Large-\(Q_T\) \(W\)-boson production at the Tevatron\(^1\)

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Abstract

The production of \(W\) bosons at large transverse momentum at the Tevatron is dominated by soft-gluon corrections. In this talk we present a calculation of these corrections at next-to-next-to-leading order. The corrections enhance the transverse momentum distribution of the \(W\) while reducing the scale dependence.

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1 Introduction

$W$ hadroproduction is useful in estimates of backgrounds to new physics (such as Higgs production). The transverse momentum, $Q_T$, distribution of the $W$ falls rapidly by several orders of magnitude as $Q_T$ increases.

Full next-to-leading order (NLO) results for $W$ hadroproduction at large $Q_T$ have been available for some time [1, 2]. At lowest order the partonic channels involved are

$q(p_a) + g(p_b) \to W(Q) + q(p_c)$

and

$q(p_a) + \bar{q}(p_b) \to W(Q) + g(p_c)$.

We define $s = (p_a + p_b)^2$, $t = (p_a - Q)^2$, $u = (p_b - Q)^2$ and $s_2 = s + t + u - Q^2$. At threshold, i.e. when we have just enough energy to produce a $W$ with a certain $Q_T$, $s_2 \to 0$.

The large-$Q_T$ distribution is enhanced by soft-gluon corrections, which are dominant near threshold. These corrections are of the form

$D_{l}(s_2) \equiv \left[ \ln\left(\frac{s_2/Q_T^2}{s_2}\right) / s \right]^l$.

For the order $\alpha_s^l$ corrections $l \leq 2n - 1$. At NLO in $\alpha_s$, we have terms with $D_1(s_2)$ and $D_0(s_2)$ logarithms, as well as $\delta(s_2)$ terms that involve the virtual corrections.

At next-to-next-to-leading order (NNLO) in $\alpha_s$, we have terms with $D_3(s_2)$, $D_2(s_2)$, $D_1(s_2)$, and $D_0(s_2)$ logarithms, as well as $\delta(s_2)$ terms for the virtual corrections. Thus, at NNLO, the leading logs (LL) are $D_3(s_2)$, the next-to-leading logs (NLL) are $D_2(s_2)$, the next-to-next-to-leading logs (NNLL) are $D_1(s_2)$, and the next-to-next-to-next-to-leading logs (NNNLL) are $D_0(s_2)$.

We can formally resum these soft logarithms to all orders in $\alpha_s$ [3, 4, 5]. This has been done explicitly for $W$ production in Ref. [6]. However, for numerical results here we expand the resummed formula to NNLO to avoid using prescriptions for the resummed cross section [7].

A unified approach and a master formula for calculating these soft logarithms at NNLO for any process has been presented in Ref. [8]. It has been applied to $W$ production in Ref. [9].

2 $W$ production with large $Q_T$ at the Tevatron

We now present our numerical results for large-$Q_T$ $W$-boson production [9] at the Fermilab Tevatron.

The $Q_T$ distribution is shown in Fig. 1 at Tevatron Run I, with $\sqrt{S} = 1.8$ TeV. In the left frame we show the differential distribution $d\sigma / dQ_T^2$ at Born (lowest order), NLO, and NNLO, all with scale $\mu = Q_T$, while in the right frame we show a plot of the scale dependence at $Q_T = 80$ GeV. For the NNLO corrections we show both NNLL and NNNLL results. The NNLL results are complete while in the NNNLL results we have included the dominant NNNLL terms (more two-loop calculations are needed for an exact NNNLL calculation [10]). Throughout we have used the MRST2002 NNLO parton densities [11]. We see that the NNLO corrections are not very large but they significantly diminish the factorization/renormalization scale dependence of the cross section.

In Fig. 2 we show similar results for Tevatron Run II, with $\sqrt{S} = 1.96$ TeV. In the left frame we plot $d\sigma / dQ_T^2$ with $\mu = Q_T$, while in the right frame we show results at $\mu = Q_T/2$ and $2Q_T$. Again, the reduction of the scale dependence at NNLO is evident: the two NNLO curves are on top of each other. Finally, we note that similar results have been derived for the related
process of direct photon production [12].

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Figure 2: $W$-boson production at large $Q_T$ at $\sqrt{S} = 1.96$ TeV.

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