pMSSM in the Light of Dark Matter Detection Experiments

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Objectives and Method

Objectives

- Our goal is to constrain the pMSSM parameters using dark matter detection data

pMSSM: phenomenological MSSM

- The most general CP/R parity-conserving MSSM
- Minimal Flavour Violation at the TeV scale
- The first two sfermion generations are degenerate
- The three trilinear couplings are general for the 3 generations

$\rightarrow$ 19 free parameters

Objectives

- We studied the influence of astrophysical uncertainties on the experimental constraints
- We focused on the type of neutralinos and range of masses that are excluded by each experiment

A neutralino will be said to be :

- Bino-like if $N_{11} > 0.9$
- Wino-like if $N_{12} > 0.9$
- Higgsino-like if $\sqrt{N_{13}^2 + N_{14}^2} > 0.9$
- Mixed, otherwise

N: neutralino mixing matrix

Method

- Scan over the 19 pMSSM parameters
  $\rightarrow$ 10 million points produced (100 000 remaining after imposing Higgs and LEP constraints)

Parameter	Range (in GeV)
$\tan\beta$	[1, 60]
M_A	[50, 5000]
M_1	[-5000, 5000]
M_2	[-5000, 5000]
M_3	[0, 5000]
$A_d = A_s = A_b$	[-15000, 15000]
$A_u = A_c = A_t$	[-15000, 15000]
$A_e = A_\mu = A_\tau$	[-15000, 15000]
μ	[-5000, 5000]
$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	[0, 5000]
$M_{\tilde{e}_R} = M_{\tilde{\mu}_R}$	[0, 5000]
$M_{\tilde{\tau}_L}$	[0, 5000]
$M_{\tilde{\tau}_R}$	[0, 5000]
$M_{\tilde{q}_{1L}} = M_{\tilde{q}_{2L}}$	[0, 5000]
$M_{\tilde{q}_{3L}}$	[0, 5000]
$M_{\tilde{u}_R} = M_{\tilde{c}_R}$	[0, 5000]
$M_{\tilde{t}_R}$	[0, 5000]
$M_{\tilde{d}_R} = M_{\tilde{s}_R}$	[0, 5000]
$M_{\tilde{b}_R}$	[0, 5000]

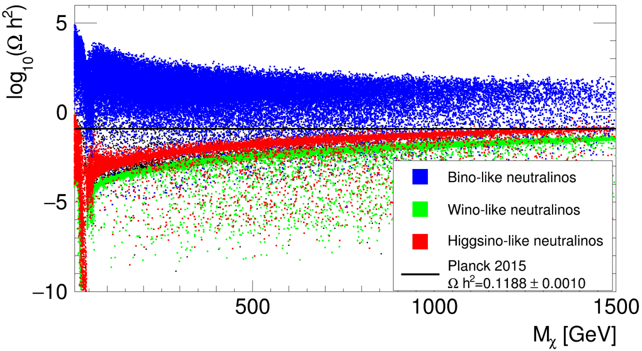
Method

- Computation of :
  - the pMSSM spectra (**SOFTSUSY**)
  - the neutralino relic density (**SuperIso Relic**)
  - Annihilation and scattering cross-sections (**micrOMEGAs**)
  - Production cross-sections (**SusHi**)
  - Higgs branching ratios (**Hdecay**)
  - Other observables for LHC analysis (**MadGraph, PYTHIA, Delphes...**)
- Then, we compared these observables to experimental constraints

Dark Matter Relic Density

Dark Matter Relic Density

Planck measure : $\Omega h^2 = \Omega h^2{}_{exp} \pm \Omega h^2{}_{err}$
with $\Omega h^2{}_{exp} = 0.1188$ and $\Omega h^2{}_{err} = 0.0010$



- With the constraint that $\Omega h^2 < \Omega h^2{}_{exp} + 3.5 \times \Omega h^2{}_{err}$, we exclude almost 94% of the binos
- With $\Omega h^2{}_{exp} - 3.5 \times \Omega h^2{}_{err} < \Omega h^2 < \Omega h^2{}_{exp} + 3.5 \times \Omega h^2{}_{err}$, more than 97% of all our points are excluded

Relic Density

- The calculation of the relic density is subject to large cosmological uncertainties concerning the expansion rate
- The relic density calculated in the standard cosmological model could then be smaller than the one observed
  $\rightarrow$ We only apply Planck upper limit

- Another argument for applying only the upper limit is to consider that the neutralino account for just a fraction of the total Dark Matter

Indirect Detection
Antiprotons
-
PAMELA and AMS

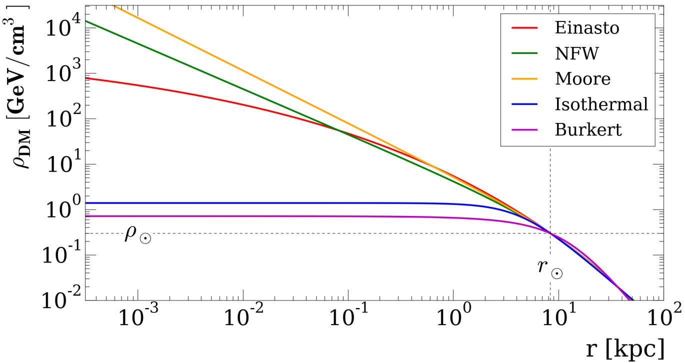
Exclusion Method

Constraints were calculated following the analysis from [Boudaud et al.] arXiv: 1412.5696

- To their theoretical background of secondary antiprotons, we added the primary antiproton spectrum from DM annihilation after propagation through the galactic medium.
  This DM spectrum was taken from the *Poor Particle Physicist Cookbook* [Cirelli et al.] arXiv:1012.4515
- We tested the validity of the total spectrum, comparing it to PAMELA data through a $\Delta\chi^2$ analysis.

Astrophysical uncertainties

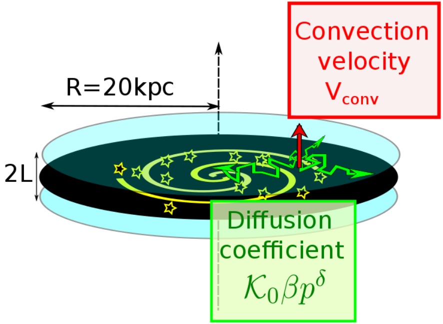
- Halo density profiles



$$r_\odot = 8.3 \text{ kpc}$$
$$\rho_\odot = 0.3 \text{ GeV/cm}^3$$

Astrophysical uncertainties

- Cosmic ray propagation through the galactic medium



Model	δ	$\mathcal{K}_0$ $[kpc^2/Myr]$	V_{conv} [km/s]	L[kpc]
MIN	0.85	0.0016	13.5	1
MED	0.70	0.0112	12	4
MAX	0.46	0.0765	5	15

Astrophysical uncertainties

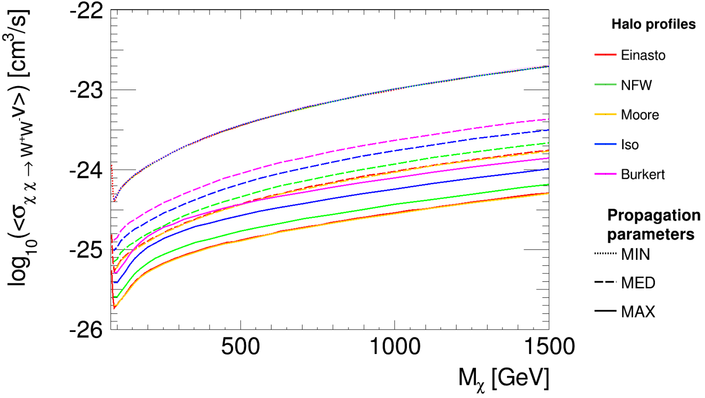
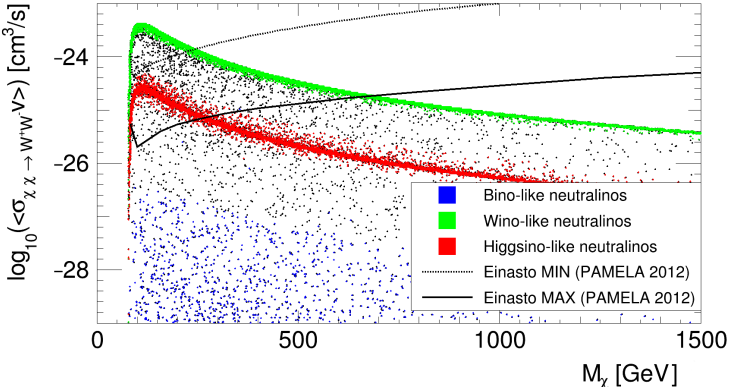


Figure: 95% CL upper limits on the thermally-averaged cross-section for DM particles annihilating into W^+ W^-

- The lowest and strongest limits corresponds respectively to Einasto MIN and Einasto MAX

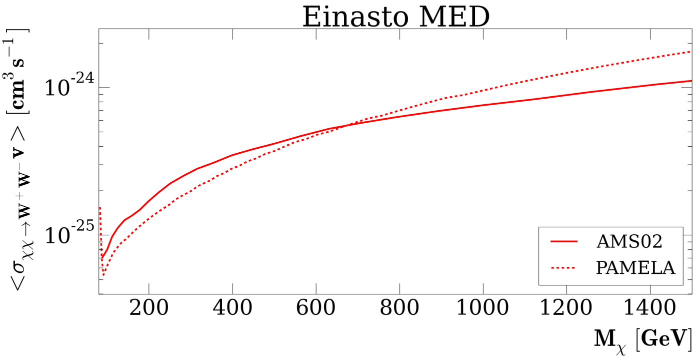
PAMELA

- Mostly neutralinos annihilating into W^+W^- are excluded



- Winos are excluded, up to a mass of 250 GeV (Ein MIN) or 700 GeV (Ein MAX)

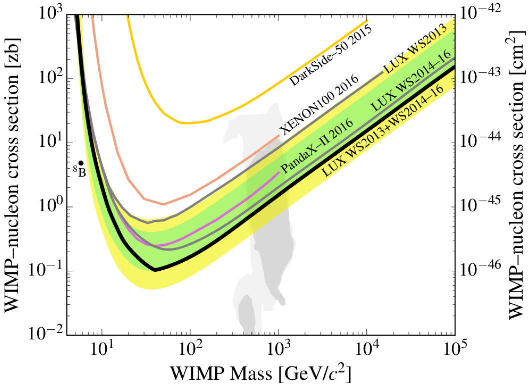
AMS-02 - Preliminary Results



- AMS-02 constraints are actually weaker than PAMELAs in our exclusion range of masses

Direct Detection
LUX

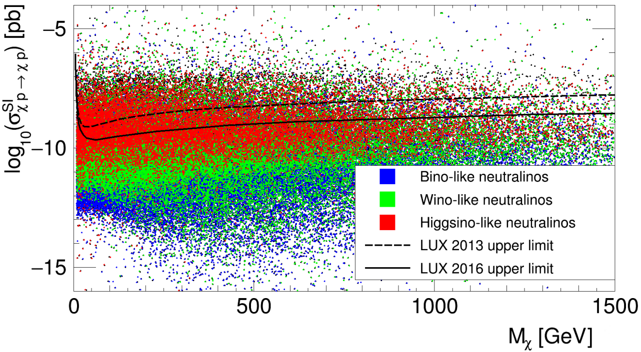
Spin-independant cross-section constraints



[Akerib et al.] arXiv:1608.07648

- For the range of masses considered, LUX experiment sets the strongest limit

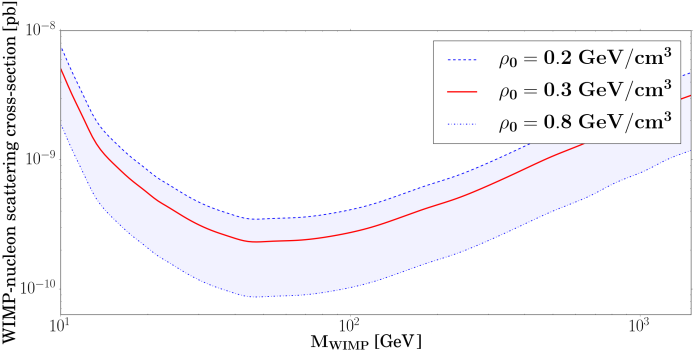
LUX



- We exclude 49% of the higgsinos, 19% of winos and 10% of binos
- That is twice the number of points formerly excluded by LUX 2013

Astrophysical uncertainties

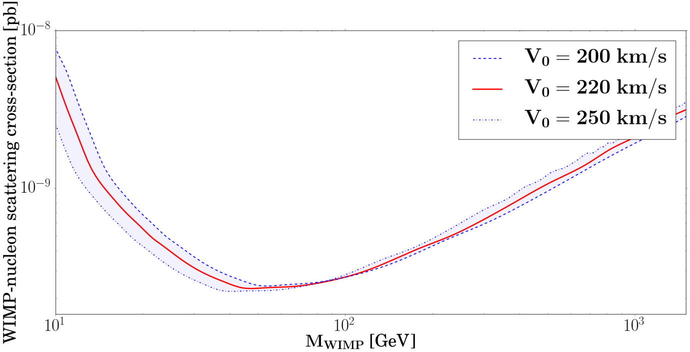
- Dark Matter local density



- The uncertainties on the local DM density affects the number of excluded higgsinos and winos : 40% of the points excluded when $\rho_\odot = 0.8$ GeV/cm^3 are not excluded when $\rho_\odot = 0.2$ GeV/cm^3

Astrophysical uncertainties

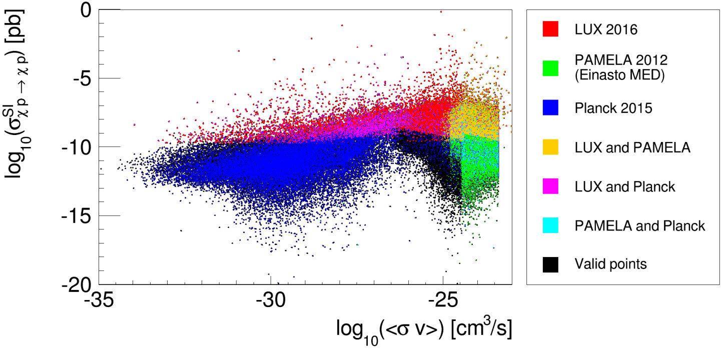
V_0 : rotation velocity of the galactic disk



- The effect of the uncertainties on V_0 are very small.

Combination of Constraints

Combination of constraints

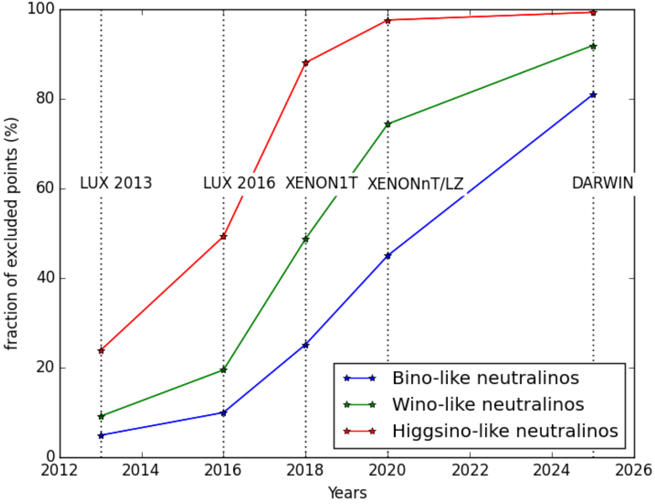


- The different types of experiments bring complementary constraints
- Still, there is an unexplored zone

Status and Prospects

- Our 8 TeV LHC analysis showed that 30% of neutralinos were excluded all over this map, independantly of the neutralino nature
- The 13 TeV analysis is in progress
- Gamma ray detection (FermiLAT, HESS), brings stronger constraints than antiprotons in certain ranges of masses
- Future experiments such as CTA (indirect detection) and DARWIN (direct detection), combined to Planck upper limit should exclude more than 99% of the points in the next 10 or 15 years, if no DM particle is discovered before then.

Prospects


LUX 2013
LUX 2016
XENON1T
XENONnT/LZ
DARWIN
fraction of excluded points (%)
Years
Bino-like neutralinos
Wino-like neutralinos
Higgsino-like neutralinos
0
20
40
60
80
100
2012
2014
2016
2018
2020
2022
2024
2026