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

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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

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  - Strong dynamics
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  - The bounds on the 4th generation quarks in the SM4 reach the perturbative limit $\sim 600 GeV$
  - Could be evaded via extended Higgs sectors.
- Vector like quarks are **not excluded** and they appear in a plethora of models:
  - 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)

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- **The Yukawa of the top is too low for condensation**

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  - Φ_h which couples to the 4G (chiral or Vector-like)
  - Φ_ℓ which is SM-like

4G2HDM: The Model

Basic Idea: In the EW basis

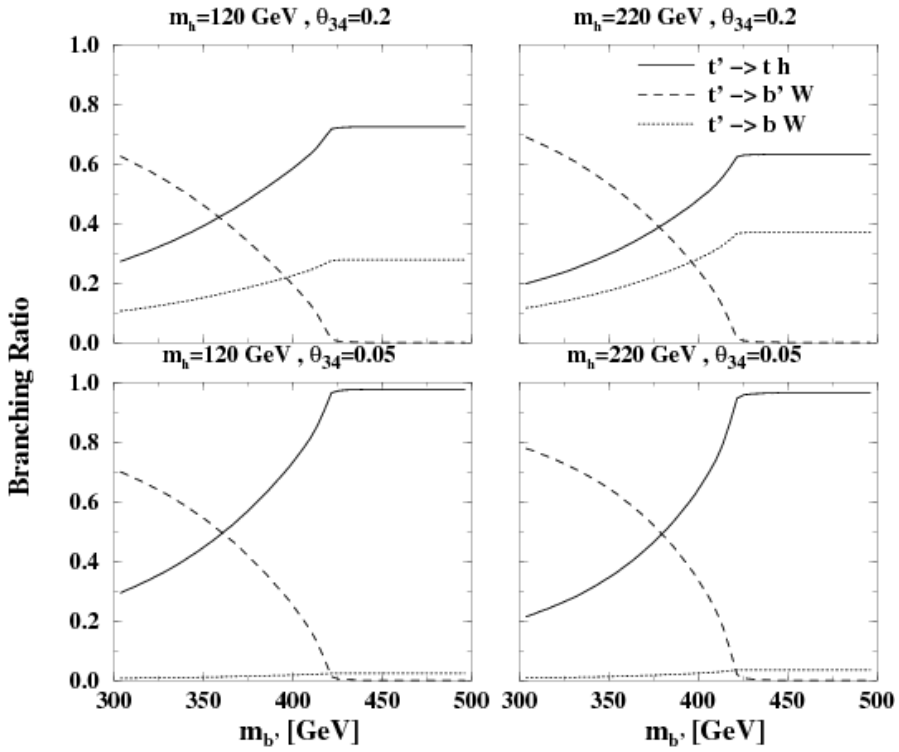
- Φ_h couples to the heavy fermions.
- Φ_ℓ couples to all the other (light) fermions.

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

- If the new fermions are Vector-like, additional terms could be present in the form: $\overline{Q}_R \Phi_h t_L$

Quark Phenomenology in 4G2HDM

- The masses of chiral quarks are bound by unitarity. For $m_{t'} > 600 GeV$ the Yukawa couplings blow up.
- For Vector-like quarks, mass terms $m\overline{Q_R}Q_L$ are allowed. These mass terms can push the spectrum up, without changing the Yukawa terms.
- Both chiral and vector-like quarks have model-dependent decay patterns: e.g. $t' \to th$, $t' \to wb$ and $t' \to Zt$



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  - $M'_b > 650$ GeV- ATLAS [ATLAS-CONF-2012-130.pdf] and $M'_b > 610$ GeV CMS [arXiv:1204.1088]
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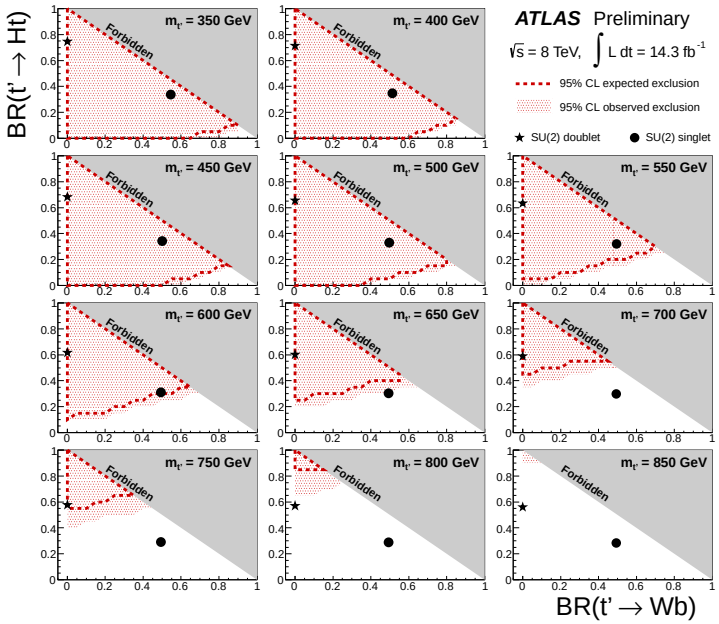
- **Possible evasion of the limits**

Quark Bounds- model independent

- New model-independent searches start to close the window for chiral quarks (and light VLQ):

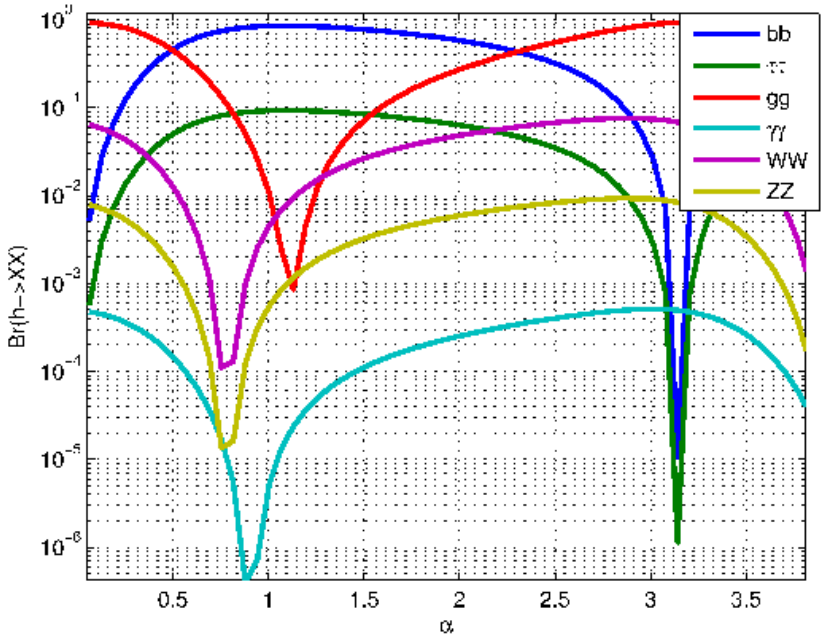


ATLAS-CONF-2013-018

- Still possible evasion if $\longrightarrow$ smaller $Br(h \to bb)$ due to increased $h \to gg, h \to invisible$.
- **Data seems to point in the heavy VLQ direction.**

Higgs Phenomenology

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



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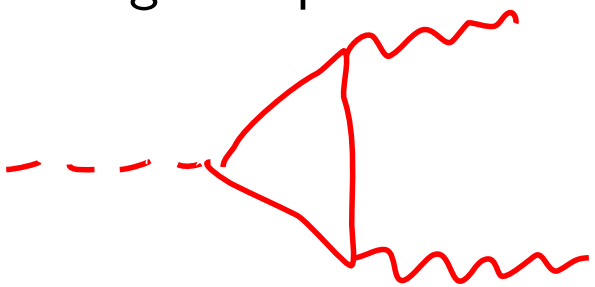

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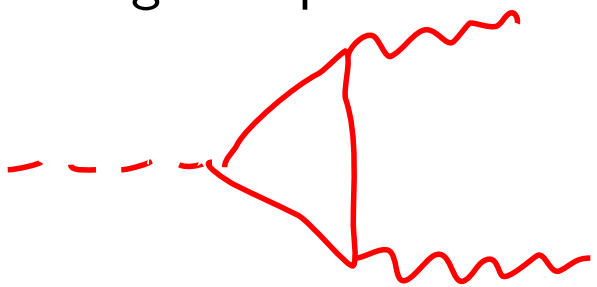

- "Matching" VLQ $\rightarrow$ Chiral: Chiral and Vector-like generation act almost the same way, up to a number of factors:

$$Y_{chiral} \rightarrow Y_{VLQ} N_{yukawa} \left[\frac{M_{chiral}}{M_{VLQ}}\right]^3$$

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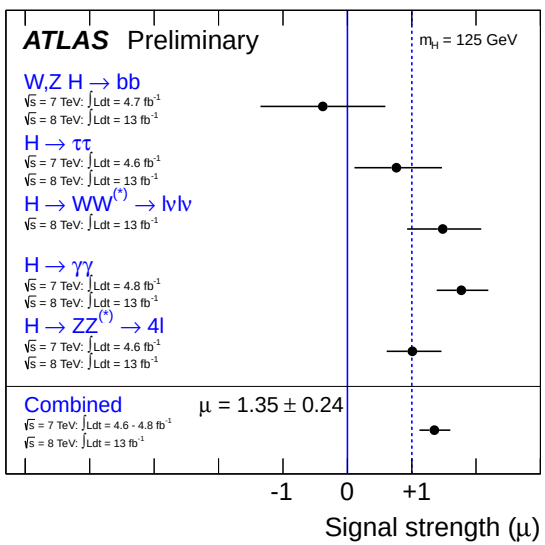
num of loops

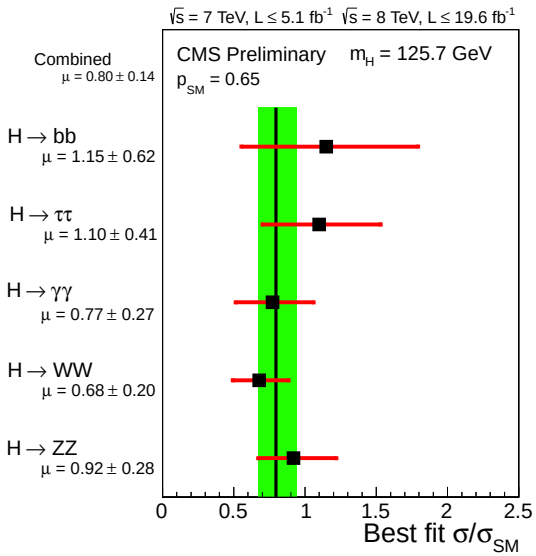
Higgs Data

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

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

- The latest data:



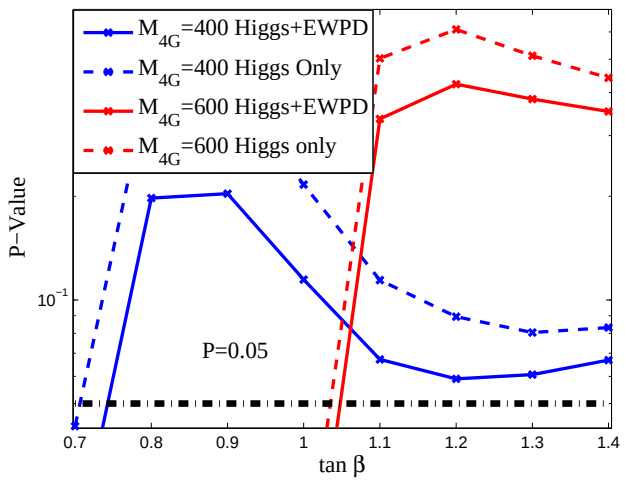


[*ATLAS Collaboration*, **ATLAS-CONF-2013-034.pdf**] [*CMS Collaboration*, **CMS-PAS-HIG-13-005.**]

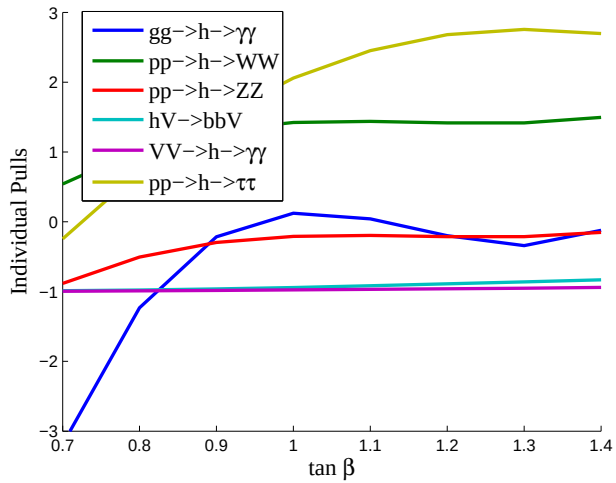
- We further split $gg \to h \to \gamma\gamma$ and $VV \to h \to \gamma\gamma$ (Dijet tagged)

Higgs Fits

- Optimized P values:



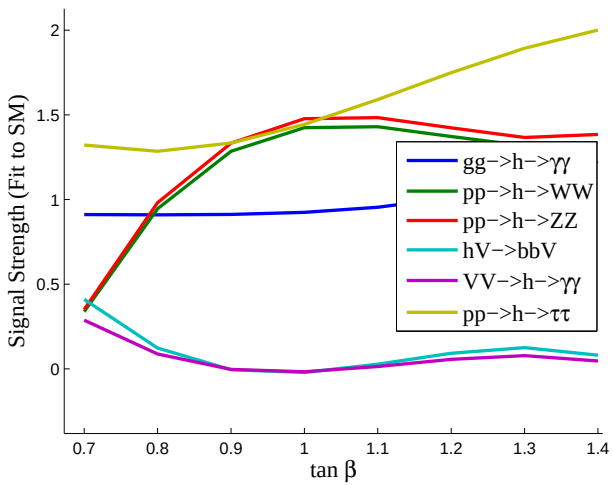
- The Individual Channels:



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

Predictions

- With more statistics: deviations from the SM:
  - A smaller signal in the electroweak production channels $VV \to h$, $pp \to hV$: ~ 0.2 the SM value.
  - An increased production in the $h \to \tau\tau$ channel: ~ 1.5 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.

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- The dynamical Higgs is too heavy- need a "light" doublet
- 2HDM with heavy quarks- fits the Higgs signals
- Deviations in the EW production and $\tau\tau$ channels
- Other scalars: $M_H > 500$ GeV while the Pseudoscalar could be as light as 130 GeV

predictions