PAMELA and FERMI limits on the neutralino-chargino mass degeneracy

Jonathan Da Silva

Laboratoire d'Annecy-le-Vieux de Physique Théorique, France

UNIVERSITÉ DE GRENOBLE

GDR Terascale@Paris, LPNHE, France, November 6, 2012

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Outline

Motivations

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- **Indirect Detection (ID) of Dark Matter (DM), namely search for anomalous features in cosmic rays ($\gamma, \nu, \mathrm{e}^+, \bar{\mathrm{p}}$) proposed at the end of the 70's to be a powerful tool to look for DM (Gunn et al., Stecker '78, Zeldovich et al. '80, ...)**
- **"Background drawback" : ID depends on the current knowledge of astrophysical sources**
  - **Remove carefully known (modelled) background**
  - **Clear features no mimicked by astrophysical sources**
- **Several claims : e^+ excess (Adriani et al. '09, Ackermann et al. '12), feature in $\mathrm{e}^+ + \mathrm{e}^-$ spectrum (Aharonian et al. '08, Abdo et al. '09, Ackermann et al. '10), γ-ray lines (Bringmann, Weniger, Tempel, Su, Boyarsky, ... '12), ...**
- **But also a huge number of data validates the modelling of astrophysical background sources in the GeV-TeV range : absence of anomalies in the $\bar{\mathrm{p}}$ spectrum less exploited (Adriani et al., Phys. Rev. Lett. 102 (2009) 051101 and Phys. Rev. Lett. 105 (2010) 121101)**

$\Rightarrow$ Possibility to set stringent constraints on DM properties by looking at DM annihilation into $W^{\pm}$, as degeneracy in the DM sector, using FERMI-LAT AND PAMELA data

Generic bounds on DM annihilation into $W^{\pm}$

From γ-rays

In DM scenarios, $W^{\pm}$ production associated with gamma-ray emission through :

- **Decay and hadronisation of the decay products of the $W^{\pm}$**
  $\Rightarrow$ continuum spectrum of γ-rays : we use FERMI-LAT analysis of the diffuse γ-ray emission from dwarf spheroidal galaxies (Ackermann et al, Phys. Rev. Lett. 107 (2011) 241302)
- **Radiation of a photon from the internal and/or final states associated with DM annihilation into $W^{\pm}$: model dependent and we find that the modification to the spectrum is negligible**
- **DM annihilation into $\gamma\gamma$ and γZ (leading to γ-ray lines), constraints are not as powerful as diffuse γ-ray emission constraints**

From $\bar{\mathrm{p}}$

$W^{\pm}$ production leads also to abundant $\bar{\mathrm{p}}$ production (after hadronization)
$\Rightarrow$ $\bar{\mathrm{p}}$ flux produced by DM annihilation determined by :

- $\sigma_{\mathrm{DM\ DM} \to W^+W^-}$
- m_{DM}
- DM halo profile (here Einasto profile)
- $\bar{\mathrm{p}}$ propagation parameters in the galactic halo :

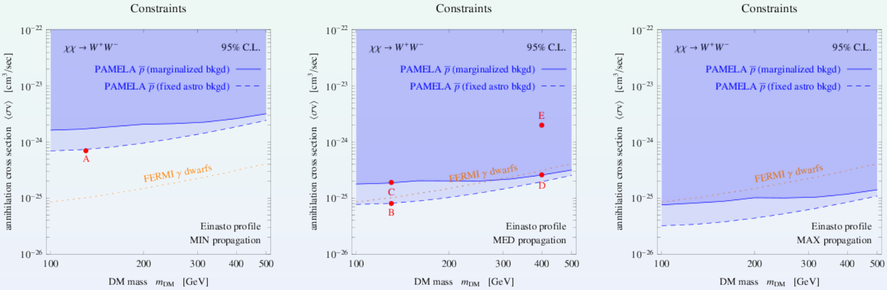
Model	δ	$\mathcal{K}_0$ [kpc^2/Myr]	V_{conv} [km/s]	L [kpc]
MIN	0.85	0.0016	13.5	1
MED	0.70	0.0112	12	4
MAX	0.46	0.0765	5	15

$\Rightarrow$ We compare the sum of the astrophysical background flux and predicted $\bar{\mathrm{p}}$ flux originating from DM with the PAMELA data, 2 methods :

- "Aggressive" procedure : fixed background (standard flux from T. Bringmann and P. Salati, Phys. Rev. D 75 (2007) 083006)
- "Conservative" procedure : marginalized background, namely standard description of the background spectrum multiplied by $A\,(T/T_0)^p$ with :
  $T = \bar{\mathrm{p}}$ kinetic energy
  $T_0 = 30$ GeV : pivot energy
  normalisation of the background spectrum : $0.6 < A < 1.4$
  spectral index : $-0.1 < p < +0.1$

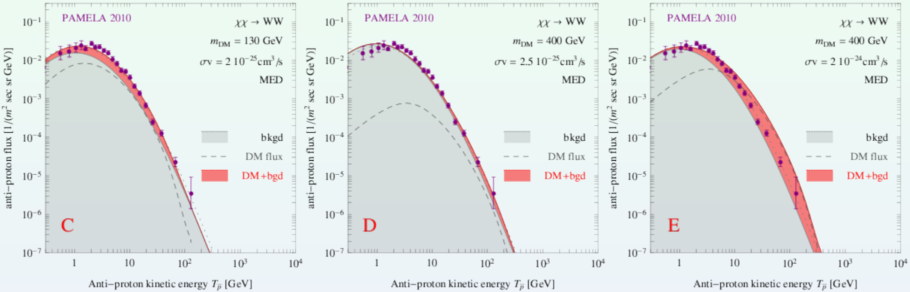
From $\bar{\text{p}}$

$$\Downarrow$$



- $(\text{'MIN'}/\text{'MAX'})_{\text{limits on } <\sigma v>} > 10$ (smaller $\bar{\text{p}}$ yield for 'MIN' propagation set)
- Variable astrophysical background $\Rightarrow$ more space for DM injection of $\bar{\text{p}}$ $\Rightarrow$ weaker limits

From $\bar{\mathrm{p}}$

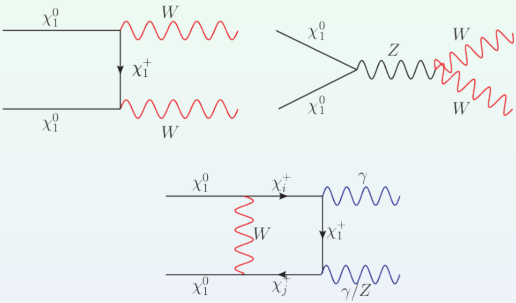


- **"Conservative" procedure approximately independent of m_{DM} : $\bar{p}$ flux from heavy DM negligible at low energy, where PAMELA set very small error bars**
- **In what follows we consider diffuse γ-ray constraints from dwarf spheroidal galaxies and $\bar{p}$ constraints using 'MED' propagation parameters + marginalized background**

Application to the pMSSM

A "simplified" version

Aim : dominant neutralino DM annihilation channels into gauge bosons



$\Rightarrow$ All sfermion masses are set to 2 TeV (except for the third generation of squarks, to get $m_h \sim 125$ GeV), CP-odd Higgs at 1 TeV + light chargino/neutralino ($m_{\chi_1^0} < 500$ GeV) such that the mass splitting $\Delta m = m_{\chi_1^\pm} - m_{\chi_1^0}$ is small

$\Rightarrow$ How powerful are the $\bar{p}$ limits on excluding parts of pMSSM parameter space and Δm values ?

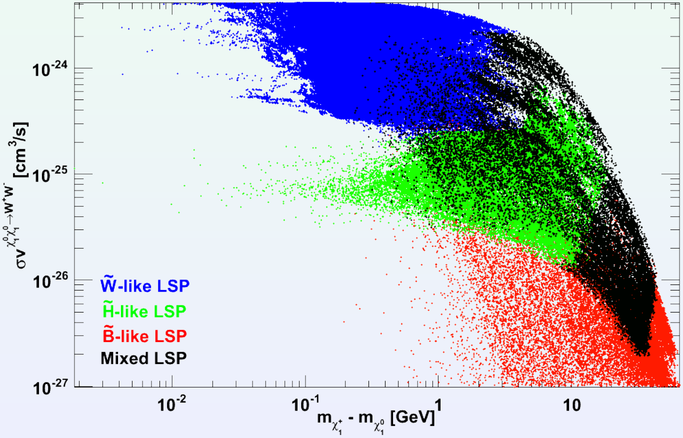
Characteristics of the scan

Free parameter	Range	Nuisance parameter (N)	Experimental value
M_1	[10, 500] GeV	m_u/m_d	0.553 ± 0.043
M_2	[100, 1000] GeV	m_s/m_d	18.9 ± 0.8
μ	[-2000, 2000] GeV	$\sigma_{\pi N}$	44 ± 5 MeV
$\tan\beta$	[2, 75]	σ_s	21 ± 7 MeV
$M_{\tilde{Q}_3}, M_{\tilde{u}_3}$	[100, 3000] GeV	m_t	173.2 ± 0.9 GeV
A_t	[-8000, 8000] GeV	range of N	[N_{exp} -3σ, N_{exp} +3σ]

Constraint	Value/Range	Tolerance	Likelihood
m_h (GeV)	[123.9, 127.9]	0.1	exp. decaying outside range
$\Omega_{\chi_1^0} h^2$	[0.001123, 0.1123]	0.0035	exp. decaying outside range
$\mathcal{B}(b \to X_s^* \gamma) \times 10^4$	3.55	0.34	gaussian
$\sigma^{SI}_{\chi_1^0 \mathrm{Xe}}$ (pb) from XENON100 (2012)	(m_{DM}, σ_N) plane	$\sigma_N(m_{\mathrm{DM}})/100$	exp. decaying when $\gtrsim$ upper bound
$\sigma v_{\chi_1^0\chi_1^0 \to W^+W^-}$ $(10^{-27}\ \mathrm{cm}^3/\mathrm{s})$	1	0.01	exp. decaying when $\lesssim$ lower bound
$\Delta a_\mu \times 10^{10}$	28.70	0.287	exp. decaying when $\gtrsim$ upper bound
$\mathcal{B}(B_s \to \mu^+\mu^-) \times 10^9$	4.5	0.045	exp. decaying when $\gtrsim$ upper bound
$\Delta\rho$	0.002	0.0001	exp. decaying when $\gtrsim$ upper bound
$R_{B^+ \to \tau^+ \bar{\nu}_\tau}(\frac{\mathrm{pMSSM}}{\mathrm{SM}})$	2.219	2.219×10^{-2}	exp. decaying when $\gtrsim$ upper bound
$Z \to \chi_1^0\chi_1^0$ (MeV)	1.7	0.3	exp. decaying when $\gtrsim$ upper bound
$\sigma_{e^+e^- \to \chi_1^0\chi_{2,3}^0} \times$ $\mathcal{B}(\chi_{2,3}^0 \to Z\chi_1^0)$ (pb)	1	0.01	exp. decaying when $\gtrsim$ upper bound

Results

- **Higgsino and mainly wino DM probed**



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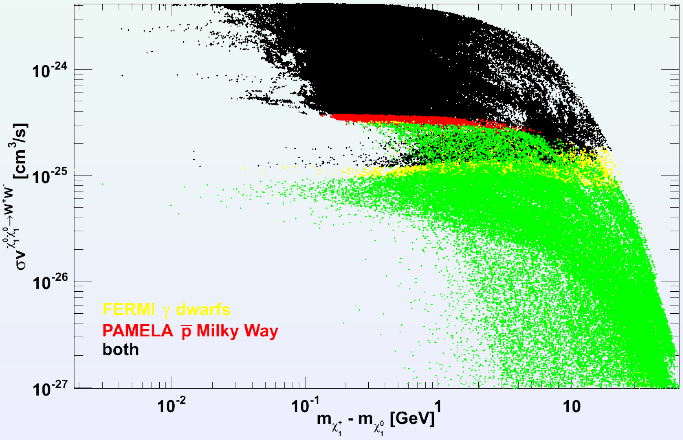
- ID constrains scenarios with $\Delta m \lesssim 20$ GeV : if $m_{\chi_1^0} < 500$ GeV and $\Delta m < 0.2$ GeV <u>wino DM ruled out</u>



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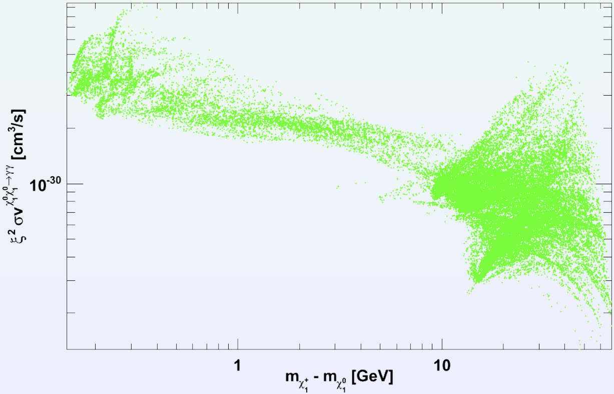
- **Caveat : DM relic density being regenerated at 100 % (but bad relic for wino without regeneration mechanism)**



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  wino DM ruled out
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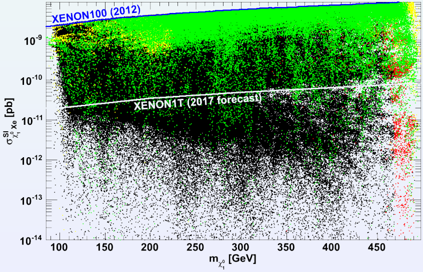
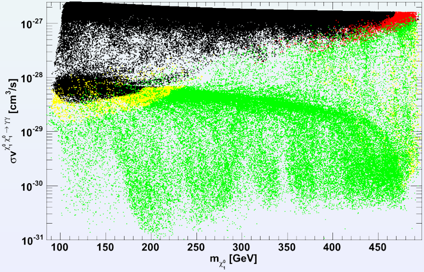
- **No explanation of the "130 GeV line" in this simplified pMSSM**
- **ID constraints really competitive with direct detection experiments**





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- $\bar{\rm p}$ constraints appear to be as powerful as γ-ray bounds
- Their applications to the studied version of the pMSSM show that they can exclude pure wino or wino-like neutralinos if they are lighter than 450 GeV, assuming regeneration mechanism
- They surpasse direct detection bounds and even the projected XENON1T limit
- If the 'anomalous' Higgs signal strength into $\gamma\gamma$ is confirmed, the pMSSM would be difficult to reconcile with the data but the principles of this analysis would remain valid and could still be used to constrain small mass degeneracies between the DM and another (e.g. t$-$channel exchange) intermediate particle
- These regions of the parameter space are difficult to probe directly at the LHC $\Rightarrow$ Fermi-LAT and Pamela data constitute modern tools to explore the supersymmetric parameter space and even beat LHC and Direct Detection searches on their own territory

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THANKS !

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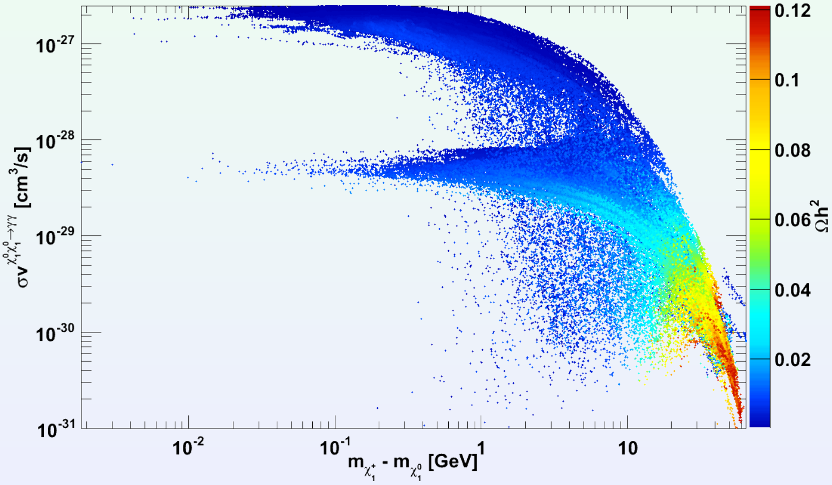
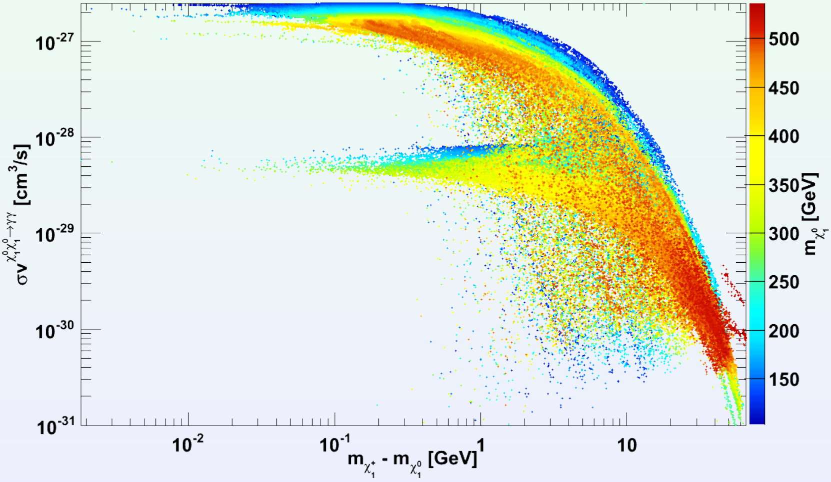


10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
$\sigma v^{\chi_1^0\chi_1^0\to\gamma\gamma}$ [cm^3/s]
10^{-2}
10^{-1}
1
10
$m_{\chi_1^+} - m_{\chi_1^0}$ [GeV]
0.12
0.1
0.08
0.06
0.04
0.02
Ωh^2

Results



10^{-27}
10^{-28}
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$\sigma v^{\chi_1^0 \chi_1^0 \to \gamma\gamma}$ [cm^3/s]
10^{-2}
10^{-1}
1
10
$m_{\chi_1^+} - m_{\chi_1^0}$ [GeV]
500
450
400
350
300
250
200
150
$m_{\chi_1^0}$ [GeV]