Fourth Generation Aspects and Supersymmetry

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Fourth Generation: Introduction

- Fourth generation of fermions: t', b', τ' and ν'_τ
- Motivation:
  - $Z \to \nu\bar{\nu} \Rightarrow$ exactly 3 neutrinos with $m_{\nu'} < M_Z/2$
  - Asymptotic freedom of QCD restricts $n_G \leq 8$ but there is no good reason why $n_G = 3$
  - Adding a fourth generation in the EW precision data prefers higher Higgs mass, this is favoured by the limit $m_H > 114.4$ GeV from LEP
  - Additional phases in the CKM matrix can give rise to extra CP violation which is needed for the EW baryogenesis to work
- Paper: 'Four Generations, SUSY and SUSY Breaking' R.M. Godbole, S.K. Vempati and A. Wingerter (arXiv:0911.1882)

Constraints from the experiment

- Most stringent mass constraints with 95% CL

$$m_{t'} > 358(450)\ \text{GeV} \qquad m_{b'} > 372(495)\ \text{GeV}$$
$$m_{\tau'} > 100.8\ \text{GeV} \qquad m_{\nu'_\tau} > 80.5\ \text{GeV}$$

- Assumptions
  - $t' \to Wq$ is dominant, requires a small mass splitting $|m_{t'} - m_{b'}|$
  - $\text{BR}(b' \to Wt) = 1$, neglects the possibility of an inverted fourth generation mass hierarchy and the FCNC to light quarks
- Weaker mass constraints with 95% CL used in the article

$$m_{t'} > 256\ \text{GeV} \qquad m_{b'} > 128\ \text{GeV}$$
$$m_{\tau'} > 100.8\ \text{GeV} \qquad m_{\nu'_\tau} > 45\ \text{GeV}$$

Perturbativity of the Yukawa couplings in MSSM4

- The Yukawa couplings in MSSM4 are given by

$$h_{t'} = \frac{m_{t'}\sqrt{2}}{v \sin\beta} \qquad h_{b'} = \frac{m_{b'}\sqrt{2}}{v \cos\beta} \qquad h_{\tau'} = \frac{m_{\tau'}\sqrt{2}}{v \cos\beta}$$

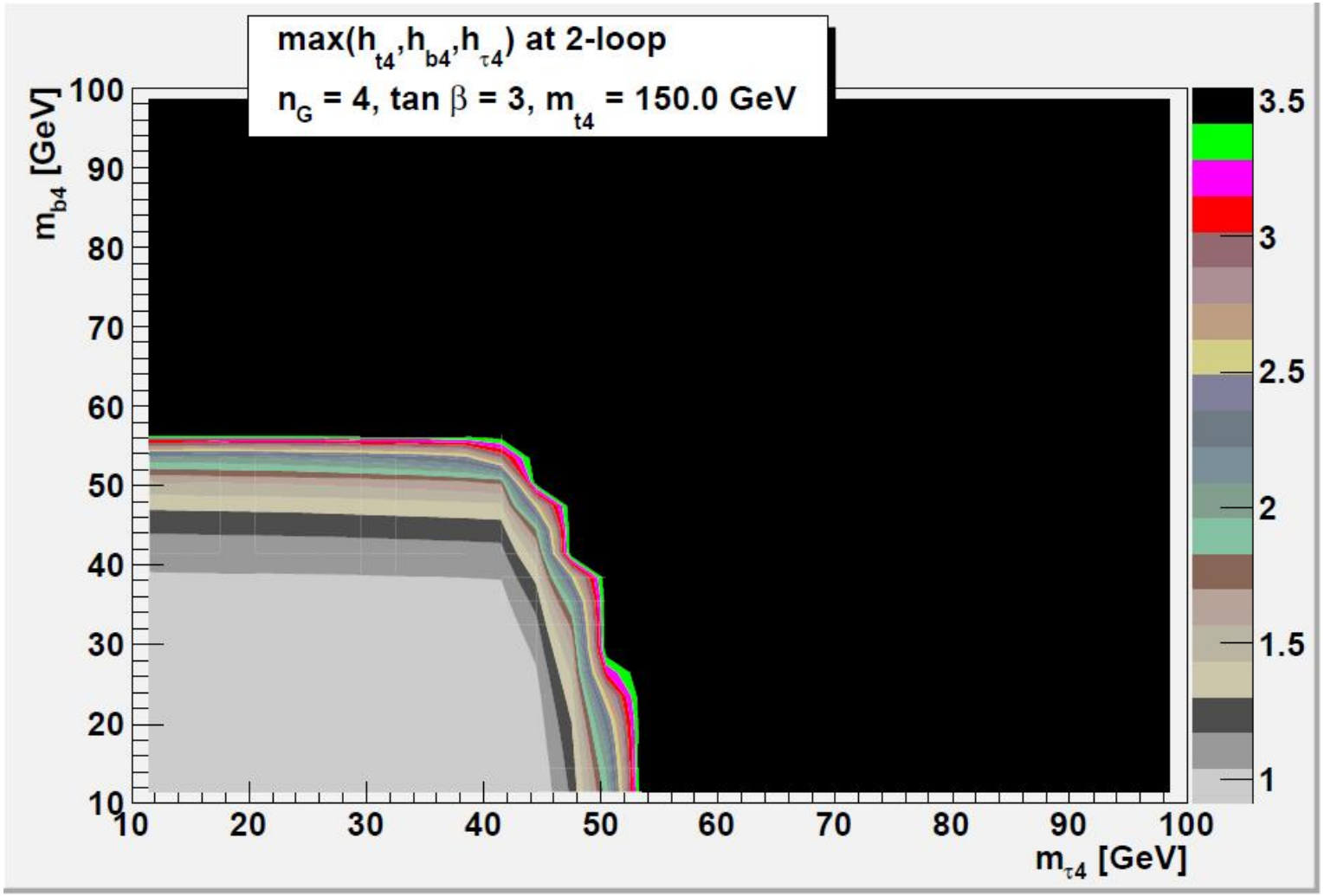
  where $v = 256$ GeV the vev of the Higgs
- RGE determine the dependence on the energy scale
- Condition for perturbativity

$$h^2 < 4\pi$$

  this must hold up to the GUT scale

Perturbativity of the Yukawa couplings in MSSM4

With $m_{t'} = 150$ GeV and $\tan\beta = 3$ We do not consider ν'_τ



$m_{t'} = 256$ GeV yields a similar figure

Perturbativity of the Yukawa couplings in MSSM4

- Result:

$$0 \leq m_{b'} \leq 56 \text{ GeV}$$
$$0 \leq m_{\tau'} \leq 53 \text{ GeV}$$
$$m_{t'} = 256 \text{ GeV}$$
$$\tan\beta = 3$$

- Excluded $\Rightarrow$ MSSM4 cannot be perturbative up to the GUT scale

Perturbativity of the Yukawa couplings in MSSM4

Reverse the logic:

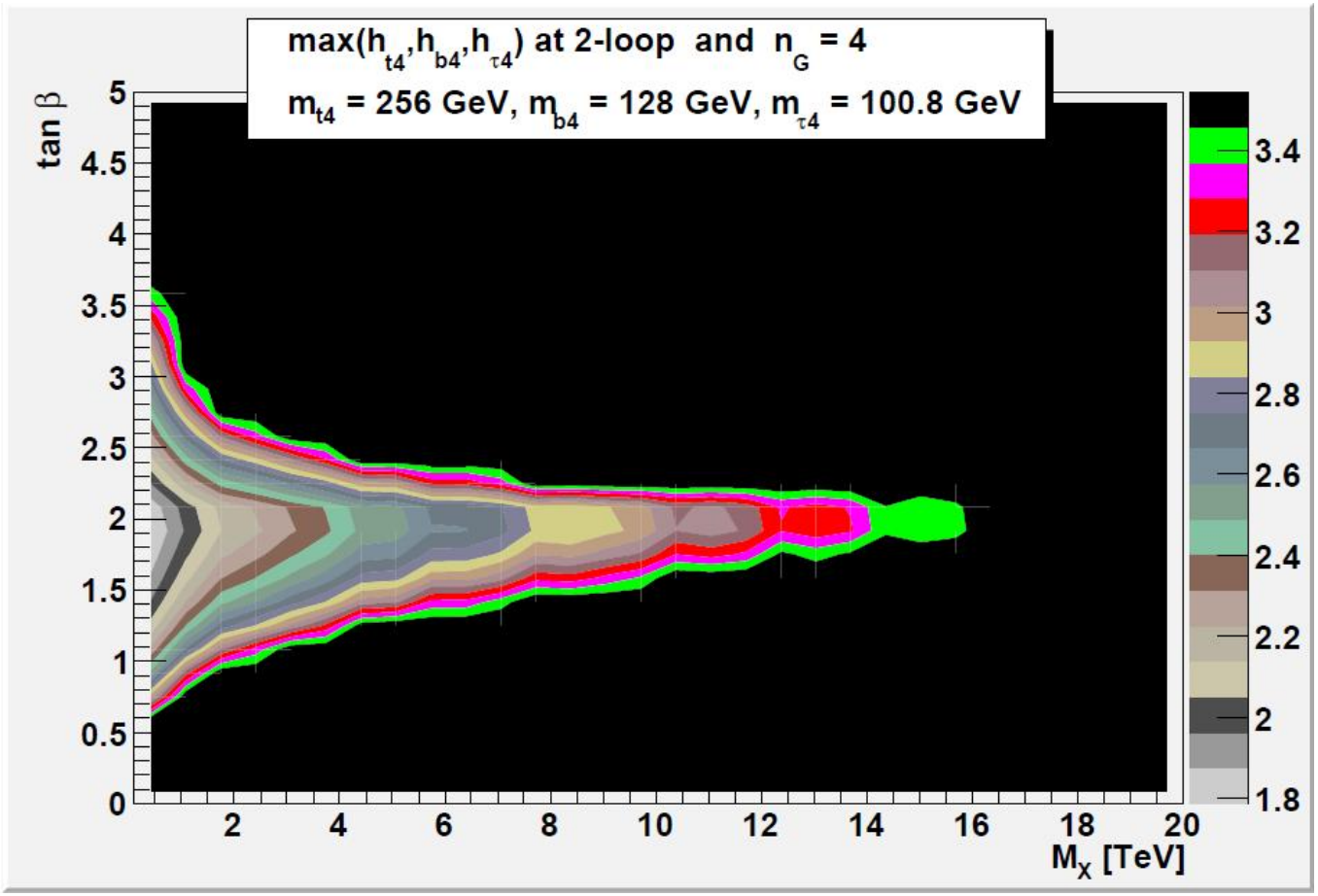
- Fix the masses

$$m_{b'} = 256 \text{ GeV}$$
$$m_{t'} = 128 \text{ GeV}$$
$$m_{\tau'} = 100.8 \text{ GeV}$$

Perturbativity of the Yukawa couplings in MSSM4

Reverse the logic:

- Plot the perturbative region in the $(\tan\beta - M_X)$-plane



- For $\tan\beta \simeq 2$ perturbative up to $M_X \simeq 15$ GeV

Perturbativity of the Yukawa couplings in MSSM4

Reverse logic:

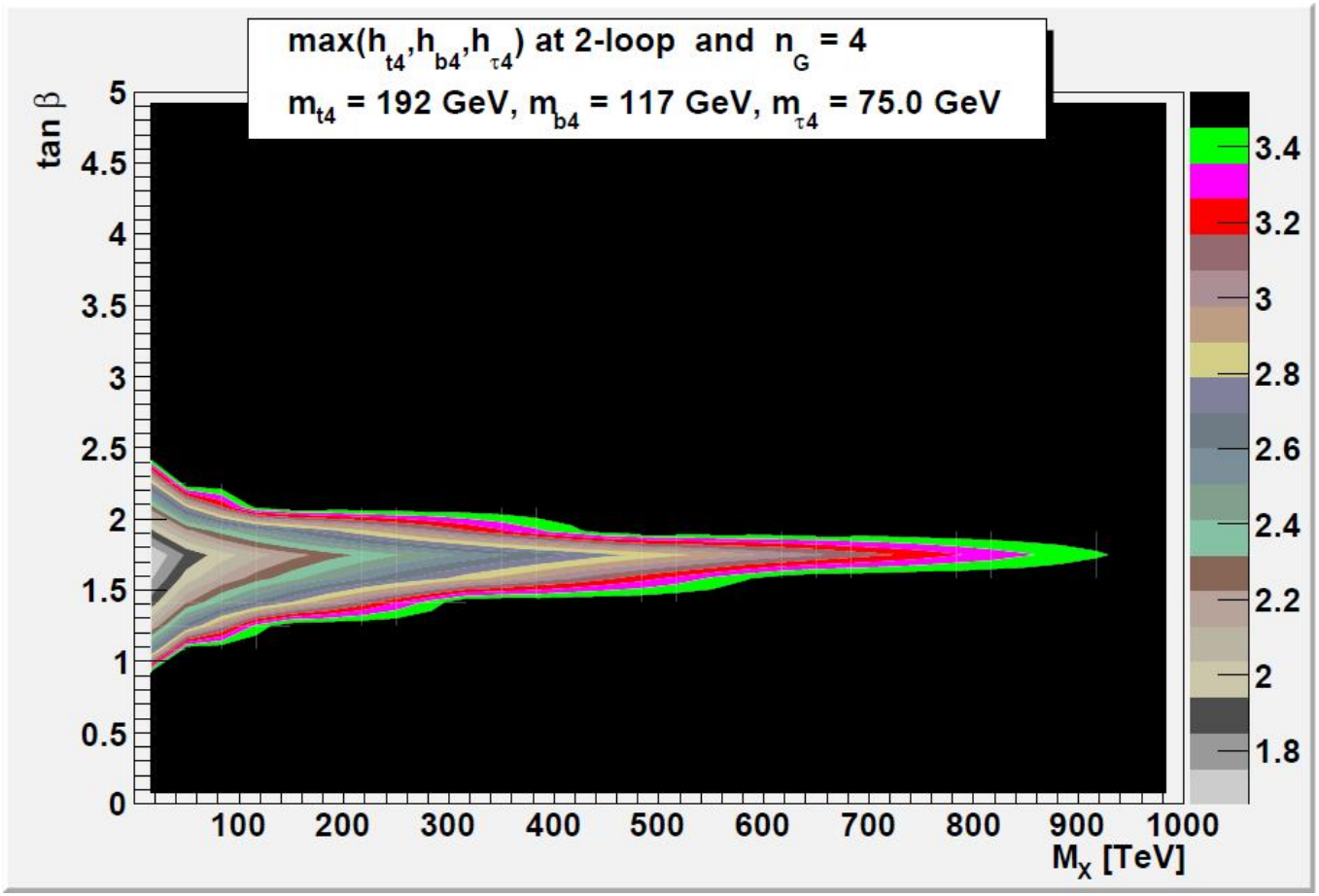
- Adjust masses to higher confidence level

$$m_{b'} = 192 \text{ GeV}$$
$$m_{t'} = 117 \text{ GeV}$$
$$m_{\tau'} = 75 \text{ GeV}$$

Perturbativity of the Yukawa couplings in MSSM4

Reverse logic:

- Plot the perturbative region in the $(\tan\beta - M_X)$-plane



- For $\tan\beta \simeq 2$ perturbative up to $M_X \simeq 900$ GeV

Perturbativity: discussion

- The existence of a fourth generation and the idea of perturbative unification are mutually exclusive
- A vectorlike fourth generation avoids this problem
- Minimal Gauge Mediation
  - Perturbativity is not required to hold up to the GUT scale
  - Fourth generation minimal gauge mediation is excluded

Possible project

- Implement MSSM4 into FeynRules
- Derive the mass spectrum of the SUSY particles based on the experimental constraints on $m_{t'}$, $m_{b'}$, $m_{\tau'}$ and $m_{\nu'}$
- Other constraints?
- Given the fact that the theory is not perturbative up to the GUT scale, is generation of the mass spectrum possible?