The MSSM with GUT-scale degenerate Higgs masses

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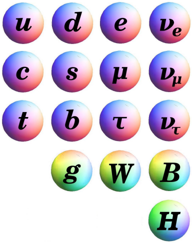
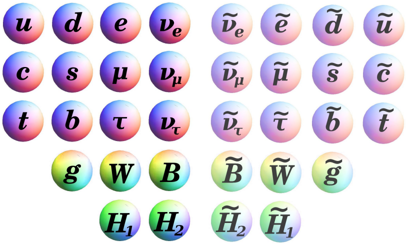
based on arXiv:0906.2957
with Sylvain Fichet, Sabine Kraml (LPSC Grenoble), and Arthur Hebecker (Heidelberg)
& on work in progress with Sylvain, Sabine, and Ritesh Singh (Würzburg)

The Standard Model



Beyond the Standard Model: The MSSM



- minimal SUSY extension of Standard Model
- $\mathcal{O}(100)$ new parameters, mostly soft SUSY breaking terms
- Still $\mathcal{O}(20)$ when demanding no contributions to $\not{CP}$ and FCNCs
- Further reduce number of parameters:
  - e.g. by imposing ad-hoc universality relations: “mSugra”. . .
  - or by assuming an underlying model of UV-scale physics

High-scale soft parameters in SUSY GUTs

Popular example: "mSugra"

- scalar soft masses equal: $m^2_{\text{sfermions}} = m^2_{H_1} = m^2_{H_2}$ $(\equiv m_0^2)$
- gaugino masses equal: $M_1 = M_2 = M_3$ $(\equiv M_{1/2})$
- trilinear soft terms equal $(\equiv A_0)$
- Higgsino mass μ and off-diagonal Higgs mass $B\mu$: from $\tan\beta$ and M_Z at low scale

In this talk instead: Models with degenerate Higgs mass matrix

- $m^2_{H_1} + |\mu|^2 = m^2_{H_2} + |\mu|^2 = |B\mu|$, i.e.

$$V_{\text{Higgs}} = (\overline{H}_1\ H_2) \begin{pmatrix} m^2 & m^2 \\ m^2 & m^2 \end{pmatrix} \begin{pmatrix} H_1 \\ \overline{H}_2 \end{pmatrix} + \ldots, \quad m^2 \equiv m^2_{H_i} + |\mu|^2 = |B\mu|$$

- $M_1 = M_2 = M_3$ (typically)
- $m^2_{\text{sfermions}} = 0$, $A = 0$ for first two generations (often)
- $\{m^2_{\text{squarks}}, A_t, A_b\}$ correlated, $\{m^2_{\text{sleptons}}, A_\tau\}$ correlated (often)
- Theoretically well-motivated by interesting UV models

Origin of mass degeneracy

SUSY GUT with chiral adjoint Φ

Adjoint of GUT group G decomposes under SM gauge group as

$$\begin{aligned} \mathbf{Ad}(G) &\to (\mathbf{1},\mathbf{2})_{-1/2} \oplus (\mathbf{1},\mathbf{2})_{1/2} \oplus \dots \\ \Phi &\to \quad H_1 \quad \oplus \quad H_2 \quad \oplus \dots \end{aligned}$$

If Higgs part of $\Phi - \Phi^\dagger$ massless at tree-level — e.g. being a

- pNGB
- gauge boson in higher dimensions
- ...

then

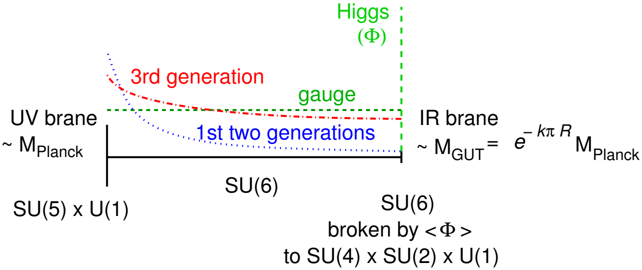
$$\begin{aligned} V \supset m^2 \,\mathrm{tr}\left(\Phi + \Phi^\dagger\right)^2 &\supset m^2 (H_1 + \overline{H}_2)(\overline{H}_1 + H_2) \\ &= m^2 |H_1|^2 + m^2 |H_2|^2 + m^2 \left(H_1 H_2 + \mathrm{h.c.}\right) \end{aligned}$$

$$\Rightarrow \; m^2_{H_1} + |\mu|^2 = m^2_{H_1} + |\mu|^2 = |B\mu|$$

Example 1: “Holographic GUT”

→ Nomura/Poland/Tweedie ’06

RS-I type model on slice of AdS_5

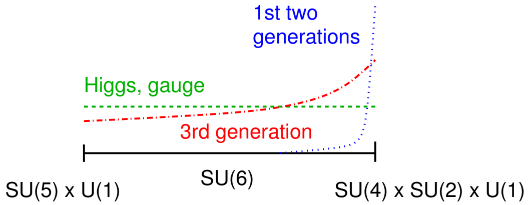


- In gaugeless limit: $\Phi - \Phi^\dagger$ contains pNGBs of broken SU(6)
- With gauge couplings: not all pNGBs eaten, no $H_1 - \overline{H}_2$ mass at tree-level
  $\Rightarrow$ Higgs mass degeneracy

Example 2a: 5d Gauge-Higgs unification

→ Burdman/Nomura '03

Flat extra dimension comactified with radius $R \sim 1/M_{GUT}$



$$\text{5d gauge supermultiplet} \rightarrow \text{4d gauge supermultiplet} \; -\theta\bar{\theta}A_\mu\sigma^\mu + \ldots$$
$$\oplus \; \text{4d chiral adjoint } \Phi = \Sigma + iA_5 + \ldots$$

5d gauge invariance: mass term only for $\Sigma \sim \Phi + \Phi^\dagger$, not for $A_5 \sim \Phi - \Phi^\dagger$

Boundary conditions: only $H_1, H_2 \subset \Phi$ have zero modes

$$\Rightarrow \; V \supset m^2(H_1 + \overline{H}_2)(\overline{H}_1 + H_2) + \ldots$$

$\Leftrightarrow$ Higgs mass degeneracy

Example 2b: Heterotic strings on orbifolds

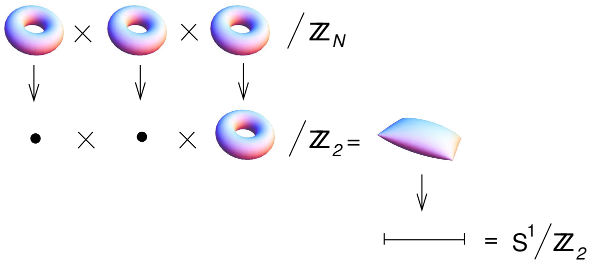
Some heterotic orbifold GUTs admit anisotropic 5d limit with gauge-Higgs unification

$\rightarrow$ same argument $\rightarrow$ s.a. Antoniadis et al. '94, Brignole et al. '97...

Schematically: $E_8 \times E_8$ heterotic on $T^6/\mathbb{Z}_N$ $\rightarrow$ e.g. Buchmüller et al. '05/'06

Compactify five radii at $\sim 1/M_{\text{Planck}}$, one at radius $\sim 1/M_{\text{GUT}}$

$\Rightarrow$ effective 5d orbifold GUT



Higgs mass degeneracy whenever anisotropic limit is possible

— not just at points in moduli space where it is acturally realized

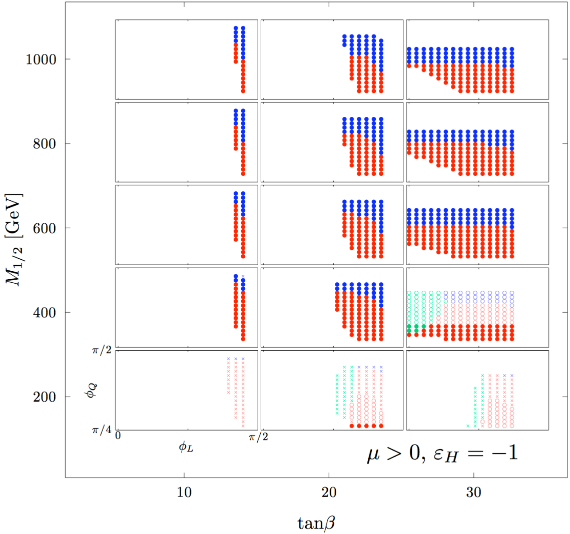
Example 2a studied in detail

Higgs mass degeneracy at GUT scale constrains Higgs potential at electroweak scale.
Can we get realistic phenomenology?

Example model: $\rightarrow$ Burdman/Nomura '03, Hebecker/March-Russell/Ziegler '08

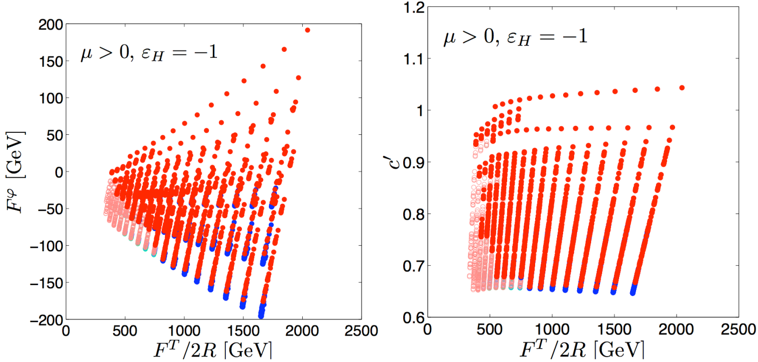
- 5d gauge-Higgs unified model
- 3rd generation in bulk
- first two generations on brane
- SUSY breaking: $F^T \neq 0$ (where $\langle T \rangle = R + F^T \theta^2$: "radion superfield") and $F^\varphi \neq 0$ (SUSY breaking in 4d gravitational multiplet)
- 5d Chern–Simons term crucial for gauge-Higgs sector soft terms $\rightarrow$ extra parameter: CS coefficient c
- 3rd generation matter soft terms $\leftarrow$ 2 bulk-brane mixing angles ϕ_Q, ϕ_L
- fundamental model parameters thus $\{F^T, F^\varphi, c, \phi_Q, \phi_L\}$ $\leftrightarrow \{M_{1/2}, \tan\beta, M_Z, \phi_Q, \phi_L\}$

Can find points with realistic EWSB. . .



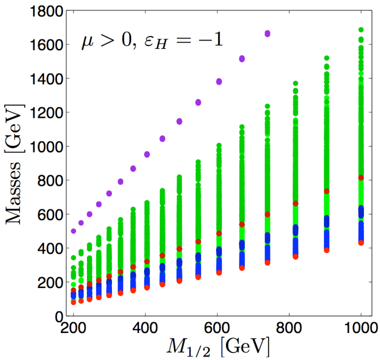
Neutralino, stau, selectron LSP. Small points excluded by LEP or B-physics

. . . for various values of fundamental parameters



Neutralino, stau, selectron LSP. Open circles excluded by B-physics
Recall $F^T/2R$ = radion contribution, F^φ = compensator contribution,
c = Chern-Simons parameter — note $c = 0$ excluded

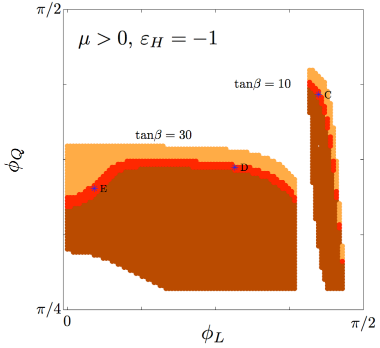
Sparticle masses in neutralino LSP region



Neutralinos, staus, selectrons, gluino

Note small NLSP-LSP mass difference
Also $\tilde{\chi}_2^0$ heavier than selectrons (sometimes also heavier than stau):
decay $\tilde{\chi}_2^0 \to \ell^\pm \tilde{\ell}^\mp \to \ell^\pm \ell^\mp \tilde{\chi}_1^0$ kinematically allowed, large BR
"Same-flavour-opposite-sign" dilepton signature at LHC

Neutralino relic density



Red band = relic density lies within 3σ of WMAP5 observation.
Orange region: Ωh^2 too low (other DM components besides $\tilde{\chi}_0$ required)
Brown region: Ωh^2 too high (with standard cosmology)

Work in progress: MCMC scan

Pheno of this example depends strongly on model details (matter sector. . .)

- What choices of parameters for MSSM with Higgs mass degeneracy are "best compatible" with phenomenology?
- What regions of parameter space are already ruled out?
- Does HMD lead to predictions independent of model details?

Explore parameter space with Markov Chain Monte Carlo methods

→ Baltz/Gondolo '04, Allanach/Lester '05, de Austri et al. '06. . .

- Random walk: Start with random parameter point
- Propose random candidate point nearby; accept or reject at random, acceptance probability depending on χ^2
- If accepted, candidate point becomes new starting point
- If rejected, propose other candidate point instead

Eventually fill parameter space with points
Regions of higher point density fit data better
More informative/efficient for parameter space sampling than grid scans

Conclusions

Summary:

- Higgs mass degeneracy $m_{H_1}^2 + |\mu|^2 = m_{H_2}^2 + |\mu|^2 = |B\mu|$ well-motivated
  Predicted by large class of high-scale models
- Can be made to work in a realistic example model:
  5d gauge-Higgs unification with radion-mediated SUSY breaking
- But probably hard to distinguish from other scenarios at LHC
- In progress: MCMC parameter space scan

Outlook:

- Work out implications for flavour physics in gauge-Higgs unified models
- Model discrimination?