Non-Universal gaugino masses and implications on the Dark Matter and Higgs searches

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Outline

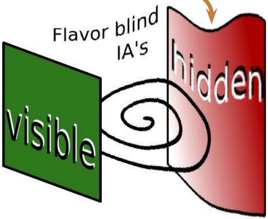
1. Recap
   - What Universality?
2. Non-Universality From SU(5) GUT
   - SU(5)
   - Breaking the Symmetries
3. Dark Matter
   - Relic Density
   - Higgses from Cascades

MSSM – Broken SUSY

SUSY breaking is supposed to be generated spontaneously

But: Exact method is not known! So:

- Supersymmetry is broken by hand by adding SUSY breaking terms
- The B- and L-breaking terms are prohibited by *R*-parity
  - → *Lightest supersymmetric particle (LSP)* is absolutely stable



- Over hundred new *free* parameters from the SUSY breaking!

Must try to reduce the parameter space

Universality Assumptions

SUSY breaking is assumed to be universal at the GUT scale

- Most of the new parameters imply flavor mixing or large CP-violation ➔ implies 'universality'

If one assumes that no flavor or CP-violation is generated:

Soft supersymmetry breaking universality

- 3 real independent gaugino masses
- 5 real squark and slepton squared masses
- 3 real scalar cubic coupling parameters
- 4 Higgs mass parameters

This is valid at the GUT scale

mSUGRA Parameters

Hidden-visible separation of superpotential (and [minimal] Kähler potential) gives a common mass scale for the squared masses, common mass for the trilinear and bilinear couplings.

But not for the gaugino masses!

1. $m_0, A_0, B_0 \leftarrow$ Common
2. $m_{1/2} \leftarrow$ Universal gaugino mass (for convenience)
3. $\mu \leftarrow$ Supersymmetric Higgs mass parameter (considered as fifth input parameter)

Usually people write $B_0\mu$.
After the EWSB μ and $B_0 \Rightarrow$ sgn(μ) and $\tan\beta = \langle H_2^0 \rangle / \langle H_1^0 \rangle$.

SUSY SU(5)

Why consider SU(5)?

1. It is the simplest model for GUT
   - $\longrightarrow$ Gives nicely the SU(3) $\times$ SU(2) $\times$ U(1) structure
2. Gives well specified non-universality for gauginos

Non-universality of gauginos can be motivated, and the predictivity is maintained!

$\Rightarrow$ Easier to see phenomenological consequences

Gaugino Mass Terms

Masses come from the coupling of the

f_{ab} gauge kinetic function
W^a gauge field strength

$$\boxed{\mathscr{L}_{g.k.} = \int d^2\theta\, f_{ab}(\Phi) W^a W^b}$$

- The gauge kinetic function must be non-minimal. Then

$$\mathscr{L}_{g.k.} \supset \frac{\langle F_\Phi \rangle_{ab}}{M_P} \lambda^a \lambda^b + \text{H.C.},$$

$\langle F_\Phi \rangle \leftarrow$ is the *vev* for the F-term of Φ

Breaks SUSY

Non-singlet w.r.t. SU(5) – breaks SU(5)

Choice of Representations

The gauge multiplets are in the adjoint representation $\Rightarrow \langle F_\Phi \rangle$ transforms as a symmetric product of two adjoints

$$\boxed{\langle F_\Phi \rangle_{ab} \, \lambda^a \lambda^b}$$

(must be gauge invariant)

Therefore, Φ can belong to any of the (irreducible) representations of

$$(\mathbf{24} \otimes \mathbf{24})_{Symm} = \mathbf{1} \oplus \mathbf{24} \oplus \mathbf{75} \oplus \mathbf{200}.$$

If Φ does not belong to rep **1**,
resulting gaugino masses are non-universal

Ratios of the Gaugino Masses

Parameters are run down to the EW-scale using RGE's

Table: Ratios of the gaugino masses at the GUT and EW scales

F_Φ	M_1^{GUT}	M_2^{GUT}	M_3^{GUT}	M_1^{EW}	M_2^{EW}	M_3^{EW}
1	1	1	1	0.14	0.29	1
24	-0.5	-1.5	1	-0.07	-0.43	1
75	-5	3	1	-0.72	0.87	1
200	10	2	1	1.44	0.58	1

Smallest of (M_1^{EW}, M_2^{EW}) characterizes the lightest neutralino

Note: Φ can also transform as a linear composition of any of the representations

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Neutralinos Are Born at the EWSB

Neutralinos are combinations of gauginos and higgsinos

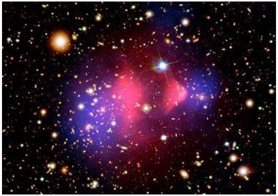
$$\boldsymbol{M}_{\tilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -c_\beta\, s_W\, m_Z & s_\beta\, s_W\, m_Z \\ 0 & M_2 & c_\beta\, c_W\, m_Z & -s_\beta\, c_W\, m_Z \\ -c_\beta\, s_W\, m_Z & c_\beta\, c_W\, m_Z & 0 & -\mu \\ s_\beta\, s_W\, m_Z & -s_\beta\, c_W\, m_Z & -\mu & 0 \end{pmatrix}$$

[$s_\beta = \sin\beta$, $c_\beta = \cos\beta$, $s_W = \sin\theta_W$, and $c_W = \cos\theta_W$]

Diagonalize $\boldsymbol{M}_{\tilde{\chi}^0} \Rightarrow$ Four neutralino masses

Relevant: Respective relations between M_1, M_2 and μ.
Remember: μ is determined by the EWSB

Dark Matter



Bullet cluster:
Blue = dark matter
Red = hot gas

Supersymmetric theories which preserve *R*-parity contain a natural candidate for the cold dark matter (CDM) particle.

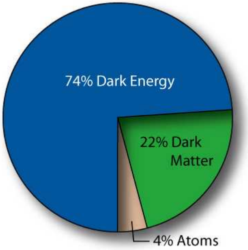
- A CDM candidate must be weakly interacting and massive (WIMP)

Neutralino!

- Usually the lightest neutralino is bino-like
  $\Rightarrow$ too high thermal relic density
- The non-universal gaugino masses changes the neutralino composition

Relic Density

1. Early universe: WIMP's in thermal equilibrium
2. Expansion & Cooling $\Rightarrow$ annihilation reduces density
3. Eventually, density is too low to maintain annihilation $\Rightarrow$ Freeze-out
4. From here on, the relic density depends only on expansion rate of the universe



Relic density Ωh^2 observed today can be calculated for each model.
($\Omega = \rho / \rho_c$ with $\rho_c =$ critical density to close the Universe)

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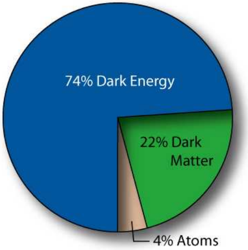

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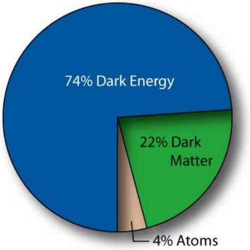

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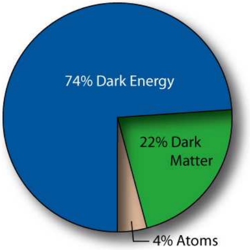

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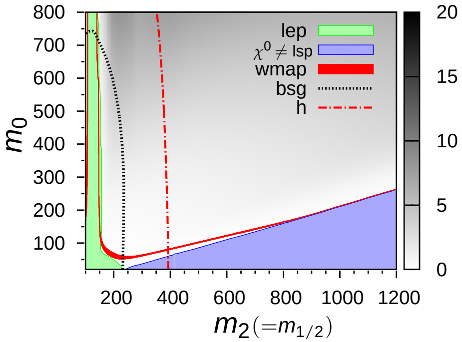

$\tan\beta = 10,\ \mathrm{sgn}(\mu) = +1,\ A_0 = 0$

$$\boxed{\Omega_{CDM}h^2 = 0.11054^{+0.00976}_{-0.00956}}$$

Three year WMAP data

Typical mSUGRA figure showing relic density stripe and collider constraints.

- The preferred relic density area is quite constrained
- Co-annihilation with $\tilde{\tau}$ helps to dilute the relic density
- Often the neutralino RD is overclosing the Universe

Rep 1

χ_1^0 is mainly bino-like

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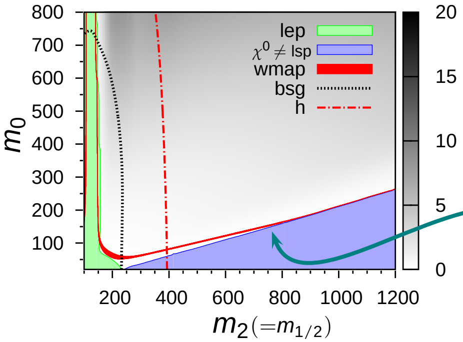

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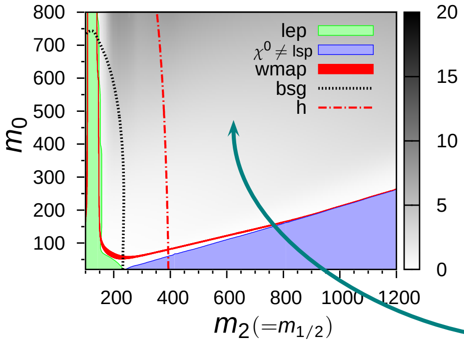

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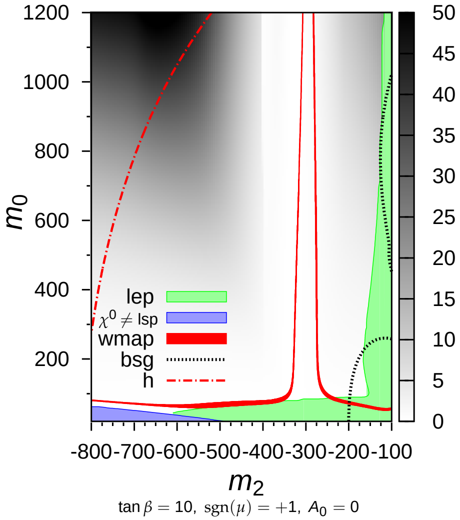
Rep 24 – Large relic density



Rep 24

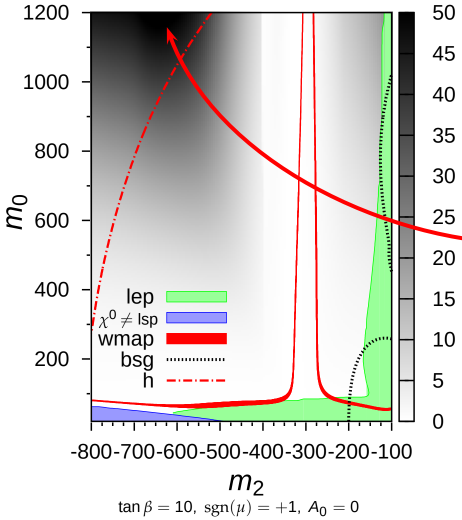
χ_1^0 is even more bino-like

- Relic density can rise very high
- Minimum: Z-peak

Many values of m_0 are allowed, but only for specified m_2

Higgsino component can be increased by increasing $\tan\beta$.

Rep 24 – Large relic density



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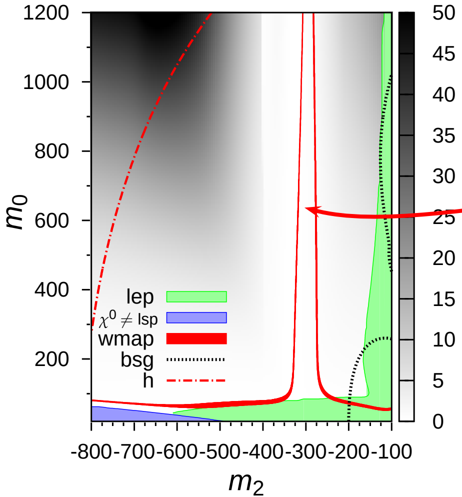

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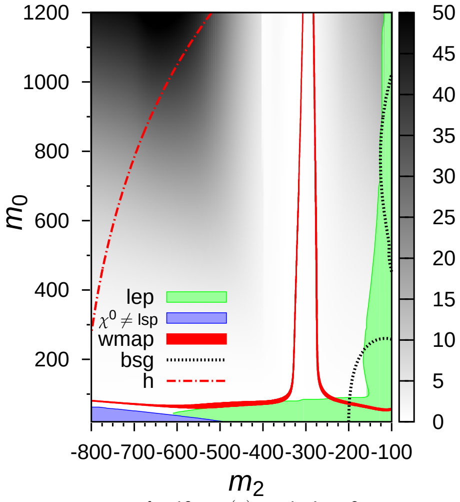

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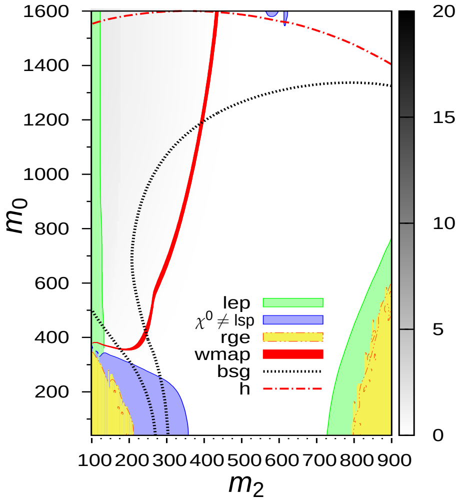
Rep 75 – Large Higgsino Component



$\tan\beta = 10,\ \mathrm{sgn}(\mu) = -1,\ A_0 = 1$ TeV

Rep 75

$\tilde{\chi}_1^0$ is mostly Higgsino-like

- Large Higgsino component increases annihilation to gauge boson pairs
- Also $m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_1^\pm} \Rightarrow$ co-annihilations
- More, $\tilde{\chi}_2^0$ may annihilate directly into gauge bosons

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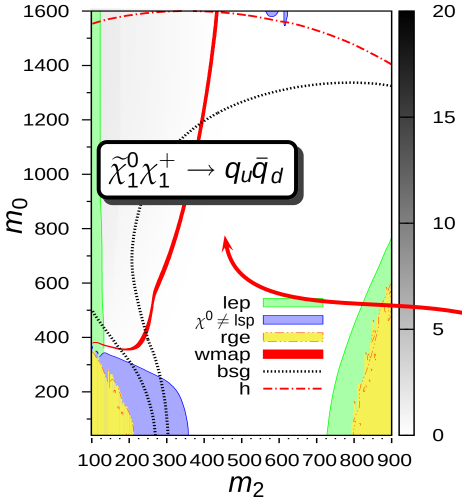

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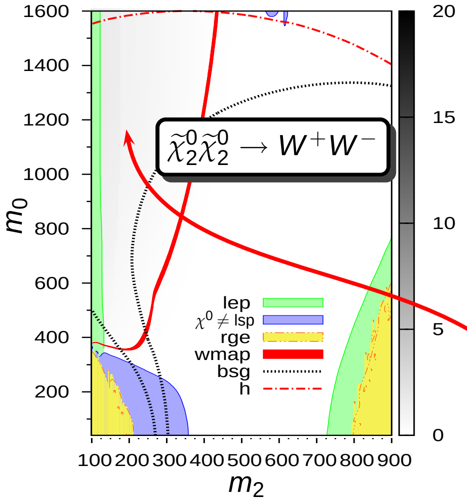

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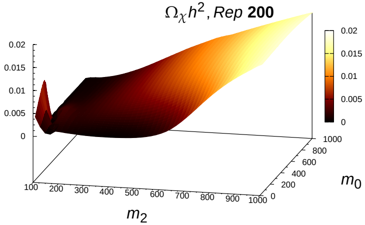
Rep 200

$\tilde{\chi}_1^0$ and $\tilde{\chi}_1^\pm$ are almost degenerate

- The co-annihilations ($\tilde{\chi}_1^0 \tilde{\chi}_1^\pm$) reduce the relic density substantially
- Also the Higgsino mixing is large
- Importantly, bino component is very small

$\Rightarrow$ Resulting relic density is very low.



Rep 200

Neutralino can not be the only source of dark matter

Higgs Production in the Cascade $\tilde{q}, \tilde{g} \to \tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$

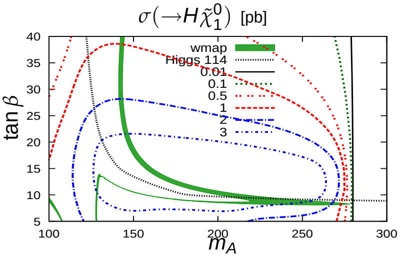
- At the LHC squarks and gluinos are produced a lot
  - If squarks and gluinos are light enough to be produced, the production cross section will be large
- A possible way to look for the Higgs bosons is through the cascade

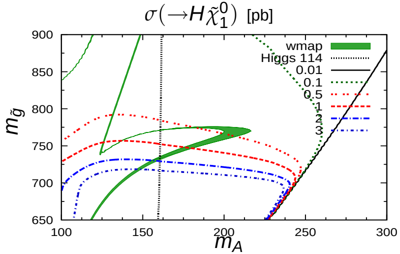
$$\tilde{q}, \tilde{g} \to \tilde{\chi}_2^0 + X \to \tilde{\chi}_1^0 h/H/A + X \to \tilde{\chi}_1^0 b\bar{b} + X$$

  e.g. for the final state $b\bar{b}b\bar{b} + X$.
- Weakly dependent on $\tan\beta \Rightarrow$ May help Higgs searches in the low and moderate $\tan\beta$ regions

Take now $m_{\tilde{g}} > m_{\tilde{q}} \Rightarrow$ Every gluino decays to a quark and the corresponding squark ($q\widetilde{q}$).

Heavy Neutral Higgs Cascade in Rep 24 at the LHC





$$\tilde{q}, \tilde{g} \to \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 H \to \tilde{\chi}_1^0 b\bar{b} + X$$

High CS's in WMAP-preferred regions!

- Light Higgs channel open
- Minimum: Around A-peak
- Rep **24** gives all channels (via h, A and H)

For comparison, rep **1** gives only the lightest higgs channel.

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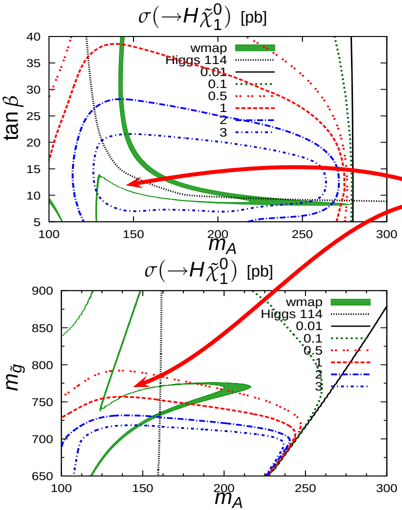

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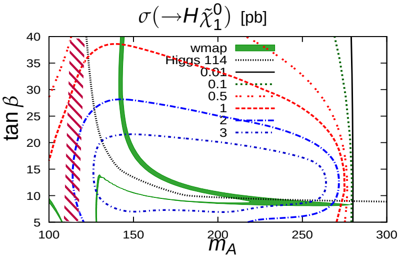

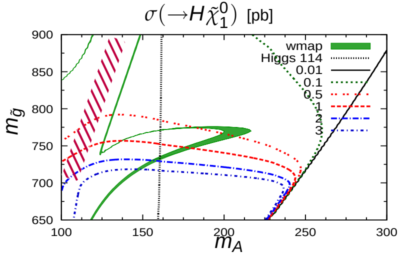

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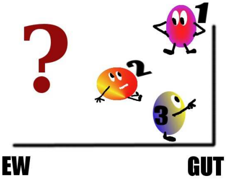
Summary

Non-universal gaugino masses can

1. help to find heavy Higgses
2. help to dilute excess relic density

The ratios of the two lightest neutralino masses changes significantly with the representation.



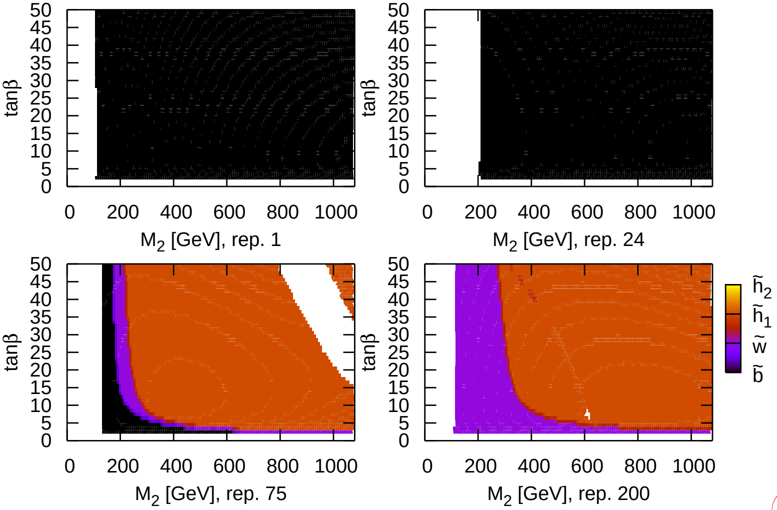
- It is important to realize that there is no automatically theoretical preference for the gaugino masses to be unified

Gaugino Non-Universality must be considered as a serious option
– Not a complication, but an opportunity!

end

4 Appendix
- Main Component of the Lightest Neutralino
- Constraints

Appendix: Main component of the χ_1^0



Constraints

For the relic density, the WMAP three year limits are used

$$\Omega_{CDM}h^2 = 0.11054^{+0.00976}_{-0.00956}.$$

The curve $m_h = 114$ GeV is depicted in the figures. For the shown parameter region, when otherwise experimentally allowed, Higgs is always heavier than 91 GeV, which is the Higgs mass limit in MSSM for $\tan\beta > 10$ assuming maximal top mixing.

The latest world average of

$$B(b \to s\gamma) = (355 \pm 24^{+9}_{-10} \pm 3) \times 10^{-6}$$

for the branching fraction for the decay $b \to s\gamma$ was used.