"Two Higgs doublets, a 4th generation and a 125 GeV Higgs"

Michael Geller

Technion, Israel

VIII Rencontres du Vietnam

Collaborators: S. Bar-Shalom, A. Soni., G. Eilam

- **"The need for new search strategies for fourth generation quarks at the LHC", M. G. , S. Bar-Shalom, G. Eilam, arXiv:1205.0575 PLB 2012**
- **"125 GeV Higgs in the context of four generations with 2 Higgs Doublets", M. G. , S. Bar-Shalom, G. Eilam, A. Soni, arXiv:1209.4081 PRD 2012**
- **"Dynamical origin for the 125 Higgs in a hybrid two Higgs doublet model model with heavy quarks ", S. Bar-Shalom, M. G. , A. Soni, work in progress**

Opening Notes

- **The SM4 is excluded!**
  - The SM4 Higgs is not compatible with 125 GeV LHC results.
  - The bounds on the 4th generation quarks in the SM4 reach the perturbative limit $\sim 600 GeV$
- New fermionic states are widely studied within the framework of Vector-Like Quarks, e.g.
  - Little Higgs Models: N. Arkani-Hamed, A. Cohen, E. Katz, and A. Nelson, JHEP 0207 (2002)
  - Top Seesaw: B. A. Dobrescu and C. T. Hill, Phys. Rev. Lett. 81 (1998
- We shouldn't abandon the entire idea of new chiral fermions, just the SM4 is excluded as expected:
  - A heavy 4G leads to a low cutoff $\mathcal{O}(\mathrm{TeV})$ where strong dynamics ensue (the Yukawa couplings blow up)
  - The natural setting for DEWSB has more than one composite doublet.
  - The heavy 4G neutrino puzzle.

Outline

4G2HDM: The Model

[**Two Higgs doublets with 4th generation fermions - models for TeV-scale compositeness**,S. Bar-Shalom et al] [**An extended scalar sector to address the tension between a fourth generation and Higgs searches at the LHC**, X.G He and G. Valencia]

Basic Idea: In the EW basis

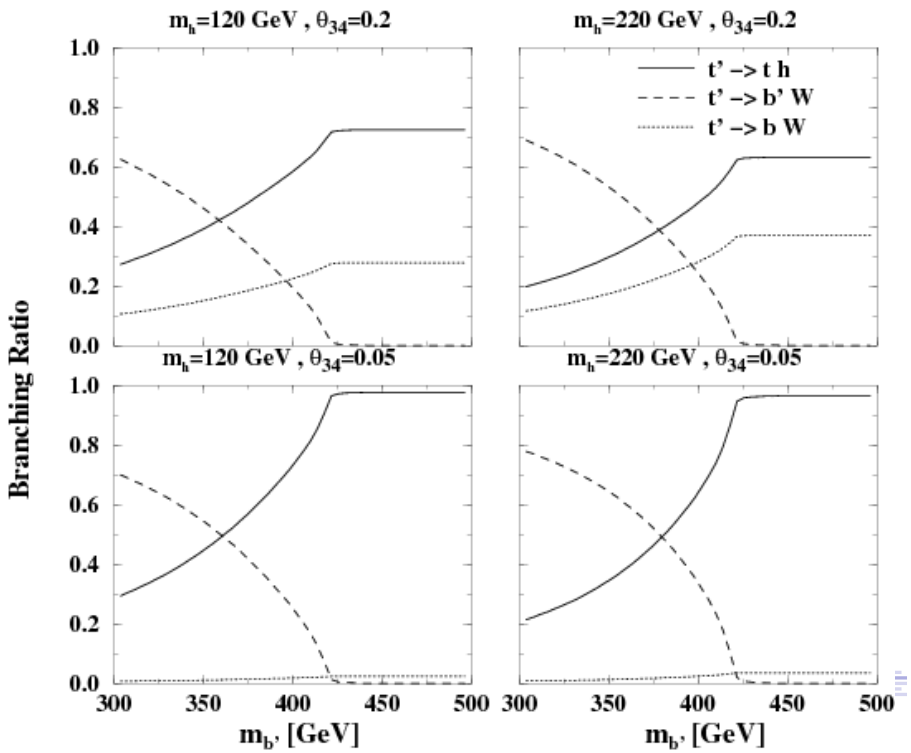
- Φ_h couples to the heavy fermions.
- Φ_ℓ couples to all the other (light) fermions.

$$
\begin{aligned}
L_Y = \quad & -\overline{Q}_L \left(\Phi_\ell F \begin{pmatrix} d_R \\ s_R \\ b_R \\ 0 \end{pmatrix} + \Phi_h F \begin{pmatrix} 0 \\ 0 \\ 0 \\ b'_R \end{pmatrix} \right) \\
& - \overline{Q}_L \left(\tilde{\Phi}_\ell G \begin{pmatrix} u_R \\ c_R \\ t_R \\ 0 \end{pmatrix} + \tilde{\Phi}_h G \begin{pmatrix} 0 \\ 0 \\ 0 \\ t'_R \end{pmatrix} \right) + h.c
\end{aligned}
$$

Quark Phenomenology in 4G2HDM

[**Two Higgs doublets with 4th generation fermions - models for TeV-scale compositeness**, S. Bar-Shalom et al]

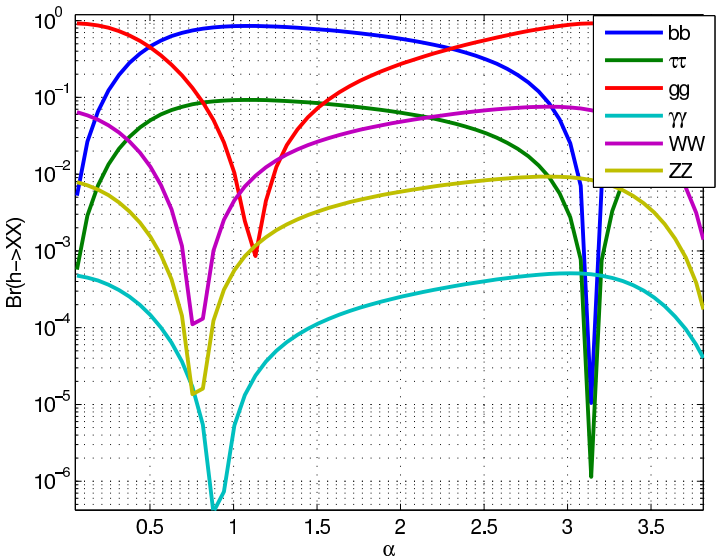
- FCNC couplings through the Higgs sector are $\mathcal{O}(1)$ between the 3rd and 4th generation.
- FCNC decays of 4G quarks are dominating in some realizations, i.e. $Br(t' \to ht) \sim 1$
- New signatures for t' and b' @ the LHC
  - $pp \to t'\overline{t'} \to hth\overline{t} \to 2W + 6b/2b + 6W$
  - $pp \to b'\overline{b'} \to hbh\overline{b} \to 6b/4W + 2b$



Higgs Phenomenology

["125 GeV Higgs in the context of four generations with 2 Higgs Doublets", M. G. et al]

- Three neutral scalars: h,H and A
- New couplings: Hff, HVV couplings are a function of $\tan\beta$ and α.



Evading the Quark Bounds

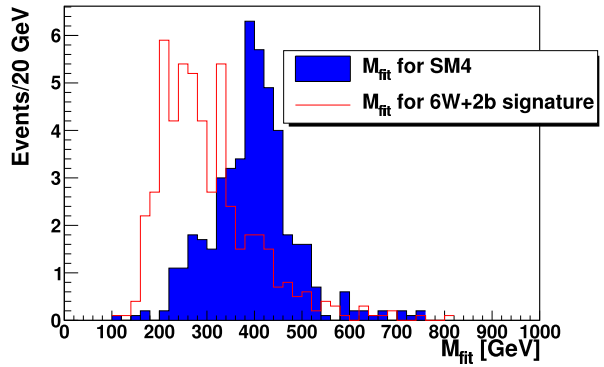
[**The need for new search strategies for fourth generation quarks at the LHC**, M. G. et al]

- The most stringent bounds on 4G quarks rely heavily on the specific kinematic topology of the SM4 events, e.g.
  - Semileptonic ($M'_t > 560$ GeV): Selecting only 4 hardest jets and fitting to the $\ell\nu bq\overline{q}\overline{b}$ topology (CMS).
  - Dilepton Search ($M'_t > 557$ GeV): Using a cut on the M_{lb}^{min}, the lowest invariant mass of a lepton and a b-jet (CMS).
  - b' searches ($M'_b > 650$ GeV): using same sign dileptons (ATLAS/CMS).
- In the 4G2HDM the bounds are significantly relaxed due to **different kinematics**

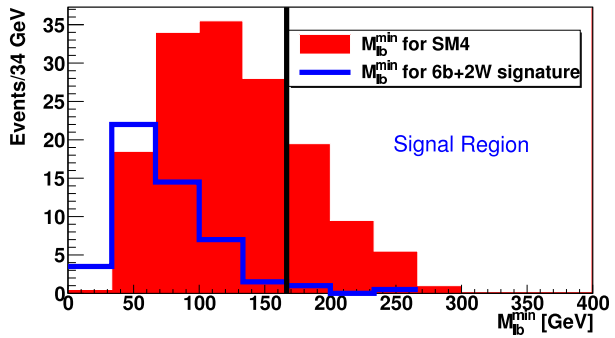
Evading the Quark Bounds

[**The need for new search strategies for fourth generation quarks at the LHC**, M. G. et al]

- Smaller reconstructed mass in the semileptonic channel



- No signal in the dilepton channel after cut:



- Overall in 4G2HDM $M_{4G} \gtrsim 400 GeV$ is consistent with most of the current data.
- New model independent searches are starting to close this window, *see e.g. P. Zalewski's talk.*

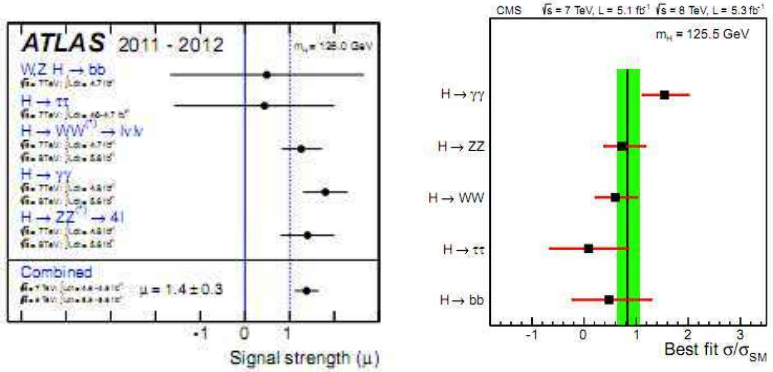
Evidence for a 125 GeV Scalar

[**125 GeV Higgs in the context of four generations with 2 Higgs Doublets**, M. G. et al]

- CMS and LHC reported evidence for a 125 GeV Scalar.
- We use the reported signal strength for our analysis:

$$\mu_{XX} = \frac{\sigma\left(pp/p\overline{p} \to h \to XX\right)_{Observed}}{\sigma\left(pp/p\overline{p} \to h \to XX\right)_{SM}}$$

- The latest data:



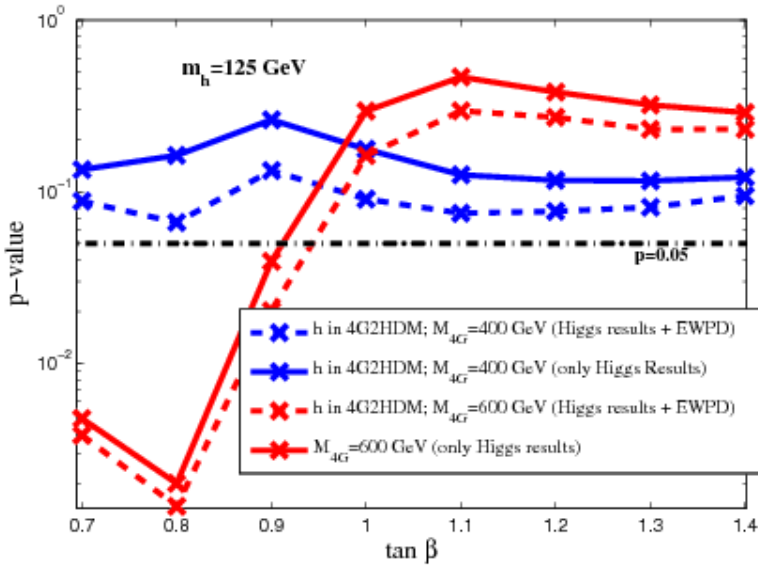
[*CMS Collaboration*, **arXiv:1207.7235 2012**] [*ATLAS Collaboration*, **arXiv:1207.7214, 2012**,]

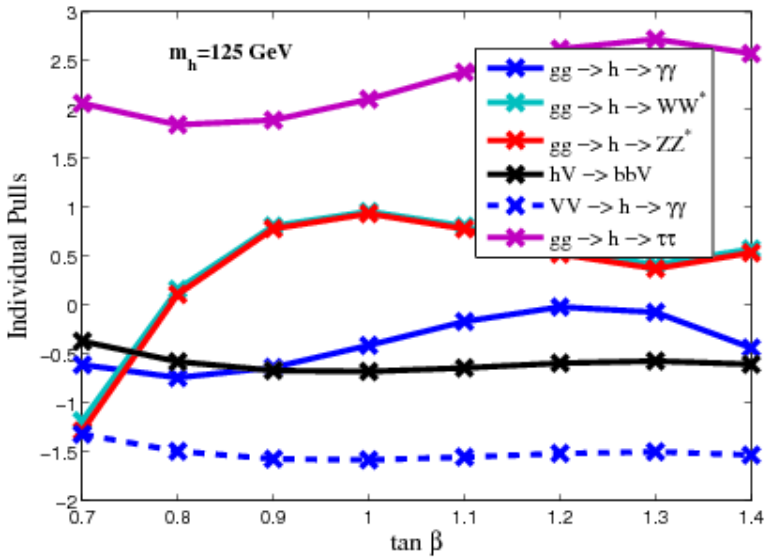
- We further split $gg \to h \to \gamma\gamma$ and $VV \to h \to \gamma\gamma$ (Dijet tagged)

125 GeV Higgs candidate in 4G2HDM

[125 GeV Higgs in the context of four generations with 2 Higgs Doublets, M. G. et al]

- Optimized P values for 4G2HDM
- The Individual Channels:



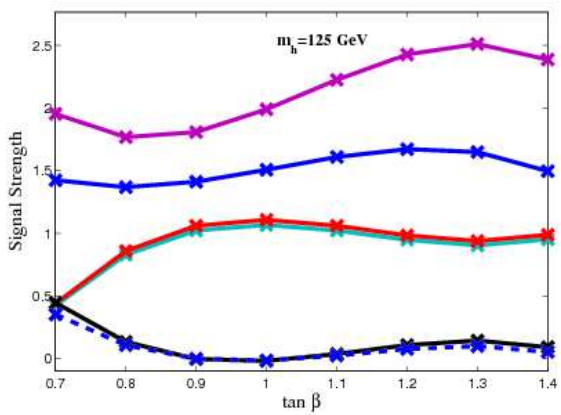


- The lightest scalar h in the 4G2HDM is consistent with both the Higgs results and EWPD for $\tan\beta \sim 1$ and $M_{4G} = 400, 600 GeV$.

Some Predictions

[125 GeV Higgs in the context of four generations with 2 Higgs Doublets, M. G. et al]

- With more statistics: a good fit in the 125 GeV channels except
  - A smaller signal in the electroweak production channels $VV \to h$, $pp \to hV$: ~ 0.1 the SM value.
  - An increased production in the $h \to \tau\tau$ channel: ~ 2 the SM value



- The other neutral scalars:
  - The CP-even H scalar is excluded up to 500 GeV
  - The CP-odd A can be as light as 130 GeV with no contradiction to the data.

Dynamic Origin of 4G2HDM

work in progress

- Dynamical Symmetry Breaking is triggered by 4f super-critical interactions involving the 4th generation at the scale $\Lambda \sim 1\,TeV$.
- Composite (auxiliary) doublet of the form

$$\Phi_h \sim g_{t'}\,\bar{Q}_L^4 t'_R + g_{b'}\,\bar{Q}_L^4 b'_R$$

- Φ_h couples to the 4G quarks and is therefore responsible for their masses.
- The other quarks get their mass via interactions which are subcritical @ $\Lambda \longrightarrow$ fundamental (for our purposes) SM-like doublet Φ_ℓ
- The low energy effective Lagrangian (for $\mu < \Lambda$) is exactly that of the 4G2HDM.

The Spectrum in Dynamic 4G2HDM

work in progress

- The full Lagrangian:

$$\begin{aligned}\mathcal{L}(\Phi_h,\Phi_\ell) &= \left|D_\mu\Phi_\ell\right|^2+\left|D_\mu\Phi_h\right|^2+\mu_\ell^2\Phi_\ell^\dagger\Phi_\ell \\ &+ \mu_h^2\Phi_h^\dagger\Phi_h-\mu_{h\ell}^2\left(\Phi_h^\dagger\Phi_\ell+h.c.\right)+\frac{1}{2}\lambda_\ell\left(\Phi_\ell^\dagger\Phi_\ell\right)^2+\frac{1}{2}\lambda_h\left(\Phi_h^\dagger\Phi_h\right)^2 \\ &+ g_u^{ij}\bar{Q}_L^i\tilde{\Phi}_\ell u_R^j+g_d^{ij}\bar{Q}_L^i\Phi_\ell d_R^j+g_{t'}\bar{Q}_L^4\tilde{\Phi}_h t_R'+g_{b'}\bar{Q}_L^4\Phi_h b_R'+h.c.\ ,\end{aligned}$$

- Boundary conditions at Λ:

$$g_{q'}(\Lambda)\to\infty\ ,\lambda_h(\Lambda)\to\infty\ ,\frac{\lambda_h(\Lambda)}{g_{q'}^4(\Lambda)}\to 0$$

- Relevant RGE:

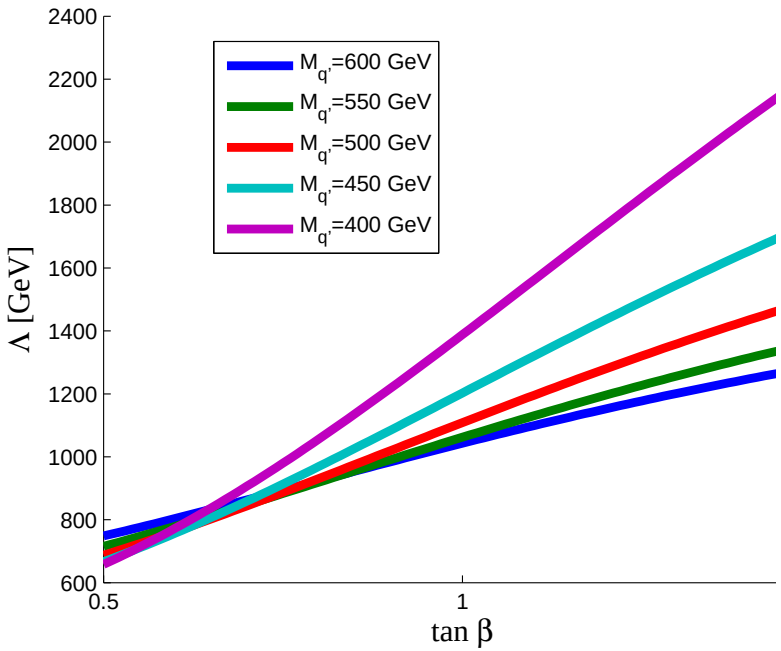
$$\begin{aligned}\mathcal{D}g_{q'} &= 6g_{q'}^3\ , \\ \mathcal{D}\lambda_h &= 4\lambda_h\left(3\lambda_h+6g_{q'}^2\right)-24g_{q'}^4\ ,\end{aligned}$$

- Viable solutions with $M_h\sim 125$ GeV:

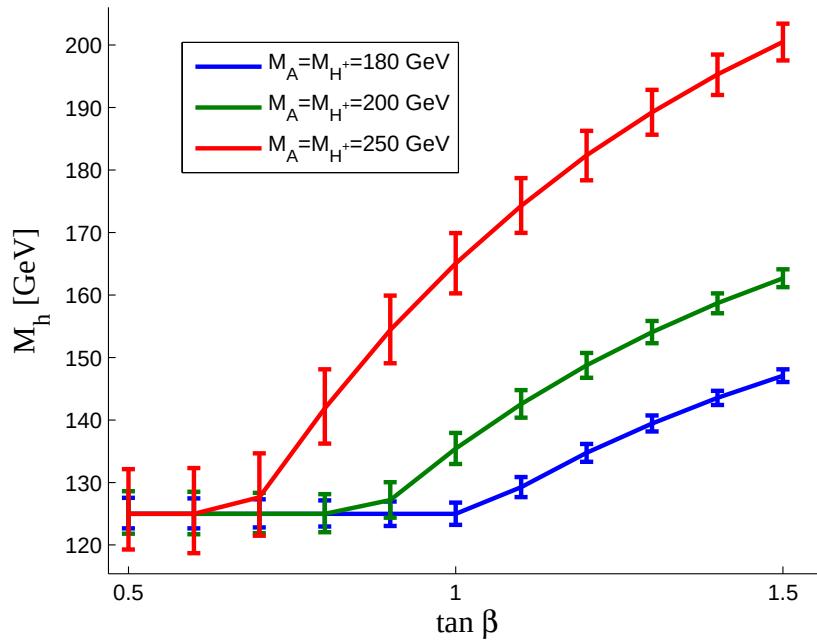
The Spectrum in Dynamic 4G2HDM

work in progress

- The mass of the 4G quarks and $\tan\beta$ determines the cutoff:



- Stable solutions for M_h that are closest to 125 GeV:



- For $M_{H^+}, M_A \sim 200$ GeV, $\tan\beta \sim 0.7 - 0.9$ and $\Lambda = \mathcal{O}(1\,TeV)$ we find solutions that are experimentally acceptable, i.e. $M_h \approx 125\,GeV$ and $M_{4G} \gtrsim 500\,GeV$

Summary

An Illustrative framework of 2HDM with new heavy chiral quarks **"4G2HDM"** :

- Avoids/Relaxes the bounds on 4G quarks from direct searches.
- Compatible with the 125 GeV discovery.
- Arises naturally from a simple DEWSB scenario.

Key Experimental Issues:

- Model-independent searches for new chiral quarks that include $t' \longrightarrow th$ are required, similarly to VLQ.
- Additional scalars could be present and they may be as hard to find as the Higgs, e.g. the pseudoscalar A can be as light as 130 GeV.
- With more data in the 125 GeV channels we should see some deviations from the SM, especially in the electroweak production channels.