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LHC Higgs WG4 group (formerly LHC-HH sub group)

Group organization

Group conveners:

Mail	ATLAS	CMS	THEORY
Mail	Stefano Manzoni (10/2022)	Fabio Monti (10/2023)	Ludovic Scyboz (02/2024) / Javier Mazzitelli (06/2018) / Maggie Mühlleitner

Group mailing list: lhc-higgs-hh

Meetings

- October 20, 2014.
- November 20, 2014.
- December 8, 2014.
- February 24, 2015.
- November 19, 2015.
- December 8, 2015.
- February 1, 2016.
- April 28, 2016.
- October 7, 2016.
- December 12, 2016.
- February 24, 2017.
- December 5, 2017.
- March 14, 2018.
- April 10, 2018.
- September 4-7, 2018 (workshop at Fermilab, USA).
- October 9, 2018.
- November 29, 2018.
- February 6, 2019.
- February 28, 2019.
- March 1, 2019.
- May 13, 2019.
- June 17, 2019.
- June 25, 2019.
- October 18, 2019 (part of the annual LHC Higgs XSWG meeting).
- January 29, 2020.
- April 27, 2020.
- July 7, 2020.
- September 25, 2020.
- November 11, 2020 (part of the annual LHC Higgs WG meeting).
- February 25, 2021
- September 29-30, 2021 (preparation for HH 2022 workshop next year in Croatia
- December 2, 2021 (part of the annual LHC Higgs WG meeting).
- May 30 - June 3, 2022 (workshop in Dubrovnik, Croatia)
- September 28, 2022

General documentation

CERN Yellow Reports: Handbook of LHC Higgs Cross Sections:

1. Inclusive Observables: CERN-2011-002, arXiv:1101.0593
2. Differential Distributions: CERN-2012-002, arXiv:1201.3084
3. Higgs Properties: CERN-2013-004, arXiv:1307.1347
4. Deciphering the Nature of the Higgs Sector: CERN-2017-002, arXiv:1610.07922

HH white paper: arXiv:1910.00012

References

Our recommendations for HH references:

References for production via gluon fusion

Minimal set of references:

NLO in large-mt limit [1].

Full NLO [2,3].

NNLO in large-mt limit [4].

NNLL in large-mt limit [5,6]: please cite if YR4 predictions are used.

NNLO FTa [7].

Combined (mtop + scale) uncertainties [8].

More... Close

[1] S. Dawson, S. Dittmaier, and M. Spira, Phys. Rev. D58 (1998) 115012, hep-ph/9805244.

[2] S. Borowka, N. Greiner, G. Heinrich, S. Jones, M. Kerner, J. Schlenk, U. Schubert, and T. Zirke, Phys. Rev. Lett. 117 (2016) 012001; erratum ibid 079901, arXiv:1604.06447.

[3] J. Baglio, F. Campanario, S. Glaus, M. Mühlleitner, M. Spira, and J. Streicher, Eur. Phys. J. C 79, arXiv:1811.05692.

[4] D. de Florian and J. Mazzitelli, Phys. Rev. Lett. 111 (2013) 201801, arXiv:1309.6594.

[5] D. Y. Shao, C. S. Li, H. T. Li, and J. Wang, JHEP07 (2013) 169, arXiv:1301.1245.

[6] D. de Florian and J. Mazzitelli, JHEP09 (2015) 053, arXiv:1505.07122.

[7] M. Grazzini, G. Heinrich, S. Jones, S. Kallweit, M. Kerner, J. M. Lindert, and J. Mazzitelli, JHEP05 (2018) 059, arXiv:1803.02463.

[8] J. Baglio, F. Campanario, S. Glaus, M. Mühlleitner, J. Ronca, and M. Spira, Phys. Rev. D 103, 056002 (2021), arXiv:2008.11626.

Additional references:

Virtual corrections for NNLO in large-mt limit [9,10].

Differential NNLO in large-mt limit [11].

More on full NLO and cross checks [12-14].

Monte Carlo full NLO [15-17].

NNLL FTa [18].

N3LO in large-mt limit [19,20].

N3LL in large-mt limit [21].

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[9] D. de Florian and J. Mazzitelli, Phys. Lett. B724 (2013) 306, arXiv:1305.5206.

[10] J. Grigo, K. Melnikov, and M. Steinhauser, Nucl. Phys. B888 (2014) 17, arXiv:1408.2422.

[11] D. de Florian, M. Grazzini, C. Hanga, S. Kallweit, J. M. Lindert, P. Maierhöfer, J. Mazzitelli, and D. Rathlev, JHEP09 (2016) 151, arXiv:1606.09519.

[12] S. Borowka, N. Greiner, G. Heinrich, S. P. Jones, M. Kerner, J. Schlenk, and T. Zirke, JHEP10 (2016) 107, arXiv:1608.04798.

[13] F. Maltoni, E. Vryonidou, and M. Zaro, JHEP11 (2014) 079, arXiv:1408.6542.

[14] R. Bonciani, G. Degrassi, P. P. Giardino, and R. Gröber, Phys. Rev. Lett. 121 (2018), 162003, arXiv:1806.11564.

[15] G. Heinrich, S. P. Jones, M. Kerner, G. Luisoni, and E. Vryonidou, JHEP08 (2017) 088, arXiv:1703.09252.

[16] S. P. Jones and S. Kuttimalai, JHEP02 (2018) 176, arXiv:1711.03319.

[17] G. Heinrich, S. P. Jones, M. Kerner, L. Scyboz, JHEP10 (2020) 021 arXiv:2006.16877

(supersedes JHEP06 (2019) 066, arXiv:1903.08137.)

[18] D. de Florian and J. Mazzitelli, JHEP08 (2018) 156, arXiv:1807.03704.

[19] L. Chen, H. T. Li, H. Shao and J. Wang, Phys. Lett. B803 (2020) 135292, arXiv:1909.06808.

[20] L. Chen, H. T. Li, H. Shao and J. Wang, JHEP03 (2020) 072, arXiv:1912.13001.

[21] A.H. Ajjath and H. Shao, arXiv:2209.03914.

References for EFT

Full NLO [22].

NLO large-mt limit [23,24].

NNLO large-mt limit [25].

Approximate NNLO QCD [26].

SMEFT, full NLO [27].

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[22] G. Buchalla, M. Capozi, A. Celis, G. Heinrich, and L. Scyboz, JHEP09 (2018) 057, arXiv:1806.05162.

[23] R. Gröber, M. Mühlleitner, M. Spira, and J. Streicher, JHEP09 (2015) 092, arXiv:1504.06577.

[24] R. Gröber, M. Mühlleitner, and M. Spira, Nucl. Phys. B925 (2017) 1, arXiv:1705.05314.

[25] D. de Florian, I. Fabre, and J. Mazzitelli, JHEP10 (2017) 215, arXiv:1704.05700.

[26] D. de Florian, I. Fabre, G. Heinrich, J. Mazzitelli, and L.Scyboz, JHEP 09 (2021) 161, arXiv:2106.14050.

[27] G. Heinrich, J. Lang, L. Scyboz, [update when published], arXiv:2204.13045.

References for other production modes

VBF NLO [28].

VBF NLO+PS [29].

VBF NNLO [30].

VBF differential NNLO [31].

VBF N3LO [32].

VBF NNLO+NLO EW [33].

Associated production with vector bosons at NNLO [28].

Production of tthh and tjhh at NLO [29].

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[31] F. A. Dreyer and A. Karlberg, Phys. Rev. D99 (2019) 074028, arXiv:1811.07918.

[32] F. A. Dreyer and A. Karlberg, Phys. Rev. D98 (2018), 114016, arXiv:1811.07906.

[33] F.A. Dreyer, A. Karlberg, J. Lang, and M. Pellen Eur.Phys.J.C 80 (2020) 11, 1037 arXiv:2005.13341.

References for MC generation

It is important to refer also to the implementation of the process in Powheg and not only to the generic Powheg-box paper, in particular:

- If the POWHEG generator ggHH is used (User-Processes-V2/ggHH) for SM predictions, ref.[15] should be cited.
- If predictions within a non-linear EFT are considered, as well as variations, ref.[17] should be cited.
- If the ggHH_SMEFT generator is used (User-Processes-V2/ggHH_SMEFT), ref.[27] should be cited.

List of tasks (under construction)

Task	Contact person	Timescale	Status
ggF: top-quark mass renormalization scheme uncertainty	M. Mühlleitner and J. Mazzitelli	**Completed**	arXiv:2008.11626 Phys. Rev. D 103, 056002 (2021)
ggF: NLO EFT frameworks and new shape benchmarks, HEFT vs SMEFT	R. Gröber and L. Cadamuro	**Completed**	CDS record
ggF: combination of H and HH (in connection with WG2 activities)	R. Gröber and S. Manzoni and N. Lu	2023	discussions with WG2 ongoing
ggF: cross section / MC for gg -> H + bb	J. Mazzitelli and S. Manzoni	**Completed**	JHEP 09 (2023), 179 (arXiv:2307.09992)
ggF/VBF: updated cross sections for 13.6TeV, various mH values and new PDF sets	J. Mazzitelli	2023	In progress
VBF: fiducial cross-sections vs coupling modifiers	R. Gröber	2023	Need external inputs
VBF: cross-sections for ggF HH+2j at hard matrix-element	J. Mazzitelli and S. Manzoni and N. Lu	Spring 2023	Ongoing. MC studies @ at LHC HH link
Resonant: benchmarks for spin-0 HH, SH and SS to be probed with 100-300/fb, including interference with non-resonant HH	M. Mühlleitner	paper complete, decision needed	arXiV:2112.12515 J. High Energ. Phys. 11 (2022)
Compositeness models: covered by EFT?	R. Gröber and M. Mühlleitner	end 2023	started

Current recommendations for HH cross-sections

Latest recommendations for gluon fusion

1) Inclusive ggF cross sections for Higgs boson pair production are reported below for different centre-of-mass energies in NNLO FTapprox, for m_H = 125 GeV with the central scale μ0 = μR = μF = M_{HH}/2 (see https://arxiv.org/abs/1803.02463). Scale uncertainties are obtained by probing six relative variations of μR and μF on top of the central one, i.e. (0.5;0.5), (0.5;1), (2;1), (1;1), (1;2), (1;0.5), (2;2): they are reported as superscript/subscript below. Uncertainties arising from the choice of renormalization scheme and scale of the top-quark mass (mtop scheme+scale unc.) and their combination with μR and μF variations (comb. unc.) are based on https://arxiv.org/abs/2008.11626. PDF uncertainties are estimated within the Born-improved approximation and are based on the PDF4LHC15nnlomc set. The uncertainties related to missing NNLO finite top-quark mass effects within the FT approximation are also presented (mtop approx. unc.).

√s	**7 TeV**	**8 TeV**	**13 TeV**	**13.6 TeV**	**14 TeV**	**27 TeV**	**100 TeV**
$_{\text{NNLO FTapprox}}$ [fb]	6.572	9.441	31.05	34.43	36.69	139.9	1224
PDF unc.	±3.5%	±3.1%	±2.1%	±2.1%	±2.1%	±1.7%	±1.7%
S unc.	±2.6%	±2.4%	±2.1%	±2.1%	±2.1%	±1.8%	±1.7%
PDF+ S unc.	±4.3%	±3.9%	±3.0%	±3.0%	±3.0%	±2.5%	±2.4%
Scale unc.	-6.5%+3.0%	-6.1%+2.8%	-5.0%+2.2%	-4.9%+2.1%	-4.9%+2.1%	-3.9%+1.3%	-3.2%+0.9%
mtop unc.	-	-	-18%+4%	-18%+4%	-18%+4%	-18%+4%	-18%+3%
Scale+mtop unc.	-	-	-23%+6%	-23%+6%	-23%+6%	-22%+5%	-21%+4%
mtop approx. unc.	*±2.2%*	*±2.3%*	*±2.6%*	*±2.7%*	*±2.7%*	*±3.4%*	*±4.6%*

The recommended uncertainties to be considered are PDF, alphaS (combined "**PDF+ S unc.**"), scale and mtop scheme (combined "**Scale+mtop unc.**").
The top mass approximation uncertainty reported in the last row should **not** be considered in analyses since it is expected to be covered by the larger mtop scheme uncertainty.

2) Inclusive ggF cross-sections for Higgs boson pair production at different values of m_H were obtained from those at m_H = 125 GeV after rescaling with the ratio $_{LO}(m_H)/_{LO}(125$ GeV$)$.

√s	**7 TeV**	**8 TeV**	**13 TeV**	**14 TeV**	**27 TeV**	**100 TeV**
$_{\text{NNLO FTapprox}}$ at m_H = 124.59 GeV [fb]	6.609	9.493	31.21	36.88	140.6	1229
$_{\text{NNLO FTapprox}}$ at m_H = 125.09 GeV [fb]	6.564	9.430	31.02	36.65	139.8	1223
$_{\text{NNLO FTapprox}}$ at m_H = 125.59 GeV [fb]	6.519	9.366	30.82	36.43	139.0	1217

3) Inclusive ggF cross-sections for Higgs boson pair production at **13 TeV**, for different values of the Higgs self-coupling modifier , obtained for m_H = 125 GeV with the central scale μ0 = μR = μF = M_{HH}/2 at $\text{NNLO}_{\text{NLO-i}}$ (rescaled to the NNLO FTapprox total cross section in the = 1 limit). For more details, see https://arxiv.org/abs/2003.01700. The central values have been updated after the bug-fixed discussed in the erratum of arXiv: 2204.13045 and https://arxiv.org/abs/2309.10525. The cross-section is found to be a quadratic function of :

= 69.18-48.803*+10.6586*^{2} in fb.

	-10	**-5**	**-1**	**0**	**1**	**2**	**2.4**	**3**	**5**	**10**
√s = 13 TeV [fb]	1623	579.7	128.6	69.17	31.05	14.20	13.45	18.69	91.63	647.0
Scale unc.	-7.3%+6.1%	-7.1%+5.7%	-6.4%+4.5%	-5.9%+3.7%	-5.0%+2.2%	-4.9%+2.1%	-5.5%+3.2%	-7.3%+6.2%	-8.4%+7.9%	-8.0%+7.3%
mtop unc.	-6%+10%	-7%+10%	-9%+8%	-12%+6%	-18%+4%	-23%+1%	-22%+4%	-15%+9%	-4%+13%	-4%+12%
Combined (Scale+mtop) unc.	**-13%+16%**	**-14%+16%**	**-15%+12%**	**-18%+10%**	**-23%+6%**	**-28%+3%**	**-28%+7%**	**-22%+15%**	**-12%+21%**	**-12%+19%**

In the table above, scale uncertainties are obtained by probing three relative variations of μR=μF, i.e. (0.5;0.5), (1;1), (2;2) and they are adjusted by a normalization factor in order to match those of the NNLO FTapprox SM prediction. The combined uncertainties are computed in https://arxiv.org/abs/2008.11626, and should be used for the Run 2 results. The upper and lower scale uncertainty bands can be parameterized in a quite accurate way with the following functions:

upper_unc[] = 76.13478 - 55.9001* + 12.5677*^{2} in fb.

lower_unc[] = 57.0153 - 42.2906* + 9.39052*^{2} in fb.

Given the central prediction versus , the percentage variation from scale uncertainties can then be computed for any given .

As for the PDF uncertainties, they have been found not to vary significantly with and are of the order of 3% over the whole range.

4) Inclusive ggF cross-sections for Higgs boson pair production at **13.6 TeV**, for different values of the Higgs self-coupling modifier , obtained for m_H = 125 GeV with the central scale μ0 = μR = μF = M_{HH}/2 at $NNLO_{NLO-i}$ (rescaled to the NNLO FTapprox total cross section in the = 1 limit). For more details, see https://arxiv.org/abs/2003.01700. The central values have been updated after the bug-fixed discussed in the erratum of arXiv: 2204.13045 and https://arxiv.org/abs/2309.10525.The cross-section is found to be a quadratic function of :

 = 76.4346-53.7587*+11.7158*^{2} in fb.

	-10	**-5**	**-1**	**0**	**1**	**2**	**2.4**	**3**	**5**	**10**
√s = 13.6 TeV [fb]	1786	638.1	141.9	76.43	34.43	15.77	14.91	20.59	100.5	710.4
Scale unc.	-7.3%+6.1%	-7.1%+5.7%	-6.4%+4.5%	-5.9%+3.7%	-4.9%+2.1%	-4.9%+2.1%	-5.5%+3.2%	-7.3%+6.2%	-8.4%+7.9%	-8.0%+7.3%
mtop unc.	-6%+10%	-7%+10%	-9%+8%	-12%+6%	-18%+4%	-23%+1%	-22%+4%	-15%+9%	-4%+13%	-4%+12%
Combined (Scale+mtop) unc.	**-13%+16%**	**-14%+16%**	**-15%+12%**	**-18%+10%**	**-23%+6%**	**-28%+3%**	**-28%+7%**	**-22%+15%**	**-12%+21%**	**-12%+19%**

In the table above, scale uncertainties are obtained by probing three relative variations of μR=μF, i.e. (0.5;0.5), (1;1), (2;2) and they are adjusted by a normalization factor in order to match those of the NNLO FTapprox SM prediction. The combined uncertainties are computed in https://arxiv.org/abs/2008.11626, and should be used for the Run 2 results. The upper and lower scale uncertainty bands can be parameterized in a quite accurate way with the following functions:

upper_unc[] = 84.1303 - 61.5633* + 13.8114*^{2} in fb.

lower_unc[] = 62.9873 - 46.5956* + 10.3251*^{2} in fb.

Given the central prediction versus , the percentage variation from scale uncertainties can then be computed for any given .

As for the PDF uncertainties, they have been found not to vary significantly with and are of the order of 3% over the whole range.

OLD recommendations for gluon fusion (from YR4)

More... Close

The table below shows NNLL-matched-to-NNLO cross-sections for gg HH with the central scale μ0 = μR = μF = $M_{HH}/2$, including top-quark mass effects at NLO. Uncertainties are evaluated using the PDF4LHC recommendation and are based on the PDF4LHC15nnlomc set. The theoretical uncertainty of 5% is related to missing finite top-quark mass effects. Prior to r27 of this twiki page, the recommended cross-sections at 13 and 14 TeV were under-estimated by a few per-mille with respect to those published in the YR4.

These are only to be used for publications related to the 2015+2016 dataset... neither for end-of-Run-2 papers nor for projections!

m_H	√s	$_{NNLO+NNLL}$ [fb]	scale unc. [%]	scale unc. [%]	th. unc. [%]	$_s$ unc. [%]	PDF unc. [%]
124.5 GeV	7 TeV	7.132	-5.7	+4.0	±5	±2.8	±3.4
	8 TeV	10.24	-5.7	+4.1	±5	±2.6	±3.0
	13 TeV	33.78	-6.0	+4.3	±5	±2.3	±2.1
	14 TeV	39.93	-6.0	+4.4	±5	±2.2	±2.1
125 GeV	7 TeV	7.078	-5.7	+4.0	±5	±2.8	±3.4
	8 TeV	10.16	-5.7	+4.1	±5	±2.6	±3.1
	13 TeV	33.53	-6.0	+4.3	±5	±2.3	±2.1
	14 TeV	39.64	-6.0	+4.4	±5	±2.2	±2.1
125.09 GeV	7 TeV	7.068	-5.7	+4.0	±5	±2.8	±3.4
	8 TeV	10.15	-5.7	+4.1	±5	±2.6	±3.1
	13 TeV	33.49	-6.0	+4.3	±5	±2.3	±2.1
	14 TeV	39.59	-6.0	+4.4	±5	±2.2	±2.1
125.5 GeV	7 TeV	7.023	-5.7	+4.0	±5	±2.8	±3.4
	8 TeV	10.09	-5.7	+4.1	±5	±2.6	±3.1
	13 TeV	33.29	-6.0	+4.3	±5	±2.3	±2.1
	14 TeV	39.35	-5.9	+4.4	±5	±2.2	±2.1

Sub-leading channels

HHjj (VBF)

The table below shows the cross-sections (in fb) for vector boson fusion (VBF) production of HHjj at N3LO QCD + NLO EW as discussed in https://arxiv.org/abs/2005.13341 and https://arxiv.org/abs/1811.07906. The renormalisation and factorisation scales are set to μ0 = μR = μF = $\sqrt{(M_H/2\times\sqrt{((M_H/2)^2+p^2_{T,HH})})}$.The first uncertainty is the scale uncertainty and the second is the PDF + s uncertainty based on the PDF4LHC21_40 set. Please cite [31], [32], [33] when using these numbers.

m_H (GeV)	√s = 13 TeV	√s = 13.6 TeV	√s = 14 TeV
124.6	1.699 $^{+0.05\%}_{-0.04\%}$ ±2.7%	1.886 $^{+0.05\%}_{-0.03\%}$ ±2.7%	2.018 $^{+0.05\%}_{-0.03\%}$ ±2.7%
125	1.687 $^{+0.05\%}_{-0.04\%}$ ±2.7%	1.874 $^{+0.05\%}_{-0.03\%}$ ±2.7%	2.005 $^{+0.05\%}_{-0.03\%}$ ±2.7%
125.09	1.684 $^{+0.05\%}_{-0.04\%}$ ±2.7%	1.870 $^{+0.05\%}_{-0.03\%}$ ±2.7%	2.001 $^{+0.05\%}_{-0.03\%}$ ±2.7%
125.38	1.676 $^{+0.05\%}_{-0.04\%}$ ±2.8%	1.861 $^{+0.05\%}_{-0.03\%}$ ±2.7%	1.992 $^{+0.05\%}_{-0.03\%}$ ±2.7%
125.6	1.671 $^{+0.05\%}_{-0.04\%}$ ±2.8%	1.856 $^{+0.05\%}_{-0.03\%}$ ±2.7%	1.985 $^{+0.05\%}_{-0.03\%}$ ±2.7%

Old HHjj recommendations

The table below shows the cross-sections (in fb) for vector boson fusion (VBF) production of HHjj at N3LO QCD with the renormalization and factorization scales set to the individual virtualities of the t-channel vector bosons. The first uncertainty is the scale uncertainty and the second is the PDF + s uncertainty based on the

PDF4LHC15nnlomc set.

m_H (GeV)	$\sqrt{s}$ = 13 TeV	$\sqrt{s}$ = 14 TeV	$\sqrt{s}$ = 27 TeV	$\sqrt{s}$ = 100 TeV
124.5	$1.739\,_{-0.04\%}^{+0.03\%}$ ±2.1%	$2.071\,_{-0.04\%}^{+0.03\%}$ ±2.1%	$8.459\,_{-0.04\%}^{+0.11\%}$ ±2.0%	$83.25\,_{-0.05\%}^{+0.15\%}$ ±2.1%
125	$1.726\,_{-0.04\%}^{+0.03\%}$ ±2.1%	$2.055\,_{-0.04\%}^{+0.03\%}$ ±2.1%	$8.404\,_{-0.04\%}^{+0.11\%}$ ±2.0%	$82.84\,_{-0.04\%}^{+0.13\%}$ ±2.1%
125.09	$1.723\,_{-0.04\%}^{+0.03\%}$ ±2.1%	$2.052\,_{-0.04\%}^{+0.03\%}$ ±2.1%	$8.394\,_{-0.04\%}^{+0.11\%}$ ±2.0%	$82.77\,_{-0.04\%}^{+0.11\%}$ ±2.1%
125.5	$1.711\,_{-0.04\%}^{+0.03\%}$ ±2.1%	$2.038\,_{-0.04\%}^{+0.03\%}$ ±2.1%	$8.349\,_{-0.04\%}^{+0.11\%}$ ±2.0%	$82.44\,_{-0.05\%}^{+0.14\%}$ ±2.1%

hhZ

Cross-section (in fb) vs centre-of-mass energy for hhZ production at NNLO QCD with the central scale μ0 = μR = μF = M_{hhZ}. The Higgs boson mass is set to 125 GeV. The first uncertainty is the scale uncertainty and the second is the PDF + s uncertainty based on the PDF4LHC15nnlomc set.

$\sqrt{s}$ = 13 TeV	$\sqrt{s}$ = 14 TeV	$\sqrt{s}$ = 27 TeV	$\sqrt{s}$ = 100 TeV
$0.363\,_{-2.7\%}^{+3.4\%}$ ±1.9%	$0.415\,_{-2.7\%}^{+3.5\%}$ ±1.8%	$1.23\,_{-3.3\%}^{+4.1\%}$ ±1.5%	$8.23\,_{-4.6\%}^{+5.9\%}$ ±1.7%

At 13 and 14 TeV, the table below shows cross-section variations with the Higgs boson mass:

m_h (GeV)	$\sqrt{s}$ = 13 TeV	$\sqrt{s}$ = 14 TeV
124.5	$0.368_{-2.6\%}^{+3.5\%}$ ±1.9%	$0.420_{-2.7\%}^{+3.6\%}$ ±1.8%
125	$0.363_{-2.7\%}^{+3.4\%}$ ±1.9%	$0.415_{-2.7\%}^{+3.5\%}$ ±1.8%
125.09	$0.362_{-2.6\%}^{+3.4\%}$ ±1.9%	$0.414_{-2.7\%}^{+3.5\%}$ ±1.8%
125.5	$0.359_{-2.7\%}^{+3.5\%}$ ±1.9%	$0.409_{-2.7\%}^{+3.5\%}$ ±1.9%

hhW^+

Cross-section (in fb) vs centre-of-mass energy for hhW^+ production at NNLO QCD with the central scale μ0 = μR = μF = M_{hhW}. The Higgs boson mass is set to 125 GeV. The first uncertainty is the scale uncertainty and the second is the PDF + s uncertainty based on the PDF4LHC15nnlomc set.

$\sqrt{s}$ = 13 TeV	$\sqrt{s}$ = 14 TeV	$\sqrt{s}$ = 27 TeV	$\sqrt{s}$ = 100 TeV
$0.329\,_{-0.41\%}^{+0.32\%}$ ±2.2%	$0.369\,_{-0.39\%}^{+0.33\%}$ ±2.1%	$0.941\,_{-0.53\%}^{+0.52\%}$ ±1.8%	$4.70\,_{-0.96\%}^{+0.90\%}$ ±1.8%

At 13 and 14 TeV, the table below shows cross-section variations with the Higgs boson mass:

m_h (GeV)	$\sqrt{s}$ = 13 TeV	$\sqrt{s}$ = 14 TeV
124.5	$0.333_{-0.41\%}^{+0.32\%}$ ±2.2%	$0.373_{-0.39\%}^{+0.33\%}$ ±2.1%
125	$0.329_{-0.41\%}^{+0.32\%}$ ±2.2%	$0.369_{-0.39\%}^{+0.33\%}$ ±2.1%
125.09	$0.329_{-0.41\%}^{+0.32\%}$ ±2.2%	$0.368_{-0.39\%}^{+0.33\%}$ ±2.1%
125.5	$0.326_{-0.41\%}^{+0.32\%}$ ±2.2%	$0.365_{-0.39\%}^{+0.33\%}$ ±2.1%

hhW^-

Cross-section (in fb) vs centre-of-mass energy for hhW^- production at NNLO QCD with the central scale μ0 = μR = μF = M_{hhW}. The Higgs boson mass is set to 125 GeV. The first uncertainty is the scale uncertainty and the second is the PDF + s uncertainty based on the PDF4LHC15nnlomc set.

$\sqrt{s}$ = 13 TeV	$\sqrt{s}$ = 14 TeV	$\sqrt{s}$ = 27 TeV	$\sqrt{s}$ = 100 TeV
$0.173\,_{-1.3\%}^{+1.2\%}$ ±2.8%	$0.198\,_{-1.3\%}^{+1.2\%}$ ±2.7%	$0.568\,_{-2.0\%}^{+1.9\%}$ ±2.1%	$3.30\,_{-4.3\%}^{+3.5\%}$ ±1.9%

At 13 and 14 TeV, the table below shows cross-section variations with the Higgs boson mass:

m_h (GeV)	$\sqrt{s}$ = 13 TeV	$\sqrt{s}$ = 14 TeV
124.5	$0.176_{-1.3\%}^{+1.2\%}$ ±2.8%	$0.200_{-1.3\%}^{+1.2\%}$ ±2.7%
125	$0.173_{-1.3\%}^{+1.2\%}$ ±2.8%	$0.198_{-1.3\%}^{+1.2\%}$ ±2.7%
125.09	$0.173_{-1.3\%}^{+1.2\%}$ ±2.8%	$0.197_{-1.3\%}^{+1.2\%}$ ±2.7%
125.5	$0.171_{-1.3\%}^{+1.2\%}$ ±2.8%	$0.195_{-1.3\%}^{+1.2\%}$ ±2.7%

HHjj (VBF)

tthh

Cross-section (in fb) vs centre-of-mass energy for tthh production at NLO QCD with the central scale μ0 = μR = μF = $M_{hh/2}$. The first uncertainty is the scale uncertainty and the second is the PDF + s uncertainty based on the PDF4LHC21_40 set.

m_H (GeV)	√s = 13 TeV	√s = 13.6 TeV	√s = 14 TeV
124.6	$0.764_{-15.0\%}^{+4.4\%}$ ±3.3%	$0.870_{-14.1\%}^{+4.1\%}$ ±3.3%	$0.947_{-13.5\%}^{+3.9\%}$ ±3.2%
125	$0.756_{-15.0\%}^{+4.3\%}$ ±3.4%	$0.860_{-14.0\%}^{+4.2\%}$ ±3.3%	$0.934_{-13.6\%}^{+3.9\%}$ ±3.2%
125.09	$0.754_{-15.0\%}^{+4.3\%}$ ±3.4%	$0.858_{-14.0\%}^{+4.2\%}$ ±3.3%	$0.931_{-13.6\%}^{+3.9\%}$ ±3.2%
125.3	$0.749_{-15.0\%}^{+4.2\%}$ ±3.4%	$0.852_{-13.9\%}^{+4.2\%}$ ±3.3%	$0.924_{-13.6\%}^{+3.9\%}$ ±3.2%
126	$0.732_{-14.9\%}^{+4.3\%}$ ±3.4%	$0.830_{-14.2\%}^{+4.1\%}$ ±3.3%	$0.903_{-13.6\%}^{+4.0\%}$ ±3.2%

Old recommendations

Cross-section (in fb) vs centre-of-mass energy for tthh production at NLO QCD with the central scale μ0 = μR = μF = $M_{hh/2}$. The Higgs boson mass is set to 125 GeV. The first uncertainty is the scale uncertainty and the second is the PDF + s uncertainty based on the PDF4LHC15nnlomc set.

√s = 13 TeV	√s = 14 TeV	√s = 27 TeV	√s = 100 TeV
$0.775_{-4.3\%}^{+1.5\%}$ ±3.2%	$0.949_{-4.5\%}^{+1.7\%}$ ±3.1%	$5.24_{-6.4\%}^{+2.9\%}$ ±2.5%	$82.1_{-7.4\%}^{+7.9\%}$ ±1.6%

At 13 and 14 TeV, the table below shows cross-section variations with the Higgs boson mass:

m_h (GeV)	√s = 13 TeV	√s = 14 TeV
124.5	$0.786_{-4.5\%}^{+1.3\%}$ ±3.2%	$0.968_{-4.6\%}^{+1.7\%}$ ±3.1%
125	$0.775_{-4.3\%}^{+1.5\%}$ ±3.2%	$0.949_{-4.5\%}^{+1.7\%}$ ±3.1%
125.09	$0.772_{-4.5\%}^{+1.7\%}$ ±3.2%	$0.949_{-4.8\%}^{+1.8\%}$ ±3.1%
125.5	$0.762_{-4.5\%}^{+1.3\%}$ ±3.2%	$0.937_{-4.5\%}^{+1.5\%}$ ±3.1%

hhtj

Cross-section (in fb) vs centre-of-mass energy for hhtj production at NLO QCD with the central scale μ0 = μR = μF = $M_{hh/2}$. The Higgs boson mass is set to 125 GeV. The first uncertainty is the scale uncertainty and the second is the PDF + s uncertainty based on the PDF4LHC15nnlomc set.

√s = 13 TeV	√s = 14 TeV	√s = 27 TeV	√s = 100 TeV
$0.0289_{-3.6\%}^{+5.5\%}$ ±4.7%	$0.0367_{-1.8\%}^{+4.2\%}$ ±4.6%	$0.254_{-2.8\%}^{+3.8\%}$ ±3.6%	$4.44_{-2.8\%}^{+2.2\%}$ ±2.4%

At 13 and 14 TeV, the table below shows cross-section variations with the Higgs boson mass:

m_h (GeV)	√s = 13 TeV	√s = 14 TeV
124.5	$0.0289_{-3.4\%}^{+5.4\%}$ ±4.6%	$0.0365_{-1.6\%}^{+4.4\%}$ ±4.7%
125	$0.0289_{-3.6\%}^{+5.5\%}$ ±4.7%	$0.0367_{-1.8\%}^{+4.2\%}$ ±4.6%
125.09	$0.0281_{-3.2\%}^{+5.2\%}$ ±4.5%	$0.0364_{-1.3\%}^{+3.7\%}$ ±4.7%
125.5	$0.0279_{-4.6\%}^{+6.1\%}$ ±6.4%	$0.0359_{-1.6\%}^{+3.8\%}$ ±4.7%

BSM predictions

Additional information about the EFT BSM parametrisation of HH can be found in the LHCHXSWG-INT-2016-001 internal note.

NMSSM benchmarks can be found here: link to NMSSM group twiki

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This topic: LHCPhysics > LHCHWGHH
Topic revision: r94 - 2024-05-23 - StefanoManzoni