ttbar @ LHCb

Rhorry Gauld
Contents

• Production at high pseudorapidity
• Theoretical uncertainties
  • top mass
  • scale
  • $\alpha_s$
• Parton Distribution Functions
• Constraining the gluon PDF
• Conclusions
ttbar production

\[ x_{1,(2)} = \frac{m_T}{\sqrt{\hat{s}}} (e^{(-)}y_3 + e^{(-)}y_4) \]
ttbar production

$W^- \rightarrow f \bar{f}'$

$W^+ \rightarrow l^+..$

$b$-jet

$\bar{b}$-jet

tops at LHCb = high $x_1$ partons

e.g. arXiv:1103.3747 A. Kagan, J. Kamenik, G. Perez, S. Stone
ttbar production

\[ W^- \rightarrow f \bar{f}' \]
\[ W^+ \rightarrow l^+ \ldots \]
\[ \bar{b} - \text{jet} \]
\[ b - \text{jet} \]

MSTW08nlo 68cl PDFs

\[ \frac{x f(x, Q^2)}{x f(x, Q^2)} \text{ at } Q^2 = 10^4 \text{ GeV}^2 \]

tops at LHCb = high $x_1$ partons

e.g. arXiv:1103.3747 A. Kagan, J. Kamenik, G. Perez, S. Stone
ttbar production

\[ W^- \rightarrow f \bar{f}' \]
\[ \bar{b} - \text{jet} \]
\[ W^+ \rightarrow l^+ .. \]

\[ \begin{array}{c}
\text{tag top charge by lepton charge!}
\end{array} \]

\[ \begin{array}{c}
tops \text{ at LHCb} = \text{high } x_1 \text{ partons}
\end{array} \]

e.g. \texttt{arXiv:1103.3747} A. Kagan et al.

see back-ups for various cross-sections
ttbar production II

\[
\frac{\partial \sigma}{\partial X_\tilde{t}} = \frac{1}{2} \left( \frac{\partial \sigma}{\partial X_t} + \frac{\partial \sigma}{\partial X_{\tilde{t}}} \right)
\]

\[\sigma^{LHCb} = \int \eta = 2 \frac{\partial \sigma}{\partial \eta_{\tilde{t}}}\]

Production mechanism ratio:

\[
\frac{q\bar{q} + |qg|}{total}
\]

LHCb probes unique region
\[ \hat{\sigma}(\beta) = \frac{\alpha_s^2}{m^2} \left( \sigma_{ij}^{(0)} + \alpha_s \sigma_{ij}^{(1)} + \alpha_s^2 \sigma_{ij}^{(2)} + \mathcal{O}(\alpha_s^3) \right) \]

TeVatron combination 8.7 fb\(^{-1}\)

173.20 ± 0.51(stat) ± 0.71(sys) GeV/c\(^2\)

arXiv:1305.3929

\[ \delta m_t = 1\,\text{GeV} \rightarrow \delta \sigma^{LHCb} = 3\% \]
Completion of inclusive NNLO calculation \texttt{arXiv:1303.6254}

M. Czakon, P. Fielder, A. Mitov

**Vary ren./factorisation**

\[
\frac{1}{2} < \frac{\mu_F \cdot m_t}{\mu_t \cdot m_t} < 2
\]

**Scale variation**

\[
\sigma_{\text{tot}} \, [\text{pb}]
\]

<table>
<thead>
<tr>
<th>Scale Variation</th>
<th>LO</th>
<th>NLO</th>
<th>NLL</th>
<th>LL</th>
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\texttt{arXiv:1305.3892} M. Czakon et al.

<table>
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<tr>
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<table>
<thead>
<tr>
<th>(\delta \sigma^{LHCb}_{\text{NLO}})</th>
<th>(+13.9%)</th>
<th>(-14.2%)</th>
<th>(+4.0%)</th>
<th>(-6.4%)</th>
<th>(+2.6%)</th>
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<td>NNLO+NNLL</td>
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</table>

**Fixed Order**

- \texttt{arXiv:1305.3892} M. Czakon et al.
**strong coupling**

\[ \sigma_{LHCb} \text{ vs. } \alpha_s(M_Z) \]

**Current PDG value**

\[ \alpha_s(M_Z) = 0.1184 \pm 0.0007 \]

**gluon PDF uncertainty**

for \( \delta \alpha_s \)

\[ \delta \alpha_s \rightarrow \delta \sigma_{LHCb} \approx 1.5\% \]
PDF uncertainties

high-x gluon PDF un-constrained

uncertainty generally grows with increasing x

Remark: ttbar at LHCb still dominated by gg-scattering (slide 7)

Compare PDF uncertainty: inclusive vs LHCb cross-section

\[ \delta \rho_{PDF} \rightarrow \delta \sigma^{NLO} = +4.4\% -4.2\% \]

\[ \delta \rho_{PDF} \rightarrow \delta \sigma^{LHCb} = +6.9\% -5.5\% \]
### Summary of Uncertainties

<table>
<thead>
<tr>
<th>Order</th>
<th>PDF</th>
<th>$\sigma$ (pb)</th>
<th>$\delta_{scale}$ (pb)</th>
<th>$\delta_{PDF}$ (pb)</th>
<th>$\delta_{\alpha_s}$ (pb)</th>
<th>$\delta_{m_t}$ (pb)</th>
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<td>$+4.6$ (+2.7%)</td>
<td>$-6.0$ (-3.5%)</td>
<td>$+8.0$ (+4.6%)</td>
<td>$+3.7$ (+2.2%)</td>
<td>$+8.0$ (+4.6%)</td>
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<td>LHCb</td>
<td>19.9</td>
<td>$+2.6$ (+13.3%)</td>
<td>$-2.7$ (-13.7%)</td>
<td>$+1.4$ (+6.9%)</td>
<td>$+0.3$ (+1.7%)</td>
<td>$+0.9$ (+4.8%)</td>
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<td>NLO</td>
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potential precision 7 TeV

Expected number of events?

Consider muon + b-jet final state

POWHEG(NLO)->pythia8
anti-kt R = 0.5 jets
ST, tch = t-channel single top

Kinematic cuts:

\[ \mu \ p_T > 20 \ GeV \]
\[ b-\text{jet} \ p_T > 60 \ GeV \]
\[ \mu, b-\text{jet} \ \eta \in [2.0 - 4.5] \]

Isolation:

\[ \Delta R(\mu, \text{jet}) > 0.5 \]

Efficiencies:

\[ \text{b mis-tag} = 1\% \]
\[ \text{b efficiency} = 70\% \]
\[ \text{muon efficiency} = 75\% \]
potential precision 14 TeV

Expected number of events?

Consider muon + b-jet final state

POWHEG(NLO)->pythia8
anti-kt $R = 0.5$ jets

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Kinematic cuts:

\[ \mu \ p_T > 20 \ GeV \]
\[ b-\text{jet} \ p_T > 60 \ GeV \]
\[ \mu, b-\text{jet} \ \eta \in [2.0 \ - \ 4.5] \]

Isolation:

\[ \Delta R(\mu, \text{jet}) > 0.5 \]

Efficiencies:

b mis-tag = 1%
b efficiency = 70%
muon efficiency = 75%
what can LHCb provide?

perform a PDF re-weighting based on LHCb cross-section measurement at 14 TeV with 4, 6, 8% exp. uncertainty

\[
W_k(\chi_k^2) = (\chi_k^2)^{\frac{1}{2}}(N_{pts.} - 1) \exp\left(-\frac{1}{2}\chi_k^2\right)
\]

\[
\langle X \rangle_{new} = \mathcal{N} \sum_{k=1}^{N_{PDF}} W_k(\chi_k^2) X_k
\]
Actually an under-estimate!!
Conclusions

- 1 year of 13/14 TeV - no longer stat. limited
- A cross-section measurement can strongly constrain the high-x gluon PDF
- Necessary ingredients:
  - $W$-jets measurement
  - high $p_T$ $b$-jet tagger trained vs light jets
  - all background modelling NLO+
  - differential NNLO $ttbar$
ttbar cross-sections for various final states. The dilepton channel is interesting as it is the best way of probing a pair of top quarks in one event and would allow a measurement of $A_c$. In this case, the minimum $p_T$ requirements in the dilepton channel are 7, 10 GeV for electrons and muons respectively. The looser cuts in this channel reflect that the QCD background for producing opposite flavour, charged leptons is small. The electron cut is looser than that of the muon as calorimetry resolution for electrons is generally poorer. Requiring the presence of a soft $b$-jet ($p_T > 20$ GeV) can greatly reduce electroweak backgrounds.

### Production cross section

The $t\bar{t}$ signal is simulated using POWHEG\[10\–13\], including 7-point scale variation for CT10wnlo\[14\], MSTW2008nlo68cl\[15\], NNPDF22\[16\] central PDF sets, and then matched to Pythia8\[17\]. The 7-point scale variation of factorisation ($\mu_F$) and renormalisation ($\mu_R$) take the reference points obtained by varying independently $\mu_F$ and $\mu_R$ such that, $1 < \mu_F \cdot m_t < 2$ (9).

This is an approximate method of evaluating the potential uncertainty arising from neglected higher-order corrections. The resulting $t\bar{t}$ cross sections in the pseudorapidity range $2 < \eta < 4.5$ relevant to LHCb are summarised in Table 1. The total uncertainty of $\approx 20\%$ corresponds to $\approx 14\%$ (scale) +8% (PDF) +10% (shower, tagging). The majority of the PDF uncertainty reflects the difference in predictions of the gluon PDF at high $x$ for the different sampled central PDF sets. The shower and tagging uncertainty arises from re-seeding the showering process whilst varying colour reconnection parameters and the shower scale, as well as an effect coming from smearing in the full decay. The higher multiplicity and dilepton channels have no considerable event yield until $\sqrt{s} = 14$ TeV centre of mass energies.

<table>
<thead>
<tr>
<th>$d\sigma$(fb)</th>
<th>7 TeV</th>
<th>8 TeV</th>
<th>14 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$l^+l^-$</td>
<td>44 ± 9</td>
<td>79 ± 15</td>
<td>635 ± 109</td>
</tr>
<tr>
<td>$l^+l^-$ $b$</td>
<td>19 ± 4</td>
<td>39 ± 8</td>
<td>417 ± 79</td>
</tr>
<tr>
<td>$l^+l^-$ $bj$</td>
<td>97 ± 21</td>
<td>198 ± 35</td>
<td>2335 ± 323</td>
</tr>
<tr>
<td>$l^+l^-$ $bb$</td>
<td>32 ± 6</td>
<td>65 ± 12</td>
<td>870 ± 116</td>
</tr>
<tr>
<td>$l^+l^-$ $bjj$</td>
<td>10 ± 2</td>
<td>26 ± 4</td>
<td>487 ± 76</td>
</tr>
<tr>
<td>$l^+l^-$ $b$</td>
<td>285 ± 52</td>
<td>504 ± 94</td>
<td>4366 ± 663</td>
</tr>
<tr>
<td>$l^+l^-$ $bj$</td>
<td>97 ± 21</td>
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Backups - asymmetry source

\[ C_{\text{planar}} = \frac{1}{16N_c^2} (f^2_{abc} + d^2_{abc}) \]
\[ C_{\text{crossed}} = \frac{1}{16N_c^2} (-f^2_{abc} + d^2_{abc}) \]

where I used,

\[ d^2_{abc} = Tr[\{T^a, T^b\}T^c]^2 \]
\[ d^2_{abc} = (N_c^2 - 1)(N_c^2 - 4)/N_c \]
\[ f^2_{abc} = (N_c^2 - 1)N_c \]

- comes from colour!
- effect is \(\mathcal{O}(\alpha_s^3)\)
- diluted by symmetric gg

Backups - asymmetry at 7/8 TeV?

Single particle asym.

\[ A_c = 1.19\%, \quad \eta_{t, \bar{t}} \in 2-5 \]

Stat. Error, dilepton in 5 fb\(^{-1}\)

forward-central asymmetry, assuming stat. error of dilepton signal at 14 TeV
Backups - published ttbar asymmetry results

$A_{fb} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$

$A_{SM}^{SM} = 8.7\%$

$A_{fb}^{CDF} (9.4 fb^{-1}) = 16.4 \pm 4.7\%$

$A_{fb}^{D0} (5.4 fb^{-1}) = 19.6 \pm 6.5\%$

$\Delta y = y_t - y_{\bar{t}}$

$A_c = \frac{N(\Delta |y| > 0) - N(\Delta |y| < 0)}{N(\Delta |y| > 0) + N(\Delta |y| < 0)}$

$A_{c}^{SM} = 1.15\%$

$A_{c}^{ATLAS} (4.71 fb^{-1}) = 2.9 \pm 1.8 \pm 1.4\%$

$A_{c}^{CMS} (5.0 fb^{-1}) = 0.4 \pm 1.0 \pm 1.1\%$

$\Delta |y| = |y_t| - |y_{\bar{t}}|
Backups - asymmetry at 7/8 TeV?

\[ A^{\mu b} = \frac{N\mu^+ b - N\mu^- b}{N\mu^+ b + N\mu^- b} \]
Backups - controlling shower effects

\[ \sqrt{s} = 7 \text{TeV}, pp \to \bar{t}, \text{Herwig+2.6.0} \]

- ratio top/atop qqbar (reco)
- ratio top/atop qqbar (parton)

- LHC(qqbar) Default
- LHC(qqbar) Phi asym = off
- anti-LHC(qqbar) Default
- anti-LHC(qqbar) Phi asym = off

\[ \sqrt{s} = 7 \text{TeV}, pp \to \bar{t}, \text{Pythia8175 LO} \]

- ratio top/atop gg (reco)
- ratio top/atop gg (parton)

- LHC(gg) Default
- LHC(gg) Phi asym = off
- anti-LHC(gg) Default
- anti-LHC(gg) Phi asym = off
Backups - truth b-tag matching

R - parameter tests for truth bjet matching to partons

Energy (right), Efficiency(lower-left)