

PAUL SCHERRER INSTITUT



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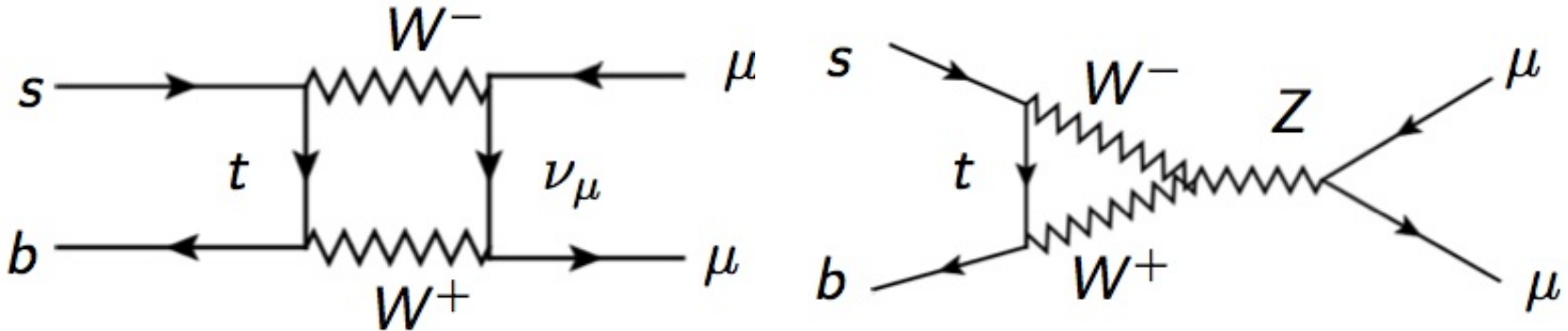
Theory Group of the Laboratory for Particle Physics

Explanations of the Flavour Anomalies

Warsaw, 08.10.2018

$b \rightarrow s \mu^+ \mu^-$

- Flavour Changing Neutral Current (FCNC)
- In the SM it is suppressed by
 - The CKM elements $V_{cb} \approx 0.04$
 - Electroweak scale m_t^2 / m_W^4
 - Loop-factor $1 / (16\pi^2)$



Suppressed and very sensitive to New Physics

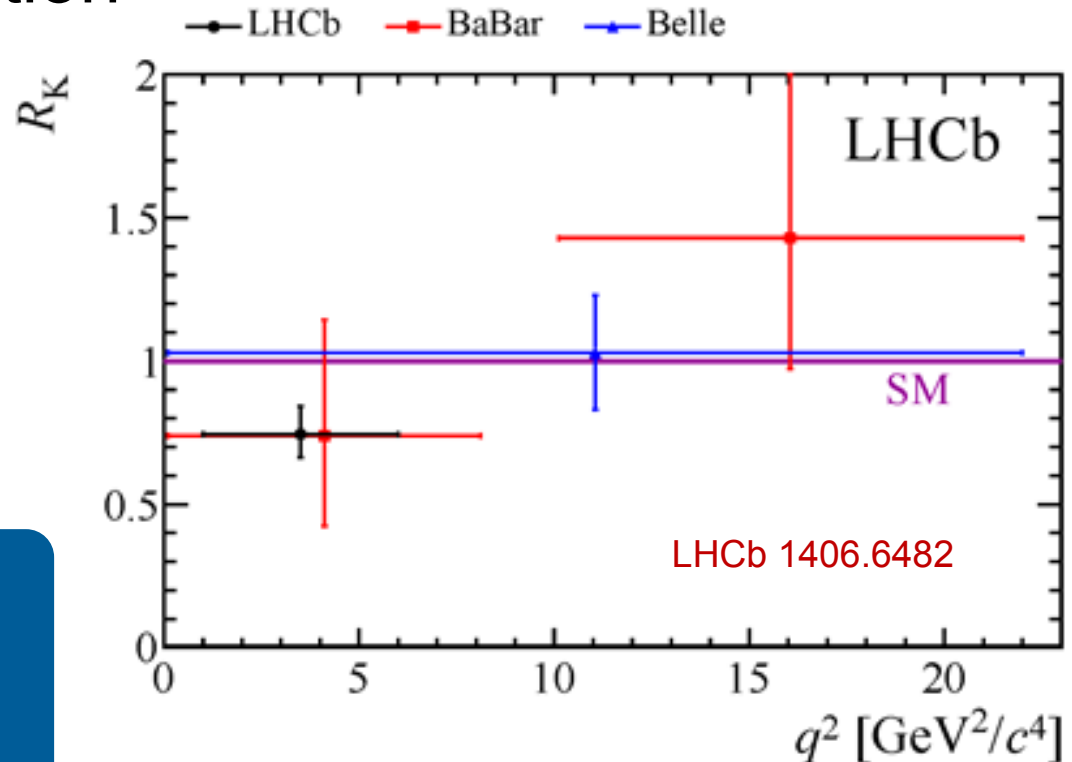
$$R(K) = B \rightarrow K \mu^+ \mu^- / B \rightarrow K e^+ e^-$$

- Lepton flavour universality violation
- 2.6 σ deviation from the theoretically rather clean SM expectation

$$R_K^{\text{SM}} = 1.0003 \pm 0.0001$$

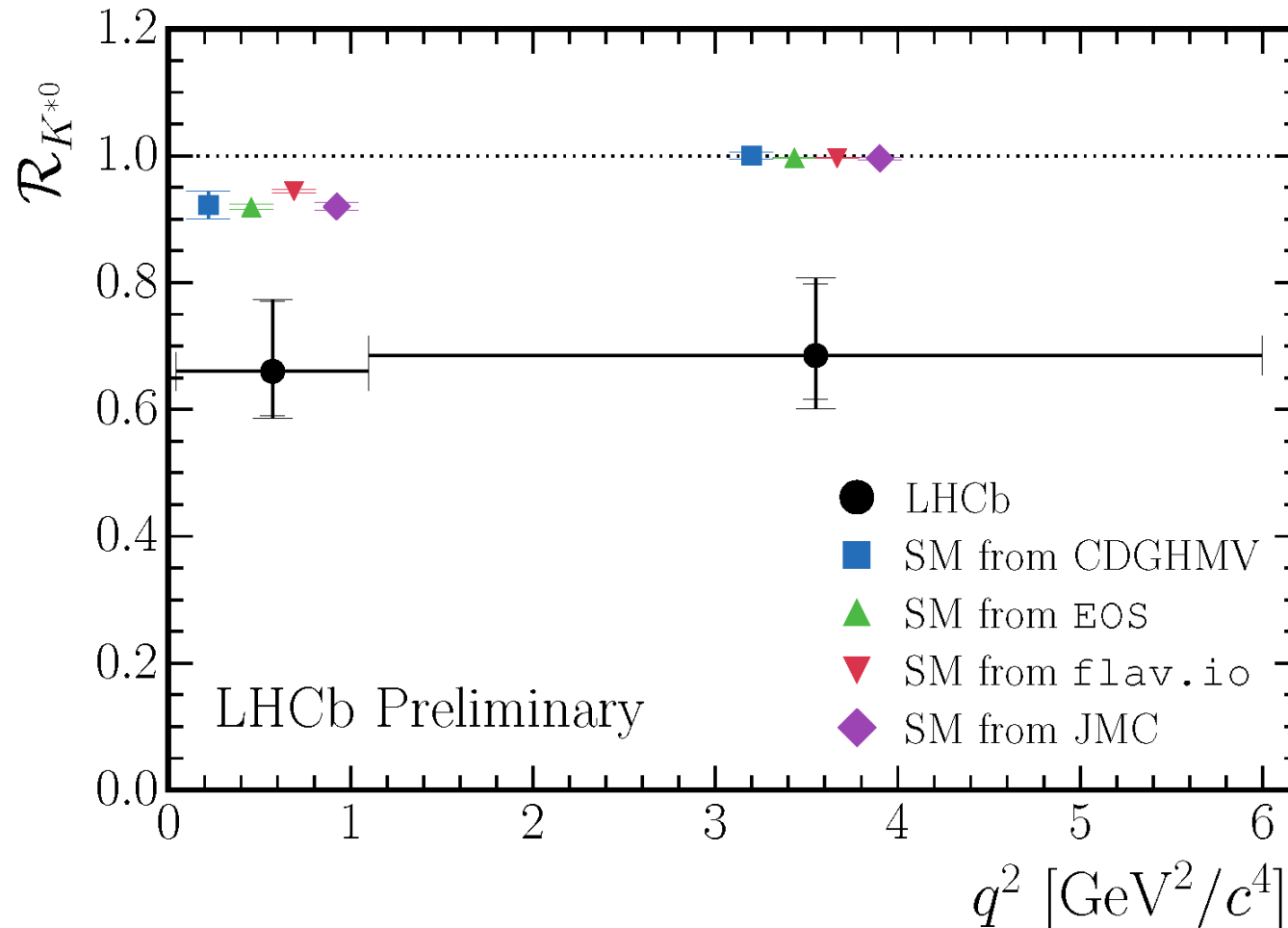
$$R_K^{\text{exp}} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

Lepton Flavour
Violation in
B decays?



$$R(K^*) = \mathcal{B} \rightarrow K^* \mu^+ \mu^- / \mathcal{B} \rightarrow K^* e^+ e^-$$

■ 2.2-2.4 σ in two bins



Global fit to $b \rightarrow s \mu^+ \mu^-$ data

■ Global analyses give a very good fit to data

■ Good fit to data:

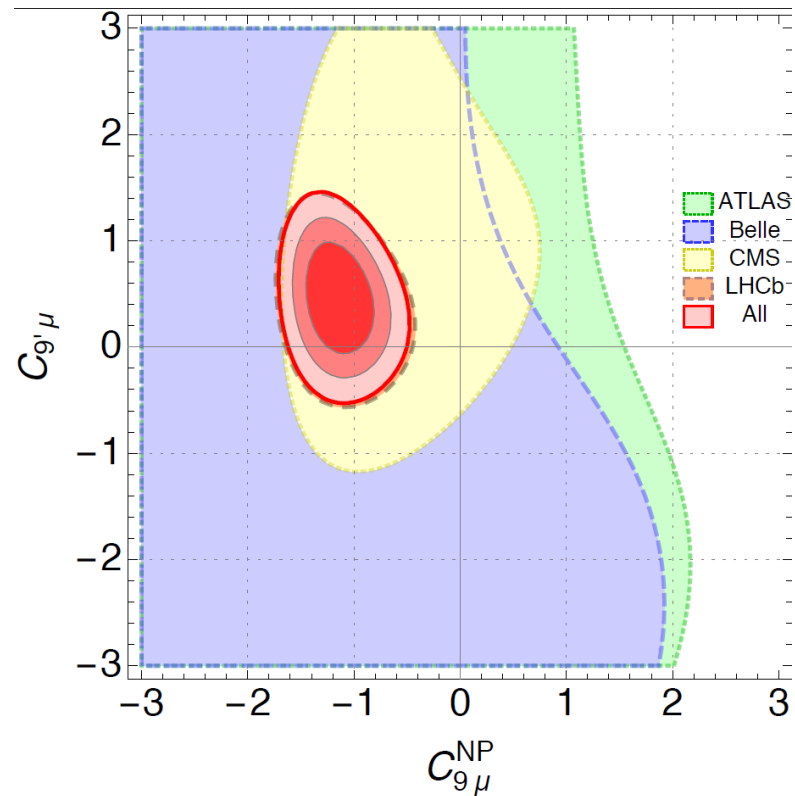
■ C_9

■ $C_9 = -C_{10}$

■ $C_9 = -C'_9$

$$O_9 = \bar{s} \gamma^\mu P_L b \bar{l} \gamma_\mu l$$

$$O_{10} = \bar{s} \gamma^\mu P_L b \bar{l} \gamma_\mu \gamma^5 l$$

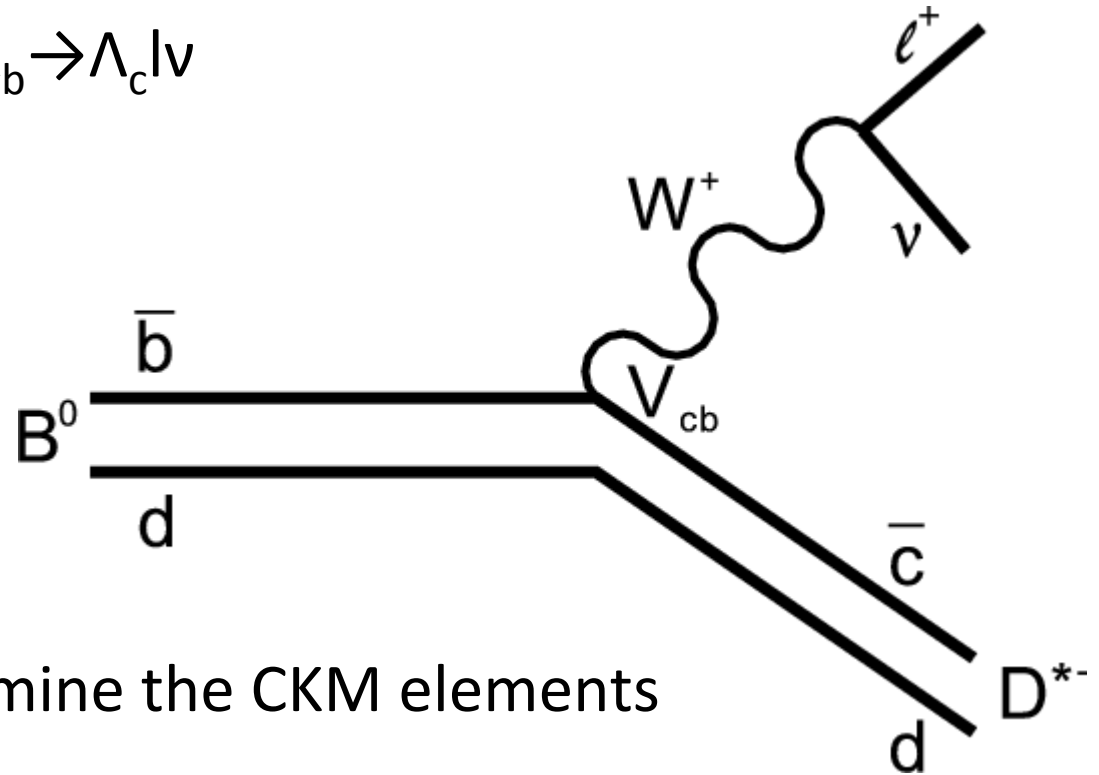


B. Capdevila, AC, S. Descotes-Genon, J. Matias and J. Virto, arXiv:1704.05340 [hep-ph].

Fit is 5-6 σ better than the SM

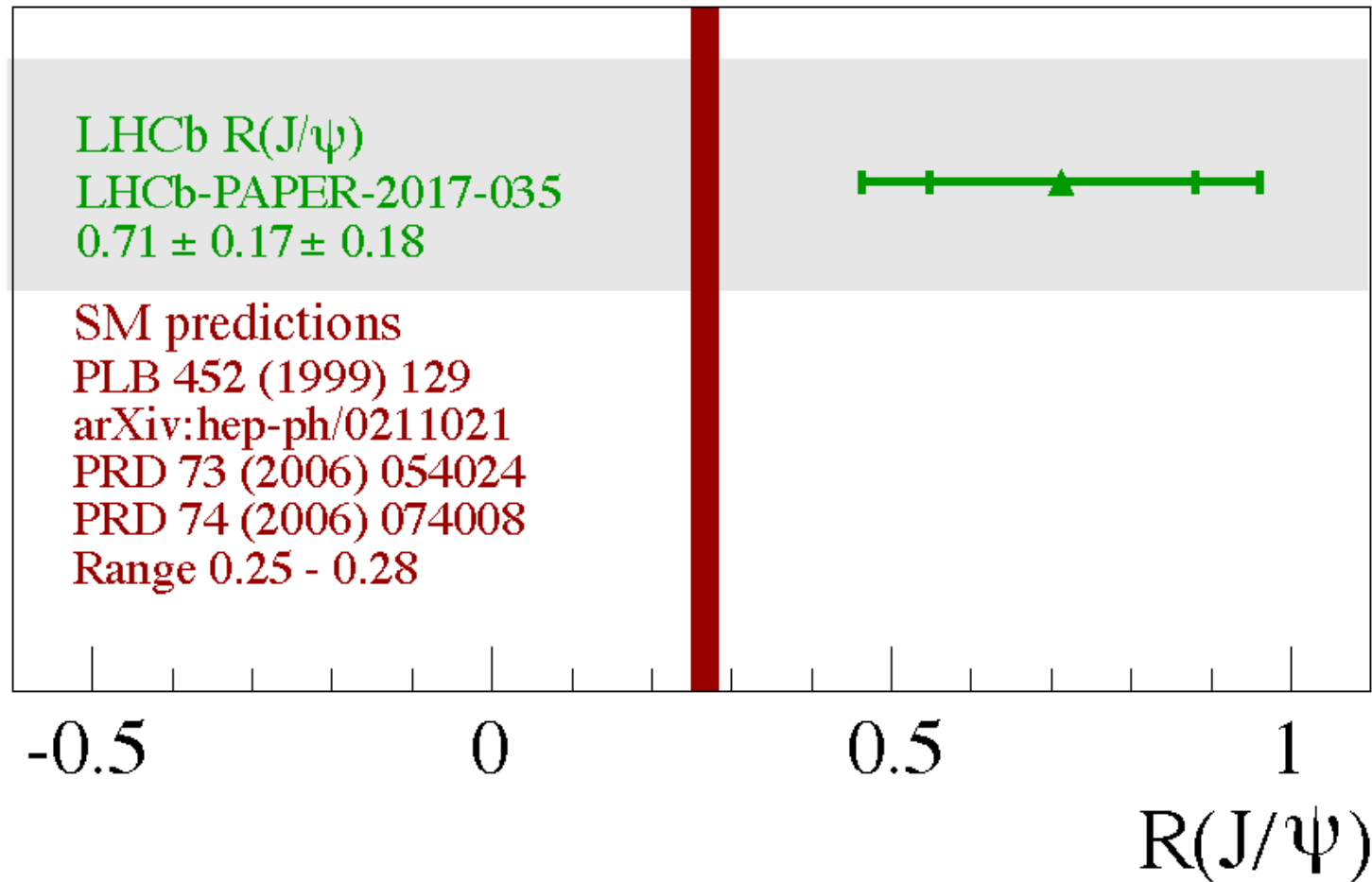
$b \rightarrow clv$ processes

- $B \rightarrow Dlv$, $B \rightarrow D^*lv$, $\Lambda_b \rightarrow \Lambda_c lv$
- Tree-level decays in the SM
- Form factors needed
- With light leptons ($l = \mu, e$) used to determine the CKM elements
- CKM fit works very well, i.e. tree-level in agreement with $\Delta F = 2$ processes



Largest B branching ratios, used to determine the CKM elements, usually assumed to be free of NP

$b \rightarrow c\tau\nu$ processes

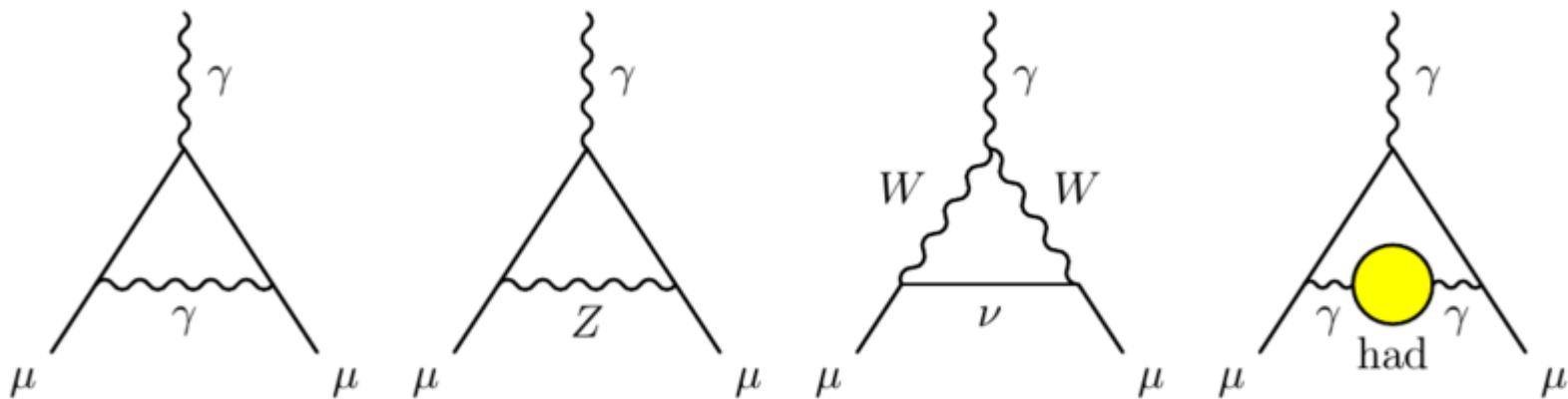


All measurements above the SM prediction
 4σ deviation

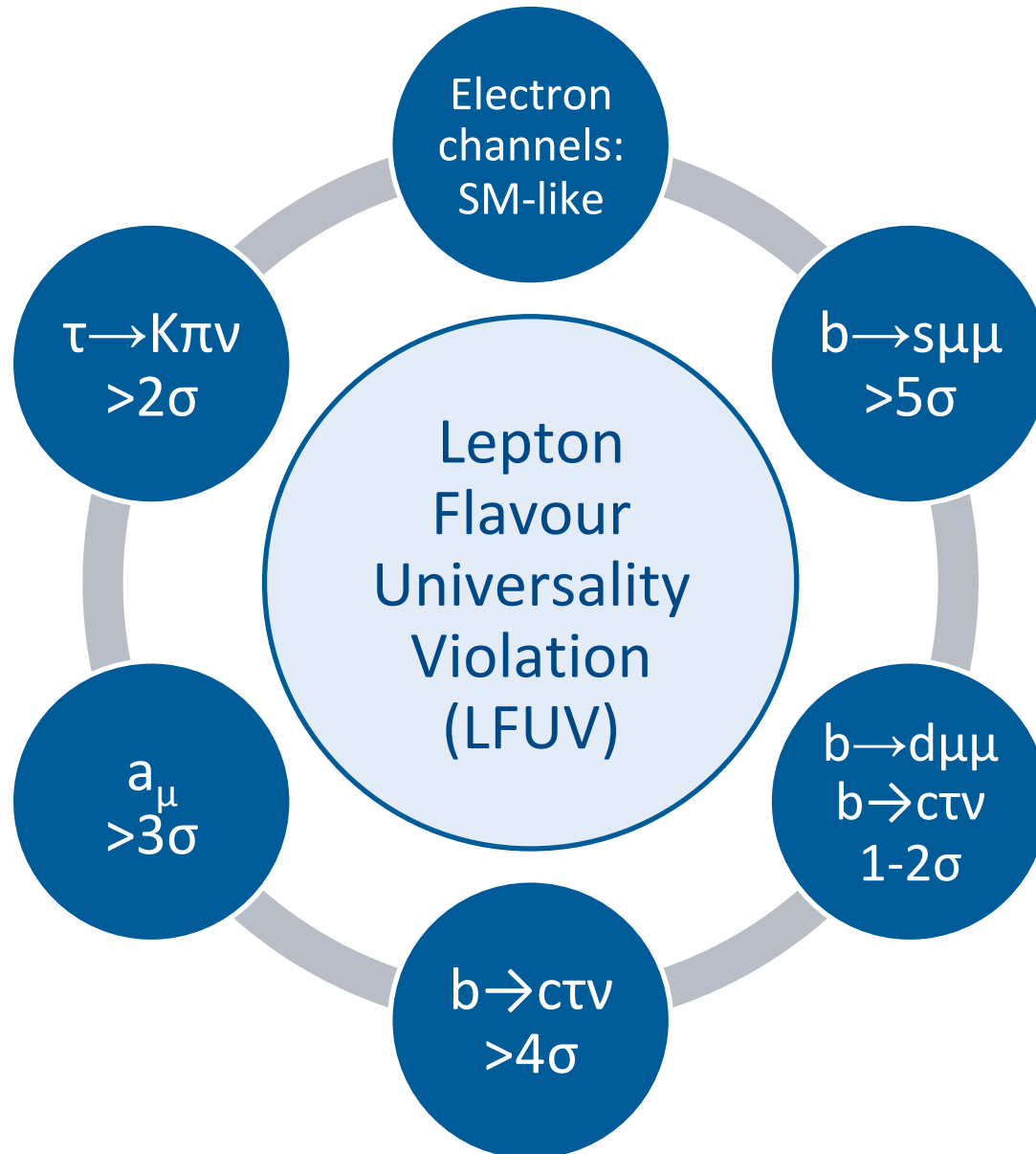
- Single measurement from BNL
- Theory prediction sound but challenging because of hadronic effects.

$$\Delta a_{\mu} = (236 \pm 87) \times 10^{-11}$$

- Soon new experimental results from Fermilab



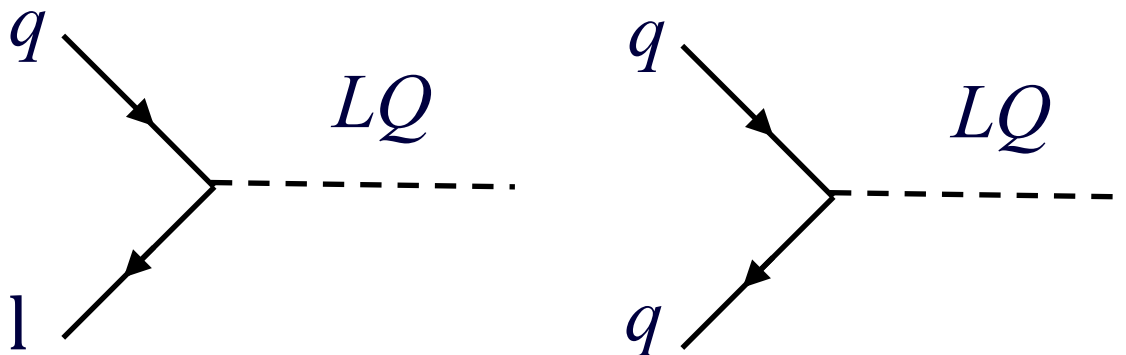
3 σ deviation (order of SM-EW contribution)



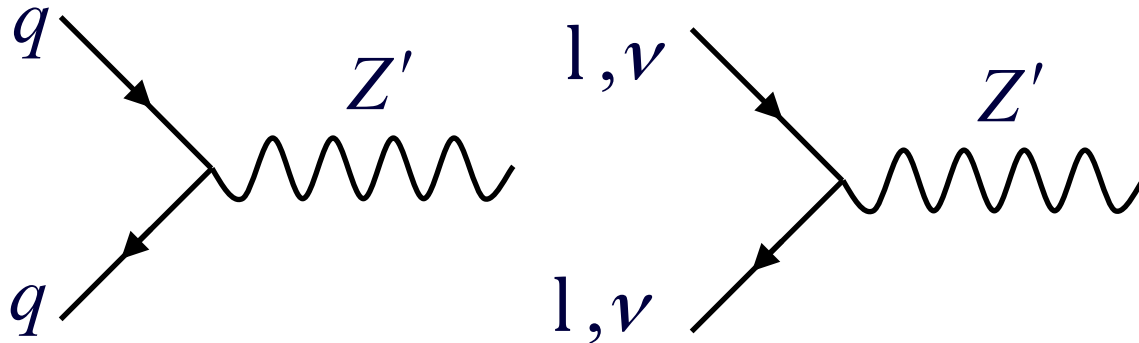
Probability
for
statistical
fluctuation
 $< 0.0001\%$

Extensions of the Standard Model to account for the flavour anomalies

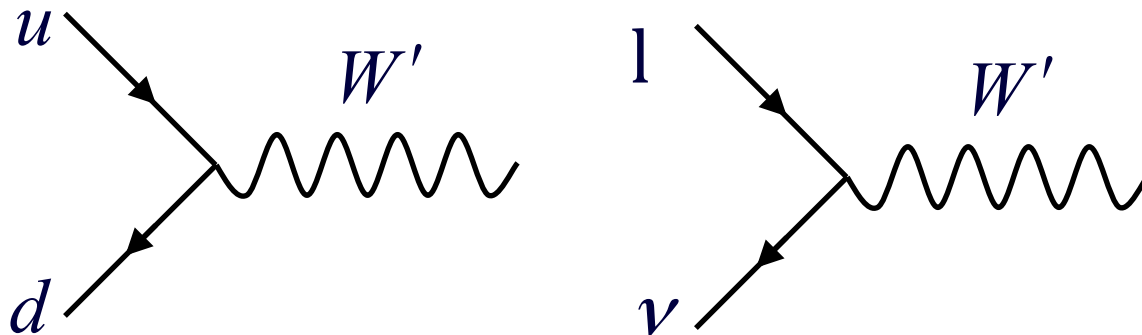
- Scalars or Vectors
- 5 gauge representations which are invariant under the SM gauge group
- Couple quarks to leptons
- Maybe also couple quarks to quarks
 - Proton decay
- Are present in Grand Unified Theories (GUTs)



- Z': neutral heavy gauge boson



- W': charged heavy gauge boson



New heavy gauge bosons

■ Charged scalars

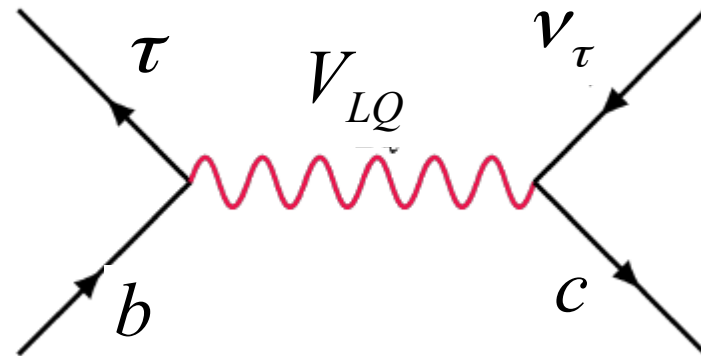
- Problems with q^2 distributions and B_c lifetime

■ W's

- Strong constraints from direct LHC searches
- Can work with right-handed neutrinos

■ Leptoquarks

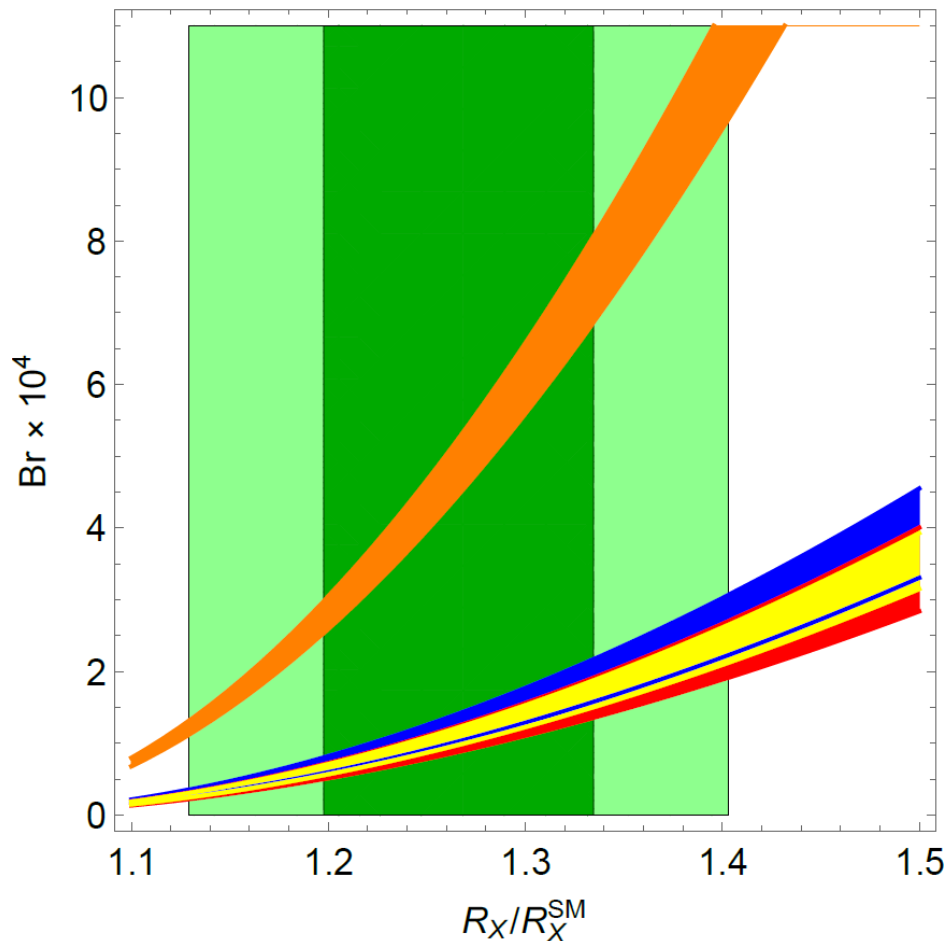
- Strong signals in $qq \rightarrow \tau\tau$ searches



Explanation difficult but possible

$R(D^{(*)})$ and $b \rightarrow s\tau\tau$ (model-independent)

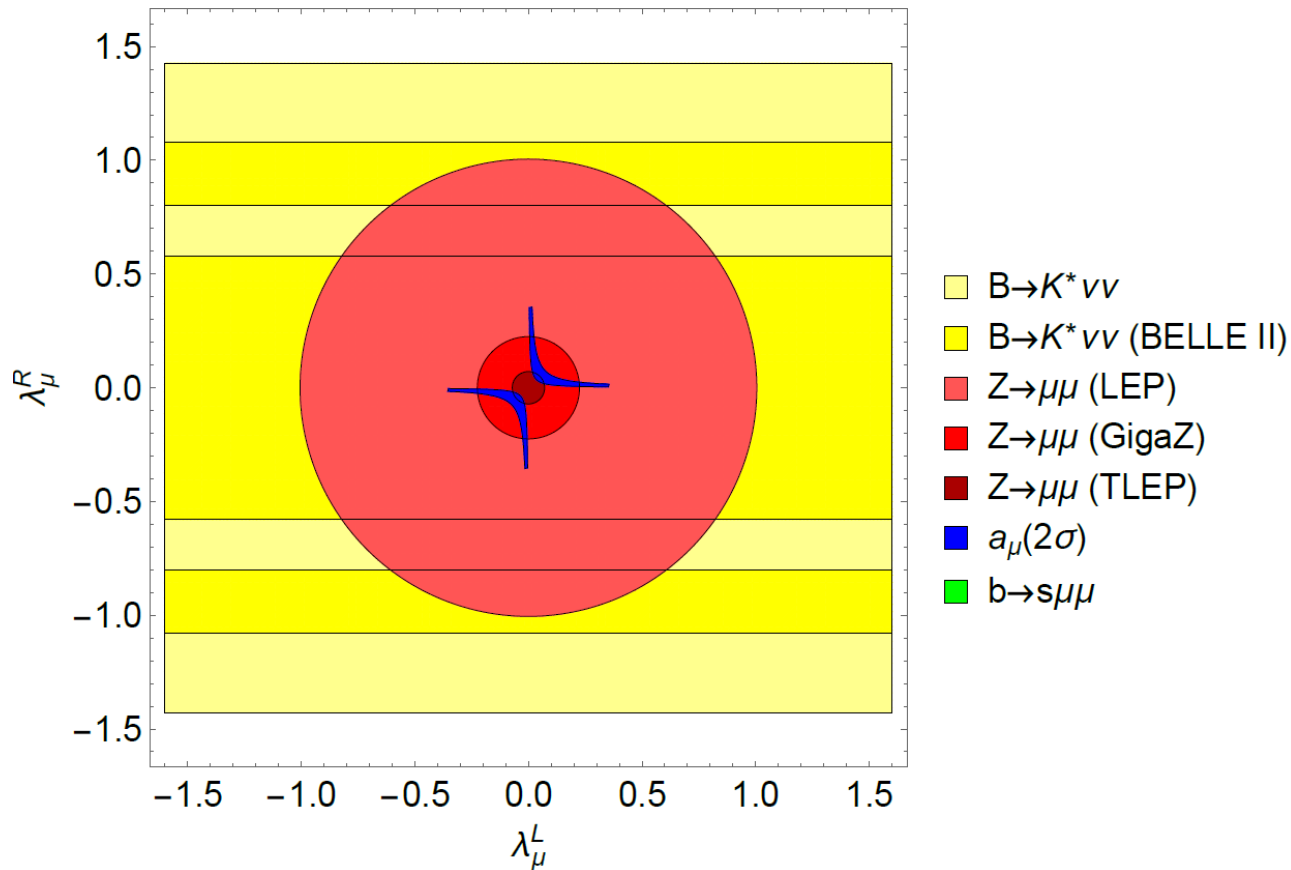
- Large couplings to the second generation
- Cancellation in $b \rightarrow svv$ needed: $C^{(1)}=C^{(3)}$



$b \rightarrow s\tau\tau$
very
strongly
enhanced

B. Capdevila, A.C., S. Descotes-Genon, L. Hofer and J. Matias, PRL.120.181802

■ Chirally enhanced effects via top-loops



$\lambda_\mu^{L,R}$

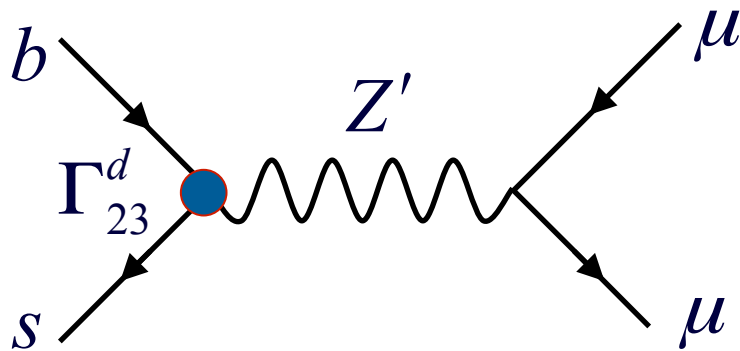
Left-, right-handed muons-top coupling

E. Leskow, A.C.,
G. D'Ambrosio,
D. Müller
arXiv:1612.06858

$Z \rightarrow \mu \mu$ at future colliders

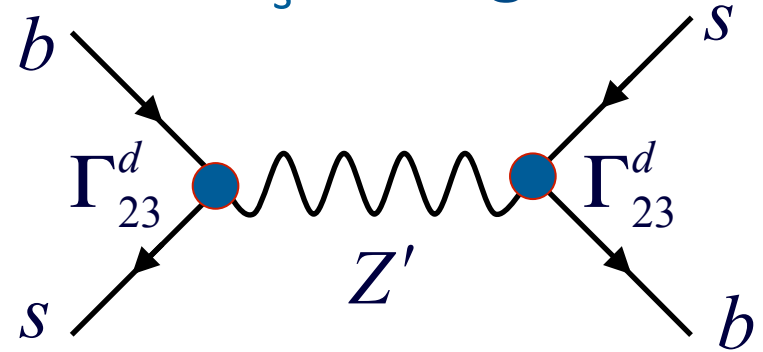
$b \rightarrow s \mu^+ \mu^-$: Z' and Leptoquarks

$b \rightarrow s \mu \mu$

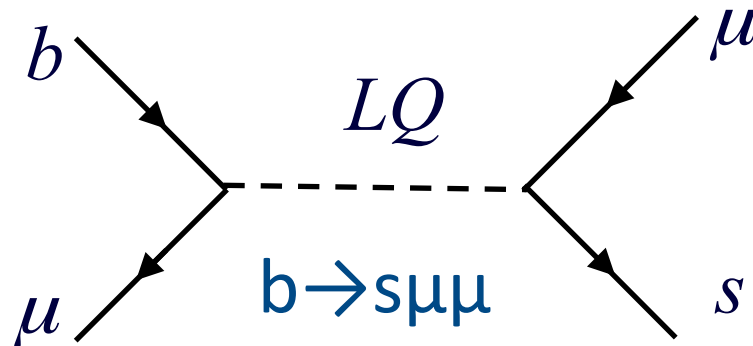


$$C_9^{\mu\mu} \propto \Gamma_{23}^{dL} g'^2 / m_{Z'}^2$$

B_s mixing



$$\frac{\Delta M_{12}}{M_{12}^{\text{SM}}} \propto (\Gamma_{23}^{dL})^2 g'^2 / m_{Z'}^2$$



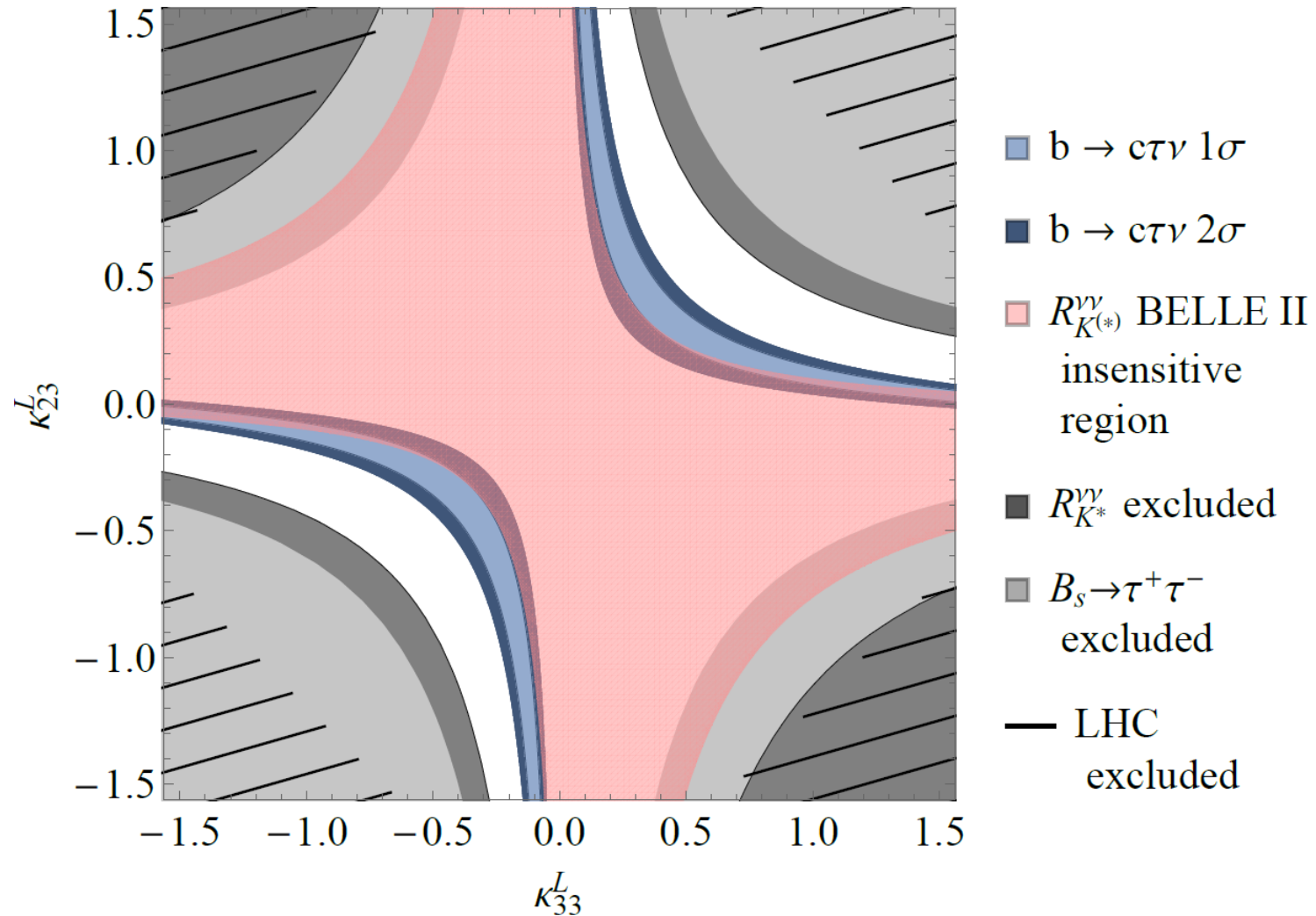
Z' affects B_s mixing

Simultaneous Explanation with the Pati-Salam Leptoquark

- Left-handed effect in $b \rightarrow s \mu \mu$
- Left-handed vector current in $R(D)$ and $R(D^*)$
- No effect in $b \rightarrow s \nu \nu$
- No proton decay
- Contained within the Pati-Salam model
- Massive vector bosons
 - Non-renormalizable without Higgs mechanism
 - Pati Salam not possible at the TeV scale because of $K_L \rightarrow \mu e$ and $K \rightarrow \pi \mu e$

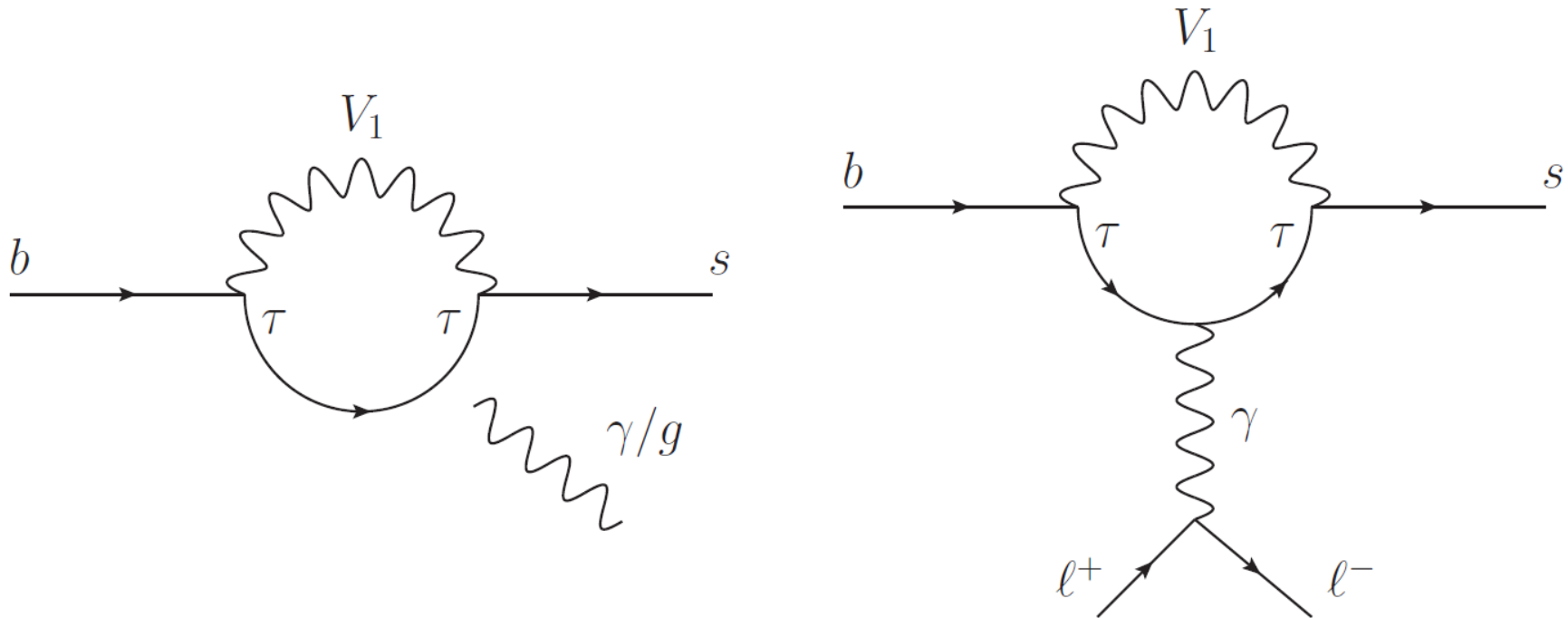
Good solution, but difficult UV completion

Vector LQ Phenomenology



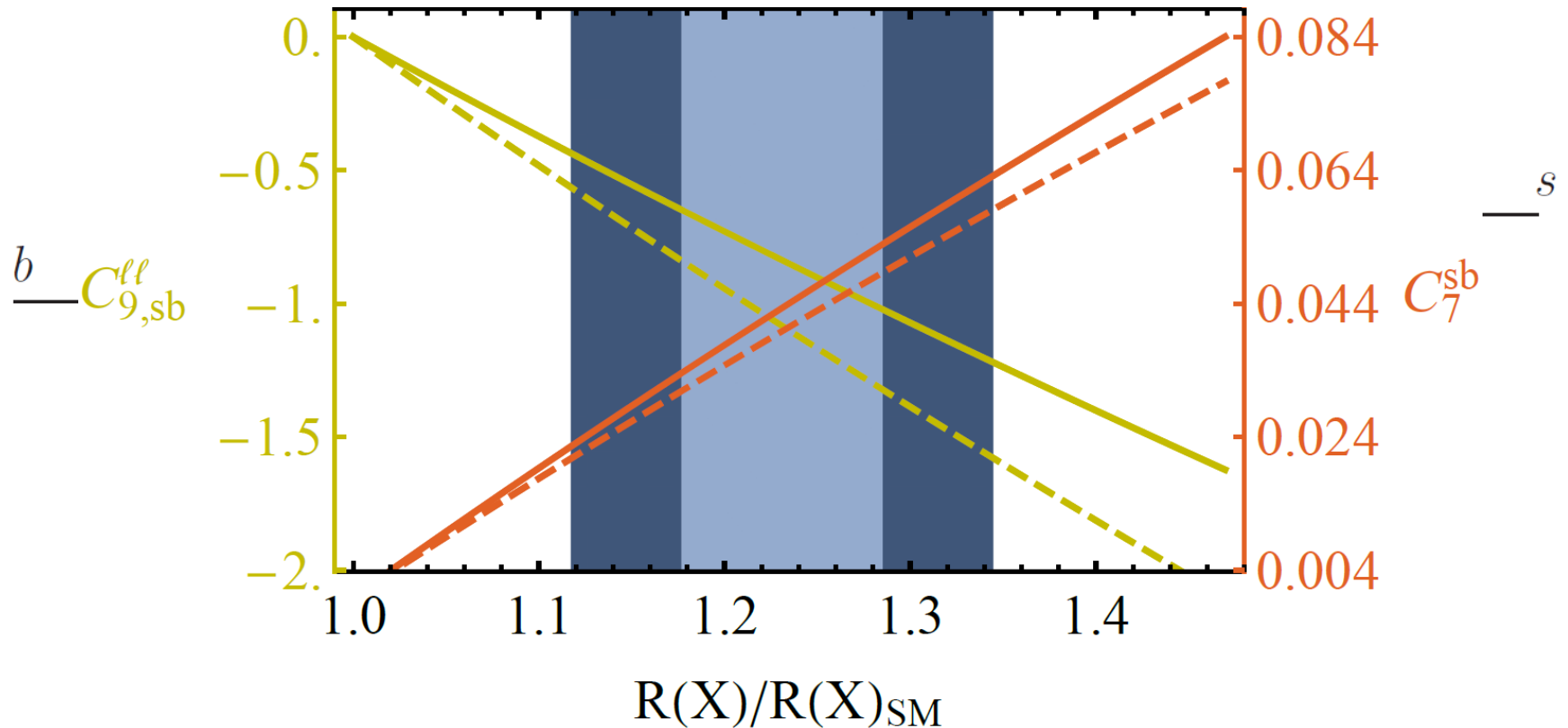
Many correlations

- Explanation of $b \rightarrow c \tau \nu$ requires large $b\tau$ and $s\tau$ couplings (follows from SU(2) invariance)



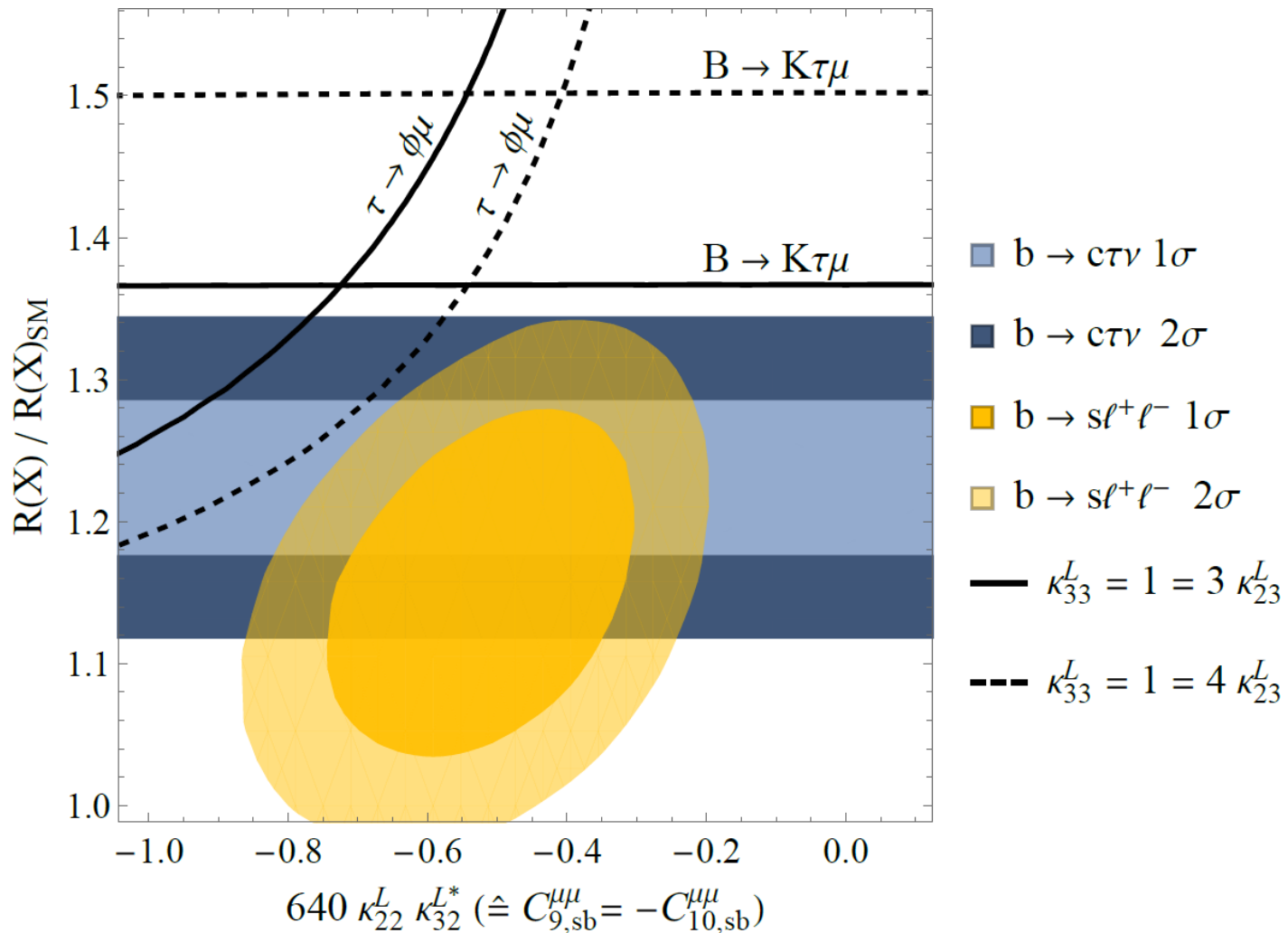
Large loop effects in $b \rightarrow s \mu \mu$

- Explanation of $b \rightarrow c \tau \nu$ requires large $b\tau$ and $s\tau$ couplings (follows from SU(2) invariance)



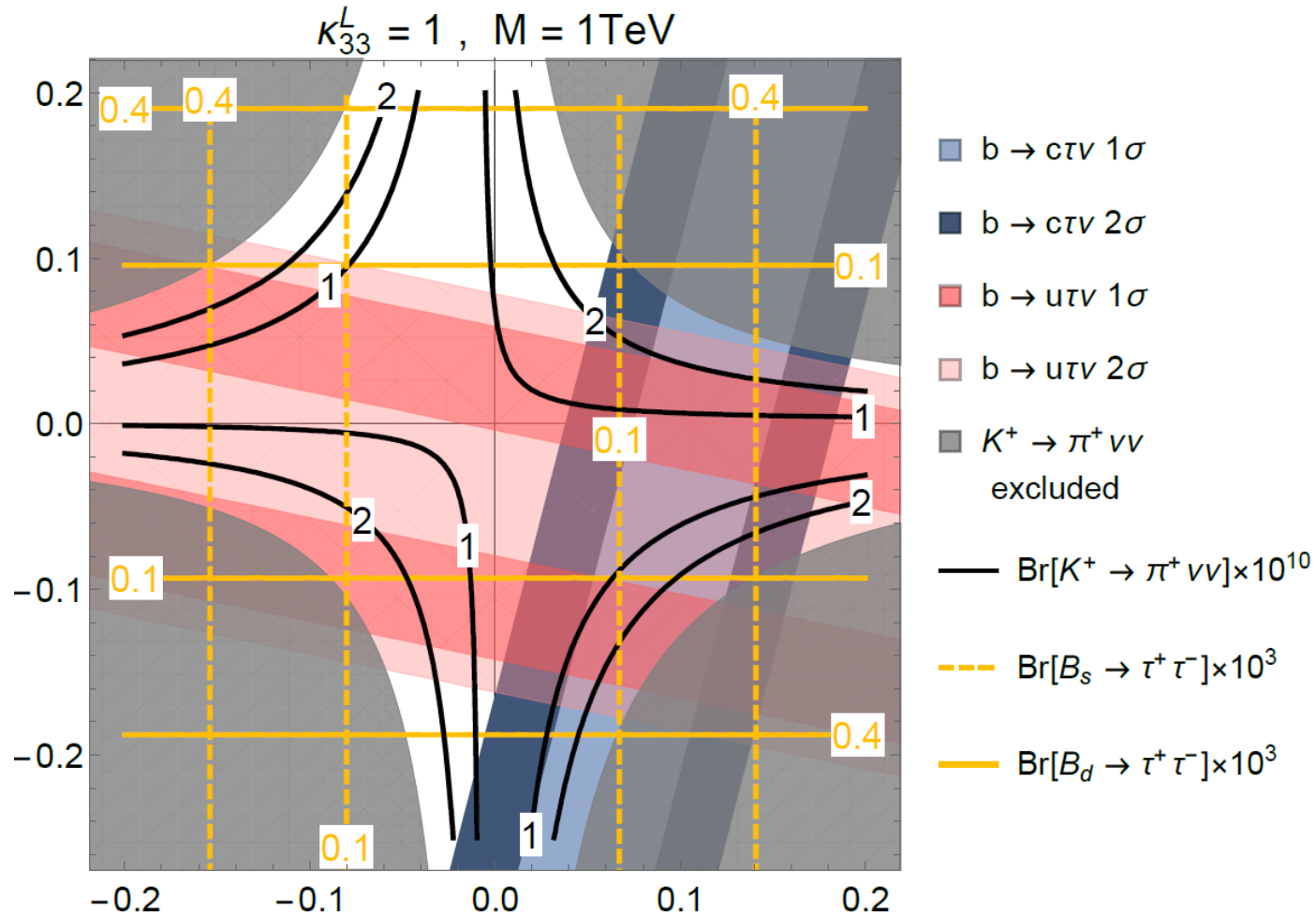
Large loop effects in $b \rightarrow s \mu \mu$

Perfect agreement with data



Pati-Salam LQ can explain the flavour anomalies

Vector LQ Phenomenology



Many correlations

