PROCEEDINGS OF SCIENCE

QCD-electroweak effects and a new prediction for Higgs production in gluon fusion process

Radja Boughezal*
Institut für Theoretische Physik, Universität Zürich,
Winterthurerstr. 190, 8057 Zürich, Switzerland
E-mail: radja@physik.uzh.ch

We discuss the recent derivation of the three-loop $\mathcal{O}(\alpha\alpha_s)$ contribution to the Higgs boson production cross section via gluon fusion arising from diagrams with light quarks, using an effective theory approach. We show results for the updated prediction of this process accounting for all the new theoretical calculations and the newest MSTW PDFs.

European Physical Society Europhysics Conference on High Energy Physics, EPS-HEP 2009,
July 16 - 22 2009
Krakow, Poland

*Speaker.

PoS(EPS-HEP 2009)233

1. Introduction

The search for the Higgs boson is a primary goal of the CERN Large Hadron Collider (LHC), and is a central part of Fermilab's Tevatron program. Recently, the Tevatron collaborations reported a 95% confidence level exclusion of a Standard Model Higgs boson with a mass in the range $160-170\,\text{GeV}$ [1]. The dominant production mode at both the Tevatron and the LHC, gluon fusion through top-quark loops, receives important QCD radiative corrections [2–4]. The inclusive result increases by a factor of 2 at the LHC and 3.5 at the Tevatron when perturbative QCD effects through next-to-next-to-leading order (NNLO) are taken into account [5]. The theoretical uncertainty from effects beyond NNLO is estimated to be about $\pm 10\%$ by varying renormalization and factorization scales. At this level of precision, electroweak corrections to the Higgs signal become important. A subset of diagrams, where the Higgs couples to the W and Z bosons which subsequently couple to light quarks, was investigated in [6, 7]. These terms are not suppressed by light-quark Yukawa couplings, and receive a multiplicity enhancement from summing over the quarks. A careful study of the full 2-loop electroweak effects was performed in Ref. [8]. They increase the leading-order cross section by up to $5-6\%$ for relevant Higgs masses. An important question is whether these light-quark contributions receive the same QCD enhancement as the top quark loops. If they do, then the full NNLO QCD result is shifted by $+5-6\%$ from these electroweak corrections. If not, this $5-6\%$ increase from light quarks would be reduced to $1-2\%$ of the NNLO result. As this effect on the central value of the production cross section and therefore on the exclusion limits and future measurements is non-negligible, it is important to quantify it. The exact computation of the mixed electroweak/QCD effects needed to do so requires 3-loop diagrams with many kinematic scales, and 2-loop diagrams with four external legs for the real-radiation terms. Such a computation is prohibitively difficult with current computational techniques.

In Ref. [9], the QCD corrections to the light-quark terms in the Higgs production cross section via gluon fusion were computed using an effective theory approach. This approach was rigorously justified by applying a hard-mass expansion procedure to the full 3-loop corrections. In addition to that, the most up-to-date QCD prediction for the Higgs boson production cross section in this channel was provided for use in setting Tevatron exclusion limits. In this contribution, we sketch the calculational approach and the results of this investigation discussed in detail in [9].

2. Calculational approach

The cross section for Higgs boson production in hadronic collisions can be written as

$$\sigma(s,M_H^2) = \sum_{i,j}\int_0^1 dx_1 \int_0^1 dx_2\, f_{i/h_1}(x_1,\mu_F^2)\, f_{j/h_2}(x_2,\mu_F^2) \int_0^1 dz\, \delta\left(z - \frac{M_H^2}{x_1 x_2 s}\right) \times z\,\hat{\sigma}_{ij}\left(z;\alpha_s(\mu_R^2),\alpha_{EW},M_H^2/\mu_R^2;M_H^2/\mu_F^2\right). \tag{2.1}$$

Here, $\sqrt{s}$ is the center-of-mass energy of the hadronic collision, μ_R and μ_F respectively denote the renormalization and factorization scales, and the $f_{i/h}$ denote the parton densities. The quantity $z\hat{\sigma}$ is the partonic cross section for the process $ij \to H+X$ with $i,j = g,q,\bar{q}$. As indicated, it admits a joint perturbative expansion in the strong and electroweak couplings. Considering QCD

and electroweak corrections and suppressing the scale dependence for simplicity, the partonic cross section can be written as:

$$\hat{\sigma}_{ij} = \sigma_{\rm EW}^{(0)} G_{ij}^{(0)}(z) + \sigma^{(0)} \sum_{n=1}^{\infty} \left(\frac{\alpha_s}{\pi}\right)^n G_{ij}^{(n)}(z) \tag{2.2}$$

The QCD corrections to the one-loop diagrams coupling the Higgs boson to gluons via a top-quark loop are given by

$$G_{ij}(z;\alpha_s) = \sum_{n=1}^{\infty} \left(\frac{\alpha_s}{\pi}\right)^n G_{ij}^{(n)}(z)$$

The cross section in Eq. (2.2) includes corrections to the leading-order result valid through $\mathcal{O}(\alpha)$ in the electroweak couplings and to $\mathcal{O}(\alpha_s^2)$ in the QCD coupling constant in the large top-mass limit upon inclusion of the known results for $G_{ij}^{(1,2)}$. Since the perturbative corrections to the leading-order result are large, it is important to quantify the effect of the QCD corrections on the light-quark electroweak contributions. This would require knowledge of the mixed $\mathcal{O}(\alpha\alpha_s)$. In lieu of such a calculation, the authors of Ref. [8] studied two assumptions for the effect of QCD corrections on the 2-loop light-quark diagrams.

- *Partial factorization*: no QCD corrections to the light-quark electroweak diagrams are included. With this assumption, electroweak diagrams contribute only a $+1-2\%$ increase to the Higgs boson production cross section.
- *Complete factorization*: the QCD corrections to the electroweak contributions are assumed to be identical to those affecting the heavy-quark diagrams.

In this case the light-quark diagrams increase the full NNLO QCD production cross section by $+5-6\%$. The last assumption was used in an earlier exclusion of a SM Higgs boson of 170 GeV by the Tevatron collaborations. The calculation of the $\mathcal{O}(\alpha\alpha_s)$, which allows to check these assumptions, can be done in the framework of an effective field theory where the W-boson is integrated out

$$\mathcal{L}_{eff} = -\alpha_s \frac{C_1}{4v} H G^a_{\mu\nu} G^{a\mu\nu}. \tag{2.3}$$

The Wilson coefficient C_1 arising from integrating out the heavy quark and the W-boson is defined through

$$\begin{aligned}
C_1 &= -\frac{1}{3\pi}\left\{1+\lambda_{EW}\left[1+a_s C_{1w}+a_s^2 C_{2w}\right]+a_s C_{1q}+a_s^2 C_{2q}\right\},\\
C_{1q} &= \frac{11}{4},\quad C_{2q} = \frac{2777}{288}+\frac{19}{16}L_t + N_F\left(-\frac{67}{96}+\frac{1}{3}L_t\right),\\
\lambda_{EW} &= \frac{3\alpha}{16\pi s_W^2}\left\{\frac{2}{c_W^2}\left[\frac{5}{4}-\frac{7}{3}s_W^2+\frac{22}{9}s_W^4\right]+4\right\},
\end{aligned}$$

where $a_s = \alpha_s/\pi$, $N_F = 5$ is the number of active quark flavors, $L_t = \ln(\mu_R^2/m_t^2)$ and s_W, c_W are respectively the sine and cosine of the weak-mixing angle. The Wilson coefficient obtained from using the complete factorization assumption is given by

$$C_1^{fac} = -\frac{1}{3\pi}(1+\lambda_{EW})\left\{1+a_s C_{1q}+a_s^2 C_{2q}\right\}.$$

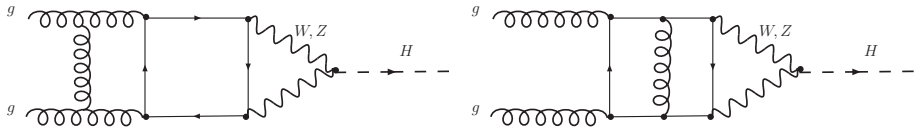

Figure 1: Example three-loop light-quark diagrams contributing to the C_{1w} term in the Wilson coefficient.

Factorization holds if $C_{1w} = C_{1q}$ and $C_{2w} = C_{2q}$. To test this assumption, the C_{1W} coefficient was calculated in [9] by expanding the 3-loop QCD corrections to the light-quark electroweak diagrams, keeping the leading term of that. The numerical effect of various choices for C_{2w} was also studied. In Fig. (1), sample diagrams involved in this calculation are shown.

3. Results

After a computation following the approach outlined above, we obtain the following result for C_{1w}:

$$C_{1w} = \frac{7}{6}. \tag{3.1}$$

Two points should be noted regarding the comparison of this with the factorization hypothesis $C_{1w}^{fac} = C_{1q} = 11/4$. First, there is a fairly large violation of the factorization result: $(C_{1q} - C_{1w})/C_{1w} \approx 1.4$. However, both expressions have the same sign, and a large difference from the $+5-6\%$ shift found before does not occur. In table (1), the numerical results for the new prediction of the gluon fusion cross section including all currently computed perturbative effects on the cross section, are shown. These are: the NNLO K-factor computed in the large-m_t limit and normalized to the exact m_t-dependent LO result, the full light-quark electroweak correction and the $\mathcal{O}(\alpha_s)$ correction to this encoded in C_{1w}, the bottom-quark contributions using their NLO K-factors with the exact dependence on the bottom and top quark masses and finally the newest MSTW PDFs from 2008 [10]. The new numerical values are $4-6\%$ lower than the numbers in Ref. [11] used in an earlier exclusion of a SM Higgs boson mass of 170 GeV with 95% CL.

4. Conclusions

In this contribution, we have briefly sketched the calculation of the mixed QCD-electroweak corrections to the Higgs boson production cross section in the gluon-fusion channel, due to diagrams containing light quarks. The leading term of this contribution was derived based on an effective Lagrangian obtained by integrating out the W-boson. This result allows us to check the factorization of electroweak and QCD corrections proposed in Ref. [7, 8]. Despite a fairly large violation of the factorization hypothesis, a significant numerical difference from the prediction of this hypothesis is not observed due to the structure of the QCD corrections. A new prediction for the Higgs production cross section via gluon fusion was also presented. The new numerical values are $4-6\%$ lower than the numbers in Ref. [11] used in an earlier exclusion of a SM Higgs boson mass of 170 GeV with 95% CL.

m_H[GeV]	σ^{best}[pb]	m_H[GeV]	σ^{best}[pb]
110	1.417 (±7% pdf)	160	0.4344 (±9% pdf)
115	1.243 (±7% pdf)	165	0.3854 (±9% pdf)
120	1.094 (±7% pdf)	170	0.3444 (±10% pdf)
125	0.9669 (±7% pdf)	175	0.3097 (±10% pdf)
130	0.8570 (±8% pdf)	180	0.2788 (±10% pdf)
135	0.7620 (±8% pdf)	185	0.2510 (±10% pdf)
140	0.6794 (±8% pdf)	190	0.2266 (±11% pdf)
145	0.6073 (±8% pdf)	195	0.2057 (±11% pdf)
150	0.5439 (±9% pdf)	200	0.1874 (±11% pdf)
155	0.4876 (±9% pdf)	–	–

Table 1: Higgs production cross section (MSTW08) for Higgs mass values relevant for Tevatron, with $\mu = \mu_R = \mu_F = M_H/2$. $\sigma^{best} = \sigma^{NNLO}_{QCD} + \sigma^{NNLO}_{EW}$ [9]. The theoretical errors PDFs are shown in the Table; the scale variation is $^{+7\%}_{-11\%}$, roughly constant as a function of Higgs boson mass.

5. Acknowledgments

This work is supported by the Swiss National Science Foundation under contract 200020-116756/2.

References

[1] [CDF Collaboration and D0 Collaboration], arXiv:0903.4001 [hep-ex].

[2] D. Graudenz, M. Spira and P. M. Zerwas, Phys. Rev. Lett. **70**, 1372 (1993); M. Spira, A. Djouadi, D. Graudenz and P. M. Zerwas, Nucl. Phys. B **453**, 17 (1995) [arXiv:hep-ph/9504378].

[3] S. Dawson, Nucl. Phys. B **359**, 283 (1991).

[4] A. Djouadi, M. Spira and P. M. Zerwas, Phys. Lett. B **264**, 440 (1991).

[5] R. V. Harlander and W. B. Kilgore, Phys. Rev. Lett. **88**, 201801 (2002) [arXiv:hep-ph/0201206]; C. Anastasiou and K. Melnikov, Nucl. Phys. B **646**, 220 (2002) [arXiv:hep-ph/0207004]; V. Ravindran, J. Smith and W. L. van Neerven, Nucl. Phys. B **665**, 325 (2003) [arXiv:hep-ph/0302135].

[6] U. Aglietti, R. Bonciani, G. Degrassi and A. Vicini, Phys. Lett. B **595**, 432 (2004) [arXiv:hep-ph/0404071].

[7] U. Aglietti, R. Bonciani, G. Degrassi and A. Vicini, arXiv:hep-ph/0610033.

[8] S. Actis, G. Passarino, C. Sturm and S. Uccirati, arXiv:0809.1301 [hep-ph]; S. Actis, G. Passarino, C. Sturm and S. Uccirati, arXiv:0809.3667 [hep-ph].

[9] C. Anastasiou, R. Boughezal and F. Petriello, JHEP **0904** (2009) 003 [arXiv:0811.3458 [hep-ph]].

[10] A. D. Martin, W. J. Stirling, R. S. Thorne and G. Watt, arXiv:0901.0002 [hep-ph].

[11] S. Catani, D. de Florian, M. Grazzini and P. Nason, JHEP **0307** (2003) 028 [arXiv:hep-ph/0306211].