Prospects and Blind Spots for Neutralino Dark Matter

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The new XENON100 result continues to challenge the interpretation of the CoGeNT and CDMS results as being due to scalar WIMP dark matter. The expected sensitivity of this dataset in absence of any signal is shown by the green-yellow region. The expected limit for the constrained supersymmetric parameter space including regions preferred by scans of supersymmetric UU MSSM is used for comparison. The maximum gap analysis uses an acceptance-corrected exposure limit for the parameter space. Poisson fluctuations in the number of events are profiled out and in the background expectation are taken into account along with the single Pz resolution. The expected sensitivity of this dataset is also taken into account.

The benchmark region fluctuates to events is shown by the green-yellow region. The expected sensitivity of this dataset in absence of any signal is shown by the green-yellow region. The expected limit for the constrained supersymmetric parameter space including regions preferred by scans of supersymmetric UU MSSM is used for comparison. The maximum gap analysis uses an acceptance-corrected exposure limit for the parameter space. Poisson fluctuations in the number of events are profiled out and in the background expectation are taken into account along with the single Pz resolution. The expected sensitivity of this dataset is also taken into account.

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what is status of SUSY DM?
the plan

1. experimental status
2. neutralino DM in SUSY
3. bino-higgsino
4. bino-wino-(higgsino)
experimental status
types of scattering:

1. spin independent: \( \bar{\chi} \chi \bar{N} N \)

\[ y \bar{\chi} \chi h \]

\[ \sigma_{SI} \approx 8 \times 10^{-45} \text{ cm}^2 \left( \frac{y}{0.1} \right)^2 \]
types of scattering:

1. spin independent: \( \bar{\chi} \chi \bar{N} N \)

\[ y \bar{\chi} \chi h \]

\[ \sigma_{SI} \approx 8 \times 10^{-45} \text{ cm}^2 \left( \frac{y}{0.1} \right)^2 \]

2. spin-dependent: \( \bar{\chi} \gamma^\mu \gamma^5 \chi \bar{N} \gamma_\mu \gamma^5 N \)

\[ c \bar{\chi} \gamma^\mu \gamma^5 \chi Z_\mu \]

\[ \sigma_{SD} \approx 3 \times 10^{-39} \text{ cm}^2 \left( \frac{c}{0.1} \right)^2 \]
spin independent status

\[ \sigma_{p,n} \text{ [cm}^2\text{]} \]

\[ m_{\text{DM}} \text{ [GeV]} \]

Spin independent

Xenon100
The image shows a graph titled "spin independent status". The x-axis represents the mass of dark matter ($m_{DM}$) in GeV, ranging from 0 to 2000 GeV. The y-axis represents the spin-independent cross section ($\sigma_{p,n}$) in cm$^2$, ranging from $10^{-47}$ to $10^{-43}$ cm$^2$.

The graph includes two regions, labeled "Xenon100" and "LUX", which represent the sensitivity limits of the respective experiments. The "Xenon100" region is shaded in red, indicating the spin-independent cross section limits for that experiment. The "LUX" region is shaded in green, showing the limits for the LUX experiment.

Additionally, the graph includes horizontal lines at $\sigma_{p,n} = 0.01$, $0.1$, and $1.0$ cm$^2$, which represent different cross section thresholds. These thresholds are marked at their corresponding $m_{DM}$ values, with $0.01$ cm$^2$ at $1500$ GeV, $0.1$ cm$^2$ at $1800$ GeV, and $1.0$ cm$^2$ at $2000$ GeV.
spin independent status

\[ \sigma_{p,n} \text{ [cm}^2] \]

\[ m_{DM} \text{ [GeV]} \]

- Xenon100
- LUX
- Xenon1T

\[ \chi^2 \]

\[ 0.01 \]

\[ 0.1 \]
what about the strange quark?

\[ f_q = \frac{m_q}{m_N} \langle N | q\bar{q} | N \rangle \]

\[ \sigma \propto f^2 \]

\[ f = \sum_q f_q \]

- Giedt, Thomas, Young 0907.4177
spin dependent status

\[ \sigma_{p,n} \text{ [cm}^2\text{]} \]

\[ m_{DM} \text{ [GeV]} \]

Xenon100

\[ \Sigma_p, n \text{ cm}^2 \]
spin dependent status

\[ \sigma_{p,n} \text{ [cm}^2\text{]} \]

\[ m_{DM} \text{ [GeV]} \]

- Xenon100
- IceCube \( t\bar{t} \)
- IceCube \( W^+W^- \)
spin dependent status

\[ \sigma_{p,n} \text{ [cm}^2] \]

\[ m_{\text{DM}} \text{ [GeV]} \]

- Xenon100
- IceCube \( t\bar{t} \)
- IceCube \( W^+W^- \)
- Xenon1T
indirect

Upper limits, Joint Likelihood of 10 dSphs

- 3 \times 10^{-26} 
- \mu^+ \mu^- Channel 
- \bar{b}\bar{b} Channel 
- W^+ W^- Channel 
- \tau^+ \tau^- Channel 

WIMP cross section [cm^3/s] 

WIMP mass [GeV]
The fit proceeds as follows. For given fixed values of the set of ROI dependent DM parameters \( \{ \theta \} \), the likelihood function \( L(\theta|data) \) is computed using the "profile likelihood" technique, which is a standard method for treating nuisance parameters in likelihood analyses. Confidence intervals or upper limits taking into account uncertainties in the nuisance parameters are then computed.

The coverage of this profile joint likelihood analysis for annihilations into the final state is shown in Fig. 1. Derived 95% C.L. upper limits on a WIMP annihilating into the \( \mu^+\mu^- \) channel and the most generic wave cross section \( \sigma_{\text{wave}} \) is plotted as a reference. Uncertainties in the J factors are included.

The combined upper limit curve shown in Fig. 2 is derived using the nominal J factors, averaged over the WIMP masses, for Segue 1 and down to Draco. Combining the mass limits yields a much milder overall increase of the upper limit curve compared to the most generic cross section \( \sigma_{\text{wave}} \) as shown in Fig. 1.

The combined upper limit curve includes the normalizations \( J \) of the J factors and the Galactic di and its energy dependences. The likelihood analyses include the J factors uncertainties. Including the J factors uncertainties

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collider

**LEP:**

\[ m_{\chi^+} \gtrsim 100 \text{ GeV} \]

\[ \mu, M_2 \gtrsim 100 \text{ GeV} \]

**LHC:**

\[ \sqrt{s} = 7 \text{ TeV}, L_{\text{int}} = 4.98 \text{ fb}^{-1} \]
neutralino DM in SUSY
fermionic dark matter

• $SM + \tilde{B}, \tilde{W}, \tilde{H}$

• assume scalar superpartners can be decoupled when computing: $\sigma_{\chi N}$, $\Omega$

• assume CP

• parameters: $M_1, M_2, \mu, \tan \beta$
is the weak scale natural?

$m_h$
is the weak scale natural?

$m_h$ 125 GeV
is the weak scale natural?

\[ m_h \]

125 GeV

natural \hspace{1cm} \text{unnatural}
is the weak scale natural?

$\lambda S H_u H_d$

$125 \text{ GeV}$

$m_h$

natural | unnatural
is the weak scale natural?

$m_h$  \hspace{1cm} 125 \text{ GeV}

natural \hspace{1cm} \text{unnatural}

$\lambda S H_u H_d$  \hspace{1cm} \text{split SUSY}
is the weak scale natural?

$m_h$ 125 GeV

natural  unnatural

$\lambda S H_u H_d$  split SUSY

$\chi$

neutralino DM interesting for both!
fermionic DM in unnatural SUSY

- the LSP is at the weak scale to avoid overclosure
  \[ \Omega \sim \frac{1}{\sigma} \sim m_{\tilde{N}}^2 \]

- the DM mass is crucial for LHC observability
  \[ m_{\tilde{g}} > m_\chi \]
fermionic DM in natural SUSY

- fermionic DM is a simplified limit of natural SUSY
  \[
  \left( \frac{m_Z}{\tilde{m}} \right)^4
  \]

- we assume any physics that raises the Higgs mass does not modify DM properties
  \[
  \theta_{N_1 \tilde{S}} \ll 1
  \]

- DM mass is important for naturalness:
  \[
  \mu \gtrsim m_\chi \quad \Rightarrow \quad \Delta \gtrsim \frac{2m^2_\chi}{m^2_h}
  \]
in this talk I’ll consider two cases:

1. non-thermal \[ \Omega_{\text{freezeout}} \neq \Omega_{dm} \]

2. thermal \[ \Omega_{\text{freezeout}} = \Omega_{dm} \]
pure eigenstate DM

• bino
• higgsino
• wino

\[ m_{\tilde{H}} \approx 1 \text{ TeV} \]

\[ m_{\tilde{W}} \approx 2.7 \text{ TeV} \]
well-tempered neutralino

N. Arkani-Hamed, A. Delgado, G. Giudice 0601041.
well-tempered neutralino

N. Arkani-Hamed, A. Delgado, G. Giudice 0601041.
hidden dark matter
hidden dark matter
hidden dark matter

1. purity

\[ \chi \rightarrow \tilde{B}, \tilde{W}, \tilde{H} \]

\[ y_{\chi\chi h} \rightarrow 0 \]

turn off mixing by decoupling higgsinos or gauginos
hidden dark matter

1. purity

\[ \chi \rightarrow \tilde{B}, \tilde{W}, \tilde{H} \quad y_{\chi\chi h} \rightarrow 0 \]

decouple higgsinos or gauginos

2. blindspots

\[ y_{\chi\chi h} = 0 \quad \text{due to cancellation} \]
purity

- tree-level Higgs coupling vanishes for pure higgsino or Wino

- loop contribution smaller than expected

- Hisano, Ishiwata, Nagata, Takesako 1104.0228
- Hill, Solon 1111.0016
blindspots

\[ y_{\chi \chi h} = 0 \]
blindspots

\[ y_{\chi\chi h} = 0 \]

- bino

\[ m_\chi = M_1 \]

\[ M_1 + \sin 2\beta \mu = 0 \]
blindspots

\[ y_{\chi\chi h} = 0 \]

- bino
  \[ m_\chi = M_1 \]

- higgsino
  \[ m_\chi = -\mu \]

1. \[ M_1 + \sin 2\beta \mu = 0 \]

2. \[ \tan \beta = 1 \]
   \[ \text{sign}(\mu) = -\text{sign}(M_1) \]
blindspots

\[ y_{\chi\chi h} = 0 \]

- bino \[ m_\chi = M_1 \]
- higgsino \[ m_\chi = -\mu \]
- wino \[ m_\chi = M_2 \]

1. \[ M_1 + \sin 2\beta \mu = 0 \]
2. \[ \tan \beta = 1 \]
   \[ \text{sign}(\mu) = -\text{sign}(M_1) \]
3. \[ M_2 + \sin 2\beta \mu = 0 \]
4. \[ M_1 = M_2 \]
   \[ \text{sign}(\mu) = -\text{sign}(M_{1,2}) \]
bino-higgsino
bino-higgsino

• decouple wino

\[
\begin{pmatrix}
  M_1 & -g' \cos \beta \frac{v}{\sqrt{2}} & g' \sin \beta \frac{v}{\sqrt{2}} \\
  -g' \cos \beta \frac{v}{\sqrt{2}} & 0 & -\mu \\
  g' \sin \beta \frac{v}{\sqrt{2}} & -\mu & 0 \\
\end{pmatrix}
\]

• parameters

\[M_1, \mu, \tan \beta\]
non-thermal

\[ \tan \beta = 2 \]

\[ \tan \beta = 20 \]
non-thermal

\[ M_1 + \sin 2\beta \mu = 0 \]

\[ \tan \beta = 2 \]

\[ \tan \beta = 20 \]
\[
\begin{align*}
\tan \beta & \rightarrow 1 \\
\text{sign}(\mu) &= -\text{sign}(M_1) \\
\tan \beta &= 2 \\
\tan \beta &= 20
\end{align*}
\]
non-thermal

tan $\beta = 2$

\begin{align*}
\mu \text{ [GeV]} & \quad 1000 \quad 5000 \\
M_1 \text{ [GeV]} & \quad -5000 \quad -1000 \quad 100 \quad 1000 \quad 5000
\end{align*}

$\Omega_{\text{thermal}} = \Omega_{\text{cdm}}$

Fermi

$\phi_{\text{det}} = 0$

LEP $\chi^- \chi^+$

$tan \beta = 20$

\begin{align*}
\mu \text{ [GeV]} & \quad 1000 \quad 5000 \\
M_1 \text{ [GeV]} & \quad -5000 \quad -1000 \quad 100 \quad 1000 \quad 5000
\end{align*}

$\Omega_{\text{thermal}} = \Omega_{\text{cdm}}$

Fermi

$\phi_{\text{det}} = 0$

LEP $\chi^- \chi^+$

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\mu \text{ [GeV]} & \quad 1000 \quad 5000 \\
M_1 \text{ [GeV]} & \quad -5000 \quad -1000 \quad 100 \quad 1000 \quad 5000
\end{align*}

$\Omega_{\text{thermal}} = \Omega_{\text{cdm}}$

Fermi

$\phi_{\text{det}} = 0$

LEP $\chi^- \chi^+$
non-thermal

\tan \beta = 2

\tan \beta = 20
non-thermal

\[ \tan \beta = 2 \]

\[ \tan \beta = 20 \]
non-thermal

\[\tan \beta = 2\]

\[\tan \beta = 20\]
well-tempered

\[ \Omega (M_1, \mu, \tan \beta) = \Omega_{DM} \]

solve for:

\[ M_1 (\mu, \tan \beta) \]
well-tempered
well-tempered

$M_1 + \sin 2\beta \mu = 0$
well-tempered

\begin{center}
\begin{tikzpicture}
\begin{axis}[
    xlabel=$\mu$ [GeV],
    ylabel=$\tan \beta$,
    xmin=-1000, xmax=1000,
    ymin=0, ymax=40,
    xtick={-1000,-500,0,500,1000},
    ytick={0,5,10,15,20,25,30,35,40},
    \addplot[only marks] coordinates {(-1000,1) (-500,2) (0,3) (500,4) (1000,20)},
    \addplot[only marks, color=black] coordinates {(-1000,1) (-500,2) (0,3) (500,4) (1000,20)},
    \addplot[fill=red!30] coordinates {(0,0) (0,40) (500,0) (500,40) (-500,0) (-500,40)},
    \addplot[fill=gray!50] coordinates {(0,0) (0,10) (500,0) (500,10) (-500,0) (-500,10)},
    \addplot[fill=red!30] coordinates {(0,0) (0,40) (500,0) (500,40) (-500,0) (-500,40)},
    \node at (axis cs:-500,0) {\text{LEP} \chi^- \chi^+},
    \node at (axis cs:0,20) {\text{XENON100}},
    \node at (axis cs:-1000,1) {c_{h\phi \chi} = 0},
    \end{axis}
\end{tikzpicture}
\end{center}
well-tempered
well-tempered
well-tempered
The new XONdd data provide the most stringent confidence level exclusion limit for spin-independent WIMP-nucleon scattering, excluding a large fraction of previously unexplored parameter space including regions preferred by scans of other experiments.

Expected limit of this run:

- DAMA/Na
- CoGeNT
- XENON10 (2011)
- CRESST-II (2012)
- SiNLE (2012)
- CDMS (2010/11)
- SIMPLE (2012)
- EDELWEISS (2011/12)
- ZEPLIN-III (2012)
- XENON100 (2012)
target
The new XeNON data provide the most stringent exclusion limit on spin-independent WIMP-nucleon cross sections. The expected sensitivity of this run is shown by the green-yellow band, and the regions preferred by supersymmetric UzMSV are also shown along with the single Pz resolution. Poisson fluctuations in the number and background expectation are profiled out and the expected sensitivity of this run fluctuates to e events is compared to other results as being due to scalar WIMP and yields a result which agrees with the regions preferred by supersymmetric UzMSV. The expected sensitivity of this run on spin-independent WIMP-nucleon scattering is shown by the green-yellow band, and the expected sensitivity of this run on spin-independent WIMP-nucleon scattering is also shown. The expected sensitivity of this run on spin-independent WIMP-nucleon scattering is also shown.
bino-wino-(higgsino)
bino-wino-(higgsino)

\[
\begin{pmatrix}
M_1 & 0 & -\frac{g'}{\sqrt{2}}\cos\beta v & \frac{g'}{\sqrt{2}}\sin\beta v \\
0 & M_2 & \frac{g}{\sqrt{2}}\cos\beta v & -\frac{g}{\sqrt{2}}\sin\beta v \\
-\frac{g'}{\sqrt{2}} v & \frac{g}{\sqrt{2}} v & 0 & -\mu \\
\frac{g'}{\sqrt{2}} v & -\frac{g}{\sqrt{2}} v & -\mu & 0
\end{pmatrix}
\]

- parameters

\[M_1, M_2, \mu, \tan \beta\]
\text{non-thermal}

\begin{align*}
\tan \beta &= 2 \\
\mu &= 750 \text{ GeV}
\end{align*}
non-thermal

\[ \tan \beta = 2 \]

\[ \mu = 750 \text{ GeV} \]
non-thermal

\[ M_2 + \sin 2\beta \mu = 0 \]

\[ \Omega_\chi = \Omega_{\text{obs}} \pm 3\sigma \]

\[ m_{\chi^0} < m_{\chi^0} \]

\[ \tan \beta = 2 \]

\[ \mu = 750 \text{ GeV} \]
non-thermal

\[ M_1 = M_2 \]

\[ \Omega_\chi = \Omega_{\text{obs}} \pm 3\sigma \]

\[ m_{\chi^+} < m_{\chi^0} \]

\[ \tan \beta = 2 \]

\[ \mu = 750 \text{ GeV} \]
non-thermal

\[ \tan \beta = 2 \]
\[ \mu = 750 \text{ GeV} \]
non-thermal

\[ \tan \beta = 2 \]

\[ \mu = 750 \text{ GeV} \]
non-thermal

\[ \tan \beta = 2 \]

\[ \mu = 750 \text{ GeV} \]
non-thermal

\[ \tan \beta = 2 \]
\[ \mu = 750 \text{ GeV} \]
well-tempered

$$\Omega (M_1, M_2, \mu, \tan \beta) = \Omega_{DM}$$

solve for:

$$M_1 (M_2, \mu, \tan \beta)$$
bino/wino coannihilation

\[ \tilde{H} \]

\[ \tilde{W} \]

\[ \tilde{B} \]

\[
\begin{pmatrix}
M_1 & 0 & -g' \cos \beta \sqrt{2}v & g' \sin \beta \sqrt{2}v \\
0 & M_2 & \frac{g \cos \beta}{\sqrt{2}}v & \frac{g \sin \beta}{\sqrt{2}}v \\
-g' \cos \beta \sqrt{2}v & \frac{g \cos \beta}{\sqrt{2}}v & 0 & -\mu \\
g' \sin \beta \sqrt{2}v & \frac{g \sin \beta}{\sqrt{2}}v & -\mu & 0
\end{pmatrix}
\]
bino/wino coannihilation

\[ \begin{pmatrix}
M_1 & 0 & -\frac{g'}{\sqrt{2}} \cos \beta v & \frac{g'}{\sqrt{2}} \sin \beta v \\
0 & M_2 & \frac{g \cos \beta}{\sqrt{2}} v & -\frac{g \sin \beta}{\sqrt{2}} v \\
-\frac{g'}{\sqrt{2}} \cos \beta v & \frac{g \cos \beta}{\sqrt{2}} v & 0 & -\mu \\
\frac{g'}{\sqrt{2}} \sin \beta v & -\frac{g \sin \beta}{\sqrt{2}} v & -\mu & 0 
\end{pmatrix} \]

how heavy can the higgsino be?
bino/wino coannihilation

how heavy can the higgsino be?

coannihilation:

\[ \langle \sigma_{\text{eff}} v \rangle = \frac{\sum_{i,j} w_i w_j \langle \sigma_{ij} v \rangle}{(\sum_i w_i)^2} \]

\[ w_i = \left( \frac{m_i}{m_1} \right)^{3/2} e^{-x \left( \frac{m_i}{m_1} - 1 \right)} \]
well-tempered

\[ \tan \beta = 2 \]
well-tempered

\[ \tan \beta = 2 \]
well-tempered

\[ \tan \beta = 2 \]

\[ \tilde{B}/\tilde{W} \]

\[ M_2 [\text{GeV}] \]

\[ \mu [\text{GeV}] \]
well-tempered

\[ \tilde{B} / \tilde{H} \]

\[ \tan \beta = 2 \]
\( \tan \beta = 2 \)

\[ M_1 + \sin 2\beta \mu = 0 \]
\[ \tan \beta = 2 \]

\[ M_1 \approx M_2 \]

\[ \text{sign}(\mu) = -\text{sign}(M_{1,2}) \]
well-tempered

\[ \tan \beta = 2 \]
well-tempered

\[ \tan \beta = 2 \]
\[ \tan \beta = 2 \]
well-tempered

\[ \tan \beta = 2 \]
well-tempered

\[ \tan \beta = 2 \]
take away points

• direct detection is finally probing neutralino DM

• large parameter space remains

• blindspots with small spin-independent cross-section evade Xenon1T
backup
Figure xy: Impact of squarks on thermal binonHiggsino dark matterk with

| µ < 0 | tan β = 20 |
|-------|-------------|
| m < 0 |             |

At each point, M_{1} has been chosen so that \( \Omega_{(th)} \chi = \Omega_{obs} \) except in the gray region where freeze-out always yields overclosure. The upper left region where freeze-out is dominated by squark-neutralino coannihilation is excluded by XENON100. However, in the lower right region the XENON100 limit becomes less powerful as the sl-channel squark exchange amplitude has the opposite sign to the tl-channel Higgs exchange diagram. The purple region is excluded by an LHC search for jets and missing transverse energy, with the gluino mass fixed at \( m_{g} = 2 \text{TeV} \). This LHC search becomes less powerful as the gluino mass is increased, and the excluded region becomes bounded by the purple dashed line if the gluino is decoupled. The currently allowed region, shown in white, mostly has a SI scattering cross section that is not far below the current bound, so that LUX will have a large discovery potential. In the absence of a signal at LUX, the only surviving region will be the narrow band between the dashed green lines.

Squark mass approaches the LSP mass, limits from supersymmetry searches at the LHC are also alleviated. In particular, we have plotted the limit on the LSP-squark-glino simplified model of \([q_{o}g]_{k}\) and recast the limit in our parameter space at \( m_{\tilde{g}} = q_{T} e^{\nu_{s i}} \text{ using pythia 6.4} \) [PGS] and NLO [qs] and NLL [qs] results. Josh will add words to describe his recasting procedure.