LHCHWG-2024-XXXX

March 13, 2024

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.

WG1 conveners: Hannah Arnold[1], Alessandro Calandri[2], Alexander Karlberg[3], Bernhard Mistlberger[4]
ggF conveners: Alessandra Cappati[5], Robin Hayes[6], Alexander Huss[3], Stephen Jones[7]
VBF conveners: Gaetano Barone[8], Jiayi Chen[9], Silvia Ferrario Ravsio[3], Mathieu Pellen[10]
VH conveners: Suman Chatterjee[11], Valerio Dao[3], Giancarlo Ferrera[12], Matthew Lim[13]
$t\bar{t}H/tH$ conveners: Josh McFayden[13], Valeria Botta[14], Malgorzata Worek[14], Marco Zaro[12]
$b\bar{b}H/bH$ conveners:
In collaboration with:

[1] *Brookhaven National Laboratory, PO Box 5000, Upton, NY 11973, USA*
[2] *ETH Zurich—Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland*
[3] *CERN, Theoretical Physics Department, CH-1211 Geneva 23, Switzerland*
[4] *SLAC National Accelerator Laboratory, Stanford University, Stanford, CA 94039, USA*
[5] *Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecóle Polytechnique, Institut Polytechnique de Paris, Av. Chasles, 91120 Palaiseau, France*

* *https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWG*

[6] *Nikhef, Science Park 105, 1098 XG Amsterdam, The Netherlands*
[7] *Institute for Particle Physics Phenomenology, Durham University, Durham DH1 3LE, UK*
[8] *Brown University, Providence, RI 02912, USA*
[9] *Department of Physics, Simon Fraser University, Burnaby, BC V5H0G9, Canada*
[10] *Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, D-79104 Freiburg, Germany*
[11] *Institute of High Energy Physics (HEPHY), Austrian Academy of Sciences (ÖAW), Nikolsdorfer Gasse 18, 1050 Vienna, Austria*
[12] *Universitá degli Studi di Milano & INFN, Sezione di Milano, Via Celoria 16, 20133 Milano, Italy*
[13] *Department of Physics and Astronomy, University of Sussex, Sussex House, Brighton, BN1 9RH, UK*
[14] *Institute for Theoretical Particle Physics and Cosmology, RWTH Aachen University, D-52056 Aachen, Germany*

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

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

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

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

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 $t\bar{t}H$

New predictions for the $t\bar{t}H$ total cross section have recently appeared in Ref. [8]. These results combine predictions accurate at NNLO in QCD [9, 10] together with soft-gluon resummation up to NNLL [11, 12, 13, 14, 15, 16, 17], and include all effects of EW origin up to NLO [18, 19, 20]. Soft-gluon resummation is carried out in two independent framework (SCET and dQCD), which makes it possible to obtain a conservatie estimate of missing higher-order uncertainties via scale variations. In Ref. [8], a thorough estimate of many sources of theoretical uncertainties is carried out. The only one which may be phenomenologically relevant (besides scale variations, PDF and α_s uncertainties) is the one stemming from the approximation of the two-loop virtual amplitude carried out in order to perform the NNLO computation. Such an uncertainty amounts to

$$\Delta_{\text{virt}} = 0.9\% \tag{9}$$

for the numbers presented here. The values for the total cross sections at 13, 13.6 and 14 TeV can be found in Table 6. For other energies, we advise to employ the numbers presented in Ref. [2].

6.2 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 y_t.

State-of-the-art predictions for these processes include corrections up to NLO QCD [21, 22] as well as NLO EW [23]. 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. [23] 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 [24, 20].

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.

For tWH, contributions belonging to $t\bar{t}H$ entering at NLO via real emissions are removed using the so-called "Diagram removal with interference" scheme (known as DR2), as implemented in MadGraph5_aMC@NLO, see Refs. [22, 25].

Tabs. 8, 9 and 10 show predictions for t-channel production of $tH + \bar{t}H$, tH and $\bar{t}H$ production. Tabs. 11, 12 and 13 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.

A Reference tables

A.1 ggF

A.2 VBF

Table 1: 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_H. For more details see section 4.

M_H[GeV]	σ^VBF[fb]	Δ_scale[%]	$\Delta_{\mathrm{PDF}/\alpha_\mathrm{s}/\mathrm{PDF}\oplus\alpha_\mathrm{s}}$[%]	Δ_TU[%]	$\sigma^\mathrm{DIS}_\mathrm{N3LO}$[fb]	δ_EW[%]	σ_γ[fb]	σ_nf[fb]	$\sigma_\mathrm{s/t/u}$[fb]
120.00	1310	$^{+0.067}_{-0.050}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1360	-4.4	9.7	–	-5.3
122.00	1285	$^{+0.065}_{-0.051}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1333	-4.4	9.6	–	-5.0
124.00	1261	$^{+0.064}_{-0.051}$	$\pm2.3/\pm0.3/\pm2.4$	±1.0	1309	-4.4	9.5	–	-4.7
124.60	1254	$^{+0.064}_{-0.051}$	$\pm2.3/\pm0.3/\pm2.4$	±1.0	1301	-4.3	9.5	–	-4.6
124.80	1252	$^{+0.064}_{-0.051}$	$\pm2.3/\pm0.3/\pm2.4$	±1.0	1299	-4.3	9.4	–	-4.6
125.00	1249	$^{+0.064}_{-0.051}$	$\pm2.3/\pm0.3/\pm2.4$	±1.0	1296	-4.3	9.4	–	-4.5
125.09	1248	$^{+0.063}_{-0.051}$	$\pm2.3/\pm0.3/\pm2.4$	±1.0	1295	-4.3	9.4	–	-4.5
125.20	1247	$^{+0.063}_{-0.051}$	$\pm2.3/\pm0.3/\pm2.4$	±1.0	1294	-4.3	9.4	–	-4.5
125.30	1246	$^{+0.063}_{-0.051}$	$\pm2.3/\pm0.3/\pm2.4$	±1.0	1293	-4.3	9.4	–	-4.4
125.38	1245	$^{+0.063}_{-0.051}$	$\pm2.3/\pm0.3/\pm2.4$	±1.0	1292	-4.3	9.4	–	-4.4
125.60	1242	$^{+0.063}_{-0.051}$	$\pm2.3/\pm0.3/\pm2.4$	±1.0	1289	-4.3	9.4	–	-4.4
126.00	1238	$^{+0.063}_{-0.051}$	$\pm2.3/\pm0.3/\pm2.4$	±1.0	1284	-4.3	9.4	–	-4.4
128.00	1215	$^{+0.061}_{-0.051}$	$\pm2.3/\pm0.3/\pm2.4$	±1.0	1260	-4.3	9.2	–	-4.1
130.00	1192	$^{+0.060}_{-0.051}$	$\pm2.3/\pm0.3/\pm2.4$	±1.0	1237	-4.3	9.1	–	-3.8

Table 2: 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_H. For more details see section 4.

M_H[GeV]	σ^VBF[fb]	Δ_scale[%]	$\Delta_{\mathrm{PDF}/\alpha_\mathrm{s}/\mathrm{PDF}\oplus\alpha_\mathrm{s}}$[%]	Δ_TU[%]	$\sigma^\mathrm{DIS}_\mathrm{N3LO}$[fb]	δ_EW[%]	σ_γ[fb]	σ_nf[fb]	$\sigma_\mathrm{s/t/u}$[fb]
120.00	1687	$^{+0.082}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1754	-4.6	13.2	–	-6.2
122.00	1657	$^{+0.081}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1722	-4.6	13.0	–	-5.9
124.00	1627	$^{+0.081}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1691	-4.5	12.9	–	-5.5
124.60	1618	$^{+0.081}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1681	-4.5	12.8	–	-5.5
124.80	1615	$^{+0.081}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1678	-4.5	12.8	–	-5.5
125.00	1612	$^{+0.081}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1675	-4.5	12.8	–	-5.4
125.09	1611	$^{+0.081}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1674	-4.5	12.8	–	-5.4
125.20	1609	$^{+0.081}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1672	-4.5	12.8	–	-5.4
125.30	1608	$^{+0.081}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1671	-4.5	12.8	–	-5.4
125.38	1607	$^{+0.080}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1669	-4.5	12.8	–	-5.4
125.60	1604	$^{+0.080}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1666	-4.5	12.8	–	-5.3
126.00	1598	$^{+0.080}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1660	-4.5	12.7	–	-5.2
128.00	1569	$^{+0.079}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1630	-4.5	12.6	–	-4.9
130.00	1542	$^{+0.079}_{-0.061}$	$\pm2.3/\pm0.3/\pm2.3$	±1.0	1601	-4.5	12.4	–	-4.6

Table 3: 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_H. For more details see section 4.

M_H[GeV]	σ^VBF[fb]	Δ_scale[%]	$\Delta_{\mathrm{PDF}/\alpha_\mathrm{s}/\mathrm{PDF}\oplus\alpha_\mathrm{s}}$[%]	Δ_TU[%]	$\sigma^\mathrm{DIS}_\mathrm{N3LO}$[fb]	δ_EW[%]	σ_γ[fb]	σ_nf[fb]	$\sigma_{\mathrm{s/t/u}}$[fb]
120.00	3967	$^{+0.13}_{-0.091}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4148	-5.2	36.1	-8.9	-11.5
122.00	3905	$^{+0.13}_{-0.092}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4082	-5.2	35.8	-8.5	-10.6
124.00	3844	$^{+0.13}_{-0.092}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4017	-5.2	35.4	-8.2	-10.2
124.60	3825	$^{+0.13}_{-0.093}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	3998	-5.2	35.3	-8.1	-10.0
124.80	3819	$^{+0.13}_{-0.093}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	3992	-5.2	35.3	-8.1	-10.0
125.00	3813	$^{+0.13}_{-0.093}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	3985	-5.2	35.2	-8.0	-10.0
125.09	3811	$^{+0.13}_{-0.093}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	3982	-5.2	35.2	-8.0	-10.0
125.20	3807	$^{+0.13}_{-0.093}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	3979	-5.2	35.2	-8.0	-10.0
125.30	3804	$^{+0.13}_{-0.093}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	3976	-5.2	35.2	-8.0	-9.9
125.38	3802	$^{+0.13}_{-0.093}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	3973	-5.2	35.2	-8.0	-9.8
125.60	3795	$^{+0.13}_{-0.093}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	3966	-5.2	35.1	-8.0	-9.7
126.00	3784	$^{+0.13}_{-0.093}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	3954	-5.2	35.1	-7.9	-9.6
128.00	3725	$^{+0.13}_{-0.093}$	$\pm2.2/\pm0.4/\pm2.2$	±1.0	3892	-5.2	34.7	-7.7	-9.2
130.00	3667	$^{+0.13}_{-0.094}$	$\pm2.2/\pm0.3/\pm2.2$	±0.9	3831	-5.2	34.3	-7.5	-8.6

Table 4: 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_H. For more details see section 4.

M_H[GeV]	σ^VBF[fb]	Δ_scale[%]	$\Delta_{\mathrm{PDF}/\alpha_\mathrm{s}/\mathrm{PDF}\oplus\alpha_\mathrm{s}}$[%]	Δ_TU[%]	$\sigma^\mathrm{DIS}_\mathrm{N3LO}$[fb]	δ_EW[%]	σ_γ[fb]	σ_nf[fb]	$\sigma_{\mathrm{s/t/u}}$[fb]
120.00	4276	$^{+0.13}_{-0.093}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4473	-5.3	39.4	-9.2	-11.9
122.00	4210	$^{+0.13}_{-0.094}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4403	-5.3	39.0	-8.8	-11.4
124.00	4144	$^{+0.13}_{-0.095}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4334	-5.3	38.6	-8.5	-10.9
124.60	4125	$^{+0.13}_{-0.095}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4313	-5.3	38.5	-8.4	-10.8
124.80	4118	$^{+0.13}_{-0.095}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4307	-5.3	38.5	-8.4	-10.7
125.00	4112	$^{+0.13}_{-0.095}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4300	-5.3	38.5	-8.3	-10.7
125.09	4109	$^{+0.13}_{-0.095}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4297	-5.3	38.4	-8.3	-10.7
125.20	4106	$^{+0.13}_{-0.095}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4293	-5.3	38.4	-8.3	-10.6
125.30	4102	$^{+0.13}_{-0.095}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4290	-5.3	38.4	-8.3	-10.5
125.38	4100	$^{+0.13}_{-0.095}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4287	-5.3	38.4	-8.3	-10.4
125.60	4093	$^{+0.13}_{-0.095}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4280	-5.3	38.3	-8.3	-10.4
126.00	4080	$^{+0.13}_{-0.095}$	$\pm2.1/\pm0.4/\pm2.2$	±1.0	4266	-5.3	38.3	-8.2	-10.3
128.00	4018	$^{+0.13}_{-0.096}$	$\pm2.1/\pm0.4/\pm2.2$	±0.9	4200	-5.2	37.9	-8.0	-9.8
130.00	3956	$^{+0.13}_{-0.097}$	$\pm2.1/\pm0.4/\pm2.2$	±0.9	4135	-5.2	37.5	-7.8	-9.1

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 5: 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_{H}. For more details see section 4.

M_{H}[GeV]	σ^{VBF}[fb]	Δ_{scale}[%]	$\Delta_{\mathrm{PDF}/\alpha_s/\mathrm{PDF}\oplus\alpha_s}$[%]	Δ_{TU}[%]	$\sigma^{\mathrm{DIS}}_{\mathrm{N3LO}}$[fb]	δ_{EW}[%]	σ_{γ}[fb]	σ_{nf}[fb]	$\sigma_{\mathrm{s/t/u}}$[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] R. Balsach et al., *State-of-the-art cross sections for ttH: NNLO predictions matched with NNLL resummation and EW corrections*, 3, 2025, 2503.15043.

[9] S. Catani, S. Devoto, M. Grazzini, S. Kallweit, J. Mazzitelli and C. Savoini, *Higgs Boson Production in Association with a Top-Antitop Quark Pair in Next-to-Next-to-Leading Order QCD*, *Phys. Rev. Lett.* **130** (2023) 111902 [2210.07846].

[10] S. Devoto, M. Grazzini, S. Kallweit, J. Mazzitelli and C. Savoini, *Precise predictions for $t\bar{t}H$ production at the LHC: inclusive cross section and differential distributions*, *JHEP* **03** (2025) 189 [2411.15340].

[11] A. Kulesza, L. Motyka, T. Stebel and V. Theeuwes, *Soft gluon resummation for associated $t\bar{t}H$ production at the LHC*, *JHEP* **03** (2016) 065 [1509.02780].

[12] A. Broggio, A. Ferroglia, B. D. Pecjak, A. Signer and L. L. Yang, *Associated production of a top pair and a Higgs boson beyond NLO*, *JHEP* **03** (2016) 124 [1510.01914].

[13] A. Broggio, A. Ferroglia, B. D. Pecjak and L. L. Yang, *NNLL resummation for the associated production of a top pair and a Higgs boson at the LHC*, *JHEP* **02** (2017) 126 [1611.00049].

$\sqrt{S}$ [TeV]	m_H [GeV]	$\sigma_{\text{NNLO+NNLL+EW}}$ [fb]	$\Delta\mu_+$ [%]	$\Delta\mu_-$ [%]	ΔPDF [%]	$\Delta\alpha_{\text{s}}$ [%]	$\Delta_{\text{TH}}V$ [%]
13.0	124.60	534.2	+1.6	−2.2			
13.0	125.00	530.6	+1.7	−2.3			
13.0	125.09	528.8	+1.6	−2.2	2.3	1.7	0.9
13.0	125.38	524.9	+1.6	−2.2			
13.0	125.60	522.1	+1.6	−2.2			
13.0	126.00	517.6	+1.6	−2.2			
13.6	124.60	599.3	+1.5	−2.2			
13.6	125.00	592.5	+1.4	−2.1			
13.6	125.09	592.1	+1.5	−2.2	2.2	1.7	0.9
13.6	125.38	588.8	+1.5	−2.2			
13.6	125.60	586.0	+1.6	−2.2			
13.6	126.00	580.5	+1.6	−2.2			
14.0	124.60	642.6	+1.3	−2.1			
14.0	125.00	638.8	+1.5	−2.2			
14.0	125.09	636.1	+1.4	−2.1	2.2	1.6	0.9
14.0	125.38	635.1	+1.6	−2.2			
14.0	125.60	630.7	+1.5	−2.2			
14.0	126.00	624.1	+1.5	−2.2			

Table 6: Predictions for the process $t\bar{t}H$ as from Ref. [8]. Predictions include effects at NNLO QCD, supplemented by NNLL soft-gluon resummation, and NLO effects of EW origin [18, 19, 11, 12, 13, 14, 20, 15, 16, 17, 9, 10].

$\sqrt{s}$ [TeV]	m_H [GeV]	σ [fb]	δ_μ	δ_{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 7: 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]	$\delta_{\mu+\mathrm{FS}}$	δ_{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 8: 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 9: 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 10: Predictions for the process $\bar{t}H$, t-channel.

$\sqrt{s}$ [TeV]	m_H [GeV]	σ [fb]	δ_{μ}	δ_{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 11: 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 12: 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 13: Predictions for the process $\bar{t}H$, s-channel.

[14] A. Kulesza, L. Motyka, T. Stebel and V. Theeuwes, *Associated $t\bar{t}H$ production at the LHC: Theoretical predictions at NLO+NNLL accuracy*, *Phys. Rev. D* **97** (2018) 114007 [1704.03363].

[15] A. Kulesza, L. Motyka, D. Schwartländer, T. Stebel and V. Theeuwes, *Associated production of a top quark pair with a heavy electroweak gauge boson at NLO+NNLL accuracy*, *Eur. Phys. J. C* **79** (2019) 249 [1812.08622].

[16] A. Broggio, A. Ferroglia, R. Frederix, D. Pagani, B. D. Pecjak and I. Tsinikos, *Top-quark pair hadroproduction in association with a heavy boson at NLO+NNLL including EW corrections*, *JHEP* **08** (2019) 039 [1907.04343].

[17] A. Kulesza, L. Motyka, D. Schwartländer, T. Stebel and V. Theeuwes, *Associated top quark pair production with a heavy boson: differential cross sections at NLO+NNLL accuracy*, *Eur. Phys. J. C* **80** (2020) 428 [2001.03031].

[18] S. Frixione, V. Hirschi, D. Pagani, H. S. Shao and M. Zaro, *Weak corrections to Higgs hadroproduction in association with a top-quark pair*, *JHEP* **09** (2014) 065 [1407.0823].

[19] S. Frixione, V. Hirschi, D. Pagani, H. S. Shao and M. Zaro, *Electroweak and QCD corrections to top-pair hadroproduction in association with heavy bosons*, *JHEP* **06** (2015) 184 [1504.03446].

[20] 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].

[21] 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].

[22] 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].

[23] 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].

[24] 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].

[25] S. Frixione, B. Fuks, V. Hirschi, K. Mawatari, H.-S. Shao, P. A. Sunder et al., *Automated simulations beyond the Standard Model: supersymmetry*, *JHEP* **12** (2019) 008 [1907.04898].