Measuring the Trilinear Higgs Coupling at the LHC

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Measurement of the Higgs Self Coupling at the LHC

Dicus and Kao (2004)

- 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

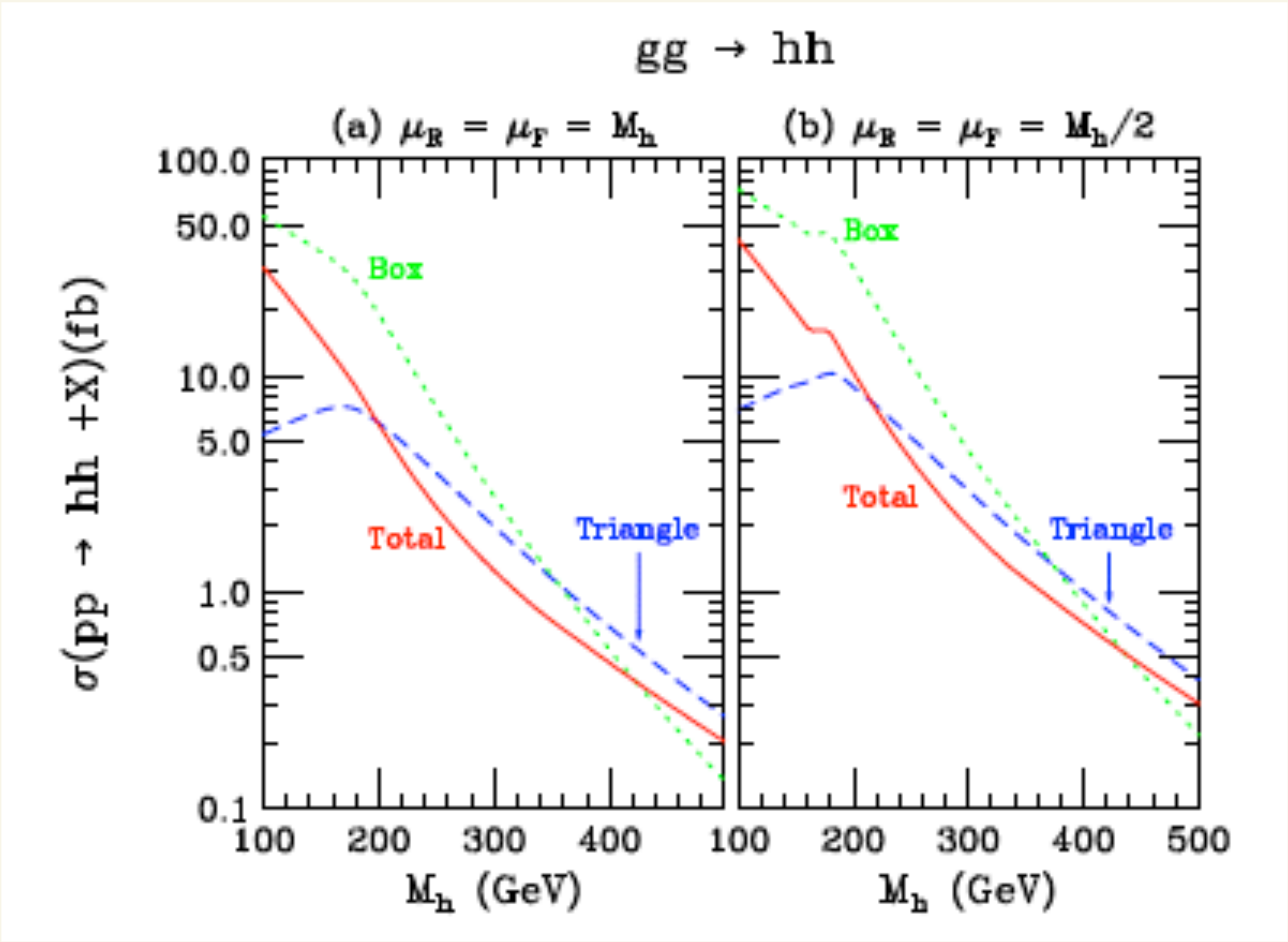
- Thus far the results from the LHC indicate that the couplings of the Higgs boson to other particles are consistent with the Standard Model.
- But the ultimate test as to whether this particle is the SM Higgs boson will be the trilinear Higgs coupling that appears in Higgs pair production.
- There are uncertainties in the factorization and renormalization scales as well as variations in the parton distribution functions.

Higgs Pairs Production from Gluon Fusion

Dicus, Kao, and Willenbrock, Phys. Lett. **B203** (1988) 457;
Glover and van der Bij, Nucl. Phys. **B309** (1988) 282.

- 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

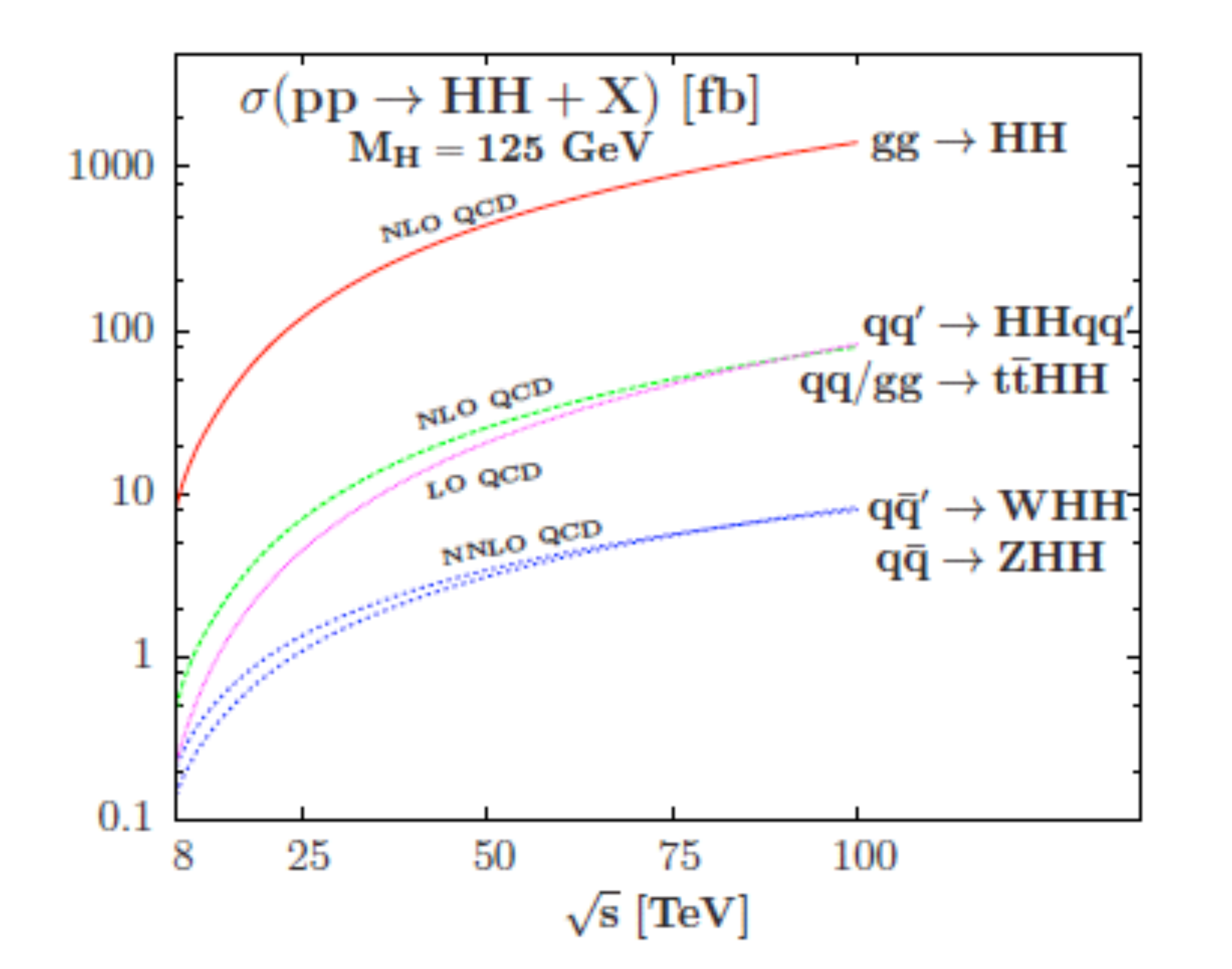


Higgs Pairs Production from Gluon Fusion

- NLO: Plehn, Spira, and Zerwas, NPB 479 (1996) 46; NPB531 (1998) 655(E); Dawson, Dittmaier, and Spira, PRD 58 (1998) 115012; Jin, Li, Li, Liu and Oakes, PRD 71 (2005) 095004; Baglio, Djouadi, Gröber, Mühlleitner, Quevillon, and Spira, JHEP 1304 (2013) 151; Grigo, Hoff, Melnikov and Steinhauser, NPB 875 (2013) 1.
  NNLO: de Florian and Mazzitelli, Phys. Rev. Lett. 111 (2013) 201801.
- MSSM: Belyaev, Drees, Eboli, Mizukoshi and Novaes, PRD 60 (1999) 075008; Bendezu and Kniehl, PRD 64 (2001) 035006.
- $bb\tau\tau$, $bb\gamma\gamma$, bbWW, bbbb: U. Baur, T. Plehn, and D. L. Rainwater, PRD 67 (2003) 033003; PRD 69 (2004) 053004; Dib, Rosenfeld, Zerwekh, JHEP 0605 (2006) 074; Grober and Muhlleitner, JHEP 1106 (2011) 020; Dolan, Englert, Spannowsky JHEP 1210 (2012) 112; Barr, Dolan, Englert, Spannowsky PLB 728 (2014) 308; Papaefstathiou, Yang and Zurita, PRD 87 (2013) 011301; Goertz, Papaefstathiou, Yang and Zurita, JHEP 1306 (2013) 016;
  de Lima, Papaefstathiou, Spannowsky arXiv:1404.7139.

Higgs Pair Production in Hadron Collisions

Baglio, Djouadi, Gröber, Mühlleitner, Quevillon, Spira, JHEP **1304** (2013) 151.



NNLO Higgs Pair Production at Hadron Colliders

de Florian and Mazzitelli, Phys. Rev. Lett. **111** (2013) 201801.

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

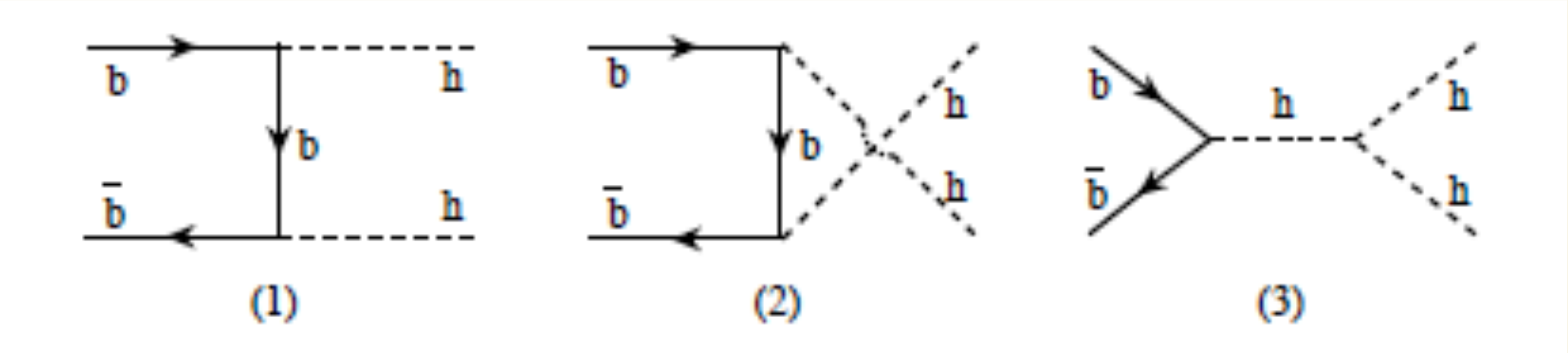
$E_{\rm c.m.}$	8 TeV	14 TeV	33 TeV	100 TeV
$\sigma_{\rm NNLO}$	9.76 fb	40.2 fb	243 fb	1638 fb
Scale [%]	$+9.0 - 9.8$	$+8.0 - 8.7$	$+7.0 - 7.4$	$+5.9 - 5.8$
PDF [%]	$+6.0 - 6.1$	$+4.0 - 4.0$	$+2.5 - 2.6$	$+2.3 - 2.6$
PDF + α_S [%]	$+9.3 - 8.8$	$+7.2 - 7.1$	$+6.0 - 6.0$	$+5.8 - 6.0$

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 Hbb 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

Dawson, Kao, Wang and Williams, Phys. Rev. D **75** (2007) 013007;
Dawson, Kao and Wang, Phys. Rev. D **77** (2008) 113005.

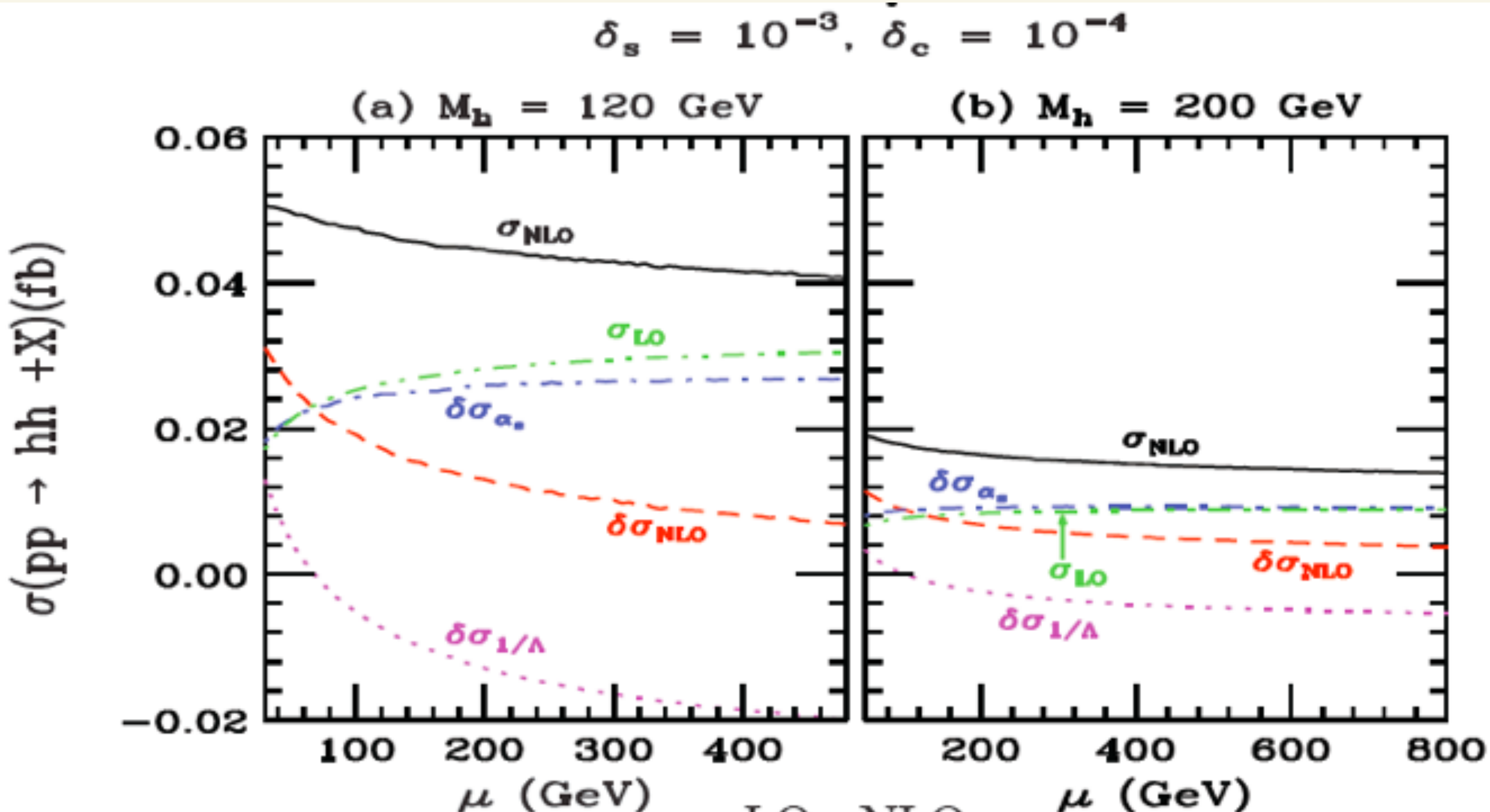


QCD CORRECTIONS TO bb → h h

Dawson, Kao, Wang and Williams, Phys. Rev. **D75** (2007) 013007.

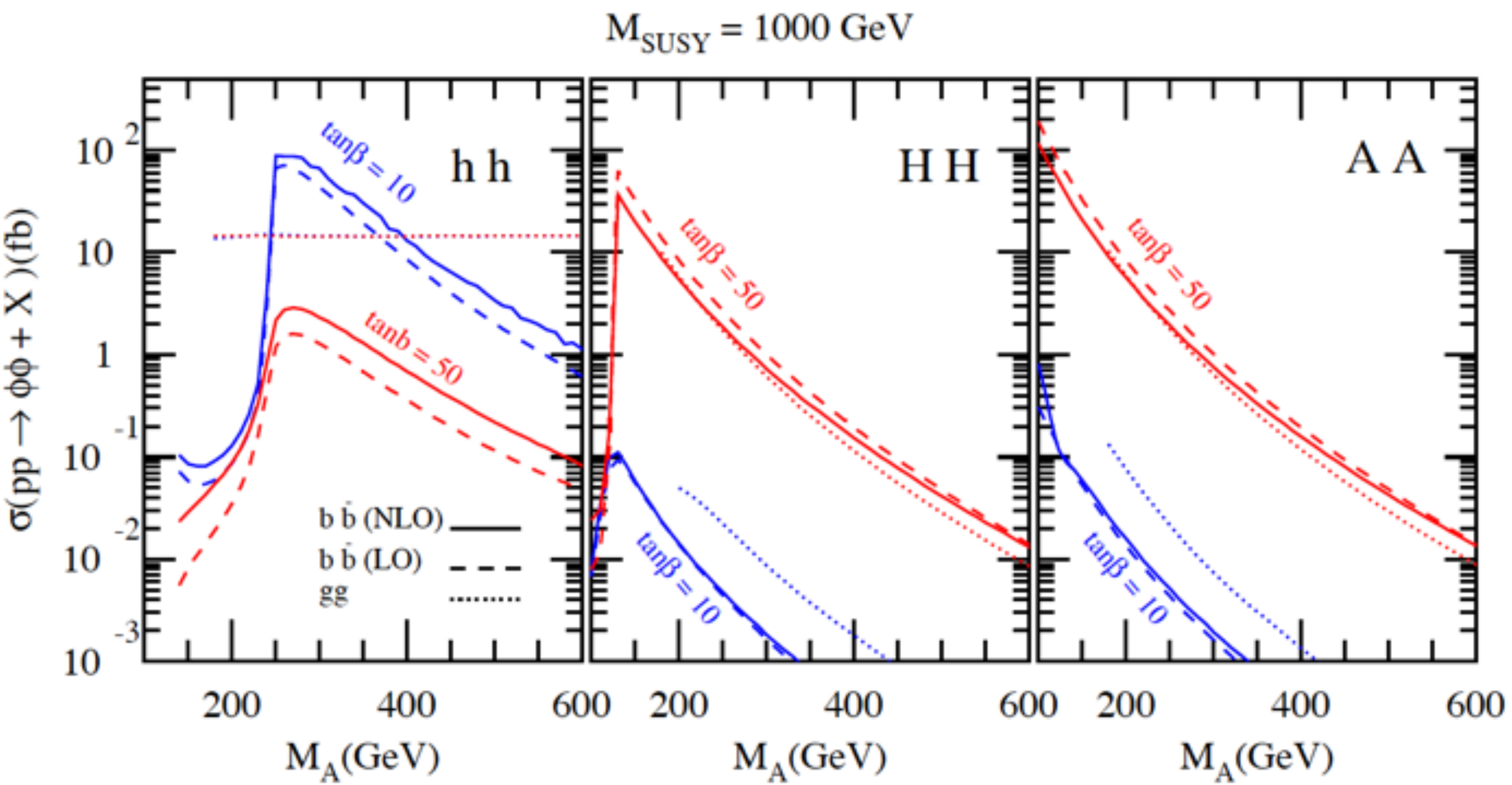
- **Next-to-Leading Order Corrections**
  - **α_s Corrections: Virtual Correction**
  - **α_s Corrections: Real Emission, bb → hhg**
  - **1/Λ Corrections: bg → bhh [Λ = ln (m_h/m_b)]**
  - **gg → bbhh Cross Section ($1/\Lambda^2$)**

NLO Corrections to bb → h h



$$K = \frac{\mathrm{LO} + \mathrm{NLO}}{\mathrm{LO}} \sim 1.5$$

NLO Corrections to bb → ϕϕ in MSSM



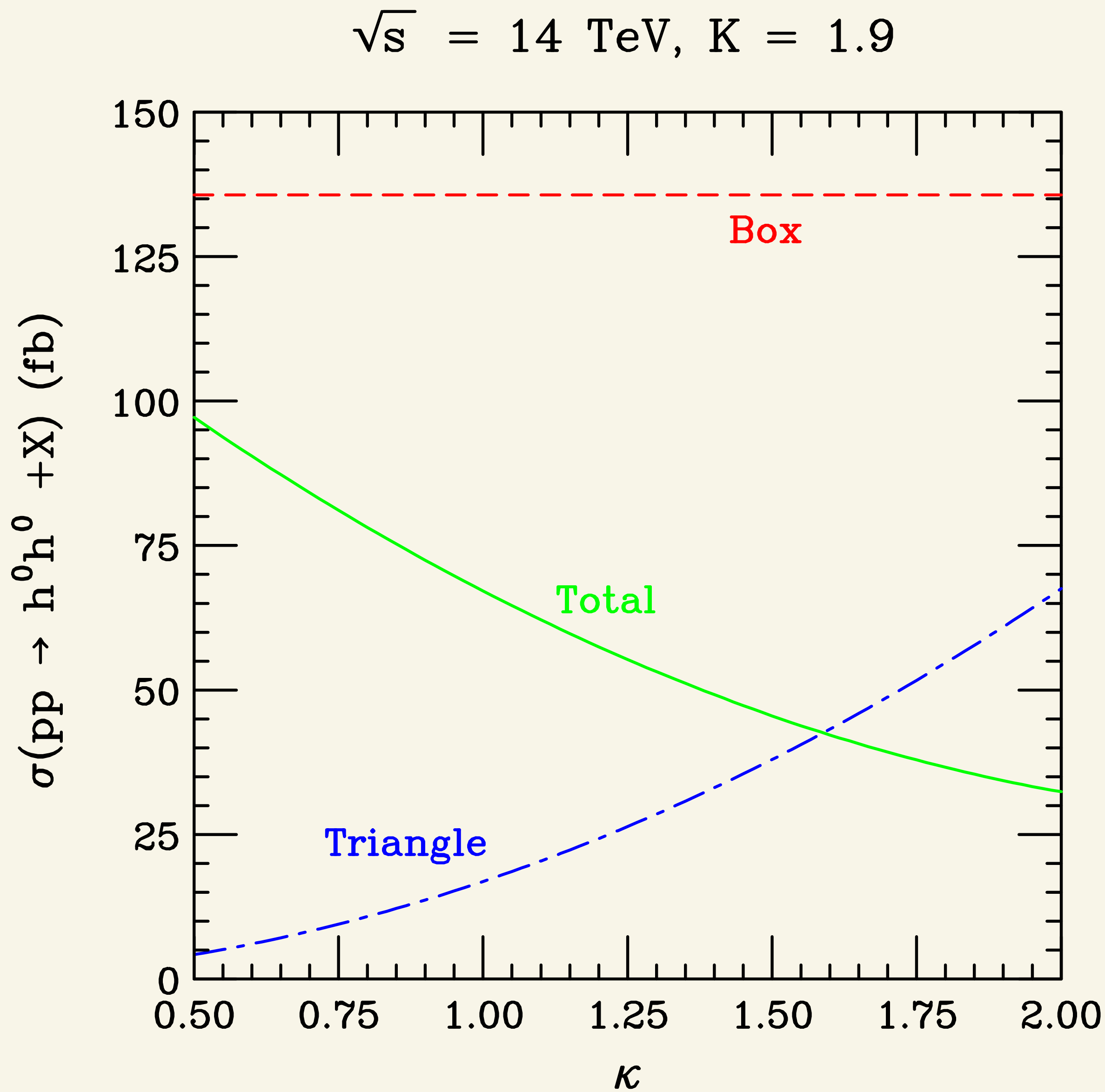
The Trilinear Higgs Coupling(s)

- 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 κ_t and κ or κ_H ,

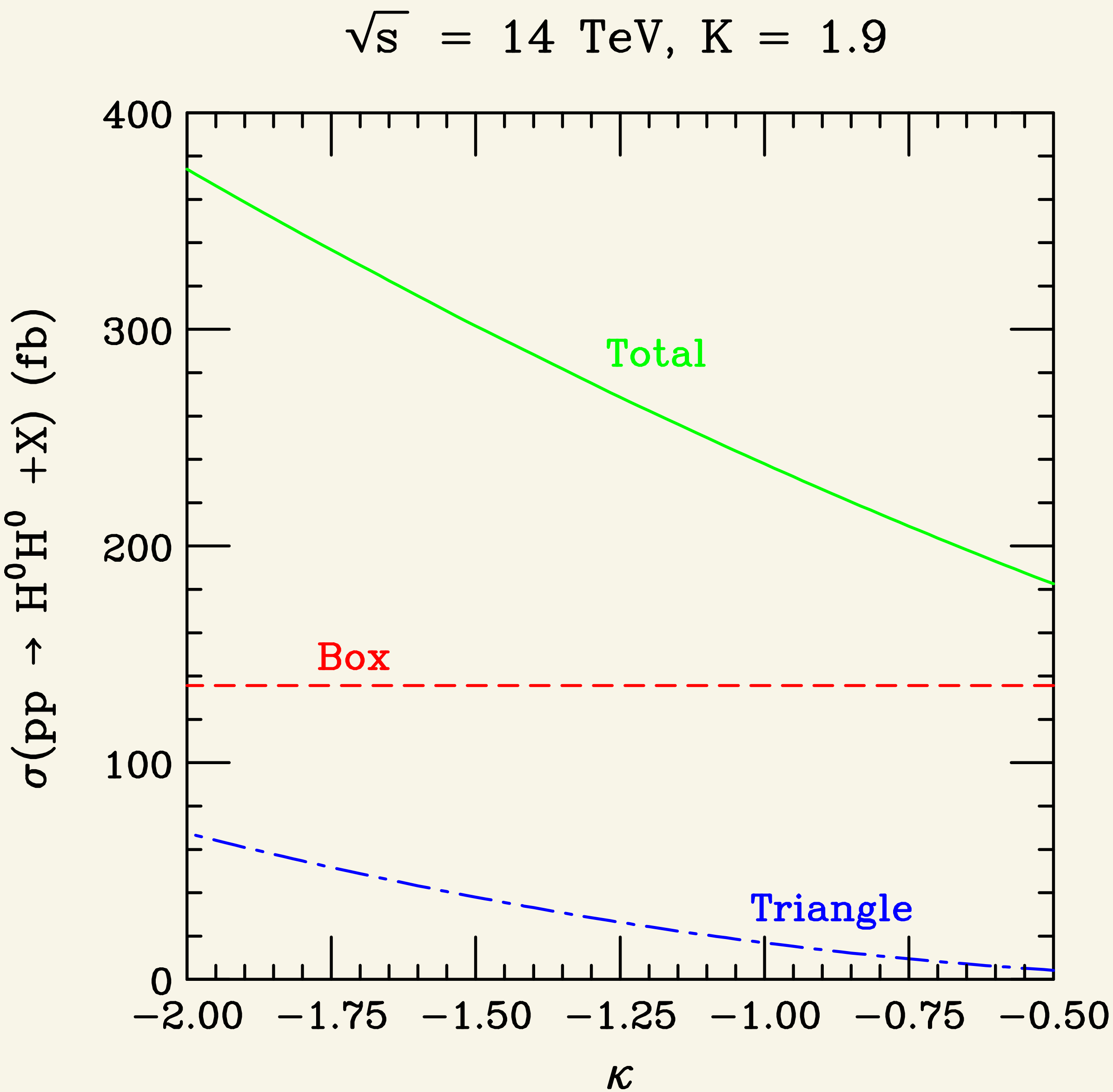
$$t\bar{t}H \; : \qquad -\frac{m_t}{v} k_t$$

$$HHH \; : \qquad -\frac{3\,M_H^2}{v}\kappa$$

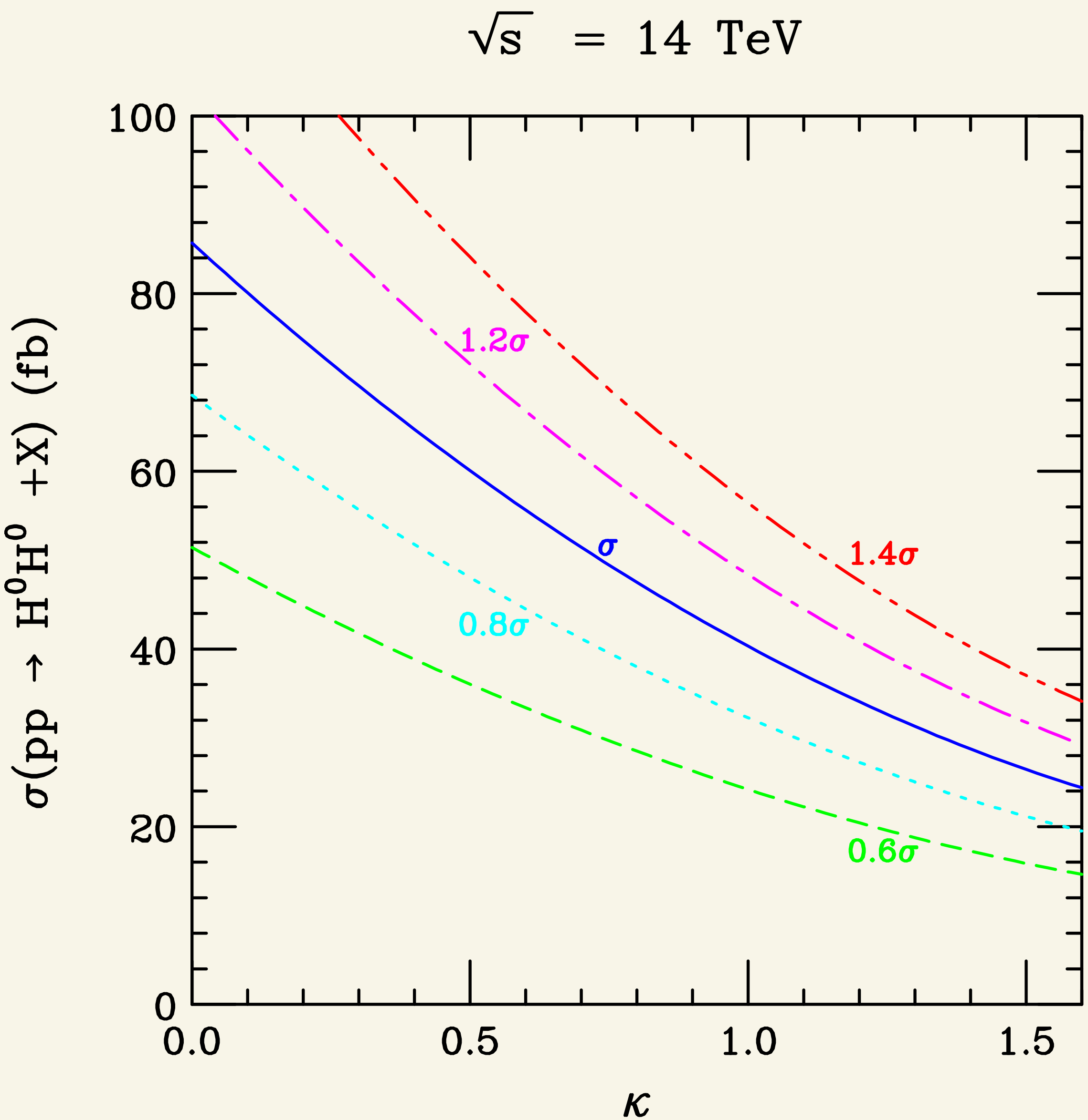
Effects of kappa with κ > 0



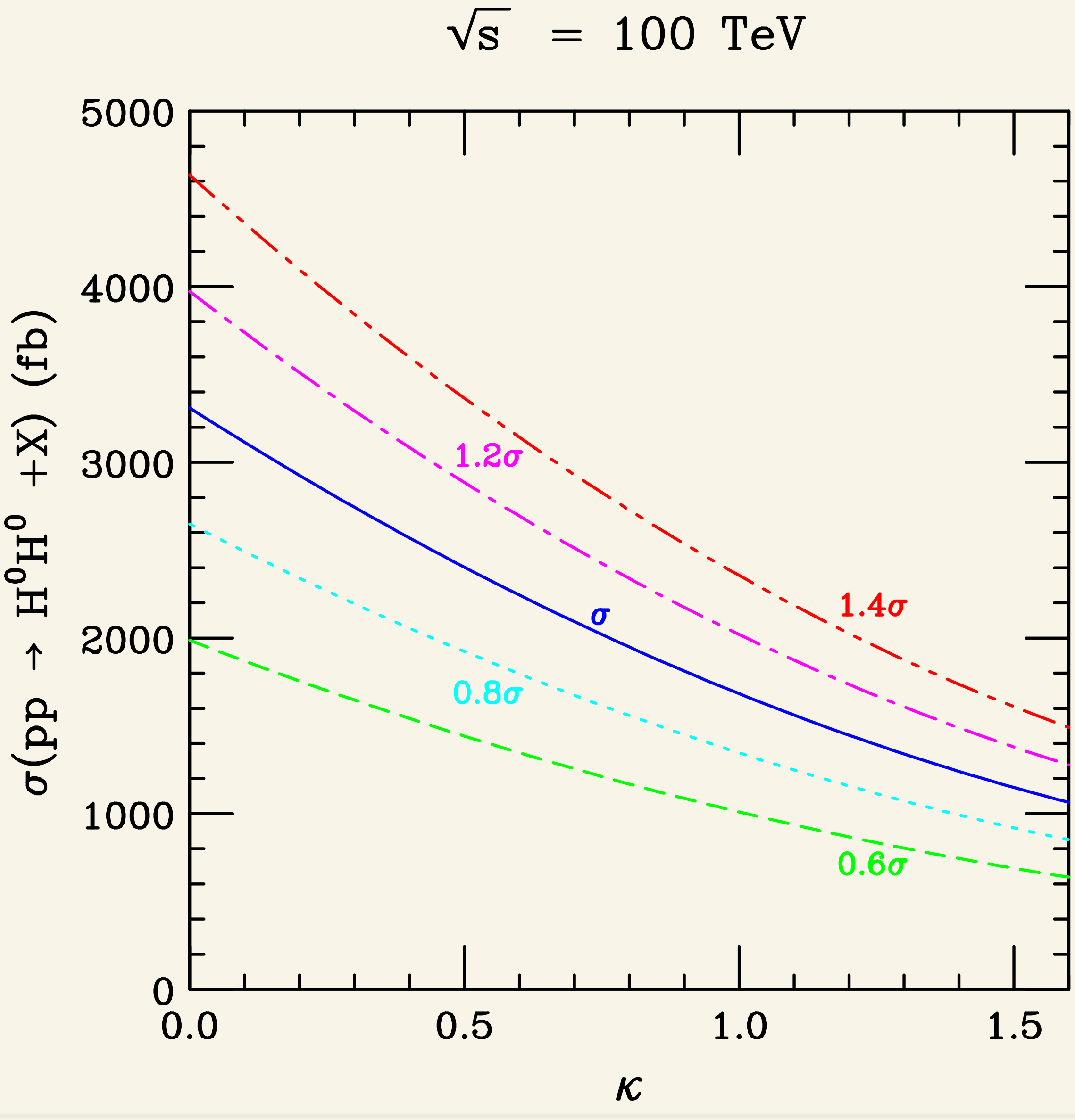
Effects of kappa with κ < 0



Uncertainties in Cross Section

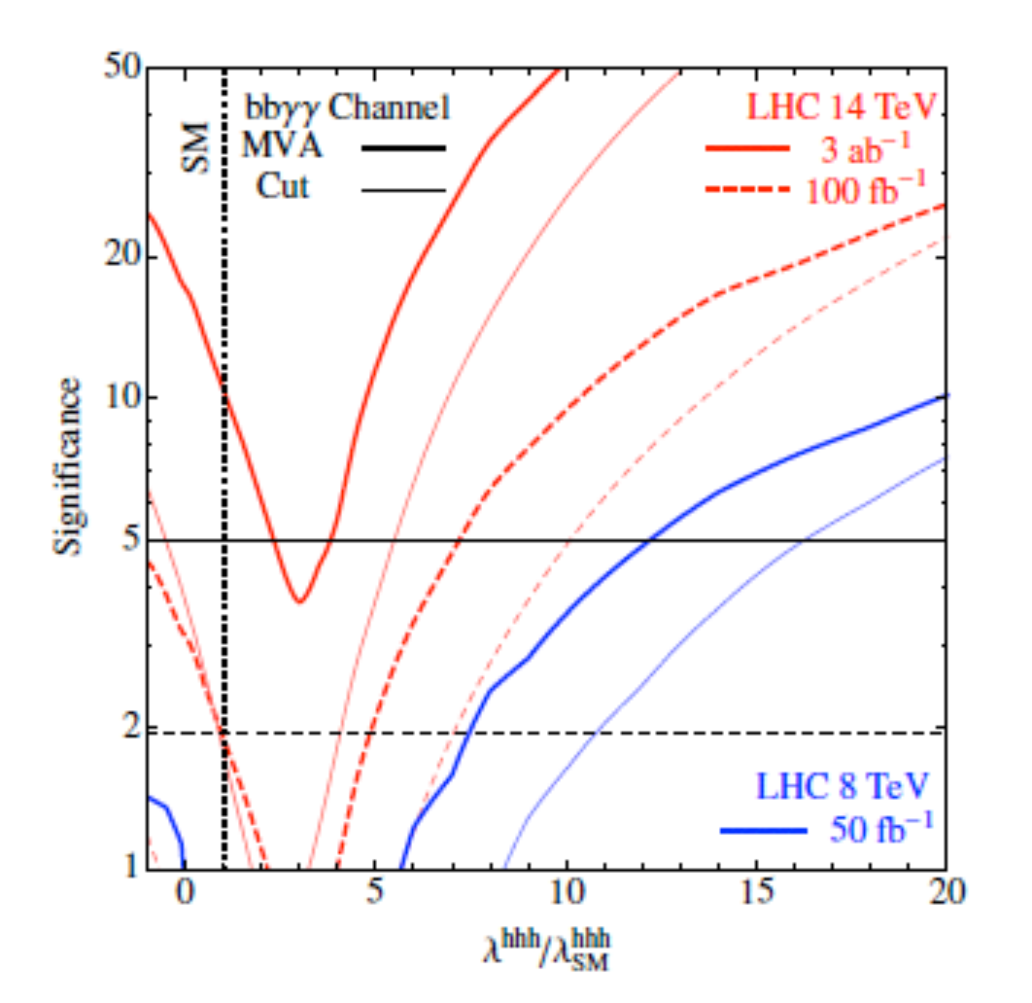


Uncertainties in Cross Section



The Discovery Potential of Higgs Pairs

Barger, Everett, Jackson, Shaughnessy, Phys. Lett. B728 (2014).



Conclusions

Barger, Everett, Jackson, Shaughnessy, Phys. Lett. B728 (2014) 433;
Goertz, Papaefstathiou, Yang and Zurita, JHEP 1306 (2013) 016;
de Lima, Papaefstathiou, Spannowsky arXiv:1404.7139.

- 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 λ_{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 λ_{hhh} within 20%–40% uncertainty.