Landau pole and 331 models

Giulia Ricciardi

Universita' di Napoli Federico II

3-3-1 Extensions of the Standard Model

SM : $SU_C(3) \times SU_L(2) \times U_Y(1)$

quarks	leptons
$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$	$\begin{pmatrix} \nu_L \\ l_L \end{pmatrix}$
- Requires one spontaneous symmetry breaking
  $SU_C(3) \times SU_L(2) \times U_Y(1) \to \times SU_C(3) \times U_{em}(1) \Rightarrow$
  $\Rightarrow$ one scalar doublet
gauge bosons = 3 + 1	
massive	massless
$W^\pm_\mu, Z_\mu$	A_μ
- Gell-Mann Nishijima relation $Q = T_3 + \frac{Y}{2}\mathbb{I}$
- Gauge anomaly cancellation for each family :

BSM : $SU_C(3) \times SU_L(3) \times U_X(1)$

quarks	leptons
$\begin{pmatrix} u_L \\ d_L \\ D_L \end{pmatrix}$	$\begin{pmatrix} \nu_L \\ l_L \\ \xi \end{pmatrix}$
- Requires two spontaneous symmetry breakings
  $SU_C(3) \times SU_L(3) \times U_X(1) \to SU_C(3) \times SU_L(2) \times U_Y(1) \to \times SU_C(3) \times U_{em}(1) \Rightarrow$
  $\Rightarrow$ two scalar triplets
gauge bosons = 8 + 1	
massive	massless
$W^\pm_\mu, Z_\mu, W'^\pm_\mu, Z'_\mu, Y^{\pm\pm}_\mu$	A_μ
- Gell-Mann Nishijima relation
  $Q = T_3 + \beta T_8 + X\mathbb{I} = T_3 + \frac{Y}{2}$ $\to \beta = \pm\sqrt{3}, \pm\frac{1}{\sqrt{3}}$
- Overall gauge anomaly cancellation: $N_F^{\text{lept}} = N_F^{\text{quark}} = N_F$,

Assumptions

- each SU (3)L charged fermion has a right-handed counterpart
- all exotic families are replicas of the standard ones

$$N_F \equiv N_q = N_\ell,$$

$$N_q^3 = \frac{2N_F - N_\ell^3}{3}$$

- QCD asymptotically free

$$n_{\text{quark}} = 3N_F < \frac{33}{2}$$

$$N_F = 3, 4, 5$$

- exotic gauge bosons of the 331 model have integer charge values
- matching the Z boson coupling

$$\beta = \pm 1/\sqrt{3}, \pm\sqrt{3}.$$

Minimal 331-model with $\beta = \sqrt{3}$

$$N_3^{\text{lept fam}} = 3,\ N_3^{\text{quark fam}} = 2,\ N_{\bar{3}}^{\text{quark fam}} = 1$$

$$\begin{pmatrix} l_L^a \\ -\nu_L^a \\ \xi_L^a \end{pmatrix}$$

	$SU_C(3) \times SU_L(3) \times U_X(1)$		
$\begin{pmatrix} u_L^{1,2} \\ d_L^{1,2} \\ D_L^{1,2} \end{pmatrix}$	3	3	$-\frac{1}{3}$
$\begin{pmatrix} b_L \\ -t_L \\ T_L \end{pmatrix}$	3	$\bar{3}$	$\frac{2}{3}$
$\begin{pmatrix} l_L^a \\ -\nu_L^a \\ \xi_L^a \end{pmatrix}$	1	$\bar{3}$	0

	$SU_C(3)$	$SU_L(3)$	$U_X(1)$
$u_R^{1,2}$	3	1	$\frac{2}{3}$
$d_R^{1,2}$	3	1	$-\frac{1}{3}$
$D_R^{1,2}$	3	1	$-\frac{4}{3}$
T_R	3	1	$\frac{5}{3}$
l_R^a	1	1	-1
ξ_R^a	1	1	-1

$$SU_C(3) \times SU_L(3) \times U_X(1) \to SU_C(3) \times SU_L(2) \times U_Y(1) \to SU_C(3) \times U_{\rm em}(1)$$

	$SU_C(3)$	$SU_L(3)$	$U_X(1)$
χ	1	3	1
ρ	1	3	0
η	1	3	-1

$$\Rightarrow \langle\chi\rangle = \begin{pmatrix} 0 \\ 0 \\ \frac{u}{\sqrt{2}} \end{pmatrix}$$

heavy

$$\Rightarrow \langle\rho\rangle = \begin{pmatrix} 0 \\ \frac{v}{\sqrt{2}} \\ 0 \end{pmatrix}, \quad \langle\eta\rangle = \begin{pmatrix} \frac{v'}{\sqrt{2}} \\ 0 \\ 0 \end{pmatrix}$$

light

gauge bosons = 8 + 1	
massive	massless
$W_\mu^\pm, Z_\mu, {W'}_\mu^\pm, {Z'}_\mu, Y_\mu^{\pm\pm}$	A_μ

$$m_Y \simeq u\,\frac{g_{2L}}{2}$$

$$\mu_{331} \sim u \gtrsim 3850\,\text{GeV}$$

Landau Pole

$$\alpha_i(\mu) = \frac{\alpha_i(\mu_0)}{1 - \frac{b_i}{2\pi}\alpha_i(\mu_0)\log\left(\frac{\mu}{\mu_0}\right)} + \mathcal{O}(\alpha_i^2)\,, \tag{16}$$

where μ_0 is some fixed reference value and b_i the first coefficient of the perturbative expansion of the β function. When $b_i > 0$, the coupling diverges at some energy scale (Landau pole).

$$b_i = \frac{2}{3}\sum_{fermions}\mathrm{Tr}(T_a T_a) + \frac{1}{3}\sum_{scalars}\mathrm{Tr}(T_a T_a) - \frac{11}{3}C_2^A.$$

$$\begin{array}{r} U(1) : C_2^A = 0 \rightarrow b_X > 0 \\ SU(N) : C_2^A = N \end{array} \quad \Rightarrow \mathrm{U(1)\ divergence}$$

Landau Pole

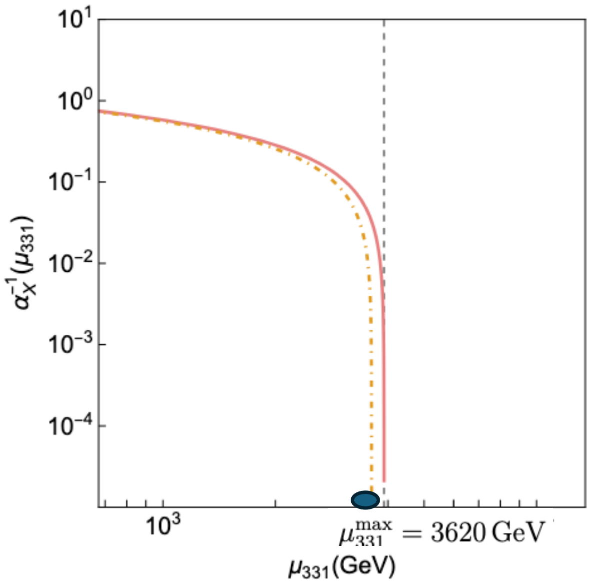


Figure 1: We report the dependence of α_X^{-1} on the energy scale μ_{331}. The dot-dashed and continuous lines correspond respectively to the cases where one and two Higgs doublets are on-shell below μ_{331}.The vertical dashed line represents the Landau pole at 3908 GeV.

$$g_{2L}(\mu_{331}) = g_{3L}(\mu_{331})\,,$$

$$\frac{1}{g_X^2(\mu_{331})} = \frac{1}{6}\left(\frac{1}{g_Y^2} - \beta^2\frac{1}{g_L^2}\right)\Bigg|_{\mu=\mu_{331}}$$

$$\mu_{331} \sim u \gtrsim 3850\,\mathrm{GeV}$$

$$3850\,\mathrm{GeV} \lesssim \mu_{331} \lesssim 3908\,\mathrm{GeV}$$ 2HDM-like

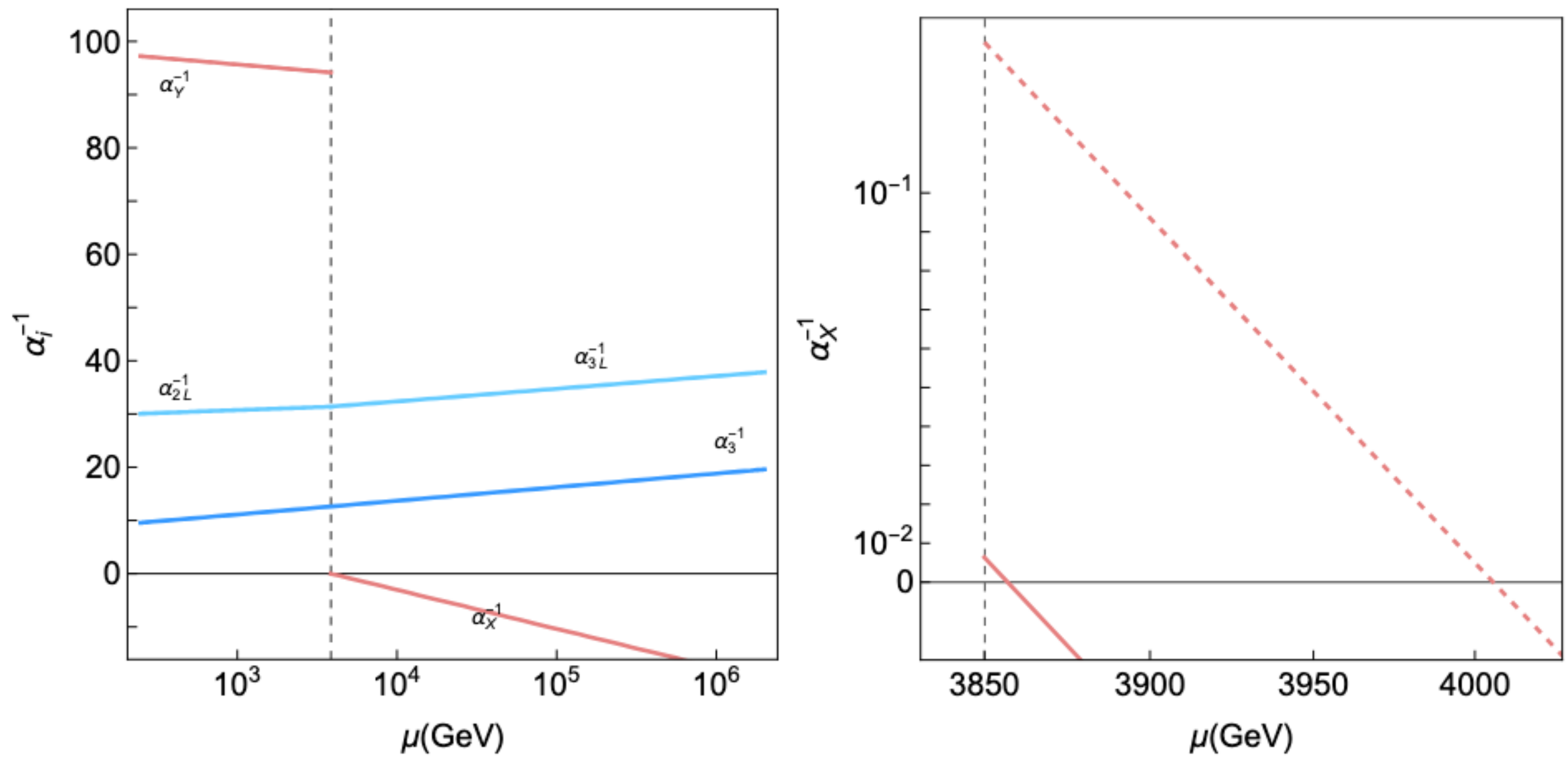


Figure 2: (*Left*) Running of α_i^{-1} with the energy scale μ. The vertical dashed line is the arbitrary 331 breaking scale μ_{331}. (*Right*) Zoom of α_X^{-1}. We compare with the multi-Higgs case with $N_H = 6$ (dashed line) considered in section 4.

1) assuming light masses for the D^1, D^2, T extra quarks;

2) relaxing the condition $\xi_L^\ell = \ell_R^c$ and including exotic leptons;

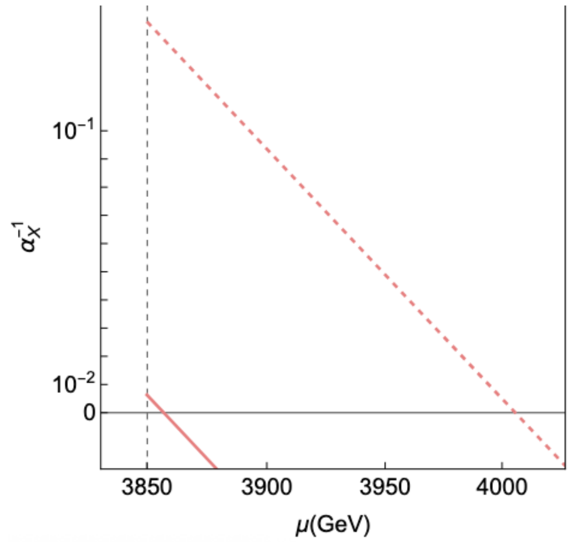
3) extending the scalar sector;

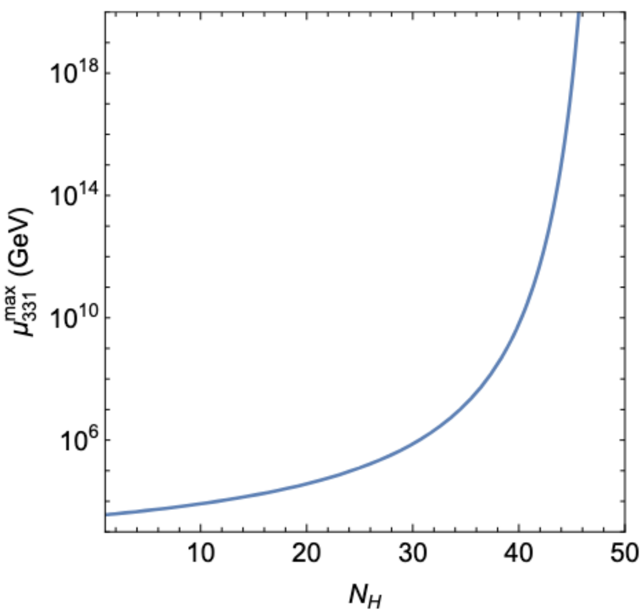
4) enlarging the number of families.

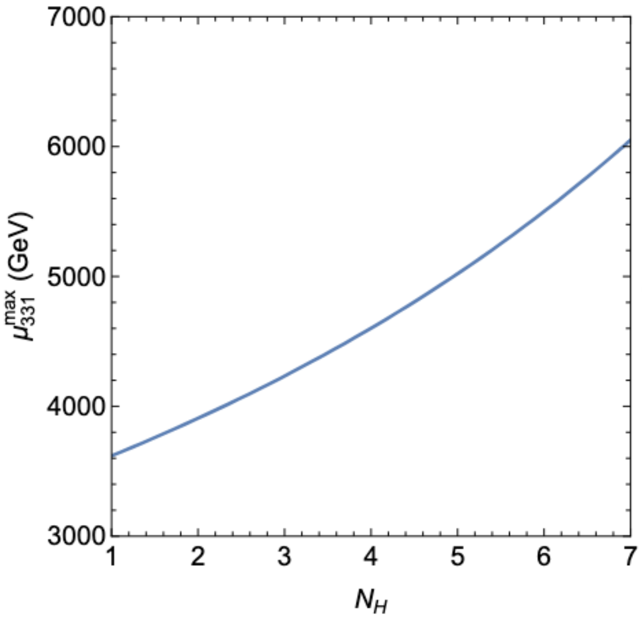
Extending the scalar sector

Let us consider extending the scalar sector of the minimal 331 model through the inclusion of $SU_L(3)$ triplets, with the aim of shifting the maximal value for μ_{331}.

$$b_Y = \frac{41}{6} + \frac{N_\rho}{6}, \qquad b_{2L} = -\frac{19}{6} + \frac{N_\rho}{6}$$







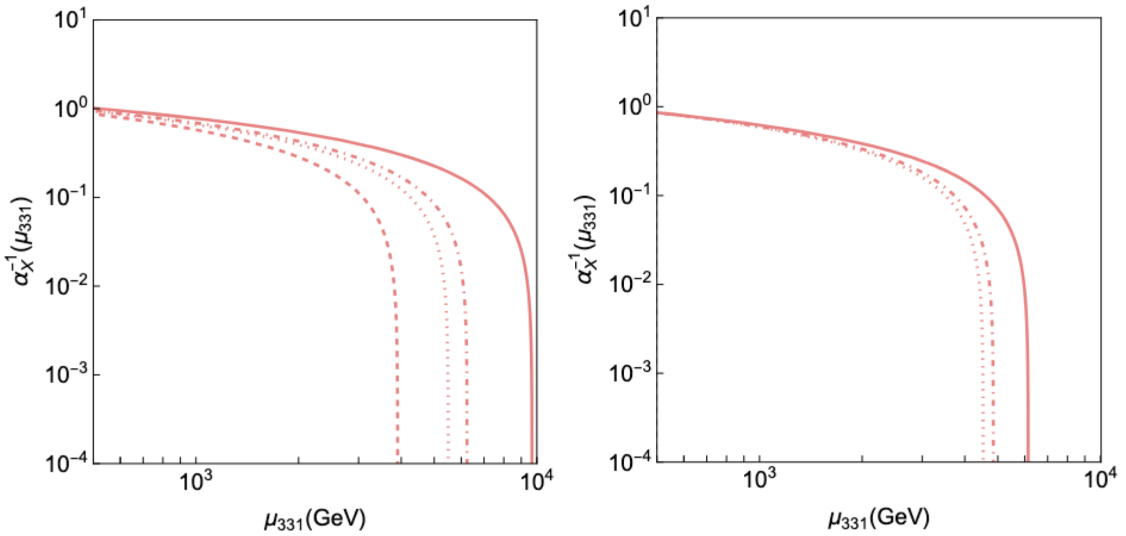


Figure 4: Running of α_X^{-1} with the energy scale μ_{331}. The left plot show different cases: 2HDM (dashed), sextet (dotted), 4th family (dot-dashed), 4th family with sextet (continuous) assuming all fermion doublets at the electroweak scale. In the right plot we show sextet (dotted), 4th family (dot-dashed) and 4th family with sextet (continuous) cases assuming extra fermion with mass $\sim$ 500 GeV.

	b_Y	$-b_{2L}$	$\mu_{\max}$ (GeV)	m_Y (GeV)
2HDM	7	3	3908	1270
sextet	49/6	13/6	4531	1472
4th fam.	83/9	5/3	4855	1578
4th fam. + sextet	187/18	5/6	6142	1996