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Determining the Jet Energy Scale uncertainty in the ATLAS detector

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ABSTRACT

Using jets from proton–proton collisions at a centre of mass energy of $\sqrt{s}=7$ TeV measured with the ATLAS detector at the LHC the Jet Energy Scale and its systematic uncertainty have been determined. Using 2010 data a Jet Energy Scale systematic uncertainty between 2–4% for jet $p_T > 20$ GeV in the pseudo-rapidity region up to $|\eta| = 4.5$ has been obtained. This uncertainty was derived from a combination of systematic variations in Monte Carlo simulations and single hadron response measurements performed *in situ* and using test beam data. The uncertainty is confirmed in *in situ* methods using 2011 data where a well measured reference object is balanced against the jet.

1. Introduction

The ATLAS detector [1] at the LHC is a general purpose detector designed to study the products of proton–proton and heavy ion collisions. For many analyses the uncertainty on the Jet Energy Scale (JES) calibration is a dominant systematic. The uncertainty is derived using Monte Carlo simulations and *in situ* data.

2. Jet reconstruction and calibration in ATLAS

The jet energy and direction in ATLAS are measured in the calorimeter system which consists of sampling, non-compensating calorimeters covering $|\eta| < 4.9$ [1]. Jets are formed from topo-clusters (topologically connected calorimeter cells) or from calorimeter towers ($\Delta\eta \times \Delta\Phi = 0.1 \times 0.1$ blocks of calorimeter cells). Jets are reconstructed using the anti-kt algorithm with a distance parameter of $R=0.4$ or $R=0.6$ [2].

Jet calibration starts from the electromagnetic (EM) scale which corrects the jet energy to the energy deposited by an electromagnetic shower. It is derived from test beam data, Monte Carlo simulation and *in situ* measurement of the Z boson mass using $Z \rightarrow ee$ events [3]. The Local Cell Weighting (LCW) scheme corrects each cluster for energy that cannot be measured in the calorimeter (e.g. from nuclear reactions) and for energy losses in dead material and due to noise thresholds. Clusters are classified as being of electromagnetic or hadronic nature and separate corrections are applied accordingly.

Starting from EM or LCW scale the Jet Energy Scale is applied to correct for detector non-compensation, dead material, leakage of particles outside the calorimeter, particles in the truth jet outside the cone of the reconstructed jet and effects due to noise thresholds and the particle reconstruction efficiency. This is known as the EM+JES or LCW+JES calibration.

Compared to 2010, in 2011 the number of multiple proton–proton interactions (pile-up) increased and the noise thresholds in the calorimeter cells were also increased. The Monte Carlo description of the detector geometry was more accurate in 2011 than in 2010.

3. The Jet Energy Scale uncertainty

The Jet Energy Scale uncertainty is derived from *in situ* single hadron response measurements and systematic variations in the Monte Carlo simulation. The uncertainty accounts for differences

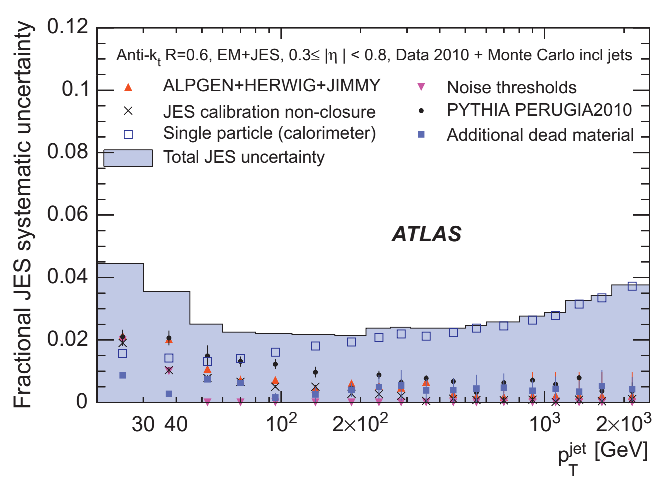

Fig. 1. The default Jet Energy Scale uncertainty derived from single hadron response measurements and Monte Carlo variations for anti-kt $R=0.6$ jets with $0.3 < |\eta| < 0.8$ calibrated with the EM+JES scheme (from Ref. [2]).

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[1] CERN for the benefit of the ATLAS collaboration.

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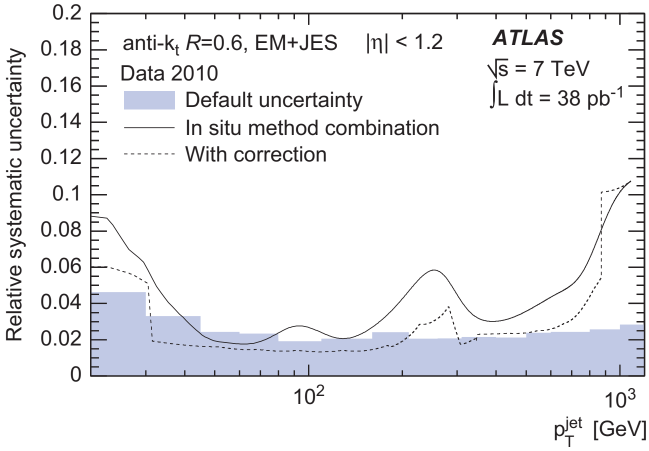

Fig. 2. The Jet Energy Scale uncertainty derived from the combination of *in situ* methods for anti-kt $R=0.6$ jets with $|\eta|<1.2$ calibrated with the EM+JES scheme (from Ref. [2]).

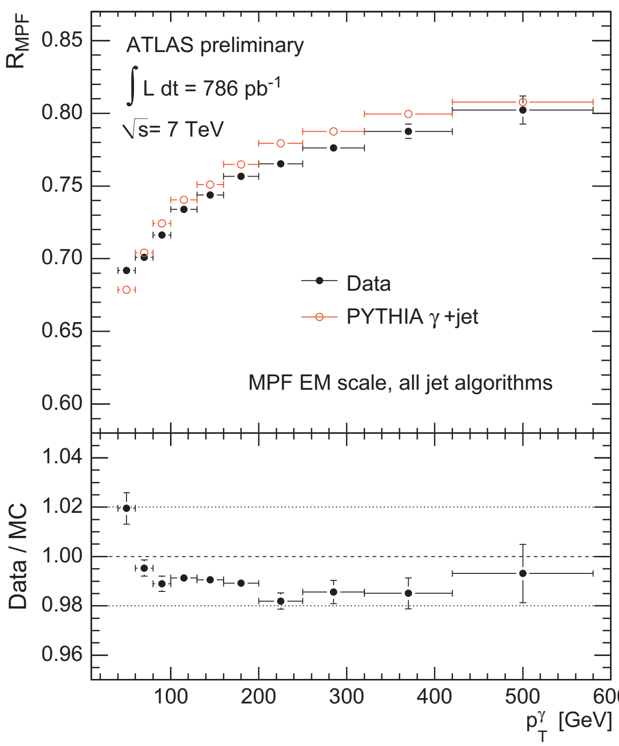

Fig. 3. The response measured using the photon+jet MPF method in data and Monte Carlo (top) and the data/Monte Carlo ratio of the responses (bottom) for anti-kt $R=0.6$ jets calibrated with the EM scheme (from Ref. [4]).

between Monte Carlo generators, the effects of pile-up and noise thresholds on the jet energy, the effects of soft modelling and any additional material in the detector. The uncertainty due to any remaining differences between the response before and after the JES calibration is applied is included. An uncertainty of 2–4% was found as is shown in Fig. 1.

Uncertainties are also derived to account for differences between gluon and quark initiated jets, for non-isolated jets and for differences in the response of b-jets.

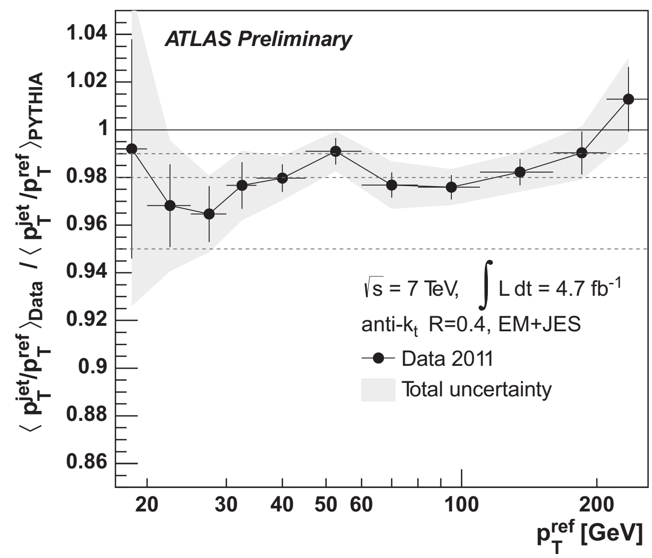

Fig. 4. Data/Monte Carlo ratio of the jet response as a function of p_T measured using Z+jet events for anti-kt $R=0.6$ jets calibrated with the EM+JES scheme (from Ref. [5]).

4. *In situ* measurements

In situ methods are used to confirm the Jet Energy Scale and its uncertainty. These methods exploit the p_T balance between a well measured object and a jet in different final states. At low p_T (10–250 GeV) the p_T balance of the jet against a Z boson is used. For middle p_T ranges (25–800 GeV) the jet is balanced either against a photon (Direct p_T Balance) or the hadronic recoil (Missing E_T Projection Fraction (MPF)). In order to probe the TeV region multi-jet balance is used where the jet is balanced against one or more lower p_T jets.

The uncertainty derived from the combination of *in situ* measurements in 2010 data is shown in Fig. 2. *In situ* measurements in 2011 data see a 1–2% lower response in data than in Monte Carlo as can be seen for MPF in Fig. 3 and for Z+jet in Fig. 4. The *in situ* methods give consistent results and these measurements confirm the Jet Energy Scale uncertainty.

5. Conclusions

Jets in the ATLAS detector have been calibrated using the Jet Energy Scale. An uncertainty on the Jet Energy Scale uncertainty of 2–4% was determined in 2010 data. This uncertainty is confirmed in 2011 data using *in situ* measurements.

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