The fate of sneutrinos in Cold Dark Matter models

Jonathan Da Silva

Laboratoire d'Annecy-le-Vieux de Physique Théorique

Student seminar, Institute for Particle Physics Phenomenology, Durham University, UK, November 21, 2011

G. Bélanger, J. Da Silva and A. Pukhov, arXiv:1110.2414 [hep-ph]

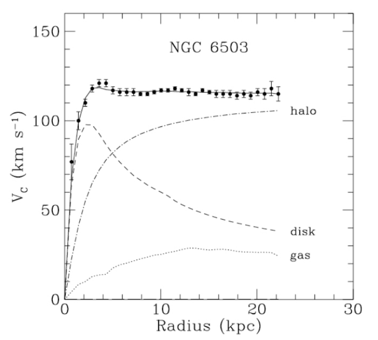
Outline

Motivations

Need of dark matter

Since 1933 and Zwicky observations, we accumulated evidences for dark matter (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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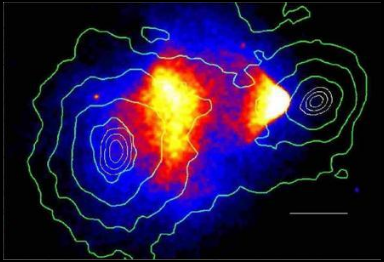
- Galaxy clusters scale : example of the bullet cluster



A direct empirical proof of the existence of dark matter, D. Clowe et al., astro-ph/0608407

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

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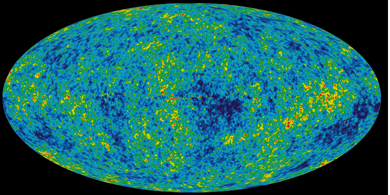

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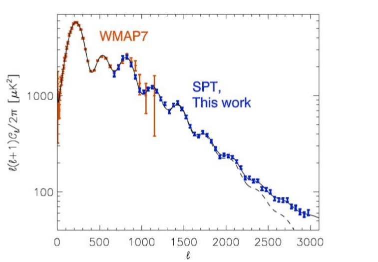

SPT

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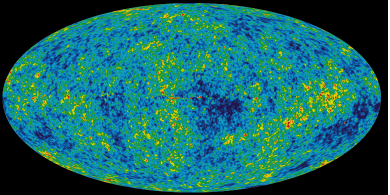

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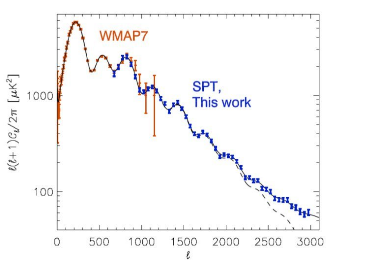

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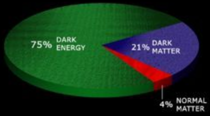

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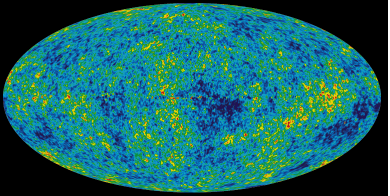

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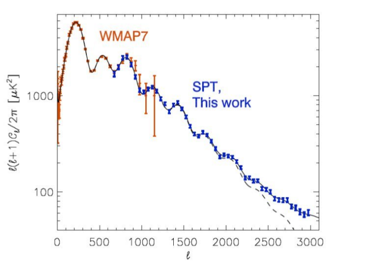

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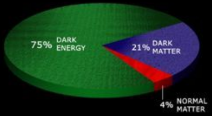

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Conservation of DM structures $\Rightarrow$ warm or cold DM

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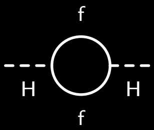

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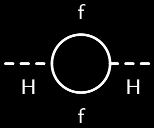

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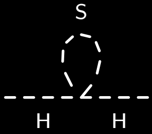
$\Rightarrow$ Supersymmetry, symmetry between fermions and bosons plays this role by adding one-loop corrections :

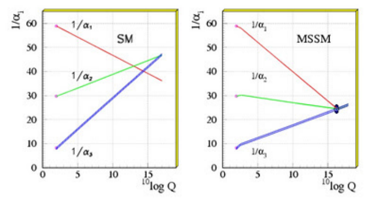


$$\Delta m_H^2 = \frac{|\lambda_S|^2}{16\pi^2}\Lambda^2 + ...$$

$\Rightarrow$ Cancellation of quadratic divergence

Need of supersymmetry

- Unification of coupling at GUT scale :



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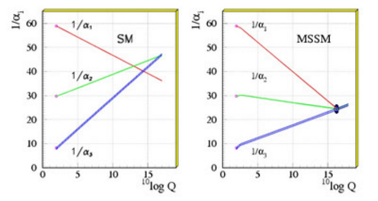

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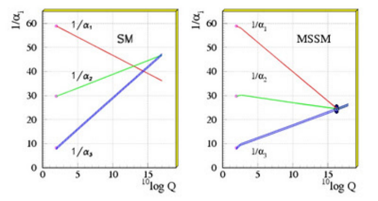

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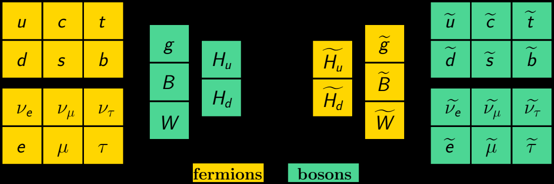

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  Some of them are weakly charged, so ...

  DM candidates in supersymmetric models ! ! !

Candidates

Some candidates

- Assuming R-parity, 2 cold DM (WIMPs) candidates in the MSSM :
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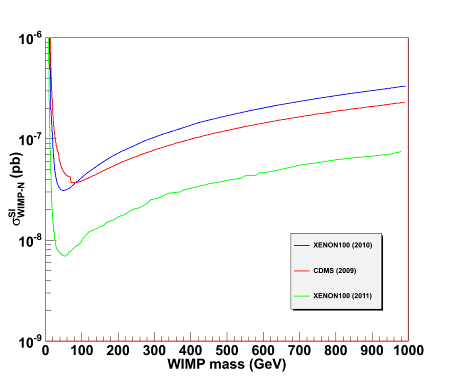

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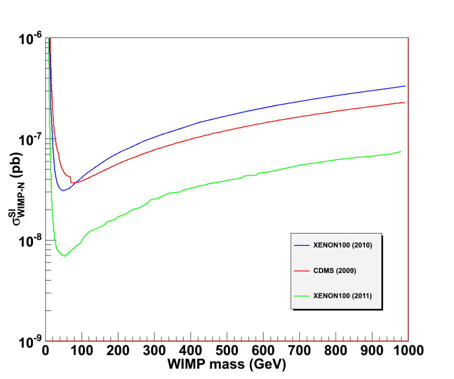

- Others SUSY candidates to DM : Gravitino, axino, ...

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  - ...
- Here we want generate RH neutrino mass 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 model

Contents

- Extending the SM gauge group is well-motivated in superstrings and grand unified theories hep-ph/9511378
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- Symmetry group : $SU(3)_c \times SU(2)_L \times U(1)_Y \times U'(1)$

  Coupling constants associated : 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 group $\Rightarrow$ it's a combination :

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

Relevant free parameters : $M_{\tilde{\nu}_R}$, μ, A_λ, M_{Z_2}, θ_{E_6}, α_Z, M_1, M_1'. Soft terms at 2 TeV

Constraints

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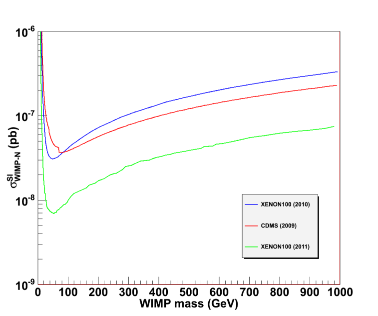
On our CDM candidate :

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



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M_{Z_2} (TeV)	1.49	1.52	1.54	1.56	1.60	1.64

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- LEP constraints on sparticles masses
- $B^0_{d,s} - \bar{B}^0_{d,s}$ mesons physics constraints : $\Delta M_{d,s}$ mass differences with one-loop supersymmetric contribution with charginos and higgsinos $\Rightarrow$ supersymmetry can increase difference between observed and standard model expected values :

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

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

CDM interactions

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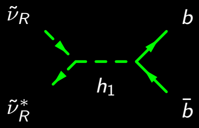

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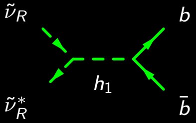

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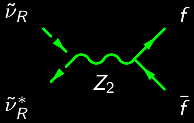

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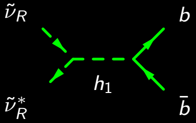

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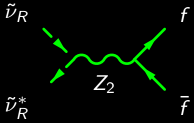

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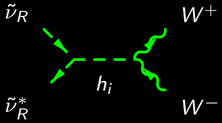

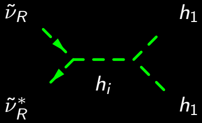

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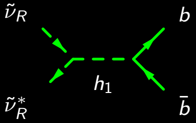

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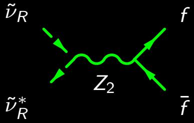

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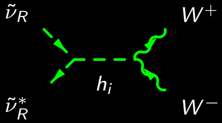
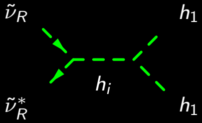
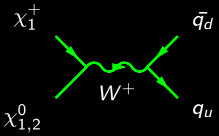
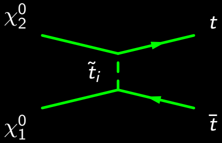




- Coannihilation processes (mainly higgsino-like) :





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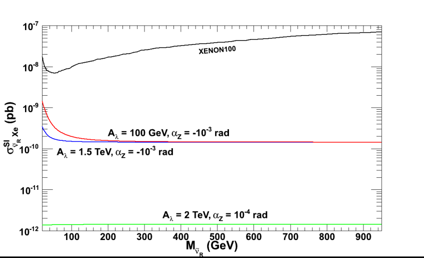

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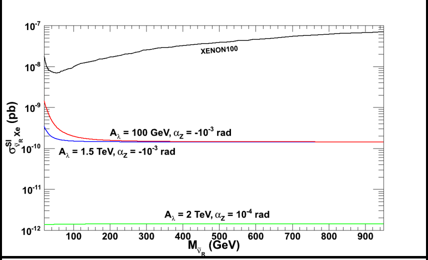
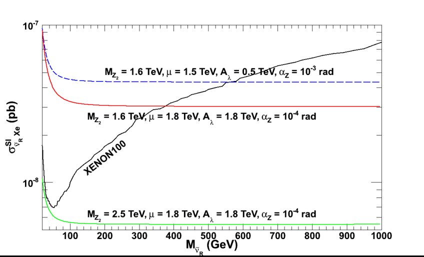


$\Rightarrow$ for other models, huge constraints on the parameter space appear :



Some results

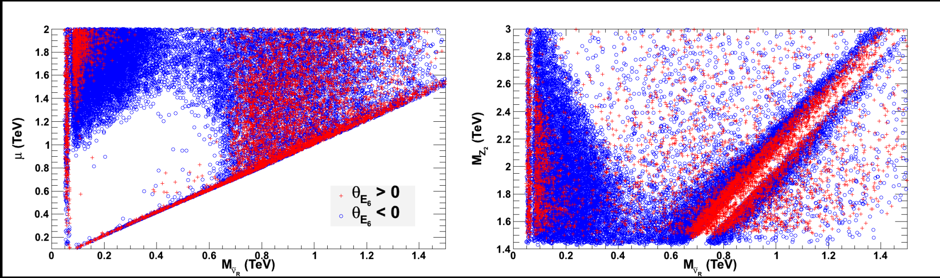
Characteristics of the global scan

Fixed parameters				**Free parameters**	
Soft terms				Name	Domain of variation
m_{Q_i}	2 TeV	m_{L_i}	2 TeV	$M_{\tilde{\nu}_R}$	[0, 1.5] TeV
$m_{\bar{u}_i}$	2 TeV	$m_{\bar{d}_i}$	2 TeV	M_{Z_2}	[1.3, 3] TeV
$m_{\bar{e}_i}$	2 TeV	$m_{\bar{\nu}_j}$	2 TeV	μ	[0.1, 2] TeV
i $\in \{1,2,3\}$, j $\in \{1,2\}$				A_λ	[0, 2] TeV
Trilinear couplings + M_K				θ_{E_6}	[-$\pi/2$, $\pi/2$] rad
A_t	1 TeV	A_b	0 TeV	α_Z	[-3.10^{-3}, 3.10^{-3}] rad
A_c	0 TeV	A_s	0 TeV	M_1	[0.1, 2] TeV
A_u	0 TeV	A_d	0 TeV	M_1'	[0.1, 2] TeV
A_l	0 TeV	M_K	1 eV	$M_2 = 2M_1$ et $M_3 = 6M_1$	

Output

Output

Interesting WIMP mass from 50 GeV to TeV-scale :



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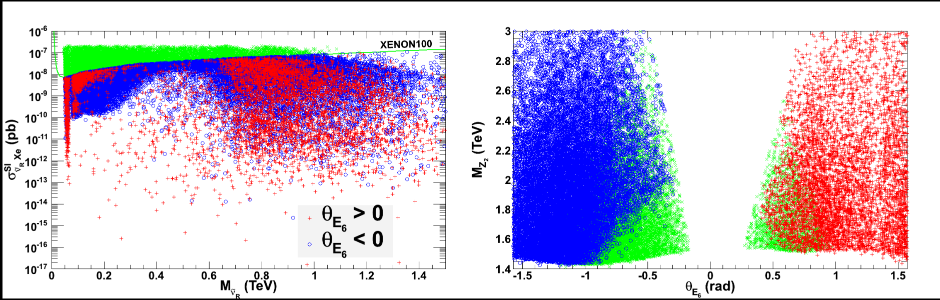
Interesting WIMP mass from 50 GeV to TeV-scale :



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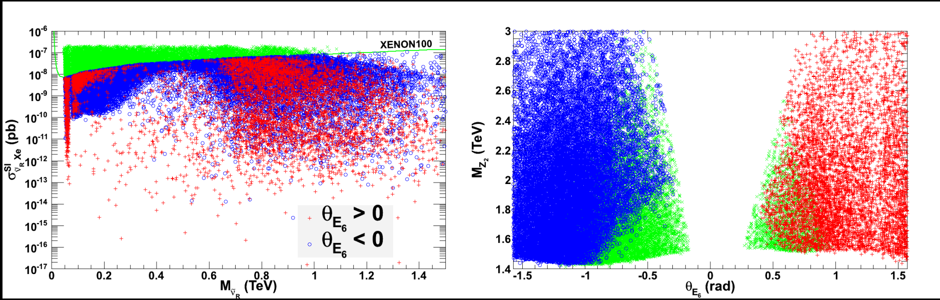
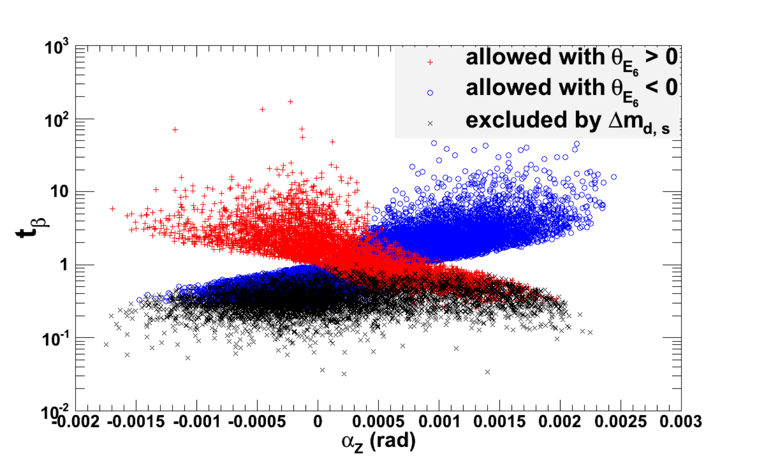


Lower is $|\theta_{E_6}|$, higher are Z_2 processes in direct detection cross section $\Rightarrow$ huge constraint

Output

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)
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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 :

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

- Soft supersymmetry breaking :

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

LanHEP, A. Semenov, arXiv :0805.0555v1 [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

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

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

M^2_{CPeven} :

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

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

$$\left(\mathcal{M}_+^0\right)_{13} = \left[\lambda^2 + Q_1' Q_S' g_{1'}{}^2\right] v c_\beta v_s - \frac{\lambda A_\lambda v s_\beta}{\sqrt{2}} + \Delta_{13}$$

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

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

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

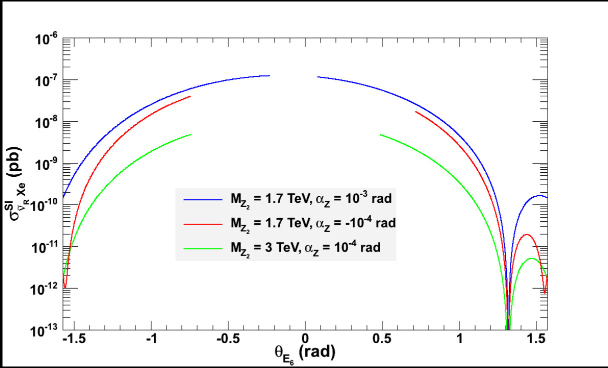
Vernon Barger, Paul Langacker, Hye-Sung Lee and Gabe Shaughnessy, arXiv :hep-ph/0603247v3

Direct detection constraint

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

Coannihilation with sfermions

Sparticles sector :

$$M_{\tilde{f}}^2 = \begin{pmatrix} m_{soft}^2 + m_f^2 + M_{Z^0}^2 \cos 2\beta (I_f^3 - e_f \sin^2\theta_W) + \Delta_f & m_f (A_f - \mu (t_\beta)^{-2I_f^3}) \\ m_f (A_f - \mu (t_\beta)^{-2I_f^3}) & m_{\overline{soft}}^2 + M_{Z^0}^2 \cos 2\beta (I_{\bar{f}}^3 - e_{\bar{f}} \sin^2\theta_W) + m_f^2 + \Delta_{\bar{f}} \end{pmatrix}$$

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