Supersymmetric models in light of colliders and astroparticles constraints

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Based on :

D. A. Vasquez, G. Belanger, C. Boehm, JDS, P. Richardson and C. Wymant, Phys. Rev. D86 (2012) 035023, arXiv:1203.3446,

C. Bœhm, JDS, A. Mazumdar and E. Pukartas, JCAP submitted (2012), arXiv:1205.2815,

G. Bélanger, C. Boehm, M. Cirelli, JDS and A. Pukhov, JCAP submitted (2012), arXiv:1208.5009

Outline



Collider searches for SUSY particles

- Context
- Weaken bounds in the NMSSM
- Results

Supersymmetric inflaton

- Models chosen
- Constraints and method
- Results

DM Indirect Detection limits on the neutralino-chargino mass degeneracy

- ID "state of the art"
- Generic bounds on DM annihilation into W[±]
- Application to the pMSSM

Conclusions

Motivations

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Inflation motivations

- Flatness problem (fine-tuning problem on Ω_k)
- Horizon problem
- Monopole problem (topological defect not seen)



 \Rightarrow Cosmic inflation (fast expansion phase in the early universe) embedded in Grand Unified Theories (GUT)

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Constraints on SUSY and DM

LAPTh, October 5, 2012

Inflation motivations

Dark matter (DM) motivations

- Galaxy scale : rotation curves of galaxies
- Galaxy clusters scale : example of the bullet cluster
- Cosmological scale (CMB), large scale structures, …



K. G. Begeman, A. H. Broeils and R. H. Sanders, 1991, MNRAS, 249, 523 A direct empirical proof of the existence of dark matter, D. Clowe et al., Astrophys. J. 648 L109-L113, 2006

 $\Rightarrow \Omega_{_{D}}h^2 = 0.0226\pm0.0005$ and $\Omega_{_{DM}}h^2 = 0.1123\pm0.0035$ DM has to be stable and weakly charged under the standard model gauge group

- Inflation motivations
- Dark matter (DM) motivations
- Supersymmetry (SUSY) motivations
 - Hierarchy problem on Higgs boson mass
 - ► Unification at GUT scale ⇒ cosmic inflation embedded in supersymmetric models
 - LSP/DM (supersymmetry breaking, R-Parity)



CMS searches on the Higgs boson

Gauge coupling unification

The lightest supersymmetric particle (LSP) is stable, at TeV scale, and can be weakly charged under the SM gauge group

 \Rightarrow DM candidates in supersymmetric models

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Constraints on SUSY and DM

Collider searches for SUSY particles

1 Motivations



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Context

Searches for exotic particles are now reaching a high level of exclusion that allow to reject a wide class of models, but limits obtained assuming simplified models of New Physics

		ATLAS SUSY Searches* - 95% CL Lower Limits (Status: SUSY 2012)			
90	MSUGRA/CMSSM : 0 lep + j's + E _{7,res}	1-53 fb ⁽¹⁾ , 8 TeV (ATLAS-CONF-2012-109) 1, 6 TeV q = g mass			
90	MSUGRA/CMSSM : 1 lep + j's + E _{7,res}	1.24 TeV (41.00 - 5.8) (b)			
910	Pheno model : 0 lep + j's + E _{7,res}	L+5.5 fb ² , 8 TeV (ATLAS-CONF-2012-109) 1.18 TeV ĝ mass (mĝ) ≤ 2 TeV, ligtt g ² J = (1.50 + 0.50) fb			
Se	Pheno model : 0 lep + j's + E _{y mini}	1.38 TeV (ATLAS-CONF-2012-109) 1.38 TeV (ATLAS-CONF-2012-109) (S = 7, 8 TeV			
hθ	Gluino med. $\tilde{\chi}^{\pm}(\tilde{g} \rightarrow q \bar{q} \tilde{\chi}^{\pm})$: 1 lep + j's + $E_{\chi \rightarrow q \bar{q}}$	1=47 m ² , 7 TeV [ATLAS-CONF-2012-041] 300 GeV g MASS (m(g) < 200 GeV, m(g)) = $\frac{1}{2}$ (m(g)) (*m(g))			
S1	GMSB : 2 lep (OS) + j's + $E_{T,rm}$	1.24 TeV [Pretiminary] 1.24 TeV [g mass (tanple < 15) AILAS			
100	GMSB : 1-2 τ + 0-1 lep + j's + E	1.20 TeV [37.5%, 7 TeV [ATLAS-CONF-2012-112] 1.20 TeV [37.0388 (str(8 > 20) Pretiminary			
	$GGM:\gamma\gamma + E_{T,miss}$	1.07 TeV [ATLAS-CONF-2012-072] 1.07 TeV [G MBSS (m(z)) > 50 GeV)			
	g→bbx, (virtual b); 0 lep + 1/2 b-j's + E _{x miss}	L=2.1 fb ⁻¹ , 7 TeV (1203.6193) 100 GeV g M355 (m(\chi_1^2) < 300 GeV)			
92.74	g→bby, (yirtual b): 0 lep + 3 b-j's + E _{1 min}	1.02 TeV (1207.4646) 1.02 TeV g mass (m(\chi^2) < 400 GeV)			
216	$\tilde{g} \rightarrow p \tilde{p} \chi_{\mu}$ (real b) : 0 lep + 3 b-j's + $E_{T min}$	1.00 TeV [0.07.4686] 1.00 TeV [0.0855 (m[2]) = 80 GeV)			
공영		L=2.1 fb ⁺ , 7 TeV [1203.6183] 710 GeV g mass (m(\chi)) < 150 GeV)			
e E		L=5.8 fb ⁴ , 8 TeV (ATLAS-CONF-2012-105) 850 GeV g mass (m(z ⁺ ₁) < 300 GeV)			
66	$\tilde{q} \rightarrow t \tilde{t} \chi^{2}$ (virtual \tilde{t}): 3 lep + j's + $E_{\tau min}$	L=4.7 m ² , 7 TeV [ATLAS-CONF-2012-108] 740 GeV g mass (arry m(z)) + m(g)			
hei i	$\tilde{g} \rightarrow t \tilde{t} \chi$ (virtual \tilde{t}): 0 lep + multi-j's + $E_{T min}$	1.00 TeV (ATLAS-CONF-2012-103) 1.00 TeV (300 GeV)			
(9.6)	$\tilde{q} \rightarrow t \tilde{t} \chi$ (virtual \tilde{t}) : 0 lep + 3 b-j's + $E_{T,max}$	L=4.7 fb ⁺ , 7 feV [1207.4666] 940 GeV g mass (m(z ⁺ ₀) < 50 GeV)			
	$\tilde{q} \rightarrow t \tilde{t} \chi^0$ (real \tilde{t}) : 0 lep + 3 b-j's + E_{T} mean	1=4.7 m ² , 7 TeV (1207,4486) 820 GeV g THASS (m(g) = 60 GeV)			
	bb, b, →by : 0 lep + 2-b-jets + E _{T min}	L=4.7 fb ⁺ , 7 TeV [ATLAS-CONF-2012-106] 480 GeV D TH3SS (m($\chi^2_{-})$ < 150 GeV)			
aks ou	$bb, b \rightarrow t \chi^{-}$: 3 lep + ['s + $E_{T \text{ max}}$	1=4.7 (5 ¹ , 7 TeV [ATLAS-CONF-2012-108] 380 GeV g mass (m(x ²) = 2 m(x ²))			
8.6	ft (very light), t→b [*] _x : 2 lep + E [*] _x and	1 mass (m(z) + 45 GeV)			
2.5	tt (light), $t \rightarrow b\chi^{\pm}$: 1/2 lep + b-jet + $E_{\chi \text{ max}}$	1 mass (m)() = 45 GeV)			
. pid	$\tilde{t}\tilde{t}$ (heavy), $\tilde{t} \rightarrow t\chi^{\circ}$: 0 lep + b-jet + $E_{T,min}$	L=4.7 fb ⁺ , 7 TeV [1208.5447] 380-465 GeV 1 mass (m(χ ⁺) = 0)			
6.0	If (heavy), I→tχ : 1 lep + b-jet + E _{T max}	L=4.7 fb ⁺ , 7 TeV [CONF-2012-073] 230-440 GeV T mass (回反) = 0)			
66	If (heavy), I→tχ [*] : 2 lep + b-jet + E _{T max}	1+4.7 fb ² , 7 TeV [CONF-2012-071] 298-305 GeV [mass (m(\chi_{1}^{2}) = 0)			
	tt (GMSB) : Z(→II) + b-jet + E	1mass (115 <mg (115<mg="" 1204.8736)="" 1<230="" 1mass="" 310="" gev="" gev)<="" th=""></mg>			
	$ _{1}, \rightarrow \chi : 2 \text{ lep } + E_{\chi \text{ max}}$	L=4.7 fb ² , 7 TeV [CONF-2012-076] 33-180 GeV TTASS (m(χ^2) = 0)			
N. C	$\vec{\chi}, \vec{\chi}, \vec{\chi}, \rightarrow iv(\vec{N}) \rightarrow iv\vec{\chi}$: 2 lep + $E_{\chi max}$	L=4.7 fb ² , 7 TeV [CONF-2012.076] 120-330 GeV $\vec{\chi}_{1}^{2}$ [m355 $(m(\vec{\chi}_{1}^{2}) = 0, m(\vec{\chi}_{2}^{2}) + m(\vec{\chi}_{1}^{2}))$			
- 0	$\tilde{\chi}_{\chi}^{2} \rightarrow 3l(lvv)+v+2\tilde{\chi}_{\chi}^{2}$: 3 lep + $E_{\chi max}$	1-4.7 fb ⁽¹ , 7 TeV [CONF-2012-077] 60-500 GeV. $\vec{\chi}_1^+$ TTASS $(\pi(\vec{\chi}_1^+) = \pi(\vec{\chi}_1^+), \pi(\vec{\chi}_1^+) = 0, \pi(\vec{\nu}_1)$ as above)			
72	AMSB (direct x, pair prod.) : long-lived x,	1 44.7 (5), 7 TeV [ATLAS-CONF-2012-111] 210 GeV X mass (1 4 ((x)) 10 m)			
ive los	Stable g R-hadrons : Full detector	1=4.7 fb ⁺ , 7 TeV (ATLAS-CONF-2012-075) 985 GeV ĝ mass			
101	Stable TR-hadrons : Full cetector	1#4.7 fb ² , 7 TeV [ATLAS-CONF-2012-075] 683 GeV 1 mass			
0.0	Metastable ĝ R-hadrons : Pixel det. only	1=4.7 to ¹ , 7 TeV [ATLAS-CONF-2012-075] 910 GeV g mass (rg) > 10 m)			
	GMSB : stable 7	1=4.7 fb ⁻⁰ , 7 TeV [ATLAS-CONF-2012-075] 310 GeV ₹ MASS (5 < un\$ < 20)			
	RPV : high-mass eµ	1.32 TeV (1102.0000) 1.32 TeV (V mass (k ₁₀ =0.10, k ₁₀ =0.05)			
2	Bilinear RPV : 1 lep + j's + E _{7,min}	1.41.0 m ² , 7 TeV (1109.6606) 740 GeV q = g mass (ct _{upe} < 15 mm)			
2	BC1 RPV : 4 lep + E _{7,rep}	1-2115 ¹⁰ , 7 TeV [ATLAS-CONF-2012-035] 1.77 TeV ĝ mass			
	RPV $\tilde{\chi}_{i}^{0} \rightarrow qq\mu$: μ + heavy displaced vertex	L=4.4 fs ² , 7 TeV [ATLAS-CONF-2012-113] 700 GeV Q MASS (3.0×10 ⁴ < 1 _{5×1} < 1.5×10 ³ 1 mm < ct < 1 m g decoupled)			
2	Hypercolour scalar gluons : 4 jets, m _g - m _g	1-4.6 50, 7 TeV (ATLAS-CONF-2012-110) 100-287 GeV SQLUON MASS (incl. limit from 1110-2803)			
40	Spin dep. WIMP interaction : monojet + E _{7,min}	1+4.7 fb ⁺ , 7 TeV [ATLAS-CONF-2012-04] 709 GeV M ⁺ SCBIE (m ₁ < 100 GeV, vector D5, Dirac g)			
° s	pin indep. WIMP interaction : monojet + E _{Y,rea}	1=47.55 ¹ , 7 TeV [ATLAS-CONF-2012-684] 548 GeV M ⁺ SCB(C (m ₂ < 100 GeV, lenner 0.9, Dirtic \chi)			
		1 I I I I I I I I I I I I I I I I I I I			
		40-1 4 40			

*Only a selection of the available mass limits on new states or phenomena shown

Mass scale [TeV]

Weaken bounds in the NMSSM

Example of the exclusion limit coming from the ATLAS 1.04 fb⁻¹ search for squarks and gluinos via jets and missing E_T

In general exclude squarks lighter than 0.6 - 1 TeV and gluinos below 0.5 TeV in the constrained MSSM via $\tilde{q} \rightarrow q\chi_1^0$ and $\tilde{g} \rightarrow q\bar{q}\chi_1^0$ decays What about the NMSSM?

- $W_{\text{NMSSM}} = W_{\text{MSSM}}(\mu = 0) + \lambda SH_u H_d + \frac{1}{3}\kappa S^3$
- $\mathcal{L}_{\text{Higgs soft}}^{\text{NMSSM}} = m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 + m_S^2 |S|^2 + (\lambda A_\lambda SH_u H_d + \frac{1}{3}\kappa A_\kappa S^3 + h.c.)$ \Rightarrow less fine tuned $m_{h_1} \sim 125 \text{ GeV}$
- 5 Neutralinos χ^0_i in the basis $(\tilde{B},\tilde{W}^3,\tilde{H}^0_d,\tilde{H}^0_u,\tilde{S})$
- Using results of a previous work (D. Albornoz Vasquez et al., 1107.1614, 1201.6150) with constraints on DM (relic density upper bound, indirect and direct detection constraints), on *B* and Higgs physics to define the relevant NMSSM parameter space
- Applying SUSY searches@LHC with ATLAS's 1.04 fb⁻¹ 0-lepton jets + missing E_T search using Herwig++ 2.5.1 and RIVET 1.5.2 ⇒ Are ATLAS limits so constraining ?

- Reduced acceptance into Jets + missing E_T search channels and more jets for singlino LSP
- $\tilde{\mathbf{q}} \rightarrow \mathbf{q} + (\chi_2^0 \rightarrow \chi_1^0 + (\mathbf{f}\bar{\mathbf{f}} \text{or } \mathbf{A}_1 \text{or } \mathbf{h}_1))$



- Reduced acceptance into Jets + missing E_T search channels and more jets for singlino LSP
- $\tilde{q} \rightarrow q + (\chi_2^0 \rightarrow \chi_1^0 + (f\bar{f}or A_1or h_1))$
- Usual exclusion (B-like LSP) :



- Reduced acceptance into Jets + missing E_T search channels and more jets for singlino LSP
- $\tilde{q} \rightarrow q + (\chi_2^0 \rightarrow \chi_1^0 + (f\bar{f}or A_1or h_1))$
- 300 GeV squarks allowed when (S-like LSP) :



Supersymmetric inflaton

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Models chosen

NUHM2

- Supersymmetric model with gravity-mediated supersymmetry breaking based on the MSSM
- Most popular : mSUGRA/CMSSM, universal scalar masses is assumed, free parameters :

 $\mathbf{m}_{0}, \mathbf{m}_{1/2}, \mathbf{A}_{0}, \tan \beta \text{ and } \operatorname{sign}(\mu)$

- Drawbacks : $m_h \sim 125 \text{ GeV}$ not easy, LSP mostly bino
- ▶ We considered a non-universal scalar masses model, with m²₀ ≠ m²_{Hu} ≠ m²_{Hu} (see H. Baer et al [hep-ph/0504001], J. R. Ellis et al [hep-ph/0210205])
- \blacktriangleright \Rightarrow Easier to reach $m_h=125$ GeV, increase DM annihilation rates with higgsino LSP
- NUHM2 free parameter :

m_0, m_{1/2}, A_0, $\tan\beta$, μ and $M_{\rm A}$

Models chosen

- NUHM2
- LLẽ and ũdd
 - Inflaton, scalar field whose flat direction potential (with a non-negligible slope) leads to the end of the inflation phase
 - Charged under the visible sector of the particle physics model considered, i.e. NUHM2
 - supersymmetric scalar potential :

$$V = \sum_{i} |F_{i}|^{2} + \frac{1}{2} \sum_{a} g_{a}^{2} D^{a} D^{a},$$

$$F_{i} \equiv \frac{\partial W}{\partial \phi_{i}}, \quad D^{a} = \phi^{\dagger} T^{a} \phi,$$

$$\Rightarrow \widetilde{LLe} \text{ and } \widetilde{udd} \text{ D-terms can be such candidates}$$
Lifted by higher order superpotential terms $W \supset \frac{\lambda}{6} \frac{\Phi^{6}}{M_{P}^{3}}, \quad \Phi \text{ scalar component : } V(\phi) = \frac{1}{2} m_{\phi}^{2} \phi^{2} - A \frac{\lambda \phi^{6}}{6 M_{P}^{3}} + \lambda^{2} \frac{\phi^{10}}{M_{P}^{6}}$

$$\phi = \frac{\widetilde{u} + \widetilde{d} + \widetilde{d}}{\sqrt{3}}, \quad \phi = \frac{\widetilde{L} + \widetilde{L} + \widetilde{e}}{\sqrt{3}}$$

$$\phi^{4}_{inflation} \simeq \frac{m_{\phi} M_{P}^{3}}{\lambda \sqrt{10}}, \quad V''(\phi_{inflation}) = 0$$
(see R. Allahverdi et al, [hep-ph/0610134], [hep-ph/0605035])

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Constraints and method

Constraints imposed on a scan made using Markov Chain Monte Carlo method :

- On inflation, explain the observed temperature anisotropy in the CMB with :
 - The amplitude of density perturbations $\delta_{\rm H} = \frac{8}{\sqrt{5}\pi} \frac{m_{\phi} M_{\rm P}}{\phi_0^2} \frac{1}{\Delta^2} \sin^2[\mathcal{N}_{\rm COBE} \sqrt{\Delta^2}]$,

$$\Delta^2 \equiv 900 lpha^2 \mathcal{N}_{\mathsf{COBE}}^{-2} \left(rac{\mathsf{M}_{\mathrm{P}}}{\phi_0}
ight)^4$$
 , $\mathcal{N}_{\mathsf{COBE}} \sim 50$

- The scalar spectral index n_s of the corresponding power spectrum $n_s = 1 4\sqrt{\Delta^2} \cot[\mathcal{N}_{COBE}\sqrt{\Delta^2}],$
- On the Cold DM candidate, $\chi_1^0: \Omega_{\rm WIMP}h^2 = 0.1123 \pm 0.0035$ (WMAP7), DM-nucleon scattering cross section bounds (XENON100)
- On NUHM2 model in general :
 - ▶ $m_h \in [115.5, 127]$ GeV
 - B-physics : BR(b \rightarrow s γ), BR(B_s $\rightarrow \mu^+\mu^-)$ and BR(B⁺ $\rightarrow \tau^+ \bar{\nu}_{\tau})$
 - ► Electroweak observables : $(g_{\mu} 2)$, $\Delta \rho$, Z → invisible, $\sigma_{e^+e^- \rightarrow \chi_1^0 \chi_{2,3}^0} \times Br(\chi_{2,3}^0 \rightarrow Z \chi_1^0)$

In our study, SUSY contributions are not large so that both $(g_\mu-2)$ and $BR(B^+\to\tau^+\bar\nu_\tau)$ are well below the measured value

The other electroweak observables apply mainly for light LSP, not the case in this study

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Constraints on SUSY and DM

- Hard to accommodate the correct LSP relic density with Higgs boson mass constraint for bino-like LSP (whose mass is close to M_A/2)
- Get mainly higgsino-like LSP, degeneracy between $\chi_{1,2}^0$ and χ_1^\pm



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- NUHM2 scenarios within LHCb and XENON1T experiments sensitivity



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- NUHM2 scenarios within LHCb and XENON1T experiments sensitivity
- Keys on inflaton mass if we discover lightest stop/stau at LHC



degeneracy

DM Indirect Detection limits on the neutralino-chargino mass degeneracy

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ID "state of the art"

- Indirect Detection (ID) of DM, namely search for anomalous features in cosmic rays $(\gamma, \nu, e^+, \bar{p})$ 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 $e^+ + e^-$ 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 p̄ 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[±], as degeneracy in the DM sector (difficult at the LHC for instance), usingFERMI-LAT <u>AND</u> PAMELA data

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Constraints on SUSY and DM

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

- From γ-rays : FERMI-LAT analysis of the diffuse γ-ray emission from dwarf spheroidal galaxies (Ackermann et al, Phys. Rev. Lett. 107 (2011) 241302)
- From $\bar{\mathbf{p}}$: derived bounds from PAMELA antiprotons data using an "aggressive" and a "conservative" procedure (see backup)



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 MCMC scan

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

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Constraints on SUSY and DM

- Higgsino and mainly wino DM probed
- $\bullet~$ ID constrains scenarios with $\Delta m \lesssim 20$ GeV, DM relic density being regenerated at 100%
- If $m_{\surd 0} < 500~GeV$ and $\Delta m < 0.2~GeV$ wino DM ruled out



- Higgsino and mainly wino DM probed
- $\bullet~$ ID constrains scenarios with $\Delta m \lesssim 20$ GeV, DM relic density being regenerated at 100%
- No explanation of the "130 GeV line" in this simplified pMSSM
- ID constraints really competitive with direct detection experiments



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- With the discovery of a new boson at the LHC, whose characteristics seem to match those of the Standard Model Higgs boson, the powerful limits imposed on exotic particles properties by colliders searches, the impressive sensitivity reached by DM direct detection experiments, the launch of new experiments aimed also on cosmology or DM ID constraints as PLANCK and AMS-02 satellites, etc., extensions of the SM and especially SUSY, which includes DM candidates, are now well probed
- Caveat on what assumptions the experimentalists make on the models (simplified New Physics models, astrophysical models, ...), and on uncertainties (astrophysical sources, non-perturbative QCD, ...)

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- With the discovery of a new boson at the LHC, whose characteristics seem to match those of the Standard Model Higgs boson, the powerful limits imposed on exotic particles properties by colliders searches, the impressive sensitivity reached by DM direct detection experiments, the launch of new experiments aimed also on cosmology or DM ID constraints as PLANCK and AMS-02 satellites, etc., extensions of the SM and especially SUSY, which includes DM candidates, are now well probed
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Thanks for your attention !

MORE SLIDES !!!!

• Scanning the NUHM2 parameter space : Markov Chain Monte Carlo method

Constraint	Value/Range	Tolerance	Likelihood	
m _h (GeV)	[115.5, 127]	1	$\mathcal{L}_1(m_h, 115.5, 127, 1)$	
$Ω_{\sqrt{0}} h^2$	[0.1088, 0.1158]	0.0035	$\mathcal{L}_1(\Omega_{\sqrt{0}} h^2, 0.1088, 0.1158, 0.0035)$	
Relaxing constraint on $\Omega_{\chi_1^0} h^2$	[0.01123, 0.1123]	0.0035	$\mathcal{L}_1(\Omega_{\chi_1^0}^{h^2}h^2, 0.01123, 0.1123, 0.0035)$	
${\sf BR}({\sf b} o {\sf s}\gamma) imes 10^4$	3.55	exp: 0.24, 0.09	$\mathcal{L}_2(10^4 BR(b o s\gamma), 3.55,$	
		th : 0.23	$\sqrt{0.24^2 + 0.09^2 + 0.23^2})$	
$({f g}_\mu-2) imes 10^{10}$	28.7	8	$\mathcal{L}_{3}(10^{10}(extbf{g}_{\mu}- extbf{2}), 28.7, 8)$	
$BR(B_{s} o \mu^+ \mu^-) imes 10^9$	4.5	0.045	$\mathcal{L}_{3}(10^{9} \mathrm{BR}(\mathrm{B_{s}} \to \mu^{+}\mu^{-}), 4.5, 0.045)$	
$\Delta \rho$	0.002	0.0001	L ₃ (Δρ, 0.002, 0.0001)	
$R_{B^+ \to \tau^+ \bar{\nu}_{\tau}}(\frac{NUHM2}{SM})$	2.219	0.5	$\mathcal{L}_{3}(R_{B^{+} ightarrow au^{+}ar{ u}_{ au}},2.219,0.5)$	
$Z o \chi^{m{0}}_1 \chi^{m{0}}_1$ (MeV)	1.7	0.3	$\mathcal{L}_{3}(Z ightarrow \chi_{1}^{0}\chi_{1}^{0}, 1.7, 0.3)$	
$\sigma_{\mathbf{e}^+\mathbf{e}^- \to \chi_1^0 \chi_{2,3}^0}$	1	0.01	$\mathcal{L}_{3}(\sigma_{e^{+}e^{-} \rightarrow \chi_{1}^{0} \chi_{2,3}^{0}})$	
$ imes Br(\chi^{m 0}_{2,3} o Z\chi^{m 0}_1)$ (pb)			$ imes Br(\chi^{m{0}}_{2,3} o Z\chi^{m{0}}_{1}), 1, 0.01)$	

Parameter	Range	Parameter	Range
<i>m</i> 0]0, 4] TeV	tan β	[2, 60]
m _{1/2}]0, 4] TeV	μ]0, 3] TeV
A ₀	[-6, 6] TeV	MA]0, 4] TeV

BACKUP

MCMC method



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Constraints on SUSY and DM

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Models

- NUHM2
- LLẽ and ũdd
 - Inflaton, scalar field whose flat direction potential (with a non-negligible slope) leads to the end of the inflation phase
 - Charged under the visible sector of the particle physics model considered, i.e. NUHM2



ID constraints from \bar{p} W^{\pm} production leads also to abundant \bar{p} production (after hadronization)

- $\Rightarrow \bar{\mathbf{p}}$ flux produced by DM annihilation determined by :
 - $\sigma_{\rm DM \ DM} \rightarrow W^+W^-$
 - m_{DM}
 - DM halo profile (here Einasto profile)
 - $\bar{\mathbf{p}}$ propagation parameters in the galactic halo :

Model	δ	\mathcal{K}_0 [kpc ² /Myr]	$V_{ m conv}$ [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 $\bar{\bf p}$ flux originating from DM with the $\rm PAMELA$ data, 2 methods :

- "Aggressive" procedure : fixed background (standard flux from T. Bringmann and P. Salati, Phys. Rev. D 75 (2007) 083006)
- <u>"Conservative" procedure</u> : marginalized background, namely standard description of the background spectrum multiplied by $A(T/T_0)^p$ with :
 - $T = \bar{p}$ kinetic energy

 $T_0=30 \ \text{GeV}: pivot \ \text{energy}$

normalisation of the background spectrum : 0.6 < A < 1.4

spectral index : -0.1

ID constraints from $\bar{\rm p}$



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