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

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

# Outline

# Introduction

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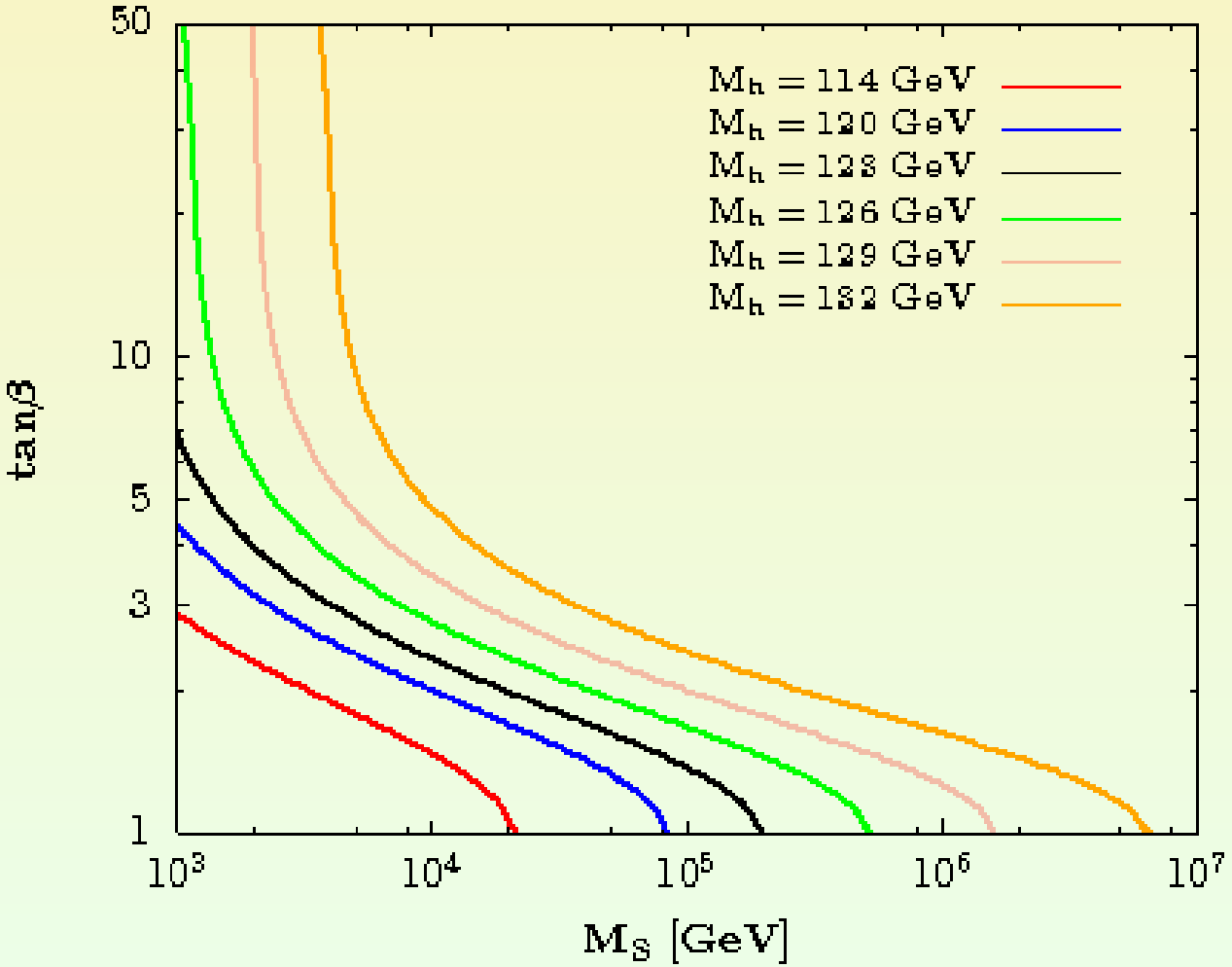
- **In the MSSM, for TeV-scale values of the SUSY–breaking scale $M_S$ :**
  **SM-like Higgs boson mass $\approx$ 125 GeV + very small $\tan\beta$, i.e. $\approx 1 \Rightarrow$ tricky**
  **$\Rightarrow$ Higgs boson mass of 125 GeV requires large $\tan\beta$**




A. Djouadi, J. Quevillon, arXiv :1304.1787

# 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 $\tan\beta$**
- **In singlet extension (e.g. NMSSM) $m_h \approx$ 125 GeV can be achieved with $\tan\beta \approx 2$**

**What about extending the gauge symmetry ?**

**➜ Here : the UMSSM**

# The model

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- **Symmetry group : $SU(3)_c \times SU(2)_L \times U(1)_Y \times U'(1)$**
  **Coupling constants : $g_3$, $g_2$, $g_Y$ and $g'_1 = \sqrt{\frac{5}{3}} g_Y$**

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

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

- **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 :**

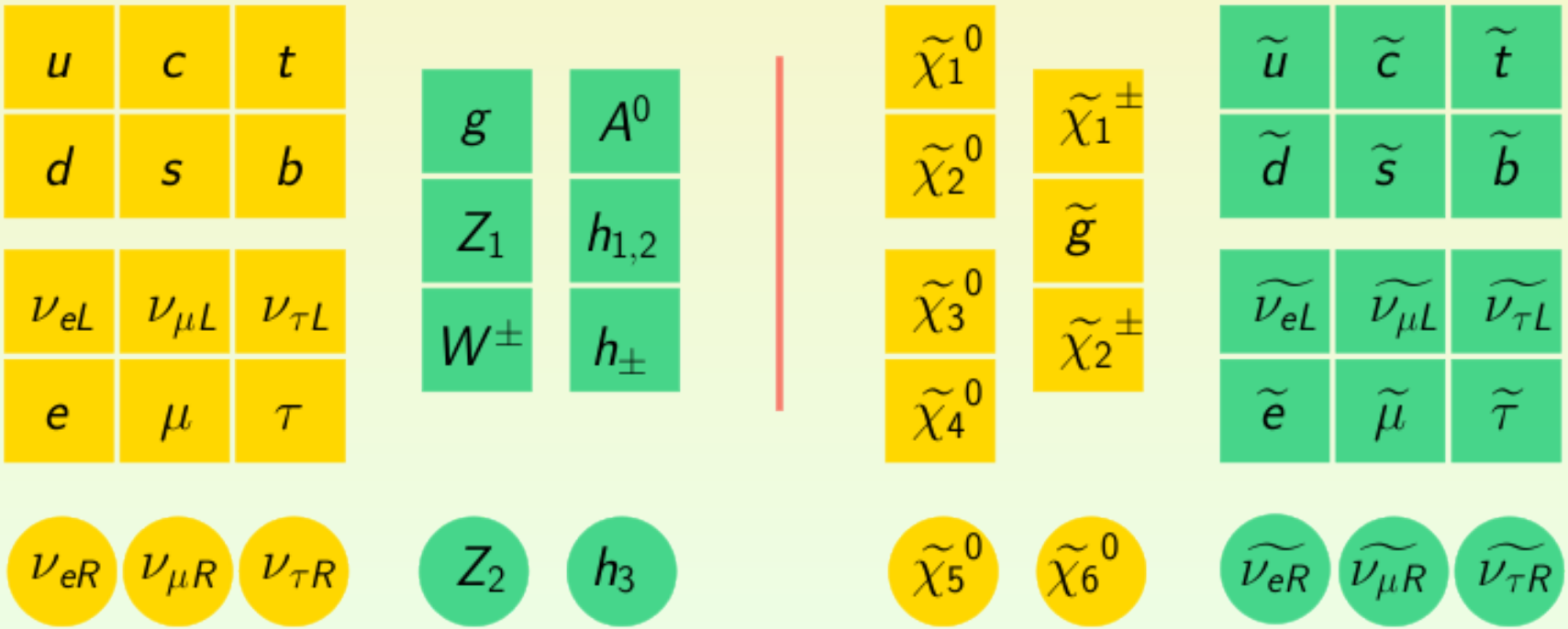
$$\mathcal{W}_{UMSSM} = \mathcal{W}_{MSSM}|_{\mu=0} + \lambda S H_u H_d + \tilde{\nu}^*_R y_\nu \tilde{L} H_u + \mathcal{O}(\text{TeVs})$$

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

- **Higgs sector : MSSM fields + 1 singlet $\Rightarrow$ 3 CP-even Higgs bosons $h_i, i \in \{1,2,3\}$**
  **New D-terms for the SM-like Higgs boson :**
  **$m^2_{h_1} \leq M_Z^2 \cos^2 2\beta + \frac{1}{2}\lambda^2 v^2 \sin^2 2\beta + g'^2_1 v^2 (\mathcal{Q}'_{H_d} \cos^2\beta + \mathcal{Q}'_{H_u} \sin^2\beta)^2 + \Delta m^2_h$**

# The model

- **Gauge sector : Physical abelian gauge bosons : $Z_1$ and $Z_2$, mixing between the Z of the SM and the $Z'$, $\alpha_Z$ 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

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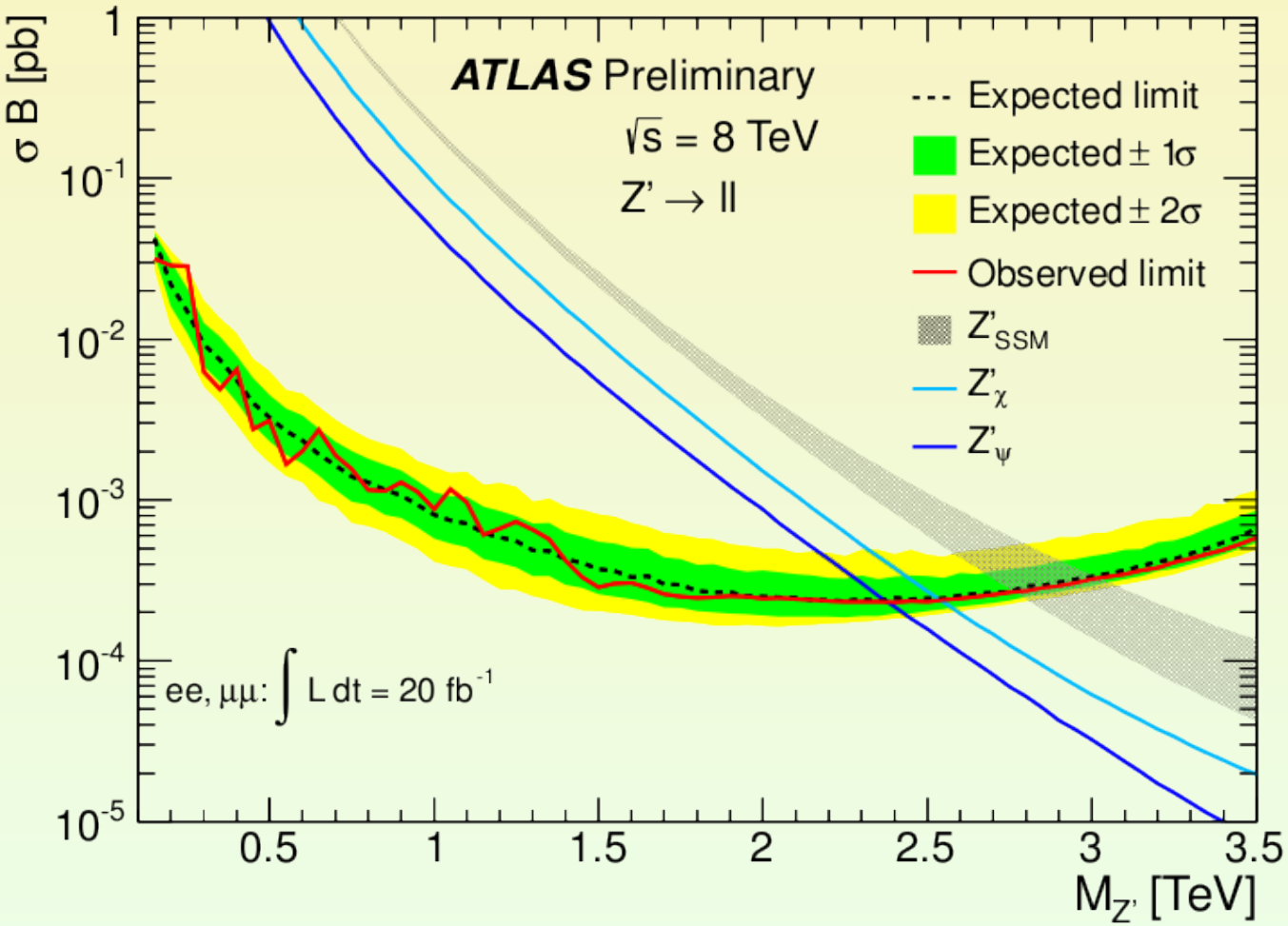
- **Z′ heavy ⇒ heavy singlet-like Higgs boson ⇒ $h_2$ mostly doublet-like**




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

# Constraints

- $Z'$ heavy $\Rightarrow$ heavy singlet-like Higgs boson $\Rightarrow$ $h_2$ mostly doublet-like
- DM observables for either neutralino or RH sneutrino DM candidate
- $m_{h_1} \in [120.63, 130.63]$ GeV
- Higgs boson signal strengths and low energy observables
  $\Rightarrow$ Modification of the `NMSSMTools` code : `UMSSMTools`

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

| Parameter | Range | Parameter | Range |
|---|---|---|---|
| $m_{\tilde{\nu}_R}$ | [0.05, 2] TeV | $A_\lambda$ | [0, 4] TeV |
| $M_{Z_2}$ | [2.2, 7] TeV | $A_t, A_b, A_\tau$ | [-4, 4] TeV |
| $\alpha_Z$ | [$-10^{-3}$, $10^{-3}$] rad | $m_{\tilde{Q}_3}, m_{\tilde{u}_3}, m_{\tilde{d}_3}, m_{\tilde{L}_3}, m_{\tilde{e}_3}$ | [0, 2] TeV |
| $\theta_{E_6}$ | [$-\pi/2$, $\pi/2$] rad | $\mu, M_1, M_1'$ | [0.1, 2] TeV |

# Results

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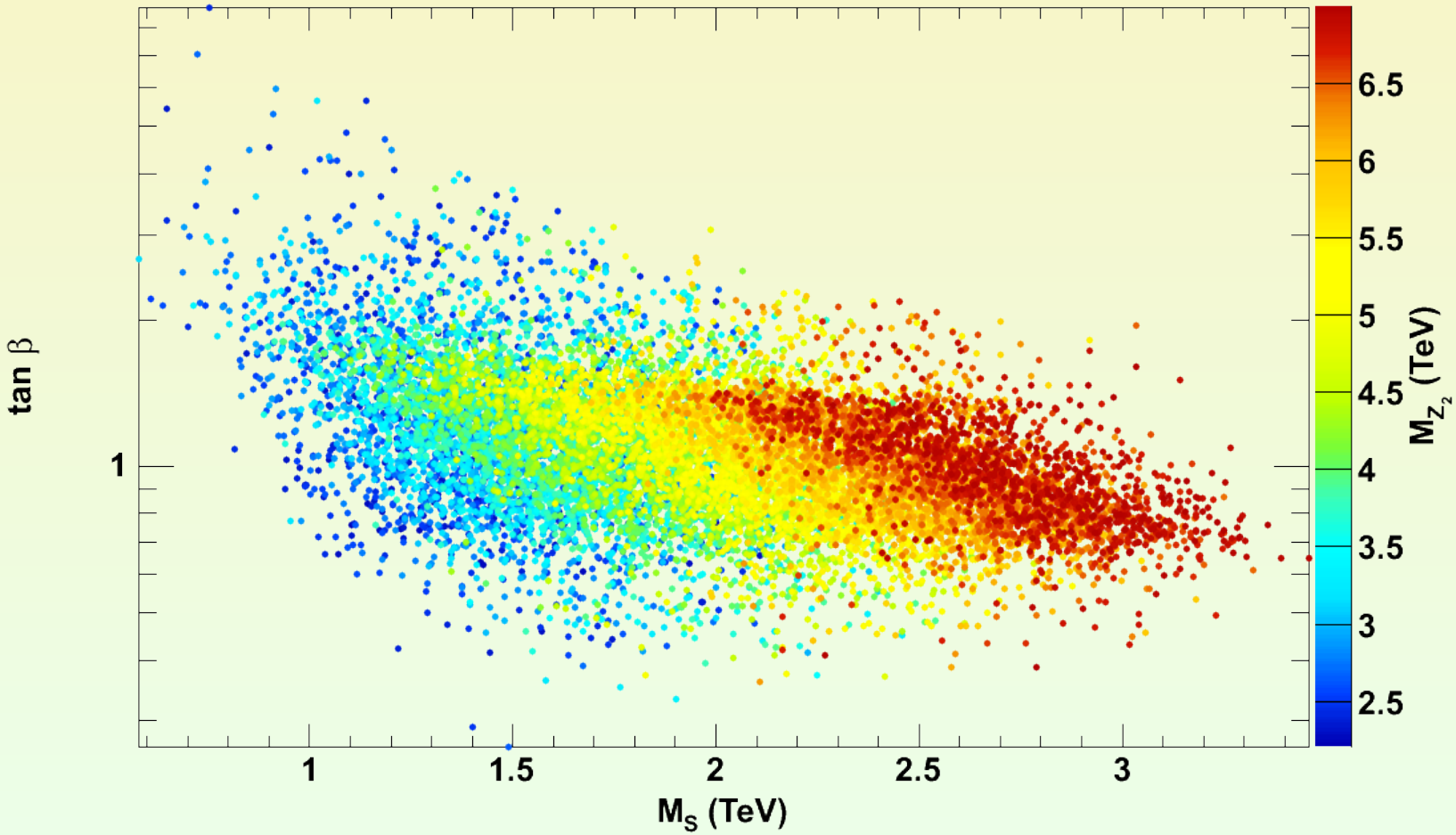
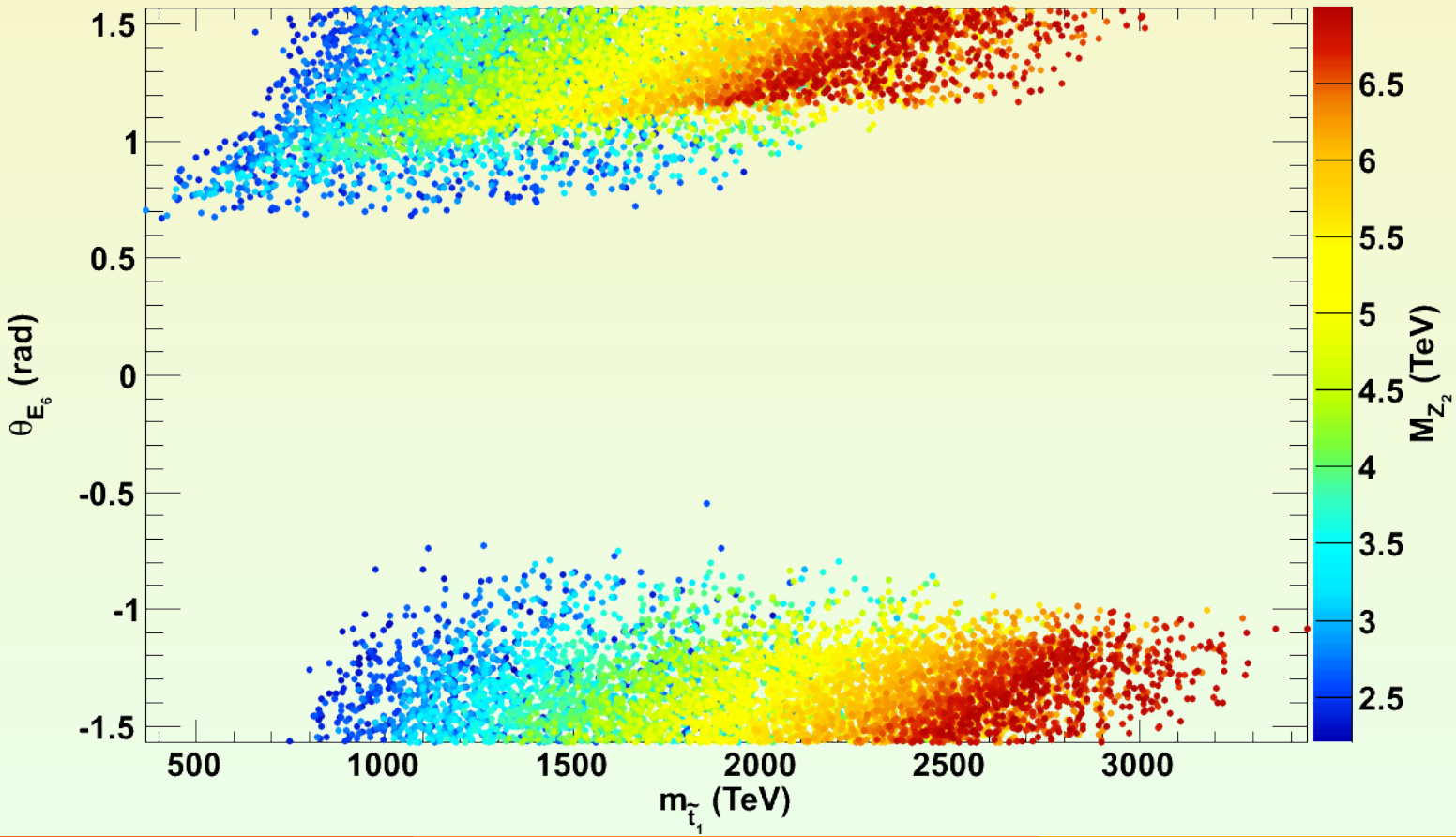
- $\tan\beta \approx 1$ + TeV-scale $M_S \Rightarrow$ expected $m_{h_1}$ :
  large contribution from pure UMSSM as well as one-loop stop terms



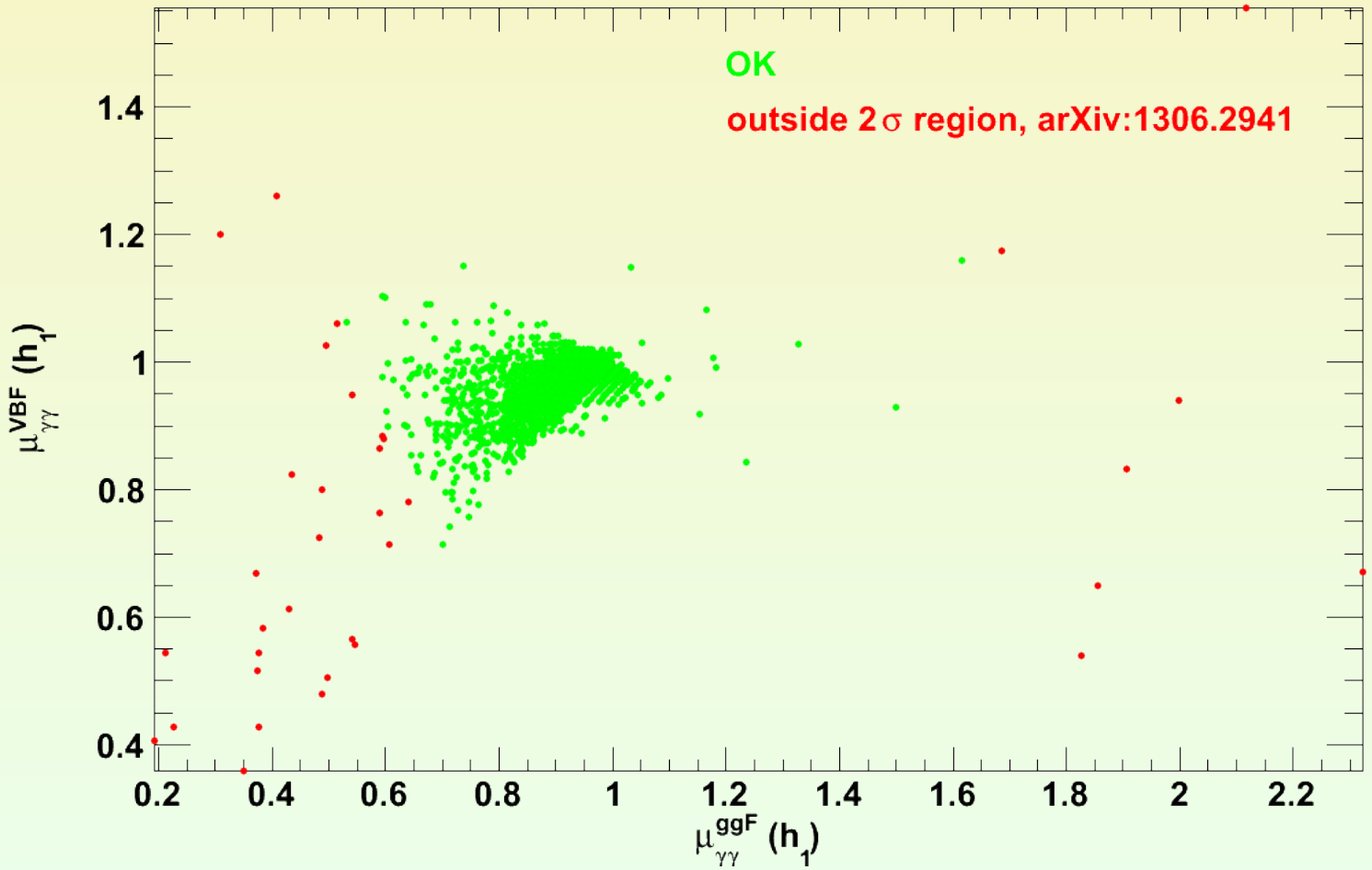
# Results

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



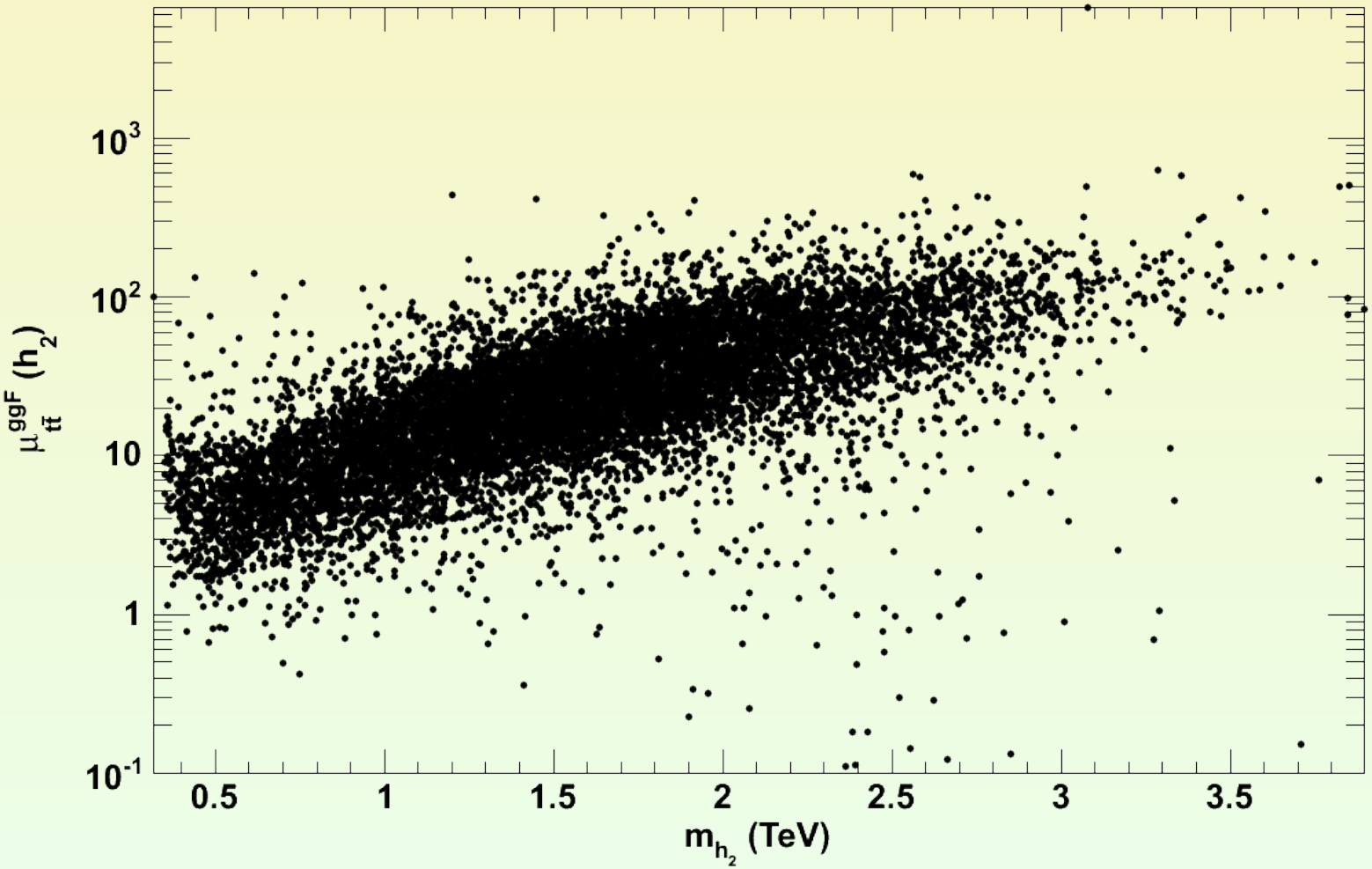
# Results

- Higgs signal strength mostly compatible with current limits (here using G. Belanger et al, arXiv :1306.2941)



# Results

- **Prospects for $h_2$ searches**



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  **$\Rightarrow$ strong constraints on the UMSSM**
- **New D-terms $\Rightarrow$ low $\tan\beta$ values still allowed for TeV-scale $M_S$**
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## Thanks !

# BACKUP

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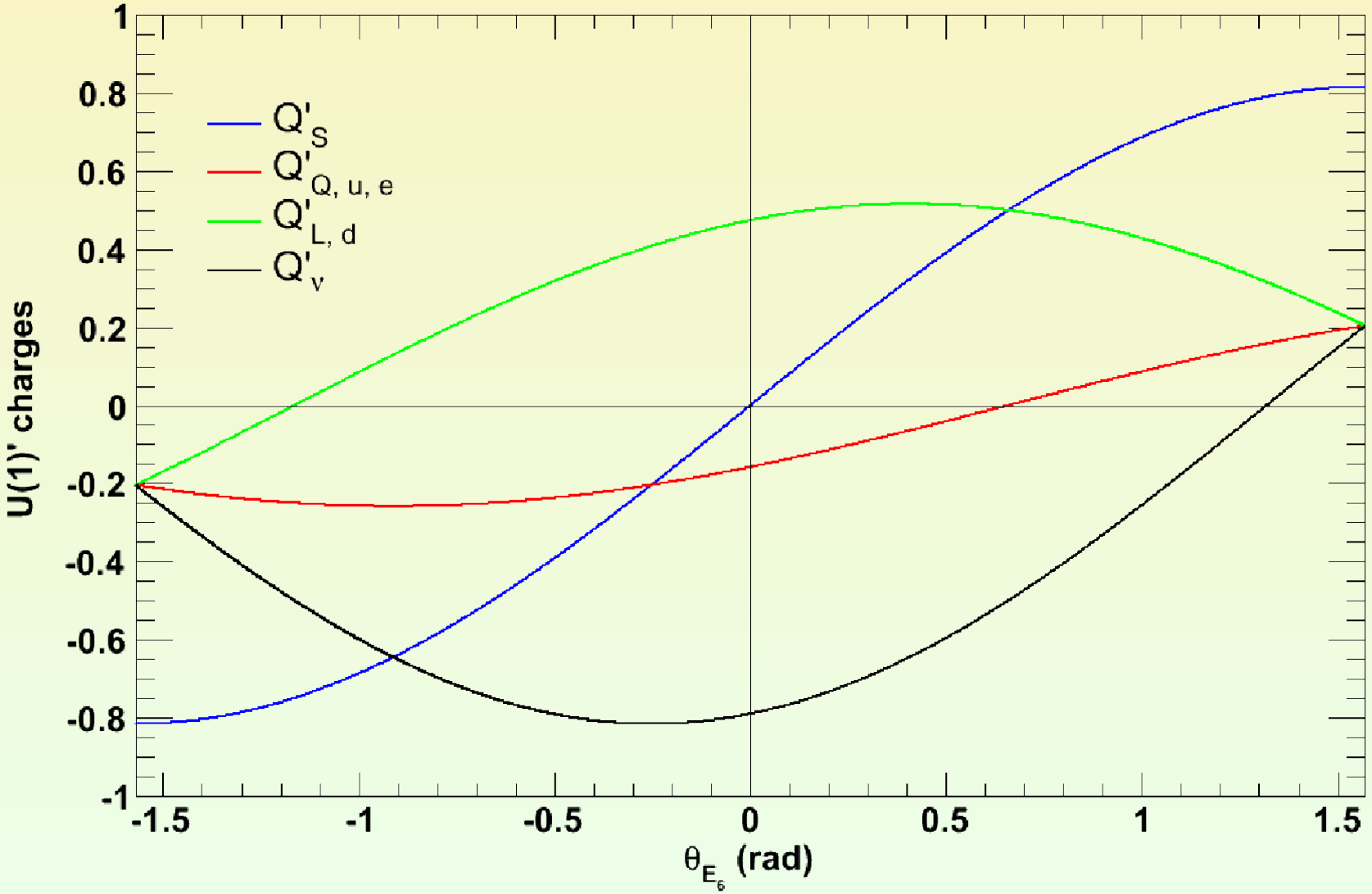
Q'S
Q'Q, u, e
Q'L, d
Q'ν
U(1)' charges
θE6 (rad)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.5
-1
-0.5
0
0.5
1
1.5