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]
***ttbarH/tH* conveners:** Josh McFayden[13], Valeria Botta[14], Malgorzata Worek[14], Marco Zaro[12]
***bbbarH/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

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

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

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	$^{+0.067}_{-0.050}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 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 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	$^{+0.082}_{-0.061}$	$\pm 2.3/\pm 0.3/\pm 2.3$	± 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 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	$^{+0.13}_{-0.091}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 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

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	$^{+0.13}_{-0.093}$	$\pm 2.1/\pm 0.4/\pm 2.2$	± 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

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.

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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}[%]	$\Delta_{\mathrm{PDF}/\alpha_{\mathrm{s}}/\mathrm{PDF}\oplus\alpha_{\mathrm{s}}}$[%]	Δ_{TU}[%]	$\sigma^{\mathrm{DIS}}_{\mathrm{N3LO}}$[fb]	δ_{EW}[%]	σ_{γ}[fb]	σ_{nf}[fb]	$\sigma_{\mathrm{s/t/u}}$[fb]
120.00	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

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