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Theory Group of the Laboratory for Particle Physics

Flavour Models for the Anomalies

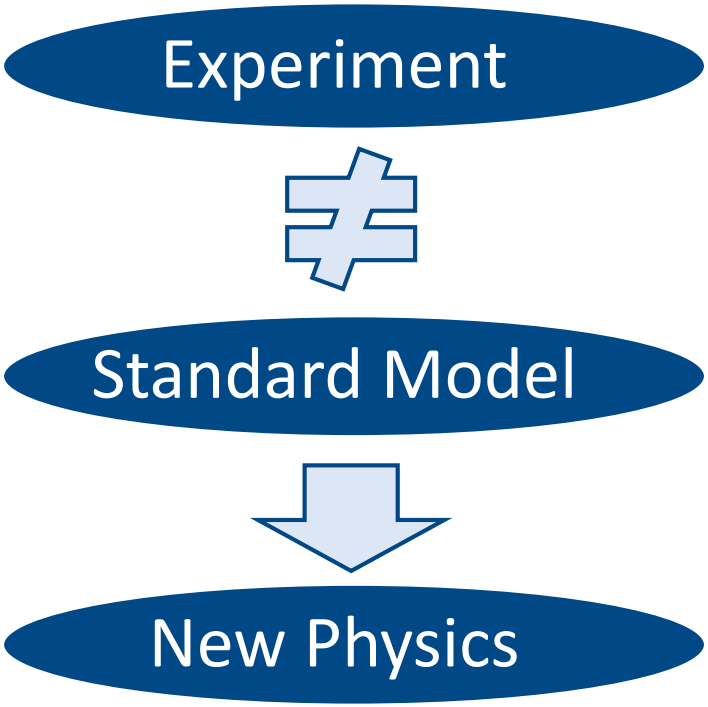
Karlsruhe, 02.10.2018

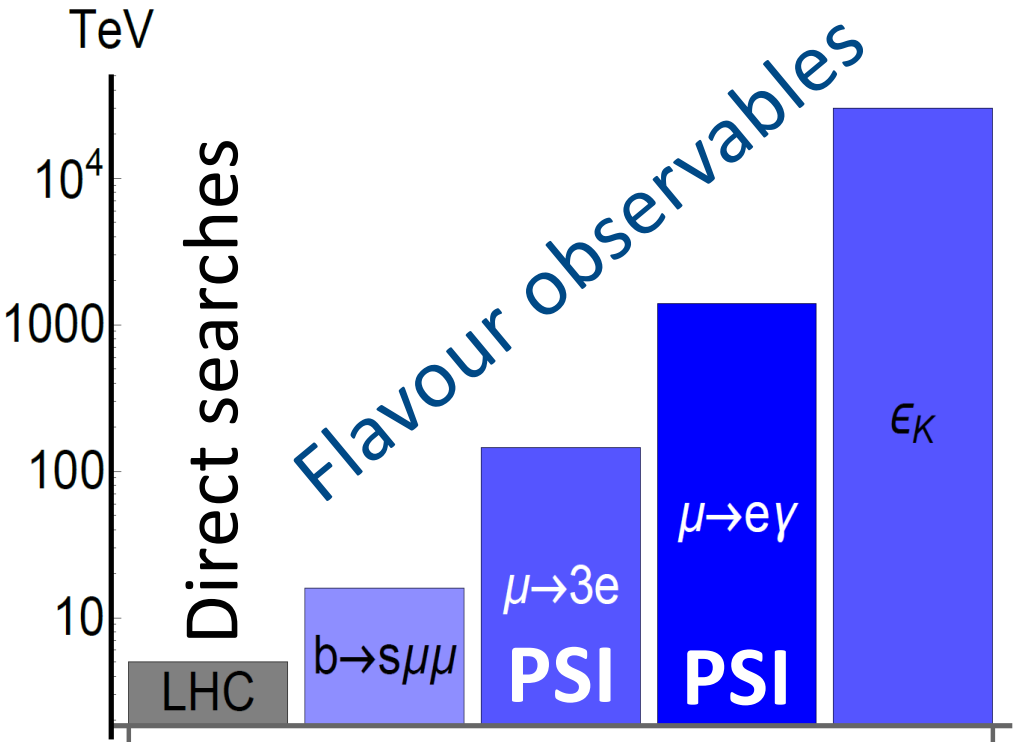
Outline

- Introduction: Searching for NP with Flavour
- Flavour anomalies
  - $b \to s\mu^+\mu^-$
  - $b \to c\tau\nu$
  - a_μ (anomalous magnetic moment of the muon)
- New Physics explanations for the anomalies
  - Z', W'
  - Leptoquarks
- The Pati-Salam leptoquark
- Conclusions

Finding New Physics with Flavour

- At colliders one produces many (up to 10^{14}) heavy quarks or leptons and measures their decays into light flavours





Flavour observables are sensitive to higher energy scales than collider searches

New Physics in the Flavour Sector

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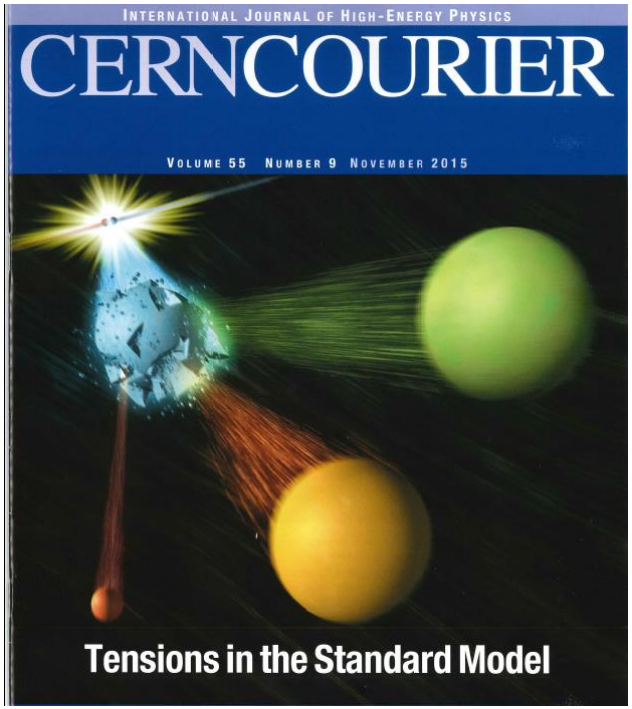
2 Accelerators Find Particles That May Break Known Laws of Physics

The LHC and the Belle experiment have found particle decay patterns that violate the Standard Model of particle physics, confirming earlier observations at the BaBar facility

By Clara Moskowitz | September 9, 2015 | Véalo en español



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Democracy suffers a blow—in particle physics

Three independent B-meson experiments suggest that the charged leptons may not be so equal after all.

Steven K. Blau 17 September 2015

"Popular news"

Tages-Anzeiger

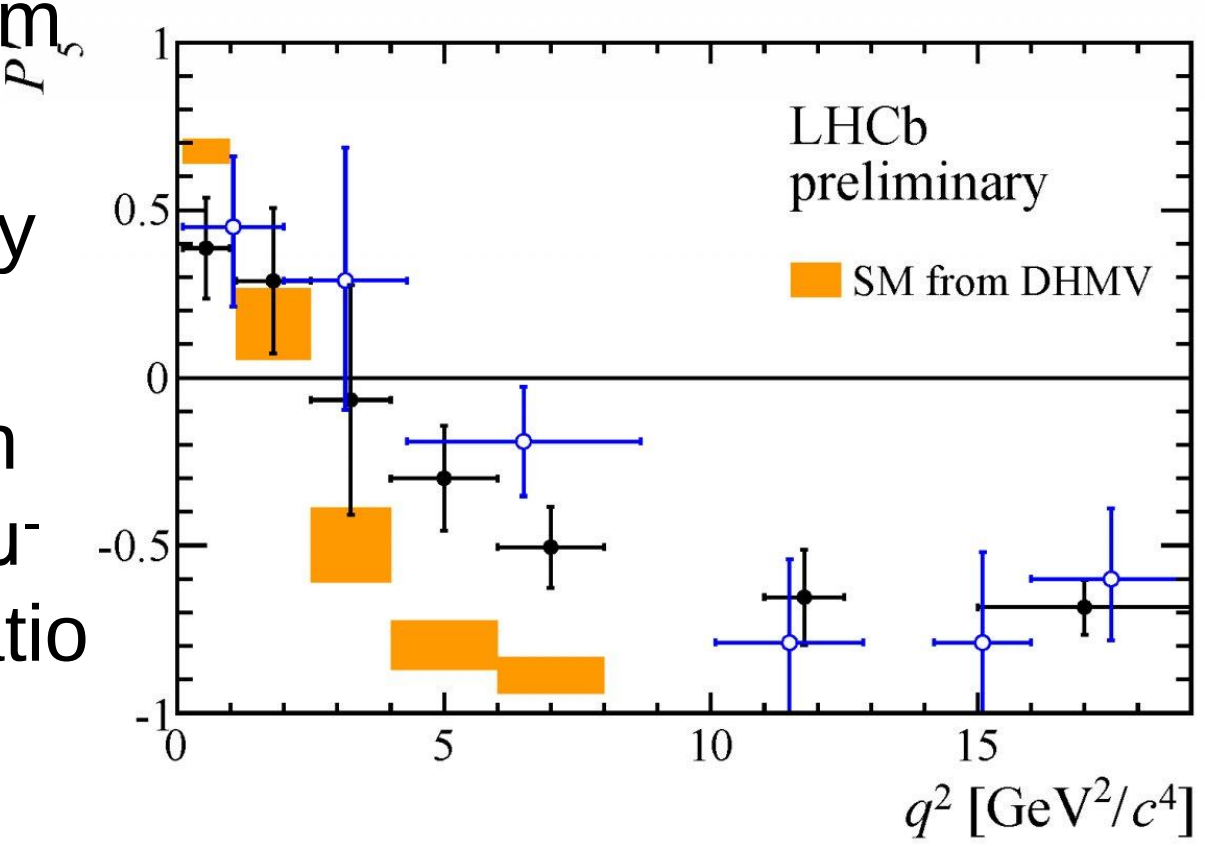
Spuren einer neuen Kraft

Ein Experiment am Cern liefert Hinweise darauf, dass das bisherige Standardmodell der Teilchenphysik nicht ausreicht, um das Universum zu erklären.

Gigantische Zahlen
Unvorstellbare Leistung am Cern

P_5' and $B_s \to \phi\mu\mu$

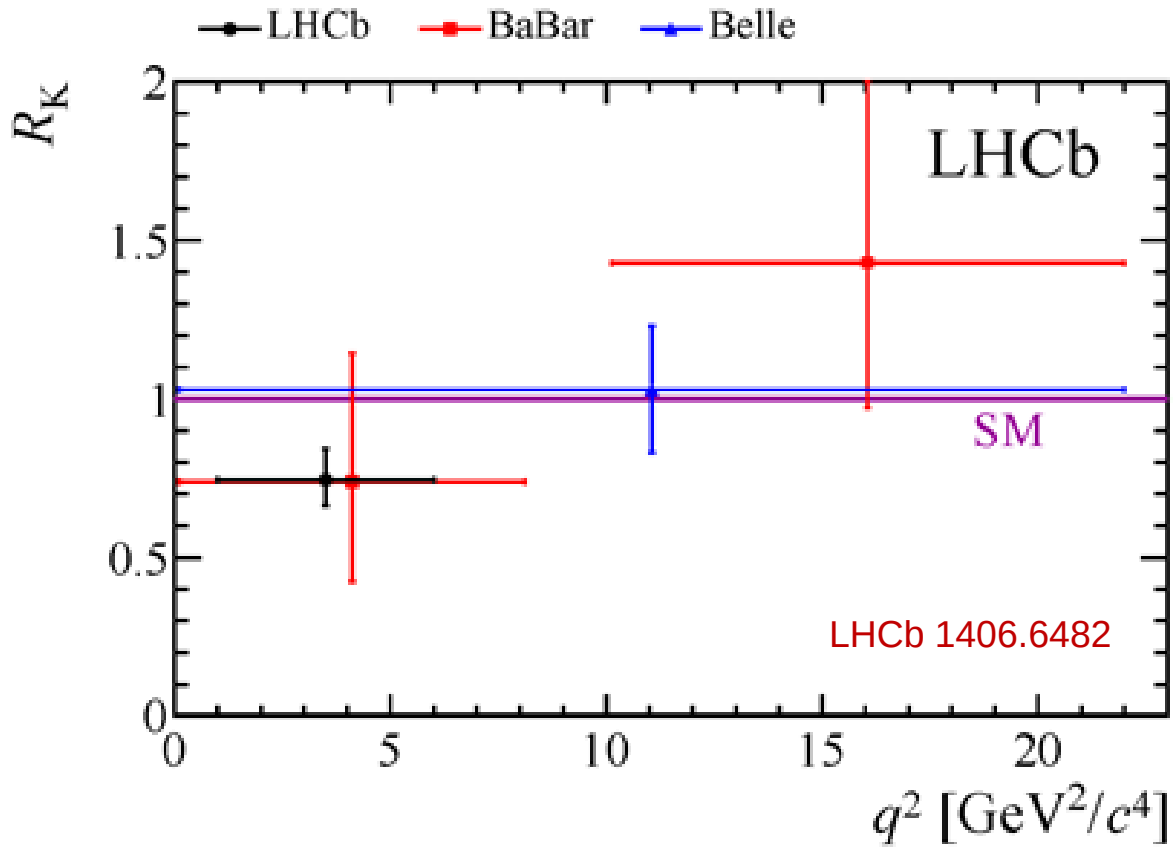
- LHCb 3σ deviation from the SM
- Confirmed by BELLE
- 2σ tension in the $B_s \to \phi\mu^+\mu^-$ branching ratio



Hadronic uncertainties or NP?

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

- 2.2-2.6σ deviation from the theoretically rather clean SM expectation



Lepton Flavour Violation in B decays?

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

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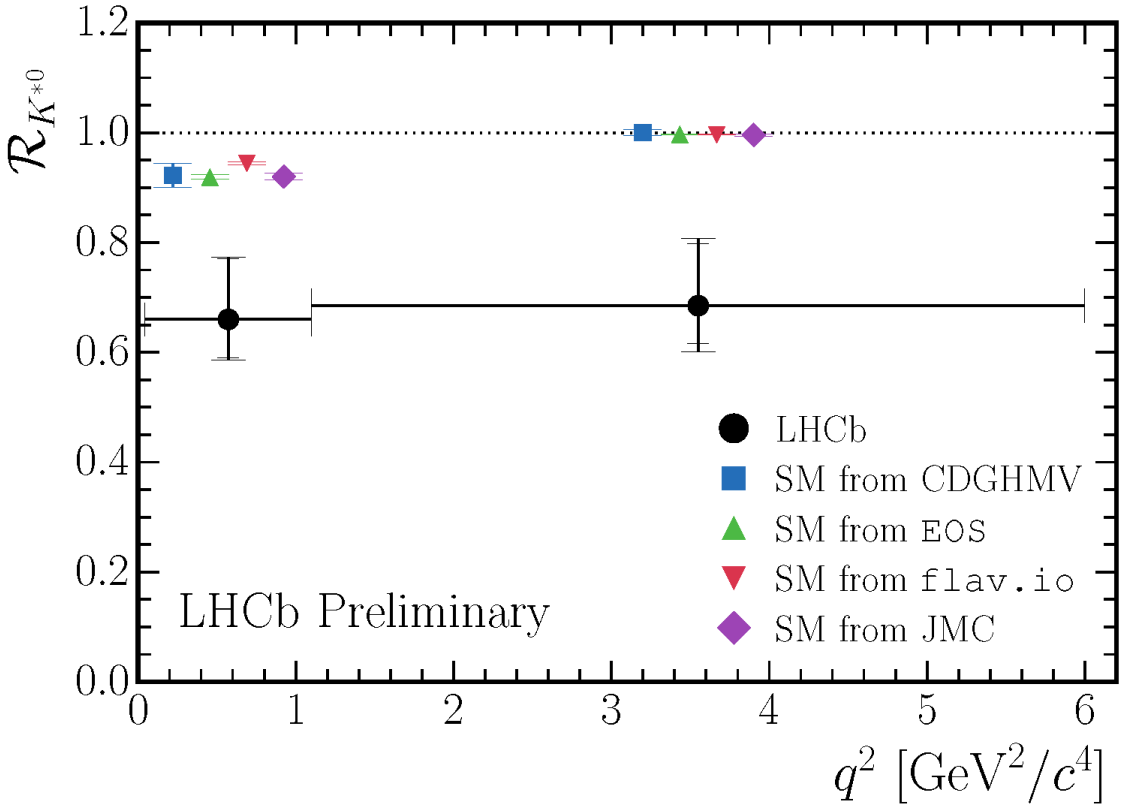


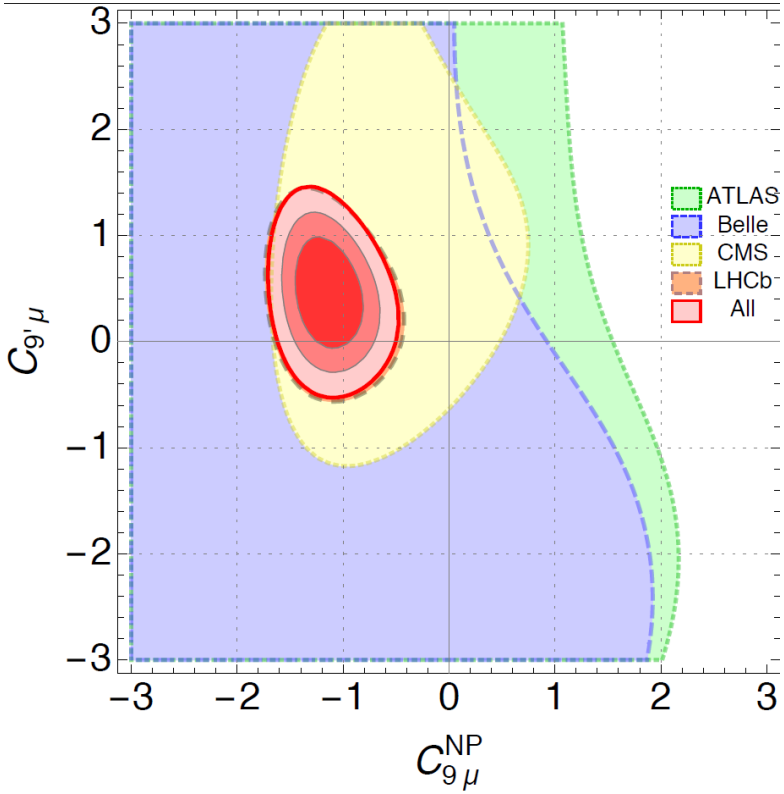
Lepton Flavour Violation in B decays?

Global fit to b→sμ⁺μ⁻ data

- Global analyses give a very good fit to data
- Good fit to data:
  - C_9
  - $C_9 = -C_{10}$
  - $C_9 = -C_9'$

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

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

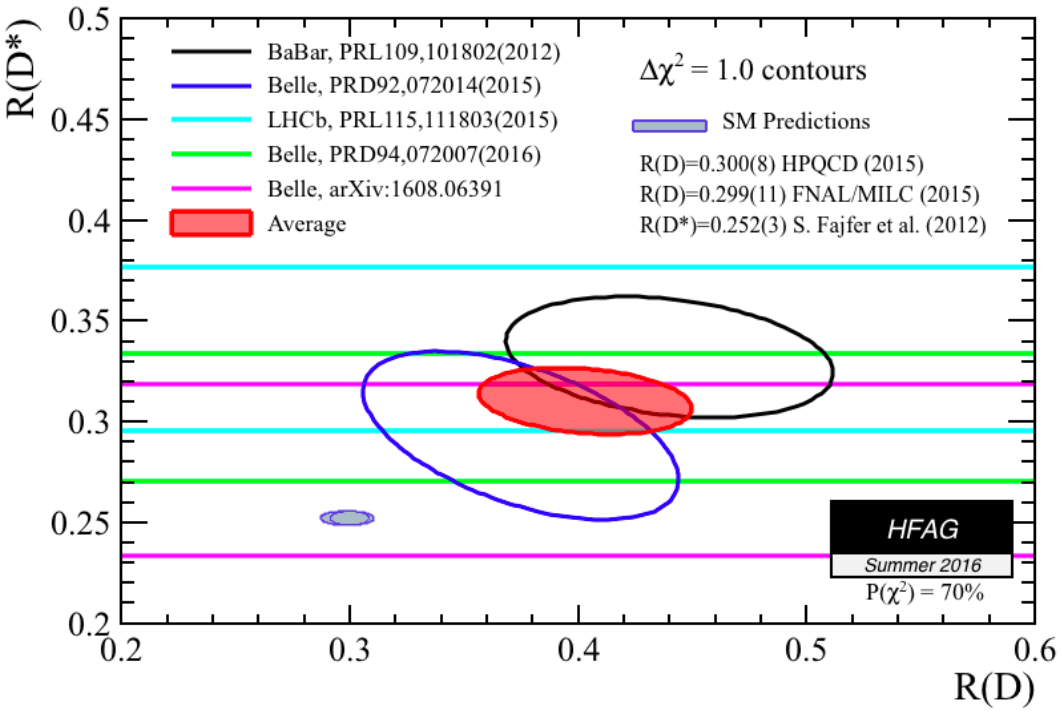


B. Capdevila, AC, S. Descotes-Genon, J. Matias and J. Virto, arXiv:1704.05340 [hep-ph].

Fit is 5-6 σ better than the SM

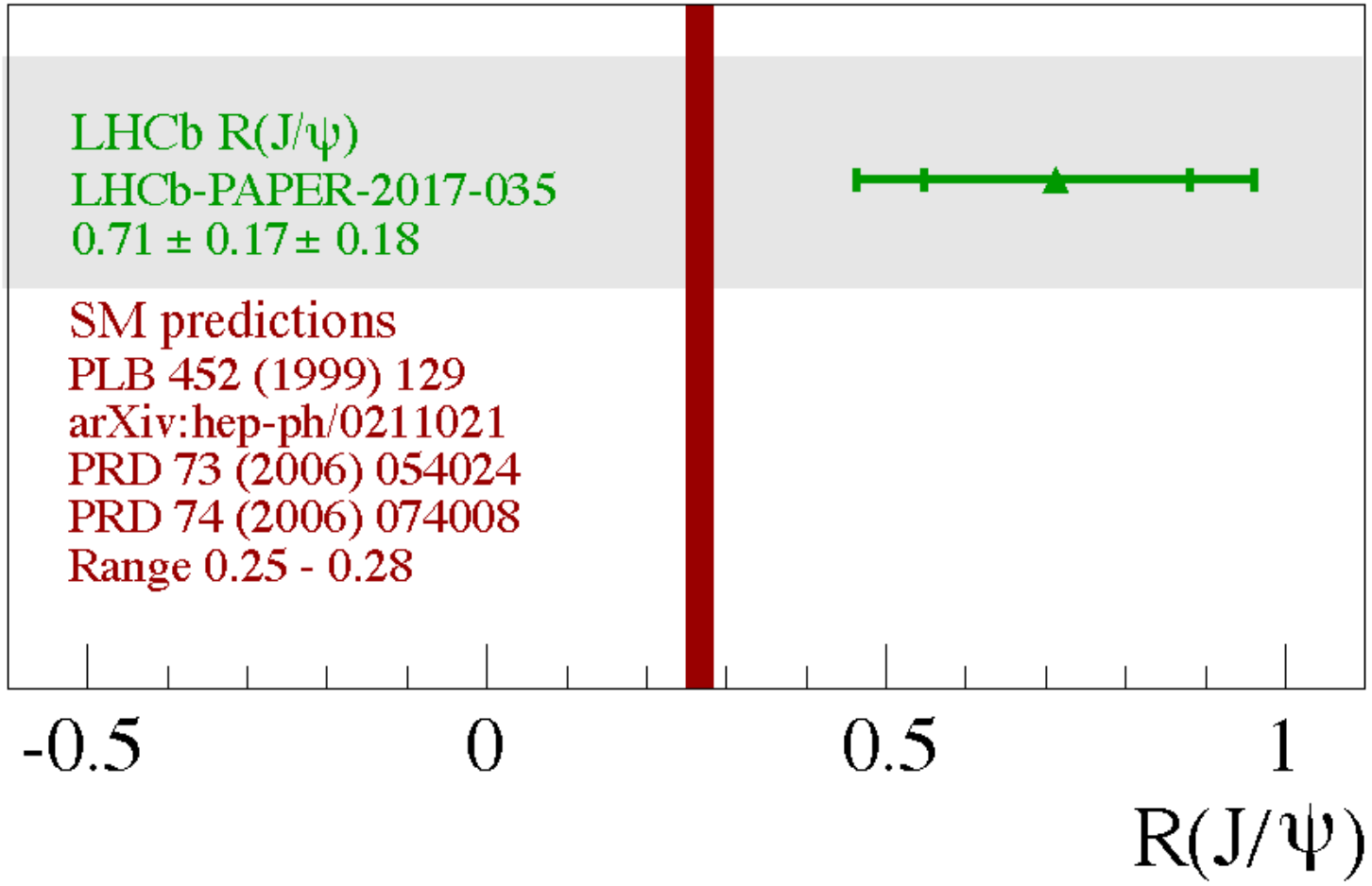
b→cτν processes

$$R\left(D^{(*)}\right) = B \to D^{(*)}\tau\nu \Big/ B \to D^{(*)}\ell\,\nu$$



All measurements above the SM prediction
4σ deviation

b→cτν processes



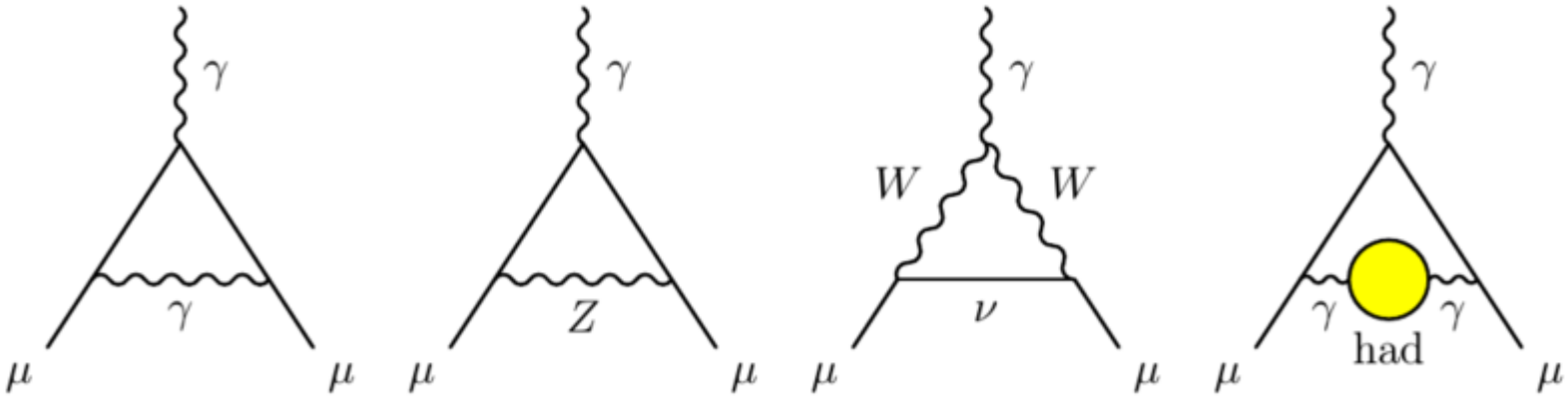
All measurements above the SM prediction
4σ deviation

Muon Anomalous Magnetic Moment

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

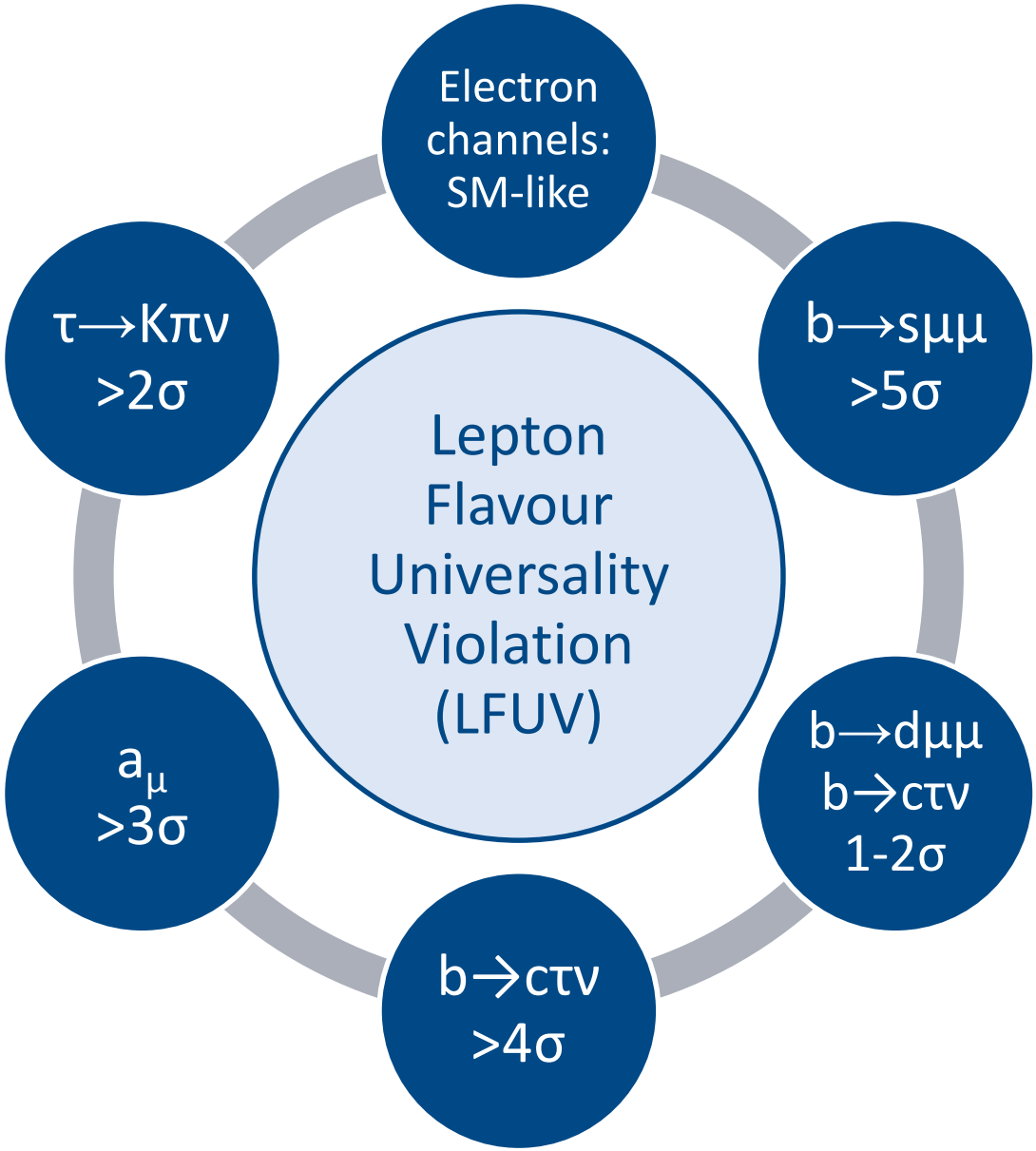
$$\Delta a_\mu = \left(236 \pm 87\right) \times 10^{-11}$$

- Soon new experimental results from Fermilab



3σ deviation (order of SM-EW contribution)

Hints for New Physics

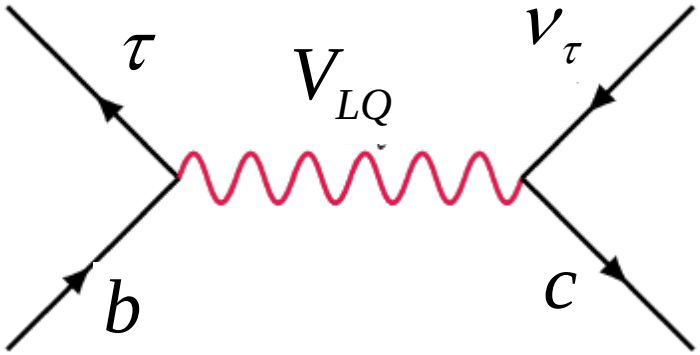


Probability for statistical fluctuation < 0.0001%

Extensions of the Standard Model to account for the flavour anomalies

R(D) & R(D*)

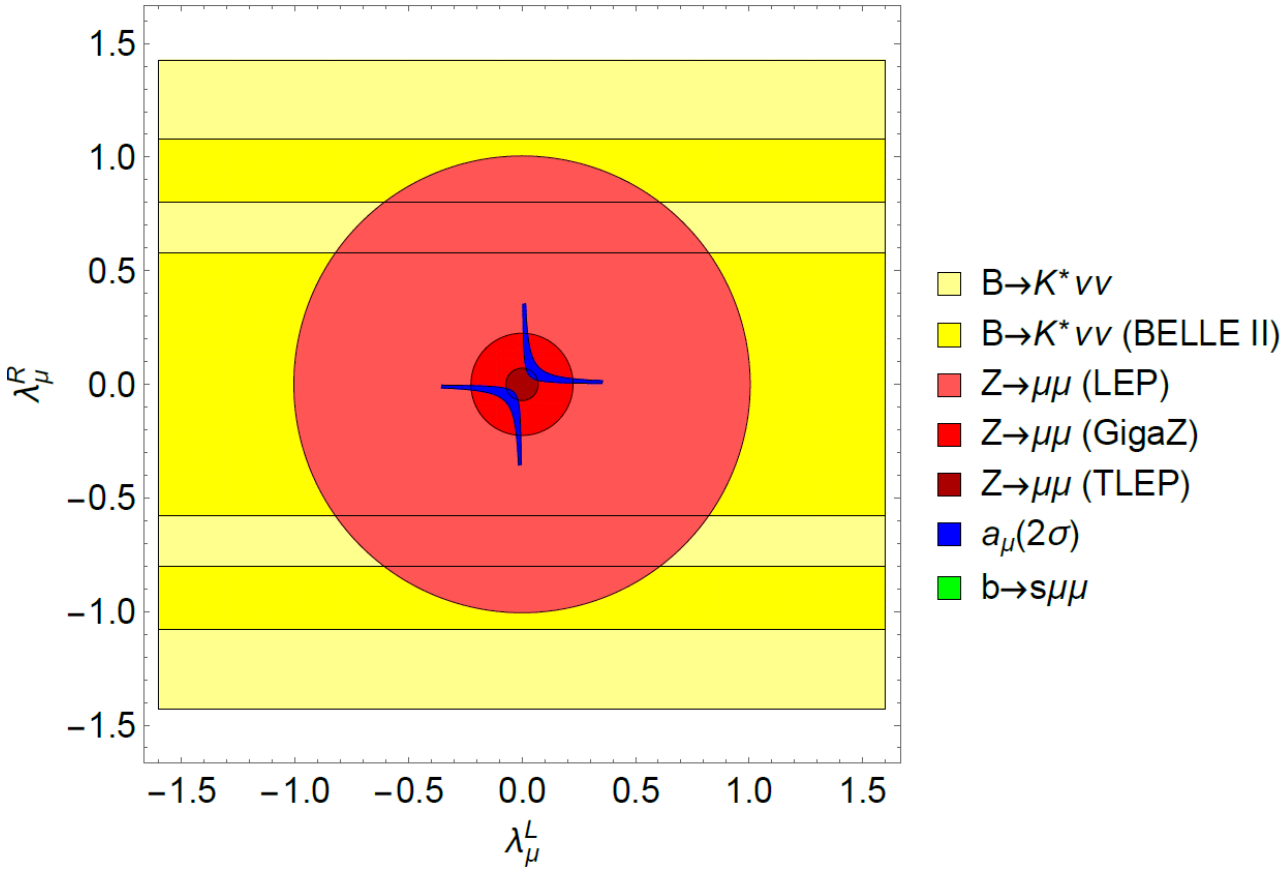
- Charged scalars
  - Problems with q^2 distributions and B_c lifetime
- W's
  - Strong constraints from direct LHC searches
  - Can work with right-handed neutrinos
- Leptoquarks
  - Strong signals in qq→ττ searches



Explanation difficult but possible

Leptoquarks in a_μ

- 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→μμ at future colliders

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

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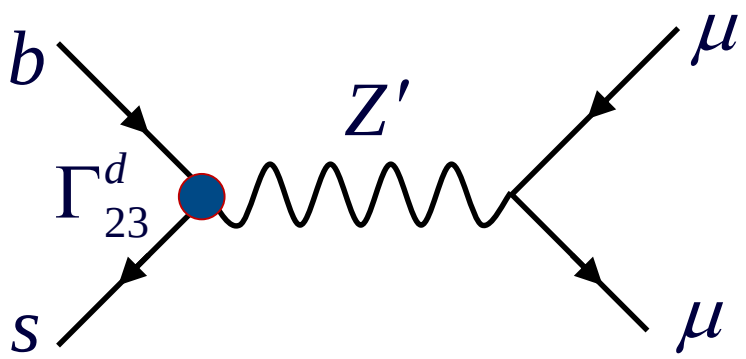
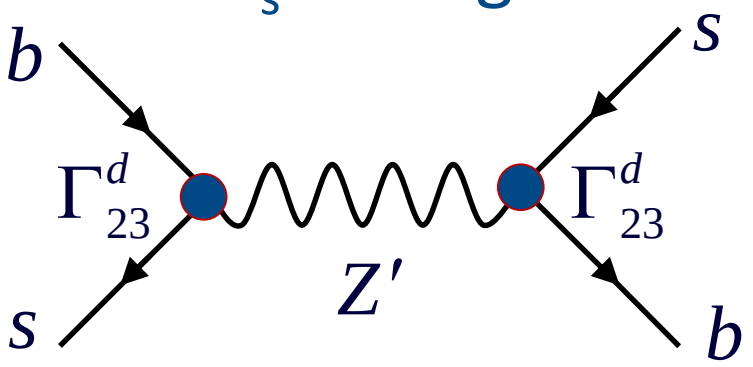
$b \to s\mu\mu$

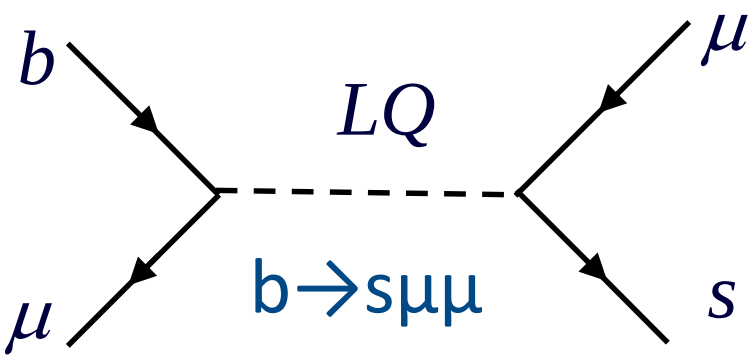


$$C_9^{\mu\mu} \propto \Gamma_{23}^{dL}\, g'^2 / m_{Z'}^2$$

B_s mixing



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



Z' affects B_s mixing

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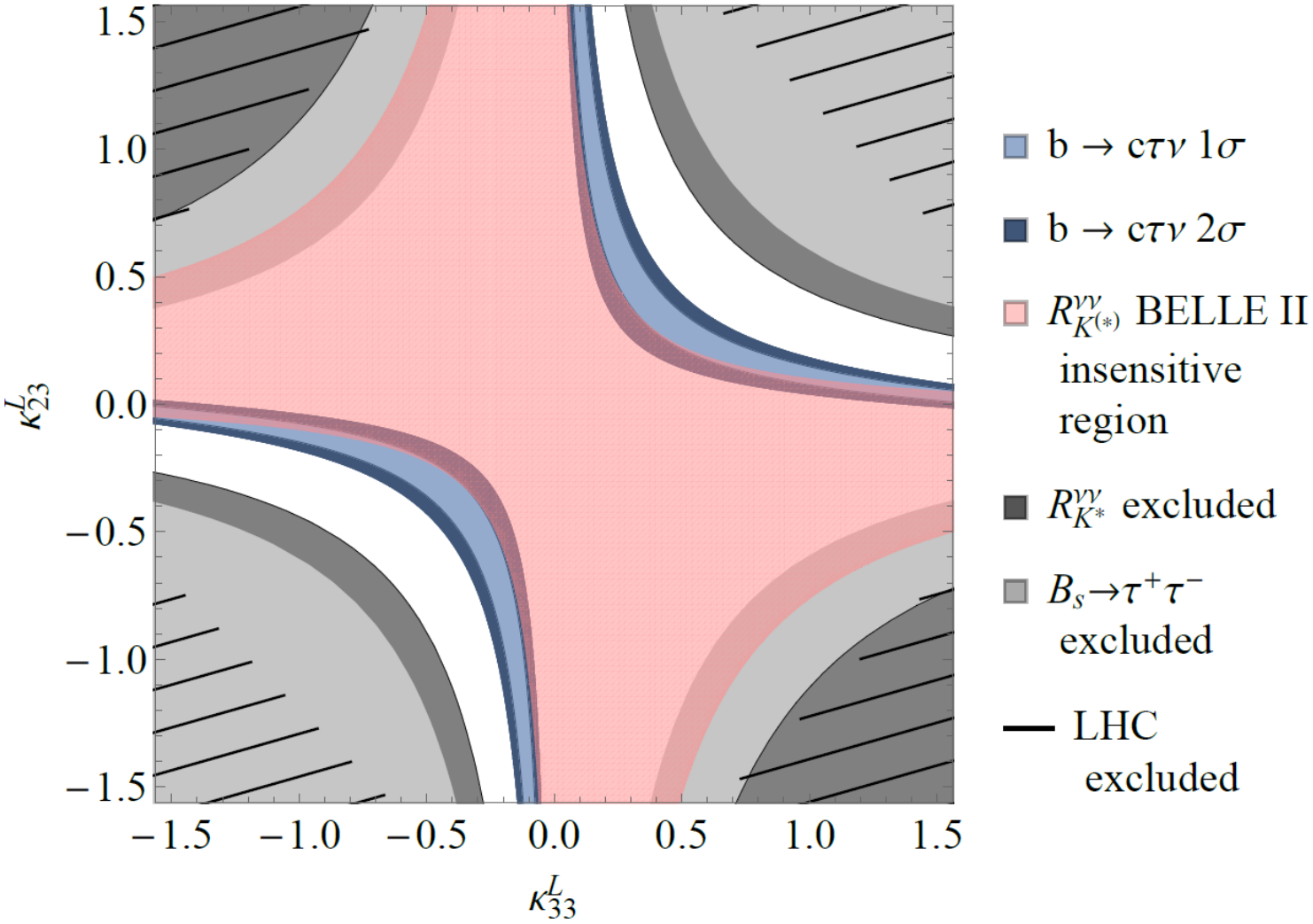
Simultaneous Explanation with the Pati-Salam Leptoquark

Vector Leptoquark SU(2) Singlet

- Left-handed effect in $b \to s\mu\mu$
- Left-handed vector current in R(D) and R(D*)
- No effect in $b \to s\nu\nu$
- 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 $K_L \to \mu e$ and $K \to \pi \mu e$

Good solution, but difficult UV completion

Vector LQ Phenomenology



Compatible with constraints for generic couplings

Important Loop-Effects

A.C., C. Greub,
D. Müller, F. Saturnino,
arXiv:1807.02068

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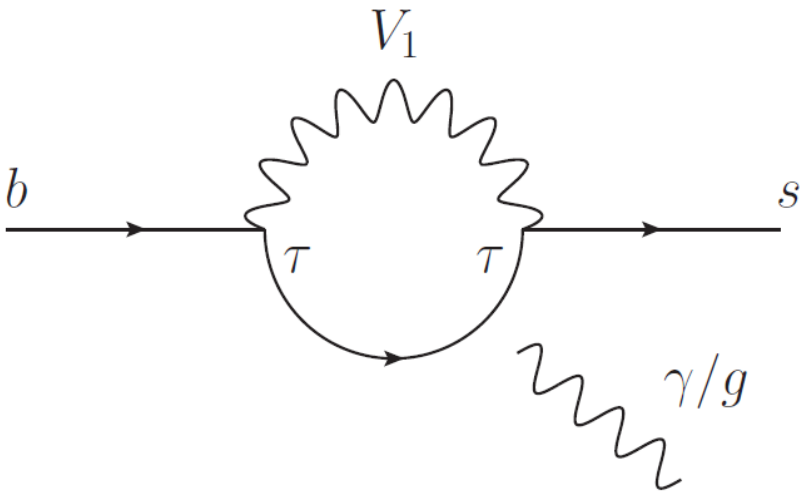
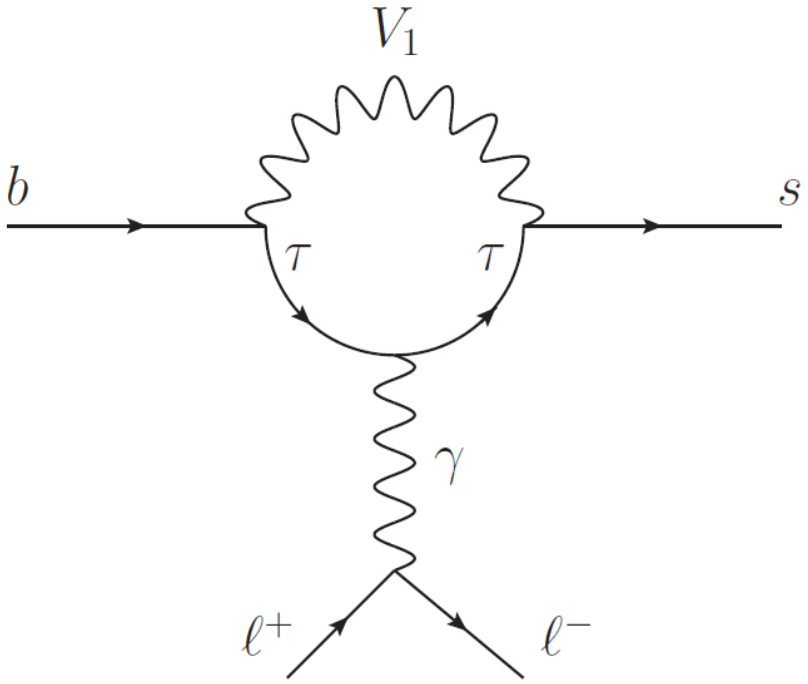
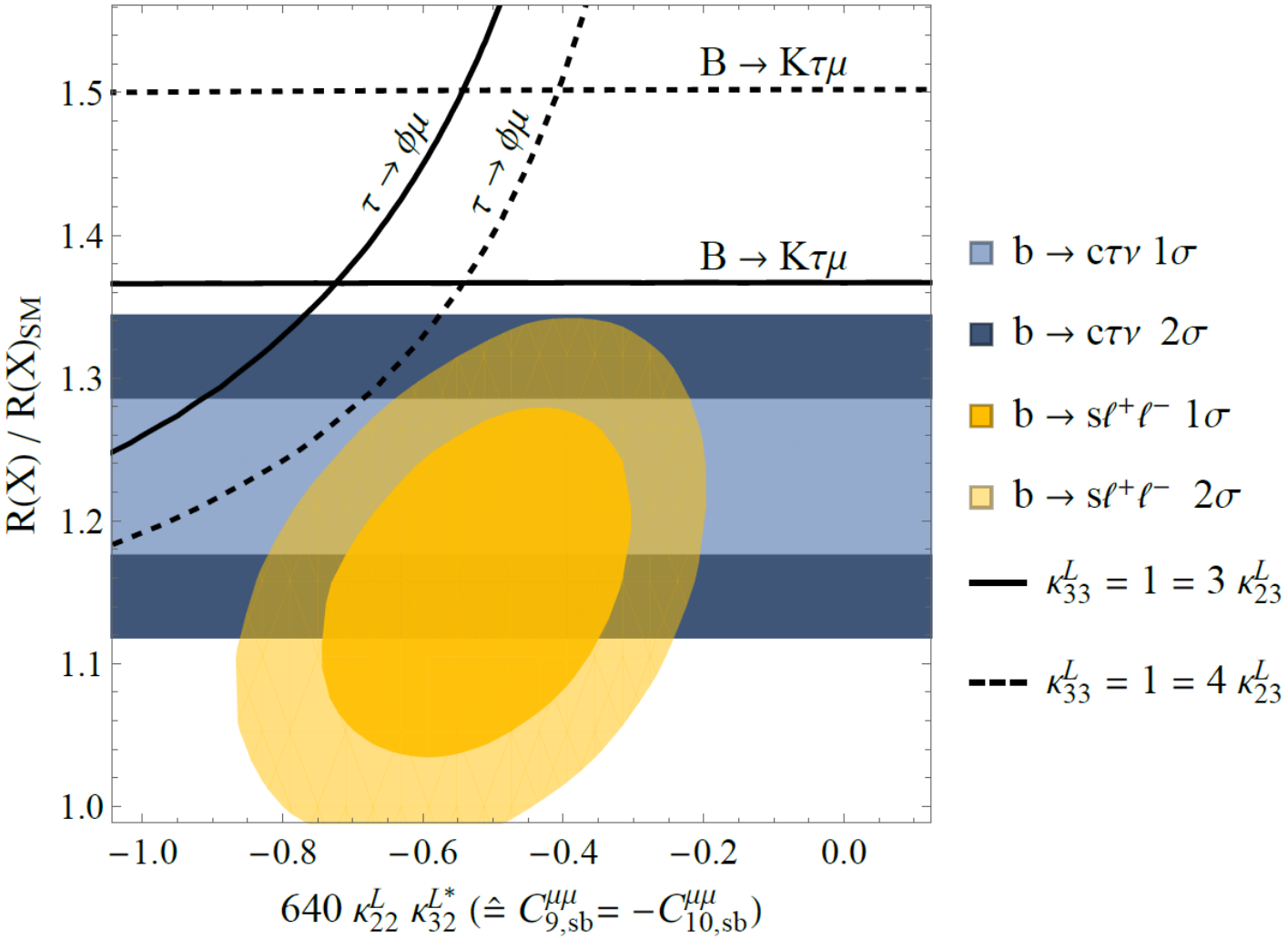
- Explanation of $b \to c\tau\nu$ requires large $b\tau$ and $s\tau$ couplings (follows from SU(2) invariance)





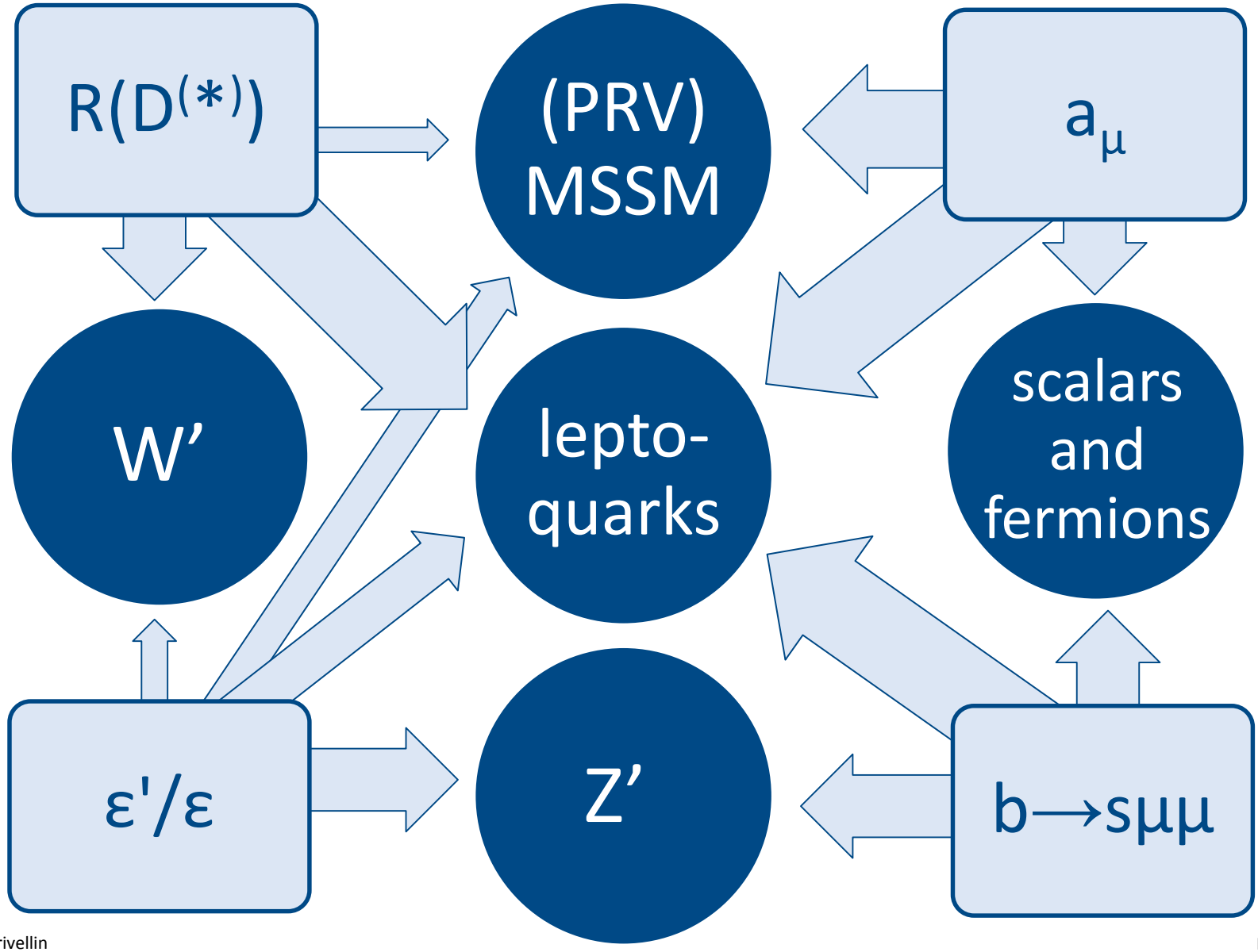
Large loop effects in $b \to s\mu\mu$

Perfect agreement with data

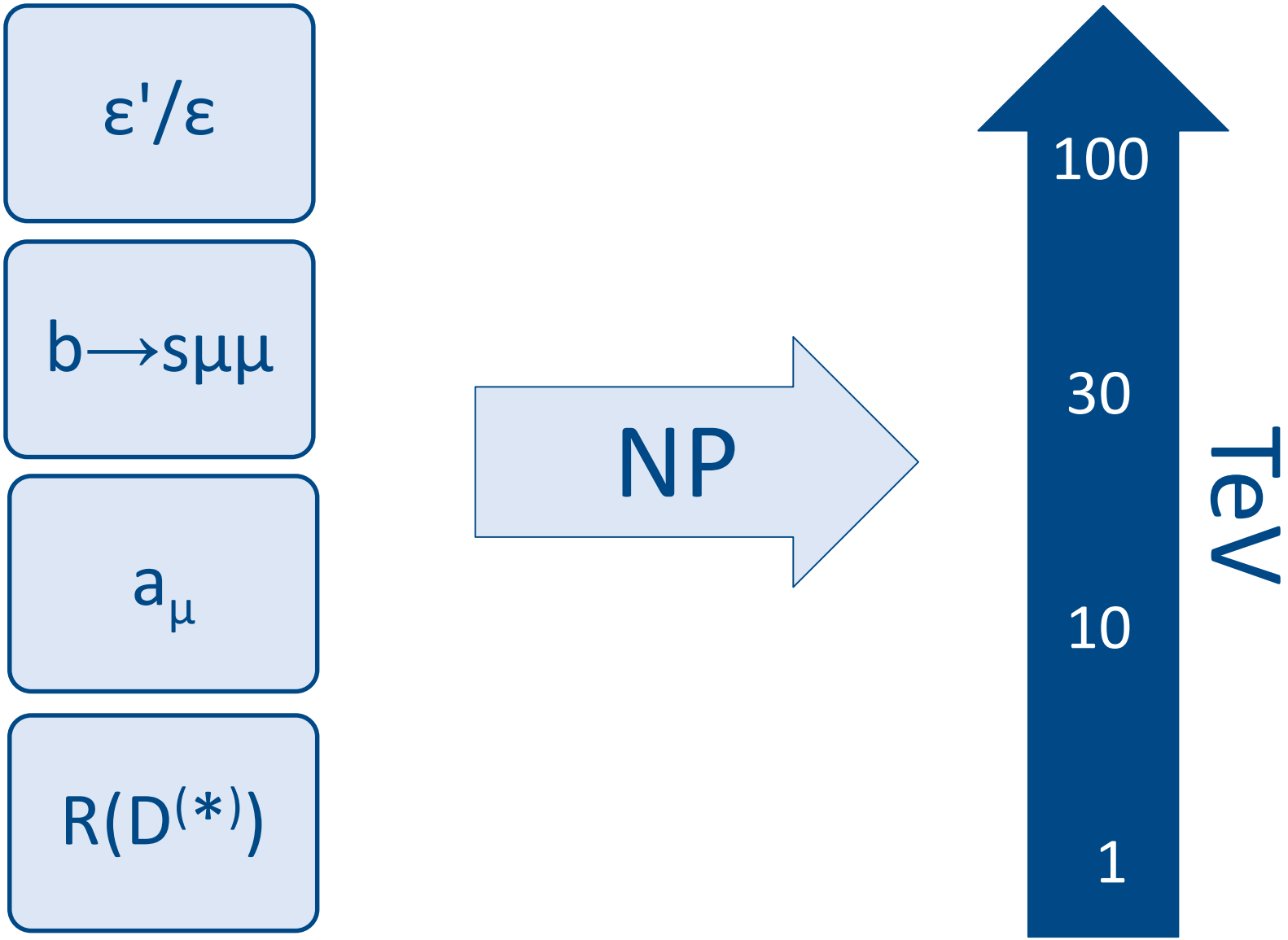


Pati-Salam LQ can explain the flavour anomalies

Conclusions



Outlook



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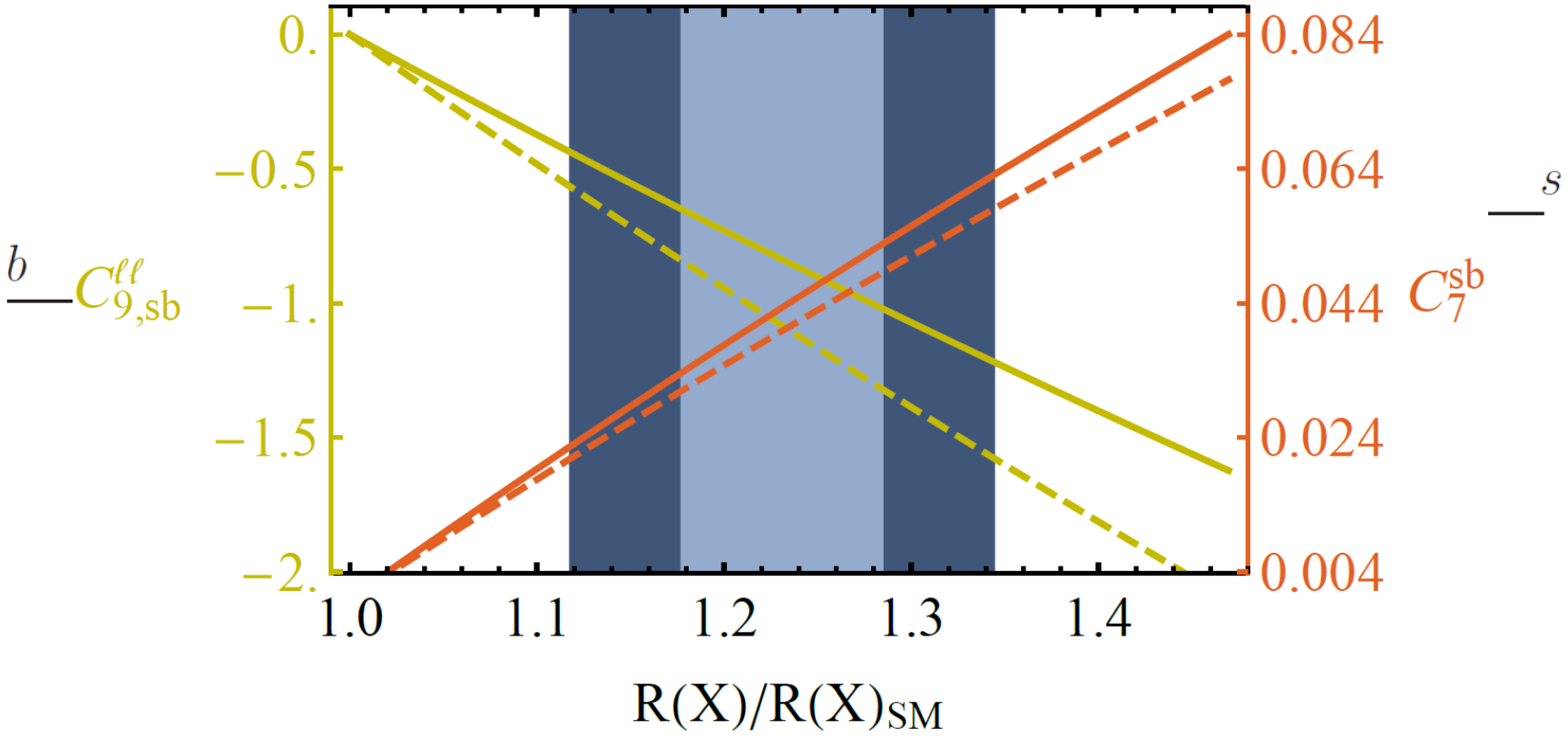
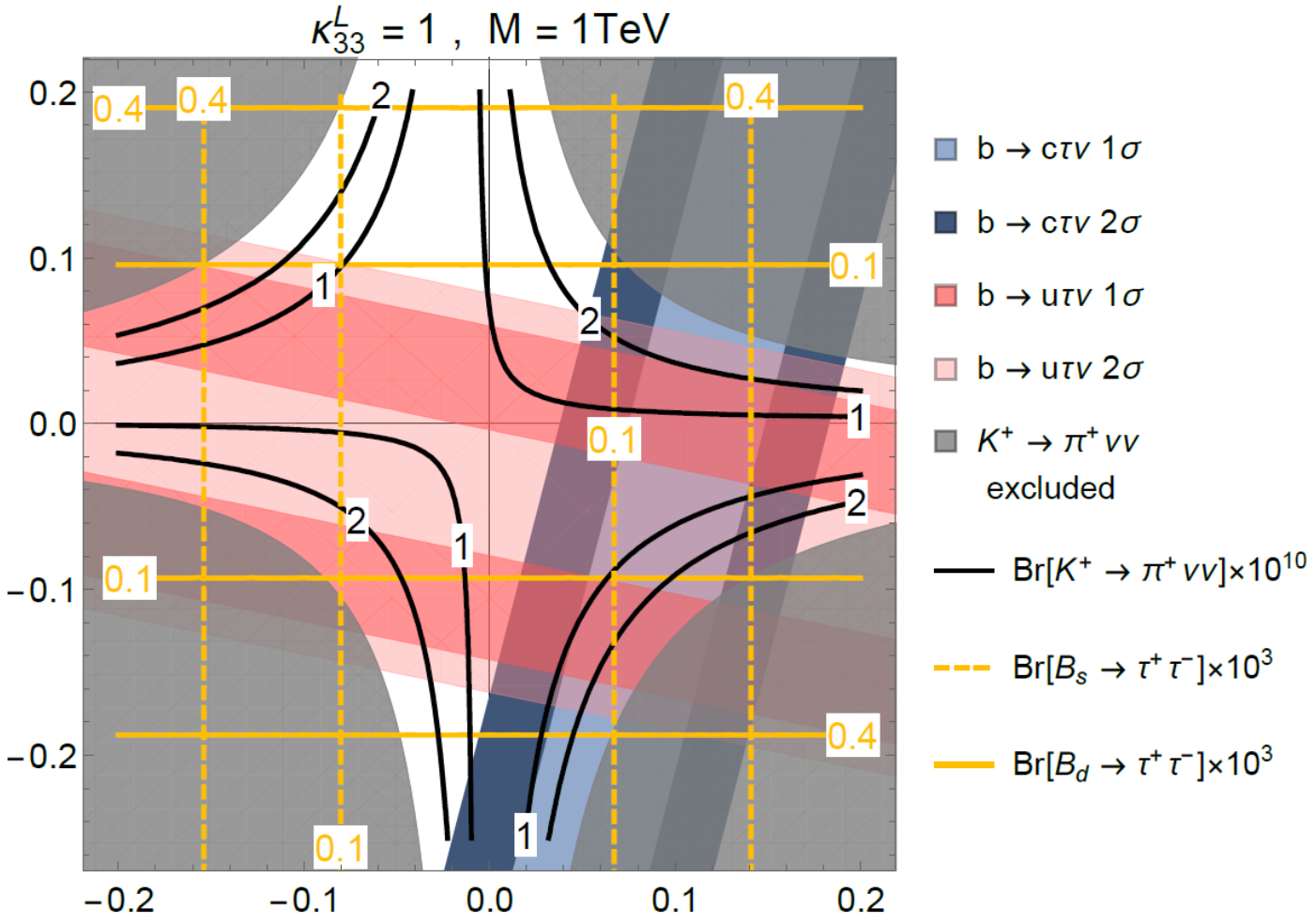


Large loop effects in b→sμμ

Vector LQ Phenomenology



Many correlations

Two Scalar Leptoquarks

AC, D. Mueller, T. Ota
arxiv:1703.09226

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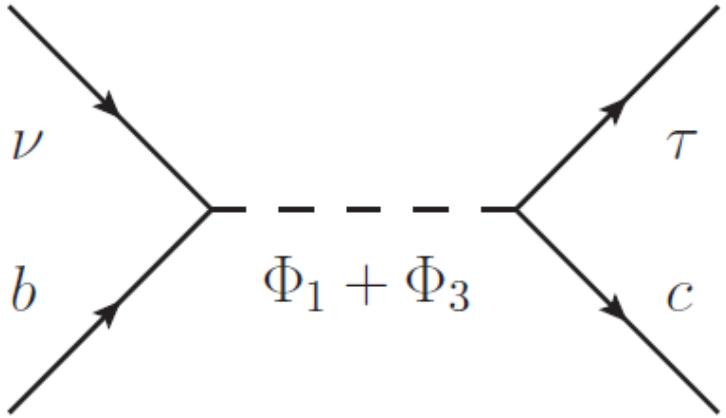
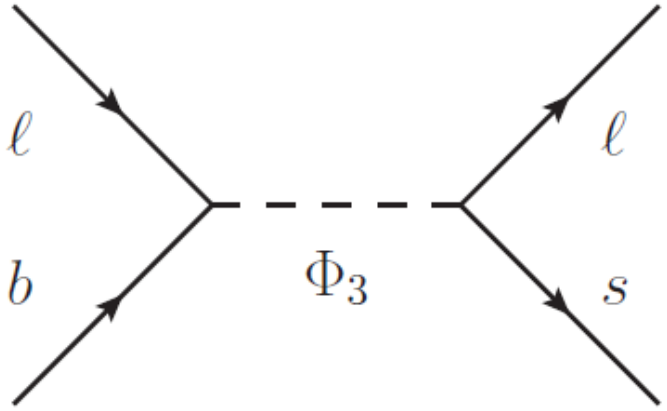
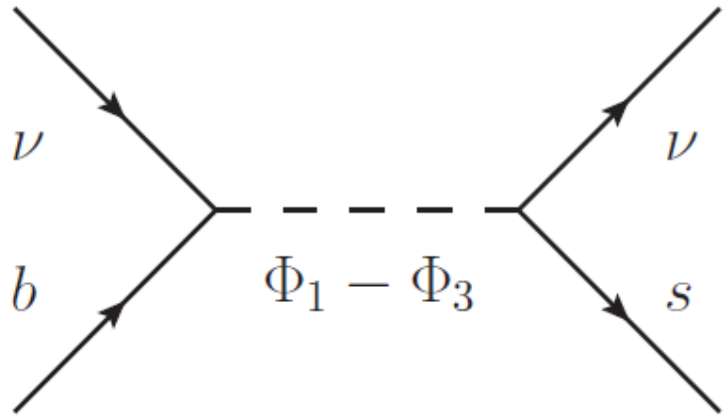
- Φ_1 scalar leptoquark singlet with Y=-2/3
- Φ_3 scalar leptoquark triplet with Y=-2/3





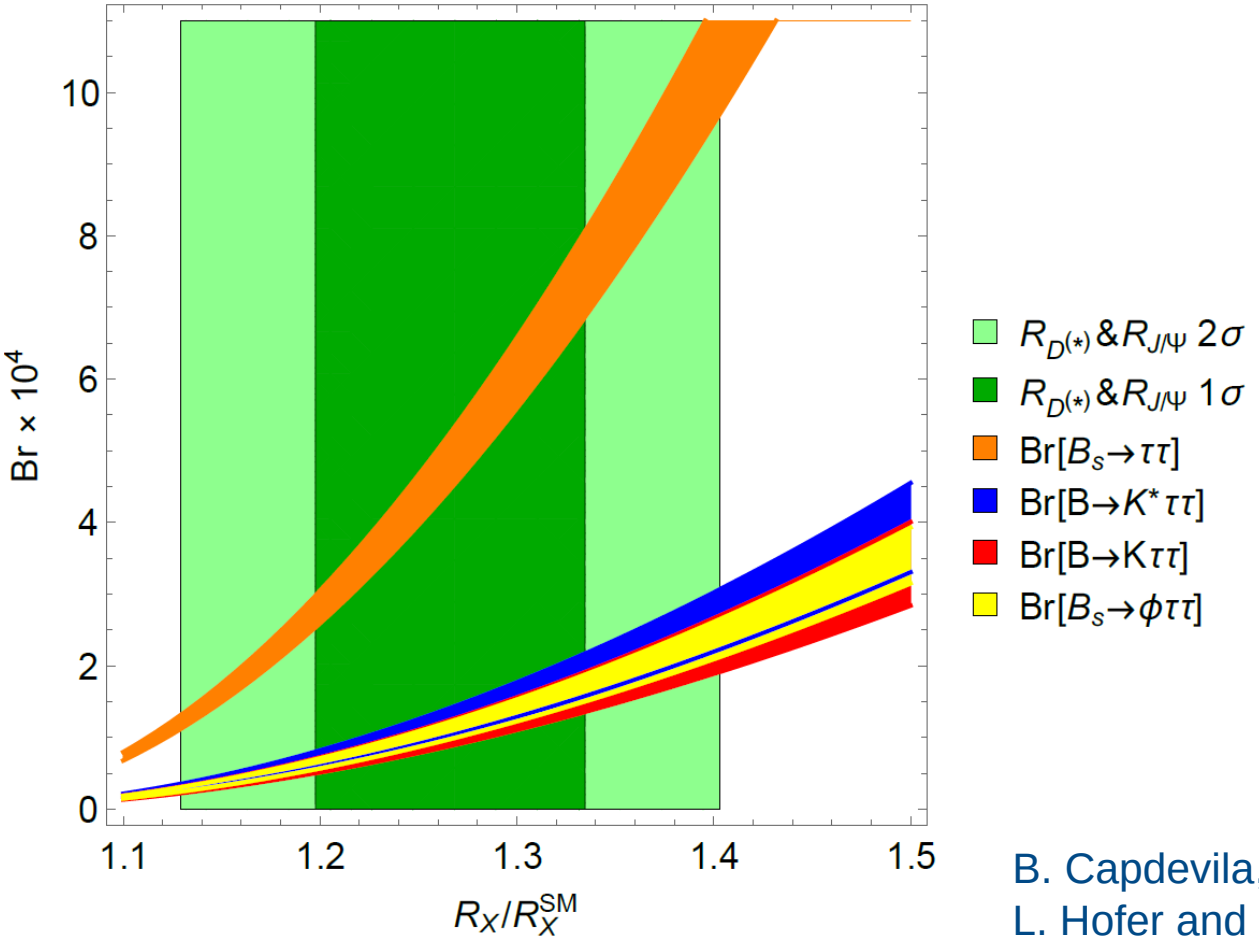


Constructive in R(D$^{(*)}$)

Destructive in b→sμμ

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

- Large couplings to the second generation
- Cancelation in $b \to s\nu\nu$ needed: $C^{(1)}=C^{(3)}$

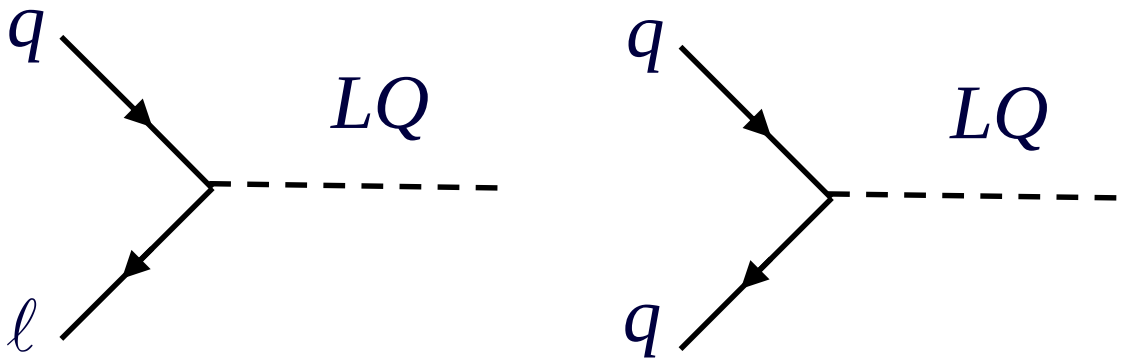


$b \to s\tau\tau$ very strongly enhanced

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

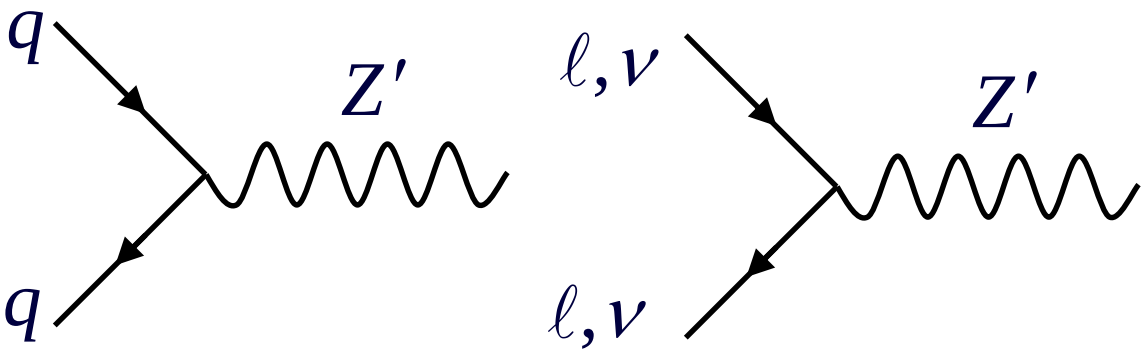
Leptoquarks

- 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)

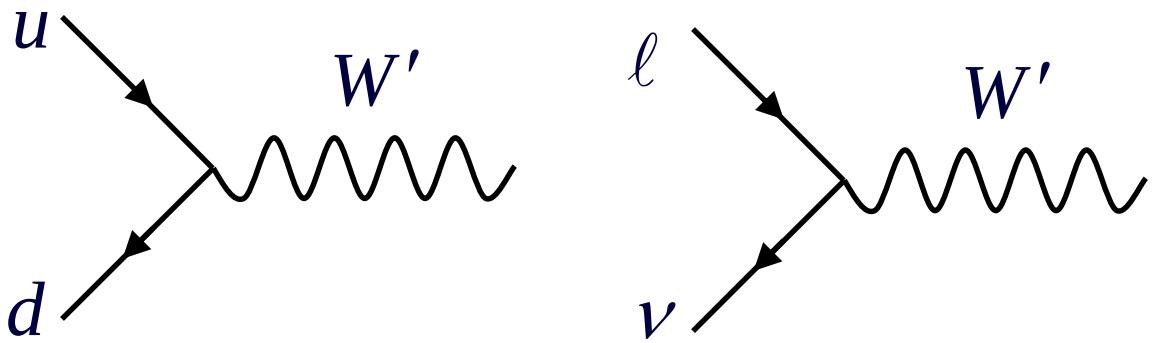


Z' and W'

- Z': neutral heavy gauge boson



- W': charged heavy gauge boson



New heavy gauge bosons