Dark Matter constraints and uncertainties in the pMSSM

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Objectives and Method

Objectives

- Our goal is to **constrain the pMSSM parameters** using dark matter detection data and to **quantify the impact of astrophysical uncertainties**.

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

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**)
  - Higgs production cross-sections (**SusHi**)
  - Higgs branching ratios (**Hdecay**)
  - Other observables for LHC analysis (**MadGraph, PYTHIA, Delphes...**)
- Then, we compared these observables to experimental constraints

Objectives

- We focused on the type of neutralinos and range of masses that are excluded by each experiment

The lightest neutralino will be said to be :

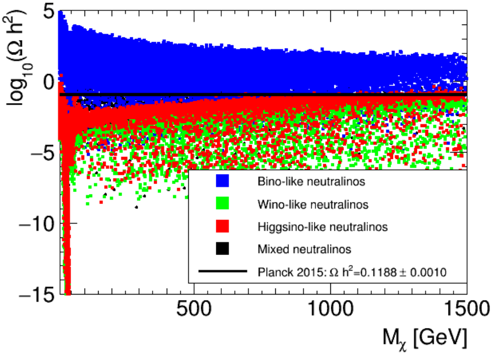
- Bino-like if $N_{11} > 0.9$
- Wino-like if $N_{12} > 0.9$
- Higgsino-like if $\sqrt{N_{13}^2 + N_{14}^2} > 0.9$
- Mixed, otherwise

N: neutralino mixing matrix

Dark Matter Relic Density

Dark Matter Relic Density

Constraints: $0.1153 < \Omega h^2 < 0.1223$, corresponding to 3.5σ of experimental and theoretical errors from Planck 2015 DM density measurements.



- Applying the upper limit only, we exclude almost 94% of the binos
- Applying both lower and upper limit, more than 97% of all our points are excluded

Relic Density

- The calculation of the relic density is subject to large cosmological uncertainties (e.g. concerning the expansion rate or the entropy content)
- 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
-
AMS-02

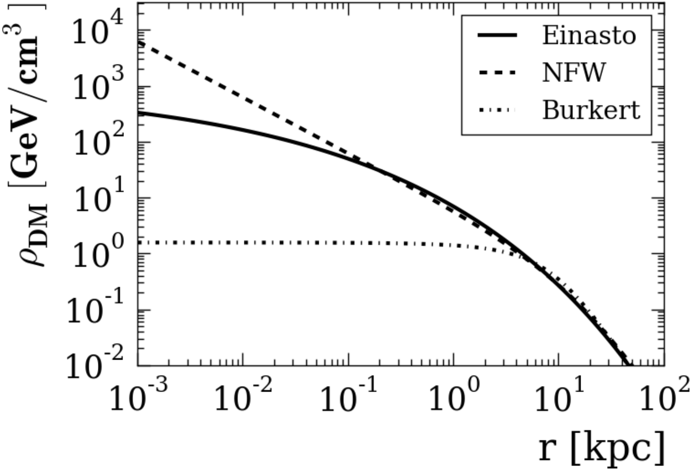
Exclusion Method

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.
- We tested the validity of the total spectrum, comparing it to AMS-02 antiproton data through a $\Delta\chi^2$ analysis.

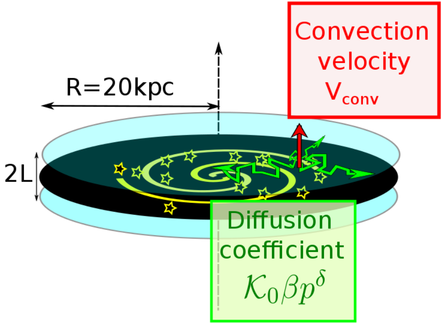
Astrophysical uncertainties

- Halo density profiles: Einasto [arXiv :0907.0018], NFW [arXiv :1608.00971] and Burkert [arXiv :1304.5127].



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

AMS-02 constraints

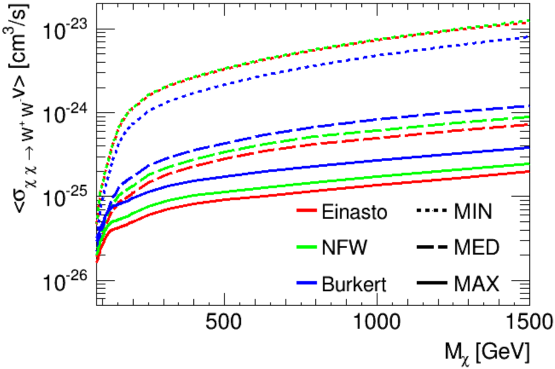
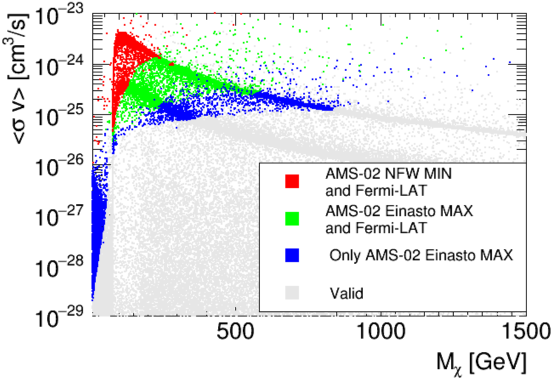


Figure: 95% CL upper limits on the thermally-averaged cross-section for DM particles annihilating into $W^+ W^-$

- The lowest and strongest limits correspond respectively to NFW MIN and Einasto MAX

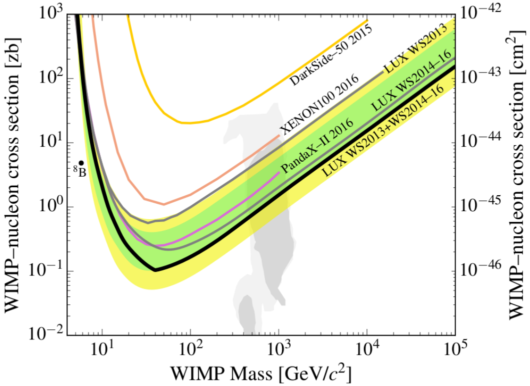
Results

- We compared the points excluded by AMS-02 antiprotons to those excluded by Fermi-LAT 19 confirmed dwarf spheroidal galaxies gamma ray fluxes [arXiv :1611.03184]



Direct Detection
LUX

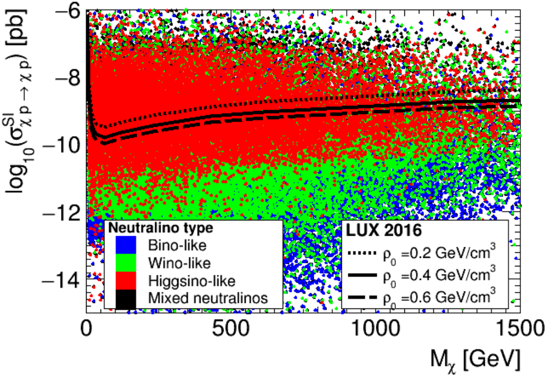
Spin-independent cross-section constraints



[Akerib et al.] arXiv:1608.07648

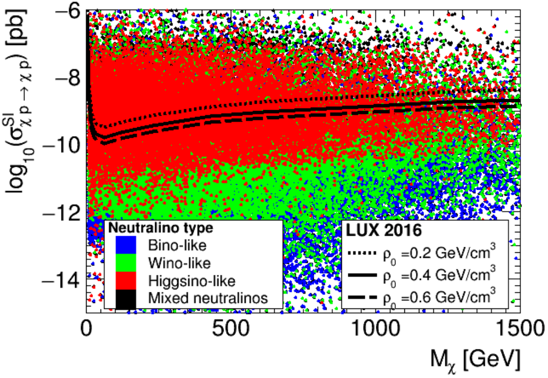
- For the range of masses considered, LUX experiment sets the strongest limit

LUX



- We exclude 55% of the higgsinos, 22% of winos and 11% of binos with a local DM density $\rho_\odot = 0.4$ GeV/cm^3
- That is twice the number of points formerly excluded by LUX 2013

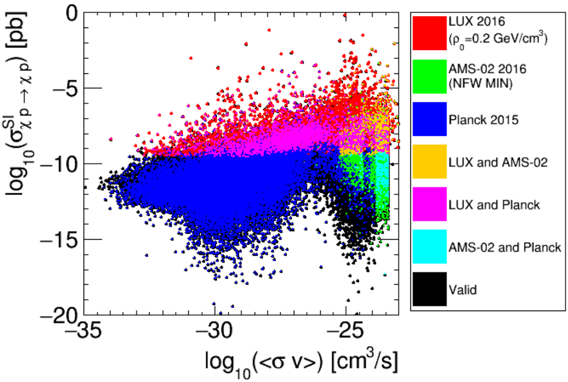
LUX



- The uncertainties coming from the local DM density are non-negligible : between the condition $\rho_\odot = 0.2$ GeV/cm^3 and $\rho_\odot = 0.6$ GeV/cm^3, the fraction of excluded higgsino-like neutralinos increases from 41% to 62%.

Combination of Constraints

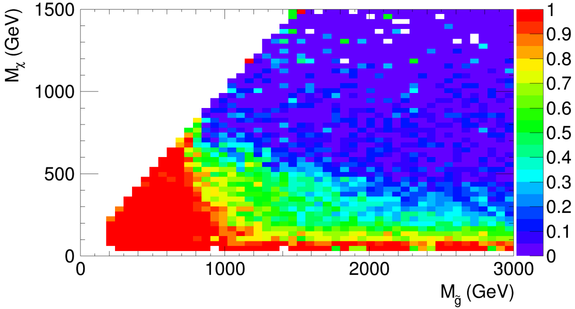
Combination of constraints



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

Particle physics contribution

- Our 8 TeV LHC analysis showed that 30% of the pMSSM point in our sample are excluded, quite independently of the neutralino nature



- CMS 13TeV limit on heavy Higgs decay $(\sigma(gg\phi) + \sigma(bb\phi)).BR(\phi \to \tau\tau)$ excludes also 26% of our points (preliminary)

Conclusions

	Binos	Winos	Higgsinos	**All**
Most conservative NFW MIN $\rho_\odot = 0.2$ GeV/cm^3	98%	60%	58%	**75%**
Most restrictive Einasto MAX $\rho_\odot = 0.6$ GeV/cm^3	98%	92%	76%	**91%**

Fraction of points excluded by the combination of constraints (astrophysical constraints+LHC 8TeV+Higgs 13 TeV) for the different neutralino types

Status and Prospects

- The LHC 13 TeV analysis is in progress
- New sets of propagation parameters, calculated from AMS-02 data, are expected before this summer.
  It should reduce the uncertainties in the fraction of excluded winos and higgsinos.
- Future experiments such as 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.