Light Dark Matter in the MSSM

based on arXiv:1308.3735, G.Belanger, G.DLR, B.Dumont, R.M.Godbole, S.Kraml, S.Kulkarni

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Outline

Which kind of dark matter?

Our DM target :

- Relic density : Ωh^2-compliant ➞ a WIMP candidate
- Direct detection : Respect bounds on σ_{SI} ➞ a light WIMP

Our playground : the MSSM

- Why SUSY? Originally motivated by naturalness and gauge coupling unification
- It also provides WIMPs
- Its DM sector can be constrained by complementary tests (colliders, flavour, ...)

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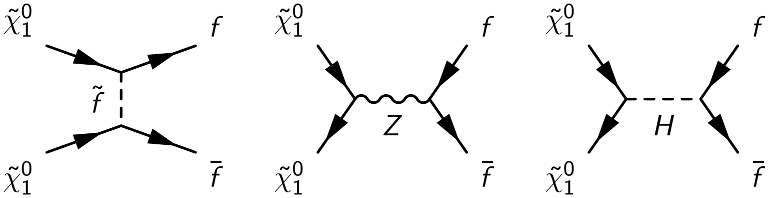

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    - if $\tilde{\chi}_1^0 = f(\tilde{B}, \tilde{H})$
  - Can be enhanced with low $\tilde{f}$ (LEP bound) or $m_{\tilde{\chi}_1^0} \sim \left(\frac{M_Z}{2}, \frac{M_H}{2}\right)$
- Consequences ?

Implications in other observables

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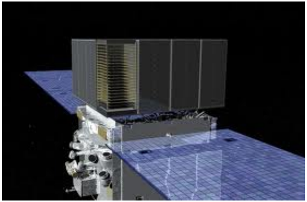

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- $\tilde{\chi}_1^0$ partly $\tilde{H}$ ➞ $\tilde{\chi}_2^0, \tilde{\chi}_1^-$ light $(100 - 200$ GeV$)$
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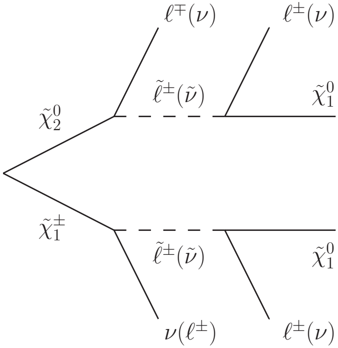

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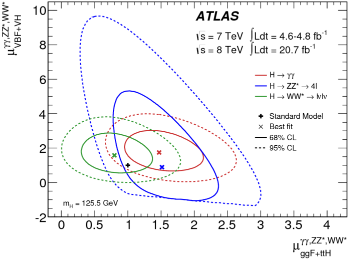

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  - what about Higgs couplings at LHC?
- Does flavour connect some of the previous observables?

Observables : the Higgs couplings

- Two constraints on Br ($h \to$ invisible):
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- **Interplay** with Ωh^2 through Higgsino fraction f_H
  - $f_H \nearrow \quad \Rightarrow \quad$ Br ($h \to$ invisible) $\nearrow$
  - $f_H \nearrow \quad \Rightarrow \quad \Omega h^2 \searrow$

Observables : the Higgs couplings (II)

Other couplings can be affected :

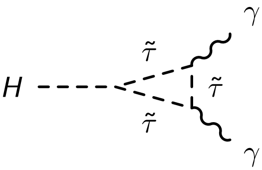
- $\kappa_{V,b,t}$ through tree-level mixings (decoupled if $M_{A^0} \gg M_Z$)
  - Decoupling $\equiv M_{A^0} \gg M_Z$, then $\kappa_V \sim 1$
  - $\kappa_{b,\tau}$ can be marginally enhanced at high $\tan\beta$

- $\kappa_g \approx 1$ since the stops are not light enough.

Observables : the Higgs couplings (II)

Other

- κ $\gg M_Z)$



- κ
- κ_γ can be generated by staus.
- κ_γ depend crucially on the stau mixing angle.

- **Interplay** with Ωh^2, since the $\tilde{\tau}_R$ couples more to $\tilde{B}$

  $\Omega h^2 \Leftrightarrow \kappa_\gamma$ via $\tilde{\tau}$ mixing

Observables : Sleptons @ LHC

- $\tilde{e}, \tilde{\mu}$ tested though direct double production :
  - Direct production dominated by Z channel
    ➡ $\sigma_{pp\rightarrow\tilde{e}^+\tilde{e}^-}$ only depends on $m_{\tilde{e}}$
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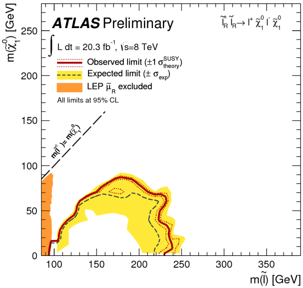

- If $m_{\tilde{\chi}_1^0} > 20$ GeV, the region $m_{\tilde{e}} \in [100, 120]$ GeV untouched

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- Focus on $\tilde{\chi}_2^0, \tilde{\chi}_1^-$
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  - Reach as σ^{excluded} depends non-trivially on $(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_1^-}, m_{\tilde{\tau}})$
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- Not so obvious to extrapolate results (2-d) to the full space
  - See the SModelS approach (talk from Suchita Kulkarni).
  - Go for a full simulation at detector level (arXiv:1307.4119 Calibbi et al.)

Observables : Flavour Physics

- Seems irrelevant : usually constrain only H^+
  - But A_0, H^+ can be easily decoupled.
- However, there is an interplay with Ωh^2 :
  - $\tilde{\chi}_1^0$ partially $\tilde{H} \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \to \bar{\ell}\ell$ enhanced at high $\tan\beta$
- With both flavour and relic density $\Rightarrow$ lower bound on M_{A^0}
  - all the more that $\tilde{\chi}_1^0$ is light

Detailed : the parameter space

- Basis : the pMSSM
- Fixed structure :
  - First and second generation parameters identified
  - Heavy $\tilde{q}$ (2 TeV), except $\tilde{t}_1$ (0.75 TeV), $A_q = 0$ (except A_t)
- Parameters of Interest :
  - Higgs sector : $\tan\beta \in [1, 50]$ and $M_{A^0} \in [0.1, 1]$ TeV
  - $\tilde{\chi}_1^0$ sector : $M_1 \in [10, 70]$ GeV and $M_2, \mu \in [0.1, 1]$ TeV
  - $\tilde{\ell}$ sector : $m_{\tilde{\tau}} \in [85, 500]$ allowing all mixings.
    - $m_{\tilde{e}_2} = 500$ GeV, $m_{\tilde{e}_1} = 500$ GeV or $m_{\tilde{e}_1} \in [100, 200]$ GeV
  - Flat scans focusing on interesting region ($\tilde{\tau}_1$ mostly right-handed, ...)

Detailed : the constraints

- LEP tests
  - Z invisible width ➞ constrain $Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$
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  - Flavour tests : Br $(B \to X_s\gamma)$ from HFAG and Br $(B_s \to \bar{\mu}\mu)$ from LHCb and CMS (CMS-PAS-BPH-13-007,LHCb-CONF-2013-012)

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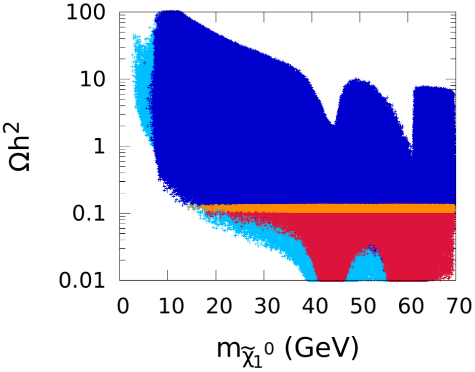
- Dark Matter
  - Ωh^2 constrained by Planck+WMAP : either exact range or upper bound.
    - In SUSY, Ωh^2 uncertainty dominated radiative corrections*➞ 10% range
  - Direct detection : $\xi \sigma_{SI}$ constrained by XENON 100.
  - Higgs Physics (more later)
  - LHC searches (more later)

Relic density and mass spectrum



- Red(Orange) all viable points (+ Ωh^2 exact range)
  Light/Dark Blue : Rejected by $\Phi \to \bar{\tau}\tau$/DM constraints.
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- What about σ_{SI} in non-resonant case?

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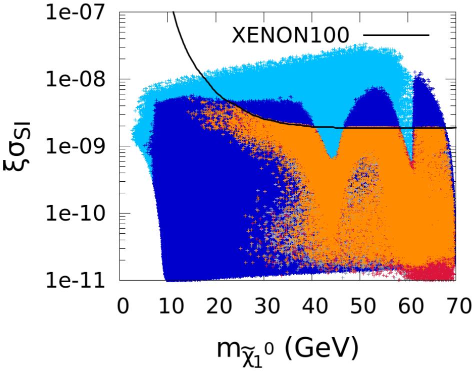

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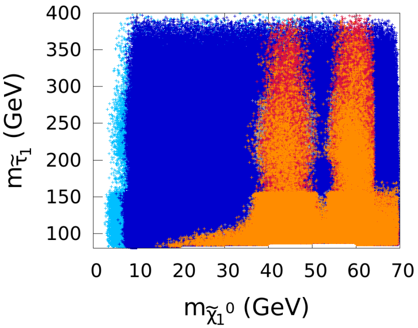

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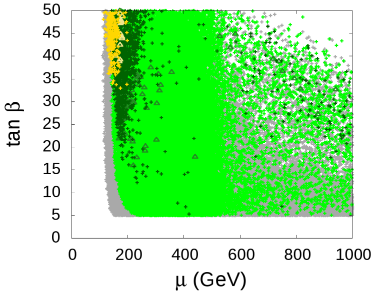
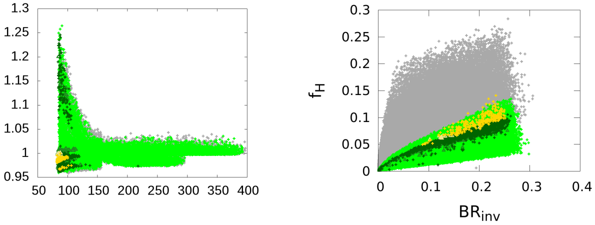


- It is indeed the $\tilde{\tau}$ that drives $m_{\tilde{\chi}_1^0}$ to low values.
- Yellow $m_{\tilde{\chi}_1^0} < 25$, Dark Green $25 < m_{\tilde{\chi}_1^0} < 35$, Green $35 < m_{\tilde{\chi}_1^0} < 50$, Gray $50 < m_{\tilde{\chi}_1^0}$ (GeV)
- Light μ is also needed
  - Increases the Higgsino fraction f_H.
  - Together with $\tan\beta$ ➞ Ωh^2 not too high

Relation : Higgs Physics

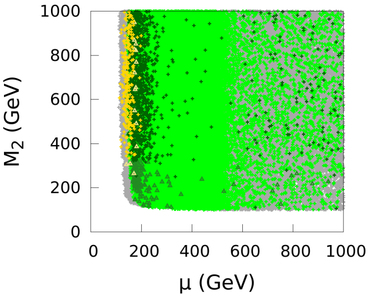
- What deviations can we expect?



- Two Distinct regions at low $m_{\tilde{\chi}_1^0}$:
  - Maximally mixed staus ➞ $\kappa_\gamma \in [1.1, 1.25]$
  - Unmixed staus ➞ $\kappa_\gamma \approx 1$
- Important effect on Br ($h \to$ invisible)

  ➞ high f_H needed for Ωh^2
- With increased accuracy, the lightest $\tilde{\chi}_1^0$ could be excluded.

Relations : LHC searches $\tilde{\chi}_2^0\tilde{\chi}_1^-$



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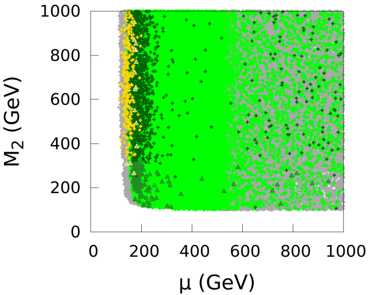
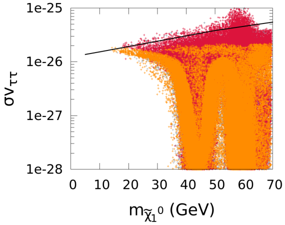


- $m_{\tilde{\chi}_1^0} < 25$ and low M_2 are excluded
- For $m_{\tilde{\chi}_1^0} < 35$ GeV, all points below $M_2 < 350$ are unsafe.
- Here a more dedicate analysis could tell what survives
- At higher $m_{\tilde{\chi}_1^0}$, it can be evaded with $m_{\tilde{\tau}} > m_{\tilde{\chi}_1^-}$

Perspective for Indirect Detection

- Requiring Ωh^2 small enough ➞ possible signals in $\tilde{\chi}_1^0 \tilde{\chi}_1^0 \to \bar{f} f$



- Fermi-LAT limit from dwarf spheroidal galaxies close to predictions for $m_{\tilde{\chi}_1^0} < 35$ GeV.
- Other constraints (Subhalo searches)
  - Subject to large astrophysical uncertainties (halo,...)

Summary

- Light dark matter can be achieved in the MSSM with a bino (and partly higgsino) neutralino.
- The different mechanisms that ensure a correct relic density are linked to other experiments
  - Z resonance ➔ $f_H \neq 0$ ➔ Higgs invisible width
  - stau exchange ➔ small μ ➔ LHC searches for $\tilde{\chi}_2^0, \tilde{\chi}_1^-$
  - slepton exchange ➔ direct search at LHC
- In particular, indirect detection could be a main probe!
- Accurate Higgs couplings and search for $\tilde{\chi}_2^0\tilde{\chi}_1^-$ are LHC best chances.

Backhup

Higgs signal strength