tau^+, t\bar{\nu}$

$\mathscr{B}(U_1 \to b\tau^+) \approx 0.5$

$pp \to U_1^+ U_1^- \to b\tau\, t\nu$

Drell-Yan t-channel exchange: $\tau\tau$



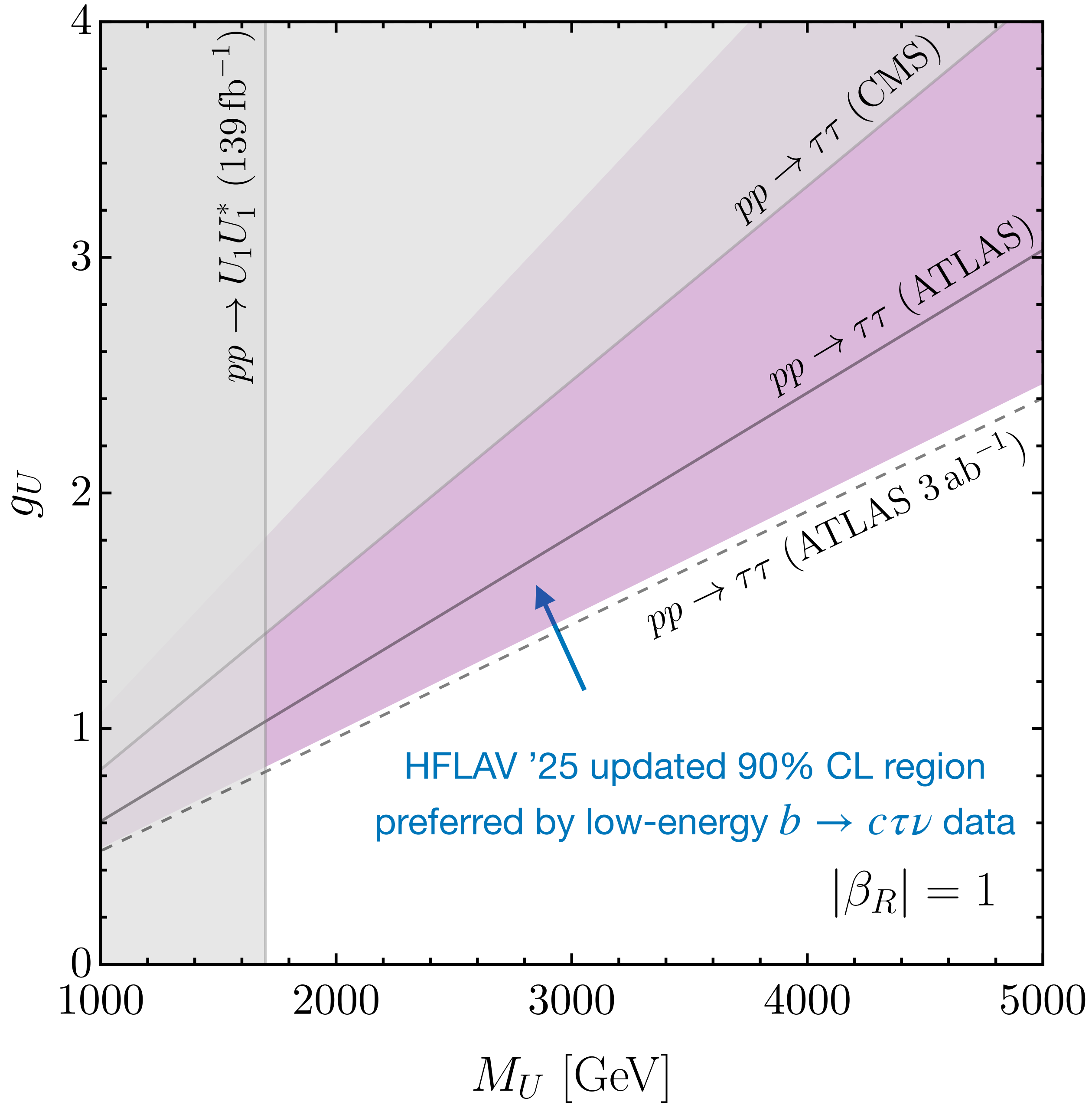
High mass Drell-Yan tails

QCD corrections: [U. Haisch, L. Schnell, S. Schulte, 2209.12780]

[J. Aebischer, G. Isidori, M. Pesut, BAS, F. Wilsch, 2210.13422]

High-energy searches: U_1 leptoquark model (L&R)

- U_1 LQ model w/ RH currents preferred region fully within the HL-LHC reach!

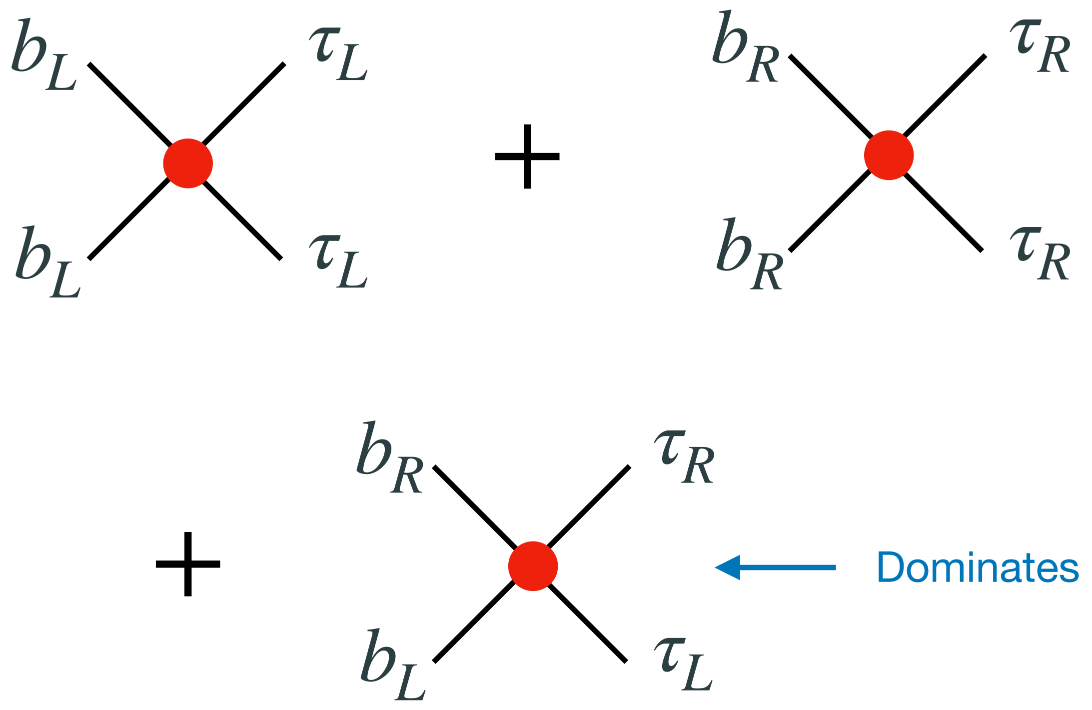


HFLAV '25 updated 90% CL region preferred by low-energy $b \to c\tau\nu$ data

$|\beta_R| = 1$

$$\mathcal{L} \supset \frac{g_U}{\sqrt{2}} U_1^\mu \left[(\bar{q}_L^3 \gamma_\mu \ell_L^3) + \beta_R^{b\tau} (\bar{b}_R \gamma_\mu \tau_R) \right] \quad (\beta_R^{b\tau} = -1)$$

- Additional RH contributions give stronger bound from t-channel Drell-Yan $\tau\tau$:



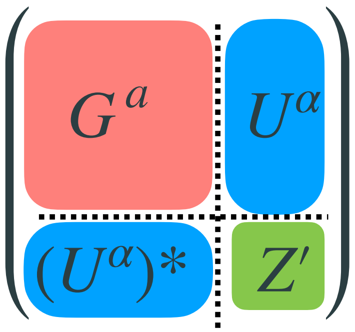
Dominates

[J. Aebischer, G. Isidori, M. Pesut, BAS, F. Wilsch, 2210.13422]

UV Completion for the U_1 Leptoquark

UV Model: New flavor non-universal gauge interactions

Based on "4321" gauge symmetry:



$$SU(4) \sim \begin{pmatrix} G^a & U^\alpha \\ (U^\alpha)^* & Z' \end{pmatrix}$$

$$\overbrace{\underbrace{SU(4)_h \times SU(3)_l}_{SU(3)_c} \times SU(2)_L \times U(1)_{l+R}}^{U(1)_Y} \xrightarrow{\langle \Omega_{1,3,15} \rangle \sim \mathcal{O}(\text{TeV})} SU(3)_c \times SU(2)_L \times U(1)_Y \quad + U_1, G', Z'$$

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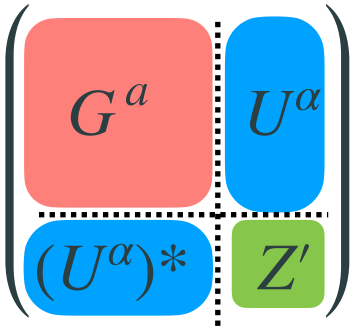
Based on "4321" gauge symmetry:

$SU(4) \sim$



$$\left(\begin{array}{c|c} G^a & U^\alpha \\ \hline (U^\alpha)^* & Z' \end{array}\right)$$

$$\overbrace{\underbrace{SU(4)_h \times SU(3)_l}_{SU(3)_c} \times SU(2)_L \times U(1)_{l+R}}^{U(1)_Y} \xrightarrow{\langle \Omega_{1,3,15} \rangle \sim \mathcal{O}(\text{TeV})} SU(3)_c \times SU(2)_L \times U(1)_Y \quad + U_1, G', Z'$$

Third-family quark-lepton unification at the TeV scale: [Greljo, BAS, 1802.04274]

$$\psi_L \sim \begin{pmatrix} q_L^3 \\ \ell_L^3 \end{pmatrix} \qquad \psi_R^+ \sim \begin{pmatrix} u_R^3 \\ \nu_R^3 \end{pmatrix} \qquad \psi_R^- \sim \begin{pmatrix} d_R^3 \\ e_R^3 \end{pmatrix}$$

- 3rd family charged under $SU(4)_h$
  $\Longrightarrow$ Direct NP couplings (L+R)
- Light families under 321 (SM-like)
- Accidental approximate $U(2)^5$ flavor symmetry: $\psi = (\boxed{\psi_1\ \psi_2}\, \boxed{\psi_3})$
- Good starting point for CKM

Leptons as the fourth "color"

[Pati, Salam, Phys. Rev. D10 (1974) 275]
(only 7 years after the SM was proposed)

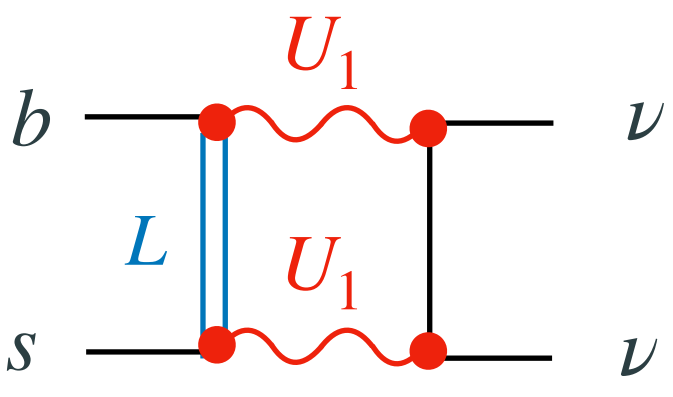
$$\psi_{L,R} = \begin{bmatrix} q^1_{L,R} \\ q^2_{L,R} \\ q^3_{L,R} \\ l_{L,R} \end{bmatrix}$$

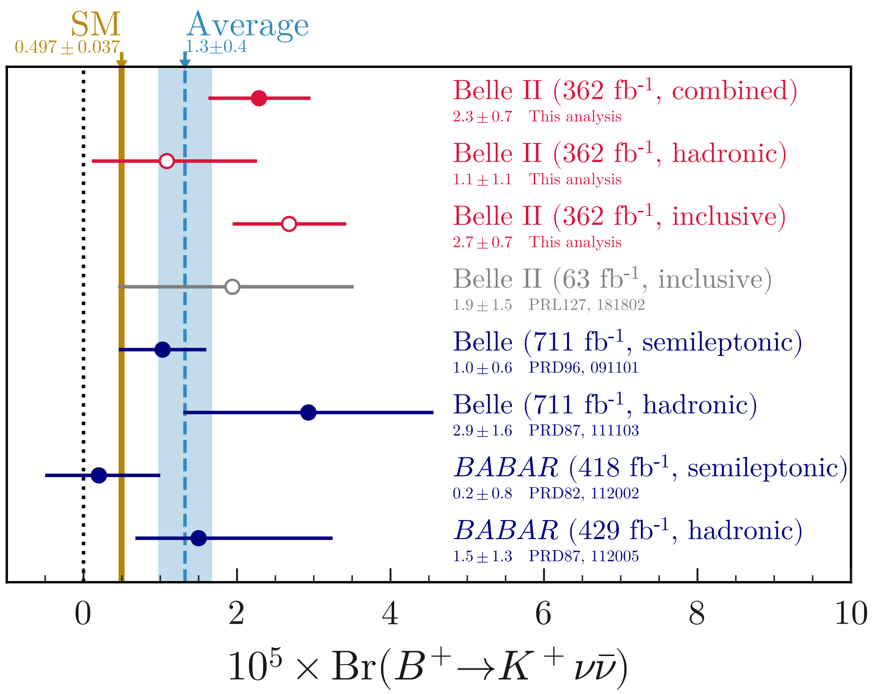
4321 models

[di Luzio, Greljo, Nardecchia 1708.08450
Bordone, Cornella, Fuentes-Martin, Isidori
1712.01368, 1805.09328;
Greljo, BAS, 1802.04274;
Cornella, Fuentes-Martin, Isidori 1903.11517]

Important 1-loop effects: $B \to K^{(*)}\nu\nu$ (4321 Model)

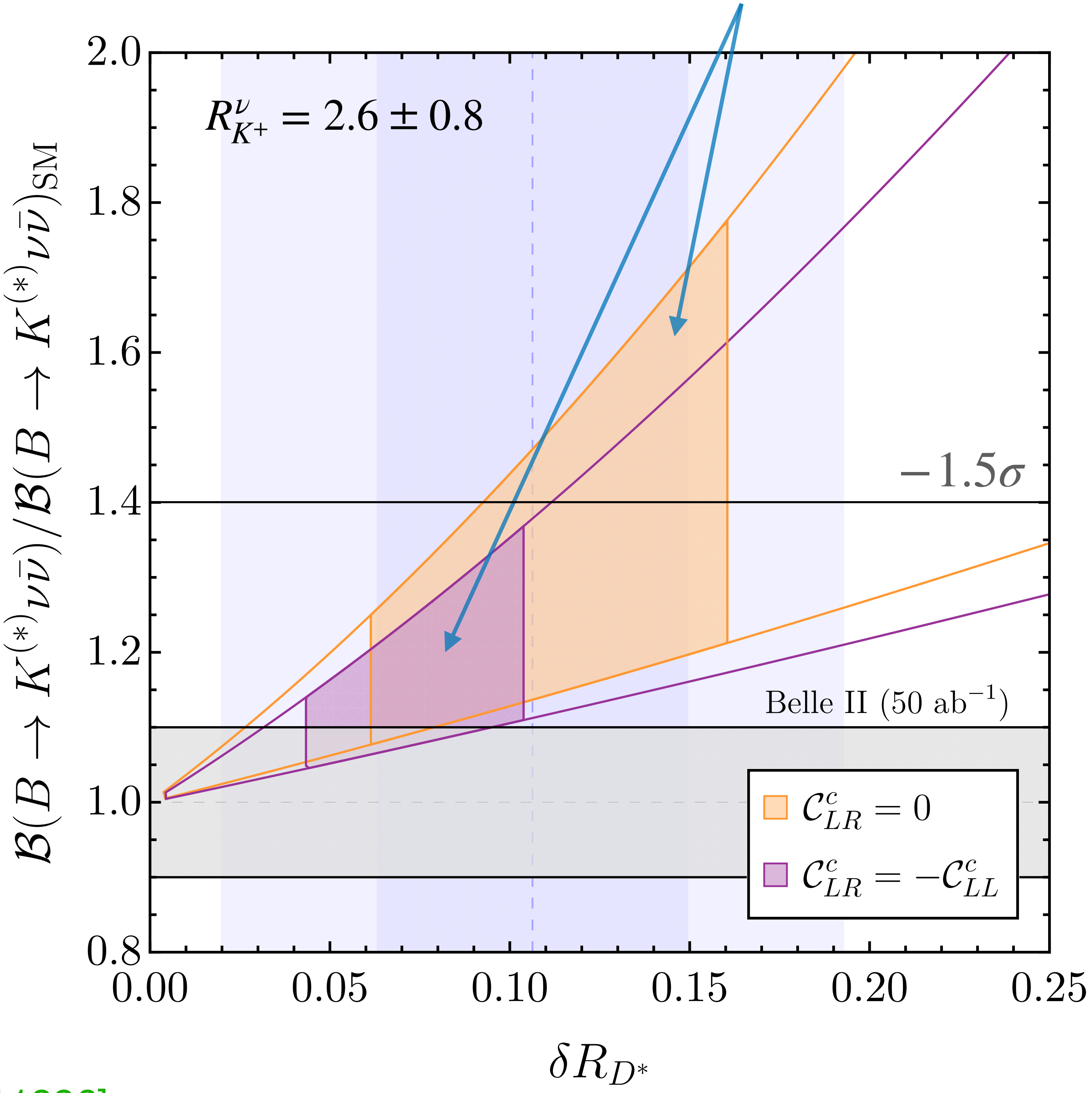
- Some (important) effects appear only at one loop. For U_1, requires UV model!





[Belle II Collaboration, 2311.14647]

HFLAV '25 updated 90% CL region preferred by low-energy $b \to c\tau\nu$ data



[Fuentes-Martin, Isidori, König, Selimovic, 2009.11296]

Conclusions

- Longstanding anomalies in $b \to c\tau\nu$ and $b \to s\mu\mu$ remain unresolved. Recently updated $b \to s\nu\bar{\nu}$ measurements also interesting and potentially connected.

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- If new physics is left handed, very natural to connect $b \to c\tau\nu$ with i) $b \to s\nu\bar{\nu}$ or ii) $b \to s\ell\ell$. The U_1 vector LQ is the only single mediator giving something in all three, albeit only a "small" contribution to $b \to s\nu\bar{\nu}$.

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- $b \to c\tau\nu$ anomalies: Could be resolved via %-level measurements at LHCb+Belle II.

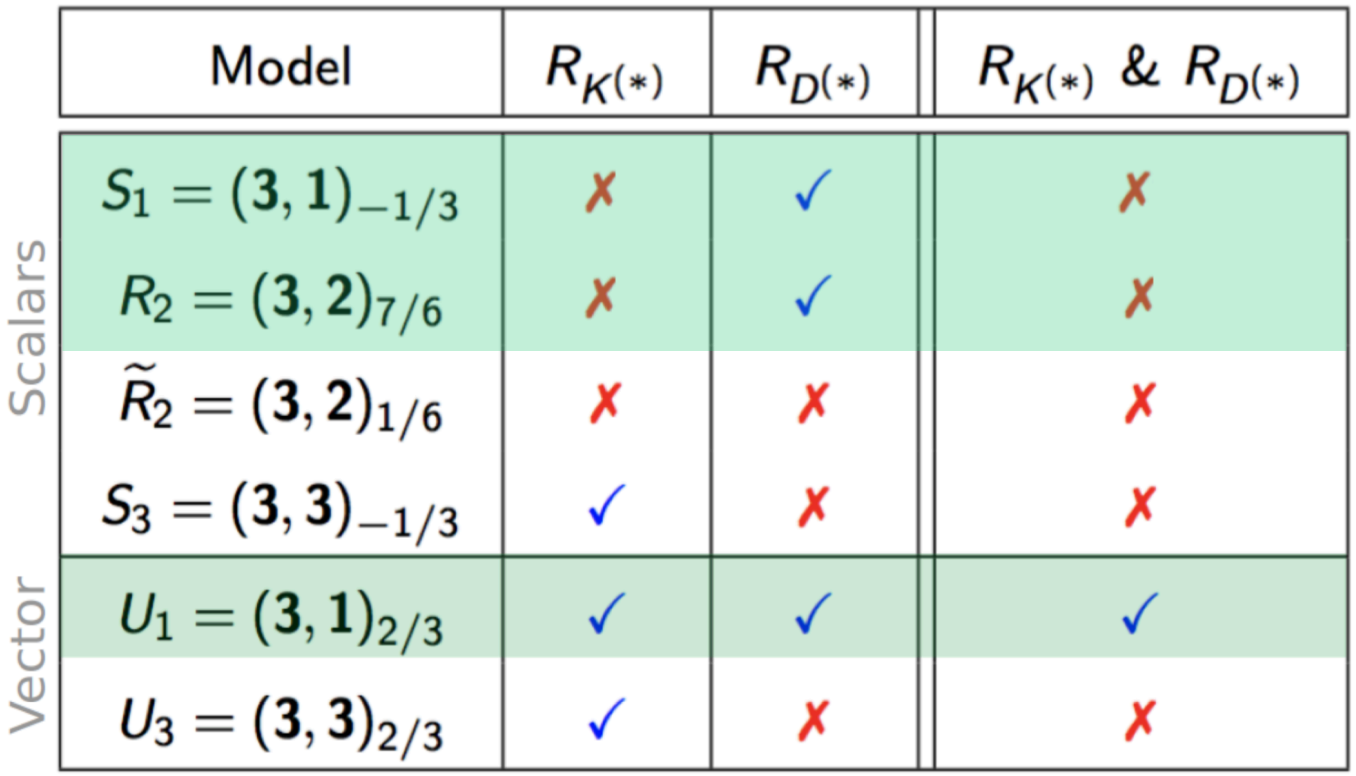
- $bs\mu\mu$ anomalies: could be concretely resolved i) experimentally by inclusive measurements or ii) theoretically via first-principles lattice computations.

- Both could take a long time, so another key experimental path is $bs\tau\tau$ measurements! No doubt of new physics if those channels are measured to be 100-1000x SM predictions…

Backup Slides

Shopping for Leptoquarks

- There are three viable options on the leptoquark market:



	Model	$R_{K^{(*)}}$	$R_{D^{(*)}}$	$R_{K^{(*)}}$ & $R_{D^{(*)}}$
Scalars	$S_1 = (\mathbf{3},\mathbf{1})_{-1/3}$	✗	✓	✗
	$R_2 = (\mathbf{3},\mathbf{2})_{7/6}$	✗	✓	✗
	$\widetilde{R}_2 = (\mathbf{3},\mathbf{2})_{1/6}$	✗	✗	✗
	$S_3 = (\mathbf{3},\mathbf{3})_{-1/3}$	✓	✗	✗
Vector	$U_1 = (\mathbf{3},\mathbf{1})_{2/3}$	✓	✓	✓
	$U_3 = (\mathbf{3},\mathbf{3})_{2/3}$	✓	✗	✗

[Angelescu, Bečirević, Faroughy, Sumensari, 1808.08179]

Scalar Leptoquarks:

★ $S_1 \sim (\bar{3},1,1/3)$

[Crivellin, Muller, Ota 1703.09226; Buttazzo et al. 1706.07808; Marzocca 1803.10972,…]

★ $R_2 \sim (3,2,7/6)$

[Bečirević et al., 1806.05689]

Vector Leptoquarks:

★ $U_1 \sim (3,1,2/3)$ (Massive spin-1, requires UV completion)

[di Luzio, Greljo, Nardecchia 1708.08450; Calibbi, Crivellin, Li 1709.00692;
Bordone, Cornella, Fuentes-Martin, Isidori 1712.01368; Barbieri, Tesi, 1712.06844; Greljo, BAS, 1802.04274]

The low-energy $b \to c\tau\nu$ effective Lagrangian

$$\mathcal{L}_{\text{eff}}^{b\to c\tau\nu} = -\frac{2V_{cb}}{v^2}\Big[\big(\overset{\text{SM}}{1} + C_{V_L}\big)\big(\bar{c}_L\gamma_\mu b_L\big)\big(\bar{\tau}_L\gamma_\mu\nu_L\big) + C_{V_R}\big(\bar{c}_R\gamma_\mu b_R\big)\big(\bar{\tau}_L\gamma_\mu\nu_L\big)$$
$$+ C_{S_L}\big(\bar{c}_R b_L\big)\big(\bar{\tau}_R\nu_L\big) + C_{S_R}\big(\bar{c}_L b_R\big)\big(\bar{\tau}_R\nu_L\big) + C_T\big(\bar{c}_R\sigma_{\mu\nu}b_L\big)\big(\bar{\tau}_R\sigma^{\mu\nu}\nu_L\big)\Big] + \text{h.c.}$$

Vector LQ:

$U_1^\mu : C_{V_L},\, C_{S_R}$ ✓

Scalar LQs:

$R_2 : C_{S_L} = 4C_T$ ⊖

$S_1 :\ C_{V_L},\, C_{S_L} = -4C_T$ ✓

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$$+ C_{S_L}(\bar{c}_R b_L)(\bar{\tau}_R\nu_L) + C_{S_R}(\bar{c}_L b_R)(\bar{\tau}_R\nu_L) + C_T(\bar{c}_R\sigma_{\mu\nu} b_L)(\bar{\tau}_R\sigma^{\mu\nu}\nu_L)\Big] + \text{h.c.}$$

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⊖ $R_2 : C_{S_L} = 4C_T$

$$\delta R_D = +7.1\,\text{Re}(C_T) + 17.2\,|C_T|^2$$

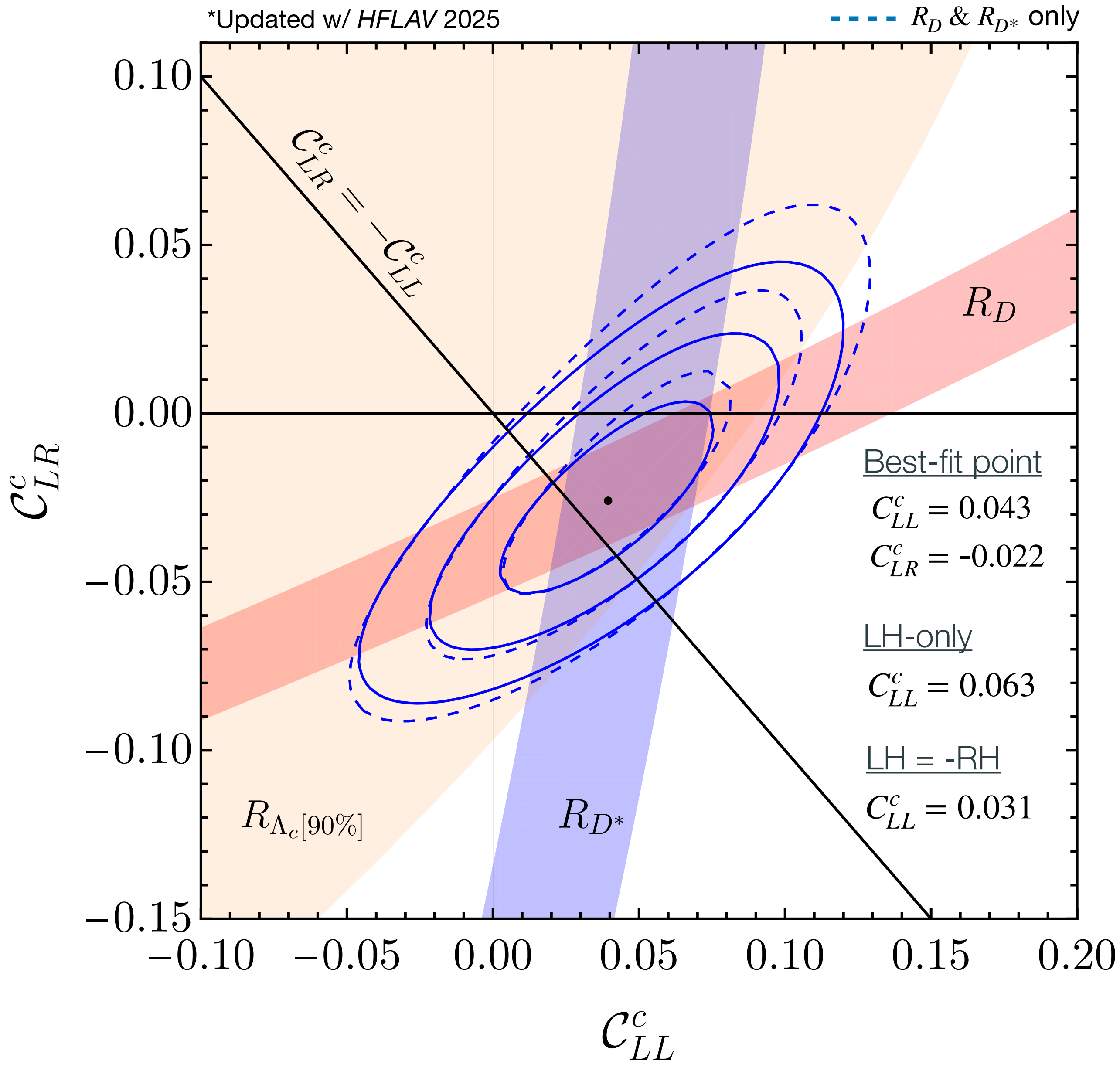
$$\delta R_{D*} = -5.6\,\text{Re}(C_T) + 16.7\,|C_T|^2$$

- This relation predicts opposite sign in R_D vs R_{D*} due to interference with the SM.
- Since interference always goes as the real part, can make the WC's purely imaginary and then do $R_{D^{(*)}}$ with NP squared.
- But then we need big WC's: ***tension*** with high-p_T and EW precision observables.

Low-energy fit for U_1 leptoquark model

$U_1 \sim (\mathbf{3}, \mathbf{1}, 2/3)$

$$\mathcal{L}_{b\to c\tau\bar{\nu}} = -\frac{2}{v^2} V_{cb} \left[\left(1 + C^c_{LL}\right) (\bar{c}_L \gamma_\mu b_L)(\bar{\tau}_L \gamma^\mu \nu_L) - 2\, C^c_{LR}\, (\bar{c}_L b_R)(\bar{\tau}_R\, \nu_L) \right]$$



$$\delta R_{D^{(*)}} \approx 2C^c_{LL} - a_{D^{(*)}} C^c_{LR} \qquad \begin{cases} a_D \approx 3.00 \\ a_{D^*} \approx 0.24 \end{cases}$$

Low-energy WC's ↔ Model parameters

$$C^c_{LL} = \frac{g_U^2 v^2}{4M_U^2}\left(1 + \frac{V_{cs}}{V_{cb}} \beta_L^{s\tau}\right), \qquad C^c_{LR} = \beta_R^{b\tau *} C^c_{LL}$$

[J. Aebischer, G. Isidori, M. Pesut, BAS, F. Wilsch, 2210.13422]

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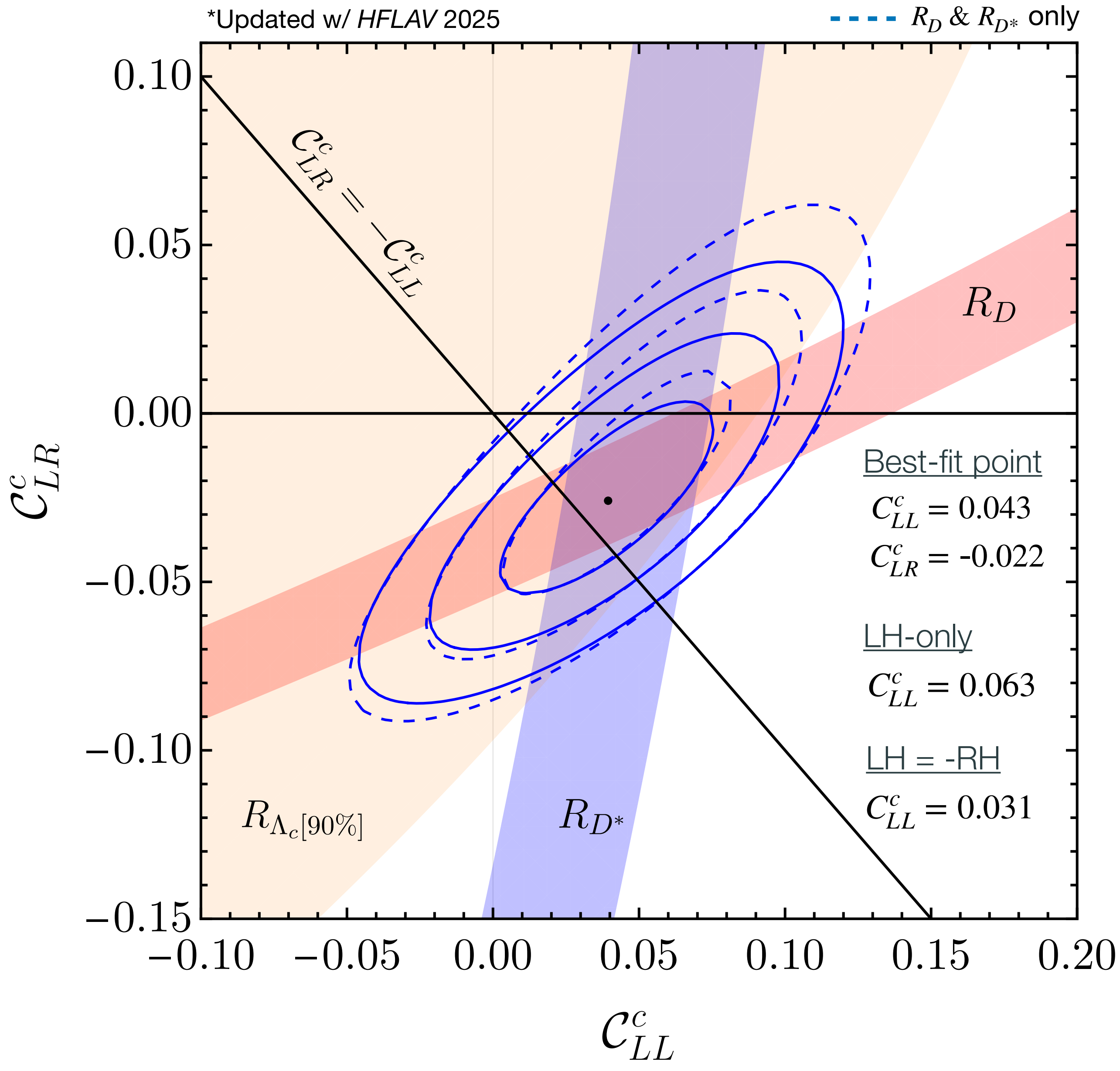

Best-fit point

$C^c_{LL} = 0.043$

$C^c_{LR} = -0.022$

LH-only

$C^c_{LL} = 0.063$

LH = -RH

$C^c_{LL} = 0.031$

$$\delta R_{D^{(*)}} \approx 2C^c_{LL} - a_{D^{(*)}} C^c_{LR} \qquad \begin{cases} a_D \approx 3.00 \\ a_{D^*} \approx 0.24 \end{cases}$$

Low-energy WC's ↔ Model parameters

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Matching: NP scale and U(2)-breaking

$$\frac{1}{\Lambda^2_{\rm NP}} = \frac{g_U^2}{2M_U^2}, \qquad V_q = \beta_L^{s\tau}$$

New physics scale preferred by low-energy fit:

$$\Lambda_{\rm NP} \approx \{1.4, 1.7, 2.0\}\ \text{TeV}, \qquad (V_q = 0.1)$$

{LH-only, BFP, LH=-RH}

[J. Aebischer, G. Isidori, M. Pesut, BAS, F. Wilsch, 2210.13422]