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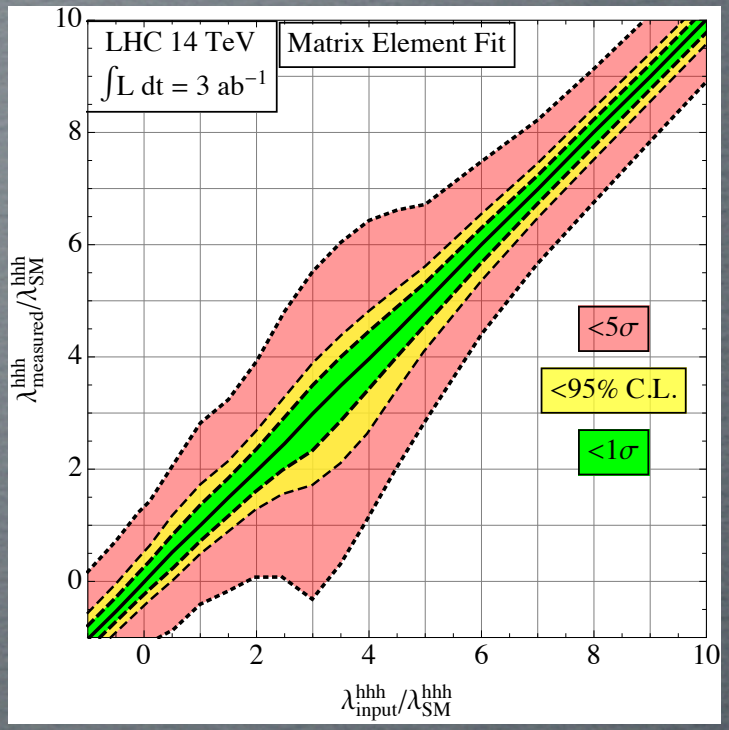
Higgs pair production at the LHC

Gabe Shaughnessy

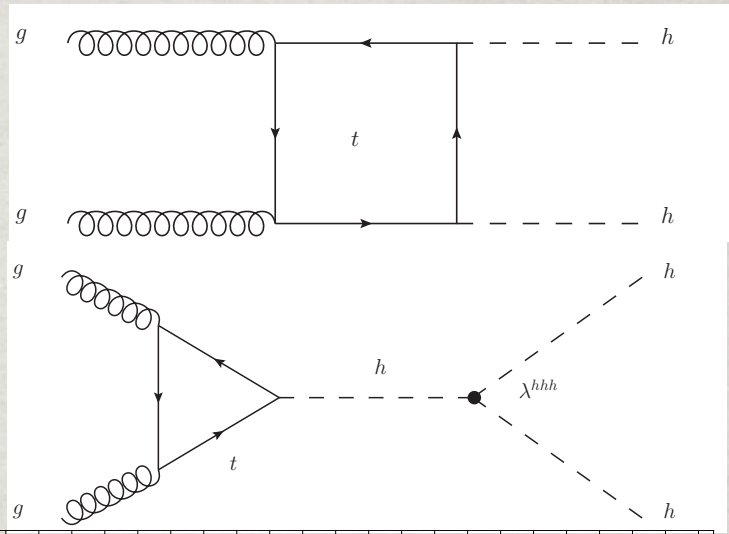
University of Wisconsin

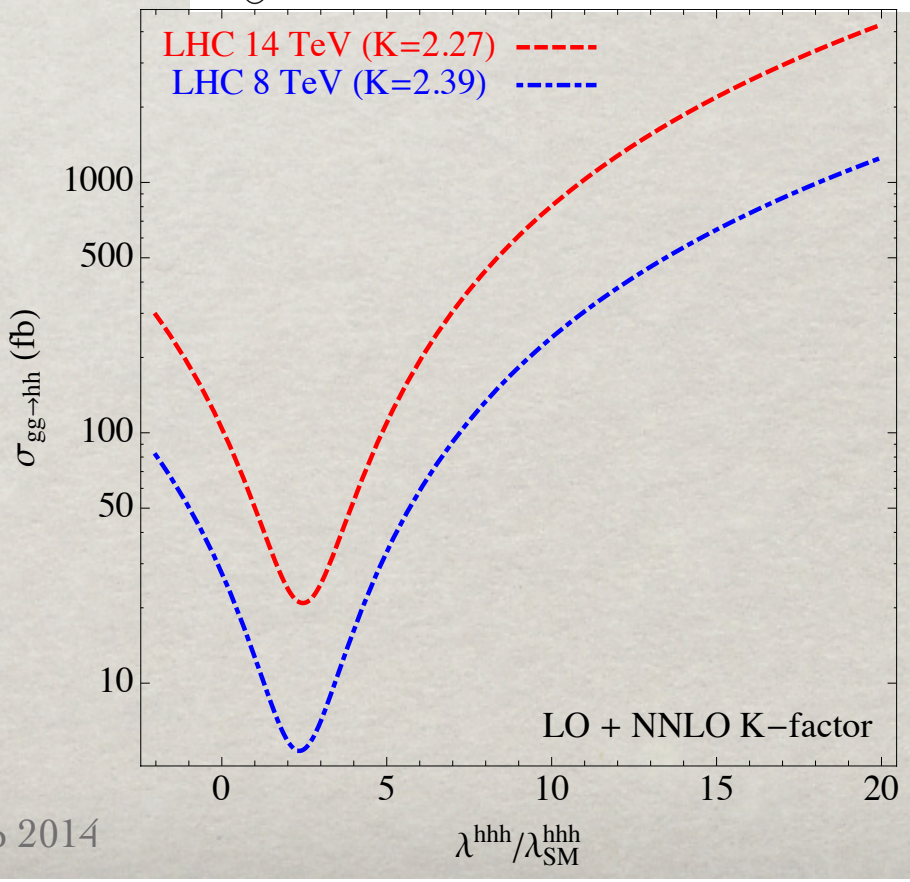


with V. Barger, L. Everett, and C. Jackson
Phys. Lett. B 728 (2014)
arXiv:1311.2931

Higgs pair production at the LHC

- Higgs pairs produced via gluon fusion
- Two competing diagrams interfere greatly impacting the total cross section
- Cross section evaluated and events generated:
  - Coded ggh and $gghh$ vertex in Madgraph5
  - NNLO K-factors
- Strong dependence on λ^{hhh}

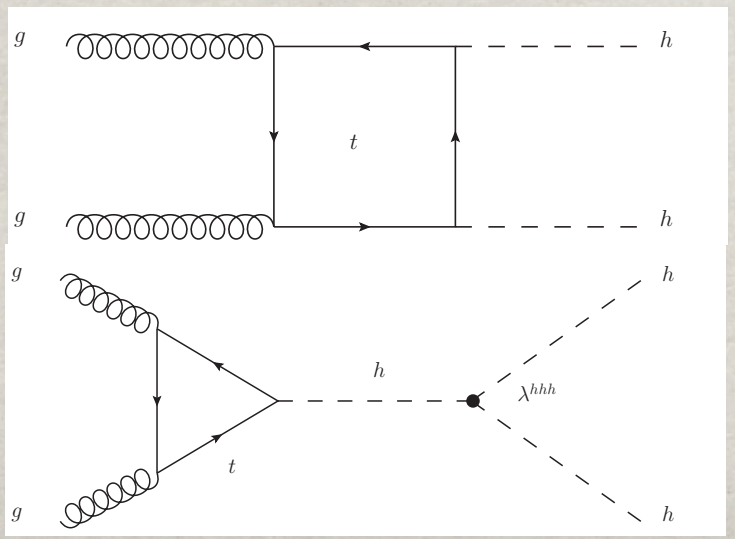


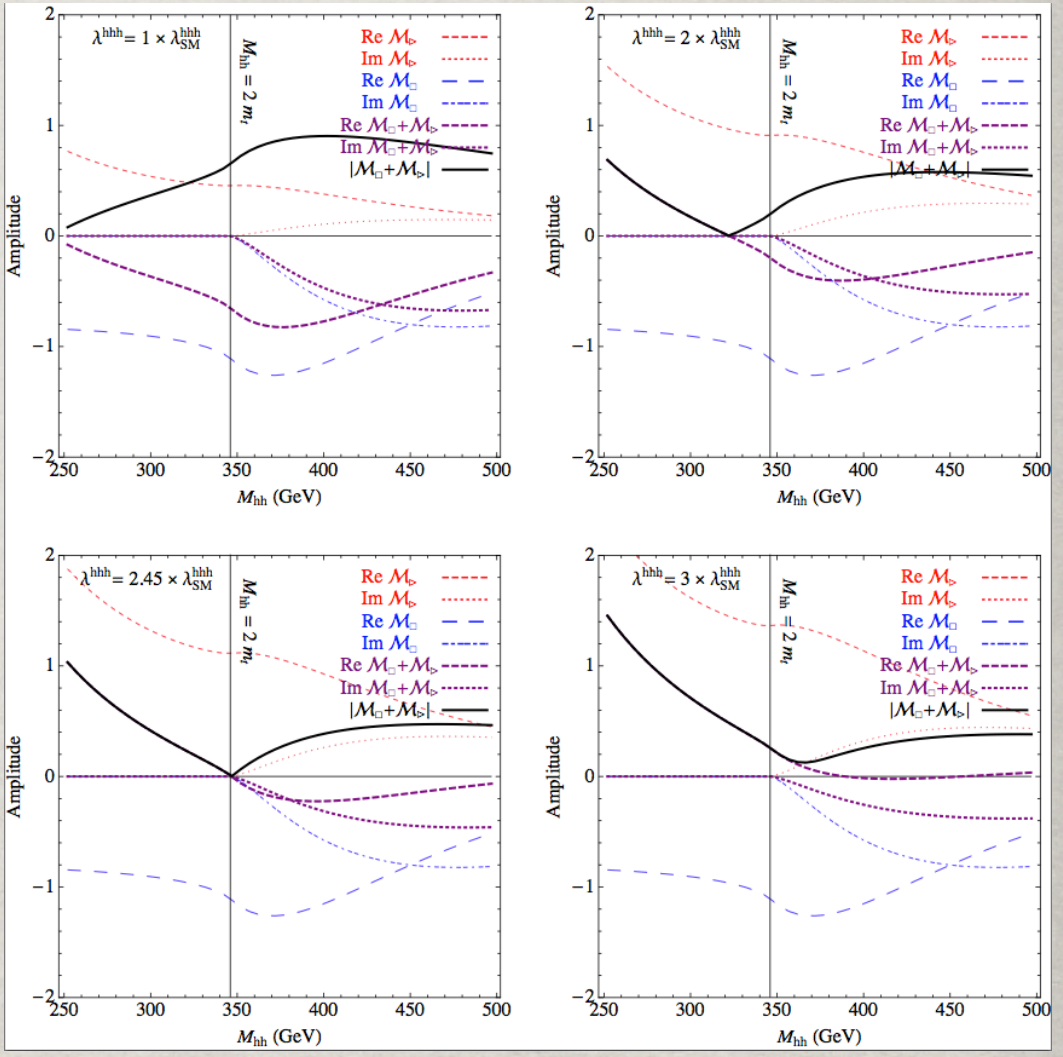


Notable Refs:
Baur, Plehn, Rainwater (2002), Eboli, Marques, Novaes, Natale (1987)
Glover, van der Bij (1988), Dicus, Kao, Willenbrock (1988)
Plehn, Spira, Zerwas (1996), Dawson, Dittmaier, Spira (1998)
Shao, Li, Li, Wang 1301.1245, Goertz et al. 1301.3492
Yao 1308.6302, de Florian, Mazzitelli 1309.6594

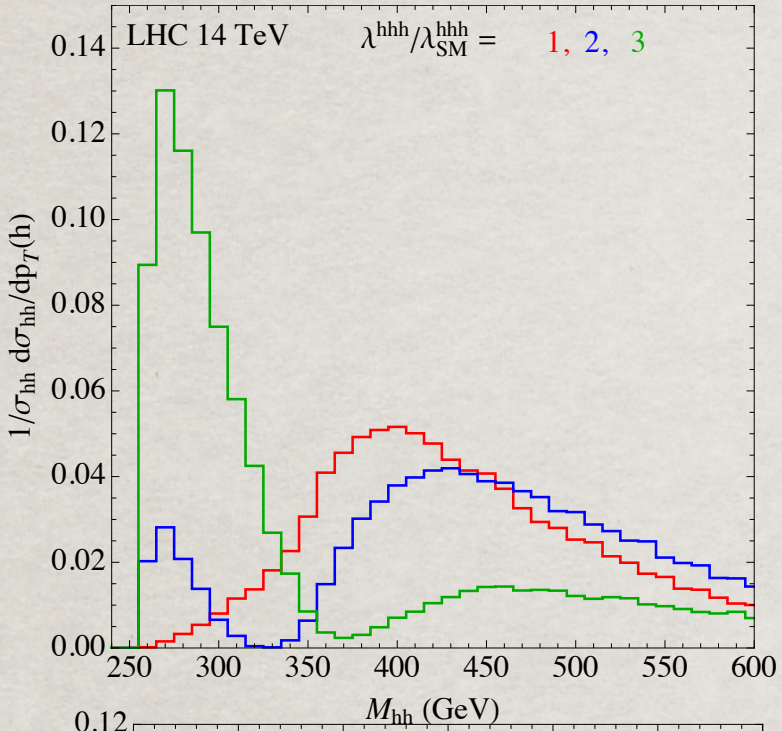
Interference impact

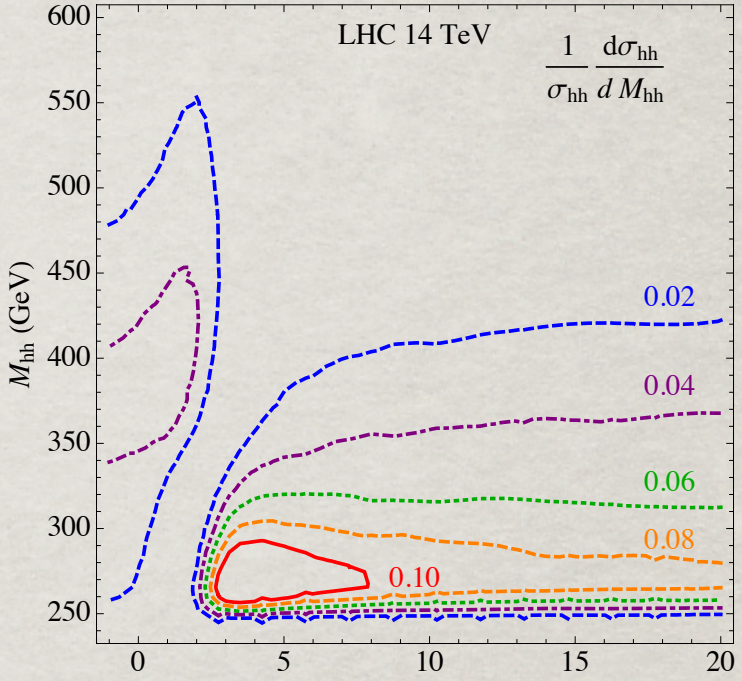
- Imaginary component for high invariant mass
- Amplitude zero possible for $M_{hh} < 2m_t$
- Location of amplitude zero dependent on λ^{hhh}
  - May offer future test of λ^{hhh}
- Both M_{hh} and $p_T(h)$ distributions reflect these features and impact the final cuts and hh search sensitivity

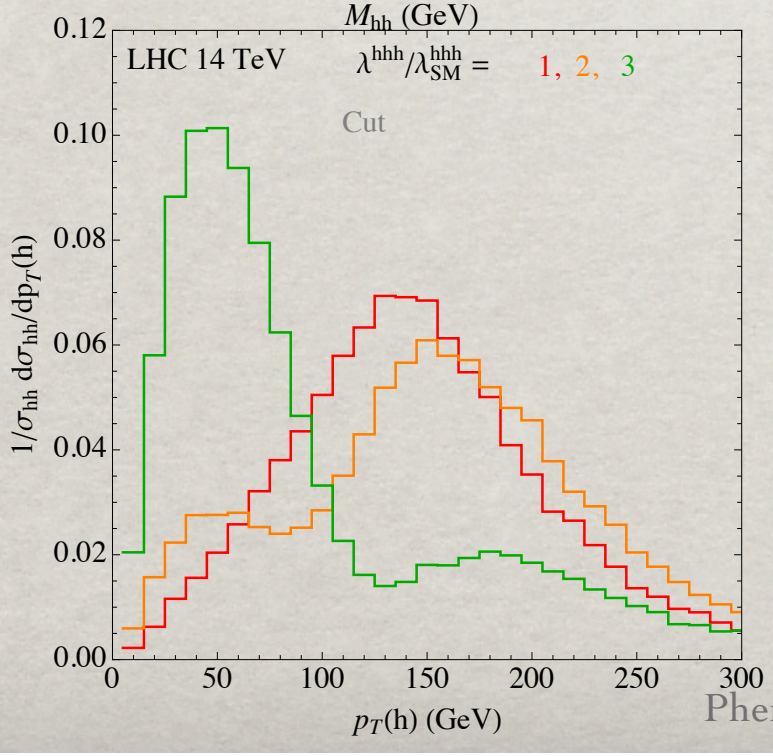


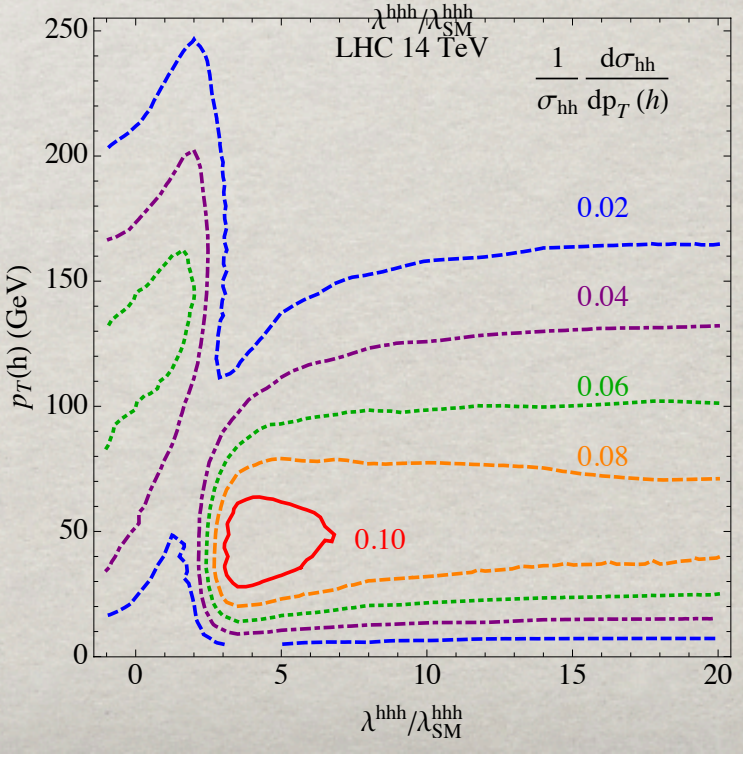


Kinematic distributions









The bb + diphoton channel

- We explore the $b\bar{b}\gamma\gamma$ channel
- Other channels not considered include $b\bar{b}W^+W^-$ (low significance) and $b\bar{b}\tau^+\tau^-$ (high multijet background)
- Backgrounds considered:
  - Irreducible $pp \to b\bar{b}\gamma\gamma$

    $$pp \to Z + h \to b\bar{b} + \gamma\gamma$$
  - Reducible $pp \to b\bar{b} + jj \to b\bar{b} + \gamma\gamma$

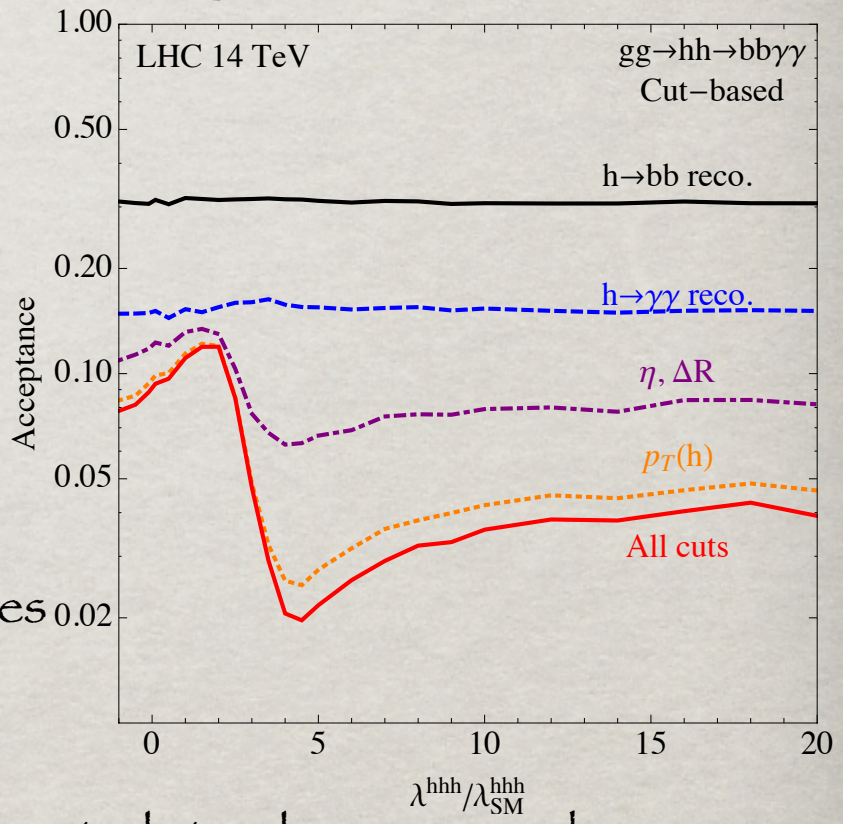
    $$pp \to t\bar{t} + h \to b\ell^+\nu\bar{b}\ell^-\bar{\nu} + \gamma\gamma$$
- Apply appropriate tagging and mis-tagging rates
- Kinematical cuts

$$\Delta R_{b\bar{b},\gamma\gamma,b\gamma} > 0.4 \qquad p_T(b) > 30 \text{ GeV}$$

$$|M_{bb} - M_h| < 12.5 \text{ GeV}$$

$$|M_{\gamma\gamma} - M_h| < 5 \text{ GeV}$$

$$p_T(b\bar{b}), p_T(\gamma\gamma) > 100 \text{ GeV} \qquad M_{b\bar{b}\gamma\gamma} > 350 \text{ GeV}$$



Final signal acceptance has strong dependence on value on λ^{hhh}

Baglio, Djouadi, Grober, Muhlleitner, Quevillion, Spira 1212.5581

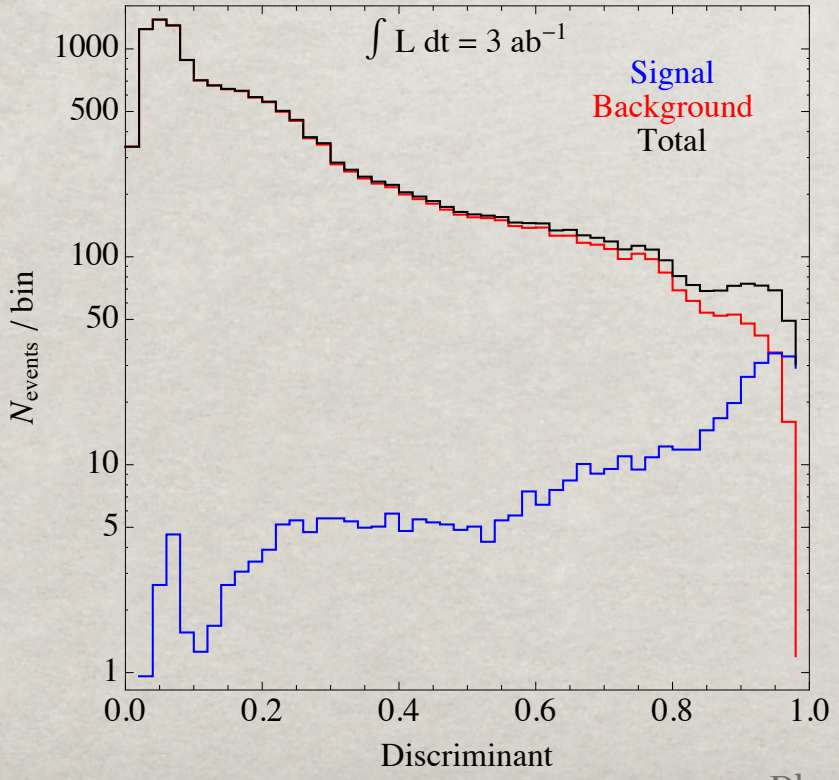
Multivariate Analysis

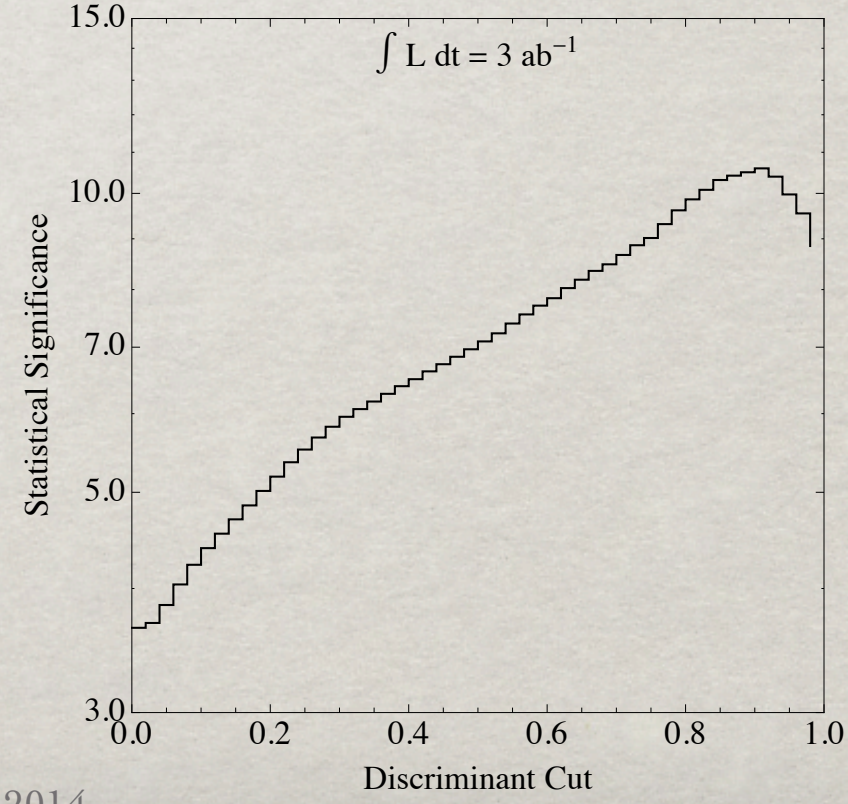
- Improvement found with multivariate analysis
- Define the Discriminant

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

- Observables going into the discriminant (toggled to maximize significance)

$$\mathcal{O} = \left\{ M_{b\bar{b}\gamma\gamma}, M_{b\bar{b}}, M_{\gamma\gamma}, p_T(b\bar{b}), p_T(\gamma\gamma), \Delta R_{b\bar{b}}, \Delta R_{\gamma\gamma} \right\}$$





MVA vs. Cut-based Comparison

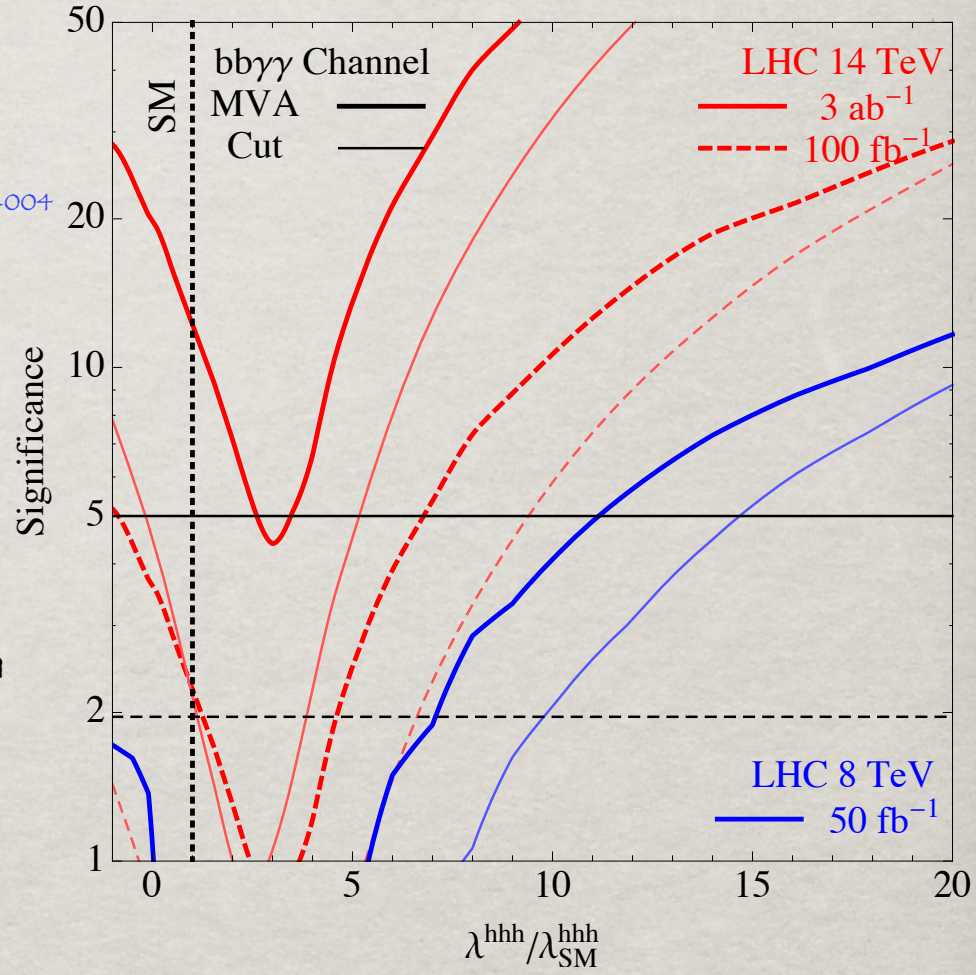
- Significance defined as

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

  - less prone to downward bkg. fluct.

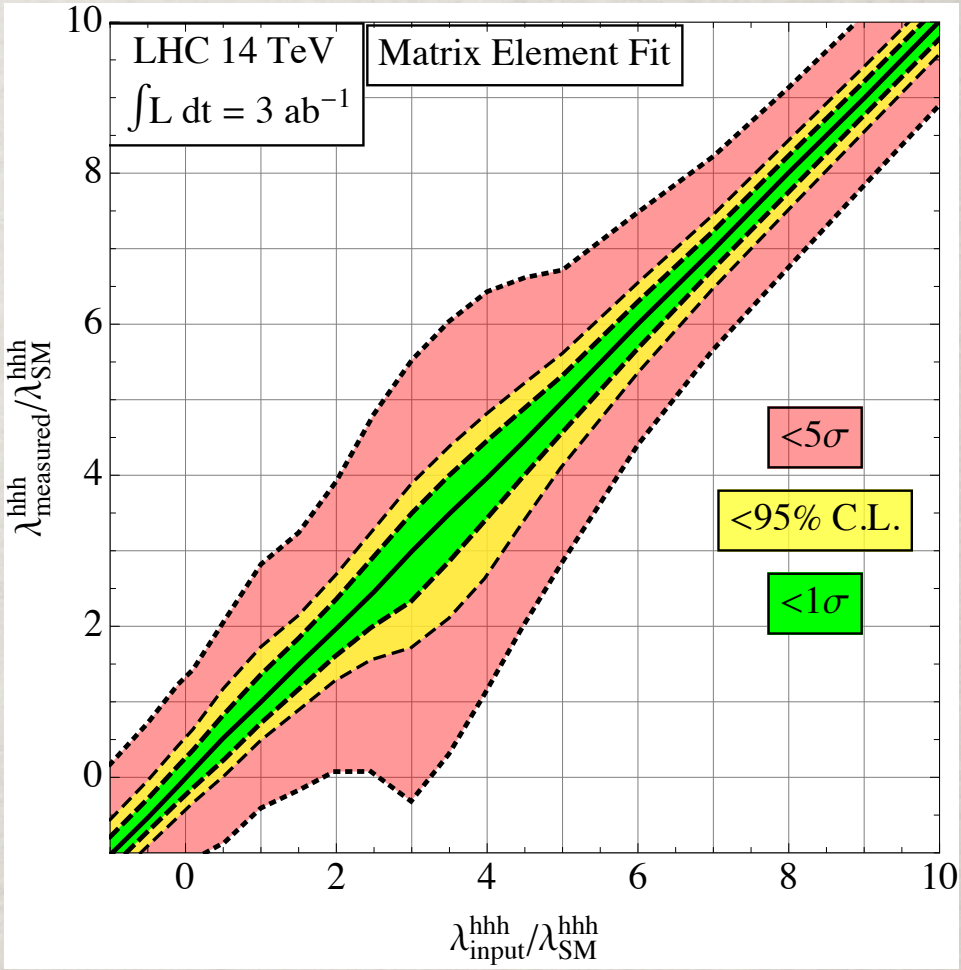
Bartsch and Quast
CERN-CMS-NOTE-2005-004

- Marked improvement for low signal cross section regions
- When signal dominates, MVA offers little benefit over Cut-based approach
- Signal from large scalar coupling is possible even in 8 TeV data!



Scalar Coupling Measurement: Matrix Element Fit

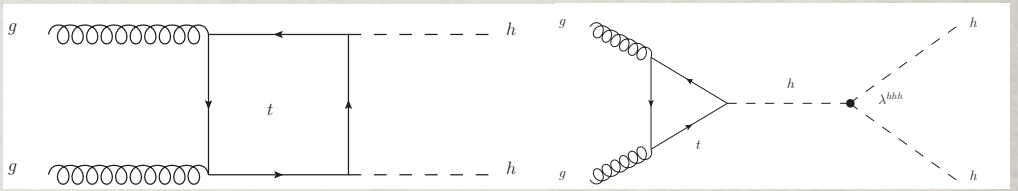
- Once signal is detected, the scalar coupling measurements must be made
- On simulated events, use hh matrix element to fit the scalar coupling via likelihood ratio
  - Background subtraction performed, serves to increase uncertainty in low M_{hh} bins
- SM coupling probed to 50% unc.
- Marked sensitivity decrease in interference region (up to 60% uncertainty)
- Large coupling deviations could be measured with 20% uncertainty

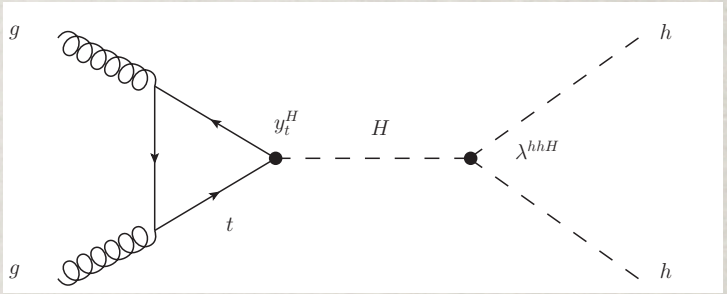


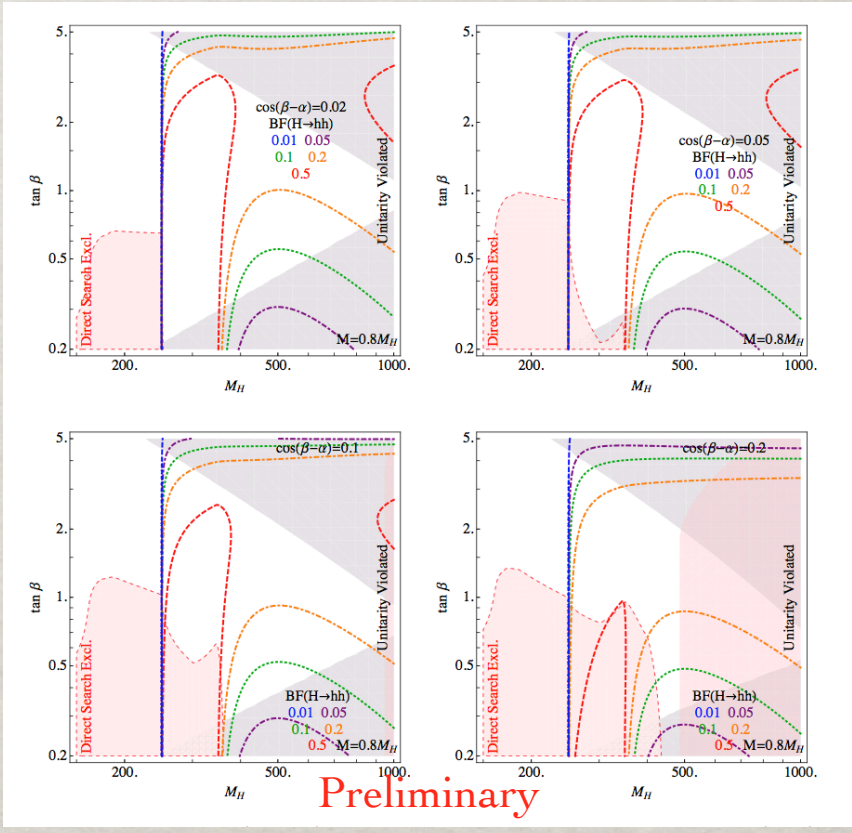
Resonant production in the 2HDM

Resonant production

- Resonant production occurs through heavy Higgs sector
- Dramatic increase in production rate for $M_H > 250$ GeV
- Adopt 2HDM-II and trade scalar couplings for masses
- 2HDM has additional complications:
  - Perturbative unitarity
  - Bounded scalar potential
  - Direct searches for Heavy Higgs
- Given LHC measurements on h, Vector bosons somewhat decoupled
  - Golden window where large $\mathrm{BF}(H \to hh)$ expected: $2m_h < M_H < 2m_t$







V. Barger, L. Everett, C. Jackson,
A. Peterson, GS, 1405.xxxx

Resonant production reach

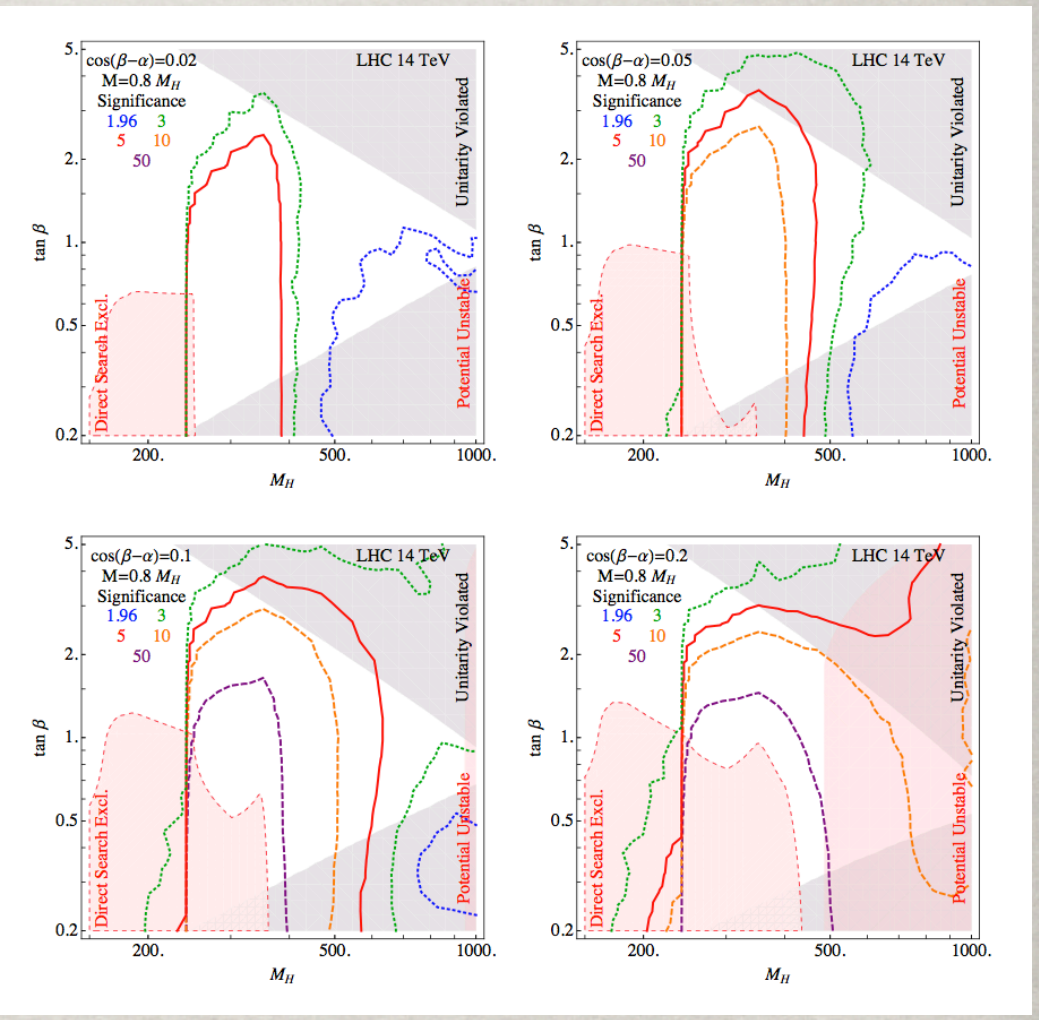
- Scalar coupling measurement of λ^{hhH} possible in 2HDM, even near the decoupling limit
- Discovery contours closely match $\mathrm{BF}(H \to hh)$ near the decoupling limit
- Beyond decoupling limit, scalar coupling increases as

$$\lambda^{hhH} = c_{\beta-\alpha}\frac{4M^2 - 2m_h^2 - M_H^2}{v} + c_{\beta-\alpha}^2\frac{2\cot 2\beta(3M^2 - 2m_h^2 - M_H^2)}{v}$$

- Long term LHC Run-II data poised to probe significant portion of parameter space
  - Excellent reach for

$$2m_h < M_H < 2m_t$$

Preliminary



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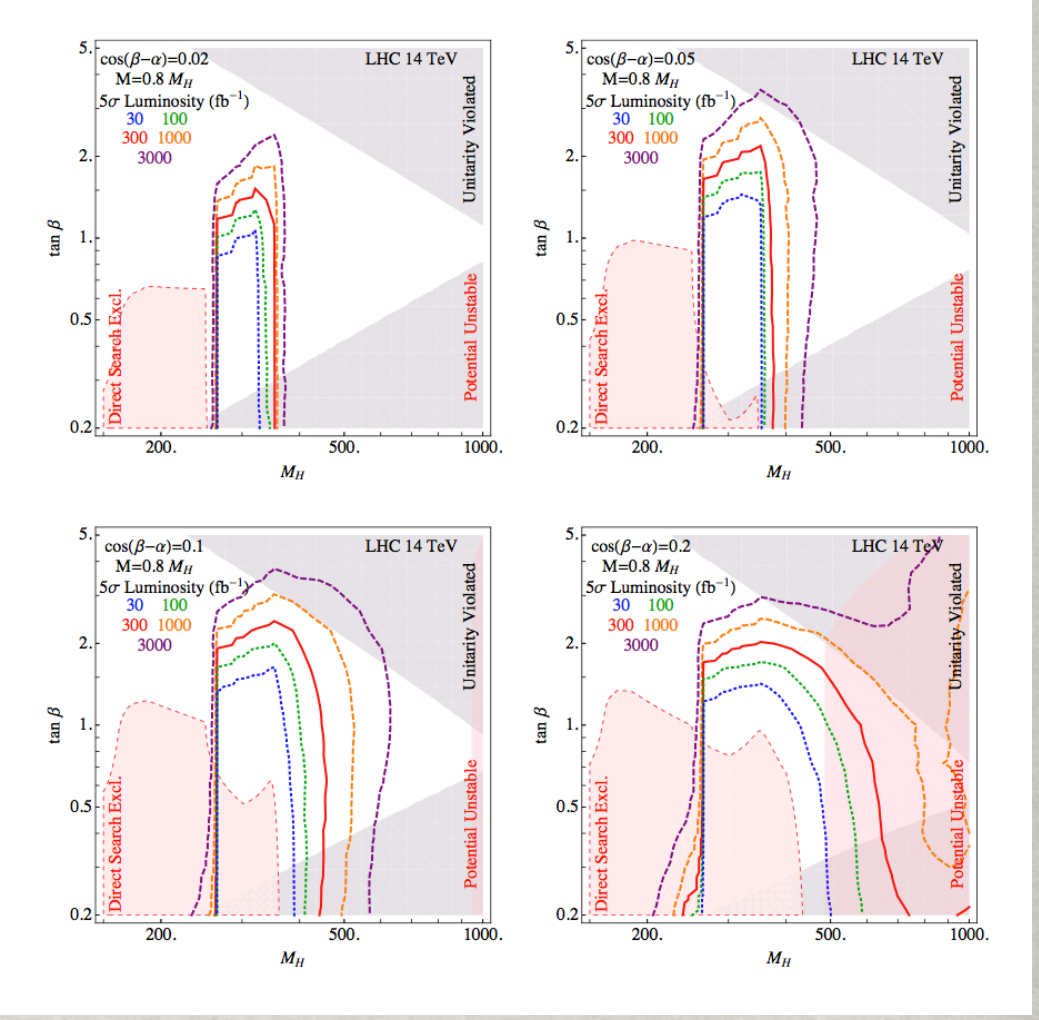
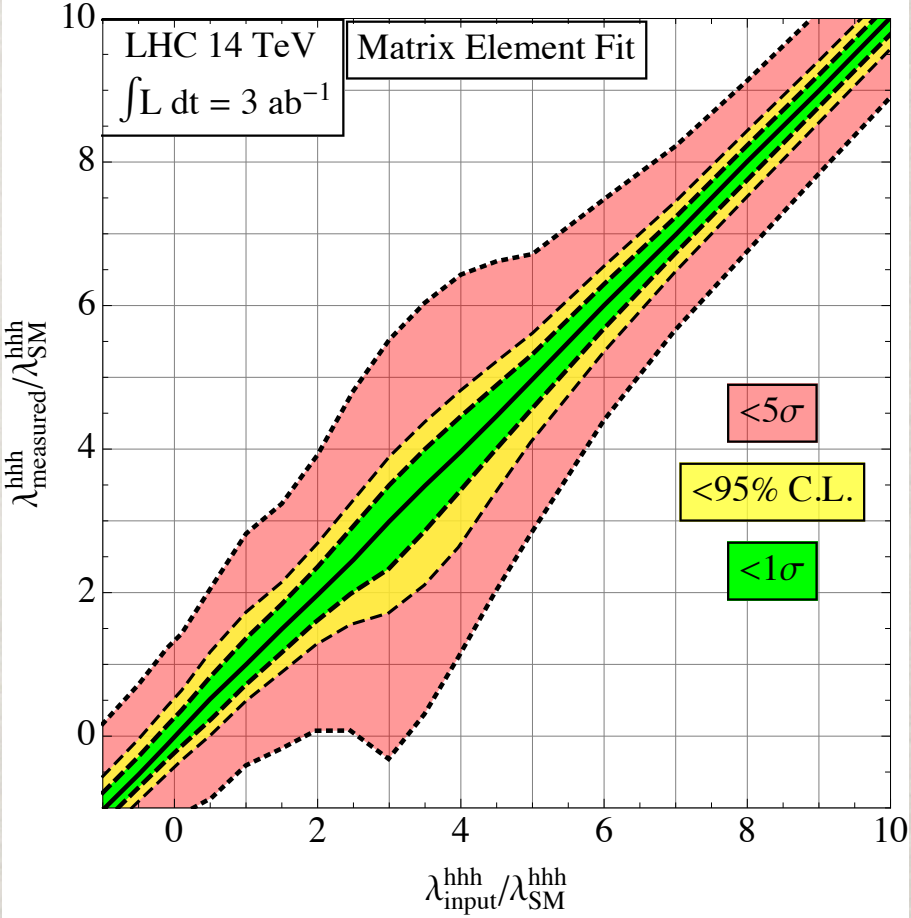


Summary

- Measuring scalar coupling is necessary to determine nature of the Higgs sector

- The $b\bar{b}\gamma\gamma$ channel provides 20-60% uncertainty measurement on λ^{hhh} by end of LHC Run-II
  - SM coupling measured at the 40% level



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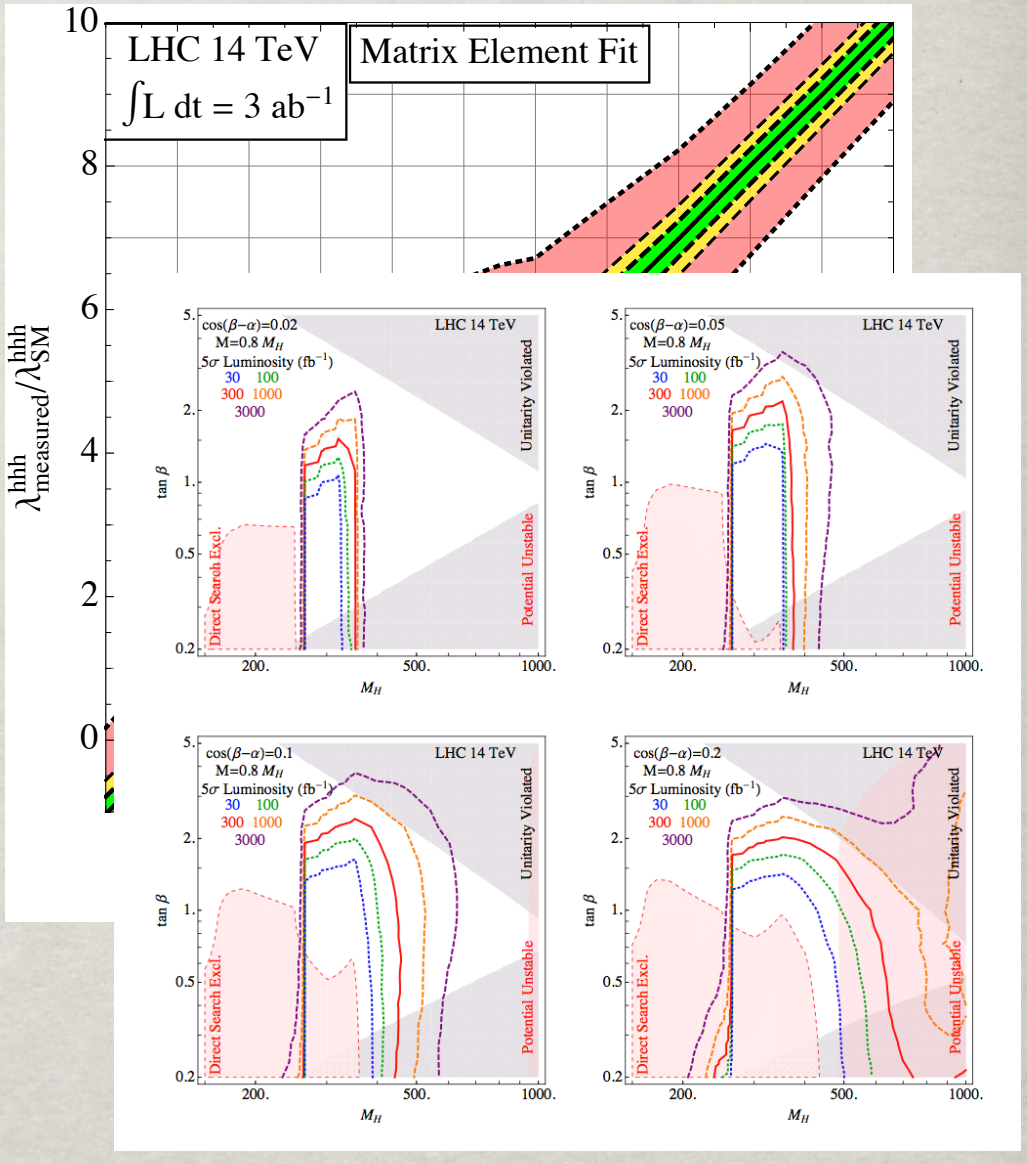
- The $b\bar{b}\gamma\gamma$ channel provides 20-60% uncertainty measurement on λ^{hhh} by end of LHC Run-II
  - SM coupling measured at the 40% level
- Resonant production in the 2HDM greatly improves picture, while providing a measurement of λ^{hhH}



For more on the 2HDM scenario see Andrea Peterson's talk Tuesday in G30 at 3:15