Gauge Coupling Unification Constraints on String–derived Models

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Planck 2013
BCTP, Bonn

arXiv:1304.4230
1106.3082
1106.5422

with Alon E. Faraggi

Nucleon Decay

- Proton lifetime $\tau_p \gtrsim 10^{34}$ years

[1203.4030 [hep-ex] Super Kamiokande]

- B and L global symmetries in SM
- τ_p indicates cutoff $\gtrsim 10^{16}$ GeV
- SUSY induces dimension-4 & -5 operators
- Suppressed/forbidden
  - R-symmetries
  - Gauged $B - L$
  - B and L gauge groups

[*e.g.* 1102.3595 [hep-ph] Raby, Ratz, Ross *et al*]

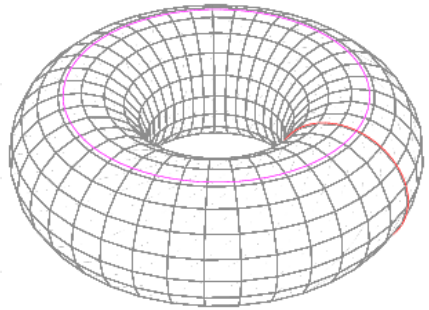
[*e.g.* 1207.0507 [hep-ph] Basso, Staub *et al*]

[*e.g.* 1304.0576 [hep-ph] Wise, Perez, Duerr]

Viability of $U(1)$

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

Free Fermionic Formulation



- Fermion Phases

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

- ABK Rules
- Generalized GSO Projections
- $U(1)$ charges

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

- Corresponds to $Z_2 \times Z_2$ orbifold

[*e.g.* hep-th/0403272 Faraggi, Donagi]

Model Construction

- NAHE set of basis vectors: $\{\mathbf{1}, \mathbf{S}, \mathbf{b_1}, \mathbf{b_2}, \mathbf{b_3}\}$
  - $SO(10) \times SO(6)_{1,2,3} \times E_8$
  - *48* generations
  - $\mathcal{N} = 1$ SUSY
- Add $\{\alpha, \beta, \gamma\}$
  - Preserves $\mathcal{N} = 1$ SUSY
  - 3 generations
  - GG: subgroup $\times\, U(1)^n \times$ hidden subgroup

$SO(10)$ Breaking

$$
\begin{aligned}
b\left\{\bar{\psi}^{1,\ldots,5}\right\} &= \{11100\} \\
&+ \\
b\left\{\bar{\psi}^{1,\ldots,5}\right\} &= \left\{\frac{1}{2}\frac{1}{2}\frac{1}{2}00\right\}
\end{aligned}
$$

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

[hep-ph/0006331 Cleaver, Faraggi, Savage]

Why LRS?

- $U(1)$ combination

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

- $U(1)$ charges

$$Q_\zeta\left(Q_L; L_L; Q_R; L_R\right) = \pm\frac{1}{2}$$

- For $SO(10) \times U(1)_\zeta \subset E_6$:

$$\mathbf{27} \to \mathbf{16}_{\pm\frac{1}{2}} + \mathbf{10}_{\mp 1} + \mathbf{1}_{\pm 2}$$

- For $SO(10) \times U(1)_\zeta \not\subset E_6$:

$$\mathbf{27} \not\to \underbrace{\mathbf{16}_{\pm\frac{1}{2}}}_{\mathbf{8}_{\frac{1}{2}} + \mathbf{8}_{-\frac{1}{2}}} + \mathbf{10}_{\mp 1} + \mathbf{1}_{\pm 2}$$

Spectra Highlights

- $SU(2)_{L/R}$ doublets cancel gauge anomalies ($\not\subset E_6$ only)
- Heavy Higgs' break $SU(2)_R$ at intermediate scale, M_R
- Singlets $\rightarrow$ Extended seesaw mechanism

  For $\subset E_6$ already in **27**
- Colour triplets $\rightarrow$ Gauge coupling unification

Gauge Coupling Unification

- Heterotic String scale $\rightarrow M_S \sim 5 \cdot 10^{17}$ GeV
- MSSM GUT scale $\rightarrow M_{GUT} \sim 2 \cdot 10^{16}$ GeV
- Resolution?

Intermediate mass scales

[hep-th/9505046 Faraggi, Dienes]

Symmetry Breaking

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

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

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

- Triplets acquire mass at M_D, SUSY scale $\rightarrow \mathrm{M}_{SUSY}$
- Mass scale hierarchy $M_S \gtrsim M_R > M_D \gtrsim M_{Z'} \gtrsim M_{SUSY} > M_Z$

RGEs

- One–loop RGEs for gauge couplings

$$\frac{4\pi}{\alpha_i(\mu)} = k_i \frac{4\pi}{\alpha_{\text{string}}} + \beta_i \log \frac{M^2_{\text{string}}}{\mu^2} + \Delta_i^{(\text{total})},$$

  where $\Delta_i^{(\text{total})}$ are corrections from I.M and I.G.

- Hypercharge embedding

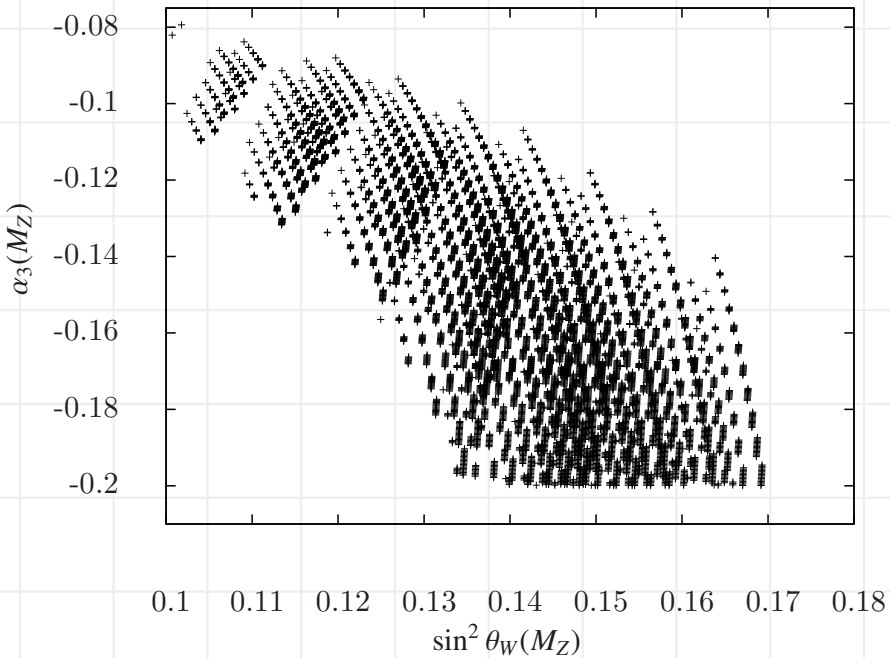
$$\alpha_1^{-1}(M_R) = \alpha_{2R}^{-1}(M_R) + \frac{2}{3}\alpha_{\hat{C}}^{-1}(M_R)$$

- At string unification scale

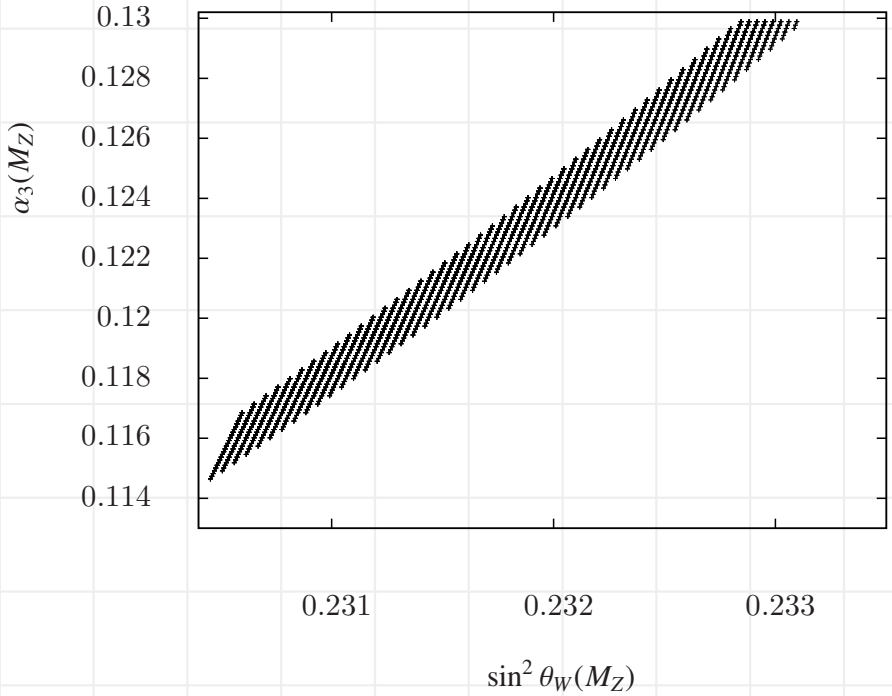
$$\alpha_S \equiv \alpha_3(M_S) = \alpha_2(M_S) = \frac{5}{3}\alpha_Y(M_S)$$

Analysis

- $SO(10) \times U(1) \not\subset E_6$



- $SO(10) \times U(1) \subset E_6$



Intermediate Thresholds

- $\not\subset E_6$:

$$\delta\left(\sin^2\theta_W(M_Z)\right)_{\text{I.T.}} = \frac{1}{2\pi}\frac{k_1\alpha}{1+k_1}\left(\frac{12}{5}\log\frac{M_S}{M_R} - \frac{24}{5}\log\frac{M_S}{M_{Z'}} - \frac{2n_D}{5}\log\frac{M_S}{M_D}\right)$$

$$\delta\left(\alpha_3(M_Z)\right)_{\text{I.T.}} = \frac{1}{2\pi}\left(\frac{3}{2}\log\frac{M_S}{M_R} - 9\log\frac{M_S}{M_{Z'}} + \frac{3n_D}{4}\log\frac{M_S}{M_D}\right)$$

- $\subset E_6$

$$\delta\left(\sin^2\theta_W(M_Z)\right)_{\text{I.T.}} = \frac{1}{2\pi}\frac{k_1\alpha}{1+k_1}\left(\frac{12}{5}\log\frac{M_S}{M_R} + \frac{6}{5}\log\frac{M_S}{M_H} - \frac{6}{5}\log\frac{M_S}{M_D}\right)$$

$$\delta\left(\alpha_3(M_Z)\right)_{\text{I.T.}} = \frac{1}{2\pi}\left(\frac{3}{2}\log\frac{M_S}{M_R} - \frac{9}{4}\log\frac{M_S}{M_H} + \frac{9}{4}\log\frac{M_S}{M_D}\right)$$

Summary

- Viable $U(1)_{Z'}$ from strings
- Problematic GCU when $SO(10) \times U(1)_\zeta \not\subset E_6$

  Unless Spinor–vector duality realised

  [hep-th/0611251 Faraggi, Kounnas, Rizos]
- $U(1)_\zeta$ desirable candidate
- Can it be embedded in E_6?

An E_6 Model

- $\mathbf{x}$ enhances $(3_C, 2_L, 2_R, 1_C, 1_\zeta) \to (4_C, 2_L, 2_R, 1_{\zeta'})$
- Anomaly free as full **27** kept
- $U(1)_{\zeta'}$ rotation of $U(1)_\zeta$
- Proton lifetime preserved