The Higgs sector in U(1) extensions of the MSSM

Jonathan Da Silva

Laboratoire d'Annecy-le-Vieux de Physique Théorique, France

LAPTh Annecy-le-Vieux

UNIVERSITÉ DE GRENOBLE

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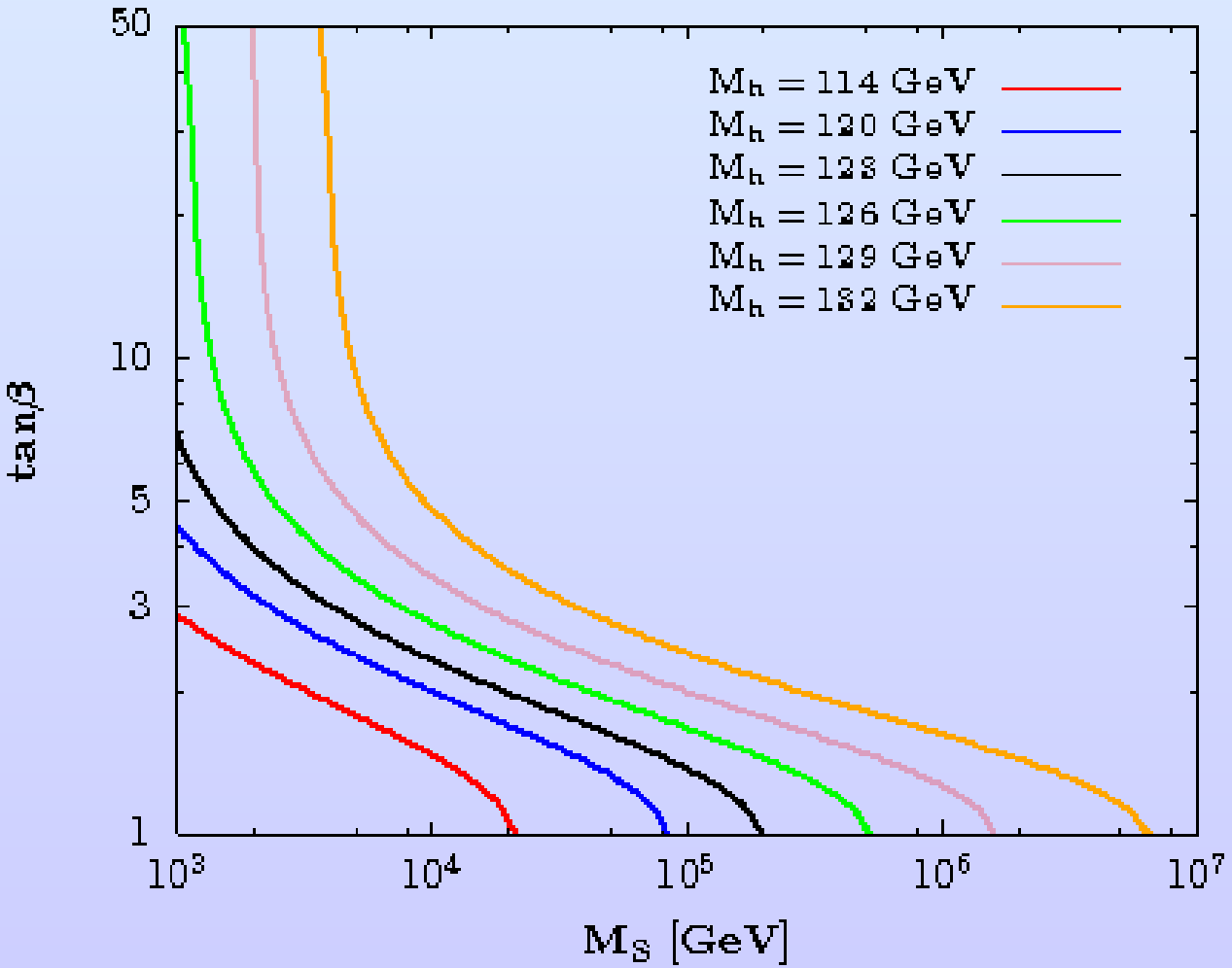
G. Bélanger, JDS and A. Pukhov, arXiv:1309.soon

Outline

Introduction

- **In the MSSM, for TeV-scale values of the SUSY–breaking scale M_S :**
  SM-like Higgs boson mass $\approx$ 125 GeV + very small $\tan\beta$, i.e. $\approx 1 \Rightarrow$ tricky
  $\Rightarrow$ Higgs boson mass of 125 GeV requires large $\tan\beta$



A. Djouadi, J. Quevillon, arXiv :1304.1787

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What about extending the gauge symmetry ?

➜ **Here : the UMSSM**

The model

- **Symmetry group : $\mathbf{SU(3)_c \times SU(2)_L \times U(1)_Y \times U'(1)}$**
  Coupling constants : $\mathbf{g_3}$, $\mathbf{g_2}$, $\mathbf{g_Y}$ and $\mathbf{g_1' = \sqrt{\frac{5}{3}} g_Y}$

- **$\mathbf{U'(1)}$ stems from string-inspired $\mathbf{E_6}$:**
  $\mathbf{E_6 \to SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_\chi \times U(1)_\psi \Rightarrow U'(1)}$ charge :

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

- **MSSM fields + RH (s)neutrinos + new gauge boson (gaugino) + new singlet (singlino) + $\mathcal{O}$(TeVs)**

	$\mathcal{Q}'_Q$	$\mathcal{Q}'_u$	$\mathcal{Q}'_d$	$\mathcal{Q}'_L$	$\mathcal{Q}'_\nu$	$\mathcal{Q}'_e$	$\mathcal{Q}'_{H_u}$	$\mathcal{Q}'_{H_d}$	$\mathcal{Q}'_S$
$\sqrt{40}\mathcal{Q}'_\chi$	-1	-1	3	3	-5	-1	2	-2	0
$\sqrt{24}\mathcal{Q}'_\psi$	1	1	1	1	1	1	-2	-2	4

- **Superpotential :**

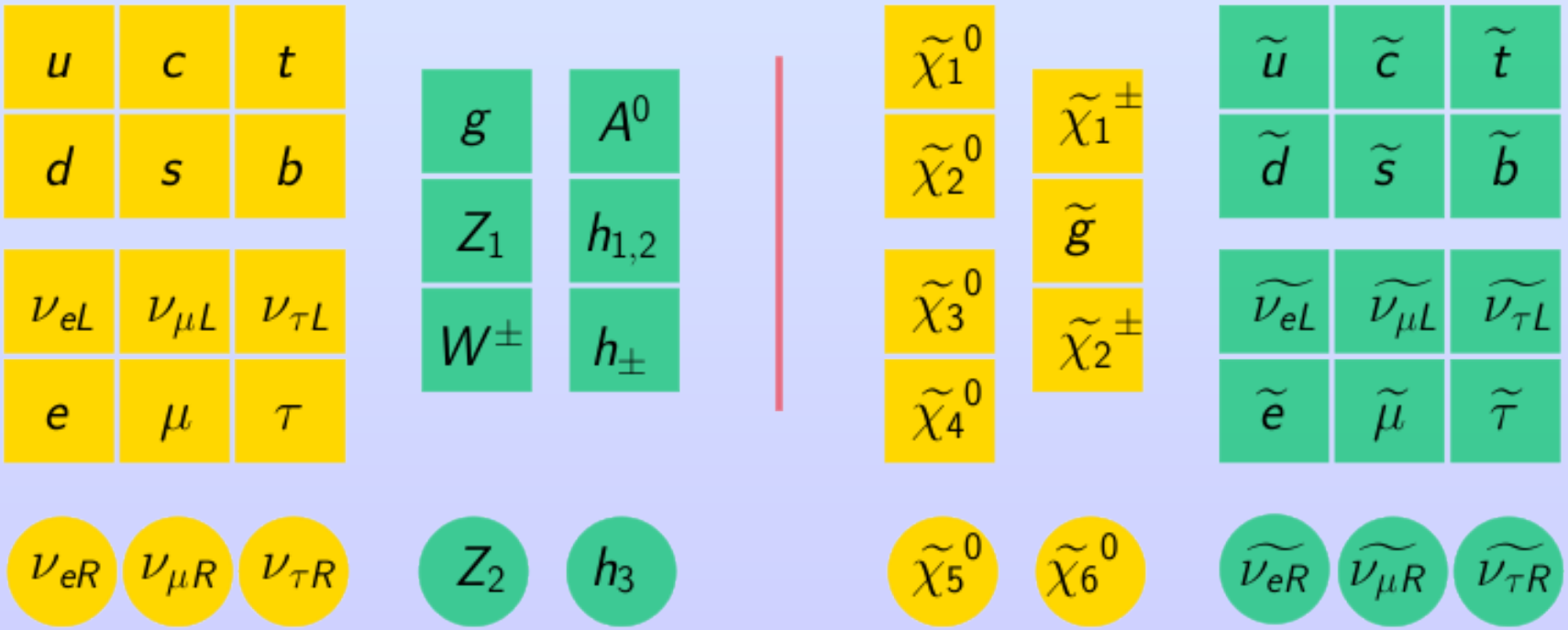
$$\mathcal{W}_{\mathbf{UMSSM}} = \mathcal{W}_{\mathbf{MSSM}}|_{\mu=0} + \lambda \mathbf{S H_u H_d} + \tilde{\nu}^*_{\mathbf{R}} \mathbf{y}_\nu \widetilde{\mathbf{L}} \mathbf{H_u} + \mathcal{O}(\mathbf{TeVs})$$

- **As the NMSSM, this model solves the μ problem : $\mu = \lambda \frac{\mathbf{v_s}}{\sqrt{2}}$**

- **Higgs sector : MSSM fields + 1 singlet $\Rightarrow$ 3 CP-even Higgs bosons $\mathbf{h_i}, \mathbf{i} \in \{1,2,3\}$**
  New D-terms for the SM-like Higgs boson :
  $\mathbf{m^2_{h_1}} \leq \mathbf{M^2_Z} \cos^2 2\beta + \frac{1}{2}\lambda^2 \mathbf{v}^2 \sin^2 2\beta + \mathbf{g_1'^2 v^2} (\mathcal{Q}'_{\mathbf{H_d}} \cos^2\beta + \mathcal{Q}'_{\mathbf{H_u}} \sin^2\beta)^2 + \mathbf{\Delta m^2_h}$

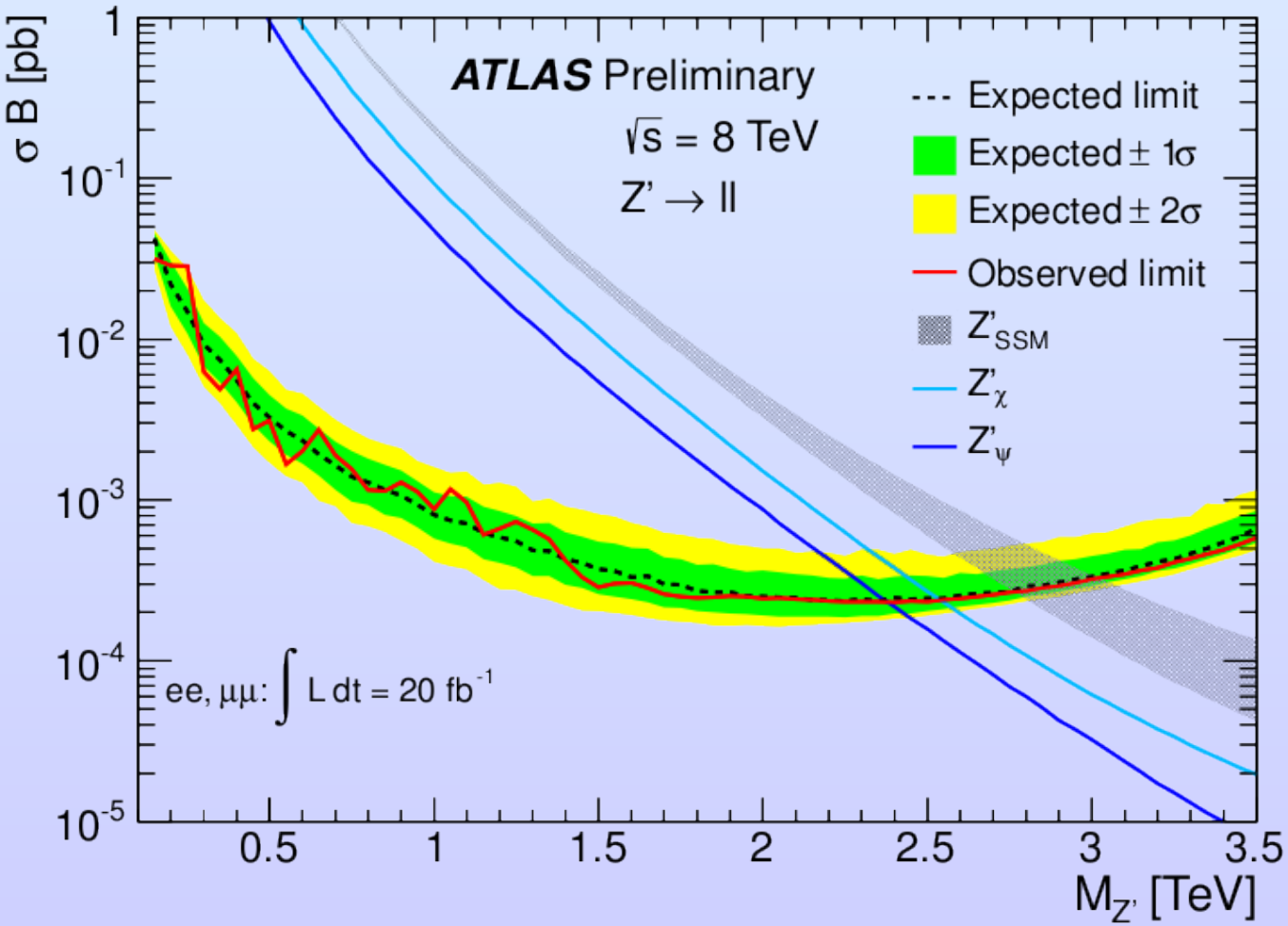
The model

- **Gauge sector : Physical abelian gauge bosons : Z_1 and Z_2, mixing between the Z of the SM and the Z', α_Z is the mixing angle $\Rightarrow \tan\beta$ constrained**
- **Gauginos sector : 6 neutralinos in the basis $(\widetilde{B}, \widetilde{W}^3, \widetilde{H}_d^0, \widetilde{H}_u^0, \widetilde{S}, \widetilde{B'})$**
- **To sum up :**



Constraints

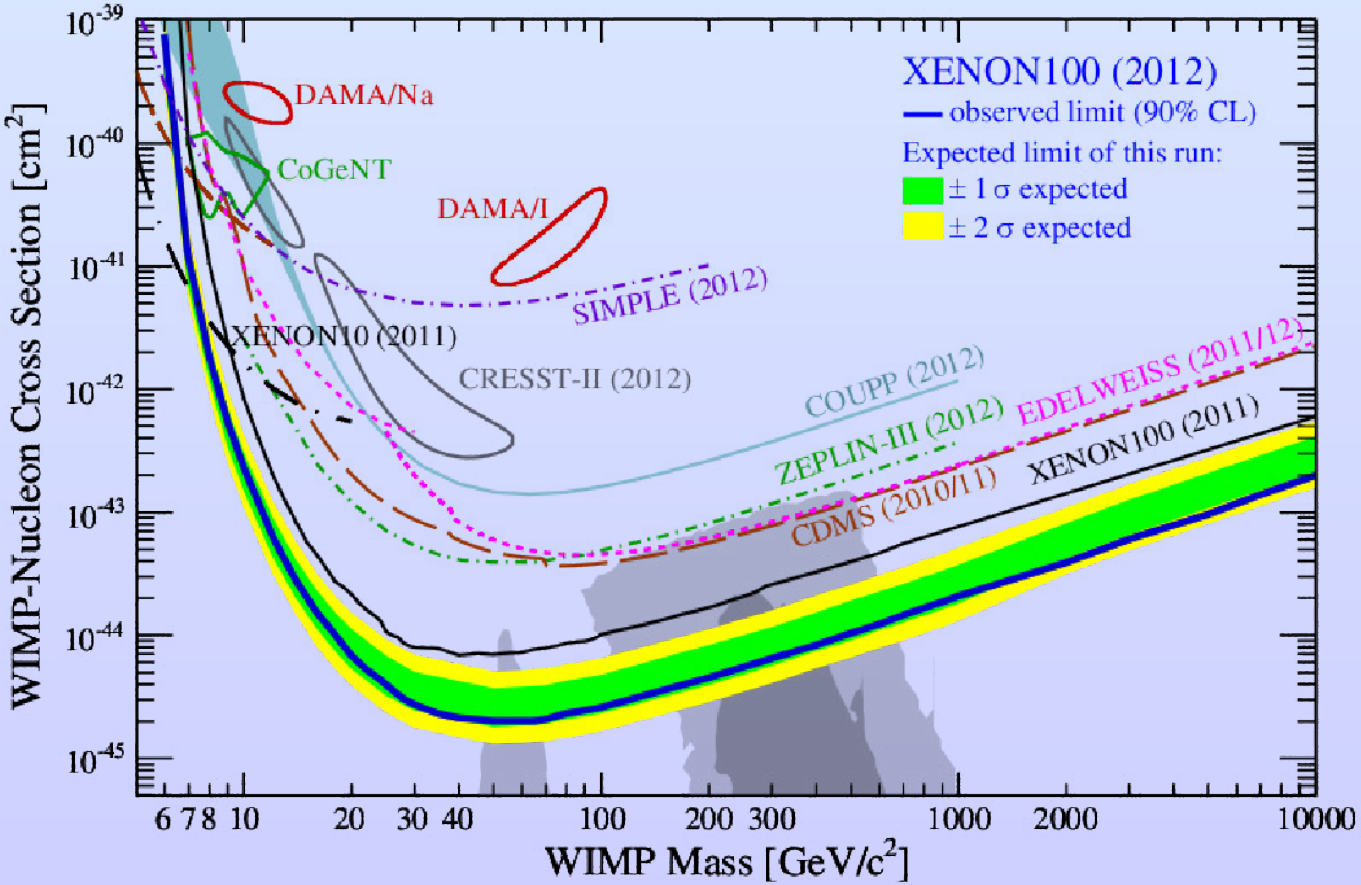
- **Z′ heavy ⇒ heavy singlet-like Higgs boson ⇒ h_2 mostly doublet-like**



ATLAS Collaboration, http ://cds.cern.ch/record/1525524

Constraints

- **DM observables for either neutralino or RH sneutrino DM candidate :**
  - $\Omega_{\rm LSP}h^2 < 0.1221$ (2σ **Planck+WP+highL+BAO upper bound**)
  - **SI WIMP-nucleon cross section limits from XENON100 (a posteriori)**



E. Aprile et al., XENON100 Collaboration, Phys. Rev. Lett. 109 :181301, arXiv :1207.5988

Constraints

- **Theoretical uncertainties (see B. C. Allanach, A. Djouadi, J. L. Kneur, W. Porod, P. Slavich, JHEP 0409 (2004) 044, arXiv :hep-ph/0406166)**
  $\rightarrow$ $m_{h_1} \in [120.63, 130.63]$ GeV
- **Higgs boson signal strengths and low energy observables (a posteriori)**
  $\Rightarrow$ Modification of the `NMSSMTools` code : `UMSSMTools`
  Limits on signal strengths using G. Bélanger, B. Dumont, U. Ellwanger, J. F. Gunion, S. Kraml, arXiv :1306.2941 : $\chi^2_i \lesssim 6$ with $h_1 \rightarrow i, \quad i \in \gamma\gamma, VV^*, b\bar{b}, \tau^+\tau^-$

Observable	Value
$\mathscr{B}(B^\pm \rightarrow \tau^\pm \nu_\tau)$	$(0.99 \pm 0.25) \times 10^{-4}$ UTfit
$\mathscr{B}(B_s^0 \rightarrow \mu^+\mu^-)$	$(2.95\,^{+0.74}_{-0.67}) \times 10^{-9}$ LHCb + CMS
ΔM_s	$17.719 \pm 0.043\ \text{ps}^{-1}$ HFAG
ΔM_d	$0.507 \pm 0.004\ \text{ps}^{-1}$ HFAG
$\mathscr{B}(\bar{B}^0 \rightarrow X_s\gamma)$	$(3.55 \pm 0.24 \pm 0.09) \times 10^{-4}$ HFAG

Constraints

Scanning the parameter space :

- **Nuisance parameters :**
  - $m_t = 175.5 \pm 1$ GeV PDG 2012
  - Quark content of the nucleon (from G. Bélanger, F. Boudjema, A. Pukhov, A. Semenov, arXiv :1305.0237)

Parameter	Value
m_u/m_d	0.46 ± 0.05
m_s/m_d	27.5 ± 0.3
$\sigma_{\pi N}$	34 ± 2 MeV
σ_s	42 ± 5 MeV

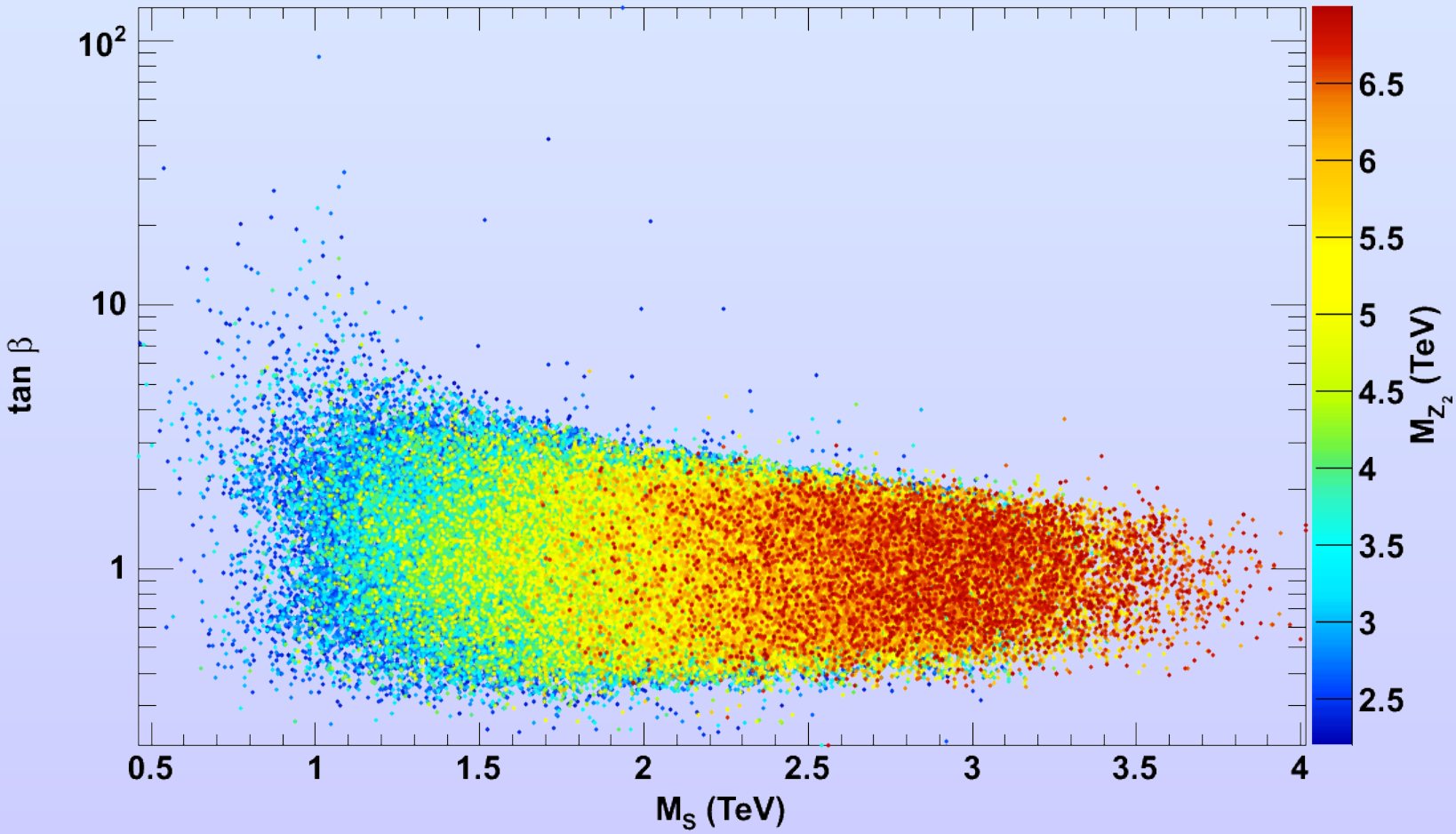
- **UMSSM parameters :**

Parameter	Range	Parameter	Range
$m_{\tilde{\nu}_R}$	[0.05, 2] TeV	A_λ	[0, 4] TeV
M_{Z_2}	[2.2, 7] TeV	A_t, A_b, A_τ	[-4, 4] TeV
α_Z	[-10^{-3}, 10^{-3}] rad	$m_{\tilde{Q}_3}, m_{\tilde{u}_3}, m_{\tilde{d}_3}, m_{\tilde{L}_3}, m_{\tilde{e}_3}$	[0, 3] TeV
θ_{E_6}	[$-\pi/2$, $\pi/2$] rad	μ, M_1, M_1'	[0.1, 2] TeV

First and second generation sfermion soft mass terms at 3 TeV

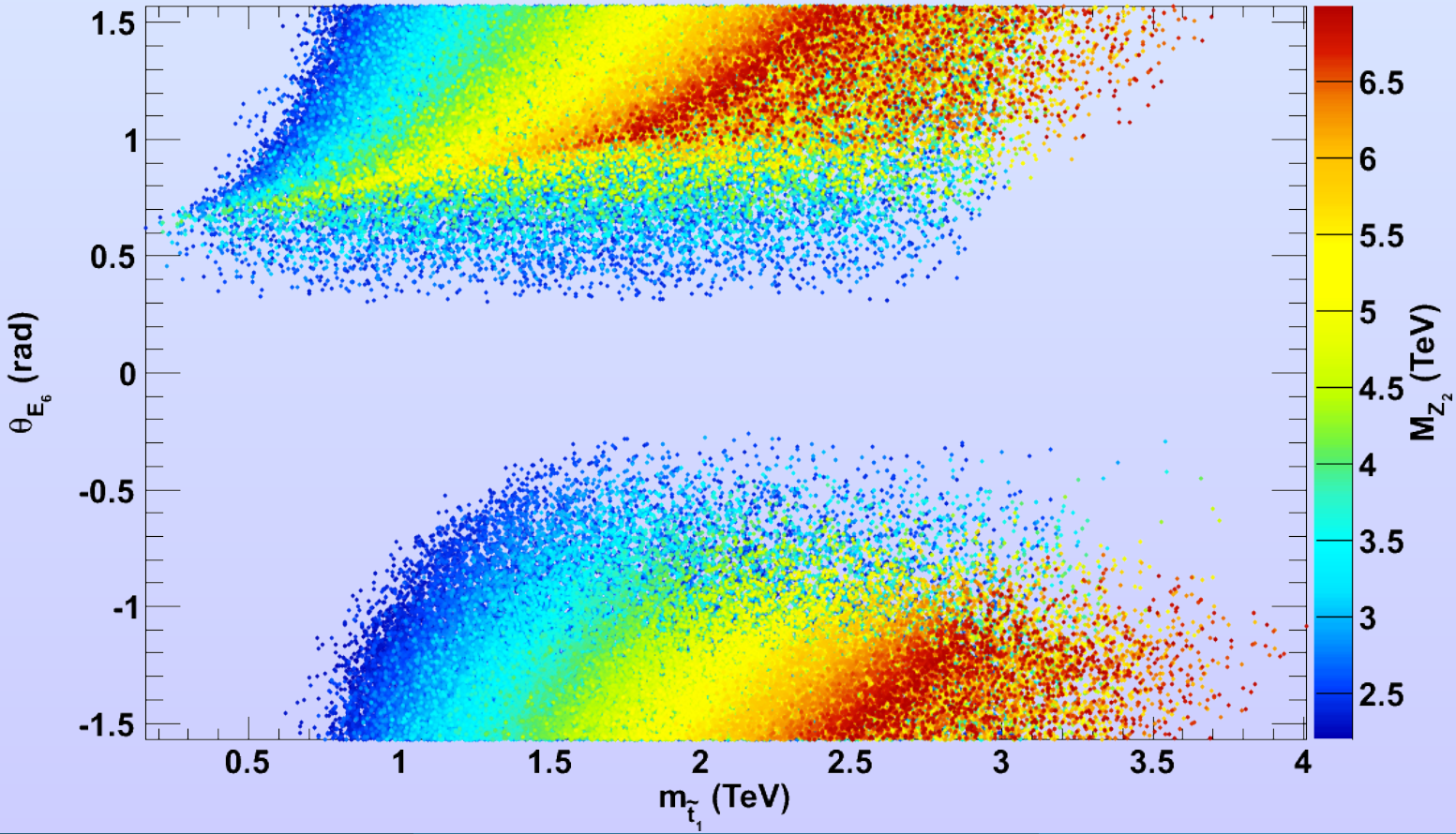
Results

- $\tan\beta \approx 1$ + TeV-scale $M_S \Rightarrow$ expected m_{h_1} :
  large contribution from pure UMSSM as well as one-loop stop terms



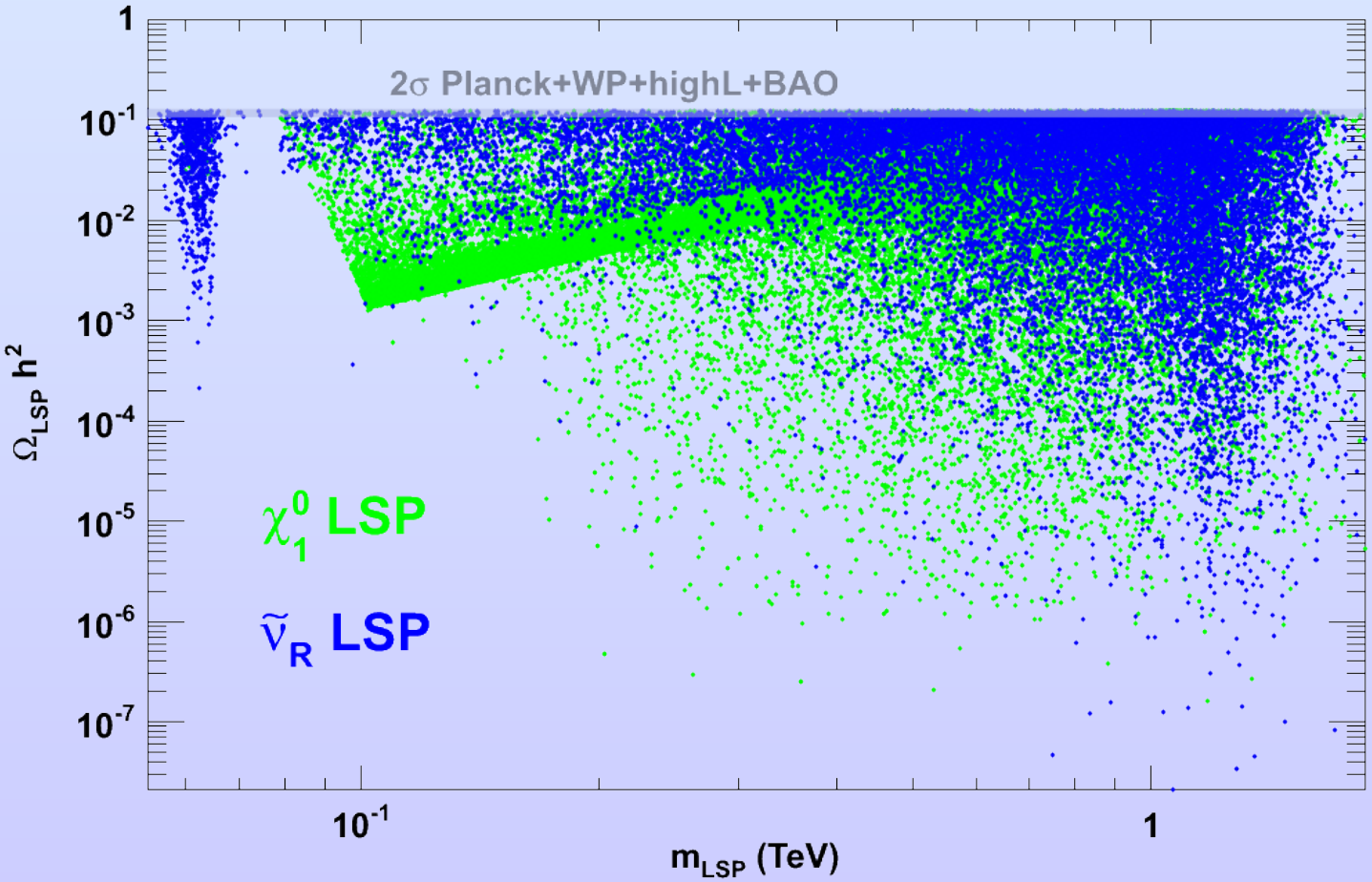
Results

- **Important UMSSM contribution to sfermion masses (dependent on θ_{E_6}) :**
  $\Delta_f = \frac{1}{2} g_1'^2 \mathcal{Q}'_f (\mathcal{Q}'_{H_d} v_d^2 + \mathcal{Q}'_{H_u} v_u^2 + \mathcal{Q}'_S v_s^2)$
  $\Rightarrow$ Condition on neutral LSP put strong constraints on θ_{E_6}



Results

- $\widetilde{B}, \widetilde{H}$ and $\tilde{\nu}_R$ LSP with the wanted abundance
- $\tilde{\nu}_R$ LSP : same annihilation processes than found in G. Bélanger, JDS, A. Pukhov, JCAP, 1112 :014, arXiv :1110.2414



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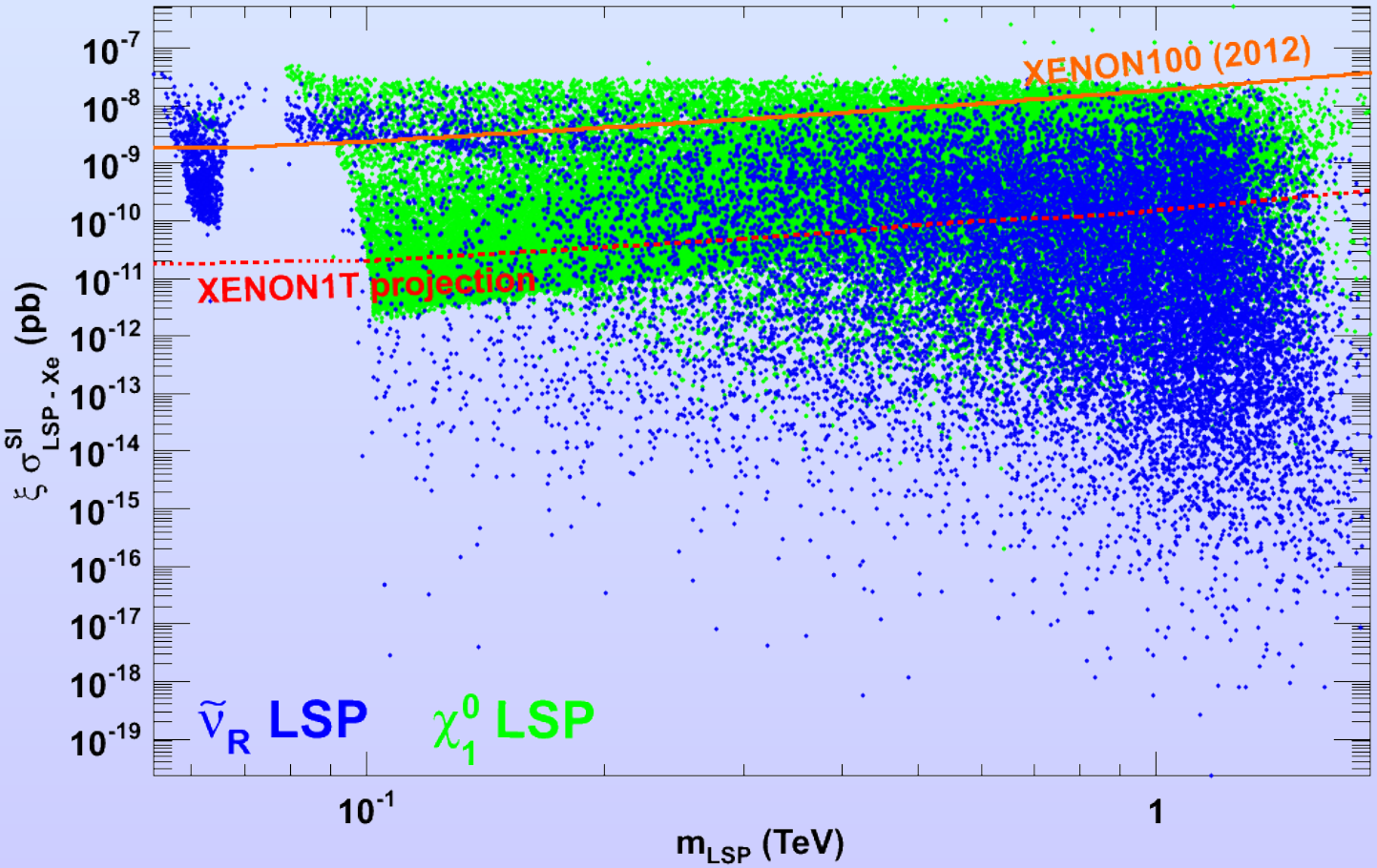
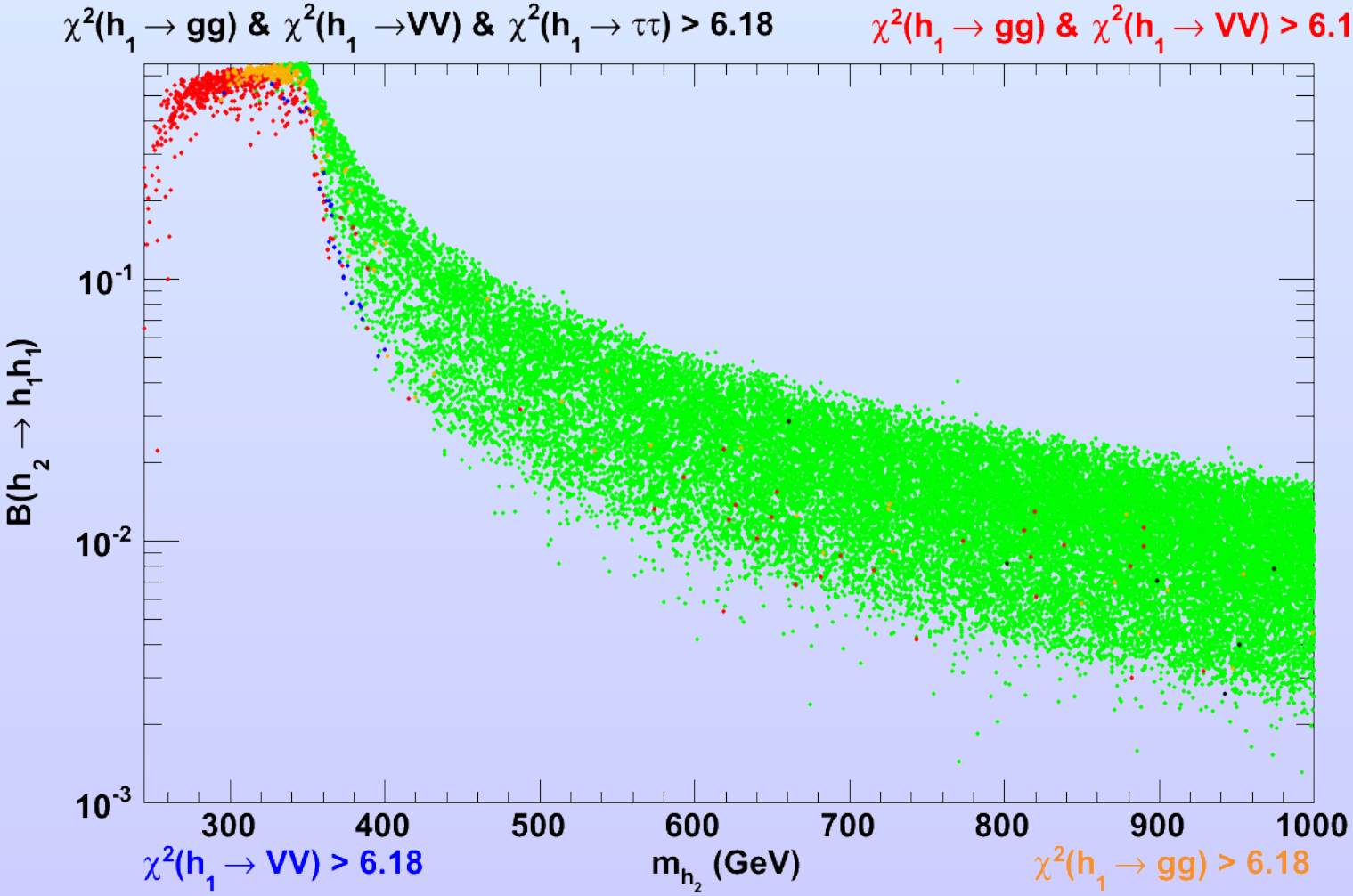


Results

- h_1 signal strength mostly compatible with current limits, but also useful to exclude "light" h_2 ($\lesssim 300$ GeV) ; large branching ratio into SM-like Higgs boson for such h_2

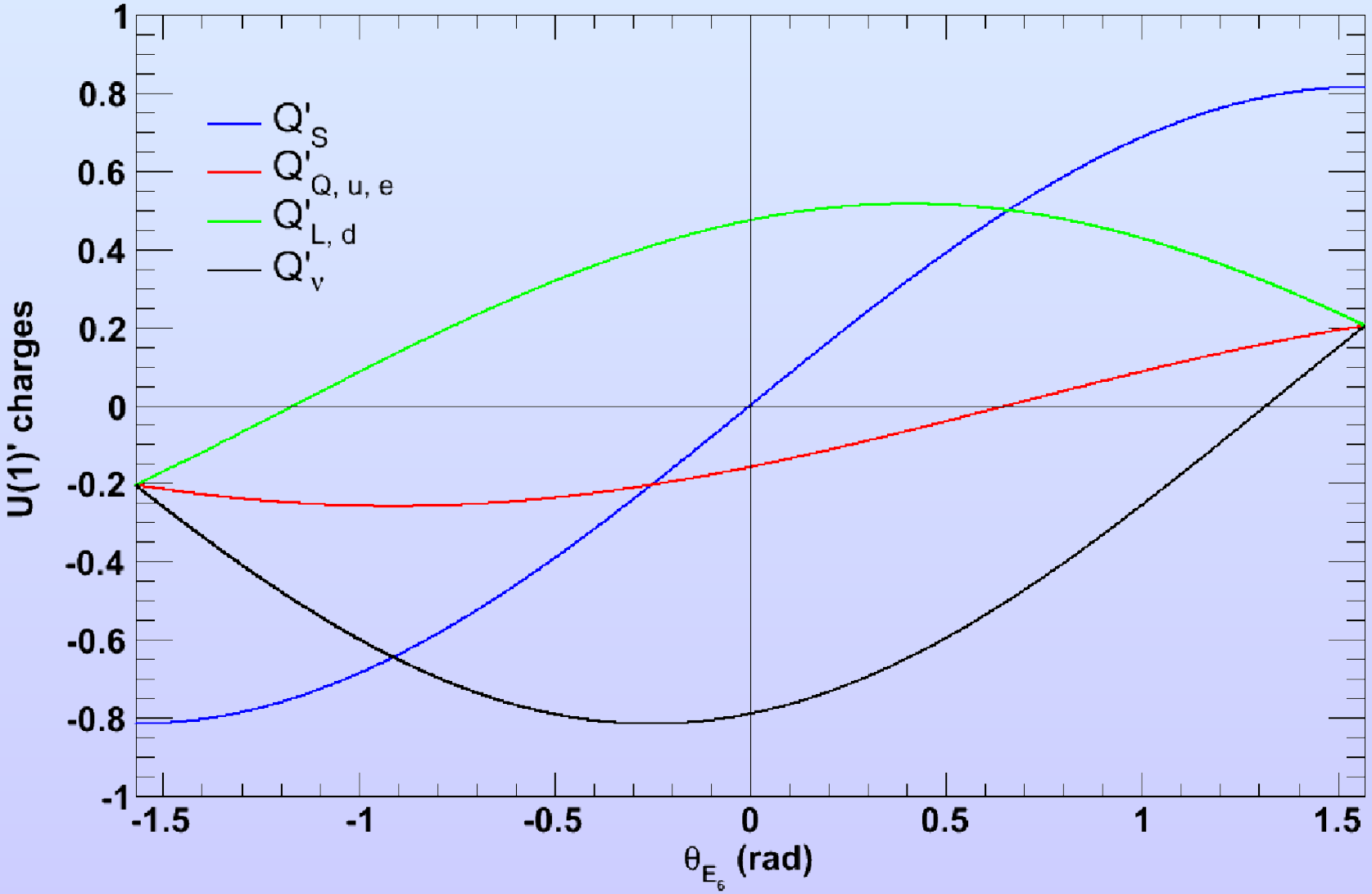


Conclusions

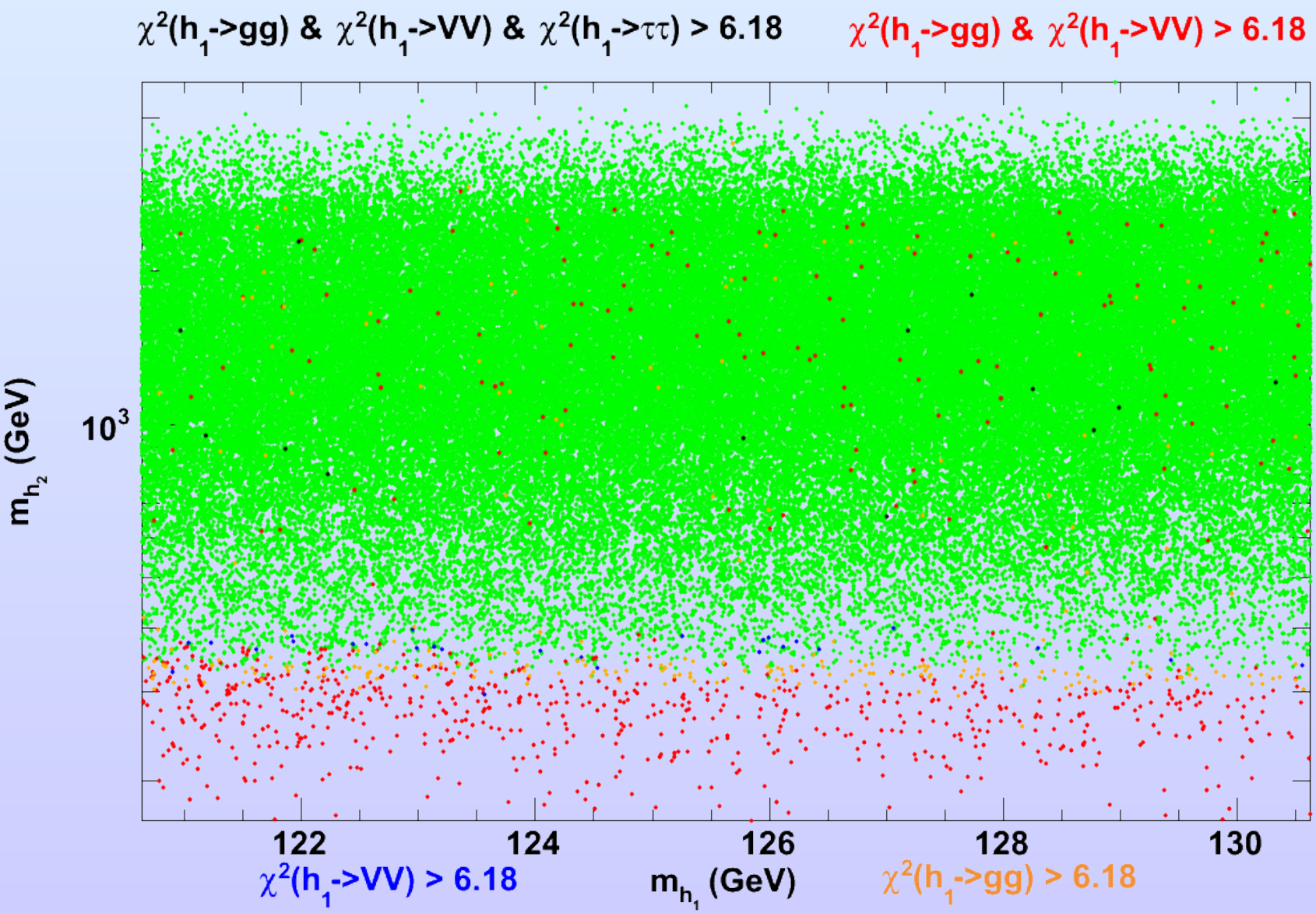
- New D-terms in the UMSSM $\Rightarrow$ low $\tan\beta$ values still allowed for TeV-scale M_S
  $\Rightarrow$ sfermion sector impacted
- χ_1^0 or $\tilde{\nu}_R$ LSP that does not overclose the Universe exclude a large region of the parameter space
- XENON1T would probe entirely some scenarios
- Study of the SM-like Higgs boson puts bounds on the second CP-even Higgs boson : $m_{h_2} \lesssim 300$ GeV excluded in the UMSSM

BACKUP

BACKUP


Q'S
Q'Q, u, e
Q'L, d
Q'ν
U(1)' charges
θE6 (rad)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.5
-1
-0.5
0
0.5
1
1.5

BACKUP


$\chi^2(h_1\text{->}gg)$ & $\chi^2(h_1\text{->}VV)$ & $\chi^2(h_1\text{->}\tau\tau) > 6.18$
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m_{h_2} (GeV)
10^3
122
124
126
128
130
$\chi^2(h_1\text{->}VV) > 6.18$
m_{h_1} (GeV)
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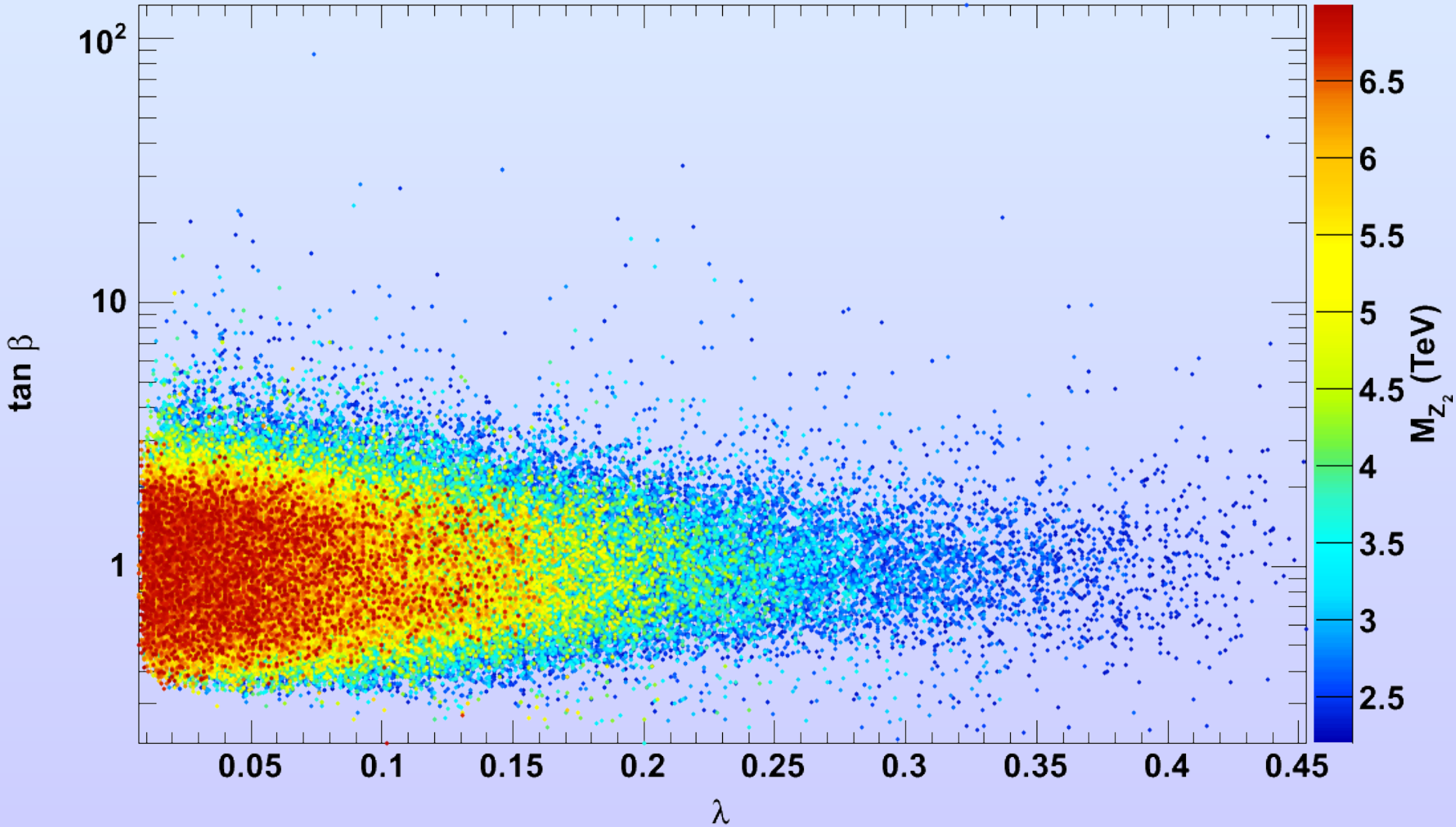
10^2
10
1
tan β
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
λ
6.5
6
5.5
5
4.5
4
3.5
3
2.5
M_{Z_2} (TeV)

BACKUP

New contribution from the Z' to $\Delta\rho$: $\Delta\rho < 2 \times 10^{-3} \rightarrow -6.5 \times 10^{-4} \lesssim \alpha_Z \lesssim 6.9 \times 10^{-4}$