PROCEEDINGS OF SCIENCE

Jet energy calibrations at the CMS experiment with 13 TeV collisions

Marc Stöver*, **on behalf of the CMS Collaboration**
Hamburg University (DE)
E-mail: marc.stoever@physik.uni-hamburg.de

The jet energy calibration (JEC) measurements, based on a data sample collected in proton-proton collisions at a center-of-mass energy of 13 TeV recorded by the CMS experiment at the LHC Run 2 are presented. The calibrations are extracted from data and simulated events and employ the combination of several channels and methods. These successively correct for contributions of pileup, and absolute scale of the jet energy scale as a function of η and p_T in simulation. To account for any residual differences with jet energy scale in data, in-situ calibrations are determined using dijet, photon+jets, Z+jets and multijet events. Several techniques are used to account for various sources of scale corrections and their uncertainties.

The European Physical Society Conference on High Energy Physics
5-12 July
Venice, Italy

*Speaker.

PoS(EPS-HEP2017)805

1. Introduction

Jets are the experimental signatures of quarks and gluons produced in high energetic processes such as proton-proton collisions at the Large Hadron Collider (LHC). The aim of jet energy calibrations at the CMS experiment [1] is to correct, on an average, the momenta of reconstructed jets to match that of particle level jets clustered from stable and visible final state particles. Several effects like initial state and final state radiation, additional energy from pileup, detector effects and electronic noise must be corrected for. A factorized approach is applied to correct for these effects at several independent correction levels. The measurements presented here use data samples of proton-proton collisions at $\sqrt{s} = 13$ TeV collected 2016 with the CMS experiment at the LHC and have been published in [2]. The results of previous measurements performed at 7 and 8 TeV can be found in [3] and [4], respectively.

2. Reconstruction of jets and correction scheme

This article reports the results for jets reconstructed with the Particle Flow approach [5] using the anti-k_T algorithm [6]. The CMS collaboration has measured the jet energy scale for jets with radius $R = 0.4$ and $R = 0.8$, and charged hadron subtraction (CHS) and the PUPPI method [7] applied for pileup mitigation. In the measurements presented here jets with distance parameter $R = 0.4$ and CHS applied are used.

The sequence of the factorized approach to correct for the various effects successively is shown in Fig. 1. After correcting for pileup offset and simulated response, residual differences between data and simulation are determined.

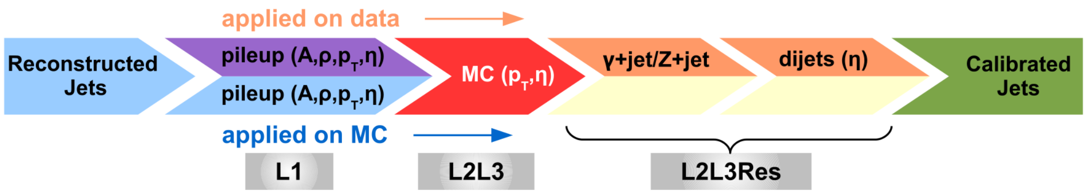

Figure 1: Scheme of the factorized approach of jet energy corrections at the CMS experiment. Reconstructed jets are succesively corrected for pileup offset, simulated response and residual differences between data simulation.

3. L1 – Pileup offset

Presence of additional pp interactions (pileup) along with that of main interest in a bunch crossing leads to additional contributions to the jet energy and to the jet momentum are referred to as pileup offset. The pileup induced offset in the reconstructed jet p_{T} is calculated in simulation. In this procedure, the same event is reconstructed with and without pileup simulation and the reconstructed jets of the two samples are matched.

A correction factor between data and MC simulation is determined by using a random cone method [3] to make sure that the simulated pileup modelling describes the data. A zero-bias data

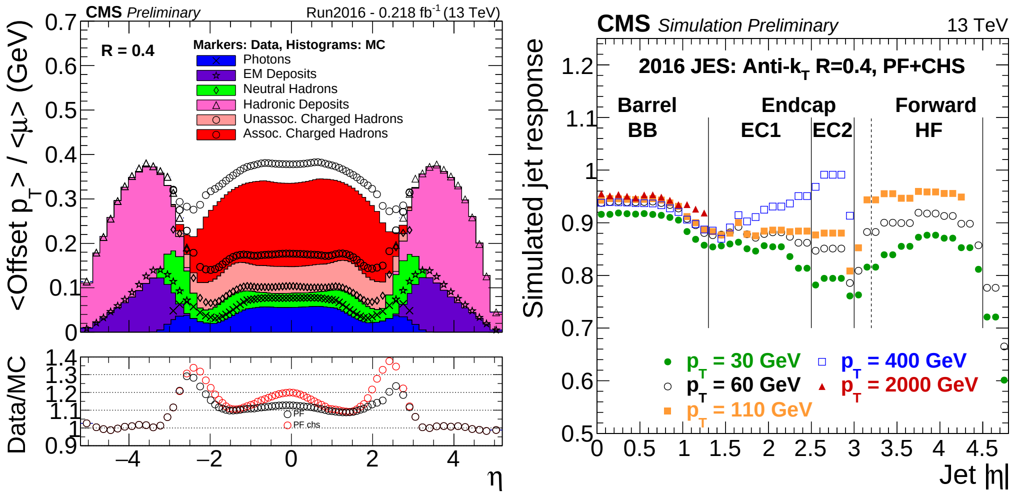

Figure 2: Left: Pileup offset measured in data and MC simulation, normalized to the average number of pileup interactions <μ> [2]. Right: Simulated jet response after pileup subtraction as a function of the jet pseudorapidity $|\eta|$ [2].

sample is used that does not contain any energy deposition from hard interactions. The measured pileup offset in data and MC simulation and the corresponding scale factor is shown in Fig. 2 (left). The offset scale factors for PF CHS jets are 10-20% at $|\eta| < 2.0$ and increase to up to 40% for $2.0 < |\eta| < 2.4$. For higher values of the jet pseudorapidity, the offset scale factors are small.

4. L2L3 – Simulated response

The simulated response corrections are derived for jets that are already corrected for pileup offset. Simulated response corrections are estimated to equalize the energy of generated jets, on average, with the energy of reconstructed jets. With these corrections several detector effects are taken into account, like the effect of non-linear calorimeter response.

A generated jet is matched to the closest reconstructed jet and a high matching efficiency is achieved by matching reconstructed and generated jets within half of the jet cone size. The simulated jet response is given by $\mathscr{R} = \frac{p_T^{\text{rec}}}{p_T^{\text{gen}}}$ and is shown as a function of the jet pseudorapidity $|\eta|$ in Fig. 2 (right). Some p_T dependence in the simulated jet response is observed.

5. L2L3Res – Residual corrections

Residual correction factors are determined to correct for differences in the mean response between data and simulation. These scale factors are derived after the jets are corrected for pileup offset and for simulated response. The residual corrections are determined in calibration samples of dijet, γ+jets and Z+jets events, where the former is referred to as L2Res correction and the others as L3Res correction. Two methods are exploited for each calibration sample.

In the p_T balance method, the jet response is determined by comparing the momenta of the reconstructed probe jet p_T^{probe} and the reference object p_T^{tag}. Depending on the selected calibration

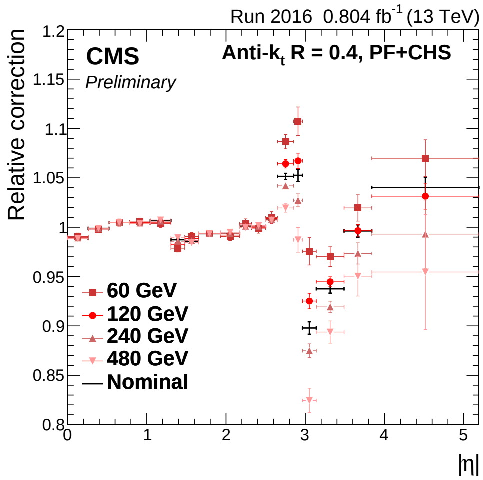

Figure 3: Relative residual correction factors with nominal and varied jet p_T as function of the jet pseudo-rapidity $|\eta|$ using the MPF method [2].

sample, the reference object is either a reconstructed jet, Z-boson or photon. The response estimator of the p_T balance method is defined as

$$\mathscr{R}_{\text{rel}}^{p_T} = \frac{1 + <\mathscr{A}>}{1 - <\mathscr{A}>}, \text{ with } \mathscr{A} = \frac{p_T^{\text{probe}} - p_T^{\text{tag}}}{2p_T^{\text{ave}}}.$$

The idea of the missing transverse energy projection fraction (MPF) method is that at parton level the reference object and the hadronic recoil are perfectly balanced in the transverse plane. The response estimator is defined as

$$\mathscr{R}_{\text{rel}}^{\text{MPF}} = 1 + \frac{\vec{p}_T^{\text{miss}} \cdot \vec{p}_T^{\text{tag}}}{(p_T^{\text{tag}})^2}.$$

In Fig. 3 the L2Res correction factors are shown using the MPF method. In case of the nominal measurement, the factors are found to be between 0.98 and 1.01 for a jet pseudorapidity of $|\eta| < 2.6$ and between 0.90 and 1.05 in the outer endcap and hadron forward region of the calorimeter. Some p_T dependence can be observed in the endcaps and hadron forward calorimeters.

The data-to-simulation ratio of the jet response has been determined in dependency of the jet p_T for each L3Res calibration sample. The results are input to a global fit. The correction factors are found to be close to unity over the whole jet p_T range.

6. Conclusions

Reconstructed jets are corrected back to particle level by jet energy calibrations. The strategy of the CMS collaboration involves sequential steps to correct jets for pileup offset, simulated response and residual η and p_T dependencies. The measurements will be updated using the full data set of 2016, which should improve the precision of the data-driven correction factors.

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