UNIVERSITÀ DEGLI STUDI DI PADOVA

University of Zurich[UZH]

On $R_{D^{(*)}}$ (and R_K) anomalies and left-handed currents

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Annecy-le-Vieux, 01.12.2016

based on: F. Feruglio, P. Paradisi, AP (arXiv:1605.00524)

Outline:

- About R_K and $R_{D^{(*)}}$
- Simultaneous explanation of R_K and $R_{D^{(*)}}$
  - crucial impact of 1-loop LFV/LFUV effects
- More about the relevance of the 1-loop effects
- Future perspectives and conclusions

On R_K and $R_{D^{(*)}}$

(why LH currents?)

Anomalies in B decays

Putative anomalies in B decays:

- $B \to K^{(*)}\ell^+\ell^-$
  - P'_5 and other smaller tensions for $B \to K^{(*)}\mu\mu$
  - LFU violation in R_K:

$$R_K = \frac{\mathcal{B}\left(B \to K\mu^+\mu^-\right)}{\mathcal{B}\left(B \to Ke^+e^-\right)} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

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Common explanation?

How to address $b \to s$ anomalies

- $B \to K^{(*)} \ell^+ \ell^-$

$$\mathcal{O}_9 = \frac{\alpha}{4\pi} (\bar{s}_L \gamma_\mu b_L)(\bar{\ell} \gamma_\mu \ell) \qquad \mathcal{O}'_9 = \frac{\alpha}{4\pi} (\bar{s}_R \gamma_\mu b_R)(\bar{\ell} \gamma_\mu \ell) \qquad \mathcal{O}_{7\gamma} = \frac{e}{4\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu}$$

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$$\Downarrow$$

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S. Descotes-Genon , L. Hofer, J. Matias, J. Virto (2015)

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$\Downarrow$

$(\bar{s}_L\gamma_\mu b_L)(\bar{\ell}_L\gamma_\mu\ell_L)$ ⇒ left-handed current

How to address $b \to d$ anomalies

- $\bar{B} \to D^{(*)} \ell \bar{\nu}$
  - Only 4 dimension-6 operators can address the R_D anomaly

$$\mathcal{O}_{lq}^{(3)} = (\bar{q}_L \gamma_\mu \sigma^a q_L)(\bar{\ell}_L \gamma_\mu \sigma^a \ell_L) \qquad \mathcal{O}_{lequ}^{(1)} = (\bar{\ell}_L e_R) i\sigma^2 (\bar{q}_L u_R)$$

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- Is a LH quark-lepton current the way?
    - simultaneous explanation of R_K, R_D
    - bonus: relaxing P'_5 (et al.) tension(s)
    - well-motivated NP models behind it (vector leptoquark, Z')

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Is it this simple?

- Simultaneous explanation of R_K and $R_{D(*)}$ anomalies:

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~25%, 2.6σ

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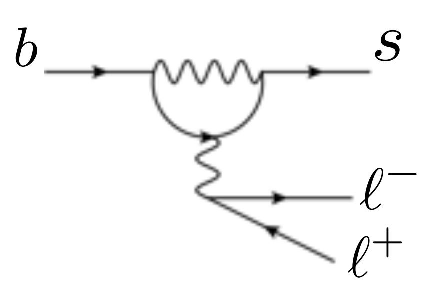
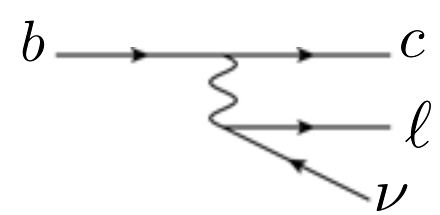
Problem: SM: 1-loop process | SM: tree-level process





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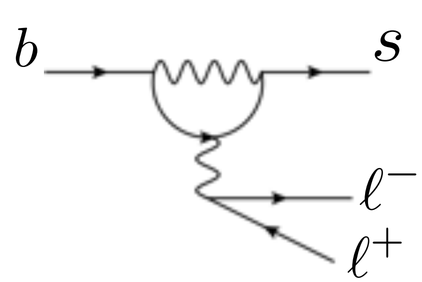

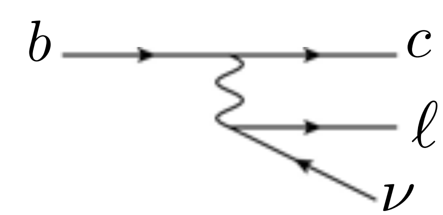

Solution:

1. Extend loop suppression to the NP sector
2. Rely on flavor symmetries (e.g *U(2)*)

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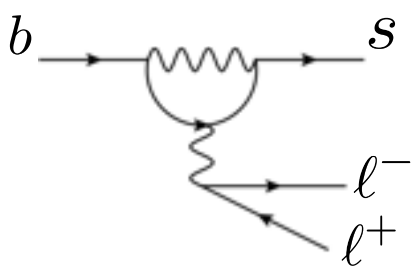

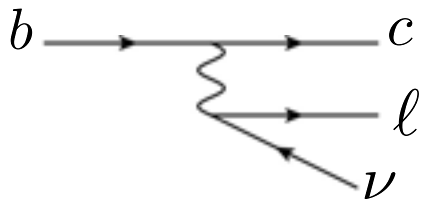

Solution:

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2. Rely on flavor symmetries (e.g *U(2)*)

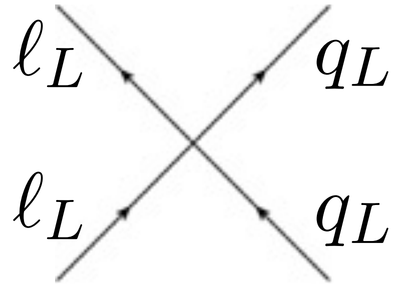
typical assumption: NP couples mostly to the third generation quarks

- Left-handed vector currents
- Parametrical suppression of interaction with second-generation

Effective Lagrangian:

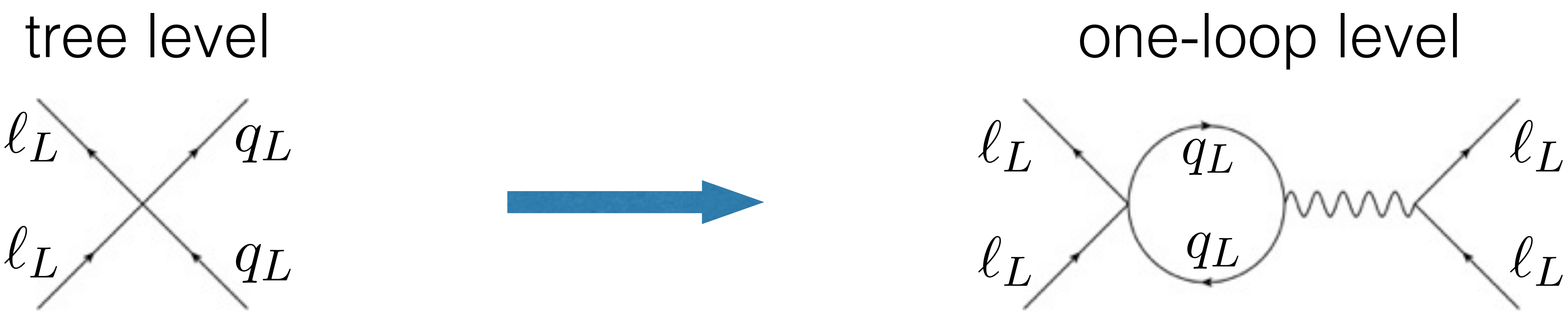
$$\mathcal{L}_{\rm eff} = \frac{C_1^{pqrs}}{\Lambda^2}\left(\bar{q}_{pL}\gamma^\mu q_{qL}\right)\left(\bar{\ell}_{rL}\gamma_\mu \ell_{sL}\right) + \frac{C_3^{pqrs}}{\Lambda^2}\left(\bar{q}_{pL}\gamma^\mu \tau^a q_{qL}\right)\left(\bar{\ell}_{rL}\gamma_\mu \tau^a \ell_{sL}\right)$$

tree level:



- fit R_K, $R_{D^{(*)}}^{\tau/\ell}$
- bounds from: $R_{D^{(*)}}^{\mu/e}$, $R_K^{\nu\nu} = \dfrac{\mathcal{B}(B\to K\nu\bar{\nu})}{\mathcal{B}(B\to K\nu\bar{\nu})_{\rm SM}}$
- benchmark: $\mathcal{B}(B\to K\tau\mu)$

What about loop contributions?



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- EW loop $\sim \dfrac{\alpha}{\pi} \sim 10^{-3}$, i.e. not so important, right?

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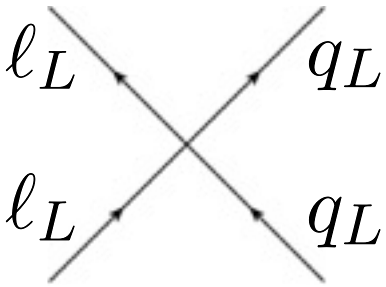
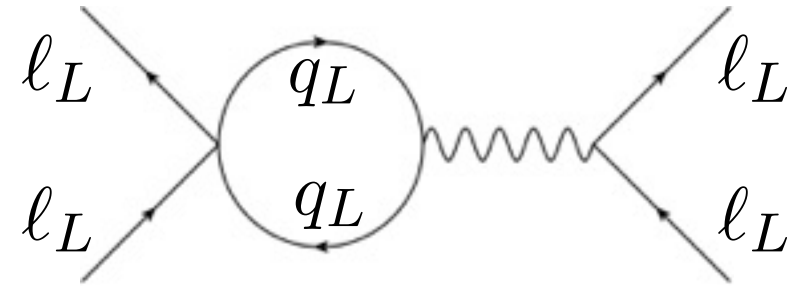


one-loop level



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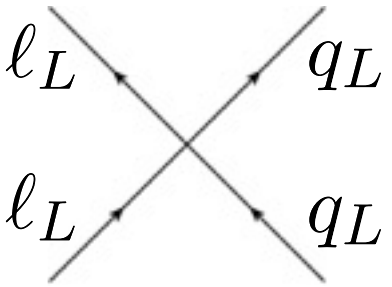
R_D (tree level in SM)

EW precision tests ($\sim 10^{-2} \div 10^{-3}$)
LFV phenomenology

$\mathcal{O}(1)$ NP effect → $\sim 10^{-3}$ NP effect

What about loop contributions?

tree level



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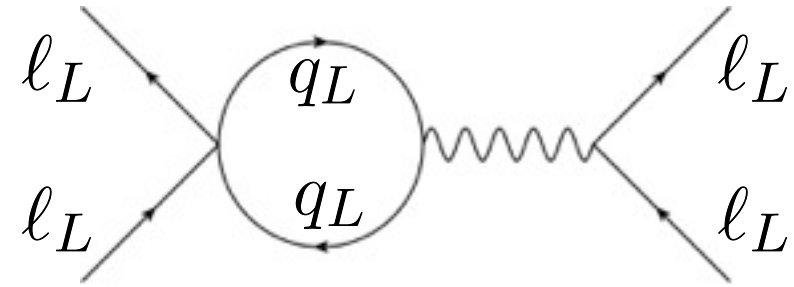

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LFV phenomenology

O(1) NP effect → $\sim 10^{-3}$ NP effect

Enhancements:
- Big logs $\sim \log\left(\dfrac{M_W^2}{\Lambda^2}\right)$
- big *O(1)* numerical factors

How to take 1-loop effects into account?

Our setup

- At NP scale Λ:

  1) Assume a basis where:

$$\mathcal{L}_{\rm eff} = \frac{C_1}{\Lambda^2}\left(\bar{q}_3\gamma^\mu P_L q_3\right)\left(\bar{\ell}_3\gamma_\mu P_L \ell_3\right) + \frac{C_3}{\Lambda^2}\left(\bar{q}_3\gamma^\mu \tau^a P_L q_3\right)\left(\bar{\ell}_3\gamma_\mu \tau^a P_L \ell_3\right)$$

  2) Go to mass basis through a rotation of generations 2-3:
    - two real parameters: θ_{bs}, $\theta_{\tau\mu}$ (assumed $\ll 1$)
    - no mixing with the 1^{st} generation

- RGE flow down to the EW scale (leading log) ← here new operators arise

- Matching to an EFT with broken *SU(2)*

- Computation of relevant observables

About Leading Log Approximation

- Eventually $\Lambda \approx 1 \div 3$ *TeV*

$$\left|\log\left(\frac{M_W^2}{\Lambda^2}\right)\right| \approx 5 \div 7$$

is it a “big” log?

⇒ it safely capture the order of magnitude of the effects

⇒ finite contributions might be $O(1)$

⇒ quantitatively correct, barring accidentally big cancellations

- Consider finite contributions? work in progress…

Relevant observables

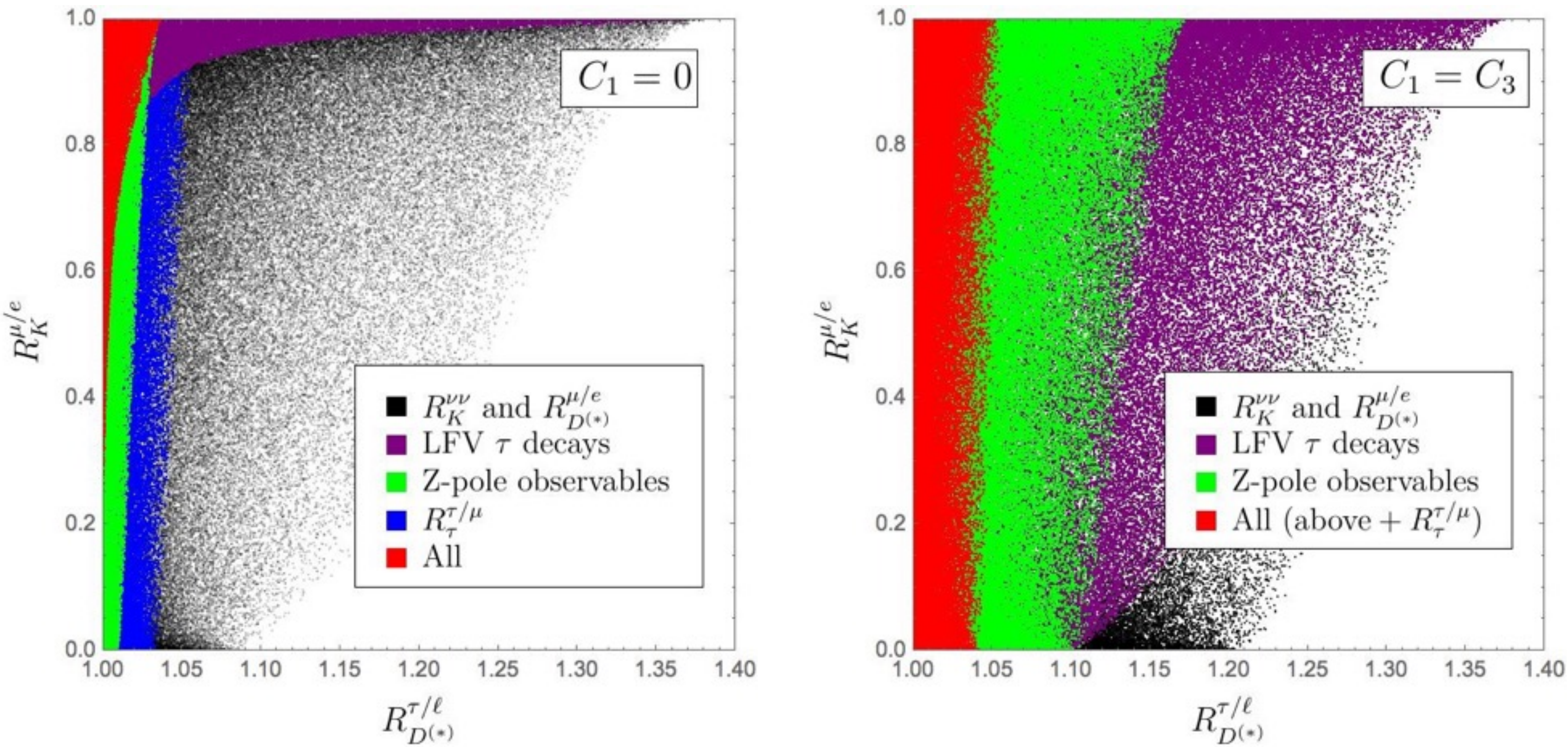
- Relevant observables:
  - $R_D^{\mu/e}, R_K^{\nu\nu}$
  - LFV in τ decays: $\tau\to 3\mu$, $\tau\to\mu ee$, $\tau\to\mu\rho$, $\tau\to\mu\pi$
  - LFU in τ decays: $R_\tau^{\tau/\mu} = \dfrac{\mathcal{B}(\tau\to e\nu\bar{\nu})_{\rm exp}/\mathcal{B}(\tau\to e\nu\bar{\nu})_{\rm SM}}{\mathcal{B}(\mu\to e\nu\bar{\nu})_{\rm exp}/\mathcal{B}(\mu\to e\nu\bar{\nu})_{\rm SM}}$
  - Z pole observables: axial and vector lepton coupling

    invisible Z decay width

- We then scan over different C_1, C_3, θ_{bs}, $\theta_{\tau\mu}$

Results

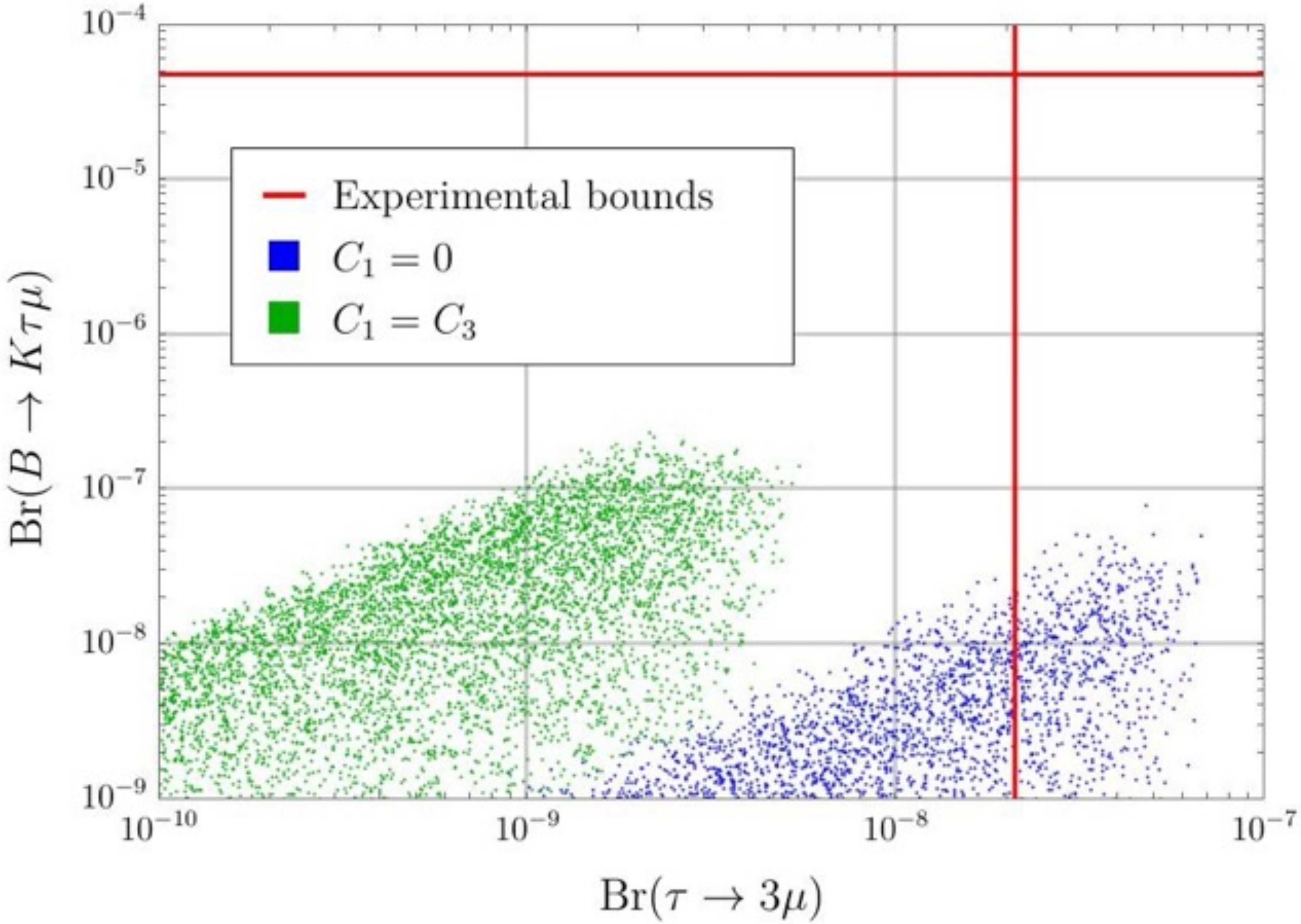
Results of the scan over the parameter space in our setup:



Simultaneous explanation of RD and RK through left-handed currents is ~~excluded~~ highly disfavoured

Results

Is $\mathcal{B}(B \to K\tau\mu)$ really <u>the</u> benchmark of these scenarios?



Scan over the parameter space, imposing:

- all discussed bounds
- R_K anomaly at 3σ
- <u>not</u> R_D

LFV τ decays are usually the most sensitive probes in these scenarios

“This looks nice.

But *what if*…”

What if…

- … we want to insist on LH current?

  ⇒ *Z'* models

What if…

- … we want to insist on LH current?

  ⇒ *Z'* models

  ⇒ furthermore:

  - tune additional tree-level contributions:

    $$(\bar{\ell}_L \gamma_\mu \tau^a \ell_L)(\bar{\ell}_L \gamma_\mu \tau^a \ell_L) \;, \quad \left(H^\dagger \overleftrightarrow{D}^a_\mu H\right)(\bar{\ell}_L \gamma_\mu \tau^a \ell_L)$$

  - very light *Z'* mass (200 - 300 GeV)

  - cancellations with additional *Z''*

What if…

- … we are interested only in R_K?

$\Rightarrow$ LH currents not necessary:

$$\mathcal{O}_9 = \frac{\alpha}{4\pi}(\bar{s}_L\gamma_\mu b_L)(\bar{\ell}\gamma_\mu\ell) \qquad \mathcal{O}_9' = \frac{\alpha}{4\pi}(\bar{s}_L\gamma_\mu b_L)(\bar{\ell}\gamma_\mu\ell)$$

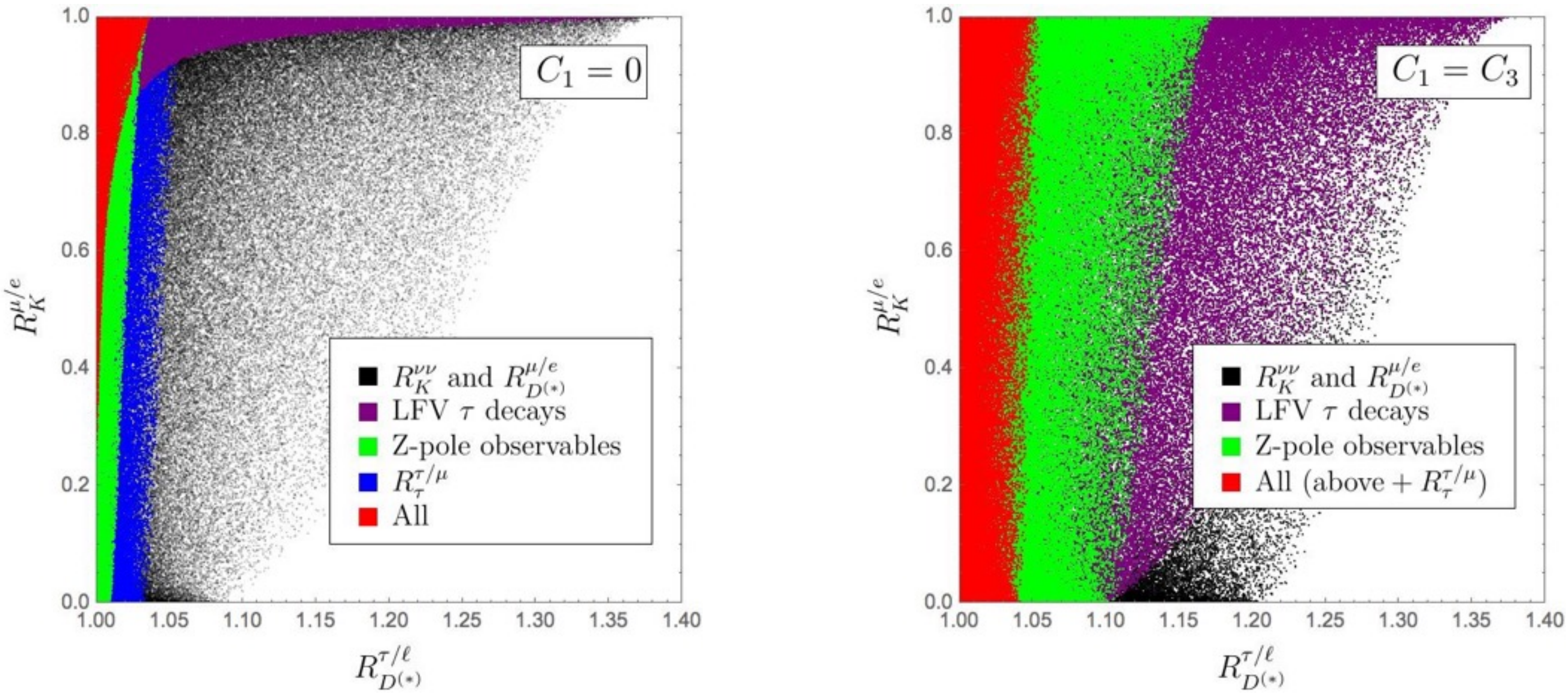
$$\mathcal{O}_{10} = \frac{\alpha}{4\pi}(\bar{s}_R\gamma_\mu b_R)(\bar{\ell}\gamma_\mu\gamma_5\ell) \qquad \mathcal{O}_{10}' = \frac{\alpha}{4\pi}(\bar{s}_R\gamma_\mu b_R)(\bar{\ell}\gamma_\mu\gamma_5\ell)$$

$\Rightarrow$ NP needed for R_K is small (compete with SM 1-loop)

$\Rightarrow$ loop effects are there, but not dangerous

What if…

- … we are interested only in R_D (still with LH currents)?



⇒ bounds from LFU violation are still there!

⇒ same caveats as before about Z' models

What if…

- … we are interested only in R_D (other operators)?

  ⇒ possible operators:

$$\mathcal{O}_{lq}^{(3)} = (\bar{q}_L \gamma_\mu \sigma^a q_L)(\bar{\ell}_L \gamma_\mu \sigma^a \ell_L)$$

$$\mathcal{O}_{ledq} = (\bar{\ell}_L e_R)(\bar{d}_R q_L)$$

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$$\mathcal{O}_{lequ}^{(3)} = (\bar{\ell}_L \sigma_{\mu\nu} e_R) i\sigma^2 (\bar{q}_L \sigma^{\mu\nu} u_R)$$

  - loop effects: suppressed by lepton Yukawa ($y_\tau \approx 10^{-2}$)
  - severe bounds from high-p_T τ lepton searches at LHC and from B_c decays.

    D. Faroughy, A. Greljo, J. Kamenik, arXiv:1609.07138
    R. Alonso, B. Grinstein, J. M. Camalich, arXiv 1611.06676

  - impossible to accommodate R_K with the same operator(s)

Future perspectives

New experimental measurements coming soon:

- Updates for R_K
  - possibility to distinguish C_9 vs. C_{10}
- New measurements for $R_{D^{(*)}}$
  - independent channel (hadronic τ tagging)
- Measurement of R_{K^*}
  - more insights into the NP needed for the anomalies

Conclusions

- B anomalies extensively studied in literature
  - simultaneous R_K and $R_{D^{(*)}}$ explanation is appealing
  - typically achieved using LH currents

- crucial 1-loop effects in the leptonic sector
  - surprisingly overlooked so far
  - highly disfavour a LH current approach to $R_{D^{(*)}}$
  - $\tau \to 3\mu$ can be a more interesting than $B \to K\tau\mu$

Backup slides