

# Flavor anomalies from asymptotic safety

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arXiv: 2007.03567 (accepted to EPJC)

*Beyond Standard Model: From Theory to Experiment*

29.03.2021

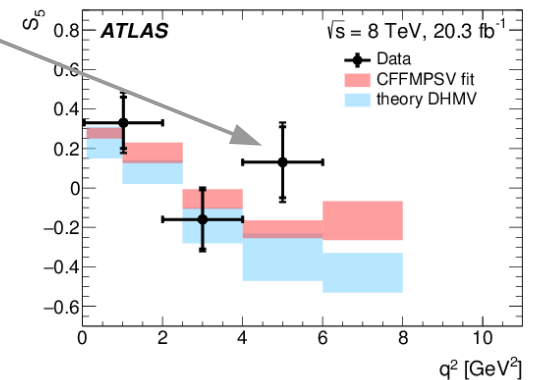
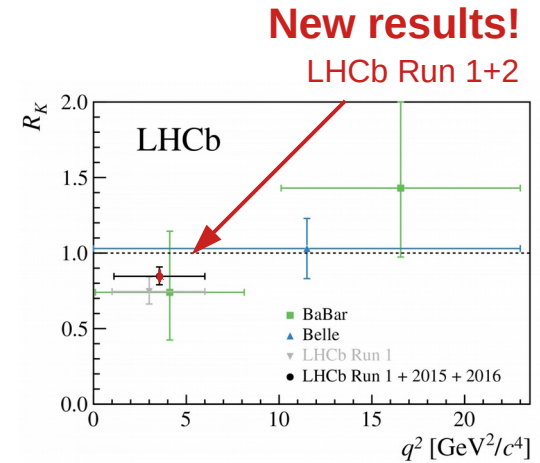
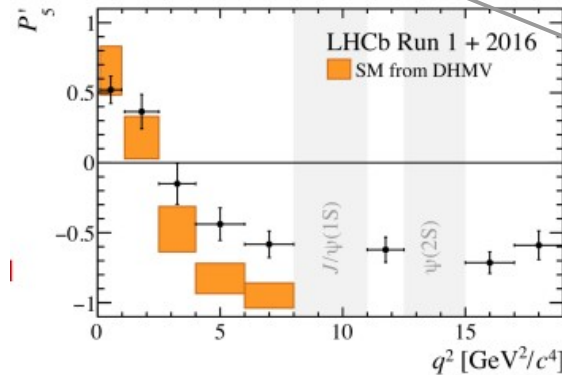
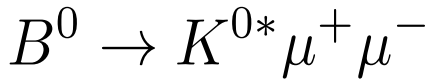
# Flavor anomalies in b to s

- lepton-flavor universality violation (LHCb:  $\sim 3.1 \sigma$ )

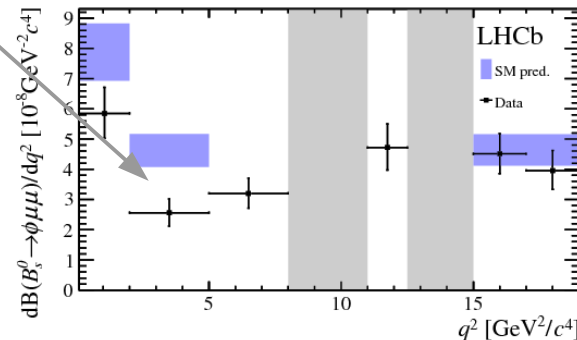
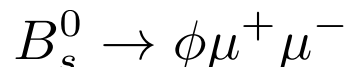
$$R_K = \frac{\text{BR}(B^+ \rightarrow K^+ \mu^+ \mu^-)}{\text{BR}(B^+ \rightarrow K^+ e^+ e^-)}$$

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

- deviations in angular observables (LHCb:  $\sim 2.5 \sigma$ )



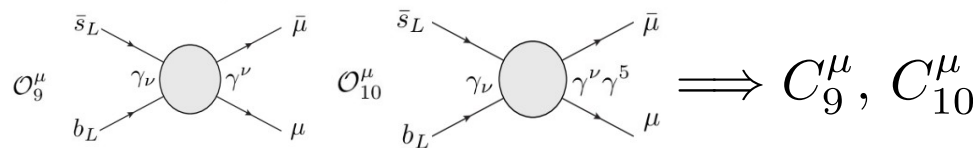
- deviations in branching ratios (LHCb:  $\sim 2-3.5 \sigma$ )



# New Physics explanations

- 140 observables with experimental + theoretical correlations
- GLOBAL FIT

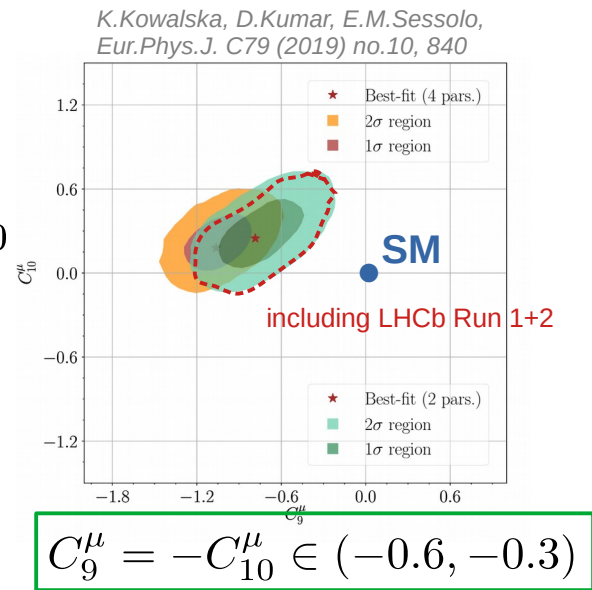
## EFT approach:



pull of the best-fit point: **5.1  $\sigma$**

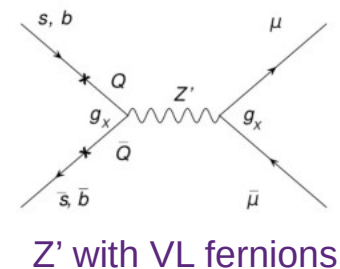
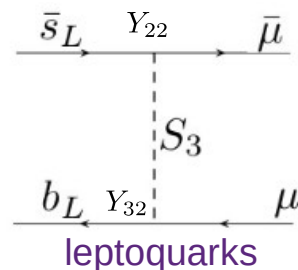
Bayes factor NP vs Standard Model:  **$10^5$  to 1** (“decisive”)

New Physics in the muon sector?



## NP models:

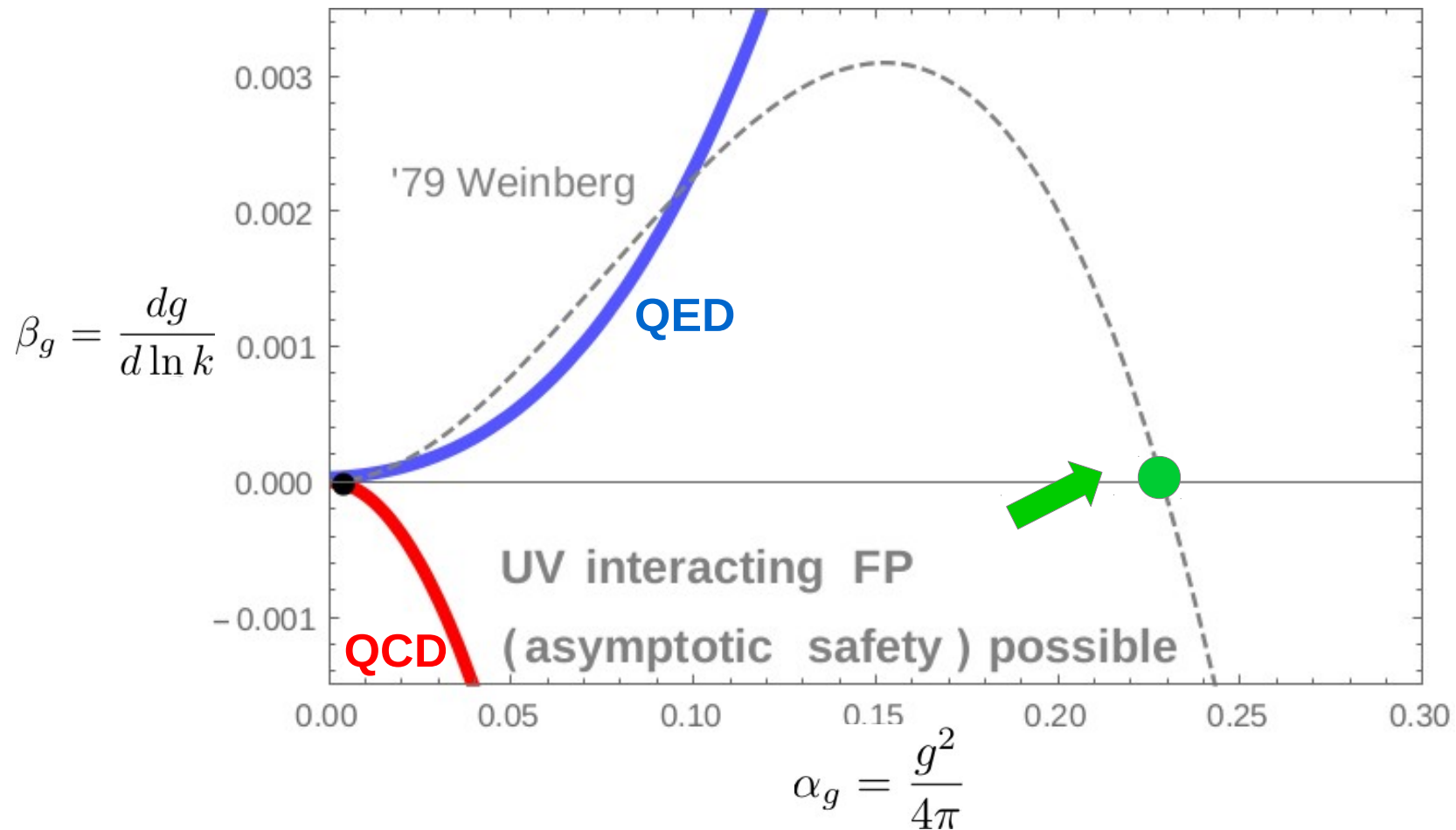
$$C_9^\mu = -C_{10}^\mu = \frac{\pi v_h^2}{V_{33} V_{32}^* \alpha_{\text{em}}} \frac{\hat{Y}_{32}^L \hat{Y}_{22}^{L*}}{m_{S_3}^2}$$



**Problem:** we know only coupling/mass ratio  $\rightarrow$  no prediction for the NP scale

**Question:** how to get a prediction?  $\rightarrow$  **asymptotic safety**

# Asymptotic behaviours

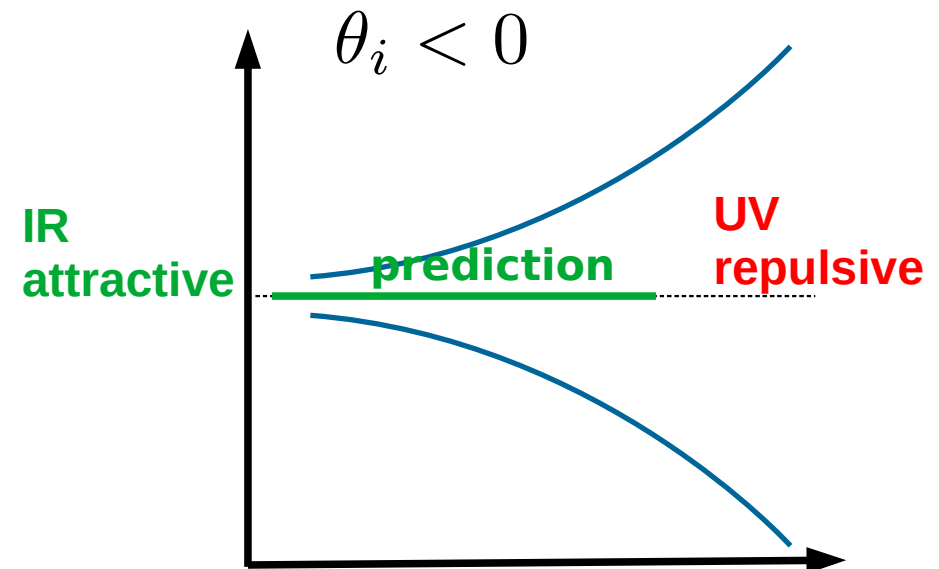
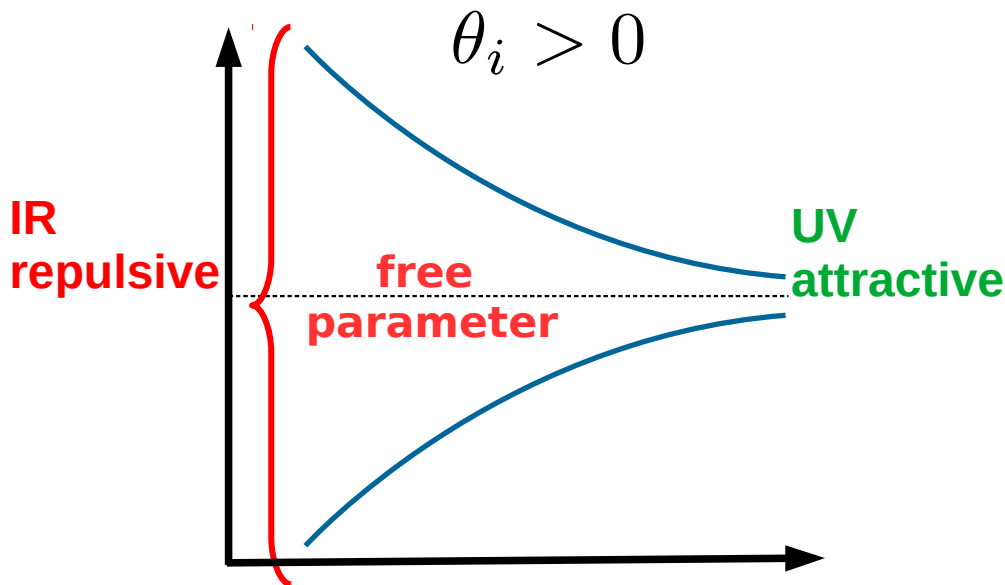


- AS originally advocated by Weinberg to improve the UV behavior of  $G_N$
- Advocated in QFT as solution to  $U(1)_Y$  triviality problem

# Fixed point properties

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

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, Pawłowski '11, Harst, Reuter '11, Christiansen, Eichhorn '17, Eichhorn, Versteegen '17, Zanusso *et al.* '09, Oda, Yamada '15, Eichhorn, Held, Pawłowski '16, Pawłowski *et al.* '18 ... many more ]

Prototype example: Einstein-Hilbert gravity

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

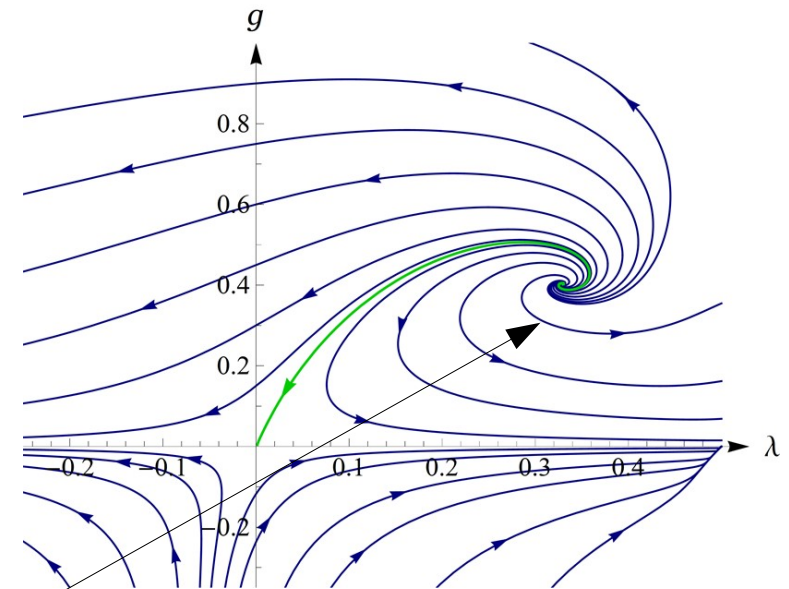
Functional renormalization group techniques (Wetterich Equation) lead to 2 fixed points

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

(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:

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

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

Quantum-gravitational contribution  
(in principle via FRG)

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

In practice  $f_g, f_y$  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

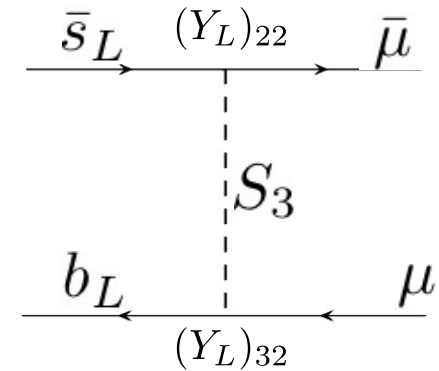
applied in SM and simple SM extensions

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

$$(d \begin{matrix} s & b \end{matrix}) \begin{pmatrix} 0 & 0 & 0 \\ 0 & \hat{Y}_{22}^L & 0 \\ 0 & \hat{Y}_{32}^L & 0 \end{pmatrix} \begin{pmatrix} e \\ \mu \\ \tau \end{pmatrix}$$

System of beta functions to solve:

$$\underbrace{g_Y, g_2, g_3}_{\text{gauge}}, \underbrace{y_t, y_b, V_{33}}_{\text{SM Yukawa}}, \underbrace{\hat{Y}_{22}^L, \hat{Y}_{32}^L}_{\text{LQ Yukawa}}$$



**UV fixed-point:**

$$\text{SM: } g_3^* = 0, g_2^* = 0, \underbrace{g_Y^* = 0.48}_{\text{fixes } f_g}, y_t^* = 0, \underbrace{y_b^* = 0.03}_{\text{fixes } f_y}, V_{33} = 0$$

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



# Prediction for the LQ mass

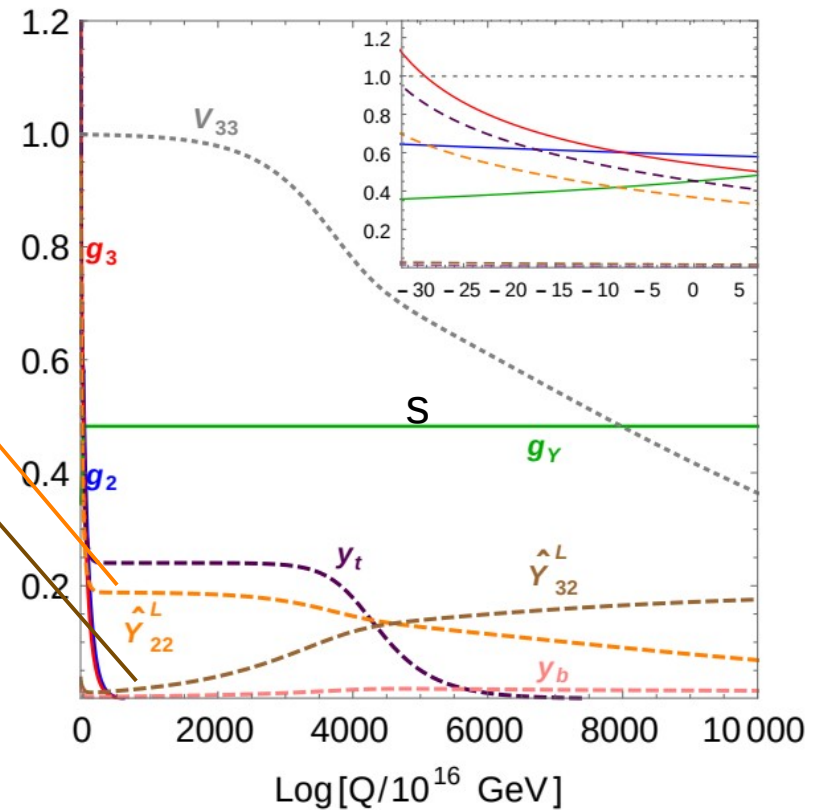
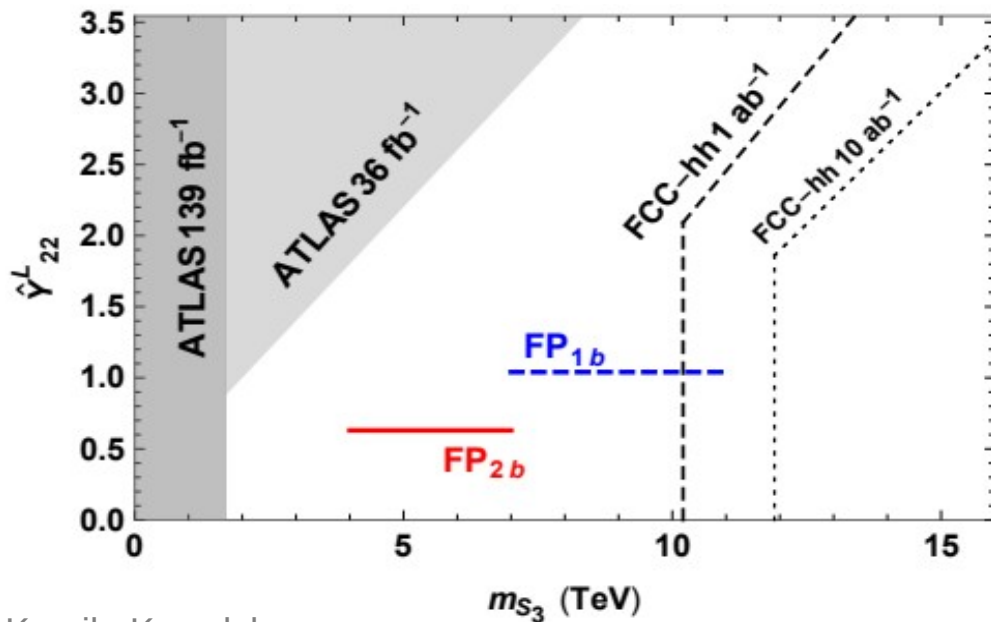
$$C_9^\mu = -C_{10}^\mu = \frac{\pi v_h^2}{V_{33} V_{32}^* \alpha_{em}} \frac{\hat{Y}_{32}^L \hat{Y}_{22}^{L*}}{m_{S_3}^2}$$

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)