SU(6) GUT breaking on a Projective Plane

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Work with Prof Stuart Raby
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Highlights

- 6D SU(6) grand unified theory with N=2 SUSY
- Extra dimensions compactified on a non-trivial orbifold, with the topology of real projective plane.
- SU(6) down to standard model; Higgs doublet-triplet splitting
- Gauge coupling unification; no power-law corrections above the compactification scale!

Supersymmetric GUTS

It is well-known that supersymmetry can ease the unification of the gauge couplings couplings.

Problems with 4D SUSY GUTS:

- Large & complicated potentials are necessary in order to break the grand unified symmetry.
- Higgs doublet-triplet splitting
- GUT scale threshold corrections are required to match electroweak data.
- Proton decay.

Solution: Orbifold GUTS

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Orbifold GUTS

- Supersymmetric orbifold GUTS retain all phenomenological successes of 4D SUSY GUTS.
  Gauge coupling unification, Low energy MSSM, Yukawa unification
- They can also be obtained as an effective theory from string theory.
  Mini-landscape of heterotic theory, Anisotropic compactifications of string theory
- However, string unification and grand unification disagree by about a factor of 20!
  It is possible that non-local breaking of the gauge symmetry may solve this problem of string unification [1]

[1] Hebecker & Trapletti, Nucl.Phys.B713(2005); G G Ross hep-ph/0411057

SU(6) GUT with N=2 SUSY

- In this work [2] we consider an 6D SU(6) grand unified theory with N=2 SUSY. Such models have been studied before [3]
- N=2 SUSY in 6D $\Leftrightarrow$ N=4 SUSY in 4D.
  N=2 SUSY vector multiplet is anomaly free.
- The MSSM Higgs doublets come from a higher dimensional gauge field. N =2 SUSY vector multiplet contains: $\{V, \Sigma_5, \Sigma_6, \Phi\}$ one vector and three chiral adjoints. The Higgs field could come from one of these three chiral adjoints.

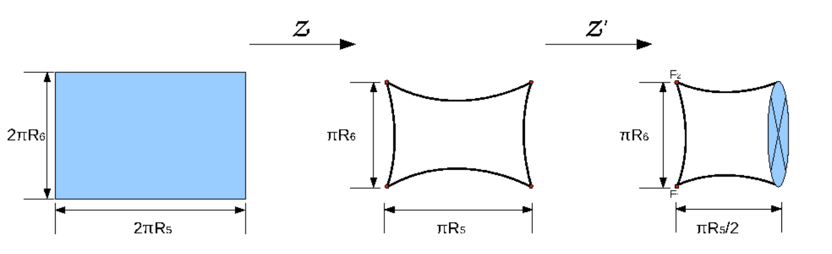
Gauge-Higgs Unification

[2] AA and Stuart Raby, hep-ph 1205.1228
[3] Hall, Nomura, Smith, Nucl.Phys.B639:307-330,2002

Real Projective Plane

Consider the following actions on the surface of a torus, T^2

$$\mathcal{Z} \qquad x_5 \to -x_5, \qquad x_6 \to -x_6$$
$$\mathcal{Z}' \qquad x_5 \to -x_5 + \pi R_5, \qquad x_6 \to x_6 + \pi R_6.$$



$\mathcal{Z}'$ is a freely acting projection: there are no fixed points under this action.

$SU(6) \rightarrow$ *Standard Model*

We break the SU(6) down to the standard model in two steps.

- SU(6) $\rightarrow$ SU(5) $\times$ U(1)$_X$: Orbifold Projection

$$\begin{aligned} \varphi(-x_5, -x_6) &= \pm\varphi(x_5, x_6); \\ \varphi(-x_5 + \pi R_5, x_6 + \pi R_6) &= \pm P\varphi(x_5, x_6)P^{-1} \end{aligned}$$

  SU(6) can be broken down to SU(5) $\times$ U(1)$_X$ by choosing P = diag$(i, i, i, i, i, -i)$

- SU(5) $\rightarrow$ SU(3) $\times$ SU(2) $\times$ U(1)$_Y$: Wilson Line constant background gauge field along the fifth direction. $A_5 = \frac{1}{4R_5}T$ where, T = diag$(1, 1, 1, -1, -1, -1)$

Non-local GUT breaking!

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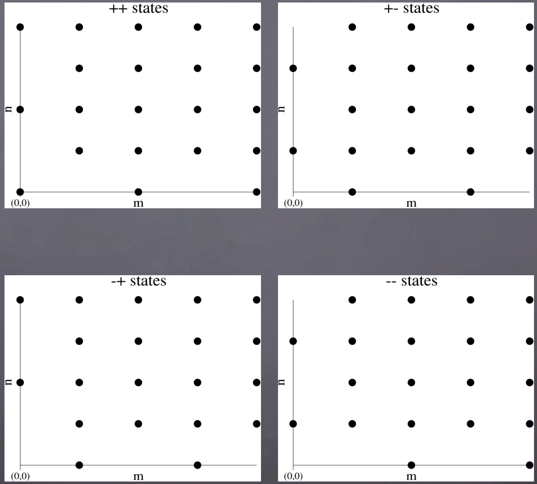
Spectrum of States

- Kaluza-Klein tower of states in 4D with mass,

$$M^2_{(m,n),\rho} = \frac{(m + \frac{I_\rho}{4})^2}{R_5^2} + \frac{n^2}{R_6^2}$$



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- States:
  - Standard model gauge bosons come from the vector multiplet V.
  - Higgs doublets come from the chiral adjoint Φ
  - Higgs triplets come from Φ. I_ρ= 2, $M^2_{(00)} = \frac{1}{4R_5^2}$
  - Exotic states come from the vector adjoint as well.
  - Matter multiplets are located at the fixed points. $(\mathbf{15_F} + 2\ \bar{\mathbf{6}}_\mathbf{F})$ [4]

Standard model gauge group and doublet-triplet splitting!

[4] N.Uekusa, Int.J.Mod.Phys.A **23**, 3535 (2008)

Gauge Coupling Unification

- The running coupling constants in the 4D MSSM can be summarized by:

$$\alpha_i^{-1}(Q) = \alpha_{GUT}^{-1} + \frac{b_i}{2\pi} log \frac{M_{GUT}}{Q} - \alpha_{GUT}^{-1} \frac{\epsilon_3}{(1+\epsilon_3)} \delta_{i3}$$

where,

$$\epsilon_3 = \frac{\alpha_3 - \alpha_{GUT}}{\alpha_{GUT}}.$$

- In the 6D orbifold theory,

$$\frac{4\pi}{g_i^2(\mu)} = \frac{4\pi}{g^2(\Lambda)} + \sum_\rho \Omega_{i,\rho}(\mu)$$

where

$$\Omega_{i,\rho}(\mu) \equiv \frac{1}{4\pi} \sum_{(m,n)\in Z} \beta_{i,\rho} \int_\xi^\infty \frac{dt}{t} e^{-\pi t \frac{M^2_{(m,n),\rho}}{\mu^2}} e^{-\pi \chi t}$$

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Results

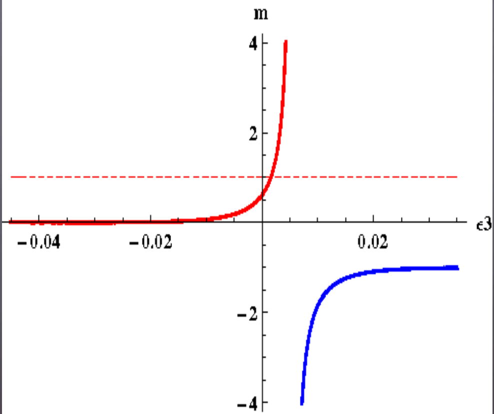
- Only logarithmic corrections to the couplings at all scale. This is unlike most extra-dimensional GUTS.
- N=2 SUSY gets rid of the quadratic corrections.
- No effective 5D limit. No linear corrections.
- Uniquely solve for M_5 and M_6 in terms of ϵ_3 and M_{GUT}; and a relation between the cut-off scale, Λ and the unified coupling at the cut-off scale.

Results

$$M_5 = \frac{M_{GUT}}{\sqrt{m}} e^{\mathcal{G}/2}$$

$$M_6 = M_{GUT} e^{\mathcal{G}/2}$$

$$\alpha^{-1}(\Lambda) = 2\mathcal{H}\ln\Lambda + \mathcal{J} - \ln M_6^2$$



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Results

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- If $M_6 > M_5$, SU(6) $\rightarrow$ standard model
- If $M_5 > M_6$, SU(6) $\rightarrow$ SU(3) $\times$ SU(3) $\rightarrow$ standard model

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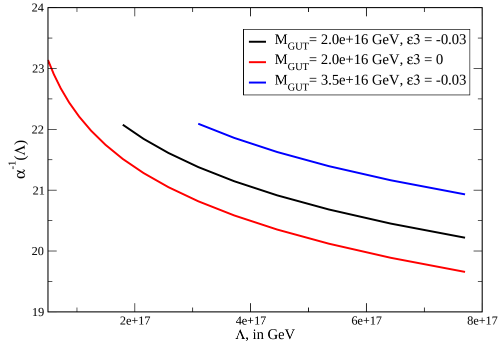

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Summary

- We considered a 6 dimensional N=2 SU(6) SUSY GUT on a projective plane.
- The orbifold projections and non-trivial background field break SU(6) to standard model.
- The states at the fixed points depend on the choice of GUT breaking (local vs. non-local).
- Studied gauge coupling unification in these models. The threshold corrections are at the percent level and can fit the electroweak data, as well as non-minimal models
- It will be intriguing to see if string compactification can produce such an effective theory. We know of none so far.

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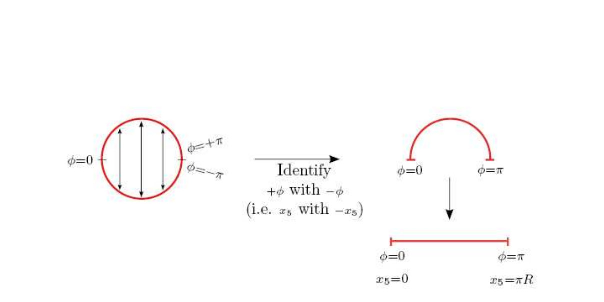
BACKUP SLIDES

Solution: Orbifold GUTS

Construct a grand unified theory on a higher dimensional space and compactify the extra-dimensions on an orbifold. *A manifold with some discrete parities modded out*[5]



[5]Raman Sundrum, TASI lectures 2004

Local vs Non-local GUT breaking

- Some orbifold projections leave certain points unchanged.
  Example $x_5 \to -x_5, x_6 \to -x_6$.
  If this action breaks the GUT symmetry, then the gauge group is broken only at certain fixed points. This is Local GUT breaking
- Some orbifold action are freely acting.
  Example: $x_5 \to -x_5 + \pi R_5, x_6 \to x_6 + \pi R_6$.
  There are no fixed points under this action. If this action breaks the GUT symmetry, then the gauge group is broken non-locally. This type of GUT breaking is equivalent to a Wilson line breaking.