Towards an asymptotically safe completion of the Standard Model

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based on 1702.01727 and work in progress
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Overview

Basics of asymptotic safety

The set of RGEs for gauge ($SU(N_c)$) and Yukawa couplings:

$$\beta_g = \frac{d\alpha_g}{d\ln\mu} = \alpha_g^2(-B + C\alpha_g - D\alpha_y)$$

$$\beta_y = \frac{d\alpha_y}{d\ln\mu} = \alpha_y(E\alpha_y - F\alpha_g)$$

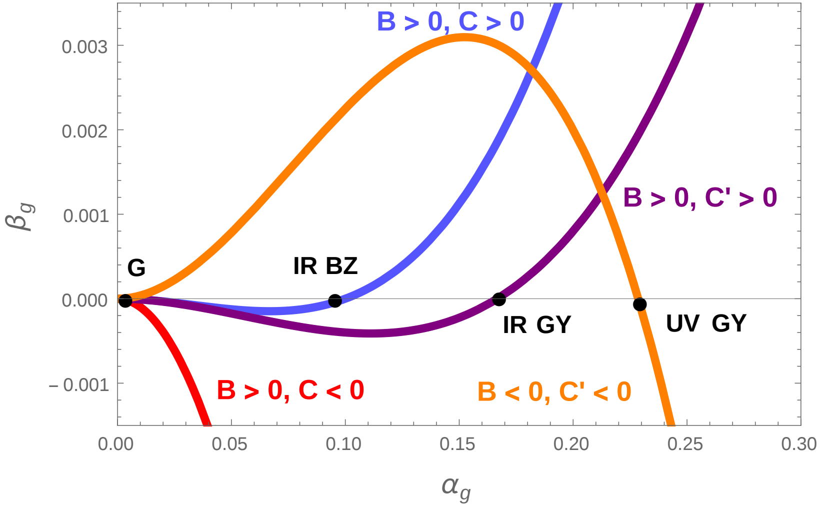
(where $\alpha_g = \frac{g^2}{(4\pi)^2}$, $\alpha_y = \frac{y^2}{(4\pi)^2}$)

- $B > 0$ (asymptotic freedom) or $B < 0$ (asymptotic safety)
- $C > 0$ if $B < 0$ in any QFT (proof in *Bond, Litim, arXiv:1608.00519)*
- $D, E, F > 0$ for any quantum field theory
- $C' = C - \frac{DF}{E}$

$$\boldsymbol{\beta_i(\alpha_i^*) = 0}$$

Basics of asymptotic safety

Different types of fixed points possible:



Asymptotically safe extensions of the SM

The setting:

(following *Litim, Sannino, JHEP 1412 (2014) 178, arXiv:1406.2337)*

N_F flavors of VL BSM fermions ψ_i

$$SU(3)_C \times SU(2)_L \times U(1)_Y$$

$$\psi_i(R_3, R_2, Y)$$

$N_F \times N_F$ scalar singlets S_{ij}

$$\mathcal{L} \sim -y(\bar{\psi}_{Li} S_{ij} \psi_{Rj} + \bar{\psi}_{Ri} S^\dagger_{ij} \psi_{Lj})$$

In this talk: we neglect the effects from the scalar potential (three loop effect) and SM Yukawas

Case 1: $\mathbf{R_3 \neq 0,\ R_2 \neq 0,\ Y = 0}$

Renormalization group equations

$$
\begin{aligned}
\beta_3 &\equiv \frac{d\alpha_3}{d\ln\mu} = (-B_3 + C_3\,\alpha_3 + G_3\,\alpha_2 - D_3\,\alpha_y)\,\alpha_3^2\,,\\
\beta_2 &\equiv \frac{d\alpha_2}{d\ln\mu} = (-B_2 + C_2\,\alpha_2 + G_2\,\alpha_3 - D_2\,\alpha_y)\,\alpha_2^2\,,\\
\beta_y &\equiv \frac{d\alpha_y}{d\ln\mu} = (E\,\alpha_y - F_2\,\alpha_2 - F_3\,\alpha_3)\,\alpha_y\,.
\end{aligned}
$$

where we define

$$
\alpha_2 = \frac{g_2^2}{(4\pi)^2}\,, \qquad \alpha_3 = \frac{g_3^2}{(4\pi)^2}\,, \qquad \alpha_y = \frac{y^2}{(4\pi)^2}
$$

UV fixed points

Possible types of fixed points:

case	gauge couplings		BSM Yuk	type	info
FP$_1$	$\alpha_3^* = 0$	$\alpha_2^* = 0$	$\alpha_y^* = 0$	**G · G**	non-interacting
FP$_2$	$\alpha_3^* = 0$	$\alpha_2^* > 0$	$\alpha_y^* > 0$	**G · GY**	partially interacting
FP$_3$	$\alpha_3^* > 0$	$\alpha_2^* = 0$	$\alpha_y^* > 0$	**GY · G**	partially interacting
FP$_4$	$\alpha_3^* > 0$	$\alpha_2^* > 0$	$\alpha_y^* > 0$	**GY · GY**	fully interacting

The existence of a UV fixed point depends on transformation properties under $SU(3)_C \times SU(2)_L$ and N_F.

UV fixed points

An example: $\mathbf{FP_3}$ ($\alpha_3^* > 0$, $\alpha_2^* = 0$)

	$\mathbf{R_2 = 1}$		$\mathbf{R_2 = 2}$		$\mathbf{R_2 = 3}$	
$\mathbf{R_3}$	N_{AF}	N_{AS}	N_{AF}	N_{AS}	N_{AF}	N_{AS}
3	10	–	6	–	3	–
6	2	37	1	77	–	116
8	1	95	–	198	–	299
10	–	17	–	34	–	51
15	–	30	–	60	–	90
$\mathbf{15'}$	–	17	–	33	–	50

- AF is lost if $B_3 < 0$
- physicality condition $D_3 F_3 - E C_3 > 0$
- $N_F \cdot \alpha_3 \sim \mathcal{O}(1 - 10)$

Matching onto the SM

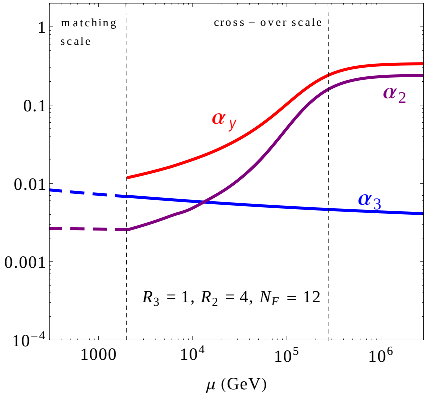
UV fixed point should be connected through a RG trajectory with the SM

- partially interacting UV fixed point: one relevant, one irrelevant, one marginal eigendirection $\rightarrow$ 2D critical surface given by $\alpha_y(\alpha_{AS})$.

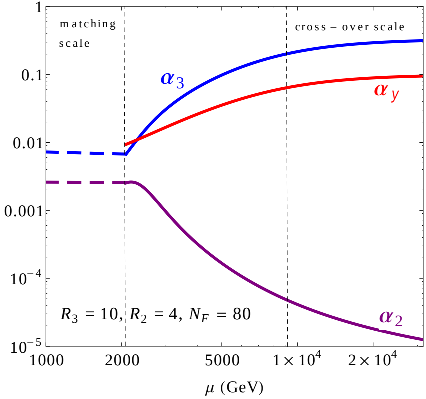
- fully interacting UV fixed point: 1 relevant, 2 irrelevant eigendirection $\rightarrow$ 1D critical surface with $\alpha_y(\alpha_3)$ and $\alpha_2(\alpha_3)$

Matching at any scale: partially interacting fixed points

FP_2
model A
$(R_3, R_2, N_F) = (\mathbf{1}, \mathbf{4}, 12)$



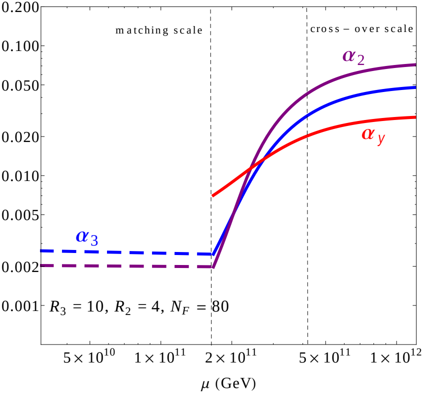
FP_3
model C
$(R_3, R_2, N_F) = (\mathbf{10}, \mathbf{4}, 80)$



Matching onto the SM

High scale matching: fully interacting fixed point

FP_4
model C
$(R_3, R_2, N_F) = (\mathbf{10}, \mathbf{4}, 80)$



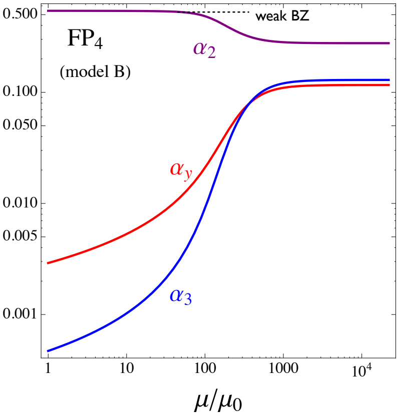
- matching scale is fixed
- enhanced predictivity with respect to the SM

$$\alpha_2 = F(\alpha_3)$$

Matching onto the SM

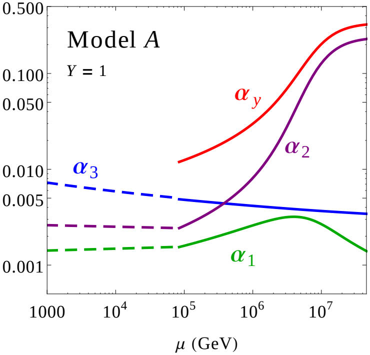
No matching (all models with $R_2 = 1$): trajectory attracted to BZ IR FP

$\mathbf{FP_4}$
model B
$(R_3, R_2, N_F) = (\mathbf{10}, \mathbf{1}, 30)$

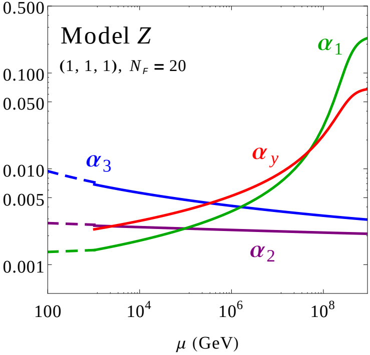


Case 2: we add Y $\neq$ 0

There is always a lower bound on the hypercharge, above which α_1 becomes asymptotically free.



It is also possible to make α_1 asymptotically safe.



Summary

- Yukawa couplings offer the **ONLY** dynamical mechanism to obtain interacting fixed points in gauge theories.
- To make the SM asymptotically safe new fermions in reps. higher then fundamental are required.
- Matching with the SM possible for certain types of FP and matter content.
- There are experimental signatures to test at the colliders (running of the couplings, precision observables, R-hadrons, diboson searches).
- Perturbativity should be closer analyzed.