A 4th generation in the MSSM

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Outline

- Motivations
- Constraints on $m_{b'}$ and $m_{t'}$ from EW precision data and the axial anomaly (ΔM_Z)
- Limits on $\tan\beta$ from the introduction of a 4th generation due to perturbativity requirements
- Introduction of model to extend limits on $\tan\beta$
- Conclusions

Motivation

- Why not have a 4th generation?
- Current experimental bounds of 4th generation (PDG): $m_{t'} > 220$ GeV , $m_{b'} > 190$ GeV, $m_{\tau'} > 100$ GeV , $m_{\nu'} > 50$ GeV
- To show there is room for a 4th generation in the MSSM
- The requirement of perturbativity limits $1 < \tan\beta < 1.17$, we would like to extend this range
- To investigate what masses are possible for b' and t'
- LHC will explore the region around 1 TeV giving a good chance to either find or rule out a 4th generation

Masses of 4th Generation Quarks

- The electroweak precision variables S, T, and U limit the **difference** between $m_{b'}$ and $m_{t'}$.
- New chiral fermions increase S, T, and U. For example[a]:

$$S_f = \frac{N_c}{6\pi}\left\{2(4Y+3)x_1 + 2(3-4Y)x_2 - 2Y\ln\frac{x_1}{x_2} + \left[\left(\frac{3}{2}+2Y\right)x_1 + Y\right]G(x_1) + \left[\left(\frac{3}{2}-2Y\right)x_2 - Y\right]G(x_2)\right\}$$

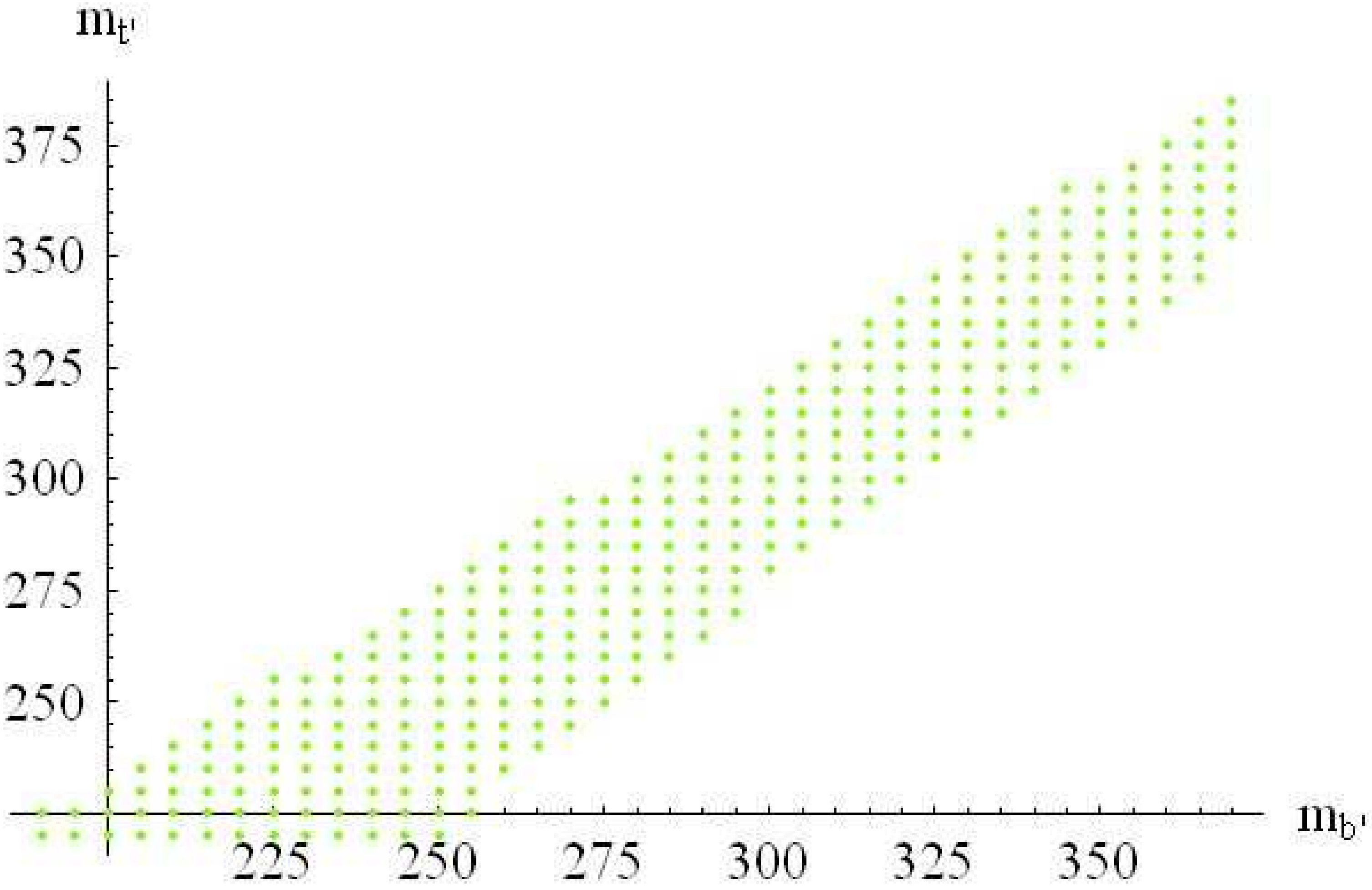
- Where $x_1 = \frac{m_1^2}{m_Z^2}$ and $G(x) = -4\sqrt{4x-1}\,\mathrm{arctan}\,\frac{1}{\sqrt{4x-1}}$

$$\begin{aligned} S &= -0.13 \pm 0.10 \\ T &= -0.13 \pm 0.11 \\ U &= 0.20 \pm 0.12 \end{aligned}$$

[a] He, Polonsky, Su, hep-ph/0102144v2

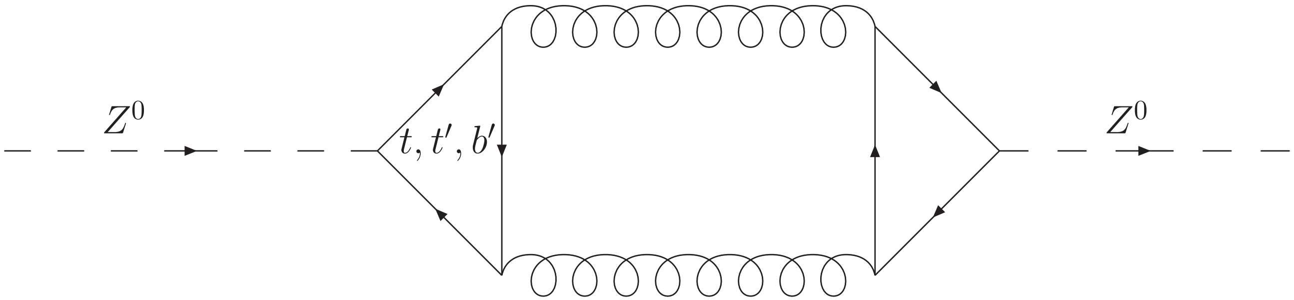
$m_{b'}$ vs $m_{t'}$ as constrained by S, T, U

$m_h = 115$ GeV, $m_{\nu'} = 100$ GeV, $m_{\tau'} = 150$ GeV, $\tan\beta = 1.5$



Axial Anomaly

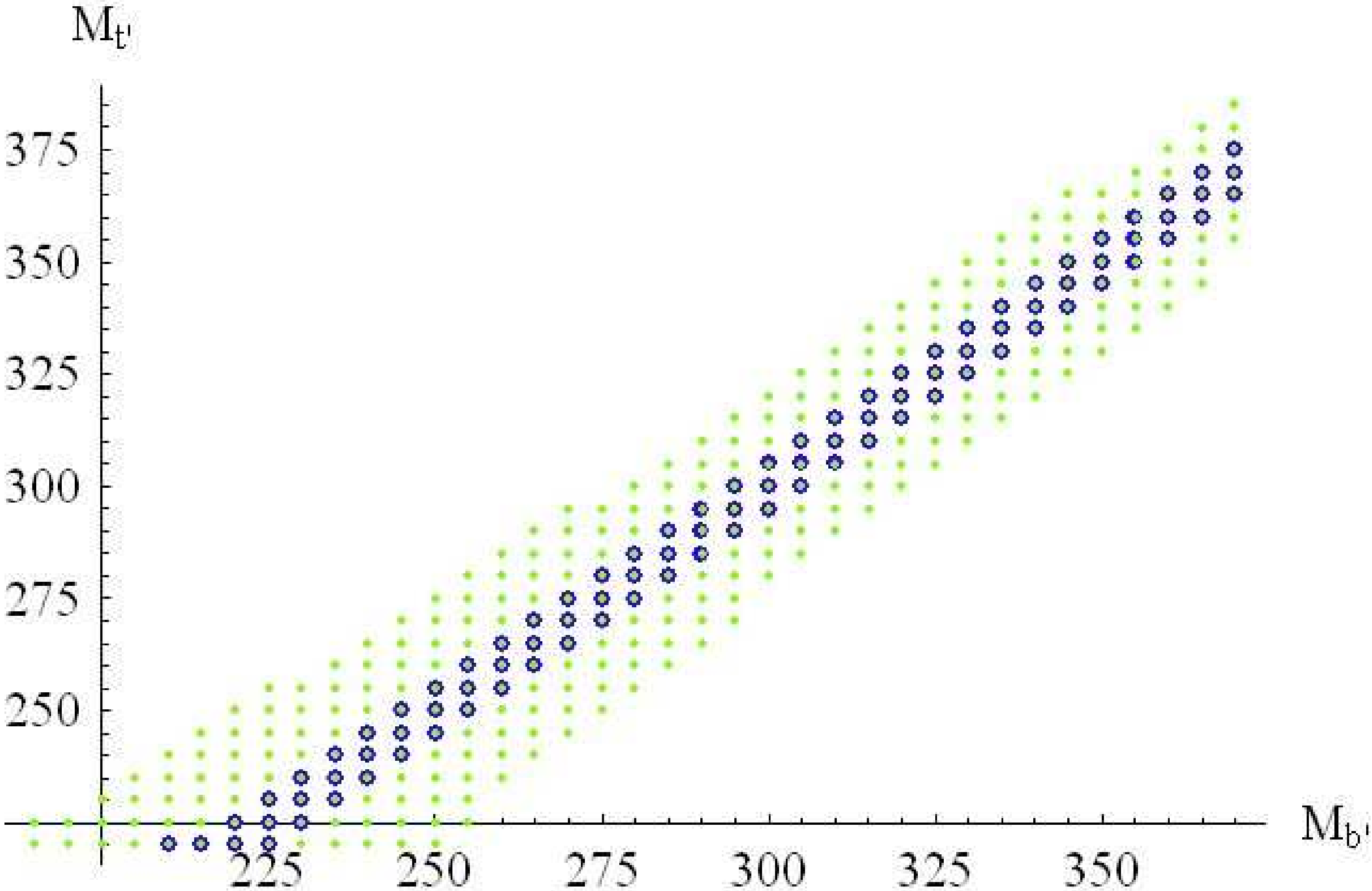
- Loop corrections to the Z^0 propagator are directly dependent upon heavy chiral fermions[a]



- Their result generalized to 4 generations:
$\Delta M_Z = \frac{1.6\times 10^{-5}}{2M_Z}(m_t^2 + m_{t'}^2 - m_{b'}^2)$
- Not considered in previous work on the 4th generation, this further constrains the difference between the masses of the b' and t'

[a] Anselm, Dombey, Leader, Phys Lett B312 (1993)

$m_{b'}$ vs $m_{t'}$ with ΔM_Z Constraint



Limits on $\tan\beta$

- In the MSSM $\tan\beta < 60$ due to b Yukawa exploding
- MSSM with 4 generations (MSSM4) was explored by Gunion, McKay, and Pois [a]. They found $\tan\beta < 3$
- The problem is that for $\tan\beta > 3$, the Yukawa coupling of the b' quark becomes non-perturbative near 1 TeV
- Current values of m_t and the lower limits on $m_{b'}$ and $m_{t'}$ cause the constraint on $\tan\beta$ to be even more restrictive
- With current data we find that no $\tan\beta$ allows perturbativity up to the GUT scale

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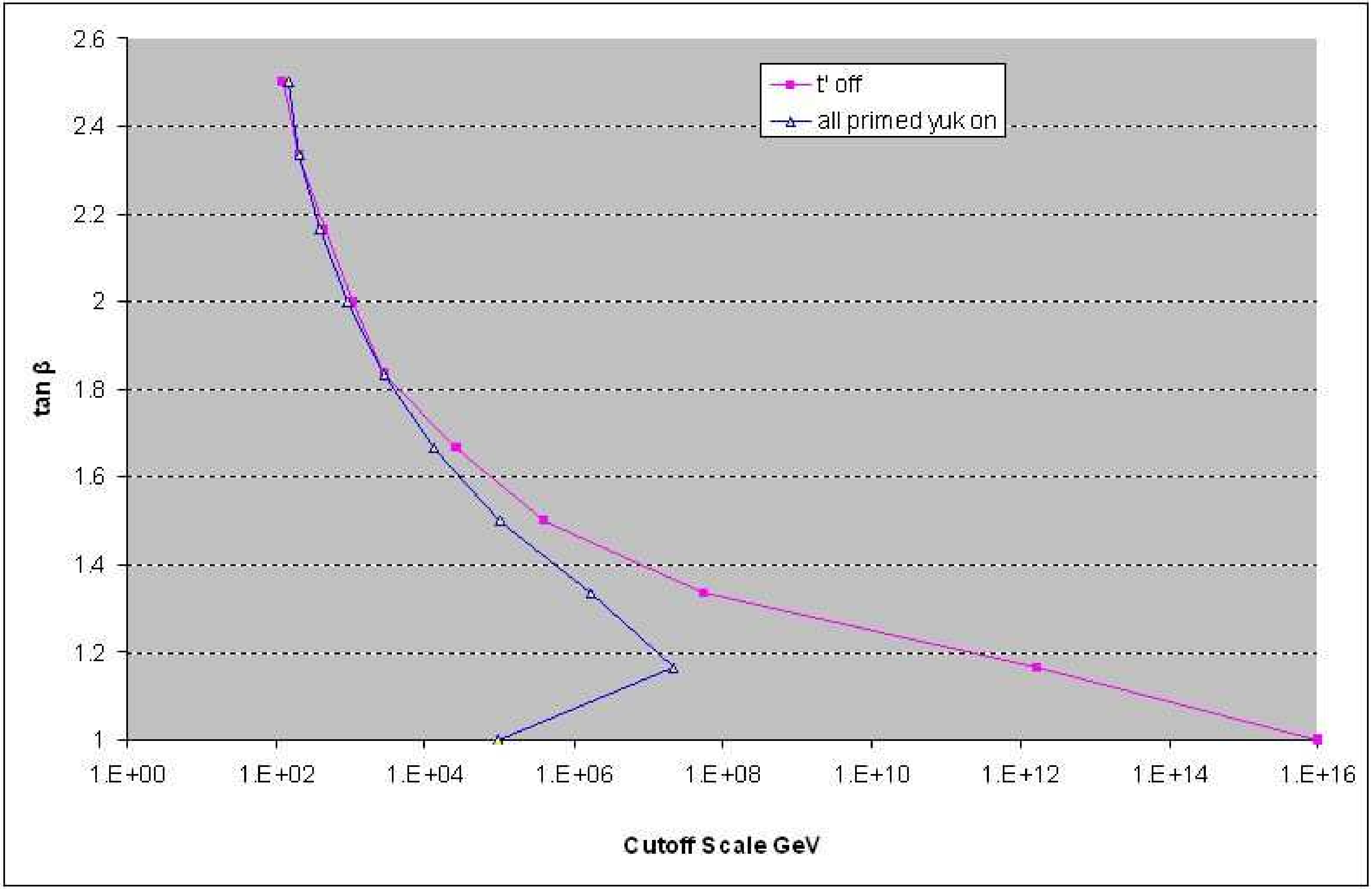
[a] Phys. Lett. B 334 pp. 339-347 (1994)

$\tan\beta$ **vs Cutoff Scale** $(\lambda > 2)$

- $y = \frac{\lambda^2}{4\pi}$, $\lambda_{b'} = \frac{m_{b'}\sqrt{1+\tan^2\beta}}{v}$

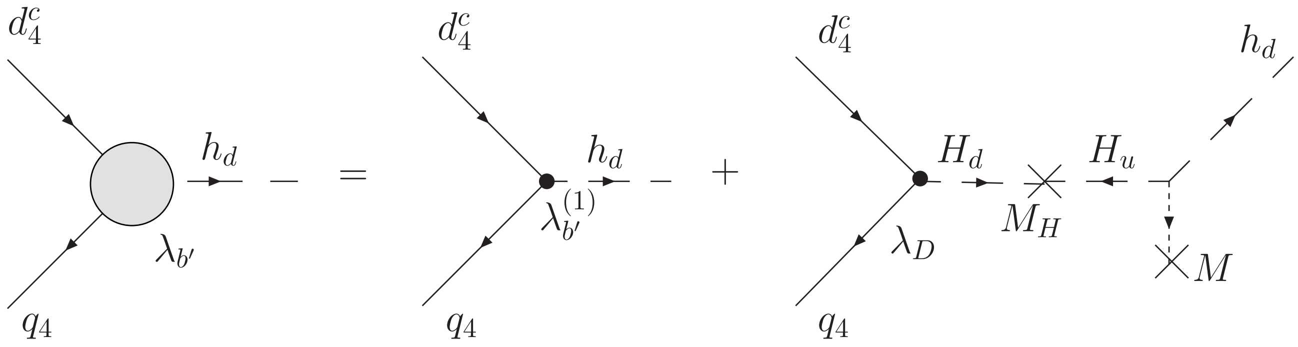


Our Model

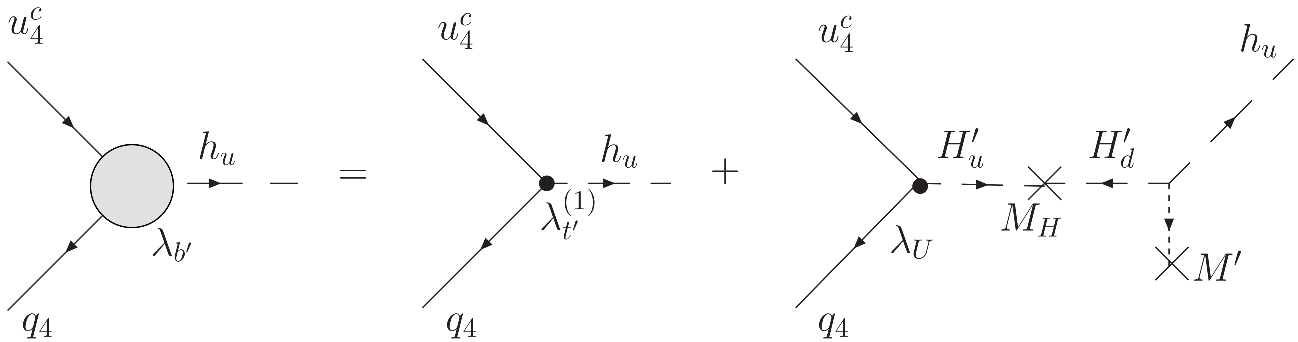
Motivations:

- The limit on $\tan\beta$ is too narrow
- We introduce two new vector like Higgs doublets at the TeV scale to redefine the Yukawa coupling of the b', t', and τ' particles
- This allows $\tan\beta$ to be as large as 2.5 while the Yukawa couplings remain perturbative **up to the GUT scale**
- Increasing $\tan\beta$ will help increase the upper limit on the Higgs mass
- Below the scale of new physics we have the low-energy effective theory of the MSSM

Model



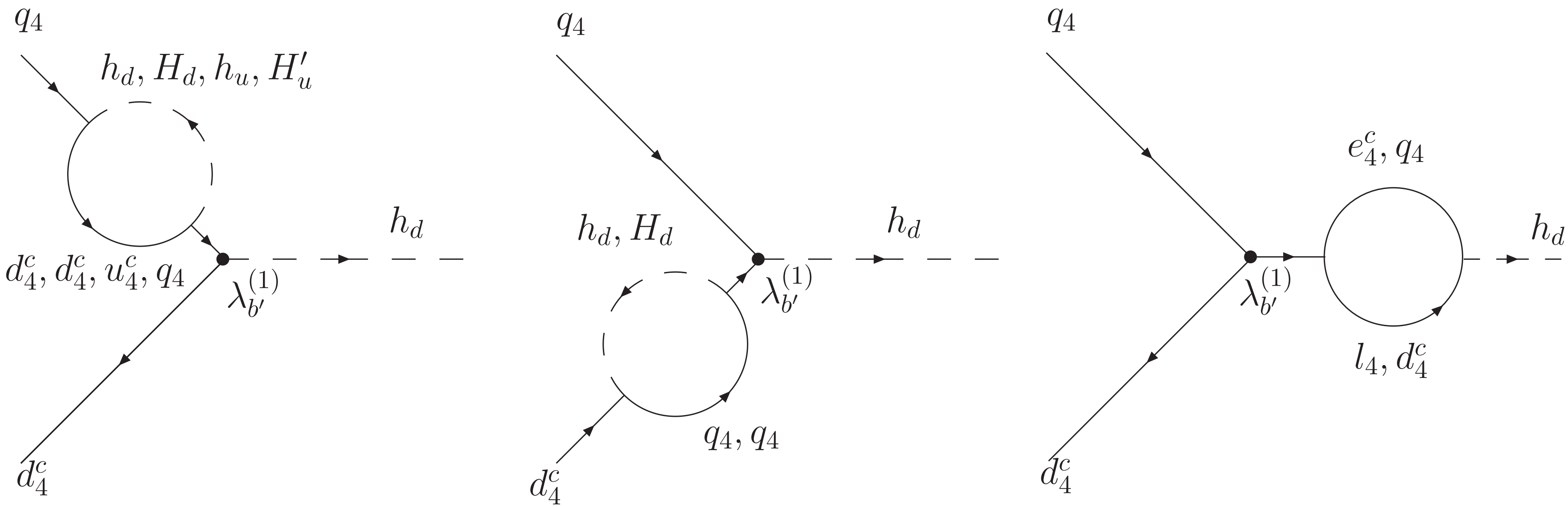
$$\lambda_{b'} = \lambda_{b'}^{(1)} + \lambda_D \frac{M}{M_H} \Theta(M - \mu)$$



$$\lambda_{t'} = \lambda_{t'}^{(1)} + \lambda_U \frac{M'}{M_H} \Theta(M' - \mu)$$

Model

The extra particles in the loops preserve the perturbativity of the Yukawa couplings $\lambda_{b'}^{(1)}$ and λ_D up to the GUT scale



$$16\pi^2 \frac{d}{dt}\lambda_{b'}^{(1)} = \lambda_{b'}\left[6\left(\lambda_{b'}^{(1)}\right)^2 + 3\lambda_D^2 + \lambda_U^2 + \left(\lambda_{t'}^{(1)}\right)^2 + \left(\lambda_{\tau'}^{(1)}\right)^2 - c_i^d g_i^2\right]$$

Conclusions and Outlook

- The 4th generation is still very much alive, but the gap to find it is closing
- The LHC will probe the likely mass range of the 4th generation extensively
- We have one model that allows Yukawa couplings to be perturbative up to GUT scale and increases the limits on $\tan\beta$
- From the axial anomaly $|m_{t'} - m_{b'}| < 10\ \mathrm{GeV}$
- Increased Higgs production due to new particles in the loop contributing to gluon fusion
- Larger $\tan\beta$ increases upper bound on m_h. At tree level, $m_h^2 = m_Z^2 \cos^2 2\beta + ...$
- New quarks increase higgs mass through new loop corrections: $\Delta(m_h^2)_{\mathrm{new}} \sim (60\ \mathrm{GeV})^2$