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Updated predictions for Higgs production at the Tevatron and the LHC

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ABSTRACT

We present updated predictions for the total cross section for Higgs boson production through gluon fusion at hadron colliders. In addition to renormalization-group improvement at next-to-next-to-next-to-leading logarithmic accuracy, we incorporate the two-loop electroweak corrections, which leads to the most precise predictions at present. Numerical results are given for Higgs masses between 115 GeV and 200 GeV at the Tevatron with $\sqrt{s} = 1.96$ TeV and the LHC with $\sqrt{s} = 7$–14 TeV.

The search for the Higgs boson is of the highest priority in the experimental programs at the Fermilab Tevatron and the CERN LHC. The lower bound for the Higgs mass obtained by the direct searches at LEP, $m_H \geqslant 114.4$ GeV at the 95% CL, has been around for several years [1]. At the beginning of this year, the CDF and D0 Collaborations published a new result which excludes Higgs bosons with a mass around $2m_W$ [2]. After a recent update, the Tevatron exclusion now covers the range 158 GeV $< m_H <$ 175 GeV [3]. On the other hand, the electroweak precision measurements favor a relatively light Higgs boson with a mass well below 200 GeV [4]. The LHC has started operation recently, and the standard model Higgs boson, if it exists, should be within reach in the next few years.

At hadron colliders, the most important production channel for the Higgs boson is the gluon fusion process. Much effort has been devoted to improving the theoretical predictions for this process, especially since it is well known that the total cross section suffers from huge QCD corrections [5–9]. In the recent papers [10,11], we have pointed out that a large portion of these corrections comes from enhanced contributions of the form $(C_A\pi\alpha_s)^n$, which arise in the analytic continuation of the gluon form factor from space-like to time-like momentum transfer. In those two papers, these large contributions, as well as threshold enhanced terms, were resummed to all orders in α_s at next-to-next-to-next-to-leading logarithmic (N^{3}LL) accuracy using renormalization-group (RG) methods.

It is however necessary to update the numerical predictions presented in [11]. One reason is that there we have only provided results for the LHC at $\sqrt{s} = 14$ TeV, while it is now clear that the LHC will operate at a lower energy for two or more years. Another reason is the recent effort to evaluate the electroweak corrections to this process [12–15]. Given that QCD effects are well under control in our result (less than 3% remaining scale uncertainty and perfect perturbative convergence), these electroweak corrections, which can be as large as 6%, are non-negligible and should be included. The $\mathcal{O}(\alpha)$ electroweak corrections can be split into two parts. The part involving a light quark loop was computed in [12]. The part involving the top quark in the loop was first calculated in [13] as an expansion in $m_H^2/(4m_W^2)$, which is therefore formally valid only for $m_H < 2m_W$. The complete $\mathcal{O}(\alpha)$ corrections including the exact top quark contributions were later evaluated in [14, 15] using numerical methods.

Given the $\mathcal{O}(\alpha)$ corrections, there are still ambiguities in how to combine them with the QCD corrections. In [14] two schemes were proposed, which were called the "partial factorization" scheme and the "complete factorization" scheme. In the partial factorization scheme the $\mathcal{O}(\alpha)$ corrections are simply added to the QCD corrected cross section, while in the complete factorization scheme the $\mathcal{O}(\alpha)$ corrections serve as a prefactor in front of the QCD corrected cross section, which then generate terms of $\mathcal{O}(\alpha\alpha_s^n)$. Since the QCD corrections in fixed-order perturbation theory are large, these two schemes can have non-negligible differences, and it was not known at that time which one is better without an explicit calculation of the $\mathcal{O}(\alpha\alpha_s)$ contributions. This task has been undertaken in [16], where it was demonstrated that although the complete factorization does not hold exactly, numer-

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Table 1
Cross sections (in pb) for different Higgs masses at the Tevatron and the LHC, using MSTW2008NNLO PDFs. As in [11], the first error accounts for scale variations, while the second one reflects the uncertainty in the PDFs.

m_H [GeV]	Tevatron	LHC (7 TeV)	LHC (10 TeV)	LHC (14 TeV)
115	$1.215^{+0.031+0.070}_{-0.007-0.075}$	$18.19^{+0.53+0.46}_{-0.14-0.57}$	$33.7^{+1.0+0.8}_{-0.2-1.0}$	$57.9^{+1.6+1.4}_{-0.4-1.8}$
120	$1.073^{+0.026+0.064}_{-0.006-0.069}$	$16.73^{+0.48+0.43}_{-0.13-0.53}$	$31.2^{+0.9+0.7}_{-0.2-1.0}$	$54.0^{+1.5+1.3}_{-0.3-1.7}$
125	$0.950^{+0.022+0.059}_{-0.005-0.063}$	$15.43^{+0.44+0.40}_{-0.12-0.49}$	$29.0^{+0.8+0.7}_{-0.2-0.9}$	$50.4^{+1.4+1.2}_{-0.3-1.6}$
130	$0.844^{+0.019+0.054}_{-0.004-0.058}$	$14.27^{+0.40+0.37}_{-0.11-0.46}$	$27.0^{+0.7+0.6}_{-0.2-0.8}$	$47.2^{+1.3+1.1}_{-0.3-1.5}$
135	$0.752^{+0.016+0.050}_{-0.004-0.053}$	$13.23^{+0.36+0.35}_{-0.10-0.42}$	$25.2^{+0.7+0.6}_{-0.2-0.8}$	$44.3^{+1.2+1.0}_{-0.3-1.3}$
140	$0.673^{+0.014+0.046}_{-0.003-0.049}$	$12.29^{+0.33+0.33}_{-0.09-0.40}$	$23.5^{+0.6+0.6}_{-0.2-0.7}$	$41.6^{+1.1+1.0}_{-0.3-1.3}$
145	$0.602^{+0.012+0.043}_{-0.003-0.045}$	$11.44^{+0.31+0.32}_{-0.09-0.37}$	$22.1^{+0.6+0.5}_{-0.1-0.7}$	$39.2^{+1.0+0.9}_{-0.2-1.2}$
150	$0.541^{+0.010+0.039}_{-0.002-0.042}$	$10.67^{+0.28+0.30}_{-0.08-0.35}$	$20.7^{+0.5+0.5}_{-0.1-0.6}$	$37.0^{+1.0+0.9}_{-0.2-1.1}$
155	$0.486^{+0.009+0.036}_{-0.002-0.039}$	$9.95^{+0.26+0.28}_{-0.07-0.33}$	$19.4^{+0.5+0.5}_{-0.1-0.6}$	$34.9^{+0.9+0.8}_{-0.2-1.0}$
160	$0.433^{+0.008+0.033}_{-0.002-0.035}$	$9.21^{+0.24+0.27}_{-0.07-0.31}$	$18.1^{+0.5+0.4}_{-0.1-0.6}$	$32.7^{+0.8+0.8}_{-0.2-1.0}$
165	$0.385^{+0.006+0.030}_{-0.002-0.032}$	$8.50^{+0.22+0.25}_{-0.06-0.29}$	$16.8^{+0.4+0.4}_{-0.1-0.5}$	$30.5^{+0.8+0.7}_{-0.2-0.9}$
170	$0.345^{+0.005+0.028}_{-0.002-0.030}$	$7.89^{+0.20+0.24}_{-0.05-0.27}$	$15.7^{+0.4+0.4}_{-0.1-0.5}$	$28.6^{+0.7+0.7}_{-0.2-0.8}$
175	$0.310^{+0.005+0.026}_{-0.001-0.027}$	$7.36^{+0.18+0.23}_{-0.05-0.26}$	$14.7^{+0.4+0.4}_{-0.1-0.5}$	$27.0^{+0.7+0.6}_{-0.2-0.8}$
180	$0.280^{+0.004+0.024}_{-0.001-0.025}$	$6.88^{+0.17+0.22}_{-0.04-0.24}$	$13.8^{+0.3+0.4}_{-0.1-0.4}$	$25.5^{+0.6+0.6}_{-0.1-0.7}$
185	$0.252^{+0.003+0.022}_{-0.001-0.023}$	$6.42^{+0.16+0.20}_{-0.04-0.23}$	$13.0^{+0.3+0.3}_{-0.1-0.4}$	$24.0^{+0.6+0.6}_{-0.1-0.7}$
190	$0.228^{+0.003+0.020}_{-0.001-0.021}$	$6.02^{+0.14+0.20}_{-0.04-0.22}$	$12.2^{+0.3+0.3}_{-0.1-0.4}$	$22.7^{+0.5+0.5}_{-0.1-0.7}$
195	$0.207^{+0.002+0.019}_{-0.001-0.020}$	$5.67^{+0.13+0.19}_{-0.04-0.21}$	$11.6^{+0.3+0.3}_{-0.1-0.4}$	$21.6^{+0.5+0.5}_{-0.1-0.6}$
200	$0.189^{+0.002+0.018}_{-0.001-0.019}$	$5.35^{+0.13+0.18}_{-0.04-0.20}$	$11.0^{+0.3+0.3}_{-0.1-0.3}$	$20.6^{+0.5+0.5}_{-0.1-0.6}$

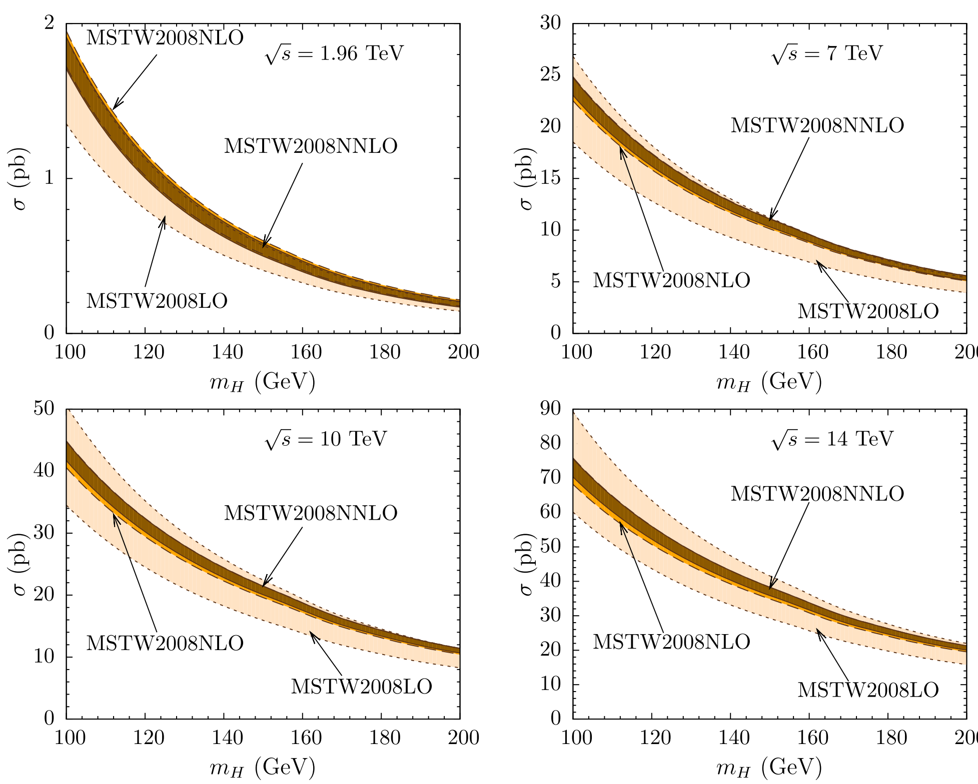

Fig. 1. Cross sections at the Tevatron for $\sqrt{s} = 1.96$ TeV and the LHC for $\sqrt{s} = 7$, 10, 14 TeV. Bands indicate scale uncertainties and PDF uncertainties combined in quadrature. Light, medium and dark bands represent LO (NLL), NLO (NNLL) and NNLO (N^{3}LL) in RG-improved perturbation theory, respectively.

ically it gives a good approximation to the $\mathcal{O}(\alpha\alpha_s)$ terms. We will therefore adopt the complete factorization approach in our result. The relative contribution of the electroweak corrections is about 4% for $m_H \sim 100$ GeV, rises to about 6% at the WW threshold, and quickly drops to about -2% for $m_H \sim 200$ GeV.

The uncertainties in our predictions come from several sources. The uncertainty concerning unknown higher-order QCD corrections can be estimated from the scale dependence of the cross section. In our approach there are four scales: μ_t, μ_h, μ_s and μ_f, and we estimate the scale uncertainty by varying the scales up and down