Impact of jet fragmentation modelling on the jet energy and the top quark mass measurement using the ATLAS detector

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Modelling uncertainty of top final states

Modelling of final state of events with top quark pairs is a focus of the LHCtopWG

Modelling uncertainties are large/dominant in many top physics measurements

Often matter of physics judgement

→ Strong push by ATLAS/CMS to provide final state measurements defined by stable particles to constrain models and their parameters

Examples of recent particle-level measurements of ATLAS and CMS:
jet multiplicities, jet veto, jet fragmentation, top kinematics (pseudo-top)

Final state Modelling uncertainties:

ISR/FSR Radiation (ren&fac scales, ME/PS matching)
MC generator (NLO ME vs multi-leg)
Choice of parton shower and hadronisaton
Parton density functions
Modelling of b-quark fragmentation

For more details see talk from May 2014

Parton shower and fragmentation uncertainty in top mass analysis

ATLAS

Comparison Powheg+Pythia and Powheg+Herwig covering:
- Choice of Parton shower:
  - pt vs angular ordered parton shower
  - Treatment of recoil, parton shower matching
- Fragmentation functions,
- hadronisation models (string vs cluster)
- underlying event

CMS:

Pythia/Herwig comparison only cross-check
Uncertainty by varying parameter effect-by-effect:
- Comparison of Pythia/Herwig++ jet response per parton flavour (flavour response systematics in JES)
- String vs cluster model from Sherpa
- Varying b-hadron fragmentation
- Varying semi-lepton branching ratios

Fit type	Channel	$\Delta m_{\rm top}^{\rm tot}$	$\Delta m_{\rm top}^{\rm stat}$	$\Delta m_{\rm top}^{\rm had}$
Two-dimensional analysis:				
	l+jets [13]	0.89%	0.20%	0.75%
Three-dimensional analysis:				
	l+jets [13]	0.89%	0.43%	0.15%
	l+jets [2]	0.79%	0.43%	0.10%

[13] ATLAS-CONF-2013-046
[2] EPJ C75 (2015) 330

To which extend there is double counting with other uncertainties ?

CMS numbers for Pythia/Herwig comparison given in LHC and world combination, but not available for latest measurement

Strategy to evaluate double counting with jet calibration

Jet calibration refers to particle jets
Top mass refers to partons in the hard scattering process
Define:

Reconstructed detector response to particle jets

$$\mathcal{R}^{\text{particle}} = \frac{p_{\mathrm{T}}^{\text{reco}}}{p_{\mathrm{T}}^{\text{particle}}}.$$

Reconstructed detector response to partons:

$$\mathcal{R}^{\text{parton}} = \frac{p_{\mathrm{T}}^{\text{reco}}}{p_{\mathrm{T}}^{\text{parton}}}$$

Strategy to evaluate double counting of Pythia/Herwig uncertainty included in JES and physics analysis:

Recalibrate Powheg+Pythia sample to match jet response in Herwig

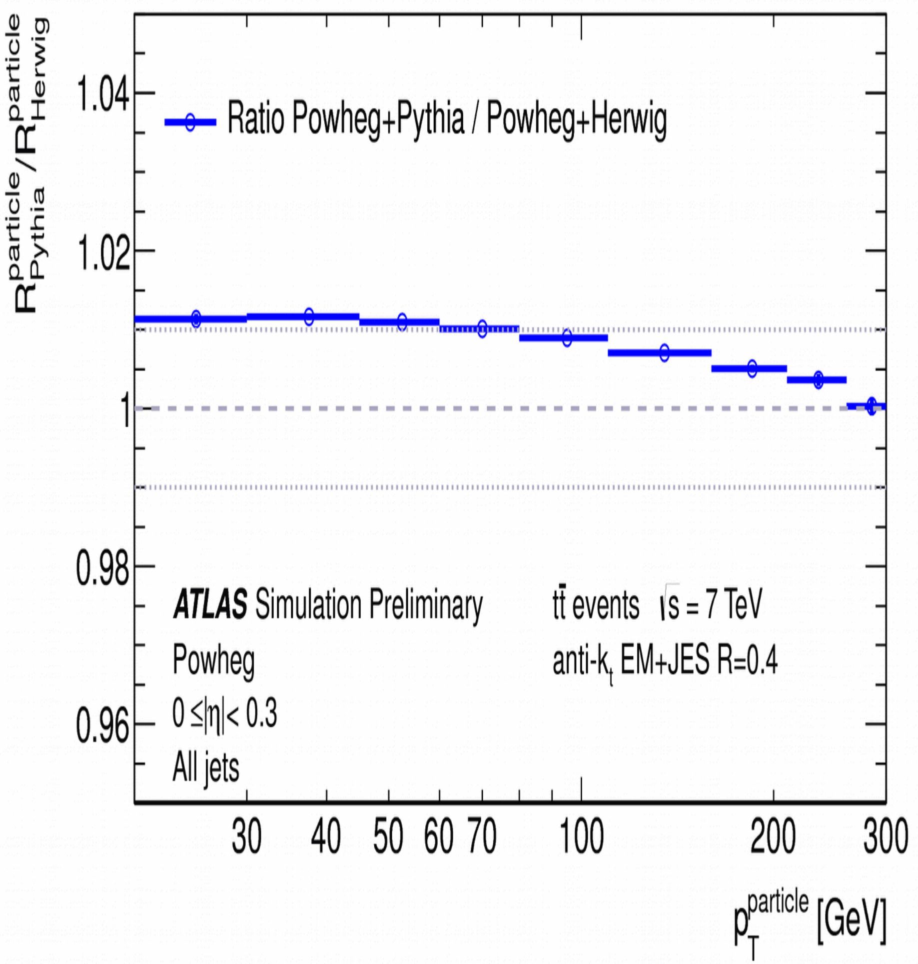
$$C = \frac{\mathcal{R}^{\text{particle}}_{\text{Herwig}}}{\mathcal{R}^{\text{particle}}_{\text{Pythia}}}$$

1) inclusive in jet flavour (remove JES double-counting)
2) flavour-by-flavour using parton matching (remove JES and bJES double counting)
   (higher energetic parton within dR<0.4)

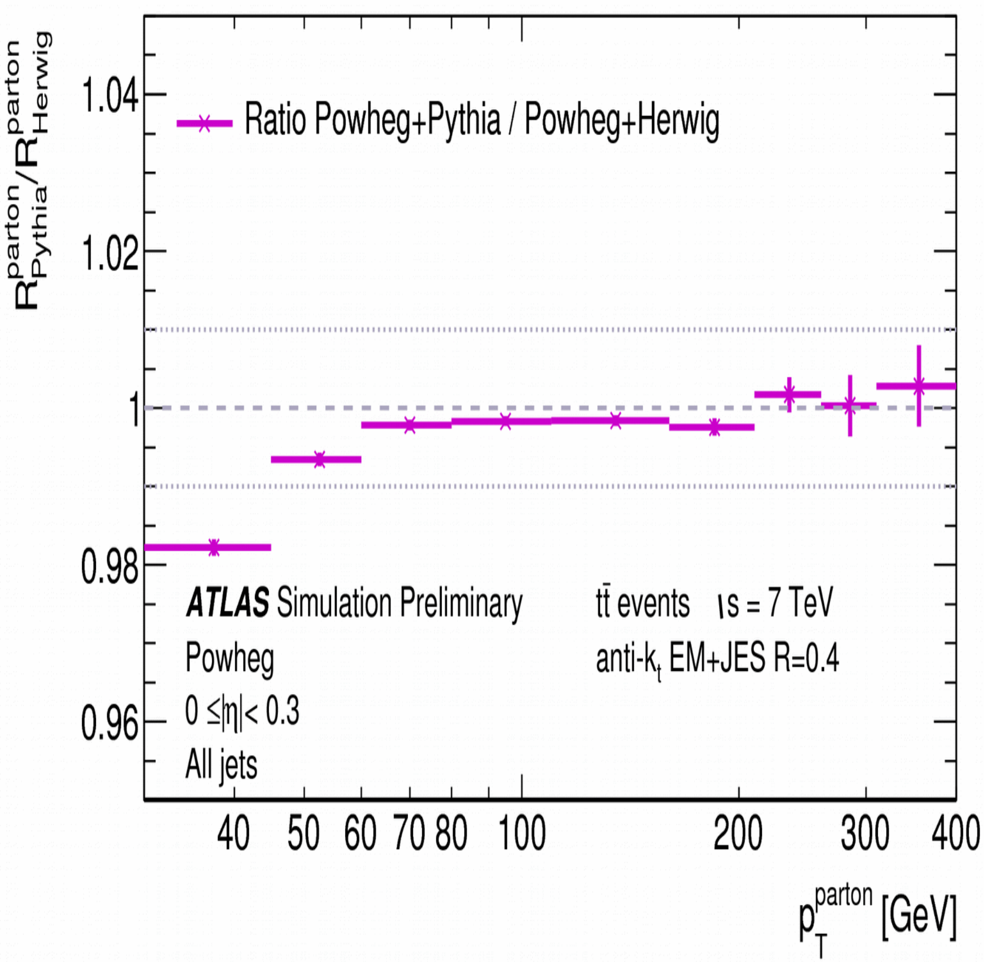
Study effect in ATLAS top mass analysis (EPJ C75 (2015) 330, l+jet 7 TeV)

Inclusive jets: Jet response differences at particle- and parton-level

Particle-level



Parton-level



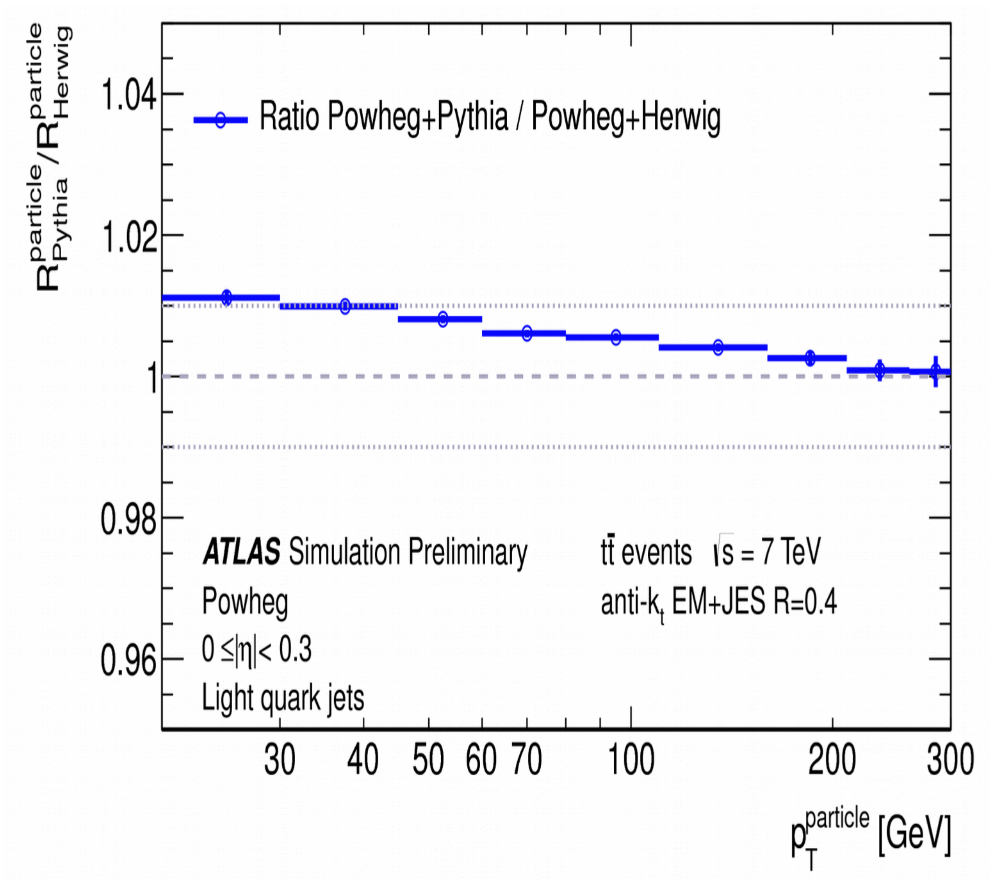
Pythia higher response up to 1.0%

Pythia lower response up to -2.0%

Detector/particle detector/parton opposite directions !

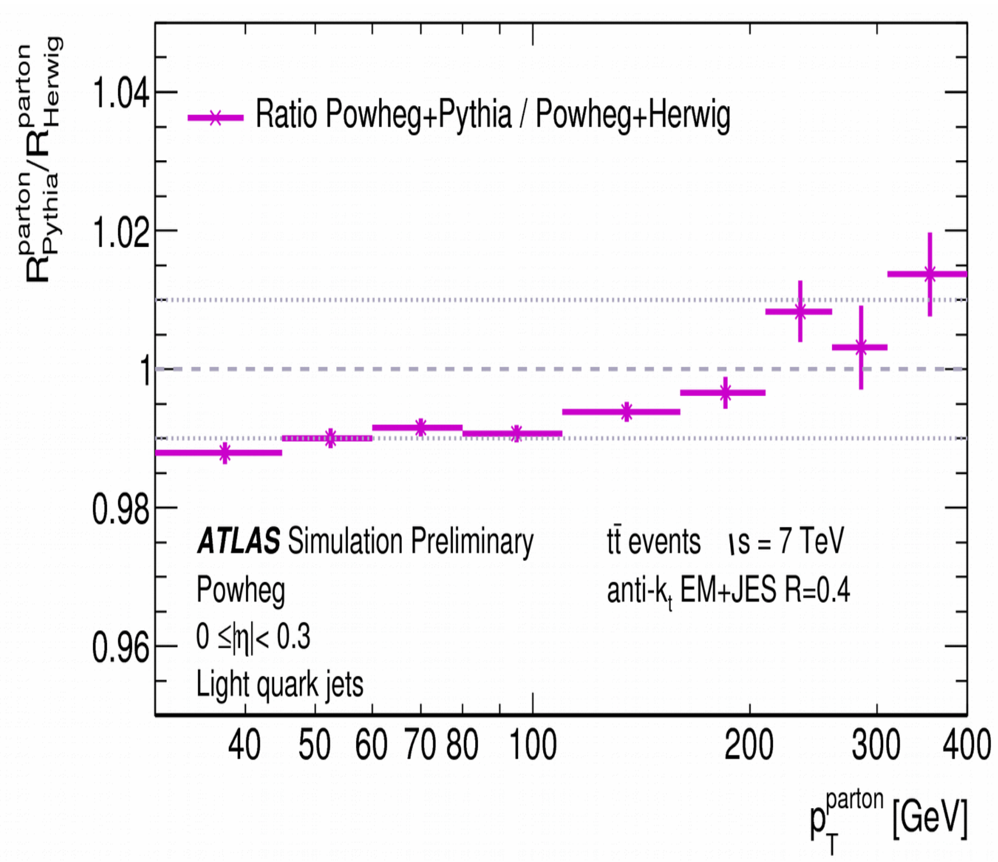
Light-quarks: Jet response differences at particle- and parton-level

Particle-level



Pythia higher response up to 1.5%

Parton-level



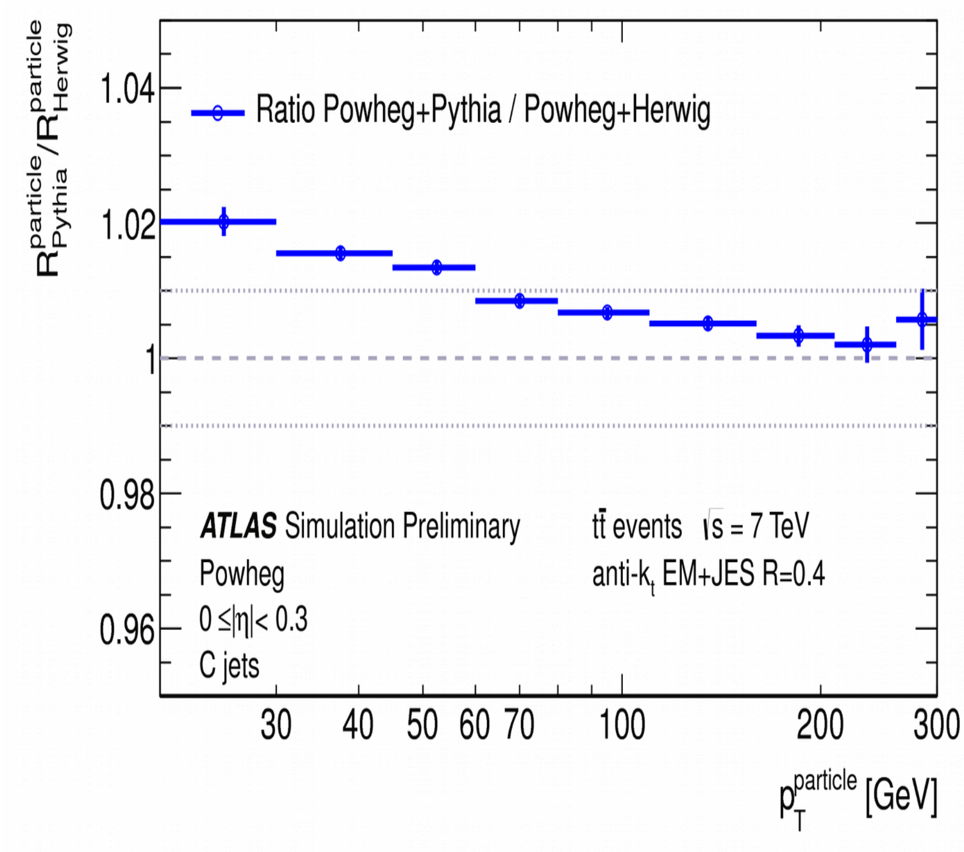
Pythia lower response up to -1.5%

Pythia/Herwig: $(p_{Treco}/p_{Tparticle})/(p_{Treco}/p_{Tparton})=p_{Tparton}/p_{Tparticle}>1$

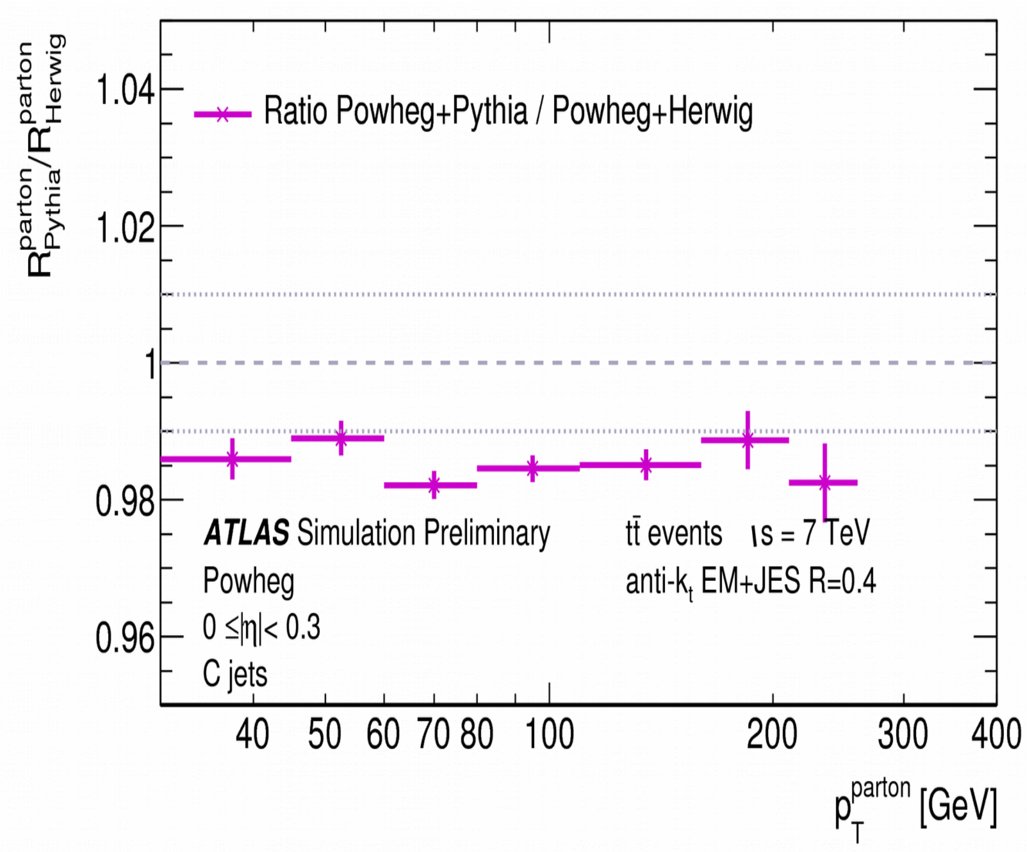
expect higher W mass for Herwig particle-level

Charm-quarks: Jet response differences at particle- and parton-level

Particle-level



Parton-level



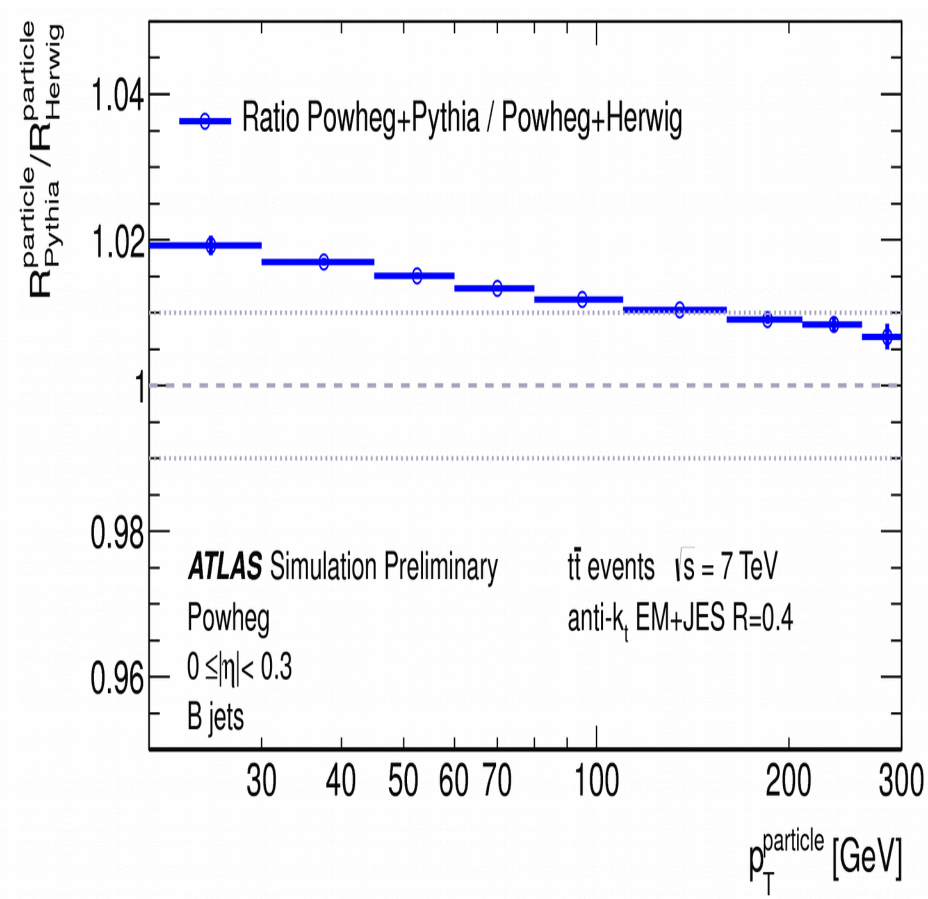
Pythia higher response up to 2%

Pythia lower response up to -1.5%

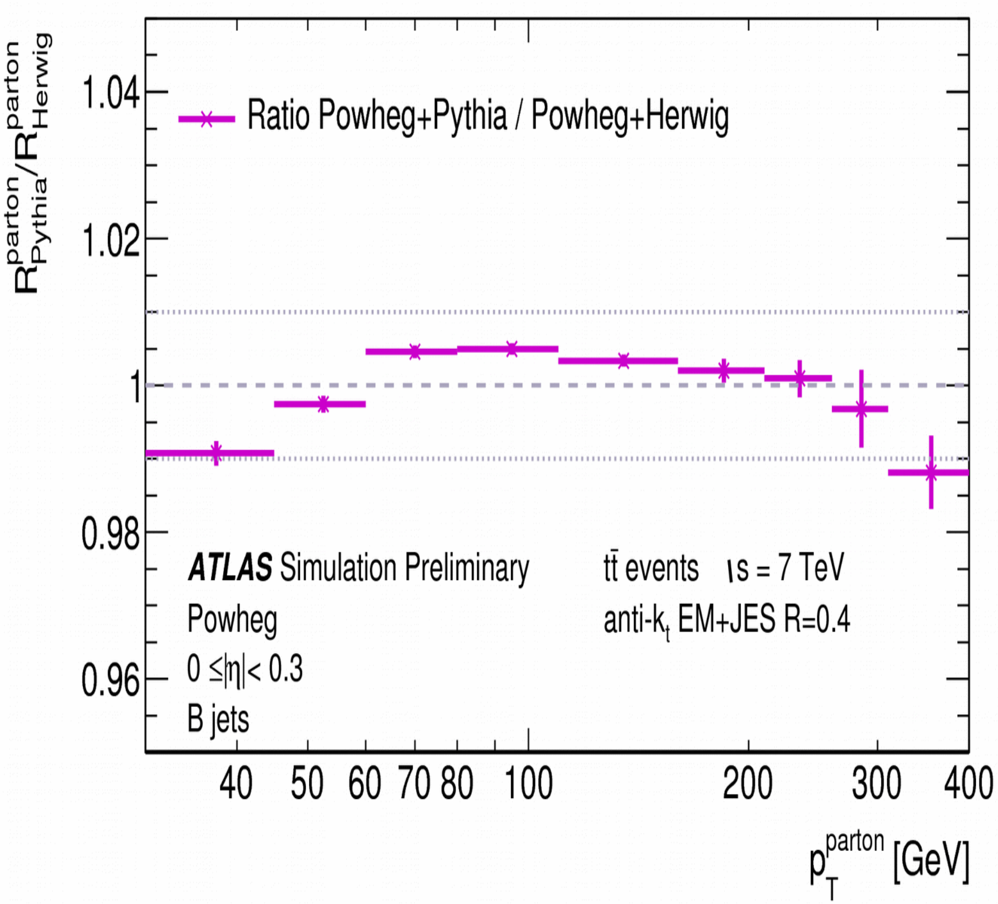
Detector/particle and detector/parton opposite directions !

Bottom-quarks: Jet response differences at particle- and parton-level

Particle-level



Parton-level



Pythia higher response up to 2%

Pythia lower response up to 1.5%

Similar picture for all jet flavours

ATLAS top mass analysis

Effect of re-calibration procedure is tested with recent ATLAS top mass measurement EPJ C 75 (2015) 7
7 TeV 2011 data using the l+jet channel

Use kinematic likelihood fit to reconstruct W mass (M_{jj}) and top mass (M_{jjb})

One, two or three parameter unbinned likelihood fit:

1) Physical fit parameter is m_{top}

2) The W mass distribution is used to constraint the jet scale factor (JSF) that rescales all jet 4-momenta

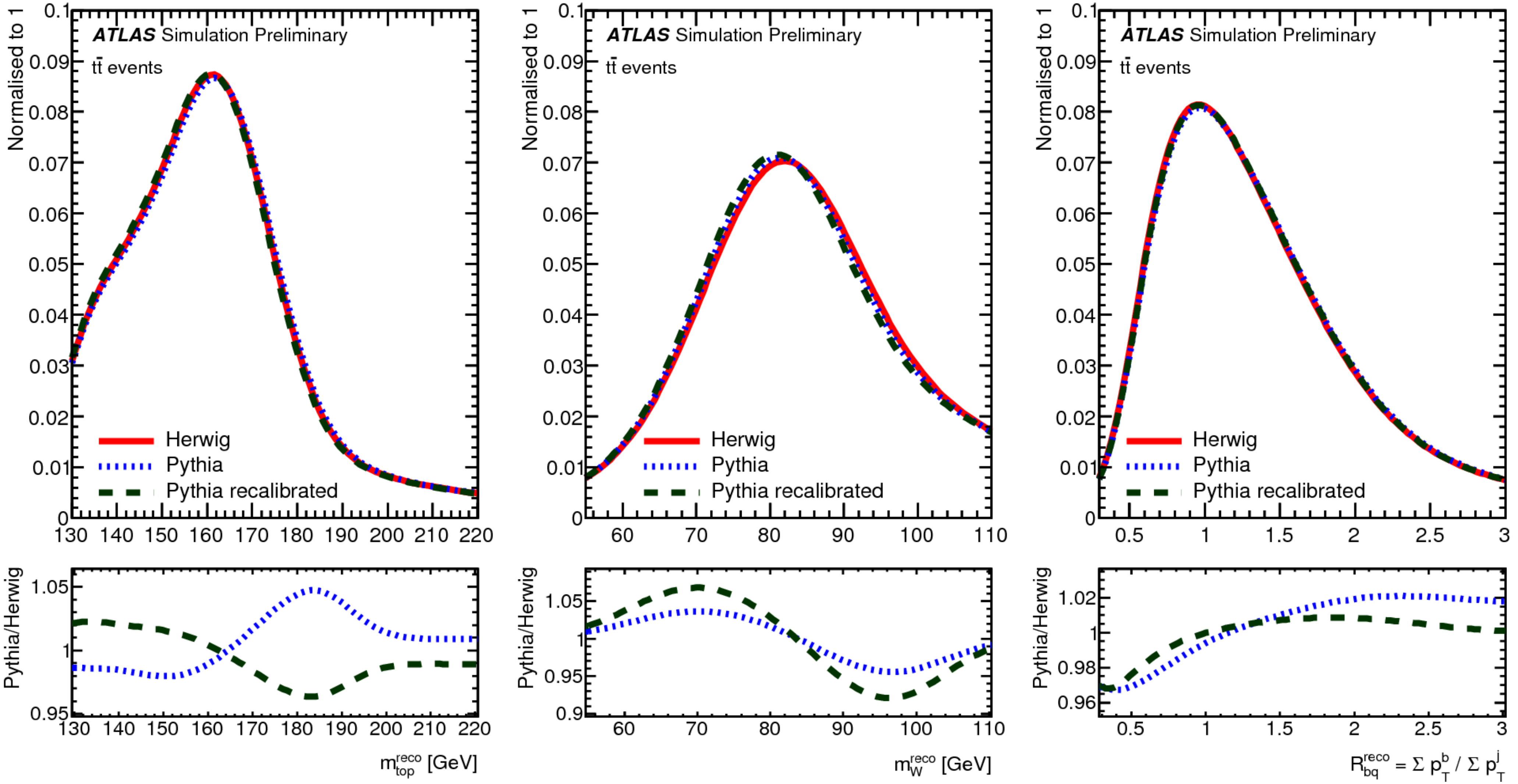
3) The ratio of the p_T of b-jet and the light-quark jets is used to constrain the b-jet scale

$$\mathcal{R}_{\mathrm{bq}} = \frac{p_{\mathrm{T}}^{b_{\mathrm{had}}} + p_{\mathrm{T}}^{b_{\mathrm{lep}}}}{p_{\mathrm{T}}^{q_1} + p_{\mathrm{T}}^{q_2}}$$

Templates of three observables (m_{top}, JSF, R_{bq}) are built and fit to the data

Jet re-calibration effect on sample mass fit

Results of best fit to m_{top}, JSF, R_{bq} to the template functions to the MC samples for the systmatic uncertainty evaluation



After jet re-calibration difference between Pythia/Herwig remain
The W mass in the re-calibrated Pythia shifted further away from Herwig

Effect on jet re-calibration on top mass result

	dim	jet calibration type	$\frac{\Delta m_{top}^{had\,new}}{\Delta m_{top}^{had\,standard}}$	$\frac{\Delta JSF^{new}}{\Delta JSF^{standard}}$	$\frac{\Delta bJSF^{new}}{\Delta bJSF^{standard}}$
m_{top}	1	inclusive re-calibration	-0.6	-	-
		flavour re-calibration	-1.0	-	-
$m_{top,}$ JSF	2	inclusive re-calibration	1.0	2.0	-
		flavour re-calibration	0.7	1.8	-
$m_{top,}$ JSF, R_{qb}	3	inclusive re-calibration	1.2	2.0	1.0
		flavour re-calibration	1.3	1.8	0.5

1-dim fit: Uncertainty changes sign after recalibration
→ effects related to jet calibration acting opposite to effects related to parton-->particle jet

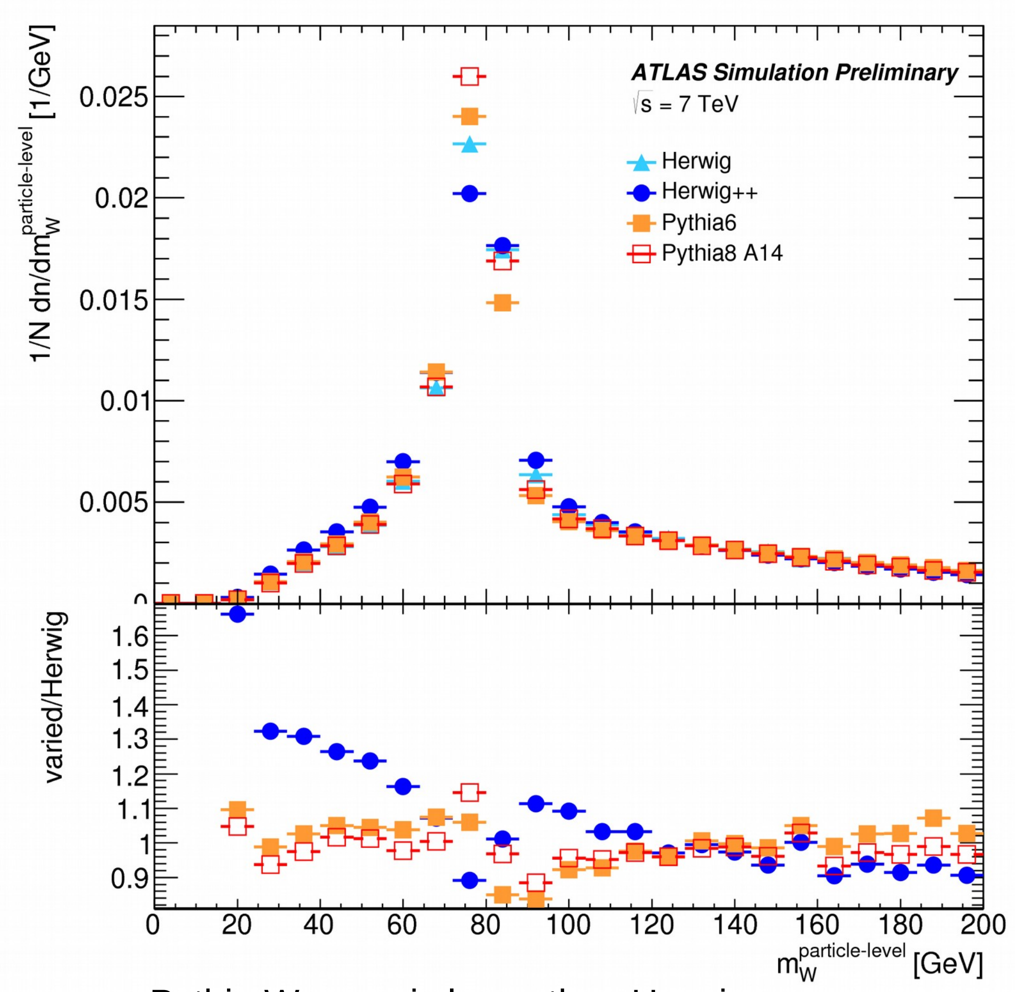
2/3-dim fit: small change in Δm_{top}, but JSF doubles
re-calibration does not bring JSF closer together → not a JES effect (related to W mass difference after jet re-calibration)

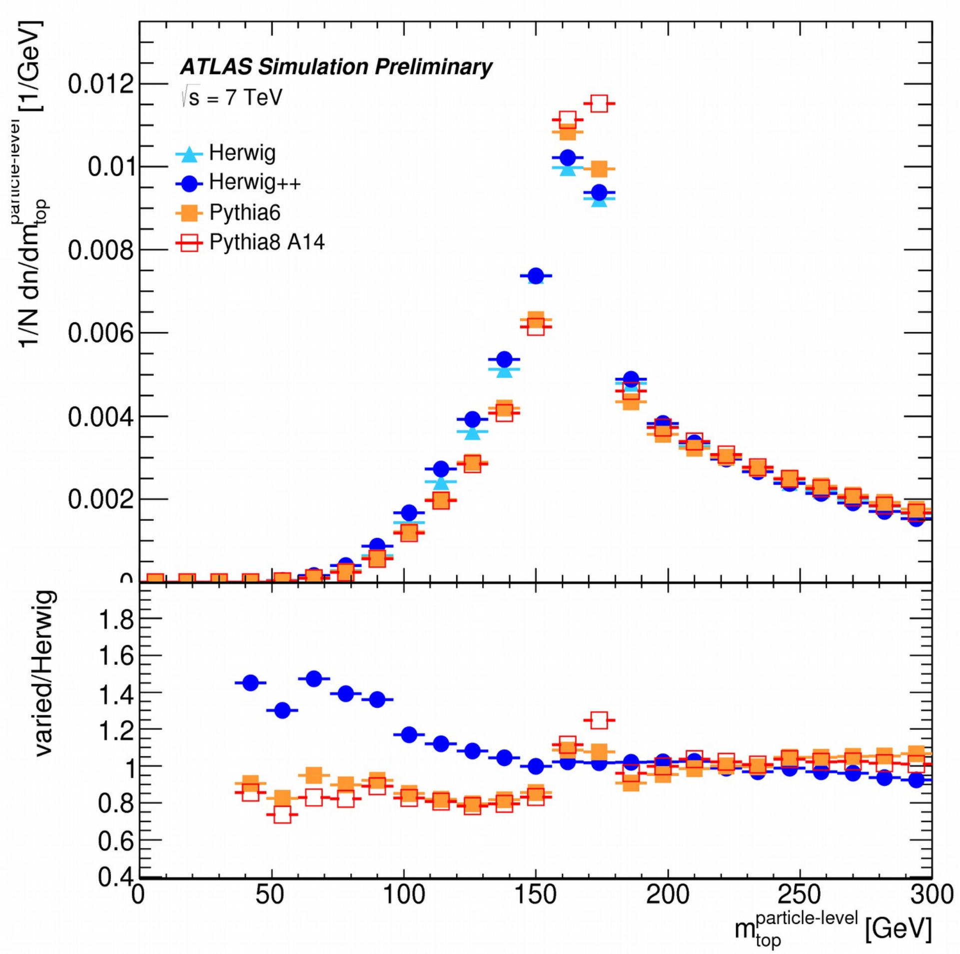
3-dim fit: bJSF decreases for flavour-dependent jet re-calibration, but ~Δm_{top}
bJSF sensitive to hadronisation effects, but overall effect is small

Δm_{top}=Pythia-Herwig

Particle-level study

Using simple top pair kinematic reconstruction based on stable particles (Pseudo-top)
Study effect on reconstructed top and W mass





Pythia W mass is lower than Herwig
Pythia6/Pythia8 similar
Herwig++ more events at low values

Pythia top mass is higher than Herwig

Conclusion

Double-counting of parton shower and fragmentation modeling systematics investigated by recalibrating Pythia jet response (detector/particle) to Herwig.

Double-counting between direct comparison of Powheg+Pythia and Powheg+Herwig for modelling systematics and Pythia/Herwig jet response differences is small in ATLAS l+jet analysis based in 2011 7 TeV data.

Effect of changing parton shower and hadronisation model extends beyond changes in the jet energy scale in the standard ATLAS analysis.

Simple study using particle-level observables: Top and W mass obtained from combination of particle-level jet, leptons and missing momentum shows differences between MC models.

More dedicated studies are needed to establish the exact behaviour of these uncertainties in precision measurements with top quarks.

Back-up

Hadronisation systematics

CMS 2011

b-JES:

b-jet response in between light-quark/gluon response
Therefore take Pythia/Herwig++ for light quark/gluons as b-jet uncertainty

CMS 2014

b-JES

Compare Pythia/Herwig++ for each jet flavour
For light-quarks, gluons and b-quark uncertainty is evaluated separately and added in quadrature

b-fragmentation

Bowler-Lund fragmentation re-tuned to ALEPH and DELPHI data
Difference between this retune and Pythia Z2 tune is uncertainty

Semi-leptonic B hadron decays

Semi-leptonic branching varied by -0.45 and +0.77% for B^0 and B^{+-} Hadrons (from PDG)

Quoted separately and not included in final result
MC@NLO+Herwig vs Powheg+Pythia Z2 tune

→ approach avoids possible double counting when changing pythia/herwig
- detector response on particle jet
- b-fragmenation
- p_T modelling

ATLAS

b-JES

- Dedicated b-JES based on MC
  Pythia/Herwig
  b-fragmentation function
  Pythia nominal/tuned Bowler-Lund
  (tuned to LEP data)
- Validation with data in situ
  (limited precision)

Parton shower and fragmentation effects on Ttbar event topology

exchange Pythia/Herwig to cover:
- -choice of parton shower
- -hadronisation effect (string vs cluster)
- -underlying event
- -b-fragmentation
- -B-Hadron decay tables

→ possible double counting with other systematics:
- effect of detector response on particle jet -> detector jet
- underlying event
- b-fragmentation

Evaluation of Ttbar modelling systematics

CMS

- Radiation
  Renormalisation and factorisation scale changed by factor of 2 in Madgraph+Pythia

  ME-PS matching threshold in Madgraph varied from from default 20 GeV by factor of 2

- MC generator
  Dilepton: MadGraph vs Powheg

  For 2014 l+jets:
  - MadGraph vs Powheg
  - p_{Ttop} reweighting

- PDF
  Based on CTEQ6,6
  For 2014 measurement: PDF4LHC prescription

- Choice parton shower model and fragmentation
  Included in jet response uncertainty
  b-fragmentation modelling varied

ATLAS

- Radiation
  ISR/FSR PS starting scale changed by factor of 2 in ACERMC+Pythia

  Radiation systematics based on ALPGEN not yet used in top mass analysis

- MC generator
  MC@NLO+Herwig vs Powheg+Herwig
  (very different jet multiplicities,
  Alpgen does not contain top width)

- PDF
  based on CT10

- Choice parton shower model and fragmentation
  Also included in jet response uncertainty,
  but would like to cover other effects (parton->jet)
  evaluate, e.g. Powheg+Pythia vs Powheg+Herwig