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Theoretical Results for Electroweak-boson and Single-top Production

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I present results from recent high-order calculations for the production of electroweak bosons and top quarks. In particular, I discuss W and Z boson production at large transverse momentum, single-top production, and FCNC top production. Theoretical predictions which include higher-order soft-gluon corrections are presented for total cross sections and differential distributions at the LHC.

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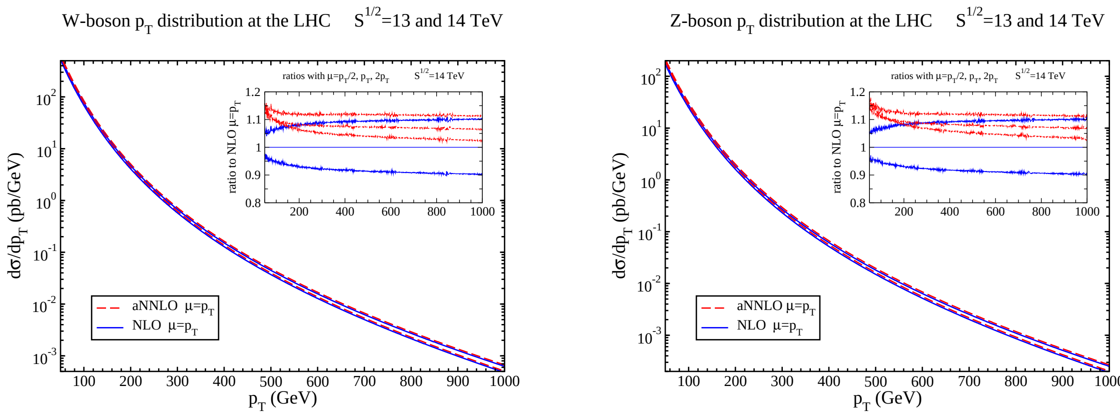


Figure 1: aNNLO W-boson (left) and Z-boson (right) p_T distributions at the LHC.

1. Introduction

Higher-order corrections are very significant for W and Z distributions at large transverse momentum, p_T, as well as for single-top production cross sections and p_T distributions. Soft-gluon contributions are an important and dominant part of the perturbative corrections.

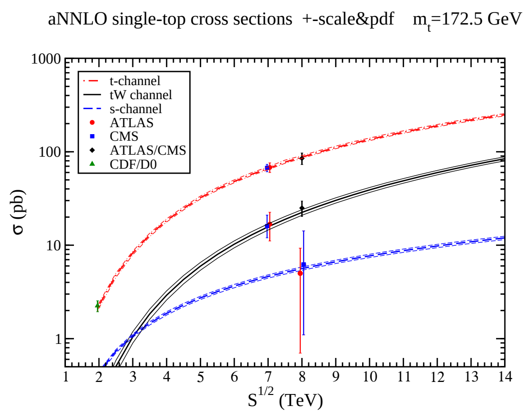
The soft-gluon terms in the nth-order corrections involve logarithms $[\ln^k(s_4/p_T^2)/s_4]_+$ for electroweak-boson production and $[\ln^k(s_4/m_t^2)/s_4]_+$ for single-top production, with $k \le 2n-1$ and s_4 the kinematical distance from partonic threshold. These soft corrections have been resummed at NNLL accuracy via the calculation of the corresponding two-loop soft anomalous dimensions. Approximate NNLO (aNNLO) differential cross sections have been derived from the expansion of the resummed expressions for electroweak-boson [1, 2] and single-top [3–6] production.

2. W and Z production at large p_T

The production of W and Z bosons is useful in testing the Standard Model and in estimates of backgrounds to Higgs production and new physics. The partonic channels at leading order 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 $s=(p_a+p_b)^2$, $t=(p_a-Q)^2$, $u=(p_b-Q)^2$ and $s_4=s+t+u-Q^2$. At threshold $s_4 \to 0$ and the soft corrections are of the form $[\ln^k(s_4/p_T^2)/s_4]_+$. The latest aNNLO results at NNLL accuracy have been derived in [1].

We begin with W production at large p_T. We use MSTW2008 pdf [7] in our calculations. In the left plot of Fig. 1 we show the aNNLO W-boson p_T distributions at the LHC at 13 and 14 TeV energies. The p_T distributions fall rapidly as the p_T of the W boson increases. The inset plot displays the ratio of the results to the central NLO result. We observe the significant contribution of the aNNLO corrections and the reduction of scale uncertainty at aNNLO.

We continue with Z production at large p_T. In the right plot of Fig. 1 we show the aNNLO Z-boson p_T distributions at LHC energies of 13 and 14 TeV. Our observations regarding the size of the corrections and the reduction of uncertainty at aNNLO are the same as for W production.



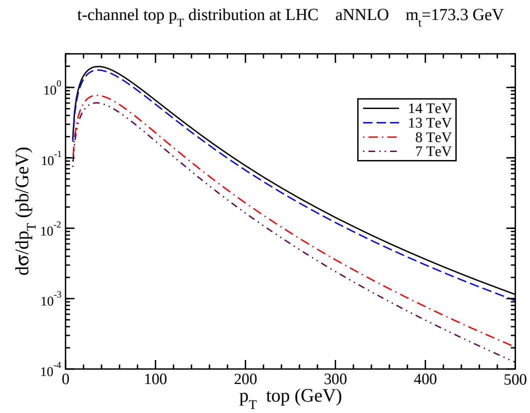


Figure 2: (Left) Single-top aNNLO cross sections compared with LHC [8–10, 15–19] and Tevatron [11] data; (Right) aNNLO t-channel top p_T distributions at LHC energies.

3. Single-top production

Single-top production can proceed via three partonic channels. At lowest order, the t-channel partonic processes are $qb \to q't$ and $\bar{q}b \to \bar{q}'t$; the s-channel processes are $q\bar{q}' \to \bar{b}t$; and the associated tW production processes are $bg \to tW^-$, and similarly for single antitop. NNLL resummation for all these processes was performed in Refs. [3–6].

LHC	t	$\bar{t}$	Total (pb)
8 TeV	$55.9^{+2.1}_{-0.3} \pm 1.1$	$30.6 \pm 0.7^{+0.9}_{-1.1}$	$86.5^{+2.8+2.0}_{-1.0-2.2}$
13 TeV	$136^{+3}_{-1} \pm 3$	$82^{+2}_{-1} \pm 2$	$218^{+5}_{-2} \pm 5$
14 TeV	$154^{+4}_{-1} \pm 3$	94^{+2+2}_{-1-3}	248^{+6+5}_{-2-6}

Table 1: aNNLO single-top and single-antitop t-channel cross sections with $m_t = 173.3$ GeV.

In Table 1 we show the single-top and single-antitop t-channel production cross sections at aNNLO at the LHC, as well as the total sum of the two. The first uncertainty is from scale variation over $m_t/2 \le \mu \le 2m_t$ while the second is from pdf errors with MSTW2008 NNLO pdf at 90% C.L. [7].

In the left plot of Fig. 2 we plot the t-channel total cross section as a function of collider energy. At 7 TeV LHC energy, we compare with t-channel data from ATLAS [8] and CMS [9]. At 8 TeV LHC energy we compare with ATLAS/CMS combination t-channel data [10]. Finally, at 1.96 Tevatron energy we compare with CDF/D0 combination data [11]. We find excellent agreement of theory with data for all collider energies.

The aNNLO ratio $\sigma(t)/\sigma(\bar{t}) = 1.82^{+0.10}_{-0.09}$ at 8 TeV which compares very well with the CMS result $1.95 \pm 0.10 \pm 0.19$ [12]. It is also in excellent agreement with the NNLO result in [13].

We continue with t-channel aNNLO p_T distributions [14]. In the right plot of Fig. 2 we display the top p_T distributions in t-channel production at various LHC energies.

In Fig. 3 we display the top and antitop p_T distributions in single-top t-channel production at 7 TeV LHC energy and compare with ATLAS data [8], finding good overall agreement.

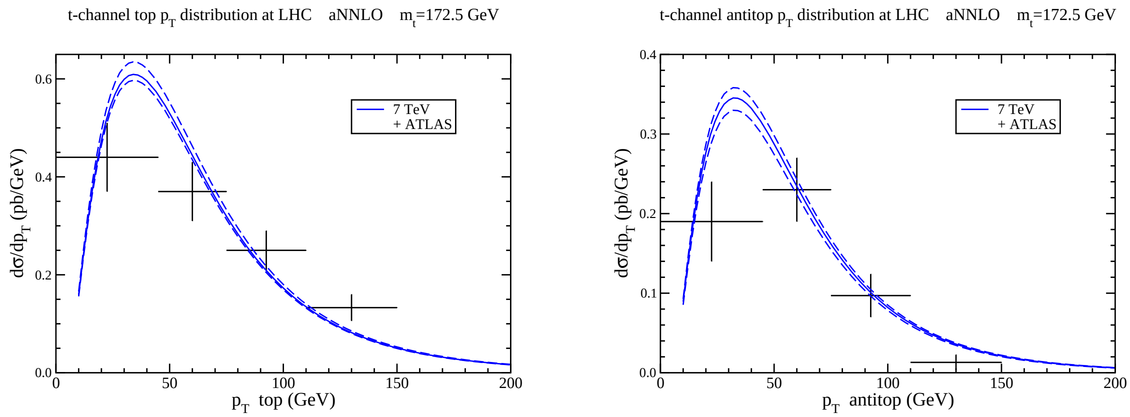


Figure 3: Top (left) and antitop (right) p_T distributions in t-channel production at 7 TeV LHC energy compared with ATLAS data [8].

LHC	t	$\bar{t}$	Total (pb)
8 TeV	$3.75 \pm 0.07 \pm 0.13$	$1.90 \pm 0.01 \pm 0.08$	$5.65 \pm 0.08 \pm 0.21$
13 TeV	$7.07 \pm 0.13^{+0.24}_{-0.22}$	$4.10 \pm 0.05^{+0.14}_{-0.16}$	$11.17 \pm 0.18 \pm 0.38$
14 TeV	$7.79 \pm 0.14^{+0.31}_{-0.24}$	$4.57 \pm 0.05^{+0.18}_{-0.17}$	$12.35 \pm 0.19^{+0.49}_{-0.41}$

Table 2: aNNLO single-top and single-antitop s-channel cross sections with $m_t = 173.3$ GeV.

Next we discuss s-channel production at the LHC. In Table 2 we show the single-top and single-antitop s-channel production cross sections at aNNLO at the LHC, as well as the total sum of the two. The first uncertainty is again from scale variation while the second is from pdf errors with MSTW2008 NNLO pdf at 90% C.L. [7].

In the left plot of Fig. 2 we plot the s-channel total cross section as a function of collider energy. At 8 TeV LHC energy we compare with data from ATLAS [15] and CMS [16]. The data from both experiments have much larger uncertainties than the theoretical prediction but are in excellent agreement with it.

In the left plot of Fig. 4 we display new aNNLO results for the top p_T distributions in s-channel production at LHC energies.

LHC	tW^-	$tW^- + \bar{t}W^+$ (pb)
8 TeV	$11.0 \pm 0.3 \pm 0.7$	$22.0 \pm 0.6 \pm 1.4$
13 TeV	$35.20 \pm 0.9^{+1.6}_{-1.7}$	$70.40 \pm 1.8^{+3.2}_{-3.4}$
14 TeV	$41.6 \pm 1.0^{+1.5}_{-2.3}$	$83.1 \pm 2.0^{+3.1}_{-4.6}$

Table 3: aNNLO tW cross sections with $m_t = 173.3$ GeV.

We continue with associated tW production at aNNLO at the LHC. In Table 3 we show the tW production cross sections at aNNLO at the LHC. The first uncertainty is again from scale variation while the second is from MSTW2008 [7] pdf errors.

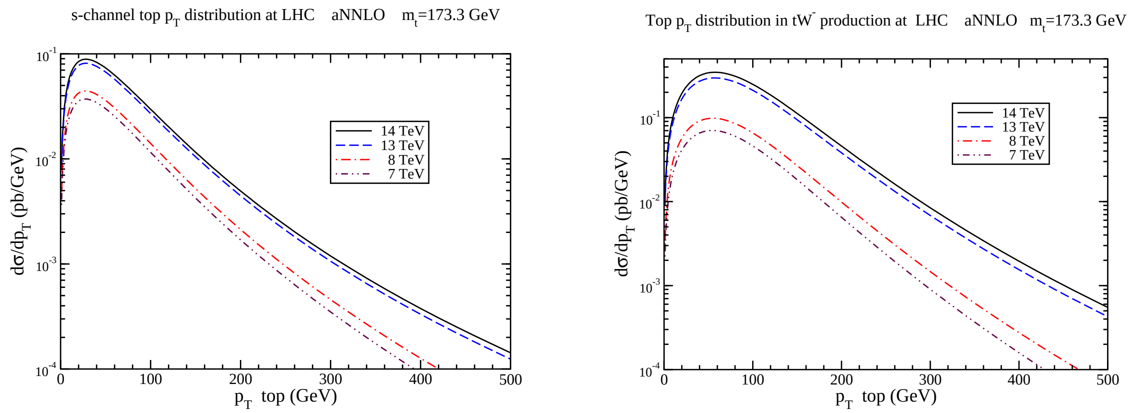


Figure 4: Top p_T distributions in single-top *s*-channel production (left) and in tW^- production (right).

In the left plot of Fig. 2 we plot the tW total cross section as a function of collider energy. At 7 TeV LHC energy, we compare with tW data from ATLAS [17] and CMS [18]. At 8 TeV LHC energy we compare with ATLAS/CMS combination data [19]. We find excellent agreement of theory with data for both LHC energies. In the right plot of Fig. 4 we display the top-quark p_T distributions in tW^- production at LHC energies.

4. FCNC top production

Finally, we consider FCNC top-quark production via anomalous gluon couplings. The partonic processes are of the form $gu \to tg$ which involve t-u-g couplings. We considered these processes beyond leading order and calculated the soft-gluon corrections at NLL accuracy in [20].

The ratio of the LO and aNLO cross sections at various choice scales to the LO result with $\mu = m_t$ was shown in [20] at both 7 and 14 TeV LHC energies. It was found that the NLO soft-gluon corrections are large and they reduce the scale dependence of the cross section. At both energies the NLO soft-gluon corrections increase the LO cross section by around 60% for $\mu = m_t$. The reduction in scale variation over $m_t/2 \le \mu \le 2m_t$ is also very significant.

5. Summary

We have presented results for NNLL soft-gluon corrections for electroweak-boson and single-top production. The aNNLO corrections are significant at the LHC and the Tevatron. There is excellent agreement for single-top production with LHC and Tevatron data in all channels. Future work will extend these results to more differential distributions and aN^{3}LO.

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