

Higgs couplings in a non-linear Effective field theory with full NLO QCD corrections

Matteo Capozzi

Based on [arXiv:1806.05162](https://arxiv.org/abs/1806.05162)

Max-Planck-Institut
für Physik



08/09/2018
Ringberg Workshop 2018

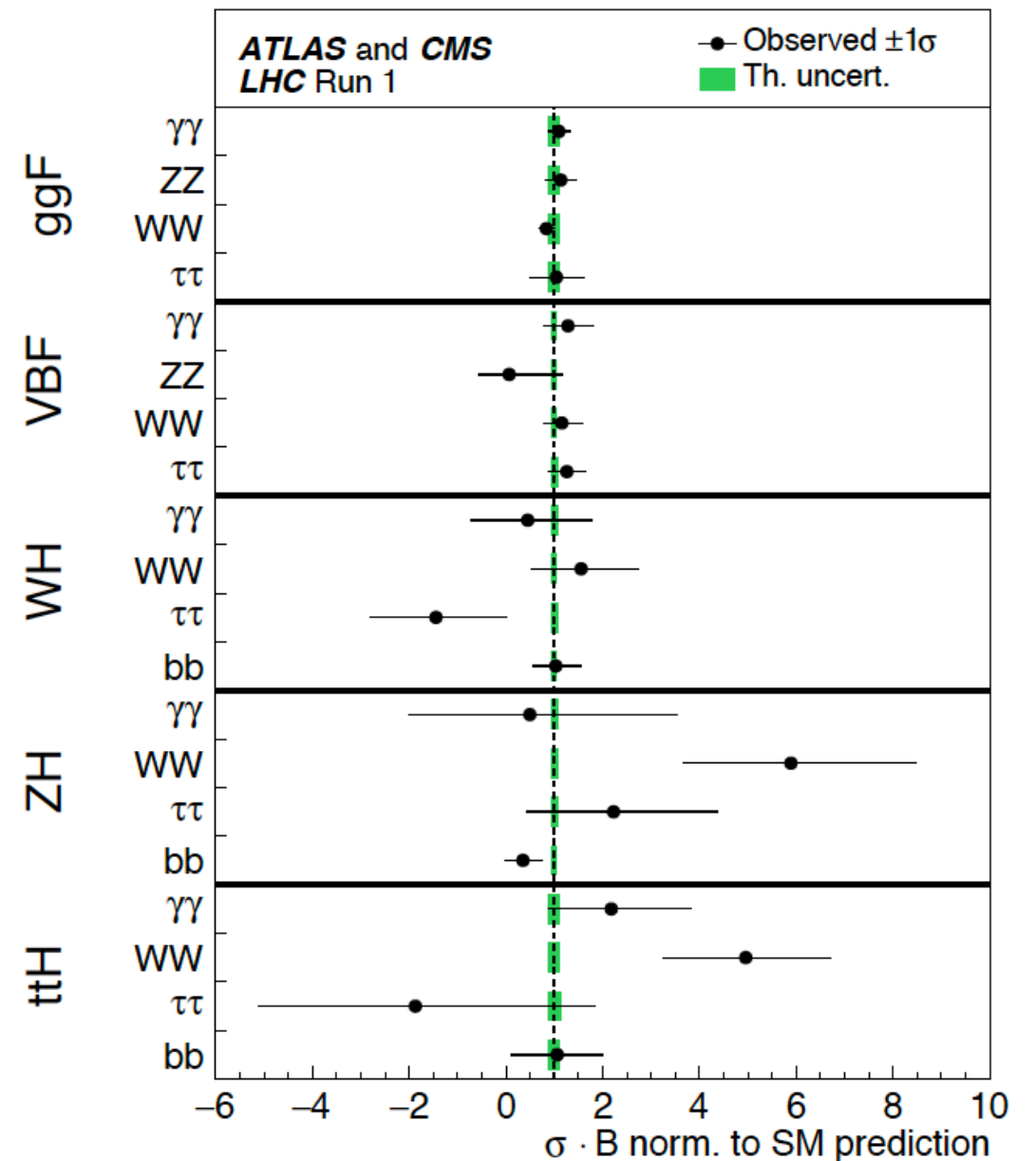
Motivations

Motivations

- ❑ Discovery of the Higgs boson: most important element in our understanding of electroweak symmetry breaking.
- ❑ The hierarchy problem and other open questions in the SM motivate us to explore extensions to the Higgs sector.
- ❑ SM is very well tested. If there are new physics effects they are likely to show up in the Higgs sector, but no evidence of new physics has been found up to date.
- ❑ New physics may hide at higher scales, therefore a low energy approximation of new physics can allow us to parametrize new physics contributions.
- ❑ So we work in an Effective Field Theory (EFT) framework, in particular the one provided by the ElectroWeak Chiral Lagrangian (EWChL) [Buchalla et al. [arXiv:1307.5017](https://arxiv.org/abs/1307.5017)].

Motivations


- EWChL provides a non linear realization of the electroweak symmetry breaking sector.
- Many of the Higgs couplings are well constrained already or can be obtained from other processes, but this is not true for the Higgs boson self coupling.
- Therefore we only consider the Higgs sector within the EWChL framework.



ATLAS, CMS collaboration
[arXiv:1606.02266](https://arxiv.org/abs/1606.02266)

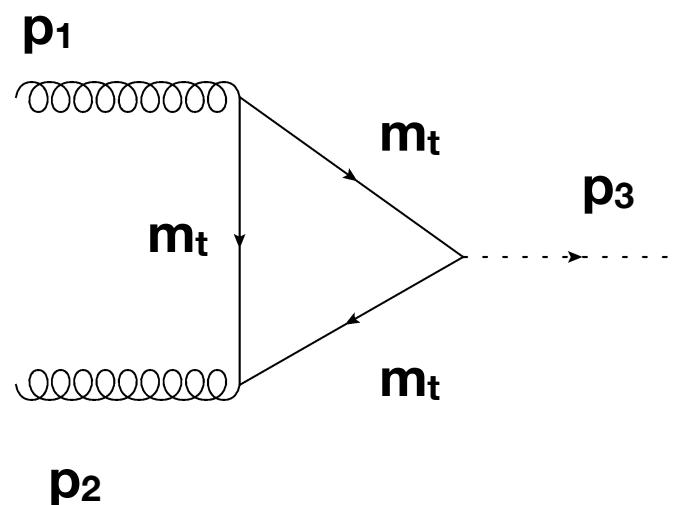
Effective field Theory

Effective field Theory (EFT)

- In order to parametrize new physics contributions in the Higgs sector we use an effective field theory.
- The basic idea is to work at energy lower than the ones where the new particles could show up  Definition of an energy scale.
- In order to build your EFT theory you have to add the effective operators to the Standard Model lagrangian.
- In the Higgs sector these new operators are at least of canonical dimension 6.

The ggH vertex

In order to understand the effective field theory let us analyze one of the diagram contributing to the Higgs boson production.



One can find the diagram is proportional to:

$$\frac{\alpha_S}{v} 4m_t^2 [2 + (4m_t^2 - m_H^2)C(0, 0, m_H^2; m_t, m_t, m_t)]$$

$$C(k_1^2, k_2^2, m_H^2; m_t, m_t, m_t) \equiv \int \frac{d^4 q}{i\pi^2} \frac{1}{[q^2 - m_t^2][(q + k_1)^2 - m_t^2][(q + k_1 + k_2)^2 - m_t^2]}$$

The ggH vertex

In the limit $\frac{4m_t^2}{m_H^2} \gg 1$ (the heavy top limit) :

$$\frac{\alpha_S}{v} 4m_t^2 [2 + (4m_t^2 - m_H^2)C(0, 0, m_H^2; m_t, m_t, m_t)] \longrightarrow \frac{\alpha_S}{v} \frac{4}{3} m_H^2$$

Let us generalize the computation, when the loop is not involving the top quark but a new physics particle.



Acting in the same way one can write the Feynman rule for the effective vertex as:

$$\frac{\alpha_S}{v} c_{ggh}$$

Here the coefficient c_{ggh} is encoding the information about the new particle.

This corresponds to insert in the Lagrangian the operator: $\frac{\alpha_S}{8\pi} c_{ggh} \frac{h}{v} G_{\mu\nu}^a G_a^{\mu\nu}$

ElectroWeak Chiral Lagrangian

ElectroWeak Chiral Lagrangian (EWChL)

The EWChL for the Higgs boson production stands:

$$\mathcal{L} \supset -m_t \left(c_t \frac{h}{v} + c_{tt} \frac{h^2}{v^2} \right) \bar{t} t - c_{hhh} \frac{m_h^2}{2v} h^3 + \frac{\alpha_s}{8\pi} \left(c_{ggh} \frac{h}{v} + c_{gghh} \frac{h^2}{v^2} \right) G_{\mu\nu}^a G^{a,\mu\nu}$$

There are 5 anomalous couplings:

- c_t, c_{hhh} rescaling of SM couplings.
- c_{tt} new Yukawa interaction.
- c_{ggh}, c_{gghh} effective interactions couplings.

ElectroWeak Chiral Lagrangian (EWChL)

- The Lagrangian is gauge invariant but not renormalizable in the common sense.
- When deviation of the couplings from SM values are smaller than unity it is useful to parametrize them by:

$$\xi \equiv v^2 / f^2$$

- $f > v$ represents a new scale related to a new strongly interacting dynamics.

ElectroWeak Chiral Lagrangian (EWChL)

- ❑ In the Lagrangian SM particles are weak coupled to the Higgs sector.
- ❑ There are SM gauge symmetries. Lepton and baryon number conserved.
- ❑ CP invariance in the Higgs sector and fermion flavour are are violated at some level.
- ❑ The EFT contains interaction terms of arbitrary canonical dimension. Therefore is not organized by canonical dimension of operator but by chiral counting.

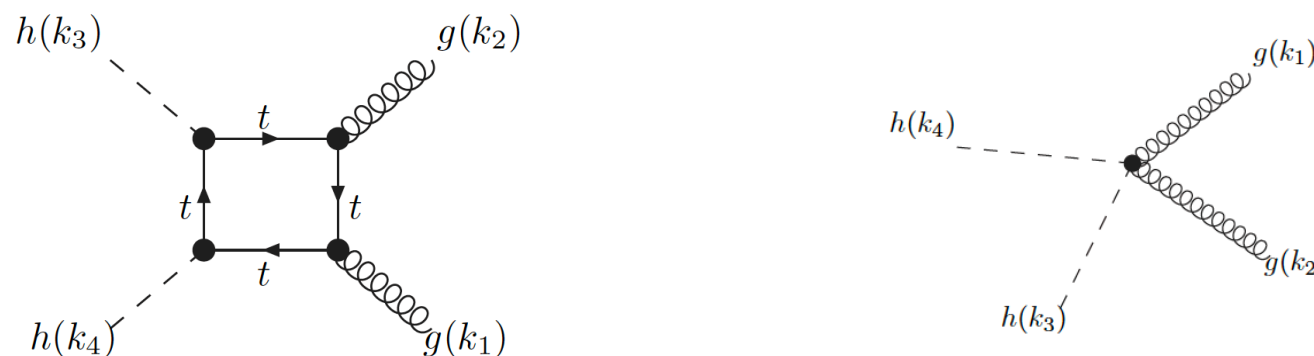
Chiral counting

Each term of the lagrangian has a chiral dimension:

- 0 for bosons
- 1 for bilinear fermions, derivatives and weak couplings.

$$[X_\mu, \varphi, h]_\chi = 0, \quad [\partial_\mu, g, y, \psi\bar{\psi}]_\chi = 1$$

The chiral dimension of a term in the Lagrangian is equivalent to its loop order $2L + 2$

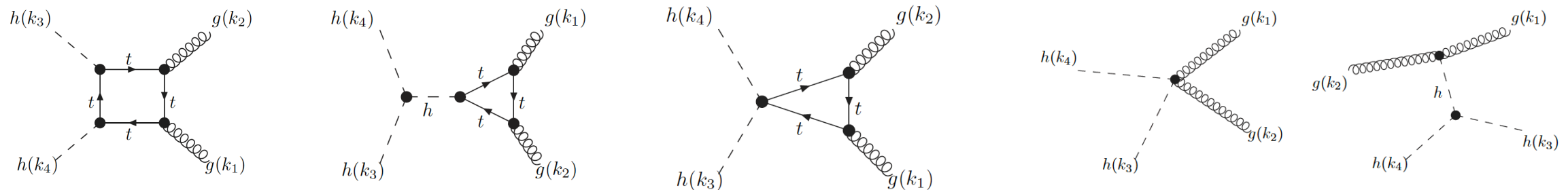


Chiral dimension 4

Higgs boson pair production

Higgs boson pair production

- In SM the process is loop-induced. Not true in the EWChL framework.
- LO mixes tree and loop diagrams.
- LO loop order = 4. NLO loop order = 6.

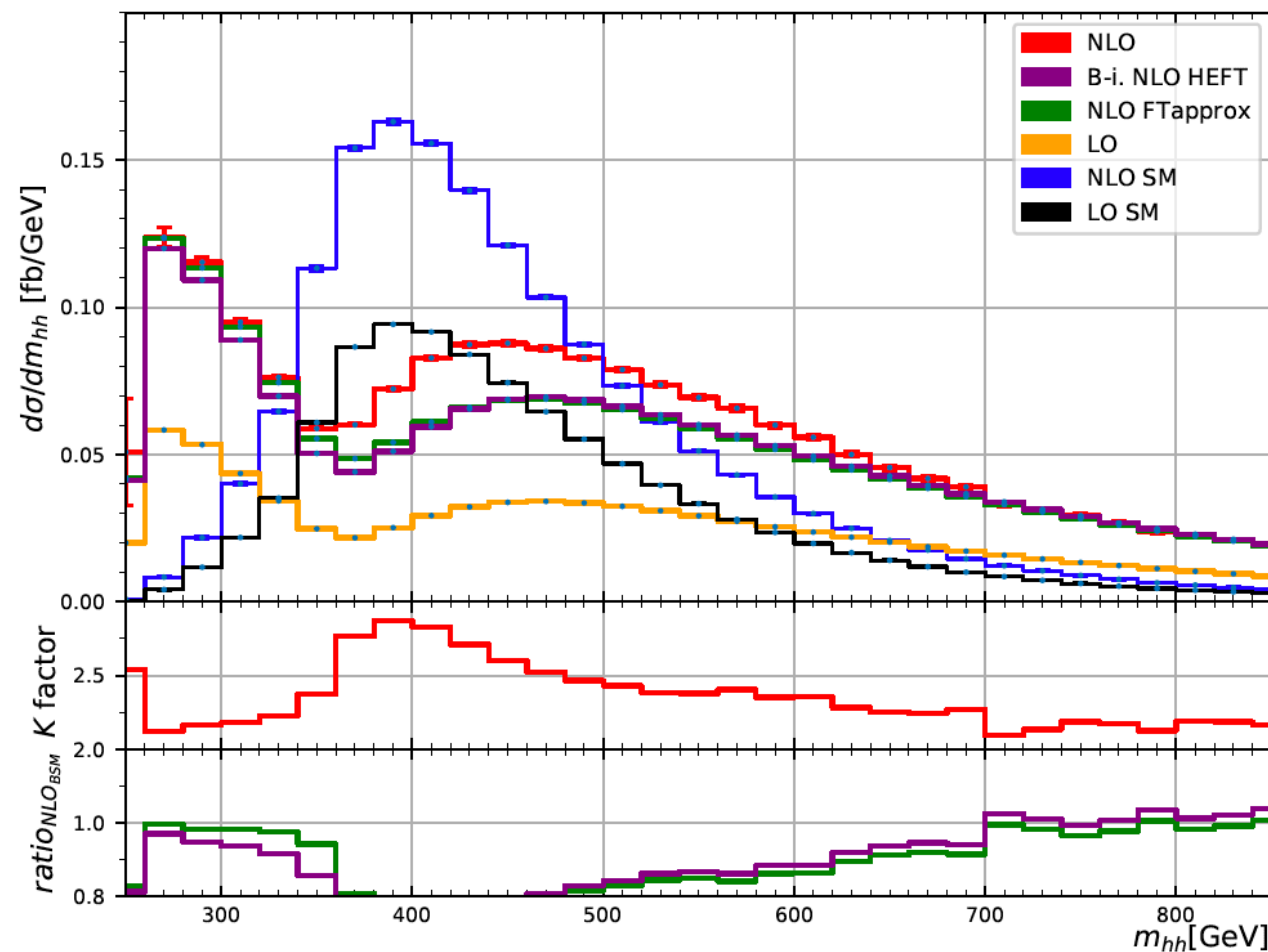


- There are 5 anomalous couplings. Two are rescaling of SM couplings while the other 3 appear in new diagrams.
- The tree-level diagrams contain effective vertices involving new physics contribution.

$$\begin{aligned}
 \frac{\sigma_{NLO}}{\sigma_{NLO,SM}} = & [A'_1 c_t^4 + A'_2 c_{tt}^2 + A'_3 c_{thh}^2 c_{hhh}^2 + A'_4 c_{ghh}^2 c_{hhh}^2 + A'_5 c_{gghh}^2 + A'_6 c_{tt}^2 c_t^2 + A'_7 c_t^3 c_{hhh} \\
 & + A'_8 c_{tt} c_t c_{hhh} + A'_9 c_{tt} c_{ggh} c_{hhh} + A'_{10} c_{tt} c_{cgghh} + A'_{11} c_t^2 c_{ggh} c_{hhh} + A'_{12} c_t^2 c_{gghh} \\
 & + A'_{13} c_t c_{hhh}^2 c_{gghh} + A'_{14} c_t c_{hhh} c_{gghh} + A'_{15} c_{ggh} c_{hhh} c_{gghh} + A'_{16} c_t^3 c_{ggh} + A'_{17} c_t c_{tt} c_{ggh} \\
 & + A'_{18} c_t c_{ggh}^2 c_{hhh} + A'_{19} c_t c_{ggh} c_{gghh} + A'_{20} c_t^2 c_{ggh}^2 + A'_{21} c_{tt} c_{ggh}^2 + A'_{22} c_{ggh}^3 c_{hhh} + A'_{23} c_{ggh}^2 c_{gghh}]
 \end{aligned}$$

Higgs boson pair production

Different values of the anomalous coupling modify the total cross sections and differential distributions.



$$\frac{\sigma_{NLO}}{\sigma_{NLO,SM}} = 1.266$$

$$c_{hhh} = 1.0, c_t = 1.0, c_{tt} = 0.5, c_{ggh} = \frac{0.8}{3}, c_{gghh} = 0$$

Conclusion and outlook

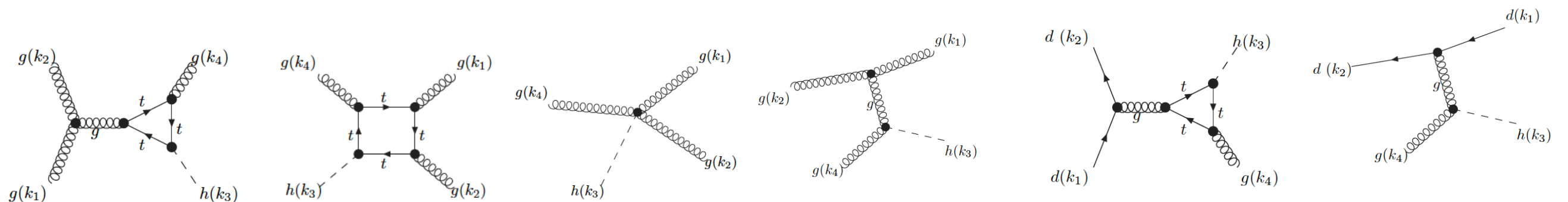
Conclusions and outlooks

Conclusions:

- Review of EFT.
- The ElectroWeak Chiral Lagrangian. New interactions and new couplings.
- Higgs boson pair production, how non standard couplings can influence the cross sections.

Outlooks:

- Higgs plus jet production in the EWChL framework.



Thanks