GUT inspired SUSY scenarios: Dark Matter versus LHC searches.

Mario E. Gómez

Departamento de Ciencias Integradas

Universidad de Huelva Spain

Universidad de Huelva

Colaboration with M. Canonni, J. Ellis, S. Lola, Ruiz de Austri
JCAP 1603 (2016)
and Q. Shafi (work on progress).

.
-GUT's and SUSY.

-NUHM: SO(10) vs SU(4)xSU(2)xSU(2)

- Neutralino relic density and DM detection.

-SUSY Masses and LHC searches

-Group with non-universal sfermions:
SU(5) and the flipped SU(5).

SUSY extension of SM

- Divergence cancellations
- Gauge unification
- Particles in the range of coming accelerators.
- DM candidate.
- Small but sizeable contribution to SM processes...

Soft SUSY Breaking Terms

The soft SUSY breaking masses

$$-\mathcal{L}_{\rm soft} = -\frac{1}{2}\left(M_3\,\lambda_{\tilde g}^a\lambda_{\tilde g}^a + M_2\,\lambda_{\widetilde W}^i\lambda_{\widetilde W}^i + M_1\,\lambda_{\widetilde B}\lambda_{\widetilde B} + \text{h.c.}\right)$$
$$+M_L^2\widetilde{L}^\dagger\widetilde{L} + M_Q^2\widetilde{Q}^\dagger\widetilde{Q} + M_U^2\widetilde{U}^*\widetilde{U} + M_D^2\widetilde{D}^*\widetilde{D} + M_E^2\widetilde{E}^*\widetilde{E} +$$
$$m_{H_d}^2\,\widetilde{H}_d^\dagger\widetilde{H}_d + m_{H_u}^2\,H_u^\dagger H_u - \left(B\mu\widetilde{H}_d^T H_u + \text{h.c.}\right)$$
$$+\left(y_\ell A_\ell\,H_d^\dagger\widetilde{L}\widetilde{E} + y_d A_d\,H_d^\dagger\widetilde{Q}\widetilde{D} - y_u A_u\,H_u^T\widetilde{Q}\widetilde{U} + \text{h.c.}\right),$$

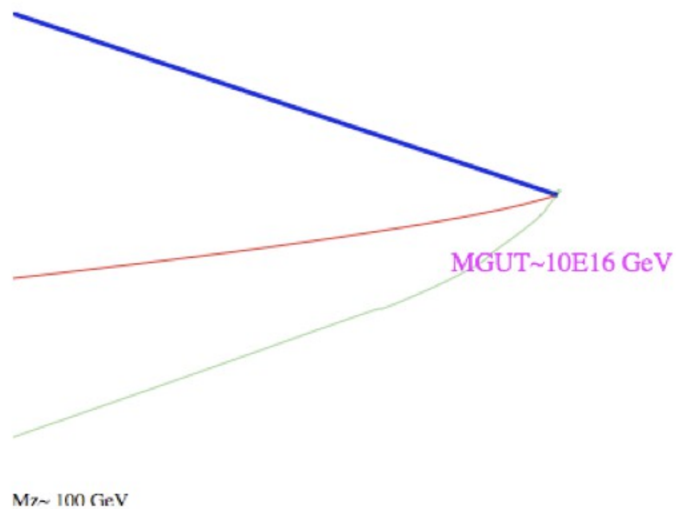
Inspired from supergravity assume universal soft breaking, $\mathcal{L}_{\rm soft}$:

$$\sum_{f,H} m_0^2\tilde{f}\tilde{f} + \sum_\lambda m_{\frac{1}{2}}\lambda\lambda + \sum_f A_0 Y_f\tilde{f}\tilde{F}H_f + B\mu H_u H_d$$

m_0, $m_{\frac{1}{2}}$, A_0, $\tan\beta$, sign(μ)

μ and A_0 can be complex, however their phases contraint to be $< 0{,}2$ rad by the bounds c

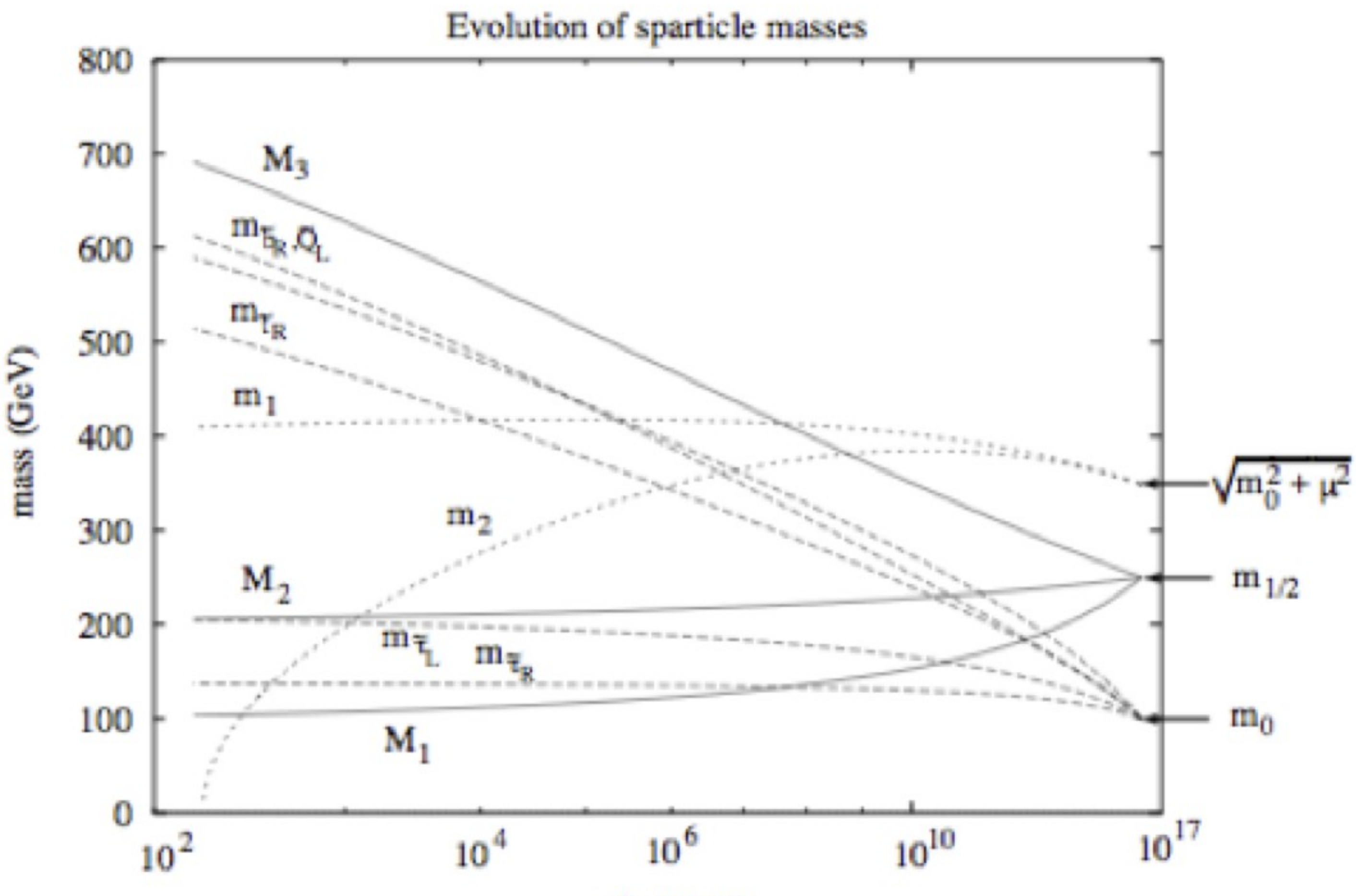
the fermion EDM.


MGUT~10E16 GeV
Mz~ 100 GeV

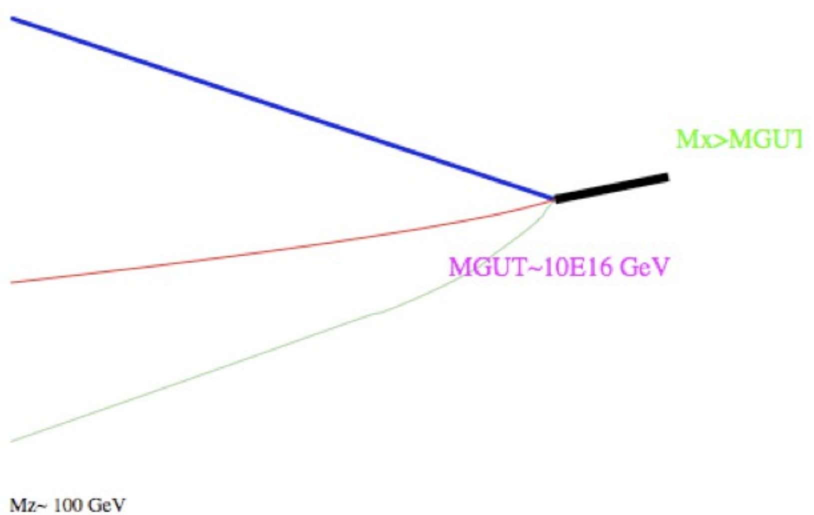
SUSY spectrum

CMSSM, mSUGRA. Parametros de masa universales:

$$m_0,\ M_{1/2},\ A_0,\ \mu_0,\ \alpha_G,\ M_{GUT},\ \tan\beta\ .$$



—


Mx>MGUT
MGUT~10E16 GeV
Mz~ 100 GeV

Non Universal scenarios

CMSSM choice:

- *m0 Universal soft masses.*
- m1/2 *Universal gaugino masses.*
- A0 *Universal Trilinear terms.*

Representation-dependent choice

$$m_r = x_r \, m_0$$

$$A_r = Y_r \, A_0 , \quad A_0 = a_0 \, m_0$$

Non Universal SO(10)

$$W_{SO(10)} = \lambda^u_{ij} 16_i 10^u 16_j + \lambda^d_{ij} 16_i 10^d 16_j$$

$$Q_L, D, U, L, E, N \subseteq 16$$

$$H_u \subset 10^u ; H_u \subset 10^u$$

The soft term masses are taken at GUT as:

$$m_{16} = m_0 ; m_u = x_u m_0 ; m_d = x_d m_0 ;$$

Trilinear terms:

$$A_0 = a_0 m_0$$

Non Universal SO(10)

$$W_{SO(10)} = \lambda^u_{ij} 16_i 10^u 16_j + \lambda^d_{ij} 16_i 10^d 16_j$$

$$Q_L, D, U, L, E, N \subseteq 16$$

$$H_u \subset 10^u ; H_u \subset 10^u$$

The soft term masses are taken at GUT as:

$$m_{16} = m_0 ; m_u = x_u m_0 ; m_d = x_d m_0 ;$$

Equivalent to NUHM

Trilinear terms:

$$A_0 = a_0 m_0$$

PATI-SALAM Unification

$$G_{PS} \equiv SU(4) \times SU(2)_L \times SU(2)_R$$

$\mathbf{4}_c\mathbf{2}_L\mathbf{2}_R$

MATTER FIELDS		
F_r	$\begin{pmatrix} d_r & -u_r \end{pmatrix}$ $\begin{pmatrix} e_r & -\nu_r \end{pmatrix}$	$(\mathbf{4},\mathbf{2},\mathbf{1})$
F_r^c	$\begin{pmatrix} u_r^c \\ d_r^c \end{pmatrix}, \begin{pmatrix} \nu_r^c \\ e_r^c \end{pmatrix}$	$(\bar{\mathbf{4}},\mathbf{1},\mathbf{2})$

$$< \tilde{\nu}_H^c > = < \tilde{\bar{\nu}}_H^c > \sim M$$

HIGGS FIELDS		
H^c	$\begin{pmatrix} u_H^c \\ d_H^c \end{pmatrix}, \begin{pmatrix} \nu_H^c \\ e_H^c \end{pmatrix}$	$(\bar{\mathbf{4}},\mathbf{1},\mathbf{2})$
$\bar{H}^c$	$\begin{pmatrix} \bar{u}_H^c & \bar{d}_H^c \end{pmatrix}$ $\begin{pmatrix} \bar{\nu}_H^c & \bar{e}_H^c \end{pmatrix}$	$(\mathbf{4},\mathbf{1},\mathbf{2})$
h	$\begin{pmatrix} h_2^+ & h_1^0 \\ h_2^0 & h_1^- \end{pmatrix}$	$(\mathbf{1},\mathbf{2},\mathbf{2})$

$$G_{PS} \to \mathrm{SU}(3)_C \otimes \mathrm{SU}(2)_L \otimes \mathrm{U}(1)_Y$$

Non universal Higgs Mass terms due to D- terms.

$$m_{H_{u,d}}^2 = m_{10}^2 \mp 2M_D^2$$

$$M_1 = \frac{3}{5}M_2 + \frac{2}{5}M_3.$$

Condition for gaugino masses.

→ SUSY SEARCH: SuperBayeS, MultiNest

→ RGE's: SoftSusy

→ Relic Density: MicroOMEGAs

→ Direct DM detection: DarkSUSY

→ Super Iso: $\delta a_\mu^{\rm SUSY}$

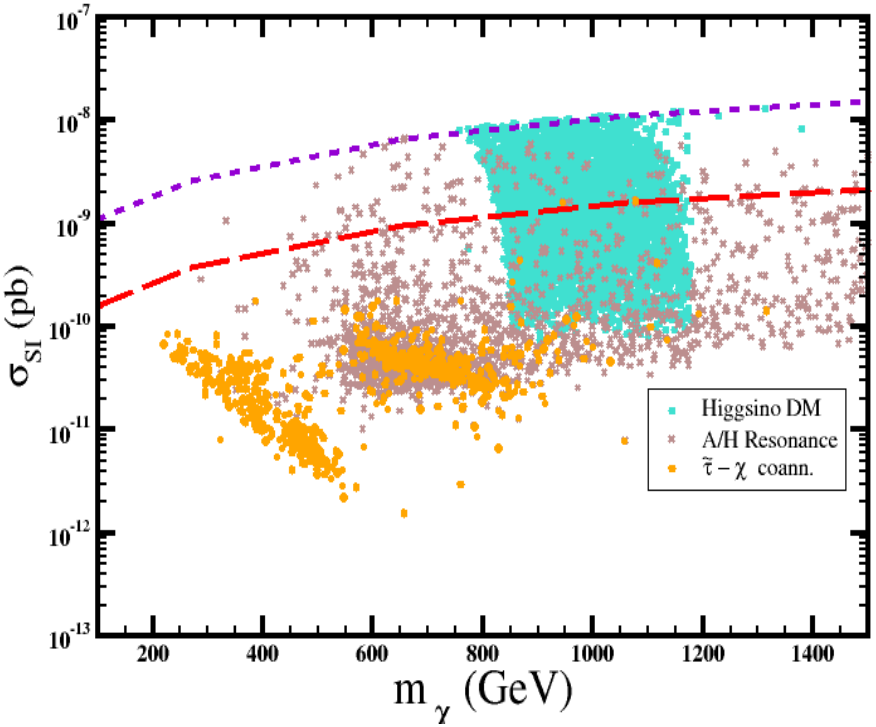
→ SusyBSG: B-Physics.

Likelyhood function:

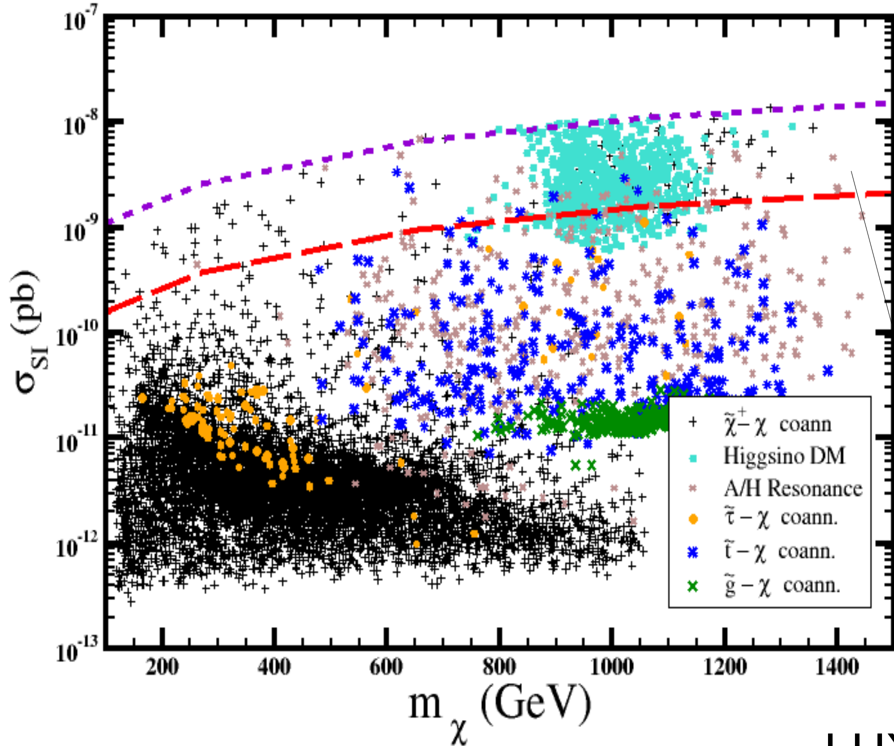
$$\begin{aligned}\ln \mathcal{L}_{\rm Joint} &= \ln \mathcal{L}_{\rm EW} + \ln \mathcal{L}_{\rm B} + \ln \mathcal{L}_{\Omega_\chi h^2} \\ &\quad + \ln \mathcal{L}_{\rm LUX} + \ln \mathcal{L}_{\rm Higgs} + \ln \mathcal{L}_{\rm SUSY} + \ln \mathcal{L}_{\rm g-2},\end{aligned}$$

Set 1	SO(10)	SU(5)	FSU(5)
$100\ \text{GeV} \leq m_0 \leq 10\ \text{TeV}$	$0 \leq x_u \leq 2$	$0 \leq x_u \leq 2$	$0 \leq x_u \leq 2$
$50\ \text{GeV} \leq m_{1/2} \leq 10\ \text{TeV}$	$0 \leq x_d \leq 2$	$0 \leq x_d \leq 2$	$0 \leq x_d \leq 2$
$-10\ \text{TeV} \leq A_0 \leq 10\ \text{TeV}$		$0 \leq x_5 \leq 2$	$0 \leq x_5 \leq 2$
$2 \leq \tan\beta \leq 65$			$0 \leq x_R \leq 2$
Set 2	SO(10)	SU(5)	FSU(5)
$100\ \text{GeV} \leq m_0 \leq 2500\ \text{GeV}$	$0 \leq x_u \leq 1$	$0 \leq x_u \leq 1$	$0 \leq x_u \leq 1$
$50\ \text{GeV} \leq m_{1/2} \leq 2500\ \text{GeV}$	$0 \leq x_d \leq 2$	$0 \leq x_d \leq 2$	$0 \leq x_d \leq 2$
$-10\ \text{TeV} \leq A_0 \leq 10\ \text{TeV}$		$0 \leq x_5 \leq 2$	$0 \leq x_5 \leq 1$
$2 \leq \tan\beta \leq 65$			$1 \leq x_R \leq 2$

SO(10)



PS(4-2-2)



LUX2016

Higgsino χ_1^0:

$$h_f \equiv |N_{13}|^2 + |N_{14}|^2 ,$$

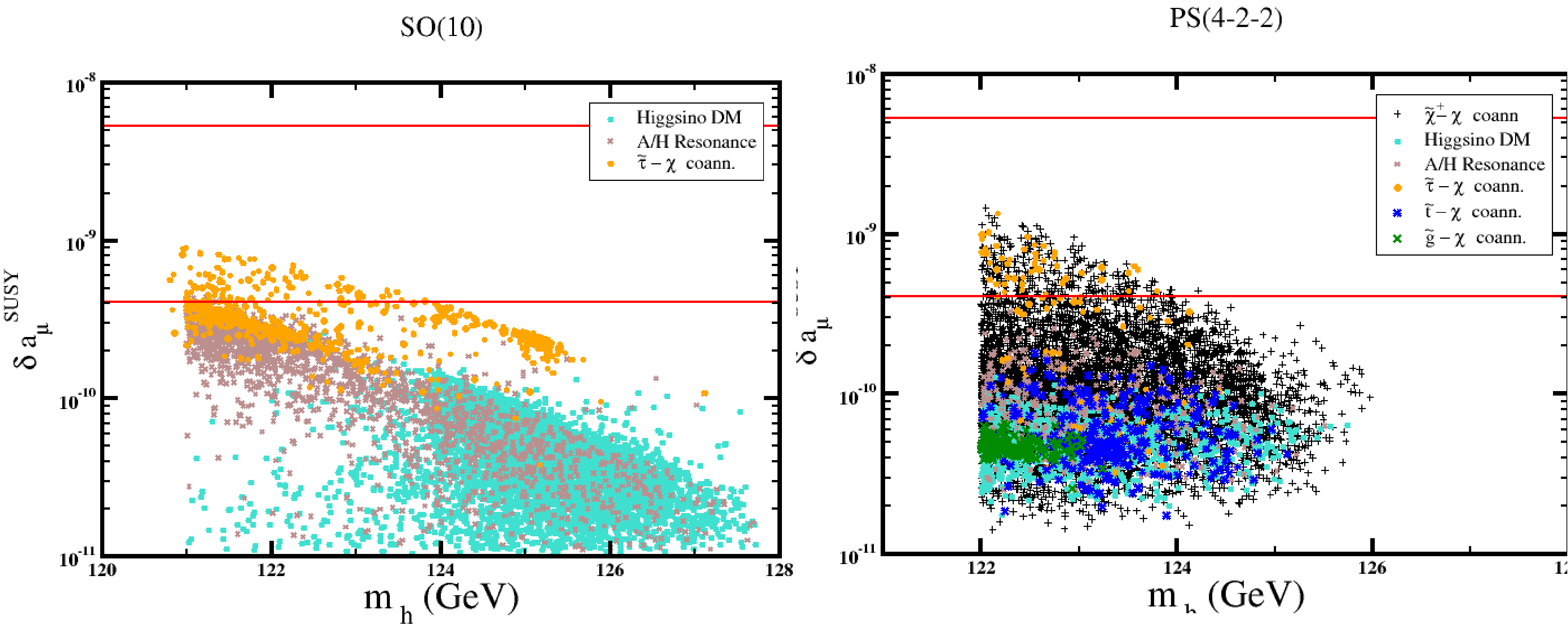
$$h_f > 0.1,$$

A/H Resonances:

$$|m_A - 2m_\chi| \leq 0.1\, m_\chi .$$

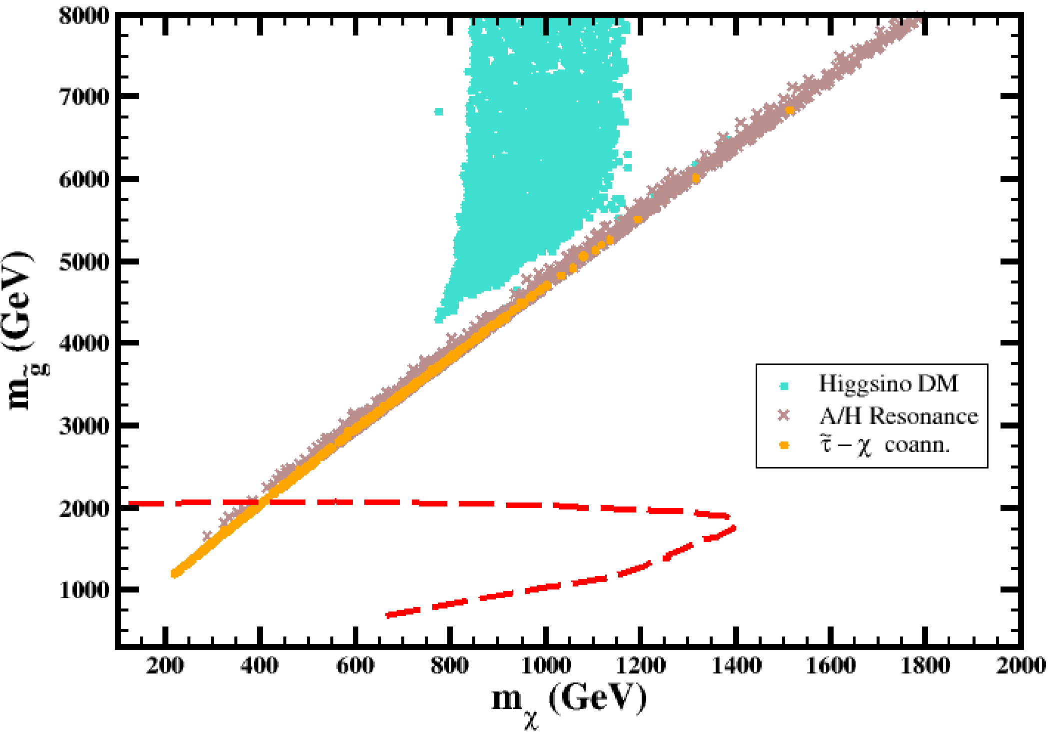
Coanihilations: $(m_z - m_{LSP}) < 0.1\, m_{LSP}$

$\tilde{\tau}$ $\tilde{\chi}^{+}$ Stop gluino

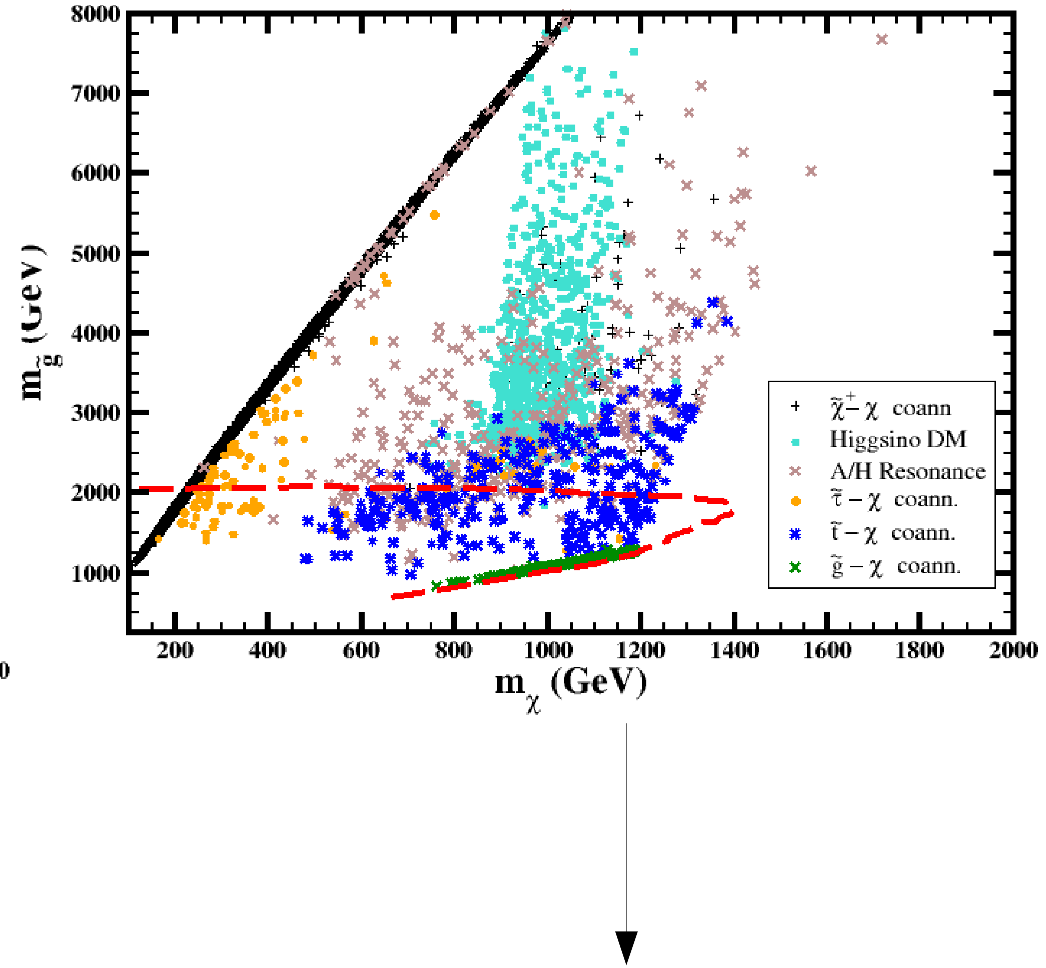


Hard to explain g-2 only with SUSY contribution.

SO(10)

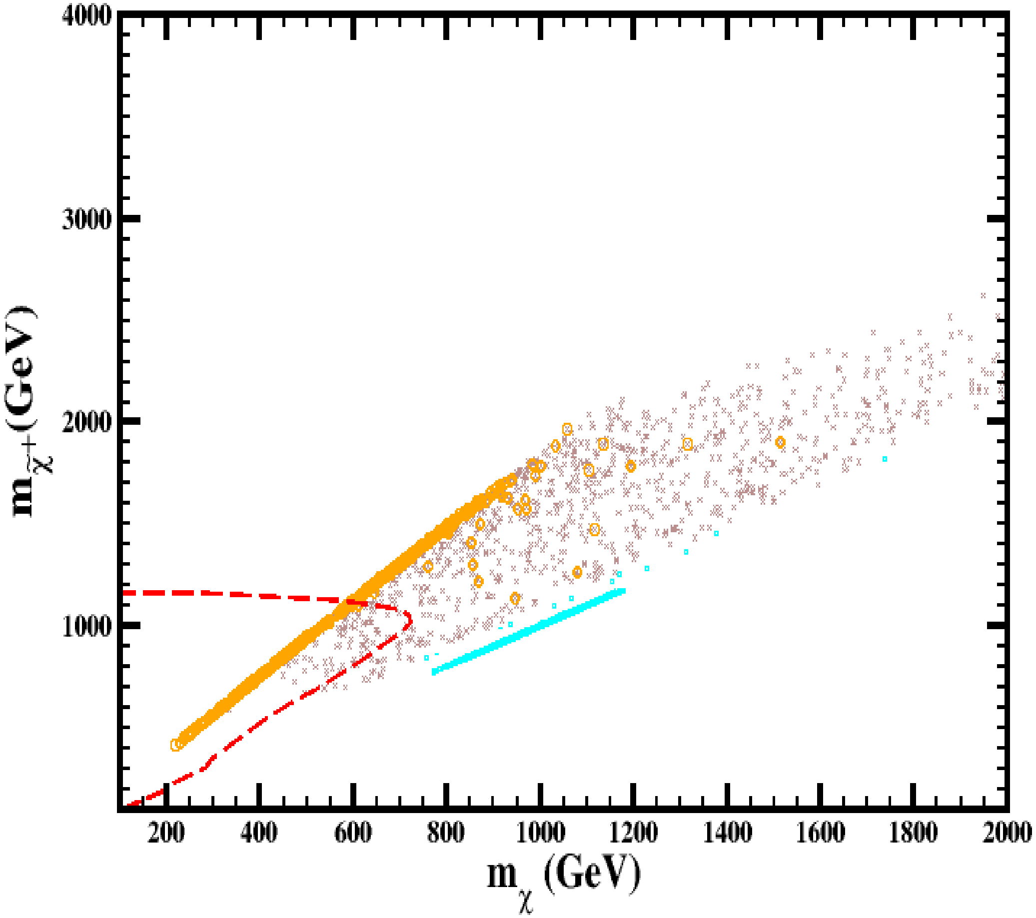


PS(4-2-2)



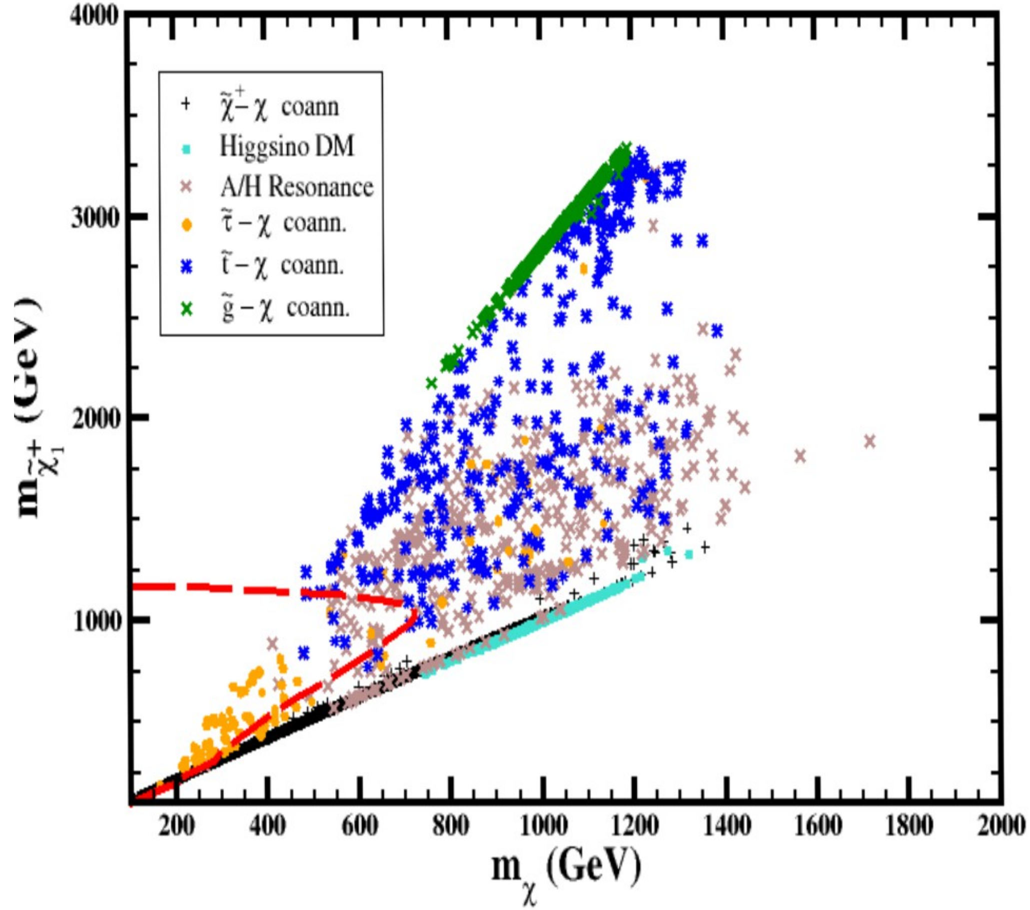
Points are filterd using the results of Atlas RUN1 using SUSY-AI (arXiv:1605.02797)

SO(10)



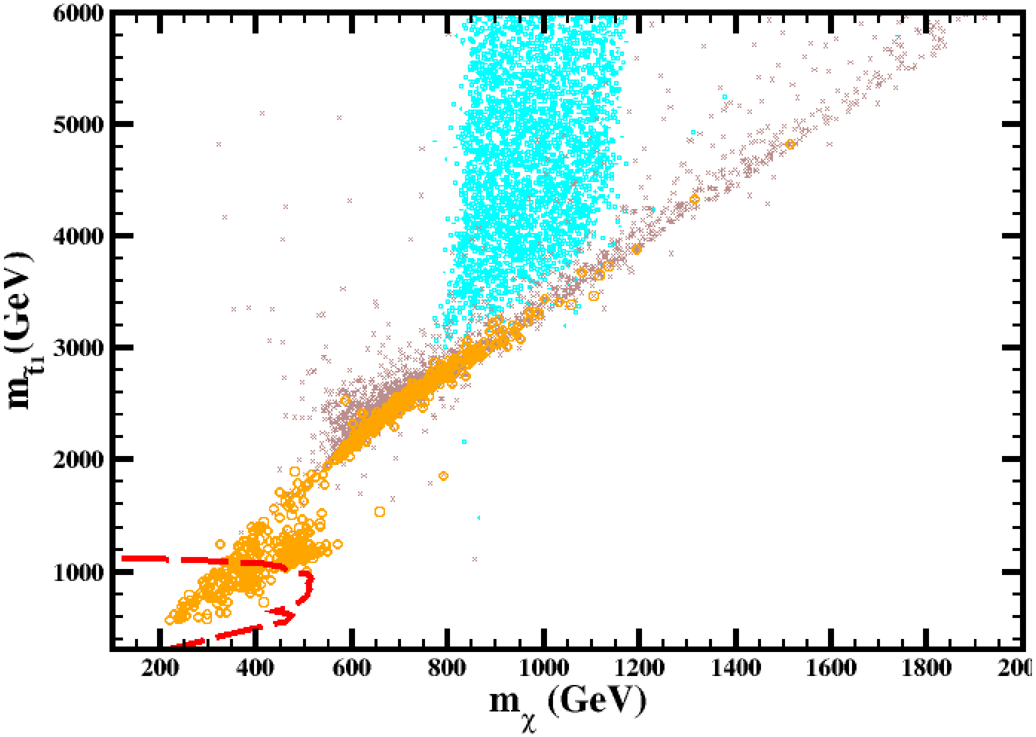
$m_{\tilde{\chi}^+}$ (GeV)
m_χ (GeV)

PS(4-2-2)

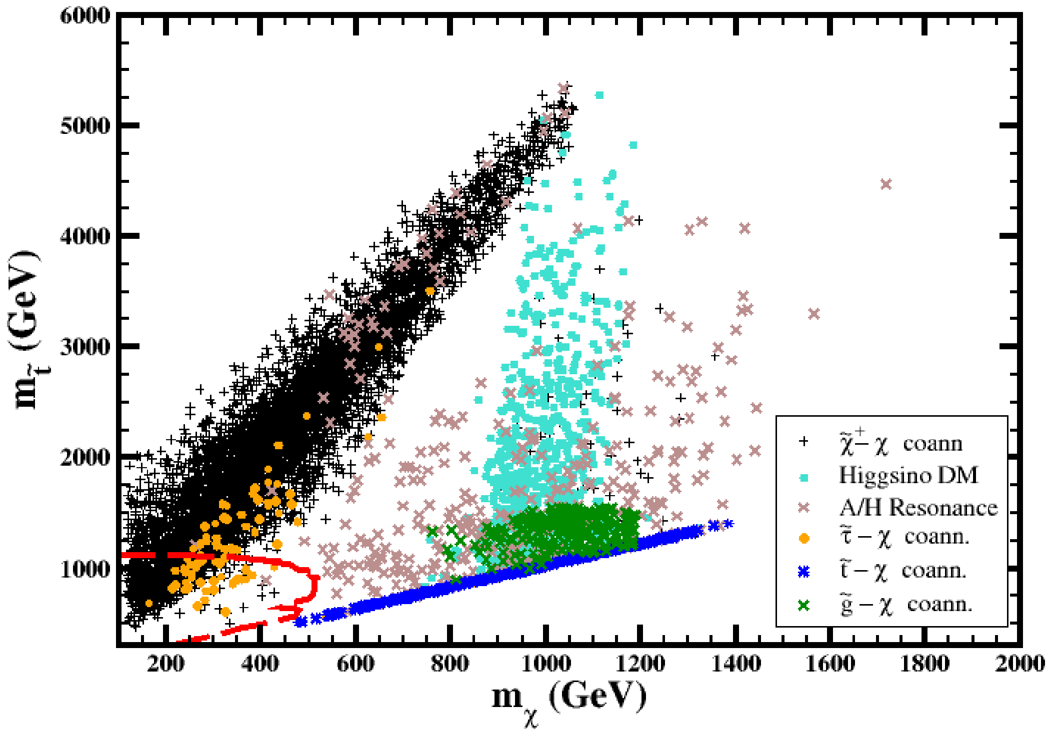


$\tilde{\chi}^+ - \chi$ coann
Higgsino DM
A/H Resonance
$\tilde{\tau} - \chi$ coann.
$\tilde{t} - \chi$ coann.
$\tilde{g} - \chi$ coann.
$m_{\tilde{\chi}_1^+}$ (GeV)
m_χ (GeV)

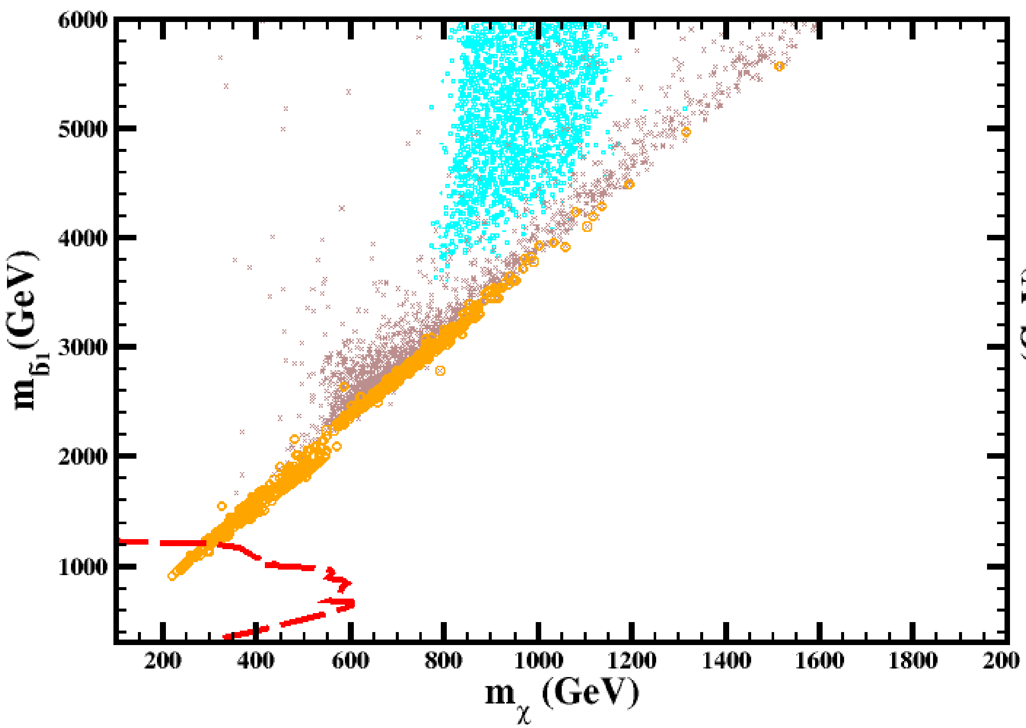
SO(10)


6000
5000
4000
3000
2000
1000
200
400
600
800
1000
1200
1400
1600
1800
200
m_χ (GeV)
m_t̃1 (GeV)

PS(4-2-2)

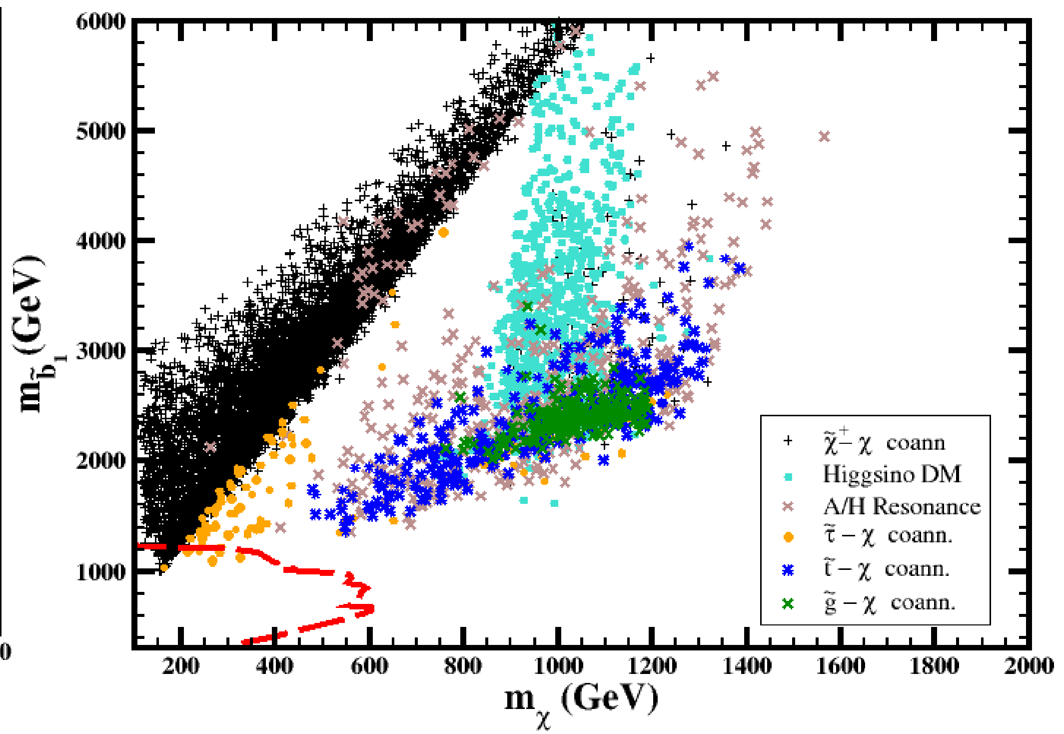

6000
5000
4000
3000
2000
1000
200
400
600
800
1000
1200
1400
1600
1800
2000
m_χ (GeV)
m_t̃ (GeV)
χ̃± – χ coann
Higgsino DM
A/H Resonance
τ̃ – χ coann.
t̃ – χ coann.
g̃ – χ coann.

SO(10)



$m_{\tilde{b}_1}$ (GeV)
m_χ (GeV)

PS(4-2-2)



$m_{\tilde{b}_1}$ (GeV)
m_χ (GeV)
$\tilde{\chi}^\pm - \chi$ coann
Higgsino DM
A/H Resonance
$\tilde{\tau} - \chi$ coann.
$\tilde{t} - \chi$ coann.
$\tilde{g} - \chi$ coann.

Non Universal SU(5)

$$W_{SU(5)} = Y_u^{ij} 10_i 10_j 5^u + Y_d^{ij} 10_i \bar{5}_j \bar{5}^d$$

$$(Q_L, U, E) \subseteq 10$$

$$H_u \subset 5^u ; H_d \subset \bar{5}^d$$

$$(D, L) \subseteq \bar{5}$$

The soft terms are taken at GUT as:

$$m_{10} = m_0 ;$$
$$m_5 = x_5 \cdot m_{10} ;$$
$$m_u = x_u \cdot m_{10} ;$$
$$m_d = x_d \cdot m_{10.}$$

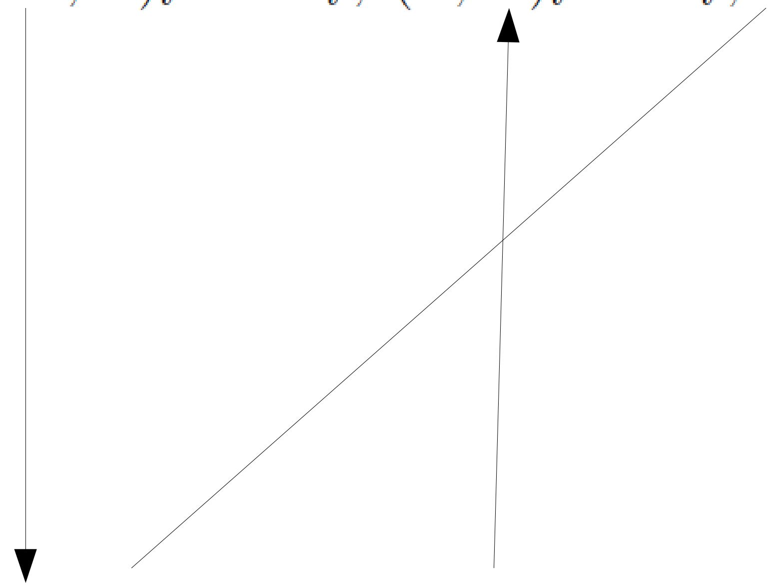
$$A_{10,5} = a_0 \cdot m_{0,}$$

Okada, Shafi, Raza

Phys.Rev. D90 (2014)

Flipped SU(5)

SU(5) $(Q, u^c, e^c)_i \in \mathbf{10}_i\,,\ (L, d^c)_i \in \bar{\mathbf{5}}_i\,,\ \nu^c_i \in \mathbf{1}_i\,.$

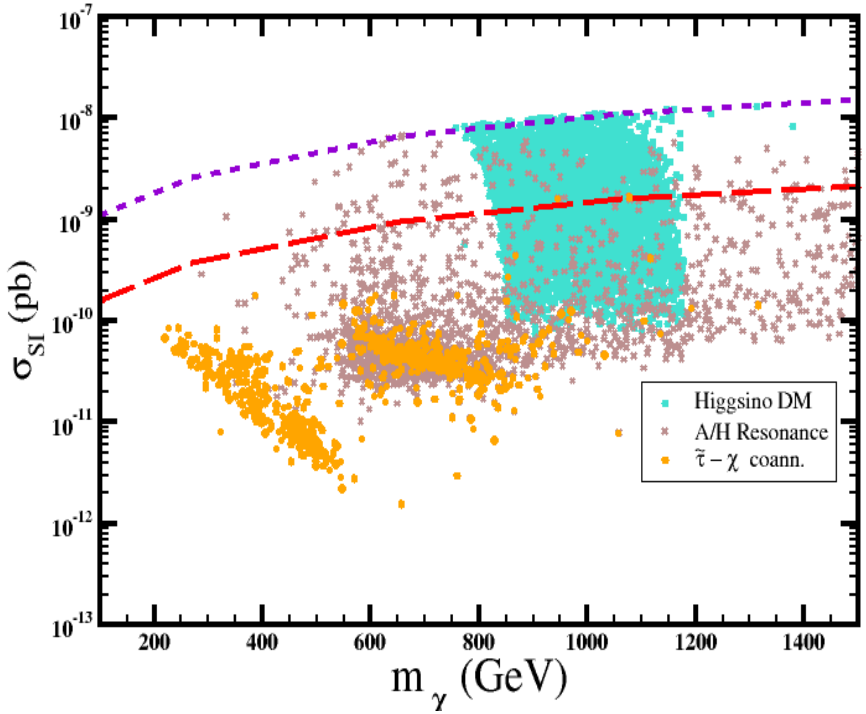


Flipped SU(5) $(Q, d^c, \nu^c)_i \in \mathbf{10}_i\,,\ (L, u^c)_i \in \bar{\mathbf{5}}_i\,,\ e^c_i \in \mathbf{1}_i\,.$

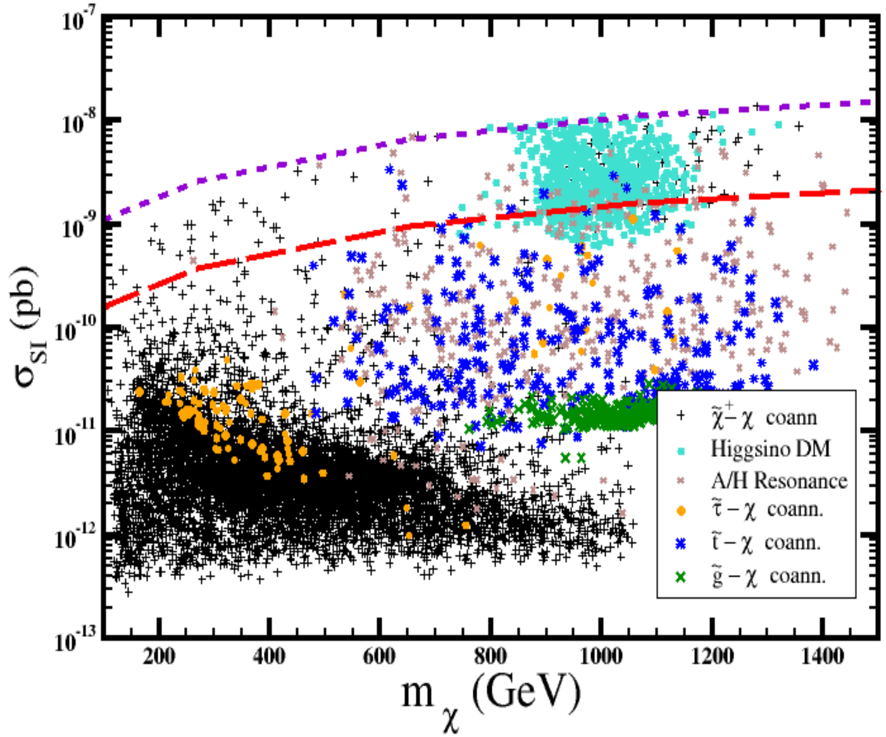
$$m_{10} = m_0, \quad m_5 = x_5 \cdot m_{10} \quad m_R = x_R \cdot m_{10}$$

$$m_{H_u} = x_u \cdot m_{10} \quad m_{H_d} = x_d \cdot m_{10}\,;$$

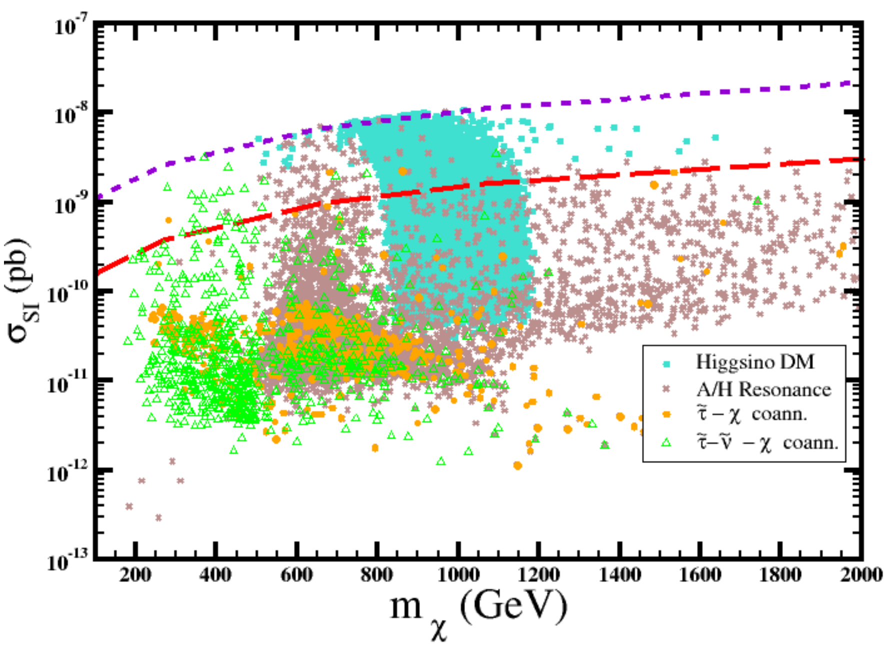
SO(10)



PS(4-2-2)

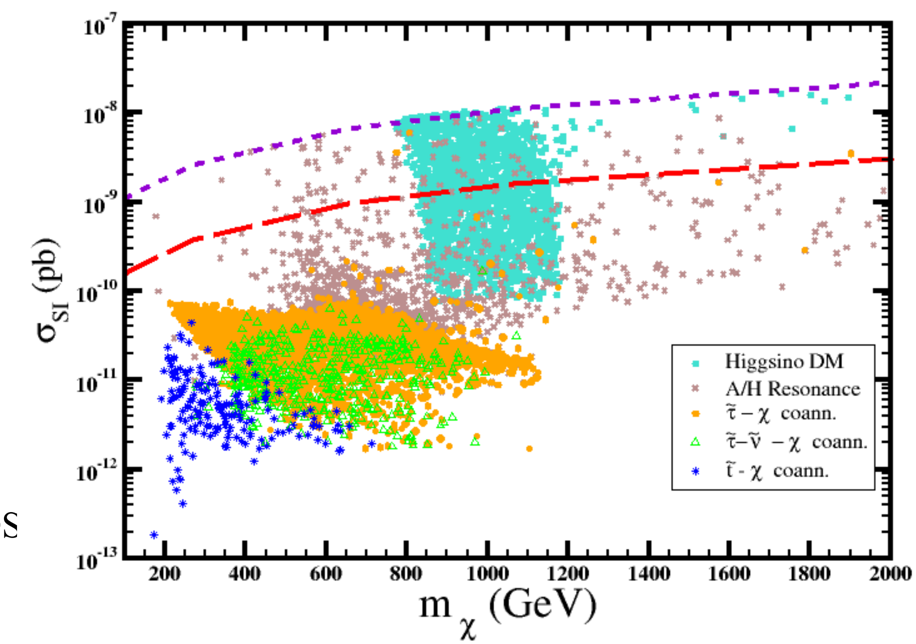


SU(5)



ez, PASCOS

Flip-SU(5)



CONCLUSIONS

We have identified different patterns of soft SUSY-breaking terms at the GUT scale, with different dark matter predictions and the constraints from LHC searches.

We have calculated the SUSY spectra for the different gauge groups, finding that the models predict different spectra for the same LSP mass, connecting possible future observations with the structure of the underlying unified theory.

None of the GUT models studied offers high prospects for reducing substantially the a_\mu discrepancy via a SUSY contribution.

We have found that SO(10),PS, SU(5) and flipped SU(5) lead to very different predictions for dark matter and LHC experiments, and thus are distinguishable in future searches. Flipped SU(5) and PS predicts stop-LSP coannihilations that are absent in the other groups and can be explored by LHC searches.

The LHC searches for generic missing E_T, charginos and stops are quite complementary, and future LHC runs will be able to constrain the models in several different ways.