IN SITU MEASUREMENTS OF THE ATLAS JET ENERGY SCALE USING 13 TeV pp DATA

LHCC Poster Session – CERN, 27 February 2019

Abstract

The quarks and gluons produced in proton-proton collisions form collimated sprays of particles, known as jets. Jets are produced with large cross-sections, and so **a precise understanding of the ATLAS detector's response to these objects improves the quality of physics analyses. The Jet Energy Scale (JES) is studied *in situ* by several analyses which are inputs to a statistical combination.** The absolute JES is measured using events where the jet recoils against a reference object, which can be a **calibrated photon, a reconstructed Z boson**, or a **system of well-measured jets with lower p_T**. The relative scale of jets in the forward and central detector regions is measured **using balanced dijet systems**.

1. *In situ* calibration methods

The *in situ* calibration is the **last step of the ATLAS calibration chain**, accounting for the **differences in the jet response between data and MC** simulation, balancing the p_T of a jet against well-measured reference object(s):

Cluster Origin Correction → Jet Reconstruction EM/PFlow scale → Pile-up Correction → Absolute Eta JES Calibration → Global Sequential Calibration → Residual *In situ* Calibration

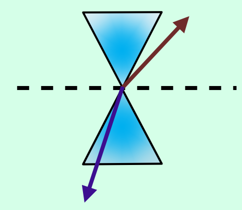
- The ***in situ* calibration is divided in sub-steps derived sequentially:**
- The **η-intercalibration** corrects the response of **forward jets** to well-measured **central jets**.
- **Three other *in situ* calibrations** correct the response of central jets to well-measured reference objects, **each focusing on a different p_T region:**

η-intercalibration → Jet Energy Calibration: [V + jet balance (Z: $20 \lesssim p_T \lesssim 600$ GeV; γ: $45 \lesssim p_T \lesssim 1200$ GeV) → Multi-jet balance ($400 \lesssim p_T \lesssim 2400$ GeV)]

- **For each stage**, the response $R_{in\ situ}$ is defined as the mean of the Gaussian fit to the p_T^{jet}/p_T^{ref} distribution.
- The ratio $R^{data}_{in\ situ}/R^{MC}_{in\ situ}$ is an **useful estimate of the JES in data and MC**. Through numerical inversion, a **correction to the jet four-momenta is derived.**

2. Relative η-intercalibration

The **relative η-intercalibration** starts by using jets in the **central detector region** ($|\eta_{det}| < 0.8$) to extend the jet calibration to the **forward detector region** ($0.8 < |\eta_{det}| < 4.5$) **using a system of equations for the jet p_T balance.**



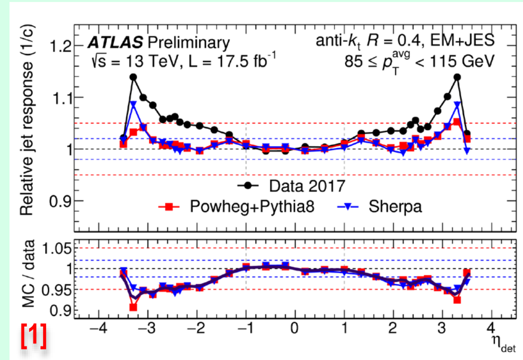
- The **matrix method** has been used, where numerous independent reference regions are chosen, measuring the jet response relative to all reference regions simultaneously.
- Dijet topologies are selected in which the two jets are expected to have equal p_T.
- The jet transverse momentum balance is quantified by the **asymmetry (A)**:

$$A = \frac{p_T^{probe} - p_T^{ref}}{p_T^{avg}},\quad p_T^{avg} = \frac{p_T^{probe} + p_T^{ref}}{2}$$

- The **response (R)** with respect to the reference region is defined as:

$$R = \left\langle \frac{p_T^{probe}}{p_T^{ref}} \right\rangle \approx \frac{2 + \langle A \rangle}{2 - \langle A \rangle}.$$

→ Calibrations were **derived separately for 2015+2016 and 2017 data**, with their corresponding **central values, statistical** and **non-closure uncertainties**.



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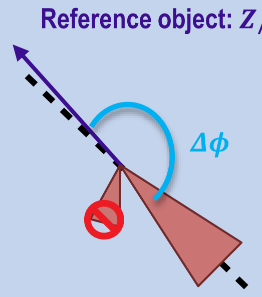
3. V + jet balance

A residual calibration of jets within $|\eta| < 0.8$ is derived through the p_T balance against a **Z boson or a photon**.

- **Two techniques** have been used for deriving the balance:
- **Direct Balance (DB):** measures the ratio between **a fully reconstructed jet's p_T** calibrated **up to the η-intercalibration** stage and a **reference object's p_T**.

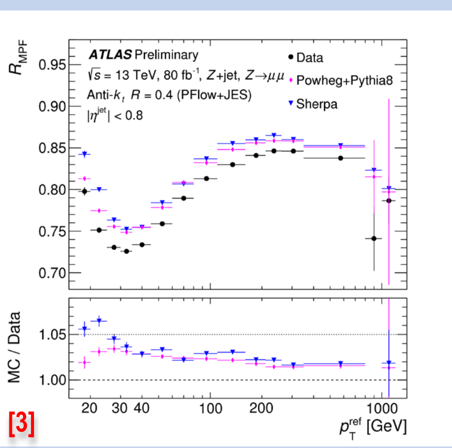
$$R_{bal} = \left\langle \frac{p_T^{jet}}{p_T^{ref}} \right\rangle,\ p_T^{ref} = p_T^{Z/\gamma} \times |\cos(\Delta\phi)|.$$



- **Missing Projection Fraction (MPF):** the reference object is balanced against the whole hadronic recoil in an event.

$$R_{MPF} = \left\langle 1 + \frac{\hat{n}_{ref} \times E_T^{miss}}{E_T^{ref}} \right\rangle.$$

- The **momentum balance could be altered** by the presence of **initial/final-state radiation** and **pile-up → mitigated with the selection criteria**
- The two methods are **sensitive to different systematic effects and provide complementary measurements of the JES. For the current recommendations, since the MPF technique is less sensitive to pile-up effects, it was taken as baseline.**



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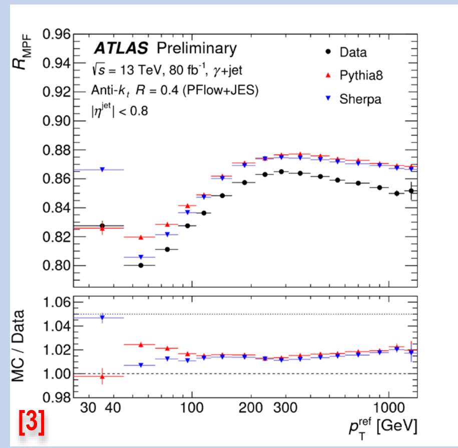
Z BOSONS:

- $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ **channels separated for combination this time.**

→ **Total uncertainty below 1% from 30 to ~ 400 GeV.** Dominated in both channels by **MC modelling.**

PHOTONS:

→ **The total uncertainty is $\sim 1\%$ above 100 GeV** and is **dominated by the Photon Energy Scale.**



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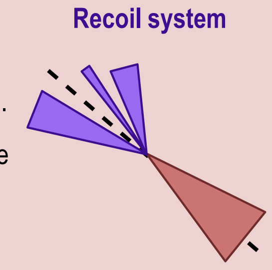
4. Multi-jet balance

The multi-jet balance uses topologies with 3 or more jets to balance a **high-p_T jet** against a **recoil system** composed of **multiple lower-p_T jets.**

- The **recoil system (high-p_T jet)** is calibrated **up to the Z/γ-jet (η-intercalibration) stage.**
- Multiple iterations are performed to extend the p_T reach.
- The **average response** between the **leading jet** and the **recoil system** is defined as:

$$R_{MJB} = \left\langle \frac{p_T^{leading}}{p_T^{recoil}} \right\rangle.$$

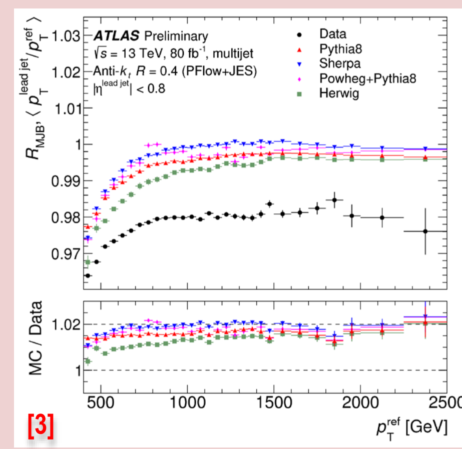


- Contamination of the **leading jet** is minimised, and **dijet balanced topologies** are supressed with the selection criteria.

- The **MJB technique** provides an *in situ* calibration for jets with $p_T < 2.4$ TeV.
- **V + jet systematics** are propagated to higher energies through the **recoil system.**

→ **The total uncertainty is $< 1\%$ for $800 < p_T < 2400$ GeV.**

→ **The propagated γ + jet uncertainty is dominant at high p_T.**



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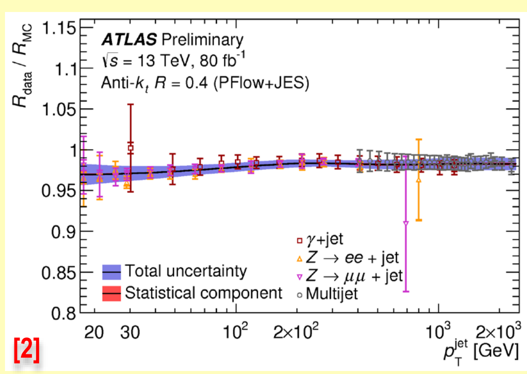
5. *In situ* combination

The data-to-MC ratio and the associated uncertainties derived from the **Z ($\rightarrow ee$) + jet, Z ($\rightarrow \mu\mu$) + jet, γ + jet** and **MJB** calibrations are **combined across overlapping regions of jet p_T.**

- Each *in situ* method is assigned a p_T-dependent weight through a **χ^2 minimization** using as inputs the response ratios and their uncertainties in each p_T bin.
- The individual *in situ* results show a **good agreement with one another** in the various regions of jet p_T.
- **The inverse of the combined data-to-MC ratio** is taken as the ***in situ* correction applied to data**:
- Response **is $\sim 2 - 3$ % higher in MC than in data.**
- The **absolute *in situ* JES uncertainty is $\leq 1\%$ from 30 GeV to 2.4 TeV.**
- **These new results show** an **important reduction** of the **total systematic uncertainty, especially at low jet p_T, where it reaches 2%.**



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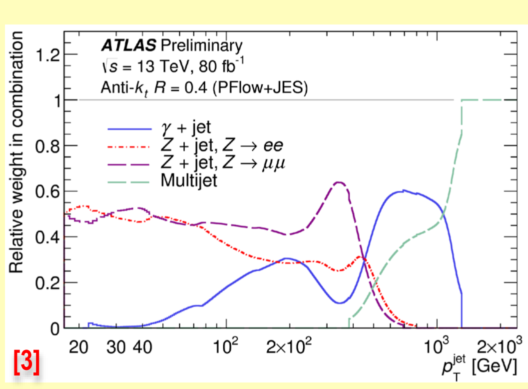

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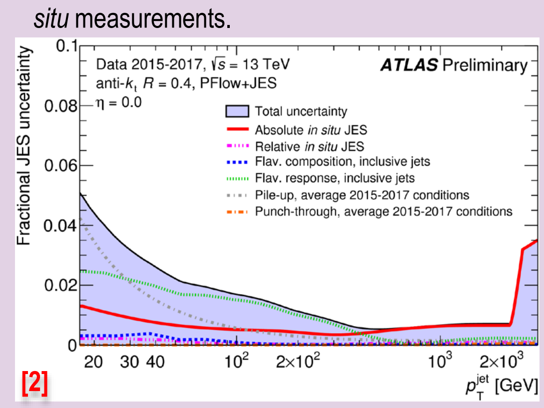
6. Systematic uncertainties

The combined uncertainties include:

- **Absolute *in situ* JES:** from Z/γ-jet and MJB.
- **Relative *in situ* JES:** from the η-intercalibration.
- **Flavour composition:** arising from how well we know the quark/gluon content of the jet.
- **Flavour response:** arising from the uncertainty in the response of jet flavours different from those in the *in situ* measurements.
- **Pile-up:** arising form pile-up dependence.
- **Punch-through:** from high energy jets not fully contained in the calorimeter.

→ **Total uncertainty is sub $1 - 2\%$ for a large range!**

Reduced sets of systematic uncertainties are produced to simplify physics analyses while keeping the loss of correlation information to a minimum.



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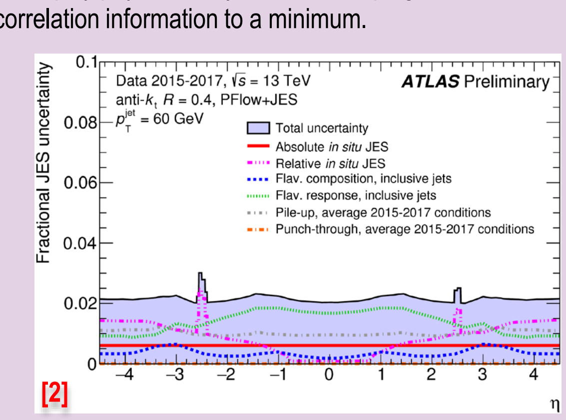

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References

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/...

[1] … = JETM-2017-008 [2] … = JETM-2018-006 [3] … = JETM-2019-02

Daniel Camarero (Universidad Autónoma de Madrid), for the ATLAS Collaboration

ATLAS EXPERIMENT