Measurement of jet multiplicity in ttbar events in ATLAS.

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6th Annual Workshop of the Helmholtz Alliance "Physics at the Terascale"

3.12.2012

HELMHOLTZ GEMEINSCHAFT

DESY

Introduction

- Measure jet multiplicity in semi-leptonic ttbar events (*e*+jets and *μ*+jets) with a number of jet pT thresholds: 25, 40, 60, and 80 GeV (ATLAS CONF note ATLAS-CONF-2012-155).
- Measured up to 8 jets (inclusive).
- Motivation:
  - Constrain radiation,
  - Test pQCD,
  - Understand background for many searches.
- Reco-level plots were compared with data in ATLAS-CONF-2011-142 (2011, 0.70 fb^{-1}).
- Present measurement fully unfolded to particle level in fiducial region using full 2011 data set (4.7 fb^{-1}).

Event selection

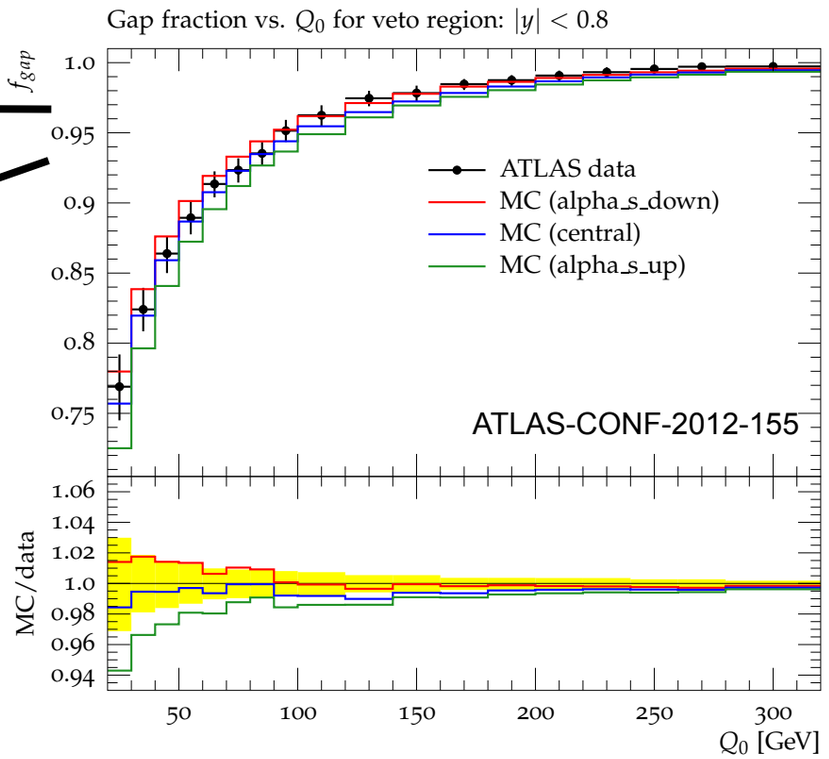
- Standard top-group semi-leptonic selections, with some exceptions (marked in red below):
  - Electron (20 and 22 GeV) or muon (18 GeV) trigger.
  - Electron $|\eta| < 2.47$, excluding $1.37 < |\eta| < 1.52$
  - Muon $|\eta| < 2.5$
  - Exactly one lepton with $p_T > 25$ GeV. No other lepton with $p_T > 15$ GeV.
  - ≥ 3 jets with $p_T > 25$ (40, 60, 80) GeV (EM+JES calibration) and |JVF| > 0.75
  - $E_T^{miss} > 30$ GeV
  - $m_T(W) > 35$ GeV in both channels
  - ≥ 1 *b*-tagged jets (MV1@60%) with $p_T > 25$ GeV

- Particle level selection, used for unfolding. Closely matched to reco-level acceptance:
  - Electron (dressed with photons in $\Delta R < 0.1$) $|\eta| < 2.47$, excluding $1.37 < |\eta| < 1.52$
  - Muon $|\eta| < 2.5$
  - Exactly one lepton with $p_T > 25$ GeV. No other lepton with $p_T > 15$ GeV.
  - ≥ 3 jets with $p_{T,truth} > 25$ GeV
  - $E_T^{miss} > 25$ GeV (neutrino sum)
  - $m_T(W) > 35$ GeV in both channels
  - ≥ 1 jet with a $p_T > 5$ GeV *b*-hadron within $\Delta R < 0.3$
  - Electrons, muons, neutrinos matched to *W*s.

Signal models and background estimation

- Baseline: ALPGEN + HERWIG (CTEQ6L1)
- ALPGEN + PYTHIA (CTEQ5L, Perugia 2011 tune)
- ALPGEN + PYTHIA (P2011, alpha_s ktfac0.5)
- ALPGEN + PYTHIA (P2011, alpha_s ktfac2.0)
- MC@NLO + HERWIG (CT10)
- POWHEG + PYTHIA (CTEQ6.6)

Used for ISR/FSR variations, as motivated by gap fraction measurement.



- Dominant backgrounds are W+jets, QCD, and single top. Using standard ATLAS top approach:
  - W+jets: MC with data-driven corrections (Normalization from charge asymmetry, Flavor-dependent scale factors)
  - Data-driven QCD multi-jet background (Matrix method)
  - Z+jets, single top, di-bosons from MC.

Systematic uncertainties

- Generally following standard ATLAS top group approach.
- Scale factors measured in data applied for
  - b-tagging
  - Jet vertex fraction (JVF) cut
  - lepton efficiencies
  - trigger.
- JES, JER
- W+jets and QCD background modeling.
- For JES n_{jets} dependence of gluon jet fraction explicitly taken into account. Estimated from ALPGEN+HERWIG and MC@NLO Monte Carlo.

Unfolding procedure

$$f_{\text{part!reco}}\ \mathbf{M}^{\text{reco}}_{\text{part}}\ f_{\text{reco!part}}\ f_{\text{accpt}}\ (1 - f_{\text{bgnd}})\ N^{\text{reco}}(n^{\text{reco}}_{\text{jets}}).$$

Background subtraction

Unfolding matrix.
Applied through iterative Bayesian method

Acceptance: All selection efficiencies except jet multiplicity, function of $n_{\text{jets,reco}}$

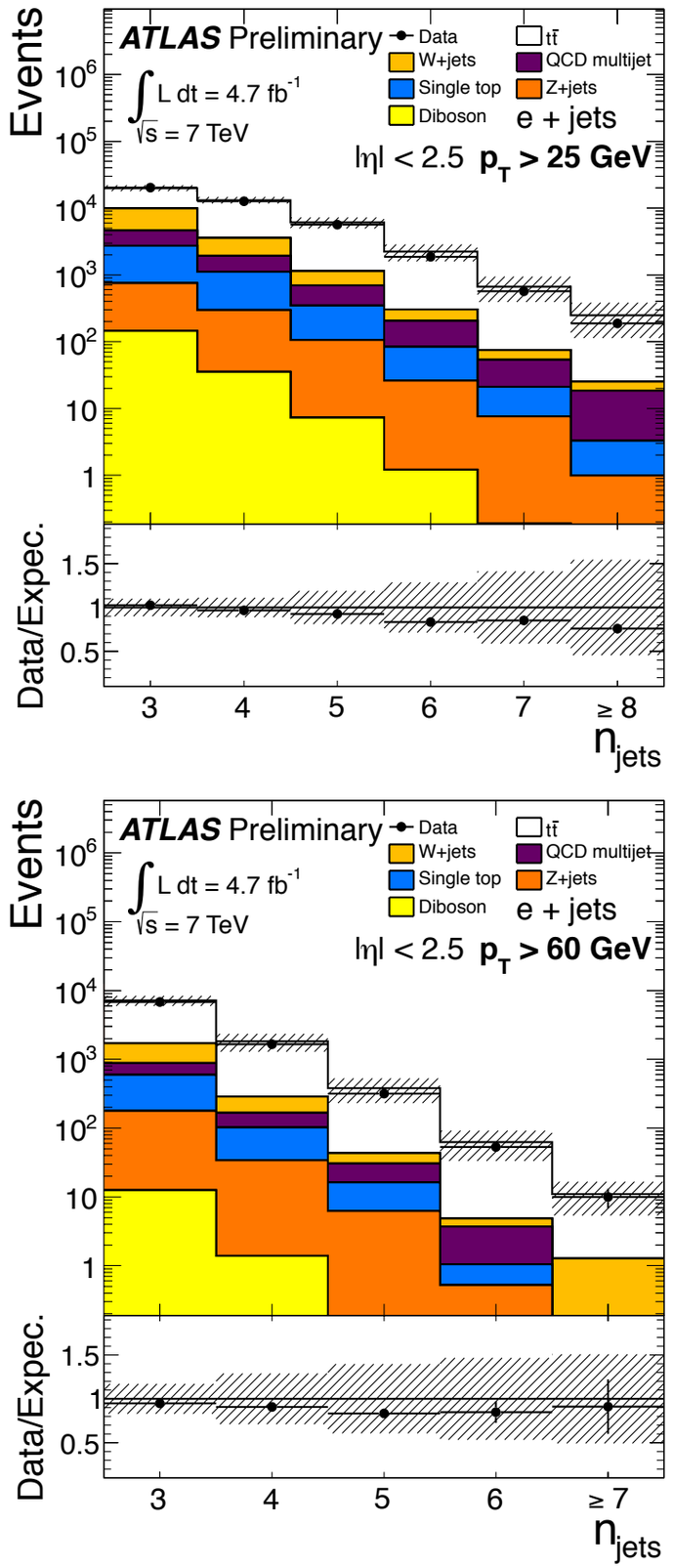
Events failing jet multiplicity requirement at reco level, but passing at particle level.
Function of $n_{\text{jets,part}}$

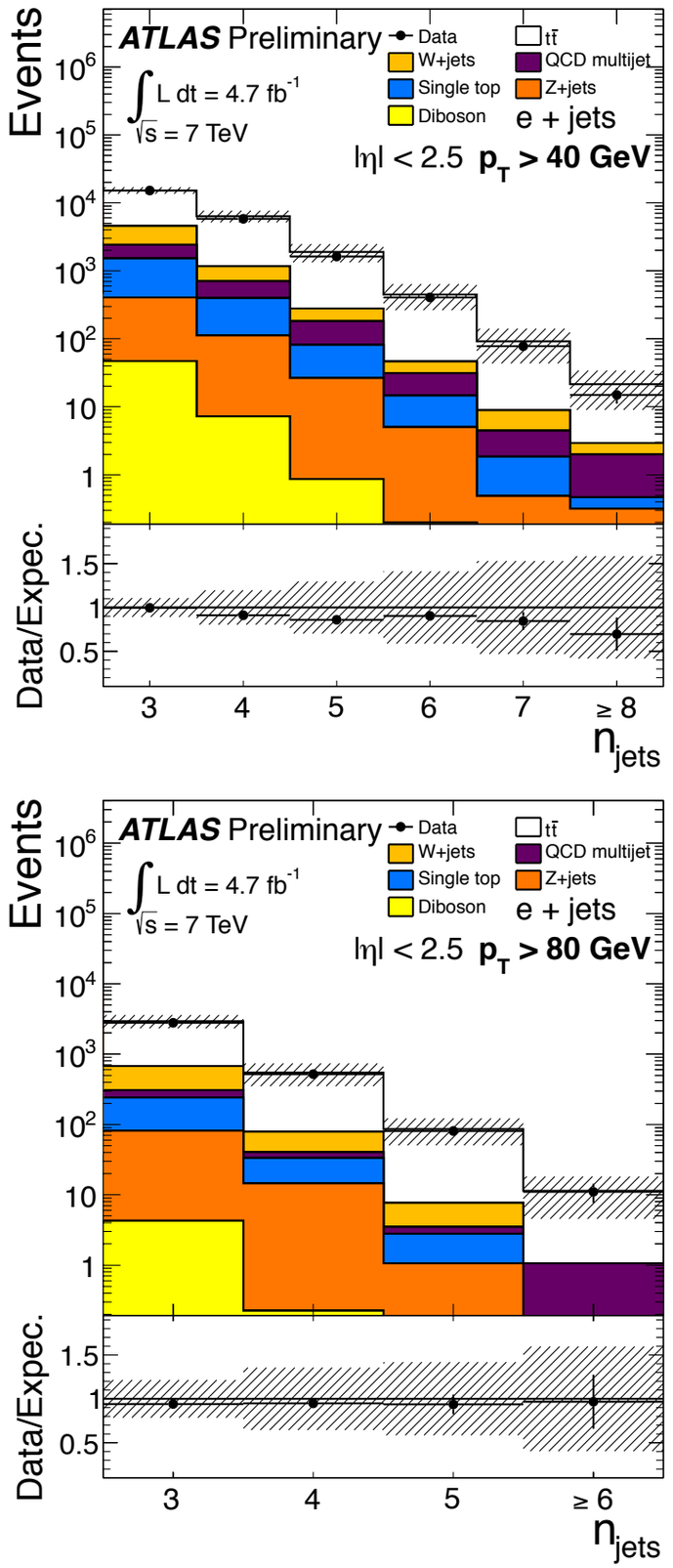
Events failing jet multiplicity requirement at particle level, but passing at reco level.
Function of $n_{\text{jets,reco}}$

- Uncertainties propagated through unfolding using pseudo-experiments:
  - Statistical uncertainty on unfolding factors
  - Background estimation
  - Reconstruction efficiencies
  - Generator bias from unfolding POWHEG+PYTHIA
  - ISR/FSR from ALPGEN+PYTHIA α_s variations.

Reco-level results, *e*+jets channel

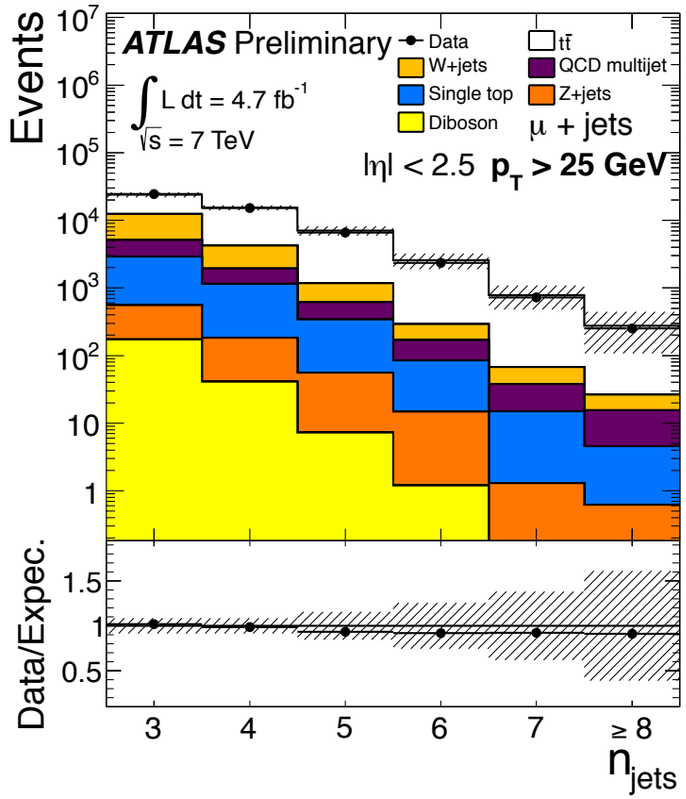
- Reco-level jet multiplicity in the e+jets channel for jet pT cuts of 25, 40, 60, and 80 GeV.
- Data compared to predicted distribution (signal+background).
- Shaded band: Total systematic and statistical uncertainty of prediction.
- Signal sample: ALPGEN +HERWIG.
- Predicted distribution (signal+background) agrees with data.

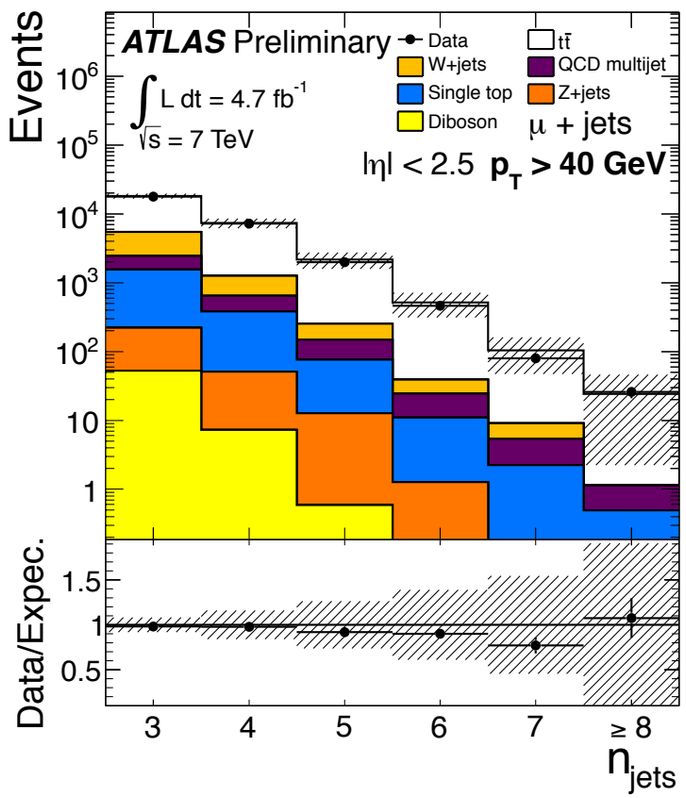


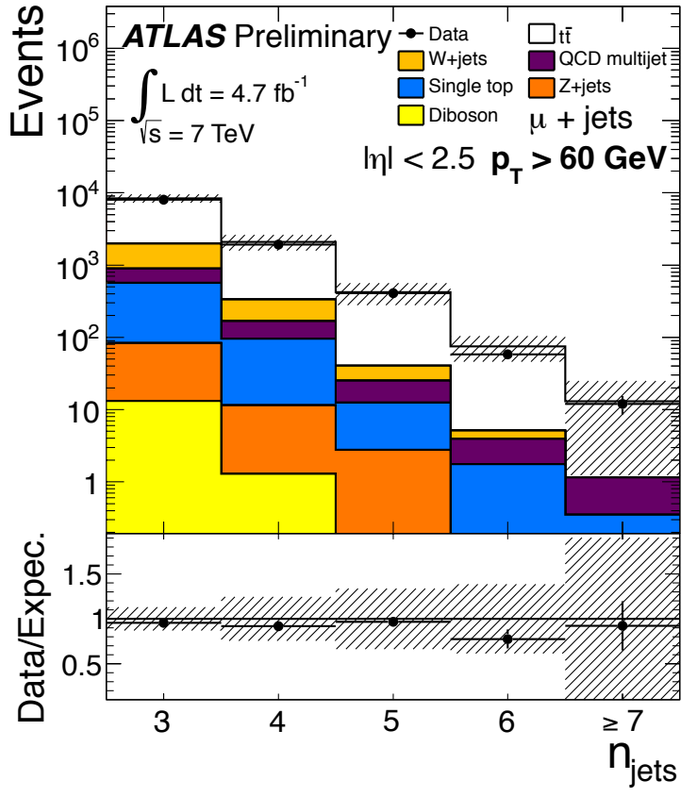


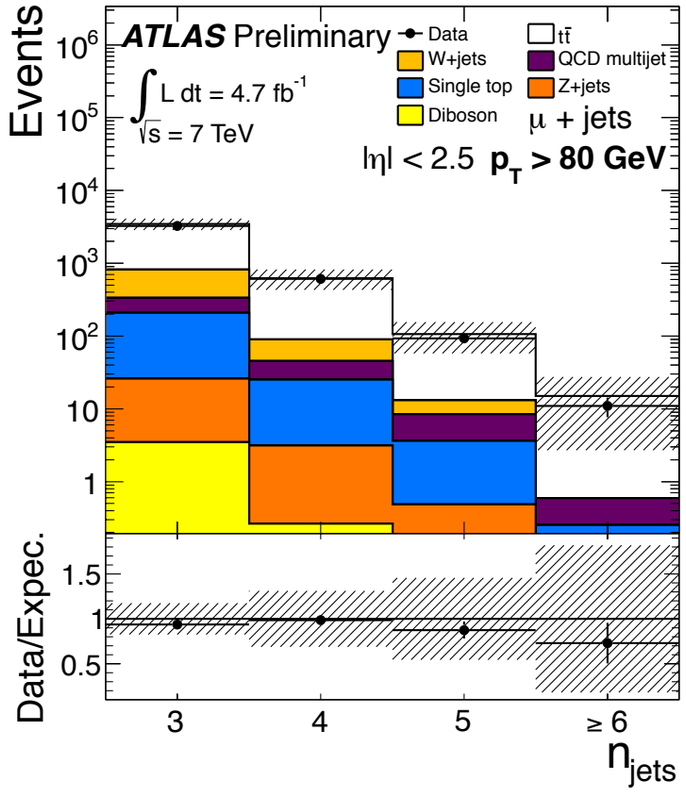
Reco-level results, μ+jets channel

- Reco-level jet multiplicity in the μ+jets channel for jet pT cuts of 25, 40, 60, and 80 GeV.
- Data compared to predicted distribution (signal+background).
- Shaded band: Total systematic and statistical uncertainty of prediction.
- Signal sample: ALPGEN +HERWIG.
- Predicted distribution (signal+background) agrees with data.



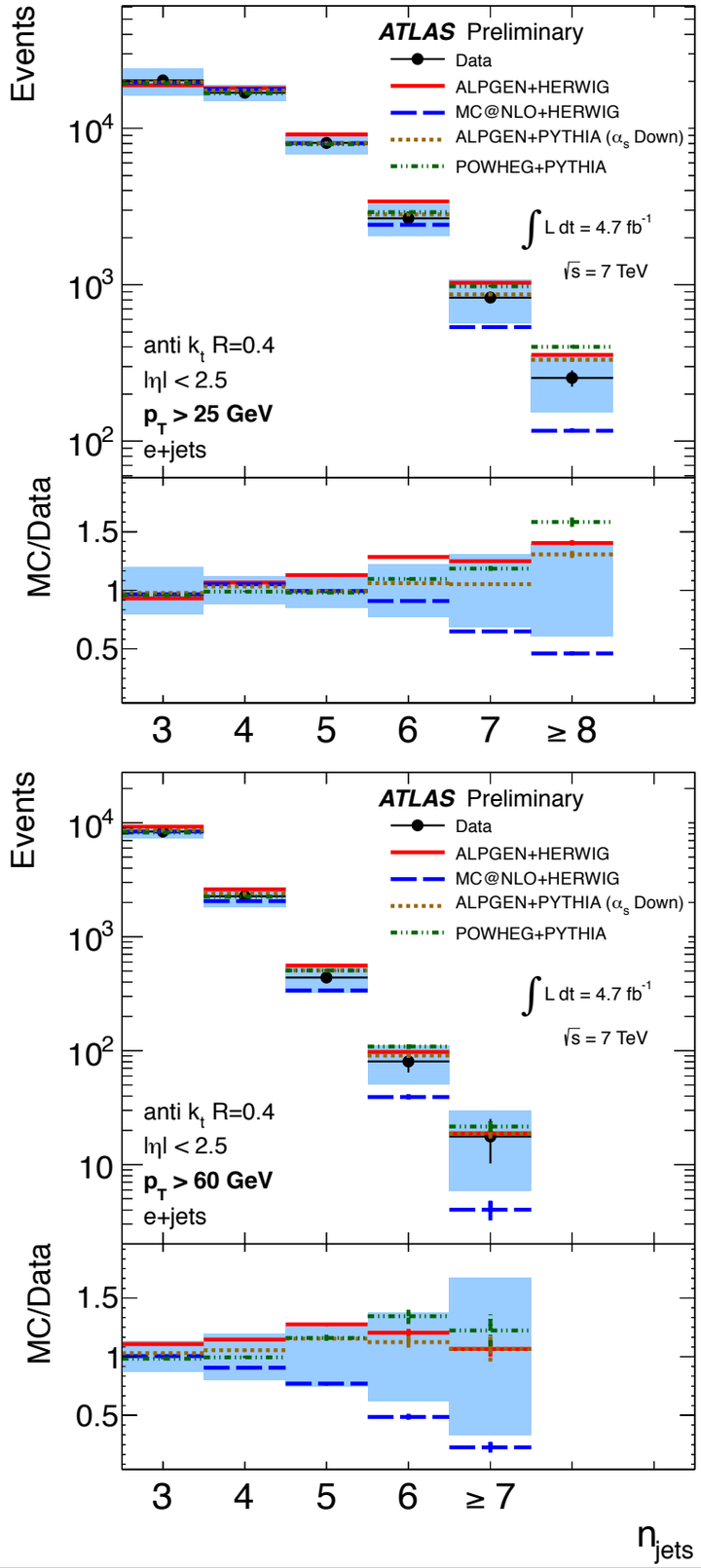


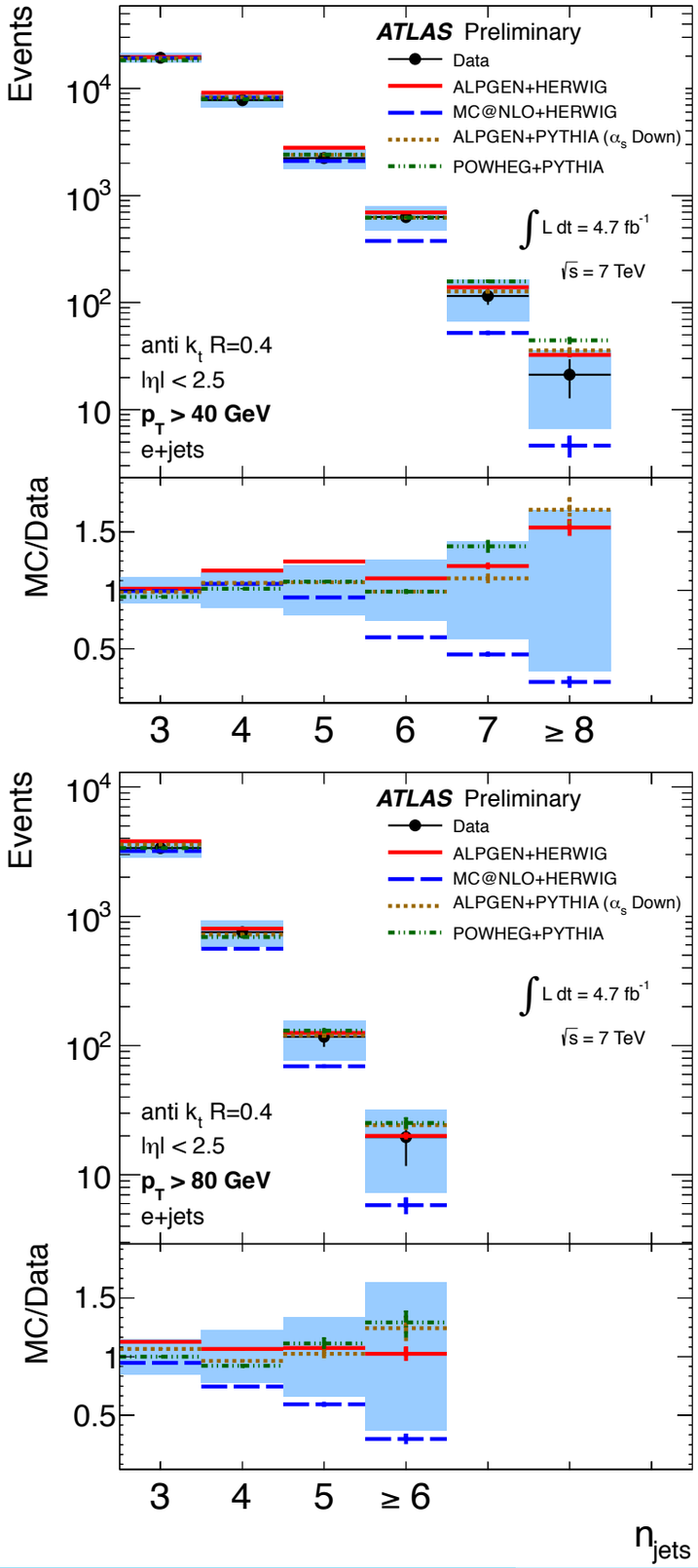




Particle-level results, e+jets channel

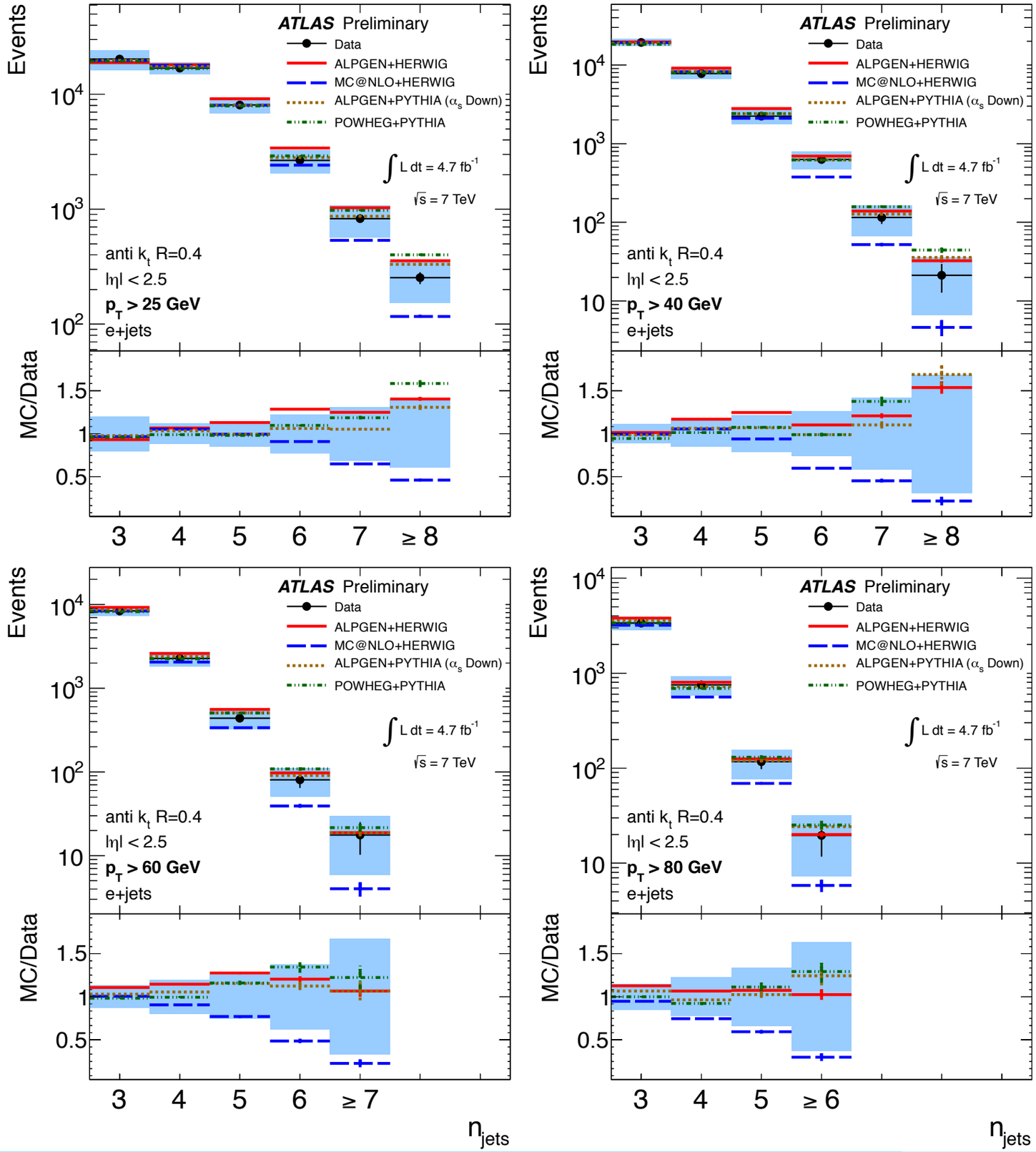
- Unfolded jet multiplicity in the e+jets channel for jet pT cuts of 25, 40, 60, and 80 GeV.
- Data after background subtraction and unfolding compared to predicted signal distribution
  - ALPGEN+HERWIG,
  - MC@NLO,
  - ALPGEN+PYTHIA α_s down
  - POWHEG+PYTHIA.
- Shaded band: Total systematic and statistical uncertainty of prediction.





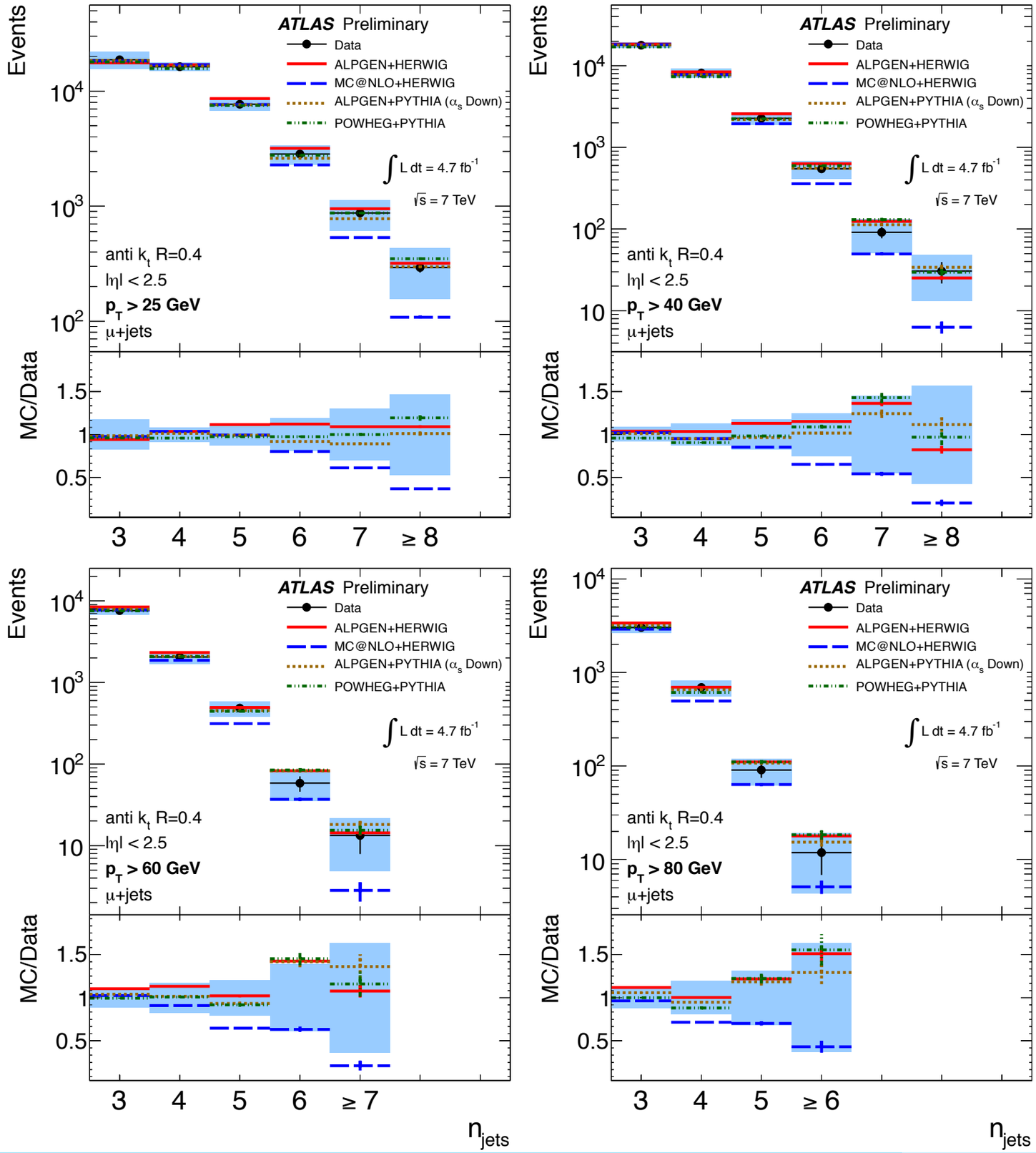
Particle-level results, e+jets channel (cont.)

- For p_T > 25 GeV, all MC predictions agree well with data for n_{jets} = 3, 4.
- MC@NLO+HERWIG agrees with data for n_{jets} = 3, 4, 5 and p_T > 25 GeV, underestimates for $n_{jets} \geq 6$. Continues to underestimate as p_T cut increases, indicating too soft pT spectrum.
- ALPGEN+HERWIG, POWHEG+PYTHIA, ALPGEN+PYTHIA α_s down in agreement with data for all p_T thresholds.



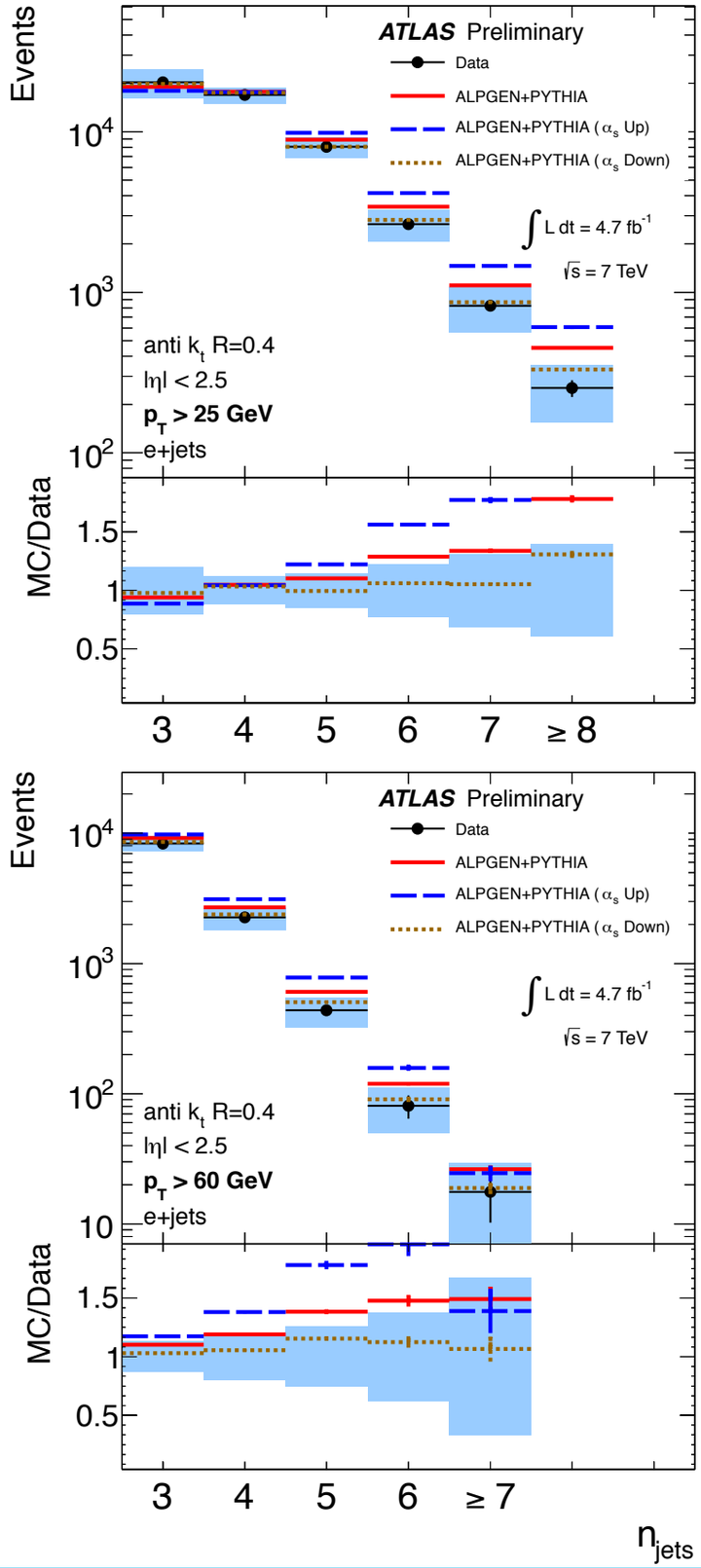
Particle-level results, μ+jets channel

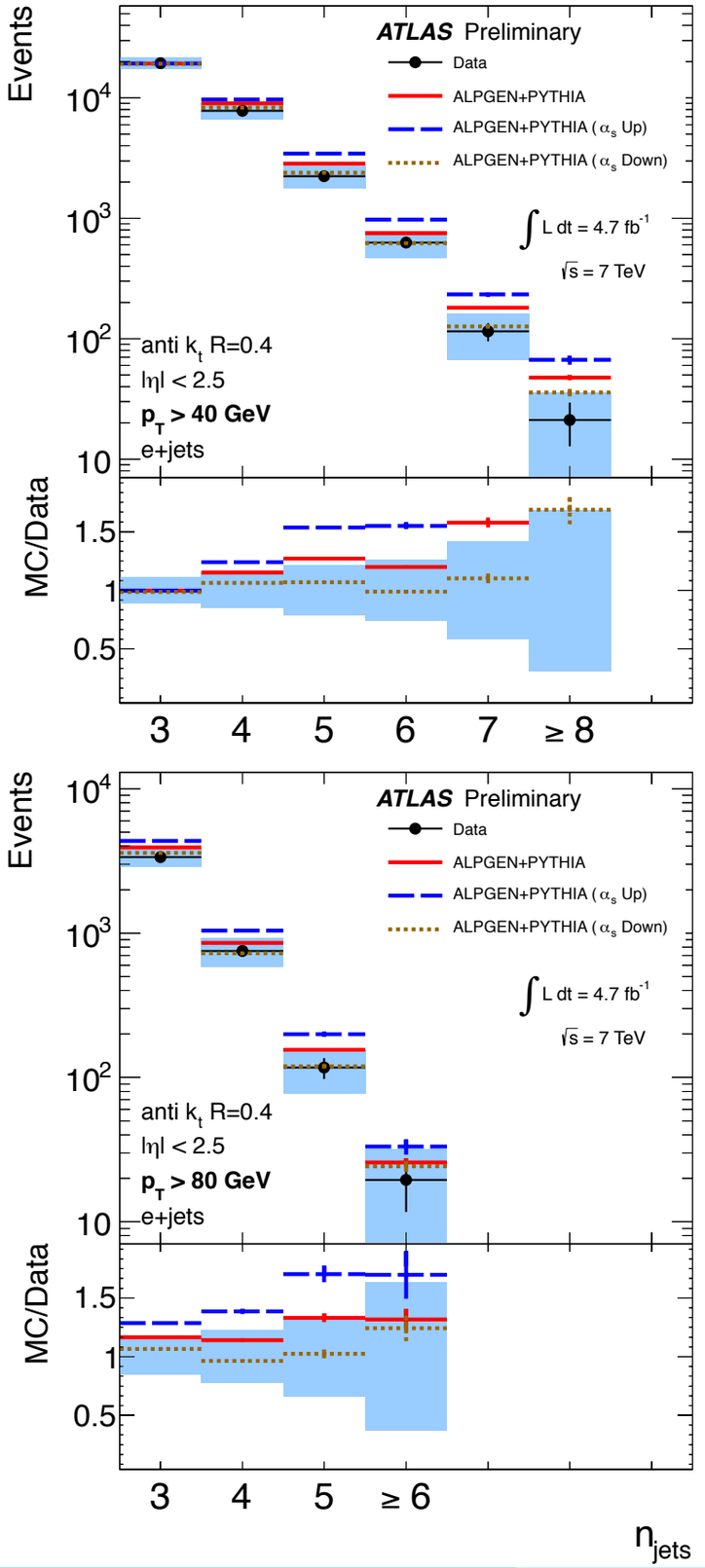
- Unfolded jet multiplicity in the μ+jets channel for jet pT cuts of 25, 40, 60, and 80 GeV.
- Same conclusions as for e+jets channel: MC@NLO underestimates data, all others in agreement.



Particle-level results, *e*+jets channel, ALPGEN+PYTHIA

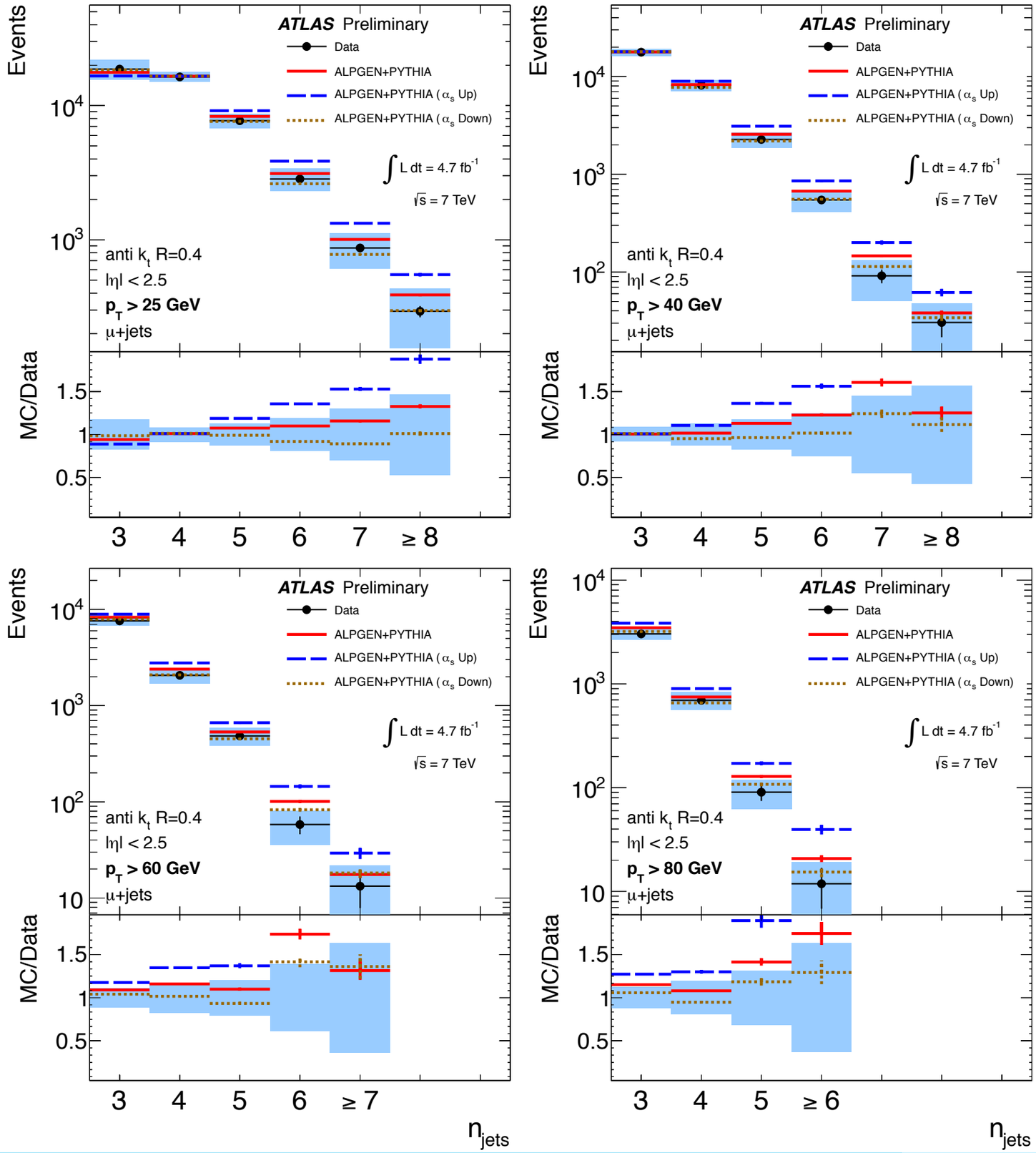
- As before, unfolded jet multiplicity in the *e*+jets channel.
- Data now compared to
  - ALPGEN+PYTHIA central
  - ALPGEN+PYTHIA α_s down
  - ALPGEN+PYTHIA α_s up
- α_s down favored by data.





Particle-level results, μ+jets channel, ALPGEN+PYTHIA

- Same conclusion in μ+jets channel: α_s down favored by data.



Conclusions and outlook

- Uncertainties dominated by systematics. Background uncertainties dominating at low n_{jets}, JES at high n_{jets}.
- MC@NLO+HERWIG: disfavored by data.
- POWHEG+PYTHIA and ALPGEN+HERWIG in resonable agreement with data for all pT thresholds and jet muliplicities.
- ALPGEN+PYTHIA: Data favors α_s down variation.
- Plans:
  - Unfolding of jet pT spectrum.
  - Measure cross section ratios to cancel out (some) systematic uncertainties.

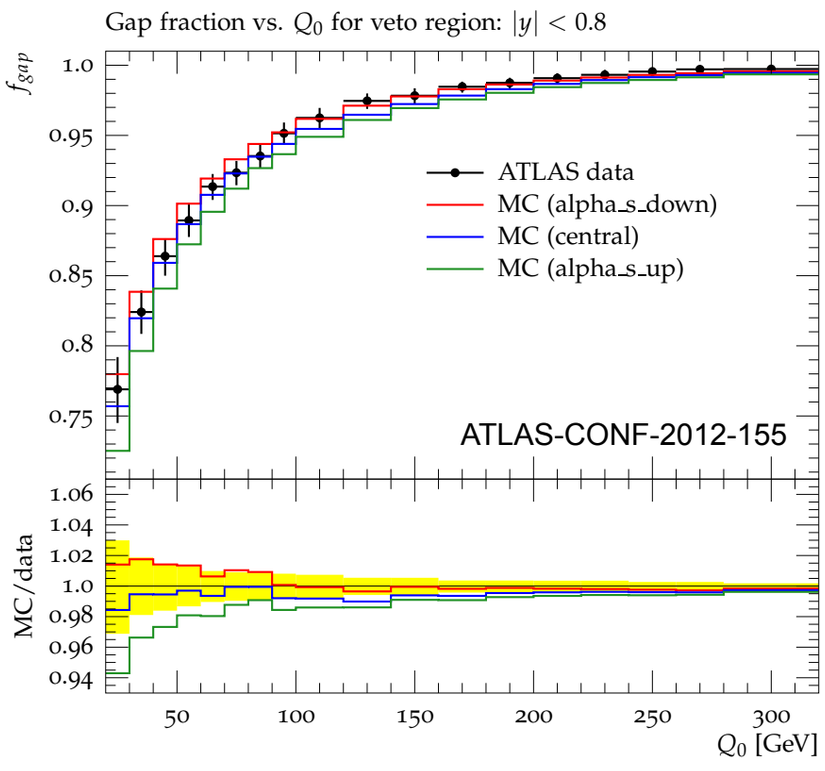
BACKUP

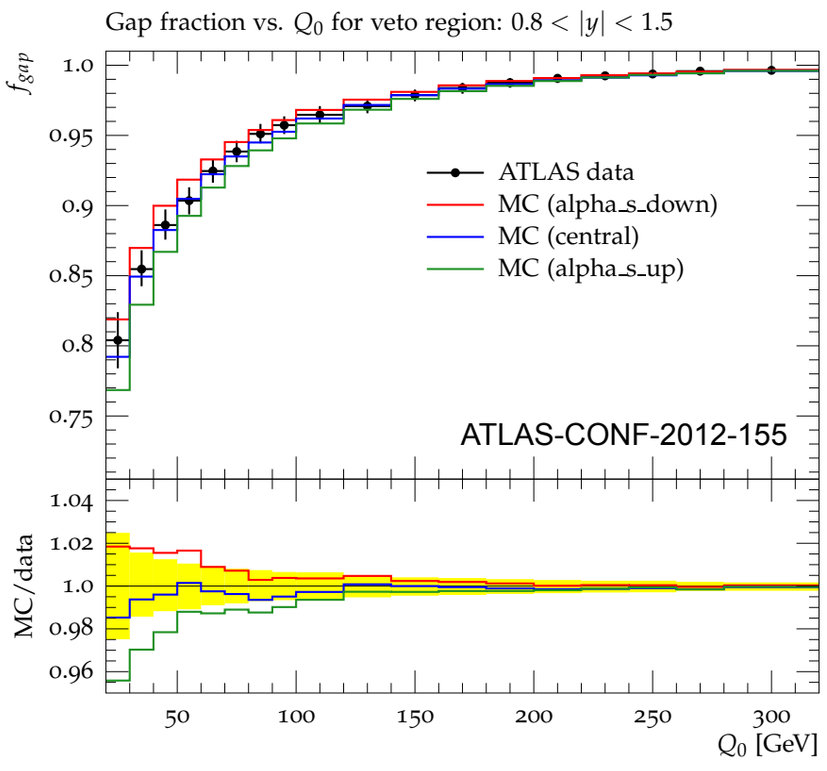
Yields – reco level

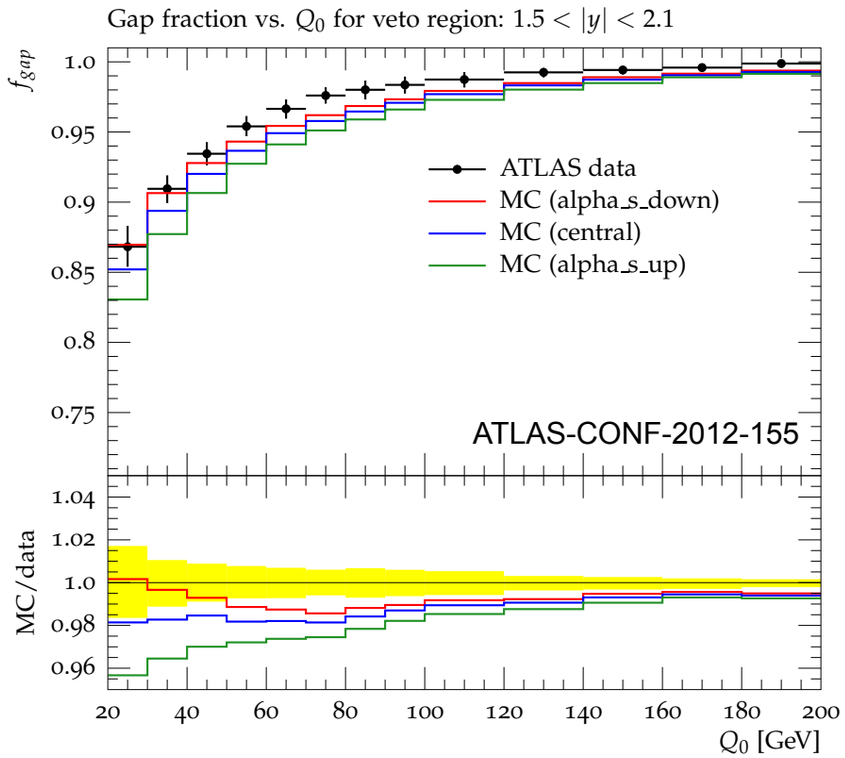
Electron channel						
Source	$n_{\text{jets}}^{\text{reco}}=3$	$n_{\text{jets}}^{\text{reco}}=4$	$n_{\text{jets}}^{\text{reco}}=5$	$n_{\text{jets}}^{\text{reco}}=6$	$n_{\text{jets}}^{\text{reco}}=7$	$n_{\text{jets}}^{\text{reco}}\geq 8$
$t\bar{t}$	9800±1100	9600±1300	4900±1100	2000±600	590±270	220±130
W+jets	5300±1300	1700±400	440±140	100±30	20±7	7±2
QCD multijet	1900±900	800±400	350±180	120±60	32±16	15±8
single top	1980±230	820±120	240±50	58±16	13±5	2±2
Z+jets	610±80	260±60	99±23	25±11	7±2	1±2
Diboson	150±60	35±14	7±3	1.2±0.6	0.19±0.19	0.11±0.11
Expectation	19800±2000	13200±1500	6100±11200	2200±600	700±270	250±140
Data	20320	12704	5632	1856	566	188

Muon channel						
Source	$n_{\text{jets}}^{\text{reco}}=3$	$n_{\text{jets}}^{\text{reco}}=4$	$n_{\text{jets}}^{\text{reco}}=5$	$n_{\text{jets}}^{\text{reco}}=6$	$n_{\text{jets}}^{\text{reco}}=7$	$n_{\text{jets}}^{\text{reco}}\geq 8$
$t\bar{t}$	11500±1200	11100±1200	5900±1100	2300±700	720±300	250±170
W+jets	7300±1500	2300±500	560±160	120±28	30±7	11±3
QCD multijet	2200±500	800±160	300±60	85±17	20±5	11±2
single top	2360±250	970±130	290±50	70±18	10±5	4±1
Z+jets	380±70	140±30	50±10	14±5	1±3	0.5±0.7
Diboson	170±70	41±16	7±3	1.2±0.6	0.0±0.3	0.13±0.17
Expectation	24000±2000	15400±1300	7100±1100	2600±700	780±300	280±170
Data	24422	15162	6578	2348	722	252

ALPGEN+PYTHIA gap fraction (Q_0)







ALPGEN+PYTHIA gap fraction (Q_{sum})