

Gauge coupling unification in a novel string-derived model



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arXiv:1106.3082;
1207.xxxx work to appear
with Alon E. Faraggi

Proton Stability

- Accidental global symmetries in the Standard Model
- Effective theory below cutoff
- Dimension-6 operators indicate cutoff $\gtrsim 10^{16}$ GeV
- SUSY theories induce dimension-4 & -5 operators
- Additional gauge symmetry?

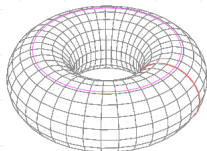
Viability of $U(1)$

- Dimension-4, -5, -6 proton decay mediating operators forbidden
- Seesaw mechanism for light neutrinos
- Yukawa couplings to EW Higgs doublets
- Anomaly Free

- Basis Vectors

$$\Xi = \sum_{i=1}^n m_i b_i$$

$$m_i = 1, \dots, N_i - 1$$



- Fermion Phases

$$f \longrightarrow -e^{i\pi\alpha(f)} f, \quad \alpha(f) \in (-1, 1]$$

- ABK Rules [NPB 289 (1987) 87]

- Generalized GSO Projection

$$\left\{ e^{i\pi(b_i F_\alpha)} - \delta_\alpha c^* \begin{pmatrix} \alpha \\ b_i \end{pmatrix} \right\} |s\rangle_\alpha = 0$$

- Mass Formula

$$M_L^2 = -\frac{1}{2} + \frac{\alpha_L^2}{8} + \sum \nu_L$$

$$= M_R^2 = -1 + \frac{\alpha_R^2}{8} + \sum \nu_R$$

- $U(1)$ charges

$$Q(f) = \frac{1}{2}\alpha(f) + F(f)$$

String Scale

- NAHE set of basis vectors $\{\mathbf{1}, S, b_1, b_2, b_3\}$

$$SO(10) \times SO(6)^{1,2,3} \times E_8$$

48 generations

- Choice of α, β, γ

\Rightarrow subgroup $\times U(1)_{1,2,3} \times$ subgroup

- 4D models with $N = 1$ SUSY
- 3 chiral generations, from b_1, b_2, b_3

Our Model

- LRS

$$b \{ \bar{\psi}^{1, \dots, 5} \} = \{ 11100 \} + b \{ \bar{\psi}^{1, \dots, 5} \} = \left\{ \frac{1}{2} \frac{1}{2} \frac{1}{2} 00 \right\}$$

$$\implies \mathbf{SU(3)}_C \times \mathbf{U(1)}_C \times \mathbf{SU(2)}_L \times \mathbf{SU(2)}_R$$

[CLEAVER, FARAGGI & SAVAGE PRD 63 (2001) 066001]

Left-right Symmetry

- $U(1)$ combination

$$U(1)_\zeta = U(1)_1 + U(1)_2 + U(1)_3$$

- GGSO fixes vacuum of $\bar{\eta}^j$ i.e.

$$c \begin{pmatrix} \gamma \\ b_j \end{pmatrix} = \pm 1$$

- $U(1)$ charges

$$Q_j(Q_L; L_L) = +\frac{1}{2}$$

$$Q_j(Q_R; L_R) = -\frac{1}{2}$$

Standard Model States

- At the GUT scale

$$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_C \times U(1)_\zeta$$

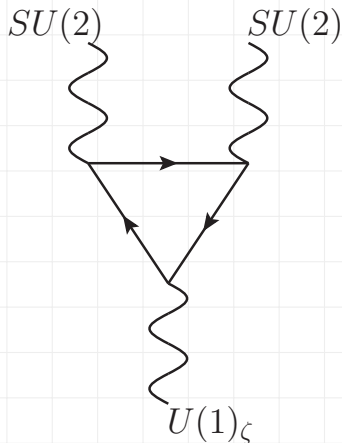
- Matter states

$$Q_L, Q_R = U + D, L_L, L_R = E + N$$

- Anomalies

$$SU(2)_L^2 \times U(1)_\zeta \rightarrow \mathcal{A}_1^{SM} = -2$$

$$SU(2)_R^2 \times U(1)_\zeta \rightarrow \mathcal{A}_2^{SM} = +2$$



Additional States

- $SU(2)_{L/R}$ doublets cancel gauge anomalies
- Heavy Higgs' break $SU(2)_R$ at intermediate scale, M_R

$$\Rightarrow U(1)_Y = T_{3R} + \frac{1}{3}U_C$$

$$\& U(1)_{Z'} = \frac{1}{5}U_C - \frac{2}{5}T_{3R} + U_\zeta$$

- Singlets \rightarrow Type III seesaw mechanism
- Colour triplets \rightarrow gauge coupling unification

Symmetry Breaking

[FARAGGI & DIENES, NPB 457 (1995) 409]

$$SO(10) \xrightarrow{M_S} SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_C$$

$$\xrightarrow{M_R} SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{Z'}$$

$$\xrightarrow{M_{Z'}} SU(3)_C \times SU(2)_L \times U(1)_Y$$

- Triplets acquire mass at M_D
- Mass scale hierarchy $M_S \gg M_R \gg M_D \gg M_{Z'} \gg M_Z$

RGEs

- Integrating between M_S and M_Z

$$\alpha_S^{-1} = \alpha_i^{-1} - \sum_{I=1}^4 \frac{\beta_{iI}}{2\pi} \ln \left(\frac{M_I}{M_{I+1}} \right)$$

where $M_{1,\dots,5} = M_{S,R,D,Z',Z}$.

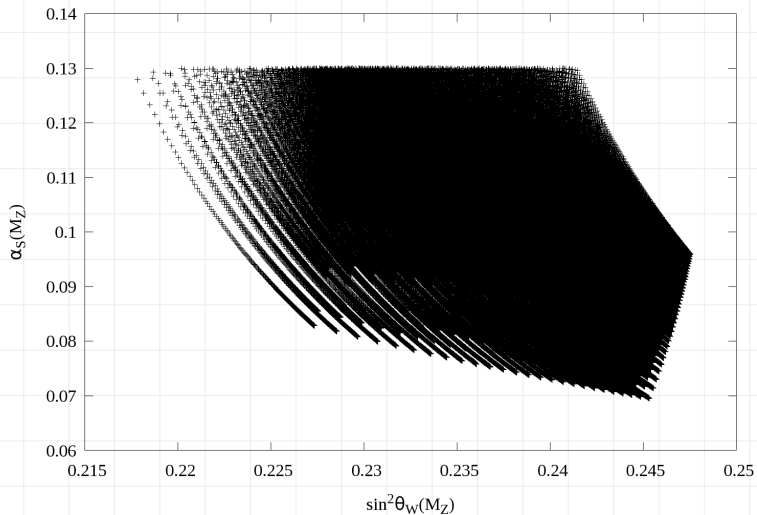
- Hypercharge embedding

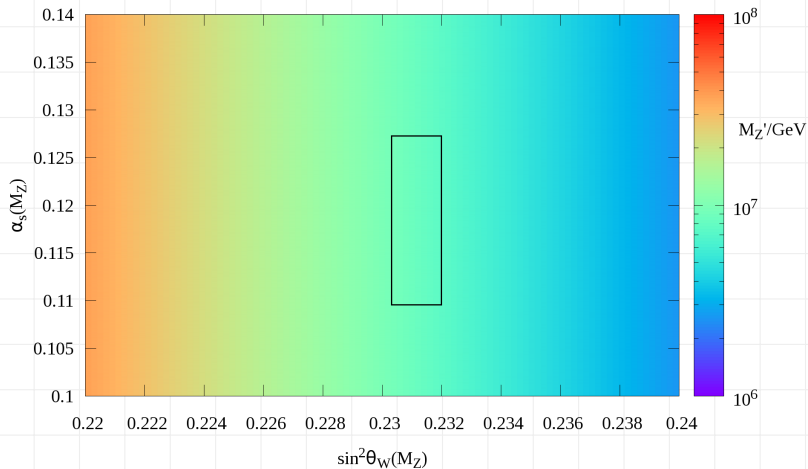
$$\alpha_1^{-1}(M_R) = \alpha_{2R}^{-1}(M_R) + \frac{2}{3}\alpha_{\hat{C}}^{-1}(M_R)$$

- At string unification scale

$$\alpha_S \equiv \alpha_3(M_S) = \alpha_2(M_S) = \frac{3}{5}\alpha_1(M_S)$$

Analysis





$$M_R: 2.2 \times 10^{16} - 2.5 \times 10^{16}$$

$$M_D: 5.2 \times 10^{11} - 1.0 \times 10^{12}$$

$$M_{Z'}: 7.3 \times 10^6 - 9.2 \times 10^6$$

All scales in GeV

Summary

- Viable $U(1)_{Z'}$ protects proton lifetime
- Exhibits string unification with new physics at $\sim 10^7$ GeV
- Interesting phenomenology \rightarrow Many additional fields