More on SUSY Gauge-Higgs Unification

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based on work in progress
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Implications of GHU relations

Notation: $m_1^2 \equiv |\mu|^2 + m_{H_1}^2$, $m_2^2 \equiv |\mu|^2 + m_{H_2}^2$, $m_3^2 \equiv B\mu$.

GHU relations

$$m_1^2 = m_2^2 = \pm m_3^2$$

hold at GUT/compactification scale $\approx 10^{16}$ GeV.

For stable Higgs potential with EWSB, need

$$m_1^2 m_2^2 - m_3^4 < 0 \qquad \text{(EWSB)}$$

$$m_1^2 + m_2^2 - 2m_3^2 > 0 \qquad \text{(D-flat directions stabilized)}$$

at minimization scale $M_{\text{soft}} \approx 1$ TeV (where $m_3^2 > 0$ by convention).

RG running will have to do this.

RG evolution of Higgs mass parameters

Generic behaviour:

- m_1^2 does not change significantly (at most by an $\mathcal{O}(1)$ factor)
- m_2^2 runs negative towards low energies ($\rightarrow$ radiative EWSB) due to large top Yukawa
- m_3^2?

For fully realistic MSSM vacua (Higgs mass above LEP bound) need

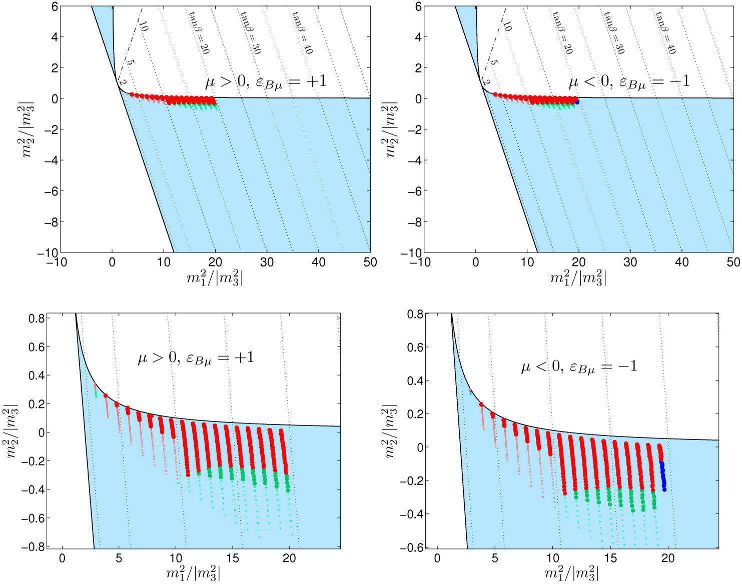
- $\tan\beta \gtrsim 5$ (to be close to tree-level Higgs mass bound)
- Small $M_Z/M_{\rm soft}$ (for large stop loop corrections to Higgs mass)

Roughly implies

- $m_3^2 \ll m_1^2$ at $M_{\rm soft}$ (using $m_1^2(M_{\rm soft}) \simeq M_{\rm soft}^2$)
- $|m_2^2| \ll m_1^2$

since $\tan\beta + \cot\beta = \frac{m_1^2 + m_2^2}{2m_3^2}, \qquad \frac{M_Z^2}{2} = (m_2^2 - m_3^2 \cot\beta)/\cos 2\beta$

Numerical results



($\color{red}{\text{Neutralino}}$,$\color{teal}{\text{stau}}$,$\color{blue}{\text{selectron}}$ LSP)

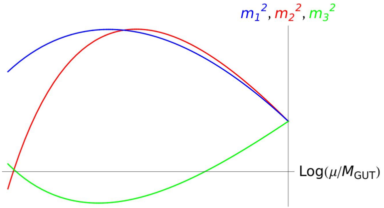
One-loop RG evolution of m_3^2

$$16\pi^2 \frac{d}{dt} m_3^2 = \mu \left(6 a_t \overline{y}_t + 6 g_2^2 M_2 + 6 a_b \overline{y}_b + 2 a_\tau \overline{y}_\tau + \frac{6}{5} g_1^2 M_1 \right)$$
$$+ m_3^2 \left(3|y_t|^2 + 3|y_b|^2 + |y_\tau|^2 - 3g_2^2 - \frac{3}{5} g_1^2 \right)$$
$$16\pi^2 \frac{d}{dt} a_t = y_t \left(\frac{32}{3} g_3^2 M_3 + 6 g_2^2 M_2 + \frac{26}{15} g_1^2 M_1 \right)$$
$$+ a_t \left(18|y_t|^2 + |y_b|^2 - \frac{16}{3} g_3^2 - 3 g_2^2 - \frac{13}{15} g_1^2 \right) + 2 a_b \overline{y}_b y_t$$
$$16\pi^2 \frac{d}{dt} M_3 = -6 g_3^2 M_3$$

- Gluino mass M_3 grows large towards low energies
- a_t at M_{GUT} positive ($a_t = y_t\, M_{1/2}$)
  Low-energy evolution of a_t dominated by M_3: driven negative + large
- Thus: Low-energy running of m_3^2 dominated by a_t,
  direction of running depends on sign(μ)

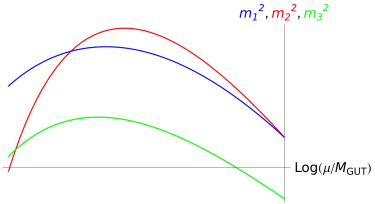
RG evolution of Higgs mass parameters

First possibility: $\mu > 0$



- m_3^2 runs up at low energies
  $\rightarrow$ must run negative first
- Large μ preferred

Second possibility: $\mu < 0$



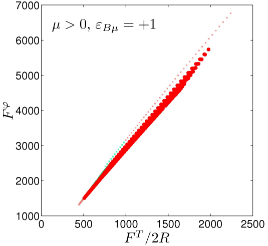
- m_3^2 runs down eventually
  $\rightarrow$ must run positive first
- Again large $|\mu|$ preferred

But: Cannot increase $|\mu|$ arbitrarily (for fixed $m_i^2(M_{\mathrm{GUT}})$)
since too large negative $m_{H_2}^2$ prevents REWSB

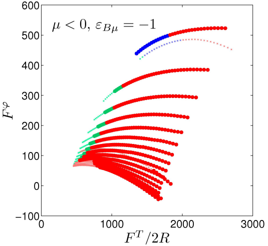
Implications for model parameters

$$\mu = \overline{F}^{\varphi} - \frac{\overline{F}^{T}}{2R} \frac{1 + 2c'}{1 + c'}$$

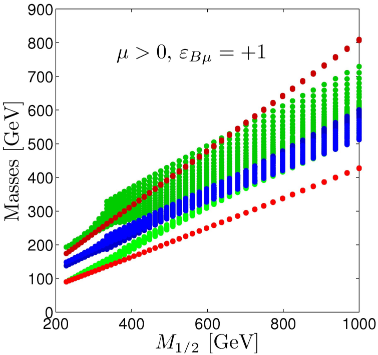
$m_3^2(M_{\mathrm{GUT}}) > 0$, μ positive and large
$\Rightarrow F^{\varphi} \gg F^T/2R$

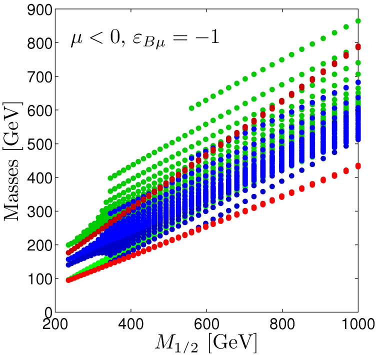


$m_3^2(M_{\mathrm{GUT}}) < 0$, μ negative, $|\mu|$ large
$\Rightarrow F^{\varphi} \ll F^T/2R$ (or negative)



LHC predictions





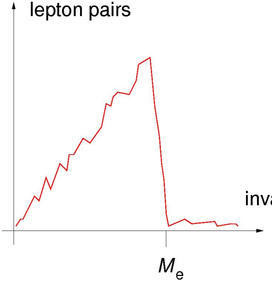
Neutralino, stau, selectron masses

- At low $M_{1/2}$, mass difference between χ_1^0 and NLSP small
- χ_2^0 (almost always) heavier than $\tilde{e}_{1,2}$ and $\tilde{\tau}_1$

LHC predictions

- Mass difference between χ_1^0 and NLSP small
- χ_2^0 heavier than $\tilde{e}_{1,2}$ and $\tilde{\tau}_1$
- χ_2^0 produced abundantly in squark decays

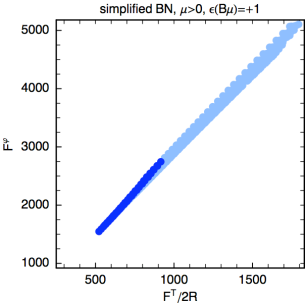
$\rightarrow$ Decays $\chi_2^0 \rightarrow \ell^\pm \tilde{\ell}^\mp \rightarrow \ell^\pm \ell^\mp \chi_1^0$ kinematically allowed, large BR
"Same-flavour-opposite-sign" dilepton signature,
allowing sparticle mass reconstruction through kinematic endpoints:

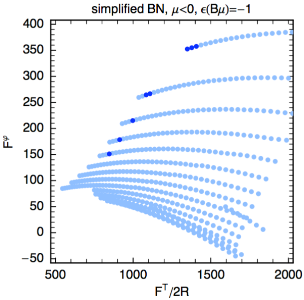


$$M_e = \sqrt{\left(m^2_{\chi_2^0}/m_{\tilde{\ell}} - m_{\tilde{\ell}}\right)\left(m_{\tilde{\ell}} - m^2_{\chi_1^0}/m_{\tilde{\ell}}\right)}$$

Cosmological constraints

- Small slepton-neutralino mass difference good for DM relic density: slepton-neutralino coannihilation
- Here: mass difference small enough only for $M_{1/2} \lesssim 400$ GeV
- $\Rightarrow$ Significant fraction of parameter space ruled out by WMAP (assuming standard cosmology): low enough relic density for dark blue points





- Expect this to improve with realistic sfermion boundary conditions — numerical analysis pending

Concluding remarks

- Phenomenology similar to "Higgs-exempt no-scale models"
  (→ Evans, Morrissey, Wells '06)
- also similar: F-theory models
  (→ Aparicio, Cerdeño, Ibáñez '08)
- and even certain regions of mSugra parameter space (small m_0)
- No "smoking gun" signature for GHU
  — but still predictions which can be falsified (or confirmed)

Outlook:

- Realistic boundary conditions for sfermions in progress
- Interesting future direction: what changes in GHU orbifold GUTs from heterotic string models?

LHC will have the final word.