Measuring the Trilinear Higgs Coupling at the LHC

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Measurement of the Higgs Self Coupling at the LHC

- Introduction
- Higgs Pair Production from Gluon Fusion
- Higgs Pair Production via Bottom Quark Fusion
- The Trilinear Higgs Coupling(s)
- The Discovery Potential of Higgs Pairs at the LHC
- Conclusions
Introduction

• Thus far the results from the LHC indicate that the couplings of the Higgs boson to other particles are consistent with the Standard Model.

• But the ultimate test as to whether this particle is the SM Higgs boson will be the trilinear Higgs coupling that appears in Higgs pair production.

• There are uncertainties in the factorization and renormalization scales as well as variations in the parton distribution functions.
Higgs Pairs Production from Gluon Fusion


• For a light Higgs boson with $M_H < 500$ GeV, the dominant source of Higgs boson pair production is gluon fusion through both triangle and box diagrams.

• The triangle diagram involves the Higgs self-coupling while the box diagrams don’t.

• For a heavy Higgs boson with $M_H \sim 1$ TeV, vector boson can become significant.
Higgs Pairs Production from Gluon Fusion

\[ gg \rightarrow hh \]

\[ \sigma(pp \rightarrow hh + X)/(fb) \]

- (a) \( \mu_R = \mu_F = M_h \)
- (b) \( \mu_R = \mu_F = \frac{M_h}{2} \)

\[ M_h \text{ (GeV)} \]

- Total
- Triangle
- Box
Higgs Pairs Production from Gluon Fusion


Higgs Pair Production in Hadron Collisions

Baglio, Djouadi, Gröber, Mühlleitner, Quevillon, Spira, JHEP 1304 (2013) 151.
NNLO Higgs Pair Production at Hadron Colliders


\[
\sigma_{\text{LO}} = 17.8^{+5.3}_{-3.8} \text{ fb,} \quad \sigma_{\text{NLO}} = 33.2^{+5.9}_{-4.9} \text{ fb,} \\
\sigma_{\text{NNLO}} = 40.2^{+3.2}_{-3.5} \text{ fb,} \quad (18)
\]

<table>
<thead>
<tr>
<th>( E_{\text{c.m.}} )</th>
<th>8 TeV</th>
<th>14 TeV</th>
<th>33 TeV</th>
<th>100 TeV</th>
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<tr>
<td>( \sigma_{\text{NNLO}} )</td>
<td>9.76 fb</td>
<td>40.2 fb</td>
<td>243 fb</td>
<td>1638 fb</td>
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<td>PDF + ( \alpha_S ) [%]</td>
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<td>+7.2 – 7.1</td>
<td>+6.0 – 6.0</td>
<td>+5.8 – 6.0</td>
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Higgs Pair Production via Bottom Quark Fusion

- In the Standard Model, bottom quark fusion is almost negligible for Higgs pair production.
- In two Higgs doublet models with Type II Yukawa interactions, the $H_{bb}$ coupling is enhanced by a large value of $\tan\beta$. Thus for $\tan\beta > 7$, bottom quark fusion makes dominant contribution.
- The physical process is $gg$ to $bbHH$.
- However, it is a good approximation to calculate $bb$ to $HH$ if no associate $b$ quarks are tagged.
Higgs Pair Production via Bottom Quark Fusion

QCD CORRECTIONS TO $bb \rightarrow hh$


- **Next-to-Leading Order Corrections**
  - $\alpha_s$ Corrections: Virtual Correction
  - $\alpha_s$ Corrections: Real Emission, $bb \rightarrow hhg$
  - $1/\Lambda$ Corrections: $bg \rightarrow bhh$ [$\Lambda = \ln (m_h/m_b)$]
  - $gg \rightarrow bbhh$ Cross Section ($1/\Lambda^2$)
NLO Corrections to $bb \rightarrow hh$
NLO Corrections to $bb \rightarrow \phi\phi$ in MSSM
The Trilinear Higgs Coupling(s)

- Higgs pair production from gluon fusion involves $ttH$ and $HHH$ couplings.
- The box and triangle diagrams are separately gauge invariant so we can vary the two couplings independently by introducing parameters $\kappa_t$ and $\kappa$ or $\kappa_H$, 

\[ ttH : \quad - \frac{m_t}{v} \kappa_t \]
\[ HHH : \quad - \frac{3 M_H^2}{v} \kappa \]
Effects of kappa with $\kappa > 0$

$\sqrt{s} = 14$ TeV, $K = 1.9$
Effects of kappa with $\kappa < 0$

$\sqrt{s} = 14$ TeV, $K = 1.9$

![Graph showing effects of kappa with $\kappa < 0$. The graph illustrates the cross-section $\sigma(pp \rightarrow H^0H^0 \pm X)$ (fb) as a function of $\kappa$, with different contributions labeled as 'Total', 'Box', and 'Triangle'.]
Uncertainties in Cross Section

$\sqrt{s} = 14$ TeV

$\sigma(\text{pp} \rightarrow H^0H^0 + X)$ (fb)

$\kappa$
Uncertainties in Cross Section

\[ \sqrt{s} = 100 \text{ TeV} \]
The Discovery Potential of Higgs Pairs

Conclusions

Goertz, Papaefstathiou, Yang and Zurita, JHEP 1306 (2013) 016;

- The $bb\gamma\gamma$, $bb\tau\tau$, $bbWW$ and $bbbb$ final states are promising channels to measure the Higgs trilinear coupling(s) at the LHC.

- LHC data at 7–8 TeV should probe large deviations of $\lambda_{hhh}$ from the SM ($\kappa_h > 7.5$ at 95% C.L.).

- At the LHC with a CM energy of 14 TeV and an integrated luminosity of 3 ab$^{-1}$, ATLAS and CMS will be able to measure $\lambda_{hhh}$ within 20%–40% uncertainty.