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Electroweak Corrections to Double Higgs Production at the LHC

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We report the results for the complete next-to-leading order electroweak corrections to $pp \to HH$ at the Large Hadron Collider. The dominant gluon-gluon fusion channel is considered. Results for the total and differential cross sections are presented.

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1. Introduction

The discovery of the Higgs boson [1, 2] opens a new frontier in exploring electroweak (EW) symmetry breaking and the Standard Model (SM). A key focus at the Large Hadron Collider (LHC) is understanding Higgs self-interactions, which are crucial for probing the structure of the Higgs potential. Higgs boson pair production, directly linked to the Higgs trilinear coupling λ_{HHH}, provides a unique window into this domain. While current LHC data begin to constrain λ_{HHH} [3–5], deviations from the SM prediction could imply modifications to the Higgs potential.

The dominant production mode for Higgs pairs at the LHC is gluon-gluon fusion, a loop-induced process in the SM. This makes precise theoretical predictions challenging, requiring advanced techniques beyond leading order (LO). Significant progress has been made, including next-to-leading order (NLO) QCD calculations [6–9], the incorporation of soft-gluon resummation and parton shower effects [10–13], and even next-to-next-to-next-to-leading order (N^{3}LO) QCD corrections within the heavy top-quark limit [14, 15].

Different from QCD corrections, the Higgs self-couplings receive corrections from high order electroweak (EW) corrections. In addition, EW corrections, driven by Sudakov logarithms [16, 17], are particularly significant at high energies. However, calculating NLO EW corrections for $gg \to HH$ is exceptionally complicated, as it involves two-loop diagrams with multiple mass scales. Previous attempts [18–23] have provided partial results.

In this proceeding, we present a complete computation of NLO EW corrections to $gg \to HH$, accounting for all two-loop diagrams and mass effects. Our results aim to enhance the precision of theoretical predictions, addressing a long-standing goal in the community [24–28].

2. Calculation

NLO EW corrections for $gg \to HH$ include only virtual contributions, due to the prohibition of $gg \to HH\gamma$ by the Furry Theorem. The two-loop Feynman diagrams and amplitudes are generated using `FeynArt` [29], with representative diagrams shown in Fig. 1.

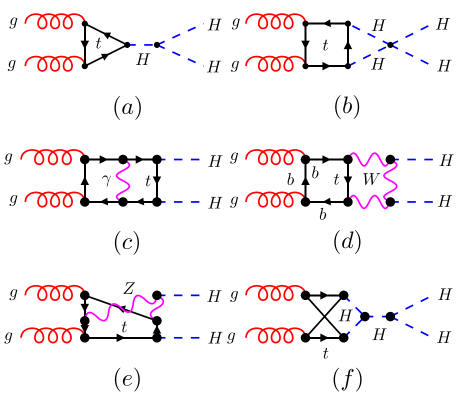

Figure 1: Representative Feynman diagrams for $gg \to HH$ at LO (a) and NLO EW corrections $(b$-$f)$.

LO squared matrix elements are obtained with the help of `MadGraph5` [30], and LO events are generated using `Parni` [31]. NLO results are obtained by reweighting the LO events. Specifically, NLO amplitudes are expressed as linear combinations of scalar integrals using `CalcLoop` [32], categorized into 3 (116) integral families for 1-loop (2-loop) contributions. These are further reduced to master integrals with `Blade` [33]. Master integrals are numerically solved via differential equations with respect to the Mandelstam variables $\hat{s}$ and $\hat{t}$, using boundary conditions from `AMFlow` [34].

To simplify computations, we set $\epsilon = \pm 1/1000$ in our calculation. This can avoid Laurent expansions and reducing resource demands, as proposed in Refs. [34]. The results based on both $\epsilon = \pm 1/1000$ can be used to check divergence cancellations and further mitigate the error caused by the finite ϵ effect.

3. Results

The total cross sections for the gluon-gluon fusion channel of $pp \to HH$ at LO and NLO are presented in Tab. 1, where three different renormalization/factorization scales are used. The scale dependence of the strong coupling α_s is the primary source of the observed $\sim$ 20% uncertainties at both LO and NLO. In contrast, the $\mathcal{K}$-factor remains stable with different μ choices. The consistent NLO EW correction, ranging from -4.6% to -4.2%, indicates that higher-order EW effects contribute only a few per mille to the total cross section.

μ	$M_{HH}/2$	$\sqrt{p_T^2 + m_H^2}$	m_H
LO	19.96(6)	21.11(7)	25.09(8)
NLO	19.12(6)	20.21(6)	23.94(8)
$\mathcal{K}$-factor	0.958(1)	0.957(1)	0.954(1)

Table 1: LO and NLO EW corrected integrated cross sections (in fb) with $\sqrt{s}$ = 14 TeV. The uncertainties arise from statistical errors in phase space integration.

In Fig. 2, we present the invariant mass distribution of the Higgs pair, M_{HH}, taken from different literatures. The upper left plot is based on our calculation, which incorporates complete NLO EW corrections. The upper right plot is from [19], based on Top-Yukawa-induced corrections. The lower left plot is from [23], containing both Yukawa and Higgs self-coupling type corrections. The lower right plot is from [22], which includes Higgs self-coupling type corrections.

We observe that M_{HH} receives significant corrections at the HH production threshold in these plots. The two plots on the right-hand side suggest that Top-Yukawa-induced corrections and Higgs self-coupling type corrections have opposite signs in the threshold region. The combination of these two contributions gives positive corrections at the HH production threshold, as shown in the lower left plot, which amount to approximately $\sim$ 30%. Our calculation shows that the complete NLO EW correction is about $\sim$ 15% with the binning we selected. The two plots on the left-hand side indicate that the gauge boson contributions are negative and important, as also pointed out in Ref. [23].

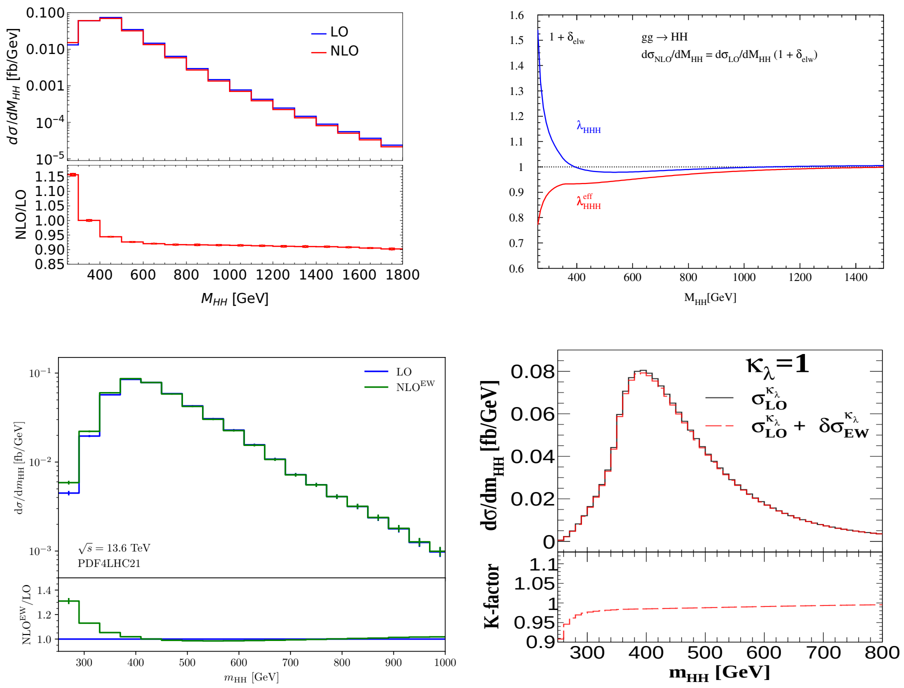

Figure 2: Invariant mass distribution of the Higgs pair. The upper left plot is based on our calculation, the upper right plot is taken from [19], the lower left plot is taken from [23] and the lower right plot is taken from [22].

4. Conclusion

We review the recent progress in the calculation of NLO EW corrections to double Higgs production at the LHC. The complete NLO EW corrections are about +4% at the total cross section level and range from −10% to +15% at the differential level.

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