Double Higgs production and the Higgs self-coupling

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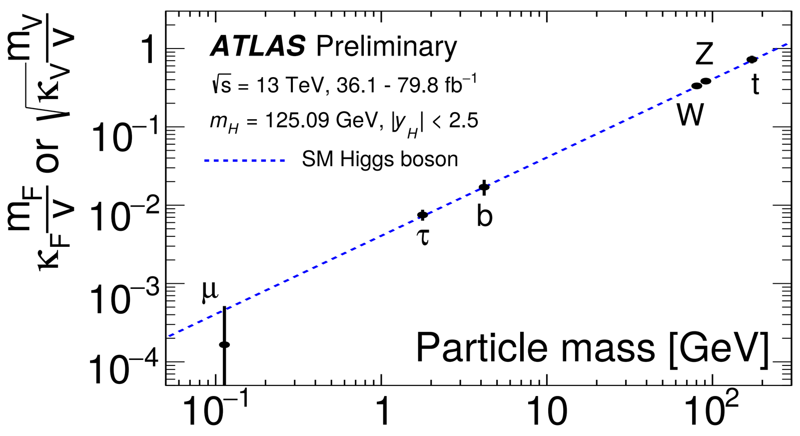
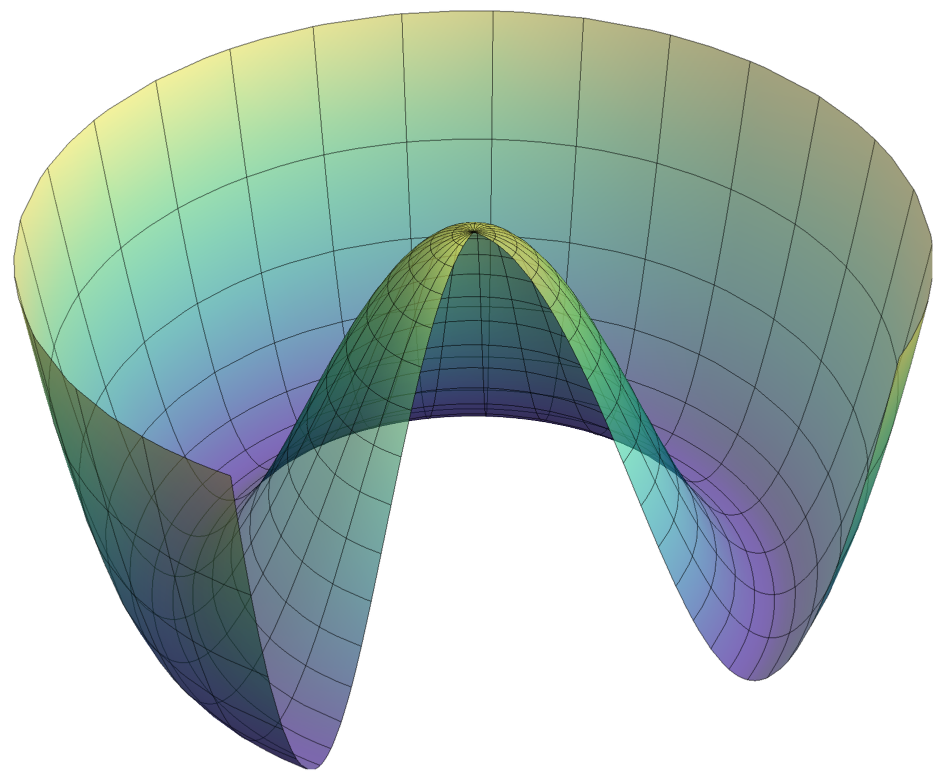
Studying the Higgs boson couplings

The Higgs boson is a key element of the Standard Model of particle physics, allowing to give a mass to gauge bosons and fermions, otherwise forbidden by symmetries.

The study of its properties is one of the main objectives of the LHC, looking for signs of new physics.



Its couplings to fermions and gauge bosons are for the moment compatible with the SM expectations.



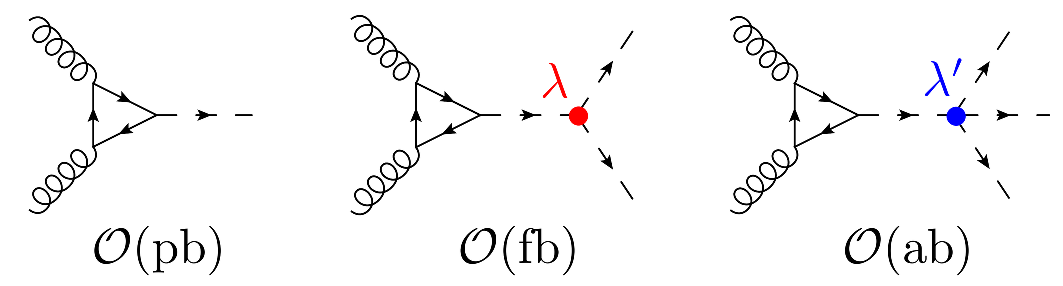
$$V(H) = \frac{1}{2}M_H^2 H^2 + \lambda v H^3 + \frac{1}{4}\lambda' H^4$$

with $\lambda = \lambda' = M_H^2/(2v^2)$ in the SM

The scalar potential, responsible for the spontaneous symmetry breaking, gives rise to triple and quartic Higgs self-interactions.

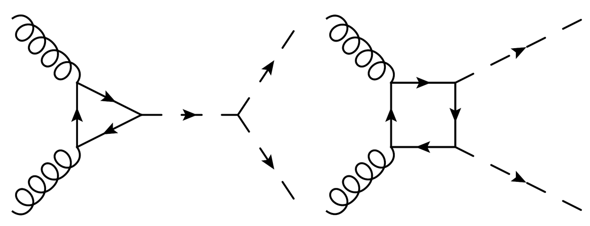
These couplings can be studied in particle colliders via the production of multiple Higgs bosons. Many BSM scenarios predict sizable deviations from the SM expectations.

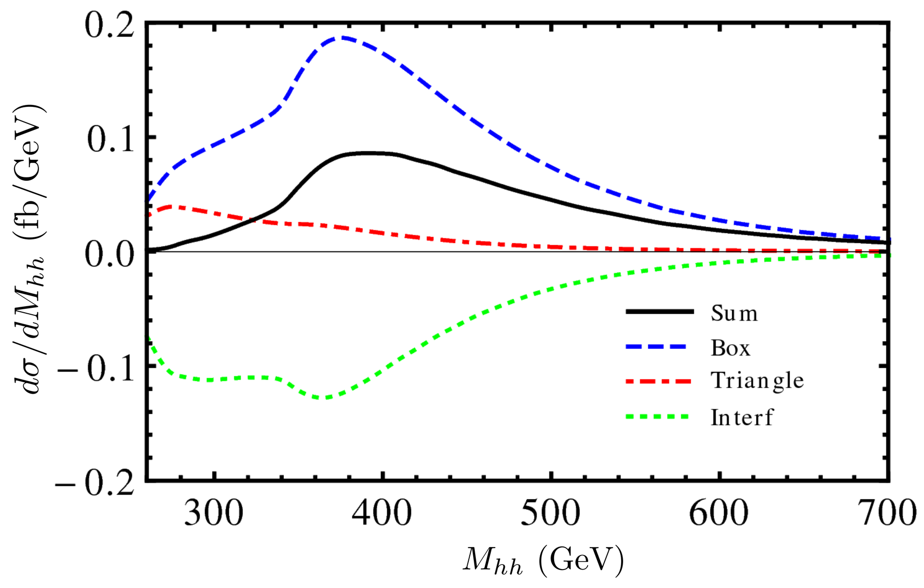
Very difficult measurements due to the small signals:



HH via gluon fusion

- Main production channel
- Two contributions at LO:

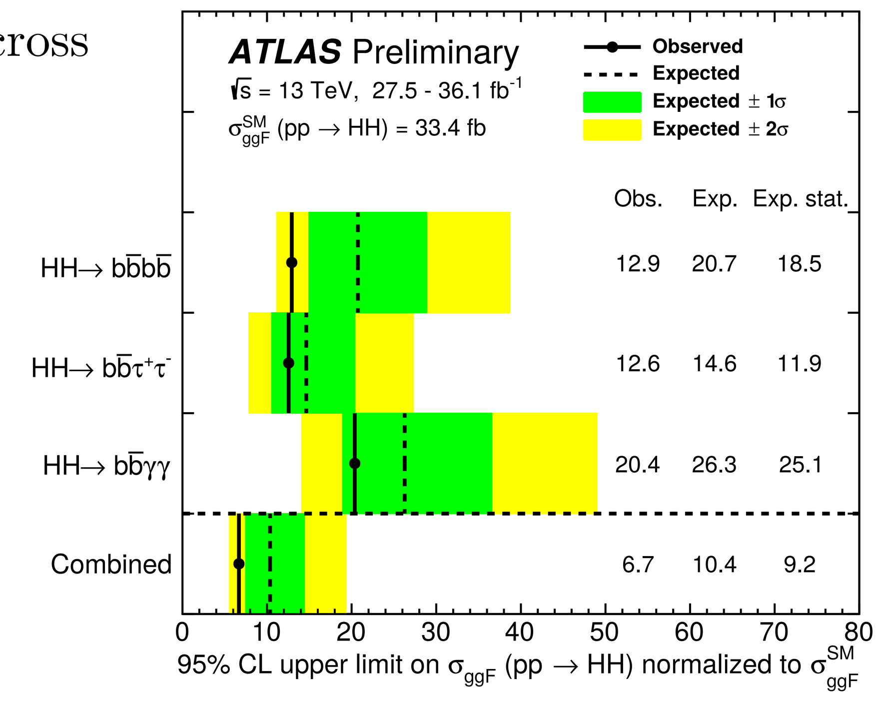




- Only triangle sensitive to λ
- Box dominant, large destructive interference
- Largest sensitivity to λ arises from the interference between the two
- Large box-triangle cancellation at threshold, very sensitive to λ variations

HH at LHC and beyond

- BSM scenarios can enhance the cross section or produce a resonance
- Both resonant and non-resonant searches performed at LHC
- Current sensitivity: $\mathcal{O}(10) \times \sigma_{\rm SM}$
- After full HL-LHC integrated luminosity, uncertainty on λ expected of $\mathcal{O}(1)$



- Complementary information from loop effects in single H observables
- Precision on λ at future colliders: HE-LHC $\sim 30\%$, FCC-100 $\sim 5\%$

Theoretical predictions for HH production

Theory predictions are computed using perturbation theory. In particular, the quantum corrections associated to the strong force (quantum chromodynamics) are typically very large.

Leading order (LO) is insufficient, and often corrections are so large that even the next order (NLO) is not enough.

For HH production, NLO corrections are huge, about 70%, and with still sizable theoretical uncertainties.

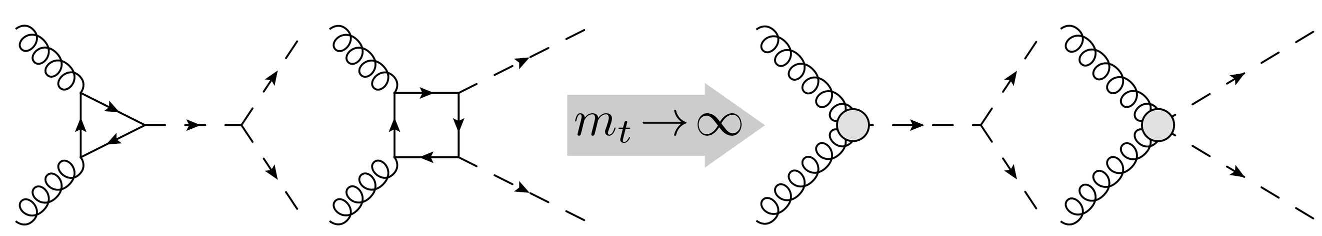
Higher orders are needed for a better precision, and their calculation is very challenging!

Real and virtual corrections are independently divergent. Only their sum is finite, and to achieve this cancellation we need to implement a subtraction method.

We use the q_T-subtraction method:

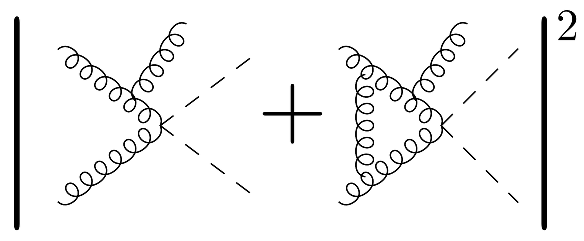
$$d\sigma^{\rm HH}_{\rm NNLO} = \mathcal{H}^{\rm HH}_{\rm NNLO} \otimes d\sigma^{\rm HH}_{\rm LO} + \left[d\sigma^{\rm HH+jet}_{\rm NLO} - d\sigma^{\rm CT}_{\rm NNLO} \right]$$

Full NNLO out of reach at present, approximations needed:

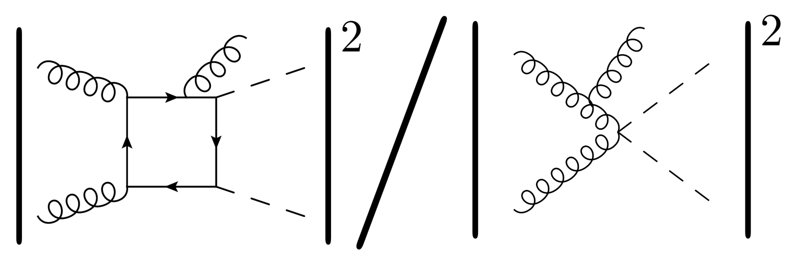


We implemented a reweighting procedure to account for finite top-quark mass effects.

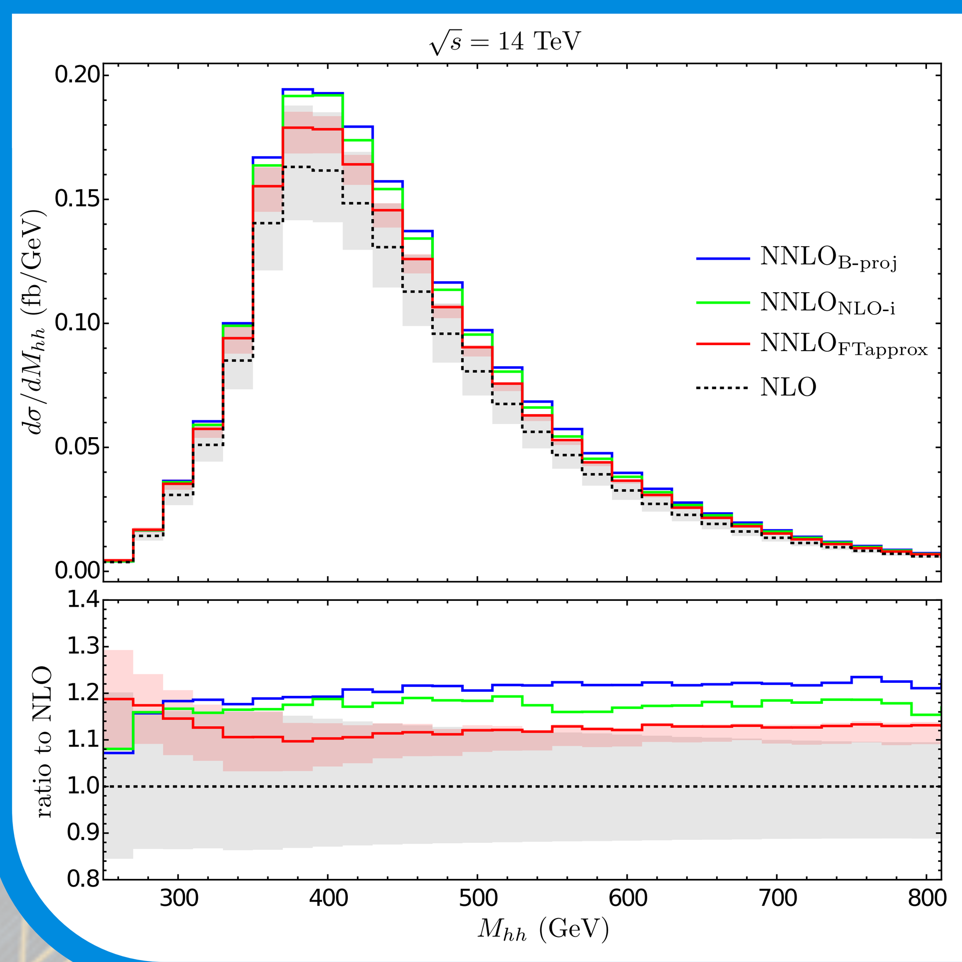
E.g. the squared matrix element:



is reweighted by the following factor:



Numerical results



- Increase of about 12% with respect to previous order
- Strong reduction of the theoretical uncertainties
- Overlap with previous order uncertainty band, showing signs of convergence
- Finite-m_t effects estimated at the few percent level, much better performance than previous approximations

Summary

- Higgs boson discovered in 2012, for the moment compatible with SM
- The study of its properties looking for new physics is one of the main objectives of the LHC
- Precise predictions are needed for its study, QCD corrections are crucial
- HH production is the main way to probe the Higgs self-coupling
- We computed QCD NNLO corrections for its production cross section, within an approximations that accurately retains finite-m_t effects
- We are just beginning to explore the Higgs potential
- **Bachelor and Master projects available!**