LHCHWG-2024-XXXX

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LHC Higgs Working Group*

Public Note

Predictions for Production Cross Sections of the Higgs Boson at the LHC and HL-LHC

Instructions for authors:

- Add your name on the author list in the appropriate group. Anyone who was/is a convener since we started this work should be listed as such. External people should be listed in the "In collaboration with". All groups should be alphabetical.
- Add your affiliation(s) and *update* the affiliation list appropriately.
- Please respect the formatting of tables etc by looking at previously committed material.
- Each chapter should serve as a review of the state-of-the-art theory. We should aim to be generous with references, and hence make sure to also cite work that is no longer state-of-the-art, but is now considered important work towards the state-of-the-art.

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Abstract This note documents state-of-the-art predictions for the production cross sections of the Higgs Boson at the LHC. Specifically, Standard Model predictions for the LHC with centre-of-mass. energy of 7, 8, 13, 13.6 and 14 TeV are presented.

Contents

1 Introduction

Production cross sections for the Higgs boson based on the Standrad Model of particle physics were collected in the CERN Yellow Report "Deciphering the Nature of the Higgs Sector" (YR4) (CERN-2017-002) [1]. Since this document became public many advancements in our abilities to predict production cross sections were achieved. Furthermore, the LHC performed measurements at a higher centre-of-mass energy of 13.6 TeV for which YR4 does not contain any predictions. Looking ahead to Run-3 and the High Luminosity phase of the LHC (HL-LHC) and the associated wealth of data that will be collected an update of the HWG recommendation of all production cross sections to reflect the current state of the art is called for. The aim of this note is to document recent advancements and review the ingredients for the prediction of Standard Model predictions for the production cross sections of the Higgs boson at the LHC (similar in spirit as in YR4). Updated numerical predictions for central values of the production cross sections and associated theoretical and parametric uncertainties are the main result of this article. This note supersedes the interpolation of Ref. [2].
For now, instructions and input parameters for the generation of numerical values can be found here: `https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWG136TeVxsec`

2 Common setup

Here we describe all input parameters and settings that are common to all predictions presented in this report. In general we have aimed to use physical parameters from the Review of Particle Physics (PDG) [3].

2.1 Fermion masses

2.2 Gauge boson masses

We use the following on-shell values for the W and Z boson masses and widths

$$\begin{aligned} M_W^{\rm OS} &= 80.379 \text{ GeV}\,, \qquad \Gamma_W^{\rm OS} = 2.085 \text{ GeV} \\ M_Z^{\rm OS} &= 91.1876 \text{ GeV}\,, \qquad \Gamma_W^{\rm OS} = 2.4952 \text{ GeV}\,. \end{aligned} \tag{1}$$

When needed for EW computations they are translated into their pole masses [4] according to

$$M_V = \frac{M_V^{\rm OS}}{\sqrt{1+(\Gamma_V^{\rm OS}/M_V^{\rm OS})^2}}\,, \qquad \Gamma_V = \frac{\Gamma_V^{\rm OS}}{\sqrt{1+(\Gamma_V^{\rm OS}/M_V^{\rm OS})^2}}\,. \tag{2}$$

We use the G_μ-scheme [5] to compute the fine structure constant α from G_F, $M_W^{\rm OS}$, and $M_Z^{\rm OS}$

$$\alpha = \frac{\sqrt{2}}{\pi} G_F (M_W^{\rm OS})^2 \sin^2\theta_W\,, \quad \sin^2\theta_W = 1 - \frac{(M_W^{\rm OS})^2}{(M_Z^{\rm OS})^2}\,, \quad G_F = 1.16638\cdot 10^{-5} \text{ GeV}^2\,. \tag{3}$$

This yields a value

$$\alpha = 0.007565210\,. \tag{4}$$

2.3 PDF and $\alpha_{\rm s}$

Following the PDF4LHC recommendation [6] we use PDF4LHC21_40 PDF set for all predictions. The value of the strong coupling, $\alpha_{\rm s}$, is given at the Z boson mass

$$\alpha_{\rm s}(M_Z) = 0.1180 \pm 0.001\,. \tag{5}$$

We estimate the $\alpha_{\rm s}$ and PDF uncertainties following the same recommendation. The 4-flavour version of the PDF is used whenever a calculations is performed in the 4-flavour scheme. The above combined PDF sets do not contain any photon content. When computing photon initiate processes we instead use the LUXqed17_plus_PDF4LHC15_nnlo_100 [7] set for the photon *only*. This is not fully consistent as the presence of the photon in the PDF inevitably impacts the distributions of all the other partons. However, since the photon-initiated component is typically very small, this inconsistency is expected to be fully contained within other theoretical uncertainties.

3 ggF

4 VBF

The results are combined according to

$$\sigma^{\rm VBF} = \sigma^{\rm DIS}_{\rm N3LO}(1+\delta_{\rm EW}) + \sigma_\gamma \tag{6}$$

and the theory uncertainties are computed as

$$\Delta_{\rm TU} = \max\left\{0.5\%, \delta^2_{\rm EW}\right\} + \frac{|\sigma_{\rm nf}| + |\sigma_{\rm s/t/u}|}{\sigma^{\rm VBF}}\% \tag{7}$$

for $\sqrt{s} = \{13, 13.6, 14\}$ TeV. For the legacy numbers correspsonding to $\sqrt{s} = \{7, 8\}$ TeV the non-factorisable contribution, $\sigma_{\rm nf}$, was not computed, and we instead set

$$\Delta_{\rm TU} = \max\left[\max\left\{0.5\%, \delta^2_{\rm EW}\right\} + \frac{|\sigma_{\rm s/t/u}|}{\sigma^{\rm VBF}}\%, 1.0\%\right]. \tag{8}$$

In fact, in this case it always corresponds to 1%.

5 VH

6 $t\bar{t}H$ and tH

6.1 Cross-section predictions for tH

In this section, we provide predictions for tH production. For this process, three main production mechanisms concur: t-channel, s-channel and tWH associated production. Their characteristics are very similar to single-top production processes. As it is the case for these processes, at LHC energies the t-channel mode is by far the dominant one. At variance with ttH, where the cross section is proportional to the square of the top-quark Yukawa, for tH it breaks down into three terms: a term independent on y_t, a linear term and a quadratic term. As such, tH production is sensitive to the *sign* of yt.

State-of-the-art predictions for these processes include corrections up to NLO QCD [8, 9] as well as NLO EW [10]. When the latter are considered, however, interferences between the three production channels cannot be neglected, and the corresponding breakdown therefore becomes ill defined. Thus, the impact of EW corrections can be only assessed by considering all the channels together (possibly imposing the selection cuts which enhance a given channel). In this case, the effect on the inclusive cross section has been found in Ref. [10] to be about -3.5%. Given the rather low rate of these processes, together with the issues related to their inclusion when keeping the three channels separate, EW corrections are not included in the reference cross sections.

All single-top and Higgs cross-sections presented below are computed with MadGraph5_aMC@NLO [11, 12].

The central value μ of the renormalisation and factorisation scales is set in a process-dependent manner:

- tH (t channel): $\mu = \frac{m_H+m_t}{4}$, both for the computation in the 4FS and in the 5FS;
- tH (s channel): $\mu = \frac{m_H+m_t}{2}$;
- tWH: $\mu = \frac{m_H+m_t+m_W}{2}$;

All numbers are computed in the five-flavour scheme. For the t-channel production mechanism, quoted scale uncertainties represent the envelope of the five- and four-flavour scheme computation, both at NLO. In this case, we employ $m_b = 4.92$GeV.

Tabs. 2, 3 and 4 show predictions for t-channel production of $tH + \bar{t}H$, tH and $\bar{t}H$ production. Tabs. 5, 6 and 7 show predictions for s-channel production of $tH + \bar{t}H$, tH and $\bar{t}H$ production. Finally, Tab. shows predictions for $tW^-H + \bar{t}W^+H$ associated production (the cross section of the two separate processes are equal to each other in this case).

7 $b\bar{b}H$

8 Conclusions

Acknowledgments

This work was done on behalf of the LHCHWG.

$\sqrt{s}$ [TeV]	m_H [GeV]	σ [fb]	δ_μ	$\delta_{\rm PDF}$	δ_{α_s}
13.0	124.60	15.52	$^{+4.6}_{-6.2}$	3.1	2.3
13.0	125.00	15.47	$^{+4.6}_{-6.1}$	3.1	2.3
13.0	125.09	15.41	$^{+4.6}_{-6.2}$	3.1	2.2
13.0	125.38	15.29	$^{+4.7}_{-6.3}$	3.1	2.3
13.0	125.60	15.13	$^{+4.8}_{-6.6}$	3.1	2.3
13.0	126.00	15.06	$^{+4.7}_{-6.4}$	3.1	2.3
13.6	124.60	17.54	$^{+4.6}_{-6.3}$	3.0	2.2
13.6	125.00	17.40	$^{+4.7}_{-6.4}$	3.0	2.2
13.6	125.09	17.37	$^{+4.7}_{-6.4}$	3.0	2.2
13.6	125.38	17.33	$^{+4.7}_{-6.3}$	3.0	2.2
13.6	125.60	17.24	$^{+4.8}_{-6.4}$	3.0	2.2
13.6	126.00	17.07	$^{+4.7}_{-6.3}$	3.0	2.2
14.0	124.60	18.98	$^{+4.8}_{-6.5}$	2.9	2.2
14.0	125.00	18.86	$^{+4.7}_{-6.3}$	2.9	2.2
14.0	125.09	18.76	$^{+4.7}_{-6.4}$	2.9	2.2
14.0	125.38	18.63	$^{+4.8}_{-6.6}$	2.9	2.2
14.0	125.60	18.61	$^{+4.7}_{-6.4}$	2.9	2.2
14.0	126.00	18.45	$^{+4.8}_{-6.5}$	2.9	2.2

Table 1: Predictions for the process $tHW^- + \bar{t}HW^+$ (with DR2). The rate of each of the two processes taken alone is half of the rate of their sum.

$\sqrt{s}$ [TeV]	m_H [GeV]	σ [fb]	$\delta_{\mu+\rm FS}$	$\delta_{\rm PDF}$	δ_{α_s}
13.0	124.60	76.17	$^{+6.5}_{-15.0}$	1.8	1.2
13.0	125.00	76.04	$^{+6.4}_{-15.9}$	1.8	1.2
13.0	125.09	75.99	$^{+6.4}_{-16.1}$	1.8	1.2
13.0	125.38	75.79	$^{+6.4}_{-15.1}$	1.8	1.2
13.0	125.60	75.67	$^{+6.4}_{-15.8}$	1.8	1.2
13.0	126.00	75.53	$^{+6.4}_{-15.5}$	1.8	1.2
13.6	124.60	85.79	$^{+6.4}_{-16.4}$	1.7	1.2
13.6	125.00	85.38	$^{+6.4}_{-15.5}$	1.7	1.2
13.6	125.09	85.34	$^{+6.3}_{-15.5}$	1.7	1.2
13.6	125.38	85.10	$^{+6.3}_{-15.6}$	1.7	1.2
13.6	125.60	85.00	$^{+6.3}_{-16.0}$	1.7	1.2
13.6	126.00	84.86	$^{+6.3}_{-15.8}$	1.7	1.2
14.0	124.60	92.22	$^{+6.3}_{-15.8}$	1.7	1.2
14.0	125.00	92.02	$^{+6.3}_{-15.0}$	1.7	1.2
14.0	125.09	91.89	$^{+6.3}_{-14.9}$	1.7	1.2
14.0	125.38	91.72	$^{+6.3}_{-16.2}$	1.7	1.2
14.0	125.60	91.75	$^{+6.3}_{-16.0}$	1.7	1.2
14.0	126.00	91.32	$^{+6.3}_{-15.4}$	1.7	1.2

Table 2: Predictions for the process $tH + \bar{t}H$, t-channel.

$\sqrt{s}$ [TeV]	m_H [GeV]	σ [fb]	$\delta_{\mu+\mathrm{FS}}$	δ_{PDF}	δ_{α_s}
13.0	124.60	50.03	$^{+6.5}_{-14.7}$	1.5	1.2
13.0	125.00	49.91	$^{+6.5}_{-15.2}$	1.5	1.2
13.0	125.09	49.89	$^{+6.5}_{-15.3}$	1.5	1.2
13.0	125.38	49.74	$^{+6.4}_{-14.5}$	1.5	1.2
13.0	125.60	49.66	$^{+6.4}_{-15.6}$	1.5	1.2
13.0	126.00	49.62	$^{+6.4}_{-15.1}$	1.5	1.2
13.6	124.60	56.14	$^{+6.4}_{-15.8}$	1.5	1.2
13.6	125.00	56.00	$^{+6.4}_{-15.2}$	1.5	1.2
13.6	125.09	55.83	$^{+6.4}_{-15.0}$	1.5	1.2
13.6	125.38	55.69	$^{+6.3}_{-15.1}$	1.5	1.2
13.6	125.60	55.65	$^{+6.3}_{-15.5}$	1.5	1.2
13.6	126.00	55.60	$^{+6.3}_{-15.4}$	1.5	1.2
14.0	124.60	60.24	$^{+6.3}_{-15.4}$	1.4	1.1
14.0	125.00	60.14	$^{+6.3}_{-14.6}$	1.4	1.1
14.0	125.09	60.03	$^{+6.3}_{-15.2}$	1.4	1.1
14.0	125.38	59.93	$^{+6.3}_{-15.9}$	1.4	1.1
14.0	125.60	60.01	$^{+6.3}_{-15.8}$	1.4	1.2
14.0	126.00	59.63	$^{+6.3}_{-14.8}$	1.4	1.1

Table 3: Predictions for the process tH, t-channel.

$\sqrt{s}$ [TeV]	m_H [GeV]	σ [fb]	$\delta_{\mu+\mathrm{FS}}$	δ_{PDF}	δ_{α_s}
13.0	124.60	26.14	$^{+6.4}_{-15.7}$	3.1	1.3
13.0	125.00	26.13	$^{+6.4}_{-17.1}$	3.1	1.3
13.0	125.09	26.10	$^{+6.4}_{-17.6}$	3.1	1.3
13.0	125.38	26.05	$^{+6.4}_{-16.3}$	3.1	1.3
13.0	125.60	26.01	$^{+6.3}_{-16.1}$	3.1	1.3
13.0	126.00	25.91	$^{+6.4}_{-16.4}$	3.1	1.3
13.6	124.60	29.65	$^{+6.3}_{-17.5}$	3.0	1.2
13.6	125.00	29.38	$^{+6.3}_{-16.3}$	3.0	1.2
13.6	125.09	29.50	$^{+6.3}_{-16.5}$	3.0	1.2
13.6	125.38	29.41	$^{+6.3}_{-16.6}$	3.0	1.2
13.6	125.60	29.35	$^{+6.3}_{-16.9}$	3.0	1.2
13.6	126.00	29.27	$^{+6.3}_{-16.5}$	3.0	1.2
14.0	124.60	31.99	$^{+6.3}_{-16.7}$	2.9	1.2
14.0	125.00	31.88	$^{+6.3}_{-15.8}$	2.9	1.2
14.0	125.09	31.86	$^{+6.3}_{-14.4}$	2.9	1.2
14.0	125.38	31.79	$^{+6.2}_{-16.7}$	2.9	1.2
14.0	125.60	31.74	$^{+6.3}_{-16.4}$	2.9	1.2
14.0	126.00	31.69	$^{+6.2}_{-16.6}$	3.0	1.2

Table 4: Predictions for the process $\bar{t}H$, t-channel.

$\sqrt{s}$ [TeV]	m_H [GeV]	σ [fb]	δ_μ	$\delta_{\rm PDF}$	δ_{α_s}
13.0	124.60	2.95	$^{+2.4}_{-1.9}$	2.4	0.2
13.0	125.00	2.93	$^{+2.4}_{-1.9}$	2.4	0.2
13.0	125.09	2.92	$^{+2.4}_{-1.8}$	2.4	0.2
13.0	125.38	2.90	$^{+2.4}_{-1.9}$	2.4	0.2
13.0	125.60	2.89	$^{+2.4}_{-1.8}$	2.4	0.2
13.0	126.00	2.87	$^{+2.5}_{-1.9}$	2.4	0.2
13.6	124.60	3.18	$^{+2.4}_{-1.8}$	2.3	0.2
13.6	125.00	3.15	$^{+2.4}_{-1.8}$	2.3	0.2
13.6	125.09	3.14	$^{+2.4}_{-1.8}$	2.3	0.2
13.6	125.38	3.13	$^{+2.4}_{-1.8}$	2.3	0.2
13.6	125.60	3.12	$^{+2.4}_{-1.8}$	2.3	0.2
13.6	126.00	3.10	$^{+2.4}_{-1.8}$	2.3	0.2
14.0	124.60	3.33	$^{+2.4}_{-1.8}$	2.3	0.3
14.0	125.00	3.30	$^{+2.4}_{-1.8}$	2.3	0.3
14.0	125.09	3.30	$^{+2.4}_{-1.8}$	2.3	0.3
14.0	125.38	3.29	$^{+2.4}_{-1.8}$	2.3	0.3
14.0	125.60	3.27	$^{+2.4}_{-1.8}$	2.3	0.3
14.0	126.00	3.24	$^{+2.4}_{-1.8}$	2.3	0.3

Table 5: Predictions for the process $tH + \bar{t}H$, s-channel.

$\sqrt{s}$ [TeV]	m_H [GeV]	σ [fb]	δ_μ	$\delta_{\rm PDF}$	δ_{α_s}
13.0	124.60	1.93	$^{+2.4}_{-1.8}$	2.5	0.2
13.0	125.00	1.92	$^{+2.4}_{-1.8}$	2.5	0.2
13.0	125.09	1.91	$^{+2.4}_{-1.8}$	2.5	0.2
13.0	125.38	1.90	$^{+2.4}_{-1.8}$	2.5	0.2
13.0	125.60	1.90	$^{+2.4}_{-1.8}$	2.5	0.2
13.0	126.00	1.88	$^{+2.4}_{-1.8}$	2.5	0.2
13.6	124.60	2.07	$^{+2.4}_{-1.8}$	2.4	0.3
13.6	125.00	2.06	$^{+2.4}_{-1.8}$	2.5	0.3
13.6	125.09	2.05	$^{+2.4}_{-1.8}$	2.5	0.3
13.6	125.38	2.05	$^{+2.4}_{-1.8}$	2.5	0.3
13.6	125.60	2.04	$^{+2.4}_{-1.8}$	2.5	0.3
13.6	126.00	2.03	$^{+2.4}_{-1.8}$	2.5	0.3
14.0	124.60	2.17	$^{+2.3}_{-1.7}$	2.4	0.3
14.0	125.00	2.15	$^{+2.3}_{-1.8}$	2.4	0.3
14.0	125.09	2.15	$^{+2.4}_{-1.8}$	2.4	0.3
14.0	125.38	2.14	$^{+2.4}_{-1.8}$	2.4	0.3
14.0	125.60	2.13	$^{+2.3}_{-1.8}$	2.4	0.3
14.0	126.00	2.11	$^{+2.3}_{-1.7}$	2.4	0.3

Table 6: Predictions for the process tH, s-channel.

$\sqrt{s}$ [TeV]	m_H [GeV]	σ [fb]	δ_μ	$\delta_{\rm PDF}$	δ_{α_s}
13.0	124.60	1.02	$^{+2.5}_{-1.9}$	2.6	0.2
13.0	125.00	1.01	$^{+2.5}_{-1.9}$	2.6	0.2
13.0	125.09	1.00	$^{+2.5}_{-1.8}$	2.6	0.2
13.0	125.38	1.00	$^{+2.5}_{-1.9}$	2.6	0.2
13.0	125.60	1.00	$^{+2.4}_{-1.8}$	2.6	0.2
13.0	126.00	0.99	$^{+2.5}_{-1.9}$	2.6	0.2
13.6	124.60	1.10	$^{+2.4}_{-1.8}$	2.5	0.2
13.6	125.00	1.09	$^{+2.4}_{-1.8}$	2.5	0.2
13.6	125.09	1.09	$^{+2.4}_{-1.8}$	2.5	0.2
13.6	125.38	1.09	$^{+2.4}_{-1.8}$	2.5	0.2
13.6	125.60	1.08	$^{+2.4}_{-1.8}$	2.5	0.2
13.6	126.00	1.07	$^{+2.4}_{-1.8}$	2.5	0.2
14.0	124.60	1.16	$^{+2.5}_{-1.8}$	2.5	0.3
14.0	125.00	1.15	$^{+2.4}_{-1.8}$	2.5	0.2
14.0	125.09	1.15	$^{+2.4}_{-1.8}$	2.5	0.3
14.0	125.38	1.14	$^{+2.4}_{-1.8}$	2.5	0.3
14.0	125.60	1.14	$^{+2.4}_{-1.8}$	2.5	0.2
14.0	126.00	1.13	$^{+2.5}_{-1.8}$	2.5	0.2

Table 7: Predictions for the process $\bar{t}H$, s-channel.

A Reference tables

A.1 ggF

A.2 VBF

Table 8: Total VBF cross sections in the SM for a LHC CM energy of $\sqrt{s} = 7$ TeV, including QCD and EW corrections and their uncertainties for different Higgs-boson masses $M_{\rm H}$. For more details see section 4.

$M_{\rm H}$[GeV]	$\sigma^{\rm VBF}$[fb]	$\Delta_{\rm scale}$[%]	$\Delta_{\rm PDF/\alpha_s/PDF\oplus\alpha_s}$[%]	$\Delta_{\rm TU}$[%]	$\sigma^{\rm DIS}_{\rm N3LO}$[fb]	$\delta_{\rm EW}$[%]	σ_γ[fb]	$\sigma_{\rm nf}$[fb]	$\sigma_{\rm s/t/u}$[fb]
120.00	1310	$^{+0.067}_{-0.050}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1360	-4.4	9.7	–	-5.3
122.00	1285	$^{+0.065}_{-0.051}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1333	-4.4	9.6	–	-5.0
124.00	1261	$^{+0.064}_{-0.051}$	$\pm 2.3/\pm 0.3/\pm 2.4$	± 1.0	1309	-4.4	9.5	–	-4.7
124.60	1254	$^{+0.064}_{-0.051}$	$\pm 2.3/\pm 0.3/\pm 2.4$	± 1.0	1301	-4.3	9.5	–	-4.6
124.80	1252	$^{+0.064}_{-0.051}$	$\pm 2.3/\pm 0.3/\pm 2.4$	± 1.0	1299	-4.3	9.4	–	-4.6
125.00	1249	$^{+0.064}_{-0.051}$	$\pm 2.3/\pm 0.3/\pm 2.4$	± 1.0	1296	-4.3	9.4	–	-4.5
125.09	1248	$^{+0.063}_{-0.051}$	$\pm 2.3/\pm 0.3/\pm 2.4$	± 1.0	1295	-4.3	9.4	–	-4.5
125.20	1247	$^{+0.063}_{-0.051}$	$\pm 2.3/\pm 0.3/\pm 2.4$	± 1.0	1294	-4.3	9.4	–	-4.5
125.30	1246	$^{+0.063}_{-0.051}$	$\pm 2.3/\pm 0.3/\pm 2.4$	± 1.0	1293	-4.3	9.4	–	-4.4
125.38	1245	$^{+0.063}_{-0.051}$	$\pm 2.3/\pm 0.3/\pm 2.4$	± 1.0	1292	-4.3	9.4	–	-4.4
125.60	1242	$^{+0.063}_{-0.051}$	$\pm 2.3/\pm 0.3/\pm 2.4$	± 1.0	1289	-4.3	9.4	–	-4.4
126.00	1238	$^{+0.063}_{-0.051}$	$\pm 2.3/\pm 0.3/\pm 2.4$	± 1.0	1284	-4.3	9.4	–	-4.4
128.00	1215	$^{+0.061}_{-0.051}$	$\pm 2.3/\pm 0.3/\pm 2.4$	± 1.0	1260	-4.3	9.2	–	-4.1
130.00	1192	$^{+0.060}_{-0.051}$	$\pm 2.3/\pm 0.3/\pm 2.4$	± 1.0	1237	-4.3	9.1	–	-3.8

Table 9: Total VBF cross sections in the SM for a LHC CM energy of $\sqrt{s} = 8$ TeV, including QCD and EW corrections and their uncertainties for different Higgs-boson masses $M_{\rm H}$. For more details see section 4.

$M_{\rm H}$[GeV]	$\sigma^{\rm VBF}$[fb]	$\Delta_{\rm scale}$[%]	$\Delta_{\rm PDF/\alpha_s/PDF\oplus\alpha_s}$[%]	$\Delta_{\rm TU}$[%]	$\sigma^{\rm DIS}_{\rm N3LO}$[fb]	$\delta_{\rm EW}$[%]	σ_γ[fb]	$\sigma_{\rm nf}$[fb]	$\sigma_{\rm s/t/u}$[fb]
120.00	1687	$^{+0.082}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1754	-4.6	13.2	–	-6.2
122.00	1657	$^{+0.081}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1722	-4.6	13.0	–	-5.9
124.00	1627	$^{+0.081}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1691	-4.5	12.9	–	-5.5
124.60	1618	$^{+0.081}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1681	-4.5	12.8	–	-5.5
124.80	1615	$^{+0.081}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1678	-4.5	12.8	–	-5.5
125.00	1612	$^{+0.081}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1675	-4.5	12.8	–	-5.4
125.09	1611	$^{+0.081}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1674	-4.5	12.8	–	-5.4
125.20	1609	$^{+0.081}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1672	-4.5	12.8	–	-5.4
125.30	1608	$^{+0.081}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1671	-4.5	12.8	–	-5.4
125.38	1607	$^{+0.080}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1669	-4.5	12.8	–	-5.4
125.60	1604	$^{+0.080}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1666	-4.5	12.8	–	-5.3
126.00	1598	$^{+0.080}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1660	-4.5	12.7	–	-5.2
128.00	1569	$^{+0.079}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1630	-4.5	12.6	–	-4.9
130.00	1542	$^{+0.079}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 1.0	1601	-4.5	12.4	–	-4.6

Table 10: Total VBF cross sections in the SM for a LHC CM energy of $\sqrt{s} = 13$ TeV, including QCD and EW corrections and their uncertainties for different Higgs-boson masses $M_{\rm H}$. For more details see section 4.

$M_{\rm H}$[GeV]	$\sigma^{\rm VBF}$[fb]	$\Delta_{\rm scale}$[%]	$\Delta_{\rm PDF/\alpha_s/PDF\oplus\alpha_s}$[%]	$\Delta_{\rm TU}$[%]	$\sigma^{\rm DIS}_{\rm N3LO}$[fb]	$\delta_{\rm EW}$[%]	σ_γ[fb]	$\sigma_{\rm nf}$[fb]	$\sigma_{\rm s/t/u}$[fb]
120.00	3967	$^{+0.13}_{-0.091}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4148	-5.2	36.1	-8.9	-11.5
122.00	3905	$^{+0.13}_{-0.092}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4082	-5.2	35.8	-8.5	-10.6
124.00	3844	$^{+0.13}_{-0.092}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4017	-5.2	35.4	-8.2	-10.2
124.60	3825	$^{+0.13}_{-0.093}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	3998	-5.2	35.3	-8.1	-10.0
124.80	3819	$^{+0.13}_{-0.093}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	3992	-5.2	35.3	-8.1	-10.0
125.00	3813	$^{+0.13}_{-0.093}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	3985	-5.2	35.2	-8.0	-10.0
125.09	3811	$^{+0.13}_{-0.093}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	3982	-5.2	35.2	-8.0	-10.0
125.20	3807	$^{+0.13}_{-0.093}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	3979	-5.2	35.2	-8.0	-10.0
125.30	3804	$^{+0.13}_{-0.093}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	3976	-5.2	35.2	-8.0	-9.9
125.38	3802	$^{+0.13}_{-0.093}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	3973	-5.2	35.2	-8.0	-9.8
125.60	3795	$^{+0.13}_{-0.093}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	3966	-5.2	35.1	-8.0	-9.7
126.00	3784	$^{+0.13}_{-0.093}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	3954	-5.2	35.1	-7.9	-9.6
128.00	3725	$^{+0.13}_{-0.093}$	$\pm 2.2/\pm 0.4/\pm 2.2$	± 1.0	3892	-5.2	34.7	-7.7	-9.2
130.00	3667	$^{+0.13}_{-0.094}$	$\pm 2.2/\pm 0.3/\pm 2.2$	± 0.9	3831	-5.2	34.3	-7.5	-8.6

A.3 VH

A.4 ttH

A.5 bbH

References

[1] LHC Higgs Cross Section Working Group collaboration, D. de Florian et al., *Handbook of LHC Higgs Cross Sections: 4. Deciphering the Nature of the Higgs Sector*, 1610.07922.

[2] A. Karlberg et al., *Ad interim recommendations for the Higgs boson production cross sections at* $\sqrt{s} = 13.6$ *TeV*, 2402.09955.

Table 11: Total VBF cross sections in the SM for a LHC CM energy of $\sqrt{s} = 13.6$ TeV, including QCD and EW corrections and their uncertainties for different Higgs-boson masses $M_{\rm H}$. For more details see section 4.

$M_{\rm H}$[GeV]	$\sigma^{\rm VBF}$[fb]	$\Delta_{\rm scale}$[%]	$\Delta_{\rm PDF/\alpha_s/PDF\oplus\alpha_s}$[%]	$\Delta_{\rm TU}$[%]	$\sigma^{\rm DIS}_{\rm N3LO}$[fb]	$\delta_{\rm EW}$[%]	σ_γ[fb]	$\sigma_{\rm nf}$[fb]	$\sigma_{\rm s/t/u}$[fb]
120.00	4276	$^{+0.13}_{-0.093}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4473	-5.3	39.4	-9.2	-11.9
122.00	4210	$^{+0.13}_{-0.094}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4403	-5.3	39.0	-8.8	-11.4
124.00	4144	$^{+0.13}_{-0.095}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4334	-5.3	38.6	-8.5	-10.9
124.60	4125	$^{+0.13}_{-0.095}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4313	-5.3	38.5	-8.4	-10.8
124.80	4118	$^{+0.13}_{-0.095}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4307	-5.3	38.5	-8.4	-10.7
125.00	4112	$^{+0.13}_{-0.095}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4300	-5.3	38.5	-8.3	-10.7
125.09	4109	$^{+0.13}_{-0.095}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4297	-5.3	38.4	-8.3	-10.7
125.20	4106	$^{+0.13}_{-0.095}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4293	-5.3	38.4	-8.3	-10.6
125.30	4102	$^{+0.13}_{-0.095}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4290	-5.3	38.4	-8.3	-10.5
125.38	4100	$^{+0.13}_{-0.095}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4287	-5.3	38.4	-8.3	-10.4
125.60	4093	$^{+0.13}_{-0.095}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4280	-5.3	38.3	-8.3	-10.4
126.00	4080	$^{+0.13}_{-0.095}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4266	-5.3	38.3	-8.2	-10.3
128.00	4018	$^{+0.13}_{-0.096}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 0.9	4200	-5.2	37.9	-8.0	-9.8
130.00	3956	$^{+0.13}_{-0.097}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 0.9	4135	-5.2	37.5	-7.8	-9.1

Table 12: Total VBF cross sections in the SM for a LHC CM energy of $\sqrt{s} = 14$ TeV, including QCD and EW corrections and their uncertainties for different Higgs-boson masses $M_{\rm H}$. For more details see section 4.

$M_{\rm H}$[GeV]	$\sigma^{\rm VBF}$[fb]	$\Delta_{\rm scale}$[%]	$\Delta_{\rm PDF/\alpha_s/PDF\oplus\alpha_s}$[%]	$\Delta_{\rm TU}$[%]	$\sigma^{\rm DIS}_{\rm N3LO}$[fb]	$\delta_{\rm EW}$[%]	σ_γ[fb]	$\sigma_{\rm nf}$[fb]	$\sigma_{\rm s/t/u}$[fb]
120.00	4486	$^{+0.14}_{-0.094}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4694	-5.3	41.7	-9.9	-12.4
122.00	4416	$^{+0.14}_{-0.095}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4620	-5.3	41.3	-9.5	-11.9
124.00	4348	$^{+0.14}_{-0.096}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4549	-5.3	40.8	-9.1	-11.2
124.60	4328	$^{+0.14}_{-0.097}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4527	-5.3	40.7	-9.0	-11
124.80	4322	$^{+0.14}_{-0.097}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4520	-5.3	40.7	-9.0	-11
125.00	4315	$^{+0.14}_{-0.097}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4513	-5.3	40.7	-8.9	-10.9
125.09	4312	$^{+0.14}_{-0.097}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4510	-5.3	40.6	-8.9	-10.9
125.20	4308	$^{+0.14}_{-0.097}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4506	-5.3	40.6	-8.9	-10.9
125.30	4305	$^{+0.14}_{-0.097}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4503	-5.3	40.6	-8.9	-10.8
125.38	4302	$^{+0.14}_{-0.097}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4500	-5.3	40.6	-8.9	-10.8
125.60	4295	$^{+0.14}_{-0.097}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4492	-5.3	40.5	-8.9	-10.6
126.00	4282	$^{+0.14}_{-0.097}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4478	-5.3	40.5	-8.8	-10.5
128.00	4216	$^{+0.14}_{-0.098}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4409	-5.3	40	-8.6	-10
130.00	4152	$^{+0.14}_{-0.099}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 1.0	4342	-5.3	39.7	-8.4	-9.5

[3] Particle Data Group collaboration, P. A. Zyla et al., *Review of Particle Physics*, *PTEP* **2020** (2020) 083C01.

[4] D. Bardin, A. Leike, T. Riemann and M. Sachwitz, *Energy-dependent width effects in e^+e^--annihilation near the z-boson pole*, *Physics Letters B* **206** (1988) 539.

[5] A. Denner, S. Dittmaier, M. Roth and D. Wackeroth, *Electroweak radiative corrections to $e^+e^- \to WW \to 4$ fermions in double pole approximation: The RACOONWW approach*, *Nucl. Phys. B* **587** (2000) 67 [hep-ph/0006307].

[6] PDF4LHC Working Group collaboration, R. D. Ball et al., *The PDF4LHC21 combination of global PDF fits for the LHC Run III*, *J. Phys. G* **49** (2022) 080501 [2203.05506].

[7] A. V. Manohar, P. Nason, G. P. Salam and G. Zanderighi, *The Photon Content of the Proton*, *JHEP* **12** (2017) 046 [1708.01256].

[8] F. Demartin, F. Maltoni, K. Mawatari and M. Zaro, *Higgs production in association with a single top quark at the LHC*, *Eur. Phys. J. C* **75** (2015) 267 [1504.00611].

[9] F. Demartin, B. Maier, F. Maltoni, K. Mawatari and M. Zaro, *tWH associated production at the LHC*, *Eur. Phys. J. C* **77** (2017) 34 [1607.05862].

[10] D. Pagani, I. Tsinikos and E. Vryonidou, *NLO QCD+EW predictions for tHj and tZj production at the LHC*, *JHEP* **08** (2020) 082 [2006.10086].

[11] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer et al., *The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations*, *JHEP* **07** (2014) 079 [1405.0301].

[12] R. Frederix, S. Frixione, V. Hirschi, D. Pagani, H. S. Shao and M. Zaro, *The automation of next-to-leading order electroweak calculations*, *JHEP* **07** (2018) 185 [1804.10017].