Jet Energy Scale and Resolution Measurements at CMS

Hirak Bandyopadhyay

CMS Collaboration

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hirakban@buffalo.edu

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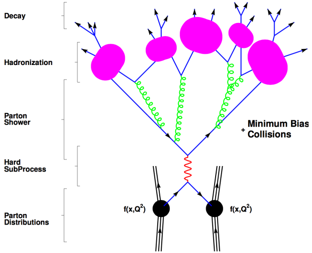
Introduction

- At the LHC, quarks and gluons are abundantly produced in proton-proton collisions at $\sqrt{s} = 13$ TeV.
- Jets are signatures of quarks and gluons.
- The production cross section of jets (QCD) is orders of magnitude higher compared to any other processes.
- Depending on the physics process, jets can either be the signal or background $\Longrightarrow$ measurement of jet 4-momentum is essential for most analyses.
- Jet reconstruction and calibration is challenging in busy LHC environment. Additional pp interactions (event pileup) produce extra unwanted energy underneath a jet, smearing its 4-momentum.



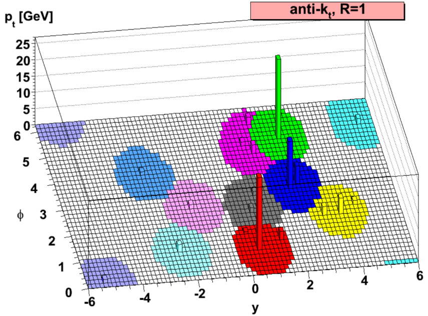
Jets at CMS

- We use infrared and collinear safe Anti-k_T recombination algorithm to cluster jets.
- PF particle list used as input. PF algorithm combines information from all CMS sub-detectors (Tracker, ECAL, HCAL, Preshower and Muon System) to precisely reconstruct produced particles.
- PFchs Jets: Clustered from identified PF particles. Charged PF particles associated to pileup vertices are removed.
- PUPPI Jets: Clustered from weighted (for pileup probability) PF particles.

- Anti-k_T Clustering:

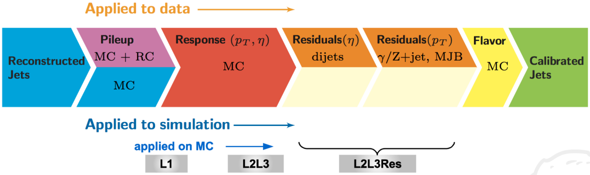
$$d_{ij} = p_{T,i}^{2x} \qquad d_{ij} = \min(p_{T,i}^{2x}, p_{T,i}^{2x})\frac{\Delta_{ij}^2}{R^2}$$

- We use Anti-k_T with distance parameter R =0.4 and 0.8.



Jet Energy Correction

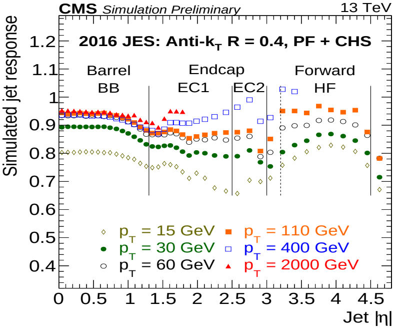
- Aim: correct Reconstructed jets to Particle Level jets.

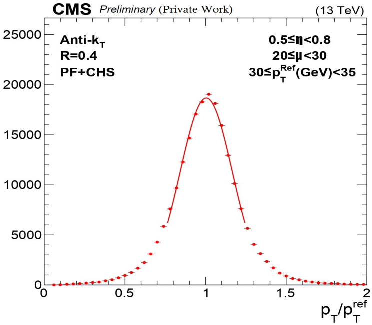


- **MC truth based calibration:**
  $< p_T^{reco} > / < p_T^{particle} >= 1$
- L1 Offset corrections: removes pileup energy. Extracted from QCD samples with and without pileup.
- L2L3Response: corrects for detector non-uniformity and response.

- **Residual Data/MC correction:**
  $< p_T^{reco} > / < p_T^{ref} >= 1$
- L1Res: Pileup residuals from Zero Bias data and MC.
- L2Res: η-dependent and coarse p_T-dependent residuals from QCD dijet.
- L3Res: Finely p_T dependent residuals from $Z(\rightarrow ee, \mu\mu)$+jet, γ+jet and multijet.

MC truth Jet Energy Scale



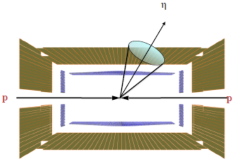


- Jet Response (Scale) $= \frac{<p_T^{reco}>}{<p_T^{particle}>}$
- Less than 1 response at low p_T due to neutral hadrons which have response ∼0.6
- Jet Response is stable in the Barrel region.
- Drops in Response at low p_T in:
  $|\eta| = [3 - 3.2]$ due to calorimeter gaps.
  $|\eta| > 4.7$ due to acceptance.

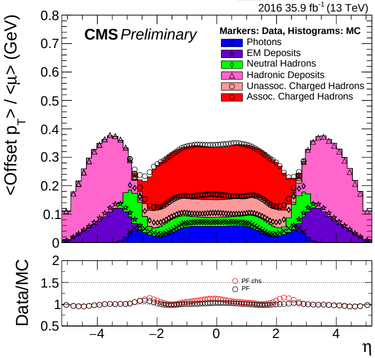
- Jet Energy Correction = reciprocal of Jet Energy Response.
- After jets are corrected by multiplicative JEC factor, Response is centered at unity.

L1 Residual Offset Correction

- Pileup Offset: Extra unwanted energy due to multiple pp interactions.
- Charged Hadron Subtraction: Hadrons associated with PU vertices are removed with CHS algorithm.
- Remaining contributions are subtracted in L1 Offset Correction.
- L1 Residual Offset is measured with Zero Bias data and MC.
- Use "Random Cone" method to derive L1 Residual.

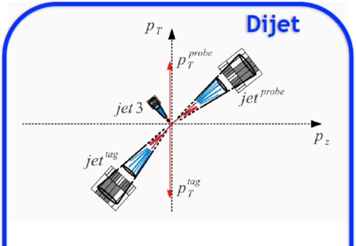


Random cone centered at η



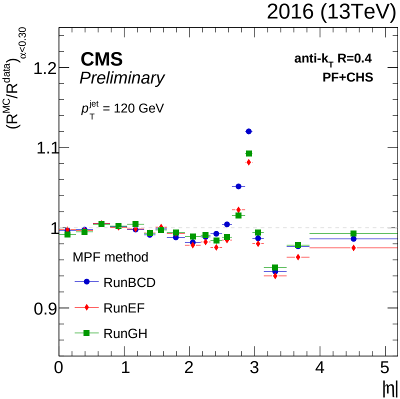
L2 Residual relative η correction

- Goal: make Data/MC jet response ratio uniform in η.



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

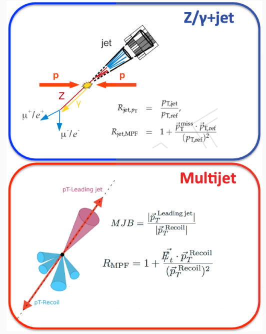
$$R_{\mathrm{jet,MPF}} = 1 + \frac{\vec{p}_\mathrm{T}^{\,\mathrm{miss}} \cdot \vec{p}_{\mathrm{T,ref}}}{(p_{\mathrm{T,ref}})^2}.$$

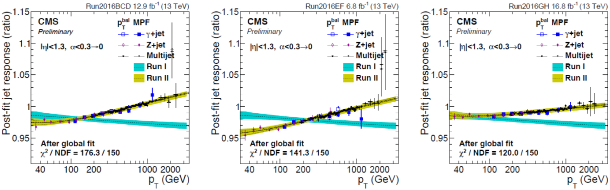


- Uses back-to-back dijet events.
- Balance Probe Jet with reference jet at central eta region ($|\eta| < 1.3$).
- Employ two complementary methods:
  - p_T balance.
  - Missing E_T projection fraction (MPF).

L3 Residual absolute p_T correction

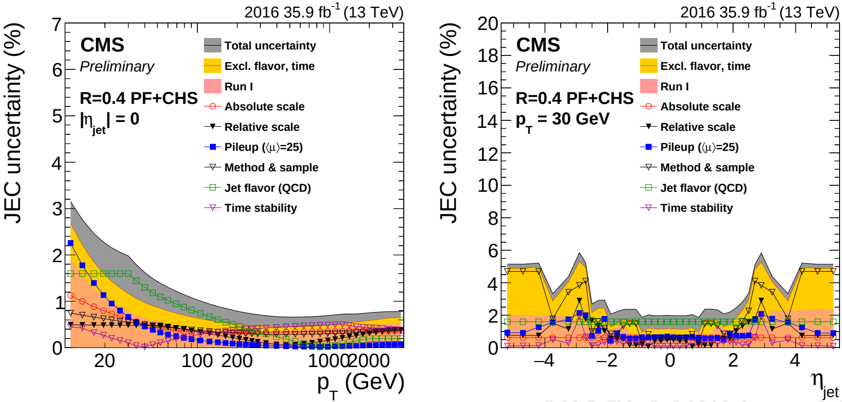
- Goal: Make residual Data/MC jet response uniform in p_T and equal to 1.





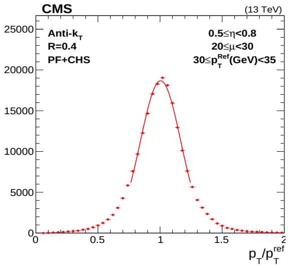
- We use several channels to cover a wide p_T range: $Z(\rightarrow ee, \mu\mu)$+jet, $\gamma+$ jet and multijet samples.
- Relative scale obtained by global fit taking into account individual scales and uncertainties of reference objects.
- Both, direct p_T balance and MPF methods are employed.

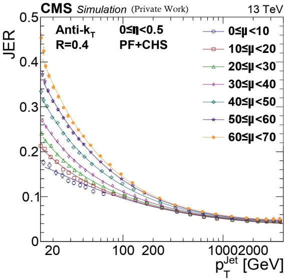
JEC Uncertainties

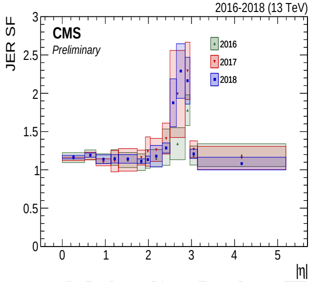


- In the Barrel, the JEC performance is close to Run I.
- Main source of uncertainty at low p_T is the pileup offset.
- Higher pileup in Run II leads to increased uncertainties in $|\eta| > 2.5$ compared to Run I.

Jet Energy Resolution







- Use fits of response distributions from MC truth.
- Resolution = σ_{fit}/μ_{fit}.

- Resolutions are stable against pileup above jet $p_T \sim 100$ GeV for all η.

- Data/MC resolution scale factors derived using dijet events.
- Scale factors ∼1.2 except for the Endcap-Forward transition region around $|\eta| = 3$.

Summary

- Hadronic jets are abundantly produced in pp collisions at the LHC.
- Precise calibration of jets is of the utmost importance for the majority of physics analyses at CMS.
- CMS uses simulation and data to calibrate jets over wide p_T and η ranges, and under increased pileup conditions.
- Zero Bias events, QCD dijet, Z($\rightarrow ee, \mu\mu$)+jet, γ+ jet and multijet events are used for in-situ calibration.
- The precision of the jet energy calibration in Run 2 is approaching that of Run 1: better than 1% precision in the central region.
- Jet energy resolutions are stable against pileup for $p_T >\sim 100$ GeV.


T H A N K
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References

[1] https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsDP20019.

[2] https://cms.cern.ch/iCMS/user/noteinfo?cmsnoteid=CMS%20DP-2018/028