

Measuring the 2HDM potential: hH associated production

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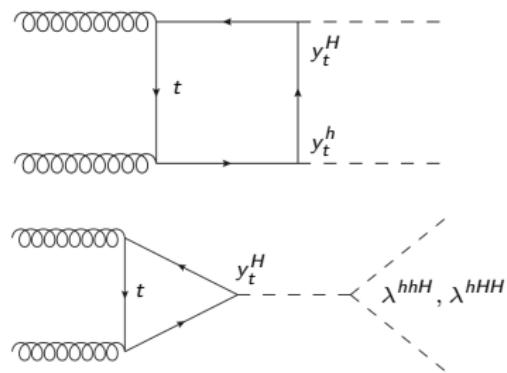
with V. Barger, L. Everett, C. Jackson, and G. Shaughnessy
arXiv:1405.xxxx

May 6th, 2014 – Pheno 2014 – Pittsburgh, PA



Higgs pair production

- Higgs pair production provides insight into scalar sector and potential new physics
 - Production through gluon fusion
 - Contributions from box and triangle diagrams interfere
- ⇒ Implement ggh , ggH , and $gghH$ vertices in MadGraph5, including NNLO K-factor



see also V. Barger, L. Everett, C. Jackson, and G. Shaughnessy, arXiv:1311.2931

Triscalar couplings

- Potential includes three triscalar terms among CP-even Higgs bosons*
- Couplings probed by multiple processes:

	Process	λ^{hhh}	λ^{hhH}	λ^{hHH}
Gabe Shaughnessy's talk yesterday →	$pp \rightarrow hh$ (continuum)	✓	✗	✗
	$pp \rightarrow H \rightarrow hh$	✓	✓	✗
Today →	$pp \rightarrow h^*/H^* \rightarrow hH$	✓	✓	✓

* Leave out for CP-odd Higgs for now, but hA is also an interesting channel.

Higgs pairs in the 2HDM

- In Type-II 2HDM, triscalar (and Yukawa) couplings are set by model parameters (M_H , M/M_H , $\tan \beta$, $\cos(\beta - \alpha)$):

$$\begin{aligned}\lambda^{hhH} &= \frac{\cos(\beta - \alpha)}{\sin 2\beta} \frac{M^2(\sin 2\beta - 3 \sin 2\alpha) + (2M_h^2 + M_H^2) \sin 2\alpha}{v} \\ &\approx \cos(\beta - \alpha) \frac{4M^2 - 2M_h^2 - M_H^2}{v} + \mathcal{O}(\cos^2(\beta - \alpha))\end{aligned}$$

$$\begin{aligned}\lambda^{hHH} &= \frac{\sin(\beta - \alpha)}{\sin 2\beta} \frac{M^2(\sin 2\beta + 3 \sin 2\alpha) - (M_h^2 + 2M_H^2) \sin 2\alpha}{v} \\ &\approx \frac{-2M^2 + M_h^2 + 2M_H^2}{v} + \mathcal{O}(\cos(\beta - \alpha))\end{aligned}$$

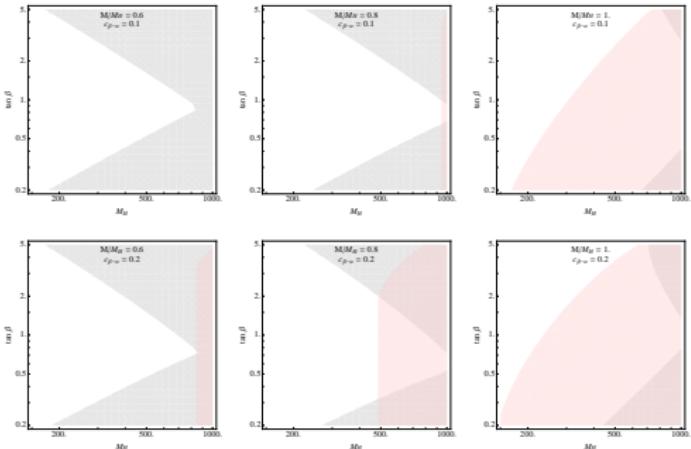
Constraints

- Constraints:

- Perturbative unitarity
- Bounded scalar potential
- Direct search for heavy Higgs

- Fix $M/M_H = 0.8$, scan over $\tan \beta$, $\cos(\beta - \alpha)$, and M_H

$$M/M_H = 0.6 \quad M/M_H = 0.8 \quad M/M_H = 1.0$$

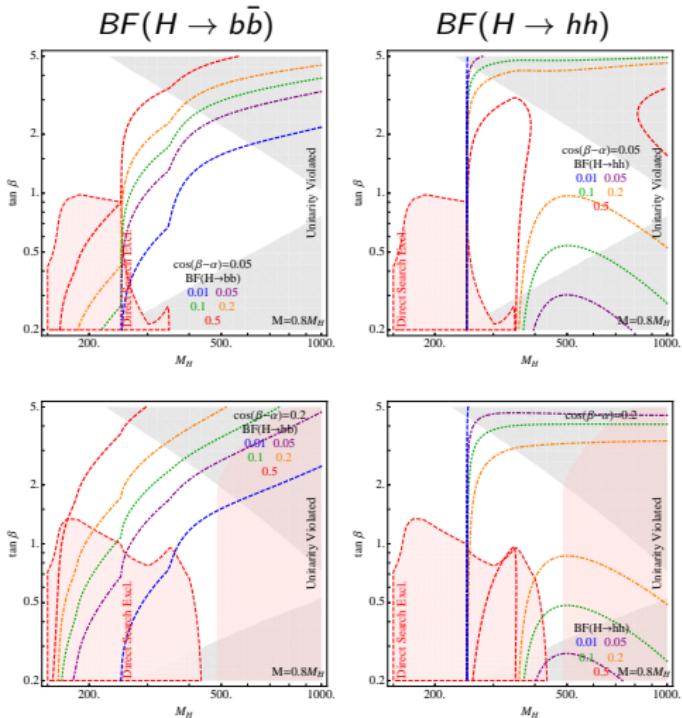


Preliminary

grey = unitarity violated, pink = potential unstable

Branching fractions

- Let $h \rightarrow \gamma\gamma$ – low backgrounds
- Consider two decay channels for H : $b\bar{b}$ and $hh \rightarrow 4b$
 - Large branching fractions
 - Sensitivity in different regions of M_H
 - Ability to fully reconstruct events



Preliminary

The $b\bar{b}\gamma\gamma$ channel

- Irreducible backgrounds:
 - continuum $b\bar{b}\gamma\gamma$
 - $b\bar{b}h$, with $h \rightarrow \gamma\gamma$
 - Zh , with $Z \rightarrow b\bar{b}$, $h \rightarrow \gamma\gamma$ (negligible for $M_{b\bar{b}} > 100$ GeV)
- Reducible backgrounds:
 - $b\bar{b}e^+e^-$
 - $b\bar{b}j\gamma$
 - $b\bar{b}jj$
 - $jj\gamma\gamma$
 - $3j + \gamma$
 - $4j$ (negligible)
- Include tagging efficiencies and mistag rates for $e^\pm \rightarrow \gamma$, $j \rightarrow \gamma$, and $j \rightarrow b$

Multivariate Analysis

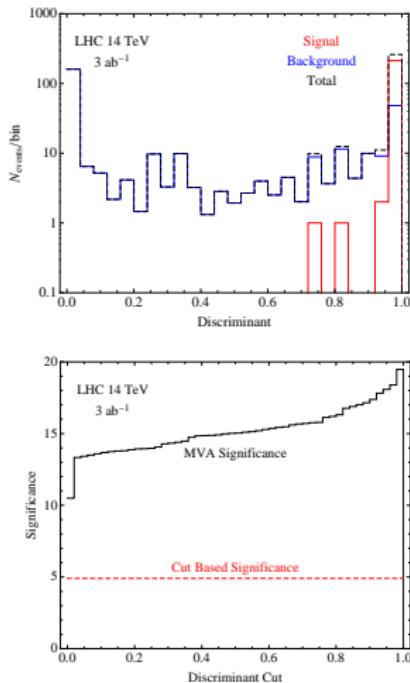
- Substantial improvement in significance using MVA
- Define MVA discriminant

$$\mathcal{D} = \frac{\prod_{i=1}^N \delta_i S(\mathcal{O}_i)}{\prod_{i=1}^N \delta_i S(\mathcal{O}_i) + \prod_{i=1}^N \delta_i B(\mathcal{O}_i)}$$

- Cut on \mathcal{D} to isolate high-signal sample
- Compute significance:

$$S = 2 \left(\sqrt{S+B} - \sqrt{B} \right)$$

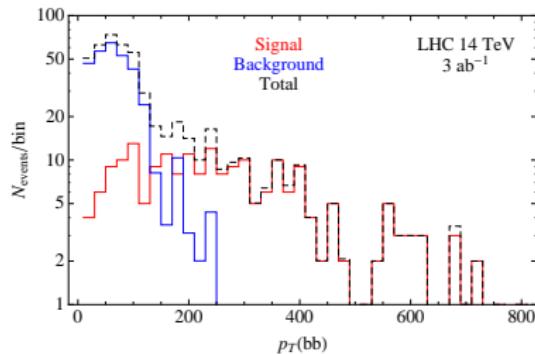
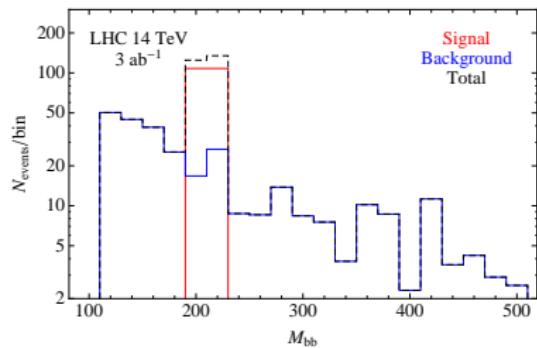
Bartsch and Quast, CERN-CMS-NOTE-2005-004



Multivariate Analysis

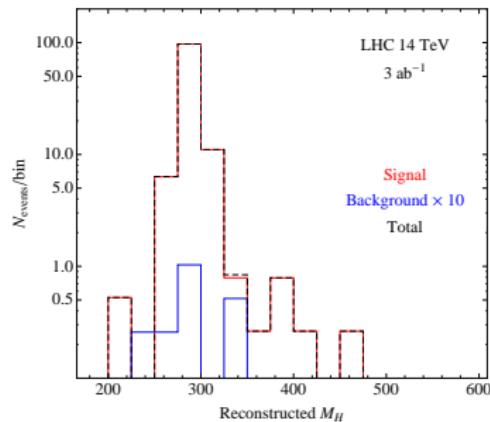
- Can toggle over included observables to maximize significance
- Best observable set for this channel:

$$\mathcal{O} = \{M_{b\bar{b}}, M_{\gamma\gamma}, p_T(b\bar{b}), p_T(\gamma\gamma)\}$$



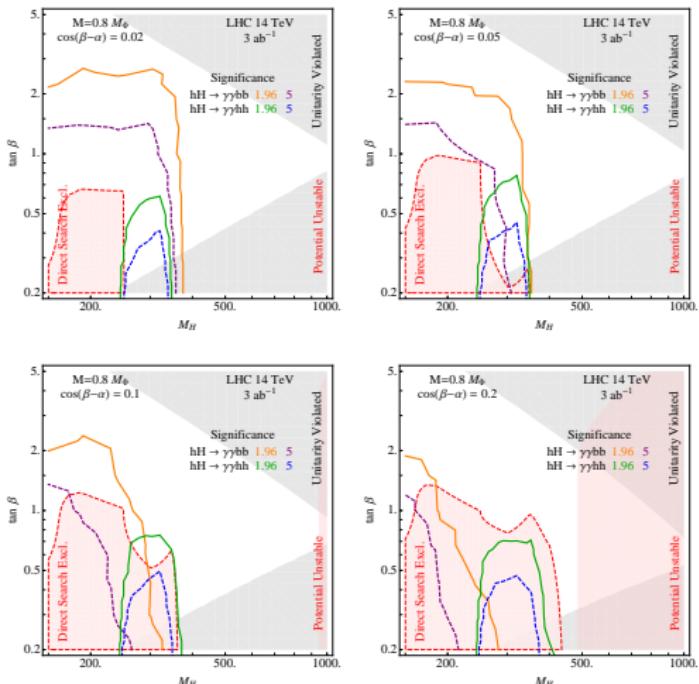
The $h h \gamma\gamma \rightarrow 4b + \gamma\gamma$ channel

- Only two important backgrounds:
 - continuum $4b + \gamma\gamma$
 - $b\bar{b}jj\gamma\gamma$
- Total background very small
 - about 3 events at 3 ab^{-1} !
 - MVA provides no advantage;
cut based analysis best
 - Cut on diphoton invariant mass
eliminates most of the background
- Event reconstruction more complicated than $b\bar{b}\gamma\gamma$ case
 - Daughters of heavy Higgs cluster together – cut on $\Delta R(h_i; h_j)$



LHC reach

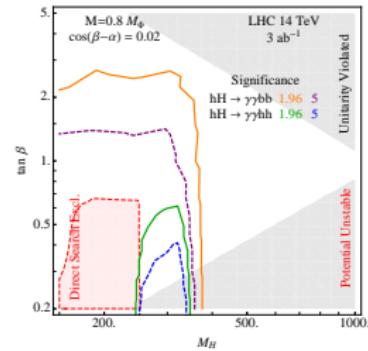
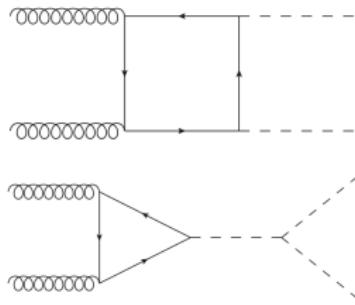
- LHC will be able to probe significant portion of parameter space
- Sensitivity is best for small $\cos(\beta - \alpha)$ – a test of the decoupling limit!
- $H \rightarrow b\bar{b}$ channel sensitive for small M_H , $H \rightarrow hh$ channel for $2M_h < M_H < 2m_t$



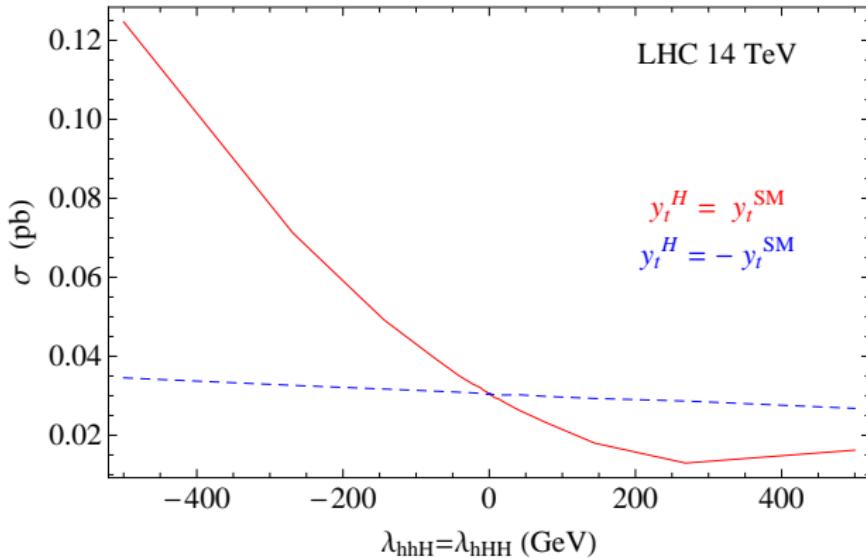
Preliminary

Summary

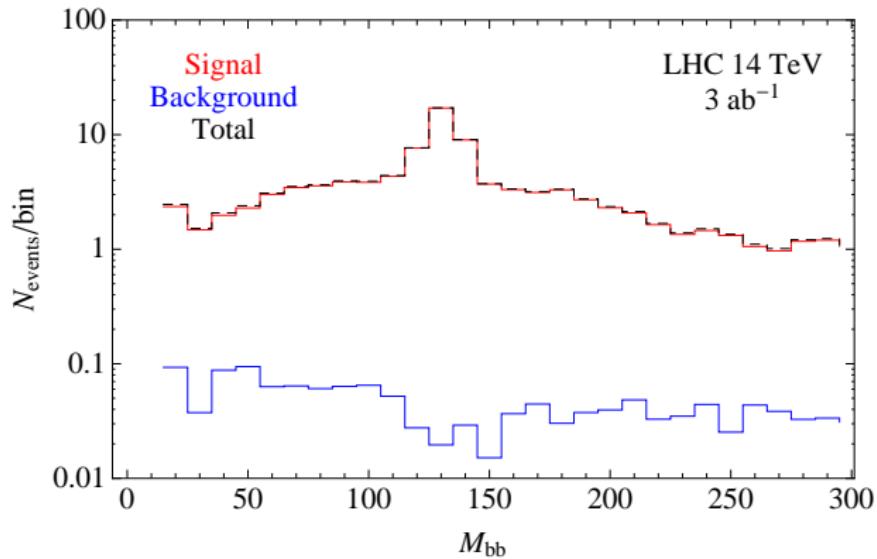
- Measuring scalar couplings is a essential part of understanding the Higgs sector and testing for new physics
- hH production directly probes couplings other processes don't
- LHC can attain good reach, especially near the decoupling limit!



Backup: Effect of interference



Backup: Higgs identification



Backup: Higgs identification

