BSM effects in B physics: Where do we stand?

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This talk assignment before Dec. 20, 2022

This talk assignment after Dec. 20, 2022

Before any anomaly

Why new physics in B decays

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Loop & CKM & sometimes GIM & sometimes chiral

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- b → s transitions are the FCNCs closest to 3rd gen. physics

Take meson mixings as an example

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[**Isidori-Nir-Perez, 1002.0900**]

Operator	Bounds on Λ in TeV ($c_{ij}=1$)		Bounds on c_{ij} ($\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
$(\bar{s}_L\gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ϵ_K
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	Δm_K; ϵ_K
$(\bar{c}_L\gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p\rvert, \phi_D$
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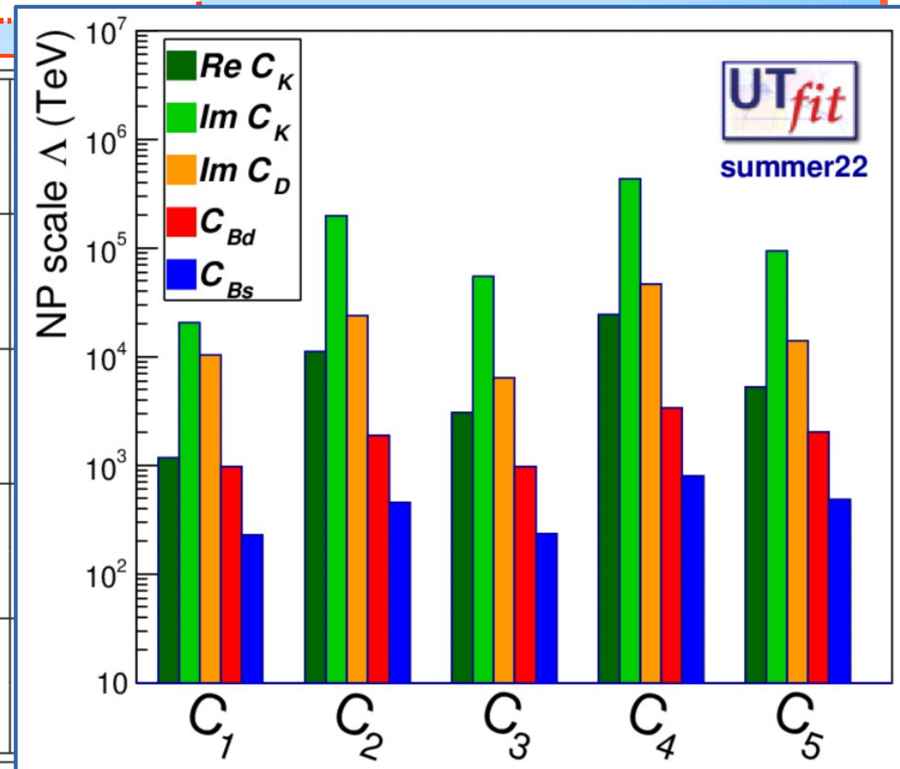

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- And if flavour is after all not just a puzzle, then flavour observables are all the more important **[Davighi-Isidori, 2303.two-days-ago]**

- In either case, if focus is on the highest scales attainable, flavour observables remain among the deepest probes

Anomalies (?)

NP before Dec. 20

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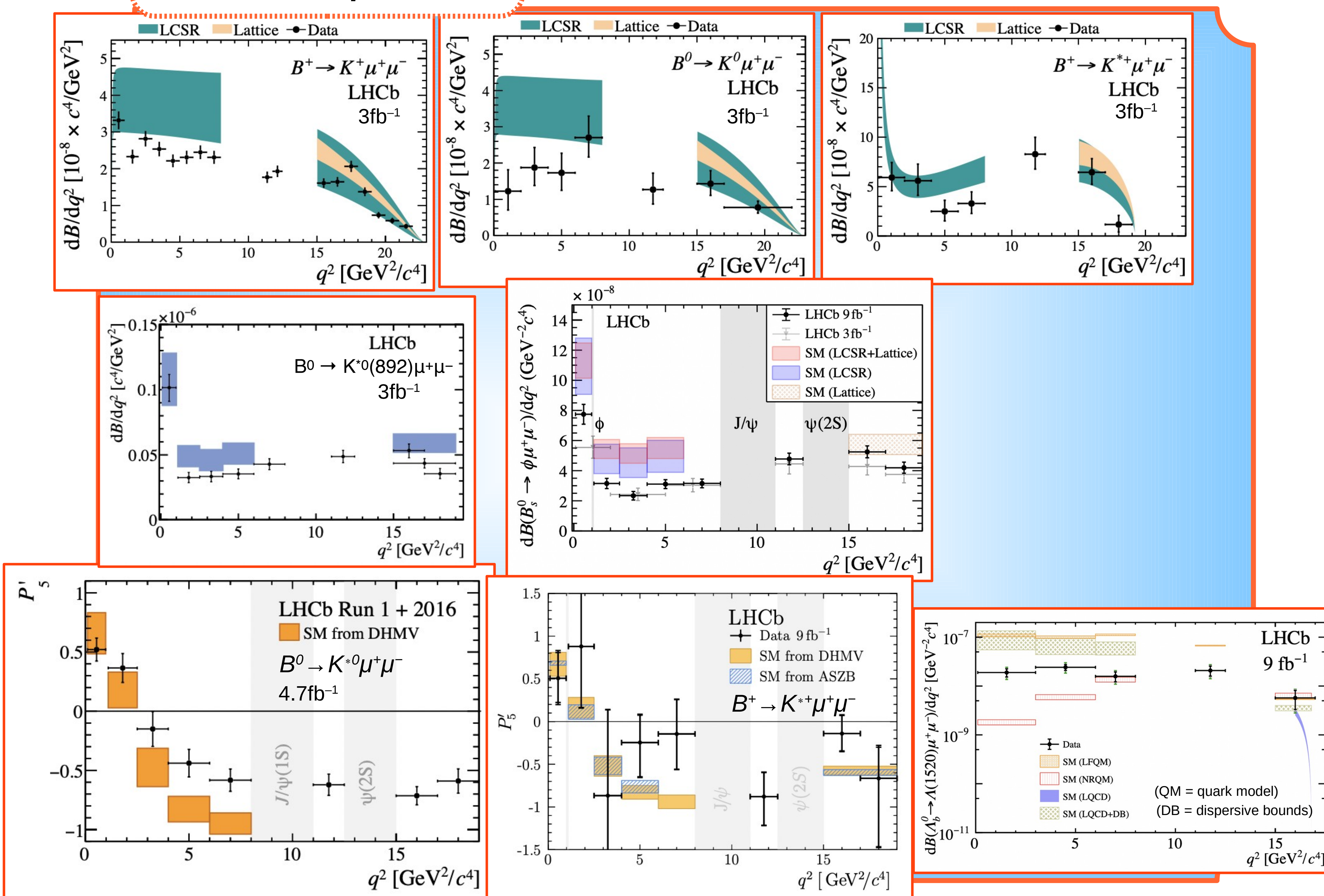
- But it was supported by a number of (less TH-clean) measurements
  - that in isolation displayed only mild disagreements
  - but in aggregate suggested a coherent picture

NP after Dec. 20

- The more (TH-)solid NP hints have disappeared – overnight.
- The remaining discrepancies (in $b \to s$ BRs and angular obs. & in $RD^{(*)}$) are debatable

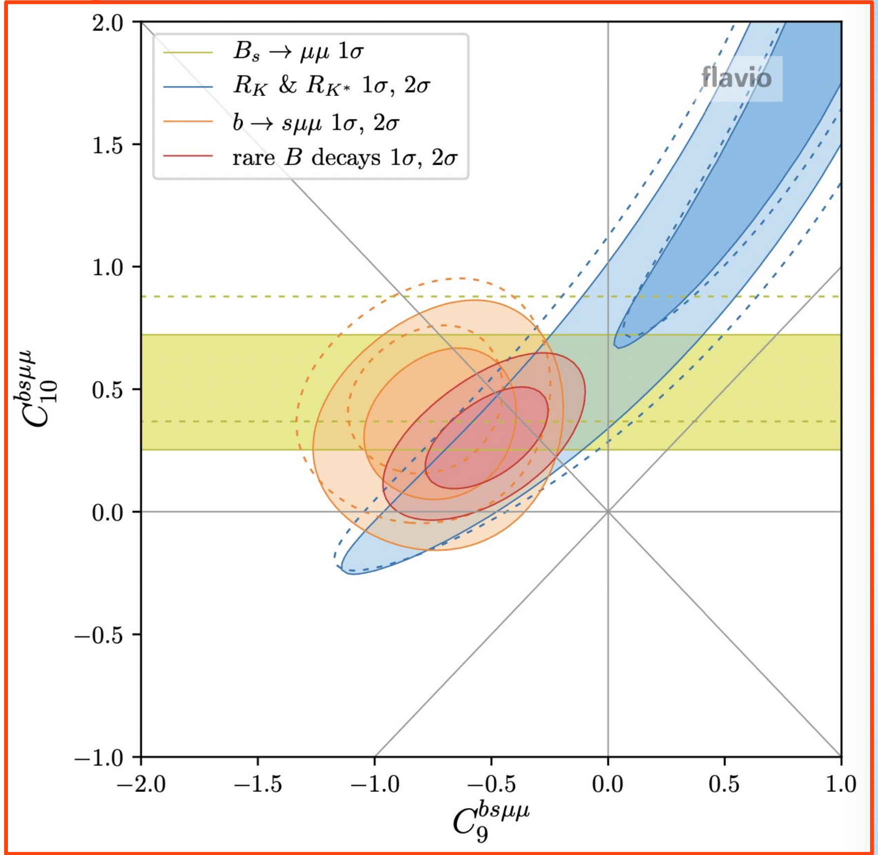
b → s discrepant data



D. Guadagnoli, La Thuile, 5-11 March, 2023

WET bounds

[Altmannshofer, Stangl, 2103.13370]



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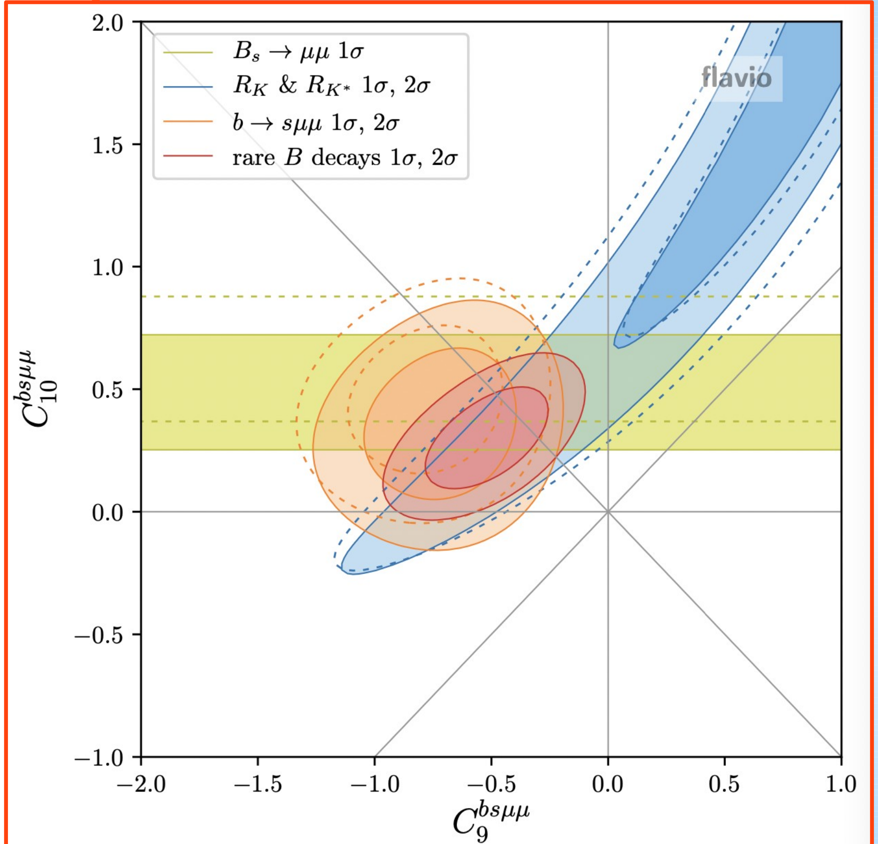
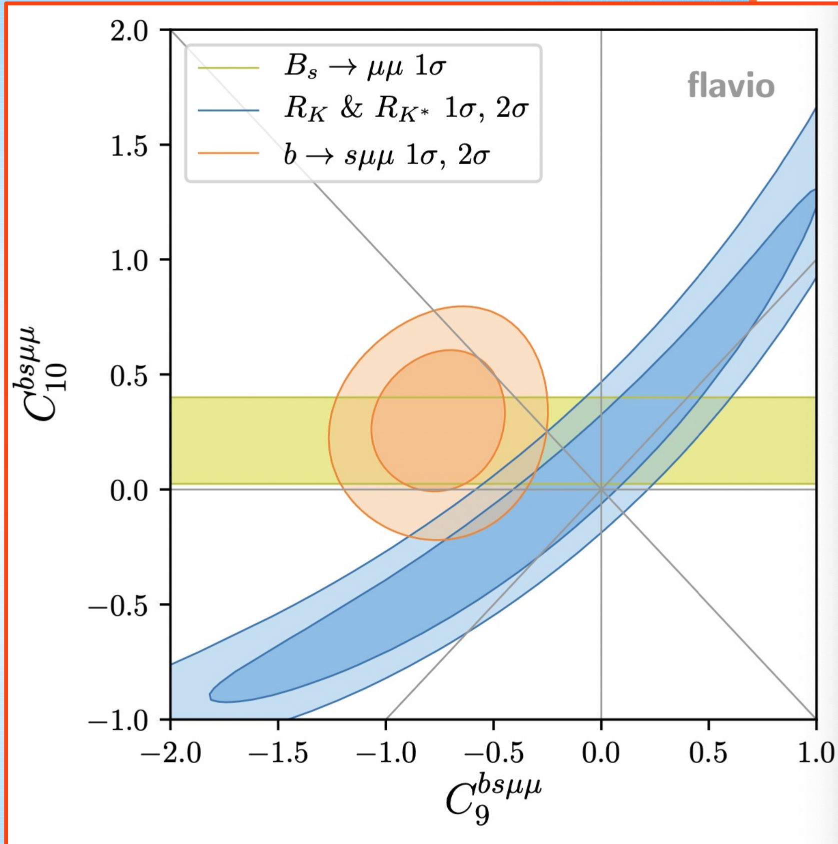


[Greljo *et al.*, 2212.10497]



Tension between LFU ratios (blue) and $b \to s\,\mu^+\mu^-$ data (orange)

WET bounds

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Tension solvable with LFU NP, in either the C_9 or the $C_9 = -C_{10}$ direction

$$C_9^{bsee} = C_9^{\text{univ.}} \qquad C_9^{bs\mu\mu} = C_9^{\text{univ.}} + \Delta C_9^{bs\mu\mu}$$

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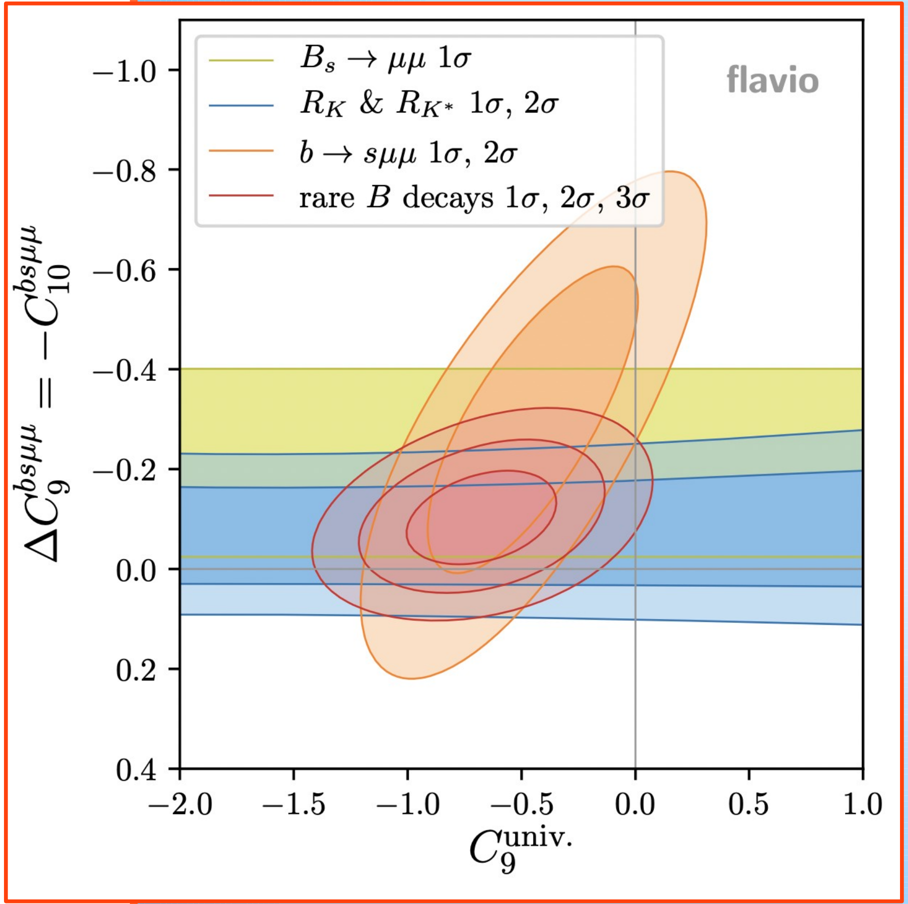

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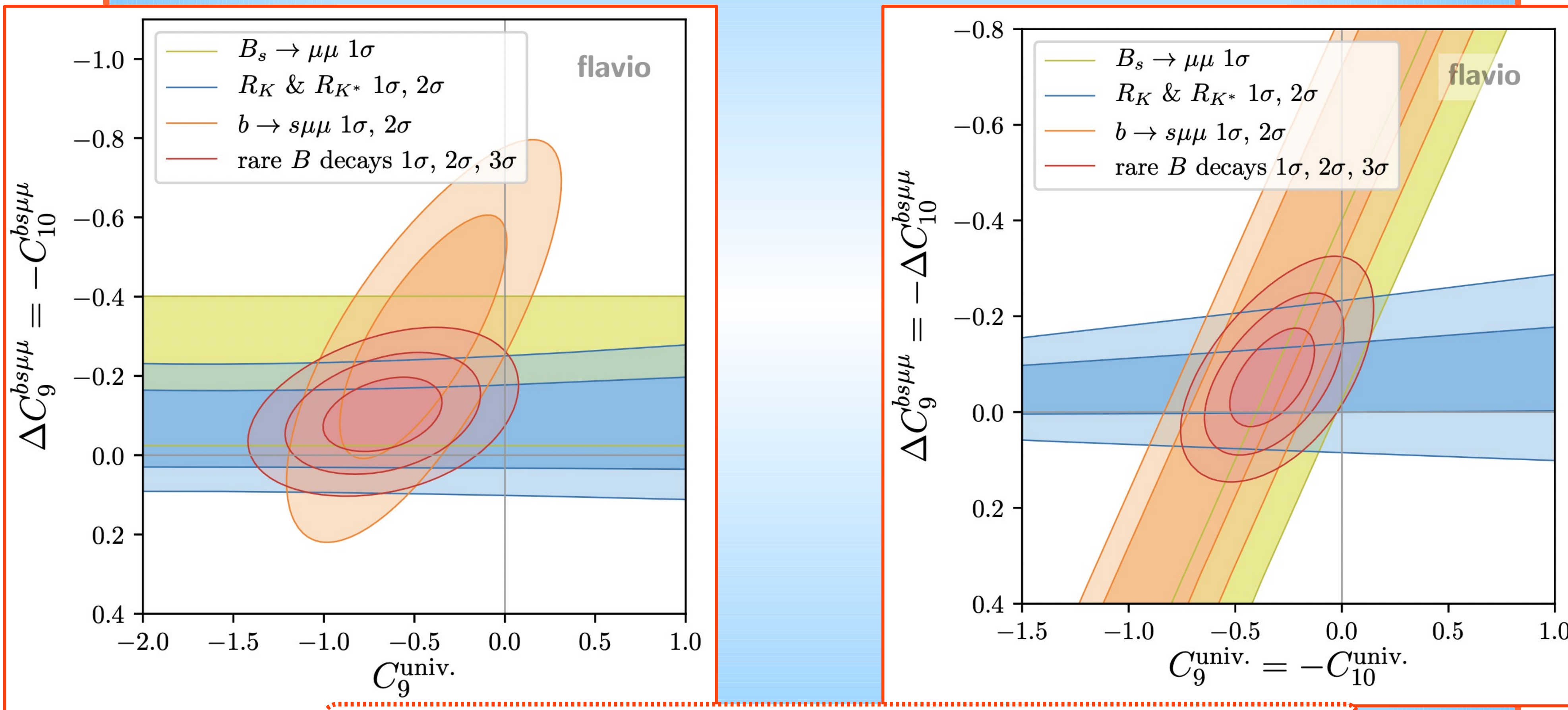

- *Purely muonic shift consistent with 0*
- *Univ. contrib. O(13%) for C_9-only, or half as much for C_L*

Connection with b → c ?

- $C_9^{\text{univ.}}$ of the correct size can be generated through RGE effects
  [**Bobeth-Haisch, 2011**][**Crivellin *et al.*, 2018**][**Aebischer *et al.*, 2019**]

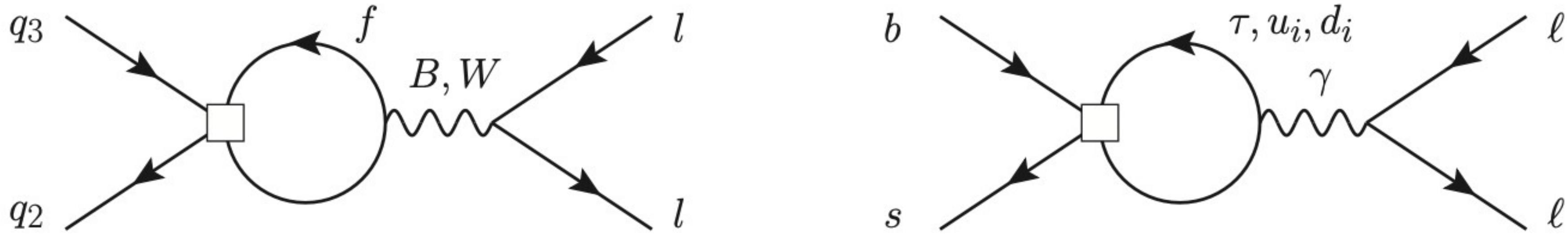

Figure 3: Diagrams inducing a contribution to C_9 through RG running above (left panel) and below (right panel) the EW scale. A sizeable contribution to C_9 is obtained when $f = u_{1,2}, d_{1,2,3}$ or l_3, see text for details.

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Exercise not yet done quantitatively AFAIK. But it will probably work:

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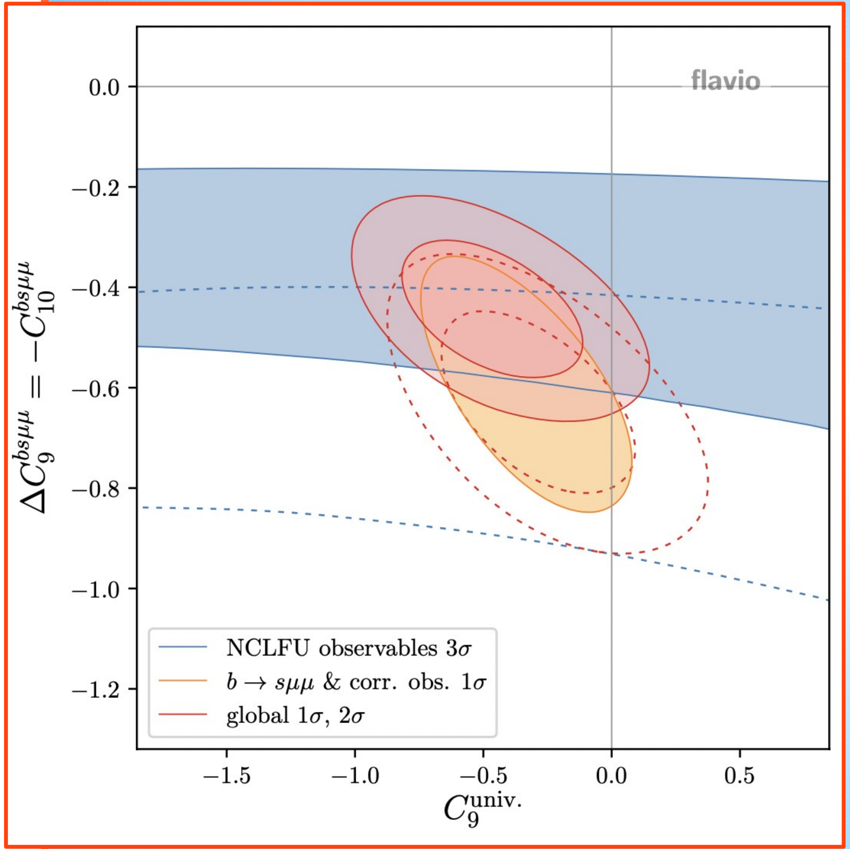

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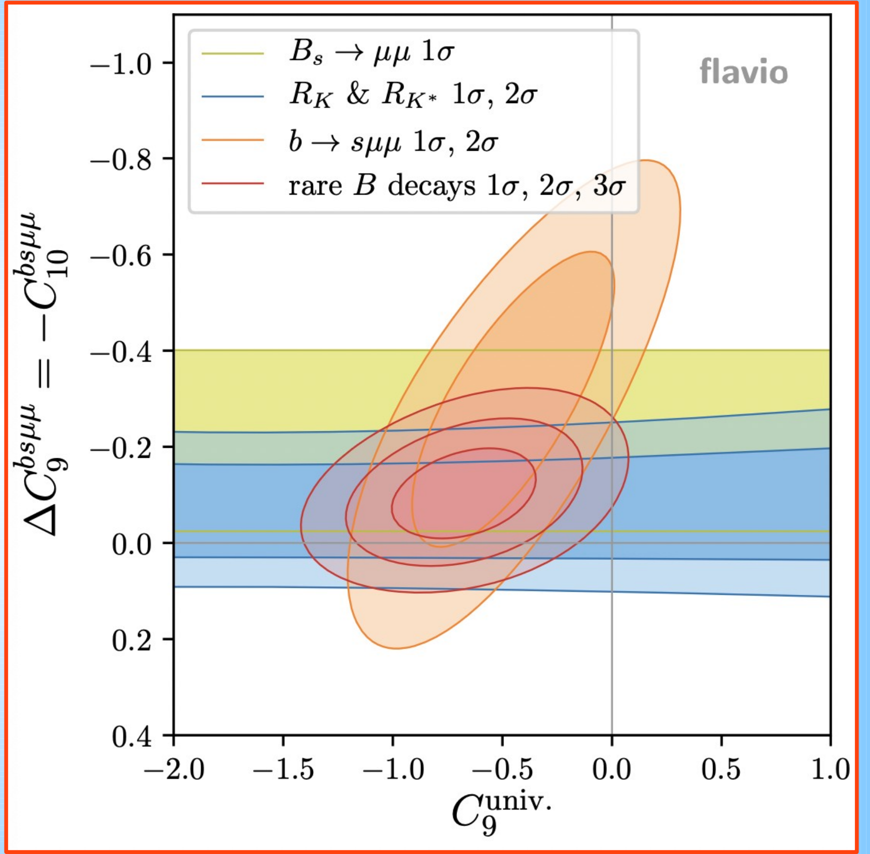

- $C_9^{univ.}$ *has slightly increased in central value from pre- to post-Dec. 20*

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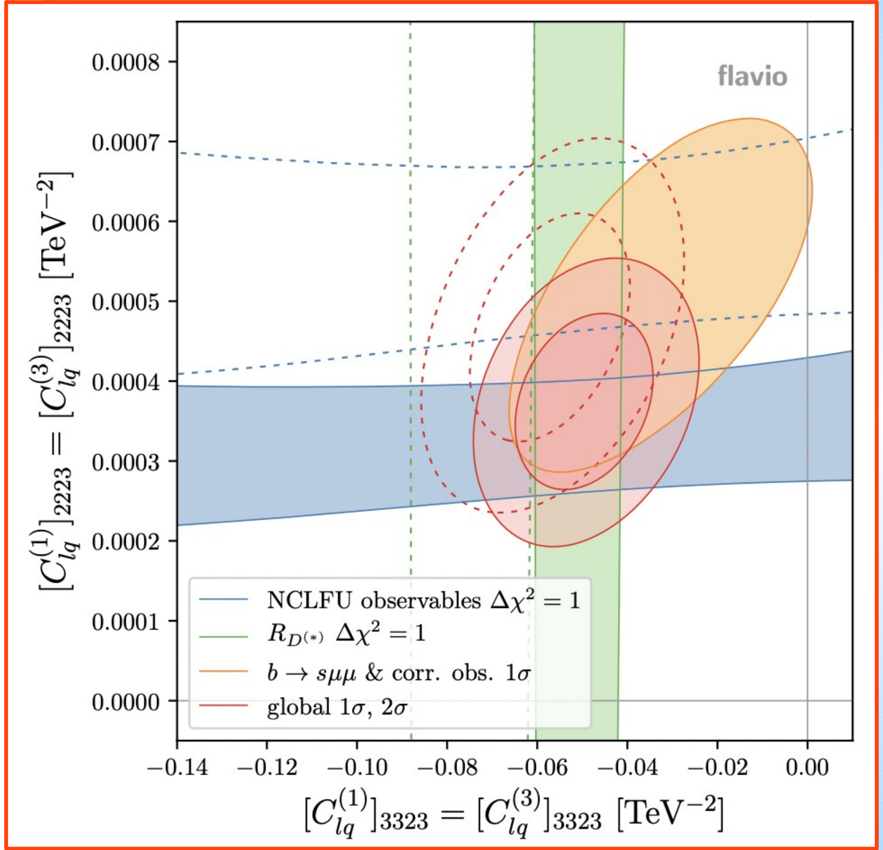

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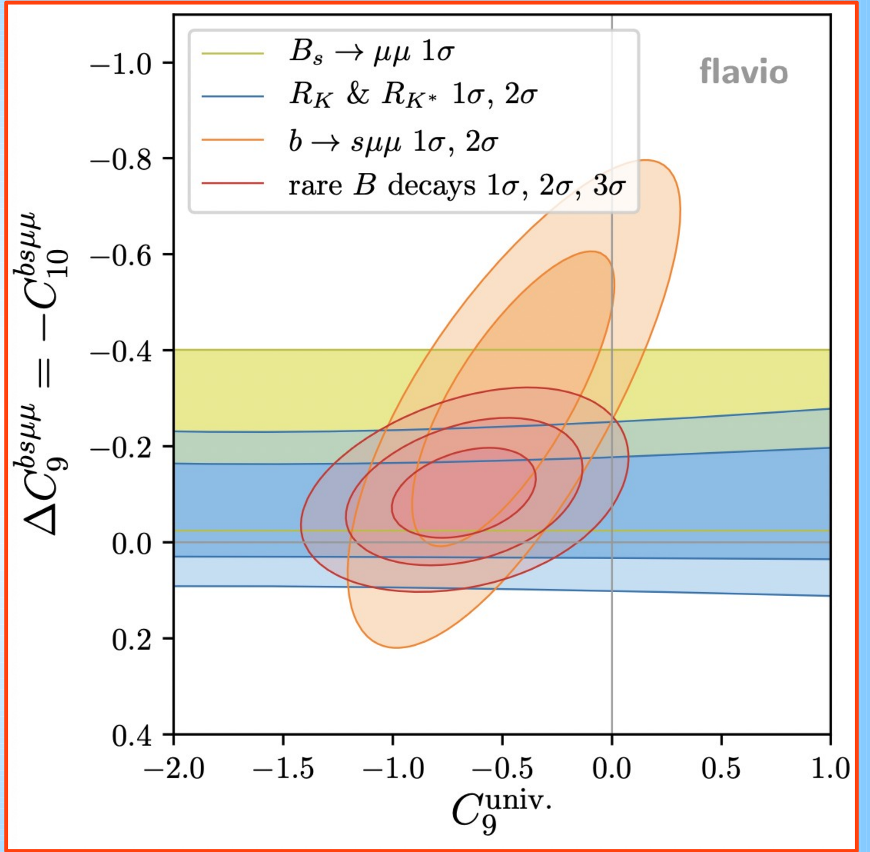

- *But RD(*) prefers the part of the yellow ellipse closer to zero (in the y-axis direction)*

Connection with $b \to c$?

Beware: *properly using LQCD + unitarity, $R(D^{(*)})$ significance ~ 1.4σ*

[Martinelli, Simula, Vittorio, 2021]

Models

[Greljo *et al.*, 2212.10497]

Post-Dec. 20 exercise:
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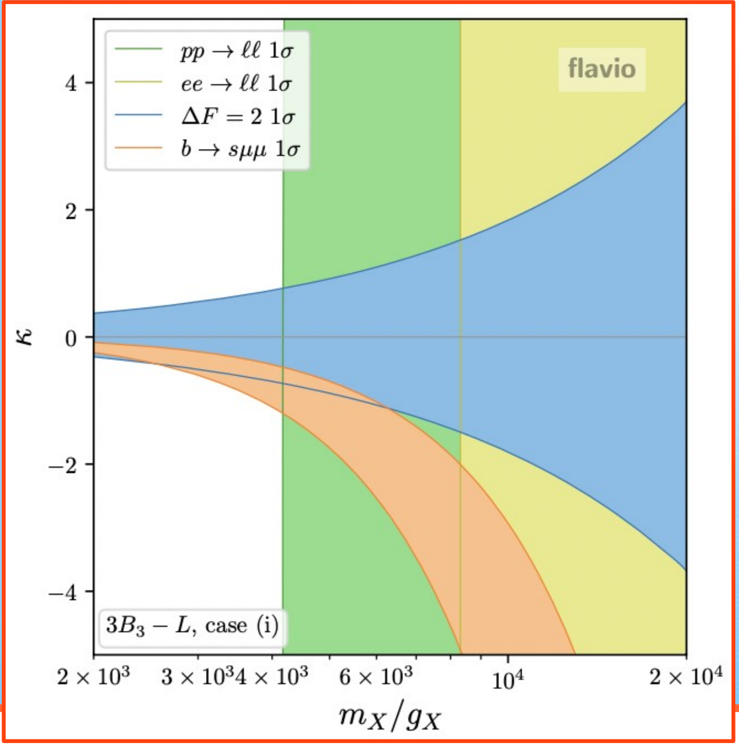
- 3[rd]-(quark)-gen-philic variant: $3\, B_3 - L$



⇨ *pp $\to \ell\ell$ gets less stringent, but tension w/ ee $\to \ell\ell$ persists*

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Scalar LQs

- Three "leptonic flavours" of S ~ ($\bar{\mathbf{3}}$, **3**, 1/3)

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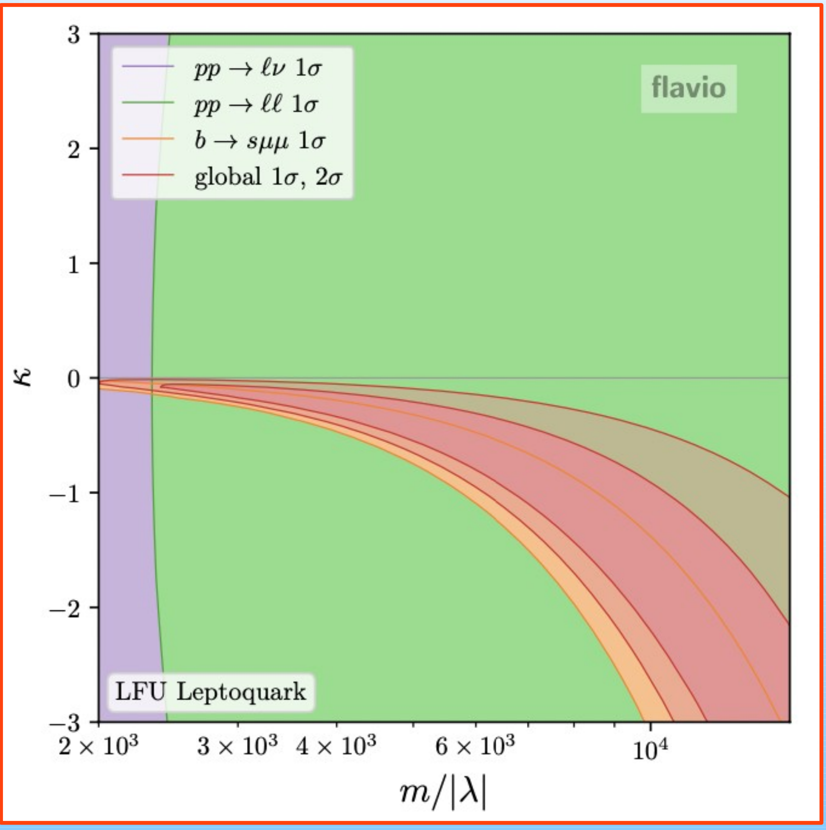
  Semilep at tree level, but ΔF = 2 & ee $\to \ell\ell$ only at loop level



Conclusive remarks

NP after Dec. 20

Main points

① The TH-cleaner bits (LUV observables; $B_s \to \mu^+\mu^-$) are gone

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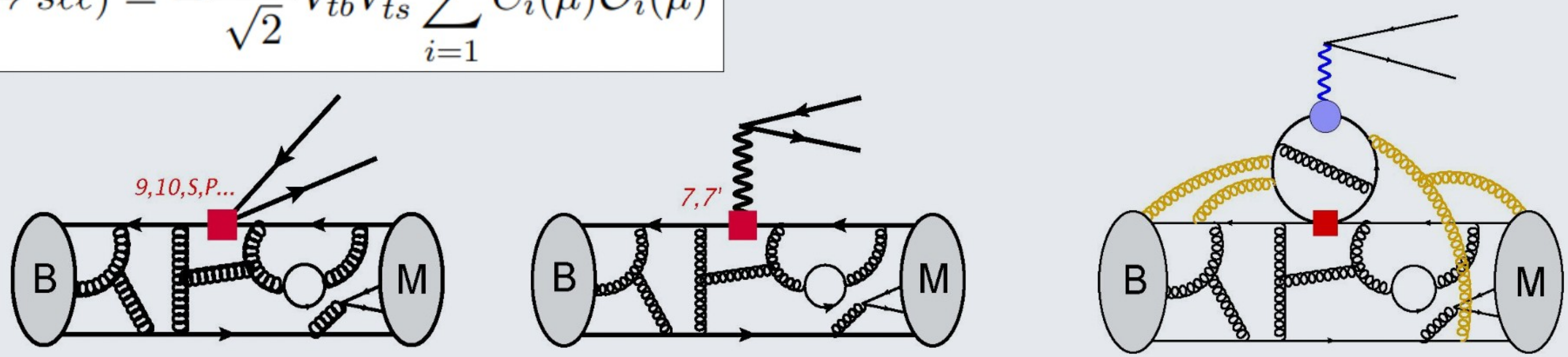
② Remaining hints suggest:

- C_9^{NP} (or C_L^{NP}) at low q^2, but not at high q^2 ?
- C_9^{NP} (or C_L^{NP}) in di-muons, and also in di-electrons?

While waiting for updates of discrepant measurements,
progress relies on a solid understanding of “non-local FFs” in $b \to s\, \ell^+\ell^-$
(because of ①)

Form factors in b → sℓℓ

$$\mathcal{H}(b \to s\ell\ell) = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum_{i=1}^{10} C_i(\mu)\mathcal{O}_i(\mu)$$



$$\mathcal{A}_\lambda^{L,R}(B \to M_\lambda \ell\ell) = \mathcal{N}_\lambda \left\{ (C_9 \mp C_{10})\mathcal{F}_\lambda(q^2) + \frac{2m_b M_B}{q^2}\left[C_7 \mathcal{F}_\lambda^T(q^2) - 16\pi^2 \frac{M_B}{m_b}\mathcal{H}_\lambda(q^2)\right]\right\}$$

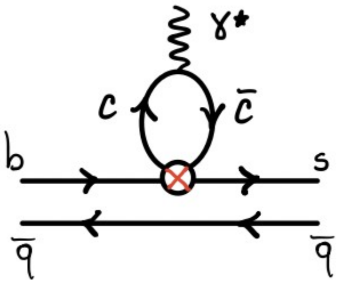
$$\mathcal{H}_\mu(k,q) = i\int d^4x\, e^{iq\cdot x} \langle \bar{M}(k)|T\{\mathcal{J}_\mu^{\text{em}}(x), \mathcal{C}_i\mathcal{O}_i\}|\bar{B}(q+k)\rangle$$

Non-local form-factors

→ Main contributions: the **“charm-loops”** $\mathcal{O}_{2(1)}^c = \left(\bar{s}_L\gamma_\mu(T^a)c_L\right)\left(\bar{c}_L\gamma^\mu(T^a)b_L\right)$

Méril Reboud - 20/10/2022

Per aspera (= long-distance contributions) ad astra



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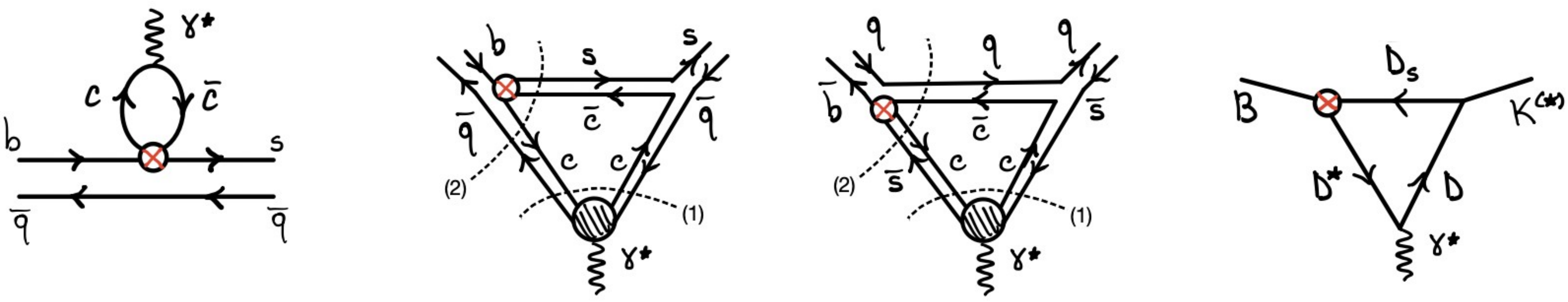
[Ciuchini *et al.*, 2212.10516]



(a) (b) (c)

Per aspera (= long-distance contributions) *ad astra*

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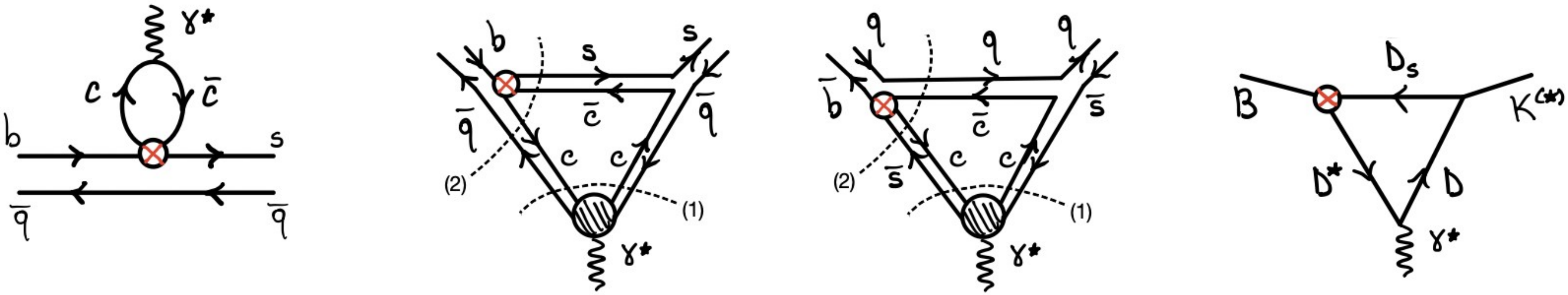

What about contribs. (b)?

In principle, well-known to be there, e.g.

▶ On-shell cuts in the variable $(q+k)^2$ (the "forward" or "decay" channel) include branch cuts from intermediate states such as $B \to \bar{D}D_s \to K^*\ell^+\ell^-$. The physical point $(q+k)^2 = M_B^2$ lies on these cuts, which implies that the functions $\mathcal{H}_\lambda(q^2)$ are complex-valued for all values of q^2. But this imaginary part is not associated with any singularity in the variable q^2. Thus, one can write $\mathcal{H}_\lambda(q^2) = \mathcal{H}_\lambda^{(\mathrm{re})}(q^2) + i\,\mathcal{H}_\lambda^{(\mathrm{im})}(q^2)$, with $\mathcal{H}_\lambda^{(\mathrm{re,im})}(q^2)$ satisfying the analytic properties of the previous point as functions of q^2, and obeying the same dispersion relation.

[Bobeth *et al.*, 2017]

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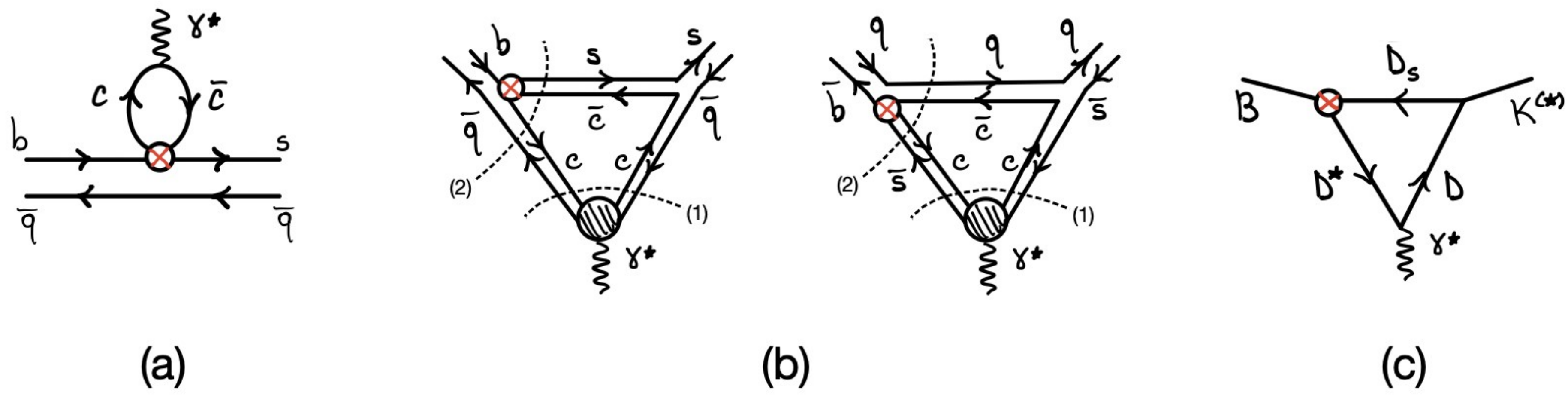

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In practice, however...

to this kind of contributions, but the analytic structure of triangle diagrams is quite involved, depending on the values of external momenta and internal masses. A dispersion relation in q^2 of the kind used in refs. [43, 45–48], based on the cut denoted by (1) in Fig. 1 **(b)**, could be written if the B invariant mass were below the threshold for the production of charmed intermediate states. However, when the B invariant mass raises above the threshold for cut (2), an additional singularity moves into the q^2 integration domain, requiring a nontrivial deformation of the path (see for example the detailed discussion in ref. [94]). Another possibility would be to get an

[Ciuchini *et al.*, 2212.10516]