The Upside of Seesaw in Anomaly Mediated Supersymmetry Breaking

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Outline

1. AMSB and EWSB
2. EWSB and SUSYLR+AMSB
3. Bosino Phenomenology

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2 EWSB and SUSYLR+AMSB

3 Bosino Phenomenology

μ Term and AMSB

- AMSB has problems other than tachyonic sleptons
- Recall that in AMSB, rescale fields $\hat{Q}\phi \to Q$, where Q is the canonical field
- Therefore

$$W_{MSSM} \supset \mu\phi^3 \hat{H}_u \hat{H}_d \to \mu\phi H_u H_d \quad (1)$$

- Breaks SUSY at tree level; $\mathcal{L}_{soft}^{tree} = \mu F_\phi \sim 10^7$. Too big for EWSB since

$$B\mu = \frac{\sin 2\beta}{2}\left(2\mu^2 + m_{H_u}^2 + m_{H_d}^2\right)$$

$$m_{susy}^2 16\pi^2 \neq \frac{\sin 2\beta}{2}\left(4m_{susy}^2\right)$$

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μ Term and AMSB

- AMSB seems to be incompatable with the MSSM
- Use the NMSSM where $\mu = \lambda\langle N\rangle$, with N a singlet

$$W_{NMSSM} \supset W_{Yukawa\ MSSM} + \lambda\phi^3\hat{N}\hat{H}_u\hat{H}_d + \frac{1}{3}\kappa\phi^3\hat{N}^3$$

$$\rightarrow W_{Yukawa\ MSSM} + \lambda N H_u H_d + \frac{1}{3}\kappa N^3$$

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EWSB in a Toy Model

- Even in this framework though, there is a problem
- Consider the toy theory

$$W = \frac{1}{3}\kappa N^3; \rightarrow \quad V = \kappa^2 |N|^4 + \frac{1}{3}\left(a_\kappa N^3 + a_\kappa^* N^{*3}\right) + m_N^2 |N|^2$$

$$\langle N \rangle = \frac{-a_\kappa \pm \sqrt{a_\kappa^2 - 8\kappa^2 m_N^2}}{2\kappa^2}$$

- Using AMSB trajectories

$$a_\kappa = \frac{F_\phi}{16\pi^2} 6\kappa^3 \quad m_N^2 = \frac{|F_\phi|^2}{(16\pi^2)^2} 12\kappa^4 \qquad \langle N \rangle = \frac{F_\phi}{16\pi^2}$$

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EWSB not possible

$$\langle N \rangle = \frac{F_\phi}{16\pi^2}\frac{\kappa}{4}\left(-6 \pm \sqrt{-60}\right)$$

- Problem with the radical: $\sqrt{a_\kappa^2 - 8\kappa^2 m_N^2}$, m_N^2 is not negative, no gauge interactions
- EWSB is not possible
- In the full NMSSM, get a little help from $a_\lambda N H_u H_d \rightarrow a_\lambda v_u v_d N$
- VEV is too small, chargino masses, $m_{\tilde{\chi}^+} \sim \mu$ is below LEP II bound:Kitano, Kribs and Murayama **hep-ph/0402215**
- Can cure this by adding colored vector-like particles do drive m_N^2 negative: Chacko, Luty, Maksymyk and Ponton **hep-ph/9905390**
- Some add a linear term W $\supset$ LN

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- In this framework though, EWSB can arises from the model
- Consider the non-renormalizable part of the superpotential

$$W_{NR} \supset \frac{\lambda_N}{M_P \phi} N^2 \,\mathrm{Tr}\left(\Delta^c \bar{\Delta}^c\right) \;\rightarrow \mu_N \equiv \frac{\lambda_N v_R^2}{M_P}$$

- An effective superpotential mass term for N. The presence of ϕ leads to tree level SUSY breaking

$$V_{Soft} \supset -\frac{1}{2} F_\phi \mu_N N^2$$

- Gives a large enough $|\langle N \rangle|$, greater than 200 GeV; R.N. Mohapatra, N. Setzer and S.S. **arXiv:0802.1208**

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VEV of N

- Turns out μ_N does not have to be too big

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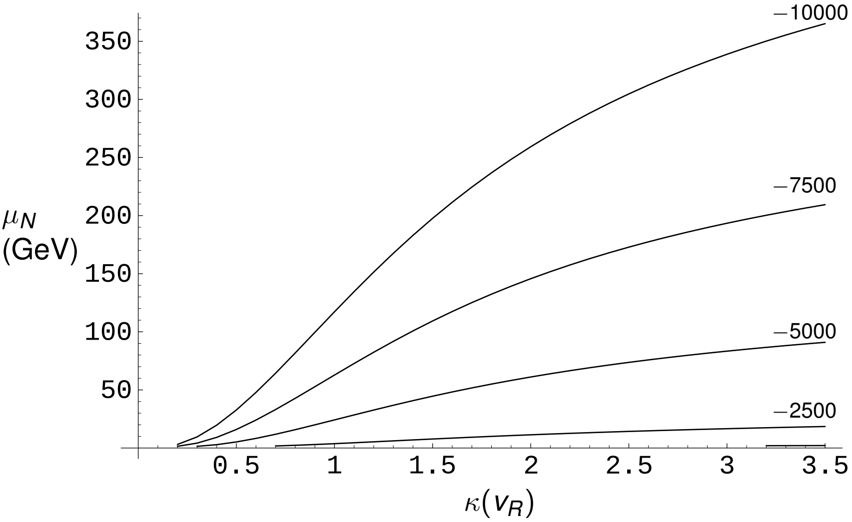

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Gauginos in mAMSB

- LSP is important for phenomenology since heavier particles cascade decay to it
- Best properties for LSP, i.e. for dark matter, come from neutralino. Composed of a mixture of: $\tilde{H}_u$, $\tilde{H}_d$, $\tilde{W}$, $\tilde{B}$ and $\tilde{N}$
- Gaugino contribution easy to see, for AMSB $M_3 : M_2 : M_1 \sim \frac{\alpha_3 b_3}{\alpha_2 b_2} : 1 : \frac{\alpha_1 b_1}{\alpha_2 b_2}$
- In mAMSB $\sim 8 : 1 : 3.5$, wino LSP

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Wino LSP in mAMSB

- Wino charginos and neutralinos form a highly degenerate isospin triplet
- In large M_2 limit, $\Delta_\chi \sim \alpha M_W \sim 165$ MeV
- Therefore, $\tilde{\chi}_1^+ \to \pi^+ \chi_1^0$
- Pion very soft, can't trigger
- Have to trigger on hard radiated photons or jets, look for chargino track. Chen, Drees, and Gunion **hep-ph/9512230**; Feng, Moroi, Randall, Strassler and Su **hep-ph/9904250**

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Neutralinos and Charginos in mAMSB

- Promising SUSY signals come from chargino leptonic decays:
  - $\chi^+\chi^+ \rightarrow l^+l^+ +$ missing energy - same sign dilepton
  - $\chi^+\chi^0 \rightarrow l^+l^-l^+ +$ missing energy - trilepton
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- Can have bino created by $\tilde{q}_R$ which can decay leptonically. But won't have signals mentioned above.

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Neutralinos and Charginos in SUSYLR+AMSB

- Here $b_2 = 6$ and $b_1 = \frac{78}{5}$
- $M_3 : M_2 : M_1 \sim 1.3 : 1 : 1.3$
- Now wino, bino and Higgsino have similar masses. LSP has significant Higgsino and wino component
- Left-handed squarks decay to heavier mostly wino or chargino state which can decay leptonically
- Δ_{χ_1} is order of magnitude larger due to $\tilde{H}_u - \tilde{H}_d$ mixing in neutralino sector, a little easier to see at a lepton collider

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- Squark mases below 1 TeV considered natural, otherwise reintroduce problem with Higgs mass
- $F_\phi < 63$ TeV
- Upper bound on bino and wino masses: $M_1 < 1350$ GeV and $M_2 < 980$ GeV
- Much larger than GMSB $M_1 < 130$ GeV and $M_2 < 260$ GeV or mAMSB $M_1 < 200$ GeV and $M_2 < 640$ GeV

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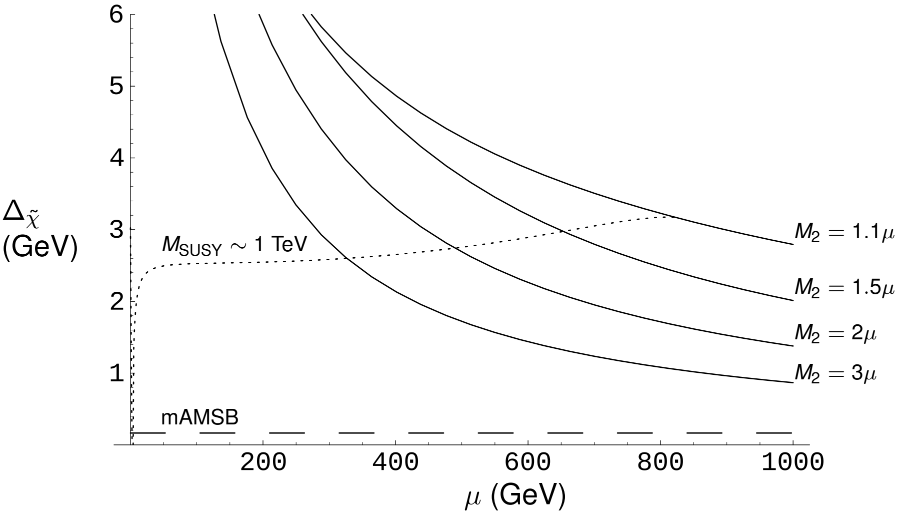
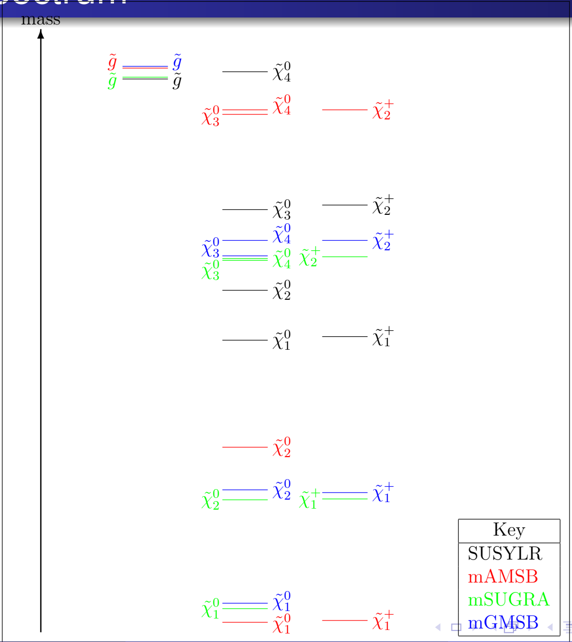


Bosino Spectrum



Dark Matter

- Mostly wino or Higgsion LSP, typically, annihilate away too fast, not enough dark matter
- In AMSB, gravitino is heavy and decays after LSP freeze out but before big bang nucleosynthesis, $\tilde{G} \rightarrow SM + LSP$
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