

Supersymmetric models with light Higgsinos

Felix Brümmer
DESY



Based on arXiv:1105.0802, 1111.6005, 1201.4338
Collaborators: S. Bobrovskyi, W. Buchmüller, J. Hajer

Supersymmetric models with light Scalinos

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Supersymmetric models with light Guralninos

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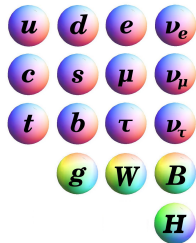
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The Standard Model



Beyond the Standard Model: The MSSM



Beyond the Standard Model: The MSSM



- minimal SUSY extension of Standard Model
- two Higgs doublets
- a scalar s-particle for every SM fermion: squarks, sleptons
- a fermionic partner for every SM boson: gauginos, **higgsinos**
- These are **gauge eigenstates**

In this talk: higgsinos also approximate **mass eigenstates** $\chi_1^0, \chi_1^\pm, \chi_2^0$
(so “light higgsinos” makes sense)

Why higgsinos are special

- Higgsino mass μ is the **only supersymmetric mass parameter** of MSSM
- **Origin** of μ ?
- μ cannot be too small (LEP chargino bound: $m_{\chi_1^\pm} \gtrsim 100$ GeV)
- μ should not be too large:

$$m_Z^2 = -2 m_{H_u}^2 - 2|\mu|^2 + \mathcal{O}(\cot^2 \beta)$$

If $|m_{H_u}^2|, |\mu|^2 \gg m_Z^2 \Rightarrow$ large cancellation needed $\Rightarrow$ **Fine-tuning!**

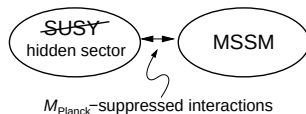
“ μ problem”

- Can we have $\mu \sim \mathcal{O}(m_Z)$?

Soft masses in gravity vs. gauge mediation

Gravity med.: $\mu \sim m_{3/2}$, $\rightarrow$ Giudice/Masiero '88

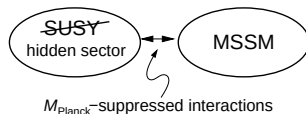
$$m_{\text{soft}} \sim m_{3/2}$$



Soft masses in gravity vs. gauge mediation

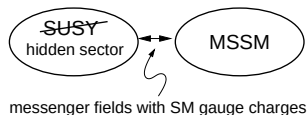
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Gauge med.: $\mu = 0$,

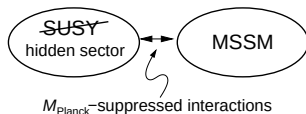
$$m_{\text{soft}} \sim m_{3/2} \cdot N_{\text{mess.}} \cdot \frac{M_{\text{Planck}}}{M_{\text{mess.}}} \cdot \frac{g^2}{16\pi^2}$$



Soft masses in gravity vs. gauge mediation

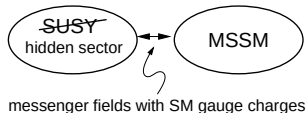
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Models with GUT-scale extra dimensions:

- typically include superheavy “exotic matter”: candidate messengers
- masses: $M_{\text{mess.}} \approx M_{\text{GUT}} \approx M_{\text{Planck}} \cdot \frac{g^2}{16\pi^2}$
- multiplicities: $N_{\text{mess.}} \sim \mathcal{O}(\text{few tens})$

Hybrid gauge-gravity mediation in higher-dimensional GUTs:

$$\mu \sim m_{3/2} \sim \mathcal{O}(100 \text{ GeV}), \quad m_{\text{soft}} \sim N_{\text{mess.}} \cdot m_{3/2} \sim \mathcal{O}(\text{TeV})$$

Example for higher-dimensional GUT: BHLR model

Model by → Buchmüller, Hamaguchi, Lebedev, Ratz '05

$E_8 \times E_8$ heterotic string theory on $T^6/\mathbb{Z}_6$ with Wilson lines

Massless spectrum:

- 3 MSSM generations
- 1 pair of massless MSSM Higgs doublets
- $\mathcal{O}(100)$ MSSM singlets $\{S_i\}$
- Messenger fields $\{\Phi_I\}$:

field	representation	multiplicity
d	$(\mathbf{3}, \mathbf{1})_{-1/3}$	4
$\tilde{d}$	$(\bar{\mathbf{3}}, \mathbf{1})_{1/3}$	4
ℓ	$(\mathbf{1}, \mathbf{2})_{1/2}$	4
$\tilde{\ell}$	$(\mathbf{1}, \mathbf{2})_{-1/2}$	4
m	$(\mathbf{1}, \mathbf{2})_0$	8
s^+	$(\mathbf{1}, \mathbf{1})_{1/2}$	16
s^-	$(\mathbf{1}, \mathbf{1})_{-1/2}$	16

GUT-scale soft terms in BHLR model

(for $m_{3/2} = 100$ GeV, $M_{\text{mess}} = 5 \cdot 10^{15}$ GeV, $\tan \phi = 1.9$)

Mainly from gauge mediation:

mass parameter	value [GeV]
M_1	1771
M_2	1583
M_3	644
m_Q	786
m_U	599
m_D	478
$m_L = m_{H_u} = m_{H_d}$	736
m_E	643

From gravity mediation:

μ	150
$\sqrt{B_\mu}$	240
A_0	150

Low-scale superparticle spectrum for BHLR model

particle	mass [GeV]
h^0	117
χ_1^0	137
$\chi_{1\pm}$	140
χ_2^0	144
χ_3^0	799
χ_4^0	1296
$\chi_{2\pm}$	1296
H_0	856
A_0	857
$H^\pm$	861
$\tilde{g}$	1453
$\tilde{\tau}_1$	713
other sleptons	910 – 1290
squarks	950 – 1750

← Light higgsinos!

What about the Higgs?

- $m_{h^0} = 124 - 126 \text{ GeV}$?
- Needs even **larger** m_{soft} $\rightarrow$ higher messenger numbers

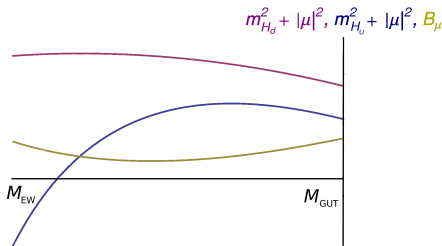
Fine-tuning problem!

Radiative electroweak symmetry breaking

- Soft SUSY-breaking masses generated at M_{GUT}
- Higgs potential:

$$V = (m_{H_u}^2 + |\mu|^2) |H_u|^2 + (m_{H_d}^2 + |\mu|^2) |H_d|^2 + B_\mu (H_u H_d + H_u^* H_d^*) + \text{quartic}$$

- Renormalization group running:



- Negative EV in mass matrix $\Rightarrow$ origin unstable $\Rightarrow$ EW symmetry broken
- Higgs mass parameters and EW scale generically $\mathcal{O}(m_{\text{soft}})$

The little hierarchy problem in the MSSM

$m_{h^0} > m_Z$ needs **large loop contributions** (from large stop masses/mixings)

$$m_{h^0}^2 = m_Z^2 + \frac{3}{4\pi^2} y_t^4 v^2 \left(\log \frac{m_{\tilde{t}}^2}{m_t^2} + \frac{A_t^2}{m_{\tilde{t}}^2} \left(1 - \frac{A_t^2}{12 m_{\tilde{t}}^2} \right) \right) + \dots$$

$$125^2 = 91^2 + 86^2$$

Need $m_{\text{soft}} \approx \text{few TeV}$

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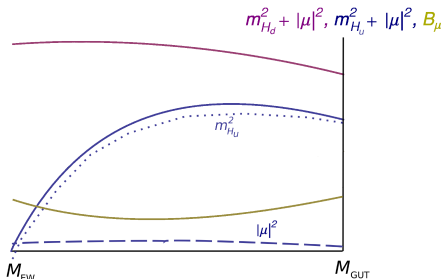
$$125^2 = 91^2 + 86^2$$

Need $m_{\text{soft}} \approx \text{few TeV}$

But m_{soft} sets magnitude for parameters in Higgs potential:

$$m_Z^2 = -2 (|\mu|^2 + m_{H_u}^2)$$

Large $m_{\text{soft}} \Rightarrow$ generically large $m_{H_u}^2 \Rightarrow$ **finely tuned large cancellation** needed



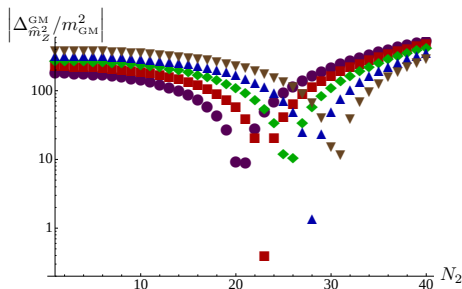
Focus points with high-scale gauge mediation

General messenger content: N_3 colour triplet pairs, N_2 weak doublet pairs

$$\Delta_{\hat{m}_Z^2}^{\text{GM}} \approx (2.25 N_3^2 - 0.45 N_2^2 + 0.19 N_2 N_3 + 3.80 N_3 - 1.16 N_2) m_{\text{GM}}^2$$

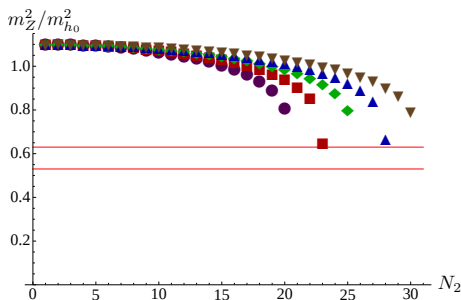
with

- $m_{\text{GM}} = m_{3/2} \cdot \frac{M_{\text{Planck}}}{M_{\text{mess.}}} \cdot \frac{g^2}{16\pi^2} \simeq m_{3/2} \simeq 100 \text{ GeV}$
- N_2 and N_3 **integers**: scan for $N_3 = 8, 9, 10, 11, 12$



Focus points with high-scale gauge mediation

- $(N_2, N_3) = (23, 9)$ or $(28, 11)$ lead to **weak scale** $\ll$ **soft mass scale**
- With $m_{\text{GM}} \simeq m_{3/2} \simeq m_Z$: can naturally have **multi-TeV soft terms**
- Helps pushing lightest Higgs mass above Z mass



Caveat: High sensitivity w.r.t. SM couplings and soft mass scale

Superparticle spectrum for $(N_1, N_2, N_3) = (28, 28, 11)$

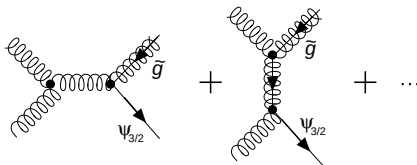
particle	mass [GeV]
h^0	124
χ_1^0	164
$\chi_{1\pm}^\pm$	166
χ_2^0	167
χ_3^0	2700
χ_4^0	4100
$\chi_{2\pm}^\pm$	4100
H_0	2200
A_0	2200
$H^\pm$	2200
$\tilde{g}$	4200
$\tilde{\tau}_1$	1900
other sleptons	2500 – 3600
squarks	2700 – 5000

$$\tan\beta = 44$$

Cosmology

Gravitino LSP is **natural dark matter candidate**

Gravitinos produced thermally during reheating at large T_R :



$$\Omega_{\psi_{3/2}} h^2 \approx 0.21 \left(\frac{T_R}{10^{10} \text{ GeV}} \right) \left(\frac{100 \text{ GeV}}{m_{3/2}} \right) \left(\frac{m_{\tilde{g}}}{1 \text{ TeV}} \right)^2$$

see e.g. → [Bolz, Brandenburg, Buchmüller '00](#)

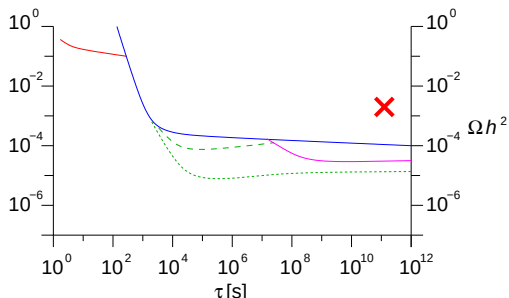
$T_R \approx 10^{10} \text{ GeV}$:

- Nicely compatible with leptogenesis
- Right order of magnitude for DM abundance

Cosmology

Problem: χ_1^0 NLSP long-lived, decays after BBN

Energetic decay products destroy nuclei, distorting light element abundances



Bounds from → Jedamzik '06:
NLSP relic density vs. lifetime
(assuming large hadronic BR)

${}^4\text{He}$, ${}^2\text{H}$, ${}^3\text{He}$, (Li)

- Higgsino NLSP relic density **low**: coannihilation with $\chi_1^\pm$
(recall first spectrum, $m_{\chi_1^0} = 137$ GeV, $m_{\chi_1^\pm} = 140$ GeV):

$$\Omega_{\chi_1^0} h^2 = 3 \cdot 10^{-3}$$

- ... but still in conflict with BBN bounds
- (Small) R-parity violation? Additional entropy production?

Collider phenomenology

None 😞

Collider phenomenology

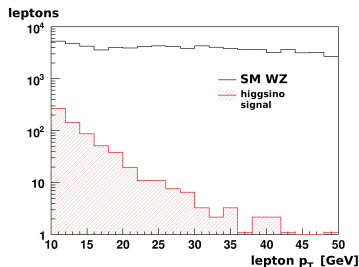
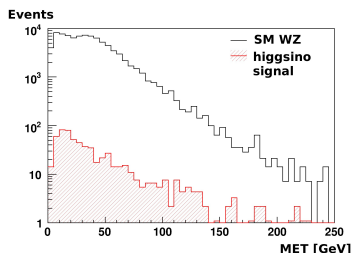
None ☹️ (at LHC, if $m_{h^0} \simeq 125$ GeV)

Collider phenomenology

None ☹️ (at LHC, if $m_{h^0} \simeq 125$ GeV)

- Higgsinos produced in electroweak processes, but decays hard to detect (see also → Baer/Barger/Huang '11)

E.g. leptons + MET signal (from $\chi_1^\pm \rightarrow \ell^\pm \chi_1^0$ or $\chi_2^0 \rightarrow \chi_1^\pm \ell^\mp \rightarrow \dots$):



- $\tilde{\tau}_1$ may also be < 1 TeV, but also hard to produce/see
- Monojets + MET from gluon ISR?
- Can find higgsinos and possibly stau at LC

Conclusions

Models with GUT-sized extra dimensions:

- nice motivation from string compactifications
- natural setting for hybrid gauge-gravity mediation

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Certain messenger multiplicities give focus points:

- EWSB scale naturally $\ll$ soft mass scale
- soft mass scale can be multi-TeV: allows for 124 GeV Higgs
- LHC might then find just the Higgs

Better ideas needed:

How to probe colourless states with near-degenerate EW-scale masses?

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Better ideas needed:

How to probe colourless states with near-degenerate EW-scale masses?

If spectrum is lighter ($m_{h^0} \lesssim 120$ GeV):

- LHC should see events in jets+MET searches
- With some luck, can even distinguish our models from e.g. CMSSM

Backup

Focus point SUSY

How to get $M_{\text{EWSB}} \ll m_{\text{soft}}$ in the MSSM?

- $m_Z = 91 \text{ GeV}$
- $m_{\text{soft}} \gtrsim 1 \text{ TeV}$

$$m_Z^2 = (-2|\mu|^2 - 2m_{H_u}^2 + \dots)|_{M_{\text{soft}}}$$

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Fine-tuning unless GUT-scale soft masses satisfy **relations**:

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- standard focus point: μ, M_i, A_0 small; $m_U^2 = m_Q^2 = m_D^2 = m_{H_u}^2 = m_{H_d}^2$
→ Feng/Matchev/Moroi '99

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→ Feng/Matchev/Moroi '99
- **now: high-scale gauge mediation**

Focus points with high-scale gauge mediation

- N_3 pairs of colour triplet messengers
- N_2 pairs of weak doublet messengers
- N_1 pairs of hypercharged messengers with hypercharge ± 1
- common messenger mass $M_{\text{mess.}} \sim M_{\text{GUT}}$

At scale M_{GUT} :

$$M_1 = \frac{6}{5} N_1 m_{\text{GM}}, \quad M_2 = N_2 m_{\text{GM}}, \quad M_3 = N_3 m_{\text{GM}}$$

$$m_Q^2 = \left(\frac{8}{3} N_3 + \frac{3}{2} N_2 + \frac{1}{25} N_1 \right) m_{\text{GM}}^2, \quad m_U^2 = \left(\frac{8}{3} N_3 + \frac{16}{25} N_1 \right) m_{\text{GM}}^2,$$

$$m_D^2 = \left(\frac{8}{3} N_3 + \frac{4}{25} N_1 \right) m_{\text{GM}}^2, \quad m_E^2 = \left(\frac{36}{25} N_1 \right) m_{\text{GM}}^2,$$

$$m_{H_{u,d}}^2 = m_L^2 = \left(\frac{3}{2} N_2 + \frac{9}{25} N_1 \right) m_{\text{GM}}^2,$$

$$\text{where } m_{\text{GM}} \equiv m_{3/2} \cdot \frac{g^2}{16\pi^2} \cdot \frac{M_{\text{Planck}}}{M_{\text{mess.}}} \sim m_{3/2}.$$