Available on CMS information server

CMS DP -2020/019

The Compact Muon Solenoid Experiment

CMS Performance Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

09 April 2020 (v3, 15 April 2020)

Jet energy scale and resolution performance with 13 TeV data collected by CMS in 2016-2018

CMS Collaboration

Abstract

We present jet energy scale and resolution performances with 13 TeV data collected by CMS in 2016-2018.

Jet energy scale and resolution performance with 13 TeV data collected by CMS in 2016-2018

The CMS Collaboration

cms-pog-conveners-jetmet@cern.ch

15th April 2020

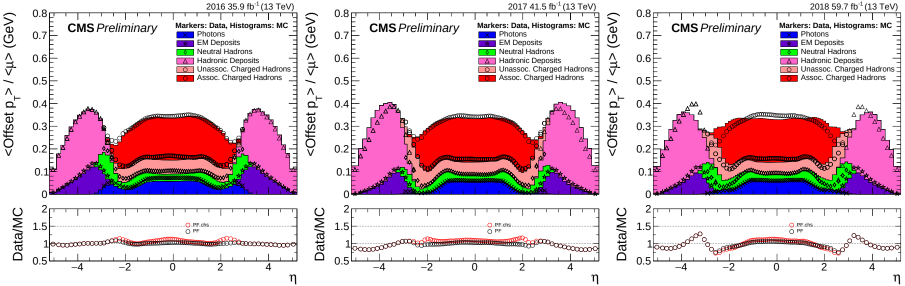
Introduction

- Jet energy correction (JEC) and resolution (JER) measurements are presented, based on data collected in pp collisions at $\sqrt{s} = 13$ TeV in 2016-2018 and reconstructed at the end of the data taking of each year. Previous results for 2016 were shown in CMS-DP-2018-028. The main detector changes are related to the phase-1 upgrade of the Pixel tracker, which took place between the 2016 and 2017 data taking periods.
- The jet energies are corrected up to the level of jets clustered from stable ($c\tau$>1 cm) and visible (non-neutrino) final state particles, referred to as particle (ptcl) jets.
- The jet energy scale (JES) is calibrated sequentially with:
  - pileup offset subtraction
  - detector response correction from simulation
  - residual corrections for differences between data and detector simulation
  - optional corrections for jet flavour composition
- Experimental techniques used:
  - Dijet and multijet p_{T}-balance, which exploit momentum conservation in the transverse plane.
  - $Z/\gamma+$ jet p_{T}-balance, in which a γ or a Z boson is used as a reference object, whose p_{T} is accurately measured from the ECAL or muon system.
  - Missing Transverse Energy Projection Fraction (MPF) used to facilitate a better understanding of systematic uncertainties and to perform cross-checks.
  - The JER is determined with dijet, $Z+$ jet and $\gamma+$ jet events.
  - Additional jet activity quantified by $\alpha = p_{\mathrm{T}}^{\text{add. jet}}/p_{\mathrm{T}}^{\text{ref}}$, with $p_{\mathrm{T}}^{\text{ref}} = (p_{\mathrm{T}}^{\text{jet1}} + p_{\mathrm{T}}^{\text{jet2}})/2$ for the dijet and multijet analyses and $p_{\mathrm{T}}^{\text{ref}} = p_{\mathrm{T}}^{Z/\gamma}$ otherwise.
- JES uncertainties evaluated as a function of η^{jet} and $p_{\mathrm{T}}^{\text{jet}}$.

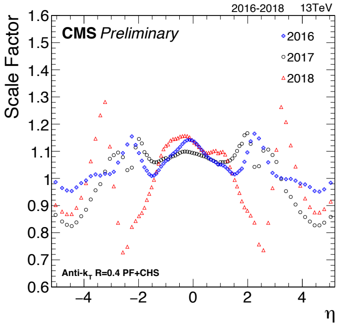
JEC – Pileup Offset Subtraction

- Average difference in p_{T} between matched jets measured in simulated samples with and without pileup overlay is subtracted in data and simulation.
- Offset residual corrections derived with Random Cone method from ZeroBias data vs. NeutrinoGun simulation.
- The average p_{T} of PF candidates in a randomly placed cone can be identified with the average offset due to pileup.
- Average offset per pileup interaction (μ) monitored for each type of PF candidates:
  - Photons, Neutral Hadrons, EM Deposits in HF, Hadronic Deposits in HF.
  - Assoc. Charged Hadrons: associated with reconstructed PU vertices and thus removed from the list of PF candidates in the jet clustering by CHS algorithm.
  - Unassoc. Charged Hadrons: not removed from the list of PF candidates by CHS algorithm.
- Corrections binned in energy density ρ, jet area, η^{jet} and $p_{\mathrm{T}}^{\text{jet}}$.

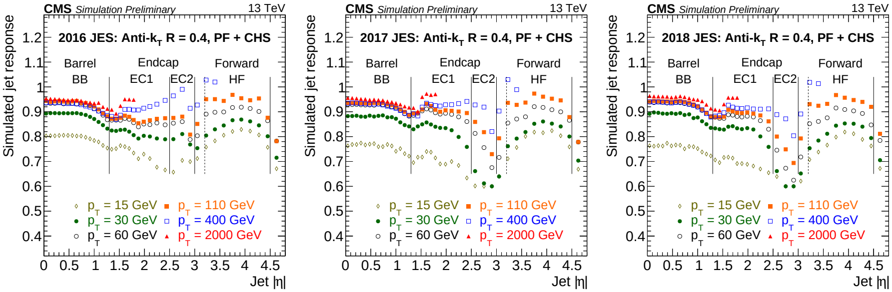
JEC – Pileup Offset Subtraction



- Upper plots: data-to-simulation comparison for average offset per pileup interaction, calculated for each type of PF candidates.
- Right plot: evolution of data-to-simulation scale factors over the years.
- Change in MC UE tune after 2016 (CUEP8M1 to CP5) results in higher energy flow in HF. Larger data-to-simulation differences in 2018 are due to additional changes in HF simulation and PF calibration.

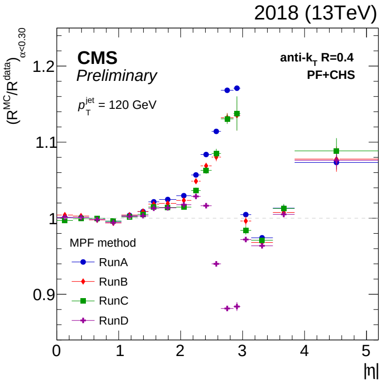


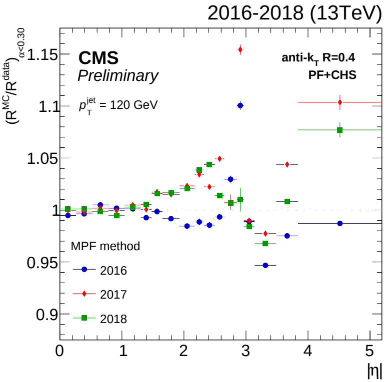
JEC – Response Correction From Simulation



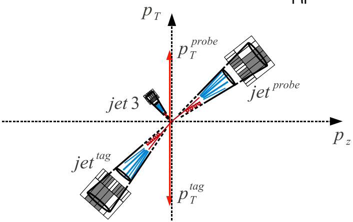
- Jet response defined as $\frac{\langle p_{\mathrm{T}}^{\textbf{reco}}\rangle}{\langle p_{\mathrm{T}}^{\textbf{ptcl}}\rangle}$. Corrections derived in bins of $|\eta^{\mathrm{jet}}|$ and $p_{\mathrm{T}}^{\mathrm{jet}}$.
- Stable response in the barrel:
  - 0.95 due to neutral hadrons response of 0.6 (accounts for $\sim 15\%$ of $p_{\mathrm{T}}^{\mathrm{ptcl}}$).
  - Drop below $p_{\mathrm{T}} < 30\,\mathrm{GeV}$ due to HCAL acceptance.
- Stronger p_{T}-dependence in EC and HF.
- Change in performance for:
  - $3.0 < |\eta| < 3.2$ due to detector transition
  - $|\eta| > 4.5$ due to acceptance
- EC2 affected by calorimeter degradation over time, lowering jet response.

JEC – Relative η-dependent Residual Correction

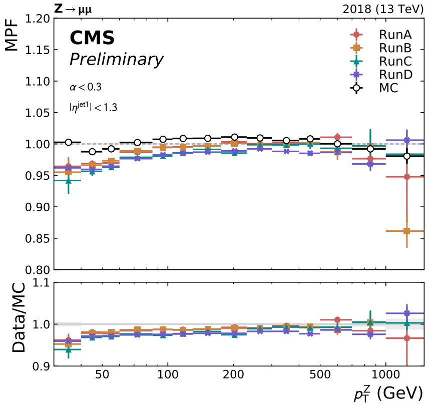


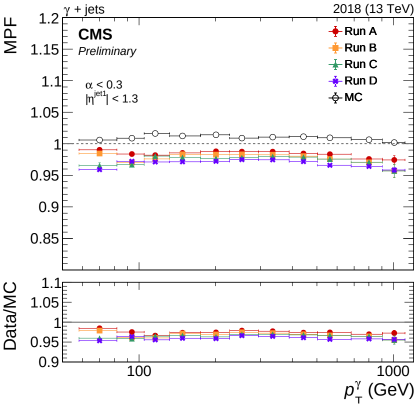


- Residual correction of jet response normalised to the response in the barrel derived in bins of η^{jet} and $p_{\mathrm{T}}^{\mathrm{jet}}$ using dijet events with MPF method.
- Time-dependent corrections address evolution and ageing of the detector in different data-taking periods and years.



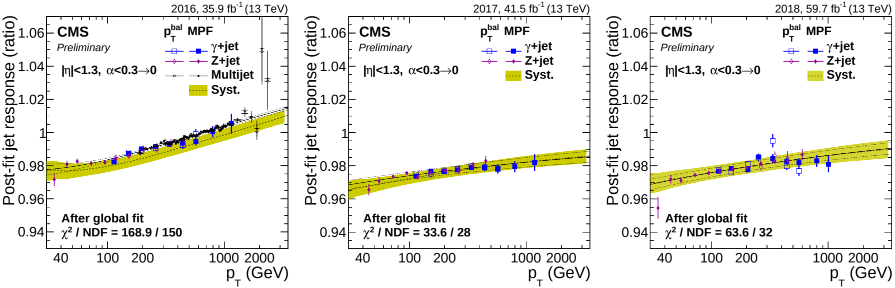
JEC – Absolute p_T-dependent Residual Correction





- Jet response dependence on p_T^Z in $Z(\to \mu\mu)$+jet events (left) and p_T^γ in $\gamma +$ jet events (right).
- JES determined relative to precisely measured reference objects (μ, e, γ).
- Response smaller than 1 due to FSR and ISR effects.

JEC – Absolute p_T-dependent Residual Correction



- Data-to-simulation comparison for the jet response dependence on p_T^{jet}.
- Combination of $\gamma +$ jet and Z $+$ jet. Multijet results used in 2016.
- Z($\rightarrow \mu\mu$)+jet and Z($\rightarrow$ee) events are pre-combined into Z $+$ jet events.
- MPF and p_T-balance methods used, but (Z $+$ jet) MPF dominates precision.
- Post global fit values for nuisance parameters (scales of reference objects) used to demonstrate the good consistency between the data sets.
- Yellow band indicates absolute scale uncertainty that is centred around the luminosity-weighted average of JEC per run. Its deviation from the fit to the combined sample (solid black line) is taken as "Time stability" uncertainty in the following slides.

JES – Systematic Uncertainties

Jet energy scale uncertainties include the following sources:

- Absolute scale: flat absolute scale uncertainties. Main uncertainties combine γ, $Z \to ee$ and Z$\to \mu\mu$ reference scale and correction for FSR+ISR.
- Relative scale: dijet uncertainties for JER SF variation and for FSR+ISR estimated from difference of L2Res obtained with Pythia8 and Herwig.
- Pileup: 5% uncertainty on data-to-simulation scale factor from the Random Cone method, plus residual difference between Random Cone offset and MC truth offset after global fit of absolute scale vs p_{T}.
- Jet flavour: based on Pythia vs. Herwig differences in uds/c/b-quark and gluon responses.
- Time stability: difference between the luminosity-weighted average of corrections per data-taking period per year.
- Pileup and flavour uncertainty dominate at low p_{T}.
- Methods and samples used:
  - MPF vs. p_{T}-balance results
  - Z/γ+jets vs. Z vs. dijet (the largest difference outside tracking) and Z/γ + jet vs. dijet (within tracking).

JES – p_{T}-dependent Uncertainties

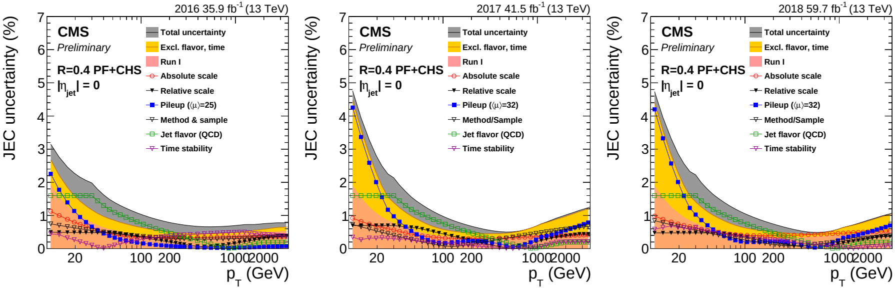


Figure: JES uncertainty sources and total uncertainty (quadratic sum of individual uncertainties) as a function of $p_{\mathrm{T}}^{\mathrm{jet}}$. Run I uncertainty without flavour and time sources shown for comparison. flavour source is the same as in Run I.

JES – η-dependent Uncertainties

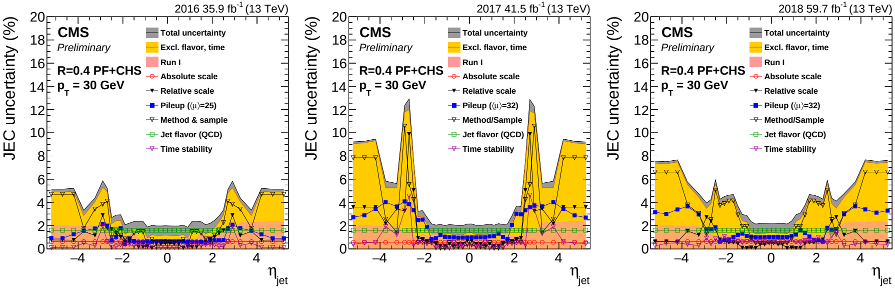


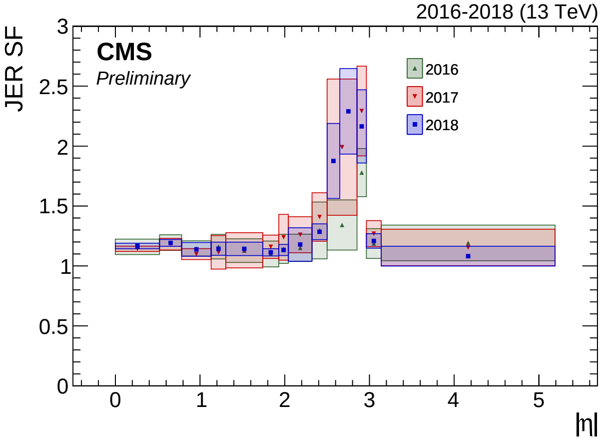
Figure: JES uncertainty sources and total uncertainty (quadratic sum of individual uncertainties) as a function of η^{jet}. Run I uncertainty without flavour and time sources shown for comparison. flavour source is the same as in Run I.

- JER measured with dijet and $Z/\gamma+$jet p_{T}-balance methods in data and simulated samples using JES-corrected jets. Worsening due to ISR/FSR taken into account by extrapolating to ideal two-body topology.

- Derivation of η-dependent data-to-simulation scale factors (SFs) with dijet method.

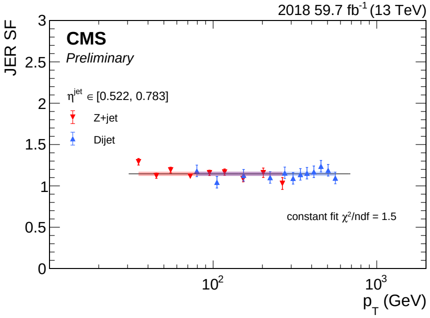
- SFs derived for $p_{\mathrm{T}} \geq 100$ GeV.

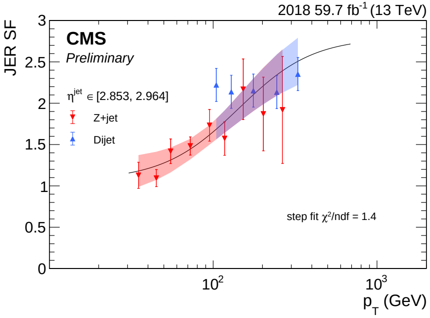
- SFs of 1.1-1.2, larger in the EC-HF transition region of $|\eta| \in [2.5, 3]$.



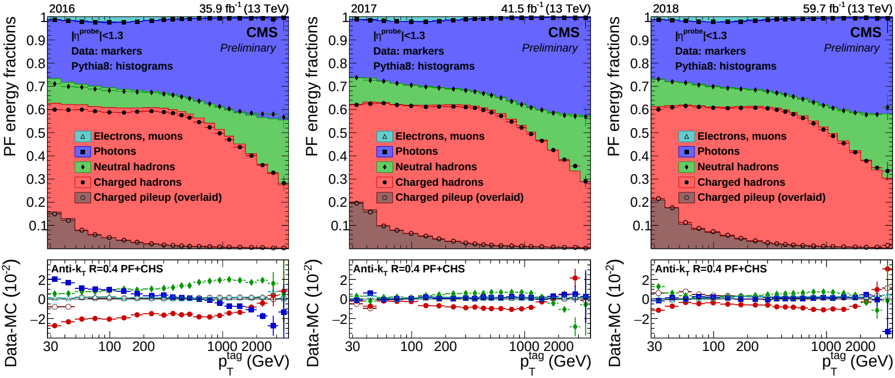
JER – p_T-dependent Scale Factors

- JER obtained from $\gamma+$jet analysis agrees with dijet results. Comparison can be used to reduce uncertainties.
- SFs p_T-dependent in $|\eta| \in [2.5, 3.0]$. No p_T-dependence observed elsewhere.
- The Z + jet analysis yields larger uncertainties for $p_\mathrm{T} > 150\,\mathrm{GeV}$, but extends dijet approach for $p_\mathrm{T} < 100\,\mathrm{GeV}$.
- The two methods are complementary and aim for full coverage in p_T and η.





Jet PF Composition



- Jet PF composition studied from dijet events using fully corrected jets.
- Cross-check comparison between data and simulation for monitoring the stability of JES.
- All categories considered: Photons, Leptons, Neutral and Charged Hadrons.
- Fraction of energy removed by CHS before jet clustering is overlaid.

—Additional Material—

JEC – Relative η-dependent Residual Correction

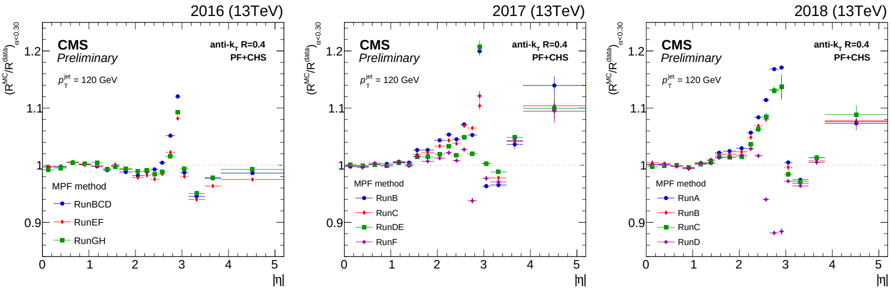


Figure: Residual correction of jet response w.r.t. barrel derived in bins of η^{jet} and $p_{\mathrm{T}}^{\text{jet}}$ using dijet events with MPF method.

Jet PF Composition 2016

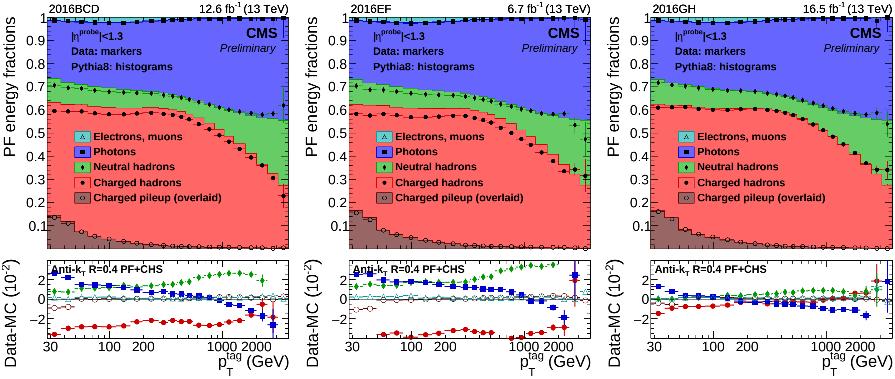


Figure: Jet PF composition studied from dijet events using fully corrected jets.

Jet PF Composition 2017

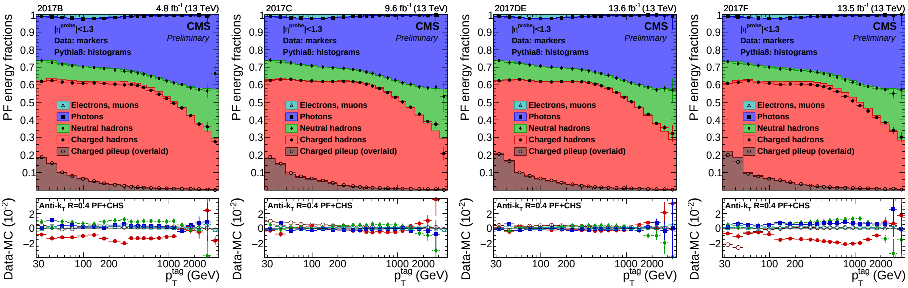


Figure: Jet PF composition studied from dijet events using fully corrected jets.

Jet PF Composition 2018

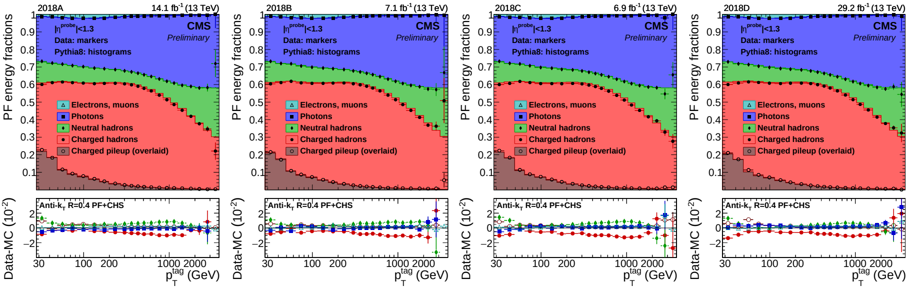


Figure: Jet PF composition studied from dijet events using fully corrected jets.