Phenomenology of Relic-Density-Consistent Models with Neutralino Dark Matter

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Exciting time for particle physics. We know the Standard Model is incomplete.

★ Neutrino masses and mixings

★ Existence of DM $\leftrightarrow$ EWSB ideas (WIMP miracle)

- LHC begins operations.

$$\frac{\text{LHC}}{\text{Tevatron}} \simeq 5 \rightarrow 7, \text{ and with higher luminosity.}$$

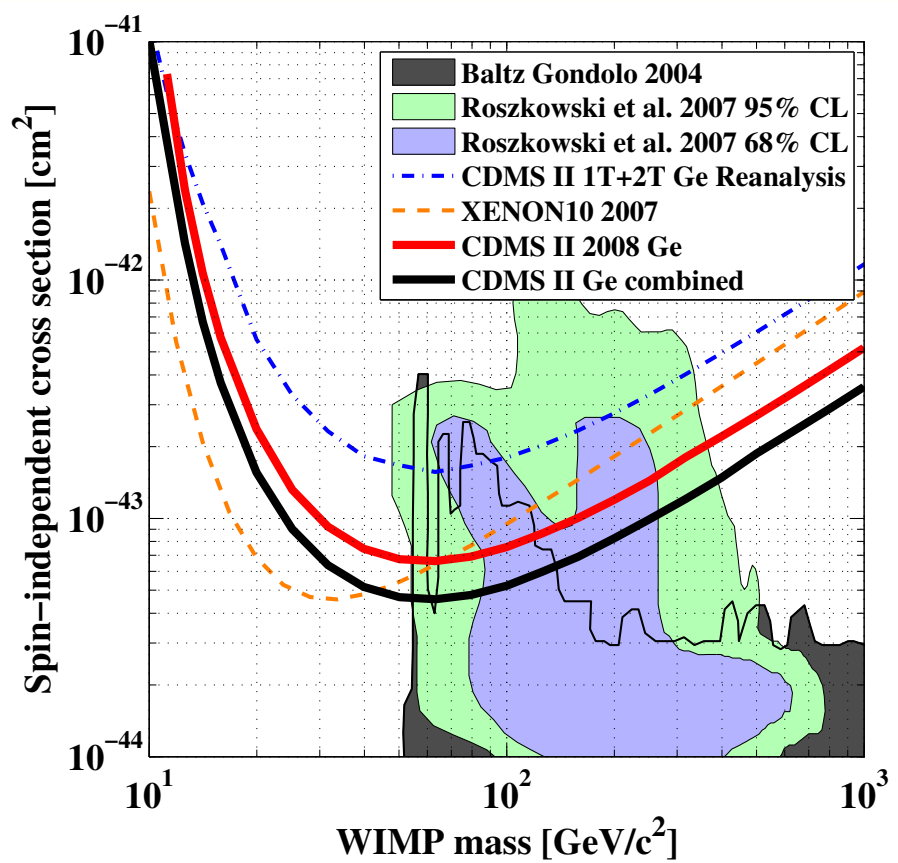
- DM searches also under way.

CDMS, XENON-10, $\longrightarrow$ superCDMS, ton-sized noble liquid detectors.

Pamela, IceCube, GLAST, + ...

Examine implications and non-implications for supersymmetry.

Direct Detection Limits



CDMS and Xenon-10 are running neck and neck. Probing $\sigma_{\rm SI}(\widetilde{Z}_1 p) \sim (5-10) \times 10^{-8}$ pb for $m_{\widetilde{Z}_1} = 100$ GeV.

Measured relic density of CDM

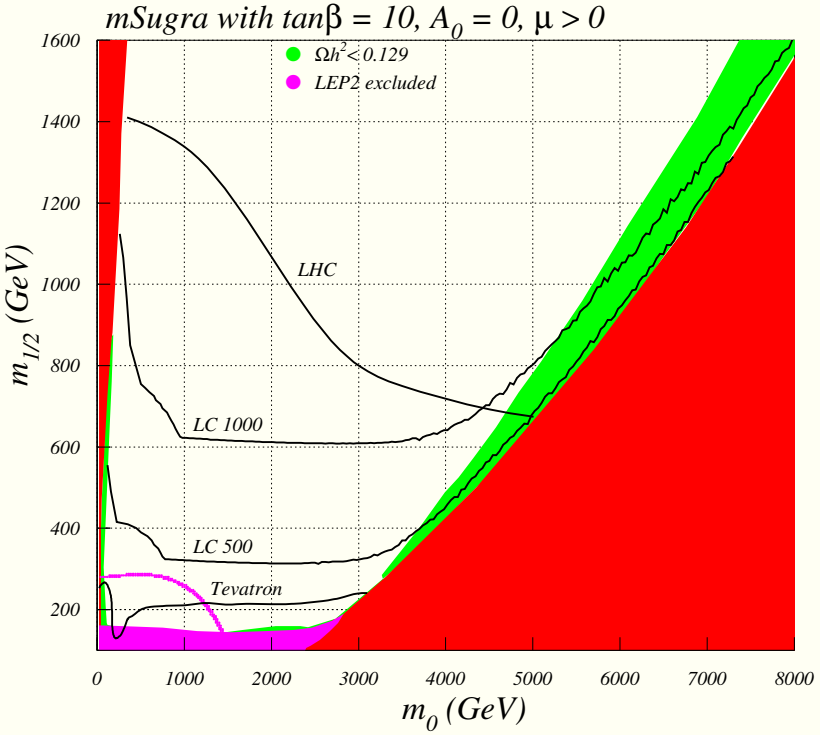
$$\Omega_{\rm DM}h^2 = 0.111^{+0.011}_{-0.015}(2\sigma)$$

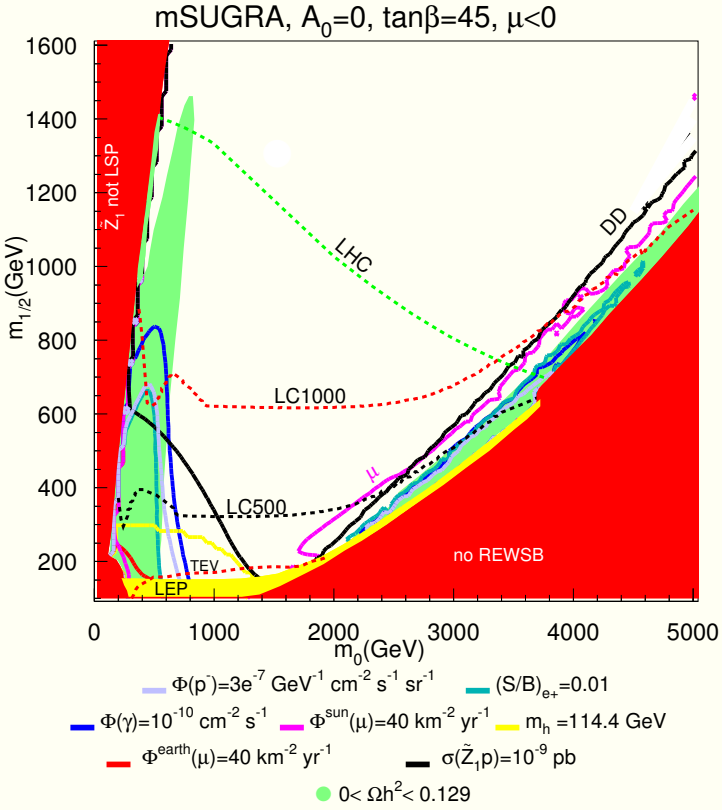
Saturated by thermal relic neutralinos from the Big Bang if:

- ⋆ Low sfermion masses.
- ⋆ neutralino LSP coannihilates with charged or coloured particle.
- ⋆ $m_{LSP} \simeq 2m_A$ (Higgs-funnel).
- ⋆ neutralino LSP has a significant higgsino component (MHDM)
- ⋆ neutralino LSP has a significant wino component (MWDM, $M_1 \simeq M_2$).
- ⋆ neutralino LSP coannihilates with the wino (BWCA, $M_1 \simeq -M_2$).

The last two alternatives cannot be realized in the paradigm mSUGRA model.

The mSUGRA situation





Various RD-allowed regions; Higgs-funnel only at large $\tan\beta$

LHC covers most RD-allowed region except in HB/FP region.

This MHDM region best covered by various DM searches.

The existence of special RD-allowed regions clearly suggests there are implications for collider phenomenology as well as for DM searches.

HOW ROBUST ARE THESE IMPLICATIONS?

Break GUT-scale universality in a controlled way for tractable phenomenology.

- ⋆ Non-universality of Higgs scalar mass parameters. $m_{H_{u,d}} \neq m_0$ (NUHM)
- ⋆ Non-universality of matter scalar masses.
- ⋆ Gaugino mass non-universality (one of $M_{1,2,3} \neq m_{1/2}$).

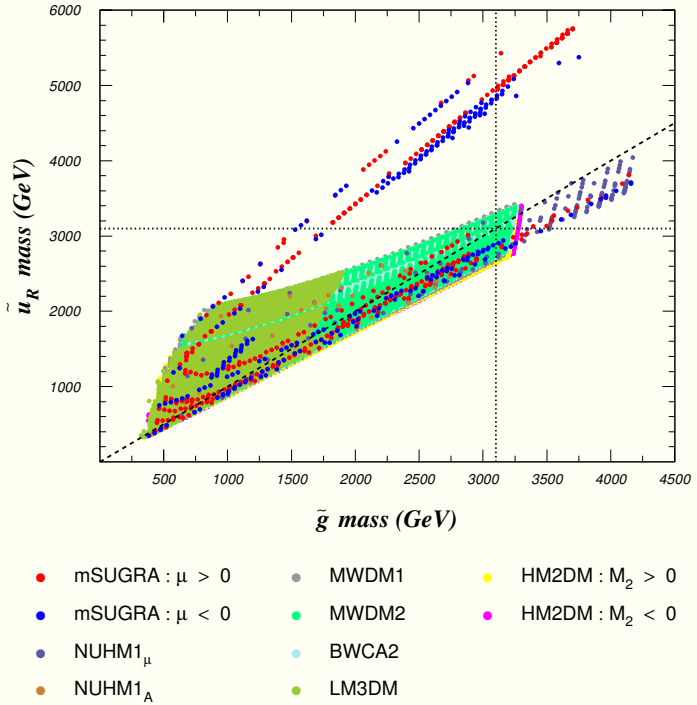
Various one-parameter extensions of mSUGRA.

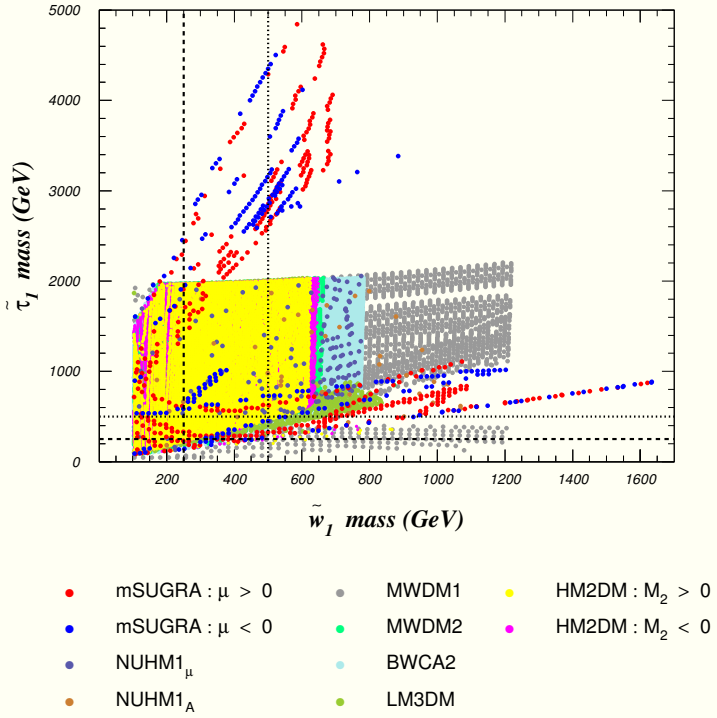
Entire $m_0 - m_{1/2}$ plane can be consistent with RD constraint.

Higgs funnel possible for all values of $\tan\beta$.

Are there things we can say that are more robust?

Scan parameter space of various models up to $m_0 = 2$ TeV, $m_{1/2} = 1.5$ TeV.



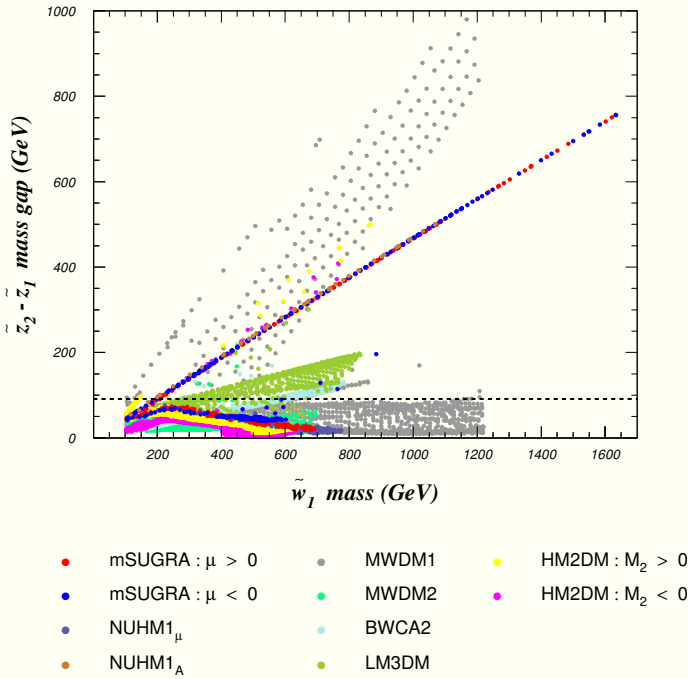


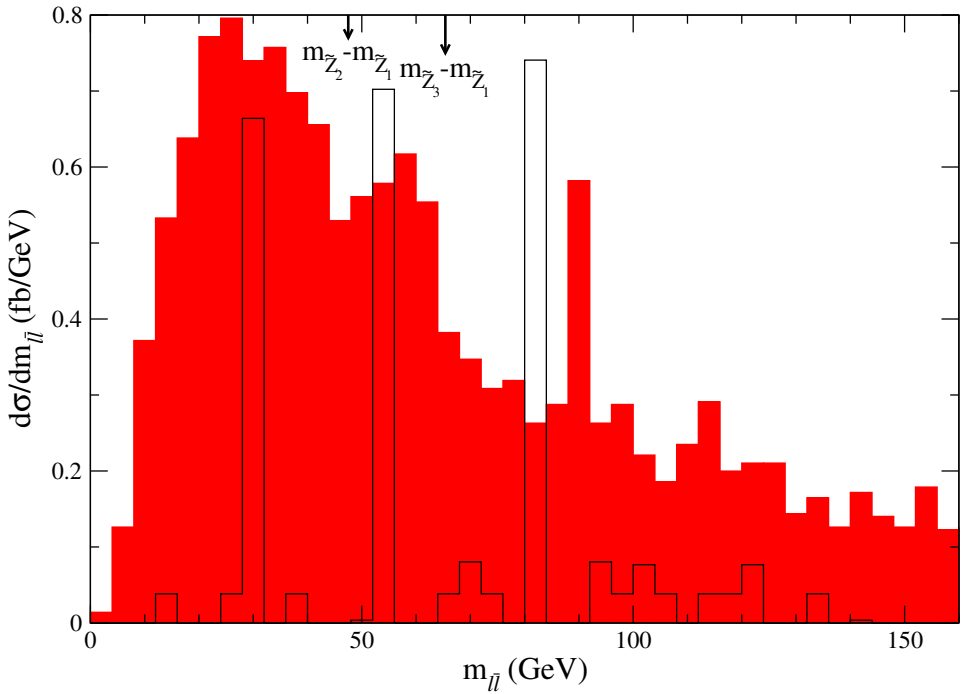
Many models with the correct neutralino RD should be accessible at the LHC.

The HB/FP region of SUGRA is an exception.

Accessibility of sparticles not guaranteed at even a 1 TeV linear collider.

m_{ll} dist. in a high M_2 DM model



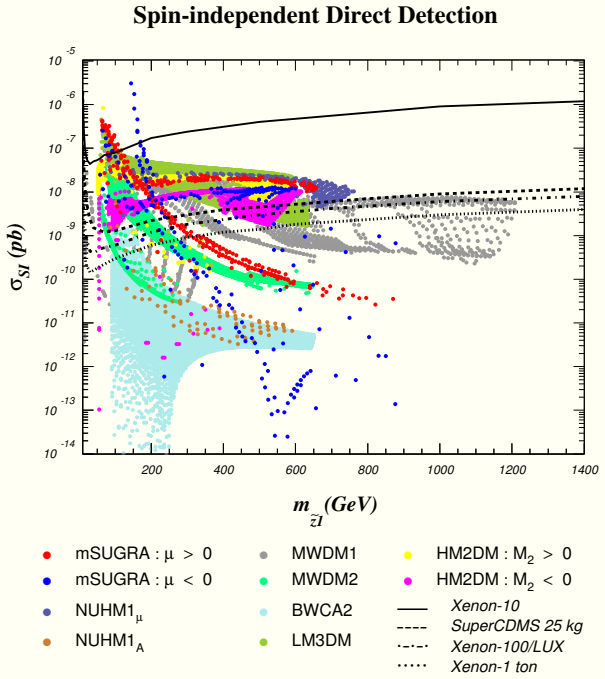


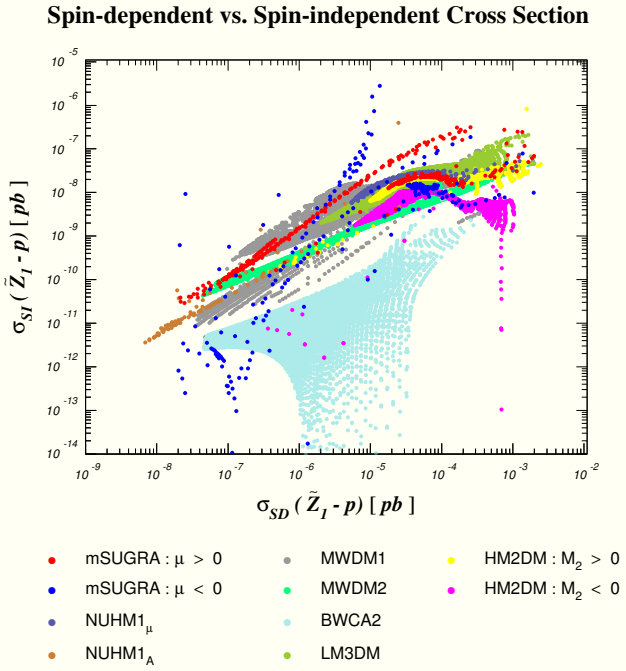
In many models $\widetilde{Z}_2$ decays via three-body decays, so that the location of the dilepton mass edge at $m_{\widetilde{Z}_2} - m_{\widetilde{Z}_1}$ may be possible at the LHC.

In MHDM models, $\widetilde{Z}_3$ may also be light, allowing multiple mass edges to be measured.

Notice the different shapes of the "two humps" in the right frame.

DIRECT DETECTION OF DARK MATTER





Current searches at CDMS and Xenon-10 beginning to cut into models.

Notice the branch from MHDM models where $\sigma_{\rm SI}(\widetilde{Z}_1 p)$ asymptotes to about 10^{-8} pb, within reach of the next round of DD searches. superCDMS, XENON-100, LUX

Ton-sized detectors essential for bino-like LSPs.1t-xenon WARP, COUPP....

Targets using multiple nuclei can reveal multiple WIMP components.

INDIRECT DETECTION OF DARK MATTER

- ⋆ IceCube should be sensitive to MHDM neutralino WIMPS accumulated in the sun up to WIMP masses of 500-600 GeV.
- ⋆ Signals from WIMP annihilation to anti-particles in our halo are sensitive to WIMP distribution. Greatest sensitivity in anti-deuterons (GAPS) and anti-protons (Pamela), and again for MHDM.
- ⋆ Gamma ray signals from our galactic centre extremely sensitive to halo profile. A signal at GLAST may serve to determine this profile!
- ⋆ Halo-annihilation signals tend to be enhanced in the Higgs-funnel region (though not always to observable levels).

mSUGRA Prejudices

- ⋆ Relic-density-consistent "bulk region" $\Rightarrow$ many light sparticles.
- ⋆ Higgs-funnel occurs only for large $\tan\beta$ values.
- ⋆ MHDM occurs only if scalars are essentially decoupled at the LHC
- ⋆ Lighter $\tilde{b}_1 \sim \tilde{b}_L$, lighter $\tilde{\tau}_1 \sim \tilde{\tau}_R$.

Each of these statements is false in one-parameter-extensions of mSUGRA that allow non-universality.

- ⋆ Rapid neutralino annihilation possible via very light $\tilde{u}_R/\tilde{c}_R$ or light $\tilde{\tau}_1 \sim \tilde{\tau}_L$ (with other scalars heavy) in NUHM models.
- ⋆ Higgs-funnel annihilation can be arranged for all values of $\tan\beta$, and MHDM for small values of scalar matter masses.
- ⋆ $\tilde{b}_L$ is very heavy if $M_2 \gg M_{1,3}$ at $Q = M_{\rm GUT}$.

Features of relic-density-consistent models

- ⋆ Most models accessible at the LHC
- ⋆ Frequently, the mass edge in $\widetilde{Z}_2 \to \widetilde{Z}_1 \ell\bar{\ell}$ decays should be observable at the LHC.
- ⋆ The mechanism that enhances neutralino annihilation in the early universe also tends to enhance the direct detection rate. MHDM models should be accessible in the next round of direct detection experiments, and possibly also at neutrino telescopes.
- ⋆ Indirect detection may facilitate the determination of the DM halo profile.