The right-handed sneutrino as thermal dark matter in U(1) extensions of the MSSM

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GDR Terascale, Lyon, April 20, 2011

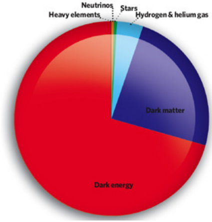
G. Bélanger, J. Da Silva and A. Pukhov, in preparation

Outline

Framework of the study

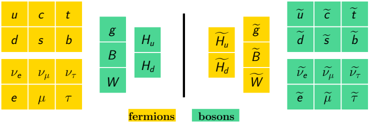
Dark matter and supersymmetry

- Dark matter :



CMB, rotation curves, Bullet cluster, ...
$\Rightarrow$ more interesting candidates : WIMPs

- Supersymmetry :



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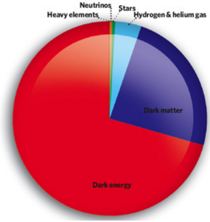

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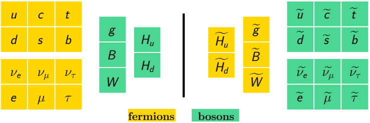

Hierarchy problem, unification of the couplings, ...
$\Rightarrow$ new particles interacting weakly with standard particles

$\Rightarrow$ Dark matter candidates in supersymmetric models

Some candidates

Assuming R-parity :

- 2 WIMPs candidates in the MSSM :
  - Lightest neutralino : a lot of studies $\Rightarrow$ good DM candidate
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  - **In this talk** : RH sneutrino couples to new vector, scalar field, adding a new abelian gauge group

The UMSSM

The new U(1) group

- Symmetry group : $SU(3)_c \times SU(2)_L \times U(1)_Y \times U'(1)$
  Coupling constants associated : g_3, g_2, g' and $g'_1 = g_1 = \sqrt{\frac{5}{3}} g'$
- Here it stems from E_6 model $\Rightarrow$ $U'(1)$ is a combination with :

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

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
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- Chiral supermultiplet S $\Rightarrow$ new vev $\Rightarrow$ μ problem resolved as the NMSSM : $\mu = \frac{\lambda v_s}{\sqrt{2}}$
- Vector supermultiplet $\Rightarrow$ new gauge boson : B'

Gauge bosons

- Electroweak and $U'(1)$ symmetry breaking :

$$\langle H_d \rangle = \frac{v_d}{\sqrt{2}} \qquad \langle H_u \rangle = \frac{v_u}{\sqrt{2}} \qquad \langle S \rangle = \frac{v_s}{\sqrt{2}}$$

- Physical abelian gauge bosons : Z_1 and Z_2 from $Z^0 = -\sin\theta_W B + \cos\theta_W W^3$ and $Z' = B'$:

$$Z_1 = Z^0 \cos\alpha_Z + Z' \sin\alpha_Z$$
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$$M^2_{Z^0} = \frac{g'^2 + g_2^2}{4} v^2, \quad v^2 = v_d^2 + v_u^2$$
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$$M_W = \cos\theta_W M_{Z^0}$$
$$\Downarrow$$
$$\text{small } \alpha_Z$$

J. Erler, P. Langacker, S. Munir and E. Rojas, arXiv :0906.2435v3 [hep-ph]

Other modifications

- Higgs sector : 1 CP odd Higgs A^0, 5 CP even Higgs : $H^\pm$, h_1, h_2 and h_3 :
  Diagonalization of 3×3 matrix M^2_{CPeven} : $M^2_{h_1,h_2,h_3} = Z_h^{-1} M^2_{CPeven} Z_h$
  Singlet-like Higgs mass near Z_2 mass
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- Gauginos sector : 6 neutralinos in the basis $(\widetilde{B}, \widetilde{W}^3, \widetilde{H}^0_d, \widetilde{H}^0_u, \widetilde{S}, \widetilde{B'})$
  J. Kalinowski, S.F. King et J.P. Roberts, arXiv :0811.2204v2 [hep-ph]
- Sparticles sector :

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

where $\Delta_f = \frac{1}{2} {g'_1}^2 Q'_f (Q'_{H_d} v_d^2 + Q'_{H_u} v_u^2 + Q'_S v_s^2)$

The case of $U(1)_\psi$ model ($\theta_{E_6} = \pi/2$)

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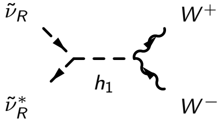

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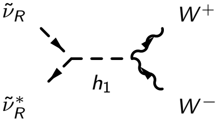

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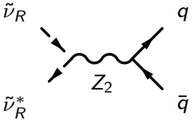

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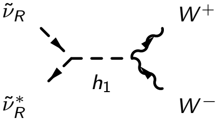

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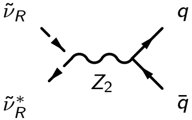

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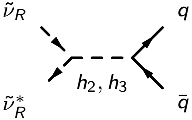

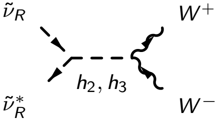

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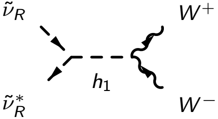

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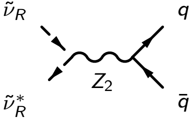

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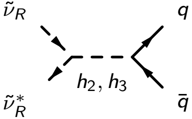
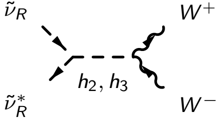
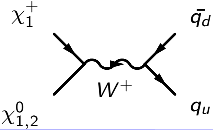




- Coannihilation processes (mainly higgsino-like) :



Relic density

- Relevant parameters : $M_{\tilde{\nu}_R}$, μ, A_λ, M_{Z_2}, $\tan\beta$, α_Z
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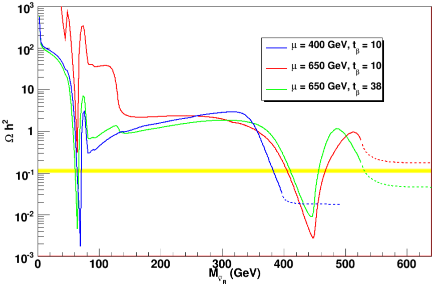

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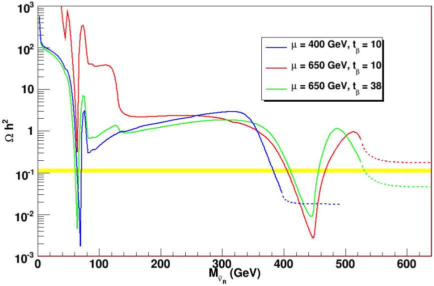

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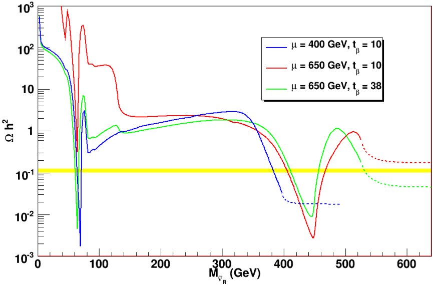

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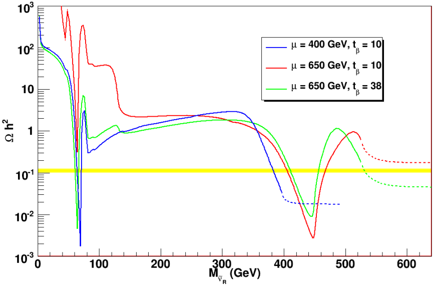

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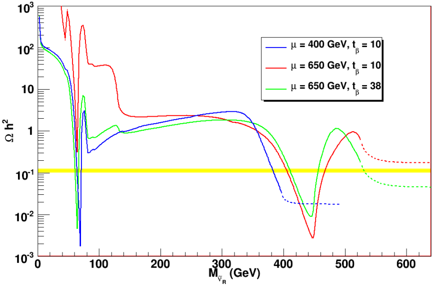

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$\Rightarrow$ since $Q'_{H_d} = Q'_{H_u}$, when $\frac{v}{v_s} \approx \frac{2Z_{h31}}{Z_{h11}}$ the coupling $\tilde{\nu}_R \tilde{\nu}_R^* h_1$ drastically decrease

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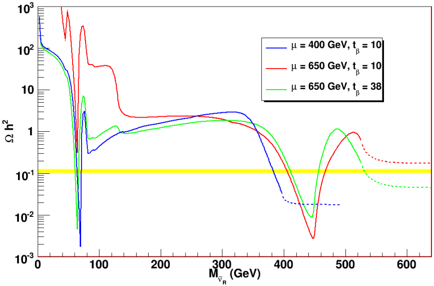

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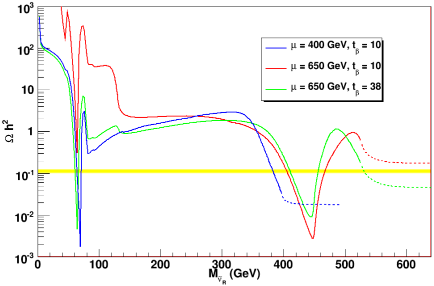

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- near Z_2/singlet-like Higgs resonance
- Coannihilation processes with NLSP higgsino-like can appear before Z_2 resonance

Direct detection

Direct detection cross section

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

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

$$\mu_{\tilde{\nu}_R N} = \frac{M_{\tilde{\nu}_R} m_N}{M_{\tilde{\nu}_R} + m_N}, \qquad Q'^d_V = Q'_Q - Q'_d$$

Direct detection cross section

- Neutral CP-even Higgs and abelian gauge bosons contribution
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in $U(1)_\psi$ model $Q'^d_V = 0$

$\Downarrow$

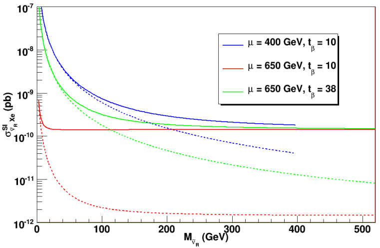
low values of $\sigma^{SI}_{\tilde{\nu}_R N}$

$+$

h_1 and Z_1 contribution

$\Downarrow$

$\sin^2\alpha_Z$ suppression of the gauge boson part (dashed line : $\alpha_Z = 10^{-4}$ rad)



Global scan

The set of parameters

Fixed parameters				Free parameters	
Soft terms				Name	Domain of variation
m_{Q_i}	1 TeV	m_{L_i}	1 TeV	$m^2_{\tilde{\nu}_3}$	[-4 000, 4 000] TeV
$m_{\bar{u}_i}$	1 TeV	$m_{\bar{d}_i}$	1 TeV	M_{Z_2}	$[M(\theta_{E_6})$, 2 000] GeV
$m_{\bar{e}_i}$	1 TeV	$m_{\bar{\nu}_j}$	2 TeV	μ	[100, 1 000] GeV
i $\in \{1, 2, 3\}$, j $\in \{1, 2\}$				A_λ	[0, 1 000] GeV
Trilinear couplings + M_K				t_β	[2, 60]
A_t	1 TeV	A_b	0 TeV	α_Z	[0, 3.10^{-3}] rad
A_c	0 TeV	A_s	0 TeV	θ_{E_6}	[-$\pi/2$, $\pi/2$] rad
A_u	0 TeV	A_d	0 TeV	M_1, M'_1	[100, 1 000] GeV
A_l	0 TeV	M_K	1 eV	$M_2 = 2M_1$ et $M_3 = 6M_1$	

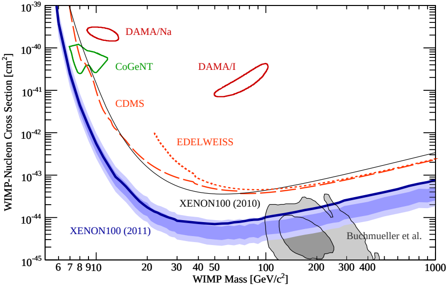
Q' choice	Q_χ	Q_ψ	Q_η	Q_I	Q_S	Q_N
M_{Z_2} (GeV)	892	878	904	789	821	861

CDF Collaboration, Phys. Rev. Lett. 102, 091805 (2009)

New limits from CMS Collaboration, arXiv :1103.0981v2 [hep-ex] not implemented yet

Constraints on the scan

- Relic density at 3σ with $\Omega_{WIMP}h^2 = 0.1123 \pm 0.0035$
  N. Jarosik et al, arXiv :1001.4744v1 [astro-ph.CO]
- Higgs mass limit for doublet-like Higgs : $m_{h_1} \geq 114.4$ GeV
  LEP Working Group for Higgs boson searches, Phys. Lett. B565(2003) 61
- LEP constraints on sparticles masses implemented in the micrOMEGAs code
  G. Bélanger, F. Boudjema, A. Pukhov et A. Semenov, arXiv :0803.2360v2 [hep-ph]
- Spin independent direct detection cross section



XENON100 Collaboration, arXiv :1104.2549v1 [astro-ph.CO]
CDMS Collaboration, arXiv :0912.3592v1 [astro-ph.CO]

Results

New processes

Interesting WIMP mass from 50 GeV to TeV-scale
As in the $U(1)_\psi$ model, constraints respected near :

- h_1 resonance
- Z_2/singlet-like Higgs resonance
- Coannihilation with NLSP neutralino

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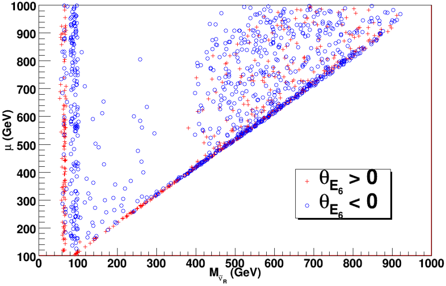

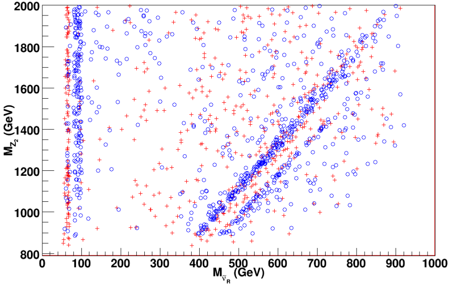

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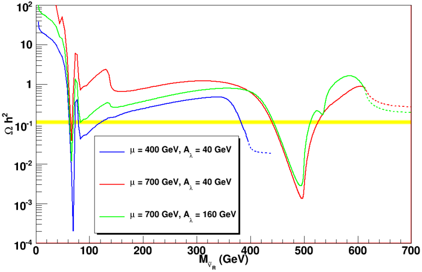
But also for :

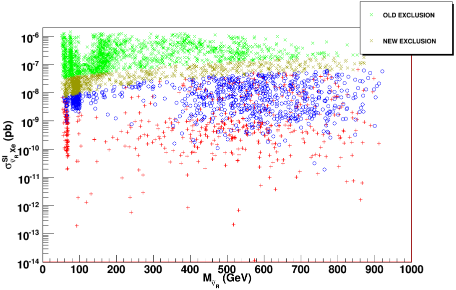
- Coannihilation with sfermions
- Annihilation into W pairs through Higgs exchange arround $M_{\tilde{\nu}_R} = 100$ GeV ($\theta_{E_6} < 0$)

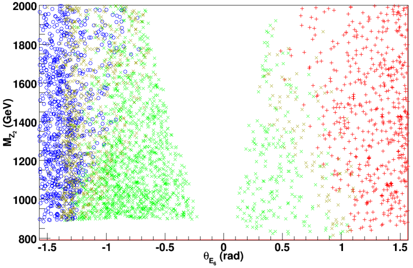


θ_{E_6} = -0.42π
$\Rightarrow$ due to the increase of $g_{\tilde{\nu}_R \tilde{\nu}_R^* h_1}$

Direct detection constraint

Small values of $|\theta_{E_6}|$ very constrained, especially for $\theta_{E_6} < 0$:





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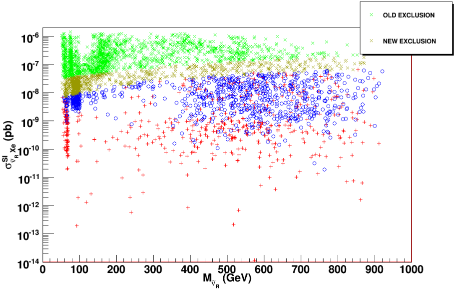

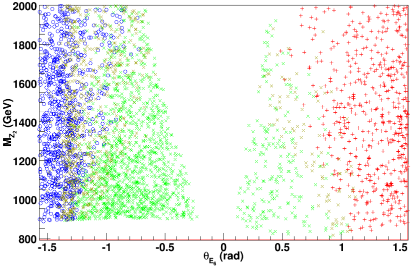

$\Rightarrow$ Lower is $|\theta_{E_6}|$, higher are Z_2 processes, barring higher M_{Z_2}

Conclusion and perspectives

Conclusion and perspectives

- **RH sneutrino is a viable dark matter candidate**

  it respects experimental limits in the case of some processes :
  - Resonance (h_1, Z_2 and singlet-like Higgs)
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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	$(\widetilde{u}_L\ \widetilde{d}_L)$	$(u_L\ d_L)$	$(\mathbf{3},\ \mathbf{2},\ \frac{1}{6},\ Q'_Q)$
	$\bar{u}$	$\widetilde{u}^*_R$	$\bar{u}_R$	$(\bar{\mathbf{3}},\ \mathbf{1},\ -\frac{2}{3},\ Q'_u)$
	$\bar{d}$	$\widetilde{d}^*_R$	$\bar{d}_R$	$(\bar{\mathbf{3}},\ \mathbf{1},\ \frac{1}{3},\ Q'_d)$
sleptons, leptons (3 families)	L	$(\widetilde{\nu}_L\ \widetilde{e}_L)$	$(\nu_L\ e_L)$	$(\mathbf{1},\ \mathbf{2},\ -\frac{1}{2},\ Q'_L)$
	$\bar{\nu}$	$\widetilde{\nu}^*_R$	$\bar{\nu}_R$	$(\mathbf{1},\ \mathbf{1},\ 0,\ Q'_{\bar{\nu}})$
	$\bar{e}$	$\widetilde{e}^*_R$	$\bar{e}_R$	$(\mathbf{1},\ \mathbf{1},\ \frac{1}{6},\ Q'_e)$
Higgs, higgsinos	H_u	$(H_u^+\ H_u^0)$	$(\widetilde{H}_u^+\ \widetilde{H}_u^0)$	$(\mathbf{1},\ \mathbf{2},\ \frac{1}{2},\ Q'_{H_u})$
	H_d	$(H_d^0\ H_d^-)$	$(\widetilde{H}_d^0\ \widetilde{H}_d^-)$	$(\mathbf{1},\ \mathbf{2},\ -\frac{1}{2},\ Q'_{H_d})$
	S	S	$\widetilde{S}$	$(\mathbf{1},\ \mathbf{1},\ 0,\ Q'_S)$

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

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 :

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

LanHEP, A. Semenov, arXiv :0805.0555v1 [hep-ph]

Higgs masses

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

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

M^2_{CPeven} :

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

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

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

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

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

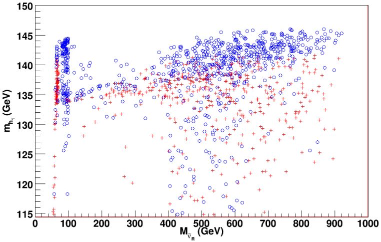
$$\left(\mathcal{M}_+^0\right)_{33} = Q_S'^2 g_1'^2 v_s^2 + \frac{\lambda A_\lambda v^2 s_\beta c_\beta}{v_s \sqrt{2}} + \Delta_{33}$$

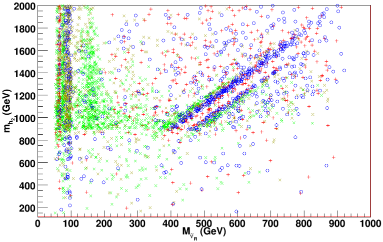
Vernon Barger, Paul Langacker, Hye-Sung Lee and Gabe Shaughnessy, arXiv :hep-ph/0603247v3

Other scan characteristics

- 2.10^6 points generated for light LSP ($M_{\tilde{\nu}_R} < 100$ GeV), 0.01% of these points pass the constraints
- 2.10^5 points generated for heavy LSP (100 GeV $< M_{\tilde{\nu}_R} < 1$ TeV), 0.5% of these points pass the constraints

- h_1 masses obtained :
- h_2 masses obtained :

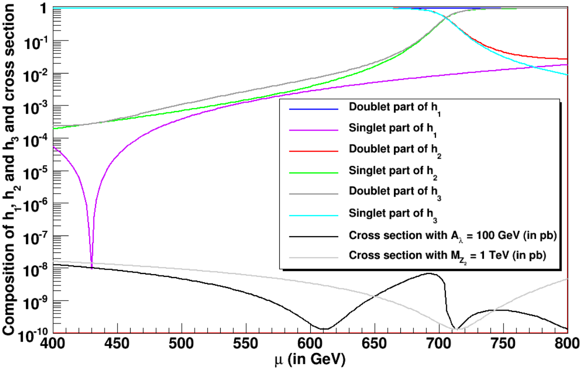




WIMP interactions

Playing with μ, A_λ, M_{Z_2} and $\tan\beta$: masses in the Higgs sector modified
$\Rightarrow$ switch of the singlet-like Higgs can also affect relic density profil

$$(g_{h_i W^+ W^-})_{\mu\nu} = g_2 M_W Z_{h1i} g_{\mu\nu}, \text{ with generally } Z_{h12} \ll Z_{h13}$$



$M_{Z_2} = 850$ GeV,
$M_{\tilde{\nu}_R} = 20$ GeV, $\tan\beta = 10$
and $A_\lambda = 100$ GeV

Arround $\mu = 600$ GeV :

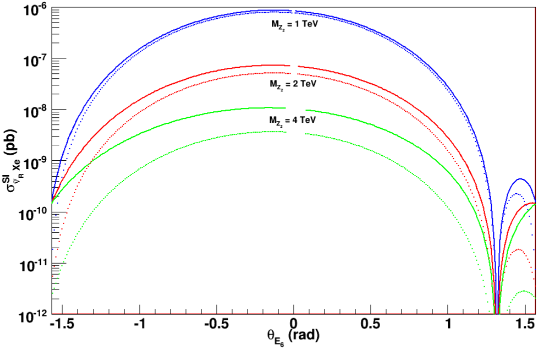
$$\frac{v}{v_s} \approx \frac{2 Z_{h31}}{Z_{h11}}$$

Direct detection constraint

Abelian gauge boson contribution to direct detection :

$$\sigma_{\tilde{\nu}_R N}^{Z_1,Z_2} = \frac{\mu_{\tilde{\nu}_R N}^2}{\pi}(g_1' Q_{\tilde{\nu}}')^2[(y(1-4s_W^2)+y')Z+(-y+2y')(A-Z)]^2$$

$$\text{with } y = \frac{g'\sin\alpha_Z\cos\alpha_Z}{4\sin\theta_W}\left(\frac{1}{M_{Z_2}^2}-\frac{1}{M_{Z_1}^2}\right),\ y' = -\frac{g_1'}{2}Q_V'^{d}\left(\frac{\sin^2\alpha_Z}{M_{Z_1}^2}+\frac{\cos^2\alpha_Z}{M_{Z_2}^2}\right)$$



$M_1 = 2.2$ TeV, $A_\lambda = 1$ TeV,
$\mu = M_{\tilde{\nu}_R} + 300$ GeV
and $M_{\tilde{\nu}_R} = M_{Z_2}/2$

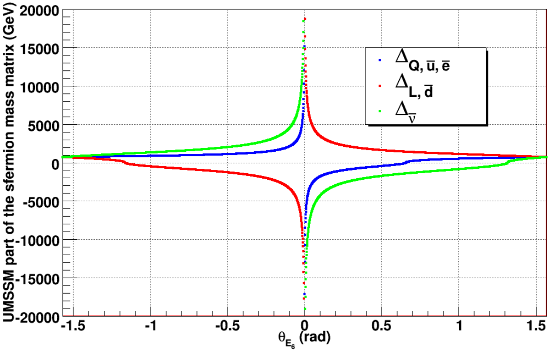
$\Rightarrow$ stringent constraints for small $|\theta_{E_6}|$ because of $Q_V'^{d}$ term

Coannihilation with sfermions

Sparticles sector :

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

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



⇒ in this graph Δ terms = $\text{sgn}(\Delta_f)\sqrt{|\Delta_f|}$

Coannihilations :
$\theta_{E_6} > 0$: generally $\tilde t_1$
$\theta_{E_6} < 0$: generally RH down sqarks