Final state measurements in top pair events produced at the LHC

DIS 2013

Dominik Duda (Bergische Universität Wuppertal)

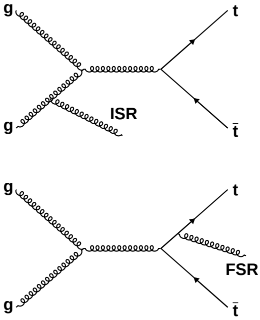
on behalf of the ATLAS collaboration

Content

- Introduction
- Measurement of the jet activity using the gap fraction
  - Eur.Phys.J. C72 (2012) 2043
  - ATL-PHYS-PUB-2013-005
- Measurement of the multiplicity of reconstructed jets
  - ATLAS-CONF-2012-155
  - ATLAS-CONF-2011-142
  - ATL-PHYS-PUB-2013-005
- Summary

Motivation

- Measurements of the top-quark properties provide a test of the SM
- Deviations from the predictions could indicate new physics
- Good description of SM production is therefore needed
- Uncertainties on the modelling have a large effect on measured top-quark properties
  - $\approx 11\%$ (total systematic uncertainty is $\approx 13\%$) on the $t\bar{t}$ production cross section with the lepton + jets data set at 8 TeV (ATLAS-CONF-2012-149)
  - $\approx 1.2\%$ (total systematic uncertainty is $\approx 2.1\%$) on the measured mass in the dilepton channel at 7 TeV (ATLAS-CONF-2012-082)



- One important aspect of the $t\bar{t}$ production modelling is the emission of quark and gluon radiation

Measuring jet activity in ATLAS data

- Measuring the fraction of $t\bar{t}$ events without additional jets
  - Dilepton $t\bar{t}$ events
  - Measurement in various |y|-bins
  - Applying unfolding to correct for detector effects
  - Comparing various MC-Generators to data
    - MC@NLO+ HERWIG
    - POWHEG+ PYTHIA
    - ALPGEN + HERWIG
    - SHERPA
    - ACERMC + PYTHIA (3 different configurations)

- Measuring the multiplicity of reconstructed jets
  - Single lepton $t\bar{t}$ events
  - Measurement for various p_T tresholds
  - Applying unfolding to correct for detector effects
  - Comparing various MC-Generators to data
    - MC@NLO+ HERWIG
    - POWHEG+ PYTHIA
    - ALPGEN + HERWIG
    - ALPGEN + PYTHIA (3 different configurations)

NLO ME

LO ME

Event selection at the particle level

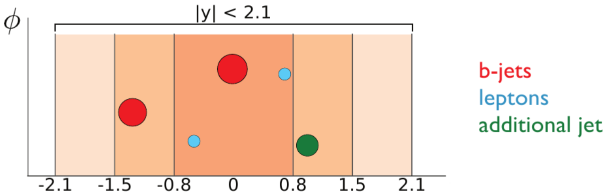
- The selection cuts at particle level $t\bar{t}$ events match those, which are applied to data:
- Electrons (only as direct decay products of W and τ)
  - $E_T > 25$ GeV
  - $|\eta| < 2.47$ (excluding $1.37 < |\eta| < 1.52$)
- Muons (only as direct decay products of W and τ)
  - $p_T > 20$ GeV
  - $|\eta| < 2.5$
- Jets are reconstructed with the anti-k_T algorithm ($R = 0.4$), using all stable particles ($c\tau > 10$ mm) except muons and neutrinos
  - $p_T > 25$ GeV
  - $|\eta| < 2.5$
- b-tagging is performed by matching the particle jets to b-hadrons
  - ($dR < 0.3$ & $p_T > 5$ GeV)
- E_T^{miss} is calculated using the vector sum of all generated neutrinos

Measuring the jet activity in dependence on |y|

- $t\bar{t}$ decays into two leptons are ideal to measure the activity of additional jets
  - Selecting exactly two b-tagged jets, high amount of missing energy and two opposite-charged leptons (6% bkg contamination)
- Quantification of the jet activity by using the gap fraction

$$f(Q_0) = \frac{n(Q_0)}{N^{t\bar{t}}} \qquad f(Q_{\mathrm{sum}}) = \frac{n(Q_{\mathrm{sum}})}{N^{t\bar{t}}}$$

  - $N^{t\bar{t}}$ is the total number of selected $t\bar{t}$ events
  - $n(Q_0)$ is the subset of events containing **NO** additional jet with a $p_T > Q_0$ in a certain rapidity region
  - $n(Q_{\mathrm{sum}})$ is the number of events in which the p_T-sum of all jets in a certain $|y|$-region **IS LESS THAN** Q_{sum}



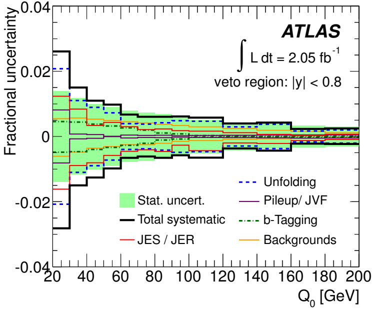
Gap fraction calculation and systematic uncertainties

Eur.Phys.J. C72 (2012) 2043

- Correcting data to particle level

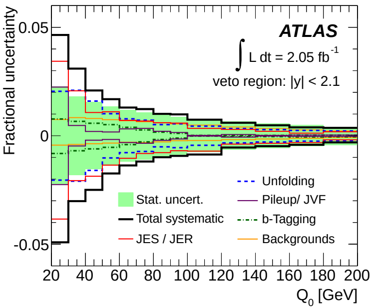
$$C(Q_0) = \frac{f^{\mathrm{truth}}(Q_0)}{f^{\mathrm{reco}}(Q_0)}$$

- central |y|-region



- Uncertainty due to unfolding is dominant

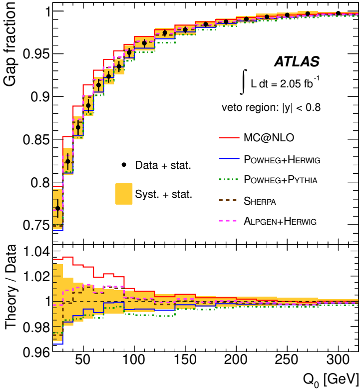
- full |y|-region



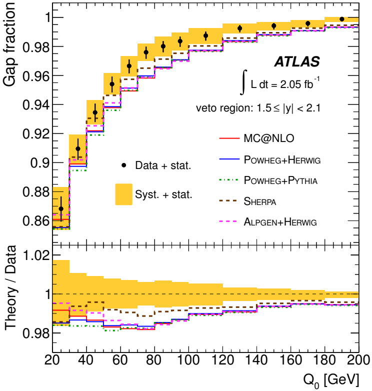
- JES and JER uncertainties are dominant

Unfolded spectra in the forward and central |y|-region

- central |y|-region



- forward |y|-region



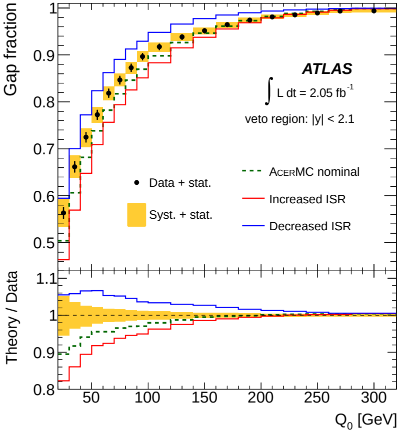
- MC@NLO predicts a too large gap fraction with respect to data (implies too little jet activity)
- Other generators show reasonable description of the data

- All generators produce too much jet activity (gap fraction is too small)

Eur.Phys.J. C72 (2012) 2043

Comparing different Pythia tunes to data

- Testing various ACERMC + PYTHIA configurations
  - default: PARP(67)=4.0 & PARP(64)=1.0
  - ISR up: PARP(67)=6.0 & PARP(64)=0.25
  - ISR down: PARP(67)=0.5 & PARP(64)=4.0
- Variation was previously used to estimate ISR uncertainties in top-quark analysis
- Data is enclosed by the different ISR scenarios
- Spread of predicted gap fractions is larger than the experimental precision by a factor of two or more
- Parameter sets are now constrained by data



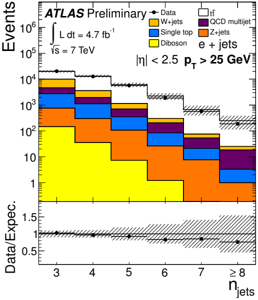
- parp(67): Suppression of ISR branchings
- $\alpha_s^{ISR} \sim \left(\log \frac{\mathrm{parp}(64) \cdot Q^2}{\Lambda^2_{QCD}}\right)^{-1}$

Eur.Phys.J. C72 (2012) 2043

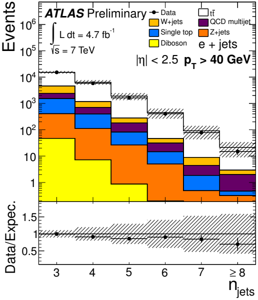
Jet multiplicity in $t\bar{t}$ final states

- Selection of single lepton events (e, μ) including cuts on E_T^{miss}, $M_{T,W}$, $N^{\mathrm{Jet}} \geq 3$ and requiring at least one b-tagged jet.
- Considering four different jet p_T thresholds
- Fair agreement comparing multiplicity of reconstructed jets in simulation (ALPGEN+HERWIG as signal) and data.

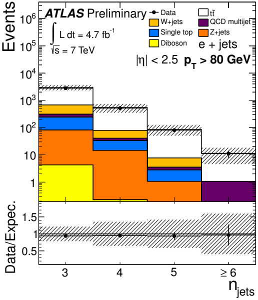
- $p_T > 25\,\mathrm{GeV}$



- $p_T > 40\,\mathrm{GeV}$



- $p_T > 80\,\mathrm{GeV}$

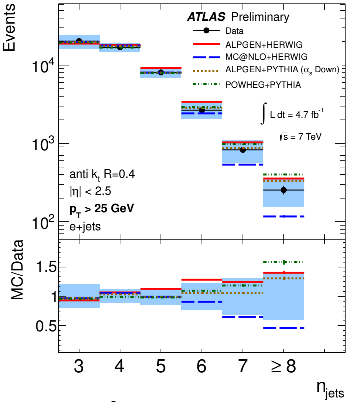


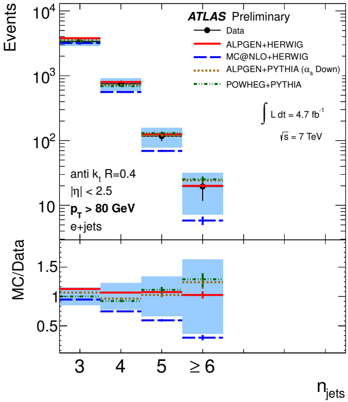
ATLAS-CONF-2012-155

Corrections to particle level and main uncertainties

- Background-subtracted reconstructed jet multiplicity spectrum in data is corrected back to particle-level by applying unfolding
- Unfolding corrections include
  - Detector efficiencies, resolutions effects and biases
- Main uncertainties
  - JES 3-40% (depending on jet multiplicity and p_T threshold)
  - ISR/FSR 1-6%.
  - MC generator (same order of magnitude as ISR/FSR)
  - Flavour tagging uncertainties (same order of magnitude as ISR/FSR)
  - MC statistics 1-11% (low p_T threshold) 40% in high jet multiplicity and p_T bins.

Results for the $p_T > 25\mathrm{GeV}$ and $p_T > 80\mathrm{GeV}$ thresholds

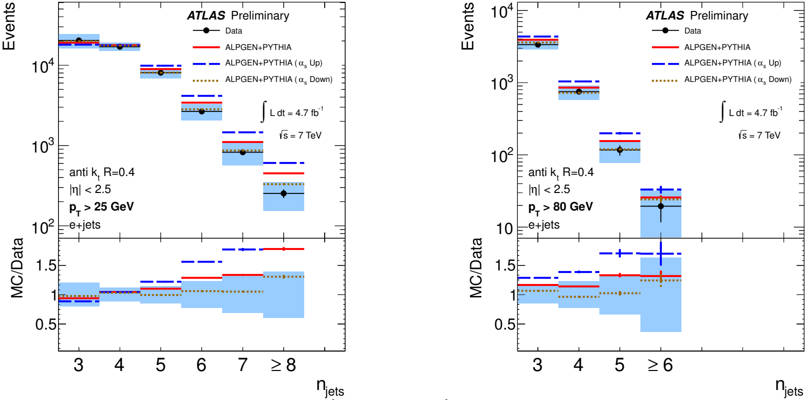




- MC@NLO + HERWIG agrees with data in the lower n_{jets} bins, but disagrees at higher jet multiplicities
- POWHEG & ALPGEN are in reasonable agreement with the data

ATLAS-CONF-2012-155

Results for different ALPGEN + PYTHIA tunes



- ALPGEN + PYTHIA (α_S down) has the best agreement with the data
- ALPGEN + PYTHIA is on the edge of the uncertainties
- ALPGEN + PYTHIA (α_S up) overestimates the number of events with > 4 jets

ATLAS-CONF-2012-155

Summary

- Measurement of the gap fraction and the reconstructed jet multiplicity were presented.
- Results of these two measurements are consistent
- Results of these measurements allow to improve theoretical description corresponding to jet activity
  - Gap fraction measurements:
    - MC@NLO underestimates the jet activity slightly in the central region
    - All generators show small deviations from data in the forward region (jet activity is overestimated)
    - Data has been used to constrain the uncertainties on the modeling of additional radiation
  - Measurement of the reconstructed jet multiplicities:
    - MC@NLO generator tends to underestimate the number of jets produced in association to $t\bar{t}$ production
    - ALPGEN + HERWIG, ALPGEN + PYTHIA, and POWHEG + PYTHIA give a reasonable description of the data
    - Results were presented only for the e + jets channel, but they are consistent to the results of the μ + jets channel

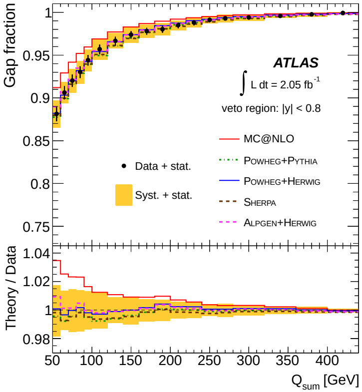
- Reconstructed jet multiplicity spectrum in data is corrected back to particle-level by

$$N_{\mathrm{part}} = f_{\mathrm{part!reco}} \cdot M_{\mathrm{part}}^{\mathrm{reco}} \cdot f_{\mathrm{reco!part}} \cdot f_{\mathrm{accept}} \cdot (N_{\mathrm{reco}} - N_{\mathrm{bkg}})$$

- $f_{\mathrm{part!reco}}$ and $f_{\mathrm{reco!part}}$ correcting events fulfilling the selection on particle (reco) level, while failing it on reco (particle) level
- N_{reco} is the number of reco events
- N_{bkg} is the background contribution
- f_{accpt} is a selection acceptance correction factor
- $M_{\mathrm{part}}^{\mathrm{reco}}$ is a response matrix

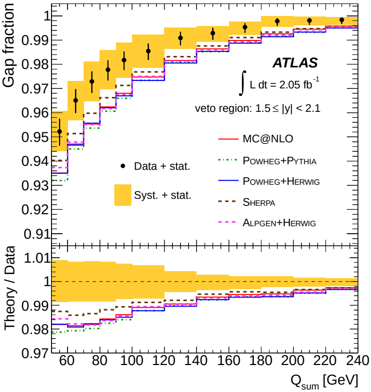
Back up – gap fraction $f(Q_{\mathrm{sum}})$

- central |y|-region



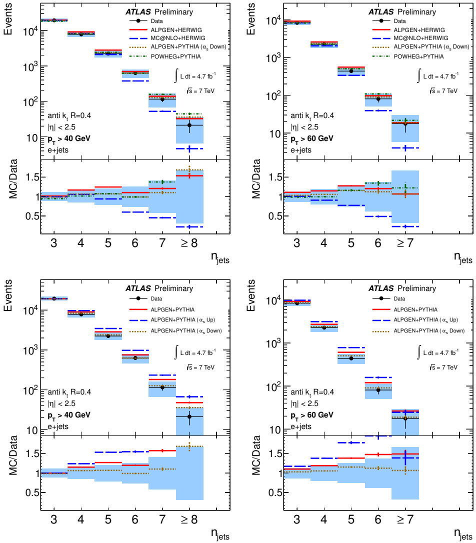
- MC@NLO predicts a too large gap fraction

- forward |y|-region



- Generators produce too much jet activity (gap fraction is too small)

Back up – particle-jet multiplicities

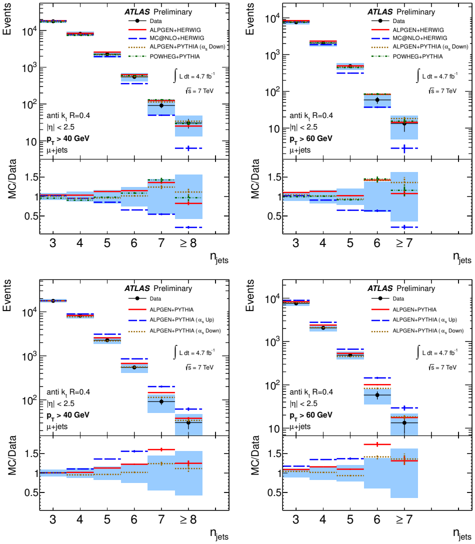


- Particle-jet multiplicities in the electron channel for the various simulation scenarios in comparison to data
- Plots show results for the $p_T > 25\text{GeV}$ and $p_T > 60\text{GeV}$ thresholds

BERGISCHE UNIVERSITÄT WUPPERTAL

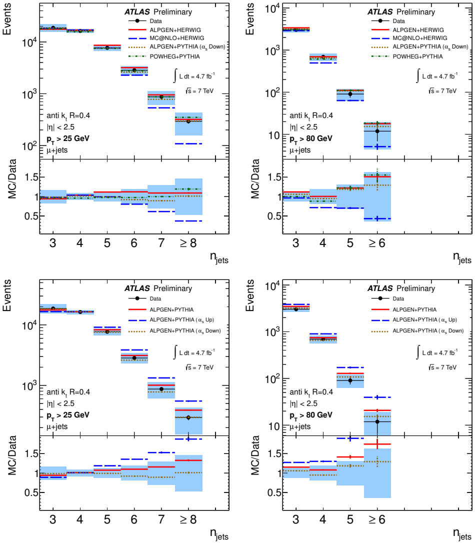
D. Duda, DIS 2013

Back up – particle-jet multiplicities



- Particle-jet multiplicities in the muon channel for the various simulation scenarios in comparison to data
- Plots show results for the $p_T > 40\mathrm{GeV}$ and $p_T > 60\mathrm{GeV}$ thresholds

Back up – particle-jet multiplicities



- Particle-jet multiplicities in the muon channel for the various simulation scenarios in comparison to data
- Plots show results for the $p_T > 25\text{GeV}$ and $p_T > 80\text{GeV}$ thresholds