Towards a last word on neutralino DM

Nishita Desai
(with J. Bramante, A. Martin, P. Fox, B. Ostdiek, T. Plehn)

Pheno 2016, Pittsburgh
10 May 2016
SUSY Dark Matter

\[ \tilde{\chi}_i^0 = N_{ij}(\tilde{B}, \tilde{W}^0, \tilde{H}_u^0, \tilde{H}_d^0) \quad \tilde{\chi}_i^\pm = V_{ij}(\tilde{W}^\pm, \tilde{H}^\pm) \]

\[ M_1, \ M_2, \mu, \text{ and } \tan \beta \]

- Find parameter space that gives the right relic density (ignore effects of sfermions)
- Look at Direct/Indirect/Collider constraints (both present and future expectations)
these to 160 MeV \[87–89\] and 350 MeV \[90–92\] respectively, before diagonalizing electroweakino mass separation between the charged and neutral components of both the wino and higgsino, setting to the freeze-out temperature.

Photon-induced Sommerfeld enhancement is significantly larger for the wino case: first, pure chargino co-annihilation with a... This relatively small... contributes much less to the complete annihilation process. Because higgsino annihilation is generally high mass degenerate, the computation of the current relic abundance has to include a combined... LSP masses colored, separates from gray points calculated without Sommerfeld enhancement when... To generate the sommerfelded surface shown in Figure 1, we first calculate electroweakino mass... Relic surface with SE

$$\Omega h^2 = 0.120 \pm 0.005$$

$$\Omega_{\tilde{W}} h^2 \approx 0.12 \left( \frac{m_{\tilde{\chi}}}{2.1 \, \text{TeV}} \right)^2 \xrightarrow{\text{SE}} 0.12 \left( \frac{m_{\tilde{\chi}}}{2.6 \, \text{TeV}} \right)^2 .$$

$$\Omega_{\tilde{H}} h^2 \approx 0.12 \left( \frac{m_{\tilde{\chi}}}{1.13 \, \text{TeV}} \right)^2 \xrightarrow{\text{SE}} 0.12 \left( \frac{m_{\tilde{\chi}}}{1.14 \, \text{TeV}} \right)^2 .$$

No S.E.
Mass Splitting

$\tan \beta = 10$

$|m_{\chi_2^0} - m_{\chi_1^0}| \leq 10 \text{ GeV}$

pure Wino $\Rightarrow$ co-annihilation with chargino

Wino-Higgsinos

pure Higgsinos $\Rightarrow$ co-annihilation with second neutralino + chargino

Bino-Winos

CLSP-LSP mass splitting

$\mu [\text{TeV}]$ $M_1 [\text{TeV}]$ $M_2 [\text{TeV}]$

NLSP-LSP mass splitting

$\mu [\text{TeV}]$ $M_1 [\text{TeV}]$ $M_2 [\text{TeV}]$
Couplings

\[ g_{Z \tilde{\chi}_1^0 \tilde{\chi}_1^0} = \frac{g}{2 \cos \theta_w} (|N_{13}|^2 - |N_{14}|^2) \]

\[ g_{h \tilde{\chi}_1^0 \tilde{\chi}_1^0} = (gN_{11} - g'N_{12}) \left( \sin \alpha N_{13} + \cos \alpha N_{14} \right) \]

\[ g_{W \tilde{\chi}_1^0 \tilde{\chi}_1^+} = \frac{g \sin \theta_w}{\sqrt{2} \cos \theta_w} \left( N_{14} V_{12}^* - \sqrt{2} N_{12} V_{11}^* \right), \]
Direct Detection

\[ \tan \beta = 10^{-4} - 3 - 2 - 1 0 1 2 3 4 \]

\[ m_\chi \text{ TeV} \]

\[ D_0 1 2 3 4 \]

\[ M_1 \text{ TeV} \]

\[ \sigma (\chi_i^{0n} \rightarrow \chi_j^{0n}) = \bullet < 10^{-50} \bullet 10^{-49} \bullet 10^{-48} \bullet 10^{-47} \bullet 10^{-46} \bullet 10^{-45} \bullet > 10^{-44} \text{ cm}^2 \]

Spin-independent \( \sigma_{xy} \)

\[ \sigma (\chi_i^{0n} \rightarrow \chi_j^{0n}) = \bullet < 10^{-45} \bullet 10^{-44} \bullet 10^{-43} \bullet 10^{-42} \bullet 10^{-41} \bullet 10^{-40} \bullet > 10^{-39} \text{ cm}^2 \]

Spin-dependent \( \sigma_{xy} \)
High-Mass Limits on spin-independent WIMP-Nucleon Scattering

SI Direct Detection limits
Community Planning Study: Snowmass 2013

universe is one of the most fundamental problems in particle physics today. The solution to this problem is the consensus of the scientific community that identifying the particle nature of the dark matter in our universe is crucial.

Summary

A. Discovery:

Direct detection describes an experimental program designed to identify the interaction of WIMPs with normal matter. Direct detection experiments aim to detect nuclear recoil energies in the 1-100 keV range. It is expected that WIMPs would interact with normal matter by elastic scattering with nuclei.

B. Evolution:

Direct detection experiments have made tremendous progress in the last three decades, with sensitivity to WIMPs doubling roughly every 18 months. This rapid progress has been driven by remarkable innovations in detector technologies that have provided extraordinary active rejection of normal matter backgrounds. A comprehensive program to model and reduce backgrounds, using a combination of methods, is essential.

C. Study:

Detection experiment, since confirmation from other experiments will be vital to convince the community in mind that, even for the simplest scenarios, the science goals are unlikely to be met with a single direct detection experiment. Choice of experiments to make choices for the next generation (G3) experimental suite. It is very important to keep in mind that, even for the simplest scenarios, the science goals are unlikely to be met with a single direct detection experiment. Fig. 40. Check any evidence for WIMP signals using complementary targets and the same target information gleaned from past experiments, detector R&D etc.

In a resource-limited environment, not every proposed direct detection experiment will be funded. Information projections (dot and dot-dashed curves) for US-led direct detection experiments that are expected to operate in each generation.

Direct detection limits

A compilation of WIMP-nucleon spin-dependent cross section limits (solid curves) and projections (dot and dot-dashed curves) for US-led direct detection experiments that are expected to operate in each generation.

\[
\text{SD WIMP-nucleon cross section [cm}^2\text{]} \quad \text{SD WIMP-proton cross section [pb]} \quad \text{SD WIMP-proton cross section [pb]}
\]

\[
\text{WIMP Mass [GeV/c}^2\text{]} \quad \text{WIMP Mass [GeV/c}^2\text{]}
\]

\[
10^{-36} \quad 10^{-35} \quad 10^{-34} \quad 10^{-33} \quad 10^{-32} \quad 10^{-31} \quad 10^{-30} \quad 10^{-29} \quad 10^{-28} \quad 10^{-27} \quad 10^{-26} \quad 10^{-25} \quad 10^{-24} \quad 10^{-23} \quad 10^{-22} \quad 10^{-21} \quad 10^{-20} \quad 10^{-19} \quad 10^{-18} \quad 10^{-17} \quad 10^{-16} \quad 10^{-15} \quad 10^{-14} \quad 10^{-13} \quad 10^{-12} \quad 10^{-11} \quad 10^{-10} \quad 10^{-9} \quad 10^{-8} \quad 10^{-7} \quad 10^{-6} \quad 10^{-5} \quad 10^{-4} \quad 10^{-3} \quad 10^{-2} \quad 10^{-1} \quad 10^0
\]
Direct Detection

\[ \tan \beta = \frac{1}{10} - \frac{1}{4} - \frac{1}{3} - \frac{1}{2} - \frac{1}{1} \]

\[ m_{\chi_1^0} \approx \text{TeV} \]

\[ \mu_{\chi_1^0} \approx \text{TeV} \]

\[ \sigma(\chi_1^0 n \rightarrow \chi_1^0 n) = \begin{cases} < 10^{-50} & \text{cm}^2 \\ 10^{-49} & \\ 10^{-48} & \\ 10^{-47} & \\ 10^{-46} & \\ 10^{-45} & \end{cases} \]

\[ \sigma(\chi_1^0 n \rightarrow \chi_1^0 n) = \begin{cases} < 10^{-45} & \text{cm}^2 \\ 10^{-44} & \\ 10^{-43} & \\ 10^{-42} & \\ 10^{-41} & \\ 10^{-40} & \end{cases} \]

Excluded: XENON100 [LUX] Projected Exclusion: XENON1T [LZ]
Indirect detection: Annihilation into photons

The neutralino annihilation cross-section to $\gamma\gamma$ is given for Milky Way dark matter halo profiles is conveniently parameterized with a

$$\frac{1}{2}\sigma_{\chi\chi \rightarrow \gamma\gamma} + \sigma_{\chi\chi \rightarrow ZZ}$$

where we take $\sigma_{\chi\chi \rightarrow \gamma\gamma}$ to be the annihilation cross-section to $\gamma\gamma$, and $\sigma_{\chi\chi \rightarrow ZZ}$ is the annihilation cross-section to $ZZ$. On the other hand, assuming a core of smaller size (e.g. we consider the Einasto profile, $\tan \beta = 10$ and $R = 20$ kpc), this results in a more stringent bound on DM annihilation.

$$\rho_{\text{NFW}}(r) = \frac{\rho_\odot}{(r/R)(1 + r/R)^2},$$

$$\rho_{\text{Ein}}(r) = \rho_\odot \exp \left[ -\frac{2}{\alpha} \left( \frac{r}{R} \right)^\alpha - 1 \right],$$

$$\rho_{\text{Burk}}(r) = \frac{\rho_\odot}{(1 + r/r_c)(1 + (r/r_c)^2)}.$$
Annihilation into photons

\[ \langle v_{\text{ann}} \rangle \langle v_{\text{ann}} \rangle \]

**FIG. 2.** Upper limits on 68% CL regions for these limits. Black crosses denote the flux ground spectra, and the gray bands denote the corresponding black lines show the mean expected limits derived from a large arrows with open data points. For both data sets, the solid signatures, derived from the CGH region (red arrows with extragalactic BM4-like (IB only) γ-ray flux from monochromatic line of cosmic-ray electrons and positrons. 

should be stressed that the latter results are valid for as predicted by the models BM2 and BM4 of [14]. Ittragalactic sky. Both regions of interest exhibit a reduced observations of the central Milky Way halo region and ex-
tation can exclude instrumental e

**IV. DISCUSSION AND CONCLUSIONS**

We summarize here the main results:

- The signal region definition and background descri-

**FIG. 6: Same as Fig. 3, but for 5 h of Galactic center observati

(Potential) Collider Searches

\[ pp \rightarrow (\tilde{\chi}_2^0 \rightarrow \gamma \tilde{\chi}_1^0) \ (\tilde{\chi}_1^\pm \rightarrow \ell^\pm \nu_\ell \tilde{\chi}_1^0) j \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^\pm \nu_\ell j , \]

\[ pp \rightarrow (\tilde{\chi}_2^0 \rightarrow \gamma \tilde{\chi}_1^0) \ (\tilde{\chi}_1^\pm \rightarrow \ell^\pm \nu_\ell \tilde{\chi}_1^0) j \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^\pm \nu_\ell j , \]

\[ \sqrt{s} = 100 \text{ TeV} \]

\[ pp \rightarrow (\tilde{\chi}_2^0 \rightarrow \gamma \tilde{\chi}_1^0) \ (\tilde{\chi}_1^\pm \rightarrow \ell^\pm \nu_\ell \tilde{\chi}_1^0) j \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^\pm \nu_\ell j , \]

\[ pp \rightarrow (\tilde{\chi}_2^0 \rightarrow \gamma \tilde{\chi}_1^0) \ (\tilde{\chi}_1^\pm \rightarrow \ell^\pm \nu_\ell \tilde{\chi}_1^0) j \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^\pm \nu_\ell j , \]
Putting it all together

$\tan \beta = 10$

$2\sigma$ Exclusions

- Direct
- Direct+Indirect
- Indirect
- Tracks
- Compr.+Direct
- Compr.
Putting it all together

- Pure winos can best be detected with tracks + indirect detection
- Pure Higgsinos as well as Wino-Higgsinos can be detected with direct (and/or) indirect detection
- Bino-Winos can only be detected with collider searches

Almost all of SUSY DM can be detected within next 10-20 years!