Flavor anomalies from asymptotic safety

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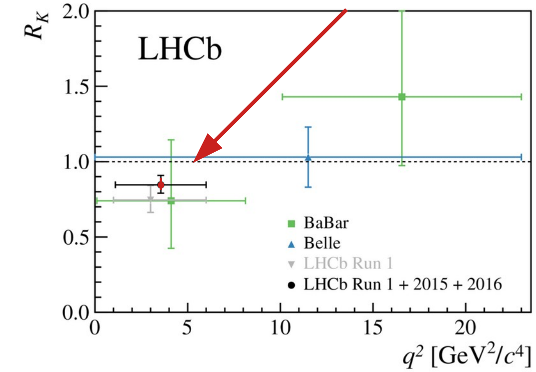
Flavor anomalies in b to s

New results!

LHCb Run 1+2



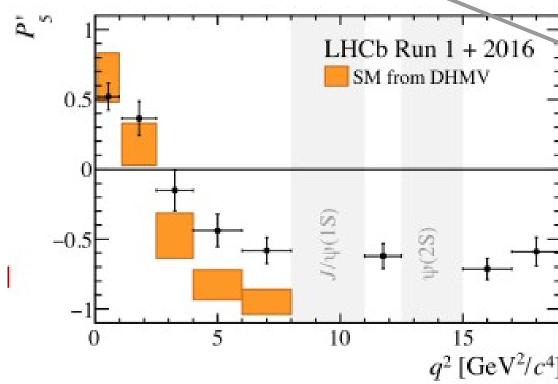
- **lepton-flavor universality violation (LHCb: ~3.1 σ)**

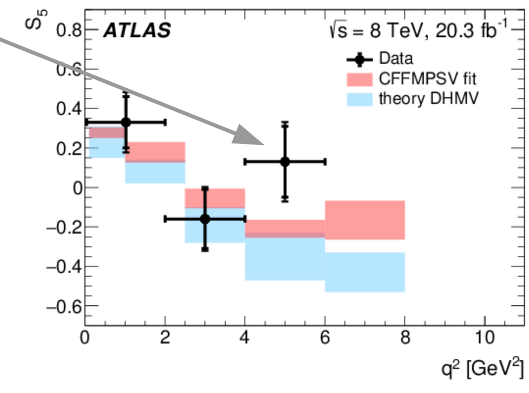
$$R_K = \frac{\mathrm{BR}(B^+ \to K^+\mu^+\mu^-)}{\mathrm{BR}(B^+ \to K^+e^+e^-)}$$

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

- **deviations in angular observables (LHCb: ~2.5 σ)**

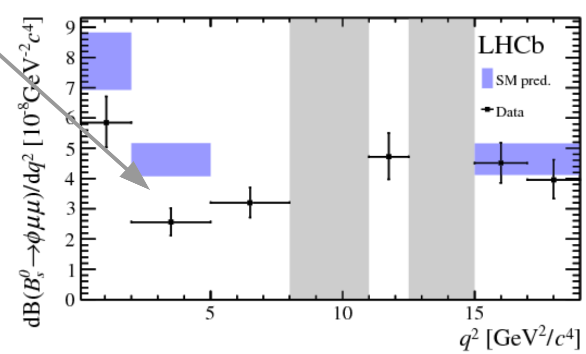
$$B^0 \to K^{0*}\mu^+\mu^-$$





- **deviations in branching ratios (LHCb: ~2-3.5 σ)**

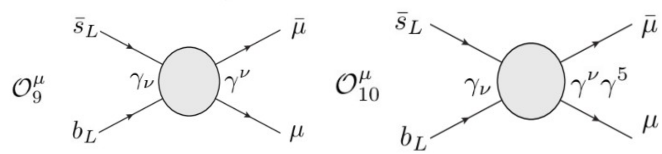
$$B^0 \to K^{0*}\mu^+\mu^-$$
$$B^0 \to K^0\mu^+\mu^-$$
$$B_s^0 \to \phi\mu^+\mu^-$$
$$\Lambda_b^0 \to \Lambda\mu^+\mu^-$$



New Physics explanations

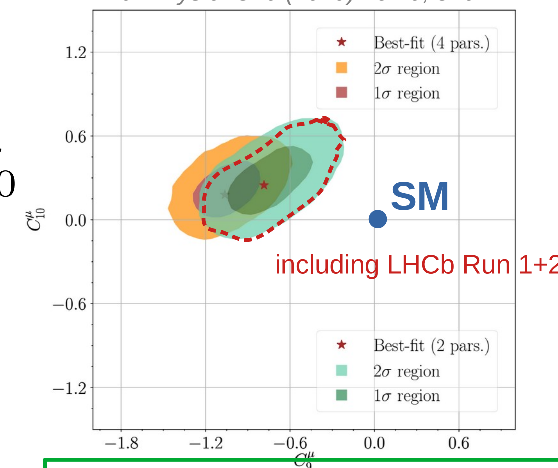
- 140 observables with experimental + theoretical correlations
- GLOBAL FIT

EFT approach:



$\Longrightarrow C_9^\mu, \; C_{10}^\mu$

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



pull of the best-fit point: **5.1 σ**

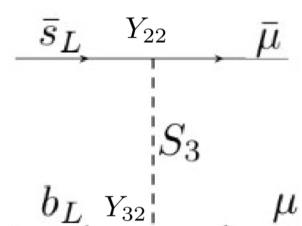
Bayes factor NP vs Standard Model: **10^5 to 1** (“decisive”)

New Physics in the muon sector?

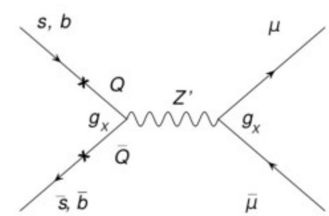
$$C_9^\mu = -C_{10}^\mu \in (-0.6, -0.3)$$

NP models:

$$C_9^\mu = -C_{10}^\mu = \frac{\pi v_h^2}{V_{33}V_{32}^*\alpha_{\rm em}} \frac{\hat{Y}_{32}^L \hat{Y}_{22}^{L*}}{m_{S_3}^2}$$



leptoquarks

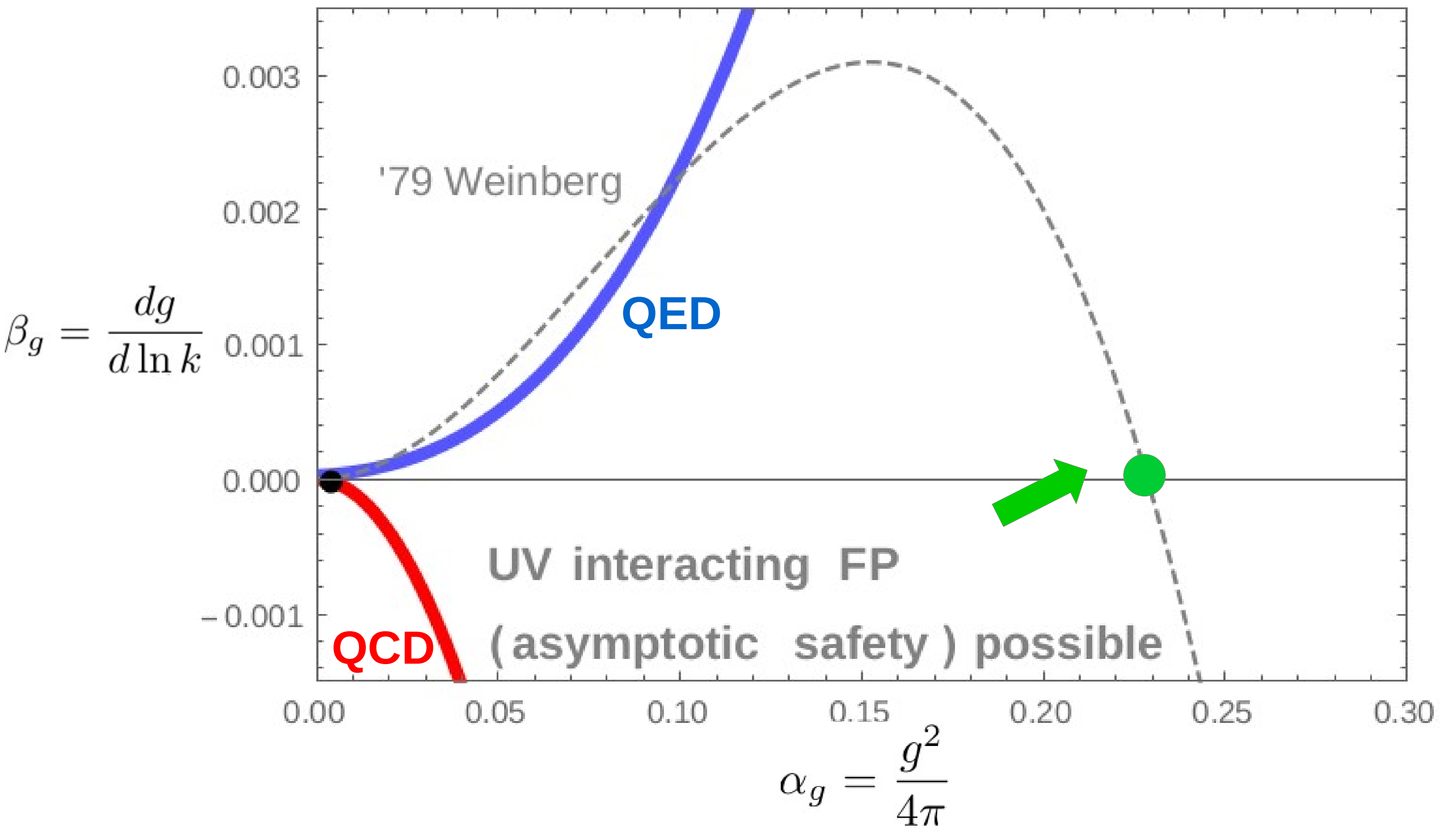


Z’ with VL fernions

Problem: we know only coupling/mass ratio → no prediction for the NP scale

Question: how to get a prediction? → **asymptotic safety**

Asymptotic behaviours



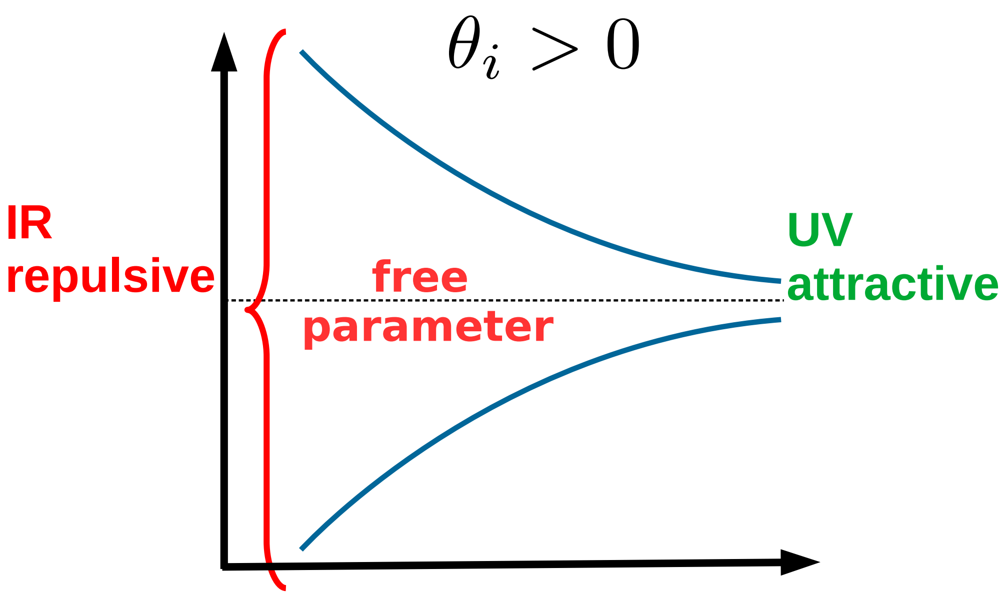
- AS originally advocated by Weinberg to improve the UV behavior of G_N
- Advocated in QFT as solution to $U(1)_Y$ triviality problem

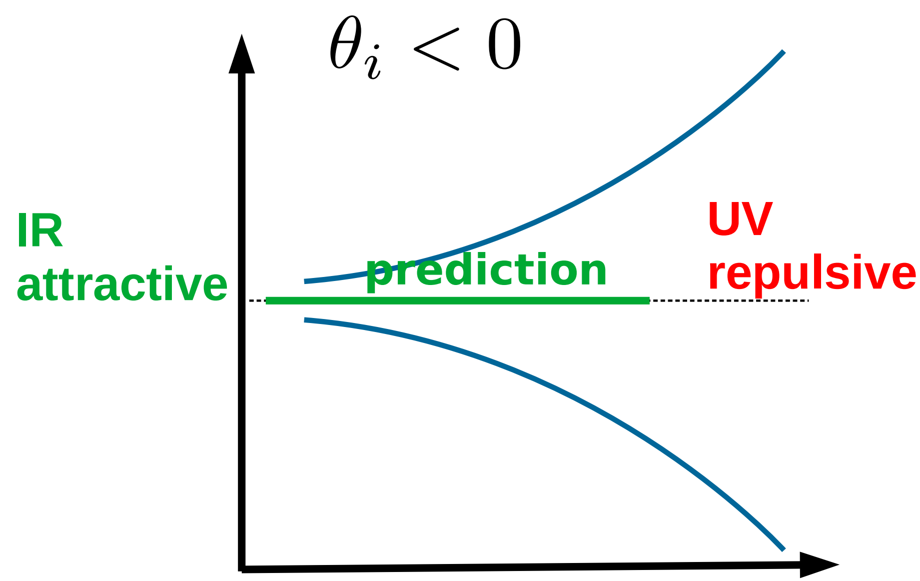
Fixed point properties

$$\boxed{\beta_i(\{\alpha_j^*\}) = 0} \longrightarrow M_{ij} = \partial\beta_i/\partial\alpha_j\big|_{\{\alpha_i^*\}} \longrightarrow \{\theta_i\}$$

stability matrix

critical exponents





Relevant couplings are free parameters of the theory

Irrelevant couplings provide **predictions**

Asymptotic safety in QG

Quantum gravity and quantum gravity + matter might feature interactive UV fixed points

[Reuter '96, Reuter, Saueressig '01, Litim '04, Codello, Percacci, Rahmede '06, Benedetti, Machado, Saueressig '09, Narain, Percacci '09, Manrique, Rechenberger, Saueressig '11, Falls, Litim, Nikolakopoulos '13, Dona', Eichhorn, Percacci '13, Daum, Harst, Reuter '09, Folkerst, Litim, Pawlowski '11, Harst, Reuter '11, Christiansen, Eichhorn '17, Eichhorn, Versteegen '17, Zanusso *et al.* '09, Oda, Yamada '15, Eichhorn, Held, Pawlowski '16, Pawlowski *et al.* '18 … many more]

Prototype example: Einstein-Hilbert gravity

$$S_{\rm EH} = \frac{1}{16\pi G_N}\int d^4x\sqrt{g}\,(-R(g)+2\Lambda)$$

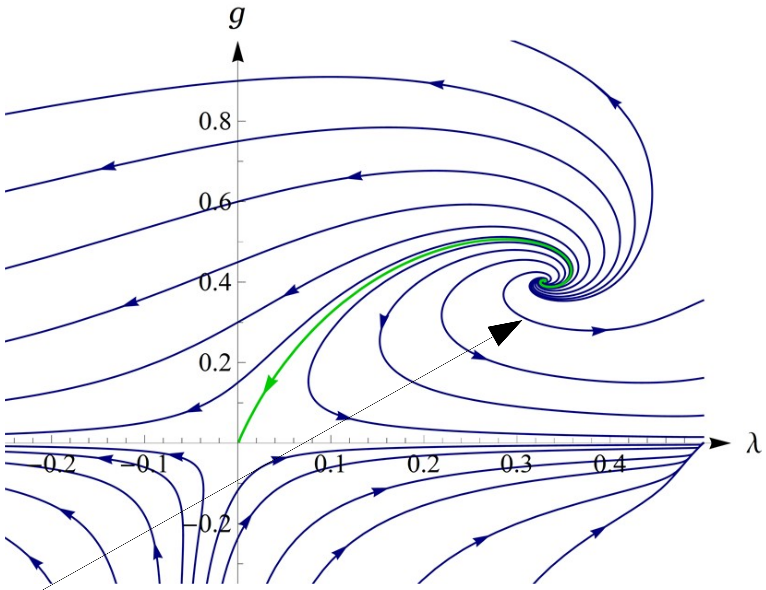
Functional renormalization group techniques (Wetterich Equation) lead to 2 fixed points

$$\beta_g \equiv \frac{dg}{d\ln k} = 0 \qquad \beta_\lambda \equiv \frac{d\lambda}{d\ln k} = 0$$

(gaussian) $g = 0 \quad \lambda = 0$

(interactive) $g = g^* \quad \lambda = \lambda^*$

Reuter, Saueressig, hep-th/0110054



Fixed point persists under the addition of new interactions

Asymptotic safety with matter

Gravity affects matter:

Gauge-Yukawa system coupled to gravity:

$$\beta_g = \beta_g^{\mathrm{SM+NP}} - g\, f_g$$

$$\beta_y = \beta_y^{\mathrm{SM+NP}} - y\, f_y$$

Quantum-gravitational contribution
(in principle via FRG)

[Daum, Harst, Reuter '09, Folkerst, Litim, Pawlowski '11, Harst, Reuter '11, Christiansen, Eichhorn '17, Eichhorn, Versteegen '17, Zanusso *et al.* '09, Oda, Yamada '15, Eichhorn, Held, Pawlowski '16, …]

In practice *fg*, *fy* are subject to large uncertainties
(truncation in number of operators, cut-off scheme dependence, etc.)

[Lauscher, Reuter '02, Codello, Percacci, Rahmede '07-'08, Benedetti, Machado, Saueressig '09, Narain, Percacci '09, Dona', Eichhorn, Percacci '13, Falls, Litim, Schroeder '18, ...]

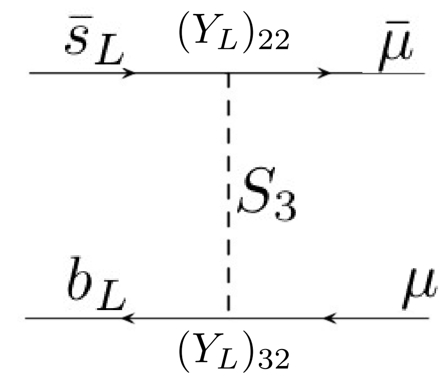
f_g, f_y free parameters determined by matching to the low-energy data

applied in SM and simple SM extensions
see *e.g.* Eichhorn, Held, 1707.01107, 1803.04027; Reichert, Smirnov, 1911.00012; Alkofer *et al.* 2003.08401

SM + S_3 leptoquark

S_3 leptoquark: $(\bar{\mathbf{3}}, \mathbf{3}, 1/3)$

$$\mathcal{L} \supset (Y_L)_{ij}\, Q_i^T (i\sigma_2) S_3 L_j + \text{H.c.}$$



Leptoquark Yukawa matrix

$$\begin{pmatrix} d & s & b \end{pmatrix} \begin{pmatrix} 0 & 0 & 0 \\ 0 & \hat{Y}^L_{22} & 0 \\ 0 & \hat{Y}^L_{32} & 0 \end{pmatrix} \begin{pmatrix} e \\ \mu \\ \tau \end{pmatrix}$$

System of beta functions to solve:

$$g_Y,\ g_2,\ g_3,\ y_t,\ y_b,\ V_{33},\ \hat{Y}^L_{22},\ \hat{Y}^L_{32}$$

gauge (g_Y, g_2, g_3) — SM Yukawa (y_t, y_b, V_{33}) — LQ Yukawa ($\hat{Y}^L_{22}, \hat{Y}^L_{32}$)

UV fixed-point:

SM: $g_3^* = 0,\ g_2^* = 0,\ g_Y^* = 0.48,\ y_t^* = 0,\ y_b^* = 0.03,\ V_{33} = 0$

fixes f_g ($g_Y^* = 0.48$) — fixes f_y ($y_b^* = 0.03$)

LQ: $\hat{Y}^{L*}_{22} = 0,\ \hat{Y}^{L*}_{32} = 0.19$ — irrelevant → low-scale predictions

Prediction for the LQ mass

$$C_9^\mu = -C_{10}^\mu = \frac{\pi v_h^2}{V_{33} V_{32}^* \alpha_{\text{em}}} \frac{\hat{Y}_{32}^L \hat{Y}_{22}^{L*}}{m_{S_3}^2}$$

0.63

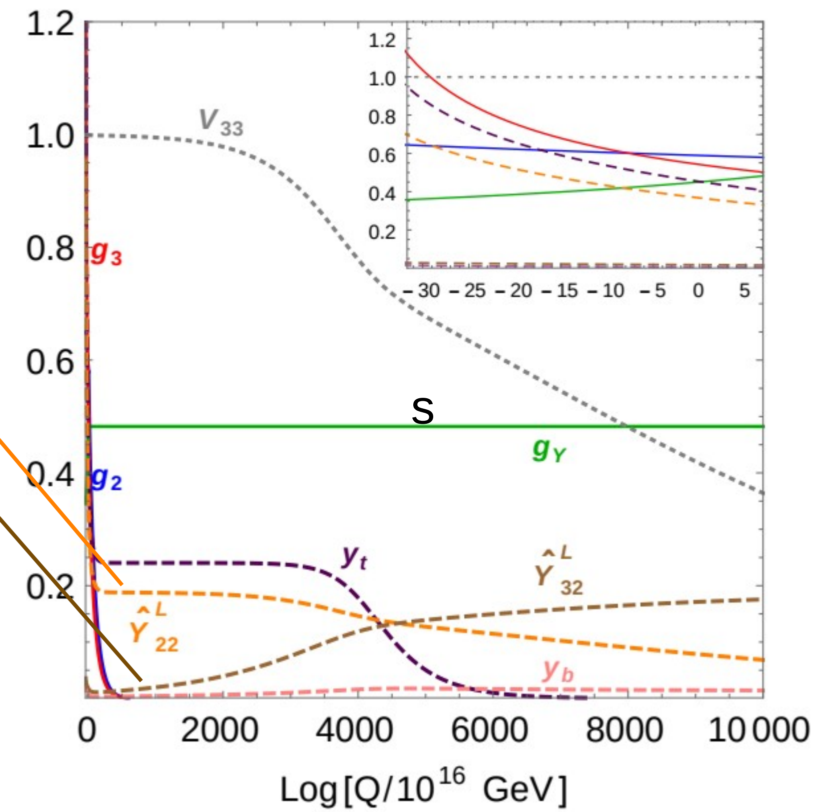
0.03

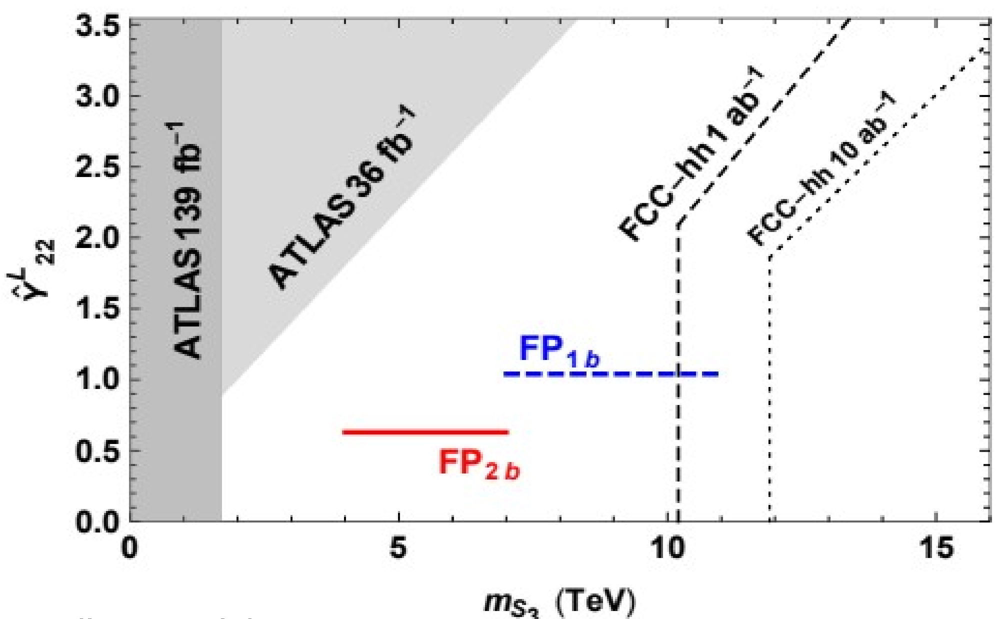
global fits:

$$C_9^\mu = -C_{10}^\mu \in (-0.6, -0.3)$$

$$M_{S_3} \in (4.5, 7)\ \text{TeV}$$

Mass predicted !





In the reach of the FCC!

To take home

- Asymptotic safety can enhance predictivity of the New Physics models
- Single leptoquark extensions of the SM with AS predicts the LQ mass between 4 and 7 TeV, in the reach of FCC
- Asymptotic safety can provide a theoretical guidance for future experiments
- Other applications (anomalous magnetic moments, dark matter, see arXiv:2012.15200)