Jet energy corrections and uncertainties: reducing their impact on physics measurements

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Most recent paper on Jet Energy Correction and Uncertainties at JINST 6 P11002 (2011)

Jet Energy Calibration

Jet energy corrections at CMS applied sequentially to correct for :

1- Pile Up energy deposition:

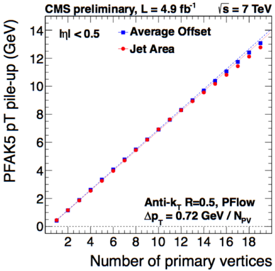
- Parameterized using both Fastjet area median approach and as a function of N_{PV}.
- Excellent linearity up to $N_{PV} = 20$.
- Little η dependance within tracker coverage.

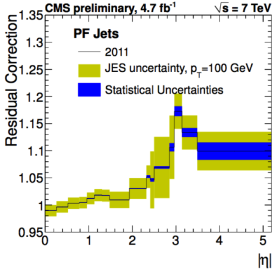
2- Dependance on η and absolute scale:

- Derived from the MC truth information.
- Closure checks within 0.5% at $p_{\mathrm{T}} > 30$ GeV.
- Flavor response modeled by MC within 1.5%.

3- Residual corrections on data only:

- Dependance on η derived from dijet events. Corrections within 5% for $|\eta| < 2.5$.
- Absolute scale from γ+jet and $Z \to \mu\mu$ events.

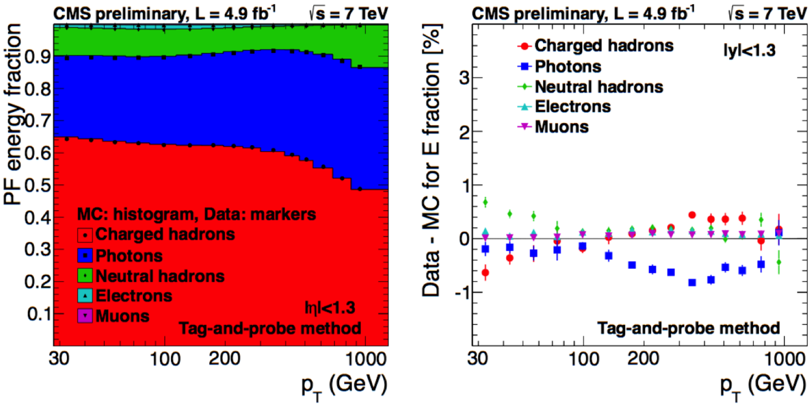




Jet Composition

MC-Data comparisons

Jet composition studies from dijet and $Z \to \mu\mu$ samples in the $|\eta| < 1.3$ region



Excellent agreement below 1% on jet composition between MC and data

Applying Jet Energy Uncertainties

Applying uncertainties

The measurement of any physical quantity at CMS includes the estimation of a systematic error propagated from the uncertainties on the jet energy calibration.

Sources of uncertainties

Uncertainties in the Jet energy corrections come from different sources:

- Physics modeling in MC (showering, underlying event, etc.)
- MC Modeling of detector properties (noise, etc.)
- Potential biases in the methodologies.

Total uncertainty on jet energy correction computed as the quadrature sum of uncertainty of each different source.

Jet Energy Uncertainty application at CMS

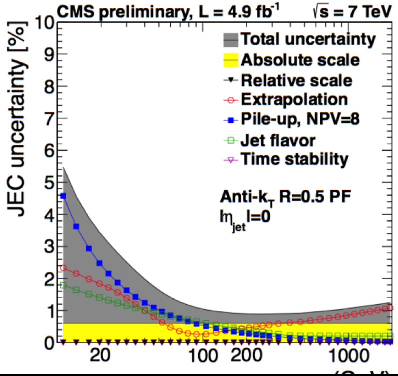
The most common practice consists of the evaluation of the change in the measured quantity when the jet energy is fluctuated up and down according to the total jet energy correction uncertainty.

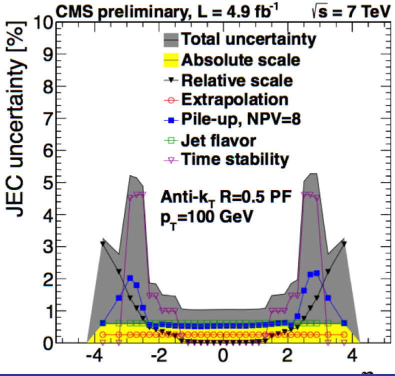
Jet Energy Uncertainties

Detailed accounting of uncertainties sources

16 sources of sub-uncertainties, each parameterized as a function of η and p_{T}

- Main uncertainty sources in $|\eta| < 1.3$ are pile up, jet flavor, and extrapolation.
- Main uncertainty sources in $2.5 < |\eta| < 3$ time dependence and out-of-time pile up.
- Total Uncertainty is the quadrature sum of all sources.
  - Below 1% for $500 < p_{\mathrm{T}} < 600$ GeV in $|\eta| < 1.3$

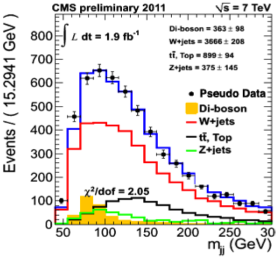




Examples from CMS analyses: Basic MC fits

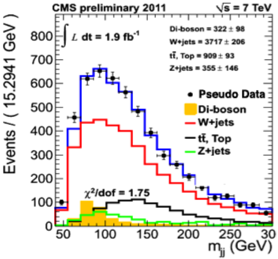
- Example fit of diboson cross section when MC has been varied up and down
  - Pseudo-data is a typical randomly-obtained set of events from MC.
  - Important channel for Higgs discovery from H$\rightarrow$WW$\rightarrow$ $l\nu jj$.

JES down by 1 σ



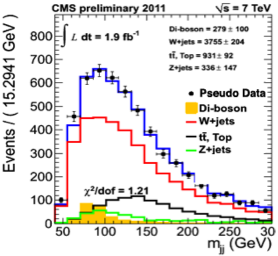
Diboson fit $= 363 \pm 98$

JES central



Diboson fit $= 322 \pm 98$

JES up by 1 σ



Diboson fit $= 279 \pm 100$

Systematic error by simply taking up and down JES variation $= \pm 43$ events.

About 13% of the signal size.

Examples from CMS analyses (2)

- Top mass measurement in the lepton + jets channel ▸ CMS PAS TOP 11-015
  - Ideogram method.
  - Simultaneous fit to jet energy scale to reduce the dependance.

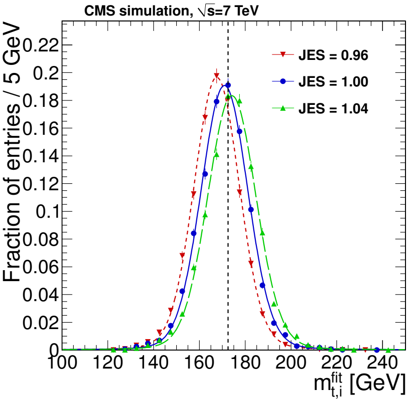


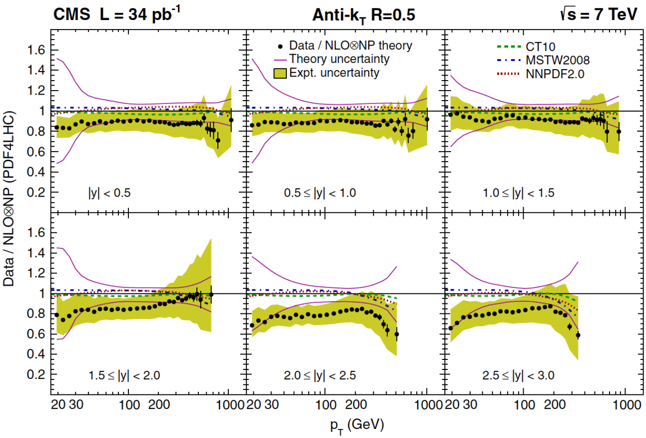
Table 1: List of systematic uncertainties

	δ_{m_t} (GeV)	δ_{JES}
Calibration	0.15	0.001
b-tagging	0.17	0.002
b-JES	0.66	0.000
p_T- and η-dependent JES	0.23	0.003
Jet energy resolution	0.21	0.003
Missing transverse energy	0.08	0.001
Factorization scale	0.76	0.007
ME-PS matching threshold	0.25	0.007
Non-$t\bar{t}$ background	0.09	0.001
Pile-up	0.38	0.005
PDF	0.05	0.001
Total	1.18	0.012

Even when doing a simultaneous fit to mass and JES, the systematic error due to JES contributes to $= \frac{\sqrt{1.18^2 - 0.69^2}}{1.18} = 23\%$ of total uncertainty.

Examples from CMS analyses (3)

- Inclusive jet cross section in *pp* collisions at $\sqrt{s} = 7\mathrm{TeV}$ PRL 107 132001, 2011
  - Measured jet differential cross section over theoretical prediction as a function of p_{T}.
  - Shaded band represents the total experimental systematic uncertainty.
  - Systematic errors dominated by jet energy uncertainties, followed by luminosity.
  - PDF uncertainties included in the theory bands.



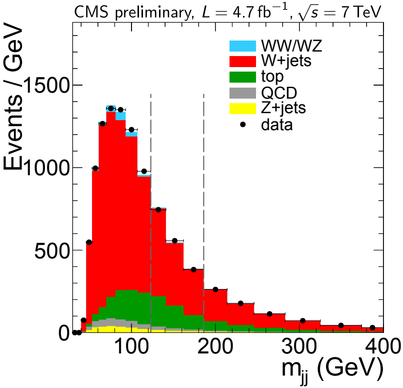
Reducing the effect of JEC Uncertainties: Better Methodologies

Many analyses already use smarter methodologies:

- top mass: in-situ jet energy scale estimation.
- jet energy scale parameter embedded into fitting algorithm.

Example: Study of W + 2 jets M_{jj} spectrum: CMS PAS EWK 11-017

- Difference in M_{jj} spectrum between MC and data taken from control region and applied to signal region.
- Need to consider jet flavor differences between those regions.
- Furthermore fit includes parameterization of jet energy scale.
- Total uncertainty due to residual jet energy scale is minimal.

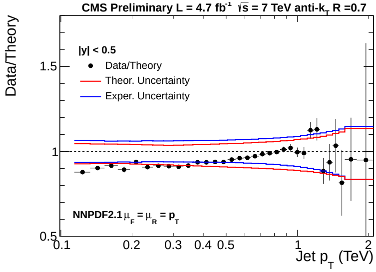


Reducing the effect of JEC Uncertainties: Data Vs MC comparisons

Some Analysis are based purely on data:

- Inclusive jet cross section measurement ▸ CMS PAS QCD 11-004
- Derived from data, virtually no contribution from MC.

Uncertainty contribution from JEC is almost irreducible



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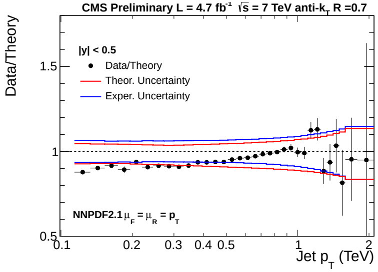
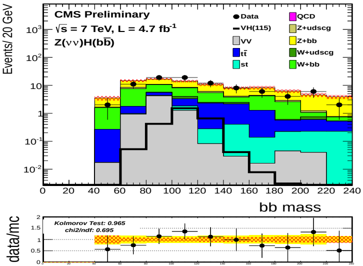


Others are based on Data-MC comparisons:

- Higgs Boson on VH production ▸ CMS PAS HIG 11-031
- Results based on comparisons between data and MC.
- Exact position of peaks in M_{jj} not so relevant.

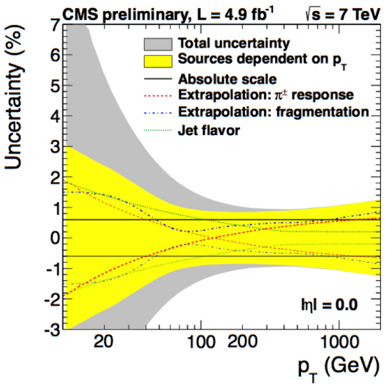


Uncertainty sources that are correlated between data and MC can be factored out.

Reducing the effect of JEC Uncertainties: Correlations

JEC uncertainties at CMS:

- Uncertainties from 16 different sources taken into account.
- The sources are mutually uncorrelated, and each represents a 1σ uncertainty on the jet energy.
- The sources can contain positive or negative variations according to the correlation.
- Notice the $\pi^{\pm}$ uncertainty crosses zero producing anti-correlation between different p_T's.



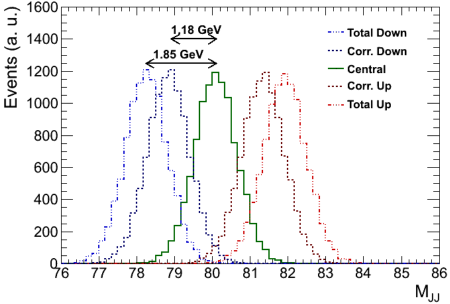
Application to physical quantities:

- For each source a systematic error on a physical quantity is obtained by $\pm 1\sigma$ variations on the JEC
- Total uncertainty on physical quantity obtained summing all systematic errors in quadrature.

Specific example

Using toy MC do a toy template analysis on M_{jj} distribution where :

- Background-subtracted distribution of M_{JJ} is obtained for a given signal
  - e.g :$m_H = 140$ GeV or other new physics parameter.
- Consider change in M_{JJ} distribution due to JEC uncertainties.
- To emphasize the difference consider a very narrow distribution; same results will apply to any peaked distribution.
- Standard Up and down approach shifts the peak 1.85 GeV.
- Using fully correlated uncertainties shift is 1.18 GeV.



Using fully correlated uncertainties is the proper way to evaluate the jet energy uncertainties effect on measured quantities

In this case the correlation reduces its effect on M_{JJ}

Conclusions

Jet energy calibrations at CMS

- Excellent understanding of jet energy calibrations.
- Total uncertainty below 1% for $500 < p_{\mathrm{T}} < 600$ GeV in $|\eta| < 1.3$.
- Main uncertainty sources are:
  - $|\eta| < 1.3$: pile up, jet flavor, extrapolation.
  - $2.5 < |\eta| < 3$: time dependence, out-of-time pile up.

Reducing the effect of jet energy uncertainties

- Many analyses already using smart techniques.
- Jet energy uncertainty sources now available to CMS users.
  - Improvements taking into account data and MC correlations of some sources.
  - Proper ways to include uncertainties effect using full correlations. More robust method and can reduce systematics on measured quantities.

Looking Ahead

- Out of time pile up and time dependance to be improved in 2012 data.
- Paper coming soon with the latest techniques.