Snowmass 2021 Letter of Interest

Precise predictions for Higgs pair hadroproduction

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Abstract

In this LoI, we propose the studies of improving the theoretical predictions of the Higgs pair production through the gluon-gluon fusion by including additional QCD radiative corrections and finite top quark mass corrections in the Standard Model based on the previous work [1, 2]. The process is important in deciphering the Higgs potential and for understanding the electroweak symmetry breaking. The precision studies of the process are relevant for both the high luminosity LHC program and the future facilities like FCC-hh. In the context of Snowmass 2021, the goal of this proposal is to provide the most precise theoretical inputs for the future analyses of the process at high-energy hadron colliders. This proposal can be in both the Theory Frontier (TF06,TF07) and Energy Frontier (EF01,EF05) topical groups.

1 Introduction

High precision theoretical predictions plays an essential role, both in the context of looking for new physics and testing the Standard Model (SM). In particular, the precision study of the Higgs potential is ultimately crucial for understanding the electroweak symmetry breaking mechanism. The measurements on the Higgs trilinear and quartic couplings are able to reveal the Higgs potential.

The direct way to probe the Higgs trilinear coupling is from the measurements of the Higgs boson pair production, which is dominated by the gluon-gluon fusion channel at the hadron colliders. The existing direct measurements of the Higgs pair cross sections at the LHC only loosely bound on the trilinear coupling λ_{hhh} [3, 4] due to the low statistics. Many studies in the literature have investigated the projected precision of the λ_{hhh} at future colliders, such as the high-luminosity LHC (HL-LHC) and high-energy LHC (HE-LHC) [5]. The ultimate percent-level determination of λ_{hhh} can be achieved at 100 TeV FCC-hh with the nominal integrated luminosity 30 ab^{-1}. Ref. [6] has shown the trilinear Higgs self-coupling λ_{hhh} can be measured as precise as $\pm(2.6-5.4)\%$ after combining several decay channels. All of these facts clearly require the precision of the corresponding theoretical predictions keeps pace with the (foreseen) experimental measurements.

We propose to advance the theoretical predictions for the Higgs pair hadroproduction process. In the previous works [1, 2], based on two-loop amplitude in Ref. [7], some of us have carried out N^{3}LO QCD corrections for the process in the effective theory, where the infinite top-quark mass limit has been taken. In the effective theory, the QCD corrections have reduced the scale uncertainties to be less than 3%, which are a factor of four smaller than the NNLO scale uncertainties. The top-quark mass effects are indispensable for the realistic phenomenological applications. Three different approximations were performed for the top-quark mass effects through reweighting at the (differential) cross section level. In the proposal, we plan to achieve N^{3}LL soft gluon resummation in $m_t \to +\infty$ and improve the finite m_t effects at N^{3}LO with the most advanced "full theory" (FT) approximation [8] approach.

2 Soft-gluon threshold resummation effects

Currently the NNLL+NNLO cross section for Higgs pair production is known [9]. Given the four-loop cusp anomalous dimension with the three-loop hard and soft anomalous dimensions are also known, it is possible to perform the N^3LL threshold resummation, which can be matched to the N^3LO fixed-order cross section in the $m_t \to +\infty$ effective theory. Similiar N^3LL calculations have been carried out by some of us for the Drell-Yan [10] and the single Higgs via $b\bar{b}$ annihilation [11] processes. The higher-order corrections for di-Higgs production are dominated by soft-virtual terms, which become significant in the threshold region and thus call for threshold resummation even at the third order. Eventually, the N^3LL resummation is expected to further reduce the scale uncertainties and improve the theoretical prediction, especially in the threshold region.

3 More on top-quark mass effects

Given only NLO QCD corrections for $pp \to hh$ in the full SM theory are known, the most advanced way to improve the predictions is to include the finite top quark mass effects and higher-order QCD radiative corrections through the so-called FT approximation approach introduced by Ref. [8]. The best prediction in the FT approximation is NNLO ($\mathrm{NNLO_{FTapprox}}$) [12]. We will apply the same approach in order to achieve the $\mathrm{N^3LO_{FTapprox}}$ or even $(\mathrm{N^3LO{+}N^3LL})_{\mathrm{FTapprox}}$ accuracy cross sections.

References

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