A Singlet Extension of the MSSM with a Dark Matter Portal

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Introduction

Supersymmetric models, among many features, are well known for providing dark matter candidates.

In this work we consider an extension of the MSSM where extra singlets are added and a Peccei-Quinn symmetry is imposed.

We constrain the parameter space and study the scalar and neutralino spectrum. We find that the lightest neutralino is a viable candidate for light dark matter.

The model

$$W = W_{Yukawa} + (\mu + \lambda S) H_u H_d + \frac{1}{2} \mu_s S^2$$

S-MSSM (Delgado, Kolda, Olson, AP 2010)

$$\longrightarrow \mu_{eff} \simeq \frac{1}{2} A_\lambda \sin 2\beta$$

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Breaks PQ-symmetry

$$\text{Ordinary Matter} \quad \overset{\hat{S}}{\Longleftrightarrow} \quad \text{Decoupled Matter}$$

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With SUSY-breaking scalar potential

$$\begin{aligned} V_{Soft} &= V_{Soft,Yukawa} + m_{H_u}^2|H_u|^2 + m_{H_d}^2|H_d|^2 + m_S^2|S|^2 + m_N^2|N|^2 \\ &+ \left(\lambda A_\lambda S H_u \cdot H_d + \rho A_\rho N S^2 + \frac{\kappa}{3}A_\kappa S^3 + c.c\right). \end{aligned}$$

Effective μ and B_μ parameters are generated and given by

$$\mu_{eff} = \lambda v_S, \qquad B_{\mu,eff} = \lambda v_S A_\lambda + 2\lambda\kappa v_S^2 + 4\lambda\rho v_S v_N.$$

The model

The spectrum contains:

Charged Higgs	$H^{\pm}$,
Neutral scalars	(h_N, h_S, h, H),
Neutral pseudo-scalars	(A_n, A_S, A).

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$$m_{h^0}^2 \approx m_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta - \frac{\left(m_Z^2 - \lambda^2 v^2\right)^2}{m_A^2} \sin^2 2\beta \cos^2 2\beta$$

$$m_H^2 \approx m_A^2 + \left(m_Z^2 - \lambda^2 v^2\right) \sin^2 2\beta + \frac{\left(m_Z^2 - \lambda^2 v^2\right)^2}{m_A^2} \sin^2 2\beta \cos^2 2\beta - \frac{\lambda^2 v^2 A_\lambda^2}{m_A^2} \sin^2 2\beta$$

$$m_{h_S}^2 \approx m_S^2 + \lambda^2 v^2 - \frac{\lambda^2 v^2 A_\lambda^2}{m_A^2}$$

$$m_{h_N}^2 \approx m_N^2.$$

$$m_A^2 \approx \frac{2B_{\mu,eff}}{\sin 2\beta}.$$

The model

Neutralino sector:

$$\psi_N = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0, \tilde{S}, \tilde{N}) \quad \Longrightarrow \quad \mathcal{L}_{\tilde{N}} = -\frac{1}{2}\psi_N^T M_{\tilde{N}} \psi_N + \text{c.c.}$$

where

$$M_{\tilde{N}} = \begin{pmatrix} M_1 & 0 & -\frac{g' m_W \cos(\beta)}{g} & \frac{g' m_W \sin(\beta)}{g} & 0 & 0 \\ 0 & M_2 & m_W \cos(\beta) & -m_W \sin(\beta) & 0 & 0 \\ -\frac{g' m_W \cos(\beta)}{g} & m_W \cos(\beta) & 0 & -\lambda v_s & -\lambda v_s \sin(\beta) & 0 \\ \frac{g' m_W \sin(\beta)}{g} & -m_W \sin(\beta) & -\lambda v_s & 0 & -\lambda v_s \cos(\beta) & 0 \\ 0 & 0 & -\lambda v_s \sin(\beta) & \lambda v_s \cos(\beta) & 2\rho v_n + 2\kappa v_s & 2\rho v_s \\ 0 & 0 & 0 & 0 & 2\rho v_s & 0 \end{pmatrix}$$

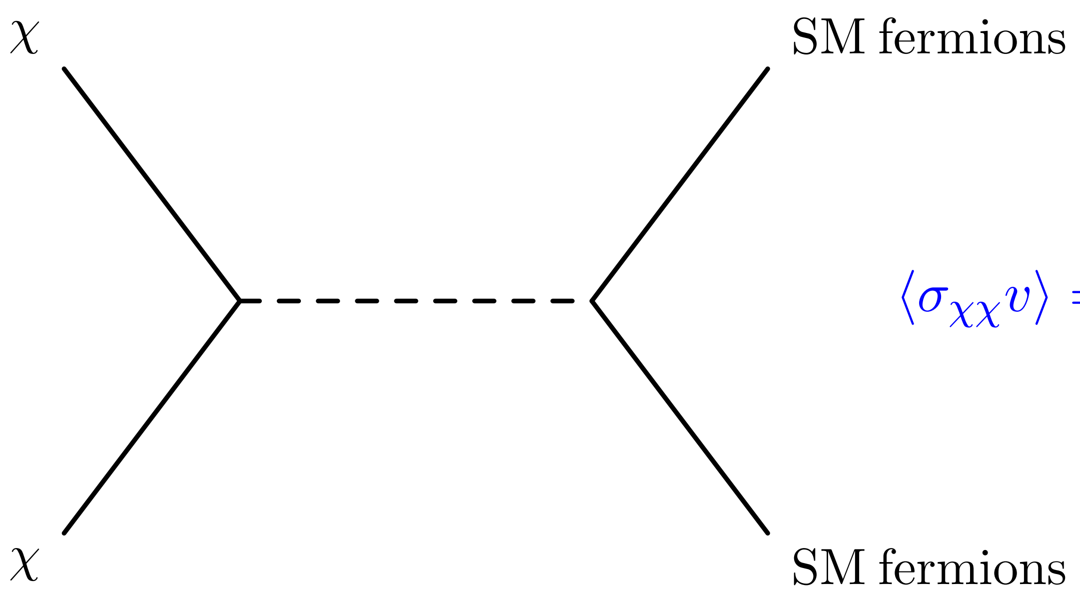
$$\tilde{\chi}_1^0 = \epsilon_u \tilde{H}_u^0 + \epsilon_d \tilde{H}_d^0 + \epsilon_W \tilde{W}^0 + \epsilon_B \tilde{B} + \epsilon_S \tilde{S} + \epsilon_N \tilde{N}$$

The lightest neutralino is mostly singlino (mostly $\tilde{N}$).

Dark Matter

$$\Omega_{\rm DM}h^2 \approx \frac{1.07\times 10^9 {\rm GeV}^{-1}}{J\, g_*^{1/2} M_{\rm Pl}} \approx 0.112, \qquad \text{with} \qquad J \equiv \int_{x_{FO}}^{\infty} \frac{\langle \sigma_{\chi\chi} v\rangle}{x^2} dx.$$

We compute the exact annihilation cross-section for the dominant processes: s-channel Higgs boson (and Z boson) exchange.



$$\langle \sigma_{\chi\chi} v\rangle = \frac{1}{8 m_\chi^4 T K_2^2\left(m_\chi/T\right)} \int_{4m_\chi^2}^{\infty} ds\, \sigma(s)(s-4m_\chi^2) s^{1/2} K_1\left(\frac{s^{1/2}}{T}\right)$$

Analysis

We analyze the parameter space that is necessary to generate a Higgs boson with a mass of 126 GeV and light singlet-like states that are consistent with LEP searches.

We also include the LEP bounds on the chargino mass and the upper bounds on the couplings between the light scalars and the Z boson.

	Description	Range
A_t	SUSY-breaking top trilinear coupling	$[0, 1000]$ GeV
$m^2_{\tilde{t}_L}$	Soft mass for left handed stop	$[650^2, 1000^2]$ GeV^2
M_2	Wino mass	$[250, 500]$ GeV
κ	Singlet self coupling	$[-0.1, 0.1]$
ρ	$\hat{S} - \hat{N}$ superpotential coupling	$[-0.05, 0.05]$
A_λ	SUSY-breaking $S - H_u - H_d$ trilinear coupling	$[0, 1000]$ GeV
A_κ	SUSY-breaking single trilinear coupling	$[0, 500]$ GeV
A_ρ	SUSY-breaking $N - S^2$ trilinear coupling	$[0, 500]$ GeV
m^2_S	SUSY-breaking mass term for S	$[0, 1000]$ GeV^2
M^2_N	SUSY-breaking mass term for N	$[0, 1000]$ GeV^2

Table 1. Model parameters and their ranges used the numerical routines.

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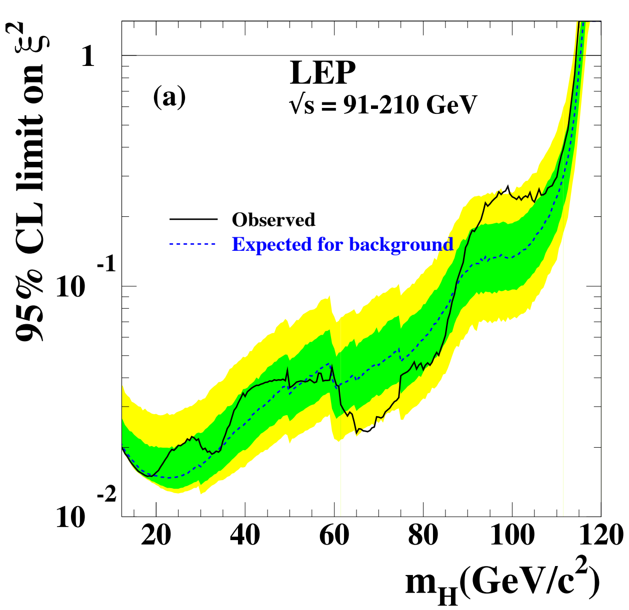
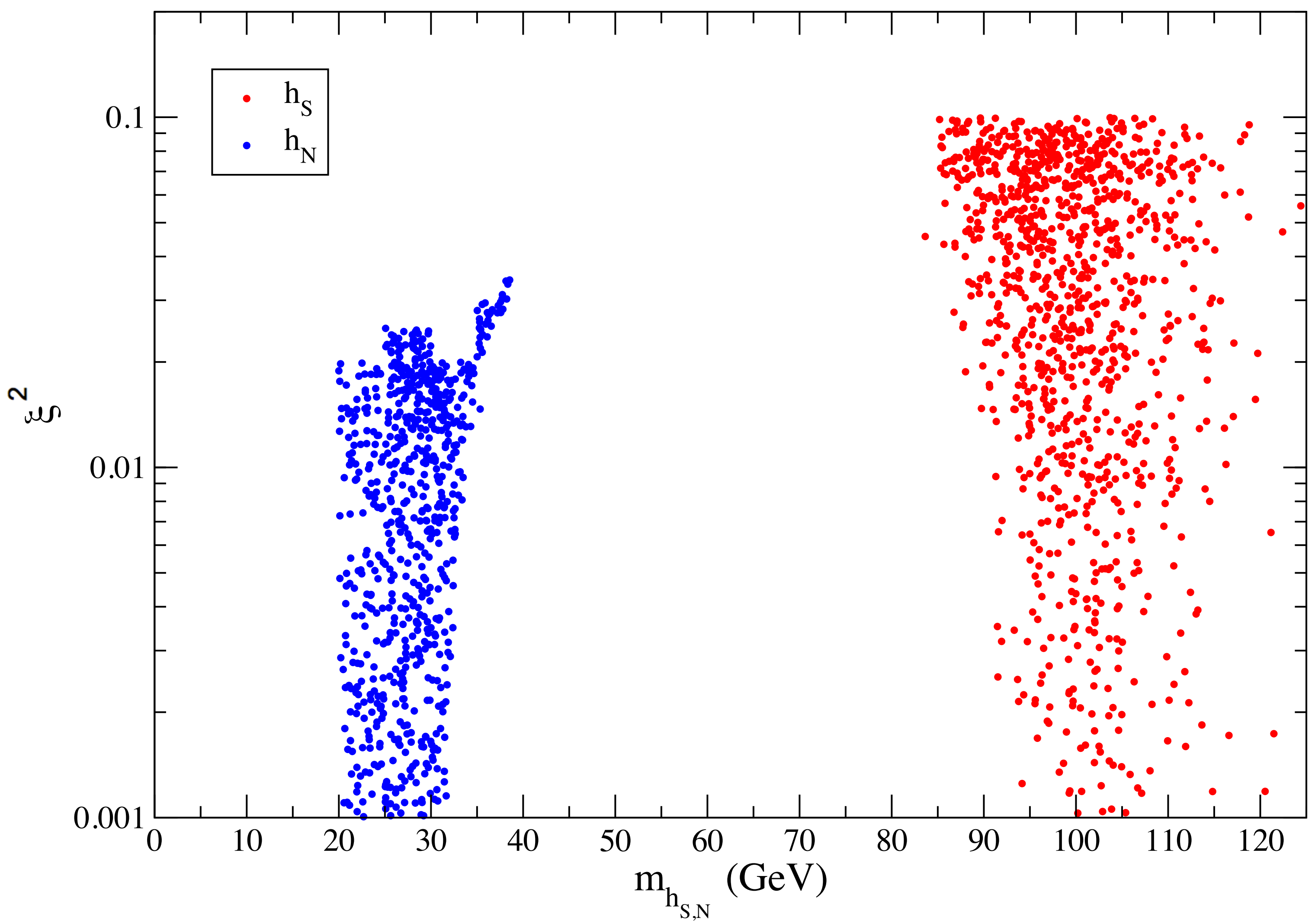
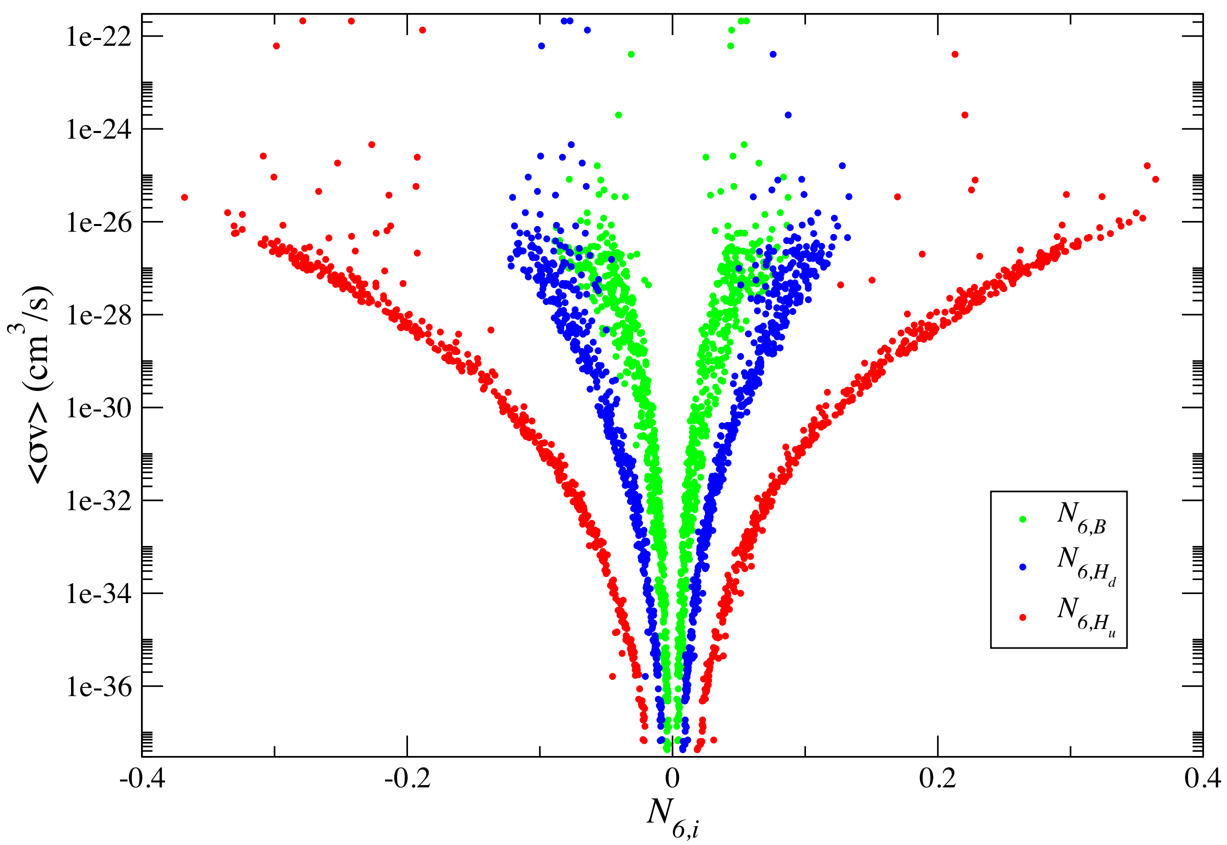


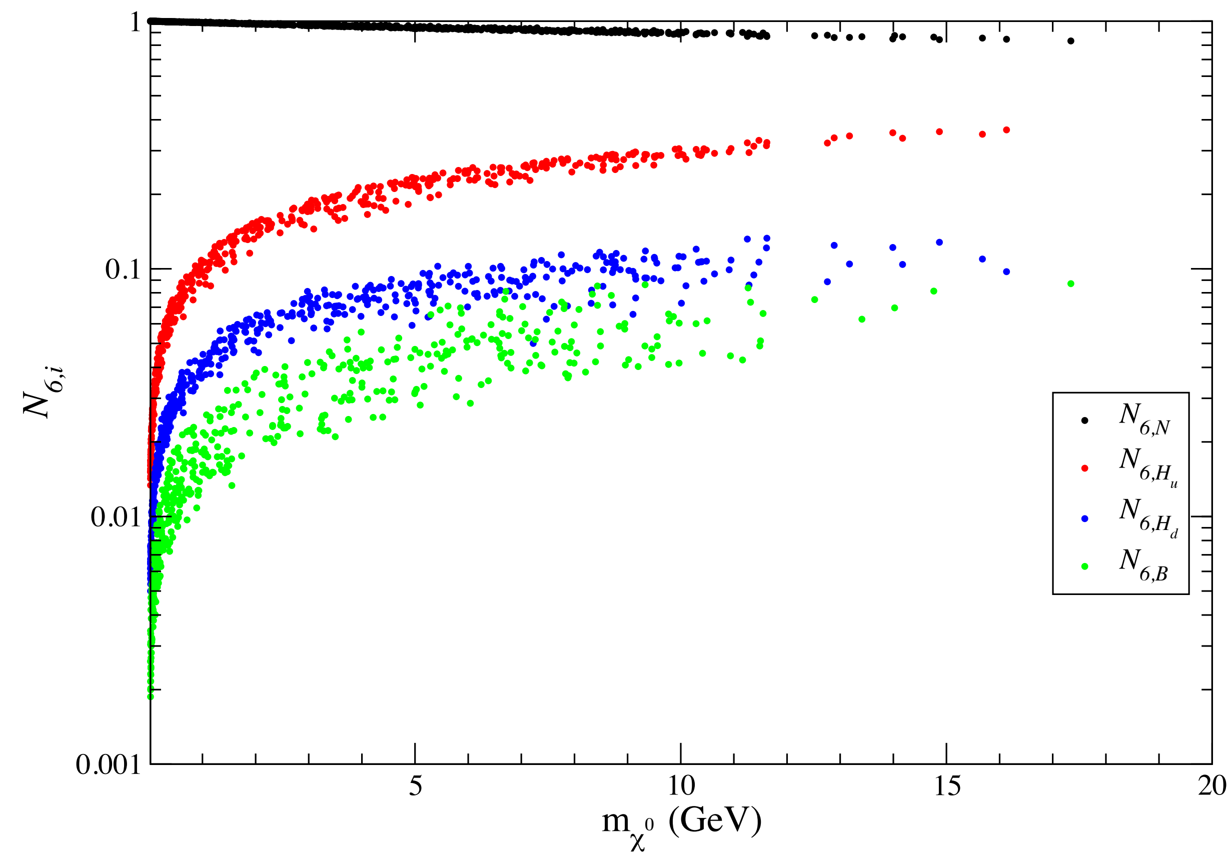
arXiv:hep-ex/0306033



Analysis

We also impose the bounds on the invisible decay width of the Z boson.





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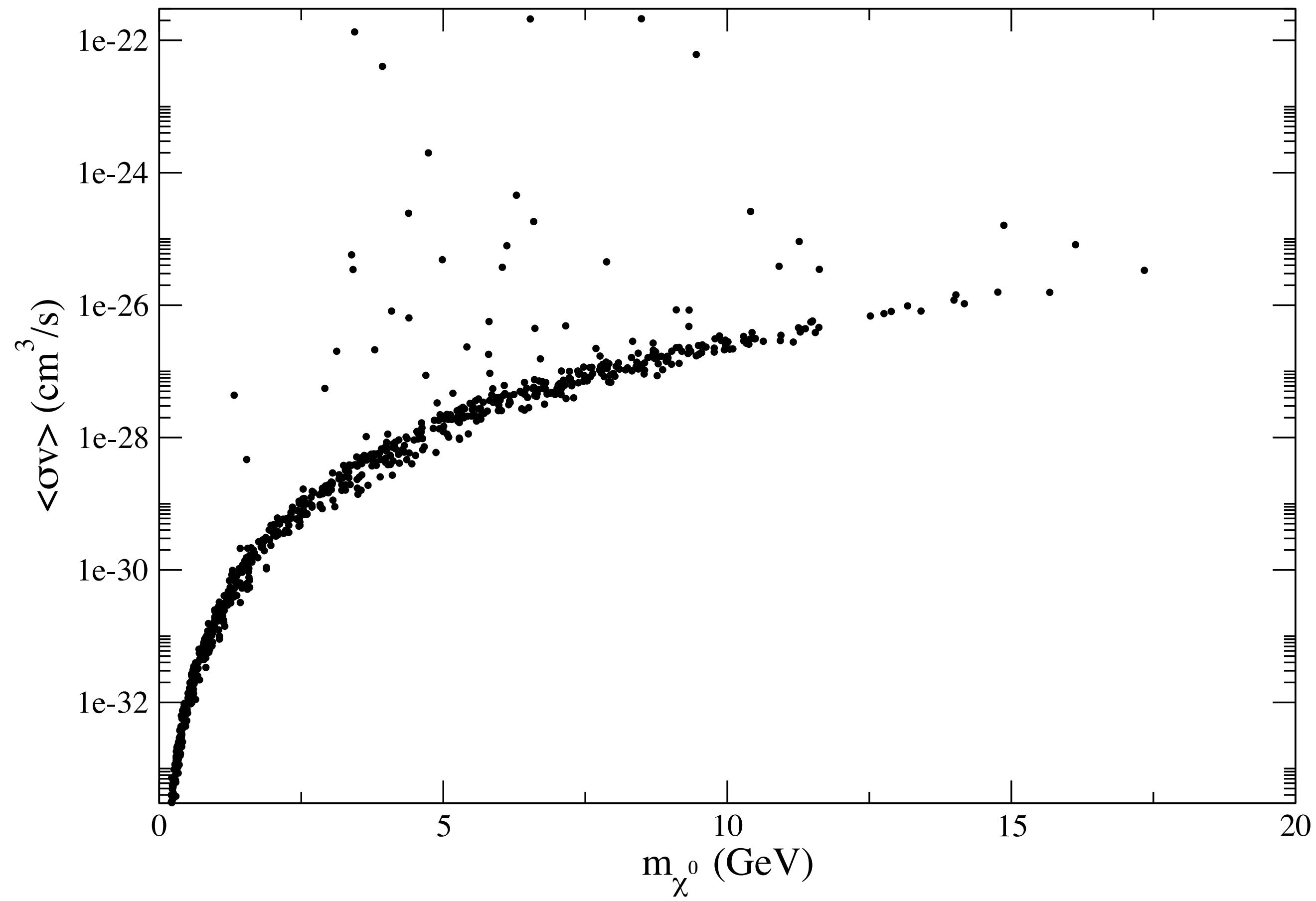

We find that a LSP with a mass ~10-14 GeV allows a relic abundance that is consistent with the DM density.

What we are doing and what we will do

Study the detection aspects of this kind of model.

Consider other models with additional PQ-breaking terms.

Connect this model with a suitable SUSY breaking mediation scenario.