Supersymmetry with Light Higgsinos

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Supersymmetry with light higgsinos

1. Why should we care?

2. What should we look for?

Why should we care?

Light higgsinos

$$\mathcal{L}_{\mathrm{MSSM}} = \mu\,\tilde{H}_u\tilde{H}_d + \text{h.c.} + \left(m_{H_u}^2 + |\mu|^2\right)\,|H_u|^2 + \left(m_{H_d}^2 + |\mu|^2\right)\,|H_d|^2 + \ldots$$

- Higgsino mass parameter μ is special: supersymmetric

A priori μ is unrelated to the scale of SUSY breaking

- 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!

Light higgsinos

Two approaches:

- μ generated supersymmetrically, around EW scale by coincidence
- effective μ generated by SUSY breaking
  in calculable models: μ/B_μ problem→ Giudice's talk $\Rightarrow$ μ still special

Naturalness wants μ around 100 GeV:

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

LHC bounds want squarks and gluinos above 1 TeV.

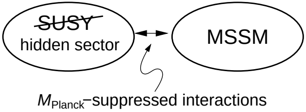
Motivates studying scenarios where higgsinos are light (EW scale)
while everything else is heavy (multi-TeV) except maybe 3rd generation

light higgsinos = near-degenerate χ_1^0, $\chi_1^\pm$, χ_2^0 around 100–200 GeV

Light higgsinos from hybrid gauge-gravity mediation

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

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



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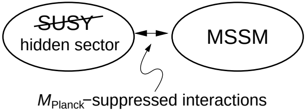
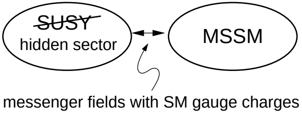


Gauge med.: $\mu = 0$,

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



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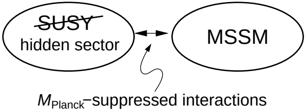

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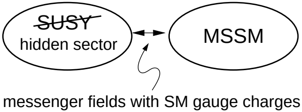


Models with GUT-scale extra dimensions:

- 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-dim. GUTs:→ FB/Buchmüller '11,'12

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

A mass spectrum from hybrid gauge-gravity mediation

particle	mass [GeV]
h^0	124
χ_1^0	164
$\chi_1^\pm$	166
χ_2^0	167
χ_3^0	2700
χ_4^0	4100
$\chi_2^\pm$	4100
H_0	2200
A_0	2200
$H^\pm$	2200
$\tilde{g}$	4200
$\tilde{\tau}_1$	1900
other sleptons	$2500 - 3600$
squarks	$2700 - 5000$

$$\tan\beta = 44$$

Light higgsinos from other models

Examples:

- “Lopsided gauge mediation”

  $\rightarrow$ Csaki/Falkowski/Nomura/Volansky ’08, de Simone/Francescini/Giudice/Pappadopulo/Rattazzi ’11

  Gauge mediation with tree-level Higgs-messenger couplings:

$$|\mu|^2 \sim m_{H_u}^2 \ll B_\mu \ll m_{H_d}^2$$

- any model where μ generated independently of SUSY breaking: μ could be anywhere between 100 GeV and M_{Planck}
  - from model-building perspective: most naturally near M_{Planck}
  - from fine-tuning perspective: most naturally near EW scale $\Rightarrow$ light higgsinos

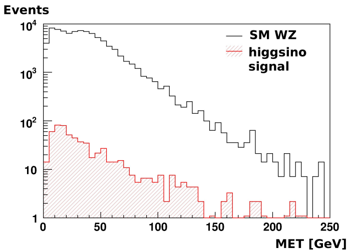
What should we look for?

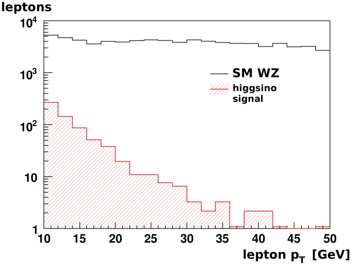
Electroweak higgsino pair production

Higgsinos produced at LHC in EW processes, but decays hard to detect

$\to$ Baer/Barger/Huang '11, Bobrovskyi/FB/Buchmüller/Hajer '11

E.g. Drell-Yan production $\to$ leptons + MET signal
(from $\chi_1^\pm \to \ell^\pm \chi_1^0$ or $\chi_2^0 \to \chi_1^\pm \ell^\mp \to \ldots$)





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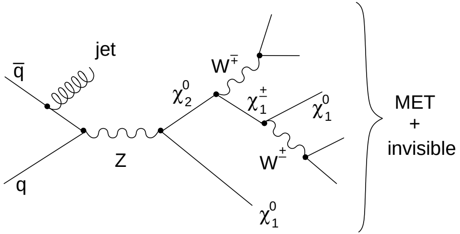
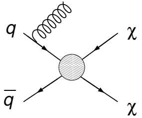
Higgsinos + monojets

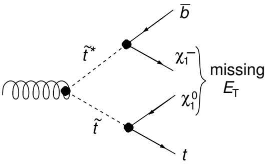


- Monojet (and -photon) signal at ATLAS and CMS
  → talks by Calfayan, Morse, Heikinheimo, Tattersall this morning
- Usual interpretation of j+MET: generic WIMP with contact interaction



- Should also provide mass limits for higgsinos!

If stops are light(ish): stop pair production



Direct stop pair production

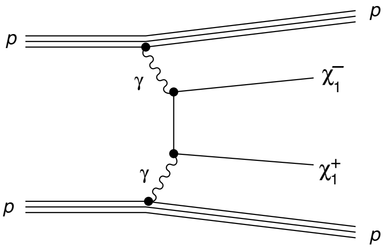
$\rightarrow$ Talks by Flaecher and Portell; talks in preceding session

- Might expect $m_{\tilde{t}}$ below $\sim$ 1 TeV (naturalness) but above $\sim$ 500 GeV (Higgs mass)
- Need to look at both $\tilde{t} \rightarrow t\chi^0_{1,2}$ and $\tilde{t} \rightarrow b\chi^{\pm}$
- Preliminary "theorist's study" $\rightarrow$ Bobrovskyi/FB/Buchmüller/Hajer '11: might be able to discriminate between light stops + bino LSP and light stops + light higgsinos from p_T spectrum of b-jets

Direct stop pair production

		before cuts	pre-cuts $N(j)$	pre-cuts $\not{E}_T$	$N(j)$	b-tag	m_{jj}^T	HT'	$\Delta\phi$	$\not{E}_T$	$N(l)$
higgsino	$\tilde{t}\tilde{t}^*$	11 220	8 909	8 729	6 093	3 158	1 928	1 378	1 238	637	575
											5
bino	$\tilde{t}\tilde{t}^*$	11 220	8 179	7 986	5 328	2 107	1 339	782	666	316	243
											2
BG	$t\bar{t}$	1×10^7	3×10^6	1×10^6	739 752	290 416	268 254	34 062	8 669	34	16
	t	1.7×10^6	160 197	23 773	21 234	6 858	6 330	907	176	6	3
											8

Charginos from photon-photon scattering?



→ Ohnemus/Walsh/Zerwas '93,. . . , de Favereau et al. '09

- Problems:
  - Low cross sections ($\lesssim$ fb)
  - pileup
  - needs dedicated forward detectors for proton tagging
- Advantages:
  - Clean environment
  - known kinematics

Linear collider

Detailed parameter measurements require linear collider

→ yesterday's talk by List; Baer/Barger/Huang '11; FB/List/Moortgat-Pick/Rolbiecki/Sert, in preparation

Two benchmark scenarios with hybrid gauge-gravity mediation:

m_{h^0}	124
$m_{\chi_1^0}$	164.2
$m_{\chi_1^\pm}$	165.8
$m_{\chi_2^0}$	166.9
M_1	1700
M_2	4400
μ	160

m_{h^0}	127
$m_{\chi_1^0}$	166.6
$m_{\chi_1^\pm}$	167.4
$m_{\chi_2^0}$	167.6
M_1	5300
M_2	9500
μ	160

- small mass splittings ⇒ pions, soft γs

Linear collider

Estimated achievable accuracy: m_χ and Δm_χ to $\sim$ (few %)

$\rightarrow$ Hensel '02

Can determine fundamental parameters to percent level without assuming a particular SUSY breaking model

Measurement strategy:

- Require hard ISR photon
- Exploit rates with two different energies: $\sqrt{s} = 350$ GeV (higher rates) and 500 GeV
- Apply different polarization asymmetries to disentangle processes $P(e^-)$ and $P(e^+)$ required!

Conclusions

- Light higgsinos = near-degenerate χ_1^0, $\chi_1^\pm$, χ_2^0 around $100 - 200$ GeV
- Motivated from naturalness
- Motivated from model-building
  E.g. hybrid gauge-gravity mediation: μ gravity-mediated, soft masses gauge-mediated
- Higgsinos hard to see: mass degeneracy $\Rightarrow$ soft decay products
- Possible experimental handles:
  Monojets; stop decays (if stops in LHC reach); $\gamma\gamma$ scattering?
- Disentangling details of spectrum will need linear collider

Backup

Focus point SUSY

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

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

$$m_Z^2 = \left(-2|\mu|^2 - 2\,m_{H_u}^2 + \ldots\right)\Big|_{M_{\text{soft}}}$$

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\begin{aligned}
m_Z^2 &= \left(-2|\mu|^2 - 2\, m_{H_u}^2 + \ldots\right)\Big|_{M_{soft}} \\
&= \Big(2.25\, M_3^2 - 0.45\, M_2^2 - 0.01\, M_1^2 + 0.19\, M_2 M_3 + 0.03\, M_1 M_3 \\
&\quad + 0.74\, m_U^2 + 0.65\, m_Q^2 - 0.04\, m_D^2 - 1.32\, m_{H_u}^2 - 0.09\, m_{H_d}^2 \\
&\quad + 0.19\, A_0^2 - 0.40\, A_0 M_3 - 0.11\, A_0 M_2 - 0.02\, A_0 M_1 \\
&\quad - 1.41\, |\mu|^2 + \ldots\Big)\Big|_{M_{\text{GUT}}}
\end{aligned}
$$

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

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

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

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  $\rightarrow$ 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}:

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

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

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

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

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

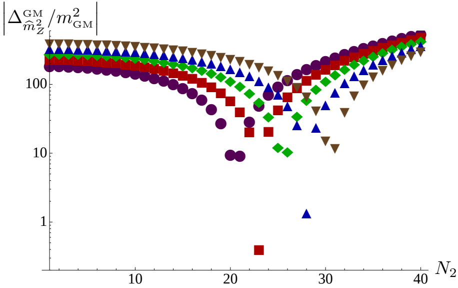
Focus points with high-scale gauge mediation

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

$$\Delta^{\rm GM}_{\widehat{m}_Z^2} \approx \left(2.25\, N_3^2 - 0.45\, N_2^2 + 0.19\, N_2 N_3 + 3.80\, N_3 - 1.16\, N_2\right) m_{\rm GM}^2$$

with

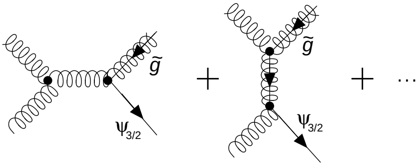
- $m_{\rm GM} = m_{3/2} \cdot \frac{M_{\rm Planck}}{M_{\rm mess.}} \cdot \frac{g^2}{16\pi^2} \simeq m_{3/2} \simeq 100$ GeV
- N_2 and N_3 integers: scan for $N_3 = 8, 9, 10, 11, 12$



Cosmology

Gravitino LSP is natural dark matter candidate

Gravitinos produced thermally during reheating at large T_R:



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

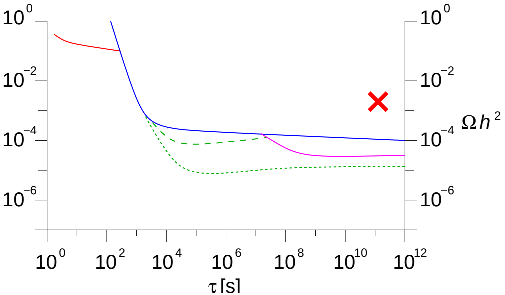
see e.g. → Bolz, Brandenburg, Buchmüller '00

$T_R \approx 10^{10}$ 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}He, ^{2}H, ^{3}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?