Next Generation Higgs Bosons

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(work done in collaboration with James D Wells

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Higgs Generations

- SM Fermions come in generations. What if there are generations of Higgs bosons?
- In supersymmetric theories additional Higgs doublets must come in $\{H_u, H_d\}$ pairs. This is required to satisfy anomaly constraints due to the presence of the fermionic partners of the Higgs.
- We encounter Higgs generations often in string phenomenology
- From an experimental point of view it is interesting to investigate scenarios with more complicated Higgs sectors as this would give us more interpretive power over the data when it comes.

An extra Higgs generation in MSSM

- Let us add an extra Higgs generation to MSSM. The superpotential becomes,

$$W = \mu_{11} H_{u1} H_{d1} + \mu_{12} H_{u1} H_{d2} + \mu_{21} H_{u2} H_{d1} + \mu_{22} H_{u2} H_{d2}.$$

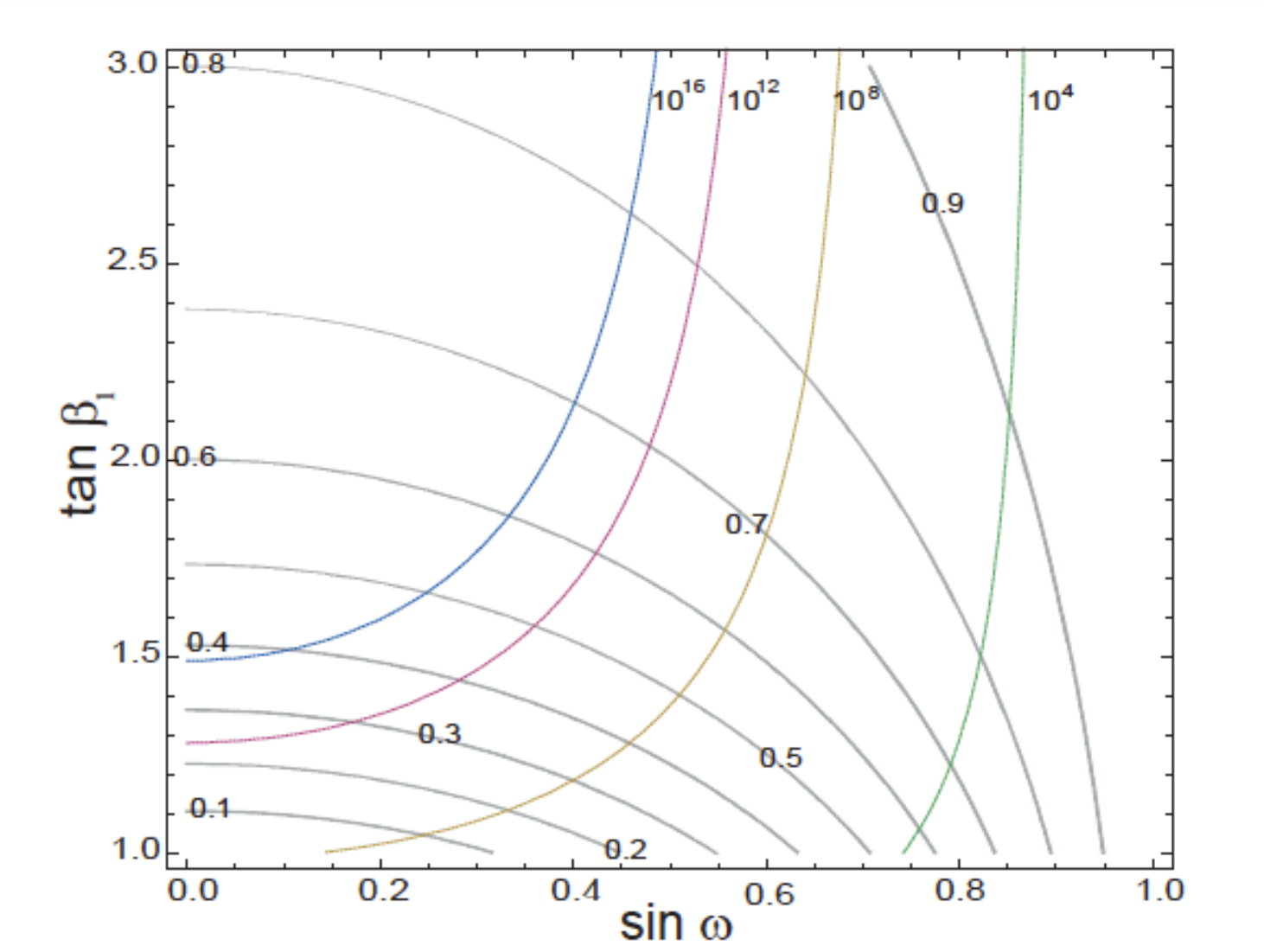
- The tree-level mass of the lightest Higgs is,

$$\begin{aligned} m_h^2 &\leq \frac{2\lambda(\sum_i (v_{di}^2 - v_{ui}^2))^2}{v^2} \\ \Rightarrow m_h &\leq M_Z |\cos^2\omega \cos 2\beta_1 + \sin^2\omega \cos 2\beta_2|, \end{aligned}$$

where $\tan\beta_i \equiv v_{ui}/v_{di}$ $\tan\omega \equiv v_2/v_1$. and $\lambda = \frac{g^2+g'^2}{8}$

(see also Ambroso et al arxiv:0807.3319)

- We find that the *SUSY fine-tuning problem* can be marginally better in this model,



$\cos 2\beta_2 = -1$

Flavor

- New Higgs doublets in general lead to tree level flavor changing neutral currents.
- In Two Higgs doublet Models for eg. the general Yukawa Lagrangian for up type quarks is,

$$L = Y_{ij}\, U_L\, \phi_1\, u_R + Y'_{ij}\, U_L\, \phi_2\, u_R$$

The two Yukawa Y and Y' matrices above are in general not simultaneously diagonalizable. These introduce tree level flavor changing couplings of the Higgs which can give large contribution to meson mixing.

- We can prevent these by applying some symmetry. In the MSSM the holomorphicity of the superpotential requires that only one of the Higgs couples only to the up type quarks and the other other only to down type quarks.
- We can also impose discrete symmetries,

(1) $\phi_2 \rightarrow -\phi_2$ this gives the *type I two Higgs doublet model (2HDM)* in which ϕ_1 does not couple to any of the quarks.

(2) $U, \phi_2 \rightarrow -U, -\phi_2$ this gives the *type 2 two Higgs doublet model (2HDM)* in which ϕ_2 couples only to up type quarks and ϕ_2 only to down type quarks.

In multi-Higgs models with 3 or more doublets at most 2 of the Higgs can couple to the quarks and the rest should not.

Next Generation Higgs doublets do not couple to fermions

Tree- Level flavor constraints can be satisfied if there is a principle/symmetry that disallows next generation Higgs bosons from coupling to SM quarks. So next generation Higgs bosons are like ϕ_2 in the type I 2HDM

From now on all the concrete results I'll present will be based on the type I 2HDM but the qualitative conclusions are true for next generation Higgs bosons/multi-Higgs doublet models in general.

Next Generation Higgs doublets have small VEVs

- v_2 spontaneously breaks the discrete symmetry.
- In the type I 2HDM the *b>s γ* process can be enhanced due to virtual $H^{+/-}$ contributions. The coupling of $H^{+/-}$ to fermions is proportional to v_2/v_1. We find for m_{H+} =200 GeV the constraint,.

$$v_2 < 75 \text{ GeV}$$

- In the small v_2 limit *h* becomes both *fermiophobic* and *bosophobic* (*ZZh, W+W-h* couplings are suppressed).
- A low vev for the next generation doublets also means that we can have a *Higgs lighter than the LEP bound* m_h< 115 GeV (from the e^+e^->Z*>Zh process) because the *ZZh* coupling is suppressed.
- It would be, however, hard to find *h* in the LHC by standard processes like *gg>h* (*hff* coupling is suppressed), *pp>Zh* (*ZZh* coupling is suppressed) .

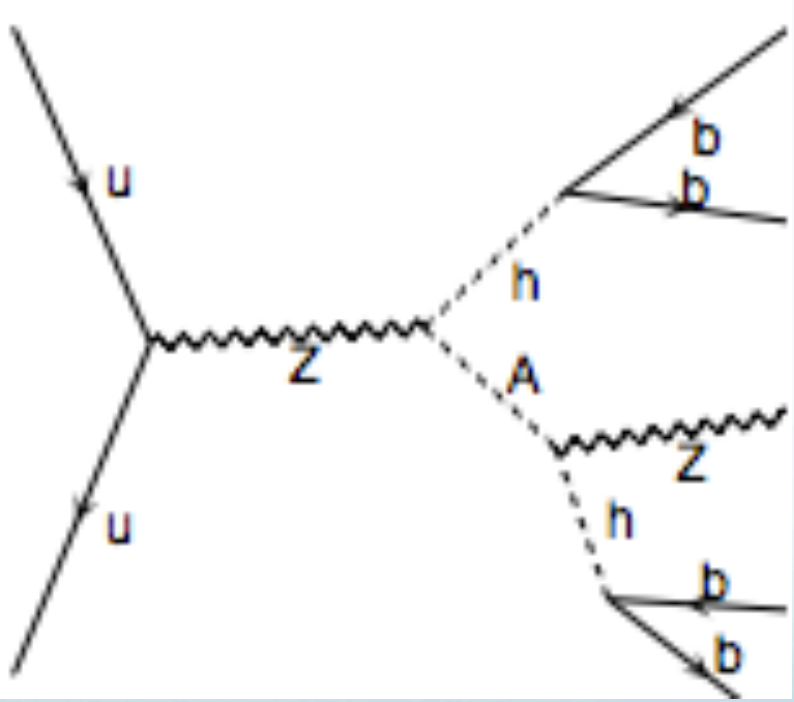
So how do we such a Higgs boson at the LHC?

The ZAh coupling has nothing to do with the vev. Indeed it is present even if there is no spontaneous symmetry breaking. This coupling is not suppressed as v_2->0.

Signature

- We perform analyses for the

  pp>A(Zh)h>Z(ll) bb bb process.

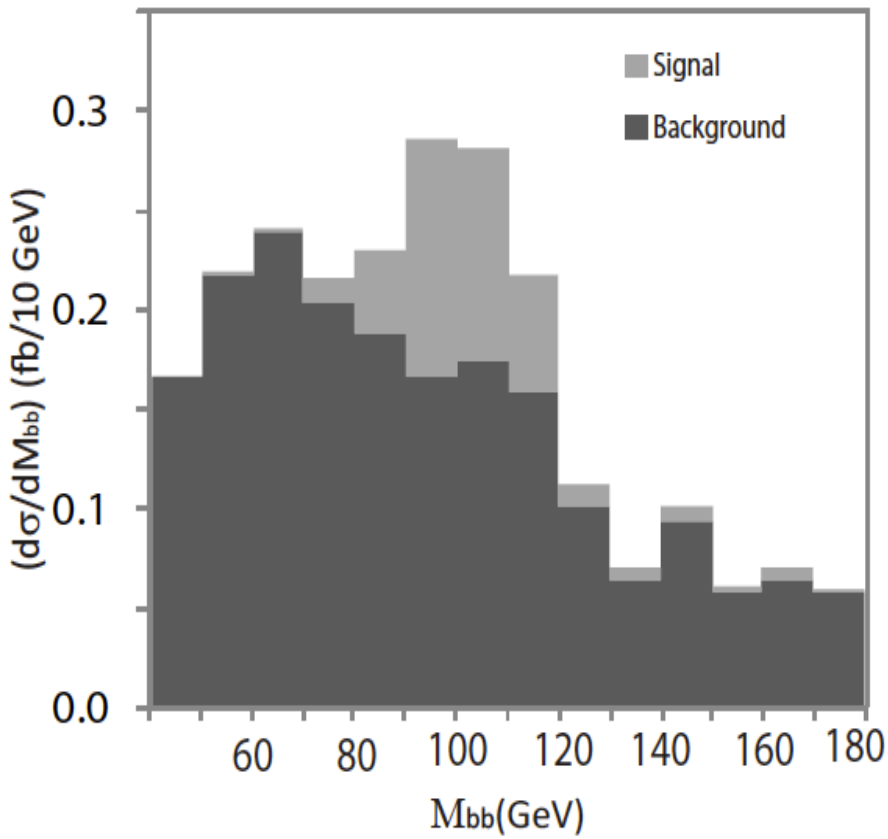


LHC Prospects

- There are 3 ways to split the 4 *b* s into 2 pairs. For each way of pairing we smear the invariant masses of the *b* pairs.
- We reduce the SM background by requiring that for at least one way of pairing

$$|M_{bb1} - M_{bb2}| < 0.2\ M_{bb}$$

- ***σ≈ 0.1 fb***



s_α=0.3, s_ω=0.1, m_h=100 GeV, m_A=200 GeV

Summary

- Next Generation Higgs doublets must not couple to quarks to satisfy flavor constraints.
- Next Generation Higgs doublets must have small VEVs.
- It would be hard to find such an *h* in the LHC by standard processes like gg>*h*, *pp*>*Zh* if the vev is small.
- We find good prospects for seeing the *pp*>*A*(*Zh*)*h*>*Z bb bb* signal at LHC.