Precision Higgs Physics at the LHC: Light Quark Effects in Higgs Boson Production

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Accurate theoretical predictions for the (inclusive and differential) Higgs gluon fusion cross section are indispensable for the determination with high precision of the Higgs boson couplings [1]. A dominant component of the gluon fusion process originates from Feynman diagrams with a virtual top quark inside the loop. Due to the hierarchy of the top quark and Higgs boson masses, this component can be accurately determined by expanding around the heavy top quark limit [2, 3, 4]. In this approach, where top quark loops are reduced to effective point-like vertices, gluon fusion cross sections are now known precisely at very high orders in perurbative QCD [5, 6, 7, 8, 9, 10, 11, 12, 13, 14].

With the achieved precision of a few percent, contributions of lighter quarks of a suppressed Higgs Yukawa coupling cannot be ignored (for a recent estimate of their effect to the inclusive Higgs cross-section see, for example, Ref. [6]). For light quarks, the top quark effective field theory calculations are inapplicable. The relevant Higgs production probability amplitudes need to be computed with their exact quark mass dependence or, alternatively, by means of a systematic expansion around the antithetic asymptotic limit in which the quark mass is vanishing. The exact quark mass dependence for the $gg \to H$ amplitude is only known through two loops [15, 16, 17, 18, 19, 20, 21, 22]. The two-loop amplitudes for the top-bottom interference in the next-to-leading order cross section [23, 24, 25] for the production of a Higgs boson in association with a jet have been computed by means of a small quark mass expansion. With the computation of the complete three-loop

$gg \to H$ amplitude [26, 27] and recent advances for two-loop $pp \to H + jet$ amplitudes [28] an exact NNLO result is within reach.

The problem of accurate theoretical description of the light quark effects, however, ultimately goes beyond the finite order perturbation theory. In the small quark mass limit the radiative corrections are enhanced by a power of the logarithm $\ln(m_H/m_q)$ of the Higgs boson to a light quark mass ratio. For the physical values of the bottom and charm quark masses the numerical value of the logarithm is quite large. For example, the effective expansion parameter for the bottom quark is $\alpha_s \ln^2(m_H/m_b) \approx 40\alpha_s$. Hence it is crucial to control the size of the logarithmic corrections to all orders in strong coupling constant α_s. For the $gg \to H$ amplitude the enhanced corrections have been evaluated in the leading (double) logarithmic approximation [29, 30] and in the next-to-leading logarithmic approximation [31] which sums up the terms of the form $\alpha_s^n \ln^{2n-1}(m_H/m_q)$ for all n. By using this result an estimate of the high-order bottom quark contribution to the Higgs boson production cross section has been obtained in threshold approximation. For the yet unknown NNLO and N^{3}LO corrections it gives -0.12 *pb* and -0.02 *pb*, respectively. With a rather conservative assessment of accuracy of the next-to-leading logarithmic and the threshold approximations this result gives a rough estimate of the bottom quark mediated contribution to the total cross section of Higgs boson production in gluon fusion beyond NLO to be in the range from -0.32 to 0.08 *pb*, thereby reducing the corresponding uncertainty by a factor of two.

However, the actual accuracy of the logarithmic and threshold approximations is difficult to estimate, and the above interval has to be further reduced by evaluating the next-to-next-to-leading logarithmic contribution and getting an approximation valid beyond the threshold region. The latter requires the analysis of the logarithmically enhanced corrections to the hard real emission which currently is not available even in the leading logarithmic approximation (only the abelian part of the double-logarithmic corrections for the $gg \to Hg$ amplitude of Higgs plus jet production has been obtained in Ref. [32]). The extension of the method [29, 30, 31] beyond the next-to-leading logarithms and to the processes with hard real radiation is one of big challenges for the modern effective field theory and is of primary phenomenological importance for the high-precision Higgs physics program at the LHC.

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