Jet Energy Scale and Resolution Measurement at CMS

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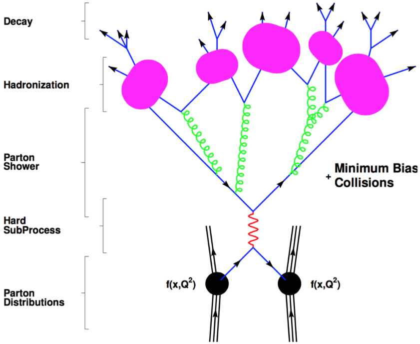
Motivation

Why do we need Jet Energy Calibration?

- **Jet production cross section is substantially large.**
  Hadronic Jets are copiously produced
  in pp collisions at LHC.
- **Jets can be signal, background or both.**
  (Jets also can fake particles like γ , e , μ or τ).
- **Like any other reconstructed object,**
  jets need to be calibrated.
- **Jet reconstruction and calibration are challenging tasks.**
  - $\longrightarrow$ Due to substantial amount of event pileup.
  - $\longrightarrow$ Due to non-uniform response of detector components for jets constituents as a function of their p_T and η.



Jet Reconstruction

- **The Sequential Recombination Algorithms are in use at LHC.**

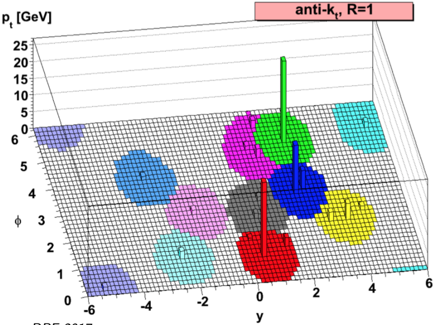
  $d_{ij} = min(p_{T,i}^{2x}, p_{T,j}^{2x}) \frac{\Delta R_{ij}^2}{R^2}$, $(\Delta R_{ij})^2 = (y_i - yj)^2 + (\phi_i - \phi_j)^2$

  $d_{iB} = p_{T,i}^{2x}$

- **Power x distinguishes between $k_T (x = 1)$, Cambridge/Aachen (x=0) and Anti-$k_T (x = -1)$ algorithms.**

- **At CMS we use Anti-k_T with radius 0.4 and 0.8 for clustering the jets .**

  Anti-k_T is collinear and infrared safe.



- **MC Particle Level Jets:**

  Reconstructed from clustering all stable and visible particles in the generated events.

- **Calorimeter (Calo) Jets:**

  Reconstructed from the energy deposits in the calorimeter towers.

- **Particle Flow (PF) Jets:**

  Reconstructed by clustering the identified PF particles. (Combining calorimeter and tracking information.)

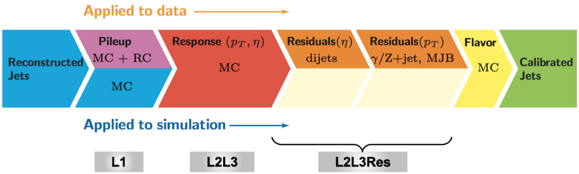
- **PUPPI Jets:**

  Reconstructed by clustering PF particles excluding pileup particles.

Jet Energy Correction

Reconstructed jets energy and momentum needs to be corrected up to their particle jet level.

At CMS jet energy correction procedure is performed in multistep factorize procedure.



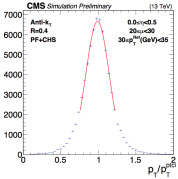
- **MC Jets Calibration** $\Rightarrow \frac{<p_T^{Reco}>}{<p_T^{ptcl}>}(p_T^{ptcl}, \eta) = 1$
- **Using simulated sample of QCD dijet events processed with and without minimum Bias[1] events overlay to derive MC Truth Corrections**

- **Scale Data to MC** $\Rightarrow \frac{<p_T^{Reco}>}{<p_T^{ref}>} = 1$
- **L1 Residual:** Using Random Cone method on Zero Bias Data and simulated Single Neutrino sample to determine PU residual corrections.
- **L2 Residual:** Using QCD Dijet sample to derive η dependence residual correction.
- **L3 Residual:** Using Z($\rightarrow\mu\mu$,ee)+jet, γ+jet and multijet sample to derive p_T dependence residual correction.

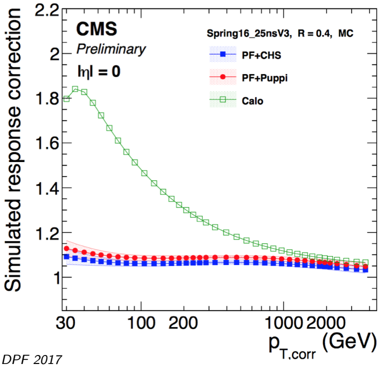
[1] Minimum Bias events is used to model PU.

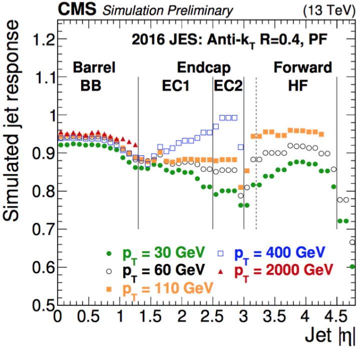
MC Truth JEC

Jet$_{ptcl}$ is matched to the closest jet$_{Reco}$ in simulated QCD.



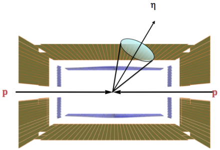
$$\text{Response} = \frac{<p_T^{Reco}>}{<p_T^{ptcl}>}[p_T^{ptcl}, \eta]$$



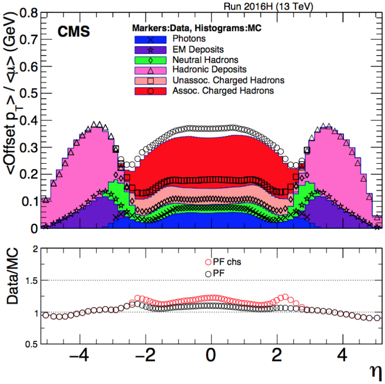


- Stable response in the barrel region.
- More than 90% of original jet p_T is retained for jets with $p_T > 30$ GeV in the barrel region.
- Neutral hadron's lower response (~ 0.6) is responsible for less than 10% loss in original jet p_T.
- In Endcap and HF regions, Response is extremely p_T dependent.

L1 Residual Offset Correction



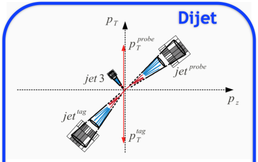
- L1 Residual offset correction aims to correct for L1 offset corrections derived from MC to match the data.
- Charged hadrons associated to PU vertices are removed using Charge Hadron Subtraction algorithm.
- Remnant of PU offset contribution can be estimated and removed in L1 Offset Corrections, by using Random Cone Method for ZeroBias data and Single Neutrino MC sample.



- L1 Residual scale factors ($\frac{\text{Data}}{\text{MC}}$) used to correct for differences in PU offset in data and MC.

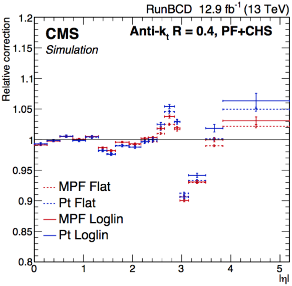
L2 Relative η Correction

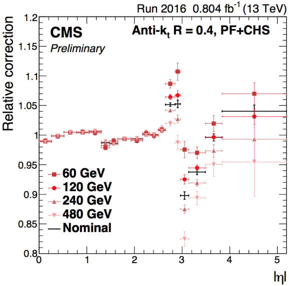
L2 Residual corrects jet response non-uniformity in η



$$R_{\mathrm{jet},p_{\mathrm{T}}} = \frac{p_{\mathrm{T,jet}}}{p_{\mathrm{T,ref}}},$$

$$R_{\mathrm{jet,MPF}} = 1 + \frac{\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}} \cdot \vec{p}_{\mathrm{T,ref}}}{(p_{\mathrm{T,ref}})^2}.$$

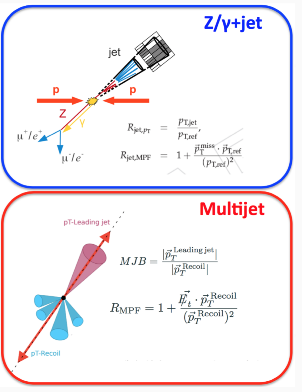


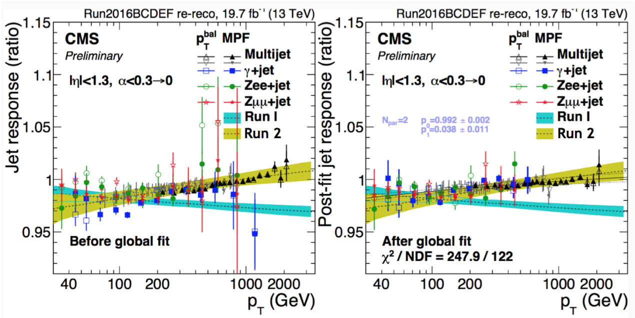


- Using QCD dijet events after MC based and L1 corrections are applied.
- Balance probe jet with the reference jet in the central region.
- 2 complementary methods are being used:
  - → p_T Balance
  - → Missing E_T Projection Fraction (MPF)
- $\frac{\text{Data}}{\text{MC}}$ residual corrections is derived to correct for the response η dependency.

L3 Residual Absolute p_T Correction

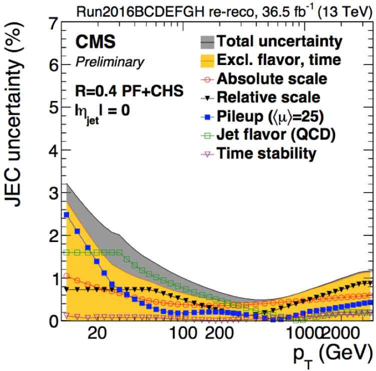
L3 Absolute corrections corrects jet response non-uniformity in jet p_T and set it to 1

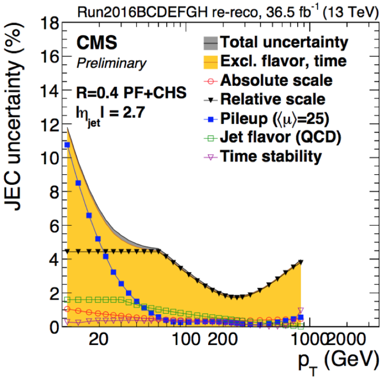




- **Using Z($\rightarrow\mu\mu$,ee)+jet, γ+jet and multijet sampleto cover a wide p_T range**
- **$\frac{\text{Data}}{\text{MC}}$ comparison to correct for jet response dependency on jet p_T.**
- **Global fit taking into account individual scales and uncertainties of reference objects.**

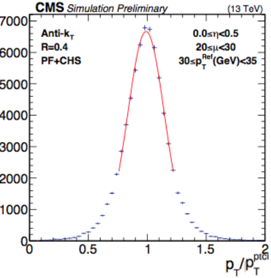
JEC Uncertainties

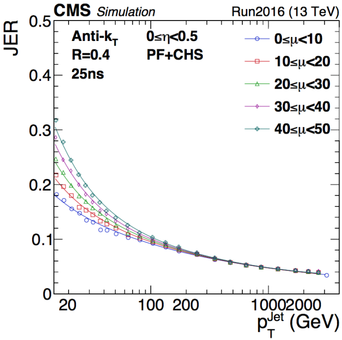


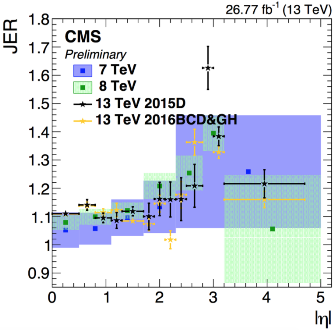


- At lower p_T, pileup is the major source of the uncertainty.
- Dominant source of the uncertainty is relative η scale.
- No drastic change in JEC performance in the barrel region in comparison with Run I.
- Uncertainty is increased outside the tracker coverage in comparison with Run I.

Jet Energy Resolution







- Fitting the MC Truth Response by a Gaussian fit.
- Resolution $= \frac{\sigma_{\text{fit}}}{\mu_{\text{fit}}}$

- For high p_T jets, resolution are stable againts pileup.
- For jets with $p_T = 20$ at very high PU rate, the resolution worsen by 50%.

- Using dijet sample we derive $\frac{\text{Data}}{\text{MC}}$ resolution scale factor.
- Scale factor gets largest in endcap-forward transition region.

Summary

- **Precise measurement and calibration of jets is crucial for majority of physics analysis at CMS.**
- **CMS uses various data and MC samples to derive corrections for wide range of p_T and full η coverage and with increased pileup condition.**
- **The precision of jet calibration is close to that of Run I.**
- **The resolution remains stable against increase in pileup.**