Top-quark pair cross-section measurement in the lepton+jets channel at ATLAS

Michele Pinamonti (INFN Udine & Università di Trieste) of behalf of the ATLAS collaboration

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**Introduction**

**Top pairs at LHC**

- $pp \rightarrow t\bar{t}$ @ 7 TeV: theoretical approx. NNLO $\sigma_{t\bar{t}} = 165^{+11}_{-16}$ pb

  $\Rightarrow$ with 35 pb$^{-1}$ >5000 $t\bar{t}$ pairs expected

- A first ATLAS $x$-section measurement (combining $\ell$+jets with $b$-tagging and di-lepton channels) already performed with 2.9 pb$^{-1}$:
  $\sigma_{t\bar{t}} = 145 \pm 31$ (stat.) $^{+42}_{-27}$ (syst.+lumi.)

  [CERN-PH-EP-2010-064, December 8, 2010]

- With 35 pb$^{-1}$ and with more sophisticated techniques a precision measurement is possible

- A measurement in $\ell$+jets channel only and without any use of $b$-tagging is here presented

  [ATLAS-CONF-2011-023, March 14, 2011]

- Complementary measurements are being finalized:
  - $\ell$+jets channel with $b$-tagging
  - di-lepton channel
  - all-hadronic channel

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**December 2010**

*Graph showing top-quark pair cross-section measurement in the lepton+jets channel at ATLAS*
The following final state selection has been chosen to isolate $e/\mu+\text{jets} \ t\bar{t}$ events and to keep sufficient statistics for the measurement:

**e+jets**
- 1 isolated $e$ with $p_T > 20$ GeV
- $\not{E}_T > 35$ GeV
- $m_T(W) > 25$ GeV
- 3 or more jets with $p_T > 25$ GeV

**\mu+jets**
- 1 isolated $\mu$ with $p_T > 20$ GeV
- $\not{E}_T > 20$ GeV
- $\not{E}_T + m_T(W) > 60$ GeV
- 3 or more jets with $p_T > 25$ GeV
Top event selection

$\bar{t}t \rightarrow e^+ + \text{jets}$ event display

Top-quark pair cross-section measurement in the lepton+jets channel at ATLAS
Top event selection

Selected events and MC expectations

<table>
<thead>
<tr>
<th>events</th>
<th>e + 3 jets</th>
<th>e + ≥4 jets</th>
<th>μ + 3 jets</th>
<th>μ + ≥4 jets</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}$</td>
<td>116</td>
<td>194</td>
<td>161</td>
<td>273</td>
</tr>
<tr>
<td>QCD*</td>
<td>62</td>
<td>22</td>
<td>120</td>
<td>51</td>
</tr>
<tr>
<td>$W$+jets</td>
<td>580</td>
<td>180</td>
<td>1100</td>
<td>310</td>
</tr>
<tr>
<td>$Z$+jets</td>
<td>32</td>
<td>18</td>
<td>70</td>
<td>25</td>
</tr>
<tr>
<td>single $t$</td>
<td>22</td>
<td>11</td>
<td>32</td>
<td>15</td>
</tr>
<tr>
<td>$WW, WZ, ZZ$</td>
<td>9</td>
<td>3</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>Data</td>
<td>781</td>
<td>400</td>
<td>1356</td>
<td>653</td>
</tr>
</tbody>
</table>

*: QCD numbers come from data-driven estimate

Top mass reconstructed as the mass of the highest-$p_T$ 3-jet combination in the event

Top-quark pair cross-section measurement in the lepton+jets channel at ATLAS
Cross-section extraction

**Multivariate Kinematic measurement**

- For each of the 4 channels a Likelihood discriminant is built.
- Using 3 variables with different distributions between $t\bar{t}$ and $W+\text{jets}$:
  1. Lepton pseudorapidity $\eta(e/\mu)$ ($\ell$ from $t\bar{t}$ more central)
  2. Lepton charge $q(e/\mu)$ ($W$ production in $pp$ collisions is charge-asymmetric)
  3. Exponential of the event Aplanarity $\exp(-8 \times A)$ (*). ($t\bar{t}$ events more isotropic)

- A combined fit is performed to extract $N_{t\bar{t}}$ and $N_{W+\text{jets}}$ (with fixed QCD and other backgrounds).
- The cross-section is obtained as $\sigma_{t\bar{t}} = \frac{N_{t\bar{t}}}{\epsilon \cdot \int L}$
  ($\epsilon$ is the $t\bar{t}$ selection efficiency $\times$ acceptance)

*: $A = \frac{3}{2} \lambda_3$, where $\lambda_3$ is the smallest eigenvalue of the normalized momentum tensor calculated using the jets and lepton in the event.

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Cross-section extraction

Results and uncertainties

$$\sigma_{t\bar{t}} = 171 \pm 17\text{(stat.)} \pm 20\text{(syst.)} \pm 6\text{(lumi.) \, pb}$$

<table>
<thead>
<tr>
<th>Source</th>
<th>$\Delta\sigma/\sigma[%]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stat.</td>
<td>9.7</td>
</tr>
<tr>
<td>$\ell$ reco, ID, trigger</td>
<td>-1.9 / +2.6</td>
</tr>
<tr>
<td>Jet energy reco</td>
<td>-6.1 / +5.7</td>
</tr>
<tr>
<td>QCD norm.</td>
<td>±3.9</td>
</tr>
<tr>
<td>QCD shape</td>
<td>±3.4</td>
</tr>
<tr>
<td>W+jets shape</td>
<td>±1.2</td>
</tr>
<tr>
<td>Other backg.</td>
<td>±0.5</td>
</tr>
<tr>
<td>ISR/FSR</td>
<td>-2.1 / +6.1</td>
</tr>
<tr>
<td>PDFs</td>
<td>-3.0 / +2.8</td>
</tr>
<tr>
<td>Parton shower</td>
<td>±3.3</td>
</tr>
<tr>
<td>NLO generator</td>
<td>±2.1</td>
</tr>
<tr>
<td>MC statistics</td>
<td>±1.8</td>
</tr>
<tr>
<td>Pile-up</td>
<td>±1.2</td>
</tr>
<tr>
<td>Total syst.</td>
<td>-10.2 / +11.6</td>
</tr>
<tr>
<td>Luminosity</td>
<td>3.4</td>
</tr>
</tbody>
</table>

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Conclusions

Summary of the current results

- A measurement of the $t\bar{t}$ cross-section in 7 TeV $pp$ collisions in $\ell+$jets channel, using the full 35 pb$^{-1}$ of data collected by ATLAS, has been shown.
- The measurement doesn’t use any $b$-tagging information.
- The total uncertainty is $\sim 15\%$ (mainly due to statistics and jet energy scale).

3 cross-check measurements using different methods show good agreement.
- Good agreement with the previous measurement ($145 \pm 31^{+42}_{-27}$ pb).
- $\ell+$jets with $b$-tagging, di-lepton & all-hadronic channels are under approval.
Backup Slides
QCD multi-jet can enter the $\ell+$jets selection:
- $e/\mu$ from heavy quarks decays
- $\gamma \rightarrow e^+e^-$
- jets reconstructed as $e$

**Data Driven estimation**

Basic idea:
- Use a looser $\ell$ definition (non isolated or failing some identification requirement)
- Assume the same shape of $E_T$ for QCD events with default and loose $\ell$ selection

**Fit Method - used in $e+$jets channel**

- Extract the $E_T$ distribution shape for QCD from loose non-tight lepton selection
- Fit $E_T$ in data with tight lepton selection

**Matrix Method - used in $\mu+$jets channel**

- Solve the 2 equation system:
  \[
  N^{\text{loose}} = N^{\text{loose}}_{\text{fake}} + N^{\text{loose}}_{\text{real}}
  \]
  \[
  N^{\text{tight}} = \epsilon_{\text{fake}} N^{\text{loose}}_{\text{fake}} + \epsilon_{\text{real}} N^{\text{loose}}_{\text{real}}
  \]
- measuring $\epsilon_{\text{fake}}$ from low $E_T$ region,
- and $\epsilon_{\text{real}}$ from $Z^- > \ell\ell$ events (*)

*: $\epsilon_{\text{fake}}$ and $\epsilon_{\text{real}}$ are the efficiencies for a loose $\ell$ event to pass the tight selection, for fake lepton (QCD) and real lepton (from W, Z, top) events.
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Details on Likelihood Discriminant

Projective likelihood approach:

- TMVA package used
- The likelihood discriminant $D_i$ for an event $i$ is defined as:
  $$D_i = \frac{L_{\text{signal}}(i)}{L_{\text{signal}}(i) + L_{\text{bkgd}}(i)}$$
- The individual likelihoods are products of the corresponding probability densities of the discriminating input variables $x_k$:
  $$L_{\text{signal}}(i) = \prod_{k=1}^{3} p_{\text{signal}}^k(x_k(i))$$
  $$L_{\text{bkgd}}(i) = \prod_{k=1}^{3} p_{\text{bkgd}}^k(x_k(i))$$

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A binned maximum likelihood fit is applied to the discriminant shapes. Likelihood functions are defined for each of the four channels and are multiplied together in a combined fit to extract the total number of $t\bar{t}$ events.

**Fit stability for different pseudo-experiments with different input x-sec**

**Pull distribution of the likelihood fit at the nominal x-sec**
Event Aplanarity

The aplanarity is defined as:

\[ A = \frac{3}{2} \lambda_3, \]

where

\[ \lambda_1 \geq \lambda_2 \geq \lambda_3, \]

are the three eigen values of the momentum tensor

\[ S^{\alpha\beta} = \frac{\sum_i p_i^\alpha p_i^\beta}{\sum_i |\vec{p}_i|^2}, \]

where \( \alpha \) and \( \beta \) are spatial components and the \( i \) runs over jets & leptons.