# *Implications of Non-Universal Masses: a Step Beyond mSUGRA*

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# Outline

- Introduction
- SUSY at the Colliders
- Indirect and Direct DM detection
- Non-universal Gaugino Masses and Other Ways to agree with WMAP
- Conclusions

# The Usual Motivation

Standard Model has “problems”:
EW symmetry breaking is not pretty,
Higgs mass has quadratically divergent corrections,
no gauge coupling unification,
CDM candidate (axion) is constrained to be unnaturally light etc.

SUSY solves some of that:
EWS breaking is radiative,
scalar particle quadratic mass divergencies cancel,
gauge couplings unify in 2 HDM,
there exists a good CDM candidate.

There are too many parameters in the MSSM for a phenomenologist.

# mSUGRA (CMSSM)

5 parameters in addition to SM:

$$m_0,\ m_{1/2},\ A_0,\ \tan(\beta) \equiv \frac{v_u}{v_d},\ sign(\mu).$$

SUSY is broken in the hidden sector and mediated to the visible sector via gravitational interactions.

LSP is neutralino. Good candidate for CDM.

# Neutralino as the Dark Matter Particle

is excluded in most of mSUGRA parameter space.

There are only several surviving regions:

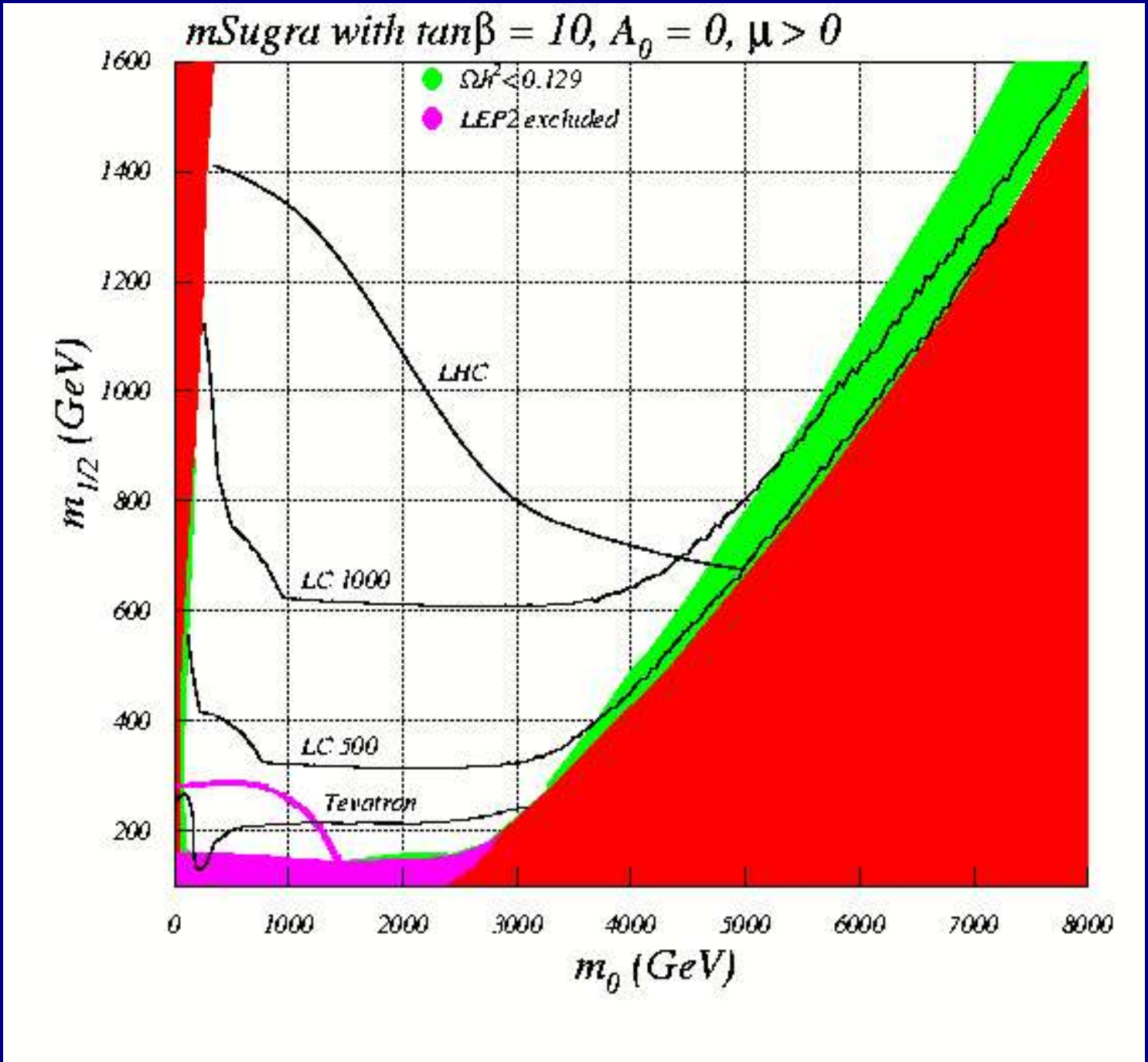
► The bulk region (low $m_0$, $m_{1/2}$). Neutralinos annihilate via t-channel exchange of light sleptons.

► Stau co-annihilation region (low $m_0$, $m_{\tilde{\tau}_1} \approx m_{\tilde{Z}_1}$).

► Hyperbolic branch/focus point region ($m_0 \sim TeV$). Neutralino $\tilde{Z}_1$ is higgsino-like and can annihilate with $\tilde{Z}_2$ and $\tilde{W}_1$.

► A-annihilation funnel (for large $\tan(\beta)$). $2m_{\tilde{Z}_1} \sim m_A$

In addition there exists a light Higgs annihilation corridor (for large $m_t$) and top squark co-annihilation region at particular values of $A_0$.




H. Baer *et al.*, JHEP 0306:054,2003

# Direct and Indirect Searches for Neutralino DM

Direct searches: neutralino scattering on nucleus.

Current limits are $\sigma_{SI} \sim 10^{-7} - 10^{-8}\, pb$ (neutralino mass dependent): CDMS, CDMS2, EDELWEISS, ZEPLIN1, DAMA.

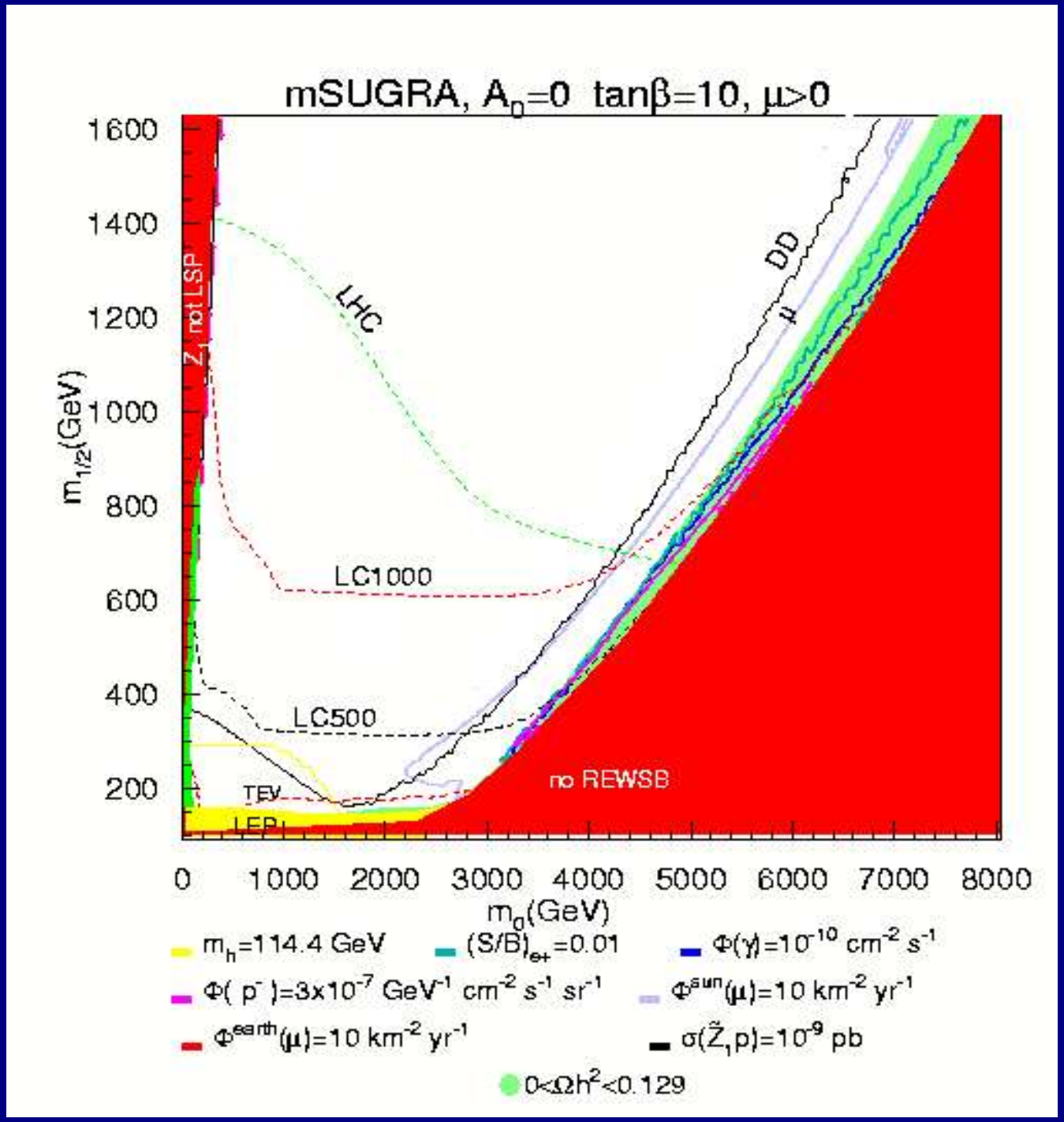
Stage 3 detectors (GENIUS, ZEPLIN4, XENON) promise $\sigma_{SI} < 10^{-9} - 10^{-10}\, pb.$

Indirect searches:

► High energy neutrinos from neutralino annihilation in the core of the Earth or the Sun.

► Gamma rays from neutralino annihilation in the galactic core or galactic halo.

► Positrons or anti-protons from neutralino annihilation in the galactic halo.




H. Baer *et al.*, JCAP 0408:005,2004

# How can we satisfy WMAP constraint but still have few model parameters?

Get rid of universality.

1. If we introduce non-universal scalars then neutralino DM density can be reduced via one of the following mechanisms:

► Pull down some scalar masses and have t-channel "bulk-like" annihilation of neutralinos.

► Bring in new near-degeneracies of sleptons or squarks with neutralinos (new co-annihilations).

► Make $m_A \approx 2 m_{\tilde{Z}_1}$.

► Reduce the value of $|\mu|$. Higgsino annihilations come into play.

All such scenarios are represented in mSUGRA. Neutralino is either bino or bino-higgsino mixture.

2. Non-universal gauginos:

$M_1 = M_2 = M_3$ at GUT scale is only true in a specific representation of GUT group. Under the universality assumption at the weak scale

$M_1 \div M_2 \div M_3 \sim 1 \div 2 \div 6.$

If one allows a combination of irreducible representations then it is possible to study different models by specifying $M_1, M_2, M_3$ at the weak scale instead of $m_{1/2}$.

3 very different possibilities:

► Mixed Wino dark matter scenario (MWDM)

H. Baer *et al.*, JHEP 0507:046,2005.

► Bino-Wino co-annihilation scenario (BWCA)

H. Baer *et al.*, JHEP 0512:011,2005.

► Mixed Higgsino dark matter scenario (MHDM)

H. Baer *et al.*, hep-ph/0603197.

► Mixed Wino dark matter scenario (MWDM):

$M_2(weak)$ is lowered from mSUGRA value while $M_1(weak)$ stays fixed.

Wino component of LSP increases and becomes dominant when $M_2(weak) < M_1(weak)$.

$\tilde{Z}_1 \tilde{W}_{1,2} W$ coupling becomes large

$\Rightarrow \tilde{Z}_1 \tilde{Z}_1 \rightarrow W^+ W^-$ gets enhanced.

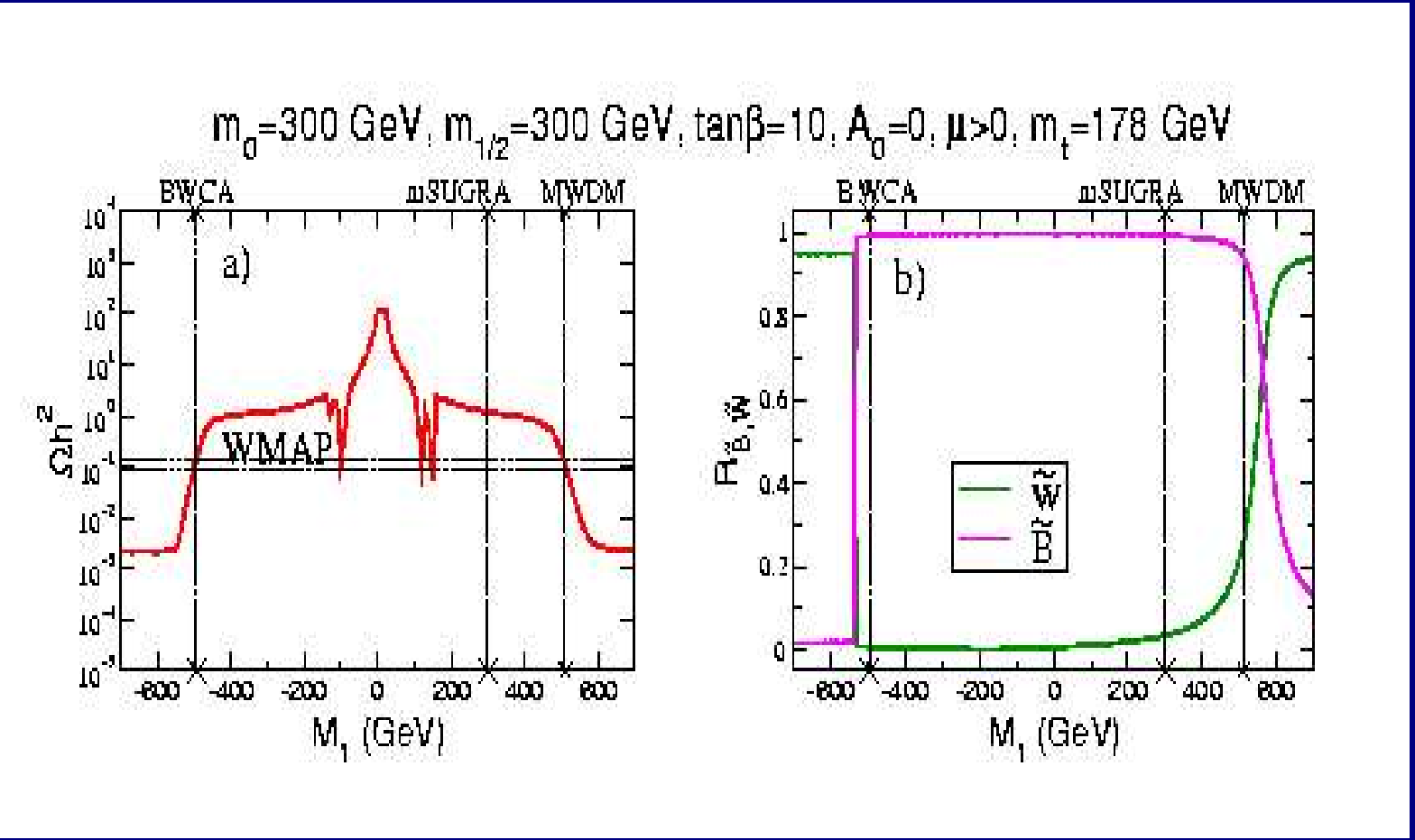
Experimental implications:

Direct and indirect DM detection is enhanced compared to mSUGRA.

2 body decay modes of $\tilde{Z}_2$ are closed due to reduced mass gap between $\tilde{Z}_2$ and $\tilde{Z}_1$. Good mass edge measurements at LHC.

► Bino-Wino co-annihilation scenario (BWCA):

$M_1$ and $M_2$ have opposite sign. We set one of them equal to $m_{1/2}$ at the GUT scale and the other is a free parameter.




H. Baer *et al.*, JHEP 0512:011,2005.

## ► Bino-Wino co-annihilation scenario (BWCA):

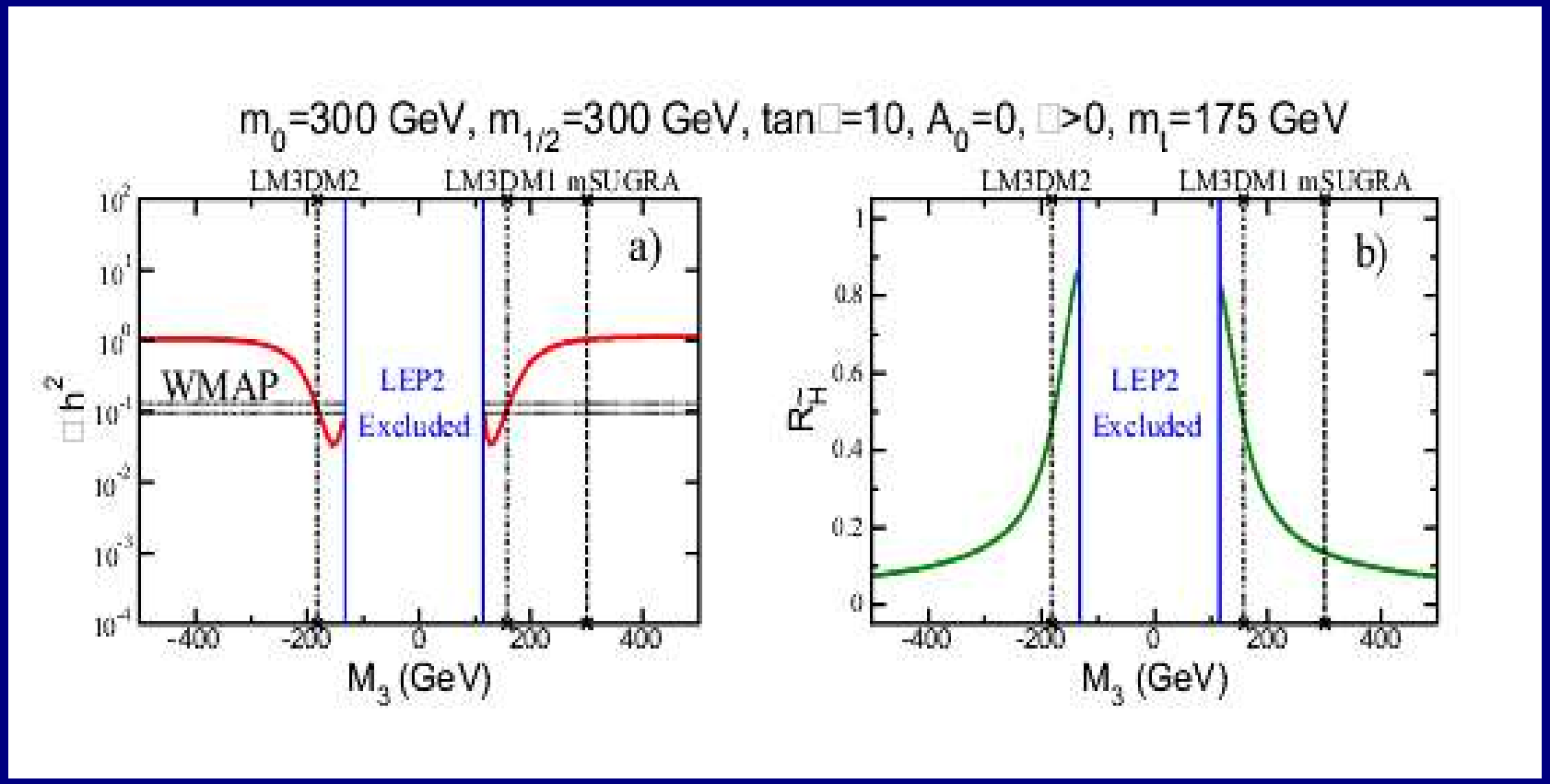
Experimental implications:

Direct and indirect DM detection rates are typically very low.

The mass gap between $\tilde{Z}_2$ and $\tilde{Z}_1$ is small, no 2 body decays allowed except for $\tilde{Z}_2 \rightarrow \tilde{Z}_1 \gamma$ which only occurs at one loop level.

LHC and possibly even Tevatron would see hard isolated photons. Also, the mass edges in dilepton invariant mass distributions would be pronounced.

► Mixed Higgsino dark matter scenario (MHDM): Reduce $|M_3|$ below its mSUGRA value.




H. Baer *et al.*, hep-ph/0603197.

Gluino is relatively light in this scenario. The entire gaugino spectrum is light enough to be reconstructed at the LHC and LC.

DM detection rates are enhanced compared to mSUGRA.

# Conclusions

- Interesting parts of mSUGRA parameter space are mostly covered by a combination of collider experiments and direct or indirect DM detection experiments.
- Going beyond mSUGRA does not have to be as radical as going back to the MSSM. There is a lot of new phenomenology just one step away.
- A combination of experiments which will be operating within the next 10 year span will allow us to (approximately) answer the questions about the existance of universalities in scalar and gaugino sectors.