UMSSM, right-handed sneutrino and cold dark matter

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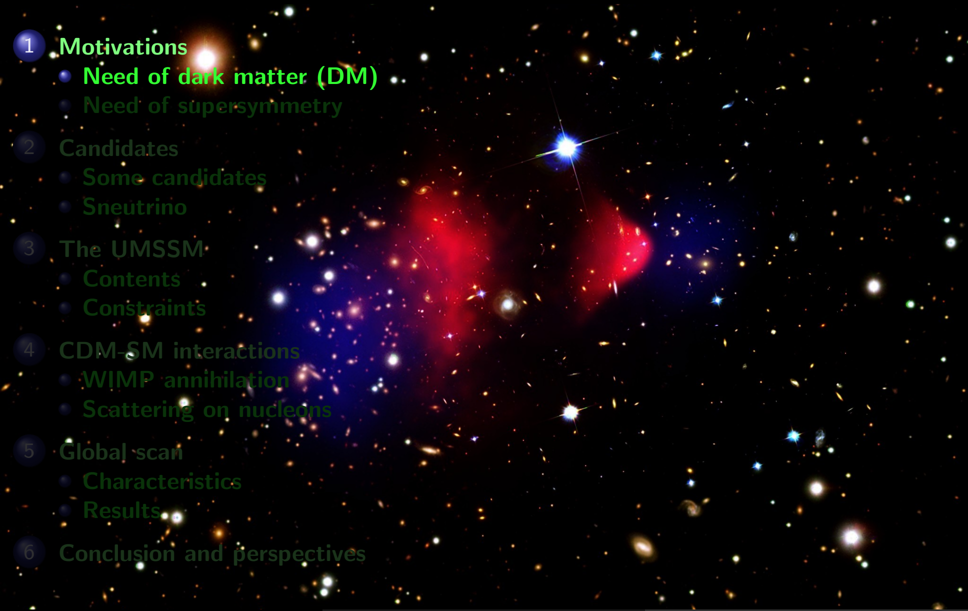
Durham University, UK, January 20, 2012

G. Bélanger, J. Da Silva and A. Pukhov
arXiv:1110.2414 [hep-ph], to appear in JCAP (2012)

Outline

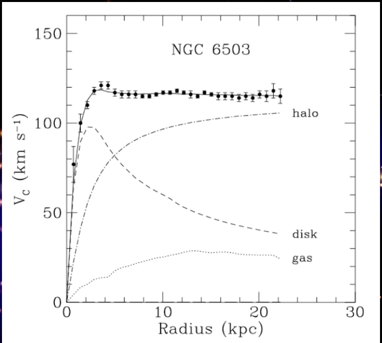
Motivations



Need of dark matter (DM)

Since 1933 and Zwicky observations, we accumulated evidences for DM existence :

- Galaxy scale : rotation curves of galaxies



K. G. Begeman, A. H. Broeils and R. H. Sanders, 1991, MNRAS, 249, 523

Circular velocity $v(r) = \sqrt{\frac{GM(r)}{r}}$ expected to fall in $\frac{1}{\sqrt{r}}$, observed approximately constant (! ?)

$\Rightarrow$ need of a halo with $M(r) \; \alpha \; r$

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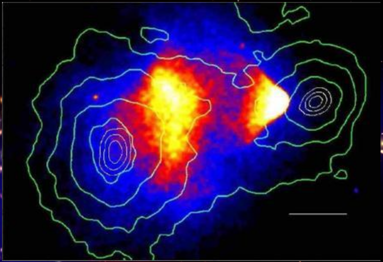

A direct empirical proof of the existence of dark matter, D. Clowe et al., Astrophys. J. 648 L109-L113, 2006

Study of X-rays and gravitational lensing effect of this cluster : discrepancy between baryonic matter and gravitational potential

$\Rightarrow$ non-negligible non-colliding component of clusters

Need of dark matter (DM)

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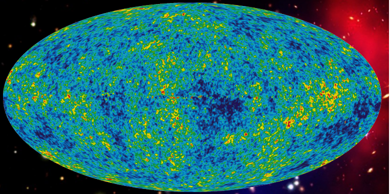
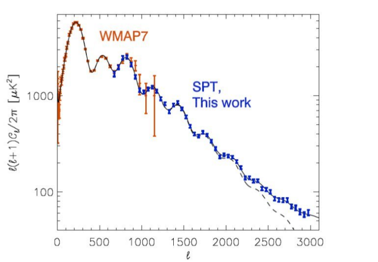
- Galaxy clusters scale : example of the bullet cluster
- Cosmological scale : the Cosmic Microwave background (CMB)



WMAP7



SPT

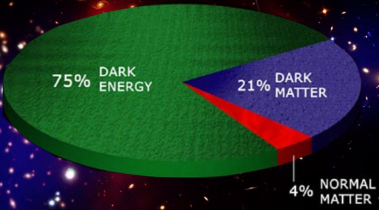
To match a cosmological model with the CMB power spectrum

$$\Rightarrow \Omega_b h^2 = 0.0226 \pm 0.0005 \text{ and } \Omega_{DM} h^2 = 0.1123 \pm 0.0035$$

Need of dark matter (DM)

Since 1933 and Zwicky observations, we accumulated evidences for DM existence :

- Galaxy scale : rotation curves of galaxies
- Galaxy clusters scale : example of the bullet cluster
- Cosmological scale : the Cosmic Microwave background (CMB)
- Large scale structures, ...

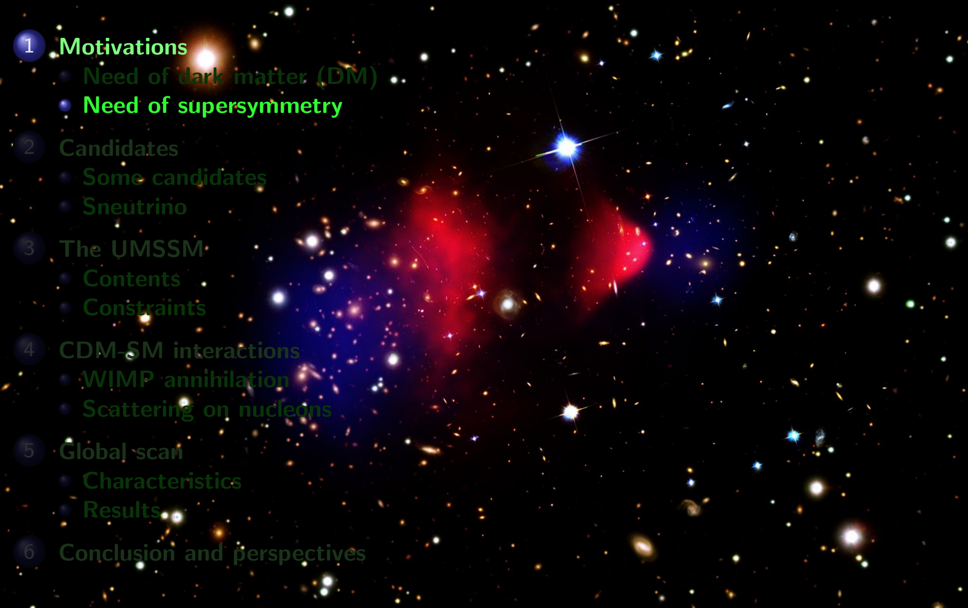


DM has to be stable and weakly charged under the standard model gauge group (otherwise we should have seen it)

Conservation of DM structures ⇒ warm vs. cold DM

here we choose CDM

Need of supersymmetry



Need of supersymmetry

- Hierarchy problem

No symmetry protects higgs mass :

$$\Delta m_H^2 = -\frac{|\lambda_f|^2}{8\pi^2}\Lambda^2 + \ldots$$

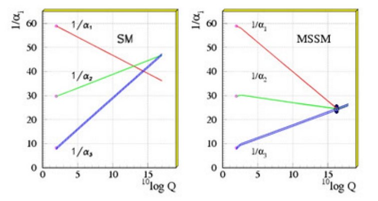
Supersymmetry, symmetry between fermions and bosons (thanks to Poincaré group extension) plays this role by adding one-loop corrections :

$$\Delta m_H^2 = \frac{|\lambda_S|^2}{16\pi^2}\Lambda^2 + \ldots$$

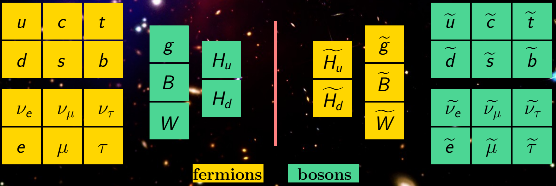
$\Rightarrow$ Cancellation of quadratic divergence

Need of supersymmetry

- Hierarchy problem
- Gauge coupling unification



Modification of RGEs in the supersymmetry framework



$\Rightarrow$ Supersymmetry allows unification at GUT scale

Need of supersymmetry

- Hierarchy problem
- Gauge coupling unification
- LSP/DM

No supersymmetric particles seen at the same mass as their standard partners
$\Rightarrow$ supersymmetry is broken, new particles (at least) at TeV scale

Supersymmetric terms give us proton decay
$\Rightarrow$ need of R-Parity to forbid them $P_R = (-1)^{3(B-L)+2s}$

$\Rightarrow$ Result : the lightest supersymmetric particle (LSP) is stable

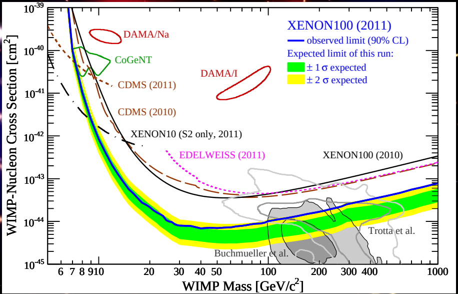
This LSP, stable, at TeV scale, can be weakly charged under the SM gauge group

$\Rightarrow$ DM candidates in supersymmetric models

Candidates

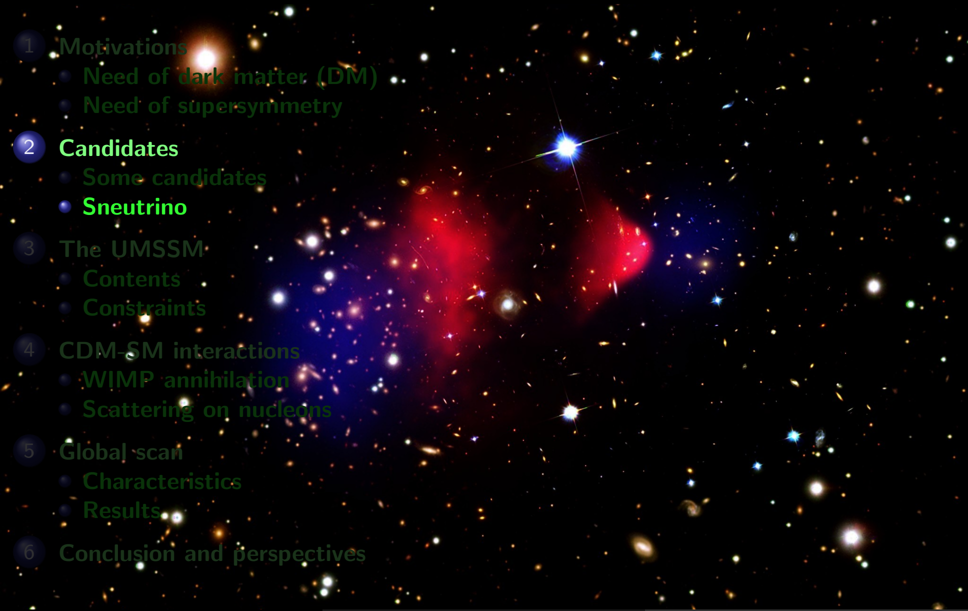
Some candidates

- Assuming R-parity, 2 CDM (WIMPs) candidates in the MSSM :
  - Lightest neutralino : a lot of studies ⇒ good DM candidate
  - Left-handed (LH) sneutrino : too high coupling with Z^0 ⇒ don't satisfy experimental constraints on spin independent direct detection ⇒ bad DM candidate



- Others SUSY candidates to DM : Gravitino, axino, ...

Sneutrino



Sneutrino

- Neutrino oscillations indicative of massive neutrinos $\Rightarrow$ possibility to add a right-handed (RH) neutrino field

  $\Rightarrow$ Extensions of the MSSM with RH (s)neutrino can provide DM candidate

- Different mechanisms appear to obtain sneutrino DM :
  - Mixing between LH and RH sneutrinos
  - Sneutrino in inverse see-saw mechanism models
  - RH sneutrino extension in the NMSSM
  - ...

- Here RH neutrino mass generated by introducing Dirac mass terms $\Rightarrow$ supersymmetric partner can be at the TeV scale

- **This candidate couples to new vector, scalar field by adding a new abelian gauge group, it's the UMSSM**

The UMSSM

Contents

- Extending the SM gauge group is well-motivated in superstrings and grand unified theories M. Cvetič and P. Langacker, Phys. Rev. D 54, 3570 (1996)
- Symmetry group : $SU(3)_c \times SU(2)_L \times U(1)_Y \times U'(1)$
  Coupling constants : g_3, g_2, g_Y and $g'_1 = g_1 = \sqrt{\frac{5}{3}} g_Y$
- $U'(1)$ stems from the breaking of E_6 :
  $E_6 \to SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_\chi \times U(1)_\psi \Rightarrow U'(1)$ charge :

$$Q' = \cos\theta_{E_6} Q_\chi + \sin\theta_{E_6} Q_\psi, \qquad \theta_{E_6} \in [-\pi/2, \pi/2]$$

- As the NMSSM, this model solves the μ problem, since it's related to the v.e.v of the singlet responsible of the breaking of the new abelian gauge group
- Superpotential :

$$W_{MSSM} = \bar{u} y_u Q H_u - \bar{d} y_d Q H_d - \bar{e} y_e L H_d + \mu H_u H_d$$
$$W_{UMSSM} = W_{MSSM}|_{\mu=0} + \lambda S H_u H_d + \bar{\nu} y_\nu L H_u$$

Q' choice	Q	$\bar{u}$	$\bar{d}$	L	$\bar{e}$	$\bar{\nu}$	H_u	H_d	S
$\sqrt{40}Q_\chi$	-1	-1	3	3	-1	-5	2	-2	0
$\sqrt{24}Q_\psi$	1	1	1	1	1	1	-2	-2	4

Contents

Some differences with the MSSM :

- Gauge sector : Physical abelian gauge bosons : Z_1 and Z_2, mixing between the Z^0 of the SM and the Z', α_Z is the mixing angle

$$M^2_{Z_1,Z_2} = \frac{1}{2}\left(M^2_{Z^0} + M^2_{Z'} \mp \sqrt{\left(M^2_{Z^0} + M^2_{Z'}\right)^2 + 4\Delta^4_Z}\right)$$

$$\sin 2\alpha_Z = \frac{2\Delta^2_Z}{M^2_{Z_2} - M^2_{Z_1}}$$

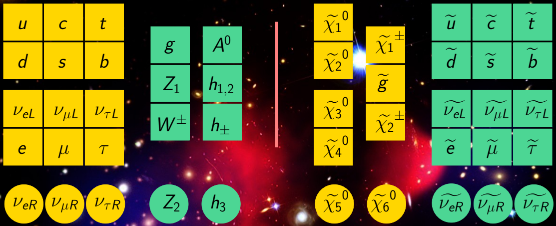
- Higgs sector : 1 CP odd higgs A^0, 5 CP even higgs : $h^\pm$, h_1, h_2 and h_3 singlet-like higgs (h_2 or h_3) mass near Z_2 mass including pure UMSSM terms + radiative corrections

  $\Rightarrow$ m_{h_1} above LEP limits

- Gauginos sector : 6 neutralinos in the basis $(\widetilde{B}, \widetilde{W}^3, \widetilde{H}^0_d, \widetilde{H}^0_u, \widetilde{S}, \widetilde{B'})$

Contents

To sum up :



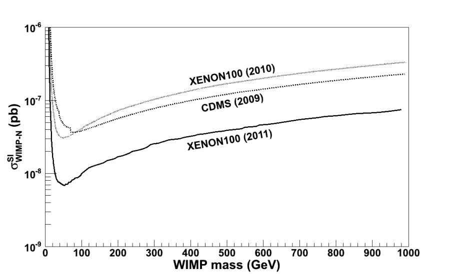
Relevant free parameters :

- WIMP mass $M_{\tilde{\nu}_R}$
- Higgs sector $\Rightarrow$ μ, A_λ
- Gauge sector : M_{Z_2} and α_Z $\Rightarrow$ t_β constrained
- Gaugino sector : M_1, M'_1 and again μ (higgsino NLSP)
- θ_{E_6}
- Soft terms at 2 TeV $\Rightarrow$ no sfermion coannihilation

Constraints

Constraints

- On our CDM candidate
  - Relic density at 3σ with $\Omega_{\text{WIMP}}h^2 = 0.1123 \pm 0.0035$
  - Spin independent direct detection cross section



Constraints

- On our CDM candidate
- On different sectors of the model
  - Higgs mass constraints from LEP and LHC : 114.4 GeV $< m_{h_1} <$ 144 GeV

    in this talk only 123 GeV $< m_{h_1} <$ 127 GeV
  - New Z boson mass constraints from ATLAS :

Q' choice	Q_ψ	Q_N	Q_η	Q_I	Q_S	Q_χ
M_{Z_2} (TeV)	1.49	1.52	1.54	1.56	1.60	1.64

  - Z^0 properties $\Rightarrow |\alpha_Z| \lesssim 10^{-3}$ ($M_W = \cos\theta_W M_{Z^0}$, not M_{Z_1} !)
  - LEP constraints on sparticles masses (especially charginos)
  - $B^0_{d,s} - \bar{B}^0_{d,s}$ mesons physics constraints : $\Delta M_{d,s}$ mass differences with one-loop supersymmetric contribution with charginos and charged higgs
    $\Rightarrow$ supersymmetry can increase the difference that appears between observed and standard model expected values :

$$\Delta m_s = 17.77 \pm 0.12\ \mathrm{ps}^{-1}(\mathrm{CDF}),\ \Delta m_s^{SM} = 20.5 \pm 3.1\ \mathrm{ps}^{-1}$$

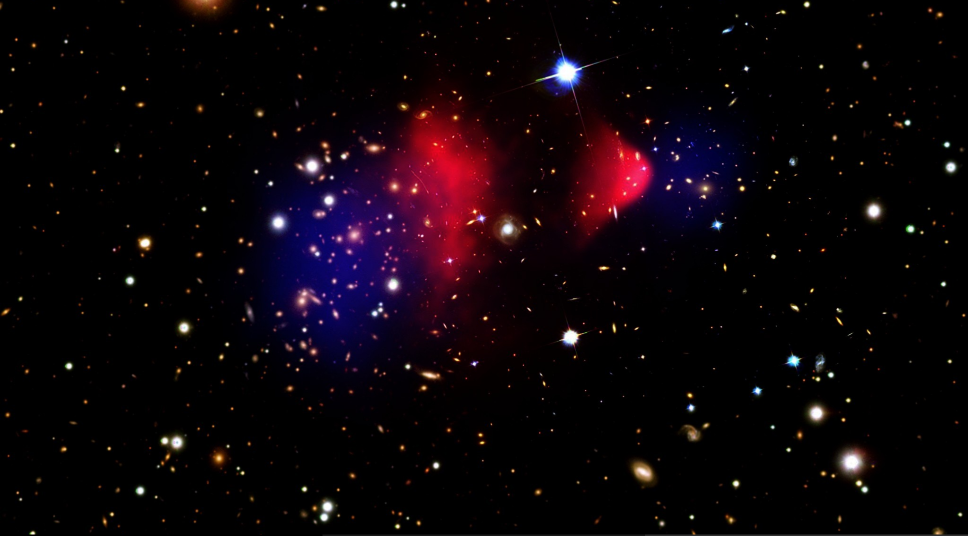
$$\Delta m_d = 0.507 \pm 0.004\ \mathrm{ps}^{-1}(\mathrm{HFAG}),\ \Delta m_d^{SM} = 0.59 \pm 0.19\ \mathrm{ps}^{-1}$$

$$\Delta m_s = 17.63 \pm 0.11\ \mathrm{ps}^{-1}(\mathrm{LHCb})$$

CDM-SM interactions

WIMP annihilation

Parameter space regions with $\Omega_{\text{WIMP}} h^2 \approx 0.1 \Rightarrow$ need to increase the annihilation cross section :



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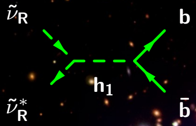

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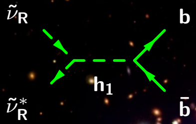
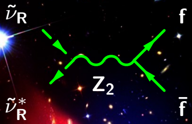


- WIMP mass near $M_{Z_2}/2$ (also $m_{h_i}/2$)



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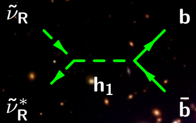

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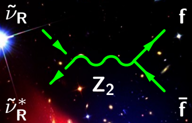
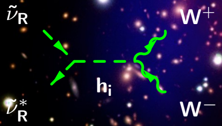
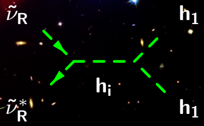


- WIMP mass near $m_{h_i}/2$ or above W pair threshold





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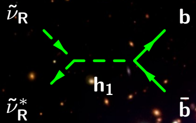

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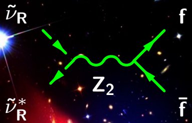

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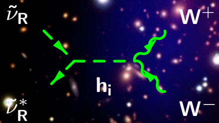
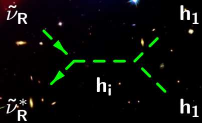
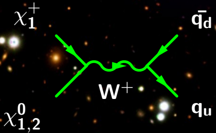
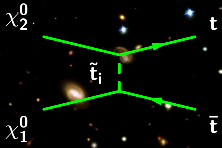




- Coannihilation processes (mainly higgsino-like)





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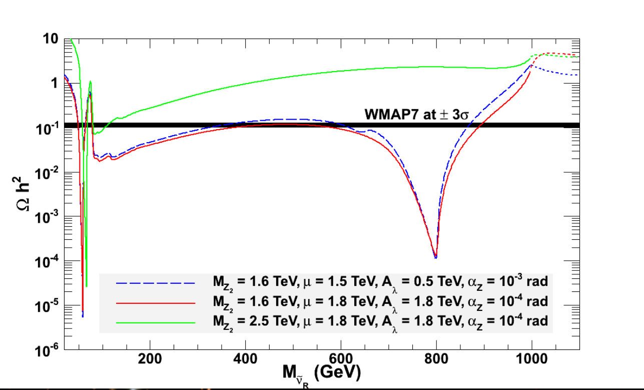
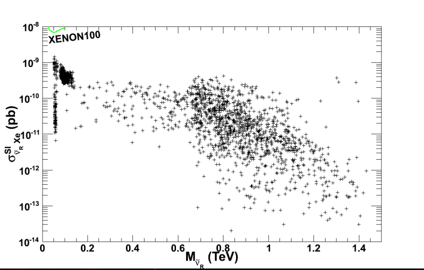


Scattering on nucleons

Scattering on nucleons

- Mainly abelian gauge bosons contribution, h_1 for LSP mass $\lesssim$ 200 GeV



$\Rightarrow$ for some $U'(1)$ models we can have a good suppression of the gauge boson or/and higgs part

here $U(1)_\psi \Rightarrow \theta_{E_6} = \pi/2$

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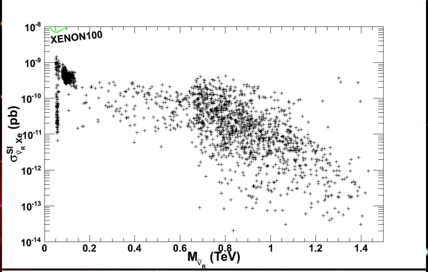

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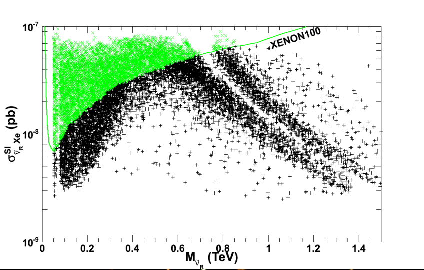


$\Rightarrow$ for other models, huge constraints on the parameter space appear

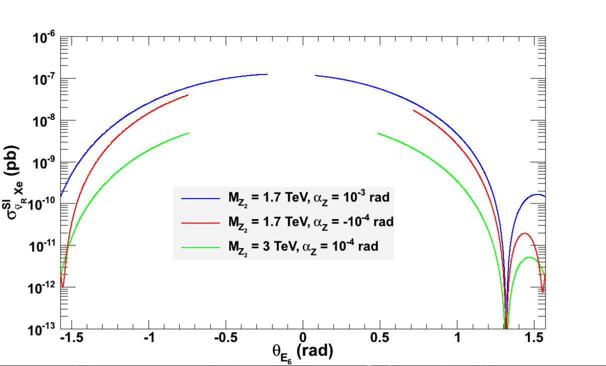
here $U(1)_\eta \Rightarrow \tan\theta_{E_6} = -\sqrt{5/3}$

Scattering on nucleons

Abelian gauge boson contribution to direct detection :

$$\sigma^{Z_1,Z_2}_{\tilde{\nu}_R N} = \frac{\mu^2_{\tilde{\nu}_R N}}{\pi}(g'_1 Q'_{\tilde{\nu}})^2[(y(1-4s^2_W)+y')Z+(-y+2y')(A-Z)]^2$$

$$\text{with } y = \frac{g' \sin\alpha_Z \cos\alpha_Z}{4\sin\theta_W}\left(\frac{1}{M^2_{Z_2}} - \frac{1}{M^2_{Z_1}}\right),\ y' = -\frac{g'_1}{2} Q'^{d}_{V}\left(\frac{\sin^2\alpha_Z}{M^2_{Z_1}} + \frac{\cos^2\alpha_Z}{M^2_{Z_2}}\right)$$

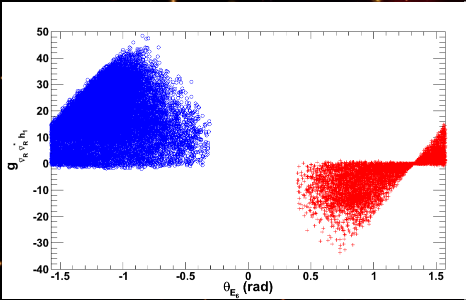


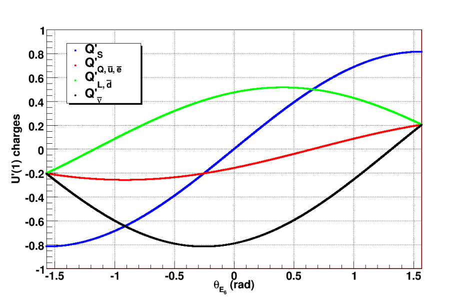
$\Rightarrow$ stringent constraints for small $|\theta_{E_6}|$ because of Q'^{d}_{V} term

Scattering on nucleons

Higgs-CDM contribution :

$$g_{\tilde{\nu}_R\tilde{\nu}_R^* h_i} = -g_1'^2 Q'_{\bar{\nu}} \left[v_d Q'_{H_d} Z_{hi1} + v_u Q'_{H_u} Z_{hi2} + v_s Q'_S Z_{hi3} \right]$$





⇒ increase of the cross section for $\theta_{E_6} < 0$ because of $Q'_{\bar{\nu}}$

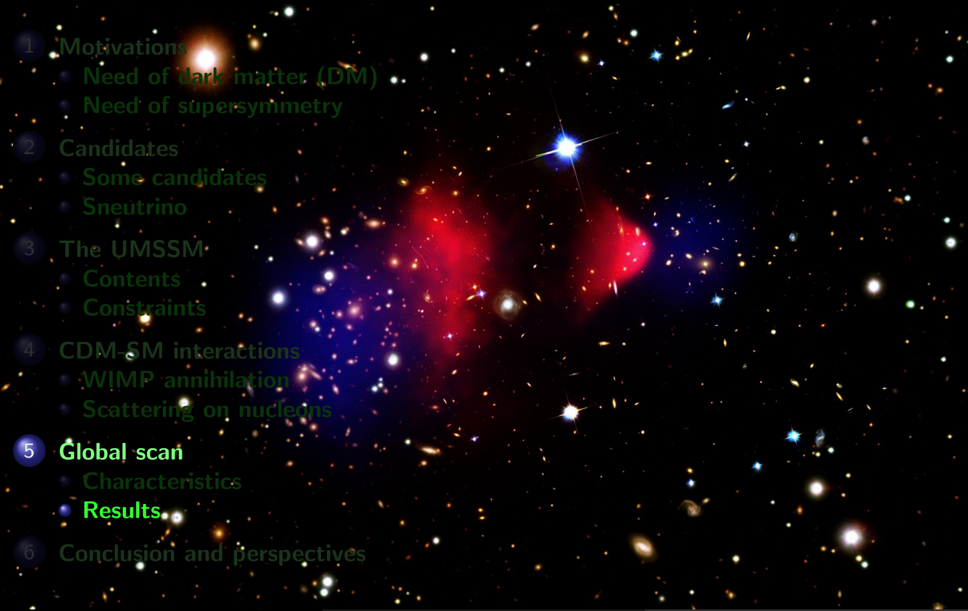
Global scan

Characteristics

Fixed parameters			
Soft terms			
m_{Q_i}	2 TeV	m_{L_i}	2 TeV
$m_{\bar{u}_i}$	2 TeV	$m_{\bar{d}_i}$	2 TeV
$m_{\bar{e}_i}$	2 TeV	$m_{\bar{\nu}_j}$	2 TeV
$i \in \{1, 2, 3\}$, $j \in \{1, 2\}$			
Trilinear couplings + M_K			
A_t	1 TeV	A_b	0 TeV
A_c	0 TeV	A_s	0 TeV
A_u	0 TeV	A_d	0 TeV
A_l	0 TeV	M_K	1 eV

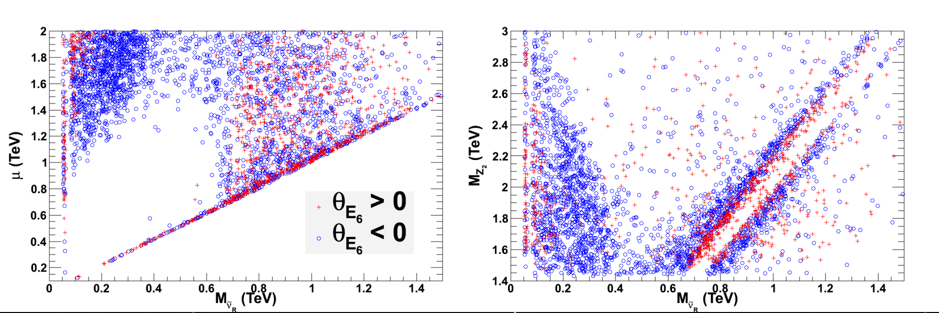
Free parameters	
Name	Domain of variation
$M_{\tilde{\nu}_R}$	[0, 1.5] TeV
M_{Z_2}	[1.3, 3] TeV
μ	[0.1, 2] TeV
A_λ	[0, 2] TeV
θ_{E_6}	[$-\pi/2$, $\pi/2$] rad
α_Z	[-3.10^{-3}, 3.10^{-3}] rad
M_1	[0.1, 2] TeV
M_1'	[0.1, 2] TeV
$M_2 = 2M_1$ et $M_3 = 6M_1$	

Results



Results

Interesting WIMP mass **from 50 GeV to TeV-scale** :



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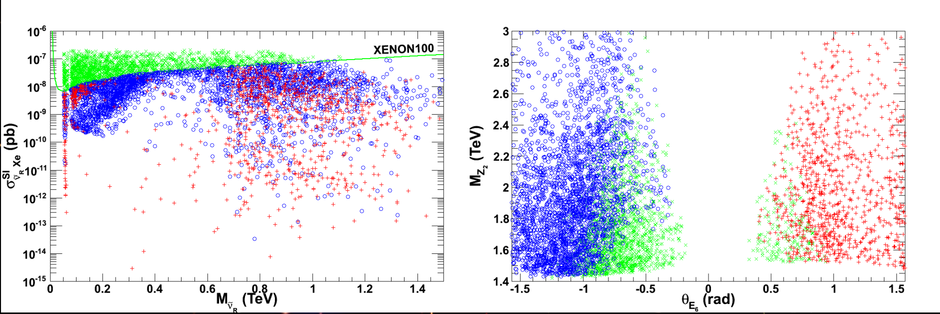
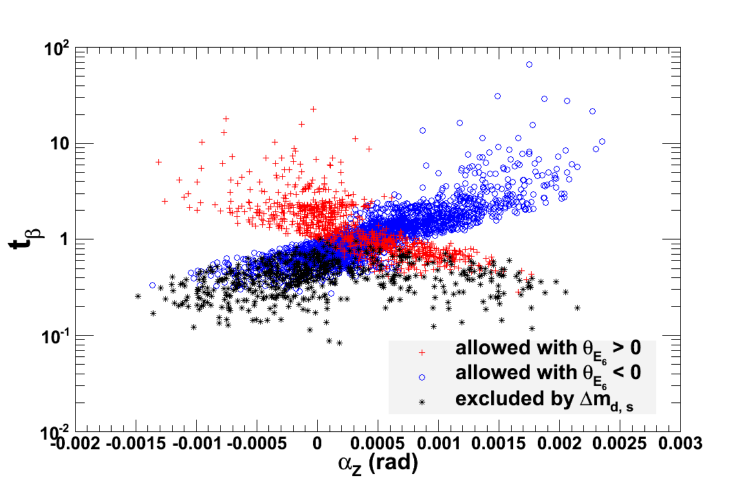


Lower is $|\theta_{E_6}|$, higher are Z_2 processes in direct detection cross section ⇒ huge constraint

Results

Large SUSY corrections proportional to $\frac{1}{t_\beta^4}$ $\Rightarrow$ small values of t_β very constrained by ΔM_s :



Conclusion and perspectives

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- RH sneutrino is a viable dark matter candidate in the UMSSM
  it respects experimental limits in the case of some annihilation processes :
  - Resonance (h_1, Z_2 and singlet-like higgs)
  - Coannihilation (neutralinos, charginos, others sfermions)
  - Annihilation into W pairs generally with exchange of h_1
- Direct detection experiments strongly constrain the model as well as ΔM_s

- Neutralino can also be a good DM candidate in this gauge extension of the MSSM J. Kalinowski, S.F. King and J.P. Roberts, arXiv :0811.2204
- More careful study of the UMSSM higgs sector to analyse implications of the excesses seen in the $\gamma\gamma$ channels at LHC

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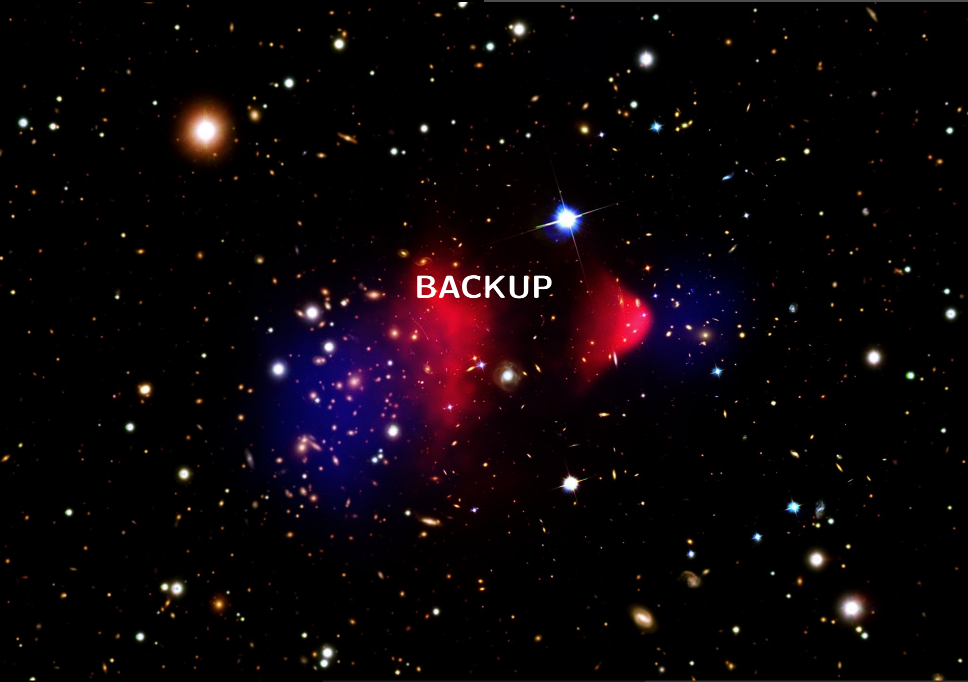
Thanks for your attention !

BACKUP



UMSSM fields

Chiral supermultiplets				
Supermultiplets		**spin 0**	**spin 1/2**	$SU(3)_c$, $SU(2)_L$, $U(1)_Y$, $U'(1)$
squarks, quarks (3 families)	**Q**	$(\tilde{u}_L\ \tilde{d}_L)$	$(u_L\ d_L)$	$(\mathbf{3},\ \mathbf{2},\ \frac{1}{6},\ Q'_Q)$
	$\bar{u}$	$\tilde{u}_R^*$	$\bar{u}_R$	$(\bar{\mathbf{3}},\ \mathbf{1},\ -\frac{2}{3},\ Q'_u)$
	$\bar{d}$	$\tilde{d}_R^*$	$\bar{d}_R$	$(\bar{\mathbf{3}},\ \mathbf{1},\ \frac{1}{3},\ Q'_d)$
sleptons, leptons (3 families)	**L**	$(\tilde{\nu}_L\ \tilde{e}_L)$	$(\nu_L\ e_L)$	$(\mathbf{1},\ \mathbf{2},\ -\frac{1}{2},\ Q'_L)$
	$\bar{\nu}$	$\tilde{\nu}_R^*$	$\bar{\nu}_R$	$(\mathbf{1},\ \mathbf{1},\ \mathbf{0},\ Q'_{\bar{\nu}})$
	$\bar{e}$	$\tilde{e}_R^*$	$\bar{e}_R$	$(\mathbf{1},\ \mathbf{1},\ \frac{1}{6},\ Q'_e)$
higgs, higgsinos	H_u	$(H_u^+\ H_u^0)$	$(\tilde{H}_u^+\ \tilde{H}_u^0)$	$(\mathbf{1},\ \mathbf{2},\ \frac{1}{2},\ Q'_{H_u})$
	H_d	$(H_d^0\ H_d^-)$	$(\tilde{H}_d^0\ \tilde{H}_d^-)$	$(\mathbf{1},\ \mathbf{2},\ -\frac{1}{2},\ Q'_{H_d})$
	S	S	$\tilde{S}$	$(\mathbf{1},\ \mathbf{1},\ \mathbf{0},\ Q'_S)$

Vector supermultiplets			
Supermultiplets	**spin 1/2**	**spin 1**	$SU(3)_c$, $SU(2)_L$, $U(1)_Y$, $U'(1)$
gluino, gluon	$\tilde{g}$	g	$(\mathbf{8},\ \mathbf{1},\ \mathbf{0},\ \mathbf{0})$
winos, W bosons	$\widetilde{W}^\pm\ \widetilde{W}^3$	$W^\pm\ W^3$	$(\mathbf{1},\ \mathbf{3},\ \mathbf{0},\ \mathbf{0})$
bino, B boson	$\widetilde{B}$	B	$(\mathbf{1},\ \mathbf{1},\ \mathbf{0},\ \mathbf{0})$
bino', B' boson	$\widetilde{B'}$	B'	$(\mathbf{1},\ \mathbf{1},\ \mathbf{0},\ \mathbf{0})$

Some new lagrangian terms

- **Superpotential :**

$$
\begin{aligned}
W_{MSSM} &= \bar{u} y_u Q H_u - \bar{d} y_d Q H_d - \bar{e} y_e L H_d + \mu H_u H_d \\
W_{UMSSM} &= W_{MSSM}(\mu = 0) + \lambda S H_u H_d + \bar{\nu} y_\nu L H_u
\end{aligned}
$$

- **Soft supersymmetry breaking :**

$$
\begin{aligned}
\mathcal{L}_{soft}^{MSSM} &= -\frac{1}{2}\left(M_3 \tilde{g}\tilde{g} + M_2 \widetilde{W}\widetilde{W} + M_1 \widetilde{B}\widetilde{B} + \mathbf{c.c.}\right) \\
&\quad - \left(\tilde{u}_R^* a_u \tilde{Q} H_u - \tilde{d}_R^* a_d \tilde{Q} H_d - \tilde{e}_R^* a_e \tilde{L} H_d + \mathbf{c.c.}\right) \\
&\quad - \tilde{Q}^\dagger m_Q^2 \tilde{Q} - \tilde{L}^\dagger m_L^2 \tilde{L} - \tilde{u}_R^* m_{\bar{e}}^2 \tilde{u}_R - \tilde{d}_R^* m_d^2 \tilde{d}_R - \tilde{e}_R^* m_{\bar{e}}^2 \tilde{e}_R \\
&\quad - m_{H_u}^2 H_u^\dagger H_u - m_{H_d}^2 H_d^\dagger H_d - \left(b H_u H_d + \mathbf{c.c.}\right) \\
\mathcal{L}_{soft}^{UMSSM} &= \mathcal{L}_{soft}^{MSSM}(b = 0) - \left(\frac{1}{2} M_1' \widetilde{B'}\widetilde{B'} + M_K \widetilde{B}\widetilde{B'} + \tilde{\nu}_R^* a_\nu \tilde{L} H_u + \mathbf{c.c.}\right) \\
&\quad - \tilde{\nu}_R^* m_{\tilde{\nu}}^2 \tilde{\nu}_R - \left(\lambda A_\lambda S H_u H_d + \mathbf{c.c.}\right) - m_S^2 S^* S
\end{aligned}
$$

LanHEP, A. Semenov, arXiv :0805.0555 [hep-ph]

Reason of constrained t_β

$$M_Z^2 = M_{Z_1}^2 \cos^2\alpha_{ZZ'} + M_{Z_2}^2 \sin^2\alpha_{ZZ'}$$
$$M_{Z'}^2 = M_{Z_1}^2 \sin^2\alpha_{ZZ'} + M_{Z_2}^2 \cos^2\alpha_{ZZ'}.$$

$$\Downarrow$$

$$\tan 2\alpha_{ZZ'} = \frac{2\Delta^2}{M_{Z'}^2 - M_Z^2} \quad \Longrightarrow \quad \sin 2\alpha_{ZZ'} = \frac{2\Delta^2}{M_{Z_2}^2 - M_{Z_1}^2}.$$

Knowing that

$$\Delta^2 = \frac{g_1'\sqrt{g'^2 + g_2^2}}{2} v^2 (Q_2' s_\beta^2 - Q_1' c_\beta^2),$$

$$\Downarrow$$

$$\boxed{c_\beta^2 = \frac{1}{Q_1' + Q_2'} \left(\frac{\sin 2\alpha_{ZZ'} (M_{Z_1}^2 - M_{Z_2}^2)}{v^2 g_1' \sqrt{g'^2 + g_2^2}} + Q_2' \right).}$$

Higgs masses

$$m_{A^0}^2 = \frac{\lambda A_\lambda \sqrt{2}}{\sin 2\phi} v + \Delta_{EA} \qquad \tan\phi = \frac{v \sin 2\beta}{2 v_s}$$

$$m_{H^\pm}^2 = \frac{\lambda A_\lambda \sqrt{2}}{\sin 2\beta} v_s - \frac{\lambda^2}{2} v^2 + \frac{g_2^2}{2} v^2 + \Delta \qquad \tan\beta = \frac{v_u}{v_d}$$

M^2_{CPeven} :

$$\left(\mathcal{M}_+^0\right)_{11} = \left[\frac{(g'^2 + g_2^2)^2}{4} + Q_1'^2 g_1'^2\right](v c_\beta)^2 + \frac{\lambda A_\lambda t_\beta v_s}{\sqrt{2}} + \Delta_{11}$$

$$\left(\mathcal{M}_+^0\right)_{12} = -\left[\frac{(g'^2 + g_2^2)^2}{4} - \lambda^2 - Q_1' Q_2' g_1'^2\right] v^2 s_\beta c_\beta - \frac{\lambda A_\lambda v_s}{\sqrt{2}} + \Delta_{12}$$

$$\left(\mathcal{M}_+^0\right)_{13} = \left[\lambda^2 + Q_1' Q_S' g_1{}'^2\right] v c_\beta v_s - \frac{\lambda A_\lambda v s_\beta}{\sqrt{2}} + \Delta_{13}$$

$$\left(\mathcal{M}_+^0\right)_{22} = \left[\frac{(g'^2 + g_2^2)^2}{4} + Q_2'^2 g_1'^2\right](v s_\beta)^2 + \frac{\lambda A_\lambda v_s}{t_\beta \sqrt{2}} + \Delta_{22}$$

$$\left(\mathcal{M}_+^0\right)_{23} = \left[\lambda^2 + Q_2' Q_S' g_1'^2\right] v s_\beta v_s - \frac{\lambda A_\lambda v c_\beta}{\sqrt{2}} + \Delta_{23}$$

$$\left(\mathcal{M}_+^0\right)_{33} = Q_S'^2 g_1'^2 v_s^2 + \frac{\lambda A_\lambda v^2 s_\beta c_\beta}{v_s \sqrt{2}} + \Delta_{33}$$

Vernon Barger, Paul Langacker, Hye-Sung Lee and Gabe Shaughnessy, arXiv :hep-ph/0603247

Coannihilation with sfermions

Sparticles sector :

$$M^2_{\tilde f} = \begin{pmatrix} m^2_{soft} + m^2_{f} + M^2_{Z^0}\cos 2\beta (I^3_f - e_f \sin^2\theta_W) + \Delta_f & m_f(A_f - \mu (t_\beta)^{-2I^3_f}) \\ m_f(A_f - \mu (t_\beta)^{-2I^3_f}) & m^2_{\bar{f}\,soft} + M^2_{Z^0}\cos 2\beta (I^3_{\bar f} - e_{\bar f}\sin^2\theta_W) + m^2_f + \Delta_{\bar f} \end{pmatrix}$$

where $\Delta_f = \frac{1}{2} g_1'^2 Q'_f (Q'_{H_d} v_d^2 + Q'_{H_u} v_u^2 + Q'_S v_s^2)$ $\Rightarrow$ **Coannihilations :**

$\theta_{E_6} > 0$ **: generally** $\tilde{t}_1$

$\theta_{E_6} < 0$ **: generally RH down sqarks**