Factorization of Jet Energy Corrections

Jet Energy Scale Task Force

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Overview

- CMS would benefit from a factorized multi-level jet correction.

- Total jet energy correction is decomposed into (semi) independent factors applied in a fixed sequence
  1. Offset: removal of pile-up and residual electronic noise.
  2. Relative (η): variations in jet response with η relative to control region.
  3. Absolute (p_T): correction to particle level versus jet p_T in control region.
  4. Flavor: correction to particle level for different types of jet (b, tau, etc.)
  5. Underlying Event: luminosity independent spectator energy in jet removed.
  6. Parton: correction to parton level.

  More details on each factor, and other possible factors, later in the talk.

- Each factor can be separately determined, refined and understood.
  - ➔ 1st MC truth (now), then data driven with MC data (next ½ year), then data driven with real data (2008).
  - ➔ Factorizing the correction allows for collaborative work and continuity.
  - ➔ Monolithic corrections are either kept or replaced: we lose prior work.
    - → All the current CMS corrections are MC truth based monolithic corrections.

Priority, Scope and Evolution

- Factorization facilitates prioritization, evolving corrections & scope

- Addressing problems one-by-one, factorization allows us to
  - Use more people to solve the jet energy correction problem quicker.
  - Address the most essential corrections first (prioritization)
    - Flattening η response of the jets, requested by Online Selection for HLT !
    - Correction of calorimeter based jets to the particle level.
    - Providing reliable corrections for significant pile-up as the luminosity ramps up.
  - Provide a framework to include less pressing but needed corrections
    - Flavor corrections and model dependent correction to the parton level.

- Factors can then evolve independently on different time scales
  - Relative correction vs. η may be redone every year as needed.
  - Absolute correction vs. p_T could change as new techniques emerge.

- Scope can gradually expand to include sophisticated jet definitions
  - Corrections for “jet plus track” algorithm, or full particle flow.
    - May not change the Offset, Underlying Event or Parton level correction.

Factorization Essentials

- Factor out the hard problem and move it away from the easier problems
  - Allows simultaneous work on both the hard and easy problems.
  - Allows re-use of stable solutions without too much coupling.
    - Prevents ambiguities in solving the hard problem from affecting the solution to the easy problem.

- The hard problem:
  - Absolute jet correction as a function of P_T in a control region in η.
    - We want to know the error of this independent of the other corrections

- The easier problems (not necessarily that easy):
  - Jet correction as a function of η relative to the control region.
  - Determination of the pile-up energy in a jet cone.

- Control Region in η is usually a single "uniform" calorimeter: the barrel.
  - Barrel covers all P_T and has earliest functioning detectors.

Level 1: Offset Correction

(see workshop talk from Olga Kodolova)

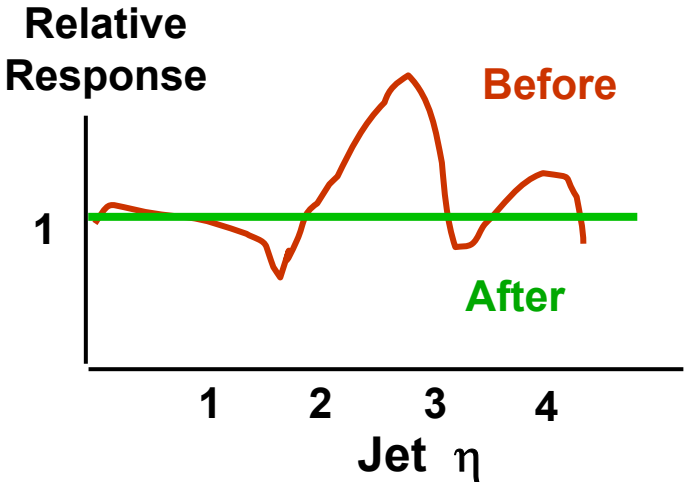
- Subtract offsets from pile-up and electronic noise.

- Pile-up (multiple pp interactions)
  - Includes luminosity dependent energy in jet (pile-up not underlying event)
  - Allows subsequent corrections to be independent of luminosity
    - Reason we think it is important to apply this correction first at CMS.
  - Correction determined from data or MC
    - Random cone method estimating energy in data or MC
    - Enegy density in phi slices at fixed η values.
    - Actual change in jets methods: pure MC or data/MC mixing
    - Average correction in beginning of run, event-by-event based on vertices later ?

- Electronic noise
  - Noise above the cell and tower thresholds
    - Although we want to keep this <u>small</u> it may be significant.
  - Correction determined from data
    - Noise in pedestal runs and special runs without zero suppression.

Level 2: Relative Correction versus η
(see workshop talk from Anwar Bhatti)

- Flattens the jet response versus η
  - Corrects energy of each jet back to the response in the barrel (control region).
  - Correction has small p_T dependence.
  - Applied to jets corrected for offsets (level 1)



- Gives a "barrel equivalent" jet response.
  - Allows difficult p_T dependent correction to be common for all jets.
- Correction well understood with many data driven methods.
  - Lots of calib data : p_T balance or MPF in dijets or γ / Z + jets.
- Important correction for uniform trigger response.
- Needs to be a smooth function of both η and p_T.
  - Binned or discontinuous corrections will produce spurious signals.

Options for Relative Correction versus η
(see workshop talk from Daniel Elvira)

- The relative correction could be further factorized
  - Jet Response vs. η = Calorimeter Correction (MPF) * Showering Correction
    - Calorimeter correction for eta variation of calorimeter response
    - Showering correction for calorimeter showering outside jet cone.

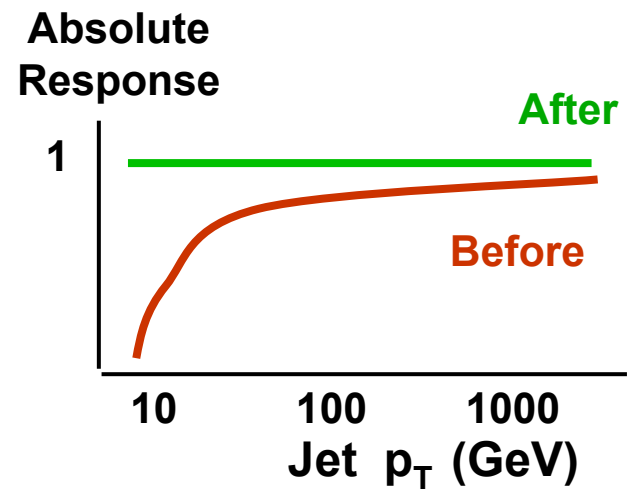
- D0 method
  - The relative correction was factorized
    - MPF was used to find the calorimeter correction versus η.
    - A <u>few percent</u> additional showering correction was applied in the forward regions.

- CDF method
  - The relative correction was not factorized any more
    - Dijet pt balance was used to find a jet correction versus η
    - This included the showering correction.

- The total relative correction should be the same in both cases.

Level 3: Absolute Correction vs. p_T
(see workshop talks from Cammin, Bhatti, Van Mulders)

- Flattens the absolute jet response of calorimeter vs. p_T
  - Corrects energy of jet back to the particle level.
  - For the barrel (control region): η independent.
  - Applied to Level 2 jets: luminosity independent.



- Last correction needed for particle level jets
  - Corrects to "observable" and predictable quantity:
    - The total p_T of colorless particles in jet algorithm (jet cone).
  - Hardest part of correction with largest systematic uncertainty.
  - Determined first with MC tuned on Test Beam, later tuned on in-situ data.
  - Data driven calibration or MC tuning samples:
    - Isolated charged tracks, γ / Z + jets, t mass & W mass.

- Must be smooth function of p_T, or we will get spurious signals.

Level 4: Jet Flavor Correction

- Corrects for jet "flavor" dependence
  - Applied to jets corrected at level 3.

- Level 3 correction was for QCD mixture of quarks and gluons
  - Other input objects will give different jet corrections.
  - For example b-jets (see workshop talk by Sasha Nikitenko).
  - Also, tau jets, gluons, light quarks, charm, etc.

- Correction is <u>optional</u>.
  - Many analyses cannot identify jet flavors, or want special corrections.
  - Correction desired for specialized analysis (top, $h \rightarrow bb$, $h \rightarrow \tau\,\tau$, etc.)
    - CMS needs a standard way to include this additional correction.
    - However, physics analysis groups must determine this correction.
  - The default value of the correction is 1, for QCD mixture.

Level 5: Underlying Event Correction
(see workshop talk by Olga Kodolova)

- Subtract underlying event energy
  - Energy in jet from spectator parton interactions
  - Luminosity independent energy
  - Applied to Level 3 corrected jets.

- Correction determined from measurements in data/MC
  - Similar to pile-up correction but with low lumi events/MC
  - Theory interest: Dedicated studies in QCD group have already begun.

- Correction is <u>optional</u> for many analyses
  - Underlying event is now a well established part of MC
  - Does not necessarily need to be corrected away
    - Unlike early Tevatron days.
  - Many parton level calculations do not have underlying event.
    - This correction is useful for comparing against those.
  - Need to know how big this is, regardless of whether we correct for it

Level 6: Parton Correction

- Correct jets to the parton level
  - Also corrects for changes in jet response between parton types
  - Applied to Level 4 corrected jets.
- Replace energy lost “outside” the algorithm (cone).
- Correction is optional
  - Many calculations (NLO and NNLO) simulate out-of-cone effects by clustering partons
  - Correction is model dependent and often undesired for QCD tests
- Correction is widely used and should be part of standard software.
  - Correction is desirable for getting parton energy scale for resonances.
    - Searches for new physics, top and higgs mass measurements, etc.
- This correction requires a parton type choice
  - Mixture of quarks and gluons from QCD jets should be supported
    - Recommend it as the "default" parton type for QCD jet analysis.
  - Single specific parton types could also be supported, with PAG assistance:
    - Gluon, light quark, charm, bottom, or even top quark at high p_T.

Uses of different levels of corrected Jets

- Level 1: Jets corrected for offsets from pile-up and electronic noise.
- Level 2: Jets corrected for η response & offsets
  - Trigger: flatten the η response at L1 and HLT w/o introducing other uncertainties into the trigger ?
- Level 3: Jets corrected to the particle level.
  - Most important level of correction for analysis. The level we must reach with priority.
- Level 4: (Optional) Flavor jets corrected to the particle level.
  - Specialized jets at particle level for top and higgs measurements.
- Level 5: (Optional) Jets corrected to particle level with underlying event removed.
  - Comparisons with perturbative QCD NLO calculations.
- Level 6: (Optional) Jets corrected to the parton level.
  - Model dependent searches for new physics, top and higgs mass measurements, etc.
- Additional Corrections:
  - As we learn, we will want to include other levels to improve jet & MET resolution
    - e.g., correcting vs. **EM fraction** improves resolution (shown by Esen & Landsberg, April 19)
  - Analysis dependent jet corrections (unsmearing, etc.) are beyond our scope.

Conclusions

- We have proposed a factorized multi-level jet correction.
  - Derived from prior HEP experience applied to the CMS environment.
  - We are at an early stage and more levels may need to be added.
- Approach facilitates completion and evolution corrections.
  - Allows simultaneous collaborative work on (semi) independent factors.
  - Allows some factors to be stable, while other factors evolve with study.
- We recommend that CMS adopt this factorized approach.
  - Software to apply corrections should be designed for multiple levels.
  - Initial values of factors could be found now from MC truth.
  - Correction can evolve to data-driven factors as methods are understood