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Flavour Anomalies

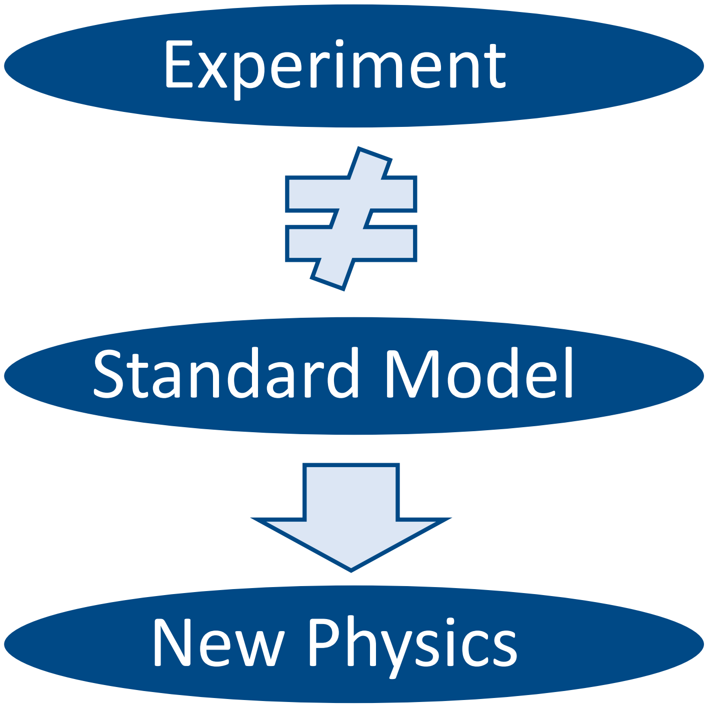
Bologna, 04.06.2018

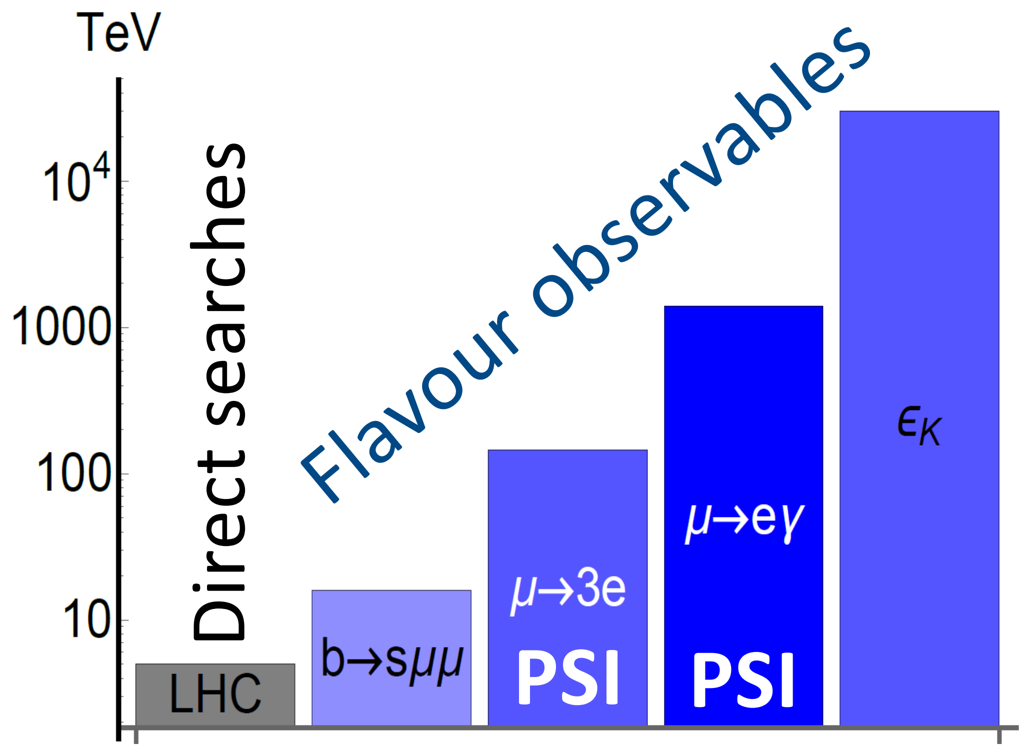
Outline

- Introduction: 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,
  - MSSM, 2HDMs, extra dimensions,…
- Simultaneous explanations with leptoquarks
- Conclusions and outlook

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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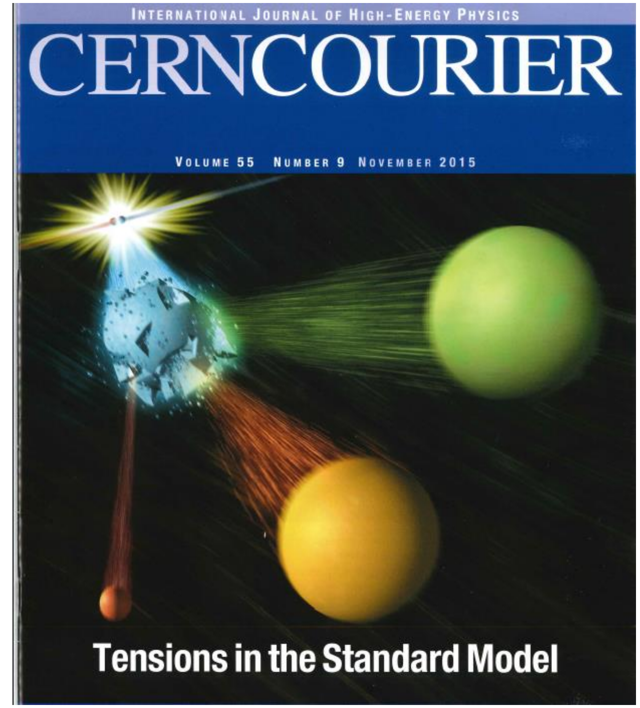
2 Accelerators Find Particles That May Break Known Laws of Physics

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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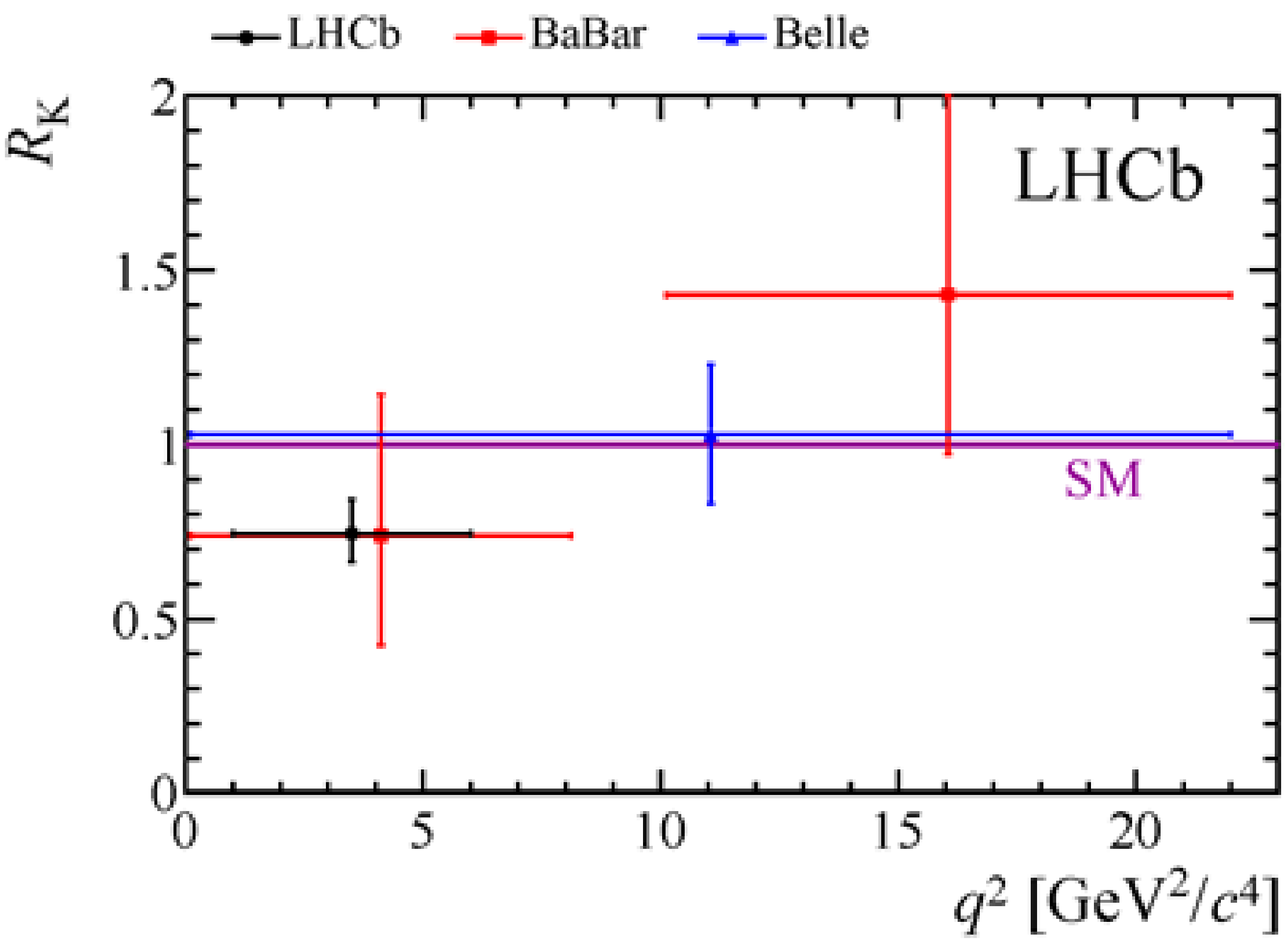
Democracy suffers a blow—in particle physics

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

Steven K. Blau 17 September 2015

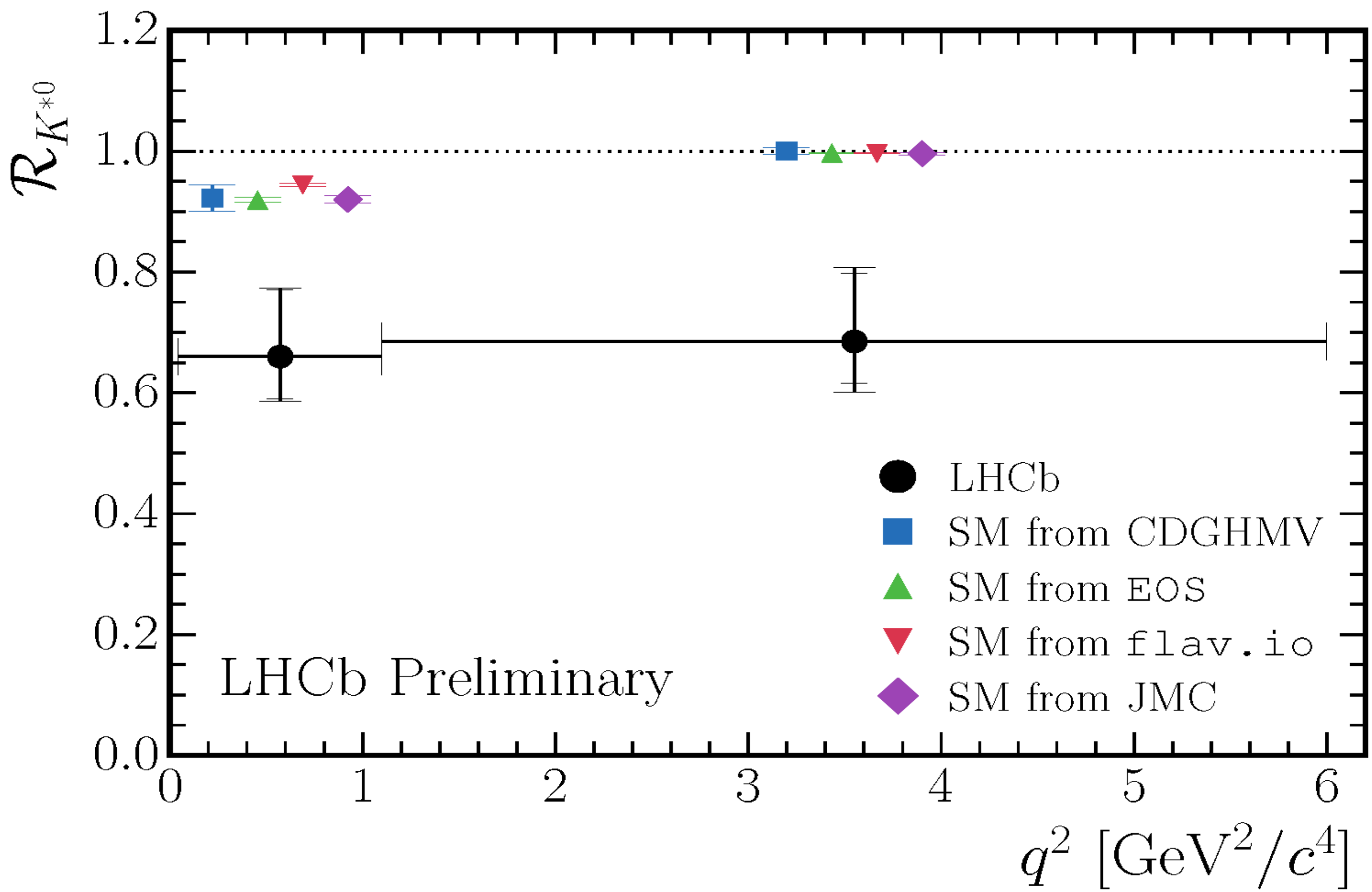
Hints for New Physics in flavour observables

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



Combined ≈ 4σ evidence for LFUV

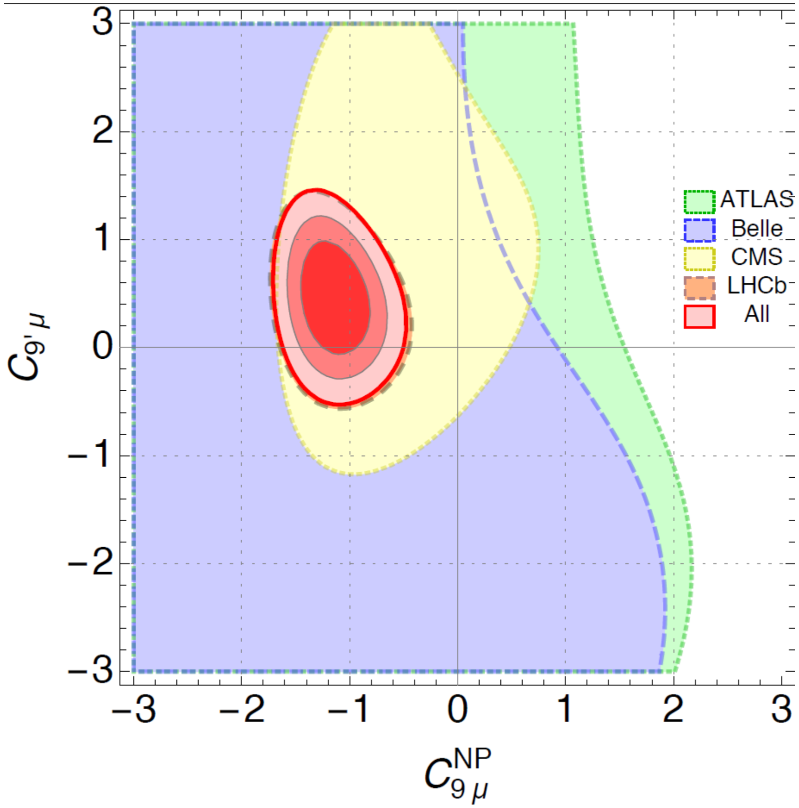
$R(K^{(*)}) = B \to K^{(*)}\mu^+\mu^- / B \to K^{(*)}e^+e^-$



Combined ≈ 4σ evidence for LFUV

Global fit to b→s$\mu^+\mu^-$ data

- Global analyses of all b→s$\mu^+\mu^-$ data gives a very good fit to data
- Good fit to data:
  - C_9
  - $C_9 = -C_{10}$
  - $C_9 = -C_9'$



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

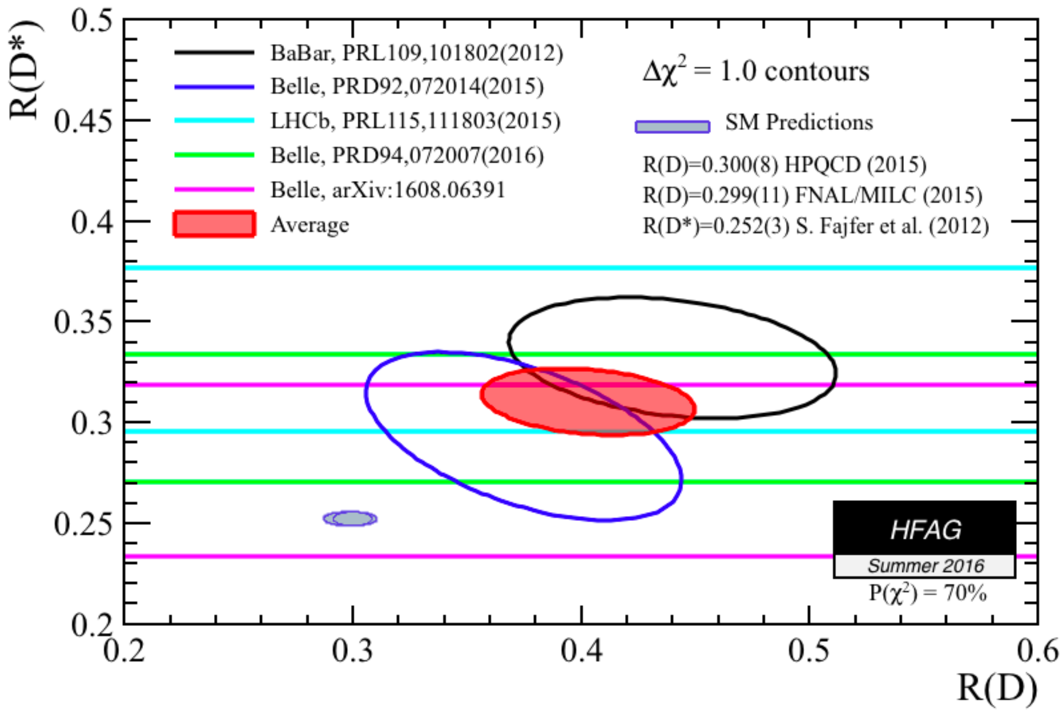
$$O_{10} = \bar{s}\gamma^\mu P_L b \bar{\ell}\gamma_\mu \gamma^5 \ell$$

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

Fit is >5 σ better than the SM

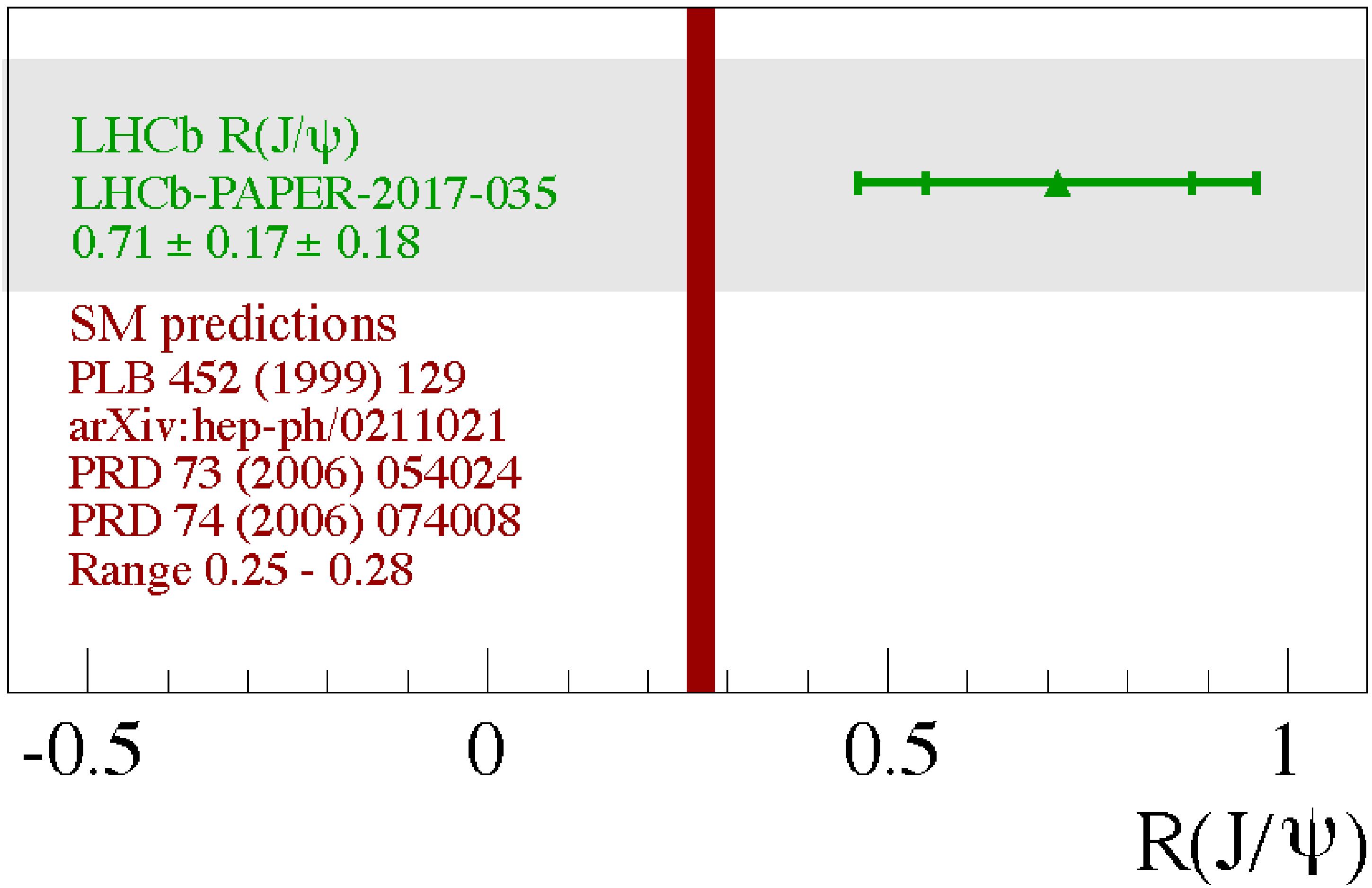
b→cτν processes

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



All measurements above the SM prediction
4σ deviation

b→cτν processes



All measurements above the SM prediction
4σ deviation

Muon Anomalous Magnetic Moment

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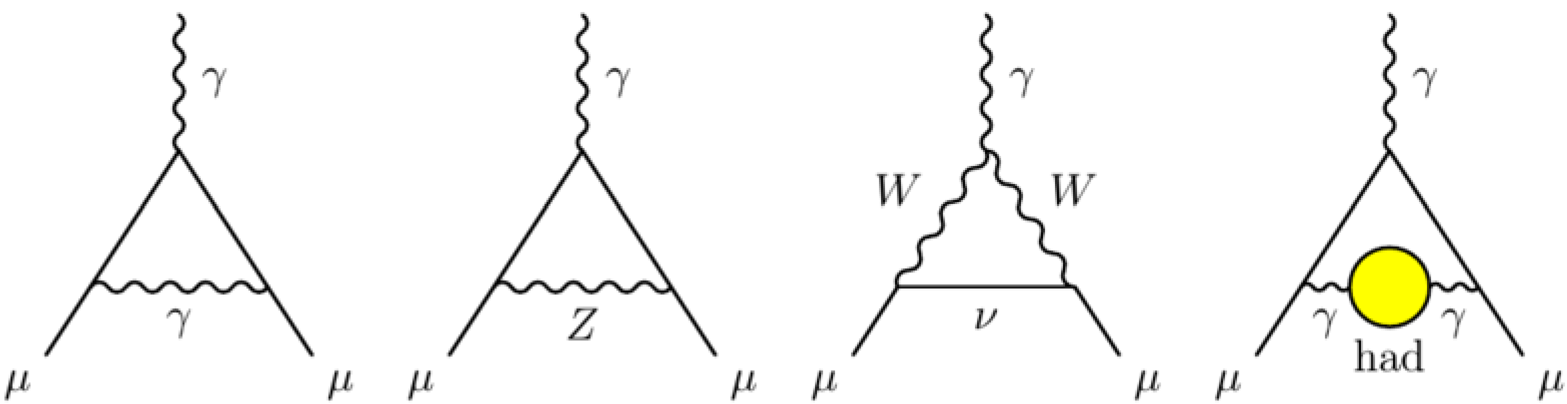
- Single measurement from BNL
- Theory prediction sound but challenging because of hadronic effects.

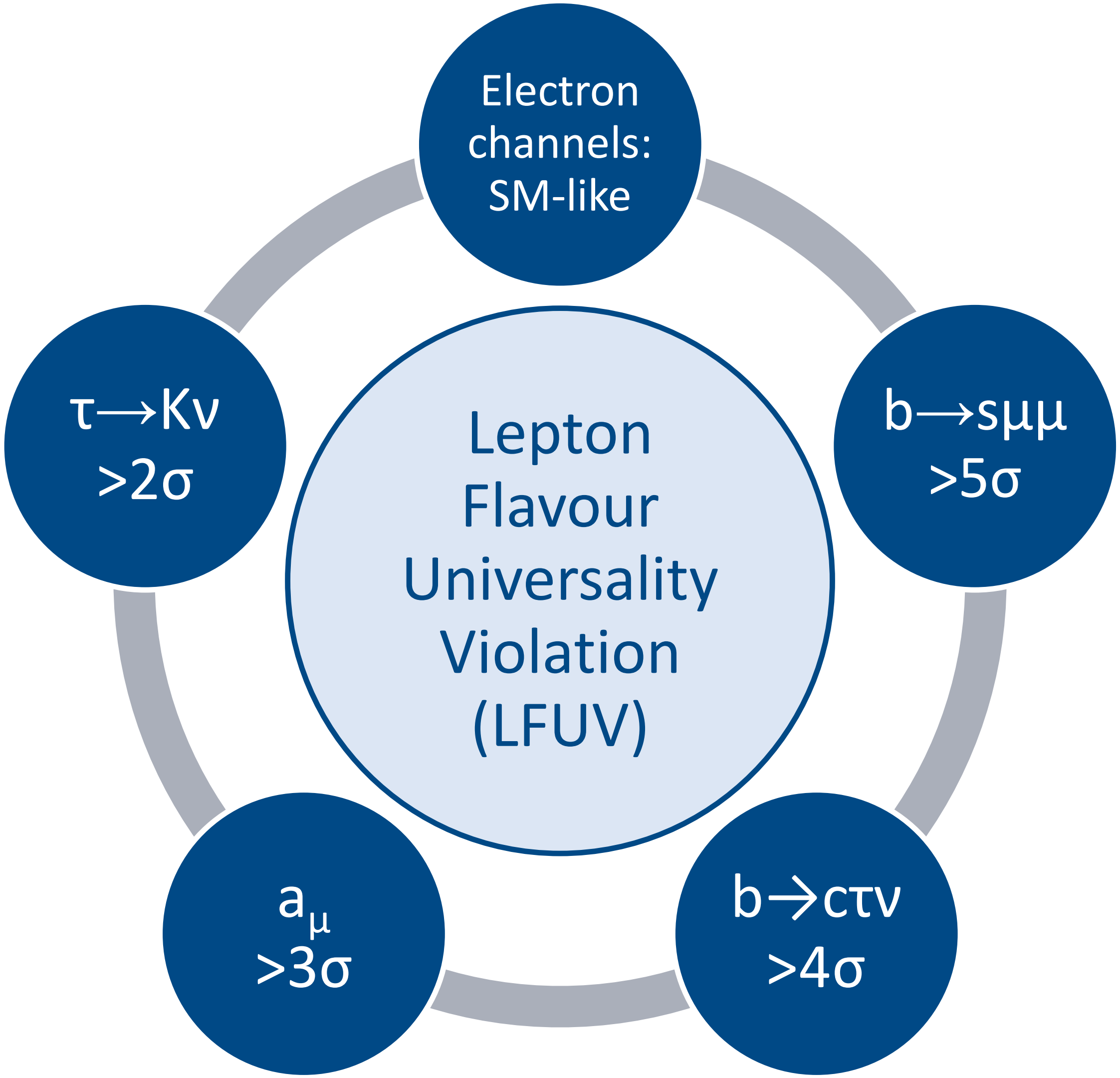
$$\Delta a_\mu = (236 \pm 87) \times 10^{-11}$$

- Soon new experimental results from Fermilab



3σ deviation (order of SM-EW contribution)

Hints for New Physics



Probability for statistical fluctuation < 0.0001%

R(D) & R(D*)

- Charged scalars
  - Problems with q^2 distributions and B_c lifetime
- W'
  - Strong constraints from direct LHC searches
- Leptoquark (also in the RPV MSSM)
  - EW precision constraints
  - Strong signals in qq→ττ searches

Explanation difficult but possible with Leptoquarks

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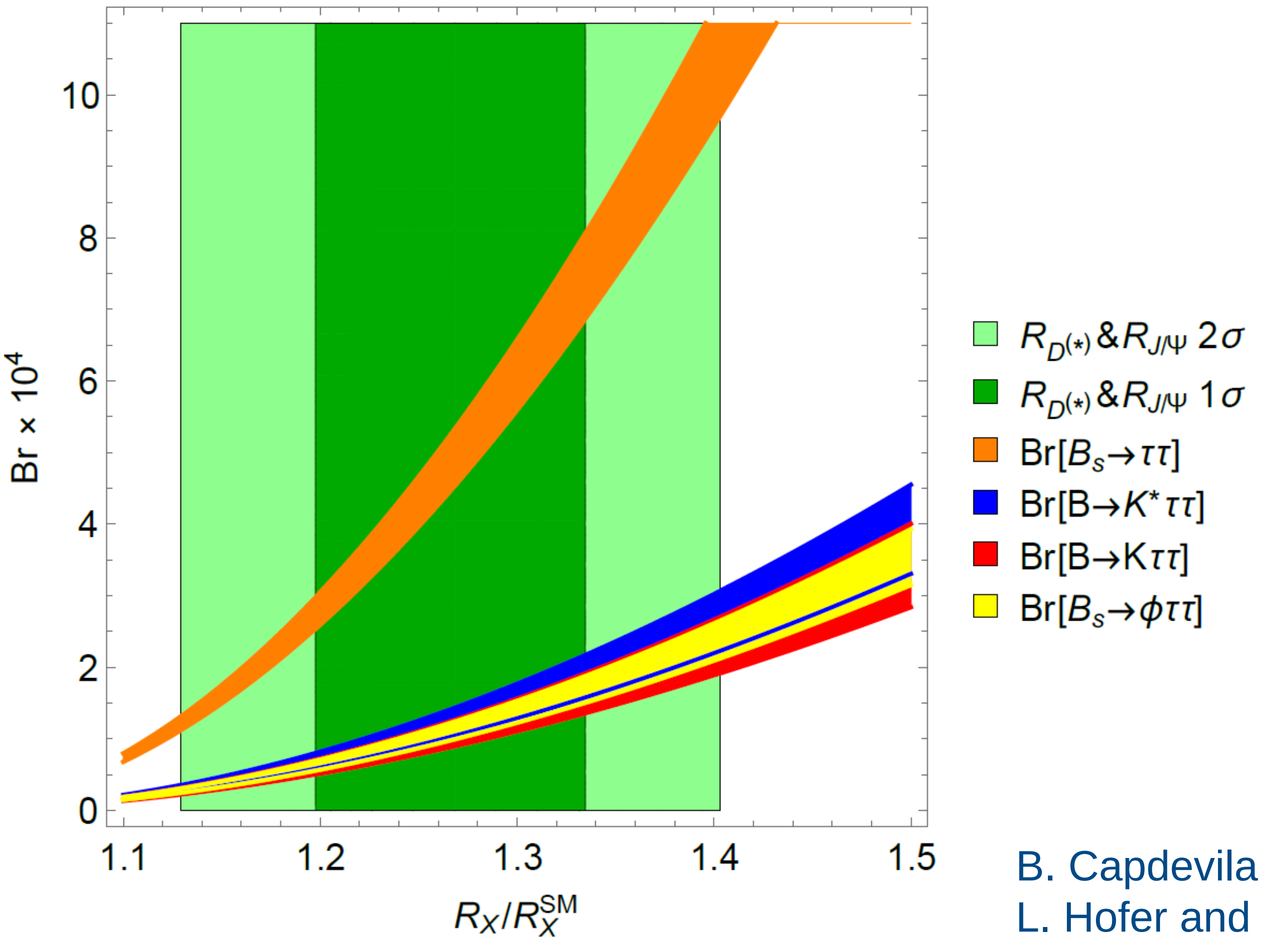
R(D$^{(*)}$) and b→sττ (model-independent)

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



b→sττ very strongly enhanced

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

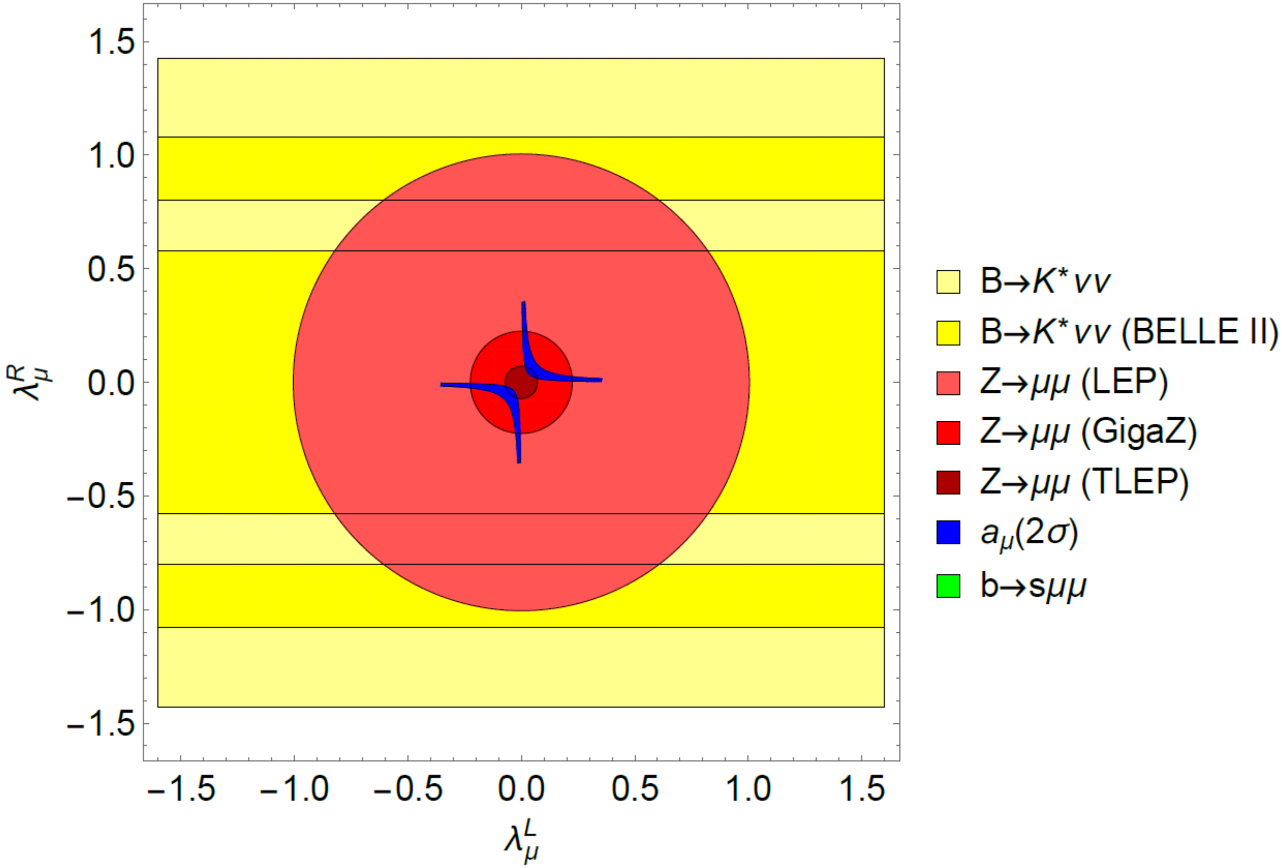
a_μ explanations

- MSSM
  - tan(ß) enhanced slepton loops
- Scalars
  - Light scalars with enhanced muon couplings
- Z’
  - Very light with τμ couplings (m_τ enhancement)
- Leptoquarks
  - m_t enhaned effects

Chiral enhancement or very light particles

Leptoquarks in a_μ

- Chirally enhanced effects via top-loops



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

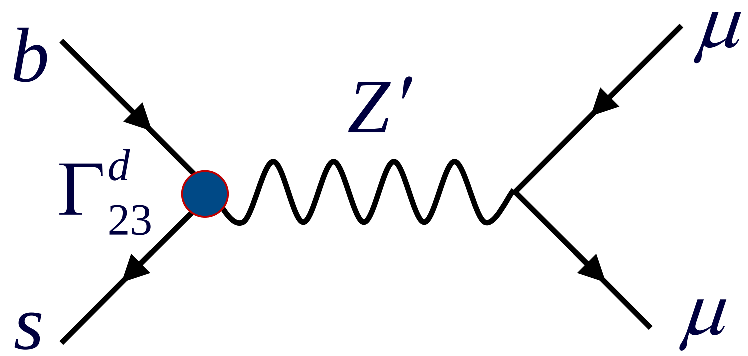
Left-, right-handed muons-top coupling

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

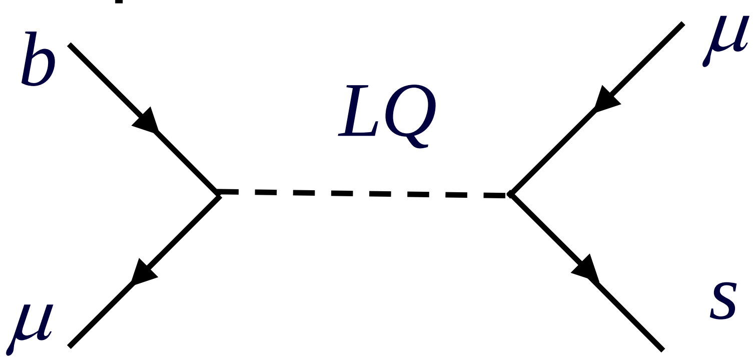
Z→μμ at future colliders

b→sμμ explanations

- Z'



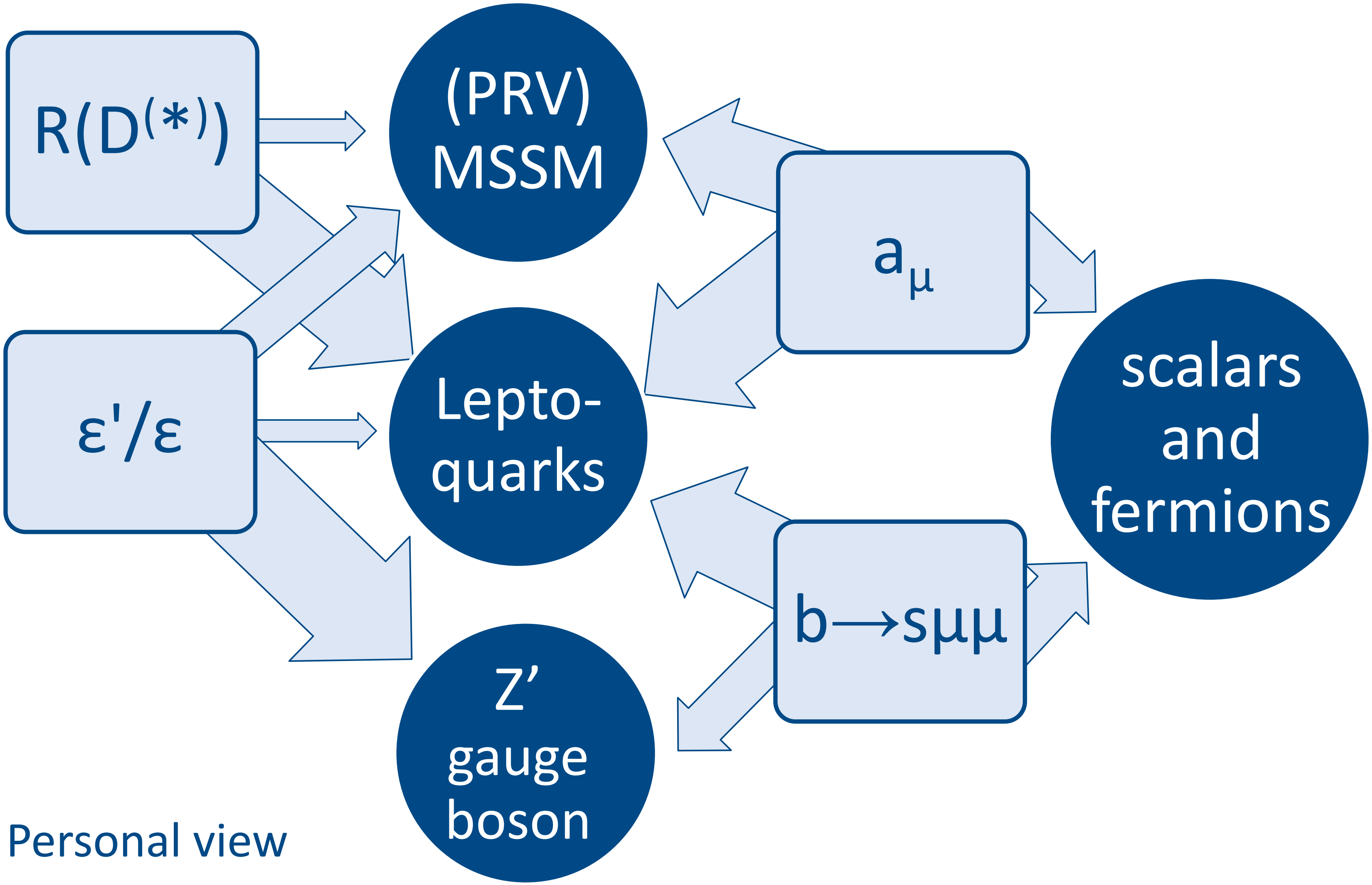
- Leptoquarks



- Loop effects of scalars and fermions

Even high scale NP explanations possible

Implications for New Particles



Personal view

Vector Leptoquark SU(2) Singlet

- $C_9 = -C_{10}$ 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

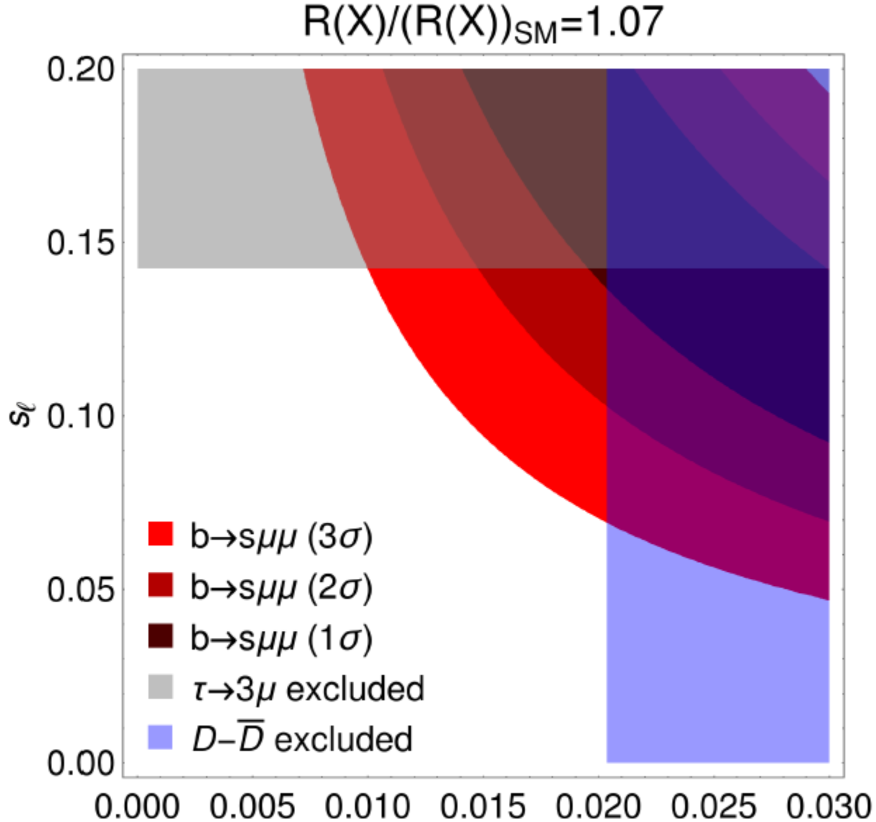
Pati-Salam + Randall-Sundrum

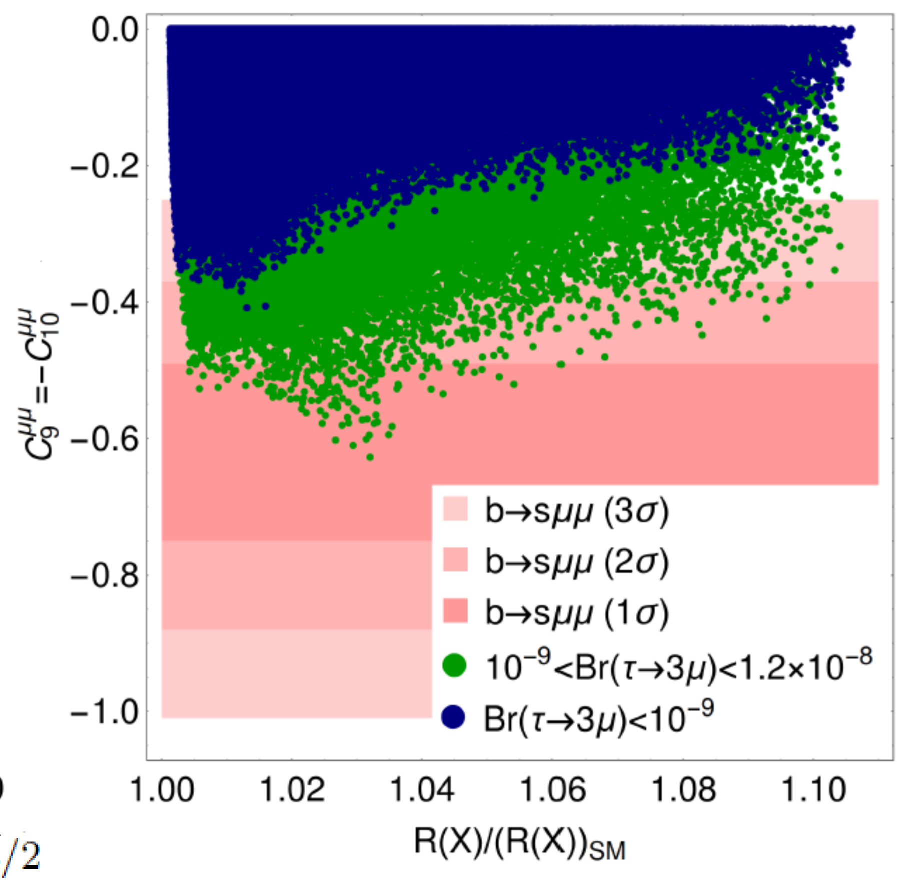
M. Blanke, AC, arXiv:1801.07256

- $SU(4)\otimes SU(2)_L\otimes SU(2)_R$ broken to the SM via boundary conditions on a compact extra dimension
- Zero modes: SM fermions
- KK modes: Vector-like fermions and massive gauge bosons
- No zero mode for the Leptoquark
- Flavour alignment to the down-sector

PS + RS naturally accounts for a vector LQ + VLFs

PS+RS Phenomenology





$M = 3\,\text{TeV},\ s_2^\ell = 0.2,\ s_3^\ell = 1/\sqrt{2}$ and $s_3^q = \sqrt{3}/2$

Modell well motivated + limited but sizable effect

Conclusions & Outlook

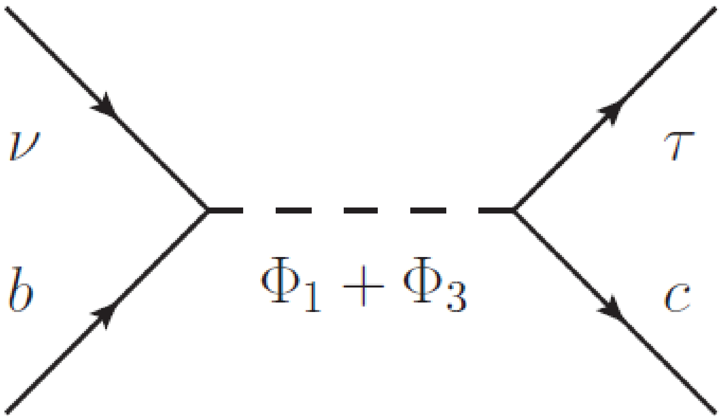
- P5’ → $b \to d\mu\mu$
- R(D) & R(D*) → $b \to s\tau\tau$
- R(K) & R(K*) → $\mu \to e\gamma$
- R(D), R(D*) & a_μ → $\tau \to \mu\gamma$
- R(D), R(D*) & $b \to s\mu\mu$ → $b \to s\tau\mu$

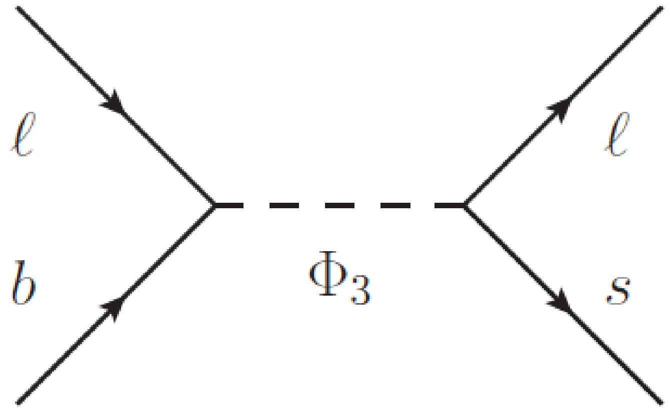
Exciting times in particle physics are ahead of us!

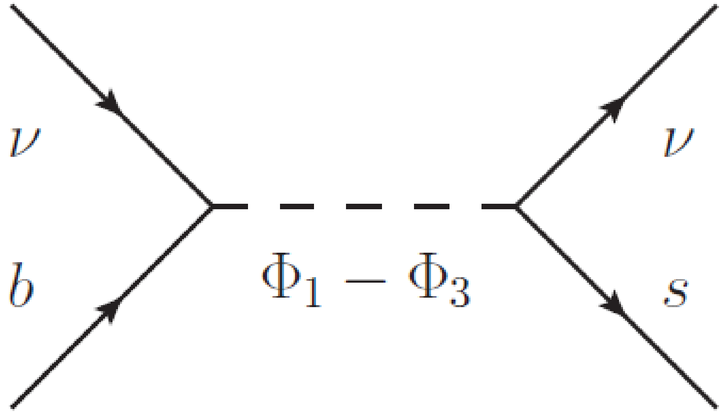
Two Scalar Leptoquarks

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

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



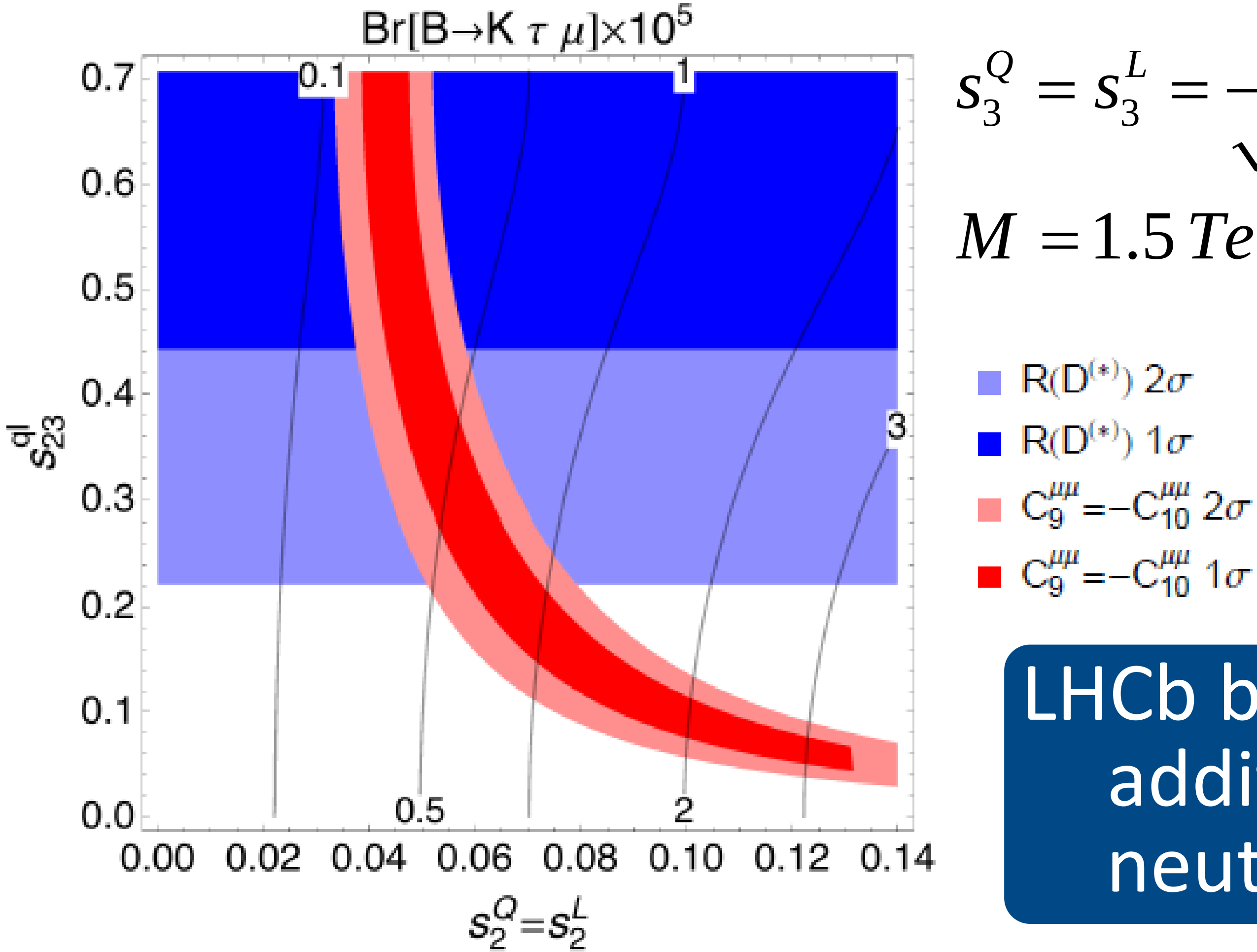




Constructive in $R(D^{(*)})$

Destructive in $b \to s\mu\mu$

R(D$^{(*)}$) and b→sμμ



$$s_3^Q = s_3^L = \frac{1}{\sqrt{2}}$$

$$M = 1.5\,TeV$$

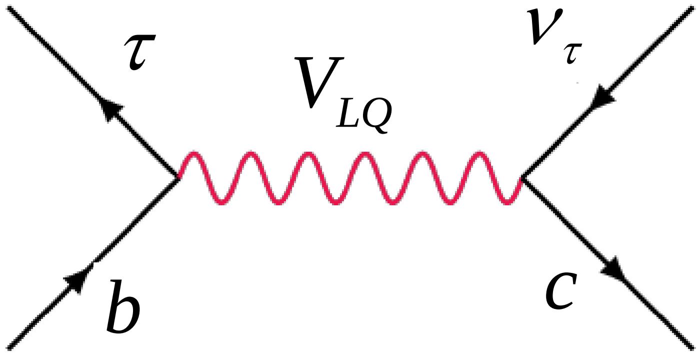
$$s_i^Q = \frac{\frac{m_{ii}^Q}{M_{ii}^Q}}{\sqrt{1 + \frac{m_{ii}^Q}{M_{ii}^Q}}}$$

LHCb bounds require additional heavy neutral fermions

Simultaneous explanation possible!
Can also account for the AMM of the muon

Flavour effects

- b→cτν



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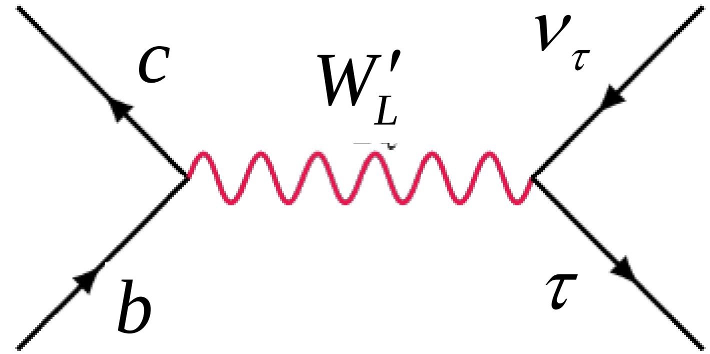
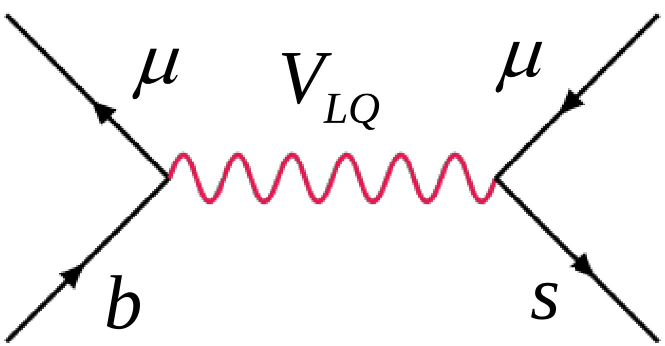
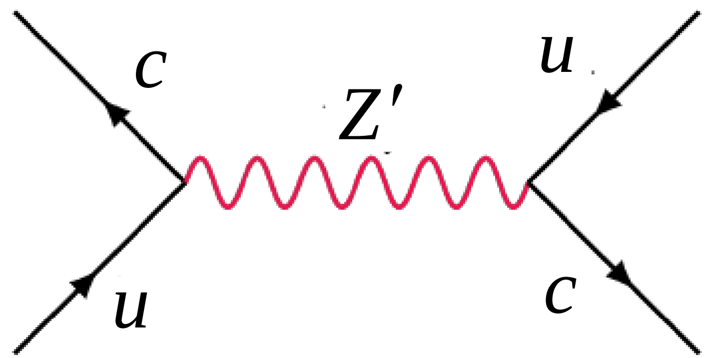


- b→sμμ

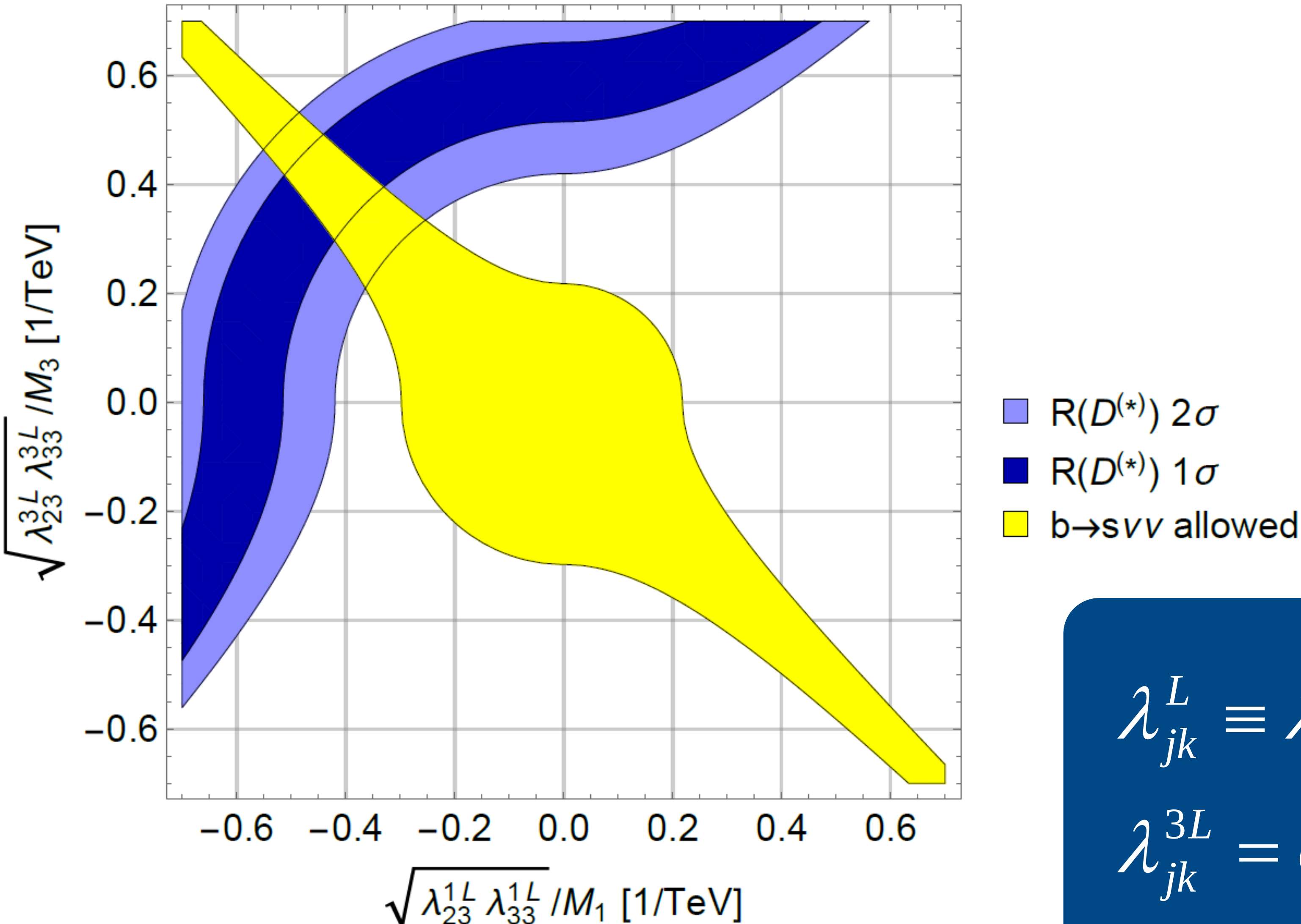


- τ → μμμ & D mixing



D mixing τ→μμμ and cannot be avoided

R(D$^{(*)}$), b→sνν with 2 Scalar LQs



$$\lambda_{jk}^{L} \equiv \lambda_{jk}^{1L}$$

$$\lambda_{jk}^{3L} = e^{i\pi j}\lambda_{jk}^{L}$$