B-decay Discrepancies:
How the Picture Changed After Moriond 2019

Diego Guadagnoli
CNRS, LAPTh Annecy

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Overall message

The TH picture has evolved while, remarkably, staying coherent – in spite of all the constraints

Based on work with
J. Aebischer, W. Altmannshofer, M. Reboud, P. Stangl and D. M. Straub

Data review

4 groups of interesting datasets, w/ different challenges

❶ $b \to s\, \mu\mu$ *BR data < SM*

Challenge: $B \to$ *light meson f.f.'s*

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❷ $B \to K^*\, \mu\mu$ *angular data*

Challenge: charm loops

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❹ $b \to c\,\tau\nu$ / $b \to c\,\ell\nu$ ratios

Challenge: stats + syst

Basic TH considerations

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($R_{D(*)}$)

⇒ *Explicable (quantitatively) w/ single-mediator simplified models*

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Our analysis includes the following data updates

(a) R_K update from LHCb Run1 + 1/3 of Run2

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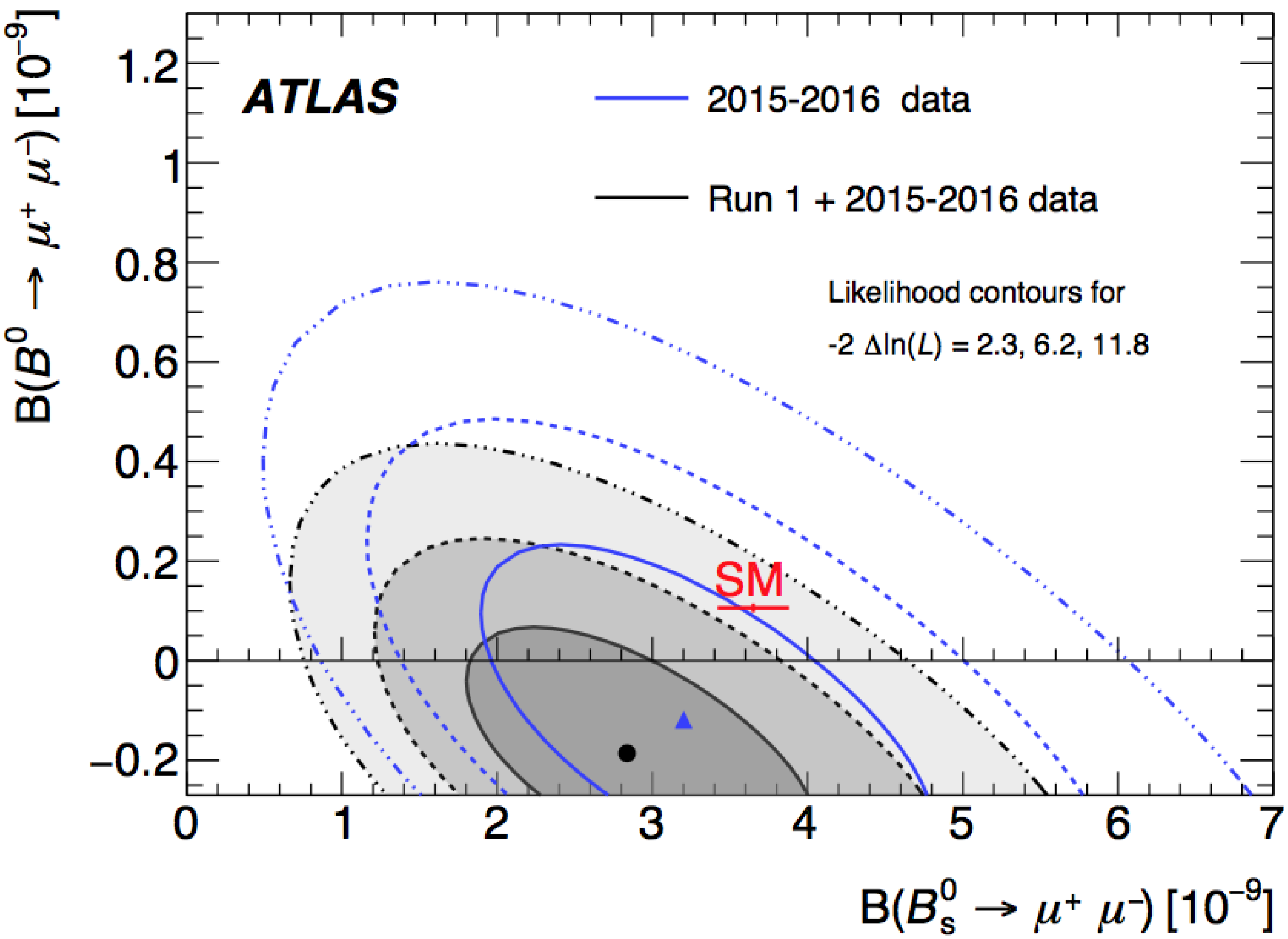
[1812.03017]



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(c) $B_s \to \mu\mu$ from ATLAS

(d) $\Lambda_b \to \Lambda\,\ell\ell$: A_{FB} and BR from LHCb

(e) $b \to s\,\gamma$ & $b \to s\,g$ dipole transitions

EW-scale

Effective-Theory picture

b → s EFT picture

- *One starts from the following Hamiltonian*

$$H(\bar{b} \to \bar{s}\mu\mu) = -\frac{4G_F}{\sqrt{2}} V_{tb}^* V_{ts} \frac{\alpha_{em}}{4\pi} \left[\bar{b}_L \gamma^\lambda s_L \cdot \left(C_9^{(\mu)} \bar{\mu} \gamma_\lambda \mu + C_{10}^{(\mu)} \bar{\mu} \gamma_\lambda \gamma_5 \mu \right) \right]$$

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- *The best-performing BSM scenarios to explain the data involve*

$$O_9 \propto \bar{b}_L \gamma^\lambda s_L \cdot \bar{\mu}\gamma_\lambda \mu \qquad O_{10} \propto \bar{b}_L \gamma^\lambda s_L \cdot \bar{\mu}\gamma_\lambda \gamma_5 \mu$$

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  - *Specifically, either O_9 alone,*
  - *or $O_9 - O_{10}$* ⇨ *again, $(V-A) \times (V-A)$ well-suited to UV-complete models*

1-Wilson-coeff. picture

Compare w/ [Algueró *et al.*; Alok *et al.*; Ciuchini *et al.*; Kowalska *et al.*]

Coeff.	best fit	1σ	2σ	pull
$C_9^{bs\mu\mu}$	-0.95	$[-1.10, -0.79]$	$[-1.26, -0.63]$	5.8σ
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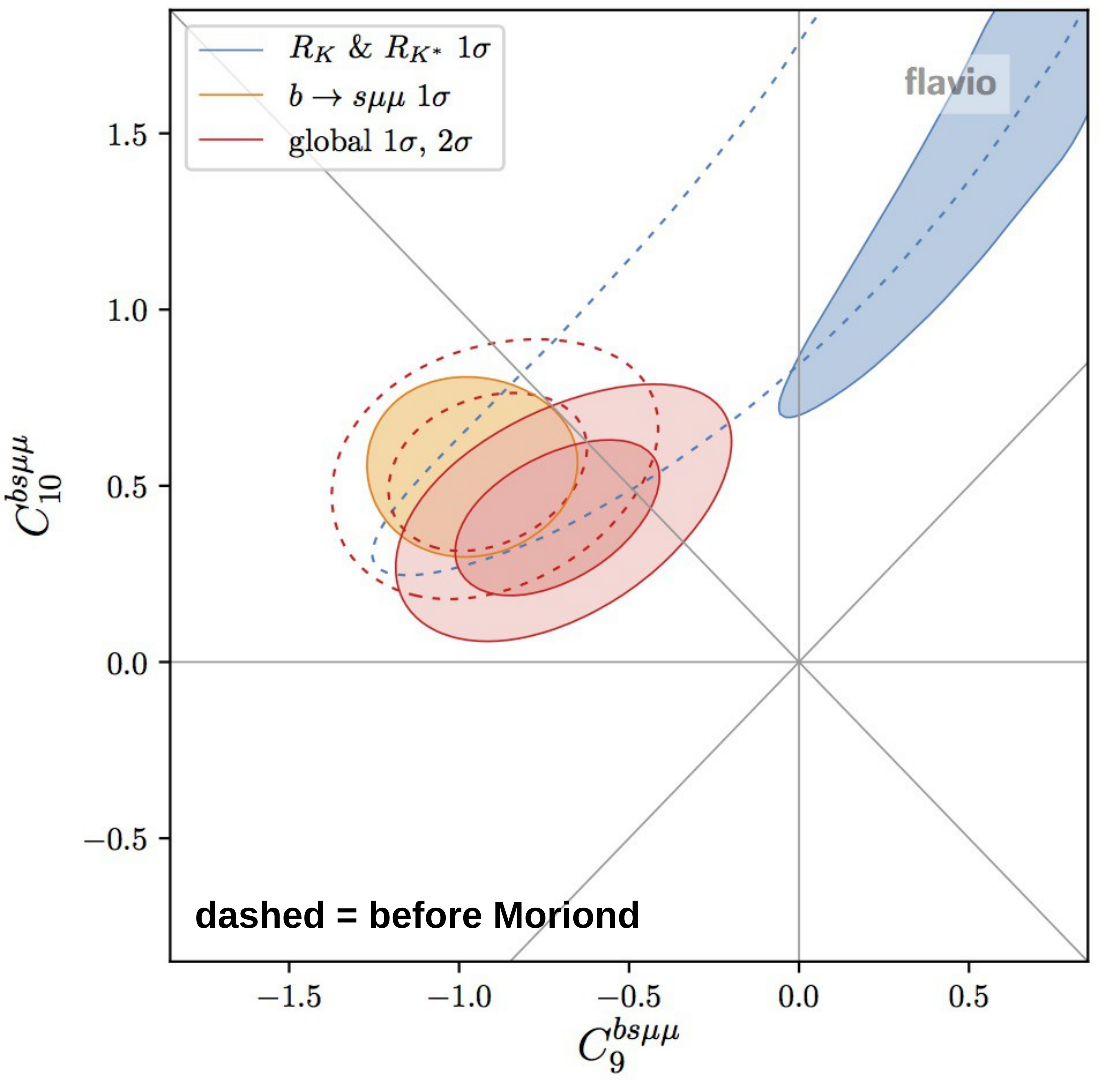
- *Two scenarios stand out: C_9 alone or $C_9 = - C_{10}$ (μμ-channel only)*
- *$C_9 = - C_{10}$ now better than C_9 alone chiefly because of $B_s \to \mu\mu$*
- *C_{10} alone also ok, but $B \to K^* \mu\mu$ unresolved*

2-Wilson-coeffs. picture



Main points

- *$R_{K(*)}$ & $b \to s\,\mu\mu$ in perfect agreement before Moriond*

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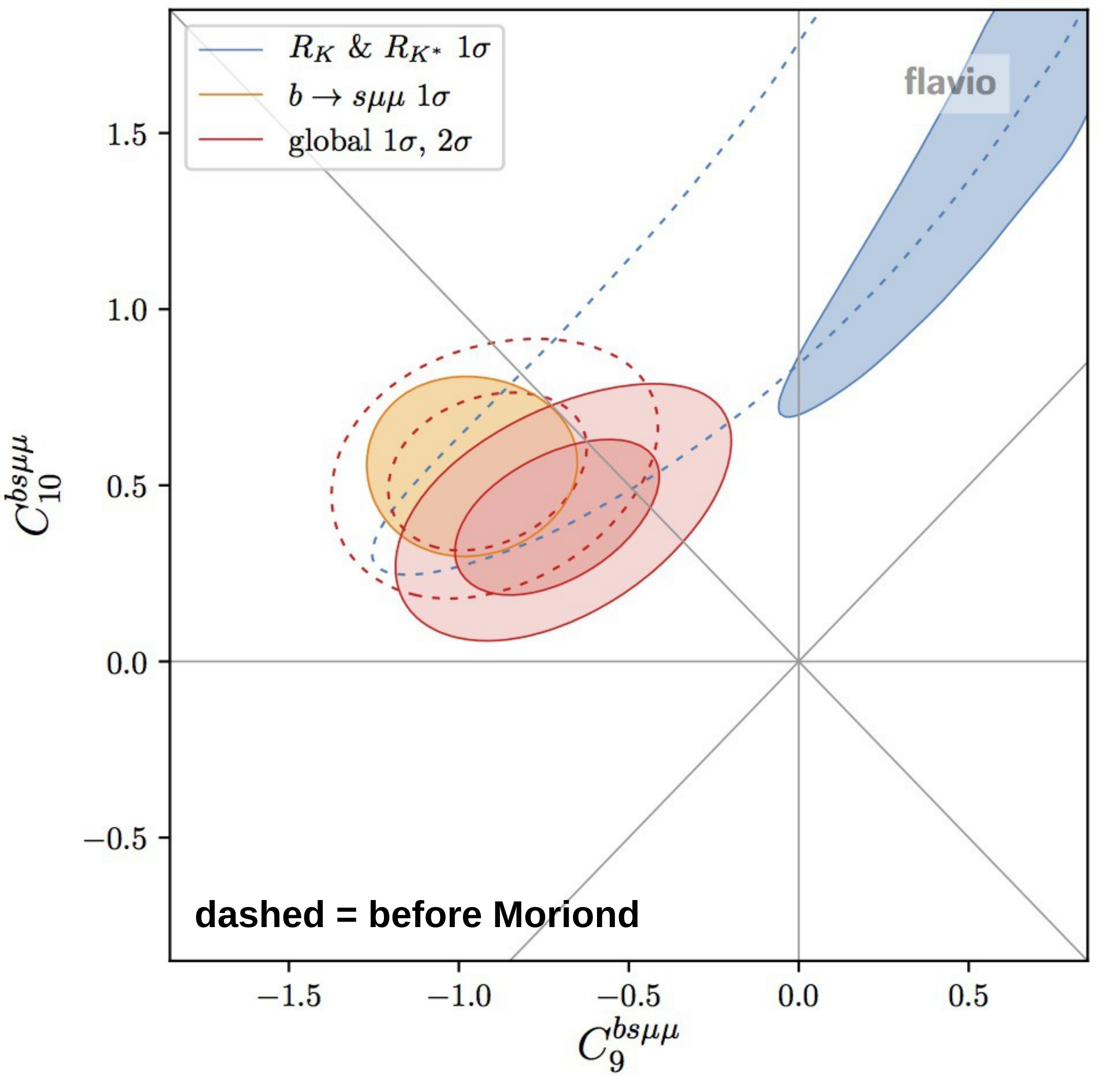

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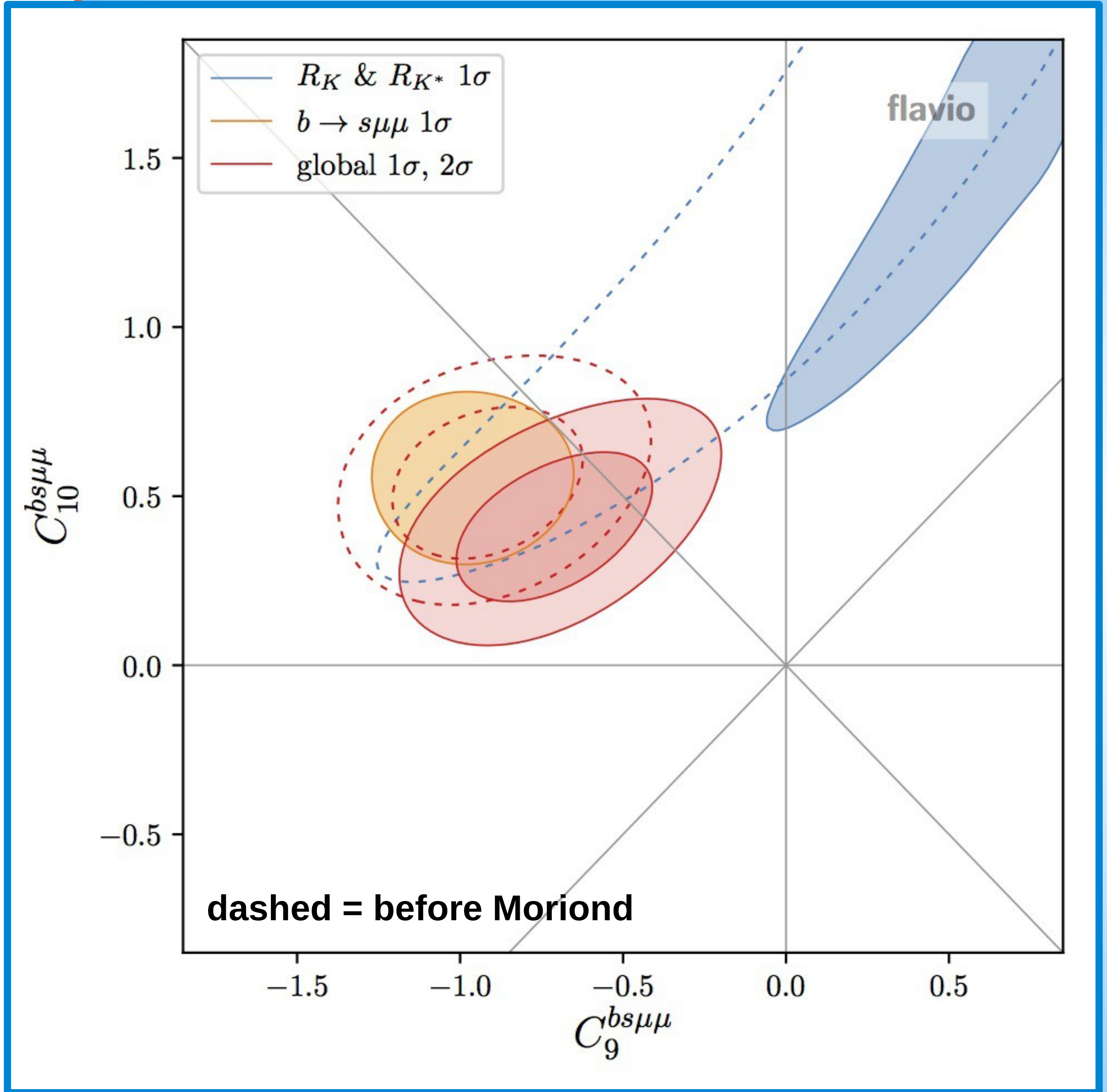

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- *now slight tension (in C_9 dir.)*

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- *also (not visible) slight tension between R_K & R_{K^*}*
  - *would be accommodated by RH quark currents, e.g. C_9'*
  - *but such shift would not accommodate $B_s \to \mu\mu$*

Univ. vs. non-univ. Wilson coeffs.

- *Note: a $C_9^{univ.}$ component would shift $b \to s\,\mu\mu$ data but <u>not</u> $R_{K(*)}$*

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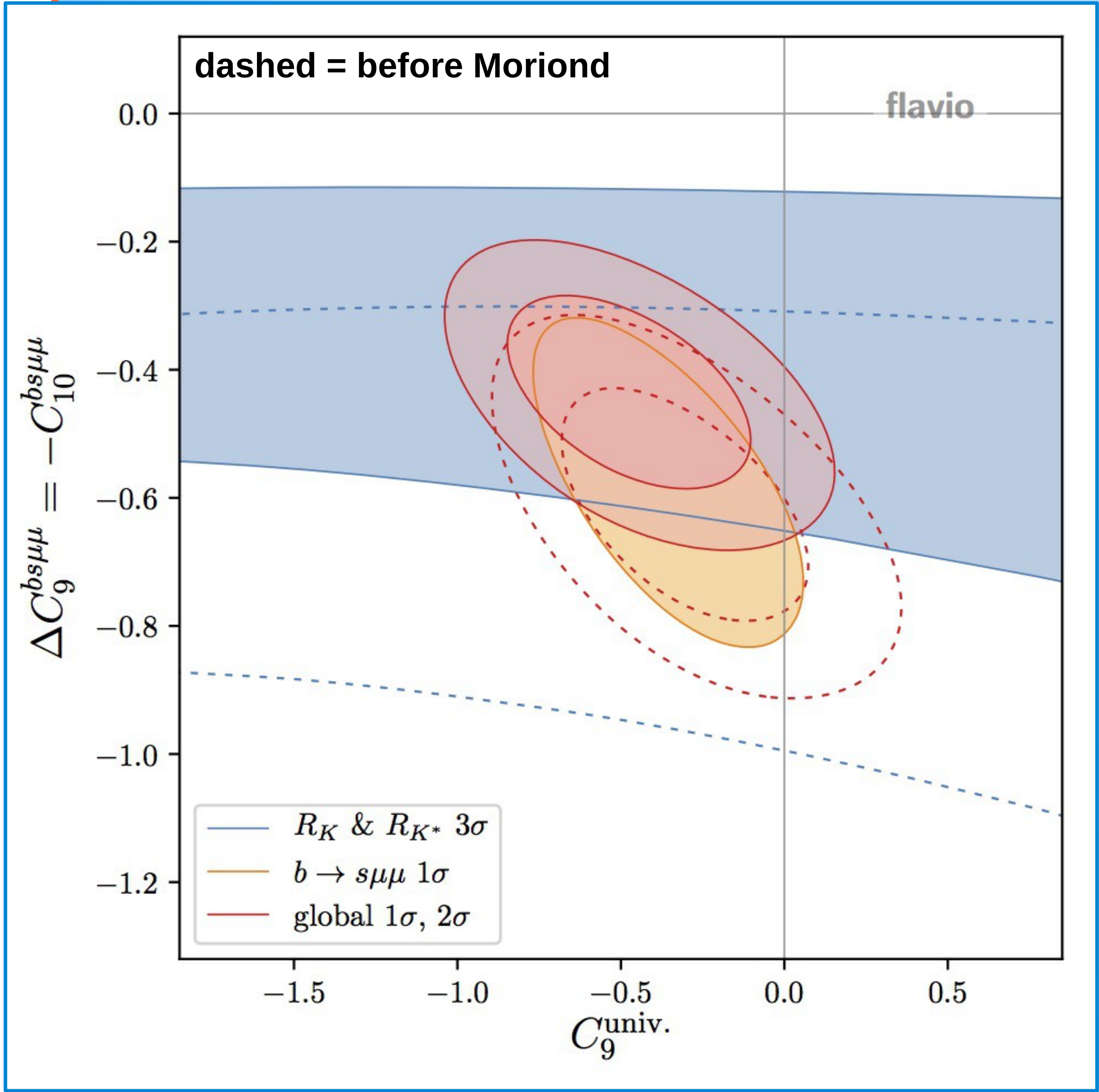

Notes

y-axis: μ-specific shift in $C_9 = - C_{10}$

x-axis: additional, lepton-univ. shift in C_9 only

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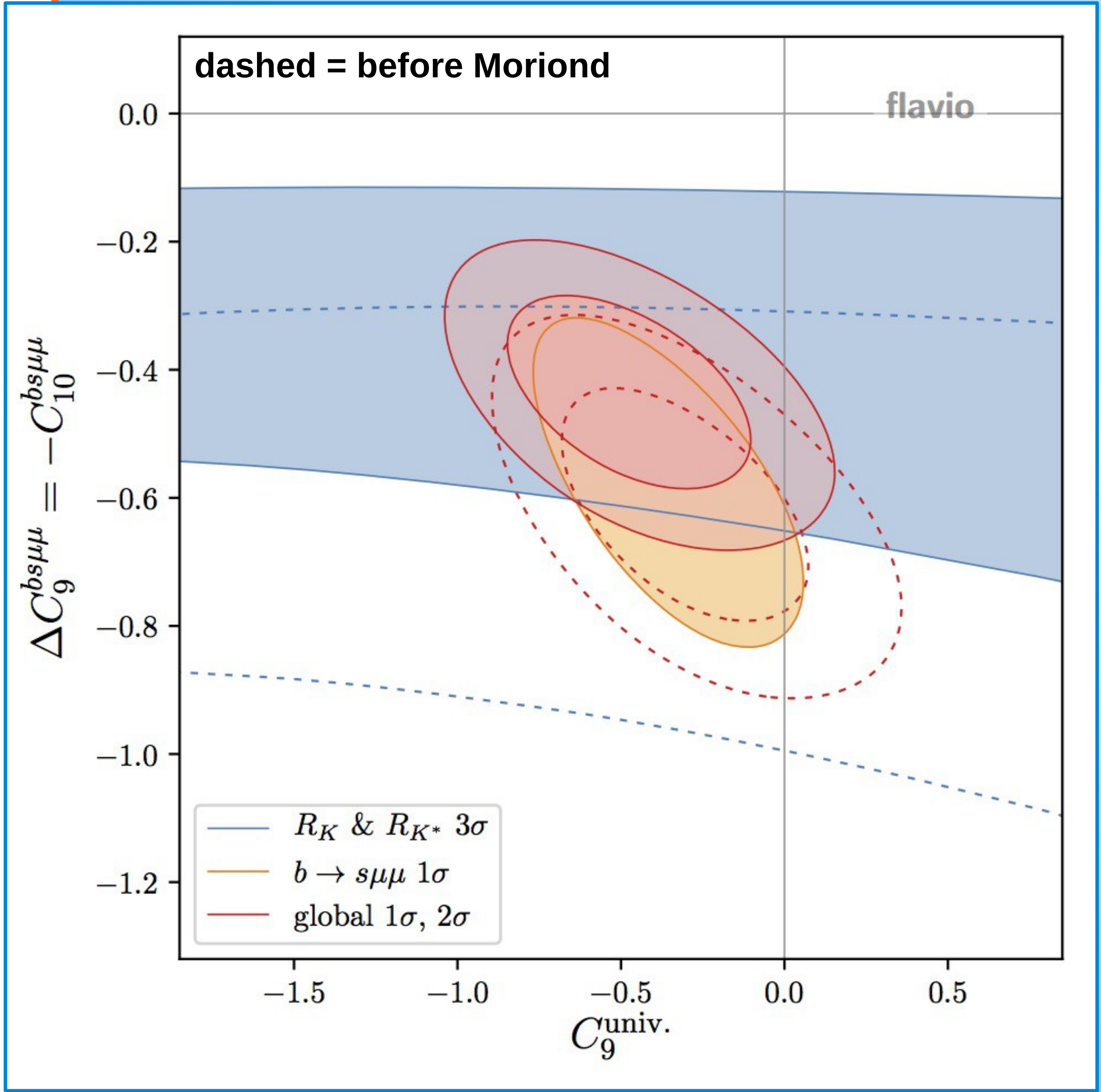

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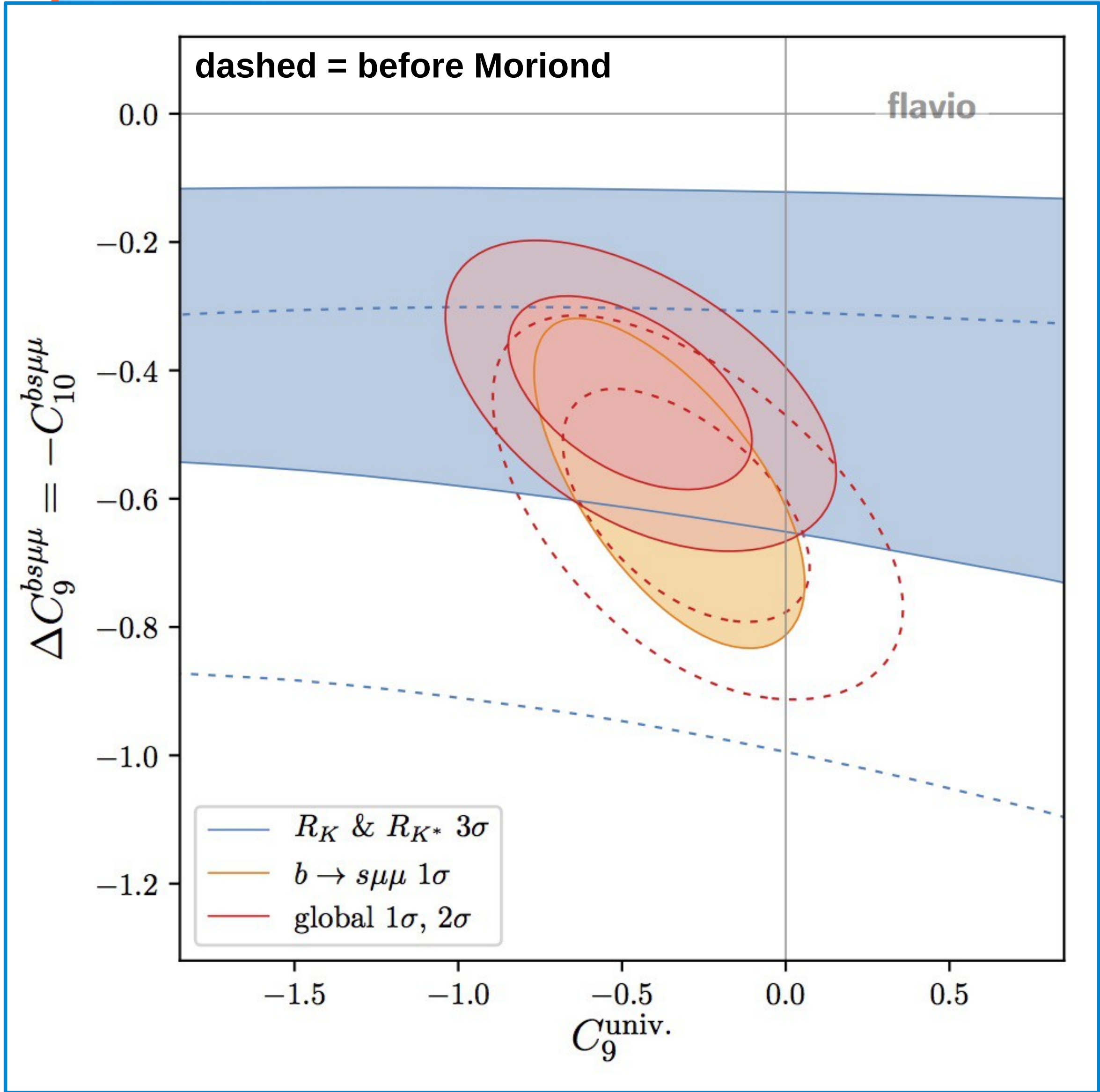

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- *Post-Moriond data tend to prefer $C_9^{univ.} \neq 0$*
- *This suggests a well-defined interpretation within SMEFT* [Crivellin-Greub-Müller-Saturnino]

Going above the EW scale

without introducing new d.o.f.:

The SM EFT

SMEFT basics

- *If NP is at a scale $\Lambda \gg M_{EW}$, with nothing new in between*

↳ *Effects below Λ are described by ops. constructed with SM fields, and invariant under the full SM group: $SU(3)_c \times SU(2)_L \times U(1)_Y$*

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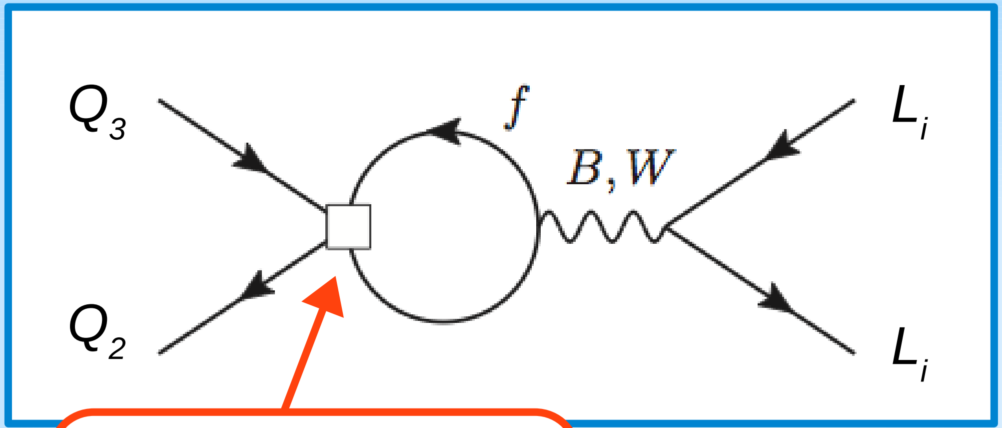
❶ *SMEFT operators directly matching onto $O_{9,10}$*

$$[O_{LQ}^{(1)}]_{2223} = \bar{L}_2 \gamma^\lambda L_2 \cdot \bar{Q}_2 \gamma_\lambda Q_3$$

$$[O_{LQ}^{(3)}]_{2223} = \bar{L}_2 \gamma^\lambda \sigma^a L_2 \cdot \bar{Q}_2 \gamma_\lambda \sigma^a Q_3$$

SMEFT basics

❷ *Besides, contribs. to $C_9^{univ.}$ can come from RGE effects, in particular:*



any suitable SMEFT 4-fermion op. here

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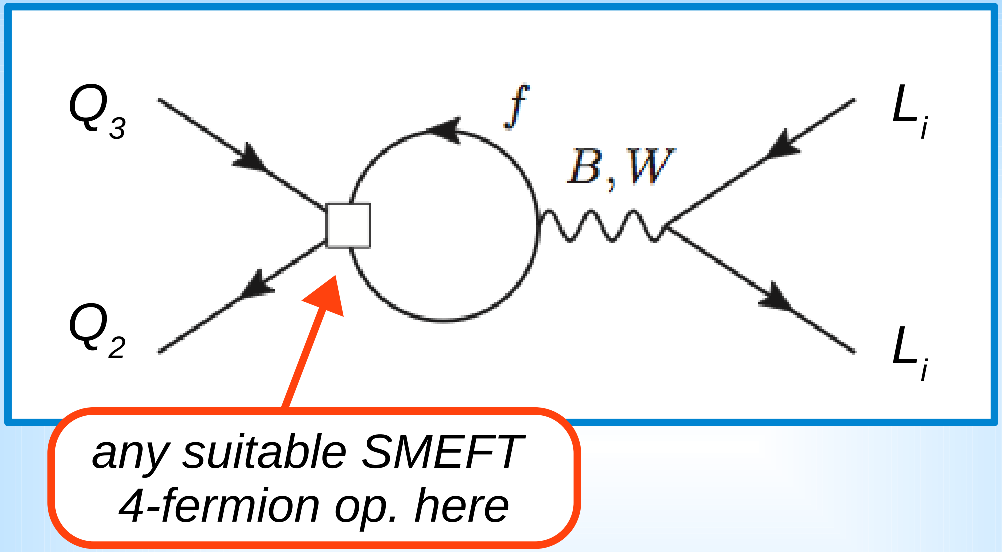

- *Case f = τ especially interesting*

  ⇨ *Connection with "semi-tauonic" ops., responsible for $b \to c\, \tau\nu$*

- *Smoking gun of such scenario: large enhancement in $b \to s\, \tau\, \tau$*

  [*B. Capdevila et al., PRL 2018*]

4-fermion, semi-tauonic ops.

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⇨ *can explain $R_{D(*)}$*

↳ *also induces $C_9^{univ.}$ w/ the right sign to potentially accommodate $b \to s\,\mu\mu$*

[Crivellin-Greub-Müller-Saturnino]

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- *Caveat: one must have* $[C_{LQ}^{(1)}]_{3323} \simeq [C_{LQ}^{(3)}]_{3323}$ *to avoid the $B \to K(*)\ \nu\nu$ constraint*

  [Buras-Girrbach-Niehoff-Straub]

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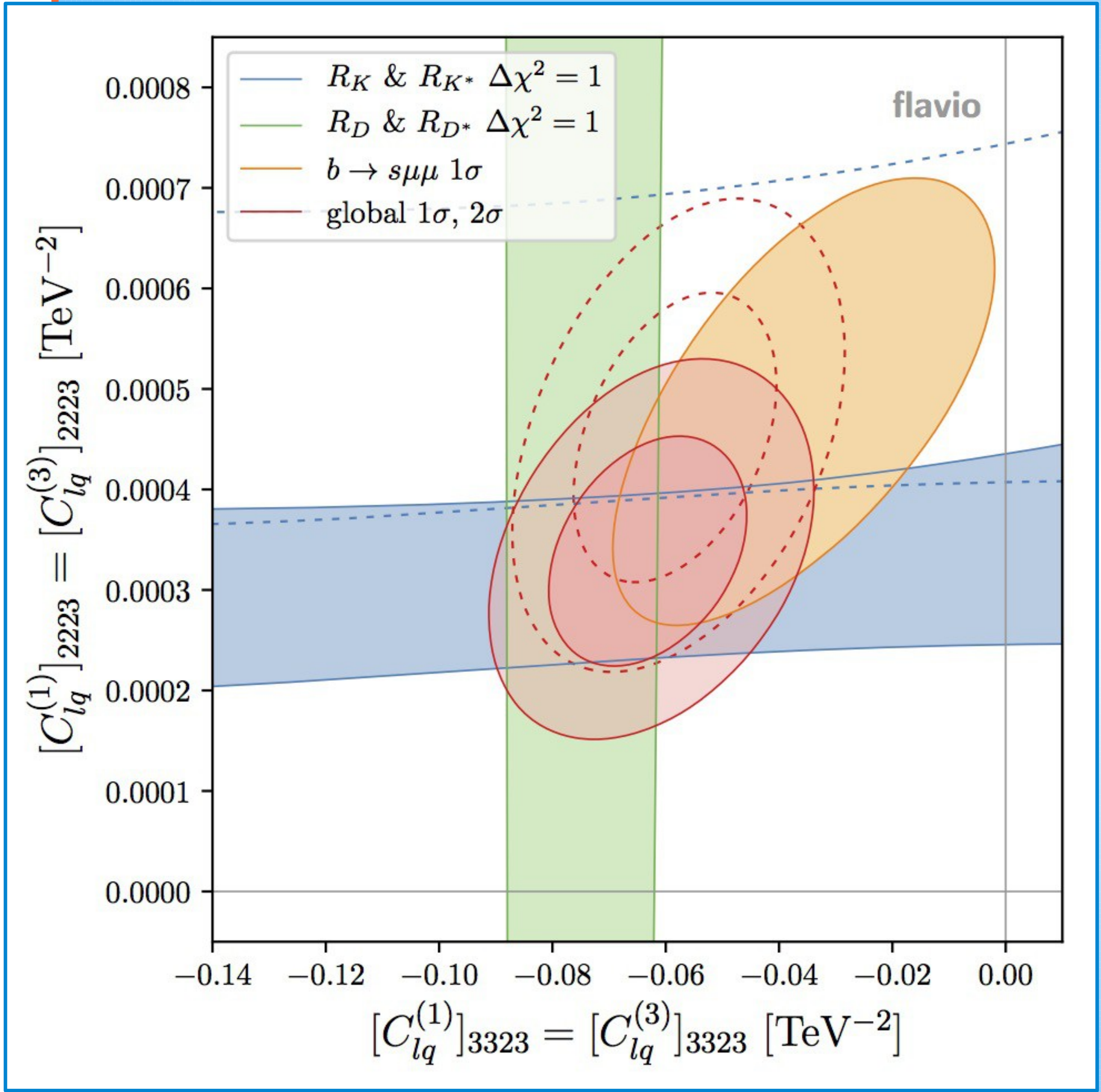

D. Guadagnoli, B discrepancies after Moriond 2019

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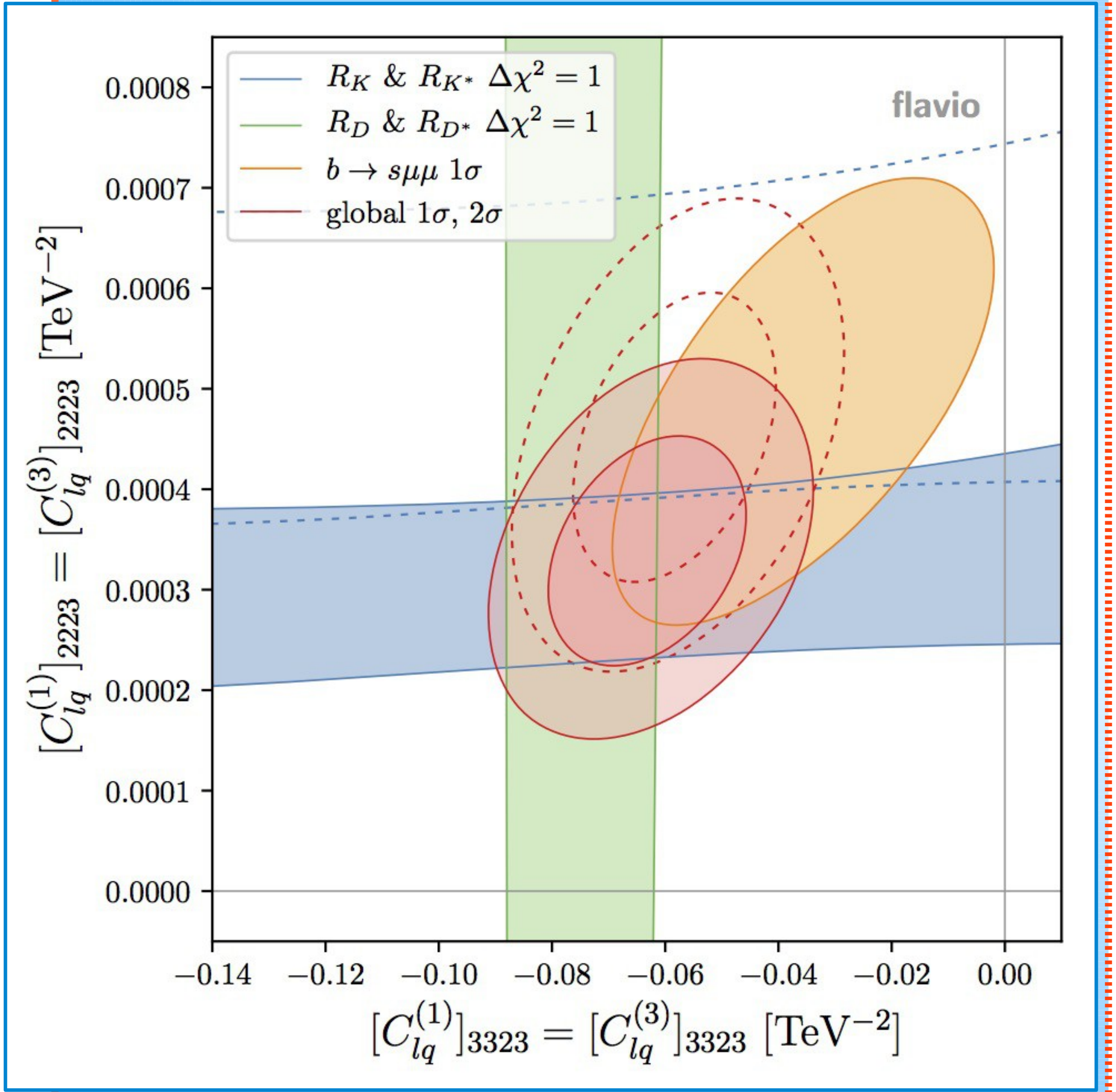

Before Moriond (dashed)

$R_{K(*)}$ (blue) and $b \to s\,\mu\mu$ (orange) were in perfect agreement (y-axis)

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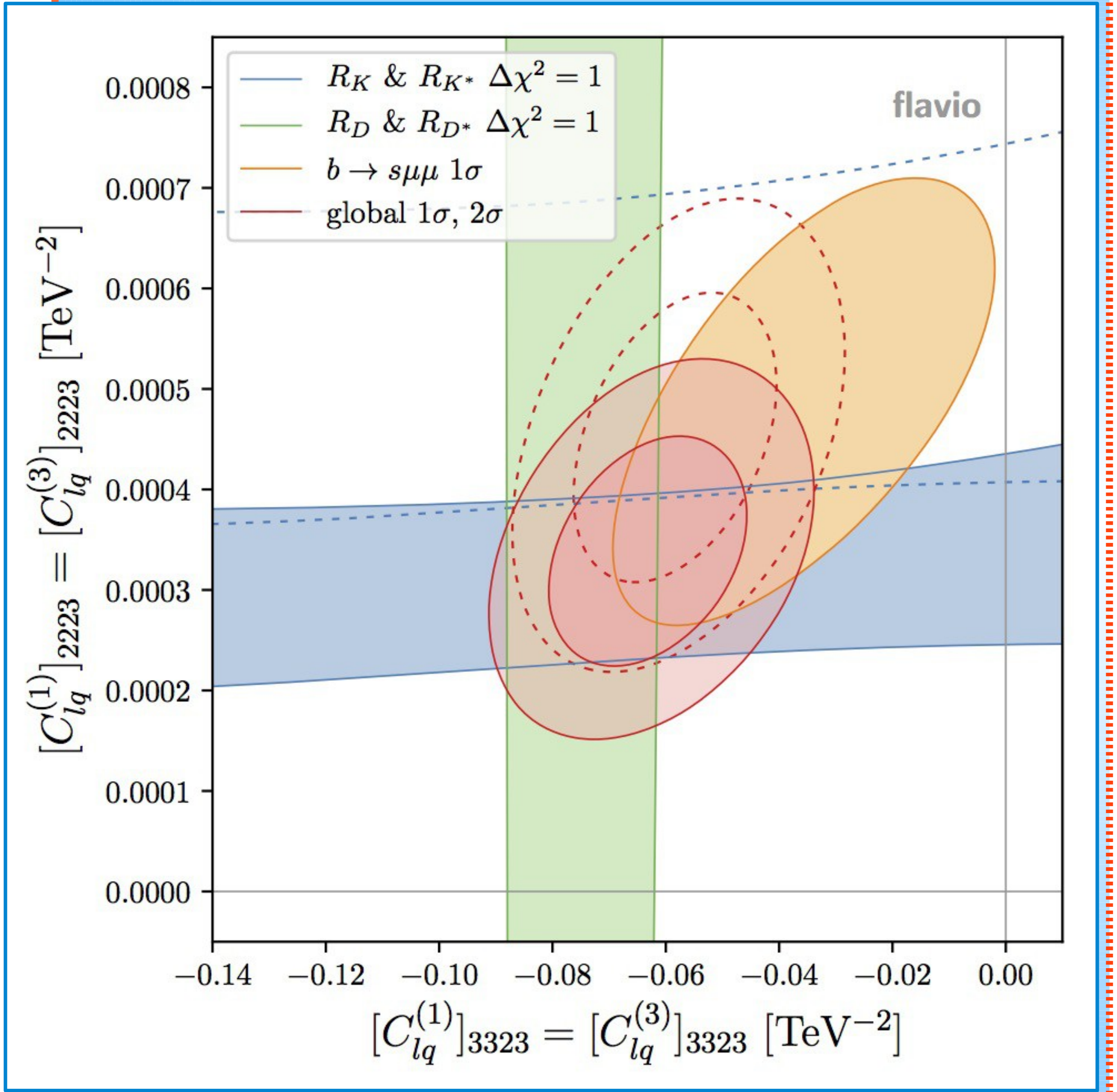

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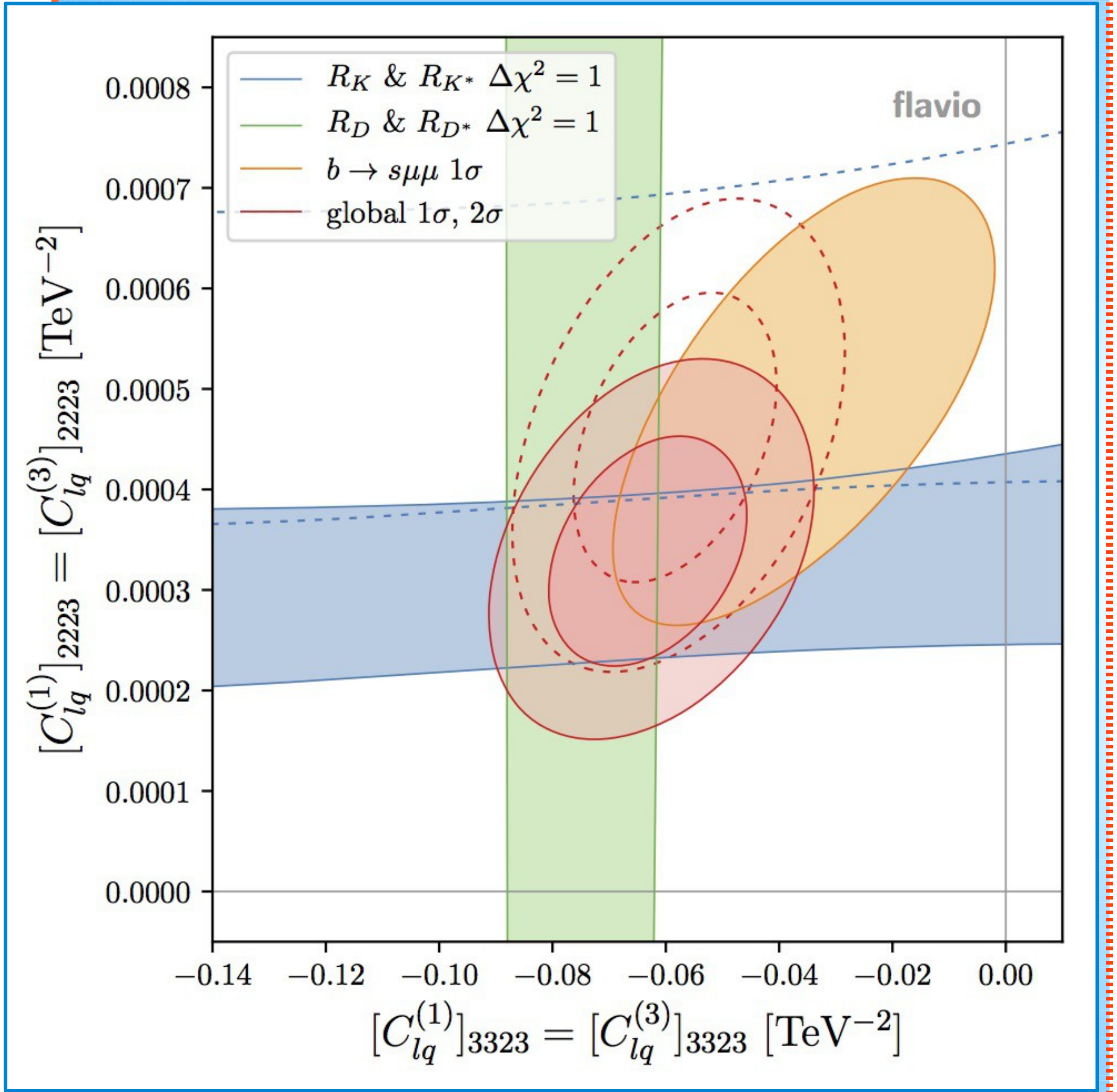

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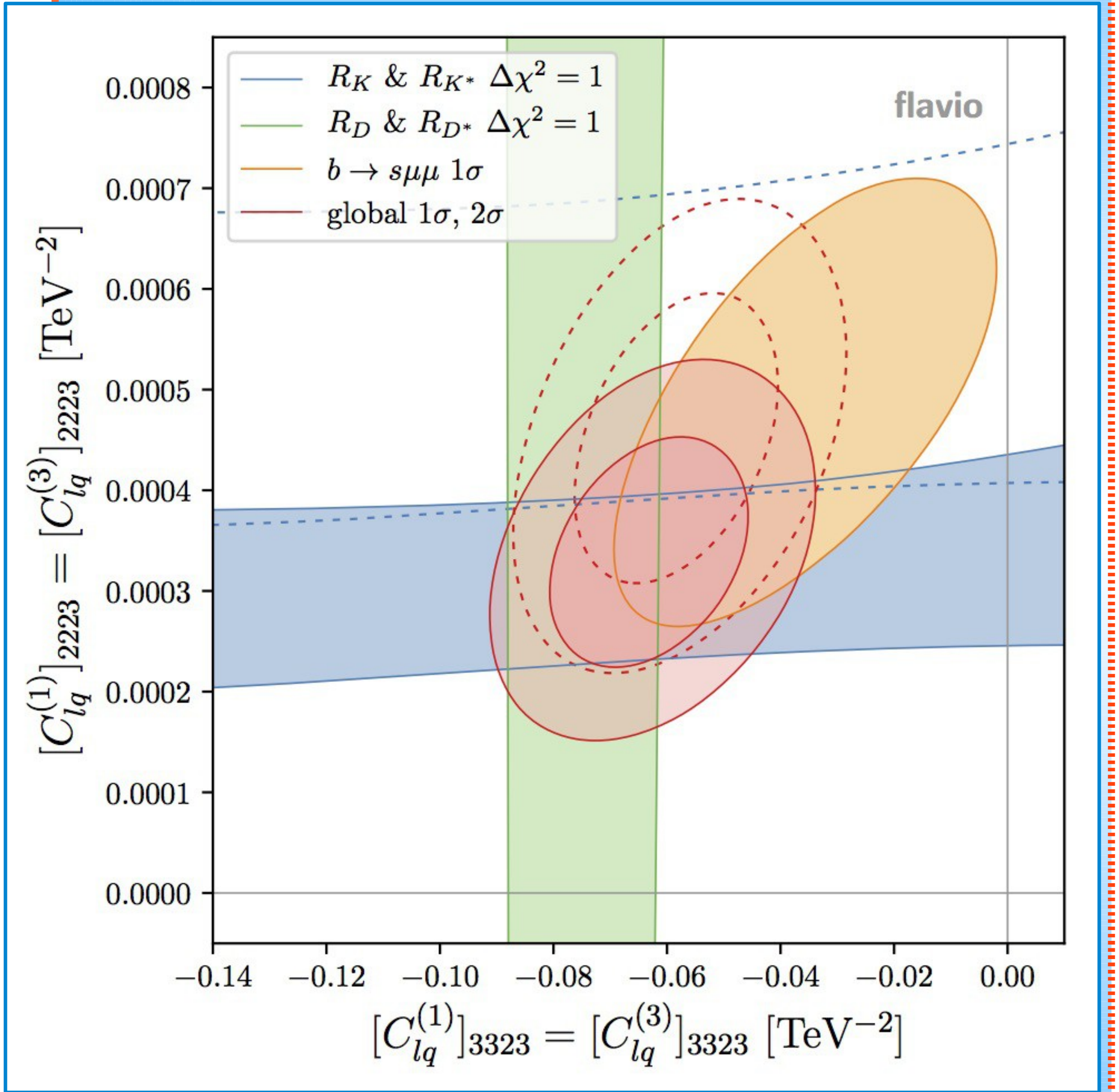
After Moriond

$R_{K^{(*)}}$ and $b \to s\,\mu\mu$ intersect in a region corresponding to x-axis values well below 0

$[C_{LQ}^{(1)}]_{3323} = [C_{LQ}^{(3)}]_{3323}$ vs. $[C_{LQ}^{(1)}]_{2223} = [C_{LQ}^{(3)}]_{2223}$



Before Moriond (dashed)

$R_{K(*)}$ (blue) and b → s μμ (orange) were in perfect agreement (y-axis)

in a region close to 0 in the x-axis

⇨ *$R_{D(*)}$ not explained*

After Moriond

$R_{K(*)}$ and b → s μμ intersect in a region corresponding to x-axis values well below 0

This region turns out to overlap substantially with the $R_{D(*)}$ region (green)

Beyond EFTs:

The picture within “simplified” models

The U_1 leptoquark

- $U_1 \sim (\mathbf{3}, \mathbf{1})_{2/3}$ *is the only single mediator known to yield*

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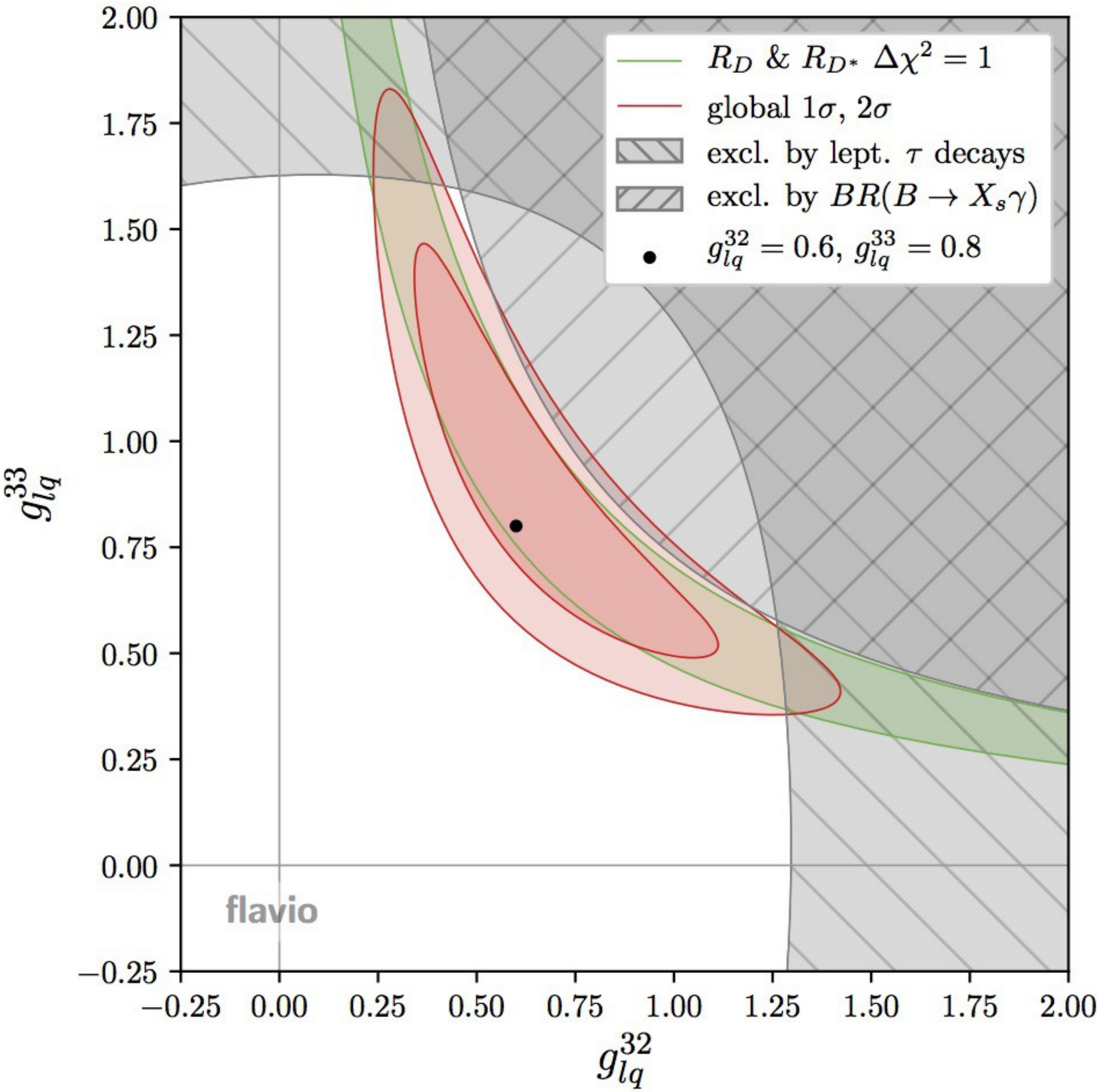
☞ *these couplings also famously constrained by*

$\tau \to \ell \, \nu\nu$ [*Feruglio-Paradisi-Pattori*]

(hence far from obvious that an $R_{D(*)}$ description achievable)

U_1 LQ: g_{lq}^{32} vs. g_{lq}^{33}



D. Guadagnoli, B discrepancies after Moriond 2019

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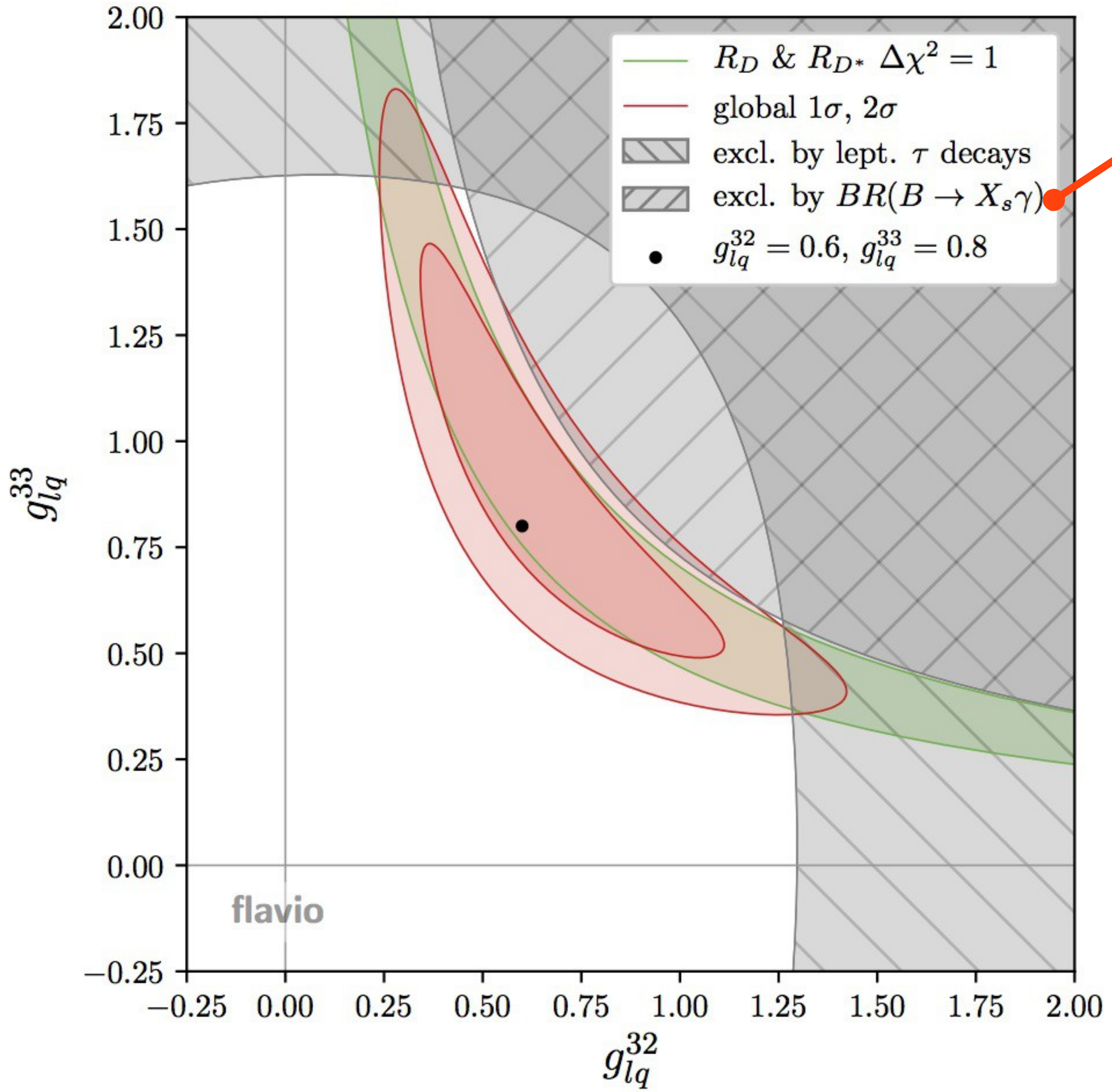

Model-dependent constraint

See discussion in

[Cornella-Fuentes-Isidori, 2019;
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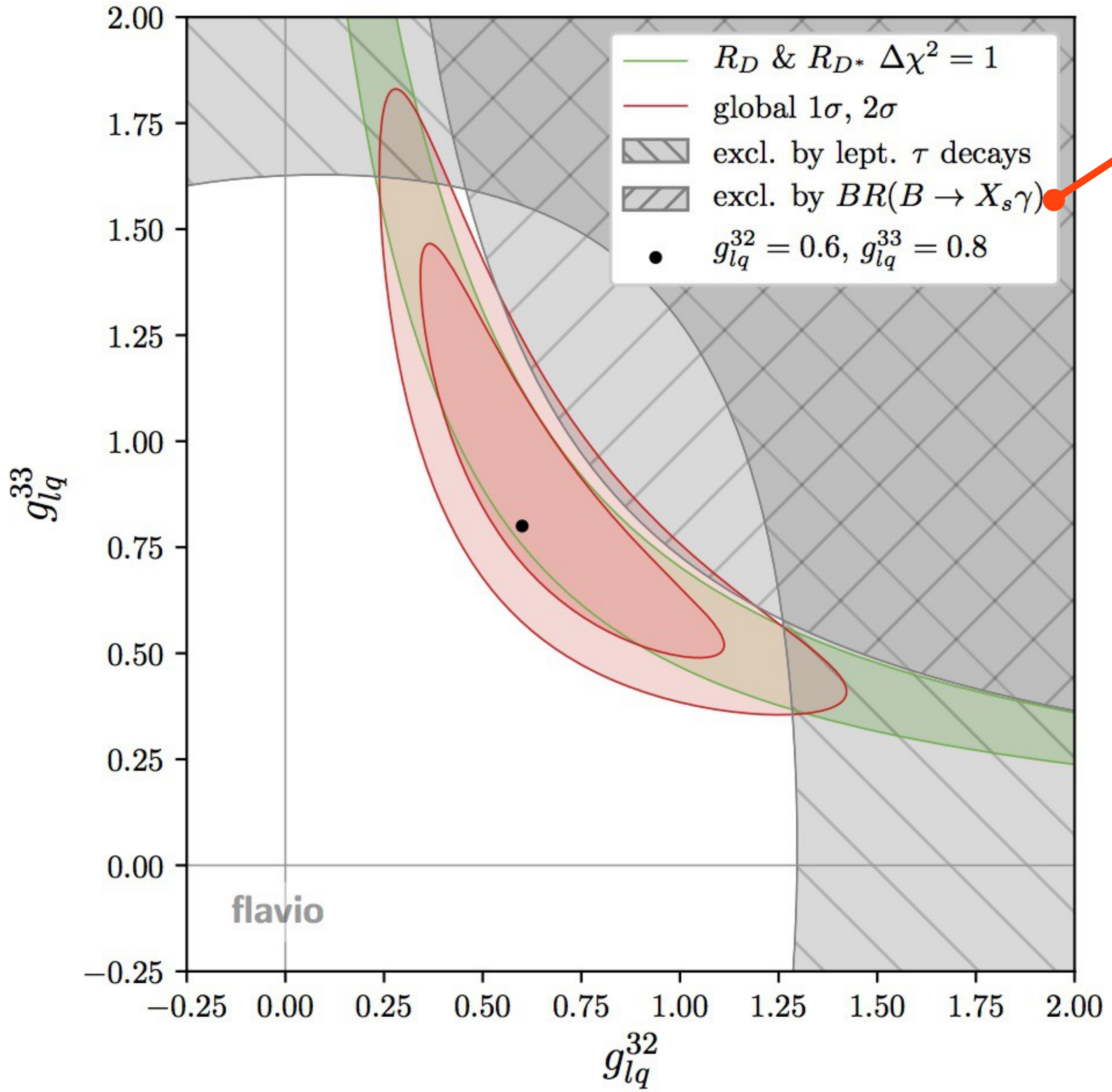

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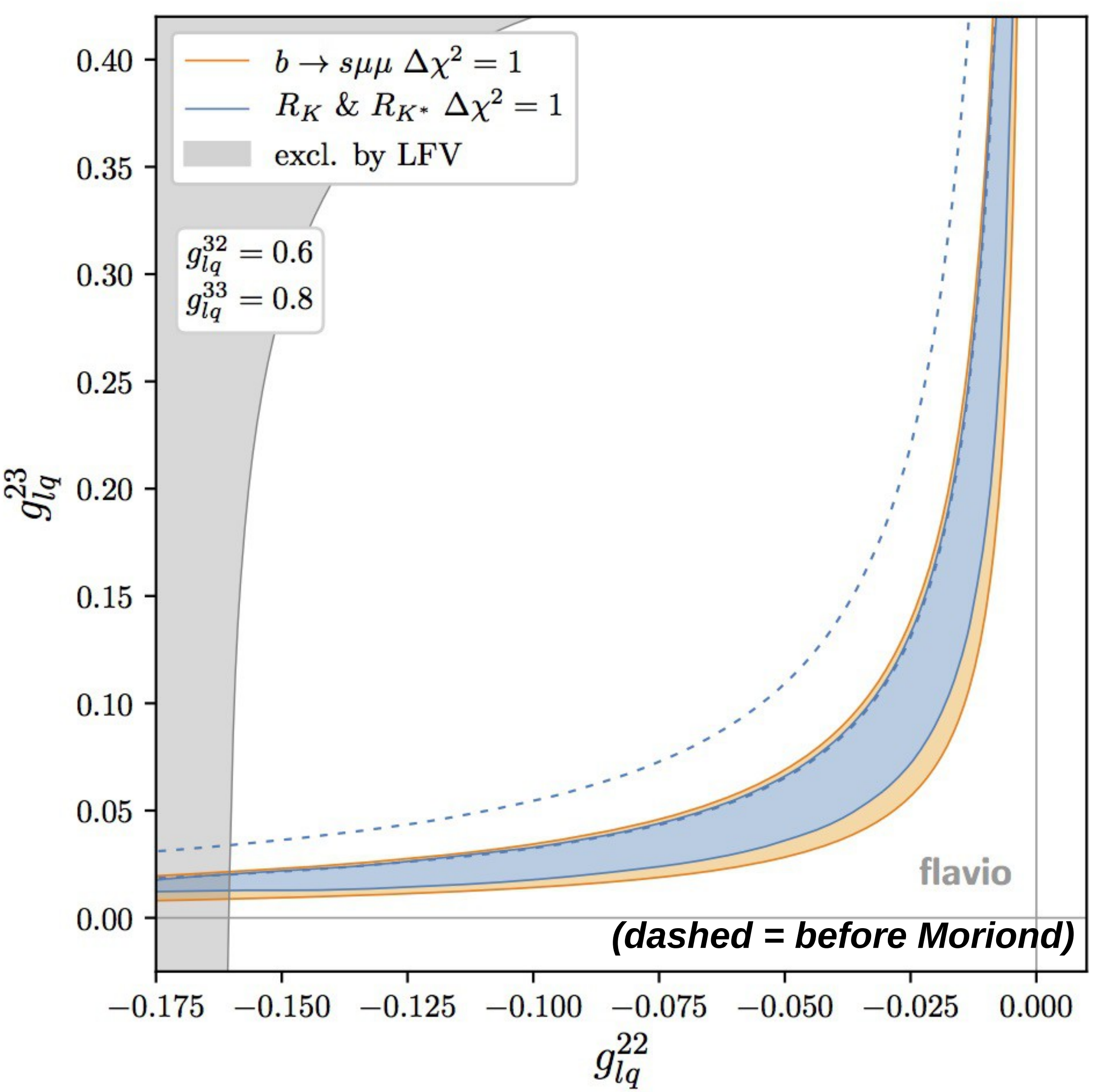
- *$R_{D^{(*)}}$ and $\tau \to \ell\ \nu\nu$ select a non-trivial region*
- *We pick a benchmark point, then constrain the other two couplings*

U_1 LQ: g_{lq}^{22} vs. g_{lq}^{23}



The plane of muonic couplings shows that the picture works better after than before Moriond

- *The $R_{K^{(*)}}$ and $b \to s\,\mu\mu$ regions now perfectly overlap*

U_1 LQ: direct constraints

Aren't such tauonic couplings also constrained by direct searches?
E.g. $pp \to \tau\tau$ *or* $\tau\nu$

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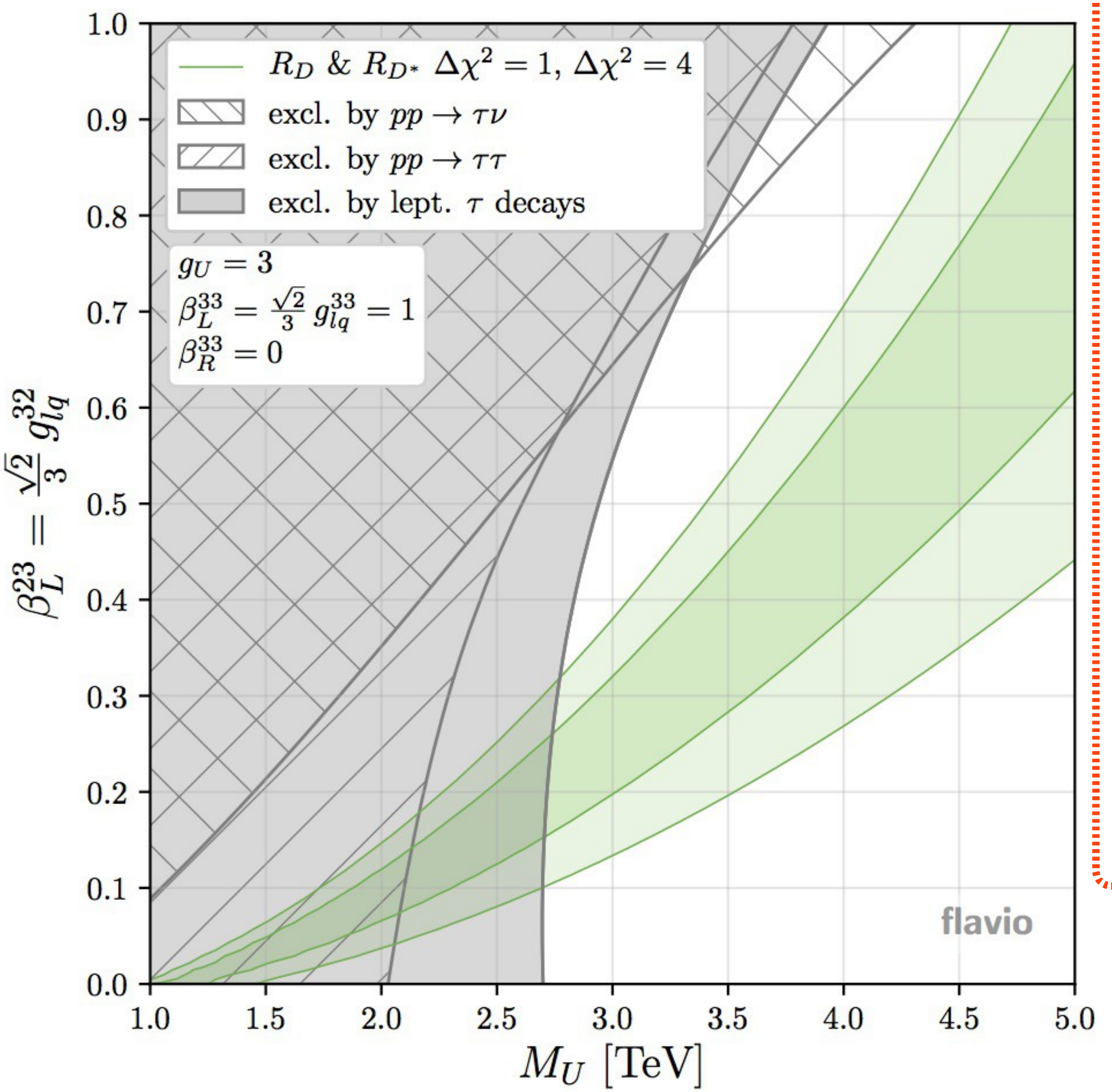

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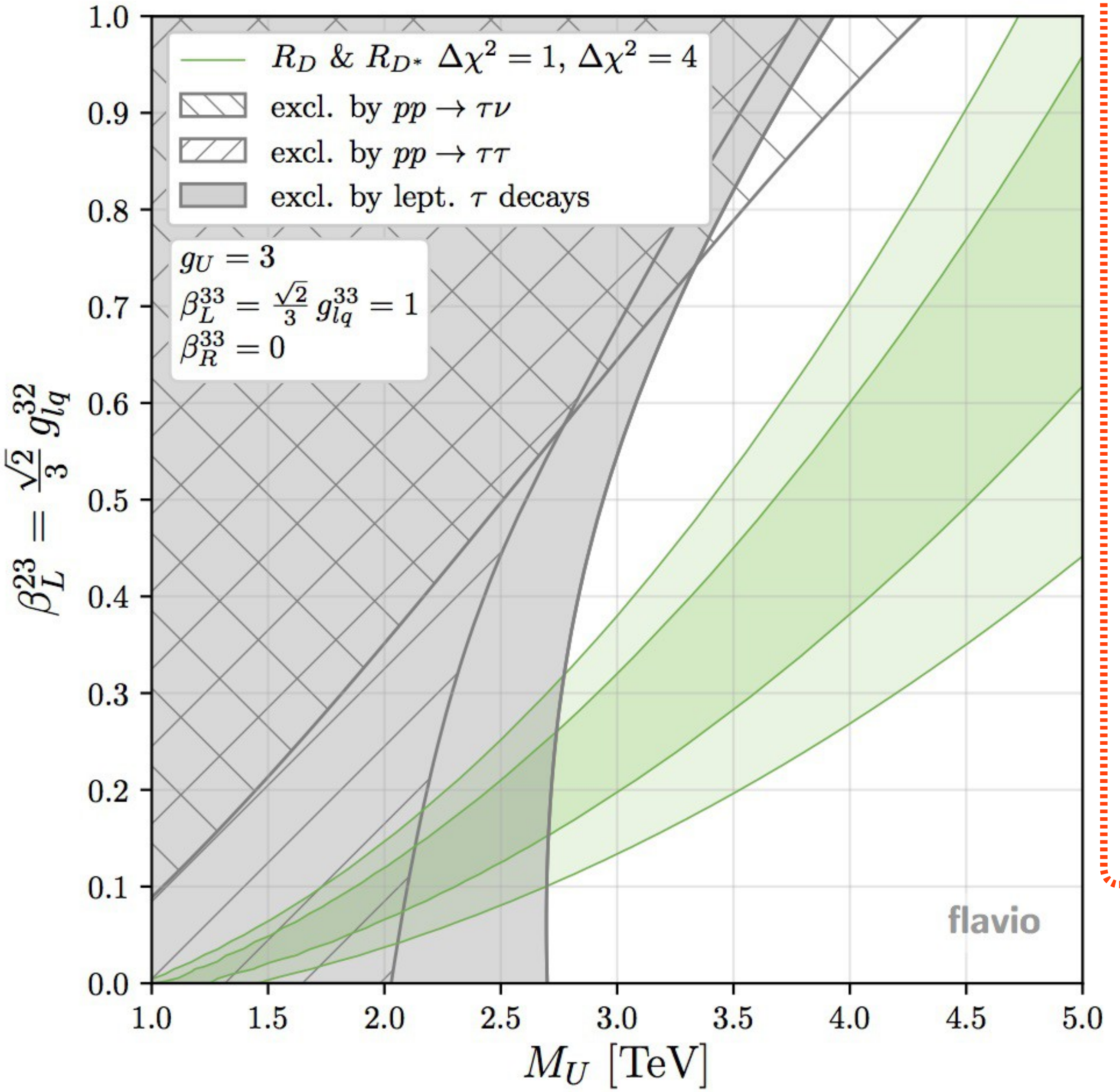

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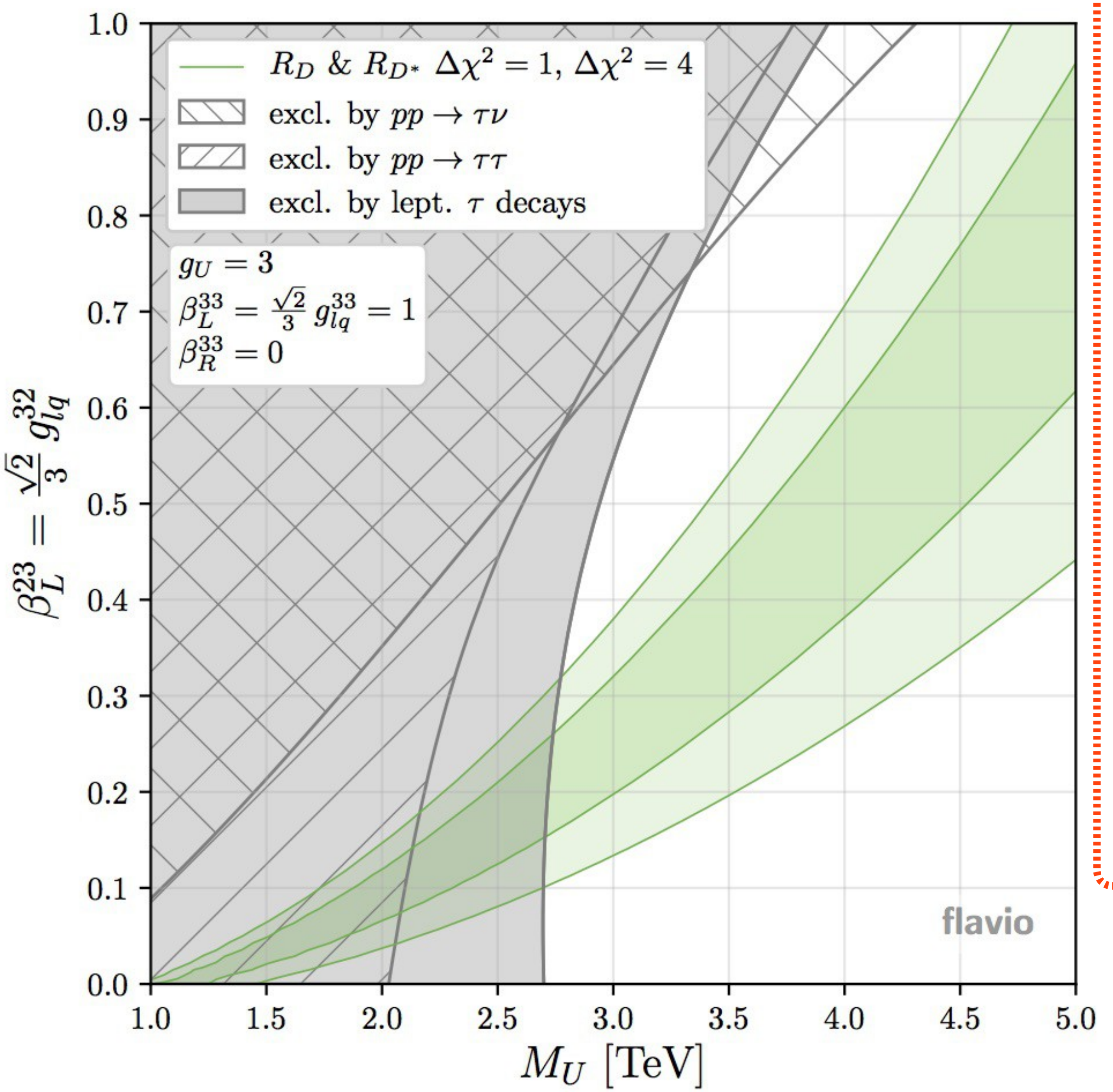

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Lower bound M_U > 2.7 TeV due to the large couplings chosen here (e.g. $g_{lq}^{32} \approx 2.1$)

I.e. it doesn't apply in general

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- *Also interestingly, this whole picture finds a natural realization in the U_1-LQ model*