Recent top quark results from ATLAS

Garrin McGoldrick
On behalf of the ATLAS collaboration

University of Toronto

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2 First 13 TeV results

3 Highlights from 8 TeV

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5 Backup
The top quark

**Top Properties**

- \( m_t = 173.3 \pm 0.7 \) GeV
- \( \Gamma = 2.0^{+0.7}_{-0.6} \) GeV
- \( \tau \approx 3.3 \times 10^{-25} \) s

- The top quark decays before hadronization can significantly modify its quantum state.
- The top’s production vertex can be probed by looking at its decays.
Top quark production at the LHC

<table>
<thead>
<tr>
<th>[pb]</th>
<th>7 TeV</th>
<th>8 TeV</th>
<th>13 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}$ (all channels)</td>
<td>177 ± 9</td>
<td>253 ± 11</td>
<td>$832^{+40}_{-46}$</td>
</tr>
<tr>
<td>single top (t-channel)</td>
<td>65 ± 2</td>
<td>88 ± 3</td>
<td>217 ± 6</td>
</tr>
</tbody>
</table>

\[\sqrt{s} \text{ [TeV]} \]

**Inclusive $t\bar{t}$ cross section [pb]**

- Tevatron combined* 1.96 TeV (L = 8.8 fb$^{-1}$)
- ATLAS $e\mu$ 7 TeV (L = 4.6 fb$^{-1}$)
- CMS $e\mu$ 7 TeV (L = 5 fb$^{-1}$)
- ATLAS $e\mu$ 8 TeV (L = 20.3 fb$^{-1}$)
- CMS $e\mu$ 8 TeV (L = 19.7 fb$^{-1}$)
- LHC combined $e\mu$ 8 TeV (L = 5.3-20.3 fb$^{-1}$)
- ATLAS $e\mu$ 13 TeV (L = 78 pb$^{-1}$)
- CMS $e\mu$ 13 TeV (L = 42 pb$^{-1}$)
- ATLAS $e\mu$ 13 TeV (L = 85 pb$^{-1}$)
- ATLAS $l+jets$ 13 TeV (L = 85 pb$^{-1}$)
- CMS $l+jets$ 13 TeV (L = 42 pb$^{-1}$)

$^*$ Preliminary

**NNLO+NNLL (pp)**

Czakon, Fiedler, Mitov, PRL 110 (2013) 252004

$m_{top} = 172.5$ GeV, PDF $\sigma_s$ uncertainties according to PDF4LHC

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Single top production cross section

ATLAS Preliminary

December 2015

Inclusive cross-section [pb]

\begin{align*}
&\text{t-channel} \\
&\text{s-channel}
\end{align*}

$\sqrt{s}$ [TeV]

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Top quark decay channels

- Leptonic decay: $t \rightarrow b + W \rightarrow b + l + \nu$
- Hadronic decay: $t \rightarrow b + W \rightarrow b + q + q'$
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Single top cross section at 13 TeV

- Measuring $p\bar{p} \rightarrow t + \text{jets} \rightarrow b + \mu + \nu_\mu + \text{jets}$.
- Process is proportional to $|f_{LV} \cdot V_{tb}|^2$.
- Background yields estimated from theory and from a fit to orthogonal data.
- Neural network discriminant used to separate background from signal.

Results:

\[ \sigma(tq) = 133 \pm 25 \text{ pb} \]
\[ \sigma(\bar{t}q) = 96 \pm 45 \text{ pb} \]
\[ |f_{LV} \cdot V_{tb}| = 1.03 \pm 0.11 \]

Theory (NLO):

\[ \sigma(tq) = 136^{+5.4}_{-4.6} \text{ pb} \]
\[ \sigma(\bar{t}q) = 81^{+4.1}_{-3.6} \text{ pb} \]
$t\bar{t}$ cross section from $e\mu$ events at 13 TeV

- Measuring $p\bar{p} \rightarrow t\bar{t} + \text{jets} \rightarrow e^\pm \mu^\mp \nu_e \nu_\mu + \text{jets}$.
- Backgrounds are very small.
- Simultaneously measure the $\sigma_{t\bar{t}}$ and the efficiency to reconstruct and b-tag a jet ($\epsilon_b$).
  - Events in 1 and 2 b-tag multiplicity bins ($N_1$ and $N_2$) are correlated.
  - Exploit this correlation to constrain b-tagging efficiency.

$$\sigma_{t\bar{t}} = 825 \pm 49 \text{ (stat)} \pm 60 \text{ (syst)} \pm 83 \text{ (lumi)} \text{ pb}$$

\[N_1 = L\sigma_{t\bar{t}}\epsilon_{e\mu} 2\epsilon_b (1 - C_b\epsilon_b) + N_1^{bkg}\]
\[N_2 = L\sigma_{t\bar{t}}\epsilon_{e\mu} C_b\epsilon_b^2 + N_2^{bkg}\]
Jets produced with $t\bar{t}$ at 13 TeV

- Measuring $t\bar{t}$ pairs decaying in the dileptonic channel as a function of additional jets (not including the $b$-jets).
- Rates depend on higher order QCD modelling.
- Distributions are an important background to Higgs and new physics measurements.
- Distributions are unfolded to the fiducial detector acceptance.
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$t\bar{t}$ differential cross section

- $t\bar{t}$ is an important background for many searches.
- Important to correctly describe $t\bar{t}$ kinematic distributions.
- Measurements extrapolated to the fiducial and partonic levels.
- High $p_T$ distributions constrains NNLO predictions, angular distributions constrain PDFs.
Charge asymmetry in highly boosted $t\bar{t}$ pairs

\[ A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)} \]

\[ \Delta|y| = |y_t| - |y_{\bar{t}}| \]

- Related to the forward-backward asymmetry observed at the Tevatron.
- High $m_{t\bar{t}}$ events have boosted hadronic decays merging into fat jets.
- High $m_{t\bar{t}}$ not included in standard analysis selection.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
\textbf{ATLAS+CMS Preliminary LHCTop WG} & $\sqrt{s} = 8$ TeV & Sept 2015 \\
\hline
\textbf{t\bar{t} asymmetry} & & \\
\hline
ATLAS $l+$jets & & \\
\textit{arXiv:1509.02358} & & \\
& $0.009 \pm 0.004 \pm 0.005$ & \\
\hline
CMS $l+$jets template & & \\
\textit{arXiv:1506.03662} & & \\
& $0.003 \pm 0.003 \pm 0.003$ & \\
\hline
CMS $l+$jets & & \\
\textit{arXiv:1507.03119} & & \\
& $0.001 \pm 0.007 \pm 0.004$ & \\
\hline
Theory (NLO+EW) & & \\
PRD 86, 034026 (2012) & & \\
& $0.0111 \pm 0.0004$ & \\
\hline
ATLAS $l+$jets boosted & & \\
($M_\ell > 0.75$ TeV $\& \& |\Delta| < 2$) & & \\
\textit{ATLAS-CONF-2015-048} & & \\
& $0.043 \pm 0.019 \pm 0.026$ & \\
\hline
Theory (NLO+EW) & & \\
JHEP 1201 (2012) 063 & & \\
& $0.0160 \pm 0.0004$ & \\
\hline
\end{tabular}
\end{table}

arXiv 1512.06092
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Summary

- First results at $\sqrt{s} = 13$ TeV in good agreement with predictions.
- Jet multiplicity studies are testing our ability to describe higher order QCD processes.
- Measurements of top quark properties are constraining new physics contributions.
- Using fat jets in boosted topologies to explore higher energy events.
- Ongoing studies to be released soon to further increase our knowledge of the top sector.
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults
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**ATLAS** Preliminary $m_{\text{top}}$ summary - Mar. 2015, $L_{\text{int}} = 4.6$ fb$^{-1}$ - 20.3 fb$^{-1}$

- **all jets**
  - arXiv:1409.0832
  - $L_{\text{int}} = 4.6$ fb$^{-1}$
  - $m_{\text{top}} = 175.1 \pm 1.8$ (1.4 ± 1.2)

- **single top**
  - CONF-2014-055
  - $L_{\text{int}} = 20.3$ fb$^{-1}$
  - $m_{\text{top}} = 172.2 \pm 2.1$ (0.7 ± 2.0)

- **$t\bar{t}$+jets**
  - arXiv:1503.05427
  - $L_{\text{int}} = 4.7$ fb$^{-1}$
  - $m_{\text{top}} = 172.33 \pm 1.27$ (0.23 ± 0.25 ± 0.67 ± 1.02)

- **dilepton**
  - arXiv:1503.05427
  - $L_{\text{int}} = 4.7$ fb$^{-1}$
  - $m_{\text{top}} = 173.79 \pm 1.41$ (0.54 ± 1.30)

- **$\sigma(\tilde{t}\tilde{t})$ dilepton**
  - $L_{\text{int}} = 4.6$-20.3 fb$^{-1}$
  - $m_{\text{top}} = 172.9 \pm 2.5$ 2.6

- **$\sigma(\tilde{t}\tilde{t}+1\text{-jet})$**
  - CONF-2014-053
  - $L_{\text{int}} = 4.6$ fb$^{-1}$
  - $m_{\text{top}} = 173.7 \pm 2.3$ 2.1

**Input to ATLAS comb.** → Preliminary, *ATLAS Preliminary*

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LHC luminosity

- Presenting results at $\sqrt{s} = 8\text{ TeV}$ from 2012 and at $\sqrt{s} = 13\text{ TeV}$ from 2015.
- 2015 was a commissioning year: collected $3.9\text{ fb}^{-1}$.
- Still produced around 60% as many $t\bar{t}$ pairs at $\sqrt{s} = 13\text{ TeV}$ than at $\sqrt{s} = 8\text{ TeV}$.
**$t\bar{t}$ inclusive cross section at 13 TeV**

- Measured in lepton+jets, and opposite-sign same-flavour dileptonic channels ($e^+e^-$ or $\mu^+\mu^-$).
- Calculated the ratio between $t\bar{t}$ and $Z$-boson production.
  - Expect cancellation in common sources of systematic uncertainty.
  - Probes the PDF composition of sea quarks and gluons.

![Graph showing ATLAS Preliminary results for $t\bar{t}$ cross section](chart.png)

**Results (dileptonic, lepton+jets):**

\[
\sigma_{t\bar{t}} = 750 \pm 120 \text{ pb} \\
\sigma_{t\bar{t}} = 820 \pm 140 \text{ pb} \\
R_{t\bar{t}/Z} = 0.445 \pm 0.039
\]

**Theory (NNLO+NNLL):**

\[
\sigma_{t\bar{t}} = 832^{+40}_{-46} \text{ pb}
\]

ATLAS-CONF-2015-049
Fiducial $t\bar{t}$ cross section with additional $b$-jets

- Measuring events with additional $b$-jets.
- Background to Higgs production.
- Results given for stable particles passing the detector acceptance.
- Events originating from different processes are $b$-tagged differently.

**Measurement results**

<table>
<thead>
<tr>
<th>Process</th>
<th>ATLAS Simulation $\sqrt{s}=8$ TeV, 20.3 fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ttbb$ dilepton fit-based</td>
<td>$2 \ell, \geq 4 j, \geq 2 b$</td>
</tr>
<tr>
<td></td>
<td>$ttbb$ dilepton cut-based</td>
</tr>
<tr>
<td>$ttb$ dilepton fit-based</td>
<td>$ttb$ dilepton cut-based</td>
</tr>
<tr>
<td>$ttb$ lepton-plus-jets fit-based</td>
<td>$ttb$ lepton-plus-jets cut-based</td>
</tr>
</tbody>
</table>

**Measurement results**

- ATLAS
- Measurement results
- stat.
- syst.
- $\oplus$ stat.


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Measurement of colour flow with jet pulls

- Coloured objects share gluons, which can be modelled by *colour-flow*.
- The exchange of gluons between two objects is correlated to the *jet pull* vector.
- Look at hadronically decaying $W$ bosons originating from a top decays.

\[ \Delta \varphi = \varphi - \varphi_{J1} \]

Legend
- Pull (vector)($J_1$)
- $\Theta_p$ Pull Angle
- Constituent of $J_1$ (size weighted by $p_T$)

\[ y = y - y_{J1} \]

\[ \sigma \frac{d^3 \sigma}{d \Omega_{J_2}} \]

ATLAS
\[ \sqrt{s} = 8 \text{ TeV}, 20.3 \text{ fb}^{-1} \]