All about the Triplet

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- Introduction
- The Georgi-Machacek model, solving the T-parameter: susy breaking
- ….. and dark matter.
- Conclusions

Introduction

- The run I of the LHC has discovered the last building block of the SM: The Higgs

- Its properties are compatible with the ones of the SM: minimal realization of the Higgs potential

- But an extended Higgs sector is not yet excluded and can have different and interesting signatures.

- One way of deviating from the minimal model is to include extra Higgses:
  - More doublets
  - singlets
  - Triplets
  - …….

- These extra fields could appear in a UV completion of the model and could remain light by the same mechanism as the SM Higgs
  - Pseudo-goldstone boson
  - Supersymmetry

- In this talk I am going to explore different aspects of an extended Higgs sector with triplets in a supersymmetric model.

- Triplets can help on the Higgs mass without destabilizing the EW scale

- In general there are two possible triplets that could mix with the Higgs, Y=0 and Y=1.

- The kind of couplings are:

$$W = \lambda_0 H_u T_0 H_d + \lambda_{+1} H_d T_{+1} H_d + \lambda_{-1} H_u T_{-1} H_u$$

- In principle the triplet will get a vev once EWSB occurs and can lead to a dangerous contribution to the T-parameter

- I will make sure that the vev of the triplet component by implementing a symmetry to avoid contributions to the T-parameter.

The (SUSY)-Georgi-Machacek model: SUSY breaking and DM

- The GM model was proposed to ensure a custodial structure with triplets.

- It was supersymmetrized in arXiv:1308.4025

$$\bar{H} = \begin{pmatrix} H_1 \\ H_2 \end{pmatrix}, \quad \bar{\Delta} = \begin{pmatrix} -\frac{\Sigma_0}{\sqrt{2}} & -\Sigma_{-1} \\ -\Sigma_1 & \frac{\Sigma_0}{\sqrt{2}} \end{pmatrix}$$

$$W_0 = \lambda \bar{H} \cdot \bar{\Delta} \bar{H} + \frac{\lambda_3}{3} \operatorname{tr} \bar{\Delta}^3 + \frac{\mu}{2} \bar{H} \cdot \bar{H} + \frac{\mu_\Delta}{2} \operatorname{tr} \bar{\Delta}^2 + h_t \, \overline{Q}_L \cdot H_2 t_R + h_b \, \overline{Q}_L \cdot H_1 b_R$$

- RGE evolution, yukawa and U(1) break the custodial limit and generate a non-zero ρ so in general:

$$W = -\lambda_a H_1 \cdot \Sigma_1 H_1 + \lambda_b H_2 \cdot \Sigma_{-1} H_2 + \sqrt{2}\lambda_c H_1 \cdot \Sigma_0 H_2 + \sqrt{2}\lambda_3 \mathrm{tr}\, \Sigma_1 \Sigma_0 \Sigma_{-1}$$
$$- \mu H_1 \cdot H_2 + \frac{\mu_{\Delta_a}}{2} \mathrm{tr}\, \Sigma_0^2 + \mu_{\Delta_b} \mathrm{tr}\, \Sigma_1 \Sigma_{-1} + h_t\, \overline{Q}_L \cdot H_2 t_R + h_b\, \overline{Q}_L \cdot H_1 b_R$$

$$V_{\mathrm{SOFT}} = m_{H_1}^2 H_1^\dagger H_1 + m_{H_2}^2 H_2^\dagger H_2 + m_{\Sigma_0}^2 \Sigma_0^\dagger \Sigma_0 + m_{\Sigma_1}^2 \Sigma_1^\dagger \Sigma_1 + m_{\Sigma_{-1}}^2 \Sigma_{-1}^\dagger \Sigma_{-1} - m_3^2 H_1 \cdot H_2$$
$$+ \Big\{ \frac{B_{\Delta_a}}{2} \mathrm{tr} \Sigma_0^2 + B_{\Delta_b} \mathrm{tr} \Sigma_1 \Sigma_{-1} - A_{\lambda_a} H_1 \cdot \Sigma_1 H_1 + A_{\lambda_b} H_2 \cdot \Sigma_{-2} H_2$$
$$+ \sqrt{2} A_{\lambda_c} H_1 \cdot \Sigma_0 H_2 + \sqrt{2} A_{\lambda_3} \mathrm{tr}\, \Sigma_1 \Sigma_0 \Sigma_{-1} + a_t\, \tilde{Q}_L \cdot H_2 \tilde{t}_R + a_b\, \tilde{Q}_L \cdot H_1 \tilde{b}_R + h.c. \Big\}$$

- I am going to embed this model into a predictive scenario of SUSY breaking like GMSB to see the deviation from the custodial limit:

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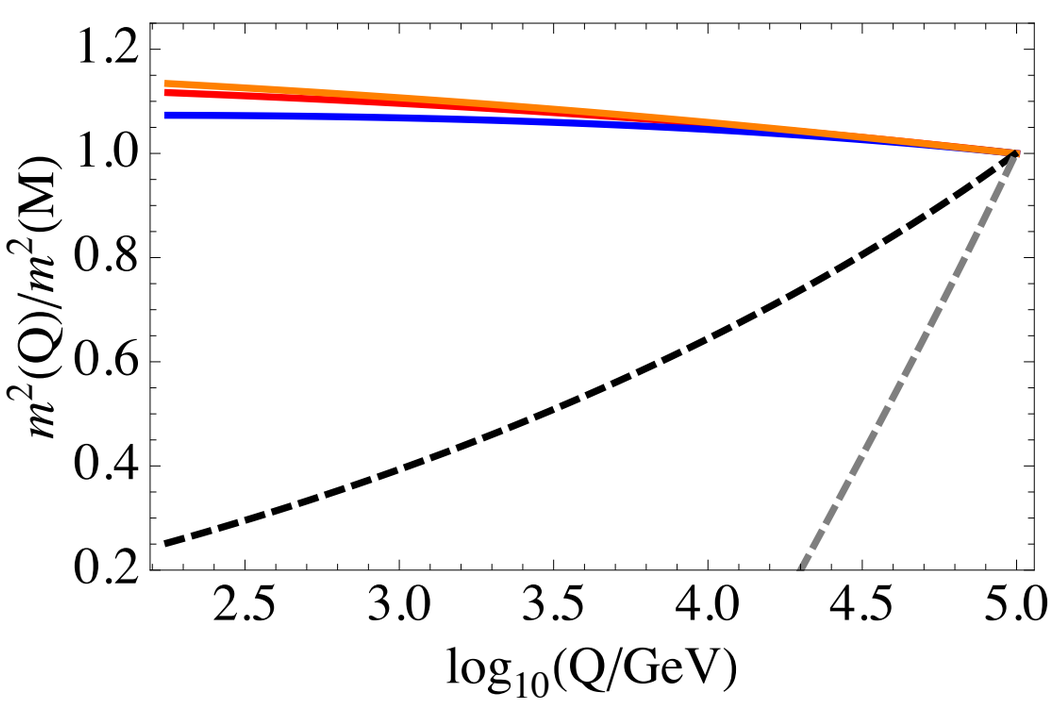
$$W = \left(\tilde{\lambda}_8^{ij} X + \mathcal{M}_8^{ij}\right) \Phi_{8i}\Phi_{8j} + \left(\tilde{\lambda}_3^{ij} X + \mathcal{M}_3^{ij}\right) \Phi_{3i}\Phi_{3j} + \left(\tilde{\lambda}_1^{ij} X + \mathcal{M}_1^{ij}\right) \bar{\Phi}_{1i}\Phi_{1j}$$

$$\begin{aligned}
M_3 &= \frac{\alpha_3(\mathcal{M})}{4\pi} 3 n_8 g(\Lambda_8/\mathcal{M})\Lambda_8 \,, \\
M_2 &= \frac{\alpha_2(\mathcal{M})}{4\pi} 2 n_3 g(\Lambda_3/\mathcal{M})\Lambda_3 \,, \\
M_1 &= \frac{\alpha_1(\mathcal{M})}{4\pi} \frac{6}{5} n_1 g(\Lambda_1/\mathcal{M})\Lambda_1 \,,
\end{aligned}$$

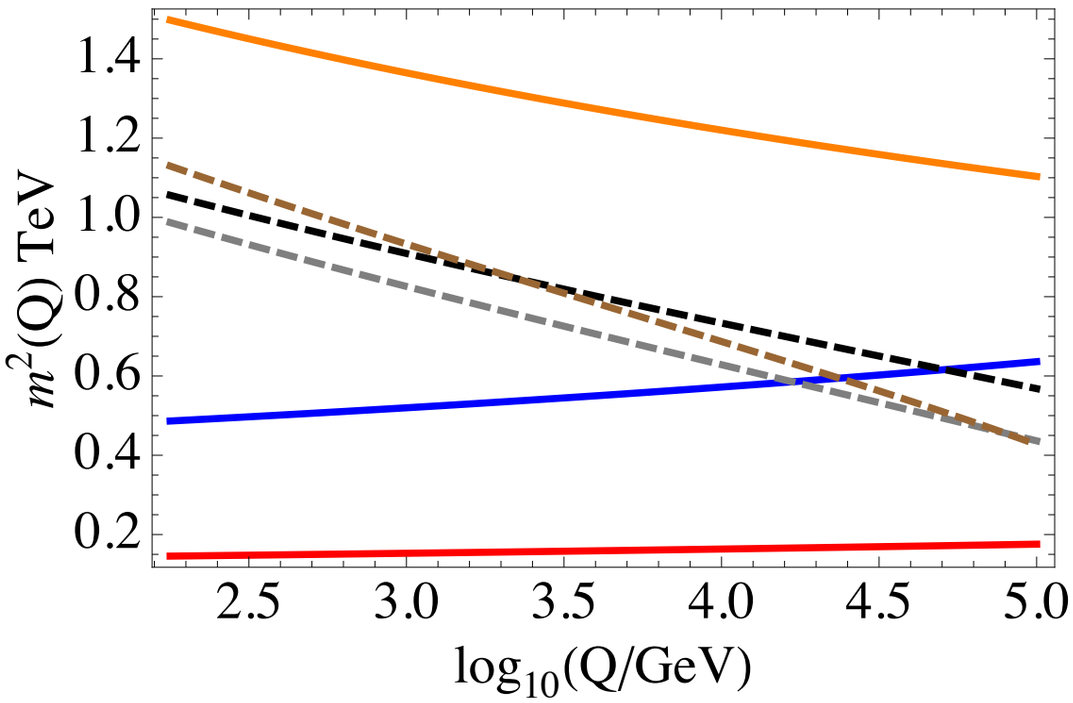
$$\begin{aligned}
m_{\tilde{f}}^2 = 2[&C_3^f \left(\frac{\alpha_3(\mathcal{M})}{4\pi}\right)^2 3 n_8 f(\Lambda_8/\mathcal{M})\Lambda_8^2 + C_2^f \left(\frac{\alpha_2(\mathcal{M})}{4\pi}\right)^2 2 n_3 f(\Lambda_3/\mathcal{M})\Lambda_3^2 \\
&+ C_1^f \left(\frac{\alpha_1(\mathcal{M})}{4\pi}\right)^2 \frac{1}{2}\left(\frac{6}{5}\right)^2 n_1 f(\Lambda_1/\mathcal{M})\Lambda_1^2] \,.
\end{aligned}$$

- The spectrum is generated at a high scale M
- Run down to the EW scale
- EWSB it is imposed
- m_h=125 GeV
- All experimental constrains (direct & indirect) are satisfied

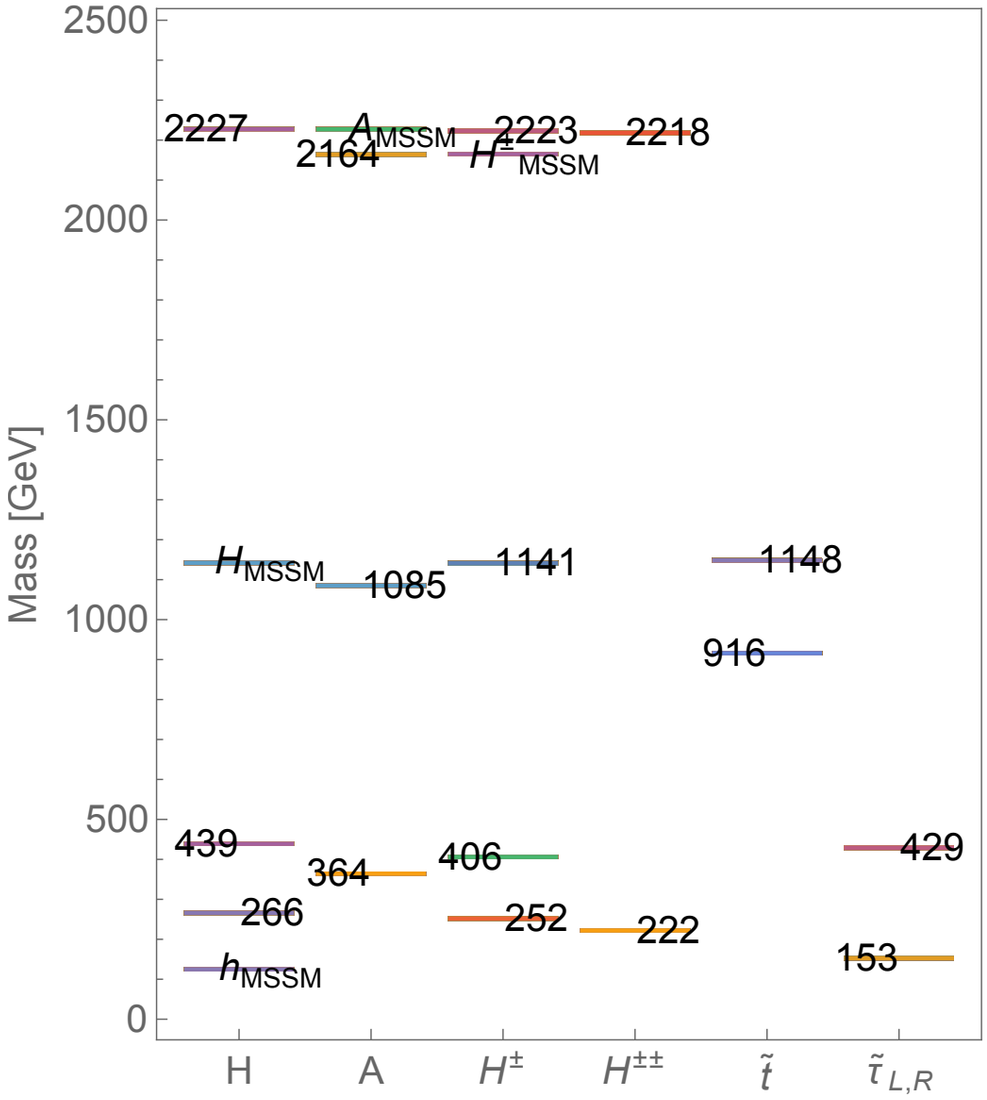
$$n_1 = 1,\ n_3 = 2,\ n_8 = 6 \quad \text{and} \quad \tilde{\lambda}_1 = 0.9,\ \tilde{\lambda}_3 = 0.5,\ \tilde{\lambda}_8 = 0.1\,.$$

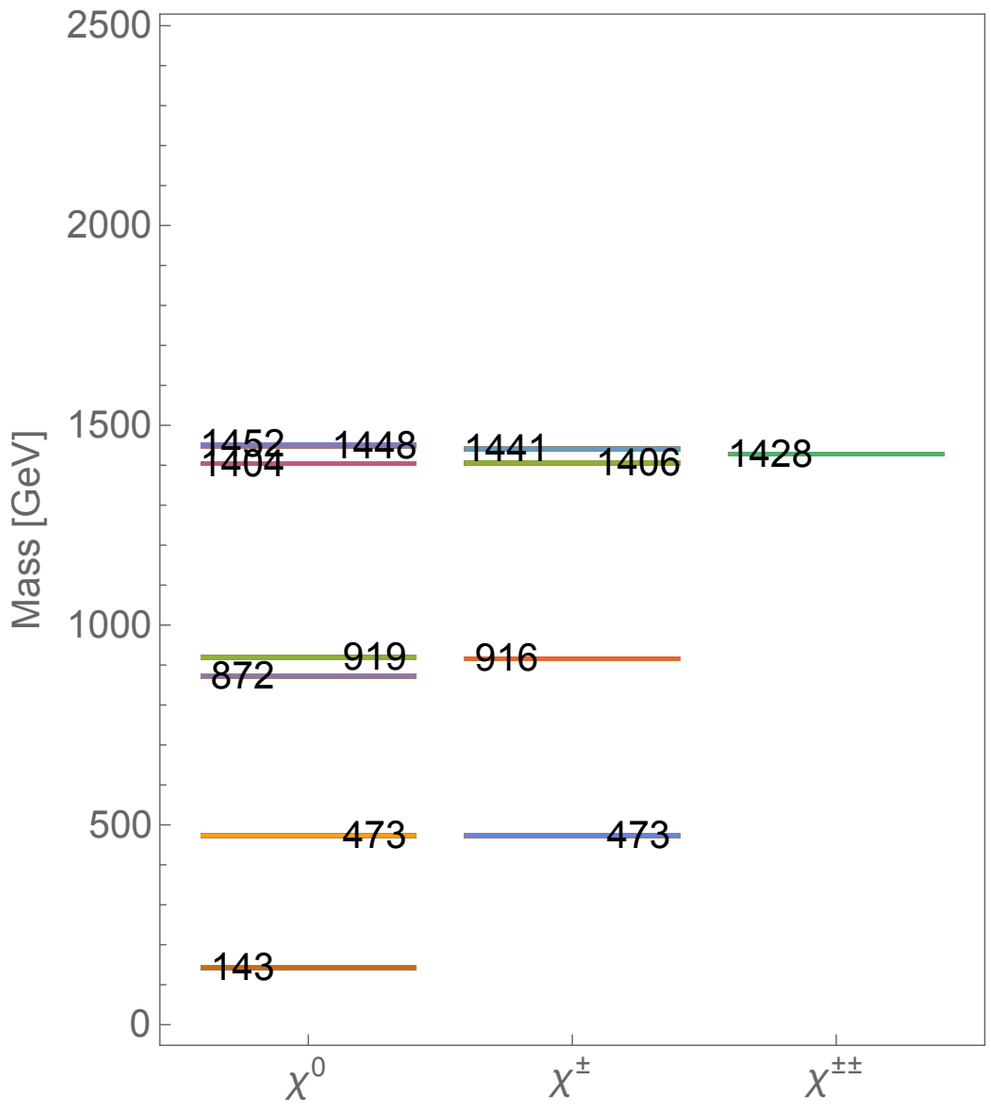


Higgses



squarks & gauginos


2500
2000
1500
1000
500
0
Mass [GeV]
2227
A_{MSSM}
2164
$H^{\pm}_{\text{MSSM}}$
2223
2218
H_{MSSM}
1085
1141
1148
916
439
364
406
429
266
252
222
153
h_{MSSM}
H
A
$H^{\pm}$
$H^{\pm\pm}$
$\tilde{t}$
$\tilde{\tau}_{L,R}$


2500
2000
1500
1000
500
0
Mass [GeV]
1452
1448
1404
1441
1406
1428
872
919
916
473
473
143
χ^0
$\chi^{\pm}$
$\chi^{\pm\pm}$

tan β=1.38

- There are deviations on Higgs properties and exotic decays like:

$$H^{\pm} \to W^{\pm} Z$$

Scenario #1	WW	ZZ	$b\bar{b}$	$t\bar{t}$	$\gamma\gamma$
r_{hXX}	1.05	1.04	1.01	1.01	1.22
$\mu_{hXX}^{(gF)}, \mu_{hXX}^{(htt)}$	1.07	1.05	1	0.99	1.45
$\mu_{hXX}^{(WF)}, \mu_{hXX}^{(Wh)}$	1.16	1.14	1.08	1.07	1.58
$\mu_{hXX}^{(ZF)}, \mu_{hXX}^{(Zh)}$	1.14	1.11	1.06	1.05	1.54

How about DM?

AD, M. García-Pepin, B. Ostdiek, M. Quirós

- Having extra fermionic states can have an impact in the composition and properties of the LSP

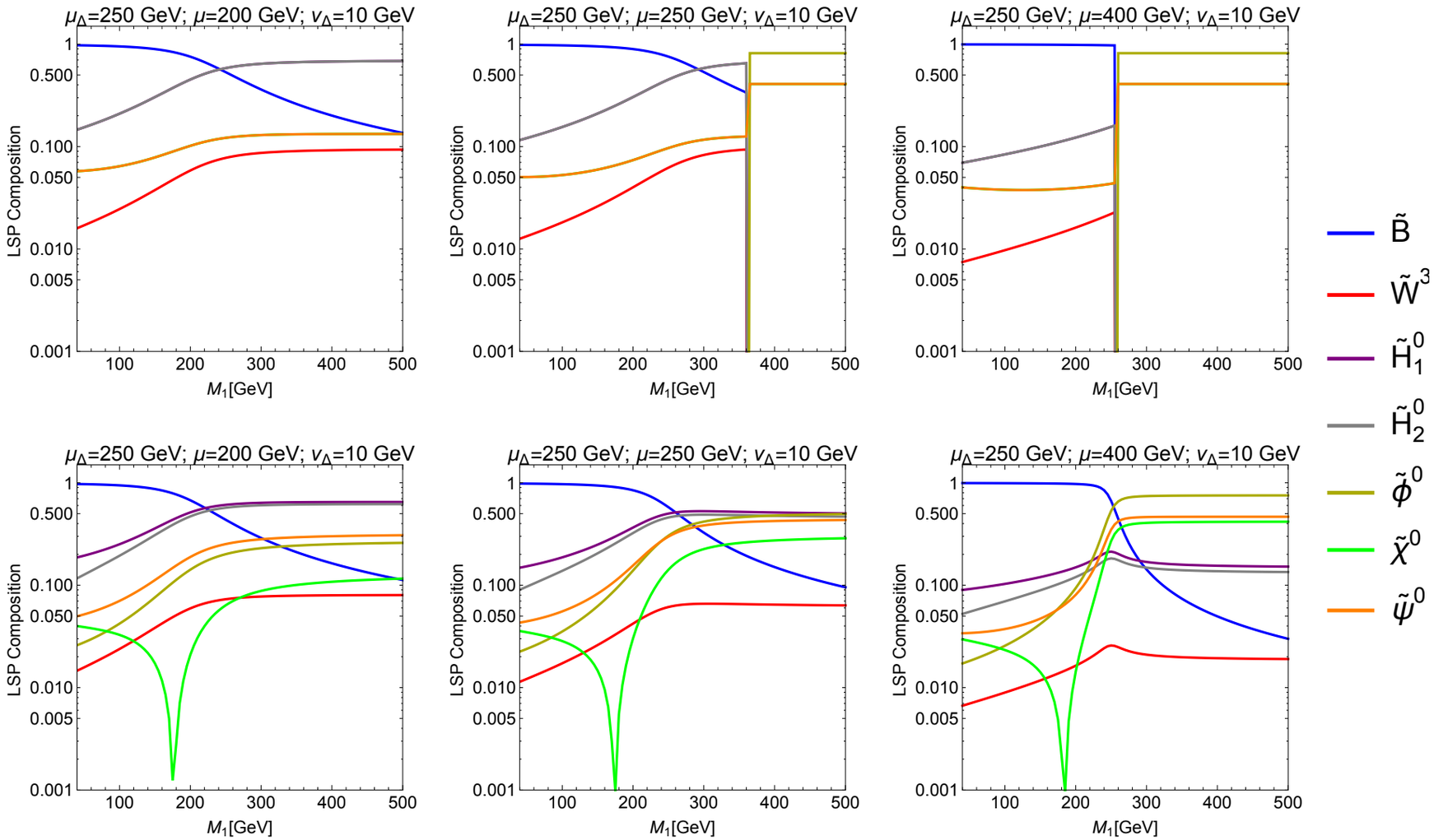
- I am going to present different cases where the relic abundance is obtained

- NB: I am deviating from GMSB. i e the gravitino is not the LSP!!!!!!

Neutralino Mass-Matrix

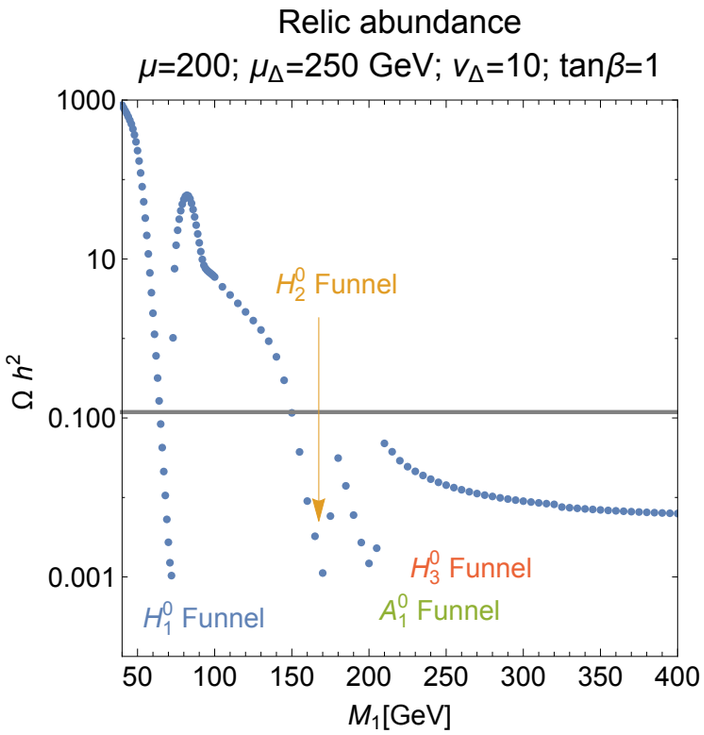
$$\mathbf{M} = \begin{pmatrix}
M_1 & 0 & -\frac{1}{\sqrt{2}}g' c_\beta v_H & \frac{\sqrt{2}}{2}g' s_\beta v_H & 0 & -g' v_\Delta & g' v_\Delta \\
0 & M_2 & \frac{\sqrt{2}}{2}g_2 c_\beta v_H & -\frac{1}{\sqrt{2}}g_2 s_\beta v_H & 0 & g_2 v_\Delta & -g_2 v_\Delta \\
-\frac{1}{\sqrt{2}}g' c_\beta v_H & \frac{1}{\sqrt{2}}g_2 c_\beta v_H & -\sqrt{2}\lambda v_\Delta & -\frac{1}{\sqrt{2}}\lambda v_\Delta - \mu & -\lambda s_\beta v_H & 0 & -2\lambda c_\beta v_H \\
\frac{\sqrt{2}}{2}g' s_\beta v_H & -\frac{1}{\sqrt{2}}g_2 s_\beta v_H & -\frac{1}{\sqrt{2}}\lambda v_\Delta - \mu & -\sqrt{2}\lambda v_\Delta & -\lambda c_\beta v_H & -2\lambda s_\beta v_H & 0 \\
0 & 0 & -\lambda s_\beta v_H & \lambda c_\beta v_H & \mu_\Delta & -\frac{1}{\sqrt{2}}\lambda_3 v_\Delta & -\frac{1}{\sqrt{2}}\lambda_3 v_\Delta \\
g' v_\Delta & g_2 v_\Delta & 0 & -2\lambda s_\beta v_H & -\frac{1}{\sqrt{2}}\lambda_3 v_\Delta & 0 & \mu_\Delta - \frac{1}{\sqrt{2}}\lambda v_\Delta \\
g' v_\Delta & -g_2 v_\Delta & -2\lambda c_\beta v_H & 0 & -\frac{1}{\sqrt{2}}\lambda_3 v_\Delta & \mu_\Delta - \frac{1}{\sqrt{2}}\lambda_3 v_\Delta & 0
\end{pmatrix}$$

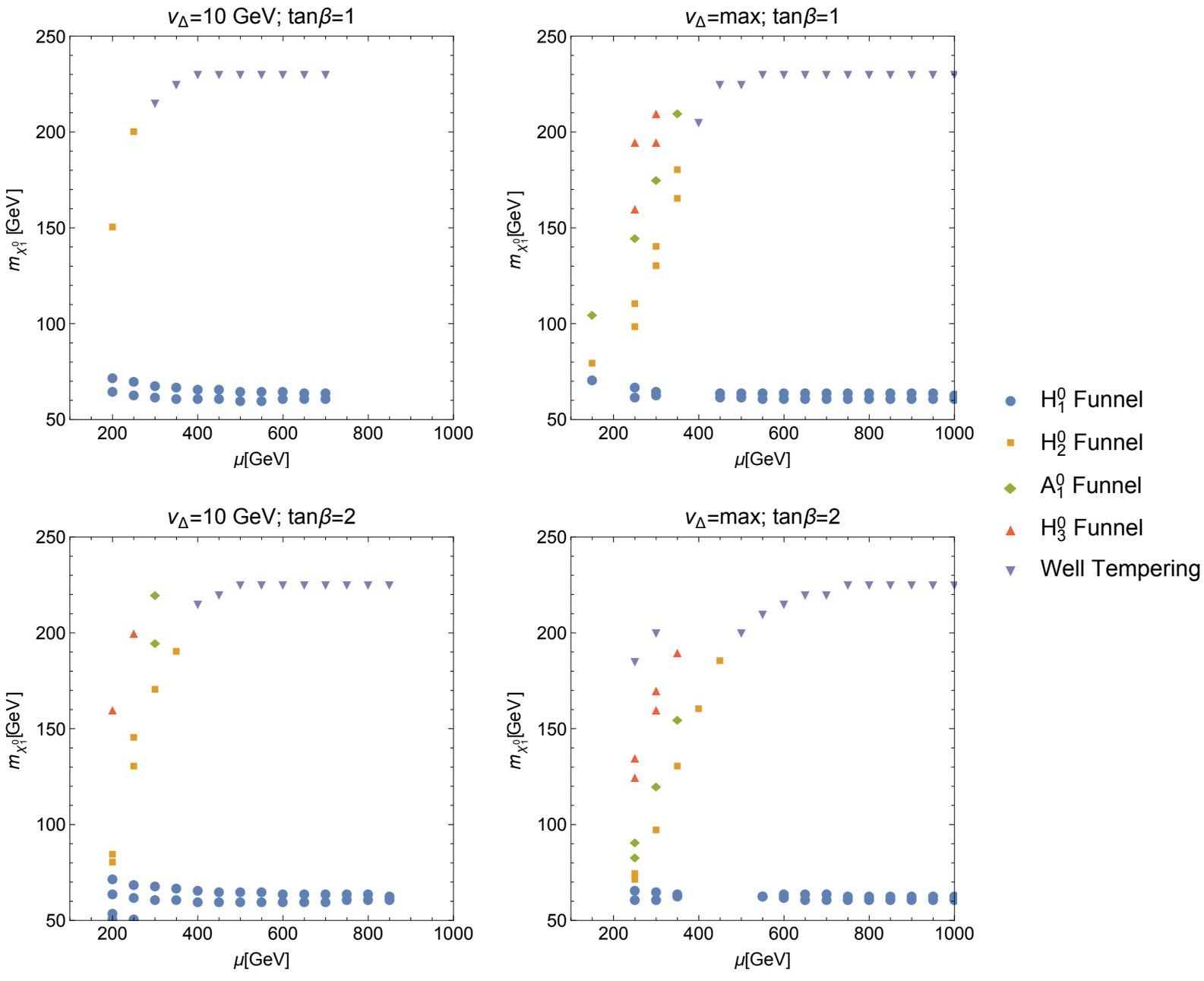
Composition of the LSP



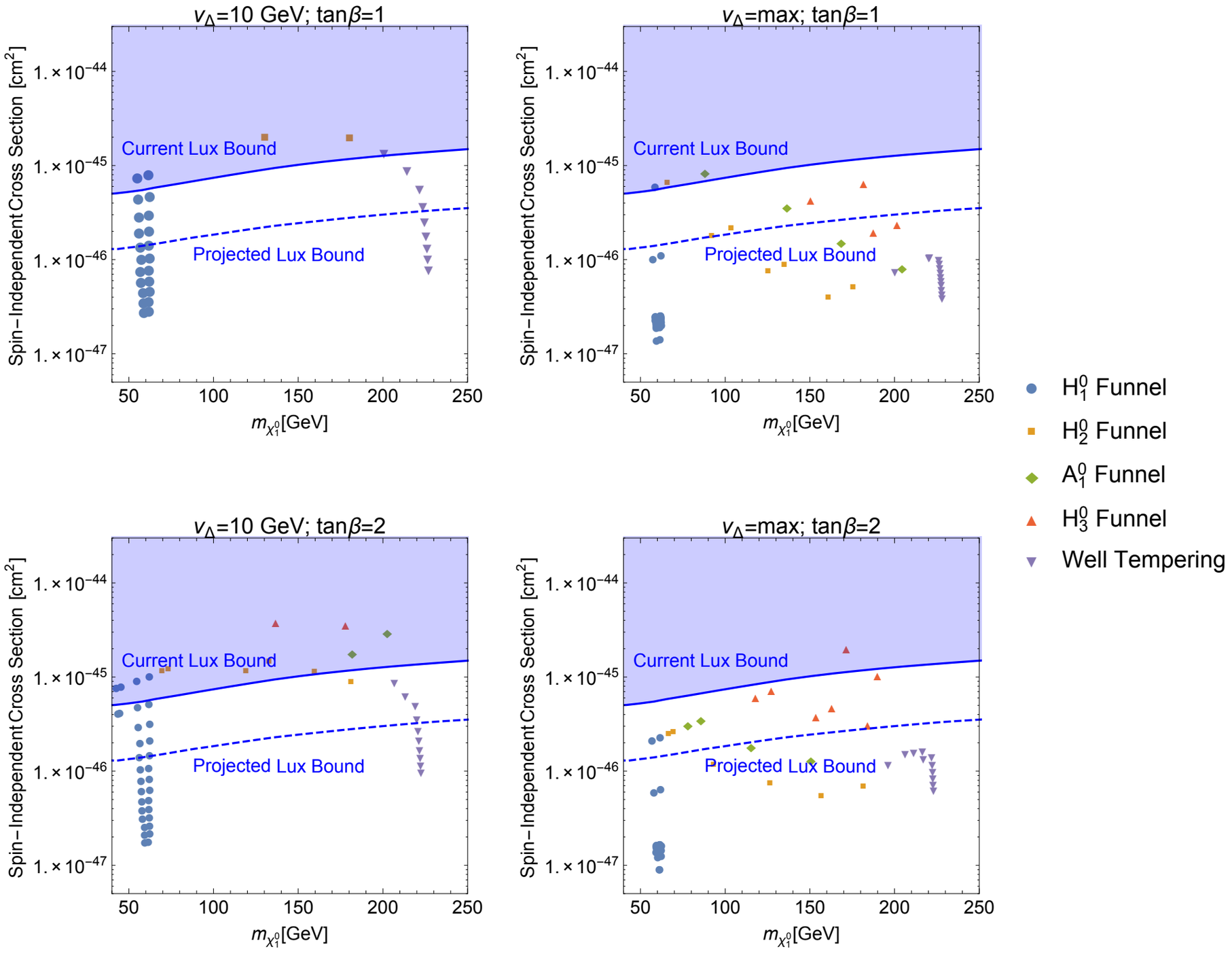
M_2=1 TeV

Relic Abudance

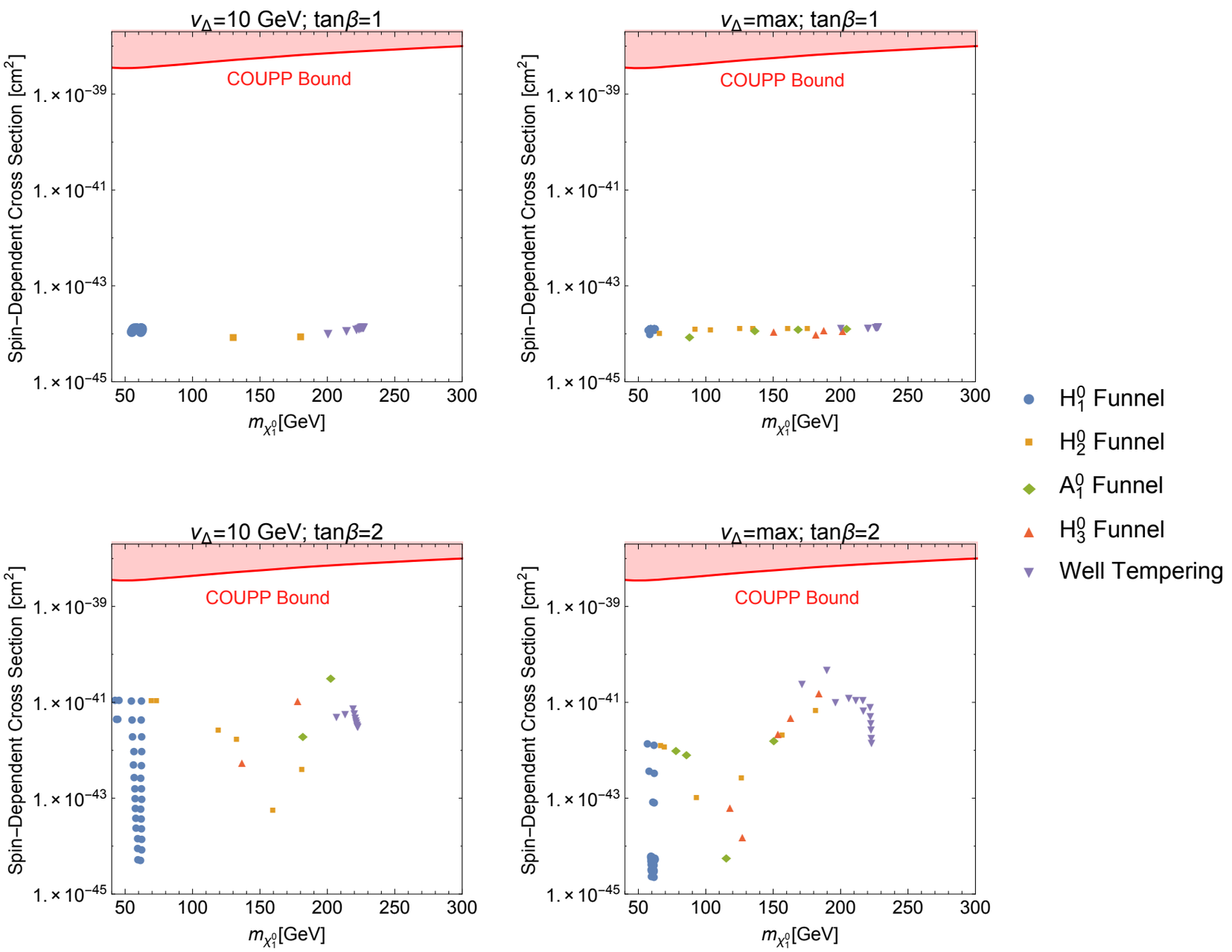




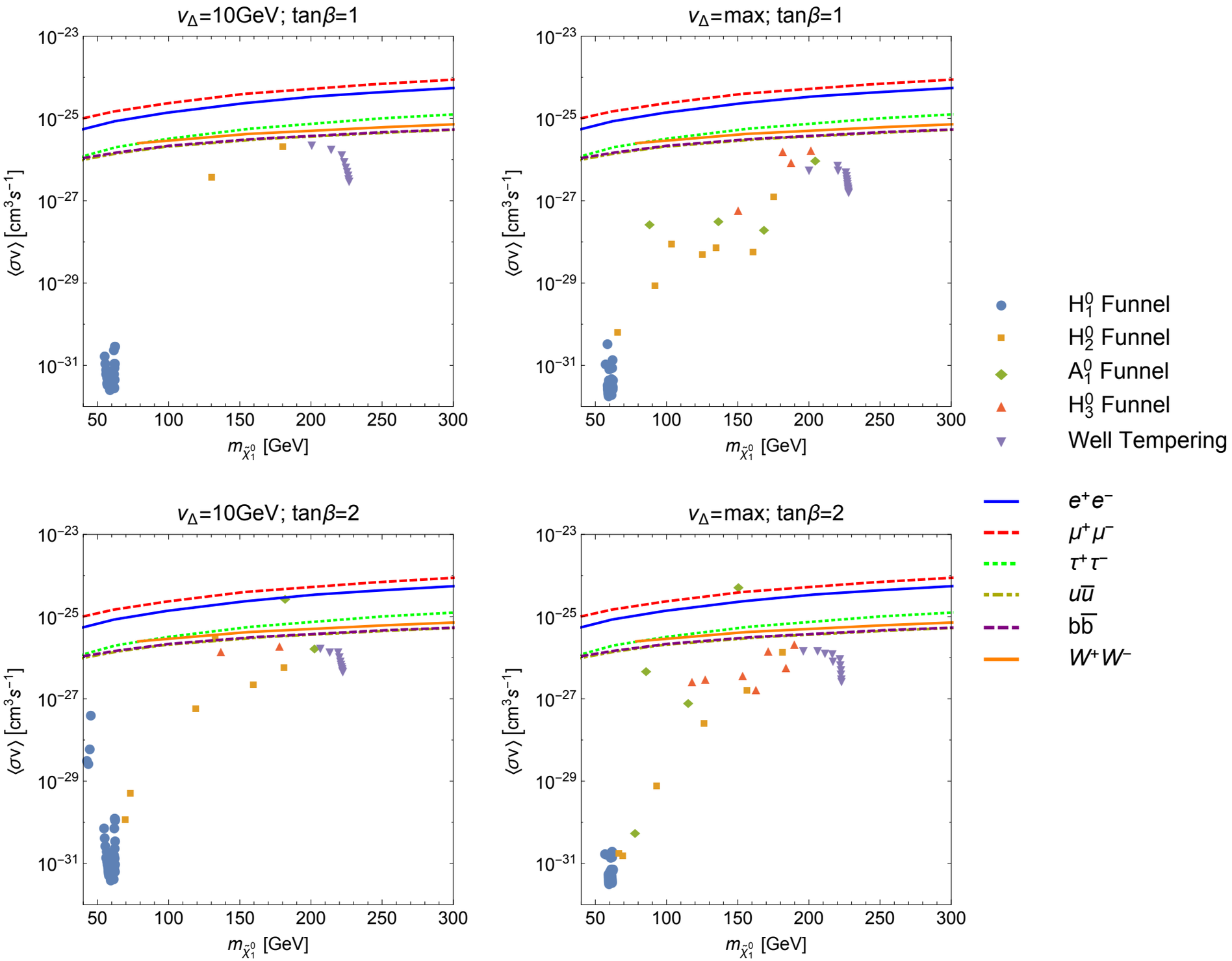
Spin independent xsec



Spin dependent xsec



Indirect detection



Conclusions

- One of the multiple possibilities for physics beyond the SM is an extended Higgs sector

- Extra scalars appear naturally in UV theories attempting to explain the Hierarchy problem

- In this talk I have supposed that supersymmetry is the explanation of the EW scale and moreover that there are triplets coupled to the usual Higgses.

- One way to automatically have the T-parameter under control is the GM model.

- I have introduced the SCTM and study how can it be embedded into GMSB

- It naturally leads to a low messenger scale

- But one can successfully have a complete model with low tan β

- Finally I have analyzed the implications that having an extended sector of neutralinos on DM.

- New regions appear that can have very interesting implications for direct and indirect detection.

- The SCTM has very exotic decays for the Higgs sectors that I am currently studying.