ALL-HADRONIC RESOLVED
DIFFERENTIAL TTBAR
CROSS-SECTION MEASUREMENTS

Riccardo Poggi
on behalf of the ATLAS collaboration
OVERVIEW OF THE ANALYSIS

- Channel with the largest BR ~ 46%
- Full kinematic reconstruction of both tops
- Study correlations between additional jet radiation and top (system) kinematics
  - New observables to describe the kinematics of the extra-jets
  - Studying the parameter related to the additional jets emission in the MC generators
- Helpful for searches where ttbar+jet is a major background
  - Reduce modelling systematic
- Particle level results
  - Rivet routine used for MC studies
- Parton level results
  - Unfolded results available as input for measurement of top pole mass and PDF fit
- Total and differential cross-section
  - Absolute and normalised
  - Fiducial and full phase-space

- Offline Selection
  - 2 b-jets exclusive (70%)
  - Zero leptons
  - Leading 6 jets $p_T > 55$ GeV
  - Extra jets $p_T > 25$ GeV
ANALYSIS STRATEGY

- Fiducial phase space at particle level
  - Analogous to detector level selection
- Full phase-space at parton level
- System reconstruction performed selecting the combination that minimises the $\chi^2$
  - $\chi^2$ computed for all possible permutations and the permutation with the smallest value is selected
  - Jet assignment based on $W$ mass constraint and top anti-top mass agreement
    - Sigma values extracted from mass distributions in simulated MC events
  - Particle level efficiency ~ 85% in 6 jets exclusive region, 60-75% in 7-9 jets region
  - Parton level efficiency ~ 75% in 6 jets exclusive, ~ 65% in 7 jets exclusive, ~45-60% in 8-9 jets regions
- Multi-jet background
  - Dominant background component
  - Data driven ABCD method
    - (see extra for more details)
  - Negligible contamination for $N_{jets} == 6$
- Unfolding
  - D’Agostini iterative, four iterations

\[ \chi^2 = \frac{(m_{p_1j_1j_2} - m_{p_2j_3j_4})^2}{2\sigma_i^2} + \frac{(m_{j_1j_2} - m_W)^2}{\sigma_W^2} + \frac{(m_{j_3j_4} - m_W)^2}{\sigma_W^2} \]
UNCERTAINTIES

SUMMARY ON INCLUSIVE XS

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Particle level</td>
</tr>
<tr>
<td>PS/hadronisation</td>
<td>8.2</td>
</tr>
<tr>
<td>Multi-jet syst.</td>
<td>7.7</td>
</tr>
<tr>
<td>JES/JER</td>
<td>6.7</td>
</tr>
<tr>
<td>ISR, PDF</td>
<td>3.3</td>
</tr>
<tr>
<td>ME generator</td>
<td>2.4</td>
</tr>
<tr>
<td>Flavour tagging</td>
<td>2.2</td>
</tr>
<tr>
<td>Luminosity</td>
<td>2.1</td>
</tr>
<tr>
<td>Multi-jet stat.</td>
<td>0.6</td>
</tr>
<tr>
<td>MC signal stat.</td>
<td>0.3</td>
</tr>
<tr>
<td>Stat. unc.</td>
<td>0.7</td>
</tr>
<tr>
<td>Stat.+syst. unc.</td>
<td>14</td>
</tr>
</tbody>
</table>

- Relative uncertainties on the inclusive cross-section
- PS/hadronisation dominant followed by multi-jet background and JES/JER

PARTICLE LEVEL

- Normalised fractional uncertainties
- Dominant systematics: JES/JER and modelling
- Multi-jet background systematic relevant only in low statistics regions
RESULTS – 1D

- Leading top $p_T$ shown here as example
- Summary of the 1D measurements
  - Angular distributions are well modelled
  - Transverse momentum distributions between tops, decay products and FSR are poorly described by MC
  - MC modelling cannot simultaneously get the top $p_T$ and the $t\bar{t}$ $p_T$ correct
- Highlight feature of extra jet radiation
  - $\Delta R$ between leading jet and leading extra jet
  - Peak at 0 is where the leading jet is from an ISR emission
  - Significant mismodelling for Shrepa, aMC@NLO+Pythia8, Powhet+Herwig7
  - Underestimate how frequently the leading jet comes from a top

16 Sep. 2020

TOP2020
RESULTS – 2D

- Chi2 and p-value agreement between MC prediction and data
  - Evaluated using the full covariance matrix due to data statistics and systematic uncertainties
  - No MC prediction is compatible with data in all 2D distribution
**COMPARISON RESULTS**

**ALL-HADRONIC wrt L+JETS**
- Same phase space and object definition at parton level
- Consistent in the overlap region
- Complementary bin resolutions between the two channels

**ALL-HADRONIC wrt BOOSTED**
- Direct comparison not possible
  - Fiducial vs. full phase-space
- Ratio consistent in the overlap region

16 Sep. 2020

**TOTAL CROSS-SECTION**

**ATLAS Preliminary**  
\( \bar{p}p = 13 \text{ TeV}, 36.1 \text{ fb}^{-1} \)

Fiducial phase-space

All-had resolved

- Nominal
- POWHEG+Pythia8*
- Alternative additional radiation
- POWHEG+Pythia8 Rad. up*
- POWHEG+Pythia8 Rad. down*
- Alternative ME/PS
- POWHEG+Herwig7*
- MG5_aMC@NLO+Pythia8*
- Sherpa 2.2.1*

Inclusive fiducial cross-section [pb]

- Powheg+Herwig7 has the largest discrepancy from total XS
  - On the other hand it has the best description for differential distributions

|------------|------------------|------|

\( ^* \) normalized to NNLO+NLL, M. Czakon and A. Mitov, Comput. Phys. Commun. 185 (2014) 2930

Scale,PSwR(\+,-) uncertainty on the k-factor
SUMMARY

• Comprehensive cross-section measurement
  − Single- and double-differential
  − Absolute and normalised
  − Particle and parton levels

• Several kinematic variables
  − Additional novel variables to study top associated jet radiation

• Data driven background estimate strategy

• Results sensitive to different aspects of MC
  − Improve top-quark MC modelling
  − Check out Simone Amoros’s talk which presents new MC studies using our Rivet routine
    • https://conference.ippp.dur.ac.uk/event/891/contributions/4891/

• Parton level results can be used for PDF and top pole mass extraction
EXTRA
**BACKGROUND ESTIMATE**

- Data driven ABCD method
  - estimated bin-by-bin for all observables
- Discriminant variables
  - Nr. of b-jets
  - Combination of top masses
- Nominal estimate
  - $A_1$, $B_1$, C, D
  - Using the 1 b-tagged region
- Alternate estimate for uncertainty
  - $A_0$, $B_0$, C, D
  - Using the 0 b-tagged region
- Gap between SR and CR region
  - White area in the chart
  - Significant reduction of the signal contamination

<table>
<thead>
<tr>
<th>mass region</th>
<th>condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(m_{t1}, m_{t2}) \in\ \text{tail}$</td>
<td>if at least one top with $m_t &lt; 120$ GeV or $m_t &gt; 250$ GeV</td>
</tr>
<tr>
<td>$(m_{t1}, m_{t2}) \in\ \text{peak}$</td>
<td>if both top have $130$ GeV &lt; $m_t$ &lt; $200$ GeV</td>
</tr>
</tbody>
</table>

Table 4: Definition of the mass region based on the $m_t$ of the two top quarks.

$$D(X) = \frac{B_1(X) \cdot C(X)}{A_1(X)}.$$ 

$$D'(X) = \frac{B_0(X) \cdot C(X)}{A_0(X)}.$$ 

$$\Delta D = D' - D$$ 

D: signal region 
$A_1, B_1$: QCD Estimate 
$A_0, B_0$: Used for uncertainty