Where we are on B-decay Discrepancies

Diego Guadagnoli
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Overall message

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

Based on 1903.10434, with
J. Aebischer, W. Altmannshofer, M. Reboud, P. Stangl and D. M. Straub

B-discrepancies

2019

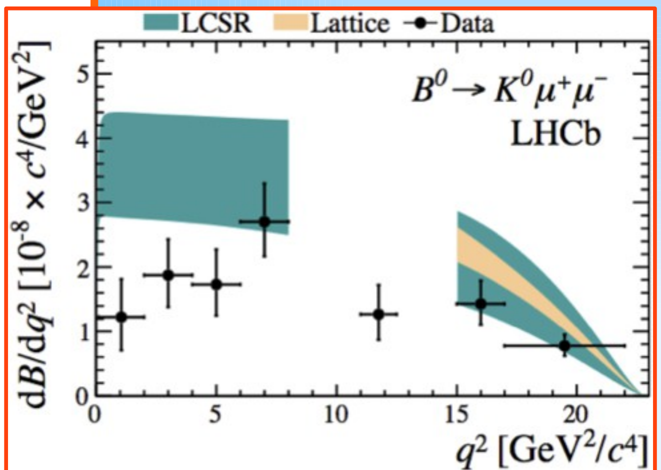
Data overview

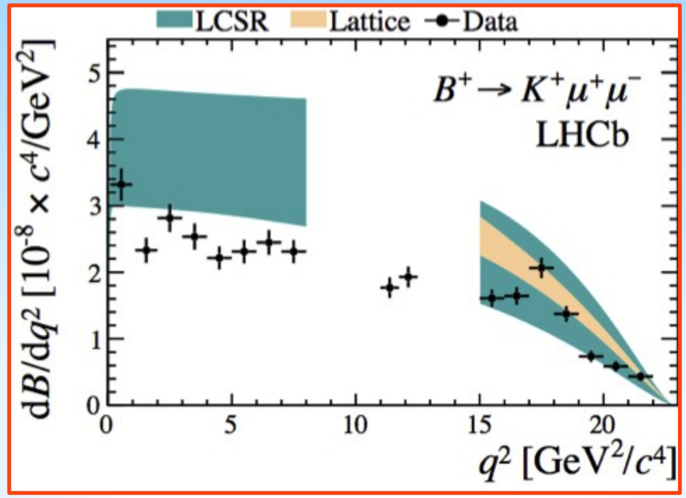
4 groups of interesting datasets, w/ different challenges

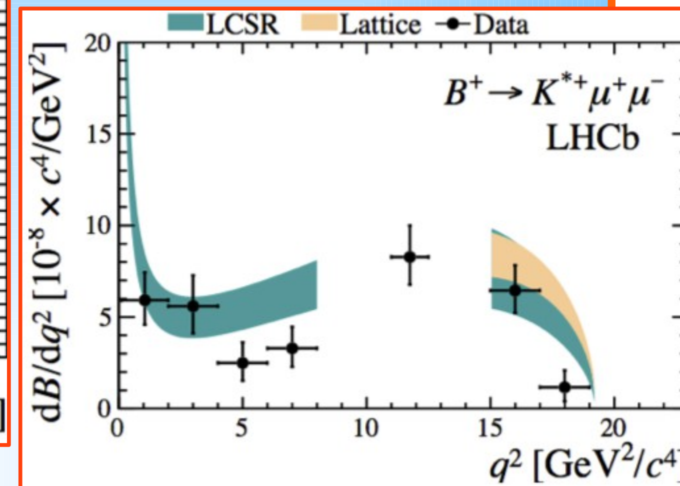
❶ $b \to s\, \mu\mu$ *BR data < SM*

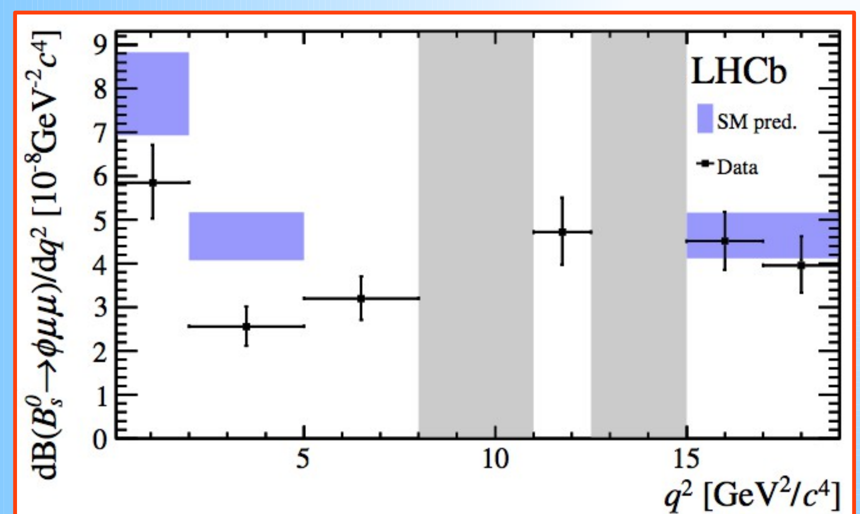
Challenge: $B \to$ *light meson f.f.'s*

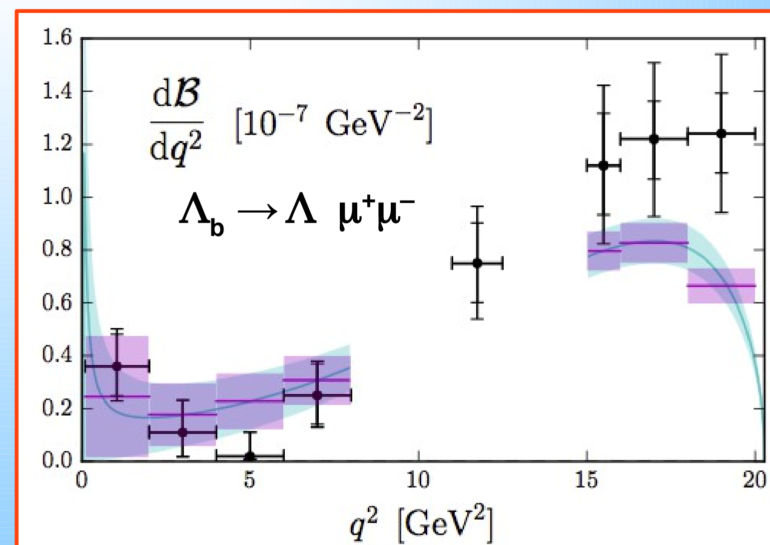
$b \rightarrow s\,\mu\mu$ BR data < SM











D. Guadagnoli, B-decay discrepancies

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❸ $b \to s\, \mu\mu$ / $b \to s\, ee$ *ratios*

Challenge: (mostly) stats

$b \to s\,\mu\mu$ / $b \to s\,ee$ ratios

$$R_K(q^2_{\min}, q^2_{\max}) \equiv \frac{\Gamma(B^+ \to K^+ \mu\mu)}{\Gamma(B^+ \to K^+ e e)}\Bigg|_{[q^2_{\min}, q^2_{\max}]}$$

A probe of Lepton-Universality Violation, by construction

- $$R_K(1\,\mathrm{GeV}^2, 6\,\mathrm{GeV}^2) = 0.846^{+0.060\,+0.016}_{-0.054\,-0.014}$$
  (2.5σ effect)

- $$R_{K^{*0}}(1.1\,\mathrm{GeV}^2, 6.0\,\mathrm{GeV}^2) = 0.685^{+0.113}_{-0.069} \pm 0.047$$
  (~2.4σ effect)

- $$R_{K^{*0}}(0.045\,\mathrm{GeV}^2, 1.1\,\mathrm{GeV}^2) = 0.660^{+0.110}_{-0.070} \pm 0.024$$
  (~2.2σ effect)

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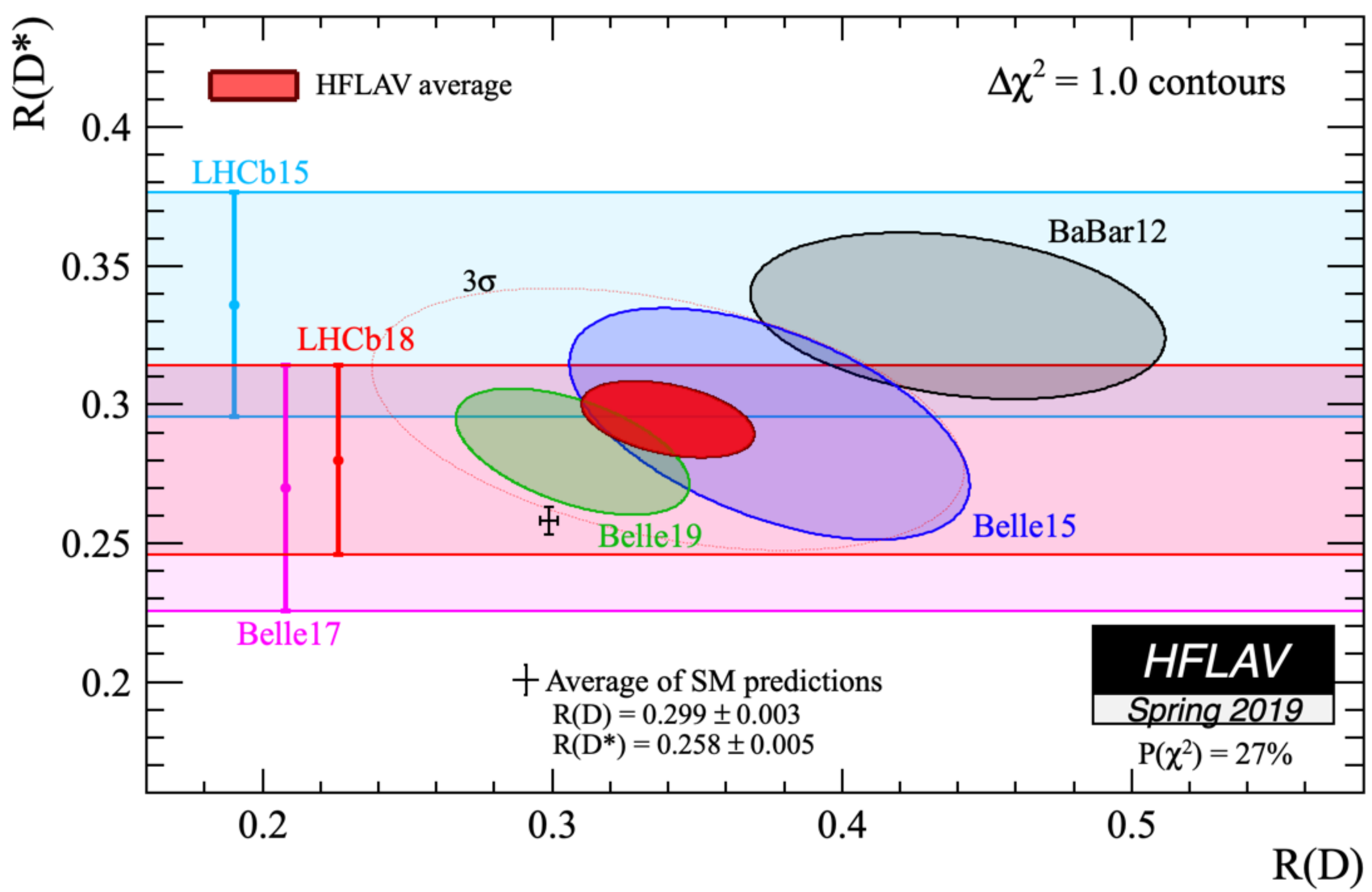
Challenge: (mostly) stats

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

Challenge: stats + syst

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

$$R_D^{(*)} \equiv \frac{\Gamma(B \to D^{(*)}\tau\nu)}{\Gamma(B \to D^{(*)}\ell\nu)}$$



Basic TH considerations

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($R_{K(*)}$)

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☞ *substantial improvement w.r.t. SM alone*

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

Data updates

Including all data as of Moriond 19 crucial to get full picture

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

$R_K \cong 0.85\,(1 \pm 7\%)$ ⇨ 2.5σ

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and more ($\Lambda_b \to \Lambda\, \mu\mu$, $b \to s\, \gamma$ & $b \to s\, g$, ...)

EW-scale

Effective-Theory picture

b → s EFT picture

- *One starts from the following Hamiltonian*

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

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About equal size & opposite sign in the SM (at the m_b scale)

(V – A) x (V – A) interaction

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

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

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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

Coeff.	best fit	1σ	2σ	pull
$C_9^{bs\mu\mu}$	-0.97	$[-1.12, -0.81]$	$[-1.27, -0.65]$	5.9σ
$C_9'^{bs\mu\mu}$	$+0.14$	$[-0.03, +0.32]$	$[-0.20, +0.51]$	0.8σ
$C_{10}^{bs\mu\mu}$	$+0.75$	$[+0.62, +0.89]$	$[+0.48, +1.03]$	5.7σ
$C_{10}'^{bs\mu\mu}$	-0.24	$[-0.36, -0.12]$	$[-0.49, +0.00]$	2.0σ
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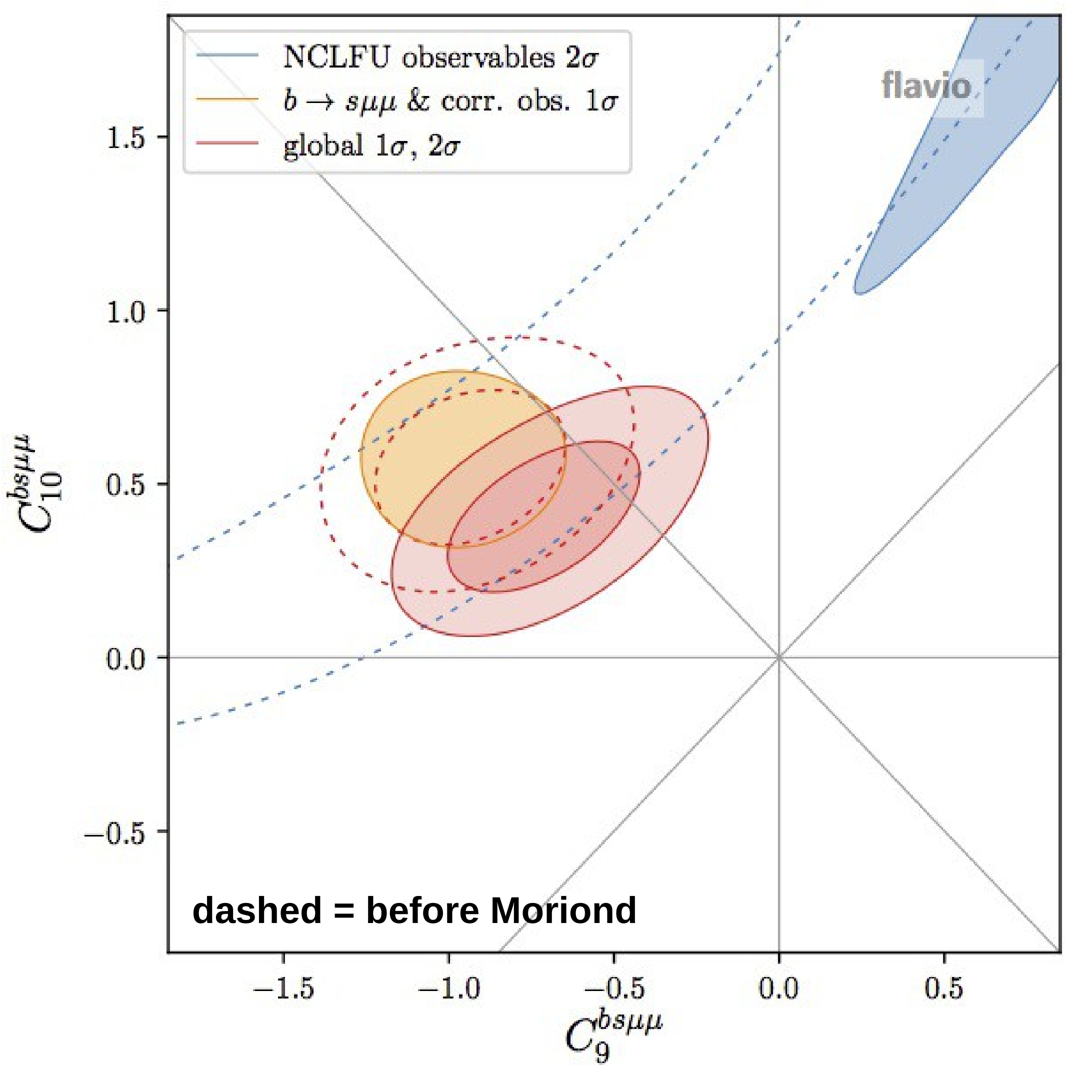
- *Two scenarios stand out: C_9 alone or $C_9 = -C_{10}$ (μμ-channel only)*
- *$C_9 = -C_{10}$ now better than C_9 alone*
- *C_{10} alone also ok, but $B \to K^* \mu\mu$ unresolved*

C_9 vs. $C_9 = - C_{10}$



Main point

- ***Before Moriond***

  $R_{K^{(*)}}$ & $b \to s\,\mu\mu$ in nearly perfect agreement

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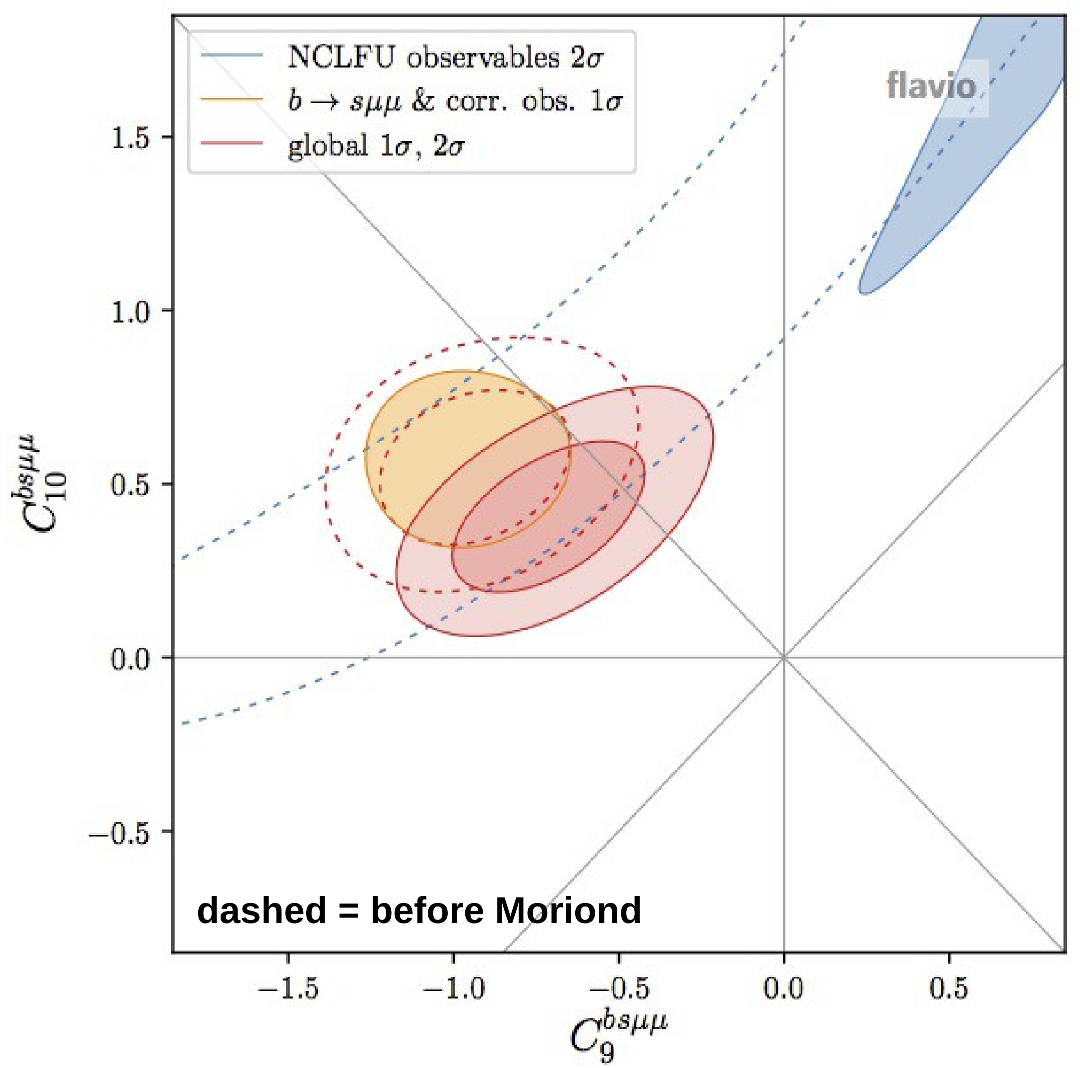

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- ***After Moriond***

  some tension in C_9 dir.

  ⇨ *but see next for a UV interpretation*

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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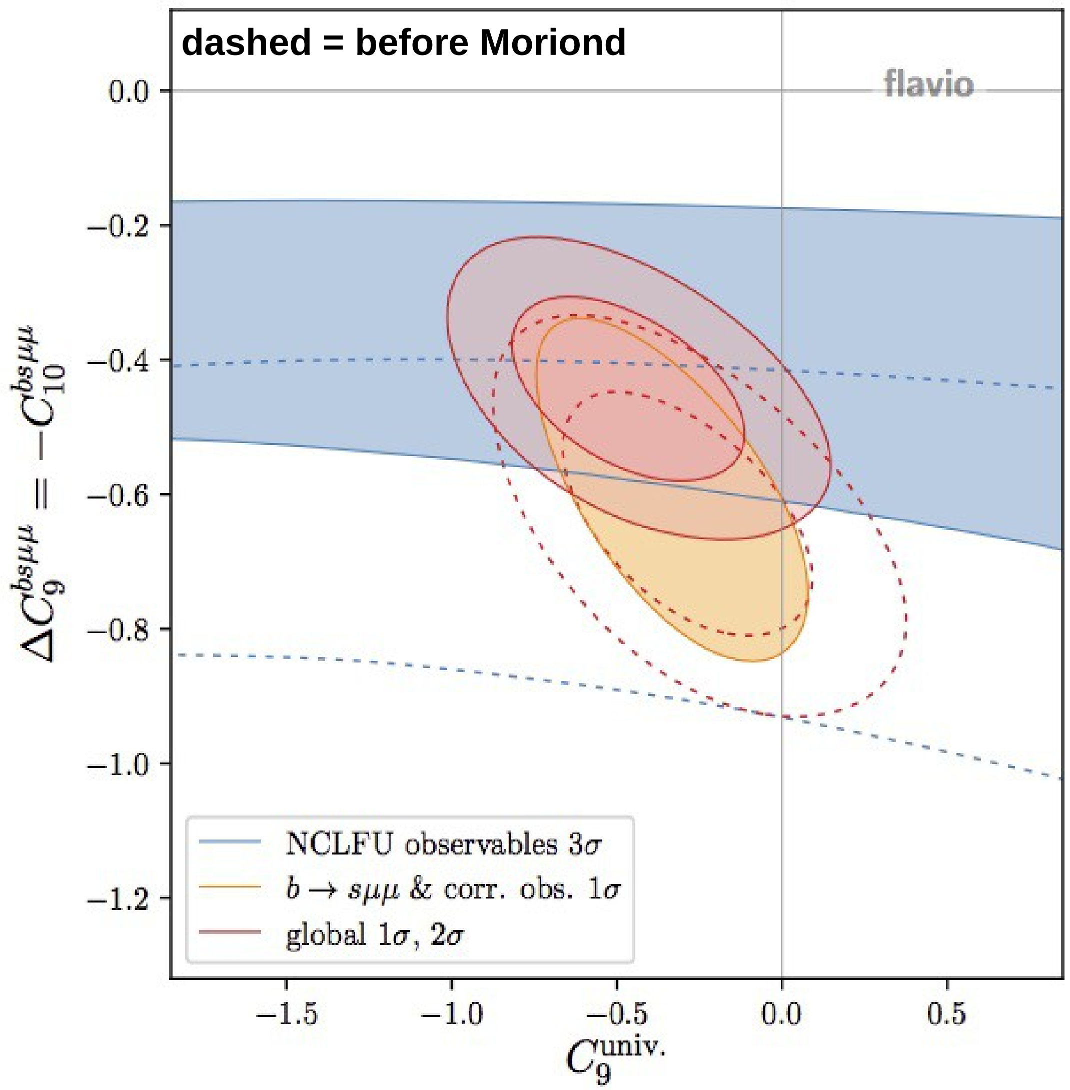

Notes

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

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

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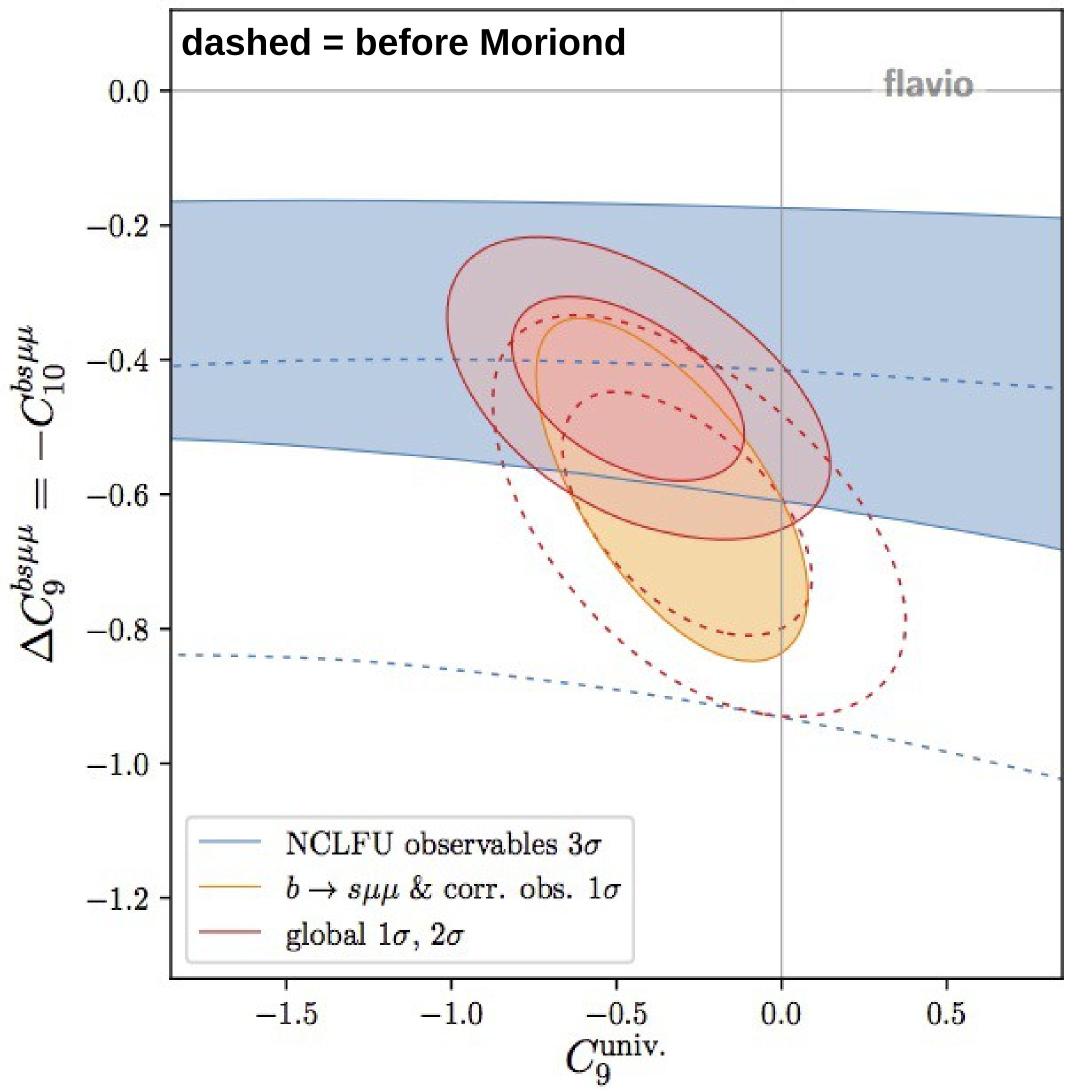

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After Moriond

Data tend to prefer $C_9^{univ.} \neq 0$

How to justify $C_9 = -C_{10}$ or $C_9^{univ.}$

above the EW scale?

The SMEFT picture

SMEFT 101

- *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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- *Such approach allows to address model-independently the question*

  What operators, above the EW scale, can generate contributions to $C_9^{(\mu)} = - C_{10}^{(\mu)}$ or $C_9^{univ.}$?

SMEFT picture

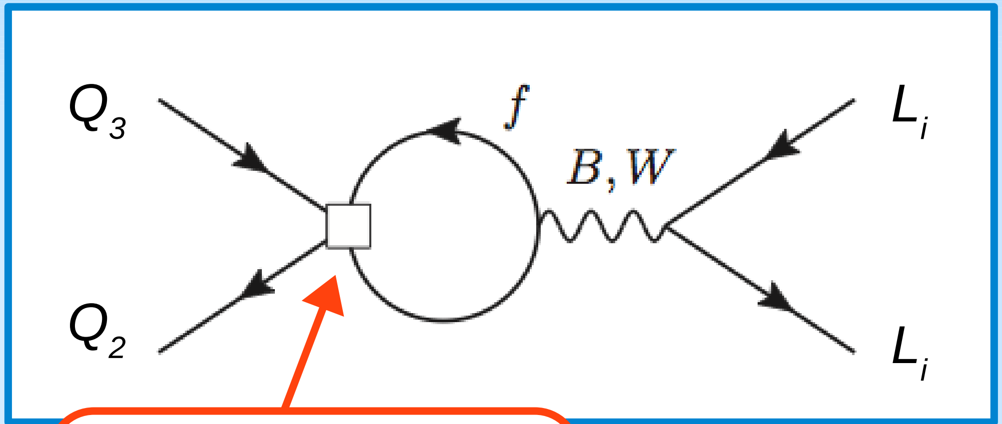
❶ *Contributions to muonic $C_9 = -C_{10}$ may come from SMEFT ops. directly matching onto $O_{9,10}$*

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

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

SMEFT picture

❷ *Contributions to $C_9^{univ.}$ can come from RGE effects:*



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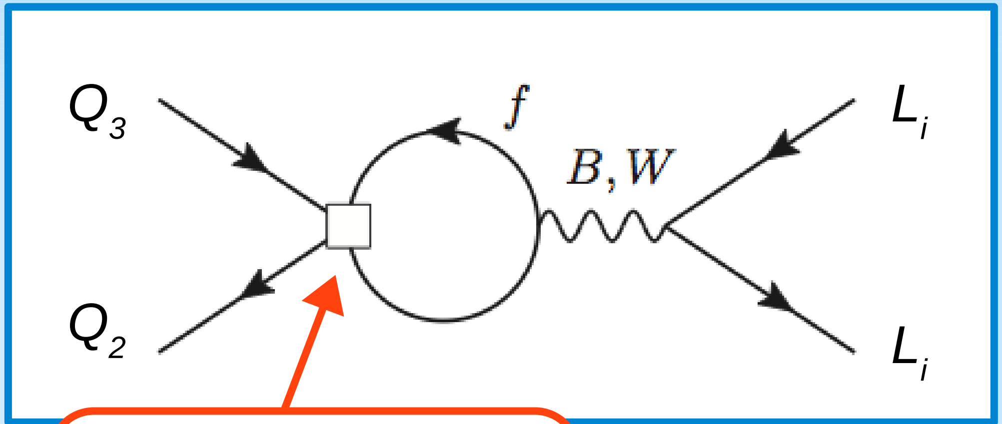

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- Case $f = \tau$ especially interesting

⇨ Connection with "semi-tauonic" ops.

$$[O_{LQ}^{(1)}]_{3323} \qquad [O_{LQ}^{(3)}]_{3323}$$

responsible for $b \to c\, \tau\nu$

Semi-tauonic ops. in short

- $[O_{LQ}^{(3)}]_{3323} \supset \bar{\tau}\gamma_L^\lambda \nu \cdot \bar{c}\gamma_{\lambda\, L} b$

  ⇨ *can explain $R_{D(*)}$*

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↳ *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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- $[O_{LQ}^{(1)\,\mathrm{or}\,(3)}]_{2223} \supset \bar{\mu}\gamma_L^{\lambda}\mu \cdot \bar{s}\gamma_{\lambda\,L} b$

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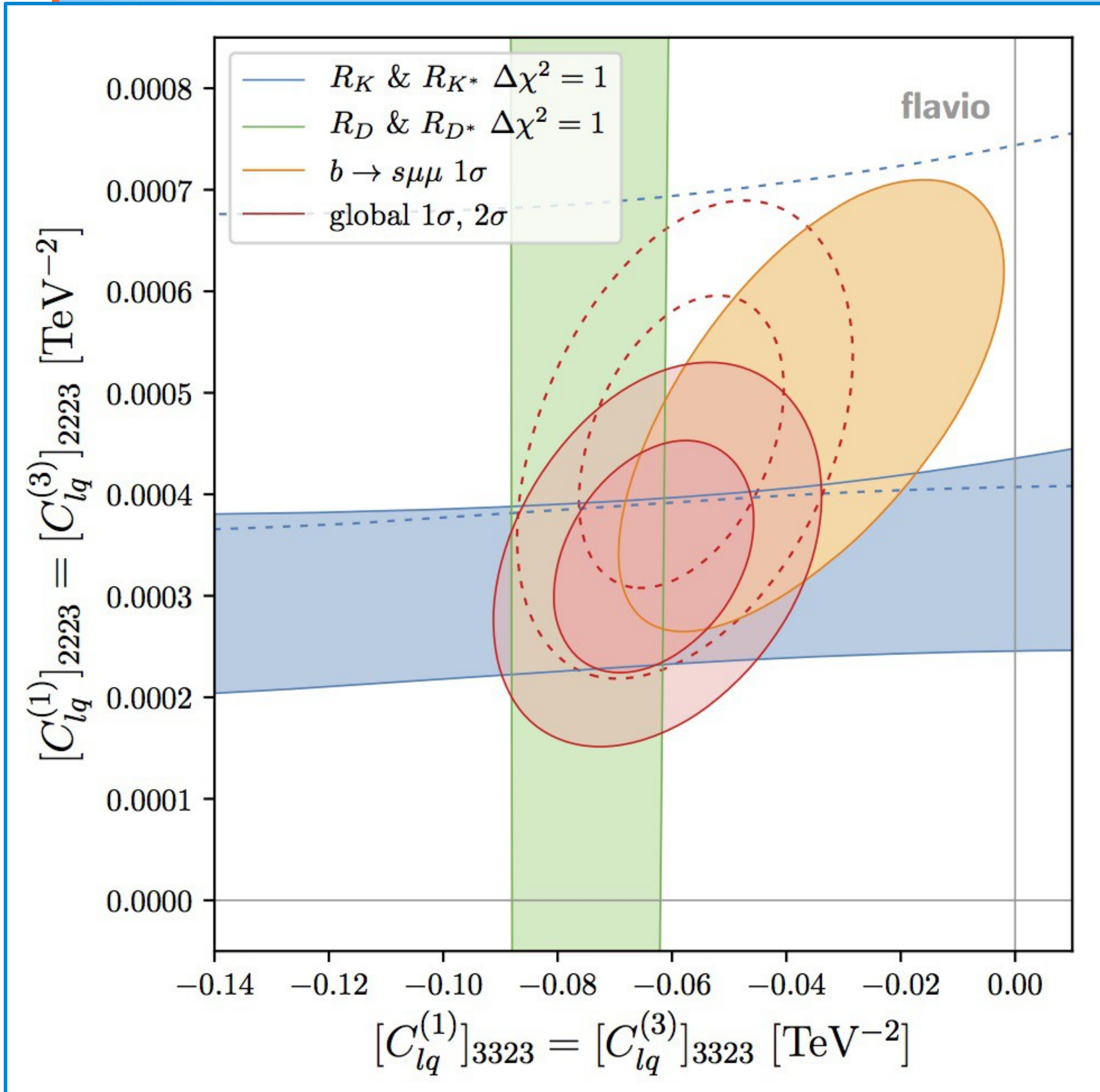
- *Caveat: one must have* $[C_{LQ}^{(1)}]_{3323} \simeq [C_{LQ}^{(3)}]_{3323}$ *to avoid the $B \to K(*)\ \nu\nu$ constraint*

  [Buras-Girrbach-Niehoff-Straub]

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



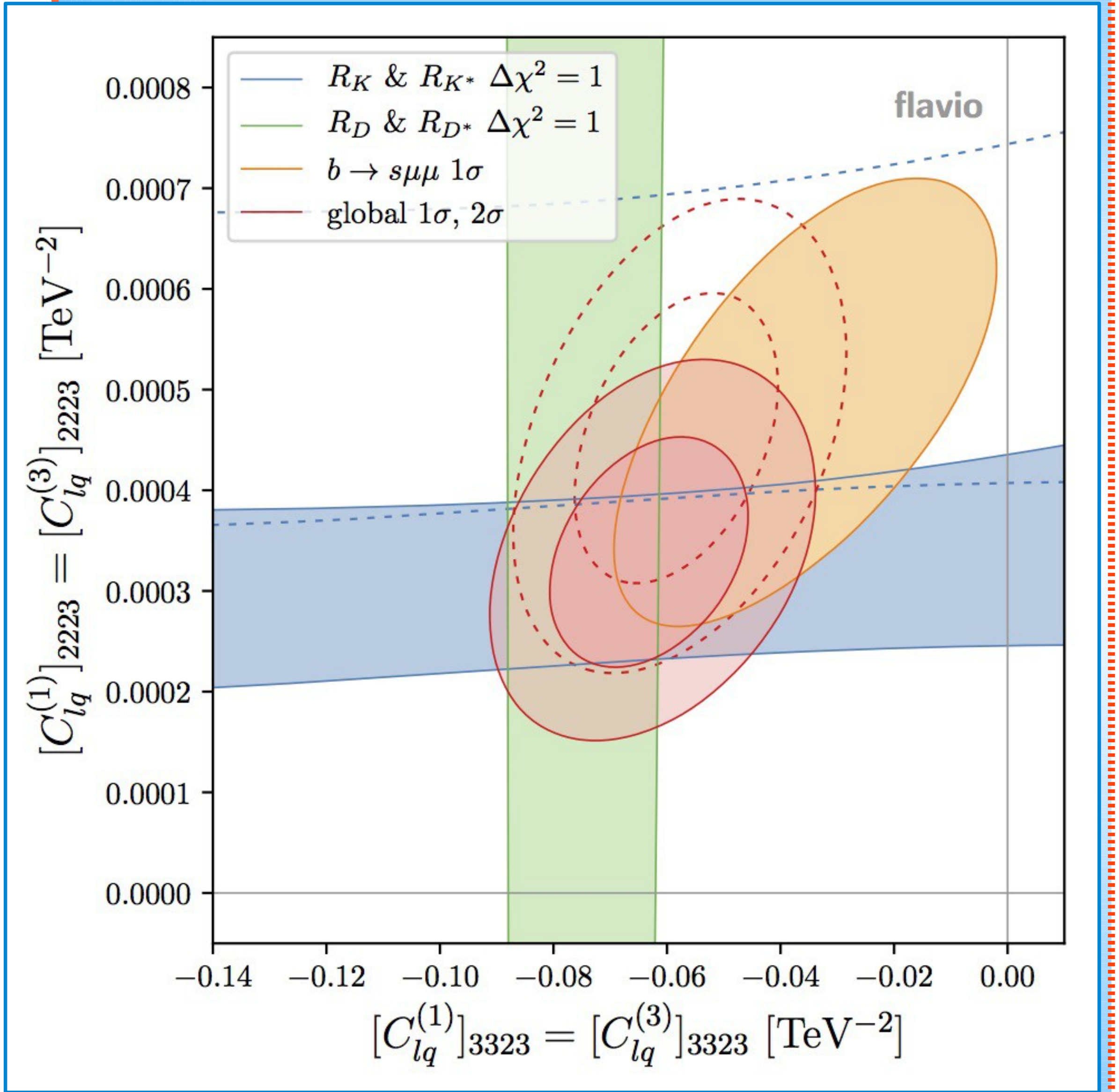
Before Moriond (dashed)

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

in a region close to 0 in the x-axis

⇒ *$R_{D(*)}$ not explained*

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



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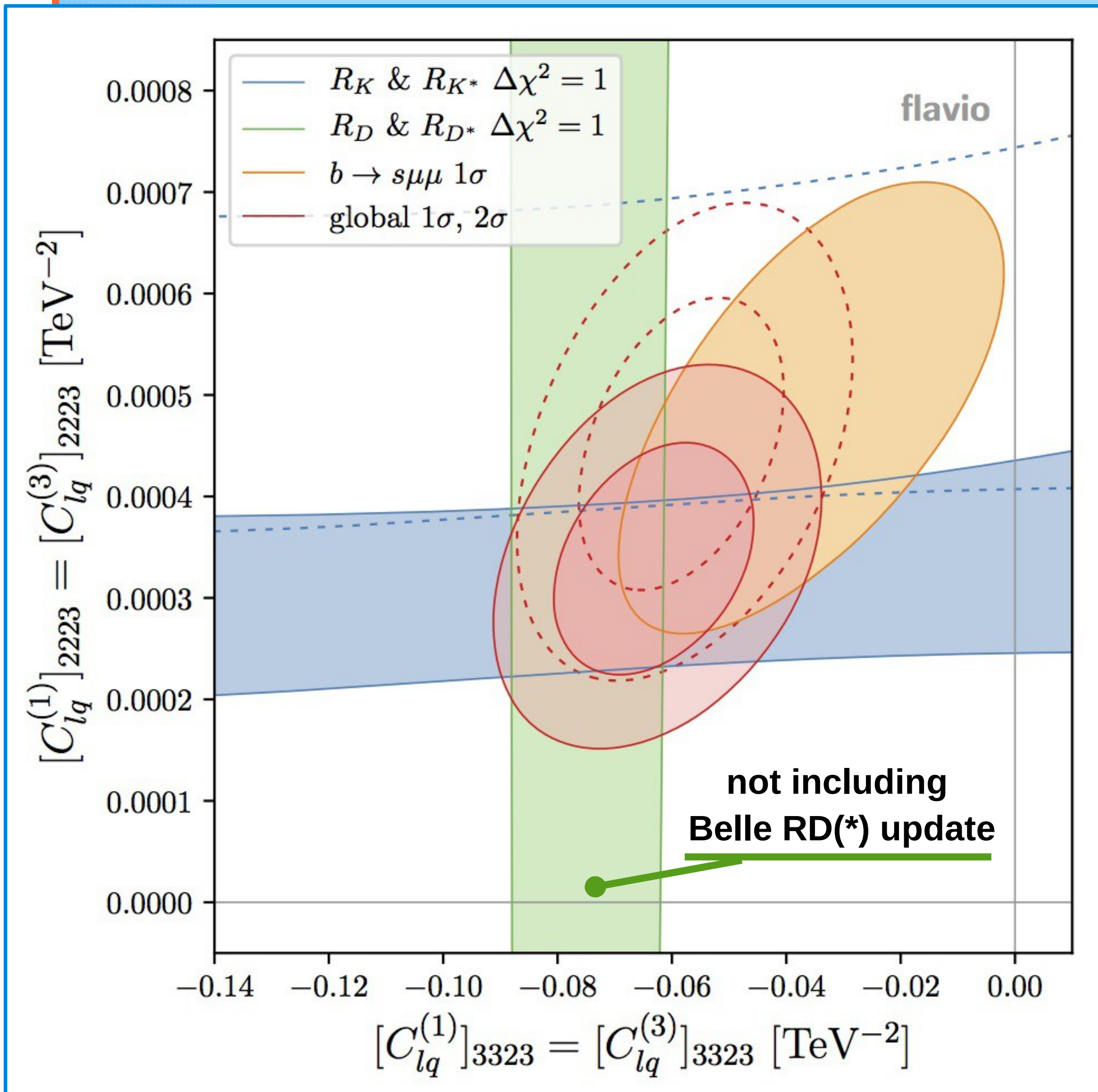
After Moriond

$R_{K(*)}$ and b → s μμ intersect

in a region with x-axis values well below 0

⇨ *Quantitative agreement with the $R_{D(*)}$ constraint (green)*

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



Before Moriond (dashed)

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

in a region close to 0 in the x-axis

⇨ *$R_{D(*)}$ not explained*

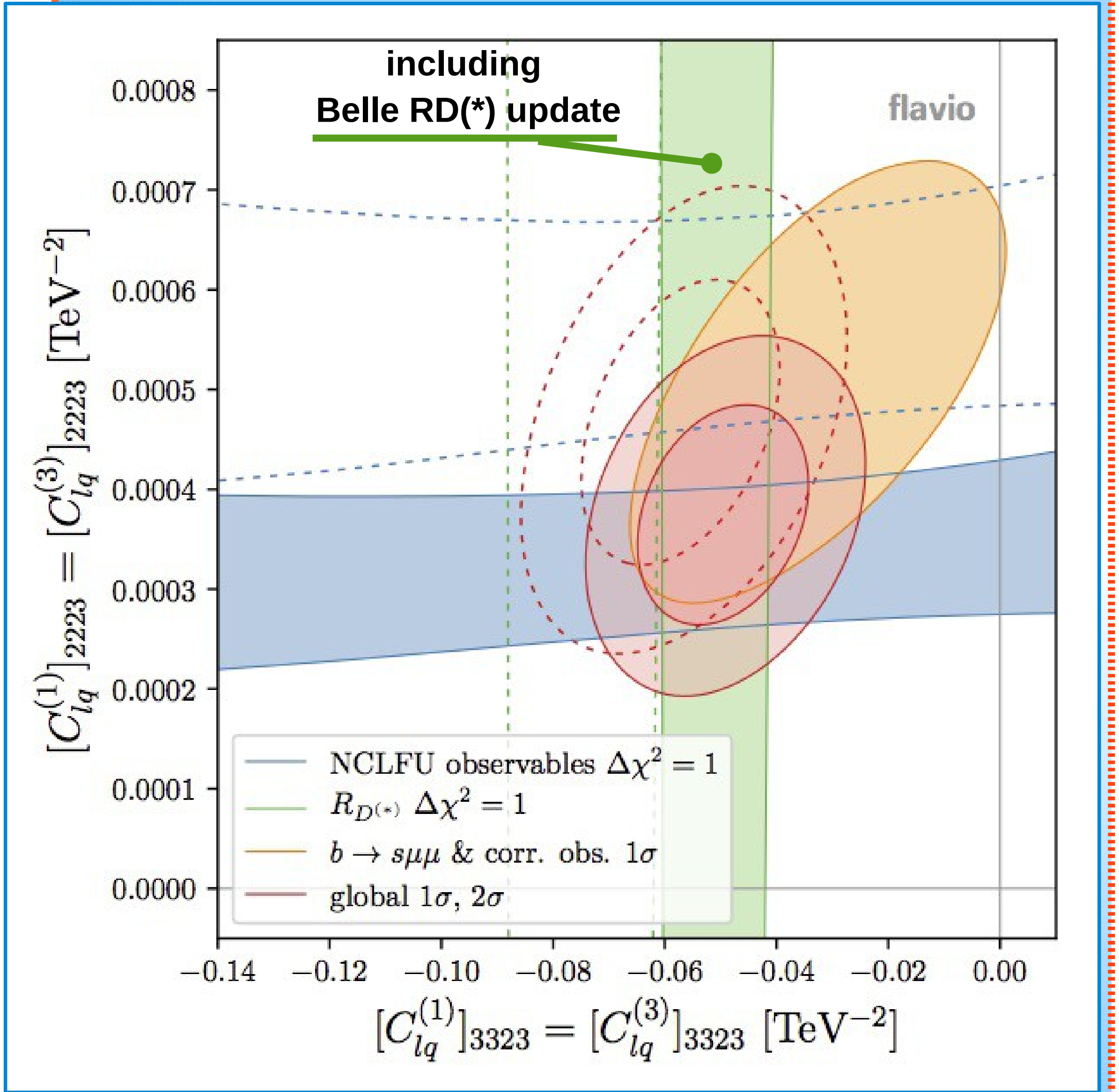
After Moriond

$R_{K(*)}$ and b → s μμ intersect

in a region with x-axis values well below 0

⇨ *Quantitative agreement with the $R_{D(*)}$ constraint (green)*

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



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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*

$$[C_{LQ}^{(1)}]_{3323} = [C_{LQ}^{(3)}]_{3323} \neq 0 \quad \&\& \quad [C_{LQ}^{(1)}]_{2223} = [C_{LQ}^{(3)}]_{2223} \neq 0$$

[*Alonso-Grinstein-Martin-Camalich, Calibbi-Crivellin-Ota, 2015*]

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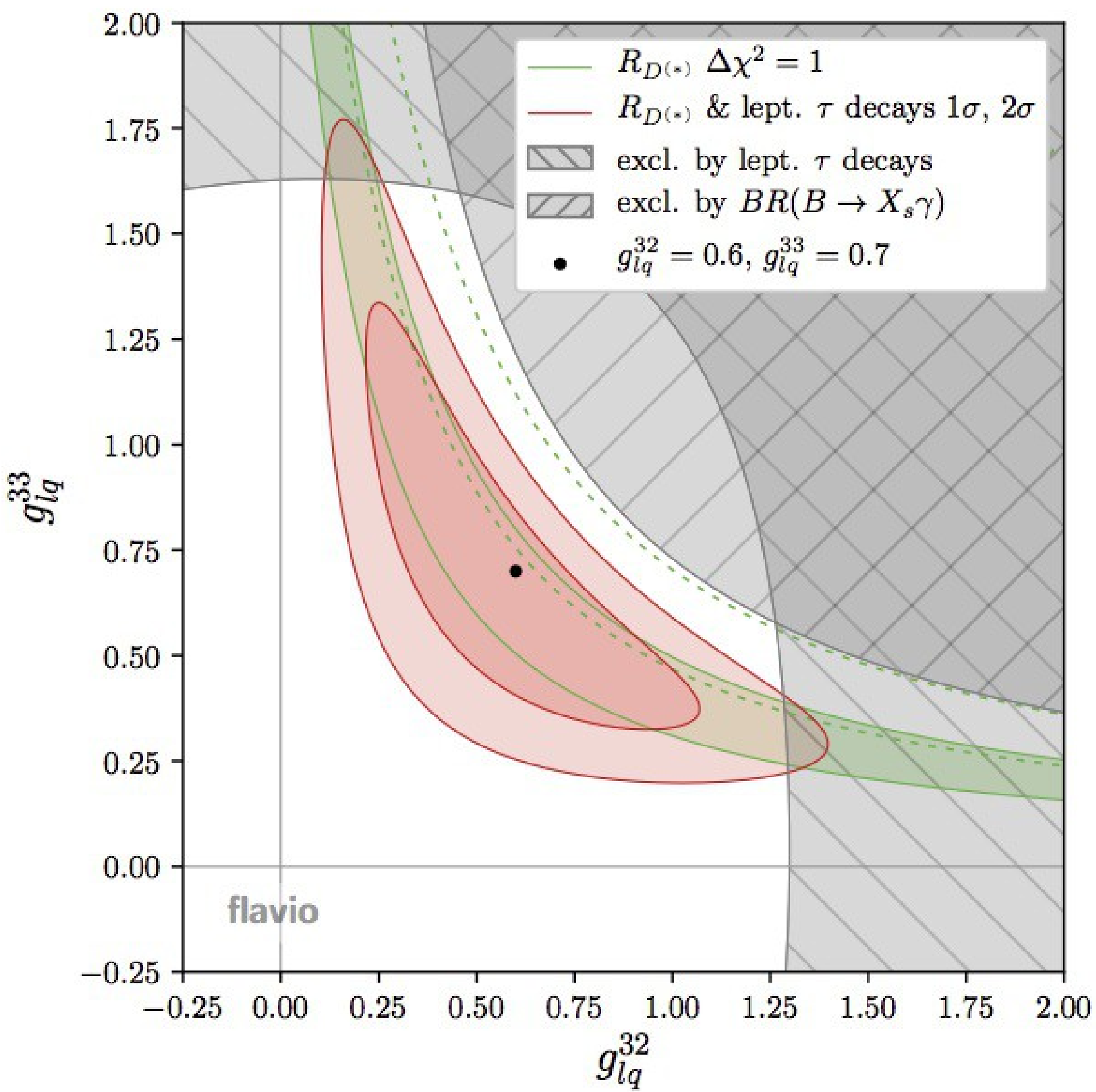
$$\boxed{\delta R_{D(*)}\big|_{\text{in } \tau \text{ channel}} \propto g^{32}_{lq} \;\&\; g^{33}_{lq}}$$

☞ *these couplings also famously constrained by*

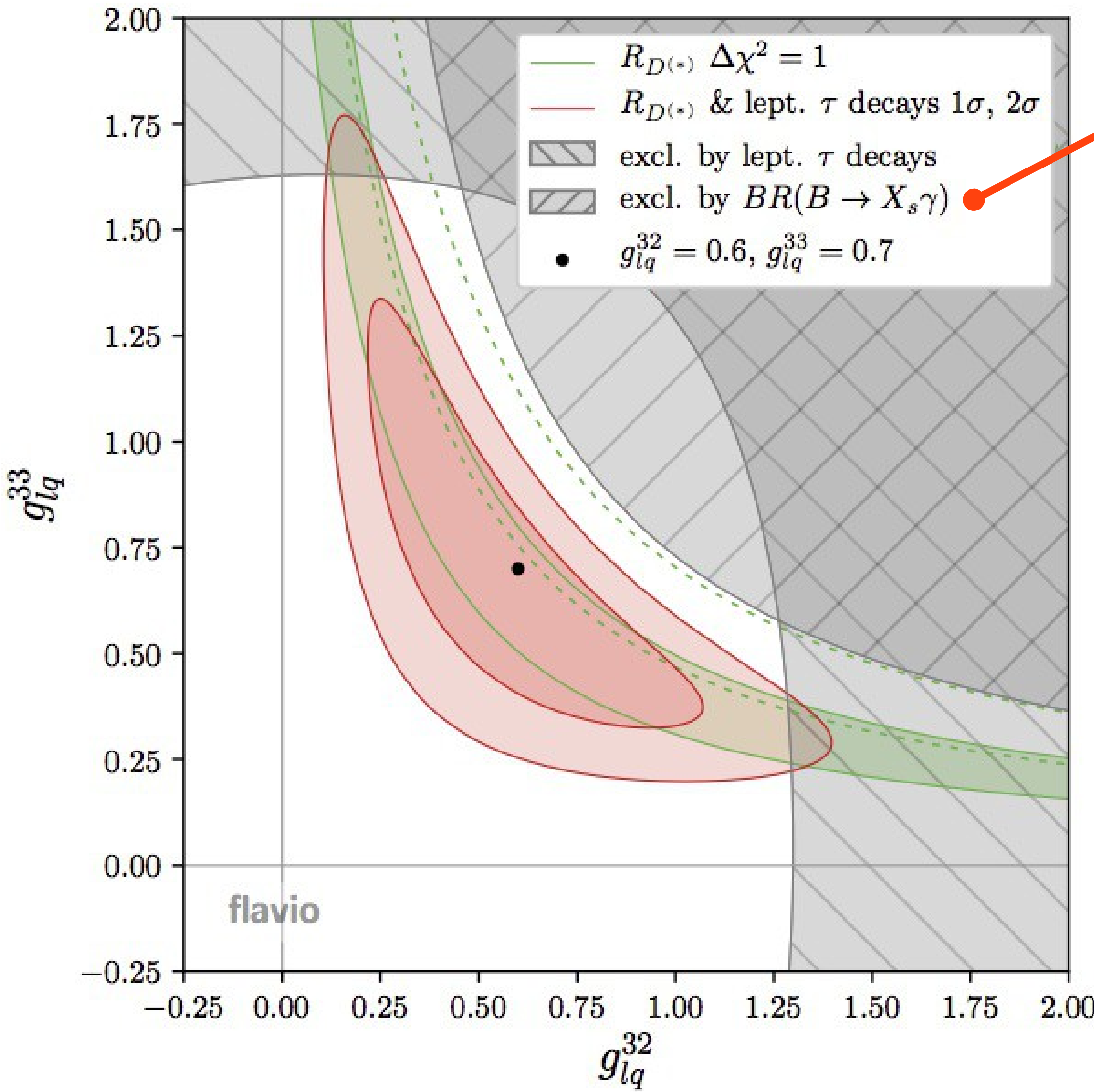
$\tau \to \ell\, \nu\nu$ [*Feruglio-Paradisi-Pattori*]

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

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



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



Model-dependent constraint

See discussion in [Cornella-Fuentes-Isidori, 2019; Calibbi-Crivellin-Li, 2018; Bordone *et al.*, 2018]

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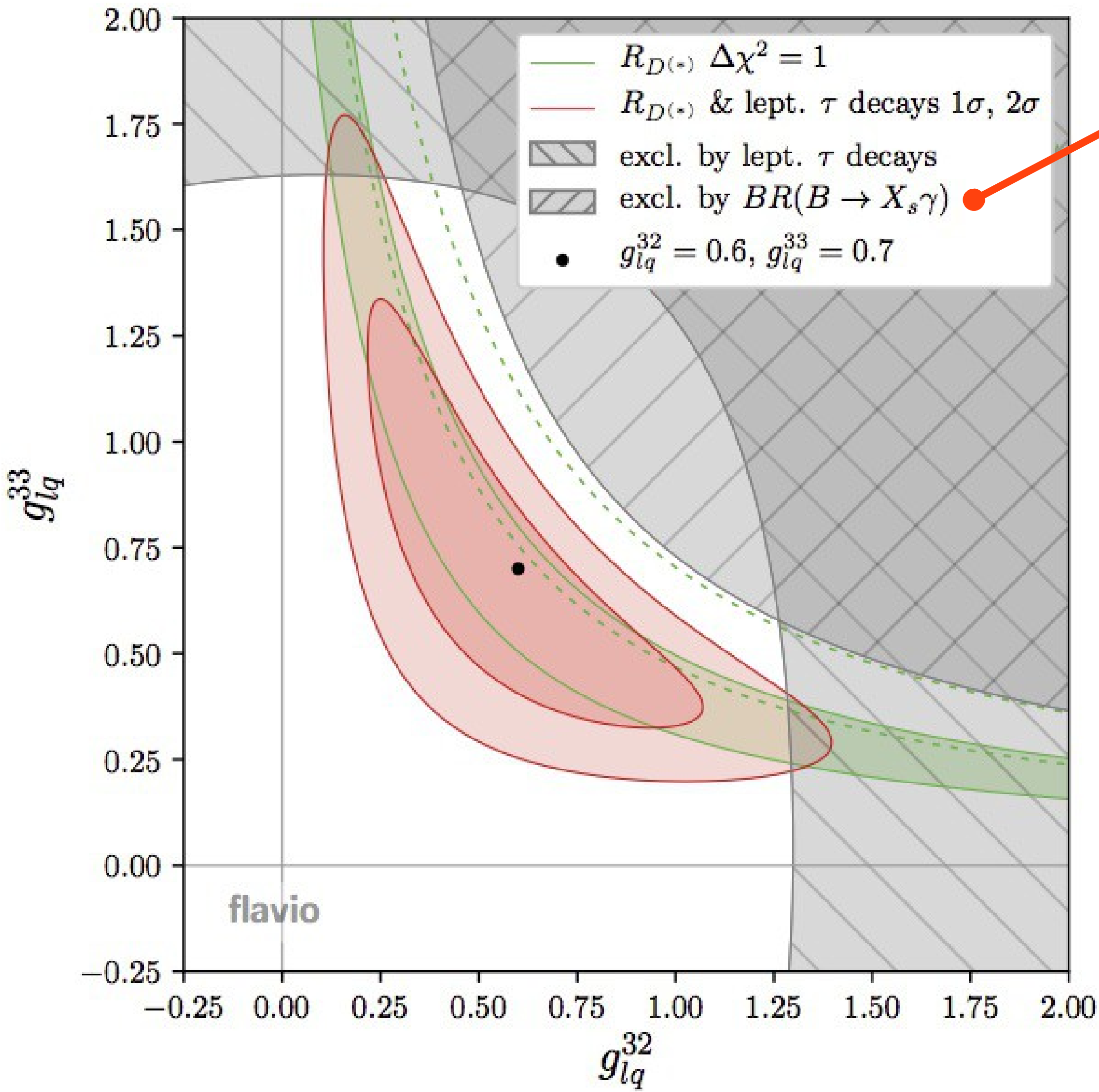

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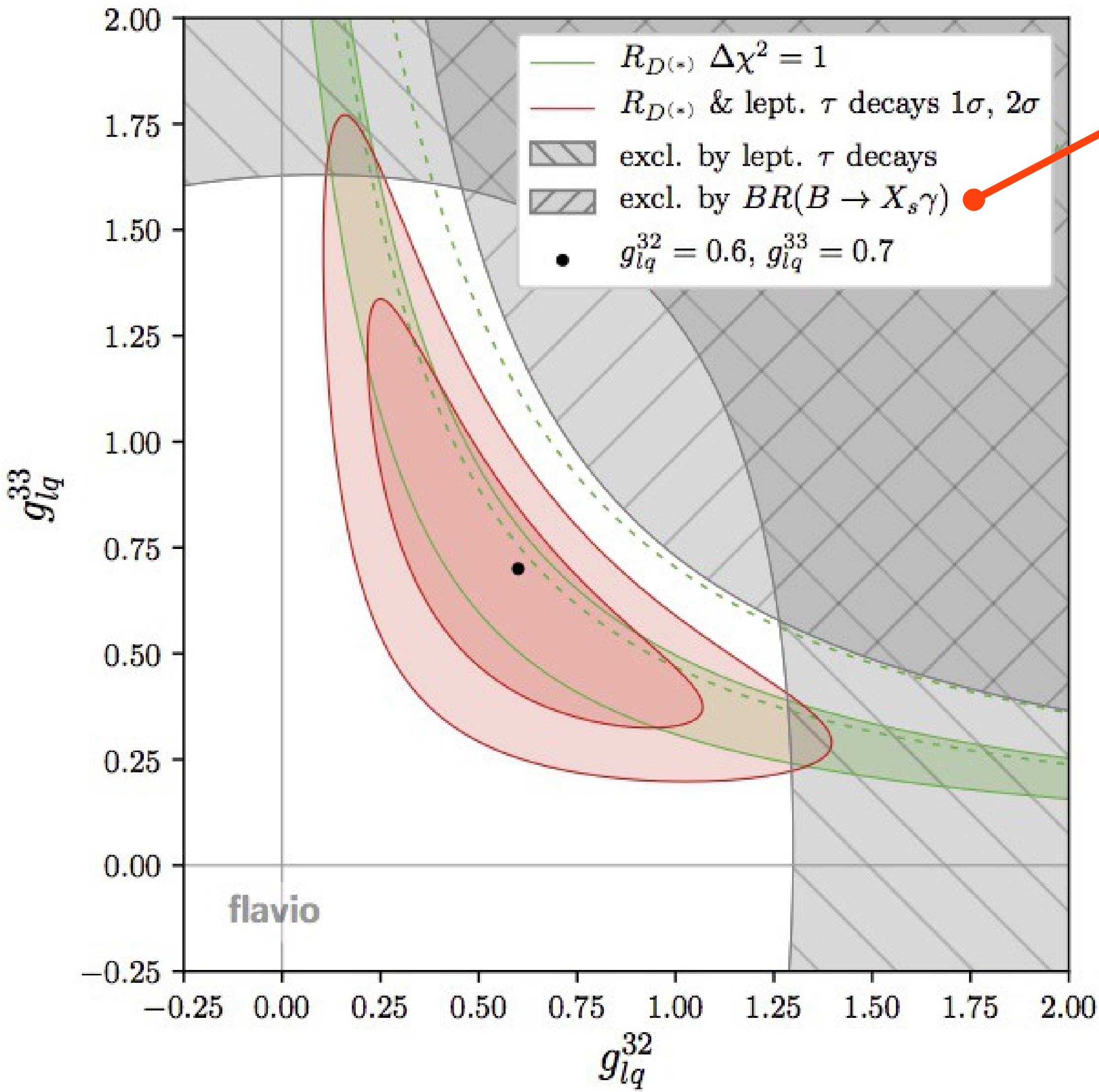

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[Cornella-Fuentes-Isidori, 2019;
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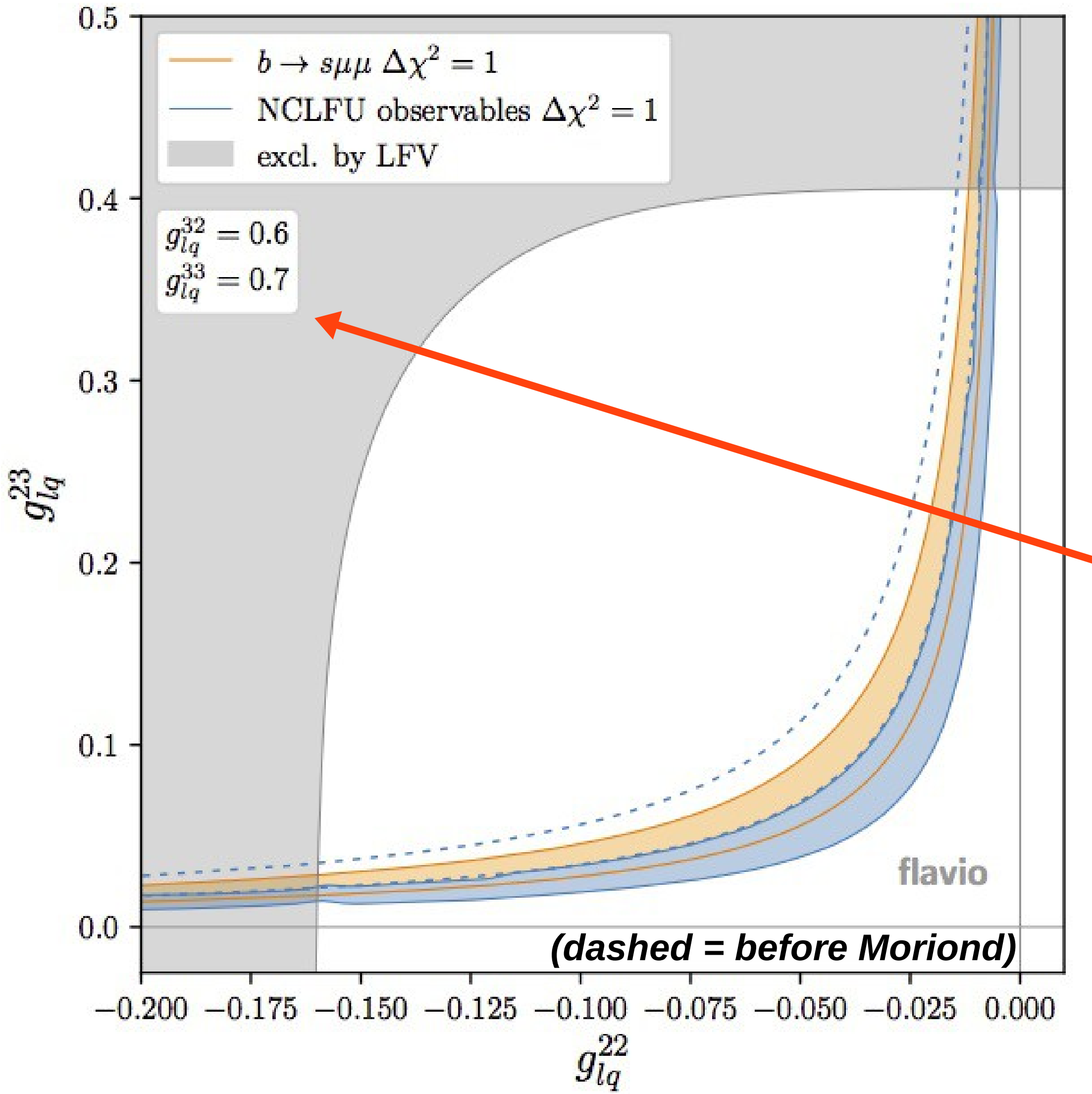
- *$R_{D(*)}$ and $\tau \to \ell\ \nu\nu$ select a non-trivial region*
- *We pick a benchmark point, then constrain the other two couplings*

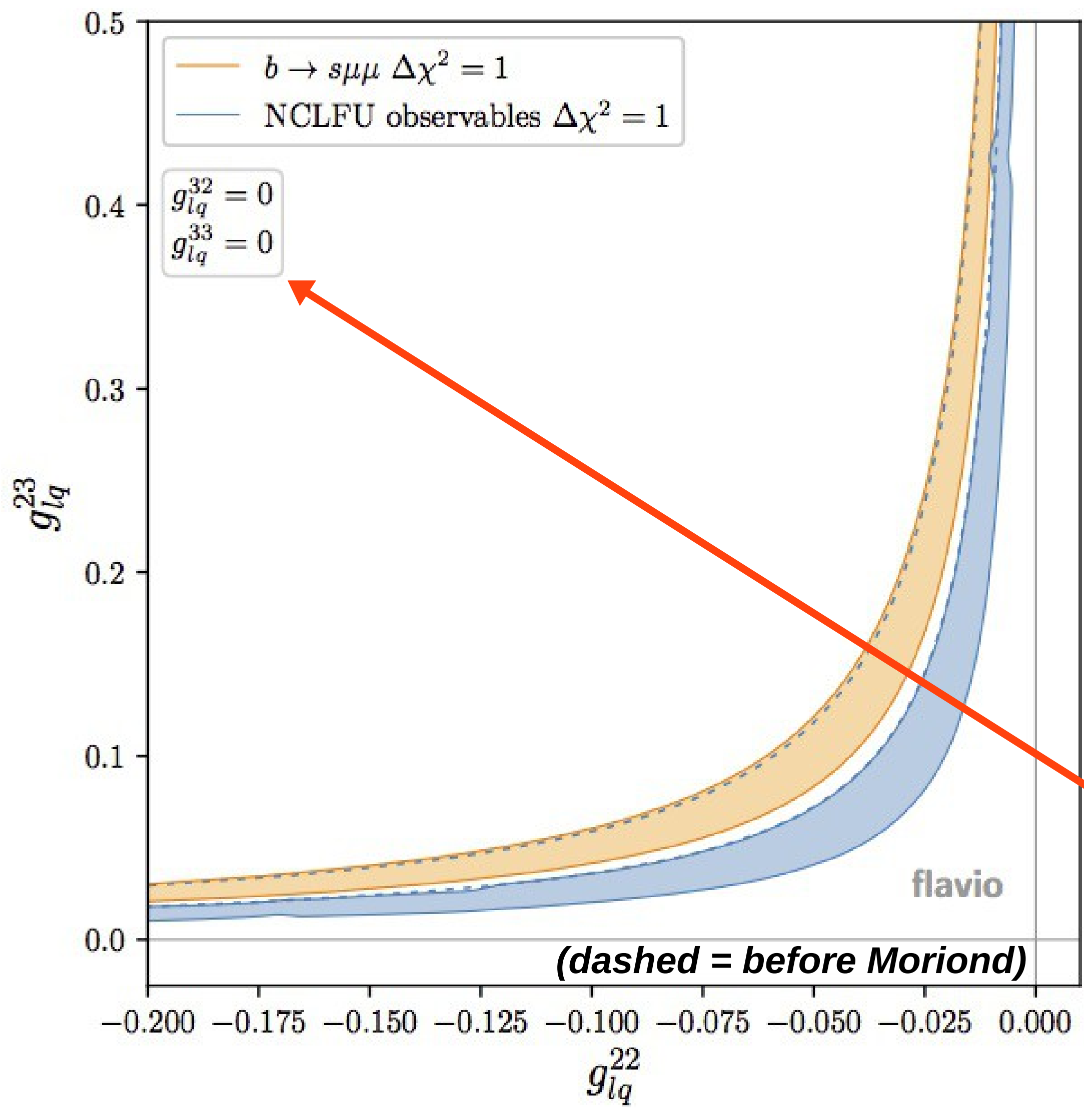
U_1 LQ: g_{lq}^{22} vs. g_{lq}^{23}



The plane of muonic couplings shows that the picture is fully consistent

- *The $R_{K^{(*)}}$ and $b \to s\,\mu\mu$ regions now nicely overlap*
- *Tauonic couplings fixed to the benchmark value explaining $R_{D^{(*)}}$*

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



The plane of muonic couplings shows that the picture is fully consistent

- *The $R_{K(*)}$ and $b \to s\,\mu\mu$ regions now nicely overlap*
- *Tauonic couplings fixed to the benchmark value explaining $R_{D(*)}$*
- *If they were set to zero, the picture would work much less*

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- *One gets a coherent picture all the way from the WET, to the SMEFT, to simplified models*

Conclusions

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- *One gets a coherent picture all the way from the WET, to the SMEFT, to simplified models*

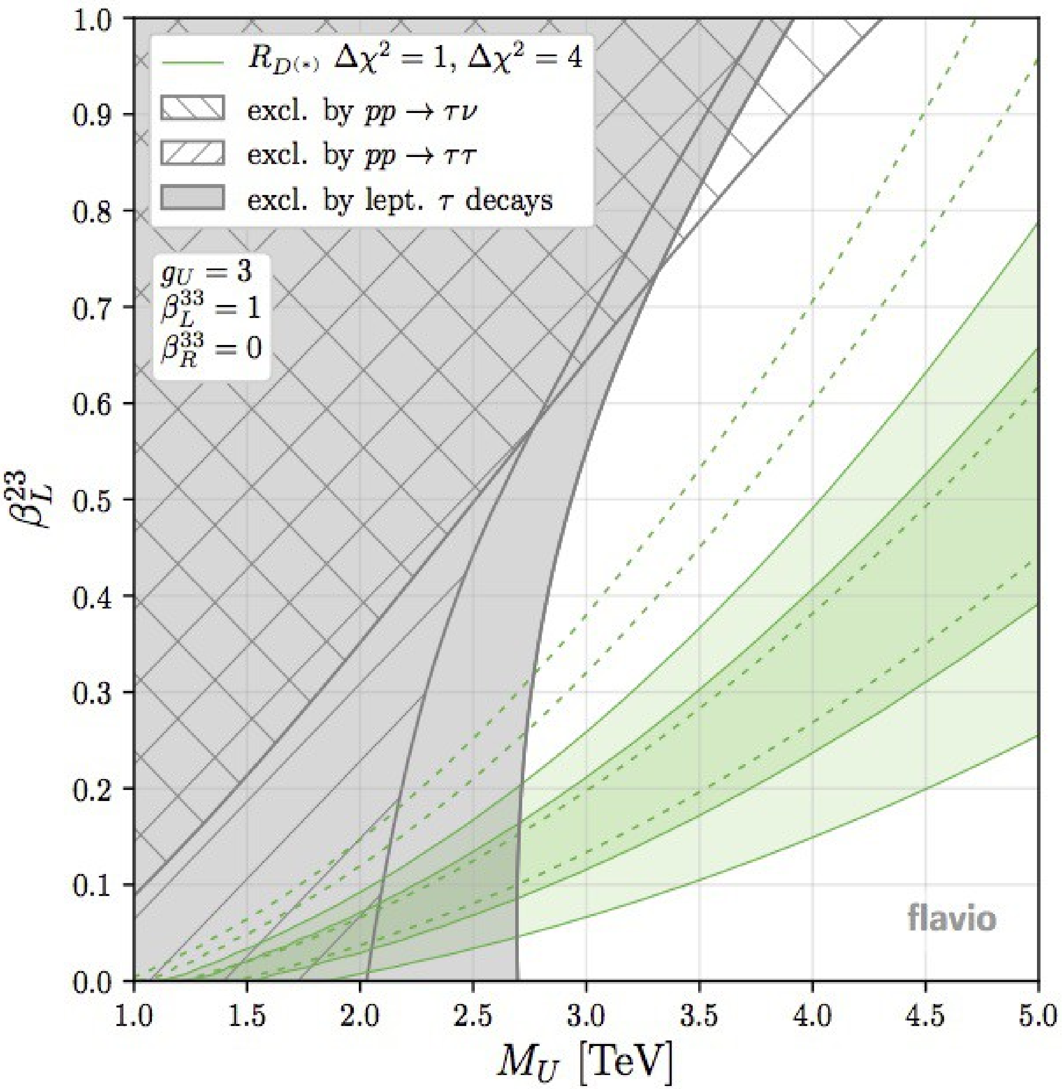
- *Time for more tests*

  More LUV observables will clarify the situation soon

Spares

U_1 LQ: direct constraints

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



For the sake of comparison, we normalized coupling values to those used in [Baker-Fuentes-Isidori-König]

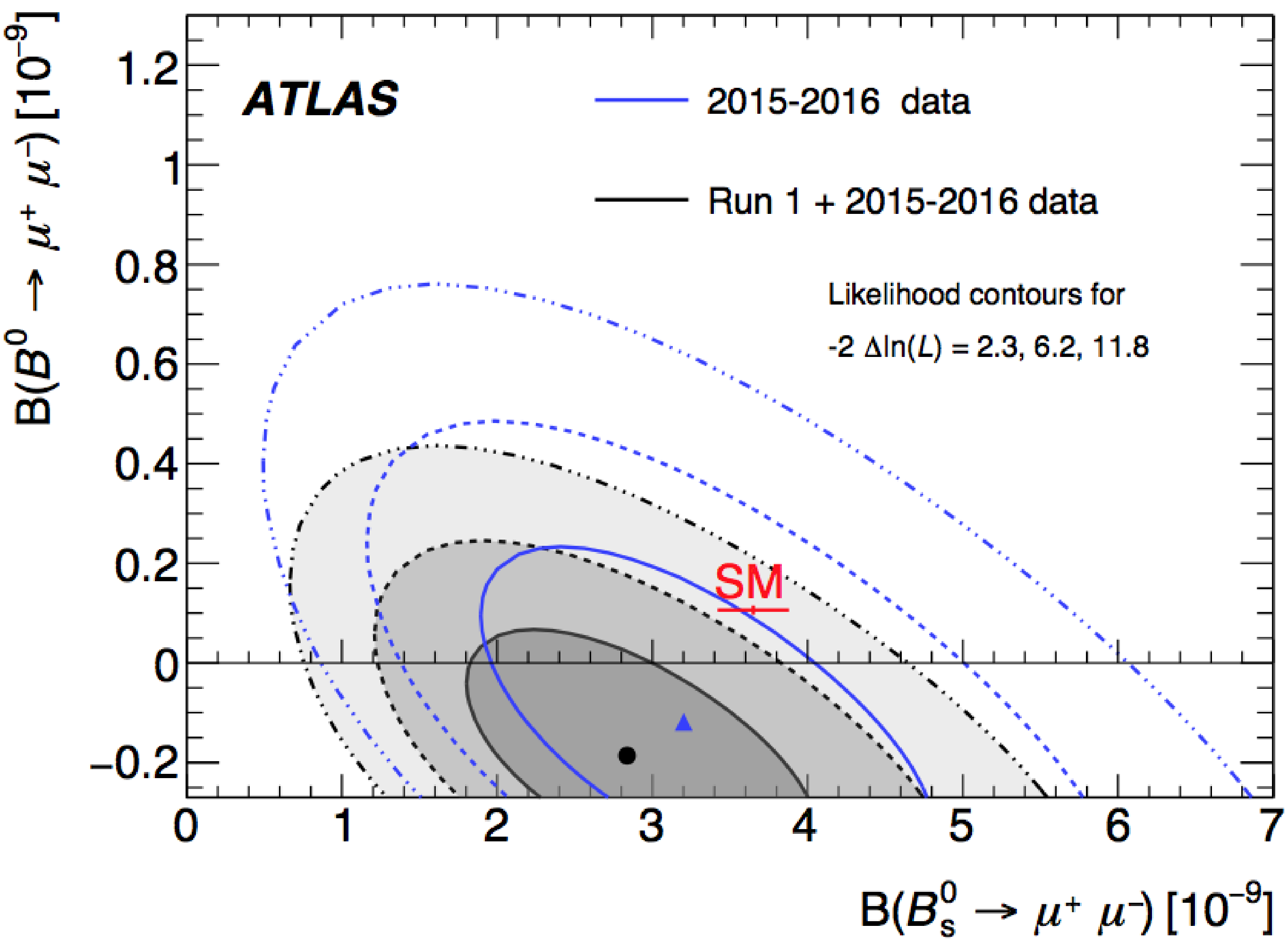
With $g_{lq}^{3i} \neq 0$ (as required by $R_{D(*)}$) LUV constraints are stronger than direct ones

Note also the large g_U value used here (as said, for comparison).

All constraints scale down with lower g_U values.

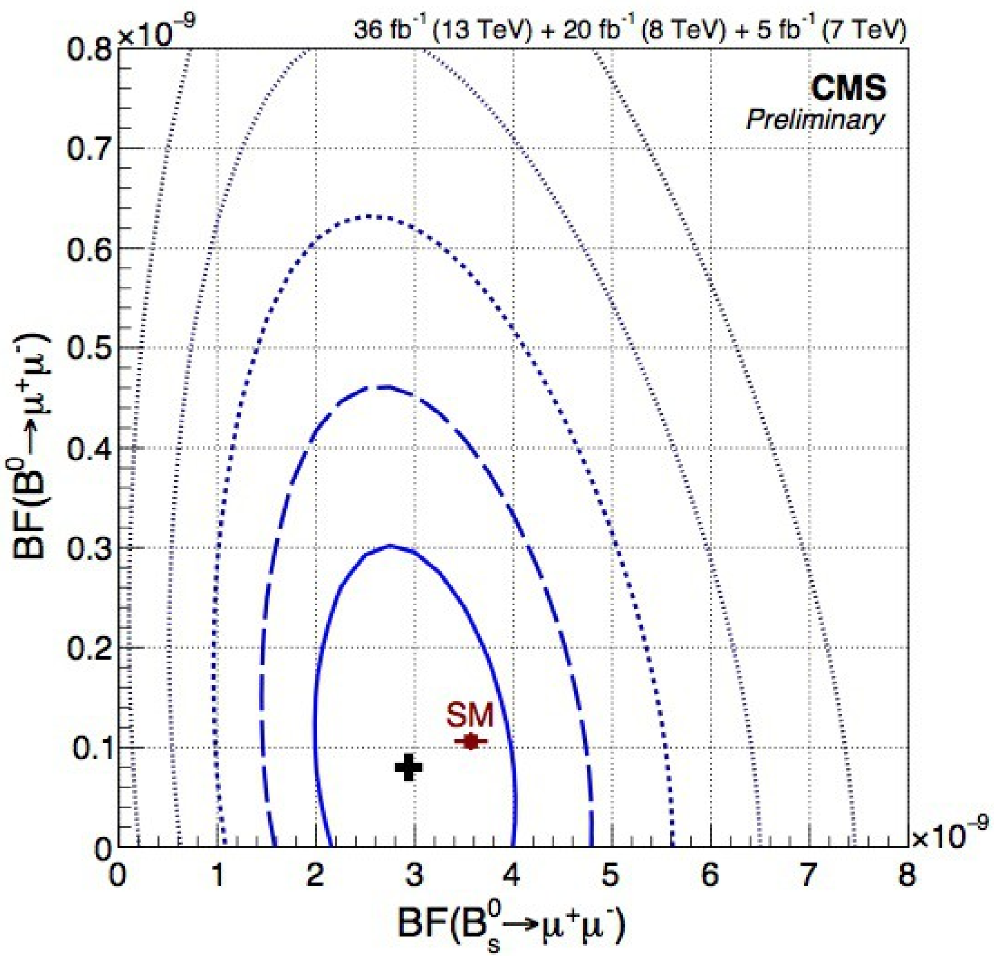
$B_s \to \mu\mu$ update

[1812.03017]



New update from CMS

$$BR\left(B_s \to \mu\mu\right) = \left(2.9^{+0.7}_{-0.6} \pm 0.2\right) \times 10^{-9}$$



CMS PAS BPH-16-004 *(2019/08/04)*