LHC Discovery Potential for Non-standard Higgs Bosons in the 3b Channel

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based on:
arXiv:1203.1041 with Marcela Carena, Stefania Gori, Aurelio Juste, A.M., Carlos E.M. Wagner and Lian-Tao Wang.

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Higgs Sector in 2HDMs

- The Neutral components acquire vevs and their ratio is $\tan\beta = v_u/v_d$.
- Neglecting CP violation in the Higgs sector, electroweak breaking leaves:

  1 CP odd Higgs A
  1 charged Higgs H^+, and
  2 CP even Higgs bosons h, H
- One CP-even (SM-like) Higgs has SM strength couplings to gauge particles.
- The other CP-even (Non-Standard) Higgs has suppressed couplings to gauge particles.

Couplings to b-quarks and τ-leptons in 2HDMs

- General 2HDM Higgs fermions couplings are

$$\begin{aligned}\mathcal{L}_{\rm Yuk} &= y_u\, H_u\bar{Q}U + y_d\, H_d\bar{Q}D + \tilde{y}_u\, H_d^\dagger\bar{Q}U \\ &+ \tilde{y}_d\, H_u^\dagger\bar{Q}D + y_\ell\, H_d\bar{L}E + \tilde{y}_\ell\, H_u^\dagger\bar{L}E + h.c.\end{aligned}$$

- d-type fermion couplings to Non-standard Higgses are:

$$g_{(A/H)f\bar{f}} \simeq \frac{\bar{m}_f}{v}\tan\beta^f_{\rm eff}$$

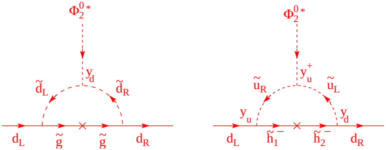
where

$$\begin{aligned}\tan\beta^f_{\rm eff} &= \frac{\tan\beta}{1+\epsilon_f\tan\beta}\left(1-\frac{\epsilon_f}{\tan\beta}\right) \\ \epsilon_f &= \frac{y_f}{\tilde{y}_f}\end{aligned}$$

Fermion couplings in the MSSM

- Including 1-loop effects both quarks couple to both the Higgs bosons so that:

$$-\mathcal{L}_{eff} = \bar{d}_R^0 \hat{\mathbf{Y}}_{\mathbf{d}} [\Phi_d^{0*} + \Phi_u^{*0} \left(\hat{\epsilon}_{\mathbf{0}} + \hat{\epsilon}_{\mathbf{Y}} \hat{\mathbf{Y}}_{\mathbf{u}}^\dagger \hat{\mathbf{Y}}_{\mathbf{u}} \right)] d_L^0 + h.c.$$



and have the structure:

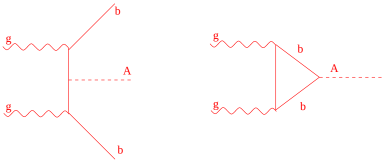
$$\epsilon_0^I \approx \frac{2\alpha_s}{3\pi} M_3 \mu C_0(m^2_{\tilde{d}_1^I}, m^2_{\tilde{d}_2^I}, M_3^2)$$

$$\epsilon_Y \approx \frac{1}{16\pi^2} A_t \mu C_0(m^2_{\tilde{t}_1}, m^2_{\tilde{t}_2}, \mu^2)$$

Kolda, Babu, Buras, Roszkowski...

- Low scale flavour structure of the squark masses determines the flavor structure of ϵ-loop factors.

Non-standard Higgs boson production and decay



- General b and τ couplings are

$$g_{Abb} \simeq \frac{m_b \tan \beta_{\text{eff}}^b}{v}; g_{A\tau\tau} \simeq \frac{m_\tau \tan \beta_{\text{eff}}^\tau}{v}$$

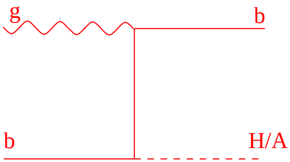
- Enhanced production and decay modes:

$$\frac{\sigma(b\bar{b} \to A)}{\sigma(b\bar{b}h)_{\text{SM}}} \mathcal{BR}(A \to b\bar{b}) \propto \frac{(\tan \beta_{\text{eff}}^b)^4 \bar{m}_b^2 N_c}{(\tan \beta_{\text{eff}}^\tau)^2 \bar{m}_\tau^2 + (\tan \beta_{\text{eff}}^b)^2 \bar{m}_b^2 N_c},$$

$$\frac{\sigma(gg, b\bar{b} \to A)}{\sigma(gg, b\bar{b} \to h)_{\text{SM}}} \mathcal{BR}(A \to \tau\tau) \propto \frac{(\tan \beta_{\text{eff}}^\tau)^2 (\tan \beta_{\text{eff}}^b)^2 \bar{m}_\tau^2}{(\tan \beta_{\text{eff}}^\tau)^2 \bar{m}_\tau^2 + (\tan \beta_{\text{eff}}^b)^2 \bar{m}_b^2 N_c},$$

Non-Standard Higgs into 3b: Production and Decay

- $\tan\beta_{\text{eff}}^{\tau}$ can be small compared to $\tan\beta_{\text{eff}}^{b}$ $\Rightarrow$ weaker reach in the $\tau\tau$ channel.
- The $H/A \to b\bar{b}$ can be enhanced enough to make it competitive with the clean $\tau\tau$ channel.
- In addition to the 4b-final state we also have:



- The Tevatron limits from this channel are signficantly weaker than the LHC $\tau\tau$ limits.

Signal and Background Simulation

- Simulation used MG5 interfaced with Pythia 6.4.
- QCD background: Separately simulated the 3b+X and 2b+j+X where X= 1,2j
- Used k_t matching, with matching scale of 30 GeV.
- Background separation into bbj and $3b$ samples does not model b jets with p_T below $\sim$ 40 GeV very well.
- b-jets are clustered using anti-k_T with $\Delta R = 0.4$.
- Jet energy smearing of $100\%/\sqrt{E/\mathrm{GeV}}$.
- We assume a constant b-tagging efficiency of 60%, a c-jet mis-tag rate of 10% and a light-jet mis-tag rate of 1%.
- Low mis-tag rate of c- and light-jets leads to the bbj and $3b$ backgrounds being comparable

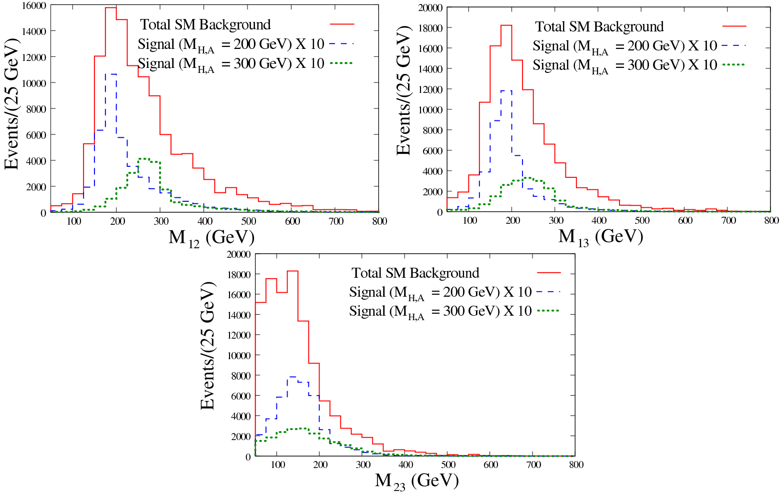
Selection I vs Selection II

- Selection I: Exactly 3 b-tagged jets with $p_T > 60$ GeV and $|\eta| < 2.0$.
- Selection II: Exactly 3 b-tagged jets with $p_T^{b_1} > 130$ GeV, $p_T^{b_{2,3}} > 50$ GeV and $|\eta| < 2.0$.
- Require M_{12}, M_{13} or M_{23} within 25 GeV window of Higgs mass.

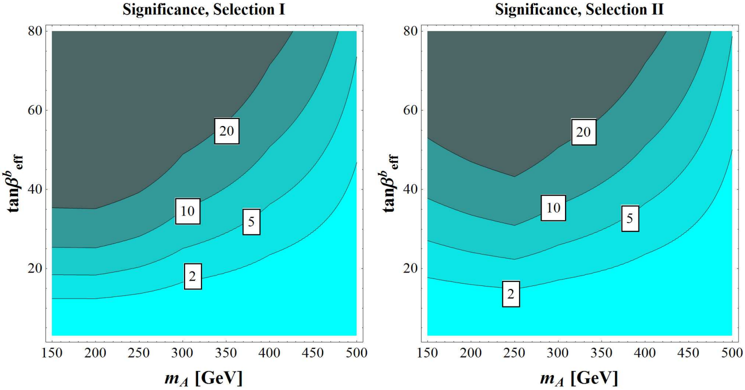
For $\tan\beta^b_{\text{eff}} = 30$ @ 30 fb^{-1} 7 TeV LHC

	Selection I		Selection II	
	S/B	$S/\sqrt{B}$	S/B	$S/\sqrt{B}$
$m_A = 150$ GeV	0.06	14.1	0.047	6.2
$m_A = 200$ GeV	0.057	14.4	0.048	7.9
$m_A = 300$ GeV	0.035	7.3	0.038	6.8
$m_A = 400$ GeV	0.027	3.4	0.028	3.3

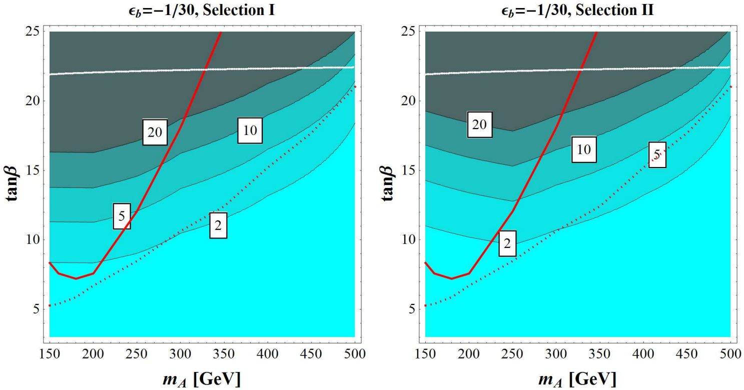
Signal and Background Distributions



Reach in the general 2HDM Model



The 3b vs $\tau\tau$ in the MSSM



Conclusions

- The $A \to \tau\tau$ LHC search puts weak limits on regions of large $\tan\beta_{\text{eff}}^{b}$ and small $\tan\beta_{\text{eff}}^{\tau}$ in 2HDMs.
- The $A/H \to b\bar{b}$ is a complementary channel that probes parametric scenarios of large $\tan\beta_{\text{eff}}^{b}$.
- The reach of the $A/H \to b\bar{b}$ channel is limited by low S/B for low to moderate $\tan\beta_{\text{eff}}^{b}$, but can be powerful at large $\tan\beta_{\text{eff}}^{b}$.