Predictions for flavorful Z' models from asymptotic safety

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In collaboration with
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Introduction

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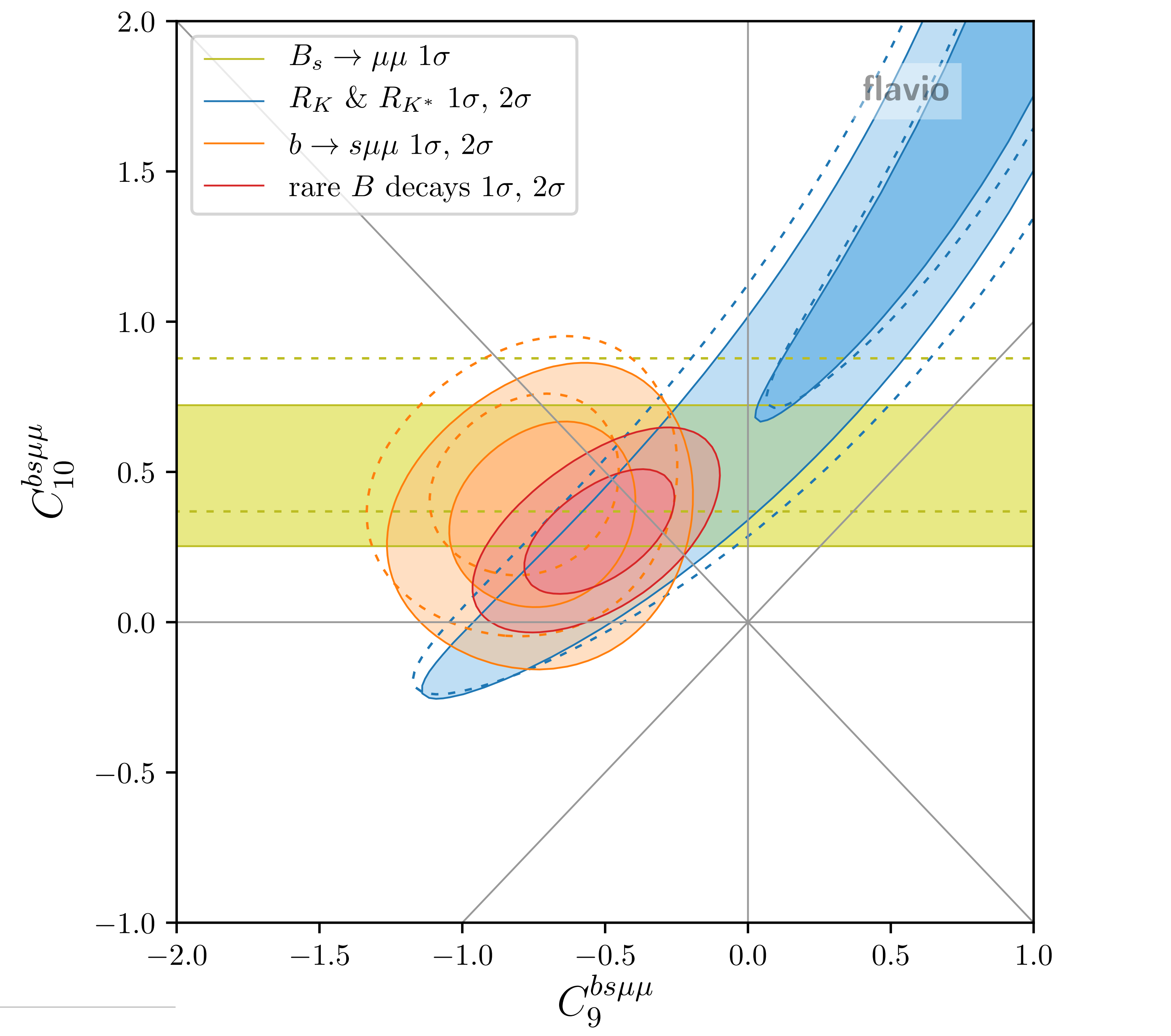
Flavor anomalies observables:

R_K , R_{K*}, branching fractions and angular observables of B-meson decays

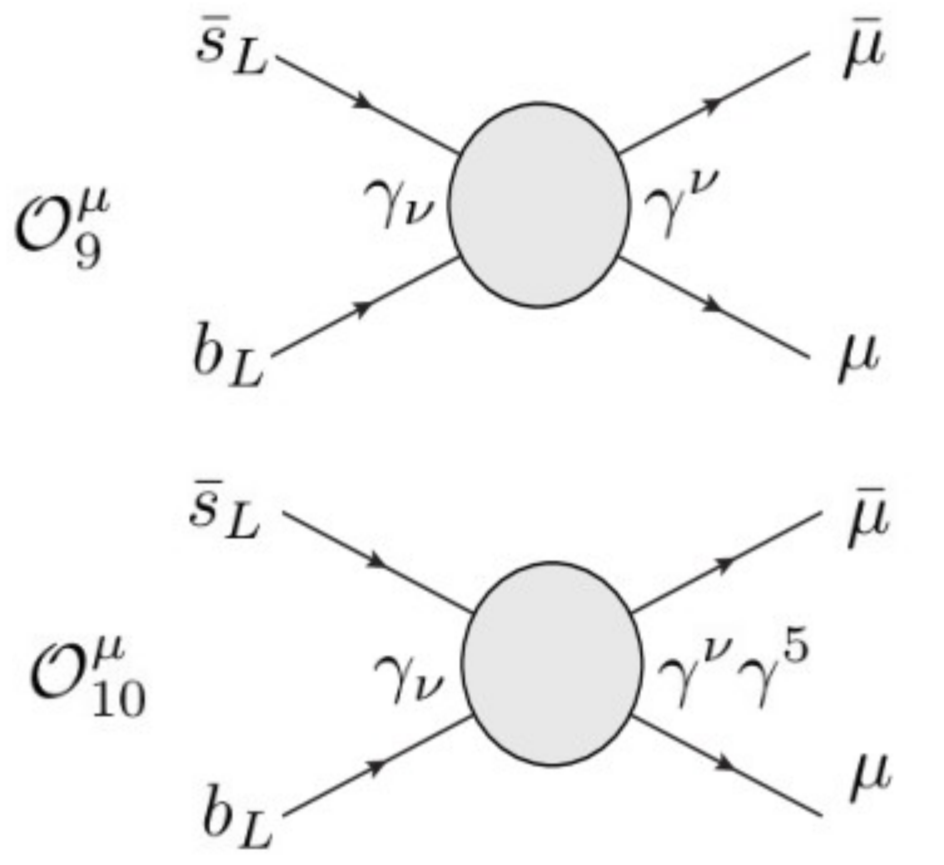
Parameterising the new physics (NP) in terms of four-fermion contact interaction

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

$$O_9^{(\prime)\mu} = \frac{e^2}{16\pi^2} (\bar{s}\gamma^\rho P_{L(R)} b)(\bar{\mu}\gamma_\rho \mu), \qquad O_{10}^{(\prime)\mu} = \frac{e^2}{16\pi^2} (\bar{s}\gamma^\rho P_{L(R)} b)(\bar{\mu}\gamma_\rho \gamma_5 \mu)$$



Altmannshofer, Stangl arXiv: 2103.13370



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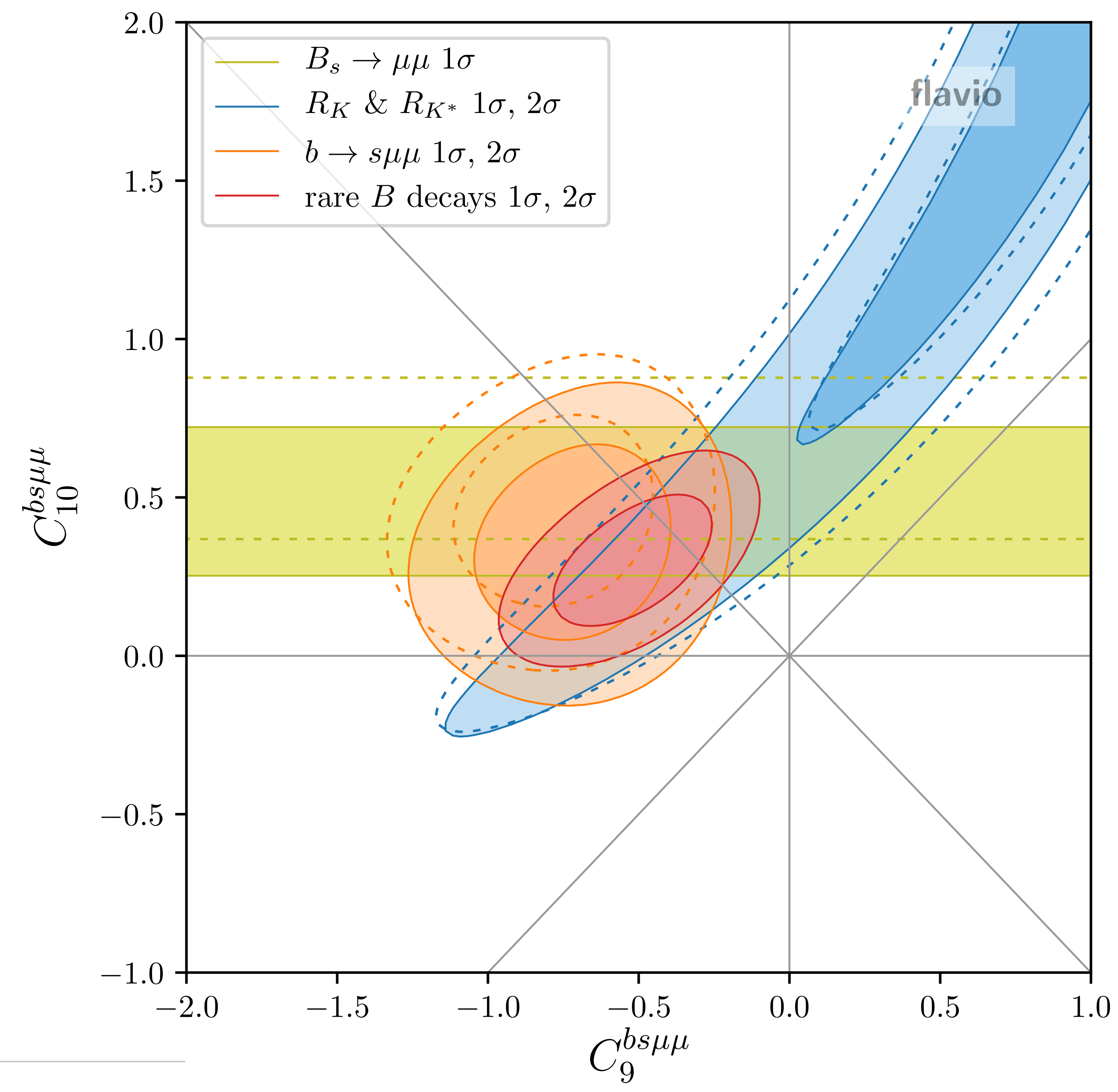

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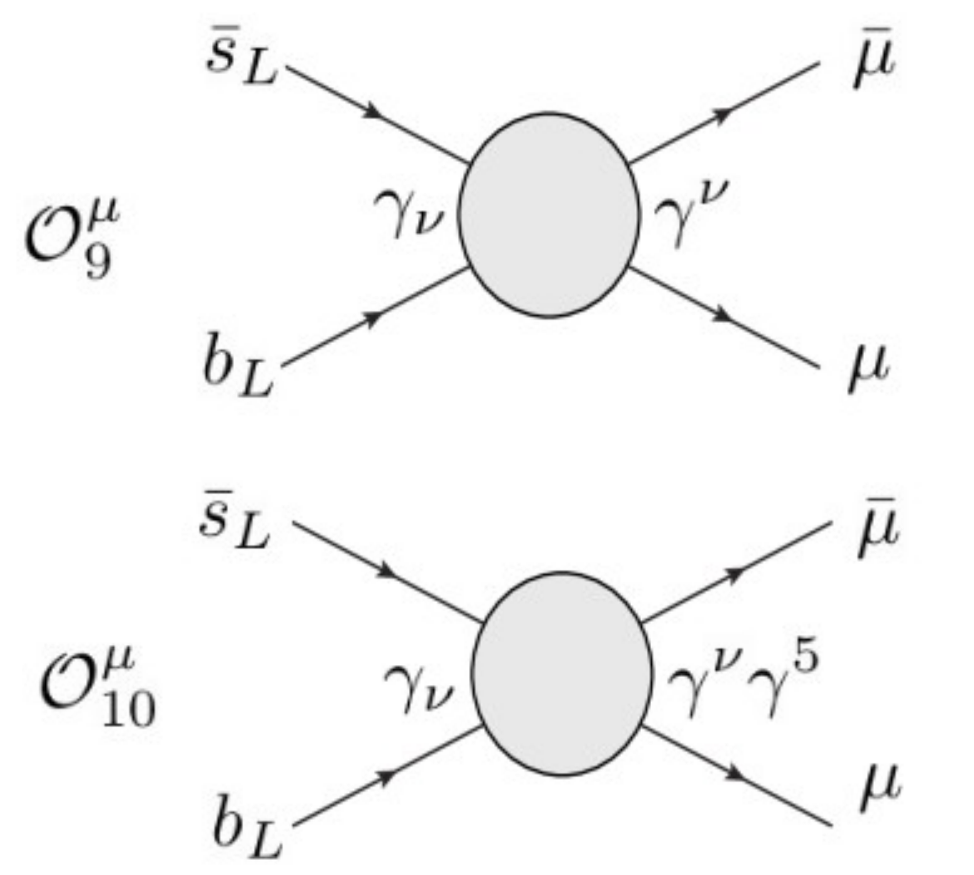
Well-known solutions:

- Scalar leptoquark
- Vector leptoquark
- $U(1)_X$



Minimal Z' models

Minimal Z' models

Generic Z' coupling for the flavor anomalies

$$\mathscr{L} \supset Z'_\rho \left(g_L^{sb}\, \bar{s}\gamma^\rho P_L\, b + g_R^{sb}\, \bar{s}\gamma^\rho P_R\, b + g_L^{\mu\mu}\, \bar{\mu}\gamma^\rho P_L\, \mu + g_R^{\mu\mu}\, \bar{\mu}\gamma^\rho P_R\, \mu \right) + \text{H.c.}$$

$$C^\mu_{9,\text{NP}} = -\,2\,\frac{g_L^{sb} g_V^{\mu\mu}}{V_{tb}V_{ts}^*}\left(\frac{\Lambda_v}{m_{Z'}}\right)^2 \quad C^\mu_{10,\text{NP}} = -\,2\,\frac{g_L^{sb} g_A^{\mu\mu}}{V_{tb}V_{ts}^*}\left(\frac{\Lambda_v}{m_{Z'}}\right)^2$$

$$g_V^{\mu\mu} = (g_L^{\mu\mu} + g_R^{\mu\mu})/2\,, \quad g_A^{\mu\mu} = (g_R^{\mu\mu} - g_L^{\mu\mu})/2\,, \quad \Lambda_v = \left(\frac{\pi}{\sqrt{2}G_F\alpha_{\text{em}}}\right)^{1/2}$$

Only marginal improvement in the fit with C'_9 and C'_{10}

Kowalska, Kumar, Sessolo, arXiv: 1903.10932

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$$C^\mu_{9,\text{NP}} = -2\,\frac{g_L^{sb} g_V^{\mu\mu}}{V_{tb}V^*_{ts}} \left(\frac{\Lambda_v}{m_{Z'}}\right)^2 \quad C^\mu_{10,\text{NP}} = -2\,\frac{g_L^{sb} g_A^{\mu\mu}}{V_{tb}V^*_{ts}} \left(\frac{\Lambda_v}{m_{Z'}}\right)^2$$

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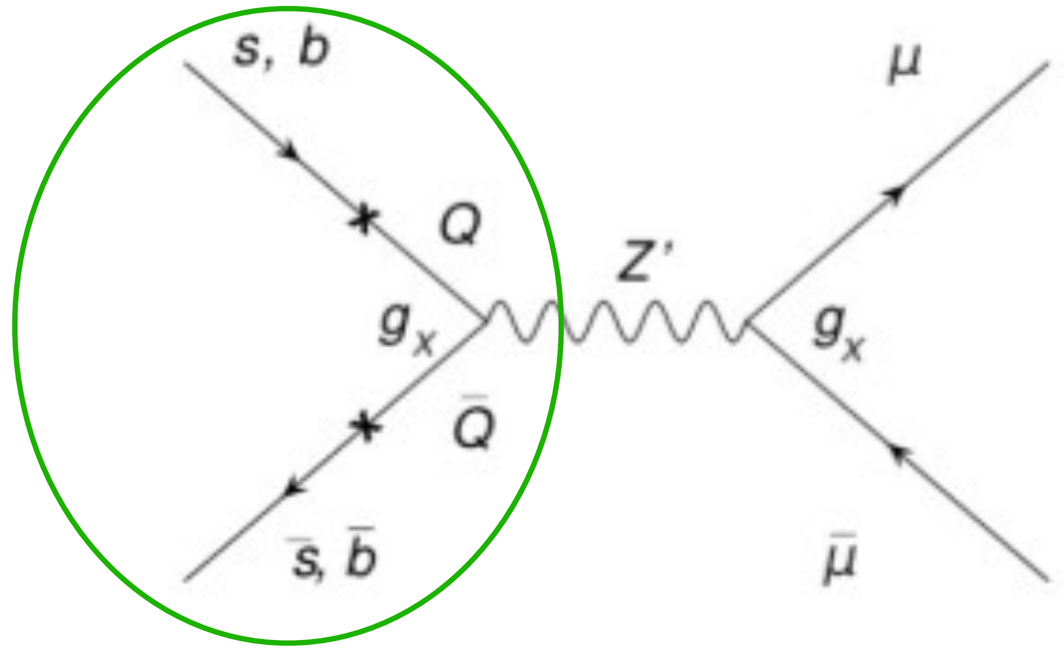
g_L^{sb} is an effective coupling:

$$\mathcal{L} \supset -\lambda_{Q,i} S Q' q_i - m_Q\, Q' Q + \text{H.c.}$$

$$\Rightarrow g_L^{sb} \approx g_X Q_S \frac{\lambda_{Q,2}\lambda_{Q,3} v_S^2}{2m_Q^2 + \left(\lambda_{Q,2}^2 + \lambda_{Q,3}^2\right) v_S^2}\,, \qquad g_R^{sb} \approx 0$$

$$SU(3) \times SU(2)_W \times U(1)_Y \times U(1)_X$$

$$S : (\mathbf{1}, \mathbf{1}, 0, Q_S)\,,$$
$$Q : (\mathbf{3}, \mathbf{2}, 1/6, Q_S) \qquad Q' : (\bar{\mathbf{3}}, \bar{\mathbf{2}}, -1/6, -Q_S)\,,$$

$g_L^{sb} \sim$ 

Minimal Z' models

Minimal Z' models

Model 1: VL Lepton mixing

$$\mathscr{L} \supset \lambda_{L,i}^{(*)} S^{(*)} L' l_i + m_L L' L + \text{H.c.}$$

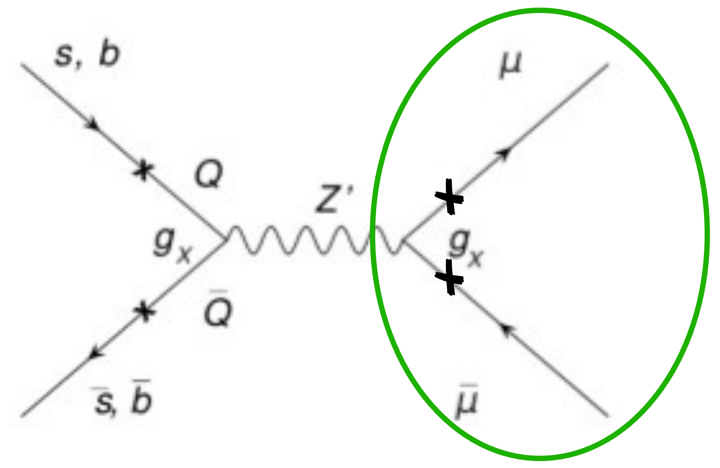
$$g_L^{\mu\mu} \approx g_X Q_L \frac{\lambda_{L,2}^2 v_S^2}{2m_L^2 + \lambda_{L,2}^2 v_S^2}, \qquad g_R^{\mu\mu} \approx 0$$

$$C_9^\mu = -C_{10}^\mu = -\frac{Q_L}{Q_S}\frac{\Lambda_v^2}{V_{tb}V_{ts}^*}\left(\frac{\lambda_{Q,2}\lambda_{Q,3}}{2m_Q^2 + \left(\lambda_{Q,2}^2 + \lambda_{Q,3}^2\right) v_S^2}\right)\left(\frac{\lambda_{L,2}^2 v_S^2}{2m_L^2 + \lambda_{L,2}^2 v_S^2}\right)$$

$L : (\mathbf{1}, \mathbf{2}, -1/2, Q_L) \qquad L' : (\mathbf{1}, \bar{\mathbf{2}}, 1/2, -Q_L)$

Model 1A: $Q_L = Q_S$

Model 2A: $Q_L = -Q_S$



$\sim g_L^{\mu\mu}$

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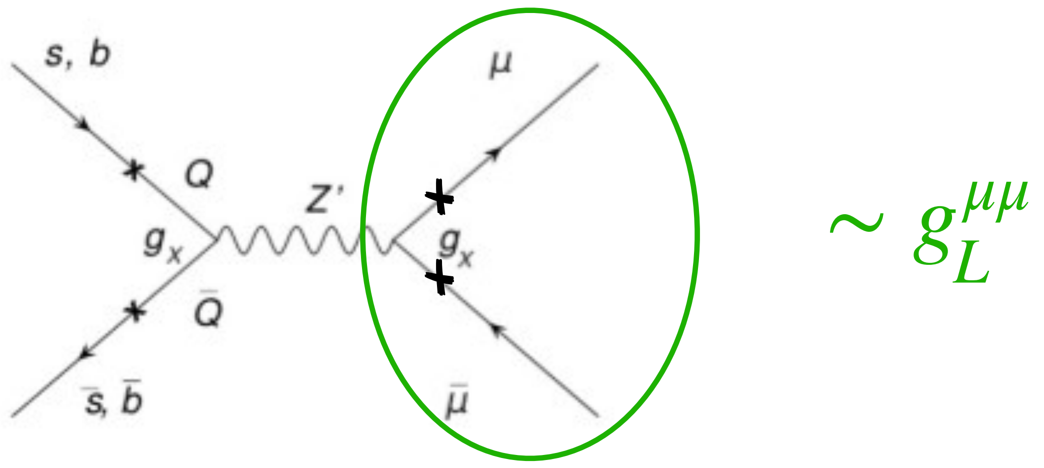


Model 2: Direct lepton coupling with $L_\mu - L_\tau$ Symmetry

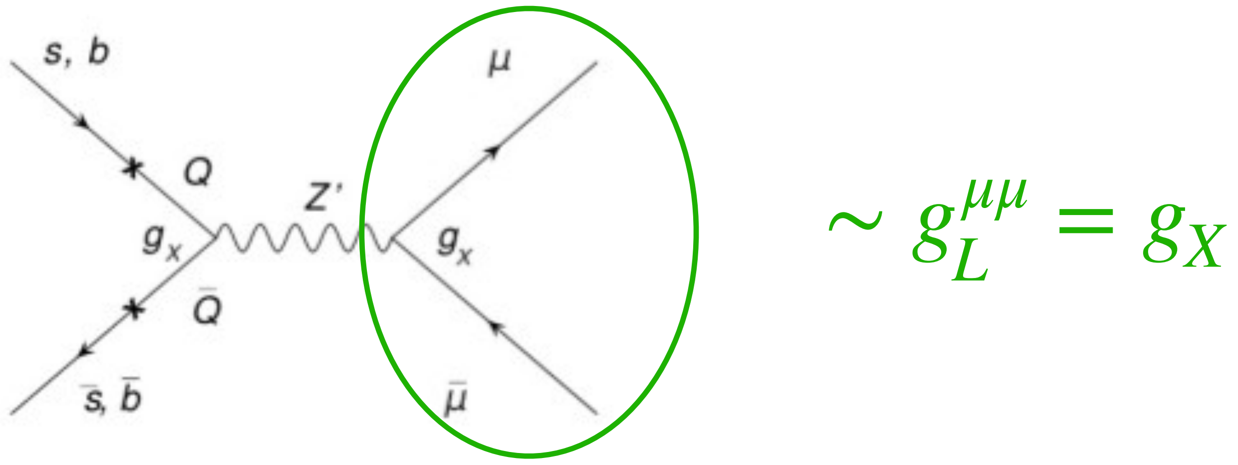
$$g_V^{\mu\mu} = g_X \qquad g_A^{\mu\mu} = 0$$

$$C_9^\mu \approx -\frac{1}{Q_S}\frac{2\Lambda_v^2}{V_{tb}V_{ts}^*}\frac{\lambda_{Q,2}\lambda_{Q,3}}{2m_Q^2 + \left(\lambda_{Q,2}^2 + \lambda_{Q,3}^2\right) v_S^2}, \qquad C_{10}^\mu = 0$$

$l_1 : (\mathbf{1}, \mathbf{2}, -1/2, 0) \qquad e_R : (\mathbf{1}, \mathbf{1}, 1, 0)$

$l_2 : (\mathbf{1}, \mathbf{2}, -1/2, 1) \qquad \mu_R : (\mathbf{1}, \mathbf{1}, 1, -1)$

$l_3 : (\mathbf{1}, \mathbf{2}, -1/2, -1) \qquad \tau_R : (\mathbf{1}, \mathbf{1}, 1, 1)$



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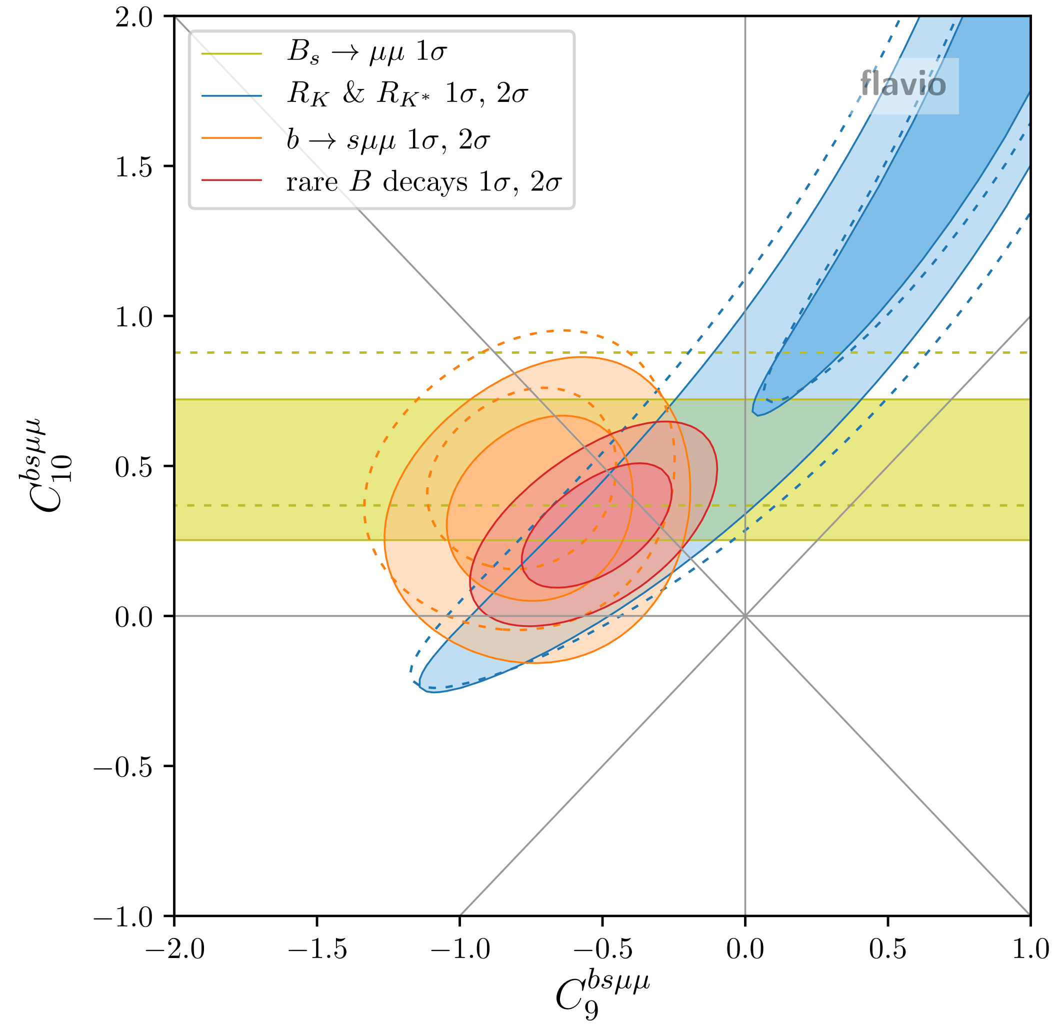
$$-0.53 \le C_9^\mu(=-C_{10}^\mu) \le -0.25$$

Model 2:

$$C_9^\mu \approx -\frac{1}{Q_S}\frac{2\Lambda_v^2}{V_{tb}V_{ts}^*}\frac{\lambda_{Q,2}\lambda_{Q,3}}{2m_Q^2+\left(\lambda_{Q,2}^2+\lambda_{Q,3}^2\right)v_S^2}, \qquad C_{10}^\mu = 0$$

$$-1.03 \le C_9^\mu \le -0.43$$



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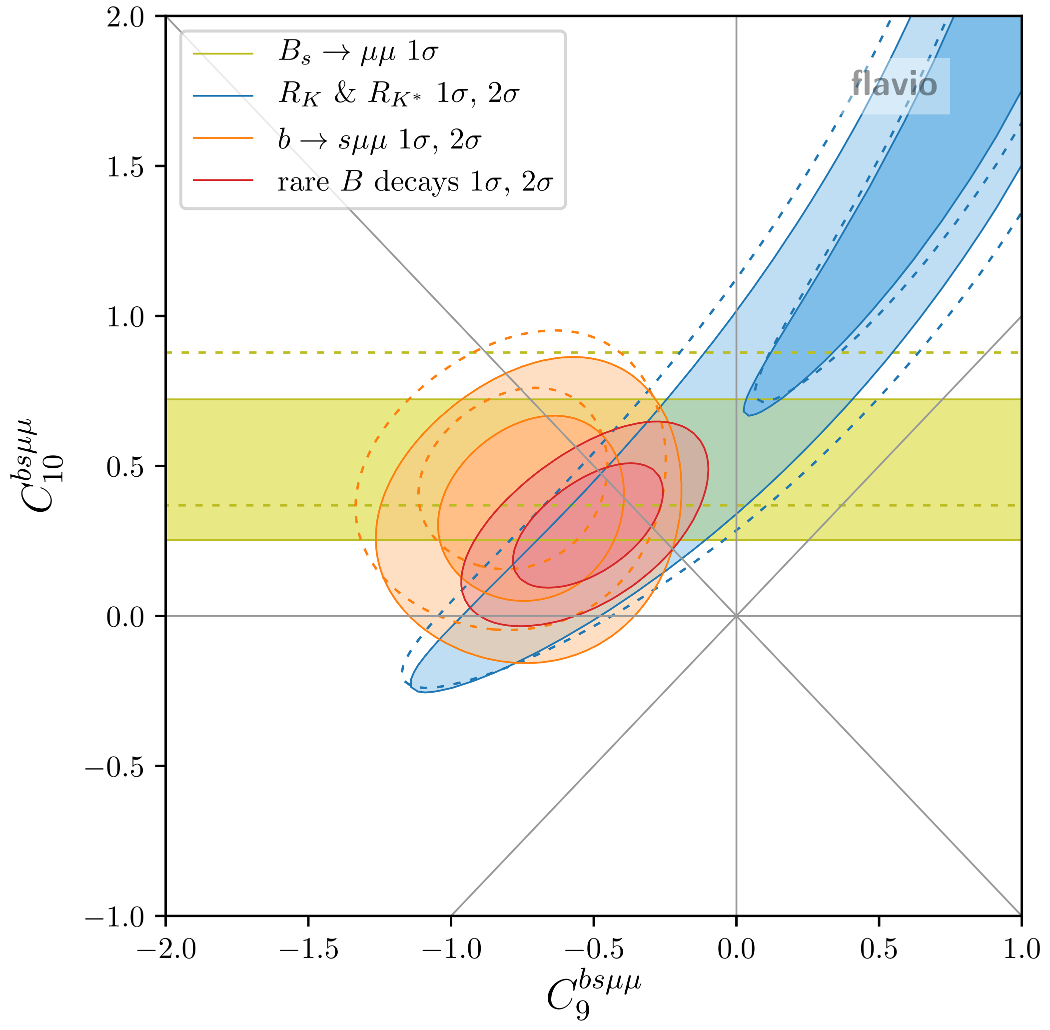

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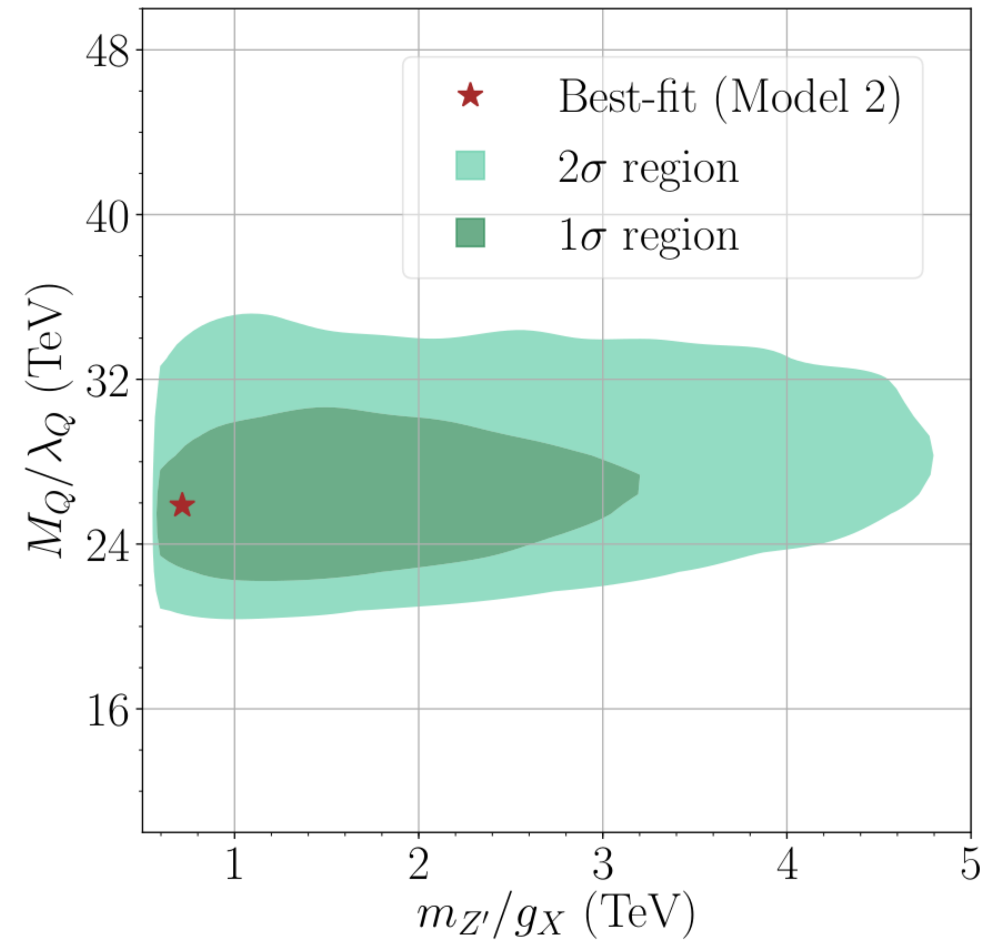

Problem: The constraints are only on the ratios of mass/couplings?

→ No prediction for the NP scale

Solution: Asymptotic safety?

Asymptotic Safety

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Coupling constants are scale dependent

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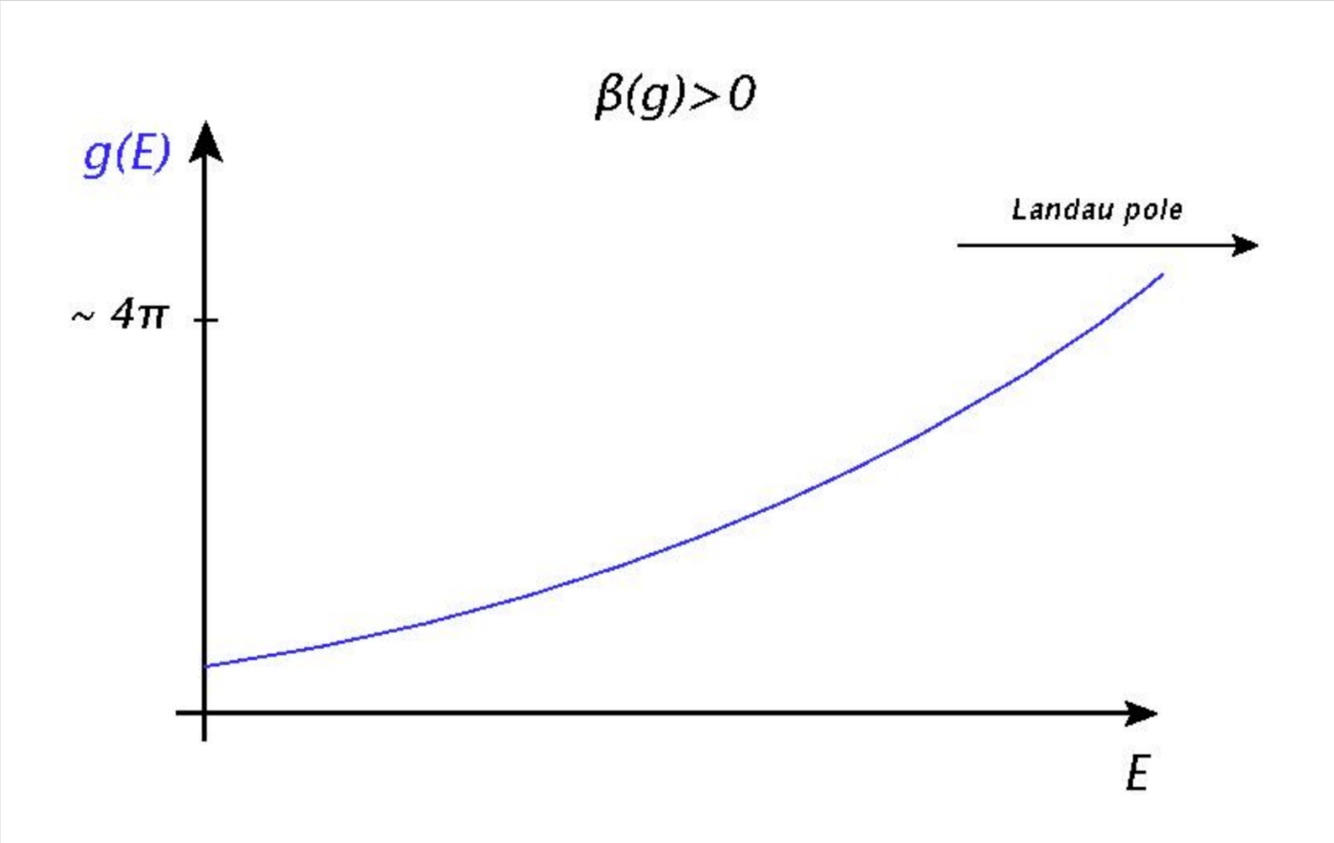
Landau pole: $g(q) \to \infty$ as $q \to q_0$

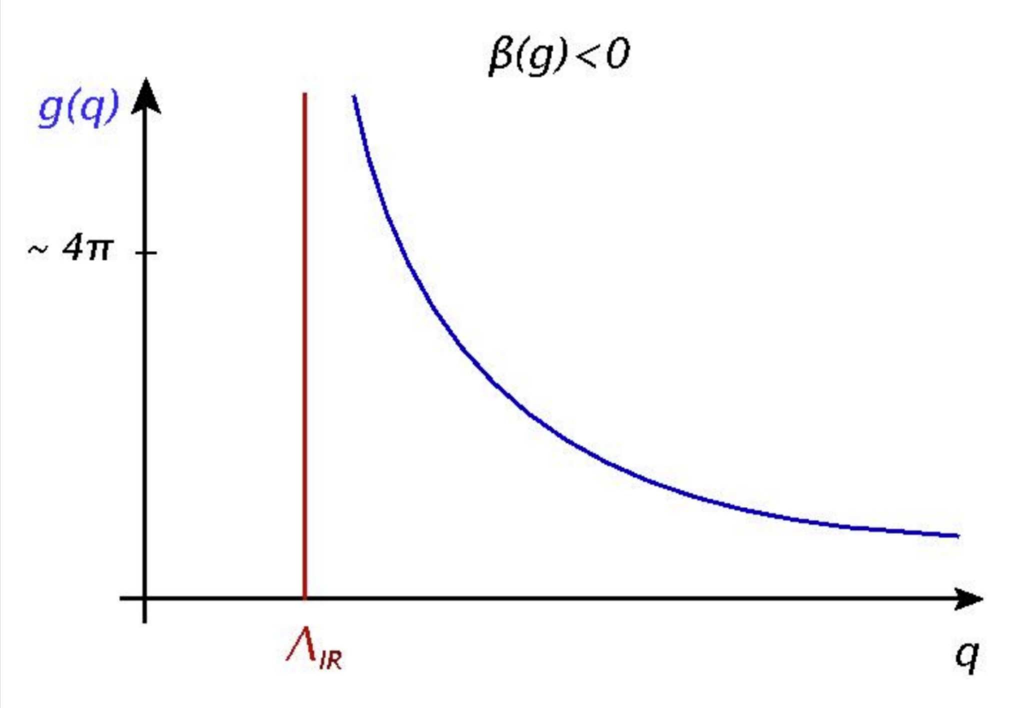
Needs UV completion



Asymptotic Safety

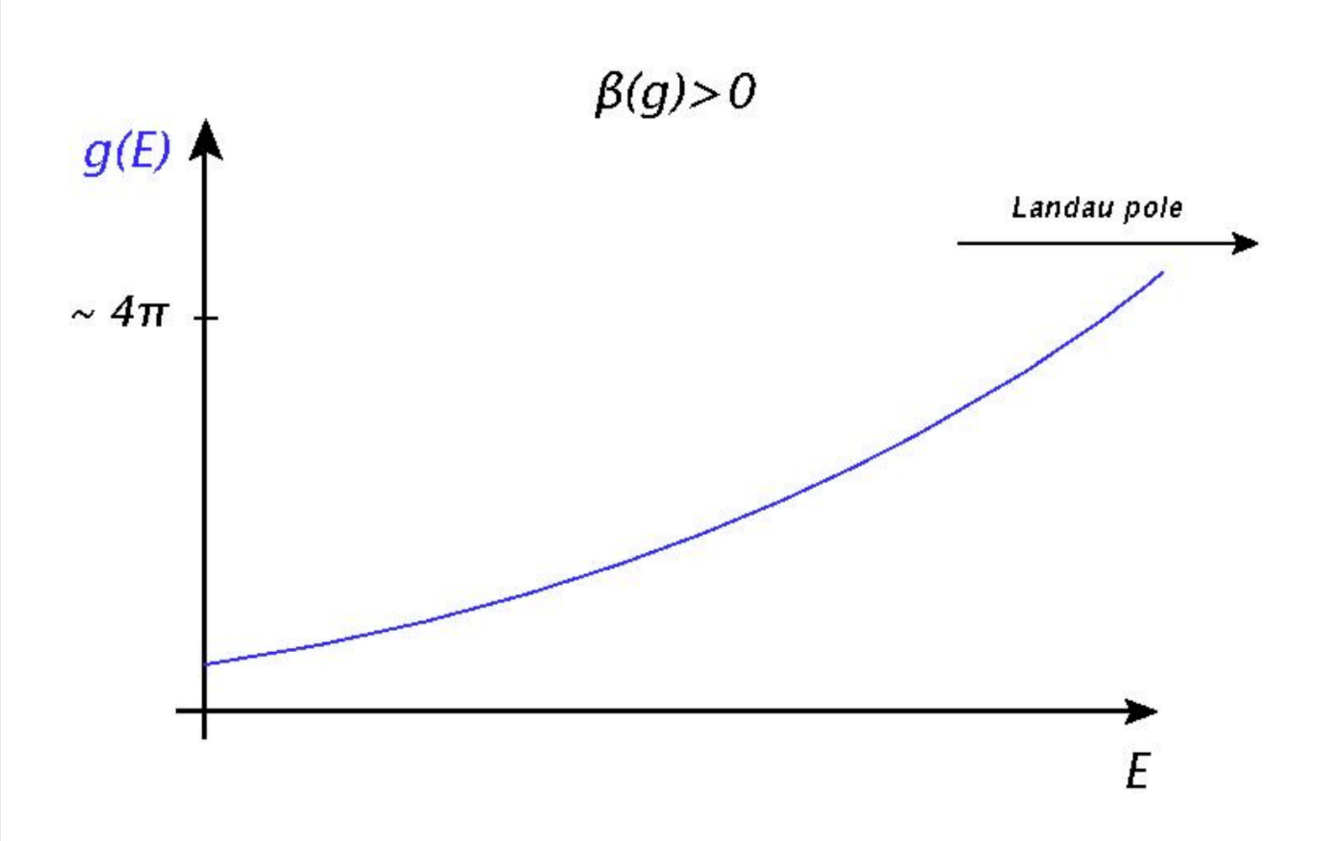
Coupling constants are scale dependent

Asymptotic freedom: $g(q) \to 0$ as $q \to \infty$



Landau pole: $g(q) \to \infty$ as $q \to q_0$

Needs UV completion



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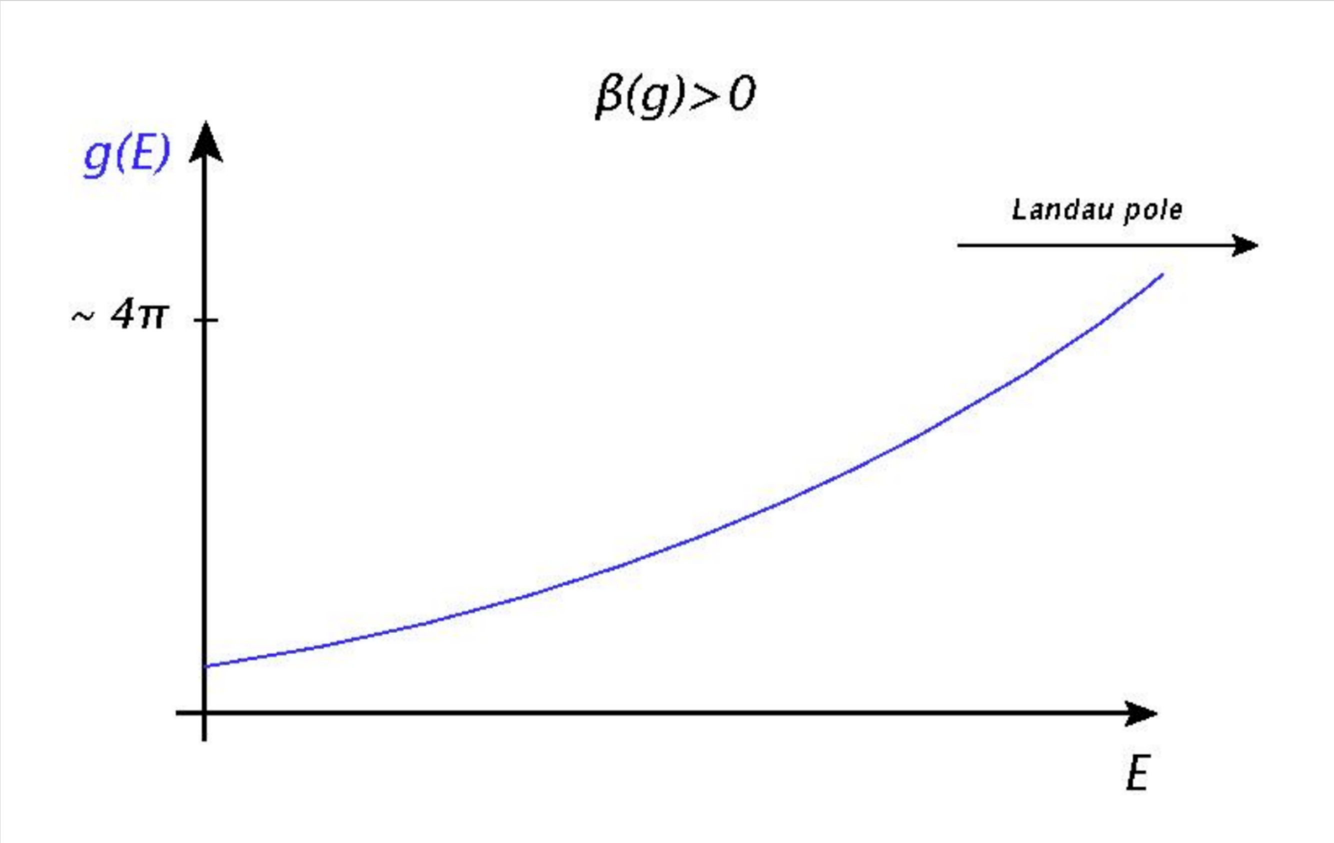

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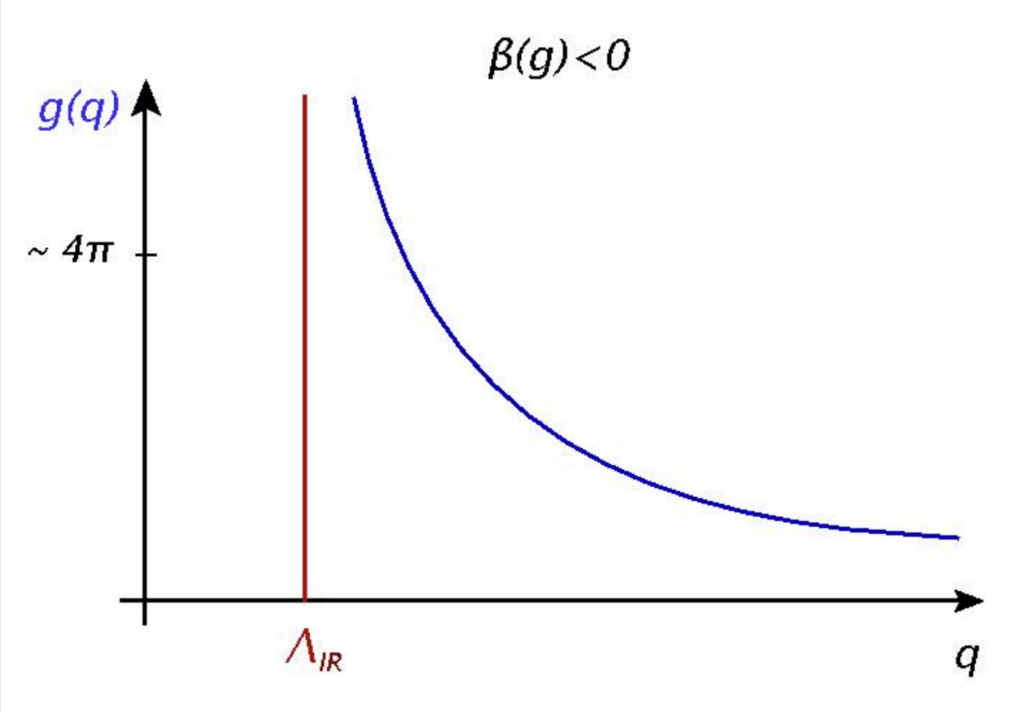
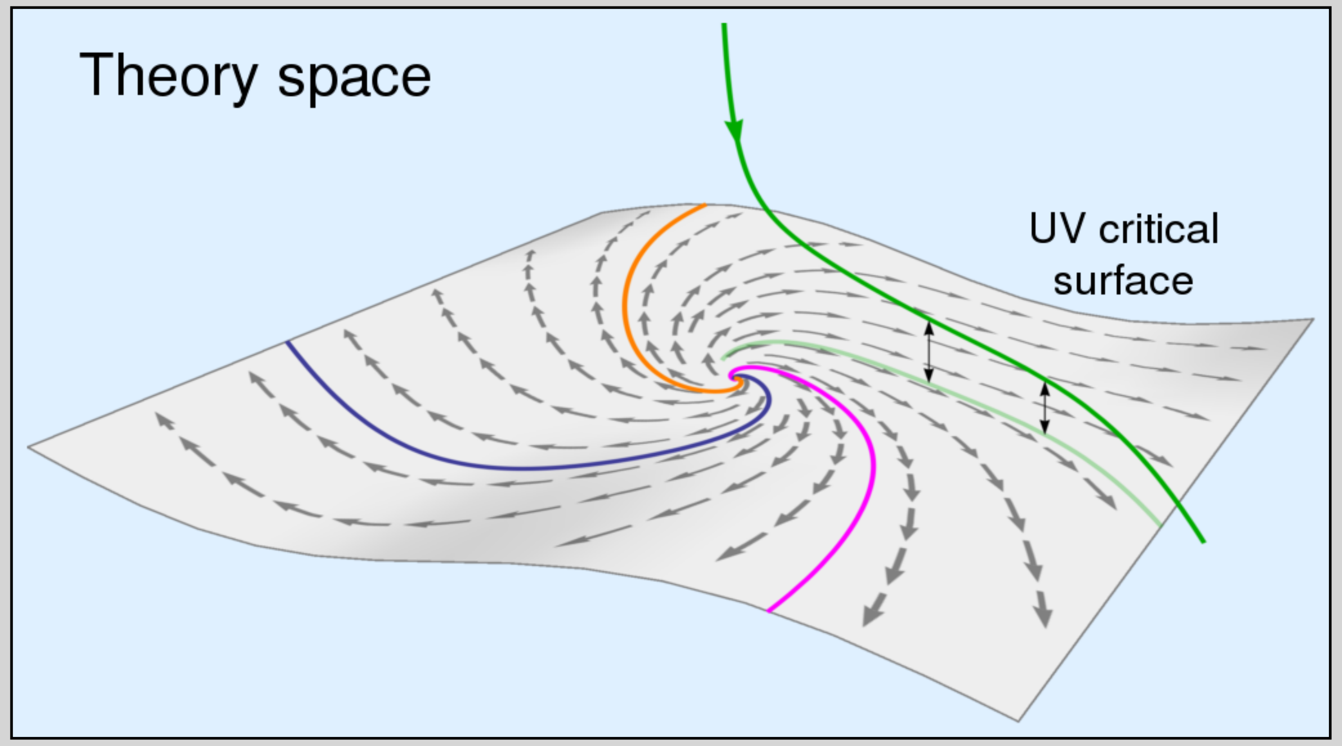
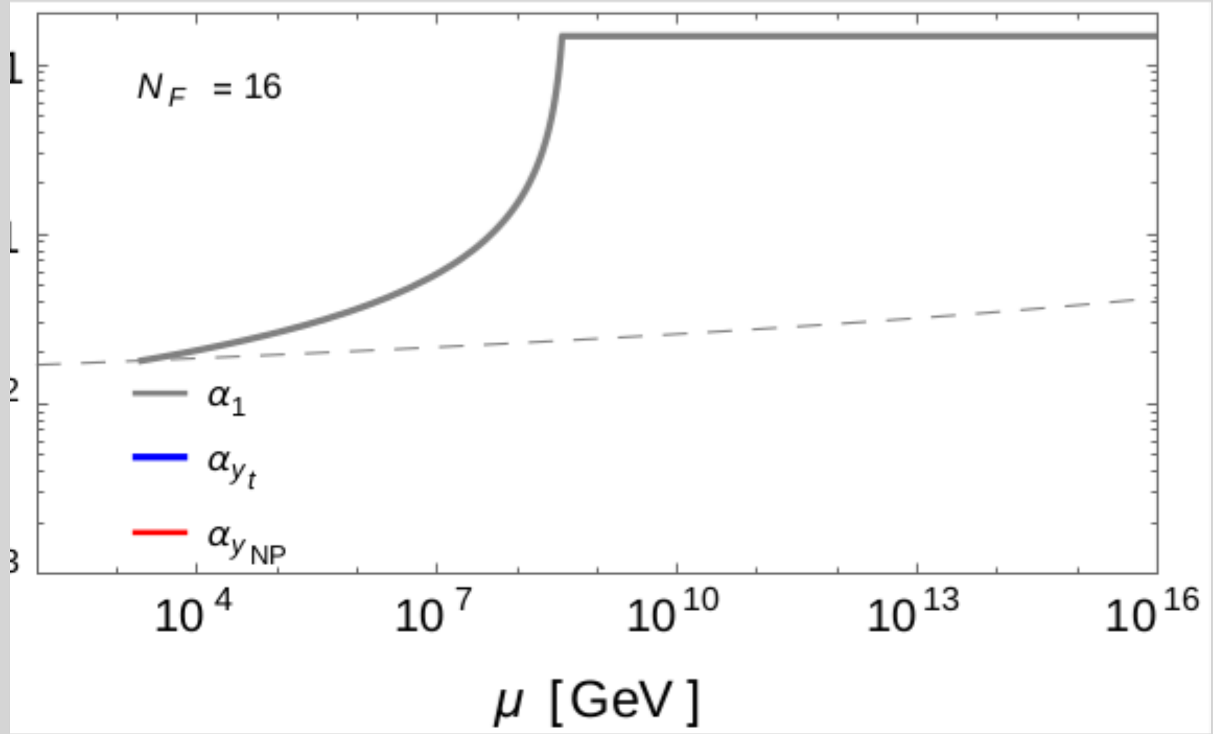


From Wikipedia





Asymptotic safety: $\{g_i\} \to \{g_i^*\}$ as $q \to \infty$

Asymptotic safety with gravity

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Gauge coupling: $\beta_g = \beta_g^{SM+NP} - f_g g$

Yukawa coupling: $\beta_y = \beta_y^{SM+NP} - f_y y$

Quantum-Gravitational contribution

In principle via FRG

Universal: Does not distinguish internal symmetry

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, ...

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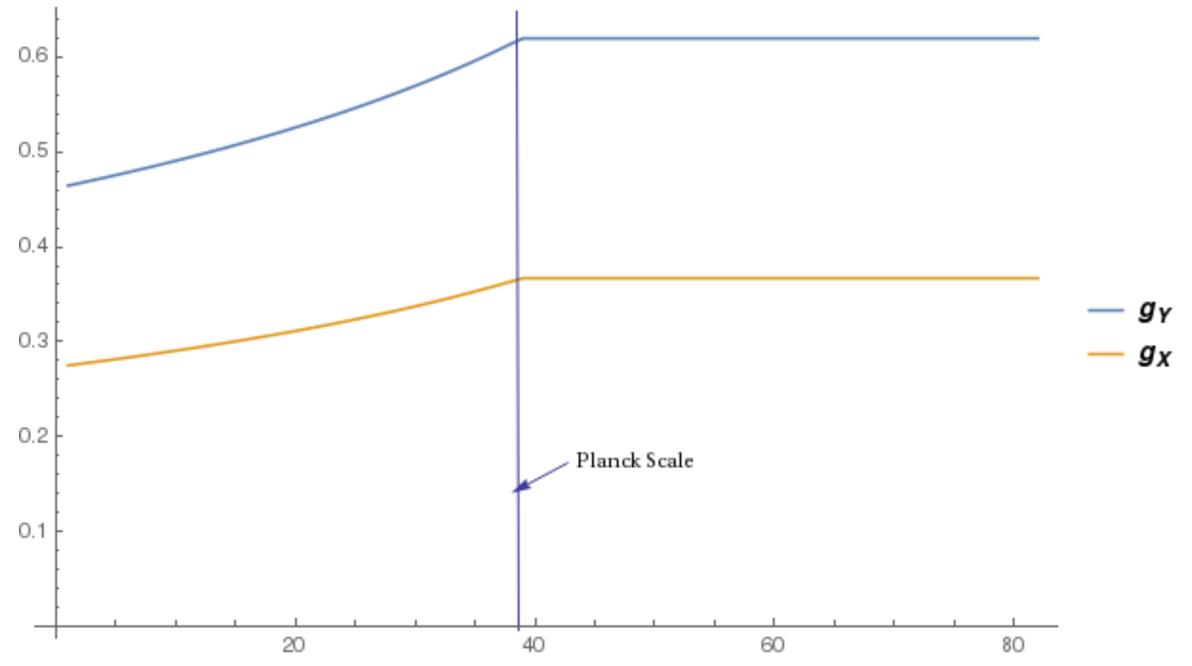
f_g and f_y are free parameters determined by matching low-energy data

Eg: $\beta_{g_Y} = \frac{139}{30} g_Y^3 - f_g g_Y \qquad \beta_{g_X} = 11 g_X^3 - f_g g_X$

FP: $\beta_i(\{g_i\})\Big|_{g_i^*} = 0; \implies g_Y^* = \sqrt{\frac{30}{139} f_g} \qquad g_X^* = \sqrt{11 f_g}$



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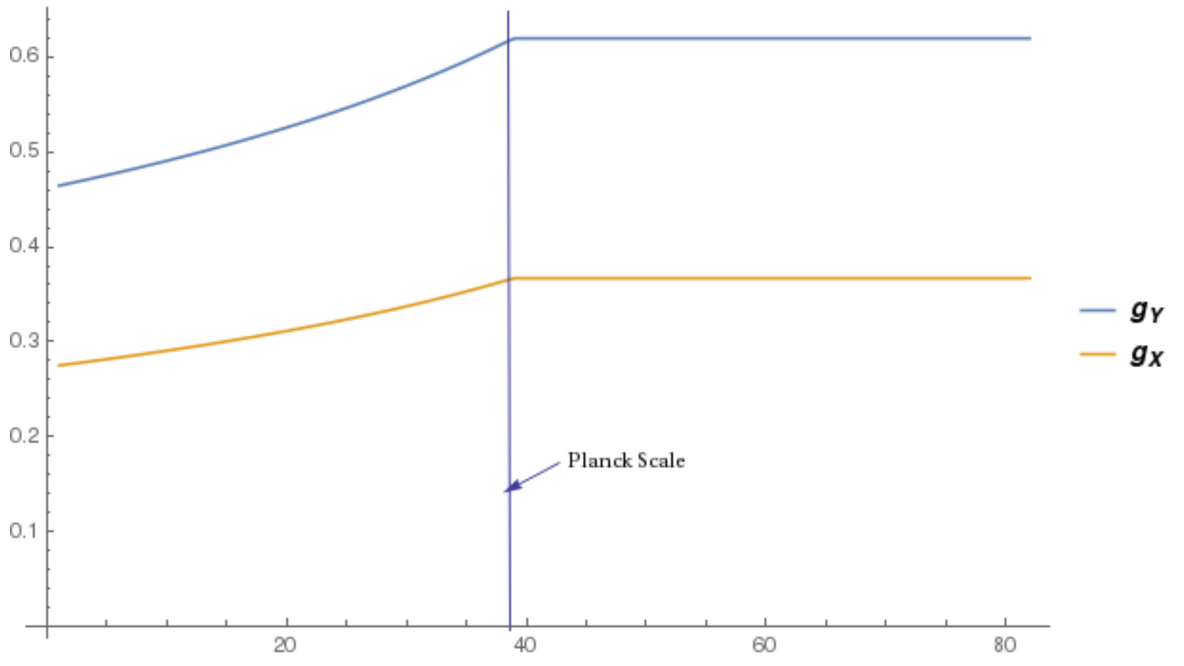
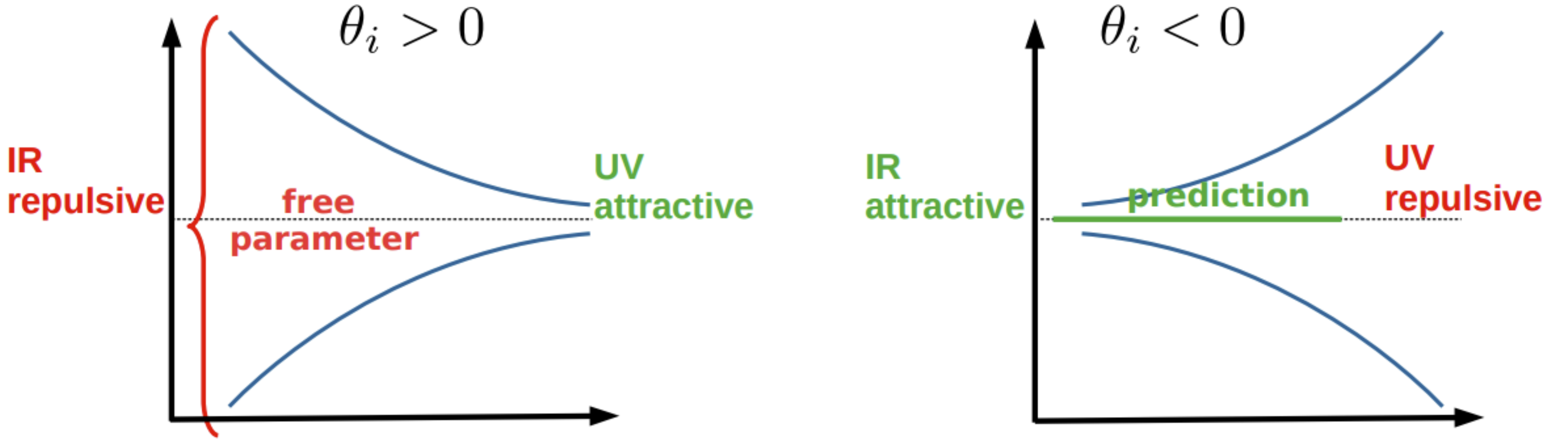


Fixed point properties:

$$\beta_i(\{g_i\}) = 0 \longrightarrow M_{ij} = \frac{\partial \beta_i}{\partial g_j}\Big|_{\{g_i^*\}} \longrightarrow \{\theta_i\}$$

Stability Matrix — Critical Exponents



Relevant couplings are free parameters of the theory

Irrelevant couplings provide predictions

Fixed Point Analysis

Fixed Point Analysis

Important couplings for flavor anomalies:

SM: $g_3, g_2, g_Y, y_b, y_t, V_{33}$

NP: $g_D, g_\epsilon, Y_{Q,2}, Y_{Q,3}, Y_{L,2}$

With 2 family approximation

Irrelevant couplings

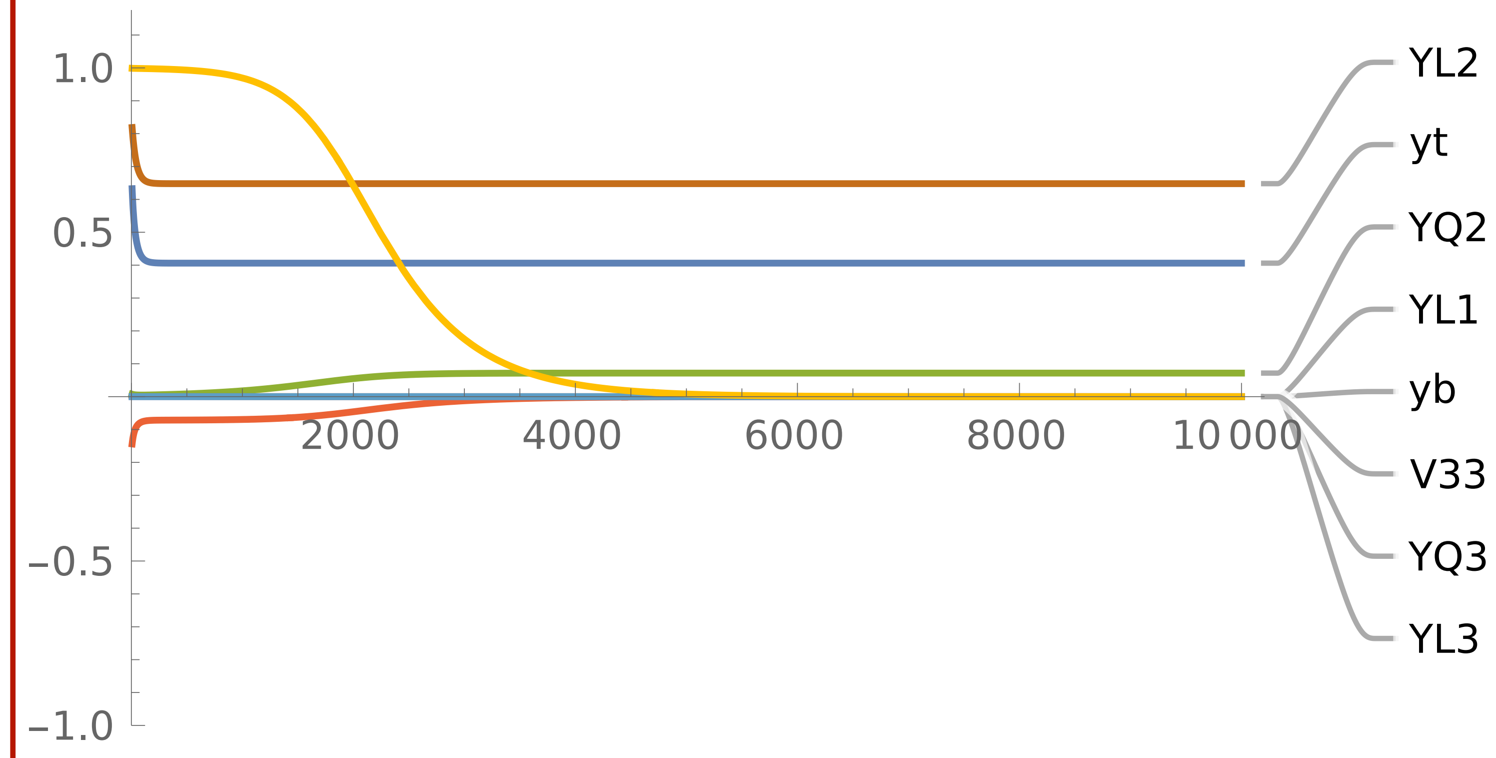
$$g_Y^* \neq 0,\ y_t^* \neq 0$$

$$g_D^* \neq 0,\ g_\epsilon^* \neq 0$$

$$Y_{Q,i}^* \neq 0,\ Y_{L,2}^* \neq 0$$

Relevant couplings

$$g_3^* = g_2^* = y_b^* = V_{33}^* = 0$$



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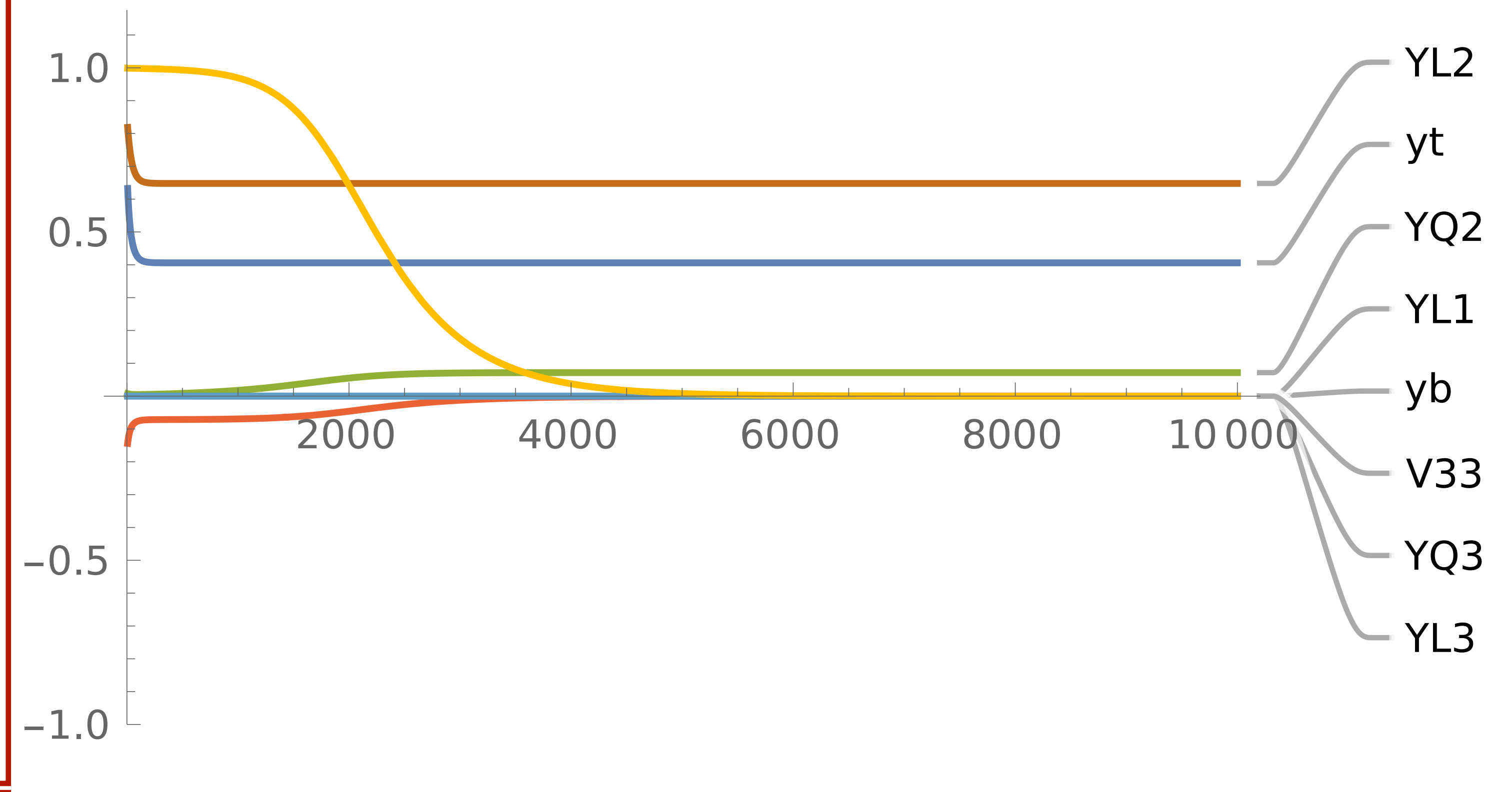

Predictions vary based on the models and the fixed points

	$g_Y(Q_0)$	$g_D(Q_0)$	$g_\epsilon(Q_0)$	$y_t(Q_0)$	$Y_{Q,3}(Q_0)$	$Y_{Q,2}(Q_0)$	$Y_{L,2}(Q_0)$
$\mathrm{FP}_{1A,a}$	0.364	0.305	0	1.08	-0.381	0.016	0.823
$\mathrm{FP}_{1A,b}$	0.364	0.305	0	1.09	0.034	0.803	0.606
$\mathrm{FP}_{1B,a}$	0.363	0.318	0.110	1.05	-0.612	0.296	0.652
$\mathrm{FP}_{1B,b}$	0.363	0.318	0.110	1.08	0.004	0.874	0.499
$\mathrm{FP}_{2,a}$	0.363	0.277	0.052	1.03	-0.700	0.638	–
$\mathrm{FP}_{2,b}$	0.363	0.277	0.052	1.10	0.040	0.988	–

CC values at $Q_0 = 2\,TeV$

Phenomenology

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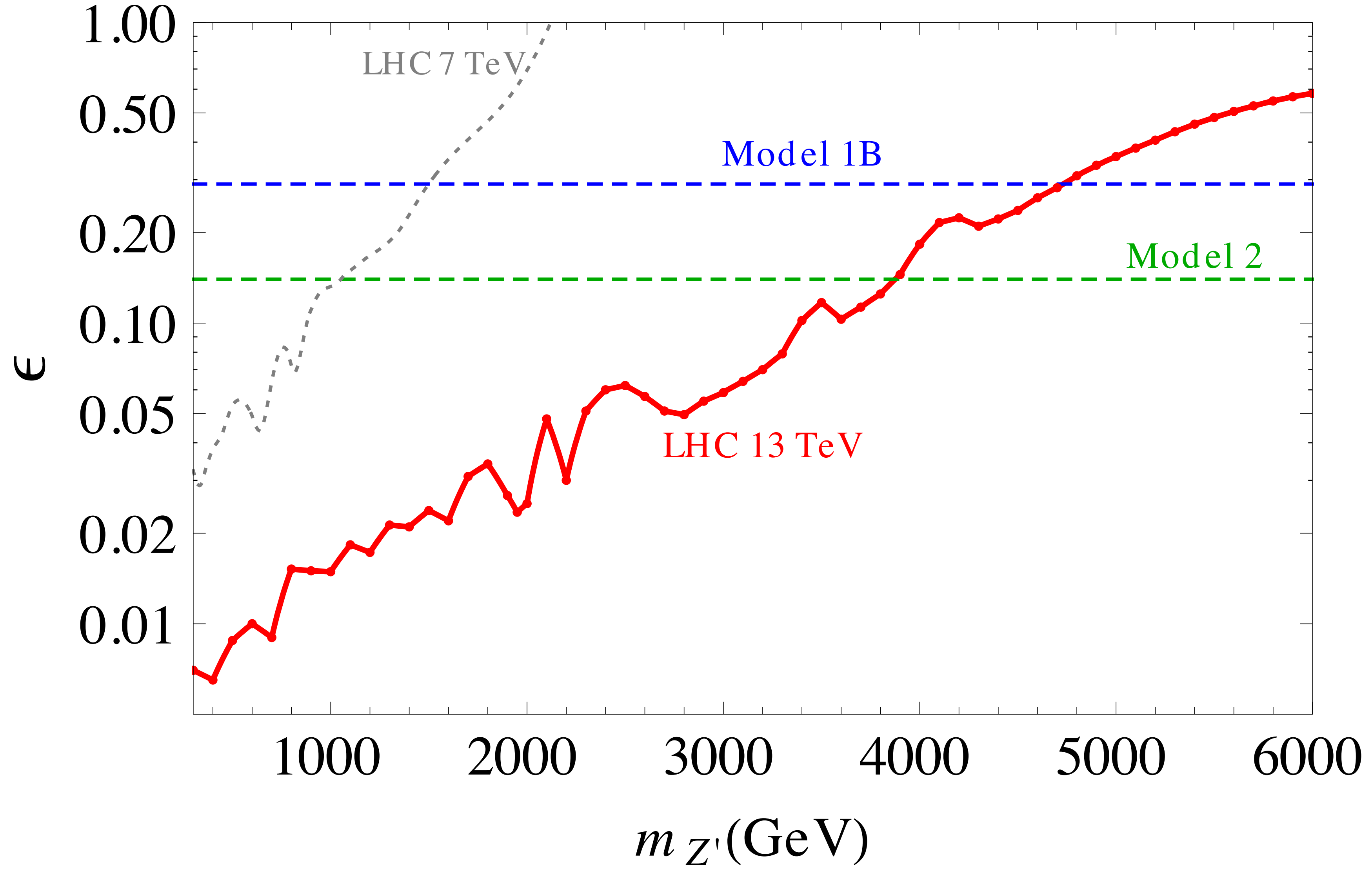
Kinetic terms of gauge coupling:

$$\mathscr{L} \supset -\frac{1}{4}W^i_{\mu\nu}W^{i\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}X_{\mu\nu}X^{\mu\nu} - \frac{1}{2}\epsilon\, B_{\mu\nu}X^{\mu\nu}$$

$$\epsilon = \frac{g_\epsilon}{\sqrt{g_y^2 + g_\epsilon^2}}$$

$\Longrightarrow m_{Z'} > 3.9$ TeV Model 2

$m_{Z'} > 4.8$ TeV Model 1B



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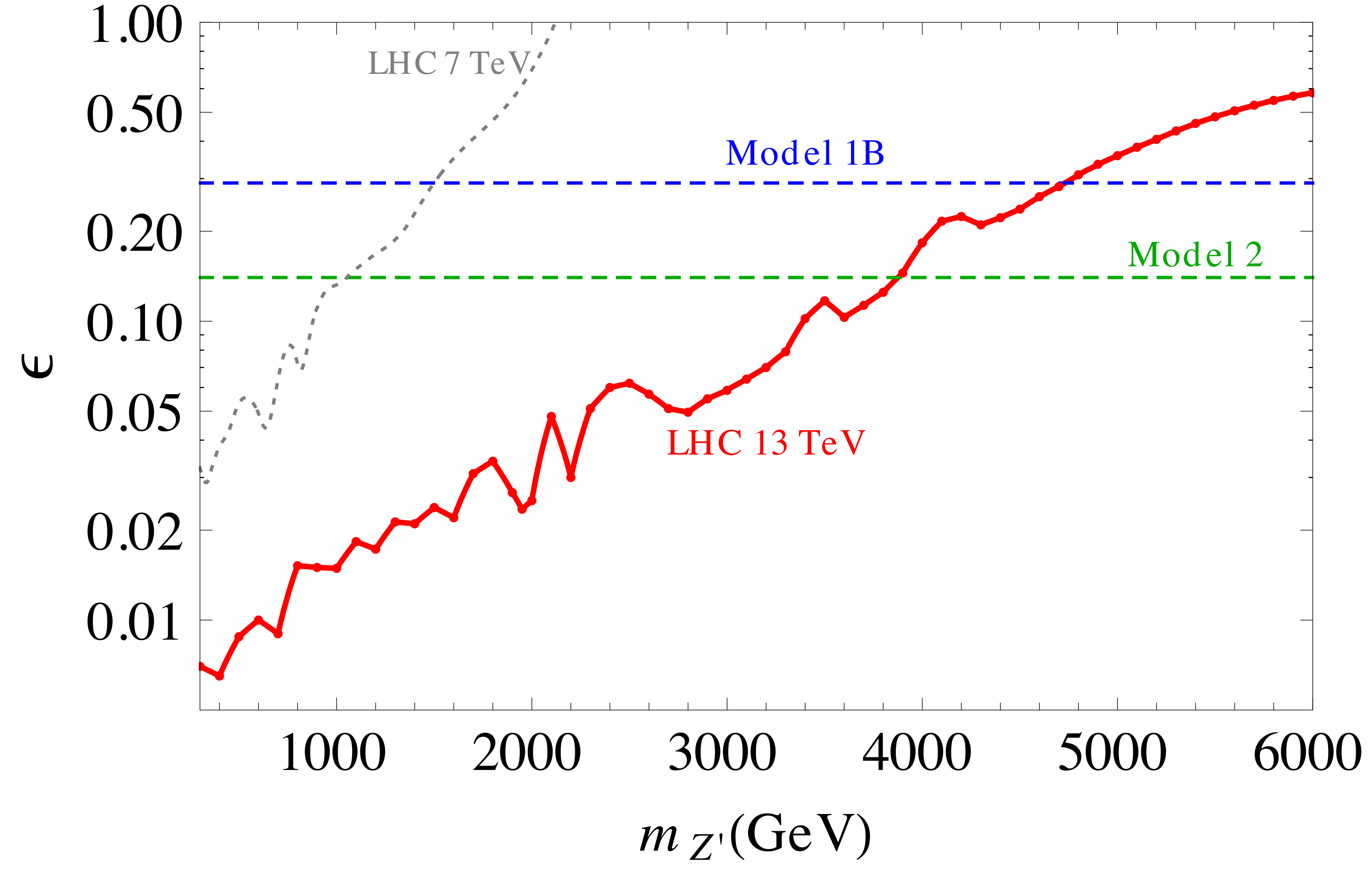
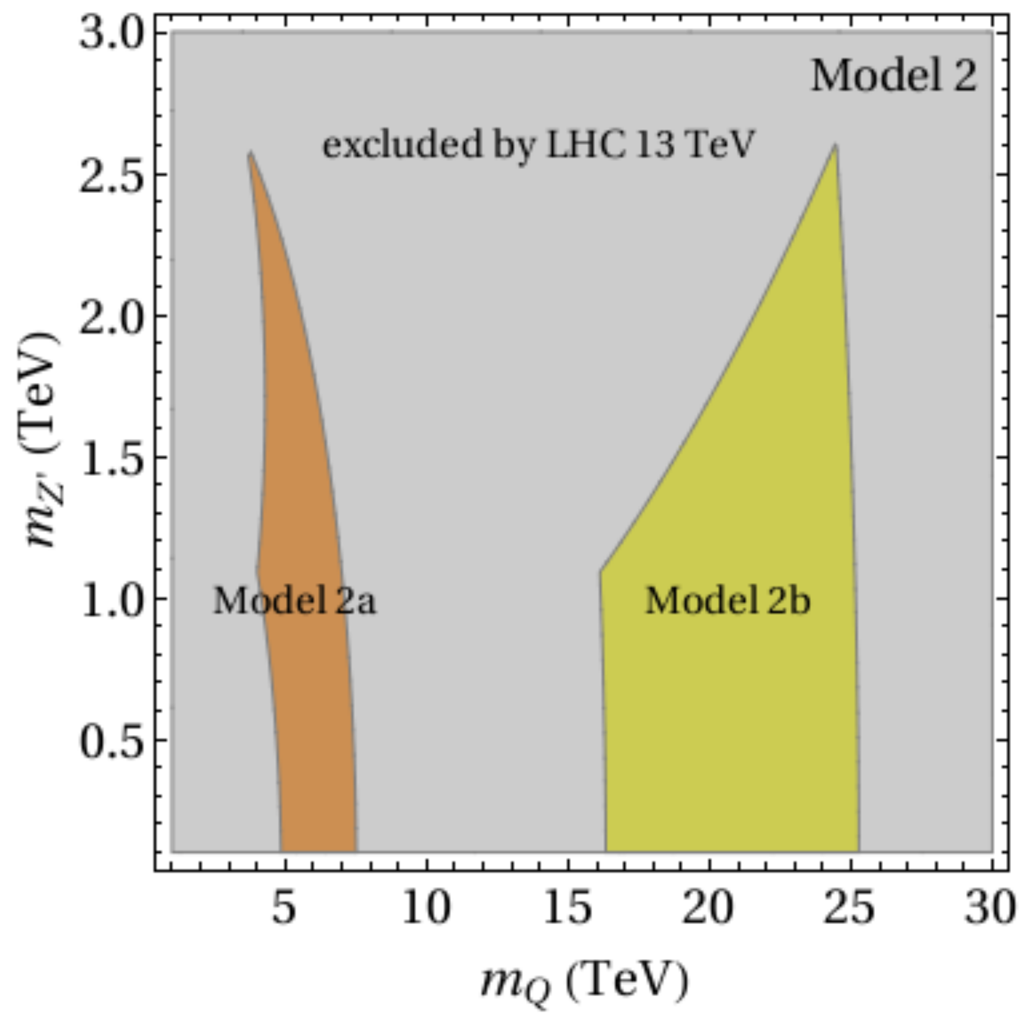
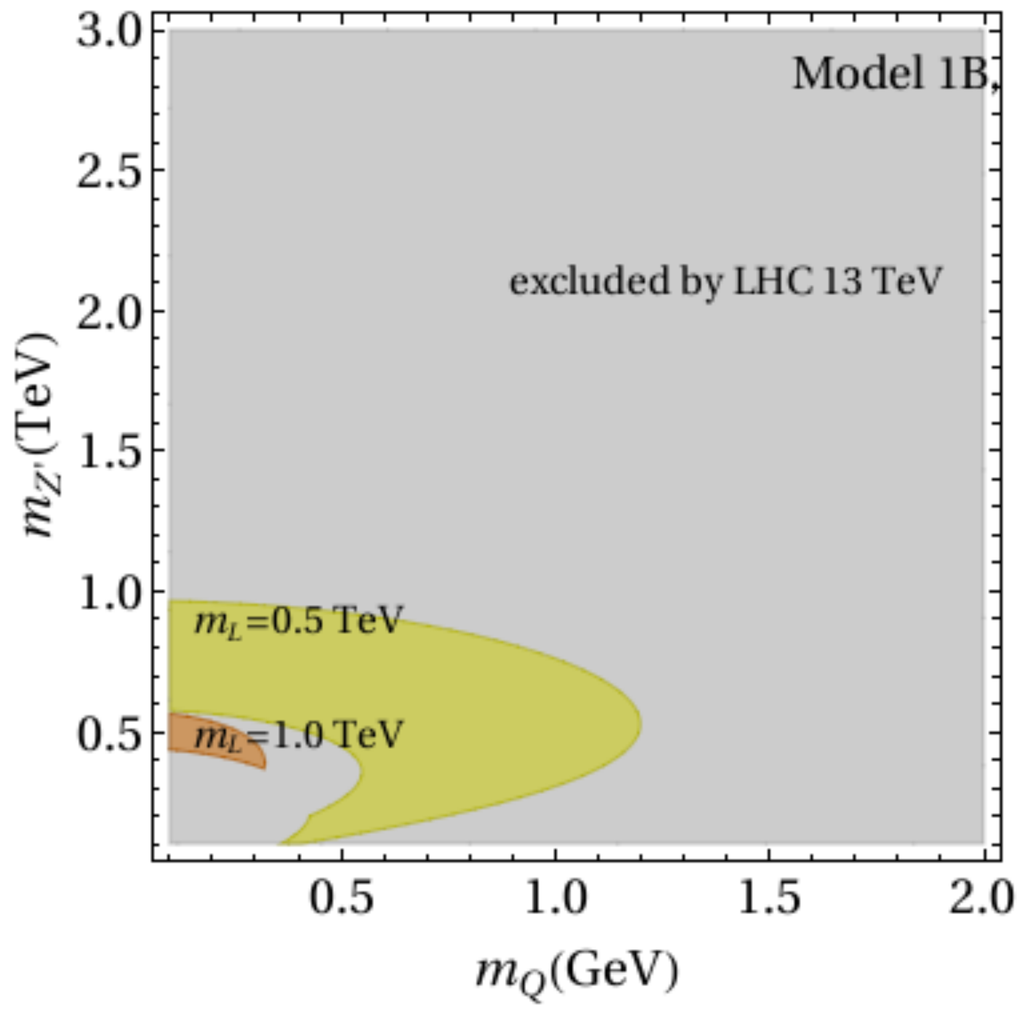
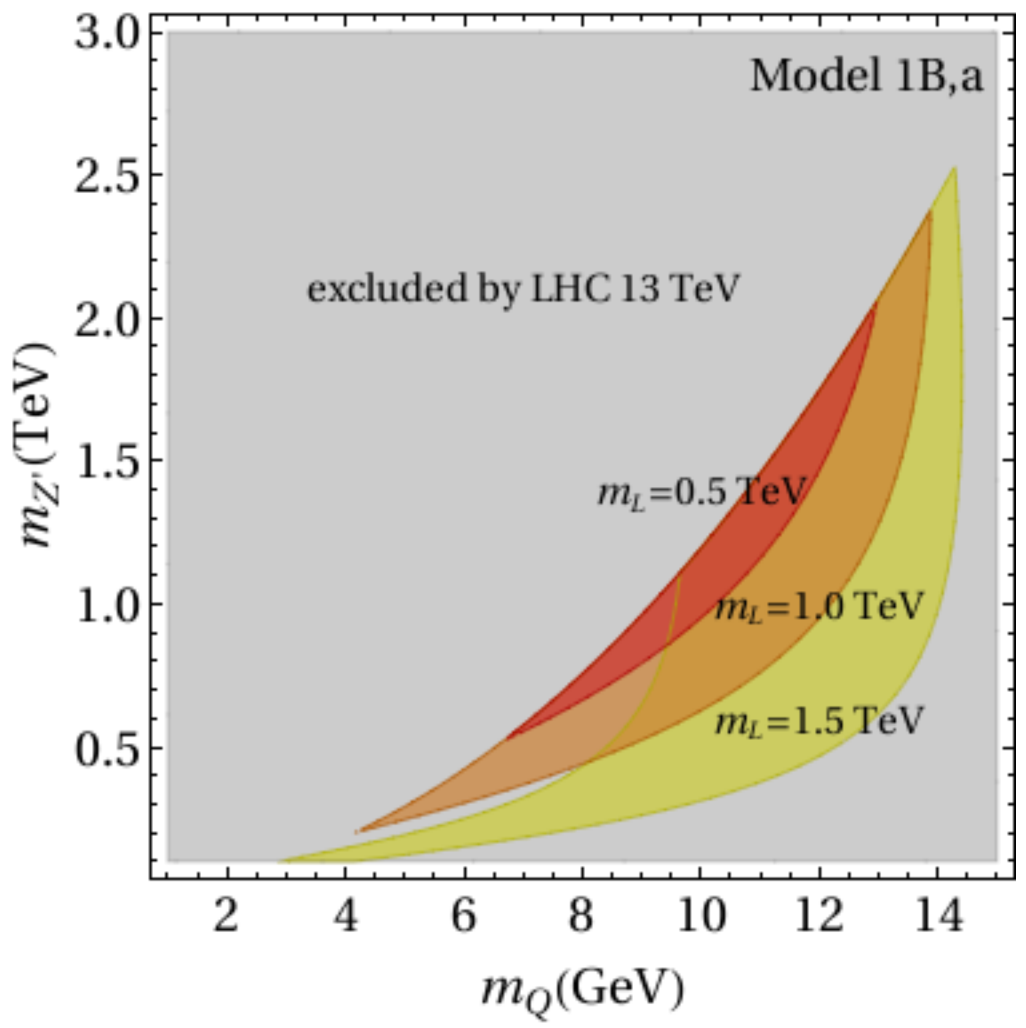
$$m_{Z'} > 4.8 \text{ TeV} \quad \text{Model 1B}$$









Phenomenology

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Model 1A:

No direct constraint from kinetic mixing

But, constraints from B-meson mixing

$$R_{\Delta M_s} = \frac{\lambda_{Q,2}^2 \lambda_{Q,3}^2 v_h^2 v_S^2}{\left(2m_Q^2 + \lambda_{Q,2}^2 v_S^2 + \lambda_{Q,3}^2 v_S^2\right)^2} \left[\frac{g_2^2}{16\pi^2} \left(V_{tb} V_{ts}^*\right)^2 S_0\right]^{-1}$$

Altmannshofer, Straub arXiv:1411.3161 [hep-ph]

Phenomenology

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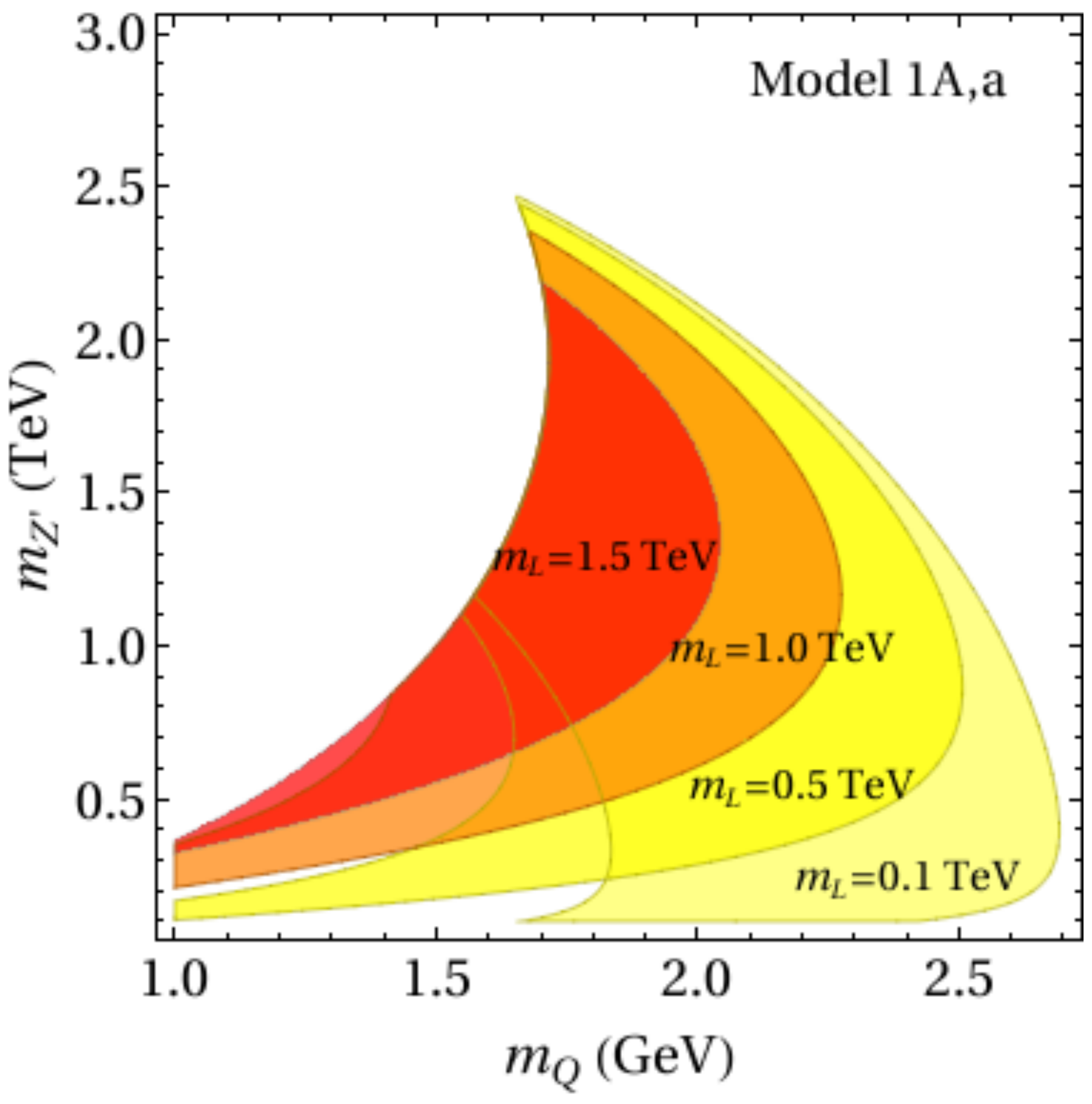
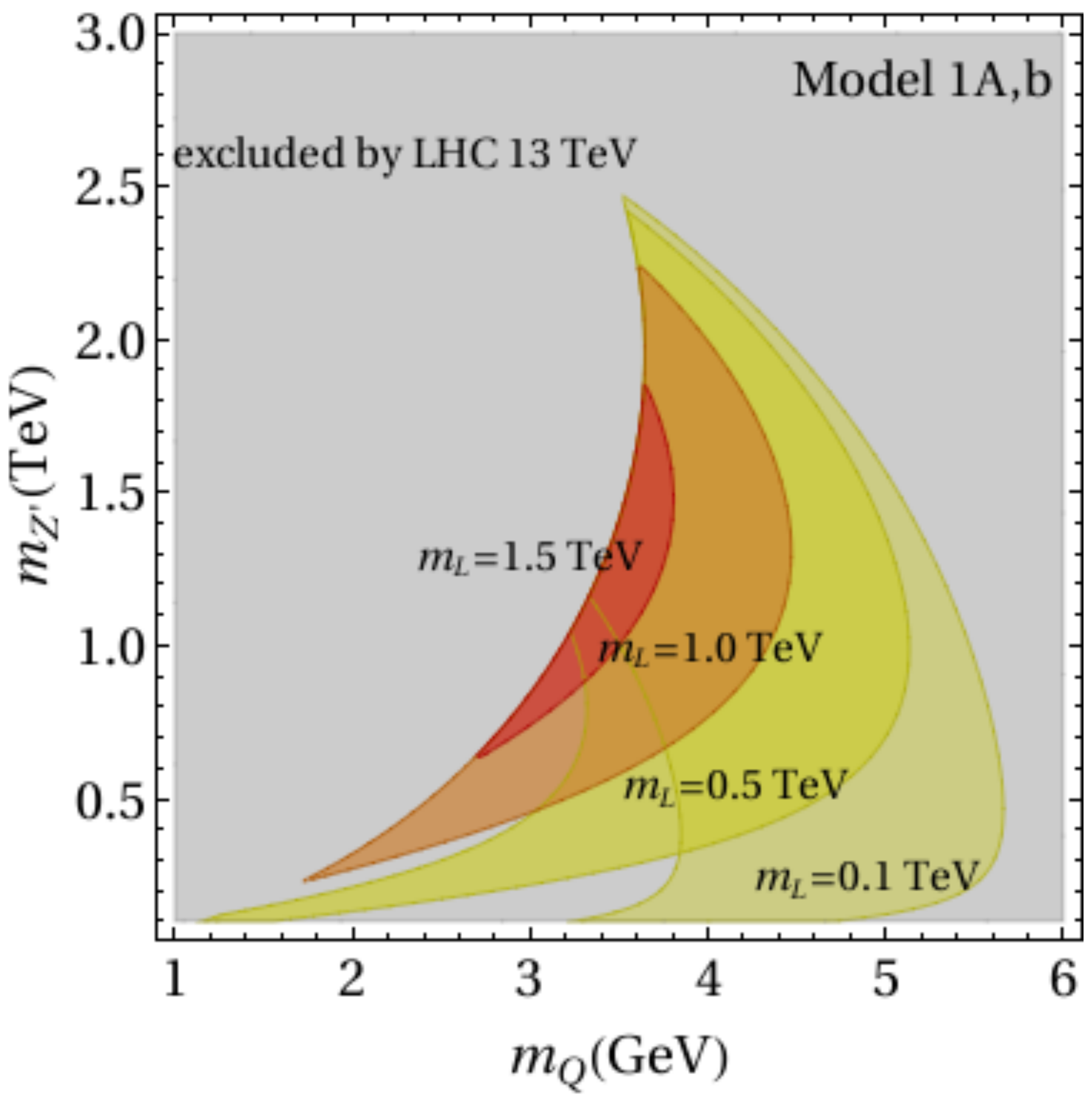
Altmannshofer, Straub arXiv:1411.3161 [hep-ph]

$Y_{Q2} = 0.016$



$Y_{Q2} = 0.803$



Conclusion

- The flow of coupling constants from an UV fixed point gave low-scale values
- Only assumption was existence of deep UV interactive fixed point
- Data from LHC Run at 13 TeV can already exclude few scenarios
- Asymptotic safety can be a new tool to further limit the parameter space of the New Physics models

Thank you