Differential and total cross sections for top pair and single top production

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• $t\bar{t}$ and single top production channels
• Higher-order two-loop corrections
• $t\bar{t}$ cross section at LHC and Tevatron
• Top $p_T$ and rapidity distributions
• $t$-channel production
• $s$-channel production
• Associated production of a top with a $W^-$ or $H^-$
Partonic processes at LO

Top-antitop pair production

- $q\bar{q} \rightarrow t\bar{t}$
  dominant at Tevatron

- $gg \rightarrow t\bar{t}$
  dominant at LHC
Single top quark production

- **t channel:** $qb \rightarrow q't$ and $\bar{q}b \rightarrow \bar{q}'t$
dominant at Tevatron and LHC

- **s channel:** $qq' \rightarrow bt$
small at Tevatron and LHC

- **associated $tW$ production:** $bg \rightarrow tW^-$
  very small at Tevatron, significant at LHC

Related process: $bg \rightarrow tH^-$
Higher-order corrections

QCD corrections significant for top pair and single top quark production

Soft-gluon corrections from emission of soft (low-energy) gluons

Soft corrections: \( \left[ \ln^k \left( \frac{s_4}{m^2} \right) \right]_+ \) with \( k \leq 2n - 1 \), \( s_4 \) distance from threshold

Soft-gluon corrections are dominant near threshold

Resum these soft corrections - factorization and RGE

Complete results at NNLL–two-loop soft anomalous dimension

NK, PRD 82, 114030 (2010); PRD 84, 011504 (2011) \((t\bar{t})\)

NK, PRD 81, 054028 (2010); PRD 82, 054018 (2010); PRD 83, 091503 (2011) \((\text{single top})\)

Approximate NNLO cross section from expansion of resummed cross section

This is the only calculation at the differential cross section level using the standard moment-space resummation in pQCD
Threshold approximation

Approximation works very well not only for Tevatron but also for LHC energies because partonic threshold is still important

![Graph of σ vs m (GeV) for pp → t̄ at LHC S^{1/2}=7 TeV μ=m with O(α_s) approx corrections and O(α_s) exact corrections.]

![Graph of dσ/dp_T (pb/GeV) vs p_T (GeV) for Top quark p_T distribution at LHC S^{1/2}=8 TeV μ=m=173 GeV with NLO approx and NLO exact corrections.]

only 1% difference between first-order approximate and exact corrections

→ less than 1% difference between NLO approximate and exact cross sections

Also true for differential distributions

For best prediction add NNLO approximate corrections to exact NLO cross section

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$t\bar{t}$ cross section at the Tevatron

$\sigma_{tt}(m_t = 173 \text{ GeV}, 1.96 \text{ TeV}) = 7.08^{+0.00+0.36}_{-0.24-0.27} \text{ pb}$

NNLO approx: 7.8\% enhancement over NLO
scale dependence greatly reduced

used MSTW 2008 NNLO pdf
\[ \sigma_{t\bar{t}}^{\text{NNLO approx}} (m_t = 173 \text{ GeV}, 7 \text{ TeV}) = 163^{+7}_{-5} \pm 9 \text{ pb} \]
\[ \sigma_{t\bar{t}}^{\text{NNLO approx}} (m_t = 173 \text{ GeV}, 8 \text{ TeV}) = 234^{+10}_{-7} \pm 12 \text{ pb} \]
\[ \sigma_{t\bar{t}}^{\text{NNLO approx}} (m_t = 173 \text{ GeV}, 14 \text{ TeV}) = 920^{+50+33}_{-39-35} \text{ pb} \]

\textbf{NNLO approx: enhancement over NLO (same pdf) is 7.6\% at 7 TeV; 7.8\% at 8 TeV; 8.0\% at 14 TeV}
Top quark $p_T$ distribution at Tevatron

Excellent agreement of NNLO approx results with D0 data

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Top quark rapidity distribution at Tevatron

Top quark rapidity at Tevatron \( S^{1/2} = 1.96 \) TeV \( m = 173 \) GeV

\[
d\sigma/dY \text{ (pb)}
\]

- NLO \( \mu = m \)
- NLO \( \mu = m/2, 2m \)
- NNLO approx \( \mu = m \)
- NNLO approx \( \mu = m/2, 2m \)

Top Forward-backward asymmetry

\[
A_{FB} = \frac{\sigma(Y > 0) - \sigma(Y < 0)}{\sigma(Y > 0) + \sigma(Y < 0)}
\]

Asymmetry significant at the Tevatron

Theoretical result at Tevatron: \( A_{FB} = 0.052^{+0.000}_{-0.006} \)

smaller than observed values
Top quark rapidity distribution at LHC

Top quark rapidity at LHC $S^{1/2}=7\,\text{TeV}$ $m=173\,\text{GeV}$

Top quark rapidity distribution at LHC $\mu=m=173\,\text{GeV}$

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\textbf{t-channel cross sections at LHC}

For $m_t = 173$ GeV

<table>
<thead>
<tr>
<th>LHC</th>
<th>$t$</th>
<th>$\bar{t}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 TeV</td>
<td>$43.0^{+1.6}_{-0.2} \pm 0.8$</td>
<td>$22.9 \pm 0.5^{+0.7}_{-0.9}$</td>
</tr>
<tr>
<td>8 TeV</td>
<td>$56.4^{+2.1}_{-0.3} \pm 1.1$</td>
<td>$30.7 \pm 0.7^{+0.9}_{-1.1}$</td>
</tr>
<tr>
<td>14 TeV</td>
<td>$154^{+4}_{-1} \pm 3$</td>
<td>$94^{+2}<em>{-1}^{+2}</em>{-3}$</td>
</tr>
</tbody>
</table>
\[
\sigma_{t\text{-channel}}^{\text{NNLO approx, total}} (m_t = 173 \text{ GeV}, 7 \text{ TeV}) = 65.9^{+2.1+1.5}_{-0.7-1.7} \text{ pb} \\
\sigma_{t\text{-channel}}^{\text{NNLO approx, total}} (m_t = 173 \text{ GeV}, 8 \text{ TeV}) = 87.2^{+2.8+2.0}_{-1.0-2.2} \text{ pb} \\
\sigma_{t\text{-channel}}^{\text{NNLO approx, total}} (m_t = 173 \text{ GeV}, 14 \text{ TeV}) = 248^{+6+5}_{-2-6} \text{ pb}
\]

Small \( \mathcal{O}(1\%) \) corrections over NLO
$t$-channel top and antitop $p_T$ distributions at LHC

$t$-channel top quark $p_T$ distribution at LHC $\mu=m_t=173$ GeV

$t$-channel antitop quark $p_T$ distribution at LHC $\mu=m_t=173$ GeV

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$t$-channel top quark production at Tevatron

Single top Tevatron $t$-channel NNLO approx (NNLL) $\mu=m_t$

Cross section for antitop $t$-channel production at Tevatron is identical

$$\sigma_{t\text{-channel}}^{\text{NNLOapprox, top}}(m_t = 173 \text{ GeV}, 1.96 \text{ TeV}) = 1.04^{+0.00}_{-0.02} \pm 0.06 \text{ pb}$$

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**s-channel cross sections**

Single top LHC  s-channel  NNLO approx (NNLL) $\mu = m_t$

![Graph showing $\sigma$ (pb) vs. $m_t$ (GeV) for 7 TeV, 8 TeV, and 14 TeV LHC.](image)

Single antitop LHC  s-channel  NNLO approx (NNLL) $\mu = m_t$

![Graph showing $\sigma$ (pb) vs. $m_t$ (GeV) for 7 TeV, 8 TeV, and 14 TeV LHC.](image)

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<tr>
<td>7 TeV</td>
<td>$3.14 \pm 0.06^{+0.12}_{-0.10}$</td>
<td>$1.42 \pm 0.01^{+0.06}_{-0.07}$</td>
</tr>
<tr>
<td>8 TeV</td>
<td>$3.79 \pm 0.07 \pm 0.13$</td>
<td>$1.76 \pm 0.01 \pm 0.08$</td>
</tr>
<tr>
<td>14 TeV</td>
<td>$7.87 \pm 0.14^{+0.31}_{-0.28}$</td>
<td>$3.99 \pm 0.05^{+0.14}_{-0.21}$</td>
</tr>
</tbody>
</table>

For $m_t = 173$ GeV

**At Tevatron $\sqrt{S} = 1.96$ TeV:** $0.523^{+0.001+0.030}_{-0.005-0.028}$ pb for top; same for antitop

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$s$-channel total cross section at LHC

LHC $s$-channel total NNLO approx (NNLL) $\mu = m_t$

$$\sigma_{s\text{-channel}}^{\text{NNLO approx, total}}(m_t = 173 \text{ GeV}, 7 \text{ TeV}) = 4.56 \pm 0.07^{+0.18}_{-0.17} \text{ pb}$$

$$\sigma_{s\text{-channel}}^{\text{NNLO approx, total}}(m_t = 173 \text{ GeV}, 8 \text{ TeV}) = 5.55 \pm 0.08 \pm 0.21 \text{ pb}$$

$$\sigma_{s\text{-channel}}^{\text{NNLO approx, total}}(m_t = 173 \text{ GeV}, 14 \text{ TeV}) = 11.86 \pm 0.19^{+0.45}_{-0.49} \text{ pb}$$

**NNLO approx: enhancement over NLO is $\sim 10\%$**

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Associated $tW^-$ production at the LHC

\[ \sigma_{tW}^{\text{NNLO approx}}(m_t = 173 \text{ GeV}, 7 \text{ TeV}) = 7.8 \pm 0.2^{+0.5}_{-0.6} \text{ pb} \]

\[ \sigma_{tW}^{\text{NNLO approx}}(m_t = 173 \text{ GeV}, 8 \text{ TeV}) = 11.1 \pm 0.3 \pm 0.7 \text{ pb} \]

\[ \sigma_{tW}^{\text{NNLO approx}}(m_t = 173 \text{ GeV}, 14 \text{ TeV}) = 41.8 \pm 1.0^{+1.5}_{-2.4} \text{ pb} \]

NNLO approx corrections increase NLO cross section by $\sim 8\%$

Cross section for $\bar{t}W^+$ production is identical
Associated production of a top quark with a charged Higgs

NNLO approx corrections increase NLO cross section by $\sim 15$ to $\sim 20\%$
Summary

• NNLL resummation for top quark pair and single top production

• $t\bar{t}$ production cross section

• top quark $p_T$ and rapidity distributions

• single top cross sections and $p_T$ distributions

• NNLO approx corrections for top pair and single top production are significant at Tevatron and LHC

• good agreement with LHC and Tevatron data