Measurement of the four-top-quark production in 13 TeV pp collisions with the ATLAS experiment

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on behalf of the ATLAS Collaboration

MoriondEW
22 March 21
Introduction

- **Four top production**: \( pp \rightarrow t \bar{t} t \bar{t} \), is a rare and theoretically challenging process
  - \( \sigma^{\text{NLO}}(tttt) = 12.0^{+/-2.4} \text{ fb at NLO QCD+EW at 13 TeV} \)
  - [arXiv:1711.02116 [hep-ph]]

- Sensitive to the top-Higgs Yukawa coupling
- Extremely high energy scale production makes it naturally sensitive to many BSM models, e.g.
  - Gluino pair production in SUSY
  - Heavy pseudoscalar/scalar boson in 2HDM
  - Four-fermion contact interaction within EFT

- **Signatures**: 
  - \( 2\ell SS / 3\ell \)
    - Low branching fraction, but small background (ttW, ttZ, non-prompt leptons, charge misidentification)
  - \( 1\ell / 2\ell OS \)
    - Dominant branching fraction, but large background from tt+jets
    - ATLAS-CONF-2021-013
Analysis Strategy (1ℓ2ℓOS Channel)

- Event signature characterized by one or two OS leptons and high jet multiplicity and b-jet multiplicities
- Main background: tt+jets (incl heavy-flavor) production, which is challenging to model accurately by the MC simulation
- Signal extracted via profile likelihood fit across all event categories accounting for a complex model of systematic uncertainties

**Example BDTs**

![Example BDT Plots](attachment:image.png)
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1ℓ/2ℓOS Result

- Good agreement obtained between data and post-fit prediction
- Dominant uncertainties on signal strength from tttt theoretical cross-section and modelling, and from tt+≥1b modelling.
- The extracted signal strength is: $\mu = 2.2^{+0.7}_{-0.7} \text{(stat.)}^{+1.5}_{-1.0} \text{(syst.)} = 2.2^{+1.6}_{-1.2}$
Signal strength in $1\ell/2\ell$OS and $2\ell$SS/3$\ell$ channels found to be in good agreement

- Combine for improved sensitivity

The combined four-top-quark production cross section is measured to be:

$$\sigma_{t\bar{t}t\bar{t}} = 25^{+7}_{-6} \text{ fb} \quad \sigma_{t\bar{t}t\bar{t}}^{SM} = 12.0 \pm 2.4 \text{ fb}$$

- with a corresponding observed (expected) signal significance of $4.7$ ($2.6$) standard deviations over background-only hypothesis

- It is consistent within $2.0$ standard deviations with the Standard Model expectation
Top Quark Production Cross Section Measurements

- Largest background by top quark pair production
  - Expected number of events during Run 2 (139 fb⁻¹)
    - ~100M events for top quark pair production
    - ~1k events for four-top-quark

**ATLAS Top public results**
Analysis Strategy (1L/2LOS Channel)

Not reviewed, for internal circulation only

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Reweighting
## Systematic Uncertainties

**ATLAS-CONF-2021-013**

<table>
<thead>
<tr>
<th>Uncertainty source</th>
<th>$\sigma_\mu$</th>
</tr>
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<tbody>
<tr>
<td><strong>Signal Modelling</strong></td>
<td></td>
</tr>
<tr>
<td>$t\bar{t}t\bar{t}$ cross section</td>
<td>+0.75</td>
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<tr>
<td>$t\bar{t}t\bar{t}$ modelling</td>
<td>+0.66</td>
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<tr>
<td><strong>Background Modelling</strong></td>
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<tr>
<td>$t\bar{t}+\geq 1b$ modelling</td>
<td>+0.72</td>
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<tr>
<td>$t\bar{t}+\geq 1c$ modelling</td>
<td>+0.41</td>
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<tr>
<td>$t\bar{t}$+jets reweighting</td>
<td>+0.30</td>
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<tr>
<td>Other background modelling</td>
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<tr>
<td>$t\bar{t}$+light modelling</td>
<td>+0.15</td>
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<tr>
<td><strong>Experimental</strong></td>
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<tr>
<td>Jet energy scale and resolution</td>
<td>+0.49</td>
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<td>$b$-tagging efficiency and mis-tag rates</td>
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<tr>
<td>MC statistical uncertainties</td>
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<tr>
<td>Luminosity</td>
<td>+0.07</td>
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<tr>
<td>Other uncertainties</td>
<td>+0.05</td>
</tr>
</tbody>
</table>

**Total systematic uncertainty**   +1.45   -1.04

**Statistical uncertainty**        +0.67   -0.65

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### Pre-fit impact on $\mu$:
- $\theta = \theta + \Delta \theta$
- $\theta = \theta - \Delta \theta$

### Post-fit impact on $\mu$:
- $\theta = \theta + \Delta \theta$
- $\theta = \theta - \Delta \theta$

- Nuis. Param. Pull

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**ATLAS Preliminary**

$\sqrt{s} = 13$ TeV, 139 $fb^{-1}$

- $t\bar{t}t\bar{t}$ cross section
- $t\bar{t}t\bar{t}$ PS choice
- $t\bar{t}b$ 5FS vs. 4FS
- $t\bar{t}+\geq 1c$ normalisation
- $t\bar{t}t$ $\mu_t$ and $\mu_{\bar{t}}$
- $b$-tagging: light jets mis-tag rates EV0
- $t\bar{t}b$ generator choice shape
- $t\bar{t}+\geq 1b$ normalisation
- $t\bar{t}+\geq 1c$ reweighting: non-$t\bar{t}$ subtraction
- $t\bar{t}+\geq 1c$ generator choice shape
- $t\bar{t}+b$ 5FS vs. 4FS
- $t\bar{t}B$ normalisation
- JES modelling EV1
- JES pile-up $\rho$-topology
- $t\bar{t}B$ 5FS vs. 4FS
- $t\bar{t}+\geq 1c$ light generator choice migration
- JES flavour composition $t\bar{t}t$
- $t\bar{t}H + \geq 1c$ cross section
- JES flavour response
- single-top-quark generator choice