SU(5) × SU(5) SUSY GUT Unification

David EMMANUEL-COSTA

with Ricardo González Felipe and Edison T. Franco, arXiv:1104.2046

Abstract

The idea of grand unification in a minimal supersymmetric SU(5) × SU(5) framework is revisited. It is shown that the unification of gauge couplings into a unique coupling constant can be achieved at a high-energy scale compatible with proton decay constraints. This requires the addition of a minimal particle content at intermediate energy scales. In particular, the introduction of the $SU(2)_L$ triplets belonging to the $(15,1)+(\overline{15},1)$ representations, as well as of the scalar triplet Σ_3 and octet Σ_8 in the $(24,1)$ representation, turns out to be crucial for unification. The masses of these intermediate particles can vary over a wide range, and even lie in the TeV region. In contrast, the exotic vector-like fermions must be heavy enough and have masses above 10^{10} GeV. We also show that, if the SU(5) × SU(5) theory is embedded into a heterotic string scenario, it is not possible to achieve gauge coupling unification with gravity at the perturbative string scale.

Motivations

- Left-Right Symmetry à la Pati-Salam
- R-parity conservation can be automatic
- No tree level proton decay via lepto-quark gauge bosons
- Can be easily embedded in superstring constructions

Breaking Pattern

$$SU(5)_L \times SU(5)_R$$
$$\downarrow \Lambda$$
$$SU(3)_L \times SU(2)_L \times U(1)_L \times SU(3)_R \times SU(2)_R \times U(1)_R$$
$$\downarrow \Lambda_{LR}$$
$$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$
$$\downarrow v_R$$
$$SU(3)_C \times SU(2)_L \times U(1)_Y$$
$$\downarrow v_L$$
$$SU(3)_C \times U(1)_{em}$$

Gauge Coupling Unification

$$k_1 = 13/3,\, k_2 = 1 \text{ and } k_3 = 2$$

$$\alpha_U = k_3\,\alpha_s(\Lambda) = k_2\,\alpha_w(\Lambda) = k_1\,\alpha_y(\Lambda)$$

$$\sin^2\theta_W = \frac{\alpha_y}{\alpha_y+\alpha_w} = \frac{1}{1+k_1/k_2} = \frac{3}{16}$$

Proton Decay

Proton decay via dimension-six operators through heavy gauge bosons is suppressed, since at tree level the latter do not mediate transitions involving only light fermions. The presence of color Higgs triplets H_C^L and H_C^R induce proton decay through dimension-five operators: $\chi\chi\chi\psi$ and $\chi^c\chi^c\chi^c\psi^c$, which lead to the effective operators $QQQL$. This requires that the mass scales of left and right color Higgs triplets should be heavy enough. In the absence of the fields $\phi_{L,R}$ and $\phi^c_{L,R}$ not only proton is stable at the renormalizable level.

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Particle Content

Matter chiral multiplets

$$\psi = \begin{bmatrix} D_1^c \\ D_2^c \\ D_3^c \\ e \\ -\nu \end{bmatrix} \sim (\bar{5},1) \quad \chi = \frac{1}{\sqrt{2}}\begin{bmatrix} 0 & U_3^c & -U_2^c & -u_1 & -d_1 \\ -U_3^c & 0 & U_1^c & -u_2 & -d_2 \\ U_2^c & -U_1^c & 0 & -u_3 & -d_3 \\ u_1 & u_2 & u_3 & 0 & -E^c \\ d_1 & d_2 & d_3 & E^c & 0 \end{bmatrix} \sim (10,1)$$

$$\psi^c = \begin{bmatrix} D_1 \\ D_2 \\ D_3 \\ e^c \\ -\nu^c \end{bmatrix} \sim (1,5) \quad \chi^c = \frac{1}{\sqrt{2}}\begin{bmatrix} 0 & U_3 & -U_2 & -u_1^c & -d_1^c \\ -U_3 & 0 & U_1 & -u_2^c & -d_2^c \\ U_2 & -U_1 & 0 & -u_3^c & -d_3^c \\ u_1^c & u_2^c & u_3^c & 0 & -E \\ d_1^c & d_2^c & d_3^c & E & 0 \end{bmatrix} \sim (1,\overline{10})$$

Higgs chiral multiplets

$\Phi_L \sim (24,1)$ and $\Phi_R \sim (1,24)$, for the first breaking of $SU(5)_L \times SU(5)_R$ at the scale Λ but preserve the discrete left-right symmetry. Left-right symmetry breaking at the scale Λ_{LR}: $\omega \sim (5,\bar{5})$, $\overline{\omega} \sim (\bar{5},5)$, $\Omega \sim (10,\overline{10})$ and $\overline{\Omega} \sim (\overline{10},10)$. The last two steps are driven by the additional Higgs fields $\phi_R \sim (1,\bar{5})$, $\phi_R^c \sim (1,5)$ and $\phi_L \sim (5,1)$, $\phi_L^c \sim (\bar{5},1)$, respectively. The representations $T_L \sim (15,1)$, $T_L^c \sim (\overline{15},1)$, $T_R \sim (1,\overline{15})$ and $T_R^c \sim (1,15)$ are crucial for unification and for the Majorana masses of neutrinos generation.

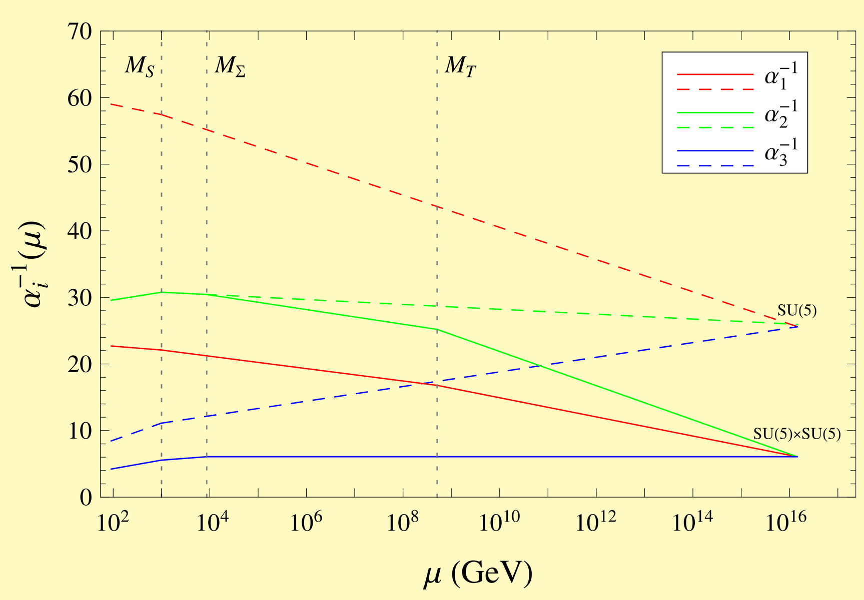
Generalised Seesaw

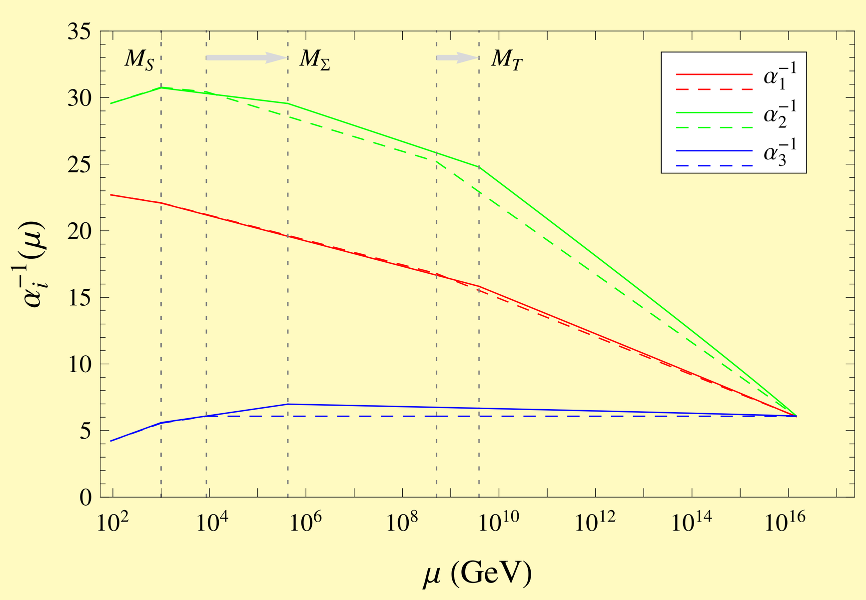
$$W_Y = \psi^c Y_1 \omega \psi + \chi^c Y_2 \Omega \chi + \sqrt{2}\psi Y_3 \chi \phi_L^c + \sqrt{2}\psi^c Y_3 \chi^c \phi_R^c + \frac{1}{4}\chi Y_4 \chi \phi_L + \frac{1}{4}\chi^c Y_4 \chi^c \phi_R$$

$$\langle\omega\rangle_k^k = \langle\Omega\rangle_{12}^{12} = \langle\Omega\rangle_{23}^{23} = \langle\Omega\rangle_{31}^{31} = \langle\Omega\rangle_{45}^{45} = \Lambda_{LR},\ \langle\phi_{L,R}\rangle = (0,0,0,0,v_{u\,L,R})^T,$$
$$\langle\phi^c_{L,R}\rangle = (0,0,0,0,v_{d\,L,R})^T, \text{ with } v^2_{L,R} = v^2_{u\,L,R} + v^2_{d\,L,R}$$

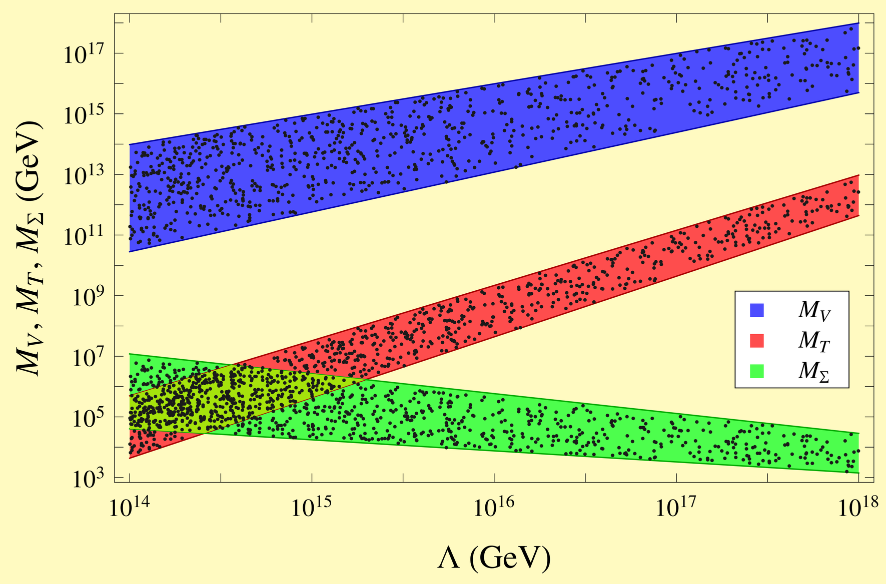
$$\mathcal{L}_m = (u \quad U)\begin{pmatrix} 0 & Y_4 v_{u\,L} \\ Y_4 v_{u\,R} & -Y_2\Lambda_{LR}\end{pmatrix}\begin{pmatrix} u^c \\ U^c \end{pmatrix} + (d \quad D)\begin{pmatrix} 0 & Y_3^{\mathsf{T}} v_{d\,L} \\ Y_3 v_{d\,R} & -Y_1\Lambda_{LR}\end{pmatrix}\begin{pmatrix} d^c \\ D^c \end{pmatrix} + (e \quad E)\begin{pmatrix} 0 & Y_3 v_{d\,L} \\ Y_3^{\mathsf{T}} v_{d\,R} & -Y_2\Lambda_{LR}\end{pmatrix}\begin{pmatrix} e^c \\ E^c \end{pmatrix}$$

Results

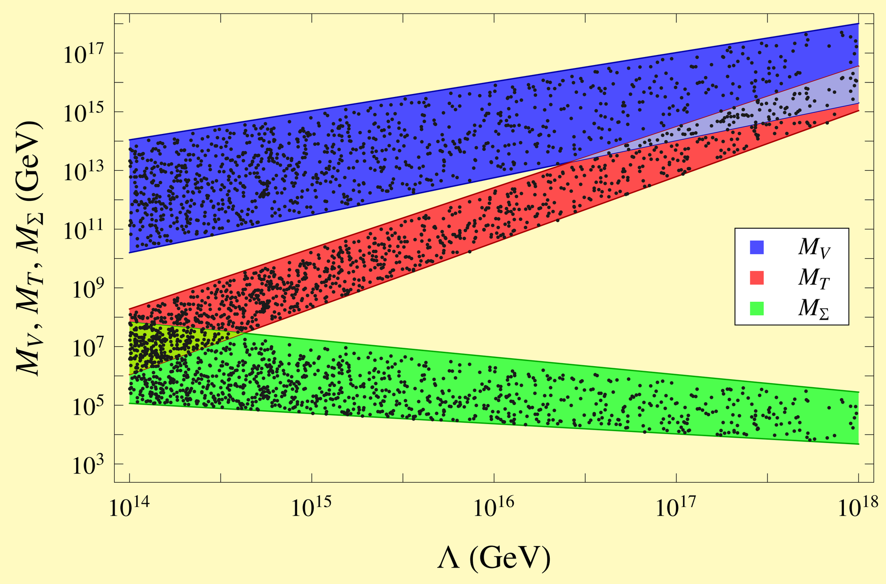




$\Lambda \simeq 2\times10^{16}$ GeV, $M_S = 1$ TeV, $M_\Sigma = 10$ TeV and $M_T = 10^9$ GeV

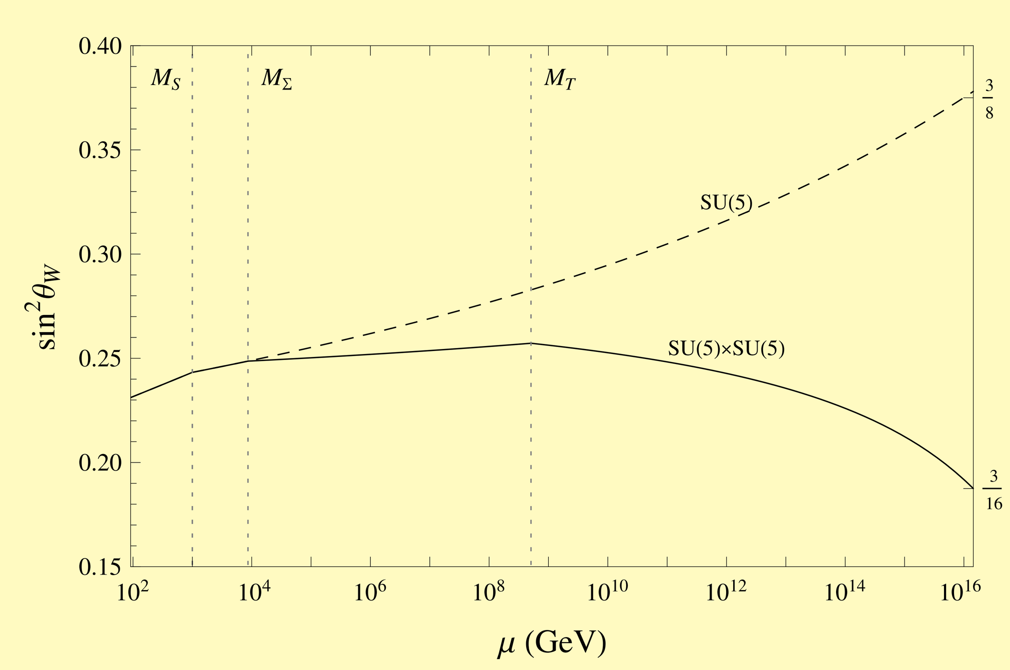


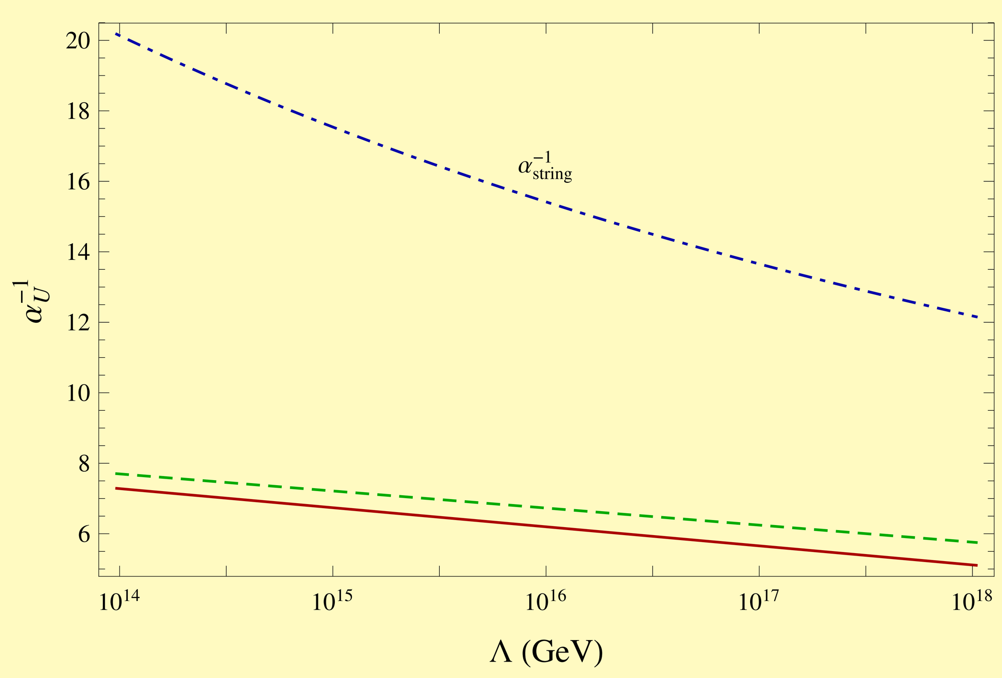
two Higgs doublets



four Higgs doublets

$$\sqrt{(\alpha_{1\Lambda}^{-1}-\alpha_{2\Lambda}^{-1})^2+(\alpha_{1\Lambda}^{-1}-\alpha_{3\Lambda}^{-1})^2+(\alpha_{2\Lambda}^{-1}-\alpha_{3\Lambda}^{-1})^2} \leq 0.1 \text{ at two loops}$$





$\sin^2\theta_W$ evolution and String Scale Unification