Balancing AMSB's Troubles: Lifting the Slepton Masses with a SUSY Seesaw

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Outline

Motivation

- Explain the small nonzero neutrino masses
- Solve the gauge hierarchy problem
- Provide a viable dark matter candidate

Neutrino Mass

- Follow other SM fermions, add right-handed neutrino

$$y_\nu L H_u \nu^c$$

- Experiment states $y_\nu \sim 10^{-6} y_e$. Why?
- Seesaw Mechanism
  - ν^c is a singlet of SM
  - add $M_R \nu^c C^{-1} \nu^c$
  - ν and ν^c mix
  - $$\begin{pmatrix} 0 & m_D \\ m_D^T & M_R \end{pmatrix} \quad m_D = y_\nu \langle H \rangle$$
  - $M_R \gg m_D$, $m_\nu = -m_D^T M_R^{-1} m_D$
  - 10^3 Gev $\leq M_R \leq 10^{15}$ GeV

Seesaw Mechanism

- Problem: M_R undetermined
- Notice that with ν^c, can gauge $B - L$
- Associate M_R with $B - L$ breaking scale
- Extend Gauge group: $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

Breaking SUSY

- SUSY solves gauge-hierarchy, but must be broken
- Require:
  - No new flavor violation
  - Predictive relation of breaking parameters
  - Ignorance of UV physics
  - No new couplings
- Anomaly Mediated SUSY breaking (AMSB) satisfies all conditions
  - SUSY breaking due to superconformal anomaly (couplings fixed by SUGRA)
  - Thresholds decouple (UV ignorance)
  - Introduce one scale, $F_\phi = m_{3/2}$ (predictive)
  - Flavor violation only from yukawa couplings

AMSB Says

$$m_{\phi_i}^2 = -\frac{1}{4}|F_\phi|^2 \left(\frac{1}{2}\frac{\partial \gamma_i}{\partial g_a}\beta_{g_a} + \frac{\partial \gamma_i}{\partial y^{jk\ell}}\beta_y^{jk\ell} + \text{h.c.} \right)$$

$$a^{ijk} = -F_\phi \beta_y^{ijk}$$

$$M_a = \frac{\alpha_a b_a}{4\pi} F_\phi \quad \text{no sum over a}$$

- These equations are renormalization scale invariant
- They are independent of physics above heavy thresholds and therefore will not lead to flavor violating physics
- Only one parameter F_ϕ; soft parameters $\sim \frac{F_\phi}{16\pi^2}$; F_ϕ should be 10s of TeV
- Gravitino mass is of order F_ϕ hence avoiding cosmological problems

AMSB Disaster

- In MSSM, AMSB scalar mass formula:
  - $\text{sgn}\left(-\frac{\partial\gamma_i}{\partial y^{jk\ell}}\beta_y^{jk\ell}\right) = \text{sgn}\left(\beta_y^{jk\ell}\right)$
  - $-\frac{\partial\gamma_i}{\partial g_a}\beta_{g_a}$ is *always negative* for asymptotically enslaved gauge groups (such as $U(1)_Y$)
  - Example e^c:

$$m^2 = -\left(\frac{|F_\phi|}{16\pi^2}\right)^2\left(\frac{198}{25}g_1^4\right)$$

- MSSM+AMSB gives charge violating vacuum!
- *Must* modify the MSSM: need new couplings or interference from UV physics

Seesaw Saves AMSB

- Seesaw mechanism introduces new couplings:

$$W_{R\,\text{seesaw}} = f_c L^c \Delta^c L^c$$

    - Δ^c is a $B - L = -2$ $SU(2)_R$ triplet
    - $\langle \Delta^c \rangle \sim M_R \sim 10^{10}$ GeV is seesaw scale
    - Uses renormalizable operators
    - $\bar{\Delta}^c$ with $B - L = +2$ needed to cancel anomalies
    - $B - L = \pm 2$ retain R-parity, $P_R = (-1)^{3(B-L)+2s}$ (dark matter)
- Insist on Parity, need Δ, $\bar{\Delta}$ $SU(2)_L$ triplets
- Introduces

$$W_{L\,\text{seesaw}} = f L \Delta L$$

Extended Symmetries

- AMSB decouples thresholds, so new couplings must survive below M_R
- Potential has extended symmetry:

$$W_\Delta = M_\Delta \,\mathrm{Tr}\big(\Delta^c\bar{\Delta}^c + \Delta\bar{\Delta}\big) + \lambda_S S\,\mathrm{Tr}\big(\Delta^c\bar{\Delta}^c + \Delta\bar{\Delta}\big)$$

- yields tree-level global symmetry: complexified $U(6)$
- After VEV, $U(6) \to U(5)$ and therefore 22 massless real fields
- Super Higgs mechanism gives mass to six
- 16 massless d.o.f.: 2 doubly charged fields, 2 $SU(2)_L$ triplets
- Non-renormalizable terms break $U(6)$, leaving $\mu_\Delta \sim v_R^2/M_{\mathrm{Pl}} \sim 1$ TeV

New Couplings Below M_R

- $W \supset f L^c \Delta^c L^c \to f e^c \Delta^{c--} e^c$
- $m_{\tilde{e}^c} \sim \left(\frac{|F_\phi|}{16\pi} \right)^2 \left(f_c^4 - f_c^2 g_1^2 - g_1^4 \right)$
- For large enough f, $\tilde{e}^c$ is not tachyonic; similar for left-hand and other generations
- Assume f, f_c are flavor diagonal to obey experimental lepton flavor violation constraints

fs

- Take a look at the seesaw couplings, f_1, f_3, f_{c1} and f_{c3}

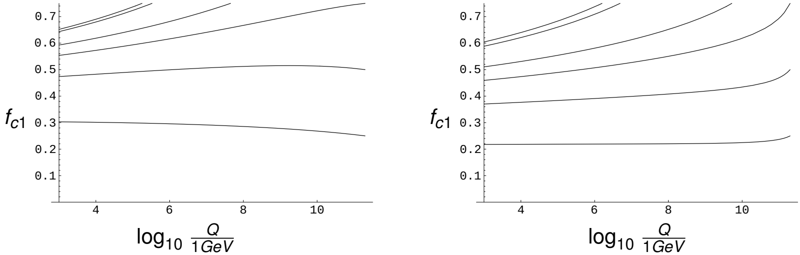
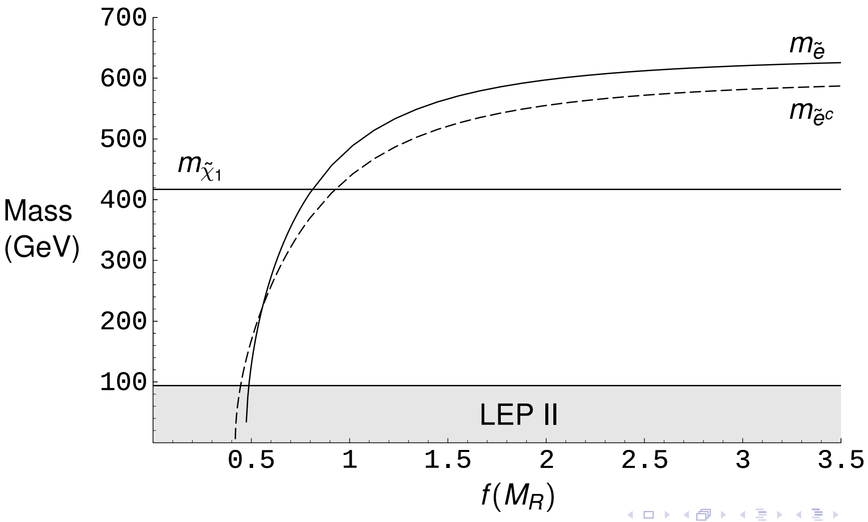


Figure: Plots of f_{c1} verses the log of the energy scale. The lines correspond, in ascending order, to $f_1(M_R)$ values of 0.25, 0.5, 0.75, 1, 2.25 and 3.5 for $f_3(M_R) = 0$ and $f_3(M_R) = 3.5$.

- Fixed point-like behavior: $f_{1,3} \sim 0.58$; $f_{c1,c3} \sim 0.62$

Slepton Masses

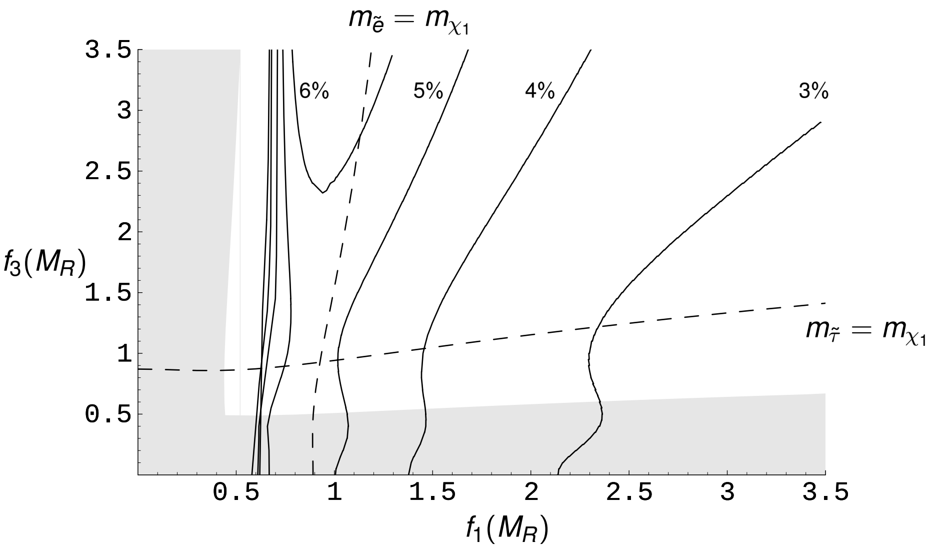
Slepton masses with $f_1 = f_3$ at M_R



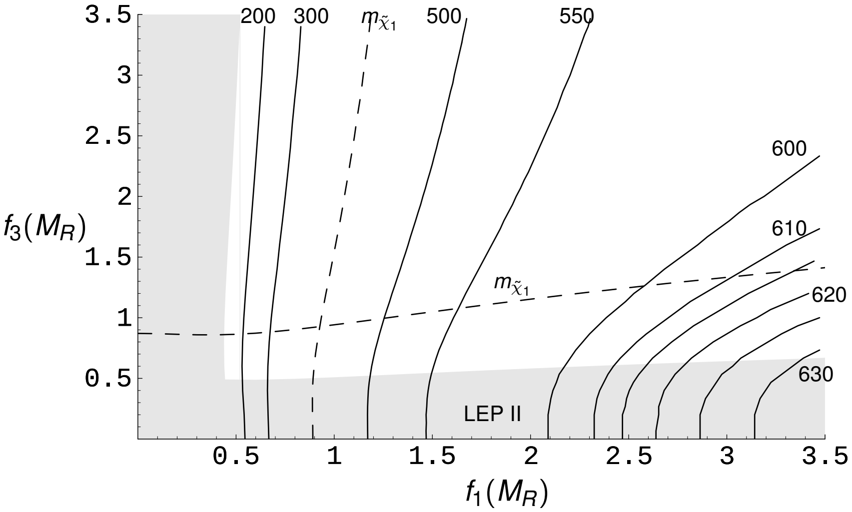
Slepton Mass Differences

- Plot shows $\tilde{e}$, $\tilde{e}^c$ fairly degenerate
- Different from mSUGRA
  - $m_{\tilde{e}} = m_{\tilde{e}^c}$ at M_P but run differently because of $\alpha_2 : \alpha_1$ hierarchy
- Different from mGMSB
  - $m_{\tilde{e}} \sim 3 m_{\tilde{e}^c}$ at M_{Mess} because of $\alpha_2 : \alpha_1$ hierarchy
- Does exist in mAMSB, even more pronounced in that case

Contours of Slepton Mass Differences



Contours of $m_{\tilde{e}^c}$ (GeV)



Limits on fs

- Previous graph suggests bounds on $f > 0.4$ at low energy due to LEP II
- Recall $m_{\Delta,\Delta^{c--}} \sim 1$ TeV
- muonium-antimuonium oscillation involves $f_1 f_2$ and doubly-charged exchange
- New flavor violation within current bounds
- But may be detectable in future experiments (PRISM)

Summary

- Same generation sleptons are degenerate
- Exotic particles might be detectable at the LHC and muonium-antimuonium oscillations
- dark matter candidate
- Bibliography:

  - Seesaw: Mohapatra and Senjanovic **Phys.Rev.Lett.44:912**,1980
  - AMSB: Giudice, Luty, Murayama and Rattazzi **JHEP 9812:027**,1998
    Randall and Sundrum **Nucl.Phys.B557:79-118**,1999
  - This Talk: Mohapatra, Spinner, and NS **Phys.Rev.D77:053013**,2008