Dark matter in split extended supersymmetry

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Plan:

- Some “trivia” about SUSY
- Split Extended-SUSY high energy setup
- Split Extended-SUSY “low” energy setup
- Dark matter and Split Extended SUSY
- Prospects for direct and indirect detection
- Conclusions
Some “trivia” about supersymmetry

- Historical motivation to introduce SUSY are:
  - Hierarchy problem
  - Grand unification
  - Connection with string theory

- MSSM with R-parity provides a stable weakly interacting particle, a viable Dark Matter candidate

- New trend is to ignore the hierarchy problem and “split” the SUSY spectrum (Harkani-Hamed and Dimopulos, Giudice and Romanino 2004)

- The Split-SUSY Dark Matter phenomenology well known (e.g. Masiero, Profumo and Ullio 2004)
Split Extended SUSY high energy setup
(Antoniadis et al. 2005)

- Intersecting branes
- Gauge bosons are in the N=2 SUSY representation
- Higgs sector is a N=2 hypermultiplet
- Matter fields are in a N=1 SUSY representation
- At one loop all the SUSY scalars and winos acquire soft masses
- Due to grand unification this scale is order $10^{13}$ GeV
Split Extended SUSY low energy setup: Higgs sector

- The lagrangian in terms of N=1 superfield reads:

\[
\mathcal{L} = \mathcal{L}_{Kin.gaug} + \int d^4\theta (H_1^\dagger e^{-2g^V} H_1 + H_2 e^{+2g^V} H_2^\dagger) + \left( \int d^2\theta g \sqrt{2} H_2 \Phi H_1 + h.c. \right).
\]

- After a straightforward computation the Higgs potential reads:

\[
V = m_1^2 |H_1|^2 + m_2^2 |H_2|^2 + m_3^2 (H_2 H_1 + h.c.) + \frac{g^2}{8} \left( H_1^\dagger \sigma H_1 - H_2 \sigma H_2^\dagger \right)^2 + \frac{g'^2}{8} \left( |H_2|^2 - |H_1|^2 \right)^2 + \frac{g'^2}{2} |H_2 H_1|^2 + \frac{g^2}{2} |H_2 \sigma H_1|^2.
\]
Split Extended SUSY low energy setup: Higgs sector

After the minimization mass eigenstates are:

- The unphysical would-be goldstone bosons

\[
G^0 = - \cos \beta \text{Im}[H_1^0] + \sin \beta \text{Im}[H_2^0] \\
G^+ = - \cos \beta (H_1^-)^* + \sin \beta (H_2^+) 
\]

- The CP-odd Higgs boson:

\[
A^0 = \sin \beta \text{Im}[H_1^0] + \cos \beta \text{Im}[H_2^0] 
\]

with mass \(m_A\)
Split Extended SUSY low energy setup: Higgs sector

• The CP-even Higgs bosons:

\[ H_2 = \cos \beta \Re[H_1^0 - \nu_1] + \sin \beta \Re[H_2^0 - \nu_2] \]
\[ H_1 = \sin \beta \Re[H_1^0 - \nu_1] - \cos \beta \Re[H_2^0 - \nu_2] \]

with mass:

\[ m_{H_2} = m_Z \]
\[ m_{H_1} = m_A \]

• The charged Higgs boson:

\[ H^+ = \sin \beta (H_1^-)^* + \cos \beta (H_2^+) \]

with mass:

\[ m_{H^+}^2 = m_A^2 + m_W^2 (2 - \tan^2 \theta_W) \]
Split Extended SUSY low energy setup: charginos and neutralinos

- There is only a chargino \( i.e. \) the Higgsino like one
- \( m_{\tilde{L}C} \sim \mu \)
- The neutral extra fermions are the two Higgsino states and two bino states
- Neutralino mass matrix is:

\[
M_{\tilde{\chi}^0} = \begin{pmatrix}
M & 0 & -m_{ZSWc_\beta} & m_{ZSWs_\beta} \\
0 & M & m_{ZSWs_\beta} & m_{ZSWc_\beta} \\
-m_{ZSWc_\beta} & m_{ZSWs_\beta} & 0 & -\mu \\
m_{ZSWs_\beta} & m_{ZSWc_\beta} & -\mu & 0
\end{pmatrix}
\]
Split Extended SUSY low energy setup: charginos and neutralinos

- There is only a chargino \textit{i.e.} the Higgsino like one

- \( m_{L_C} \sim \mu \)

- The neutral extra fermions are the two Higgsino states and two bino states

- Neutralino masses are in the form:

\[
m_{\chi_i} = \frac{1}{2} \left[ (M + \epsilon_1 \mu) - \epsilon_2 \sqrt{(M - \epsilon_1 \mu)^2 + 4m_Z^2 \sin^2 \theta_W} \right]
\]

Neutralino masses are \textit{independent} from \( \tan \beta \)!
Split Extended SUSY low energy setup: charginos and neutralinos

- There is only a chargino \( i.e. \) the Higgsino like one
  
  - \( m_{\text{LCH}} \sim \mu \)

- The neutral extra fermions are the two Higgsino states and two bino states

- Lightest Neutralino eigenstate has the form:

\[
N_{1,i\alpha} \left( -\frac{2m_Z \sin \theta_W (c\beta + s\beta)}{M - \mu + \sqrt{(M - \mu)^2 + 4m_Z^2 \sin^2 \theta_W}}, \frac{2m_Z \sin \theta_W (s\beta - c\beta)}{M - \mu + \sqrt{(M - \mu)^2 + 4m_Z^2 \sin^2 \theta_W}}, -1, 1 \right)
\]

This means no coupling with the Z boson!
Split Extended SUSY low energy setup: summary of free parameters

- We are left with four free parameter: $M$, $\mu$, $m_A$, $\tan\beta$.
- We will make the simplifying assumption $m_A \rightarrow \odot$
- In this limit the radiative corrections are the same for the split-susy scenario (Giudice and Romanino 2004). Having the GUT constraint set the scalar masses to be $\sim O(10^{13})$ GeV we expect to find $m_{H_2} \sim 170$ GeV
- In the end the free parameter are only 3
Dark matter and Split Extended SUSY: relic abundance

- Neutralino thermal relic abundance is settled by annihilations in gauge bosons and coannihilation with Lightest Chargino
Dark matter and Split Extended SUSY: relic abundance

- Neutralino thermal relic abundance is settled by annihilations in gauge bosons

\[ \Omega h^2 > 0.110 + 3\sigma \]

High mixing region

\[ \Omega h^2 < 0.110 - 3\sigma \]
Dark matter and Split Extended SUSY: relic abundance

- We introduce the finetuning indices:

\[ \frac{d \log \Omega h^2}{d \log \mu}, \]

\[ \frac{d \log \Omega h^2}{d \log M} \]

- We have a huge finetuning in the High-Mixing region
Dark matter and Split Extended SUSY: direct detection

- The goal is to measure the energy deposited in elastic scatterings on target nuclei by dark matter.
- Only the diagram with Higgs boson exchange is present then we can scan only the high mixing region.
- Since two binos are present the plot is $\tan \beta$ independent.
Dark matter and Split Extended SUSY: direct detection
Dark matter and Split Extended SUSY: indirect detection

- The goal is observe neutralino annihilation product

- To predict antimatter fluxes from annihilation in the Dark Matter Galactic halo we need the local CDM distribution. We will refer to a “Burkert” halo profile (cored)

- To understand the discovery potential of positron and antiproton flux measurements, an useful quantity is:

\[ I_\Phi \equiv \int_{E_{\text{min}}}^{E_{\text{max}}} dE \frac{[\Phi_s(E)]^2}{\Phi_b(E)}, \]

- We will refer to PAMELA experiment for antiprotons and positrons searches and to GAPS experiment for antidiuterons search
Dark matter and Split Extended SUSY: indirect detection

- Due to the absence of a spin-dependent coupling neutrino flux is negligible
- Only a portion of the High mixing of the WMAP allowed region can be scanned with this techniques
- The situation is better with less conservatives DM halos
Dark matter and Split Extended SUSY: indirect detection

- Direct Detection
- Muon Flux/Sun
- Antideuterons (?)
- Antiprotons
- Positrons

$\Omega h^2 > 0.13$

$\Omega h^2 < 0.110 - 3\sigma$

- Antideuterons
- Antiprotons
- Positrons

Excluded by current Antiproton Data
Conclusions

- We find some regions in the parameter space where the thermal relic abundance of the Lightest Neutralino is in the WMAP range
- Only a portion of this area can be scanned at future experiments
- Complementarity between different experiments is crucial to distinguish this model from split-SUSY