Hints of New Physics in flavor anomalies

Enrico Maria Sessolo

BP-2

NCBJ Symposium

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NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

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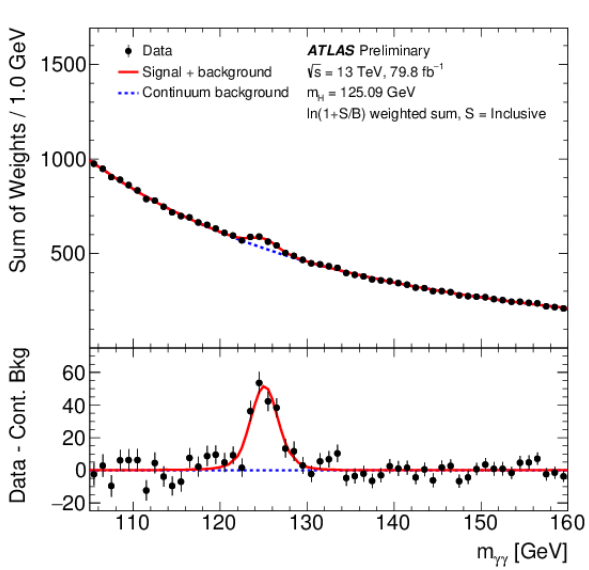
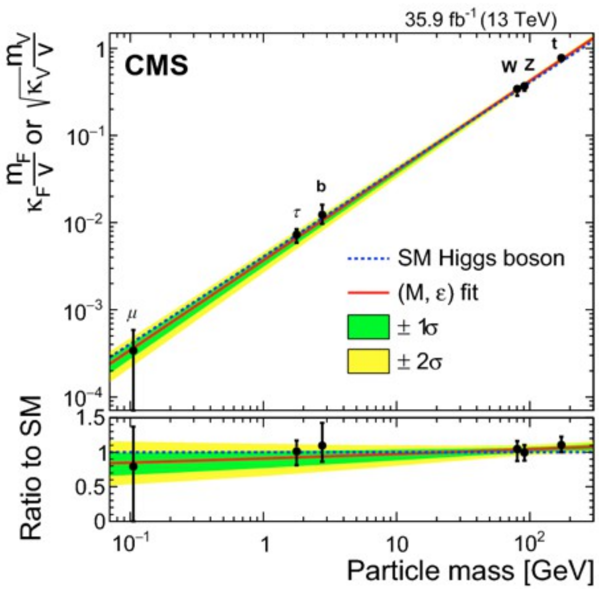
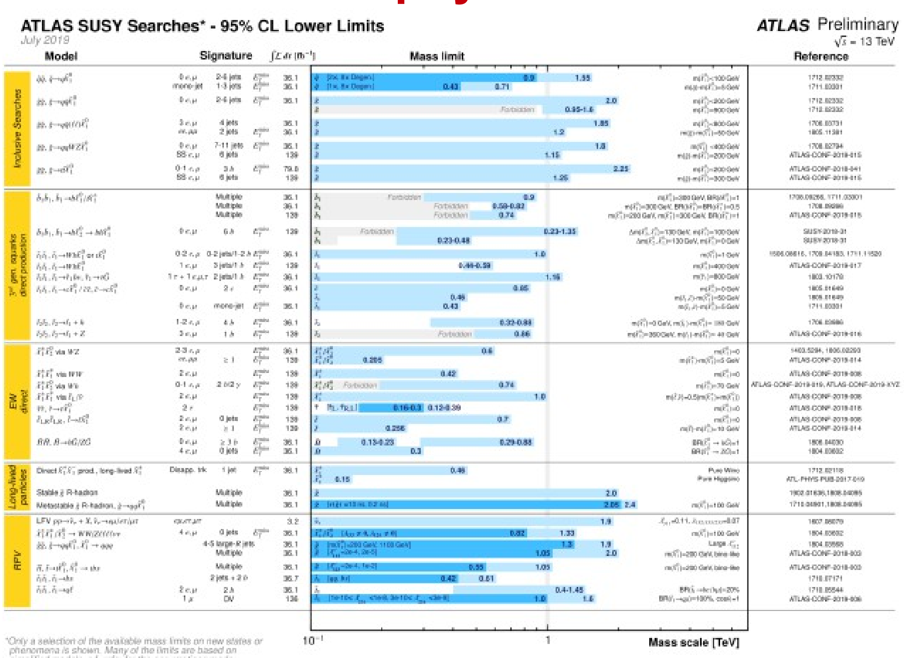
Direct searches at the LHC

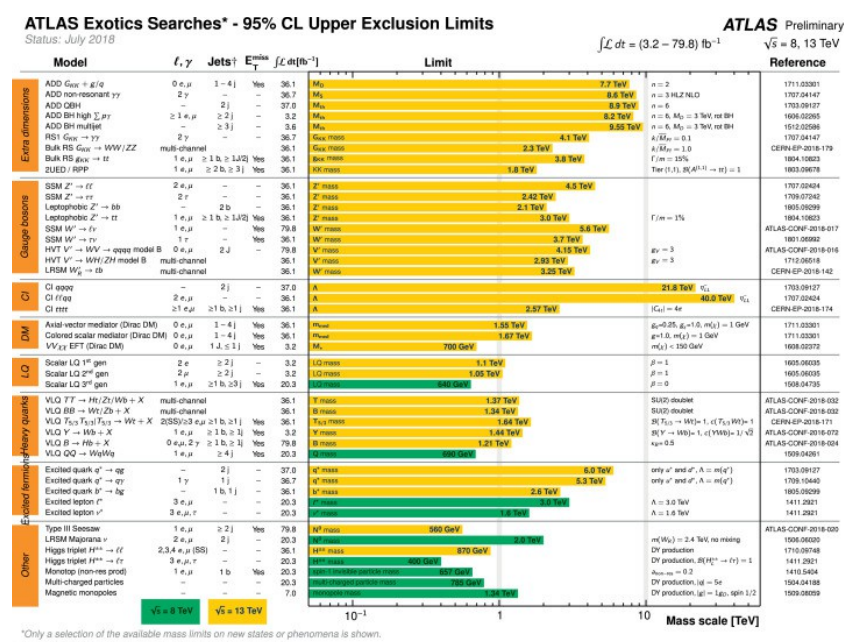
A very SM-like Higgs boson at 125 GeV...





… but no new physics below 1-2 TeV!





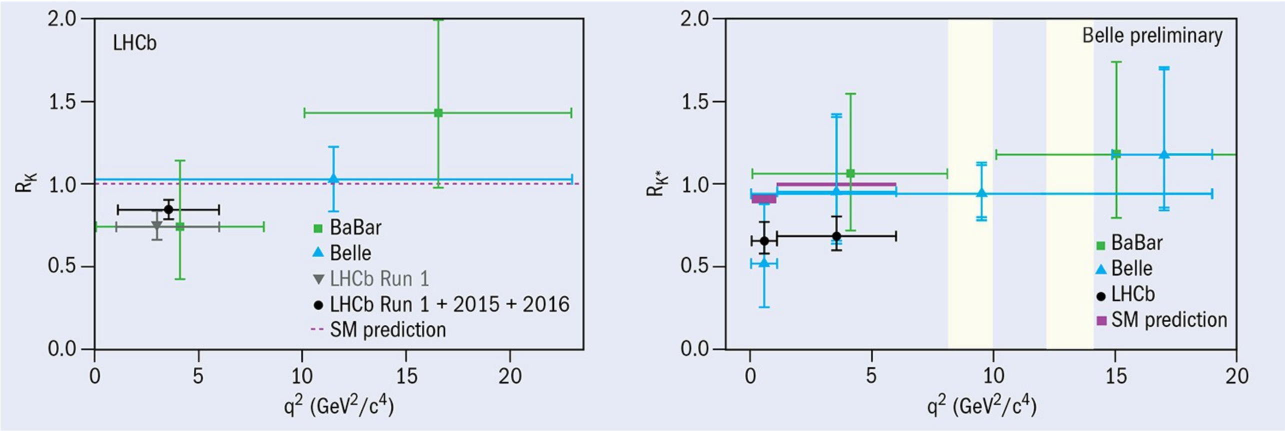
Indirect hints for BSM physics from LHCb

- Violation of lepton-flavor universality (LHCb, **~ 2.5 σ**)

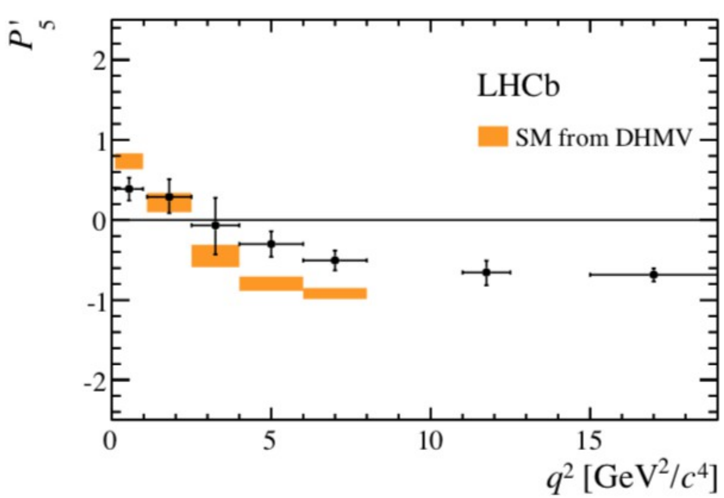
$$R_K = \frac{BR(B^+ \to K^+\mu^+\mu^-)}{BR(B^+ \to K^+e^+e^-)}$$

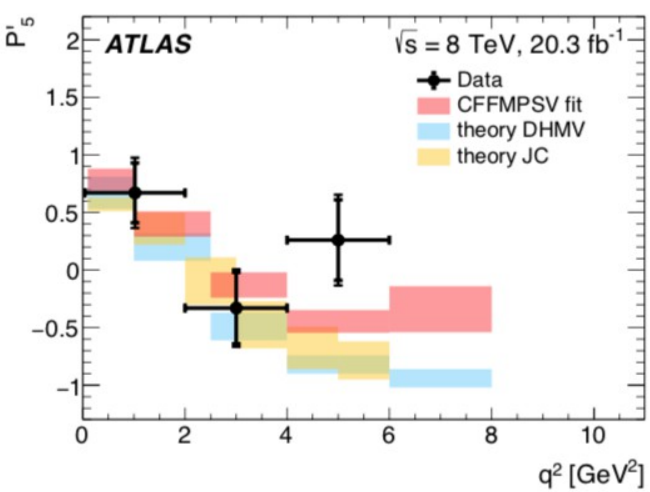
$$R_{K^*} = \frac{BR(B^0 \to K^{0*}\mu^+\mu^-)}{BR(B^0 \to K^{0*}e^+e^-)}$$

Data was updated in March 2019!



- Deviations in angular observables of $B^0 \to K^{0*}\mu^+\mu^-$ (LHCb and ATLAS, **~ 3 σ**)

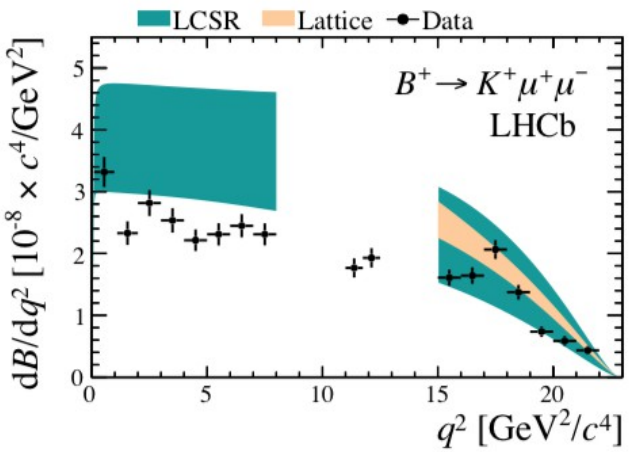


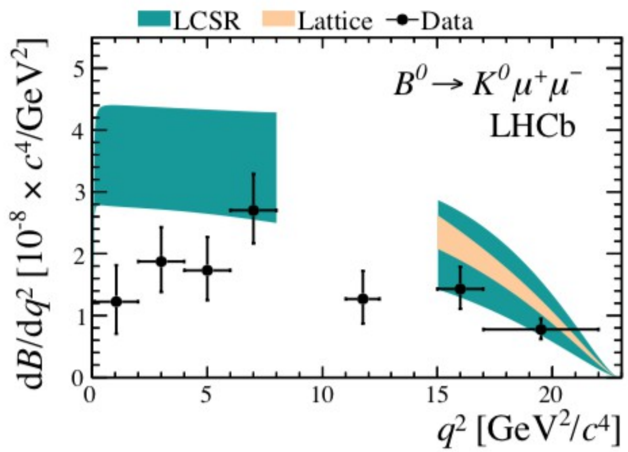


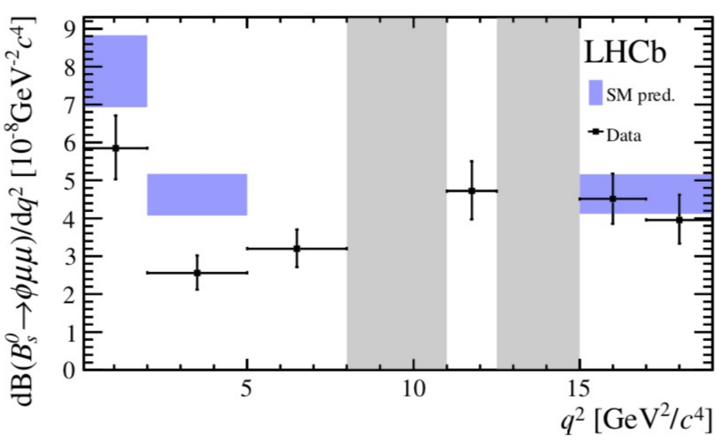
Indirect hints for BSM physics from LHCb

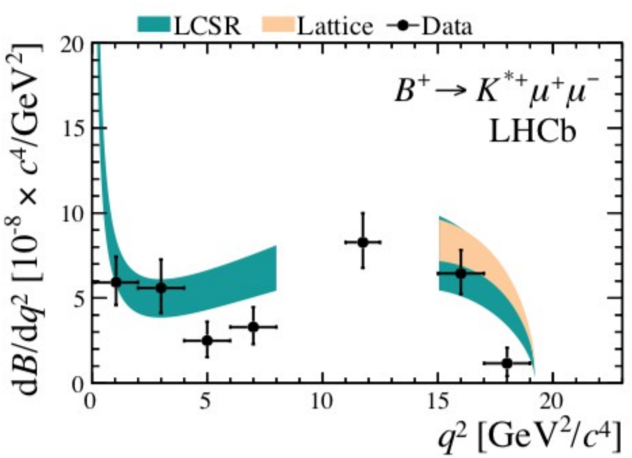
- Deviations in differential branching ratios $\frac{d\mathrm{BR}}{dq^2}$ (LHCb, **2 σ – 3.5 σ**)

$$B^0 \to K^{*0}\mu^+\mu^-$$
$$B^0 \to K^0\mu^+\mu^-$$
$$B^+ \to K^{*+}\mu^+\mu^-$$
$$B_s^0 \to \phi\mu^+\mu^-$$
$$\Lambda_b^0 \to \Lambda\,\mu^+\mu^-$$









Statistical evidence of New Physics

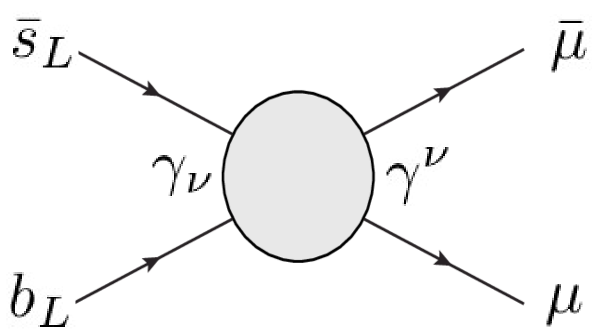
In the last 4-5 years the flavor anomalies have generated speculations about New Physics (NP)

- > 300 papers in the literature
- ~ 15 global fits

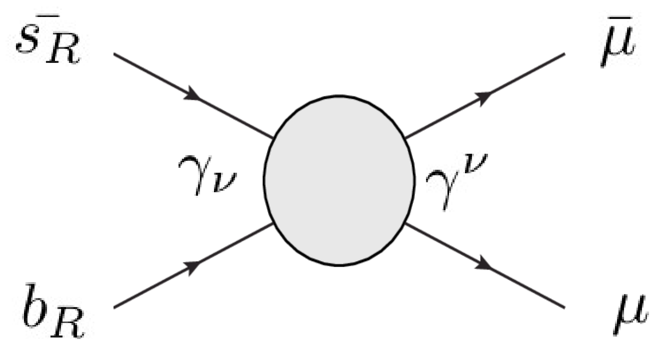
- Emerging dominant NP operators in the effective Hamiltonian approach:

$$\mathscr{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i,l} (C_i^l O_i^l + C_i'^l O_i'^l) + \text{H.c.}$$

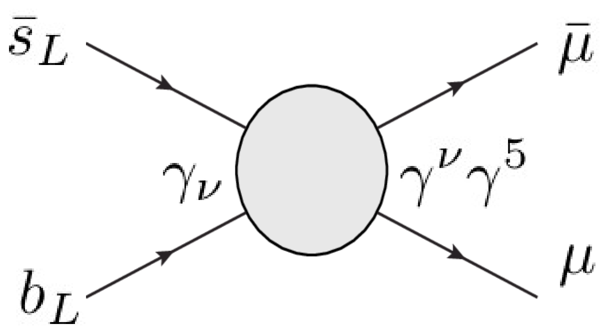
$\mathcal{O}_9^\mu$



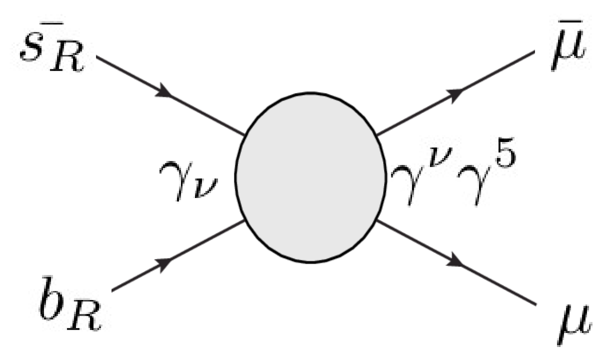
$\mathcal{O}_9'^\mu$



$\mathcal{O}_{10}^\mu$



$\mathcal{O}_{10}'^\mu$



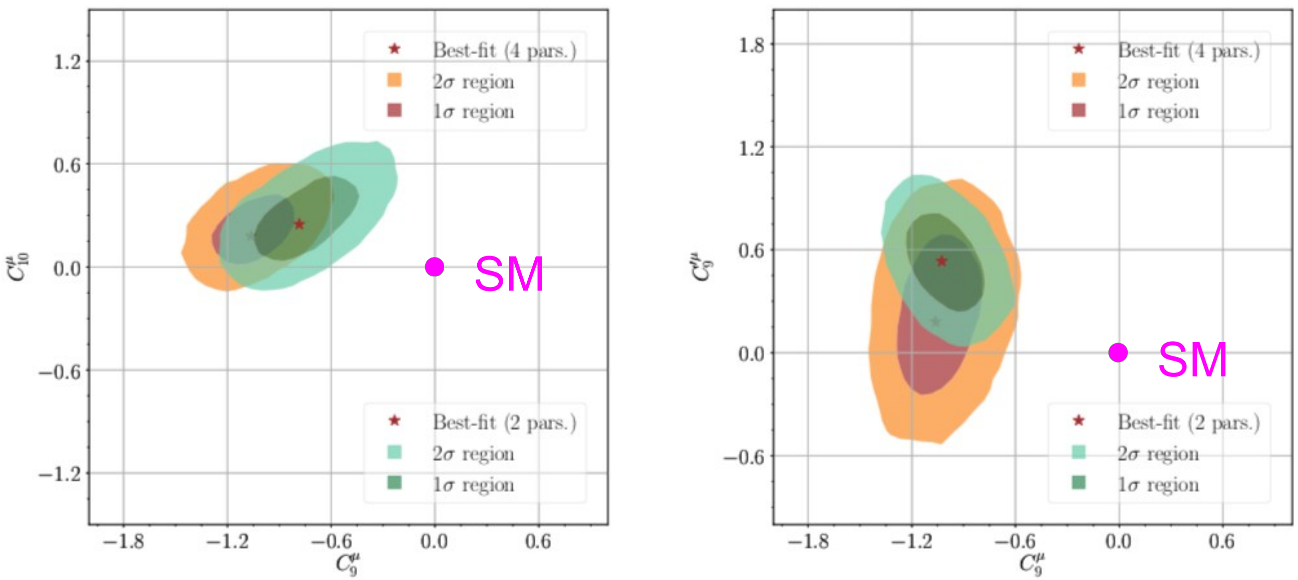
Statistical evidence of New Physics

After the March '19 update we published the only **fully Bayesian** fit on the market

K.Kowalska, D.Kumar, E.M.Sessolo,
Eur.Phys.J. C79 (2019) no.10, 840

- 140 observables with experimental + theoretical correlations
- Up to 9 parameters scanned simultaneously
- Employed both the effective field theory and NP models approach

Posterior PDF:

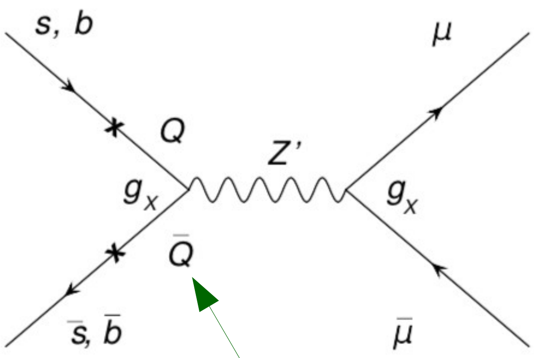


- Pull of the best-fit point: **5.1 σ**
- Bayes factor NP vs Standard Model: **10^5 to 1** ("decisive")*

* unless underestimating hadronic uncertainties, unknown systematics, etc.

Models of New Physics for the flavor anomalies

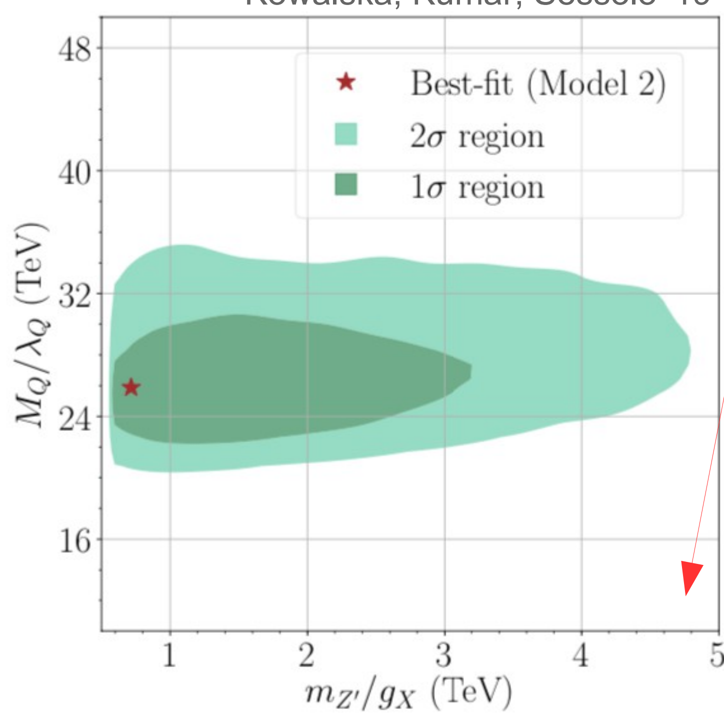
- Option 1 **New heavy gauge boson *Z′***



Requires a heavy quark mixing with *b* and *s:*

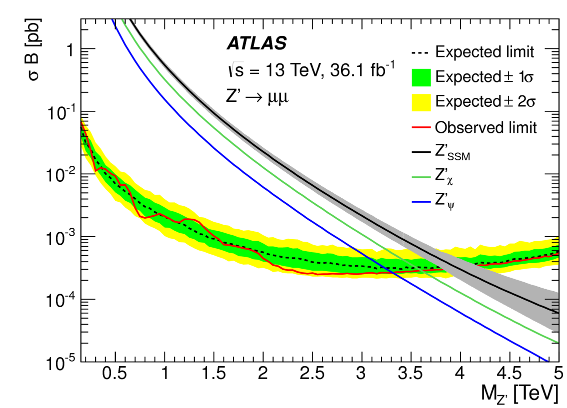
$$\mathcal{M}_d = \begin{pmatrix} & Y_{d,ij}\, v_d & & \lambda_{Q,1} v_1/\sqrt{2} \\ & & & \lambda_{Q,2} v_1/\sqrt{2} \\ & & & \lambda_{Q,3} v_1/\sqrt{2} \\ 0 & 0 & 0 & -M_Q \end{pmatrix}$$

Kowalska, Kumar, Sessolo '19



heavy quark
25 - 30 TeV

Z′ in LHC reach?



Models of New Physics for the flavor anomalies

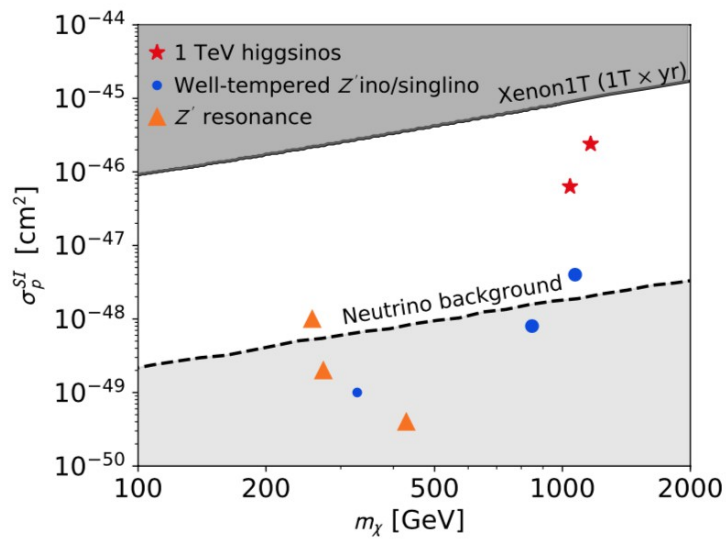
- There is *at least* one extra scale in the picture... What is its origin?

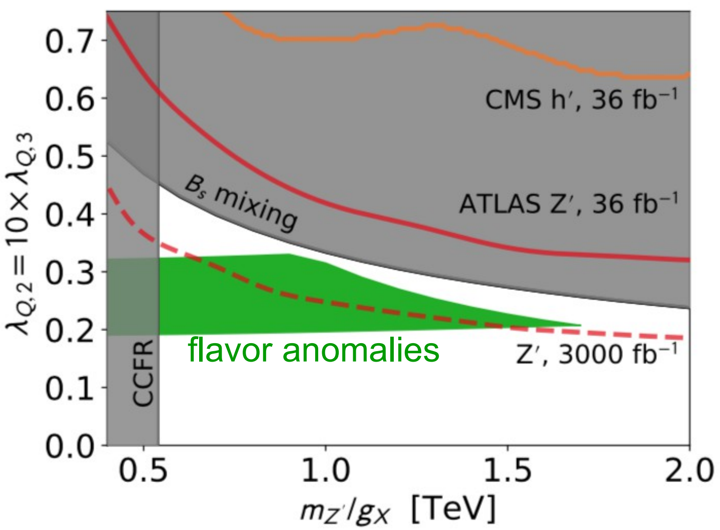
One option is supersymmetry-breaking...

- It protects all scalar mass parameters
- It agrees with expectations from the Higgs boson mass (SUSY ~ 10s TeV)

- Enticing connections with dark matter
- Complementary signatures (LHC, muon *g*-2)

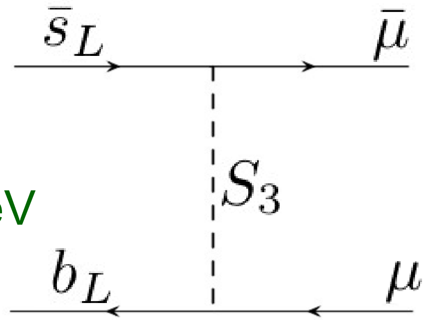
L.Darmé, K.Kowalska, L.Roszkowski, E.M.Sessolo, *JHEP 1810 (2018) 052*



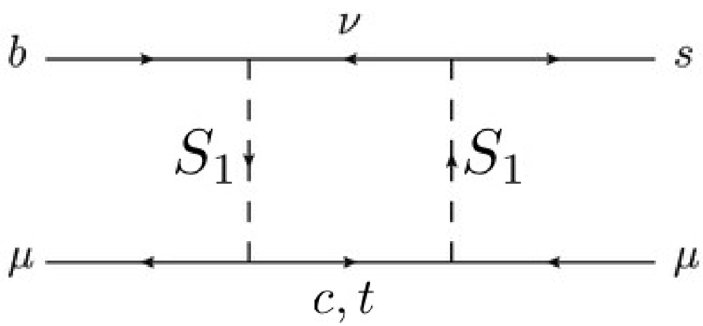


Models of New Physics for the flavor anomalies

- Option 2 **Leptoquarks**



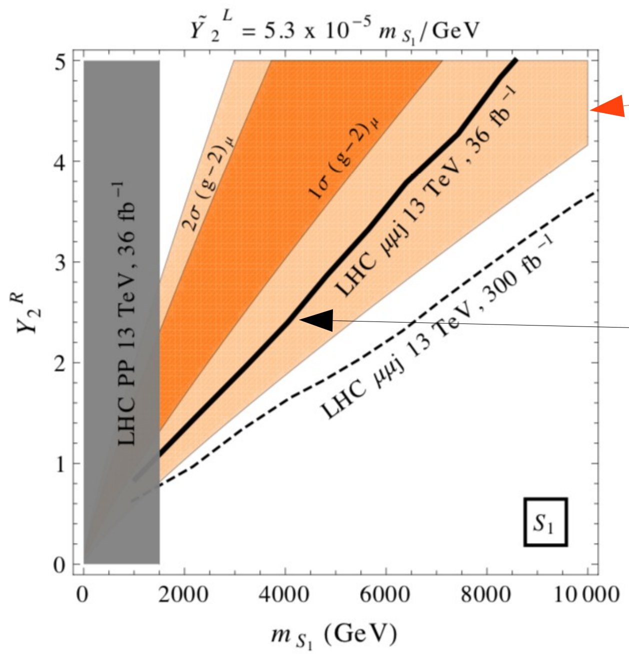
Tree level:
m_{S3} / λ = 25-30 TeV



Loop level: $m_{S1} / \lambda \sim$ 2 TeV

Rich phenomenology <u>intersecting flavor decays, muon *g*-2, and collider bounds</u>:

K.Kowalska, E.M.Sessolo, Y.Yamamoto,
Phys.Rev. D99 (2019) no.5, 055007



Muon *g-2* (2σ region)

LHC direct bound
(numerical recast)

To take home

- The statistical evidence for NP in flavor anomalies at LHCb and others remains very strong

- Possibilities include heavy states (new gauge bosons, leptoquarks, vector-like heavy fermions) and light feebly interacting particles (not discussed here)

- NCBJ has been able to enter this competitive subfield with a number of relevant contributions

- Exciting times ahead?