W-boson production with large transverse momentum at the LHC

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Abstract

We study W-boson production with large transverse momentum, Q_T, in pp collisions at the LHC. We calculate the complete NLO corrections and the soft-gluon NNLO corrections to the differential cross section. The NLO corrections are large but they do not reduce the scale dependence relative to LO, while the NNLO soft-gluon corrections, although small, significantly reduce the scale dependence and thus provide a more stable result.

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1 Introduction

W hadroproduction at large Q_T is useful in testing the Standard Model and in estimating backgrounds to Higgs production and to new physics such as new gauge bosons. Accurate theoretical predictions for W production at the LHC, scheduled to begin operation in 2007, are thus needed.

Calculations of the NLO cross section for W production at large transverse momentum at the Fermilab Tevatron collider were presented in Refs. [1,2]. The NLO corrections contribute to enhance the differential distributions in Q_T of the W boson and they reduce the factorization and renormalization scale dependence of the cross section at the Tevatron. More recent studies [3, 4] included soft-gluon corrections through NNLO, which provide additional enhancements and a further reduction of the scale dependence [4].

Here we discuss W production with large Q_T at the LHC. The results presented are based on Ref. [5]. The partonic channels at LO are $q(p_a)+g(p_b) \longrightarrow W(Q)+q(p_c)$ and $q(p_a) + \bar{q}(p_b) \longrightarrow W(Q) + g(p_c)$. We define the kinematical invariants $s = (p_a + p_b)^2$, $t = (p_a - Q)^2$, $u = (p_b - Q)^2$ and $s_2 = s + t + u - Q^2$. At threshold $s_2 \to 0$. The NLO cross section is

$$E_Q \frac{d\hat{\sigma}_{f_a f_b \to W(Q)+X}}{d^3Q} = \delta(s_2)\alpha_s(\mu_R^2)\left[A(s,t,u) + \alpha_s(\mu_R^2)B(s,t,u,\mu_R)\right] + \alpha_s^2(\mu_R^2)C(s,t,u,s_2,\mu_F). \tag{1.1}$$

$A(s,t,u)$ arises from the LO processes. $B(s,t,u,\mu_R)$ is the sum of virtual corrections and of singular terms $\sim\delta(s_2)$ in the real radiative corrections. $C(s,t,u,s_2,\mu_F)$ is from real emission processes away from $s_2 = 0$.

The soft-gluon corrections [6] are of the form $[\ln^l(s_2/Q_T^2)/s_2]_+$, where for the order α_s^n corrections $l \leq 2n-1$. These corrections can be calculated at higher orders using the formulas in Ref. [7], which have also been applied recently to other electroweak processes [8].

2 Numerical results

We consider W production at large transverse momentum in pp collisions at the LHC with $\sqrt{S} = 14$ TeV. We use the MRST2002 parton densities [9].

In Figure 1 we plot the transverse momentum distribution, $d\sigma/dQ_T^2$, at large Q_T. Here we set $\mu_F = \mu_R = Q_T$ and denote this common scale by μ. We plot the LO, NLO, and NNLO-NNNLL results. Here NNLO-NNNLL means that we include the (approximate) NNNLL soft-gluon terms at NNLO in α_s. The NLO corrections provide a significant enhancement of the LO Q_T distribution, a 30% to 50% increase

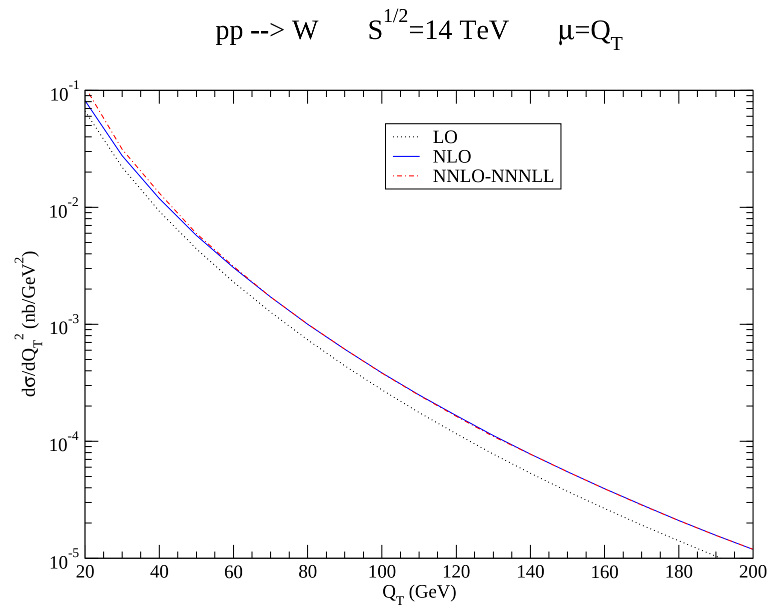

Figure 1: The differential cross section, $d\sigma/dQ_T^2$, for W production at the LHC.

in the Q_T range shown. The NNLO-NNNLL corrections provide a further rather small enhancement which is hardly visible in the plot.

In Figure 2 we plot the scale dependence of $d\sigma/dQ_T^2$ for $Q_T = 80$ GeV. We note that, surprisingly, the scale dependence of the cross section is not reduced when the NLO corrections are included, but we have an improvement when the NNLO-NNNLL corrections are added. We find similar results for other Q_T values. If we plot the LO scale dependence separately for μ_F and μ_R with the other held fixed (see fig. 4 of Ref. [5]), we find that the cross section increases with positive curvature as the renormalization scale μ_R is decreased (as expected due to asymptotic freedom), but that the μ_F dependence has negative curvature and the cross section increases with scale. The latter behavior is due to the fact that the cross section is dominated by $qg \to Wq$ and the gluon density in the proton increases rapidly with scale at fixed x smaller than $\sim$0.01. At LHC energies, the μ_R and μ_F dependencies cancel one another approximately.

In Figure 3 we plot $d\sigma/dQ_T^2$ at high Q_T for two values of the scale, $Q_T/2$ and $2Q_T$, often used to display the uncertainty due to scale variation. We note that while the variation of the LO cross section is significant and the variation at NLO is similar to LO, at NNLO-NNNLL it is very small: the two NNLO-NNNLL curves lie very close to each other.

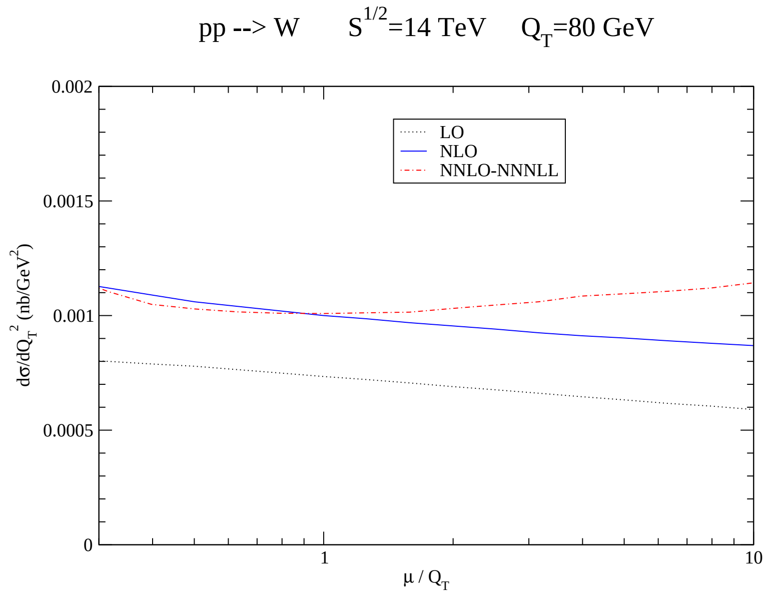

Figure 2: $d\sigma/dQ_T^2$ for W production at the LHC with $Q_T = 80$ GeV and $\mu = \mu_F = \mu_R$.

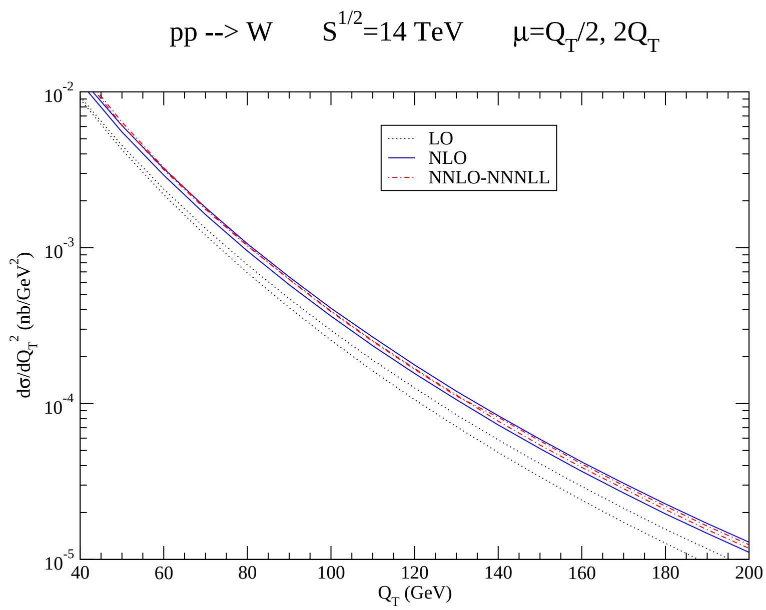

Figure 3: $d\sigma/dQ_T^2$ for W production at the LHC with $\mu = \mu_F = \mu_R = Q_T/2$ (upper lines) and $2Q_T$ (lower lines).

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