Top quark measurements at ATLAS

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Top Mass
- in $t\bar{t} \rightarrow \ell + jets$

Top Properties
- Colour flow measurement
- FCNC $t \rightarrow qZ$
- Charge asymmetry combination
- Direct $t$ decay width measurement

Top Cross Section
- $t\bar{t}$ in all-hadronic boosted

Single Top
- in association with $W$ or $Z$ boson
Overview of New Results

New results with 5 fb$^{-1}$ @ 7 TeV

\[ A_C^{\text{LHC7}} = 0.005 \pm 0.007\text{(stat)} \pm 0.006\text{(syst)} \]

New results with 20 fb$^{-1}$ @ 8 TeV

\[ A_C^{\text{LHC8}} = 0.0055 \pm 0.0023\text{(stat)} \pm 0.0025\text{(syst)} \]
\[ m_{\text{comb}}^{\text{top}} = 172.51 \pm 0.27\text{(stat)} \pm 0.42\text{(syst)} \text{ GeV} \]
\[ \Gamma_t = 1.76 \pm 0.33\text{(stat)}^{+0.79}_{-0.68}\text{(syst)} \text{ GeV} \]

New results with 14.7 fb$^{-1}$ @ 13 TeV

\[ \sigma_{\text{fid}}^{\text{t\bar{t}(boost)}} = 374 \pm 13\text{(stat)}^{+111}_{-92}\text{(syst)} \text{ fb} \]

New results with 36 fb$^{-1}$ @ 13 TeV

\[ \sigma_{tZ(3\ell)} = 600 \pm 170\text{(stat)} \pm 140\text{(syst)} \text{ fb} \]

Single top w/ W boson in agreement with predictions

Colour flow according to SM preferred by data

BR\((t \rightarrow uZ) < 1.7 \times 10^{-4}\) @95% CL (Exp. 2.4 \times 10^{-4})

BR\((t \rightarrow cZ) < 2.3 \times 10^{-4}\) @95% CL (Exp. 3.2 \times 10^{-4})
Object Selection @ 13 TeV (8 TeV)

Primary vertex and Tracks
- minimum # tracks with $p_T > 0.4$ GeV
- Largest $|p_T|^2$ sum associated
- Quality tracks impact params: $d_0, z_0$

Small and Large-R Jets
- anti-$k_T$ clustering 0.4 and 1.0 radius
- Calibrated ($p_T, \eta$), in-situ correction
- Reject beam-halo, noise, overlap
- $p_T > 25$ GeV, $|\eta| < 2.5$
- Pile-up reduction for low $p_T$ jets
- flavor tagging WP, high efficiency, light-q/gluon rejection

Muons
- Consistent MS and ID good quality track match
- $p_T > 25$ GeV, $|\eta| < 2.5$
- Separated from jets
- Track isolation

Electrons
- Track and calorimeter quality and match criteria, exclude $1.37 < |\eta| < 1.52$
- Cluster energy deposit shape
- $E_T > 15$ GeV ($p_T > 25$ GeV), $|\eta| < 2.47$
- Jet overlap removal
- Track and energy isolation

$E_T^{miss}$
- Vector sum of transverse momenta of all calibrated leptons and jets, and unassociated PV ID tracks
Top Mass in $t\bar{t} \rightarrow \ell + jets$ @ 8 TeV

$m_{\text{top}}^\text{comb} = 172.51 \pm 0.27(\text{stat}) \pm 0.42(\text{syst})$ GeV

- $m_{\text{top}}^{\ell+jets} = 172.08 \pm 0.39(\text{stat}) \pm 0.82(\text{syst})$ GeV
- 13 vars BDT to suppress bad events. 3D template fit method (w/ JSF, bJSF).
- $0.91 \pm 0.06(\text{stat})$ uncertainty mainly by JES, b-tag, MC modelling
- larger dataset, 29% improvement w.r.t. 7 TeV
- combination with previous measurements taking correlations in account
  - $\chi^2$ probability 78%
  - 41% improvement w.r.t. $t\bar{t} \rightarrow \ell\ell$ @ 8 TeV
Final state $t\bar{t} \rightarrow b\bar{b}W(\rightarrow \ell\nu)W(\rightarrow q\bar{q})$
- $\geq 4$ jets, $\geq 2b$-tag
- $1e/\mu$, $E_T^{\text{miss}} > 20$ GeV
- Use ghost-associated inner detector tracks
  - Signal colour flow: highest $p_T$ jets from $W \rightarrow$ fwd/bkd pull angle
  - Spurious: $b$-tagged jets from tops $\rightarrow$ di-b-jet pull-angle

Unfolding at particle level after bkg sub
Sensitive observables poorly modelled by MC
Data agrees with SM predictions w.r.t. colour flipped exotic model
FCNC $t \rightarrow qZ$

Use $t\bar{t} \rightarrow qZ (\rightarrow \ell\ell) \bar{b}W (\rightarrow \ell\nu)$:
- $\geq 2$ jets, $p_T > 25$ GeV, $= 1b$-tag
- $= 3e/\mu$, $E_T^{\text{miss}} > 40$ GeV
- Minimize kinematic $\chi^2$
- Comb SR and 5 CRs fit

GIM suppressed in SM loop

### Sample Yields

<table>
<thead>
<tr>
<th>Operator</th>
<th>Pre-fit Yields</th>
<th>Post-fit Yields</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}Z$</td>
<td>$37 \pm 5$</td>
<td>$37 \pm 4$</td>
</tr>
<tr>
<td>$WZ$</td>
<td>$32 \pm 19$</td>
<td>$33 \pm 8$</td>
</tr>
<tr>
<td>$ZZ$</td>
<td>$6.2 \pm 3.2$</td>
<td>$6.6 \pm 3.1$</td>
</tr>
<tr>
<td>Non-prompt leptons</td>
<td>$26 \pm 11$</td>
<td>$20 \pm 7$</td>
</tr>
<tr>
<td>Other backgrounds</td>
<td>$23 \pm 4$</td>
<td>$23 \pm 4$</td>
</tr>
<tr>
<td>Total background</td>
<td>$124 \pm 26$</td>
<td>$120 \pm 10$</td>
</tr>
<tr>
<td>Data</td>
<td>116</td>
<td>116</td>
</tr>
<tr>
<td>Data / Bkg</td>
<td>$0.93 \pm 0.21$</td>
<td>$0.97 \pm 0.12$</td>
</tr>
<tr>
<td>Signal $t \rightarrow uZ$ (BR = 0.1%)</td>
<td>$101 \pm 8$</td>
<td>$103 \pm 8$</td>
</tr>
<tr>
<td>Signal $t \rightarrow cZ$ (BR = 0.1%)</td>
<td>$85 \pm 7$</td>
<td>$87 \pm 7$</td>
</tr>
</tbody>
</table>

### EFT constraints

<table>
<thead>
<tr>
<th>Operator</th>
<th>Observed</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>C_{uB}^{(31)}</td>
<td>$</td>
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<tr>
<td>$</td>
<td>C_{uW}^{(31)}</td>
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$A_C = \frac{N^{\Delta|y|>0} - N^{\Delta|y|<0}}{N^{\Delta|y|>0} + N^{\Delta|y|<0}}$

$\Delta|y| = |y_t| - |y_{\bar{t}}|$
Object and Event selection

- $p_T^{t,1} > 500$ GeV, $p_T^{t,2} > 350$ GeV
- Large-$R$ anti-$k_t$ $R = 1.0$ radius
- $p_T > 300$ GeV, $|\eta| < 2.0$, top-tagging
- Associated anti-$k_t$ $R = 0.4$ b-jets, $p_T > 25$ GeV
- No additional $p_T > 25$ GeV leptons

Unfolding differential cross-sections

- Normalized to the total for fiducial phase-space
- Corrections for acceptance and efficiency
- Migration matrix for detector/particle-level events
- $y_B^{t\bar{t}} = \frac{1}{2}(y^{t,1} + y^{t,2})$ sensitive to PDF
- $\chi^{t\bar{t}} = \exp 2|y^*|$, $y^* = \frac{1}{2}(y^{t,1} - y^{t,2})$ sensitive to $t\bar{t}$ production modelling

Fiducial phase-space total cross-section

$$\sigma_{t\bar{t}(\text{boost})}^{\text{fid}} = 374 \pm 13(\text{stat})^{+111}_{-92}(\text{syst}) \text{ fb}$$
Single $t$ associated w/ $W$ boson x-sec

- $= 2e/\mu$, $p_T > 20$ GeV
- $= 1e/\mu$, $p_T > 27$ GeV
- veto $m_{\ell\ell} < 40$ GeV, $81 < m_{\ell\ell} < 101$ GeV
- $= 1b$-jet, $E_T^{\text{miss}}$ cut
- BDT separate $t\bar{t}$ bkgd

Unfolded event yields converted to cross-section:

$$\frac{d\sigma_i}{dX} = \frac{N_i^{\text{ufd}}}{L\Delta_i}$$

Fiducial cross-section:

$$\sigma_{\text{fid}} = \sum_i \frac{N_i^{\text{ufd}}}{L}$$, $L = $luminosity
Single $t$ associated w/ $Z$ boson x-sec

- $3e/\mu$, $p_T > 28, 25, 15$ GeV
- OSSF: $81 < m_{\ell\ell} < 101$ GeV
- $m_T(\ell, \nu) \geq 20$ GeV
- $2$ jets, $p_T > 30$ GeV, $1b$-jet
- NN multivariate analysis

$\sigma_{tZ(3\ell)} = 600 \pm 170^{\text{(stat)}} \pm 140^{\text{(syst)}}$ fb
**t decay width in t\bar{t}+ jets channel**

\[ \Gamma_{\text{NLO}} = 1.33 \text{ GeV}, \quad \Gamma_{\text{NNLO}} = 1.322 \text{ GeV} \]

### Object and Event selection

- \( = 1e/\mu, \ p_T > 25 \text{ GeV} \)
- \( \geq 4 \text{ jets, } p_T > 25 \text{ GeV, } \geq 1b\text{-tag} \)
- \( E_T^{\text{miss}} > 20 \text{ GeV, } E_T^{\text{miss}} + m^W_T > 60 \text{ GeV (} = 1b\text{-tag)} \)

\[
m^W_T = \sqrt{2p^\ell_T E_T^{\text{miss}} (1 - \cos \Delta \phi(\ell, E_T^{\text{miss}}))}
\]

- Split into central/forward (\( \geq 1 \text{ jet } |\eta| > 1 \))
- \( e/\mu \) lepton flavor, and \( b\)-tag (\( = 1 \) or more)
- Likelihood-based assignment of reco jet to partons
- Template fit in 8 regions using \( m_{\ell b} \) and \( \Delta R_{\min}(j_b, j_l) \)
  - Good sensitivity to \( \Gamma_t \)
  - Reduces leading jet and signal model systematic uncertainties

### Results

\[ \Gamma_t = 1.76 \pm 0.33^{+0.79}_{-0.68} \text{ GeV} \]
Large range of new results in *top* quark physics

- Measurements of $t\bar{t}$ differential cross-sections in the all-hadronic channel with the ATLAS detector using highly boosted top quarks in pp collisions at $\sqrt{s} = 13$ TeV
  [http://cds.cern.ch/record/2217231](http://cds.cern.ch/record/2217231)

- Combination of inclusive and differential $t\bar{t}$ charge asymmetry measurements using ATLAS and CMS data at $\sqrt{s} = 7$ and 8 TeV

- Measuring Colour Flow at 13 TeV with the ATLAS Experiment
  [https://cds.cern.ch/record/2278365](https://cds.cern.ch/record/2278365)

- Measurement of differential cross-sections of a single top quark produced in association with a W boson with ATLAS at $\sqrt{s} = 13$ TeV
  [https://cds.cern.ch/record/2262346](https://cds.cern.ch/record/2262346)

- Search for flavour-changing neutral current top quark decays $t \rightarrow qZ$ in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS Detector
  [https://cds.cern.ch/record/2284483/](https://cds.cern.ch/record/2284483/)

- Measurement of the top quark mass in the $t\bar{t} \rightarrow$lepton+jets channel from $\sqrt{s} = 8$ TeV ATLAS data
  [https://cds.cern.ch/record/2280644](https://cds.cern.ch/record/2280644)

- Direct top-quark decay width measurement in the $t\bar{t} \rightarrow$lepton+jets channel at $\sqrt{s} = 8$ TeV with the ATLAS experiment

- Measurement of the production cross-section of a single top quark in association with a Z boson in proton-proton collisions at 13 TeV with the ATLAS detector
  [https://cds.cern.ch/record/2273868](https://cds.cern.ch/record/2273868)
Summary

- Precision results with 8 TeV data
  - Measurements of top properties (mass, width, charge asymmetry)
- Newest @ 13 TeV, with 2015+2016 dataset
  - New differential cross-section measurements in $t\bar{t}$ and single top
  - Studied colour flow and flavour-changing neutral current
- Results in agreement w/ SM expectations
- More results in the pipeline using new coming ATLAS data!
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