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Top Quark and Charged Higgs Production at Hadron Colliders

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Top quark and charged Higgs production at hadron colliders

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Abstract

I present a brief theoretical update on top quark pair production at the Tevatron and give values of the NNLO-NNNLL cross section for both $m_t = 175$ and 178 GeV. I then present a calculation of the cross section for charged Higgs production in association with a top quark at the LHC, including NNLO soft-gluon corrections.

1 Top quark production at the Tevatron

The properties of the top quark, in particular its mass and production cross section, are subjects of intense study at the Tevatron [1, 2]. The most accurate theoretical prediction [3] for top quark pair production at the Tevatron includes soft-gluon corrections [4, 5, 6] through next-to-next-to-next-to-leading logarithmic (NNNLL) accuracy at next-to-next-to-leading order (NNLO), denoted as NNLO-NNNLL [3]. These corrections are sizable and provide a dramatic decrease in the scale dependence of the cross section. Results have been derived in both single-particle-inclusive (1PI) kinematics and pair-invariant-mass (PIM) kinematics. There are differences in the results in the two kinematics due to subleading terms, and the best estimate is given by the average of the two kinematics.

For a top quark mass $m_t = 175$ GeV the theoretical value of the cross section is [3]

$$\sigma_{t\bar{t}}^{NNLO-NNNLL}(\sqrt{S} = 1.8 \text{ TeV}, m_t{=}175 \text{ GeV}) = 5.24 \pm 0.31 \text{ pb} \quad \text{and}$$

$$\sigma_{t\bar{t}}^{NNLO-NNNLL}(\sqrt{S} = 1.96 \text{ TeV}, m_t{=}175 \text{ GeV}) = 6.77 \pm 0.42 \text{ pb}$$

at Run I and Run II, respectively. The uncertainty indicated is due to the kinematics ambiguity; the scale uncertainty is much smaller.

Some recent data from the Tevatron suggest a value for the top quark mass around $m_t = 178$ GeV. For that value of top mass the theoretical cross sections become

$$\sigma_{t\bar{t}}^{NNLO-NNNLL}(\sqrt{S}=1.8 \text{ TeV}, m_t{=}178 \text{ GeV}) = 4.76 \pm 0.28 \text{ pb} \quad \text{and}$$

$$\sigma_{t\bar{t}}^{NNLO-NNNLL}(\sqrt{S}=1.96 \text{ TeV}, m_t{=}178 \text{ GeV}) = 6.15 \pm 0.38 \text{ pb}.$$

Results for the top quark transverse momentum distributions at NNLO-NNNLL are also available [3].

2 Charged Higgs production via $bg \to tH^-$

A future discovery of a charged Higgs boson would be an umistakable sign of new physics beyond the Standard Model [7]. The LHC has good potential for such a discovery through the partonic process $bg \to tH^-$. The Born cross section is proportional to $\alpha\alpha_s(m_b^2 \tan^2\beta + m_t^2 \cot^2\beta)$, where $\tan\beta = v_2/v_1$ is the ratio of the vacuum expectation values (vev's) of two Higgs doublets in the MSSM.

Full NLO calculations have recently become available [8, 9], and they show that the NLO corrections are big. Since charged Higgs production will be a near-threshold process at the LHC, given the expected large mass of this particle (hundreds of GeV), threshold soft-gluon corrections can provide significant enhancements of the cross section. A next-to-leading logarithm (NLL) calculation of these corrections at NNLO, denoted as NNLO-NLL [10], showed that indeed the soft-gluon corrections are substantial and they decrease the scale dependence of the cross section, thus providing a better theoretical prediction.

For the process $b(p_b)+g(p_g) \longrightarrow t(p_t)+H^-(p_{H^-})$ we define $s=(p_b+p_g)^2$, $t=(p_b-p_t)^2$, $u=(p_g-p_t)^2$, and $s_4 = s+t+u-m_t^2-m_{H^-}{}^2$. At threshold $s_4 \to 0$. The soft-gluon corrections take the form $[(\ln^l(s_4/m_{H^-}^2))/s_4]_+$. For the order α_s^n corrections, $l \leq 2n-1$. The leading logarithms (LL) are those with $l=2n-1$, while for the NLL $l=2n-2$. We calculate NLO and NNLO corrections at NLL accuracy.

In Figure 1 we plot the cross section versus charged Higgs mass for pp collisions at the LHC with $\sqrt{S}=14$ TeV. We use the MRST2002 approximate NNLO parton distributions functions (PDF) [11] with the respective

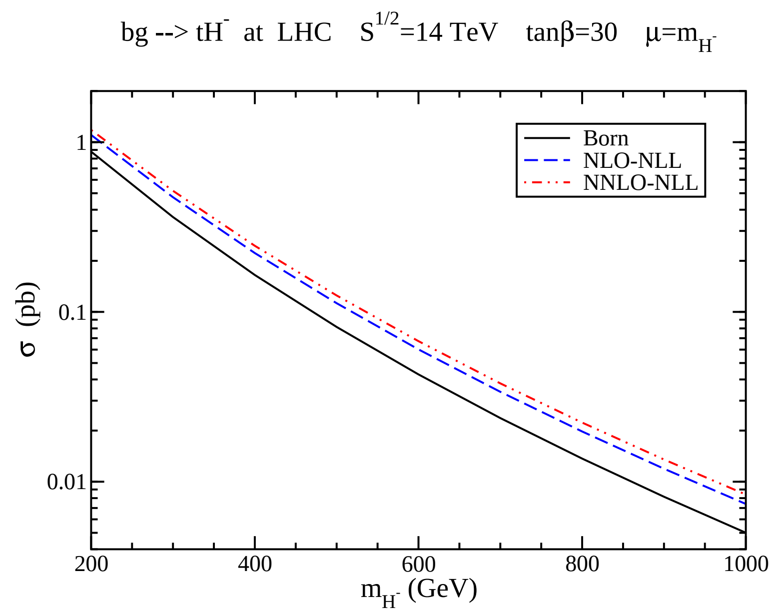

Figure 1: The total cross section for charged Higgs production at the LHC.

three-loop evaluation of α_s. We set the factorization scale equal to the renormalization scale and denote this common scale by μ. We show results for the Born, NLO-NLL, and NNLO-NLL cross sections, all with a choice of scale $\mu = m_{H^-}$. In our calculations we use $\tan\beta = 30$. The NLO and NNLO threshold corrections are positive and provide a significant enhancement to the lowest-order result. We note that the cross sections for the related process $\bar{b}g \to \bar{t}H^+$ are exactly the same.

In Figure 2 we plot K-factors, i.e. ratios of cross sections at various orders. On the left-hand side, the NLO-NLL / Born curve shows that the NLO threshold corrections enhance the Born cross section by approximately 25% to 50% depending on the mass of the charged Higgs. The NNLO-NLL / Born curve shows that if we include the NNLO threshold corrections we get an enhancement over the Born result of approximately 35% to 70% in the range of masses shown. Finally, the NNLO-NLL / NLO-NLL curve shows clearly the further enhancement over NLO that the NNLO threshold corrections provide, between 7% and 14%. On the right-hand side we compare our NLO-NLL results with the exact results that have been derived in [8]. To make the comparison with [8], the NLO-NLL result is calculated here for $\mu = m_{H^-}+m_t$,

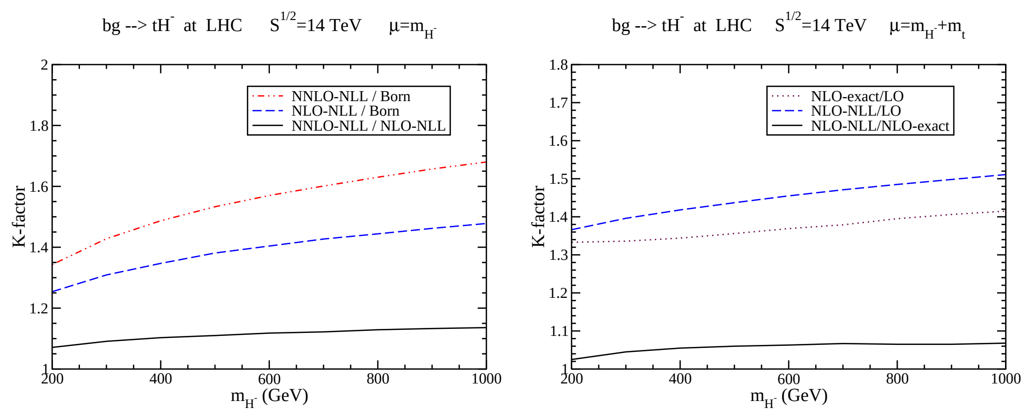

Figure 2: K-factors for charged Higgs production at the LHC.

the choice of scale used in that reference, and also using a two-loop α_s. Also the use of K-factors removes any discrepancies arising from different choices of parton distribution functions. The NLO-NLL / NLO-exact curve is very close to 1 (only a few percent difference), and this shows that the NLO-NLL cross section is a remarkably good approximation to the exact NLO result. As noted before, we might have expected this on theoretical grounds since this is near-threshold production, and also from prior experience with many other near-threshold hard-scattering cross sections [3, 5, 12].

In Figure 3, we plot the scale dependence of the cross section for a fixed charged Higgs mass $m_{H^-} = 500$ GeV. We plot a large range in scale, $0.1 \leq \mu/m_{H^-} \leq 10$, and see indeed that the threshold corrections greatly decrease the scale dependence of the cross section. The NNLO-NLL curve is relatively flat. For comparison we also plot the results using only a leading logarithm (LL) approximation. We see that the LL results display a large scale dependence at both NLO and NNLO, and are not an improvement over the Born result. The NLL terms are essential in diminishing the scale dependence. The difference between the LL and NLL results at both NLO and NNLO can be very substantial. Thus having a complete NLL calculation, as provided here, is crucial in providing stable theoretical predictions.

Finally, we note that even higher-order corrections may provide sizable contributions to hard-scattering cross sections. In particular current calculations of next-to-next-to-next-to-leading order (NNNLO) soft-gluon corrections indicate a non-negligible enhancement of the cross section for charged

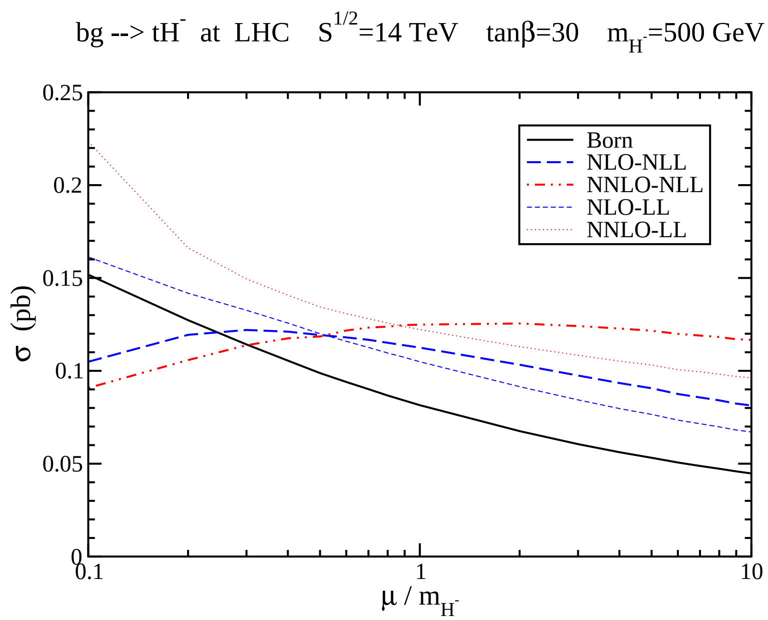

Figure 3: The scale dependence of the charged Higgs cross section.

Higgs production.

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