PROCEEDINGS OF SCIENCE

Higgs boson production at the LHC and theoretical uncertainties

Massimiliano Grazzini[*†]
Institute for Theoretical Physics, University of Zurich, CH-8057 Zurich, Switzerland
E-mail: grazzini@physik.uzh.ch

The status of the theoretical predictions for inclusive Higgs boson production at the LHC is briefly discussed, focusing on the gluon fusion channel. The corresponding theoretical uncertainties are reviewed.

VI Italian workshop on p-p physics at the LHC,
8-10 May 2013
Acquario di Genova, Ponte Spinola, Area Porto Antico, Genova, Italy

[*]Speaker.
[†]On leave of absence from INFN, Sezione di Firenze, Sesto Fiorentino, Florence, Italy.

PoS(LHCPP2013)001

Gluon–gluon fusion through a heavy-quark loop [1] is the main production channel of the Standard Model Higgs boson at hadron colliders. At the LHC the $gg \to H$ cross section is typically at least one order of magnitude larger than the cross section in the other channels for a wide range of Higgs boson masses. The main contribution comes from the top loop, due to its large Yukawa coupling to the Higgs boson. The QCD radiative corrections to this process have been computed at next-to-leading order (NLO) both in the large-m_t limit [2] and by including the exact dependence on the masses of the top and bottom quarks [3, 4, 5]. The impact of the NLO correction is very large, of the order of 80-100%. The NNLO corrections have been computed in the large-m_t limit [6, 7, 8] and further increase the cross section by about 25%. After the completion of the NNLO calculation, the calculation has been improved in many respects. The logarithmically enhanced contributions due to multiple soft emissions have been resummed up to next-to-next-to-leading logarithmic accuracy (NNLL) and the result has been consistently matched to the fixed order NNLO result [9]. Soft gluon resummation leads to an increase of the cross section of about 8% at the LHC ($\sqrt{s} = 8$ TeV) and to a slight reduction of scale uncertainties. Such result [9] has been used as the reference theoretical prediction for few years. The quantitative impact of soft-gluon resummation is confirmed by the computation of the soft terms at N^{3}LO [10]. Considerable work has been done also for the computation of the EW corrections. Two-loop EW corrections have been computed [11, 12, 13, 14, 15] and their effect increases the cross section by $+5\%$ for $m_H = 125$ GeV [15]. Mixed QCD-EW effects have been studied in Ref. [16]. EW corrections from real radiation have been studied in Ref. [17, 18]: both effects are at the 1% level or smaller.

Significant work has been done to estimate the uncertainties of the Higgs production cross section. The accuracy of the large-m_t approximation has been studied by computing subleading terms in the large-m_t limit [19, 20, 21, 22, 23, 24]. Such works have shown that the approximation works remarkably well, to better than 1% for $m_H < 300$ GeV. Admittedly, this was a decisive step in having the theoretical prediction for the $gg \to H$ cross section under good control. In the case of a light Higgs boson produced at the LHC the total theoretical uncertainty is of about $\pm 15 - 20\%$. We refer the reader to the discussion in Ref. [25] for more details.

Various updated calculations on the $gg \to H$ cross section have been presented in the last few years, and we discuss them in turn. The calculation presented in Ref. [16] and refined in Ref. [25] starts from the exact NLO QCD calculation (including the dependence on the masses of the top and bottom quarks) and adds the NNLO corrections in the large-m_t limit, and the EW corrections [15] assuming complete factorization. Mixed QCD-EW effects are evaluated in an effective field theory approach. It also includes some (small) EW effects from real radiation [17]. The effect of soft-gluon resummation is mimicked by choosing $\mu_F = \mu_R = m_H/2$ as central values for factorization and renormalization scales.

The calculation of Ref. [26], refined in Ref. [25], starts from the exact NLO cross section and includes soft-gluon resummation up to NLL. Then, the top-quark contribution is considered and the NNLL+NNLO corrections [9] are consistently added in the large-m_t limit. The result is finally corrected for EW contributions [15] in the complete factorization scheme. The results of this calculation are used as reference at the Tevatron and the LHC. Recently, this calculation was further updated by including the effect of the charm quark, which decreases the cross section by about 1% [27].

Other updated calculations have appeared in the literature. We first discuss the calculation of

Refs. [28, 29]. As far as the central value is concerned such calculation does not add much to the ones mentioned above. However, the work of Refs. [28, 29] presented the first extensive, though extremely conservative, estimate of the various sources of theoretical uncertainties affecting the $gg \to H$ cross section. According to Ref. [29], the total uncertainty on the $gg \to H$ cross section for a light Higgs boson at the LHC ($\sqrt{s} = 7$ TeV) is about $\pm 25\%$.

An independent computation of the inclusive $gg \to H$ cross section was presented in Ref. [30]. Such calculation is based on the NNLO result obtained in the large-m_t limit (the known dependence on top and bottom quark masses up to NLO is not taken into account), corrected with EW effects [15] and includes a resummation of soft-gluon contributions, including the so-called "π^2 terms". This calculation leads to QCD scale uncertainties of about a factor of three smaller than the calculations discussed above, and, most likely, not reliable as true perturbative uncertainties.

Recently, a new calculation, implemented in the numerical program `iHixs` has been presented [31, 32]. Such calculation includes essentially the same perturbative contributions of the one of Refs. [16, 25] (the additional diagrams considered here give a very small effect). The new important features of `iHixs` are the inclusion of finite-width effects and the possibility to extend the calculation to models with anomalous Yukawa and electroweak couplings.

For $m_H = 125$ GeV and LHC with $\sqrt{s} = 8$ TeV the calculation of Ref. [27] gives

$$\sigma = 19.31^{+7.2\%}_{-7.8\%}(\text{scale})^{+7.5\%}_{-6.9\%}(\text{PDF} + \alpha_S) \tag{1}$$

whereas the calculation of Ref. [32] gives

$$\sigma = 20.69^{+8.4\%}_{-9.3\%}(\text{scale})^{+7.8\%}_{-7.5\%}(\text{PDF} + \alpha_S) \tag{2}$$

which is 7% higher, although still compatible within uncertainties.

The perturbative uncertainties could be reduced by extending the QCD calculation to N^{3}LO. At this order, there are four contributions: emission of three partons at tree level, emission of two partons at one loop, emission of one parton at two loops, and the purely virtual correction at three loops. Of these four contributions the three loop correction is known [33, 34], and recently the three parton contribution at tree level has been evaluated as an expansion around the partonic threshold [35]. What is still missing are the emission of one and two partons at two- and one-loop order, respectively. Also the convolutions of the NNLO coefficients functions with the anomalous dimensions needed at N^{3}LO have been evaluated [36, 37]. The other relevant source of uncertainty on the $gg \to H$ cross section are PDFs and the QCD coupling α_S. As discussed above, at present this uncertainty is about $\pm 7 - 8\%$. With the accurate measurements that are expected of processes sensitive to the gluon distribution and the QCD coupling α_S, such as the production of $t\bar{t}$ pairs and inclusive jet production, accompanied by more precise theoretical predictions for the corresponding cross sections [38, 39], we may expect that also the PDF+α_S uncertainty will also be reduced in the near future.

References

[1] H. Georgi, S. Glashow, M. Machacek, and D. V. Nanopoulos, *Higgs Bosons from Two Gluon Annihilation in Proton Proton Collisions*, Phys.~Rev.~Lett. **40** (1978) 692.

[2] S. Dawson, *Radiative corrections to Higgs boson production*, Nucl.~Phys. **B359** (1991) 283–300.

[3] A. Djouadi, M. Spira, and P. Zerwas, *Production of Higgs bosons in proton colliders: QCD corrections*, Phys.~Lett. **B264** (1991) 440–446.

[4] D. Graudenz, M. Spira, and P. Zerwas, *QCD corrections to Higgs boson production at proton proton colliders*, Phys.~Rev.~Lett. **70** (1993) 1372–1375.

[5] M. Spira, A. Djouadi, D. Graudenz, and P. Zerwas, *Higgs boson production at the LHC*, Nucl.~Phys. **B453** (1995) 17–82, `arXiv:hep-ph/9504378 [hep-ph]`.

[6] R. V. Harlander and W. B. Kilgore, *Next-to-next-to-leading order Higgs production at hadron colliders*, Phys.~Rev.~Lett. **88** (2002) 201801, `arXiv:hep-ph/0201206 [hep-ph]`.

[7] C. Anastasiou and K. Melnikov, *Higgs boson production at hadron colliders in NNLO QCD*, Nucl.~Phys. **B646** (2002) 220–256, `arXiv:hep-ph/0207004 [hep-ph]`.

[8] V. Ravindran, J. Smith, and W. L. van Neerven, *NNLO corrections to the total cross-section for Higgs boson production in hadron hadron collisions*, Nucl.~Phys. **B665** (2003) 325–366, `arXiv:hep-ph/0302135 [hep-ph]`.

[9] S. Catani, D. de Florian, M. Grazzini, and P. Nason, *Soft gluon resummation for Higgs boson production at hadron colliders*, JHEP **0307** (2003) 028, `arXiv:hep-ph/0306211 [hep-ph]`.

[10] S. Moch and A. Vogt, *Higher-order soft corrections to lepton pair and Higgs boson production*, Phys.~Lett. **B631** (2005) 48–57, `arXiv:hep-ph/0508265 [hep-ph]`.

[11] A. Djouadi and P. Gambino, *Leading electroweak correction to Higgs boson production at proton colliders*, Phys. Rev. Lett. **73** (1994) 2528–2531, `hep-ph/9406432`.

[12] U. Aglietti, R. Bonciani, G. Degrassi, and A. Vicini, *Two loop light fermion contribution to Higgs production and decays*, Phys.~Lett. **B595** (2004) 432–441, `arXiv:hep-ph/0404071 [hep-ph]`.

[13] G. Degrassi and F. Maltoni, *Two-loop electroweak corrections to Higgs production at hadron colliders*, Phys.~Lett. **B600** (2004) 255–260, `arXiv:hep-ph/0407249 [hep-ph]`.

[14] S. Actis, G. Passarino, C. Sturm, and S. Uccirati, *NNLO computational techniques: the cases $H \to \gamma\gamma$ and $H \to gg$*, Nucl.~Phys. **B811** (2009) 182–273, `arXiv:0809.3667 [hep-ph]`.

[15] S. Actis, G. Passarino, C. Sturm, and S. Uccirati, *NLO Electroweak Corrections to Higgs Boson Production at Hadron Colliders*, Phys.~Lett. **B670** (2008) 12–17, `arXiv:0809.1301 [hep-ph]`.

[16] C. Anastasiou, R. Boughezal, and F. Petriello, *Mixed QCD-electroweak corrections to Higgs boson production in gluon fusion*, JHEP **0904** (2009) 003, `arXiv:0811.3458 [hep-ph]`.

[17] W.-Y. Keung and F. J. Petriello, *Electroweak and finite quark-mass effects on the Higgs boson transverse momentum distribution*, Phys.~Rev. **D80** (2009) 013007, `arXiv:0905.2775 [hep-ph]`.

[18] O. Brein, *Electroweak and Bottom Quark Contributions to Higgs Boson plus Jet Production*, Phys.~Rev. **D81** (2010) 093006, `arXiv:1003.4438 [hep-ph]`.

[19] S. Marzani, R. D. Ball, V. Del Duca, S. Forte, and A. Vicini, *Higgs production via gluon-gluon fusion with finite top mass beyond next-to-leading order*, Nucl.Phys. **B800** (2008) 127–145, `arXiv:0801.2544 [hep-ph]`.

PoS(LHCPP2013)001

[20] R. V. Harlander and K. J. Ozeren, *Top mass effects in Higgs production at next-to-next-to-leading order QCD: Virtual corrections*, Phys.Lett. **B679** (2009) 467–472, arXiv:0907.2997 [hep-ph].

[21] R. V. Harlander and K. J. Ozeren, *Finite top mass effects for hadronic Higgs production at next-to-next-to-leading order*, JHEP **0911** (2009) 088, arXiv:0909.3420 [hep-ph].

[22] R. V. Harlander, H. Mantler, S. Marzani, and K. J. Ozeren, *Higgs production in gluon fusion at next-to-next-to-leading order QCD for finite top mass*, Eur.Phys.J. **C66** (2010) 359–372, arXiv:0912.2104 [hep-ph].

[23] A. Pak, M. Rogal, and M. Steinhauser, *Virtual three-loop corrections to Higgs boson production in gluon fusion for finite top quark mass*, Phys.Lett. **B679** (2009) 473–477, arXiv:0907.2998 [hep-ph].

[24] A. Pak, M. Rogal, and M. Steinhauser, *Finite top quark mass effects in NNLO Higgs boson production at LHC*, JHEP **1002** (2010) 025, arXiv:0911.4662 [hep-ph].

[25] LHC Higgs Cross Section Working Group Collaboration, S. Dittmaier et al., *Handbook of LHC Higgs Cross Sections: 1. Inclusive Observables*, arXiv:1101.0593 [hep-ph].

[26] D. de Florian and M. Grazzini, *Higgs production through gluon fusion: Updated cross sections at the Tevatron and the LHC*, Phys.~Lett. **B674** (2009) 291–294, arXiv:0901.2427 [hep-ph].

[27] D. de Florian and M. Grazzini, *Higgs production at the LHC: updated cross sections at $\sqrt{s} = 8$ TeV*, Phys.~Lett. **B718** (2012) 117–120, arXiv:1206.4133 [hep-ph].

[28] J. Baglio and A. Djouadi, *Predictions for Higgs production at the Tevatron and the associated uncertainties*, JHEP **1010** (2010) 064, arXiv:1003.4266 [hep-ph].

[29] J. Baglio and A. Djouadi, *Higgs production at the lHC*, JHEP **1103** (2011) 055, arXiv:1012.0530 [hep-ph].

[30] V. Ahrens, T. Becher, M. Neubert, and L. L. Yang, *Updated Predictions for Higgs Production at the Tevatron and the LHC*, Phys.~Lett. **B698** (2011) 271–274, arXiv:1008.3162 [hep-ph].

[31] C. Anastasiou, S. Buehler, F. Herzog, and A. Lazopoulos, *Total cross-section for Higgs boson hadroproduction with anomalous Standard Model interactions*, JHEP **1112** (2011) 058, arXiv:1107.0683 [hep-ph].

[32] C. Anastasiou, S. Buehler, F. Herzog, and A. Lazopoulos, *Inclusive Higgs boson cross-section for the LHC at 8 TeV*, JHEP **1204** (2012) 004, arXiv:1202.3638 [hep-ph].

[33] P. Baikov, K. Chetyrkin, A. Smirnov, V. Smirnov, and M. Steinhauser, *Quark and gluon form factors to three loops*, Phys.Rev.Lett. **102** (2009) 212002, arXiv:0902.3519 [hep-ph].

[34] T. Gehrmann, E. Glover, T. Huber, N. Ikizlerli, and C. Studerus, *The quark and gluon form factors to three loops in QCD through to $O(\varepsilon^2)$*, JHEP **1011** (2010) 102, arXiv:1010.4478 [hep-ph].

[35] C. Anastasiou, C. Duhr, F. Dulat, and B. Mistlberger, *Soft triple-real radiation for Higgs production at N3LO*, arXiv:1302.4379 [hep-ph].

[36] M. Höschele, J. Hoff, A. Pak, M. Steinhauser, and T. Ueda, *Higgs boson production at the LHC: NNLO partonic cross sections through order ε and convolutions with splitting functions to N^3LO*, Phys.Lett. **B721** (2013) 244–251, arXiv:1211.6559 [hep-ph].

[37] S. Buehler and A. Lazopoulos, *Scale dependence and collinear subtraction terms for Higgs production in gluon fusion at N3LO*, arXiv:1306.2223 [hep-ph].

[38] A. G.-D. Ridder, T. Gehrmann, E. Glover, and J. Pires, *Second order QCD corrections to jet production at hadron colliders: the all-gluon contribution*, arXiv:1301.7310 [hep-ph].

[39] M. Czakon, P. Fiedler, and A. Mitov, *The total top quark pair production cross-section at hadron colliders through* $O(\alpha_S^4)$, arXiv:1303.6254 [hep-ph].