

ATLAS jet reconstruction

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on behalf of the ATLAS collaboration



Top LHC WG meeting, 20th May 2015, CERN

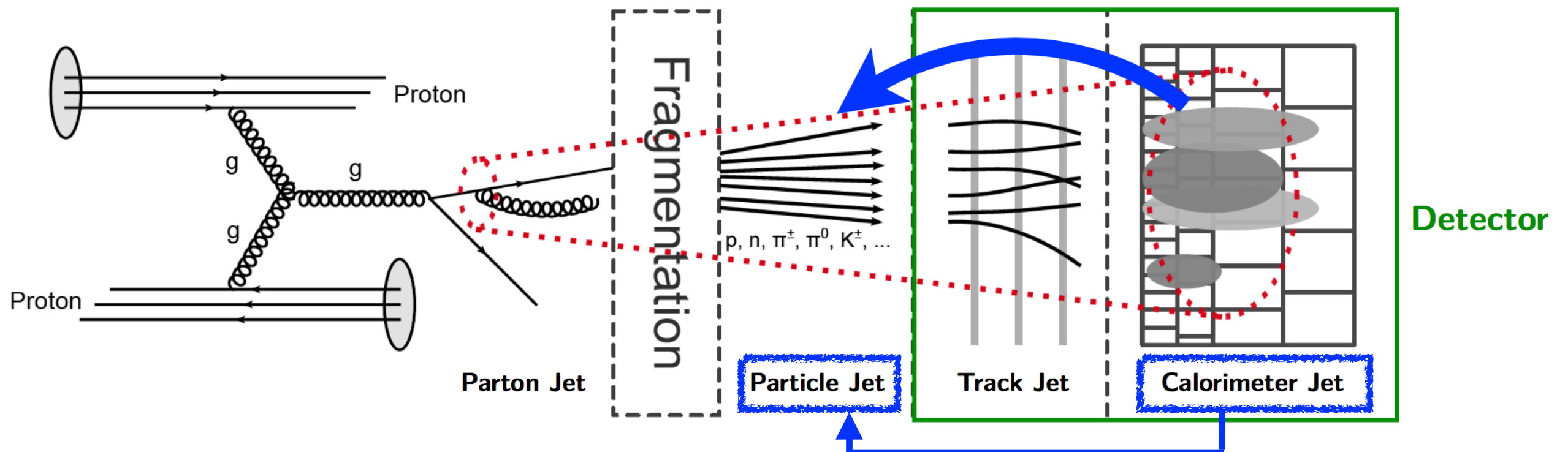
Outlook

- Original title of the presentation
 - *“ATLAS jet reconstruction plans for Run-II”*
 - ➔ Our plans for Run-II is to **calibrate** jets and evaluate the JES uncertainties using the **same methods** we used during **Run-I**

Therefore..

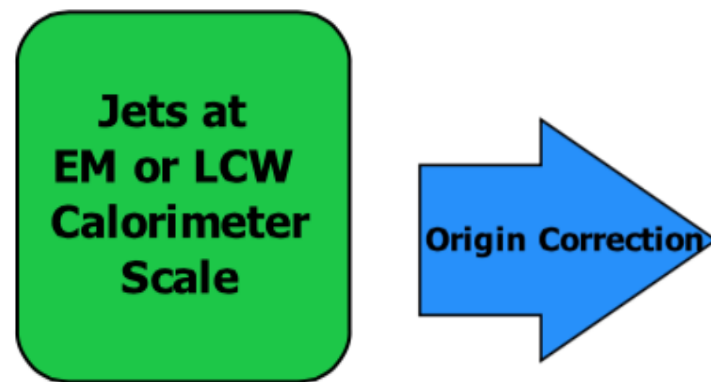
- I'll give an overview of the Run-I techniques emphasising on recently published results
 - ♦ Focus on the systematic uncertainties
- ATLAS plans to have a complete published documentation of Run-I jet performance soon
 - ♦ A few remaining final Run-I updates are close to finalisation

Jet reconstruction in ATLAS



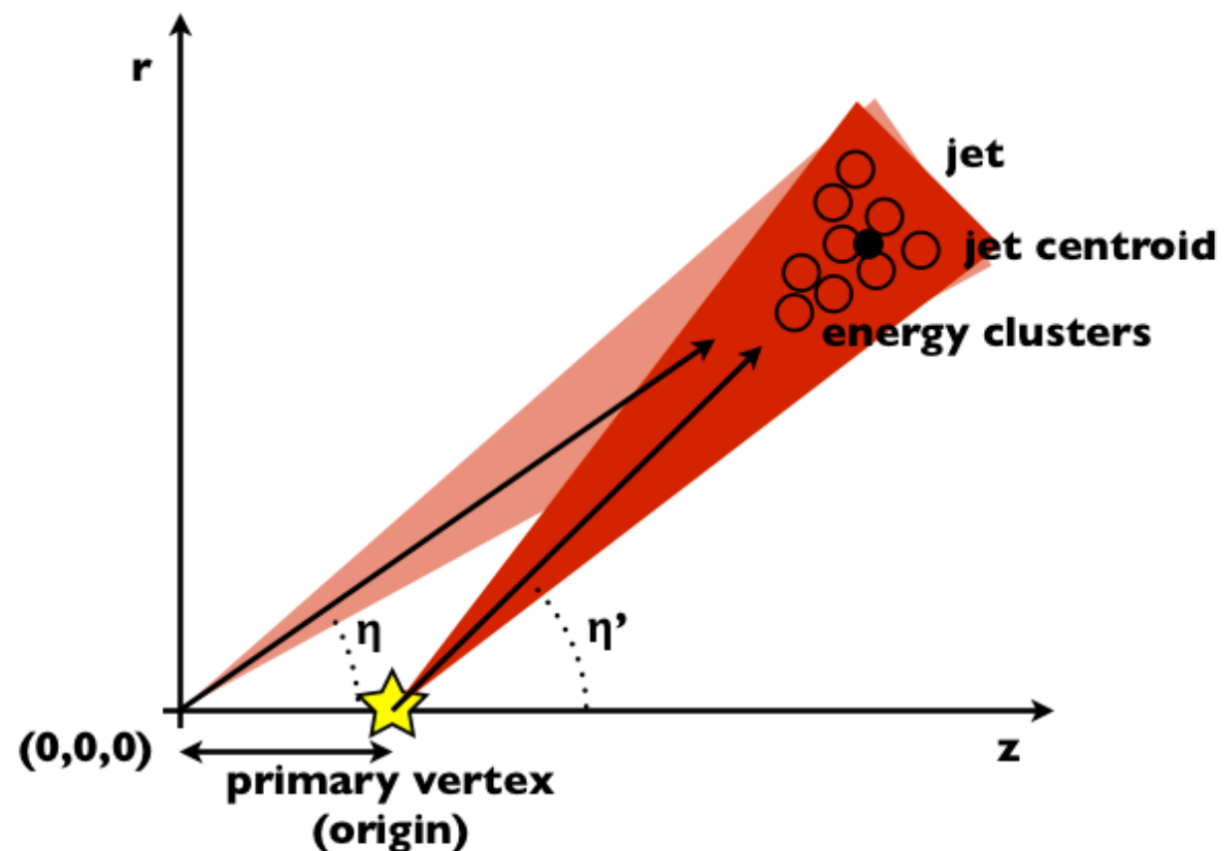
- Raw **calorimeter signals** need to be calibrated to the jet calibration reference scale: **truth jet (particle jet)**
- Calo cell signals are grouped into 3D topological cluster objects: **topoclusters**
- Jets created from topoclusters at one of two energy scales:
 - ♦ **EM:** Electromagnetic detector scale
 - ♦ **LCW:** Local cluster weighting scale
 - ✦ Deposits classified as being either electromagnetic or hadronic using shower shape variables
- **Anti- k_T** algorithm, to create jets from topoclusters several cone sizes
 - ♦ 0.4 is used for the resolved top analyses

Jet calibration chain

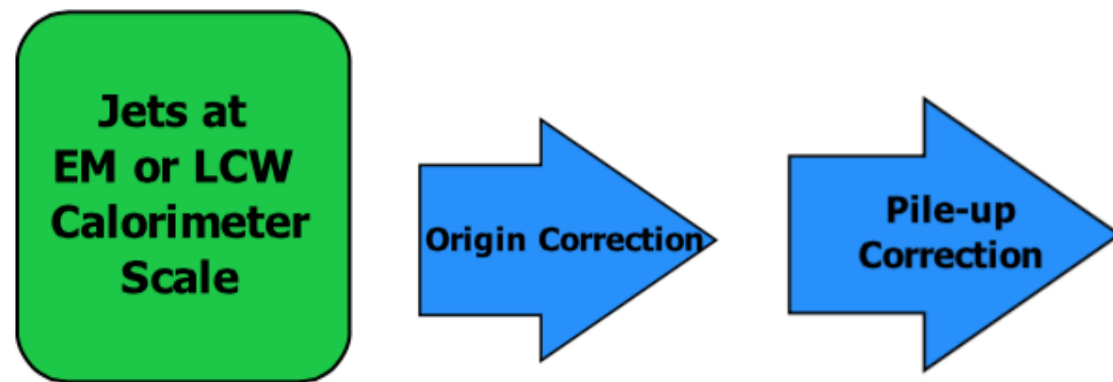


- Start from input EM or LCW jets

- **Origin correction:** to account for the hard scattering primary vertex. Changes the jet direction

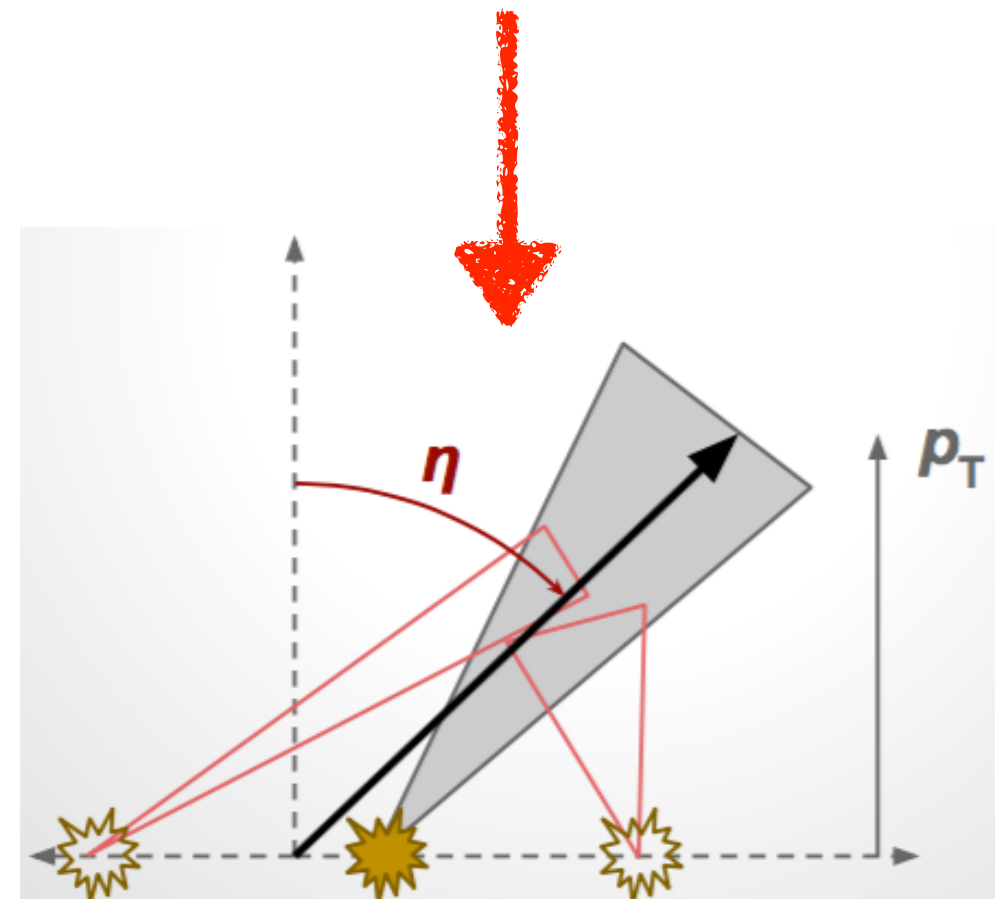
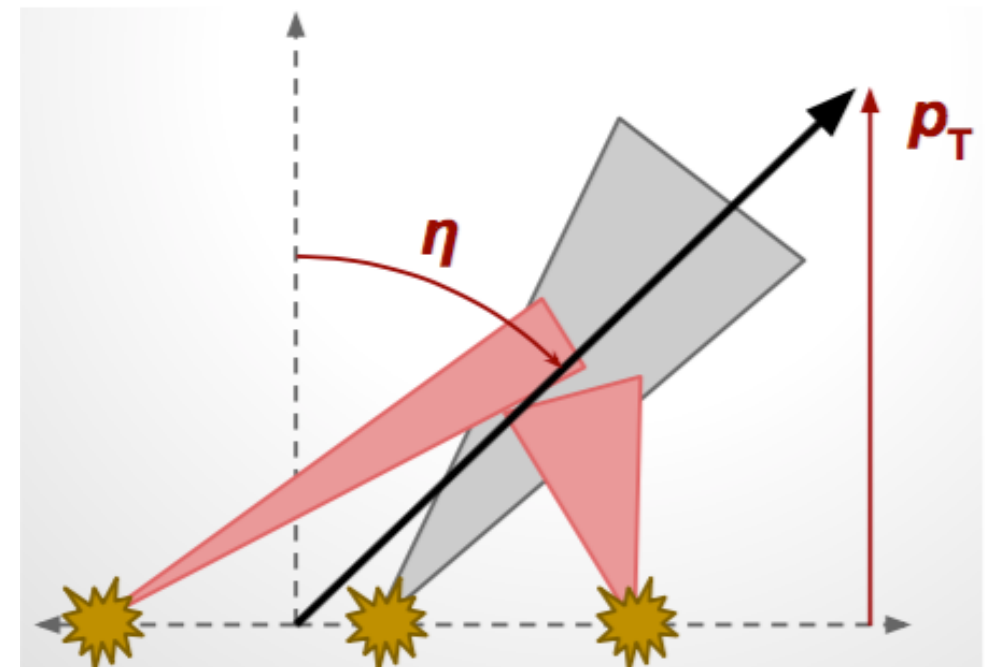


Jet calibration chain

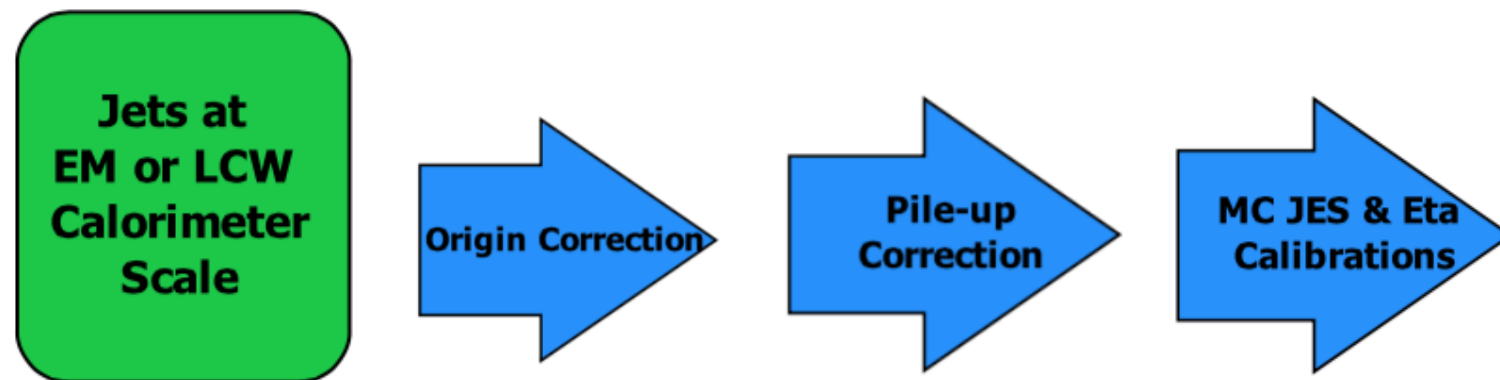


- Start from input EM or LCW jets
 - **Origin correction:** to account for the hard scattering primary vertex. Changes the jet direction
 - **Jet area and residual pile-up corrections** to decrease pile-up contamination

illustration from D. DeMarco

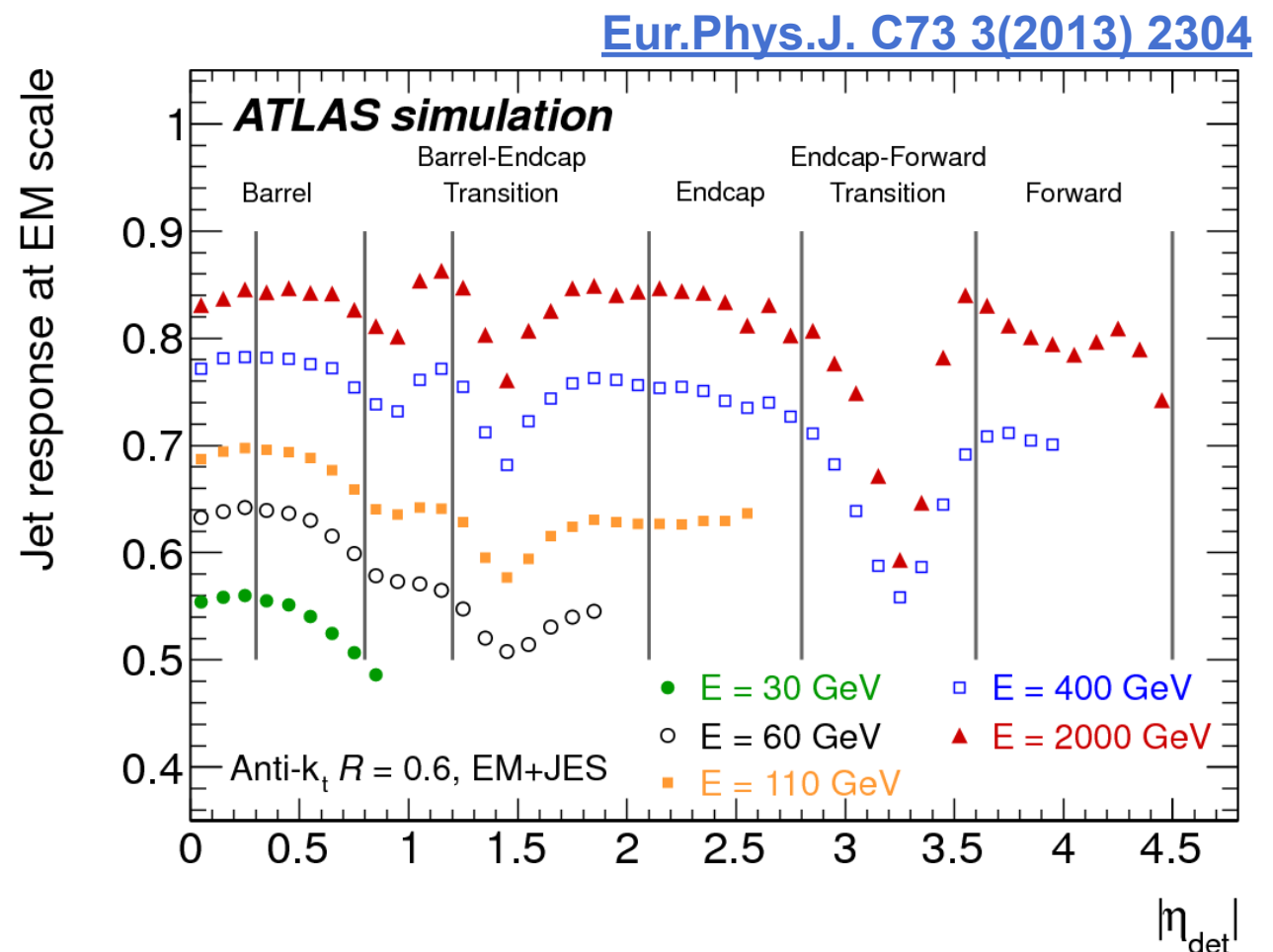


Jet calibration chain

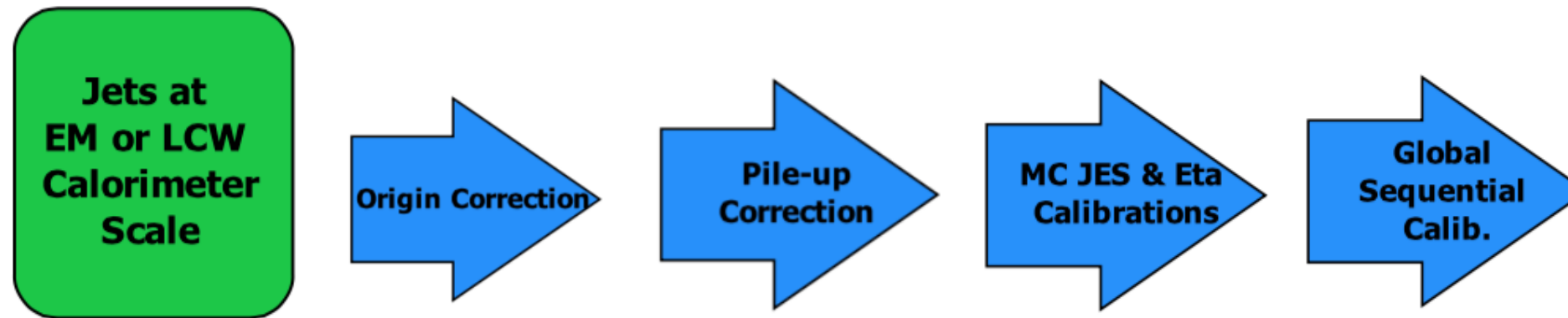


- Start from input EM or LCW jets

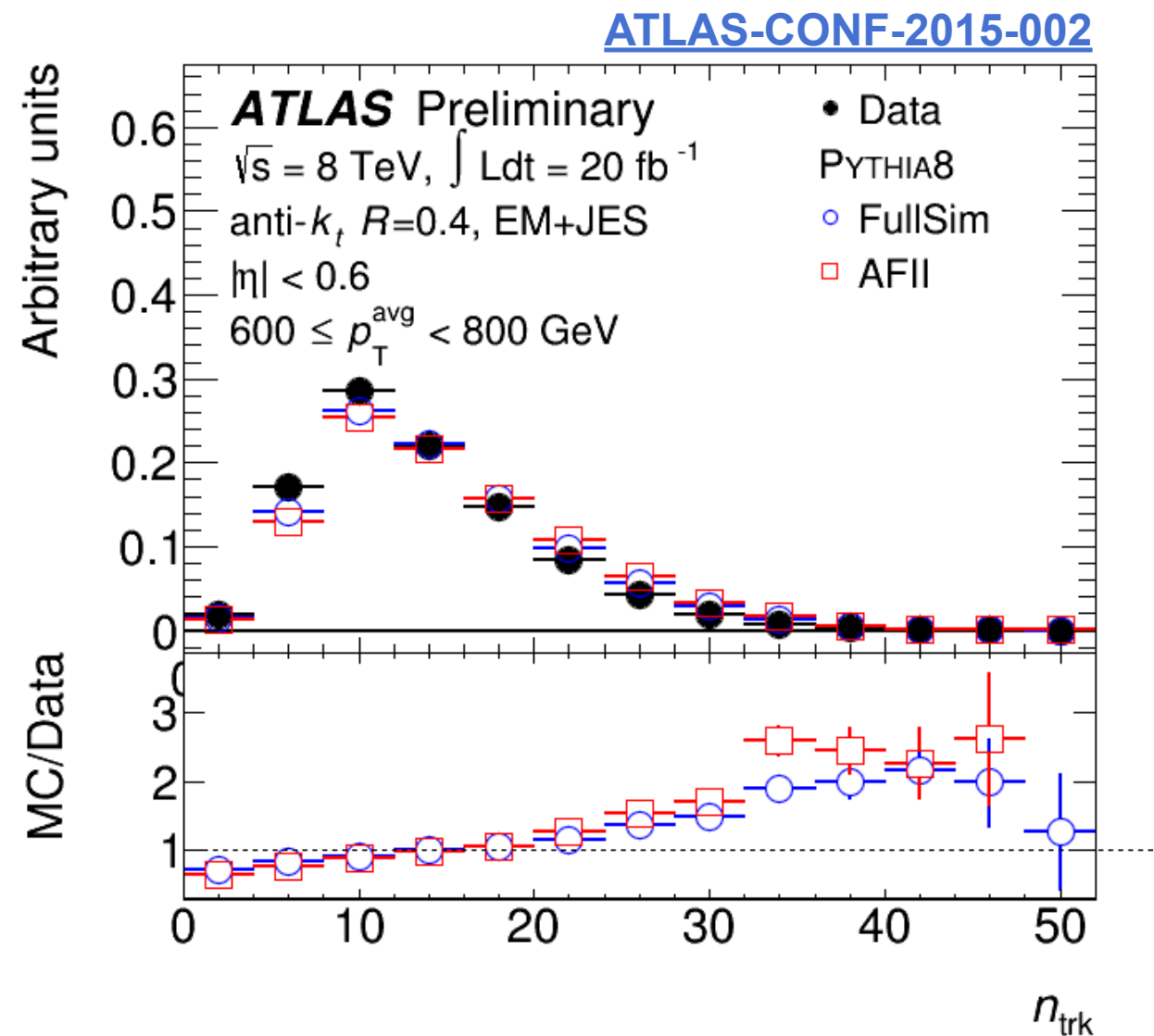
- **Origin correction:** to account for the hard scattering primary vertex. Changes the jet direction
- **Jet area and residual pile-up corrections** to decrease pile-up contamination
- **MC JES:** Calibrates the jet energy and pseudo rapidity to the reference scale



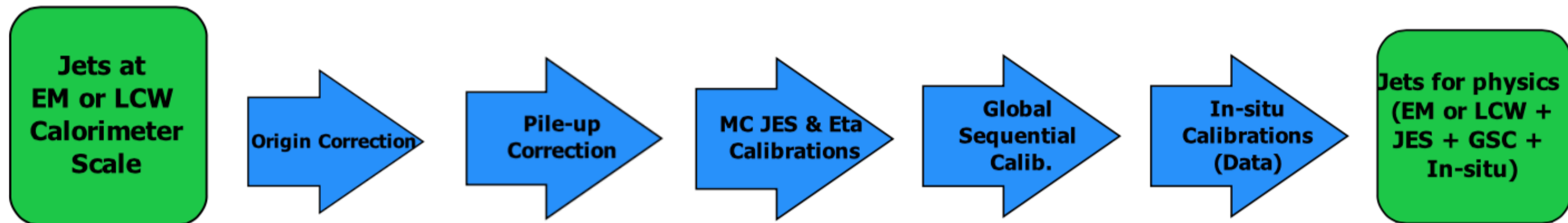
Jet calibration chain



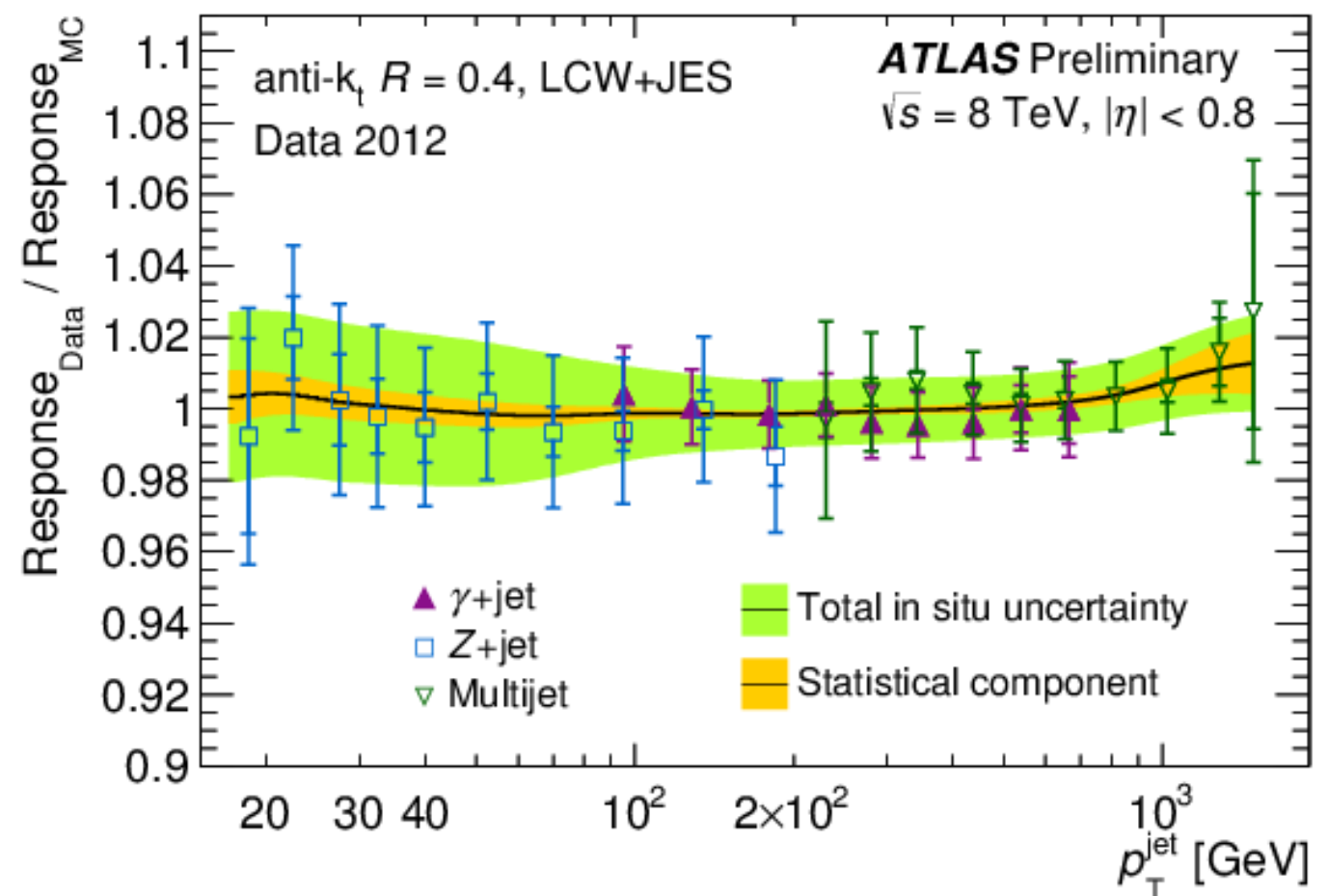
- **Global Sequential Calibration (GSC)** corrects jet energy dependence with respect to global jet observables. Improves energy resolution and and flavour dependence



Jet calibration chain



- **Global Sequential Calibration (GSC)** corrects jet energy dependence with respect to global jet observables. Improves energy resolution and and flavour dependence
- **In-situ calibration** applied to data. Measured in Data and MC using physics events having an well calibrated object as a reference



Correcting pile-up

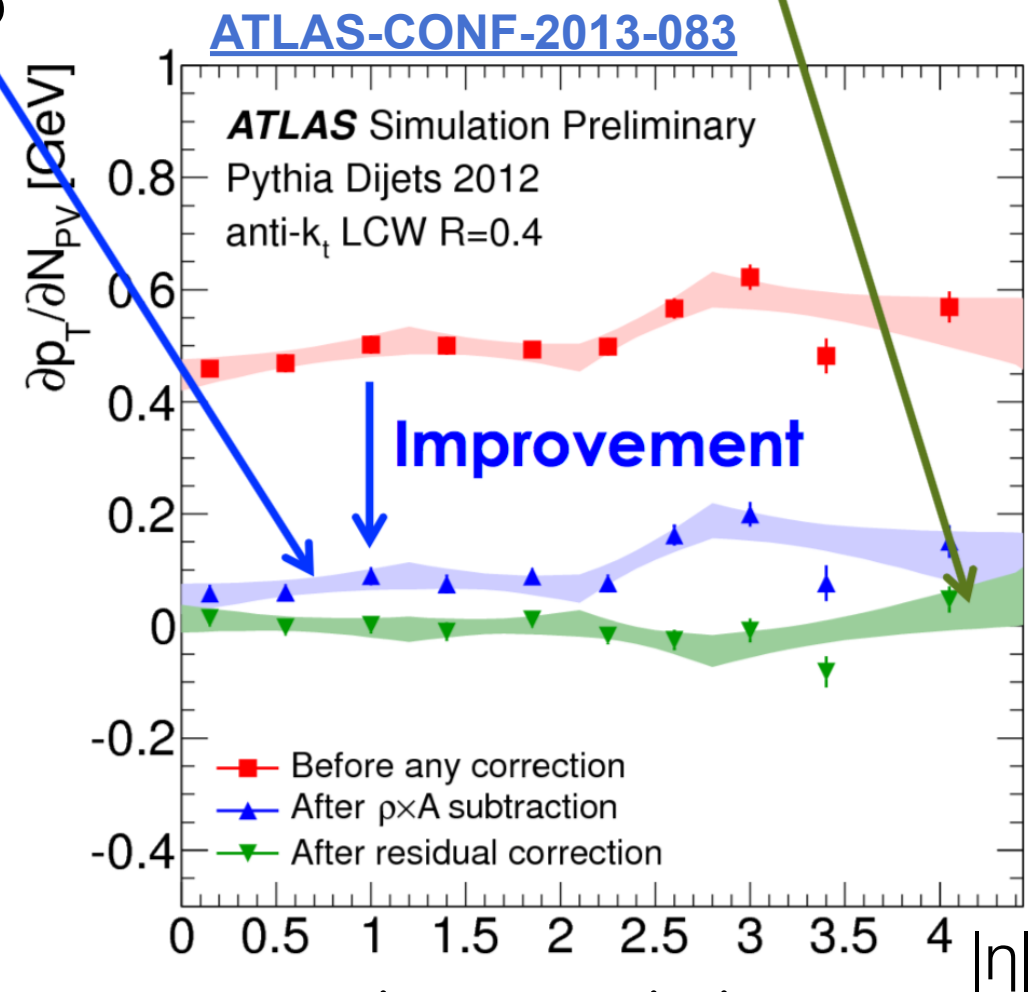
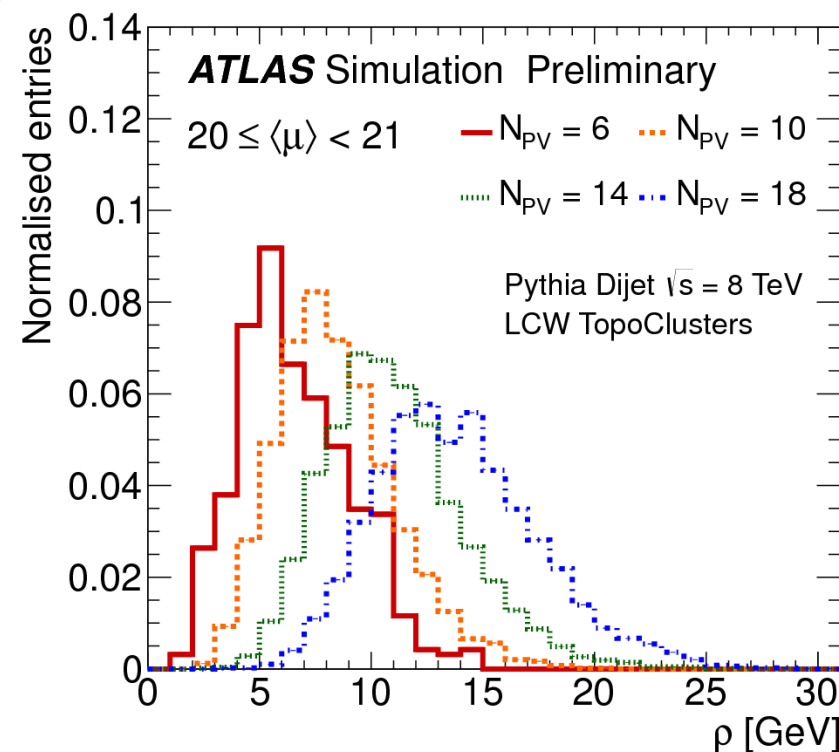
Jet area correction

$$p_T^{\text{corr}} = p_T - \rho A_T -$$

Residual correction (MC-based)

$$\alpha(N_{\text{PV}} - 1) - \beta\langle\mu\rangle$$

- **Median p_T density, ρ :** Event-by-event pile-up activity



- **Jet Area, A_T :** Jet-by-jet pile-up sensitivity

Residual correction

- Takes into account topology/threshold effects, and out-of-time pileup effects

- 4 systematic uncertainties

- p_T dependence of residual correction: in MC
- Uncertainty on the two coefficients α, β : estimated in data
- ρ modelling: Evaluated in data, in different topologies

Global Sequential Corrections (GSC)

- Jet calibration correct jets to particle level reference on **average**
- Need to **reduce** fluctuation **effects**
 - ✦ Use jet-by-jet information to correct the response of each jet individually: **GSC**

GSC variable sequence

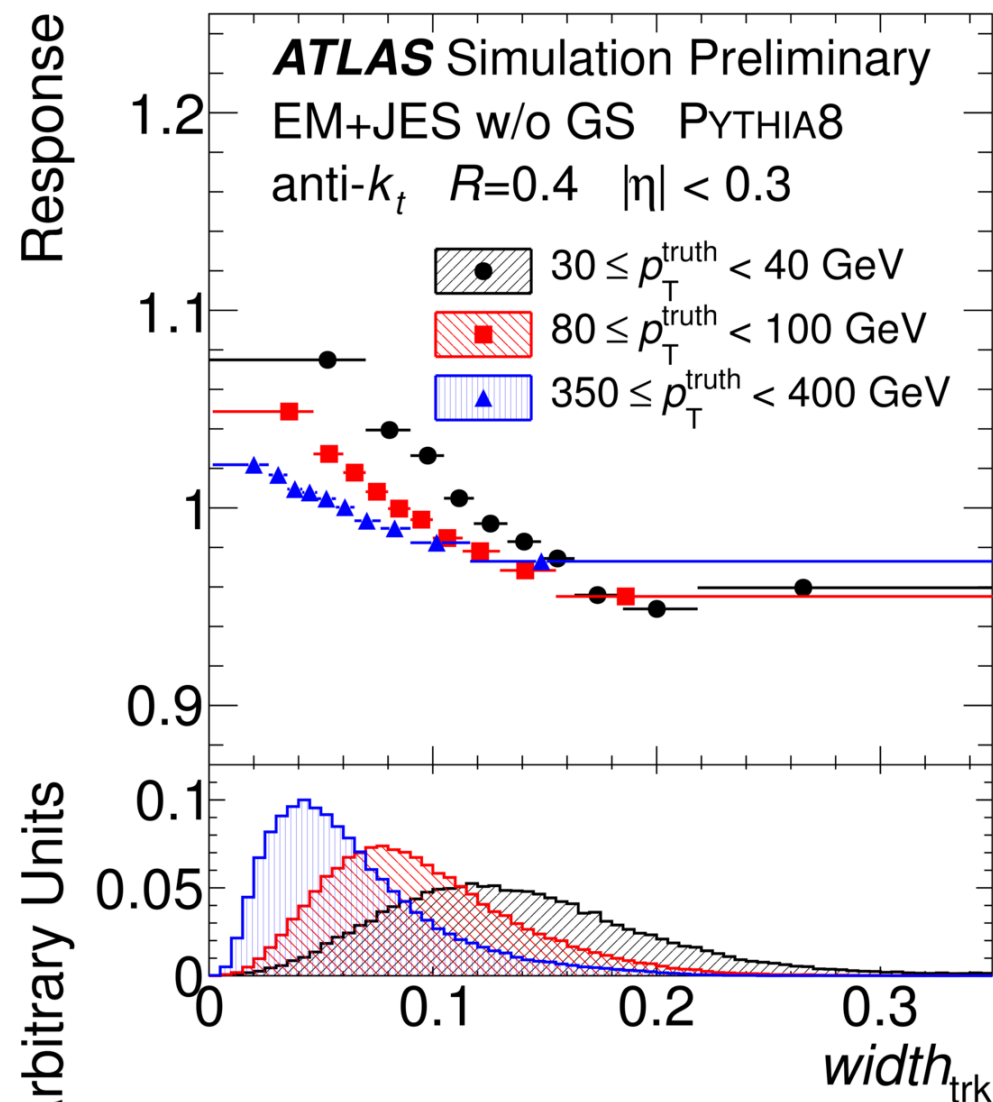
- **Global:** using info from whole detector: calo, tracker and muon spectrometer
 - **Sequential:** 5 **corrections** derived/applied sequentially
 - Decreased dependence on showering and fragmentation, improves JER and systematics (in particular the flavour related ones)
- Longitudinal structure of the energy depositions within the calorimeters
 - Track information associated to the jet
 - Information related to the activity in the muon chamber behind a jet

Global Sequential Corrections (GSC)

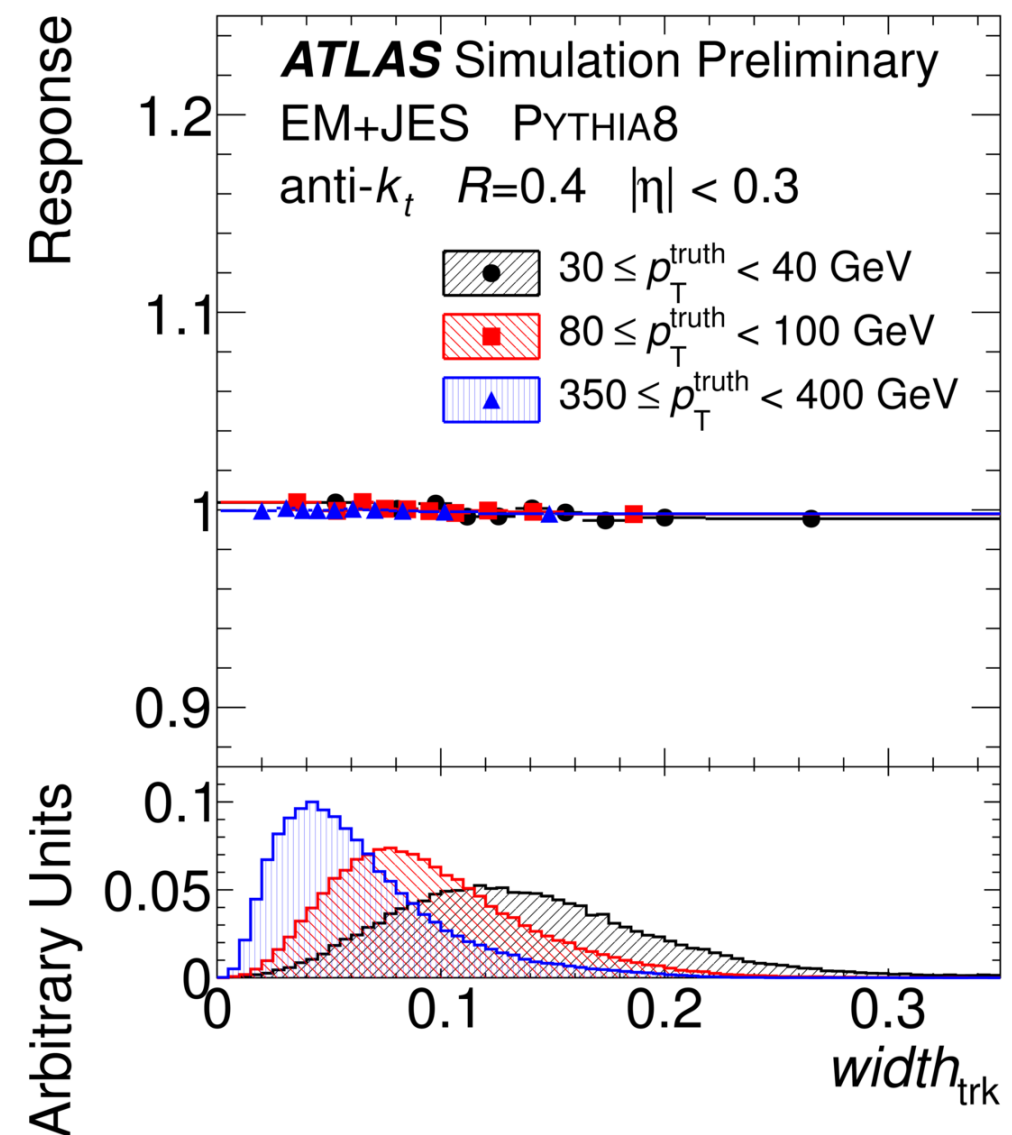
ATLAS-CONF-2015-002

- Derived using MC, parametrised in p_T and η
- GSC corrects response significantly

Before GSC



After GSC



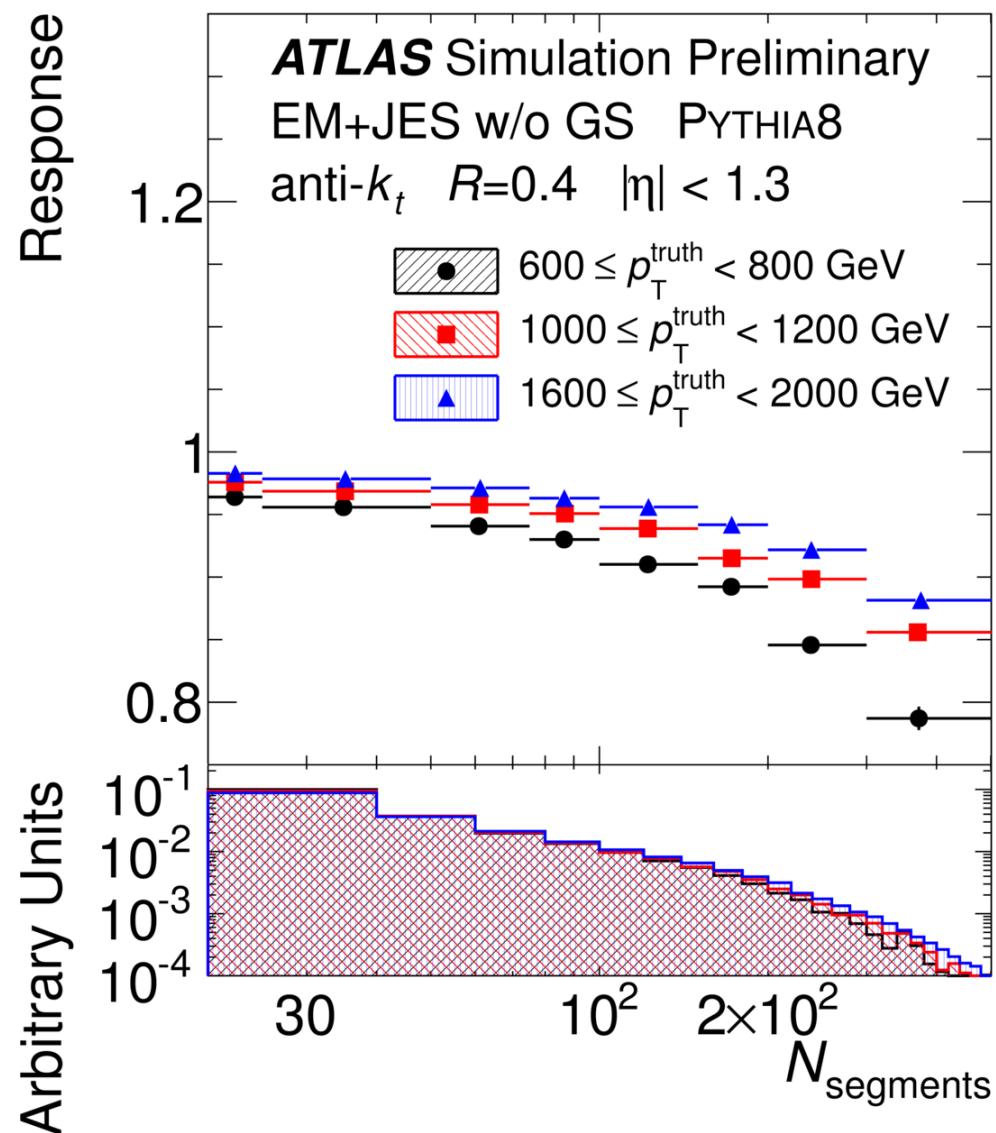
$$width_{\text{trk}} = \frac{\sum_i p_T^i \Delta R(i, \text{jet})}{\sum_i p_T^i}, \quad \text{average distance between tracks associated to jets and jet axis}$$

Global Sequential Corrections (GSC)

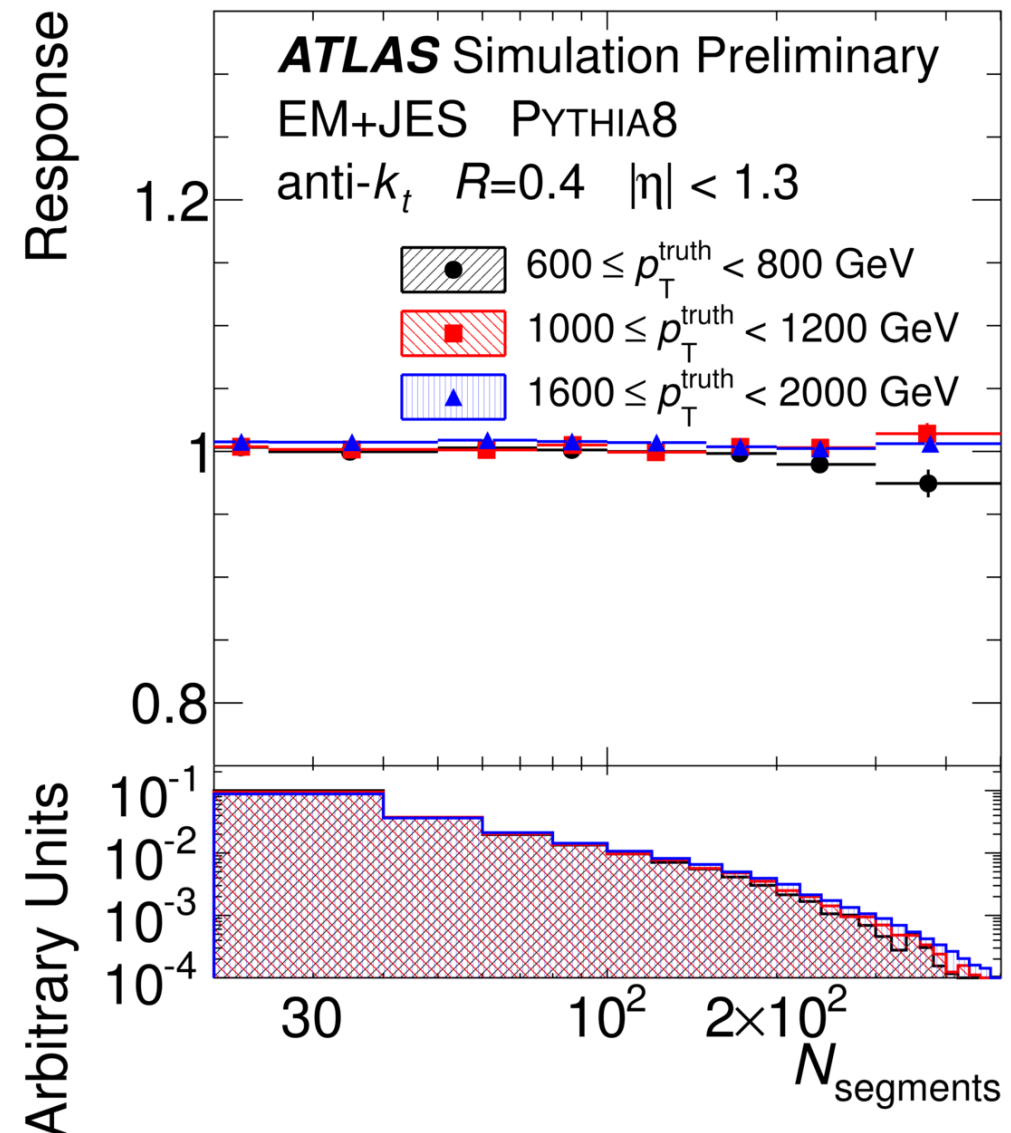
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Before GSC



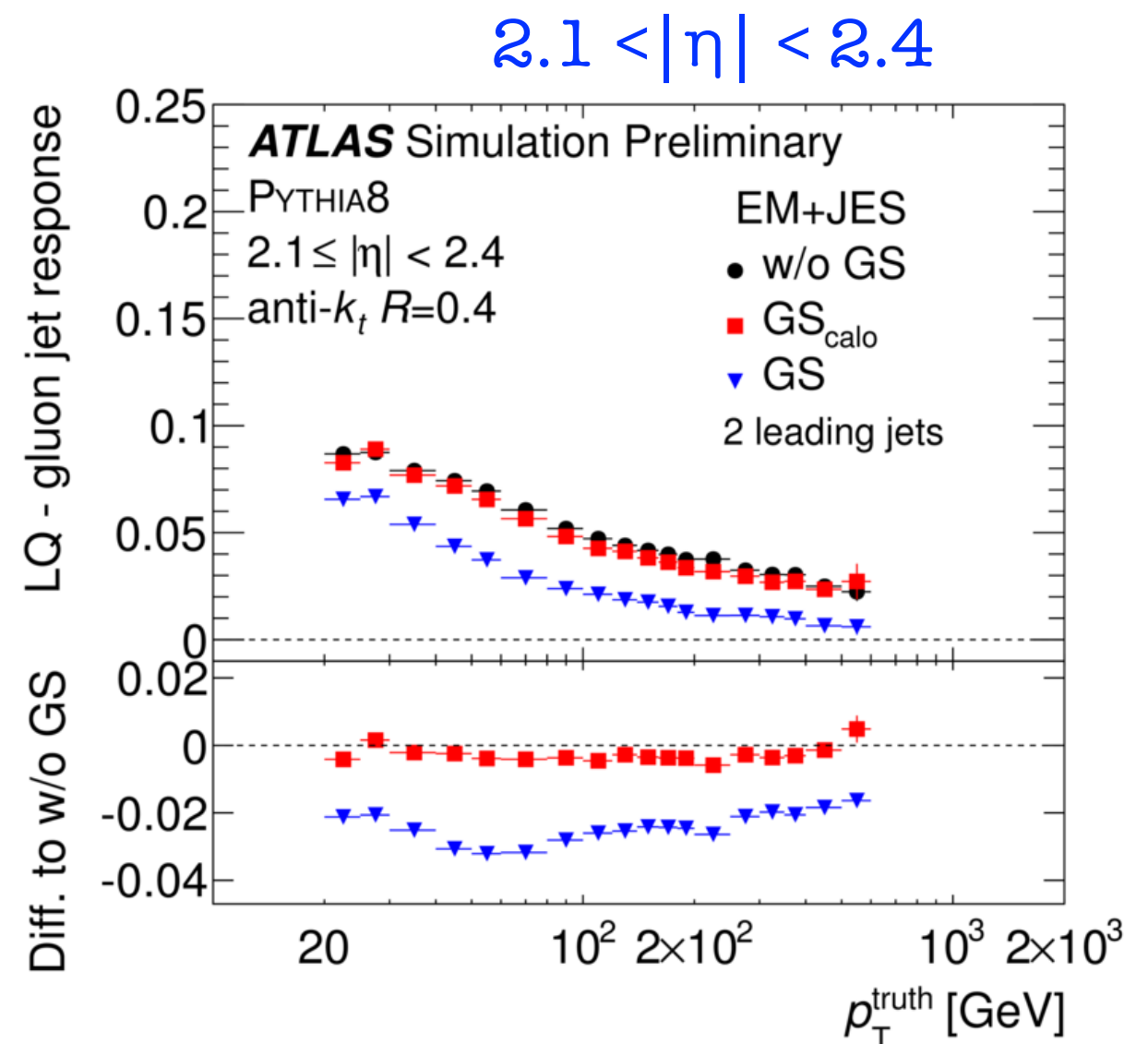
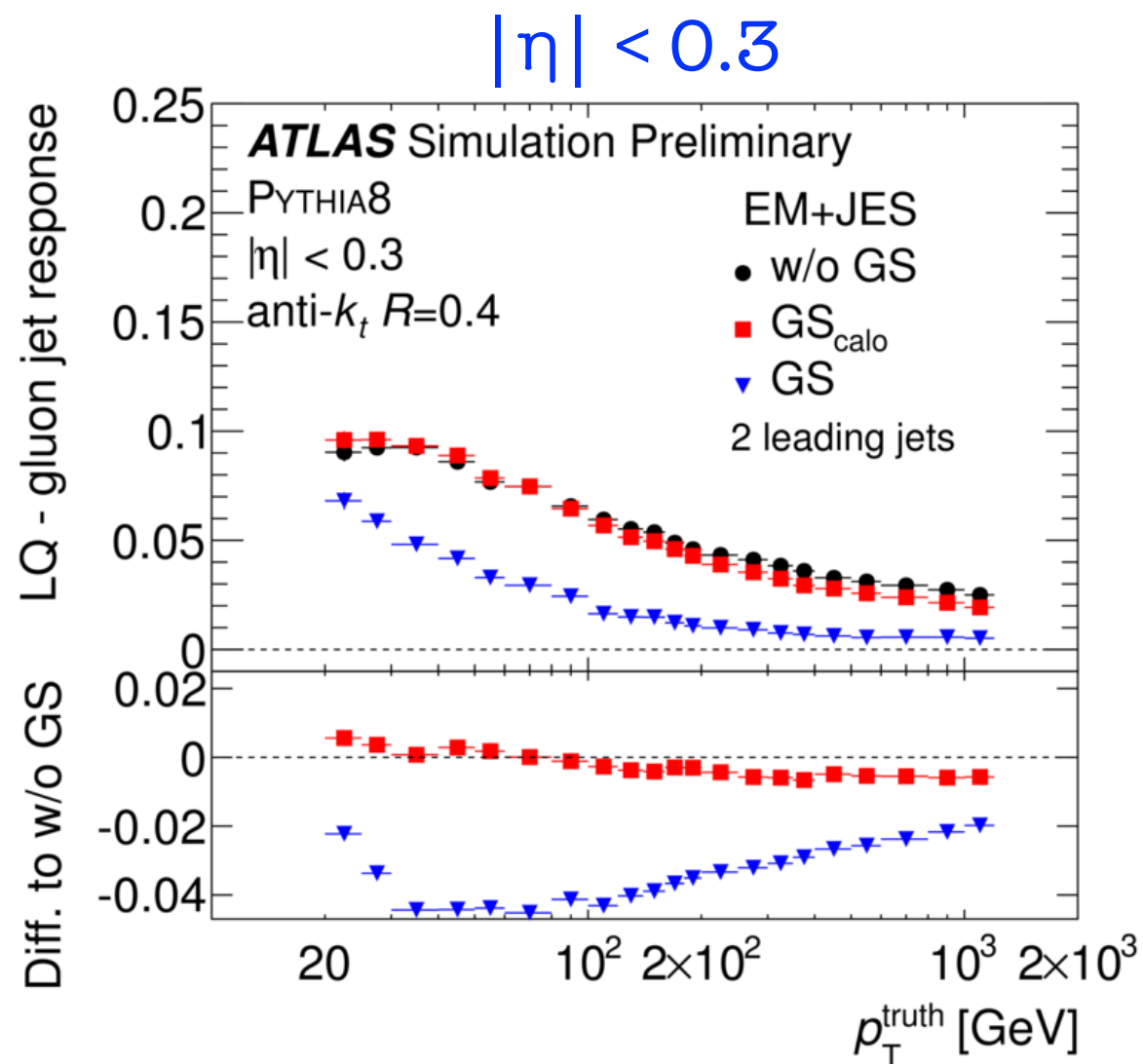
After GSC



Global Sequential Corrections (GSC)

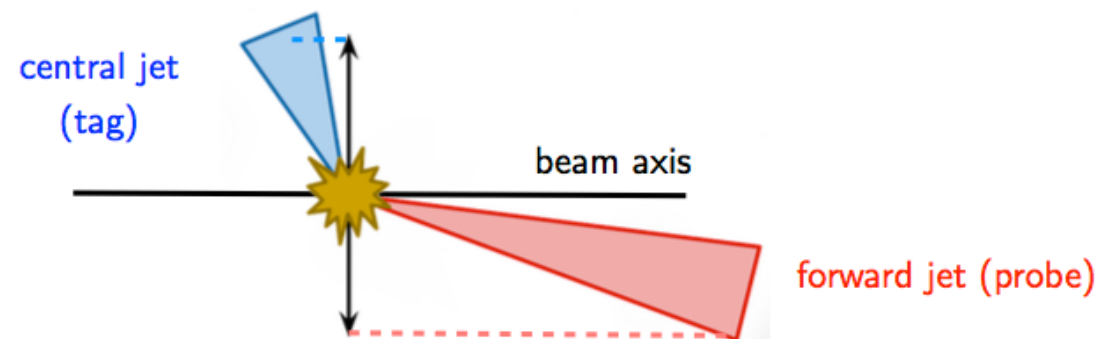
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- GSC significantly improves jet flavour response, and consequently the related uncertainty
- Tracking variables discrimination power with respect to jet flavour

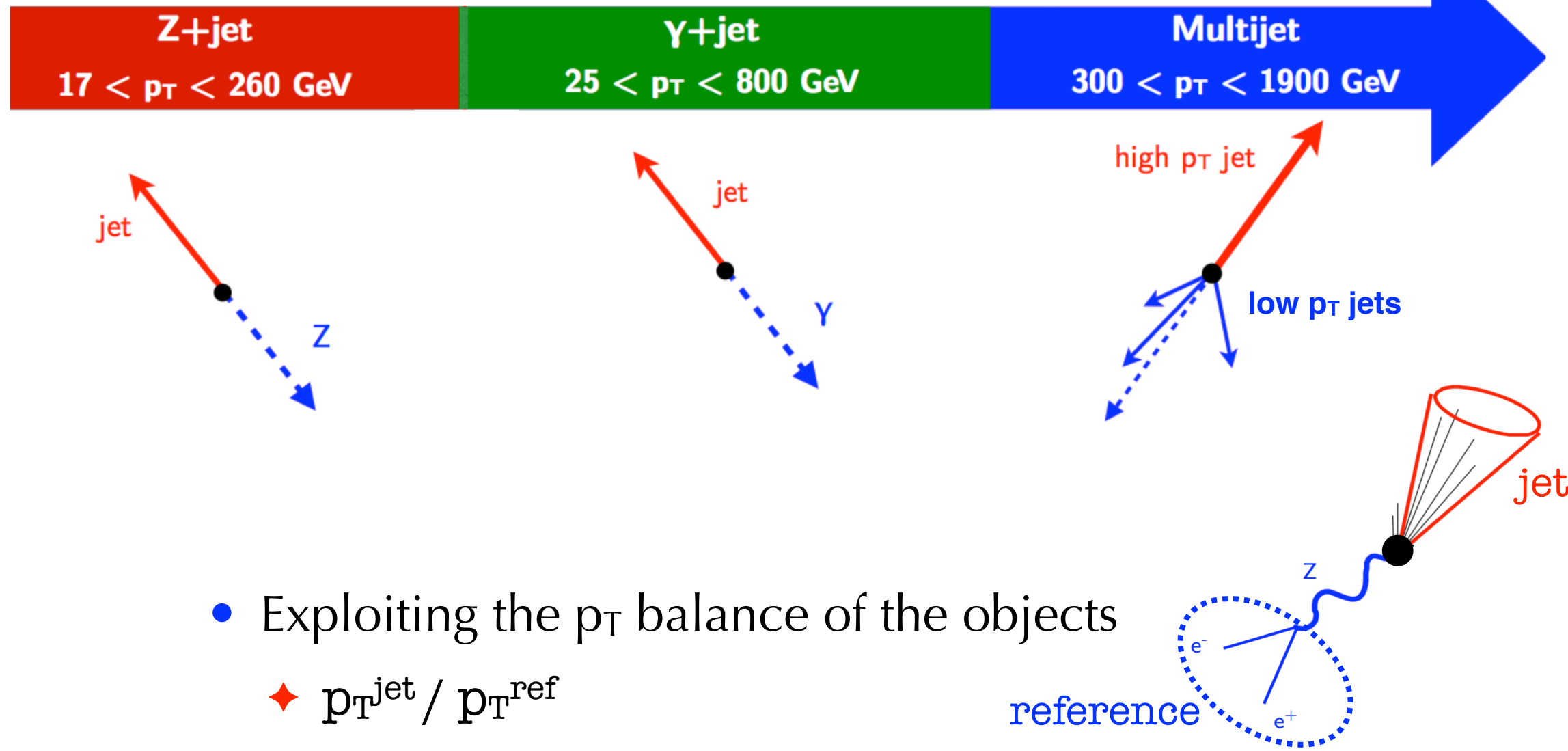


Data in-situ corrections

- In situ measurement using a **well-calibrated** object as a **reference**, recoiling against **jet**
- η intercalibration using dijet events \Rightarrow corrects η dependence of jet response



- Different reference objects depending on jet p_T



- Exploiting the p_T balance of the objects

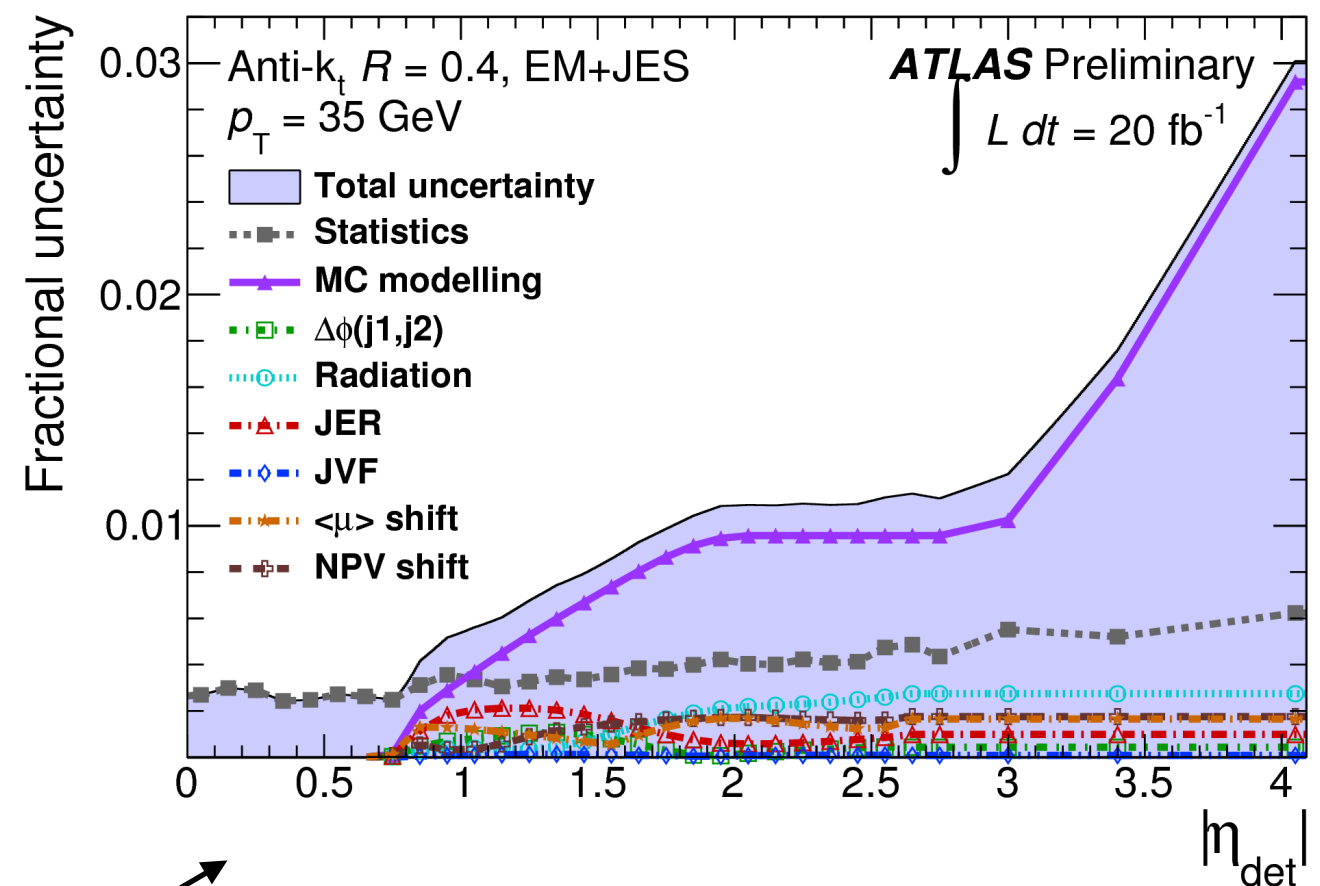
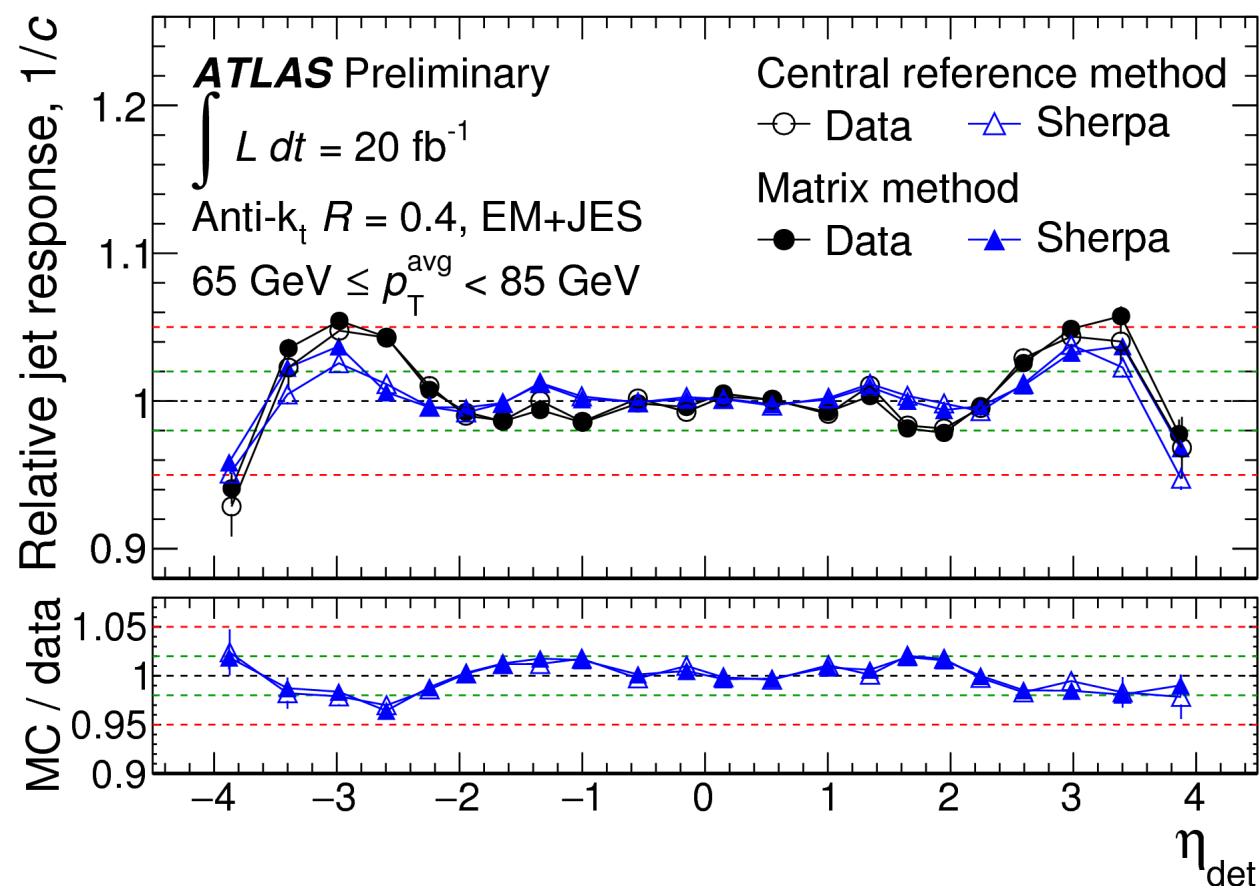
♦ $p_T^{\text{jet}} / p_T^{\text{ref}}$

reference

η intercalibration

ATLAS-CONF-2015-017

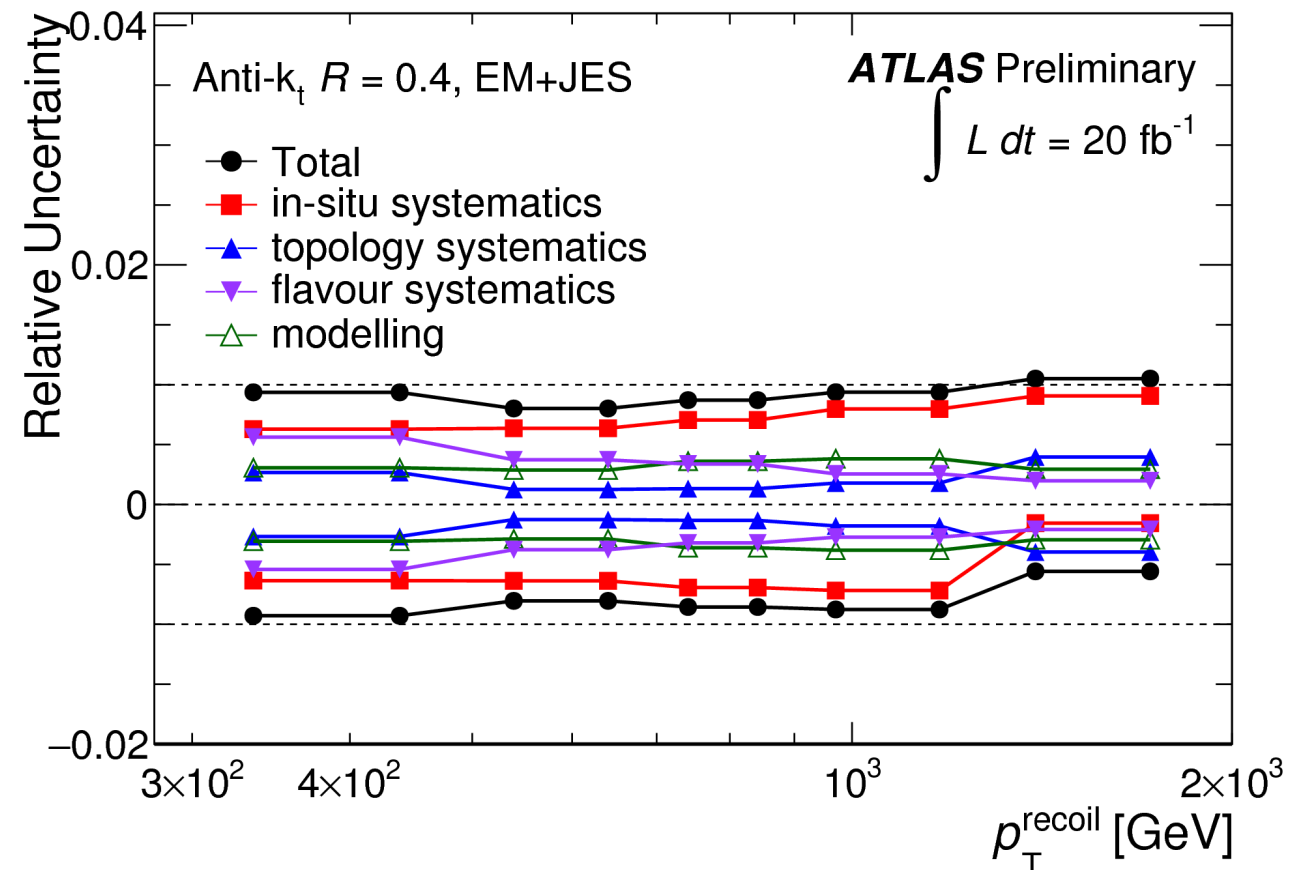
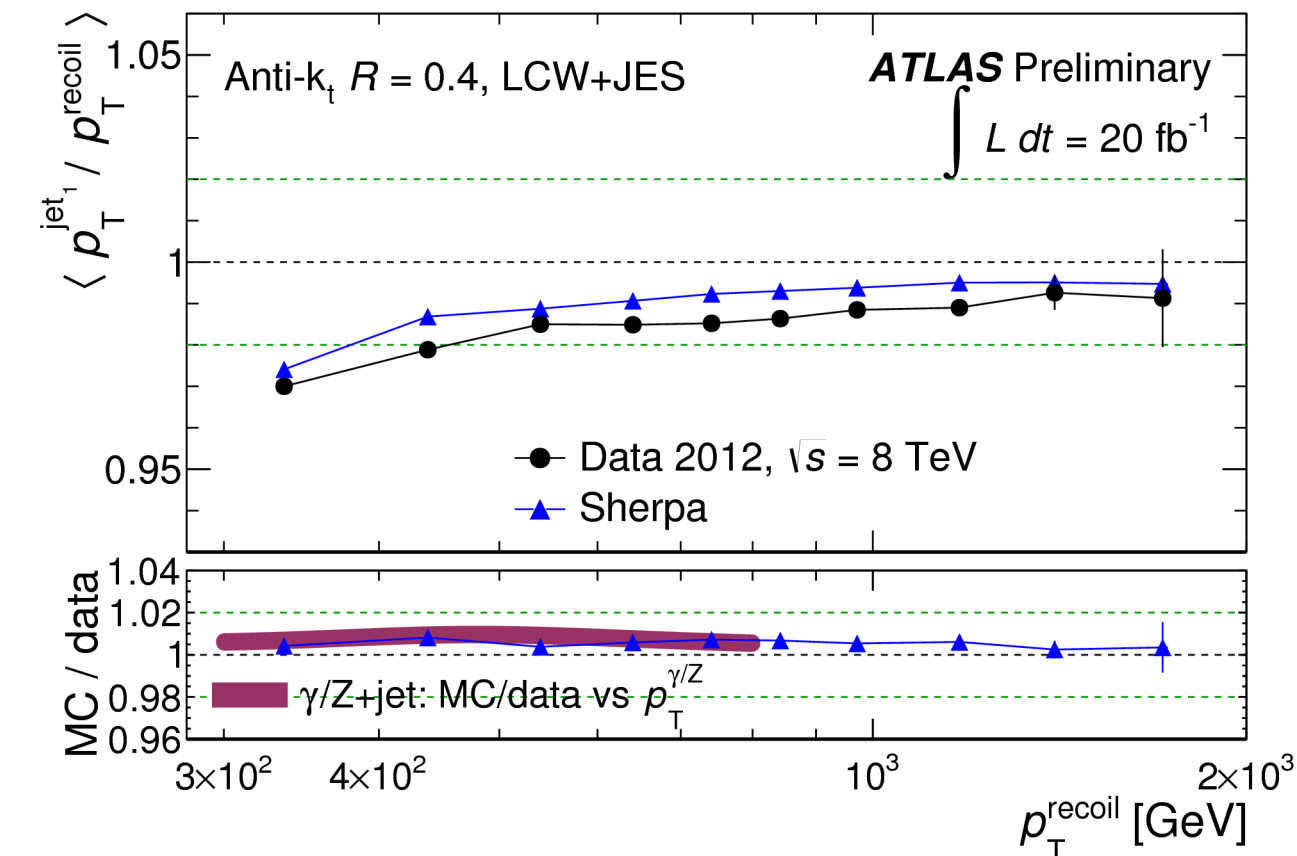
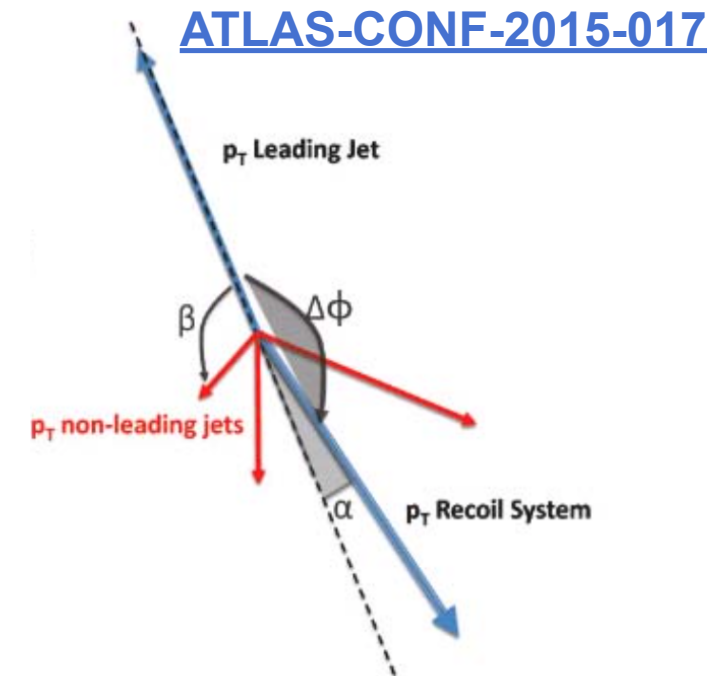
- Get uniform p_T response across $\eta \Rightarrow$ calibrate forward jets to same scale as central jets
 - ♦ Forward jets with $|\eta| > 0.8$ balanced against central reference jets
- Systematics dominated by MC generator modelling differences
- NLO Sherpa used as baseline, compared with Powheg+Pythia for uncertainty



“MC modelling” and “Statistics” bunches all together

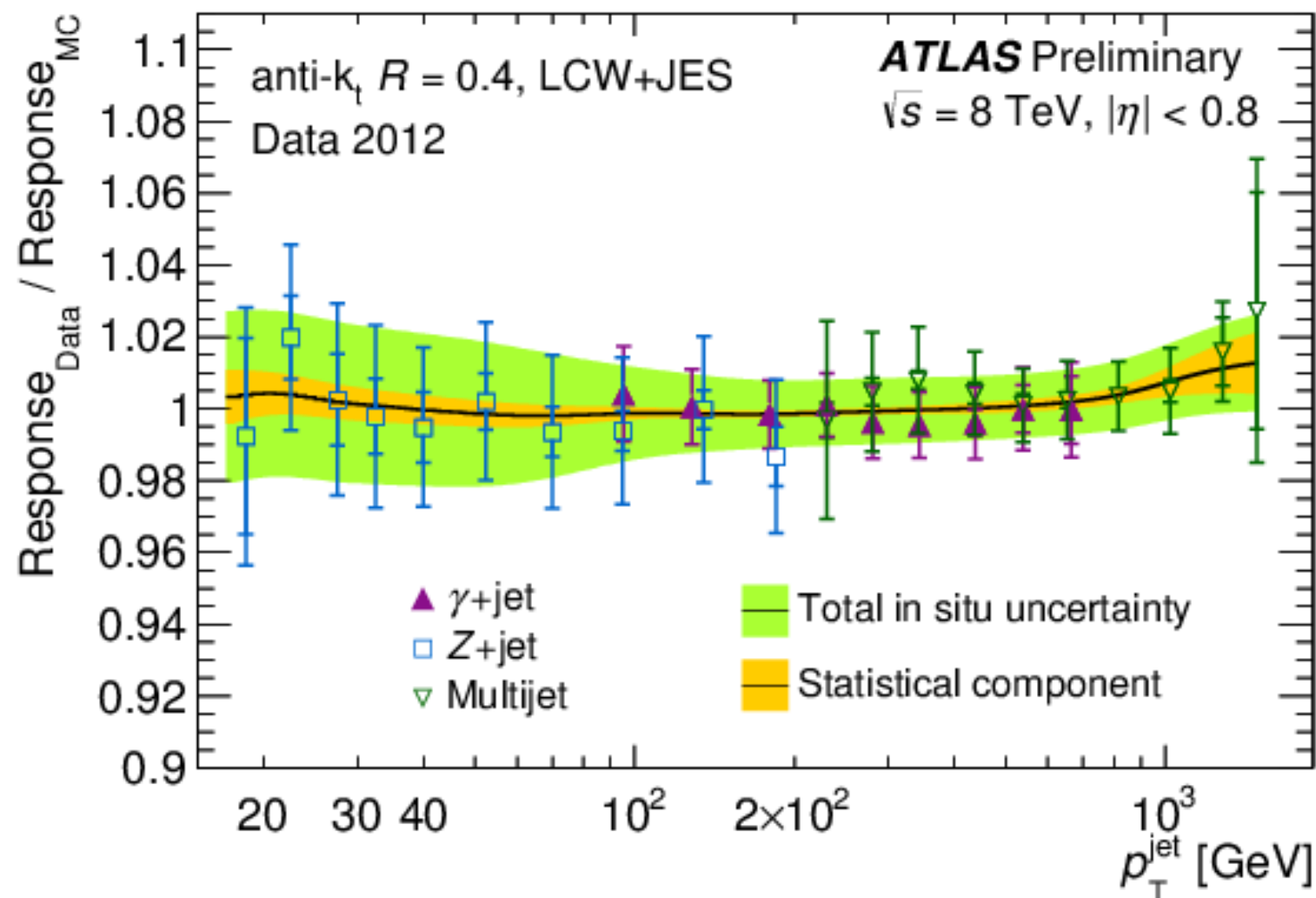
Multi-jet balance

- Multi-jet balance (MJB), when the highest- p_T jet is produced back-to-back with a recoil system of low p_T jets
- $R_{\text{MJB}} = \frac{p_T^{\text{leading}}}{p_T^{\text{recoil}}}$
- R_{MJB} measured both in Data and MC
- Systematics
 - ♦ In-situ systematics / Event selection criteria / Flavour related systematics / MC modelling by comparing different MC generators



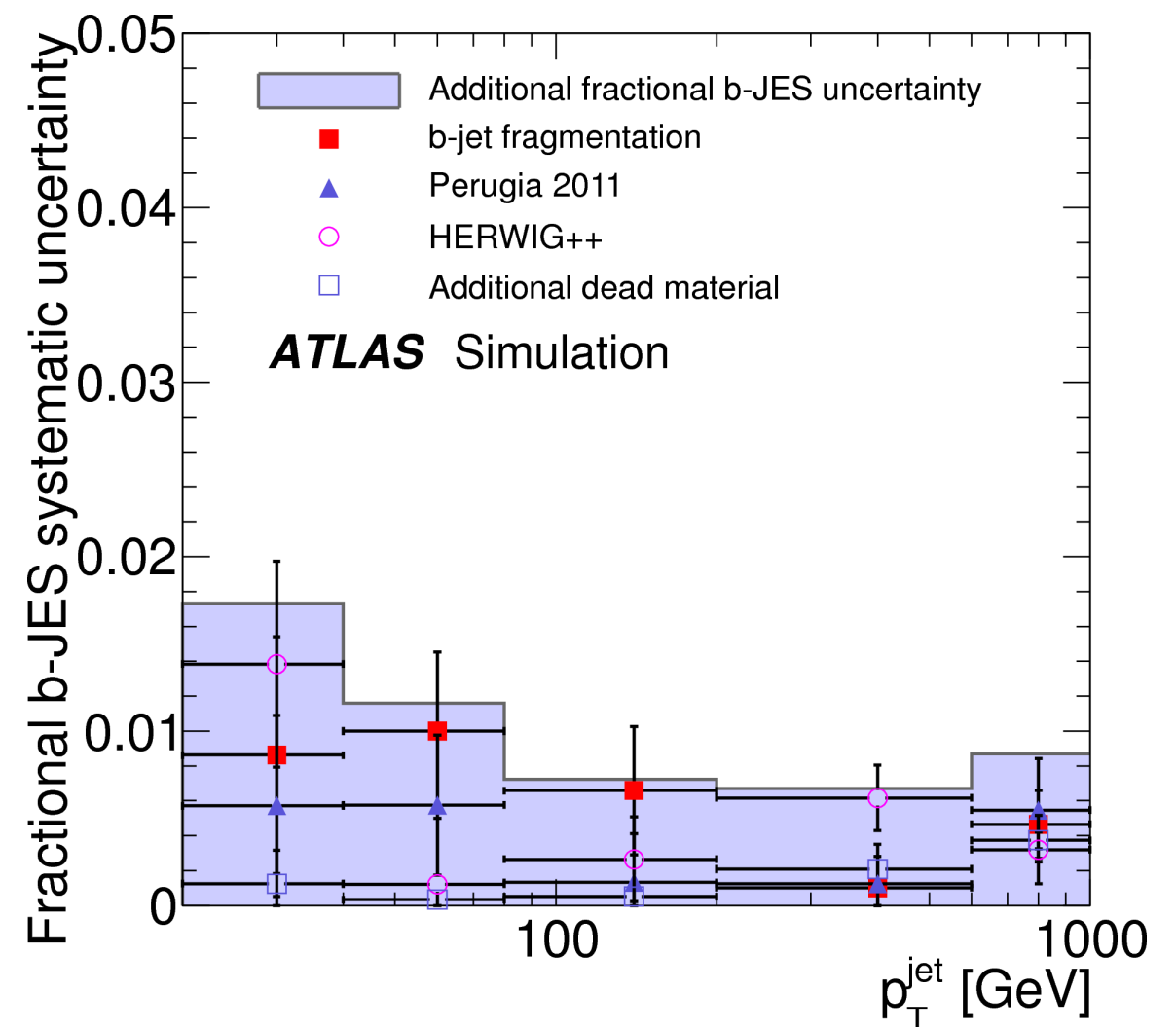
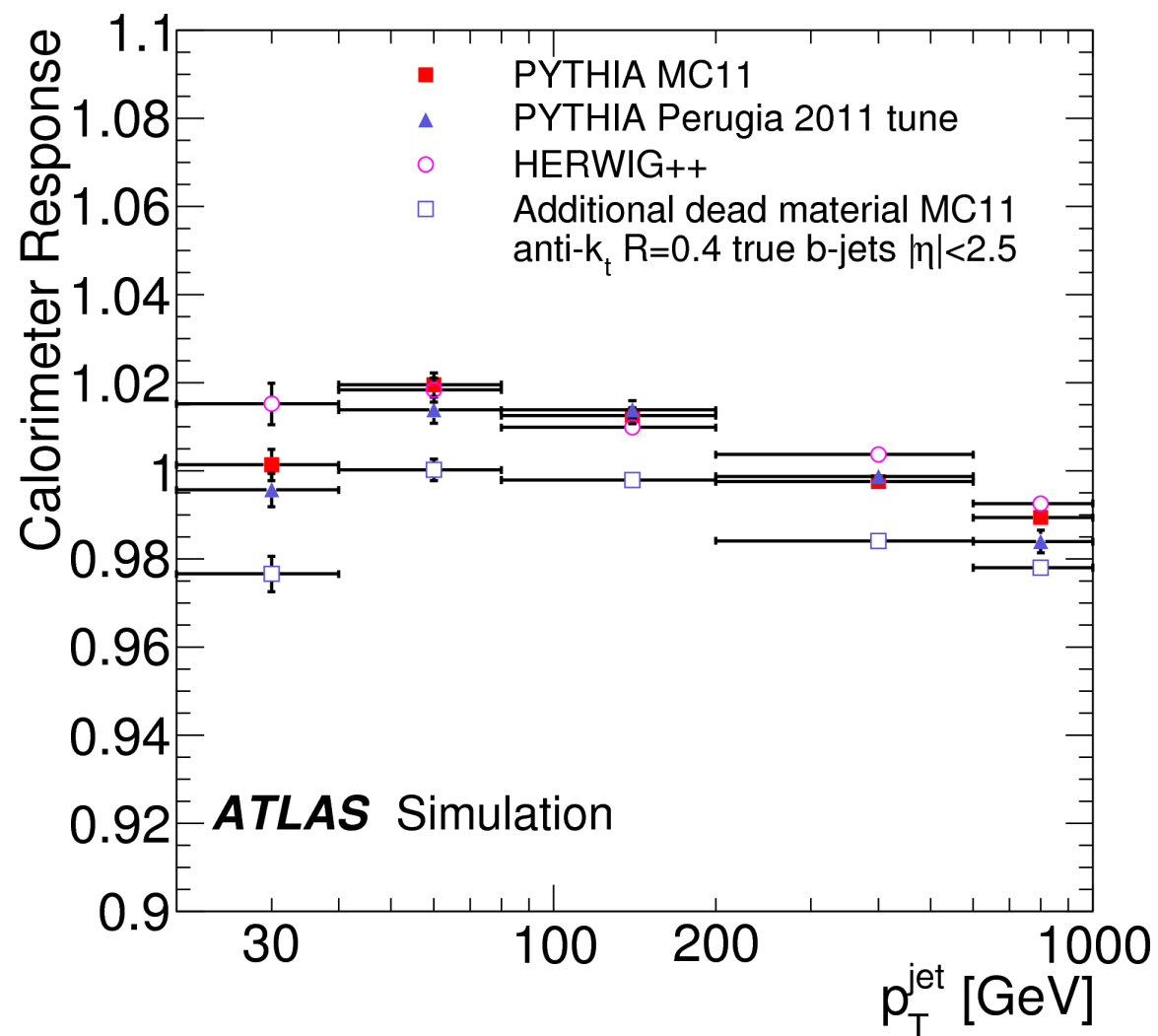
Combination of in-situ corrections

- Final in-situ calibration: combination of 3 in-situ measurements
 - ♦ γ +jet
 - ♦ Z+jet
 - ♦ Multijet
- Binned in p_T and η
- Total in-situ systematic uncertainty $\sim < 2\%$ at central region

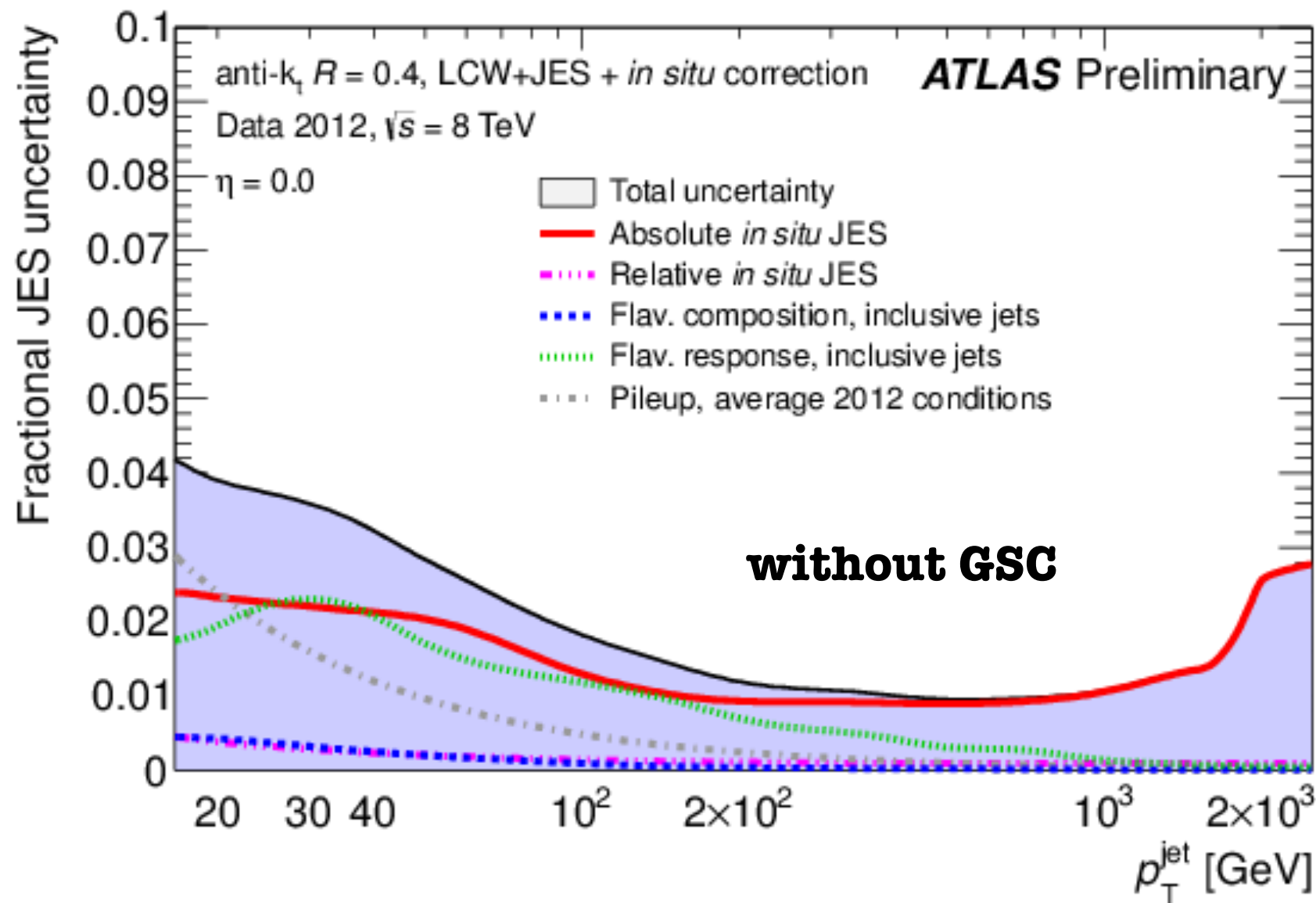


bJES

- Derived from MC variations γ +jet
 - ♦ Derived from systematic samples with different b-jet parameters (fragmentation), different MC tunes, added material in calorimeter
- Validated in data using dijet et tT samples



Jet energy scale uncertainties



- Final JES uncertainties, a combination of in-situ components and components estimated upstream in calibration chain
 - ♦ Pile-up, punch-through, flavour dependence (though reduced after GSC)

Reminder: JES unc. correlation ATLAS Vs CMS

- Categorise uncertainty components based on its source and correlations
 - ♦ *Detector description*
 - ♦ *statistics/method*
 - ♦ *Physics modelling*
 - ♦ *Mixed: detector & modelling*

Description	Component names, CMS	Component name, ATLAS
1a. Statistical	RelativeStatEC2; RelativeStatHF; AbsoluteStat	Statistical components for <i>in situ</i> calibration, Z -jet width
1b. Detector	AbsoluteScale; RelativeJEREC1; RelativeJEREC2; RelativeJERHF	Electron/photon energy scale, γ -jet jet energy resolution
2. Modeling uncertainties for γ-jet and Z-jet	AbsoluteMPFBias	γ -jet and Z -jet: radiation suppression, out-of-cone and MC generator difference; γ -jet photon purity; Z -jet extrapolation;
3. Modeling uncertainties for relative correction	RelativeFSR	η -intercalibration modeling
4. Uncertainties related to jet partonic flavor	Flavor; AbsoluteFlavorMapping	Flavor composition and response
5. b-jet uncertainties	Flavor	b -jet response
6. Pileup correction	PileUpDataMC; PileUpPtBB; PileUpBias; PileUpOOT; PileUpJetRate; PileUpPtEC; PileUpPtHF	Pileup calibration; effects of pileup on <i>in situ</i> methods
7. High-p_T uncertainties	HighPtExtra; SinglePion	High- p_T
8. Close-by jet uncertainties		Close-by
9. Other uncertainties not matching between the two experiments	Time	Multijet balance components, Closure of the calibration

- For more details see [here](#)

Reminder: JES unc. correlation ATLAS Vs CMS

- Categorise uncertainty components based on its source and correlations

♦ *Detector description*
 ♦ *statistics/method* treated as uncorrelated in ATLAS-CMS combination

♦ *Physics modelling*
 ♦ *Mixed: detector & modelling* likely to contain correlated components

Description	Component names, CMS	Component name, ATLAS	Correlation range
1a. Statistical	RelativeStatEC2; RelativeStatHF; AbsoluteStat	Statistical components for <i>in situ</i> calibration, Z-jet width	Uncorrelated
1b. Detector	AbsoluteScale; RelativeJEREC1; RelativeJEREC2; RelativeJERHF	Electron/photon energy scale, γ -jet jet energy resolution	Uncorrelated
2. Modeling uncertainties for γ-jet and Z-jet	AbsoluteMPFBias	γ -jet and Z-jet: radiation suppression, out-of-cone and MC generator difference; γ -jet photon purity; Z-jet extrapolation;	0-50%
3. Modeling uncertainties for relative correction	RelativeFSR	η -intercalibration modeling	50-100%
4. Uncertainties related to jet partonic flavor	Flavor; AbsoluteFlavorMapping	Flavor composition and response	0-100%
5. b-jet uncertainties	Flavor	b -jet response	50-100%
6. Pileup correction	PileUpDataMC; PileUpPtBB; PileUpBias; PileUpOOT; PileUpJetRate; PileUpPtEC; PileUpPtHF	Pileup calibration; effects of pileup on <i>in situ</i> methods	Uncorrelated
7. High-p_T uncertainties	HighPtExtra; SinglePion	High- p_T	Uncorrelated
8. Close-by jet uncertainties		Close-by	Uncorrelated
9. Other uncertainties not matching between the two experiments	Time	Multijet balance components, Closure of the calibration	Uncorrelated

- For more details see [here](#)

Reminder: JES unc. correlation ATLAS Vs CMS

- Categorise uncertainty components based on its source and correlations

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Description	Component names, CMS	Component name, ATLAS	Correlation range
1a. S	RelativeStatEC2; RelativeStatHF; Absc	Statistical components for in situ cal	ated
1b. D			ated
2. M and 2			
3. M tive c			
4. U tonic			
5. b-			
6. Pileup correction	PileUpDataMC; PileUpPtBB; PileUp-Bias; PileUpOOT; PileUpJetRate; Pile-UpPtEC; PileUpPtHF	Pileup calibration; effects of pileup on <i>in situ</i> methods	Uncorrelated
7. High- p_T uncertainties	HighPtExtra; SinglePion	High- p_T	Uncorrelated
8. Close-by jet uncertainties		Close-by	Uncorrelated
9. Other uncertainties not match- ing between the two experiments	Time	Multijet balance components, Closure of the calibration	Uncorrelated

→ **Pile-up uncertainties have been updated since 2011 treatment.**

→ Jet area method is used like in CMS

→ Perhaps need to revisit pile-up uncorrelated treatment?

→ **Close-by effect is well described in simulation**

→ Dropped in 2012

- For more details see [here](#)

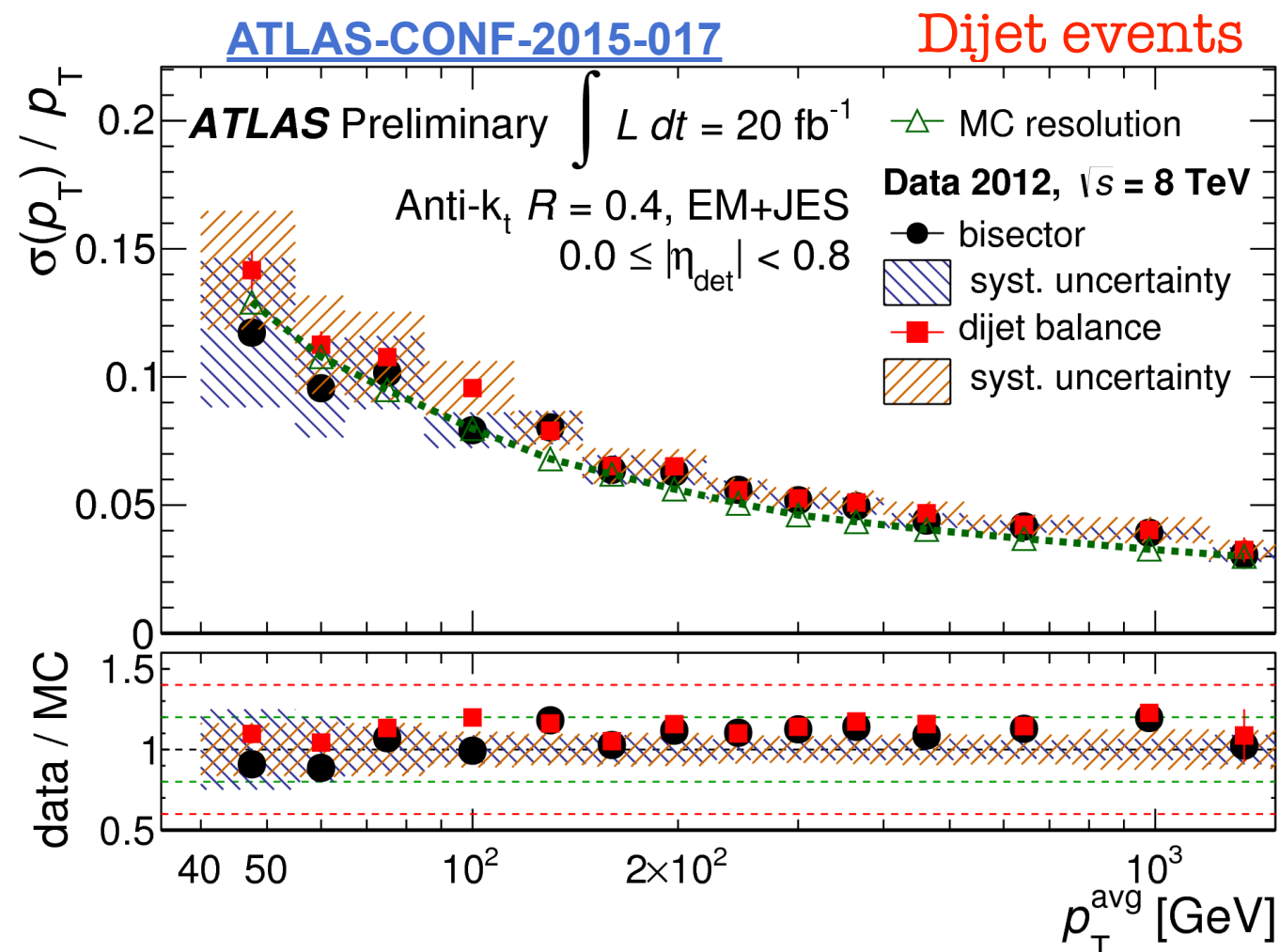
Jet energy resolution

- Jet energy resolution:

$$\frac{\sigma_{p_T}}{p_T} = \frac{N}{p_T} \oplus \frac{S}{\sqrt{p_T}} \oplus C \rightarrow \text{constant}$$

noise term stochastic term constant

- Plan to combine the three γ +jet, Z+jet and dijet in-situ measurements similarly to what is done for the JES
- In high p_T JER is driven from dijet analysis with a precision of 3-12%



Conclusions and Run-II

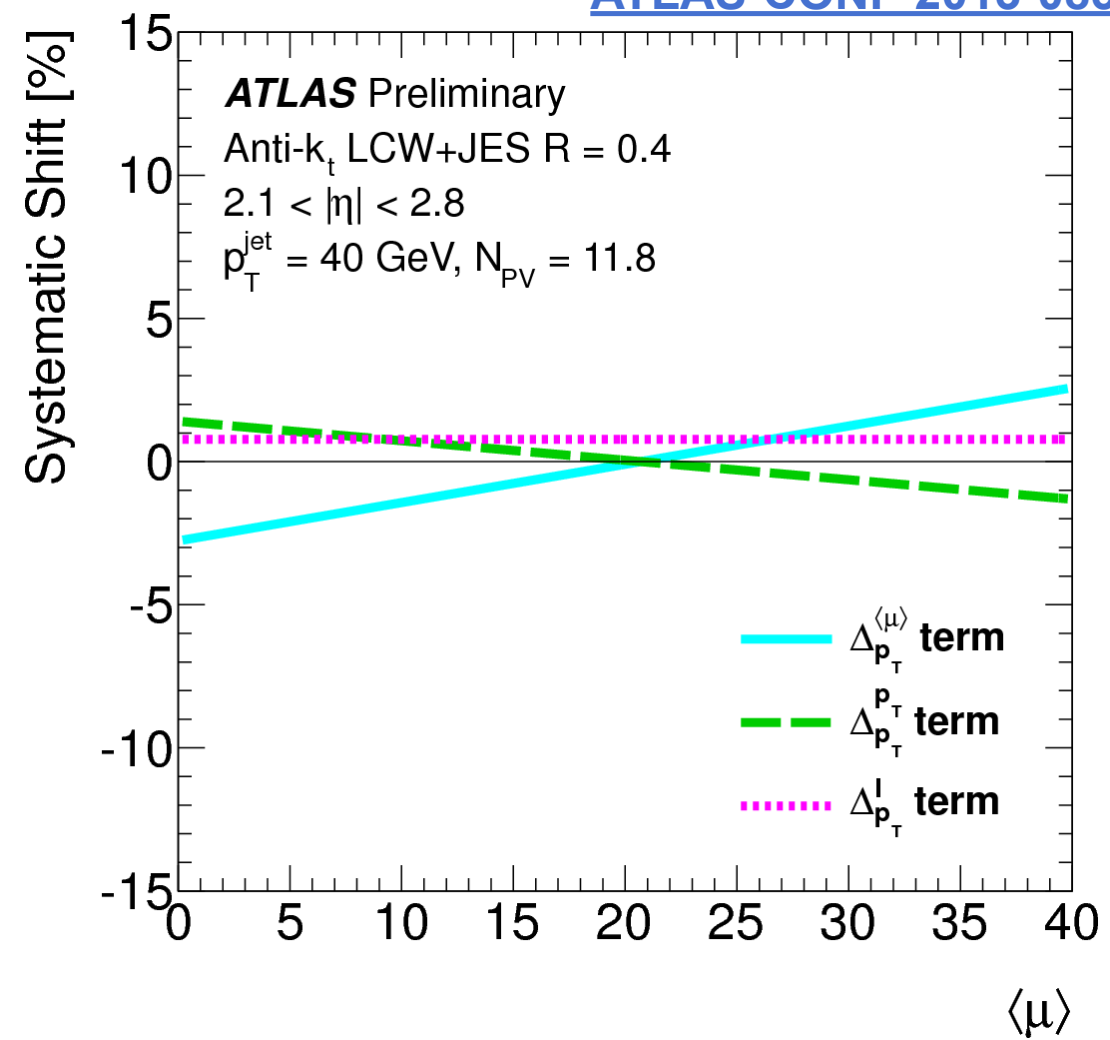
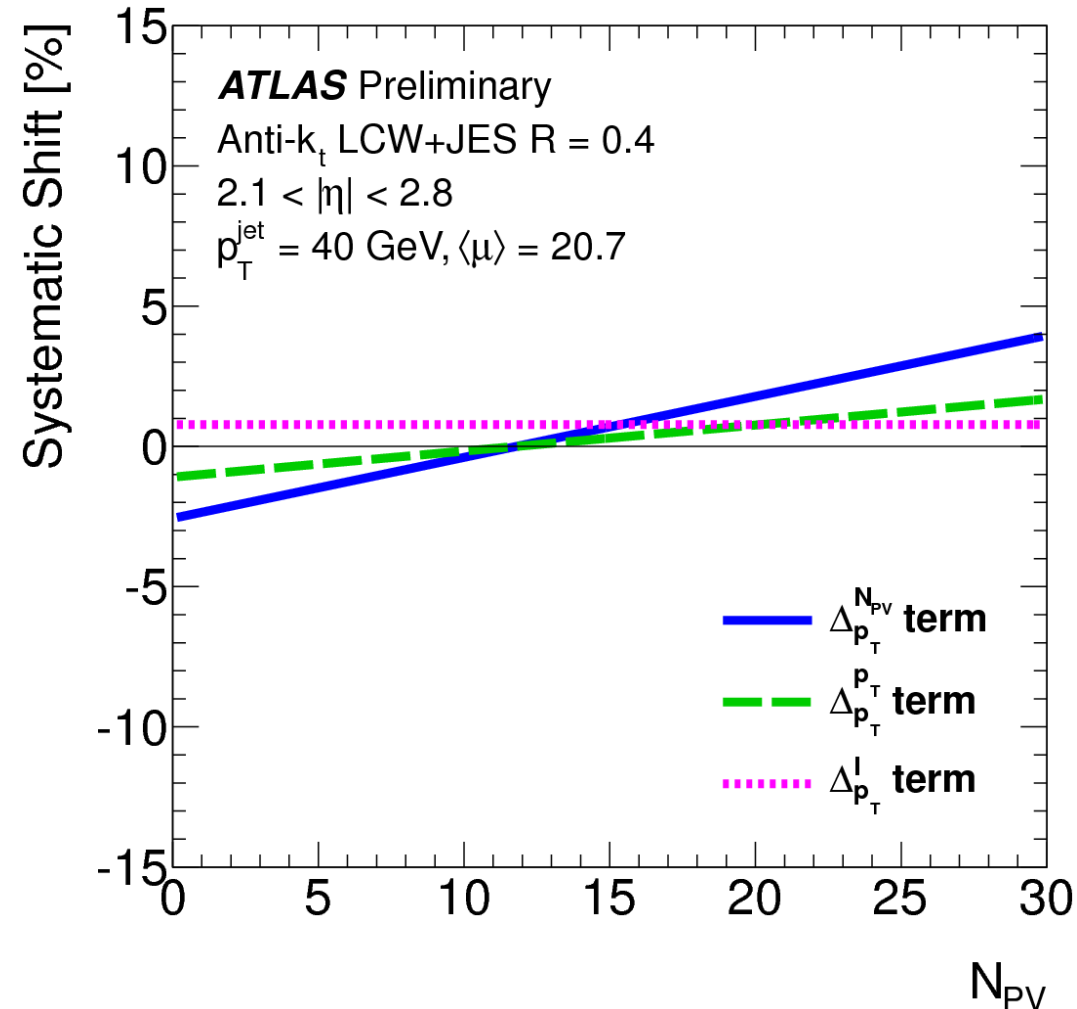
- **Run-I paves the way**
- Plan to repeat the same calibration chain
 - ♦ **MC Calibration validated with Data where relevant**
 - ✦ Origin correction
 - ✦ Pile-up correction
 - ✦ MC energy and η calibrations
 - ✦ Global sequential correction
 - ♦ **In-situ data calibration**
 - ✦ η intercalibration / Z/γ + jet balance / Multijet balance
- Timeline: Moriond 2016

Back-up

Pile-up correction related systematics

- 4 different systematic uncertainties
 - ♦ p_T dependence of residual correction
 - ✱ MC-based
 - ♦ Uncertainty on the two coefficients α, β of residual correction
 - ✱ Estimated using data
 - ♦ ρ modelling
 - ✱ Evaluated using data by studying different topologies

[ATLAS-CONF-2013-083](#)



Jet energy scale uncertainties @ 7 TeV

in-situ uncertainties summary

Name	Description	Category
Common sources		
Electron/photon E scale	electron or photon energy scale	det.
Z-jet p_T balance (DB)		
MC generator	MC generator difference between ALPGEN/HERWIG and PYTHIA	model
Radiation suppression	radiation suppression due to second jet cut	model
Extrapolation	extrapolation in $\Delta\phi_{\text{jet-Z}}$ between jet and Z boson	model
Pileup jet rejection	jet selection using jet vertex fraction	mixed
Out-of-cone	contribution of particles outside the jet cone	model
Width	width variation in Poisson fits to determine jet response	stat./meth.
Statistical components	statistical uncertainty for each of the 11 bins	stat./meth.
γ-jet p_T balance (MPF)		
MC Generator	MC generator difference HERWIG and PYTHIA	model
Radiation suppression	sensitivity to radiation suppression due to second jet cut	model
Jet resolution	variation of jet resolution within uncertainty	det.
Photon Purity	background response uncertainty and photon purity estimation	det.
Pileup	sensitivity to pileup interactions	mixed
Out-of-cone	contribution of particles outside the jet cone	model
Statistical components	statistical uncertainty for each of the 12 bins	stat./meth.
Multijet p_T balance		
α selection	angle between leading jet and recoil system	model
β selection	angle between leading jet and closest sub-leading jet	model
Dijet balance	dijet balance correction applied for $ \eta < 2.8$	mixed
Close-by, recoil	JES uncertainty due to close-by jets in the recoil system	mixed
Fragmentation	jet fragmentation modeling uncertainty	mixed
Jet p_T threshold	jet p_T threshold	mixed
p_T asymmetry selection	p_T asymmetry selection between leading jet and sub-leading jet	model
UE, ISR/FSR	soft physics effects modeling: underlying event and soft radiation	mixed
Statistical components	statistical uncertainty for each of the 10 bins	stat./meth.
η-intercalibration		
η -intercalibration modeling	modeling of extra parton radiation in relative calibration (comparison between PYTHIA and HERWIG++)	model
η -intercalibration: stat.	statistical uncertainties in relative calibration	stat./meth.

4 categories

- *Detector description*
- *Physics modeling*
- *Statistics and method*
- *Mixed detector and modeling*

Jet energy scale uncertainties @ 7 TeV

non in-situ uncertainties summary

Name	Description	Category
High- p_T	jets outside the reach of <i>in situ</i> techniques (single particle)	det.
Flavor composition and re- sponse	modeling of light-quark/gluon differences	model
Response of jets containing b -hadrons (b -jets)	modeling of b -quark jets	model
Closure of the calibration	JES calibration closure in fast simulation samples	special
Pileup	p_T dependence of the correction, validation of MC-based offset correction from <i>in situ</i> studies	special
Close-by	response and modeling for close-by jet topologies	mixed

4 categories

- *Detector description*
- *Physics modeling*
- *Statistics and method*
- *Mixed detector and modelling*

- ATLAS and CMS combination
 - ♦ *Detector description* and *statistics/method* uncorrelated
 - ♦ *Physics modelling* and *mixed detector* likely to contain correlated components
- For more details see [here](#)

Reducing the components

- Start from ~60 JES uncertainty components
- Categorise into 4 groups
- **Perform components reduction *per category* maintaining a sufficient accuracy of all correlations**
 - ♦ Covariance matrix is built from the independent unc. components (nuisance parameters)
 - ♦ Eigenvector decomposition of the matrix performed
 - ♦ Eigenvectors provide a new representation of the JES uncertainty
 - ♦ Accurate approximation of covariance matrix by separating out a small subset of eigenvectors with the largest eigenvalues
 - ♦ From the quadratic sum of the remaining components a residual, left-over uncertainty is determined