Constraining QCD modelling uncertainties in ttbar events at ATLAS

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Outline

- MC generators used for ttbar
- Measurements constraining uncertainties
- Alternative uncertainty prescriptions
- Summary
MC Generators used for ttbar

- The Monte Carlo event generators currently used for ttbar can be split into two categories:
  - Next-to-leading order + parton shower. E.g. MC@NLO/Powheg + Herwig/Pythia

```
  ttbar @ NLO
  ttbar + 1 jet @ LO
  More jets from parton shower
```

“NLO+PS”
MC Generators used for ttbar

- The Monte Carlo event generators currently used for ttbar can be split into two categories:

  - **Next-to-leading order + parton shower.** E.g. MC@NLO/Powheg + Herwig/Pythia

    
    ![Diagram for ttbar @ NLO](image1)
    ![Diagram for ttbar+1 jet @ LO](image2)
    ![Diagram for More jets from parton shower](image3)

    "NLO+PS"

  - **Multi-leg leading order + parton shower.** E.g. Alpgen + Herwig/Pythia, Sherpa.

    
    ![Diagram for ttbar @ LO](image4)
    ![Diagram for ttbar+1/2/3/4j @ LO](image5)
    ![Diagram for More jets from parton shower](image6)

    "ME+Ps"
MC Generators used for ttbar

- Future generators:
  - aMC@NLO + Herwig++/Pythia8, released recently, will provide $t\bar{t} + 1j @ NLO$, + parton shower.
  - Sherpa 2.0, hopefully released 'soon', will provide $t\bar{t} + 1j @ NLO$, +2/3/4 @ LO + parton shower. ($"MEPS@NLO"$)

- Lots of nice tools for generating events.
- Important not to just blindly accept that what the generator gives us is the whole truth.
- Always uncertainties associated with the MC predictions.

- Scales can be varied by a factor 2.
  - Factorization, renormalization, resummation scales.
- Parameters controlling $ME+Ps$ matching - MLM, CKKW.
Measurements constraining uncertainties

Measurement of $t\bar{t}$ production with a veto on additional central jet activity in $pp$ collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector

Measurements constraining uncertainties

- Study the fraction of ttbar events which do not contain an additional jet, in a central rapidity region, with \( p_T > Q_0 \).

\[
f_{gap}(Q_0) = \frac{n_{gap}(Q_0)}{N_{tt}}
\]

\[
f_{gap}(Q_{sum}) = \frac{n_{gap}(Q_{sum})}{N_{tt}}
\]

- Alternatively take the sum of the \( p_T \) of jets falling into each rapidity region and define:

- Use dilepton-channel events with two tagged b-jets, to easily identify any additional jet(s).

- Four rapidity regions: \( |y| < 0.8, \ 0.8 \leq |y| < 1.5, \ 1.5 \leq |y| < 2.1, \ |y| < 2.1 \)

- Measurement corrected for detector effects and presented in a well-defined fiducial region.
Measurements constraining uncertainties

- The gap fraction can be expressed in terms of a ratio of cross-sections:

$$f_{\text{gap}}(Q_0) = \frac{n_{\text{gap}}(Q_0)}{N_{tt}} = \frac{\sigma^f_{tt+0\ j}}{\sigma^f_{tt}} = 1 - \frac{\sigma^f_{tt+\geq1\ j}}{\sigma^f_{tt}}$$

- Where:

  $$\sigma^f_{tt} = \text{Fiducial cross-section for dilepton ttbar events}$$

  $$\sigma^f_{tt+0\ j} = \text{Fiducial cross-section for dilepton ttbar events with no additional jet with } p_T > Q_0 \text{ GeV.}$$

  $$\sigma^f_{tt+\geq1\ j} = \text{Fiducial cross-section for dilepton ttbar events with at least one additional jet with } p_T > Q_0 \text{ GeV.}$$
Measurements constraining uncertainties

- In general, both the NLO+PS and ME+Ps generators give a good description of the data.
- MC@NLO overshoots the data in the most central (|y| < 0.8) region (not enough radiation).
Measurements constraining uncertainties

- All generators predict too much radiation into the region $1.5 \leq |y| < 2.1$
- Best overall description given by Sherpa.
Measurements constraining uncertainties

- Nominal AcerMC curve not consistent with the data.
- Spread of increased/decreased ISR curves much larger than the total experimental uncertainty.
- This was one of the dominant uncertainties in many Top group analyses.
- These variations have since been ‘re-tuned’ to be more consistent with the data uncertainty.
- Difference between more & less PS approx. the same as expt. uncertainty.
- Parton shower-related uncertainty is now smaller: (by approx. factor of 2).
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After ATLAS data

\[ f_{\text{gap}} \]

MC/data

\[ Q_0 [\text{GeV}] \]

ATLAS Work In Progress
Alternative uncertainty prescriptions

- Work is ongoing to produce an alternative estimate of this additional radiation uncertainty.
  - Varying scales in Alpgen+Pythia.
  - Parameter: $k_t f ac$
  - “...a prefactor directly on the renormalization scale argument of $\alpha_s$...”
    \[
    \alpha_s(k_t^2) \frac{1 - \text{loop}}{b_0 \ln(k_t^2/\Lambda^2)} = \frac{1}{b_0 \ln(k_t^2/\Lambda^2)}
    \]

- Some care must be taken to make sure the scale is varied consistently on either side of the ‘matching-boundary’
  - I.e. in the matrix element and parton shower.
  - Alpgen samples with varied $\alpha_s$ give a reasonable envelope.
  - Samples with increased $\alpha_s$ not consistent with data.
    (Consistent picture between gap fraction and jet multiplicity.)
Alternative uncertainty prescriptions

- Work is ongoing to produce an alternative estimate of this additional radiation uncertainty.
- Varying scales is an option.
- Parameter: $kt\text{fac}$
  - "$\ldots a prefactor of the scale argument $\alpha_s(k^2)^{1-\epsilon}\ldots$"
- Some care must be taken to make sure the scale is varied consistently on either side of the ‘matching-boundary’
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Scale variation studies w/ Sherpa also ongoing.
- E.g. Renormalization scale varied by $x0.5$ and $x0.75$.
- ATLAS data, EPJ C72 (2012) 2043
  - Alpgen+Pythia(as.down.central)
  - Alpgen+Pythia(as.down.radLo)
  - Alpgen+Pythia(central)
  - Alpgen+Pythia(as.up.radHi)
  - Alpgen+Pythia(as.up.central)

Scale vs. $Q_0$ for veto region: $|y| < 0.8$

$\langle y \rangle = \frac{1}{2}$
Summary

- Many MCs used to generate ttbar events. Each with their associated uncertainties.
- Size of some uncertainties can be constrained by the data.
  - Ttbar + jet veto analysis constrained ISR/FSR systematic.
  - Reduced uncertainties for many other analyses.
- Alternative systematics prescription under investigation by varying scales in Alpgen & Sherpa
  - Should eventually replace AcerMC variations.
Backup slides
### ttbar + jet veto - analysis cuts

<table>
<thead>
<tr>
<th>Selection</th>
<th>Channel</th>
<th>ee</th>
<th>μμ</th>
<th>eμ</th>
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<tbody>
<tr>
<td>Electrons</td>
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<td>2 with $E_T &gt; 25$ GeV,</td>
<td>-</td>
<td>1 with $E_T &gt; 25$ GeV,</td>
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<tr>
<td></td>
<td></td>
<td>$</td>
<td>\eta</td>
<td>&lt; 2.47$</td>
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<tr>
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<td>-</td>
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<td>1 with $p_T &gt; 20$ GeV,</td>
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<tr>
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<td>$&gt; 40$ GeV</td>
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<td>-</td>
<td>$&gt; 130$ GeV</td>
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<td>$m_{\ell\ell}$</td>
<td></td>
<td>$&gt; 15$ GeV</td>
<td>$&gt; 15$ GeV</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
<td>$</td>
<td>m_{\ell\ell} - 91$ GeV</td>
<td>$</td>
</tr>
<tr>
<td>$b$-tagged jets</td>
<td></td>
<td>At least 2 with $p_T &gt; 25$ GeV, $</td>
<td>y</td>
<td>&lt; 2.4$, $\Delta R(j, \ell) &gt; 0.4$</td>
</tr>
</tbody>
</table>
Gap fraction vs. $Q_0$ - Systematic uncertainties

\[ \int L \, dt = 2.05 \, fb^{-1} \]

- Systematic uncertainties

\[ Q_0 \, [GeV] \]

Stat. uncert.  
Total systematic  
b-Tagging  
JES / JER  
Unfolding  
Pileup/ JVF  
Backgrounds

veto region: $|y| < 0.8$

veto region: $0.8 \leq |y| < 1.5$

veto region: $1.5 \leq |y| < 2.1$

veto region: $|y| < 2.1$

L dt = 2.05 fb$^{-1}$

ATLAS
Gap fraction vs. $Q_{\text{sum}}$
Gap fraction vs. $Q_{\text{sum}}$ - systematic uncertainties

\begin{align*}
\text{veto region: } |y| < 0.8 \\
L dt = 2.05 \text{ fb}^{-1} \\
\end{align*}

\begin{align*}
\text{veto region: } 0.8 \leq |y| < 1.5 \\
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\end{align*}
AcerMC parameter variations

- PARP(67): controls high-pt ISR branchings phase-space;
  ISR branchings with \( pT_{\text{evol}} > \frac{m_{\text{dip}}}{2} \times \text{PARP}(67) \) are
  power suppressed by a factor \( \left( \frac{m_{\text{dip}}}{2pT_{\text{evol}}} \right)^2 \)

- PARP(64): multiplicative factor of the mom. scale^2 in running
  alpha_s used in ISR

- PARP(72): multiplicative factor of the \( \text{lam}_{\text{QCD}} \) in
  running alpha_s used in FSR central param. setting is
  motivated by ATLAS FSR QCD jet shapes,
  variations correspond to *1/2 and *1.5 central value

- PARJ(82): FSR low-pt cutoff

  - Defaults: \( \text{PARP}(67) = 4, \quad \text{PARP}(64) = 1 \)
  - ISR Down: \( \text{PARP}(67) = 0.5, \quad \text{PARP}(64) = 4 \)
  - ISR Up: \( \text{PARP}(67) = 6, \quad \text{PARP}(64) = 0.25 \)
Measurements constraining uncertainties

- Work is ongoing to produce an alternative estimate of this additional radiation uncertainty.
  
  - Varying scales in Alpgen+Pythia.

  - Parameter: $k_t \text{fac}$

  - \textit{“...a prefactor directly on the renormalization scale argument of $\alpha_s$...”}

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