New Techniques for Jet Energy Scale Measurements in the ATLAS Detector

Abstract

Jets are collimated groups of particles that result from the fragmentation of high energy quarks and gluons. The calibration of jets corrects the measured jet energy and direction for imperfections in the ATLAS detector response and plays an important role in most ATLAS analyses.
This poster presents **new strategies** for the **Jet Energy Scale (JES)** calibration that were developed and tested with **LHC Run 2 data**, to lay the foundation for their use in the Run 3 jet calibration.

The ATLAS jet calibration chain involves a number of steps:

1. Reconstructed Jets

***Jet finding** applied to tracking-based and/or calorimeter-based inputs.*

2. Pile-up Calibrations

Area based correction

***Subtracting the expected contribution from pile-up** based on the area and median p_T density in the event.*

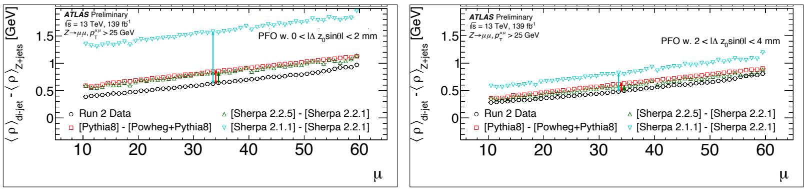
Median pile-up density, ρ, is estimated for each event by the median p_T density (p_T/A) of all clustered jets.

- Old method – Inputs to ρ calculation satisfy jets for $0 < |z_0 \sin\theta| < 2$mm

→ large topology dependence for Pflow.

- New sideband method– Inputs to ρ calculation satisy $2 < |z_0 \sin\theta| < 4$mm

→ Reduces dependency on hard scattering topologies.



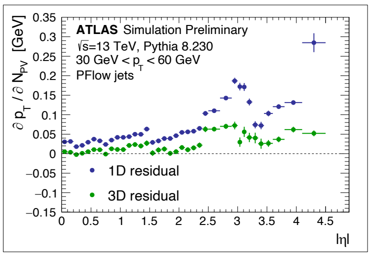
Topology uncertainty much lower in the new sideband method.

Residual pile-up correction

***Further reduces impact of pile-up** based on the number of reconstructed primary vertices (N_{PV}), the mean number of interactions per bunch crossing (μ), the jet p_T, and the jet pseudorapidity, η.*

The 3D residual correction significantly reduces pile-up dependence, especially at high p_T.

- 1D residual correction only removed impact of pile-up on jet pT scale.
- 3D residual correction combines the corrections due to pile-up with corrections due to detector effects



$$p_T^{3D} = p_T^{area} - \Delta p_T^{area-truth}(N_{PV}, \mu, \eta, p_T^{area})$$

3. MCJES Calibration

***Provides a calibration function for the energy response** as a function of the pseudorapidity η and the reconstructed jet energy E_{reco}.*

- **The individual JES, r,** is defined for each reconstructed jet that is matched to a truth jet by:

$$r = \frac{E_{reco}}{E_{true}}$$

- The average JES, fit with a gaussian distribution after residual calibration is applied as a function of E_{true} and η_{det}.

- Two methods are used for the fit functions:
  - Polynomial fits
  - Penalized Splines (new)

For low energies, the spline method provides better closure than the polynomial fit.

In addition to the jet energy, a simiilar approach is used to calibrate η.

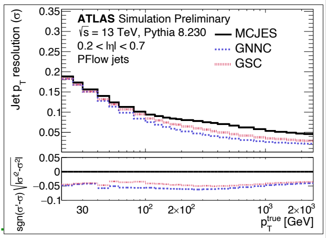
4. Global Calibration

***Further calibration on jet response for individual factors** such as distribution of energy in the jet, distribution of energy across different calorimeter layers, and flavour dependence.*

Quark and gluon responses are **different** on average. Two options are compared for **the reduction of flavour uncertainties:**

- **Global sequential calibration (GSC)** – Multiplicative reductions based on a number of jet observables to account for diffences in the calorimeter response to different types of jets.
- **Global NN calibration (GNNC)** – Trains NN to learn the response from input variables. Enables use of correlated variables so allows for more observables as inputs.

GNNC provides better results than the GSC for jet response and jet resolution.
→ Better uncertainties on flavour response and flavour composition.



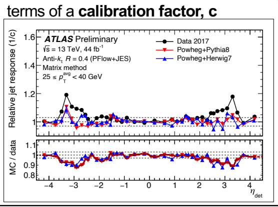
5. Residual Insitu Calibration

*A calibration that **corrects for differences in data/MC**. Correction only applied to data. **The New MC calibration methods were validated with insitu analyses.***

η – Intercalibration

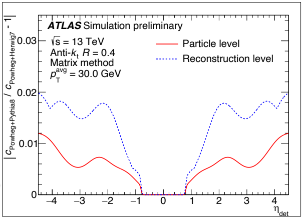
*η-intercalibration **uses well-measured central jets (|η_{det}| < 0.8) to correct for forward jets (0.8 < |η_{det}| < 4.5)** that are calibrated relative to each other **in every | η_{det} | region.***

- **The jet pT balance in two distinct regions** is defined as **asymmetry (A)**
- The **relative ratio between left and right jets** is given in terms of a **calibration factor, c**



$$c = \frac{p_T^{probe}}{p_T^{ref}}$$

$$R = \frac{c^{left}}{c^{right}} = \frac{2 + <A>}{2 - <A>}$$

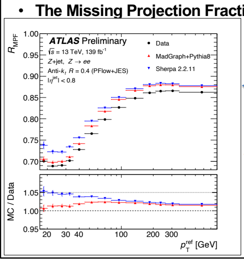


Further studies to show that separating physics effects from detector effects would greatly reduce MC modelling uncertainties.

Z/gamma+jet insitu

Residual calibration of central jets within the range |η| < 0.8 is obtained through **pT balance between a jet recoiling with a well-calibrated object** such a **photon/Z-boson.**

- **The Missing Projection Fraction (MPF)** method – Reference object balanced against the whole hadronic activity of an event.

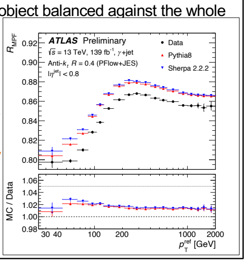


MC-to-Data ratio ∝ JES

Z Bosons:

- $Z \to ee$ JES overestimated by 0.1-5% in MC.
- $Z \to \mu\mu$ JES overestimated by 0.1-5% in MC.

Photons:
JES overestimated by 1-3% in MC.

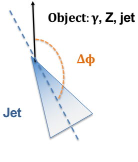


bJES in gamma+jet Events

*The measurement of the **balance between a b-jet and a well-calibrated photon** is tested and compared to inclusive jet balance.*

Here the **Direct Balance (DB)** method:

$$R_{DB} = < \frac{p_T^{jet}}{p_T^{ref}} >, \ p_T^{ref} = p_T^{Object} \times |\cos(\Delta\phi)|$$

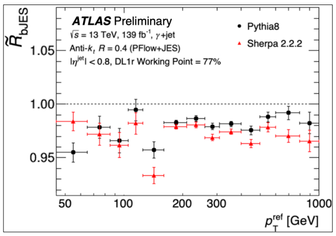


- Samples of b-jets and c-jets are selected using a multi-variate b-tagging algorithm Dl1r.
- b-tagging efficiencies available correspond to the working points (WP) 60% ,70% ,77%, and 85%
  - Higher working points → lower purity of b-jets but higher statistics.

A double ratio of MC over data and b-tagged sample over inclusive sample is measured:

$$R_{bJES} = \frac{R_{b-tagged}^{MC} / R_{b-tagged}^{data}}{R_{inclusive}^{MC} / R_{inclusive}^{data}}$$

The b-tagged ratio **underestimates the JES** (relative to the inclusive) by:
Pythia – 1% (WP60), 1.6% (WP70), 2.2% (WP77), 1.1% (WP85)
Sherpa – 1.6% (WP60), 2.6% (WP70), 3.4% (WP77), 2.1% (WP85)



Naseem Bouchhar, for the ATLAS Collaboration
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