ATLAS and CMS jet calibration and uncertainties: 8 TeV and beyond

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Introduction

- ATLAS and CMS place strong constraints on top-related observables
  - Combining results further improves these precision measurements
  - Requires knowledge of the inter-experimental uncertainty correlations
- The Jet Energy Scale/Correction (JES/JEC) uncertainties are often the dominant experimental systematics in top combinations
- A correlation procedure was previously defined for 7 TeV
- This procedure has now been updated for 8 TeV combinations
  - New today: ATL-PHYS-PUB-2015-049, CMS PAS JME-15-001
  - An incremental update, similar to the 7 TeV recommendation
- 8 TeV references for the JES calibration and uncertainties:
  - ATLAS Global Sequential Calibration note: ATLAS-CONF-2015-002
  - ATLAS di-jet and multi-jet note: ATLAS-CONF-2015-017
  - ATLAS combination and uncertainties note: ATLAS-CONF-2015-037
  - ATLAS Z/γ+jet note: ATLAS-CONF-2015-057
  - ATLAS pileup paper+note: arXiv:1510.03823, ATLAS-CONF-2013-083
  - CMS Run-I jet performance paper: JME-13-004 (in final approval)

The JES calibration

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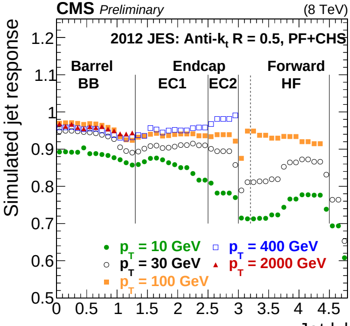

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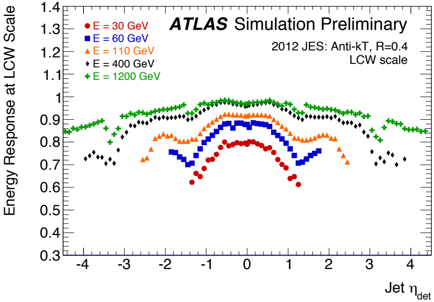

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- The JES calibration accounts for the detector response profile
  - Different detector features are visible
- Similar general trends seen in both ATLAS and CMS
  - In the central region, orange points are roughly the same p_{T}
  - In the forward region, black points are roughly the same p_{T}

The JES uncertainties

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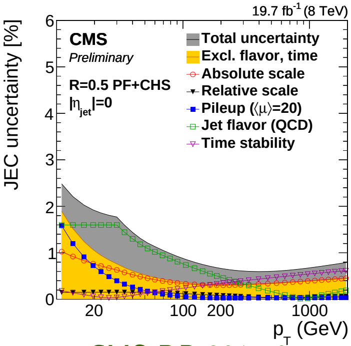

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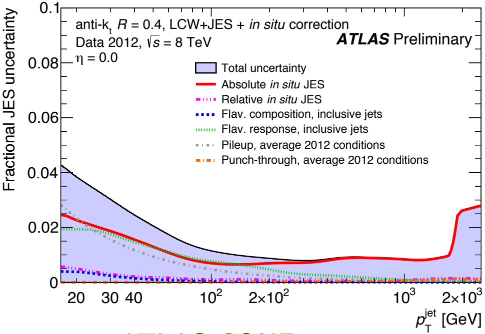

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- The main JES calibration is derived in MC and applied to data
- *In situ* measurements are necessary to quantify/fix differences
    - Residual calibrations and associated uncertainties derived *in situ*
    - Additional systematic sources added for other effects
- Note that the plots above have a different vertical scale

How to compare the JES between experiments

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- The JES uncertainty is built from many uncertainty sources
  - First step: merge components of similar types into groups
- Experiments have JES uncertainties to cover roughly the same effects
  - Absolute scale, relative scale, pileup, flavour, ...
  - Second step: identify corresponding groups of uncertainty components
- The methods used to derive the uncertainties may vary
  - Different MC generators for differences, different parametrizations, ...
  - Third step: determine the degree of similarity in the derivation method
- The following slides quickly cover the recommendation
  - The recommendation is divided into nine groups of components

Absolute and relative balance *in situ* terms

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Description	Components, CMS	Components, ATLAS	Corr. range
1a. Statistical *in situ* terms	AbsoluteStat, SinglePionHCAL, RelativeStat[FSR][EC2][HF]	[11] **Z**-jet balance `stat./meth.` terms (p_T), [13] γ-jet balance `stat./meth.` terms (p_T), [10] multi-jet balance `stat./meth.` terms (p_T), η-intercalibration statistical term (p_T,η)	0%
1b. Detector *in situ* terms	AbsoluteScale, SinglePionECAL, RelativeJER[EC1][EC2][HF], RelativePt[BB][EC1][EC2][HF]	**Z**-jet balance `det.` term, γ-jet balance `det.` term, [2] correlated **Z**/γ-jet balance `det.` terms (p_T)	0%
2. Absolute balance modeling	AbsoluteMPFBias	[7] **Z**-jet balance `model` + `mixed` terms (p_T), [4] γ-jet balance `model` + `mixed` terms (p_T), [2] correlated **Z**/γ-jet balance terms (p_T), [5] multi-jet balance `model` + `mixed` terms (p_T)	0-50%
3. Relative balance modeling	RelativeFSR	η-intercalibration modeling (p_T,η)	50-100%

- ATLAS and CMS measure the scale *in situ* with the same methods
  - Absolute scale: balance jets with a well-known reference object/system
  - Relative scale: balance forward probe jets with central reference jets
- Statistical and detector terms: uncorrelated between experiments
- Absolute balance modelling: correlation at the level of 0-50%
  - Similar sources, but many are not fully independent of the detector
- Relative balance modelling: correlation at the level of 50-100%
  - Similar techniques, similar MC generators, some analysis differences

Flavour terms

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Description	Components, CMS	Components, ATLAS	Corr. range
4. *g*-jet fragmentation	FlavorPureGluon	Flavor response (p_T,η)	100%
5. *b*-jet fragmentation	FlavorPureBottom	*b*-jet response (p_T)	50-100%
6. Other fragmentation types	FlavorPureQuark, FlavorPureCharm	Flavor composition (p_T,η)	0%

- ATLAS and CMS treatment of flavour uncertainties is quite different
- ATLAS: assume *in situ* calibrates to light quark scale (u/d/s/c)
  - Uncertainties for deviations from pure light quarks (bottom, gluon)
- CMS: label each jet as light quark (u/d/s), charm, bottom, or gluon
  - Different uncertainties for each jet flavour
- Gluon fragmentation uncertainties: 100% correlated
  - Both derived from PYTHIA vs HERWIG++ response differences
- Bottom fragmentation uncertainties: 50-100% correlated
  - Both derived from PYTHIA vs HERWIG++ response differences
  - Due to lack of stats, ATLAS flattens in η and CMS flattens in p_T
- Other fragmentation uncertainties: uncorrelated
  - Procedures are not directly comparable, very different approaches

Flavour terms continued

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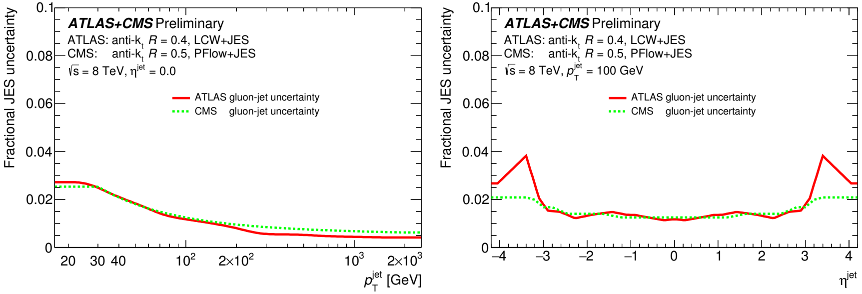

- ATLAS and CMS gluon modelling is strikingly similar at 8 TeV
  - ATLAS uses a Global Sequential Calibration (GSC), exploits tracking
  - CMS uses particle flow, which naturally includes tracking
  - Level of agreement is still surprising
- This is additional motivation for the 100% correlation statement
  - Same shapes are observed within primary region of interest
  - Increases our confidence that the same effects are being covered

Other terms

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Description	Components, CMS	Components, ATLAS	Corr. range
7. Pileup	PileupDataMC, PileupPt[Ref][BB][EC1][EC2][HF]	N_{PV} offset (p_{T},η,N_{PV}), $\langle\mu\rangle$ offset (p_{T},η,$\langle\mu\rangle$), p_{T} term (p_{T},η,N_{PV},$\langle\mu\rangle$), ρ topology (p_{T},η)	0%
8. High-p_{T}	Fragmentation	High-p_{T} (p_{T})	0%
9. Single-experiment terms	TimeEta, TimePt	Fast simulation closure (p_{T},η), punch-through (p_{T},η,N_{segments})	0%

- ATLAS and CMS now use similar jet-areas pileup suppression
  - The method for evaluation uncertainties is completely different
  - CMS averages over N_{PV} and $\langle\mu\rangle$, ATLAS parametrizes in N_{PV} and $\langle\mu\rangle$
- Pileup uncertainties are uncorrelated for these reasons and more
- High-p_{T} uncertainties are uncorrelated
  - Different methodologies and test beam energies are used
  - Experiments have different detector responses
- Single-experiment terms are all uncorrelated
  - There is no matching component to correlate across experiments

Overall combination procedure

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Description	Components, CMS	Components, ATLAS	Corr. range
1a. Statistical *in situ* terms	AbsoluteStat, SinglePionHCAL, RelativeStat[FSR][EC2][HF]	[11] **Z**-jet balance `stat./meth.` terms (p_T), [13] γ-jet balance `stat./meth.` terms (p_T), [10] multi-jet balance `stat./meth.` terms (p_T), η-intercalibration statistical term (p_T,η)	0%
1b. Detector *in situ* terms	AbsoluteScale, SinglePionECAL, RelativeJER[EC1][EC2][HF], RelativePt[BB][EC1][EC2][HF]	**Z**-jet balance `det.` term, γ-jet balance `det.` term, [2] correlated **Z**/γ-jet balance `det.` terms (p_T)	0%
2. Absolute balance modeling	AbsoluteMPFBias	[7] **Z**-jet balance `model` + `mixed` terms (p_T), [4] γ-jet balance `model` + `mixed` terms (p_T), [2] correlated **Z**/γ-jet balance terms (p_T), [5] multi-jet balance `model` + `mixed` terms (p_T)	0-50%
3. Relative balance modeling	RelativeFSR	η-intercalibration modeling (p_T,η)	50-100%
4. g-jet fragmentation	FlavorPureGluon	Flavor response (p_T,η)	100%
5. b-jet fragmentation	FlavorPureBottom	b-jet response (p_T)	50-100%
6. Other fragmentation types	FlavorPureQuark, FlavorPureCharm	Flavor composition (p_T,η)	0%
7. Pileup	PileupDataMC, PileupPt[Ref][BB][EC1][EC2][HF]	N_{PV} offset (p_T,η,N_{PV}), $\langle\mu\rangle$ offset (p_T,η,$\langle\mu\rangle$), p_T term (p_T,η,N_{PV},$\langle\mu\rangle$), ρ topology (p_T,η)	0%
8. High-p_T	Fragmentation	High-p_T (p_T)	0%
9. Single-experiment terms	TimeEta, TimePt	Fast simulation closure (p_T,η), punch-through (p_T,η,$N_{segments}$)	0%

- There are nine uncertainty groups to correlate between experiments
  - Uncertainties should be merged within each experiment for each group
  - The nine resulting per-experiment components should be combined (pairwise across experiments) following the specified correlation range
  - These nine terms *should not be merged* before the combination

Limitations of the procedure

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- The procedure described is useful, but not perfect
- Combinations must pay attention to the following limitations
  1. The correlation ranges are motivated, but the endpoints are arbitrary
     - If large differences are observed near endpoints when scanning over the range, extend the endpoint and perform more detailed studies
  2. Merging the components within a given group throws away shape info
     - Procedure is primarily aimed at single-observable results (top mass)
     - Limited uses when applied to multi-observable results (differential xsec)
- The procedure is expected to work well for most top combinations

Potential for future gains

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- Combinations are trivial if ATLAS and CMS do the same thing...
  - That is not the intent of the following suggestions
  - Combination potential must always be balanced by the need to maximize the single-experimental potential

1. Flavour uncertainties are large, work toward more similar procedures
   - The same parametrization should be used when stats are insufficient
2. *b*-jet fragmentation: investigate the use of *in situ* studies if possible
3. Work toward harmonized pileup uncertainty procedures
4. Very high-p_{T} uncertainty methods can be made more similar
5. The method used for combining absolute *in situ* terms can be unified

Summary of 8 TeV effort

- Updated procedure for ATLAS/CMS JES uncertainty combinations
  - The procedure is valid for single-observable measurements
  - Multi-observable measurements will encounter limitations
- Nine groups of components to combine have been identified
- A correlation range has been assigned to each component group
  - If large differences are observed near correlation range endpoints, expand the endpoint and study it in more detail
- A table mapping the full set of individual experimental uncertainty components to each group has been provided
- More details are available in the note

Looking forward to Run-II: 2015 (and beyond)

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- Methods used to derive 8 TeV uncertainties were finalized recently
  - They are still mostly up to date with 13 TeV techniques
- 2015 is a busy year with tight deadlines and $< 4\,\mathrm{fb}^{-1}$ of useable data
  - Some new techniques may appear, but it won't be the focus
  - The main effort will go toward reproducing what was done at 8 TeV
- The 8 TeV combination recommendations are a good start
  - Further confirmation will need to wait until the 2015 JES is finalized

- The coming years should provide much more data and new ideas
  - Possible improvements have already been presented
  - Good starting point: produce more *b*-jet MC to resolve the unnecessary parametrization difference between ATLAS and CMS
- Lots of data is on the way - time to get ready for the next stage!

Backup Material

In situ JES combination

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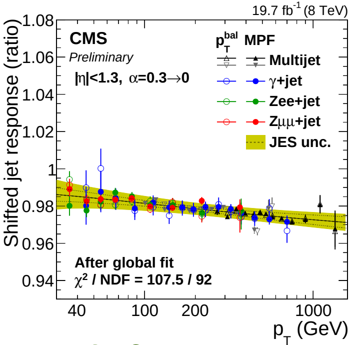

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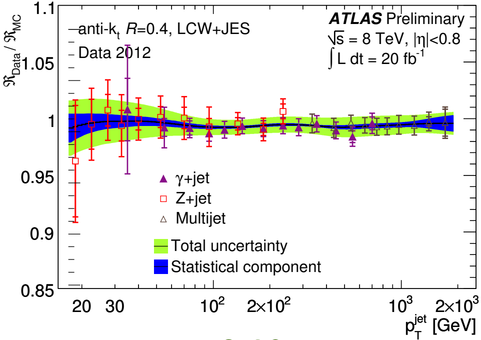

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