Supersymmetric Dark Matter After LHC Run I

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Based on 1508.01173
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- Joint theory and experimental collaboration
- Experiment: LHCb and CMS
- Theory: SUSY, DM, Flavour, Precision Electroweak/Higgs
The Global Fit Game

See also talks from GAMBIT, Fittino, BayesFits, Sven Heinemeyer
Experimental Constraints

We use a suite of constraints from

- Higgs Physics
- Precision Electroweak
- Direct Detection and Cosmology
- Flavour Physics
- LHC SUSY Searches

Softsusy, FEWZ, FeynHiggs, SuFla, SuperIso, MicroMegas, SSARD, HiggsSignals, HiggsBounds, ATOM, Scorpion, Fastlim
Dark Matter Phenomenology

Fits provide a rich dataset

How is relic density set in pMSSM?

How does LHC probe pMSSM by mechanism?

Direct detection prospects?
Relic Density Mechanisms

Relic density depletion requires relations between sparticle masses

In the MSSM this happens through resonant DM annihilation ('funnel')
or co-annihilation

Resonant/funnel/s-channel
Co-annihilation/t-channel

Credit: Cohen/Wacker 2013
Relic Density Mechanisms

Also for
- Light Higgs $h$
- Heavy Higgs $A/H$

Resonant/funnel/s-channel

Also for
- Stau co-annihilation
- Chargino Co-annihilation

Co-annihilation/t-channel

Credit: Cohen/Wacker 2013
Relic Density Mechanisms

How to quantify this?

\( \tilde{\tau}_1 \text{ coann. (pink)}: \quad \left( \frac{m_{\tilde{\tau}_1}}{m_{\tilde{\chi}_1^0}} - 1 \right) < 0.15, \)

\( \tilde{\chi}_1^\pm \text{ coann. (green)}: \quad \left( \frac{m_{\tilde{\chi}_1^\pm}}{m_{\tilde{\chi}_1^0}} - 1 \right) < 0.1, \)

\( \tilde{t}_1 \text{ coann. (grey)}: \quad \left( \frac{m_{\tilde{t}_1}}{m_{\tilde{\chi}_1^0}} - 1 \right) < 0.2, \)

\( \text{h funnel (magenta)}: \quad \left| \frac{M_h}{m_{\tilde{\chi}_1^0}} - 2 \right| < 0.4, \)

\( \text{Z funnel (orange)}: \quad \left| \frac{M_Z}{m_{\tilde{\chi}_1^0}} - 2 \right| < 0.4. \)

\( \text{A/H funnel (blue)}: \quad \left| \frac{M_A}{m_{\tilde{\chi}_1^0}} - 2 \right| < 0.4, \)

\( \text{focus point (cyan)}: \quad \left( \frac{\mu}{m_{\tilde{\chi}_1^0}} \right) - 1 < 0.3. \)

Conditions cross-checked from MicroMegas output
Constrained Models

- 300/fb 95% exclusion estimate
pMSSM results

Squark-neutralino mass plane

Current LHC exclusion with decoupled gluinos

Estimate of 3/ab reach with and w/out decoupled gluinos
pMSSM results
Squark Gluino mass plane

Current and projected SMS limits with massless LSP

Legend:
- stau coann.
- A/H funnel
- hybrid
- \( \tilde{\chi}_1^\pm \) coann.
- stop coann.
- focus point
- h funnel
- Z funnel
pMSSM results
Lightest chargino-neutralino mass plane

\[
\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow W/Z + E_T
\]

\[
\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow W/h + E_T
\]

\[
\tilde{\chi}_1^\pm \tilde{\chi}_2^0, \tilde{\chi}_1^0 \tilde{\chi}_1^\pm \rightarrow \tau, \tilde{\tau} \rightarrow 2, 3 \tau' s + E_T
\]

Current and projected SMS limits for different decay channels
pMSSM results
Stop neutralino mass plane

$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$

Current and projected SMS limits for different decay channels

- stau coann.
- A/H funnel
- hybrid
- $\tilde{\chi}_1^\pm$ coann.
- stop coann.
- focus point
- h funnel
- Z funnel
pMSSM results

Co-annihilation requires LSP and other sparticle to be degenerate.

Possibility of long-lived particles?

We don't find this in the pMSSM
Long-lived sparticles

In constrained models, squark/gluino limits push up the LSP mass.

Heavier LSP implies greater NLSP degeneracy for correct annihilation cross-section.

CMSSM
Long-lived sparticles

In constrained models, squark/gluino limits push up the LSP mass

Heavier LSP implies greater NLSP degeneracy for correct annihilation cross-section

NUHM2
Direct Detection Phenomenology

Projected LZ bound

- stau coann.
- A/H funnel
- hybrid
- $\tilde{\chi}_1^\pm$ coann.
- stop coann.
- focus point
- h funnel
- Z funnel
## Summary of Detectability

<table>
<thead>
<tr>
<th>DM mechanism</th>
<th>Exp’t</th>
<th>CMSSM</th>
<th>NUHM1</th>
<th>NUHM2</th>
<th>pMSSM10</th>
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<tbody>
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<td>$\tilde{\tau}_1$ coann.</td>
<td>LHC</td>
<td>√ $E_T$, √ LL (✓)</td>
<td>(✓)</td>
<td>(✓)</td>
<td>×</td>
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<tr>
<td>DM</td>
<td>DM</td>
<td>(✓)</td>
<td>(✓)</td>
<td>(✓)</td>
<td>(✓)</td>
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<tr>
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<td>×</td>
<td>×</td>
<td>(✓)</td>
</tr>
<tr>
<td>DM</td>
<td>DM</td>
<td>–</td>
<td>✓</td>
<td>✓</td>
<td>(✓)</td>
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<td>–</td>
<td>✓ $E_T$</td>
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<tr>
<td>DM</td>
<td>DM</td>
<td>–</td>
<td>–</td>
<td>×</td>
<td>–</td>
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<tr>
<td>$A/H$ funnel</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>(✓) $E_T$</td>
</tr>
</tbody>
</table>
Indirect Detection

Interesting to include recent Fermi-LAT dwarf limits

Indirect detection constraints from Fermi-HESS constrain heavier (wino) states
Summary

DD and collider searches in Run II will probe a variety of DM mechanisms

Charged track searches in constrained models

Run II + CTA/HESS/Fermi-LAT = Interesting times