

Physics at the LHC

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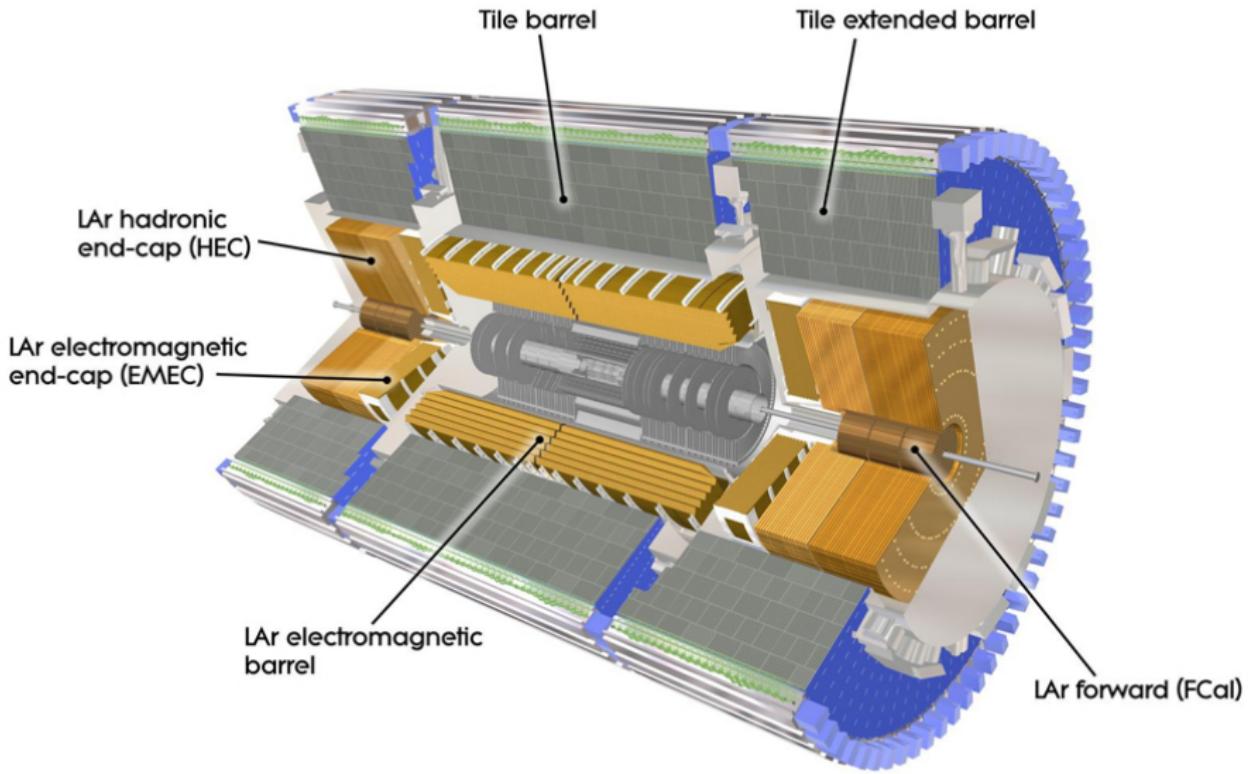
October 25, 2021



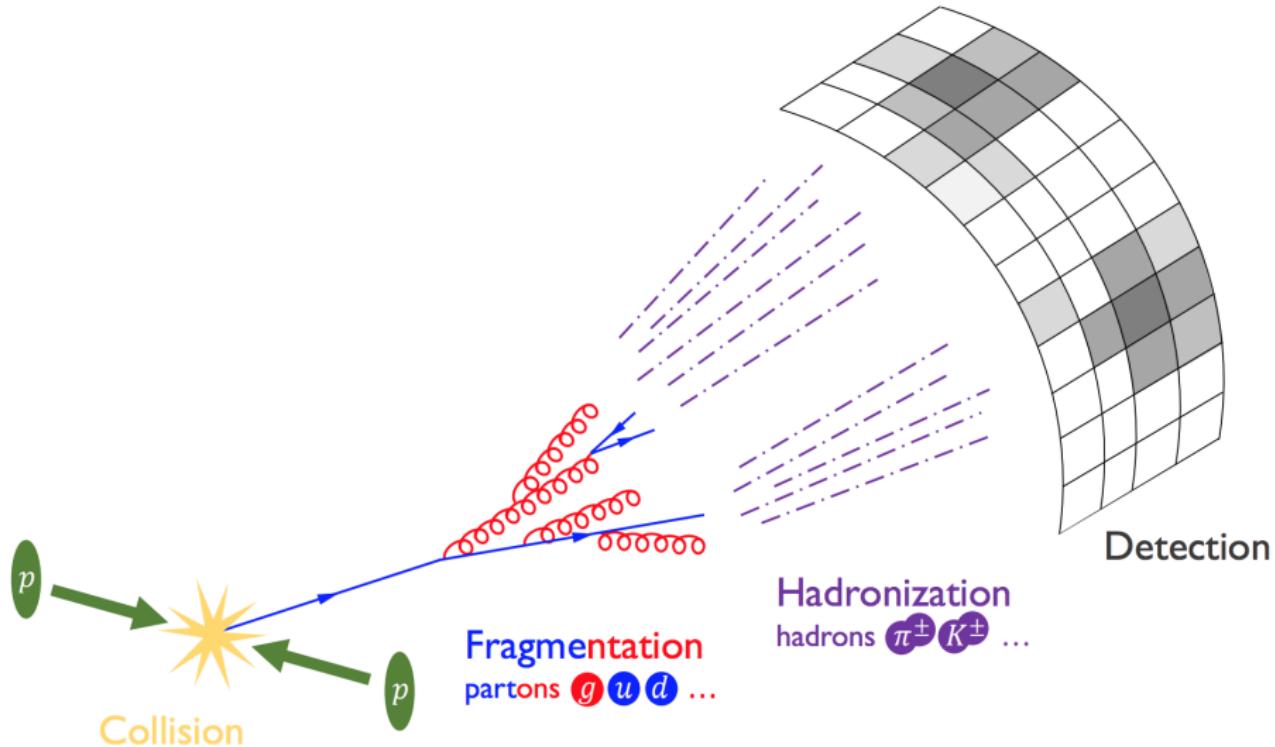
Outlook

- Large Hadron Collider
 - ▶ proton-proton collisions, pileup, event size, bandwidth and triggering.
- ATLAS detector
 - ▶ Calorimeters : electromagnetic and hadronic
- Jet definition, reconstruction and calibration
 - ▶ jet algorithms, infra-red stability, pileup mitigation, topo-clusters, jet energy calibration
- Jet cross-section measurements at 13 TeV
 - ▶ trigger strategy, event selection, detector effects, theory model, quantitative data to theory comparison
- Searches for a low-mass dijet resonance at 13 TeV
 - ▶ trigger strategy, data analysis, fit model, interpretation

ATLAS Calorimeters

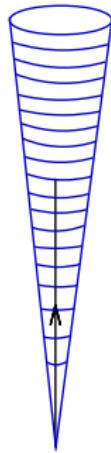


Jet life

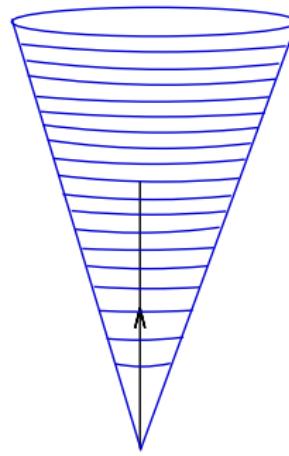


Small- vs Large-R jets

Small jet radius



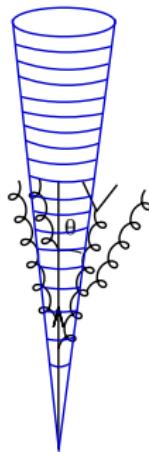
Large jet radius



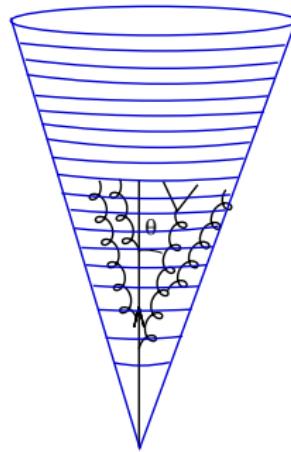
single parton @ LO: **jet radius irrelevant**

Small- vs Large-R jets

Small jet radius



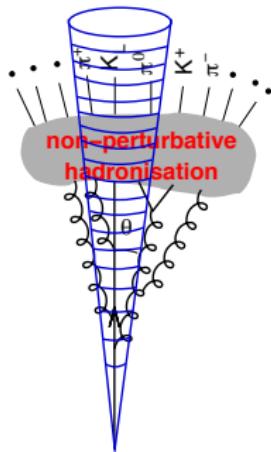
Large jet radius



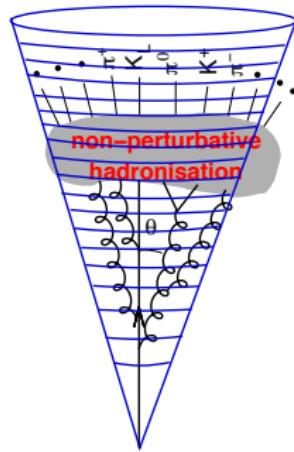
perturbative fragmentation: **large jet radius better**
(it captures more)

Small- vs Large-R jets

Small jet radius



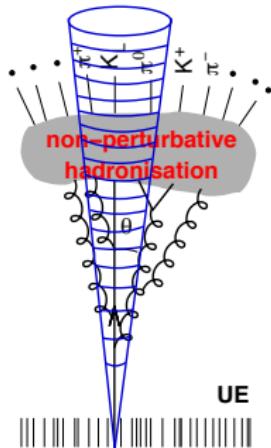
Large jet radius



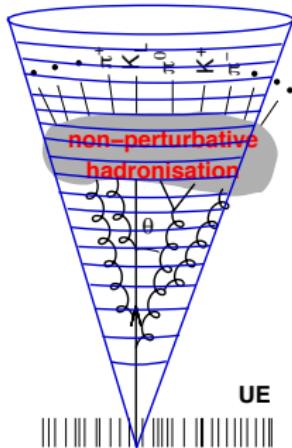
non-perturbative fragmentation: **large jet radius better**
(it captures more)

Small- vs Large-R jets

Small jet radius



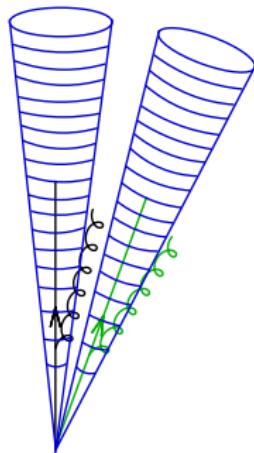
Large jet radius



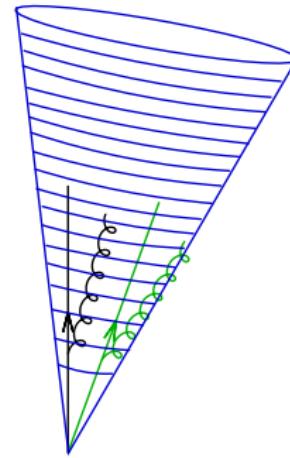
underlying ev. & pileup “noise”: **small jet radius better**
(it captures less)

Small- vs Large-R jets

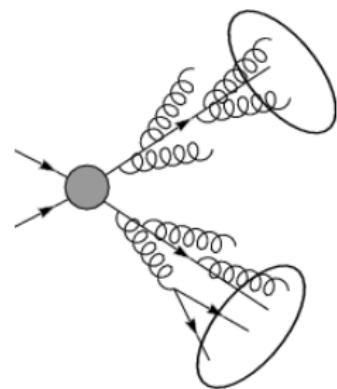
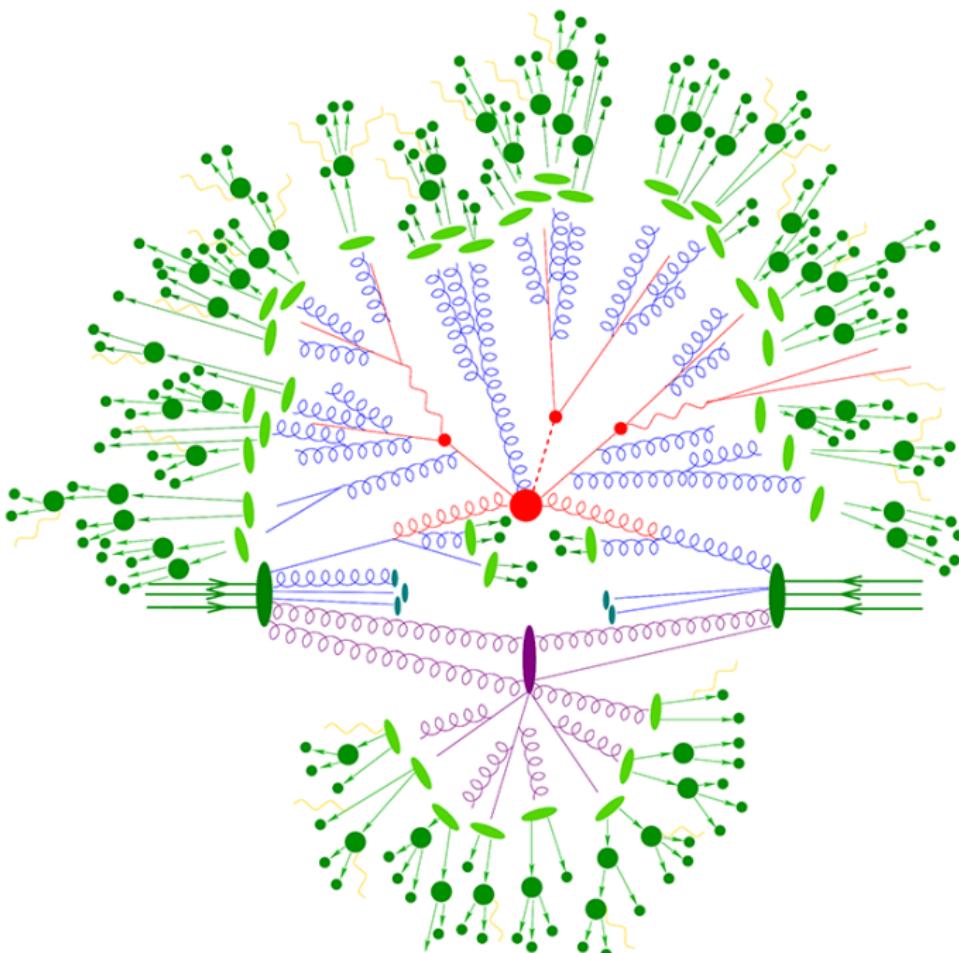
Small jet radius



Large jet radius

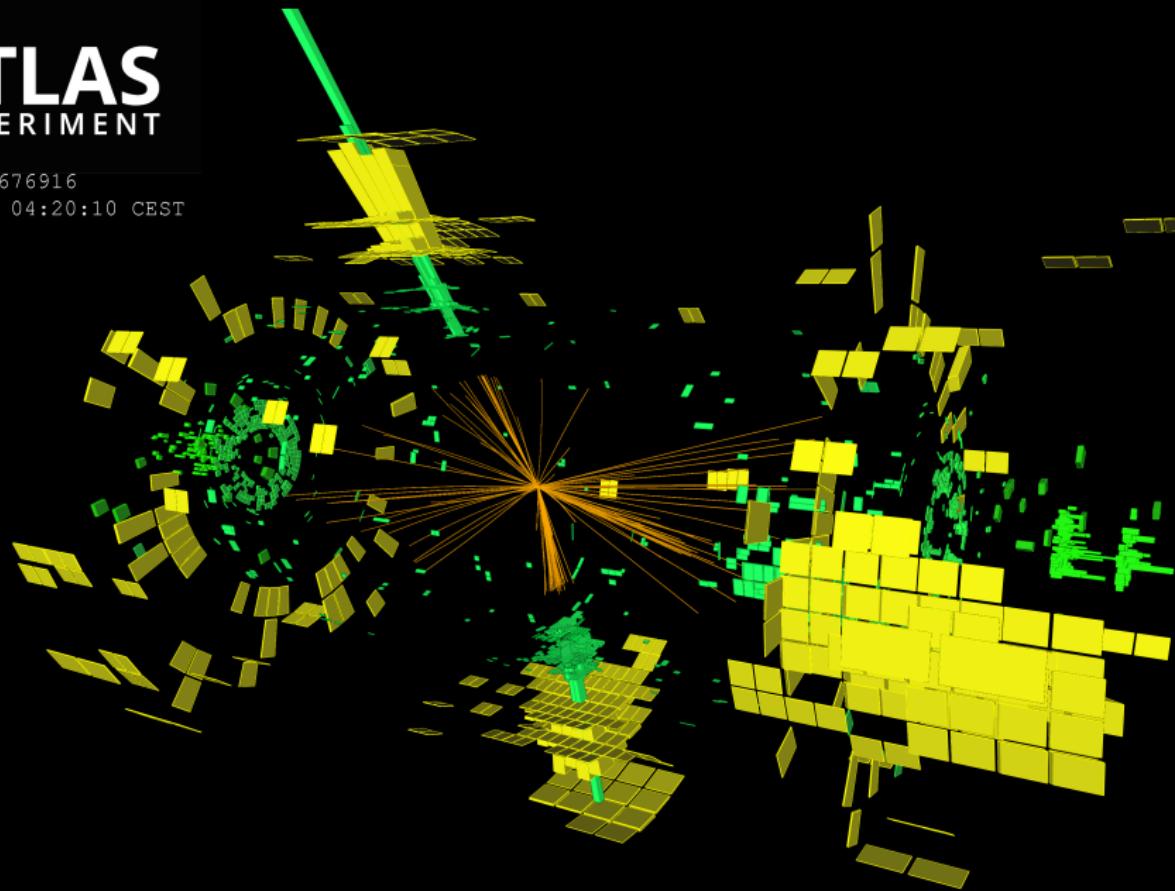


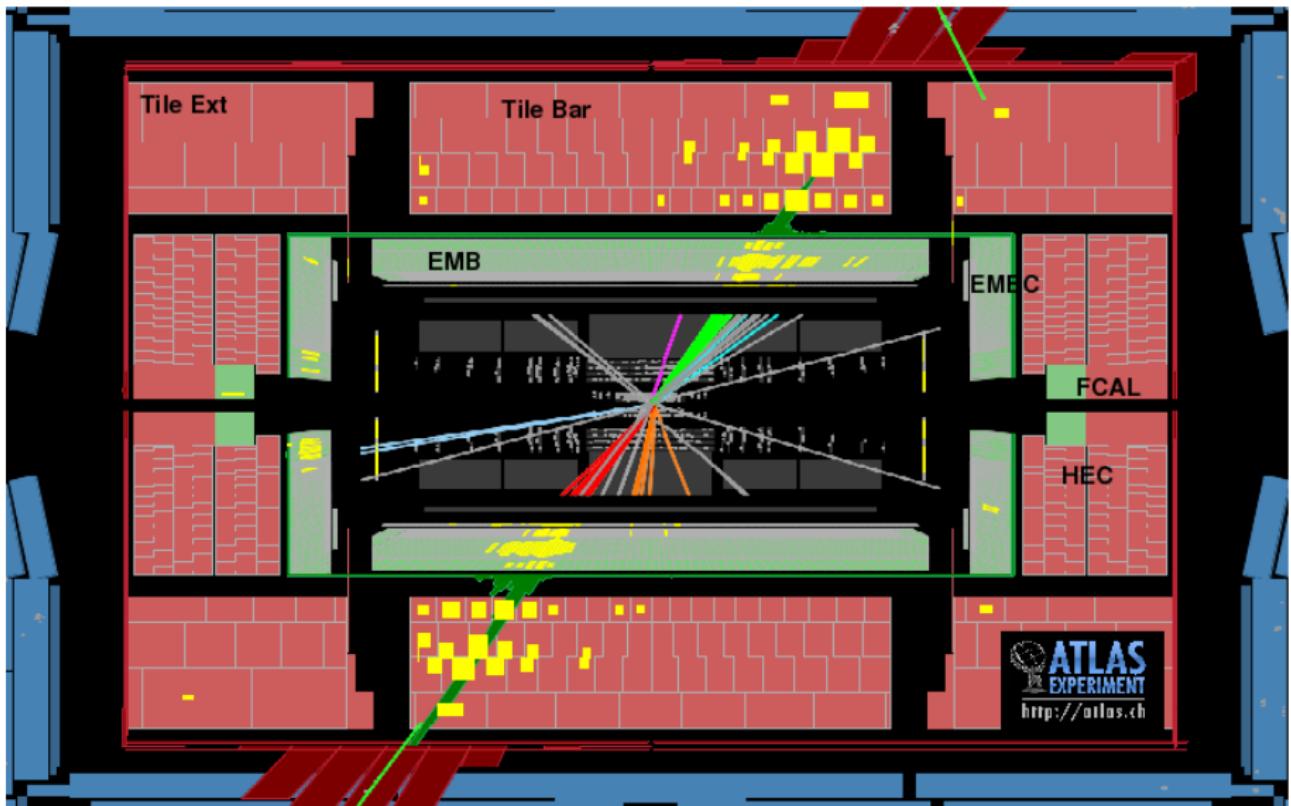
multi-hard-parton events: **small jet radius better**
(it resolves partons more effectively)



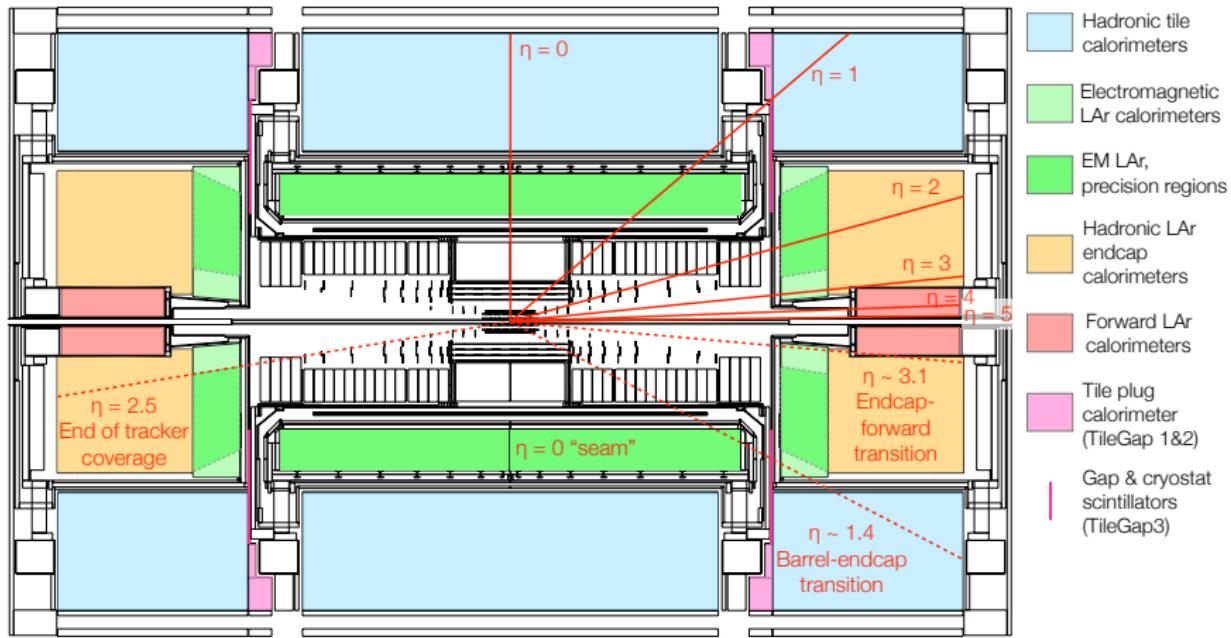


Event: 531676916
2015-08-22 04:20:10 CEST

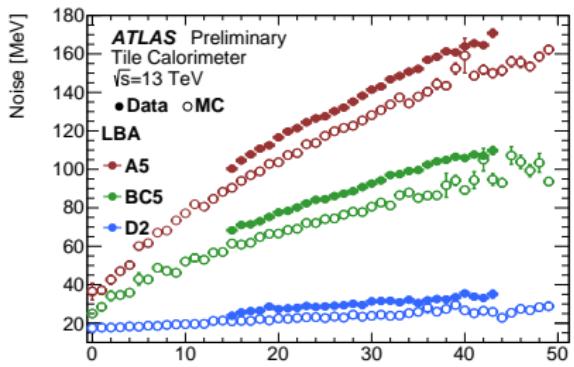
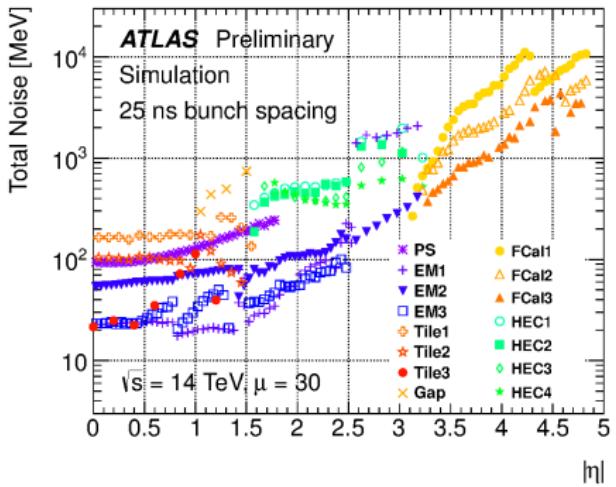
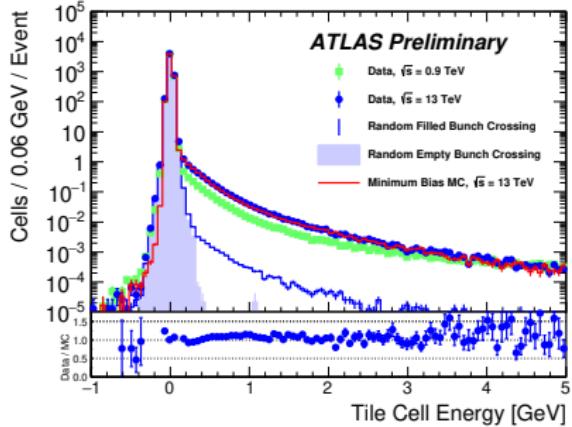




Pseudorapidity



Physics noise in calorimeters



Topological clustering

- topological cluster is a set of topologically connected cells with a significant signal above noise
- clusterization (seed, neighbour, perimeter cells)
- the thresholds 4-2-0

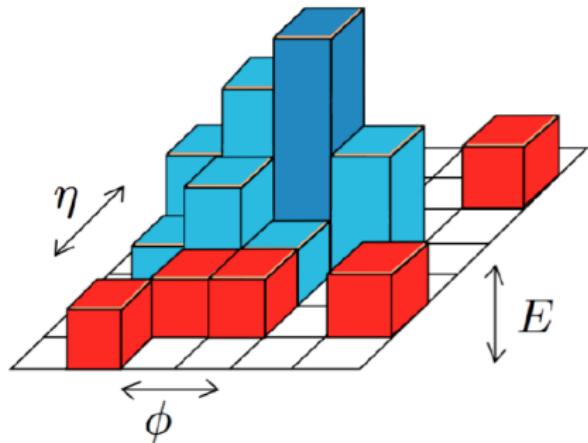
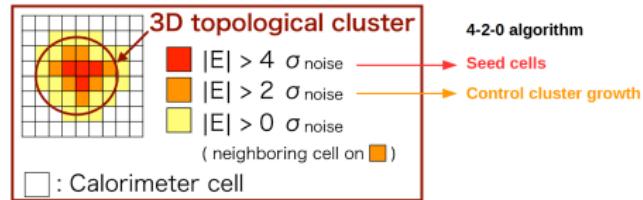
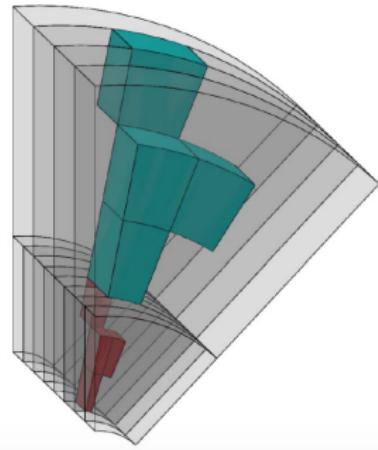


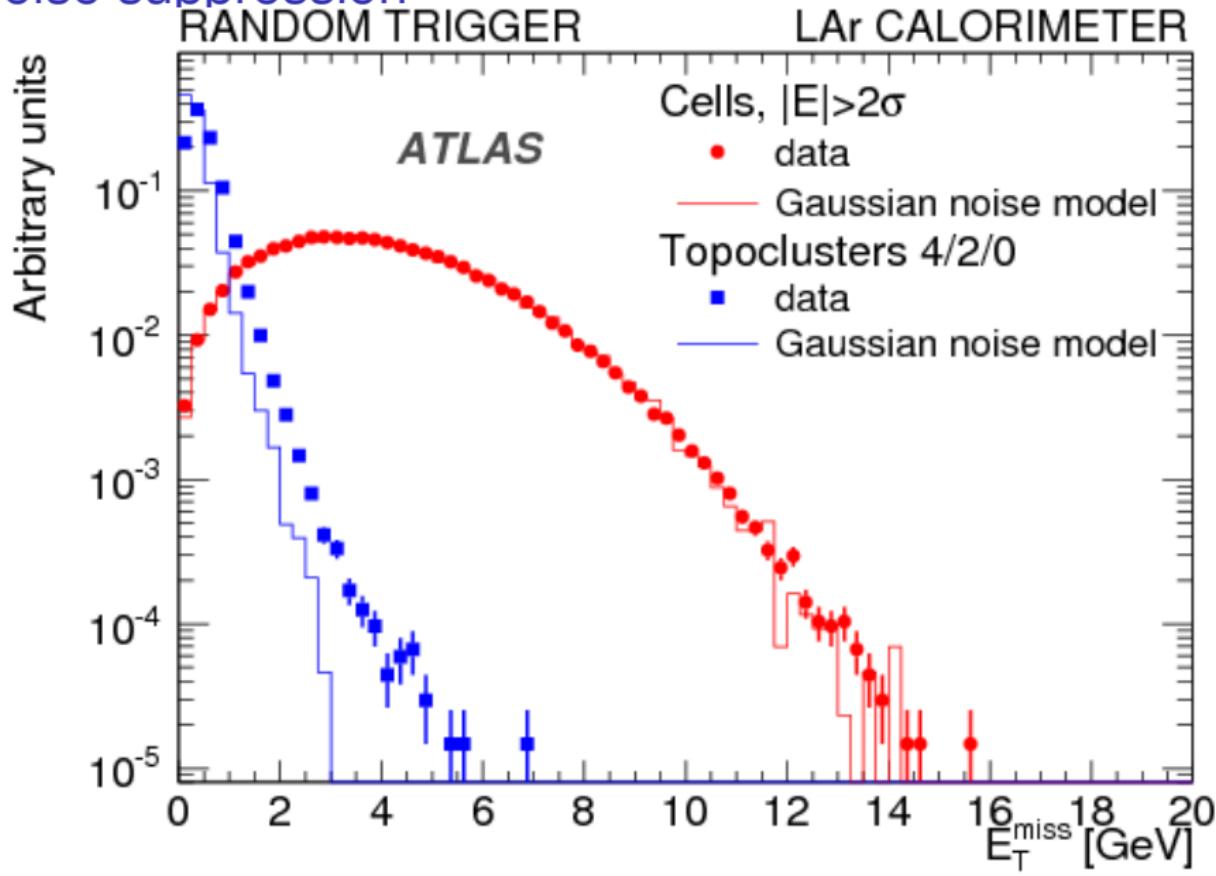
Illustration of a topological cluster:

dark blue seed cell

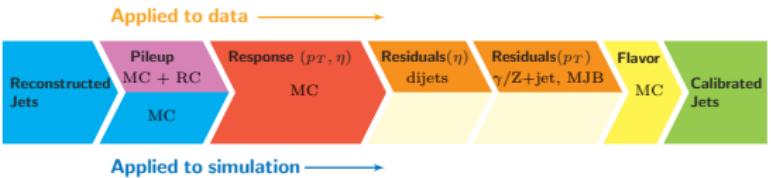
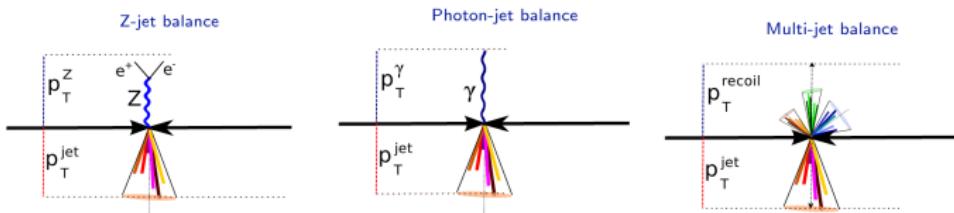
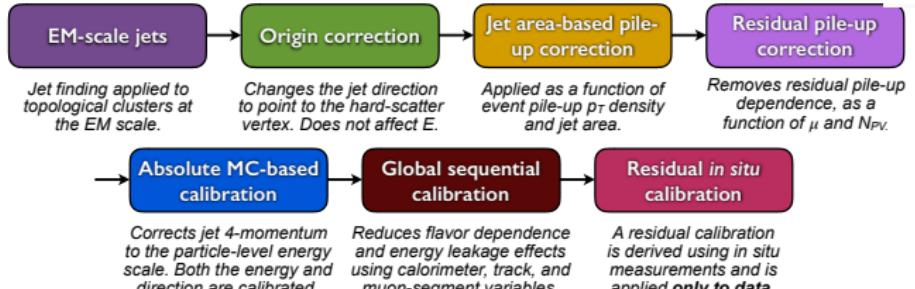
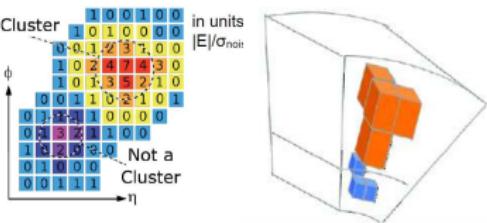
light blue selected adjoint and neighboring cells

red rejected cells

Noise suppression

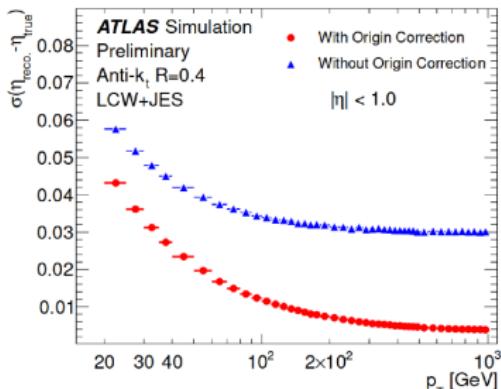
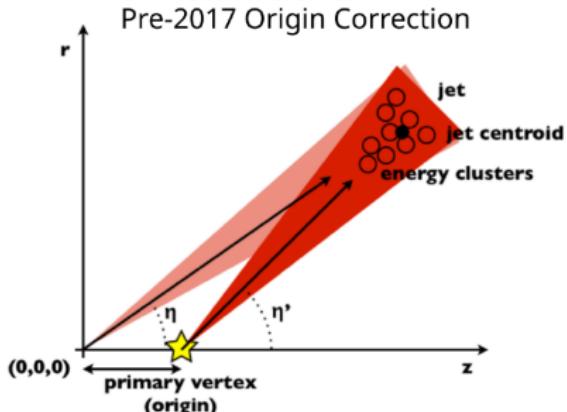


Jet reconstruction & calibration



Origin correction

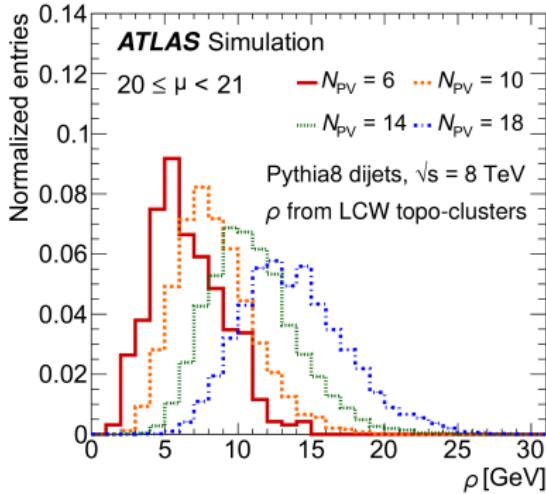
- Origin correction: applied event-by-event to every topo-cluster based on its depth within the calorimeter and pseudorapidity to account for the position of the primary vertex.
- The 4-momentum of the individual topo-clusters initially points to the centre of the detector.
- The Origin Correction corrects the topo-cluster 4-momentum to point to the primary vertex of the hard scattering.
- The Origin Correction results in a dramatic improvement in the η resolution of the jets ($\sigma(\eta_{\text{reco}} - \eta_{\text{truth}})$):



Pileup correction

- First, the jet area-based subtraction of the per-event pileup contribution to the jet pT is performed.
- Jet area (A): a measure of the susceptibility of the jet to pileup (from the number of ghost particles) associated with a jet after clustering.
- Median of the jet pT density (an estimate of the pileup contribution)
 $\rho = \text{median}(p_T \times A)$
- Determined event-by-event using k_T jets with $R = 0.4$ (more sensitive to soft radiation);

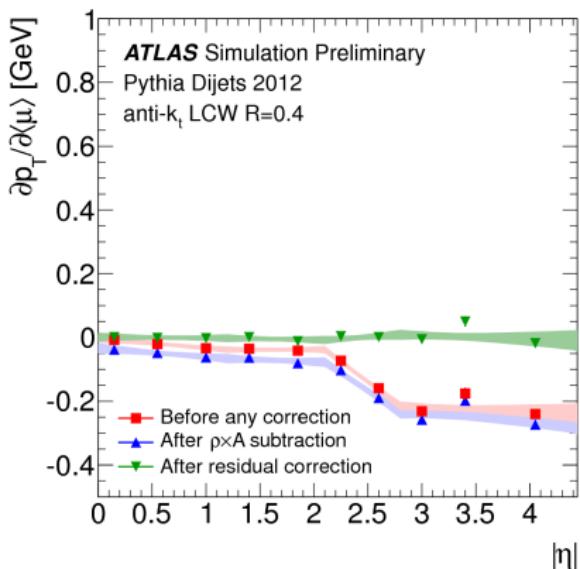
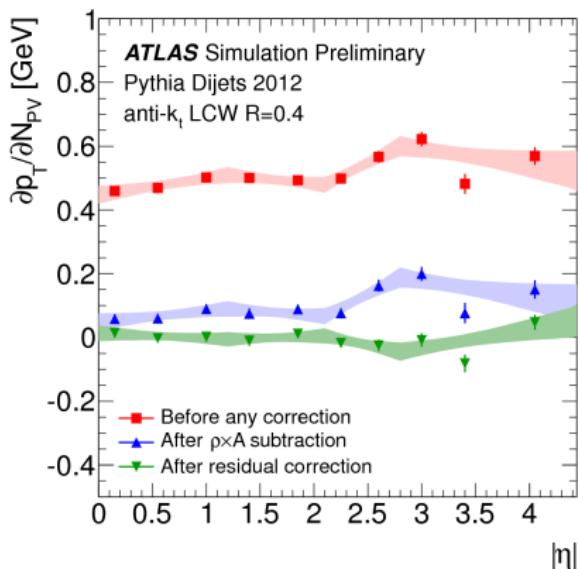
$$p_T^{\text{corr}} = p_T^{\text{reco}} - \rho \times A - \dots$$



Pileup residual correction

The residual p_T dependence on $N_{PV}(\alpha)$ and $\langle \mu \rangle(\beta)$ are observed to be fairly linear and independent of one another.

$$p_T^{\text{corr}} = p_T^{\text{reco}} - \rho \times A - \alpha \times (N_{PV} - 1) - \beta \times \langle \mu \rangle$$



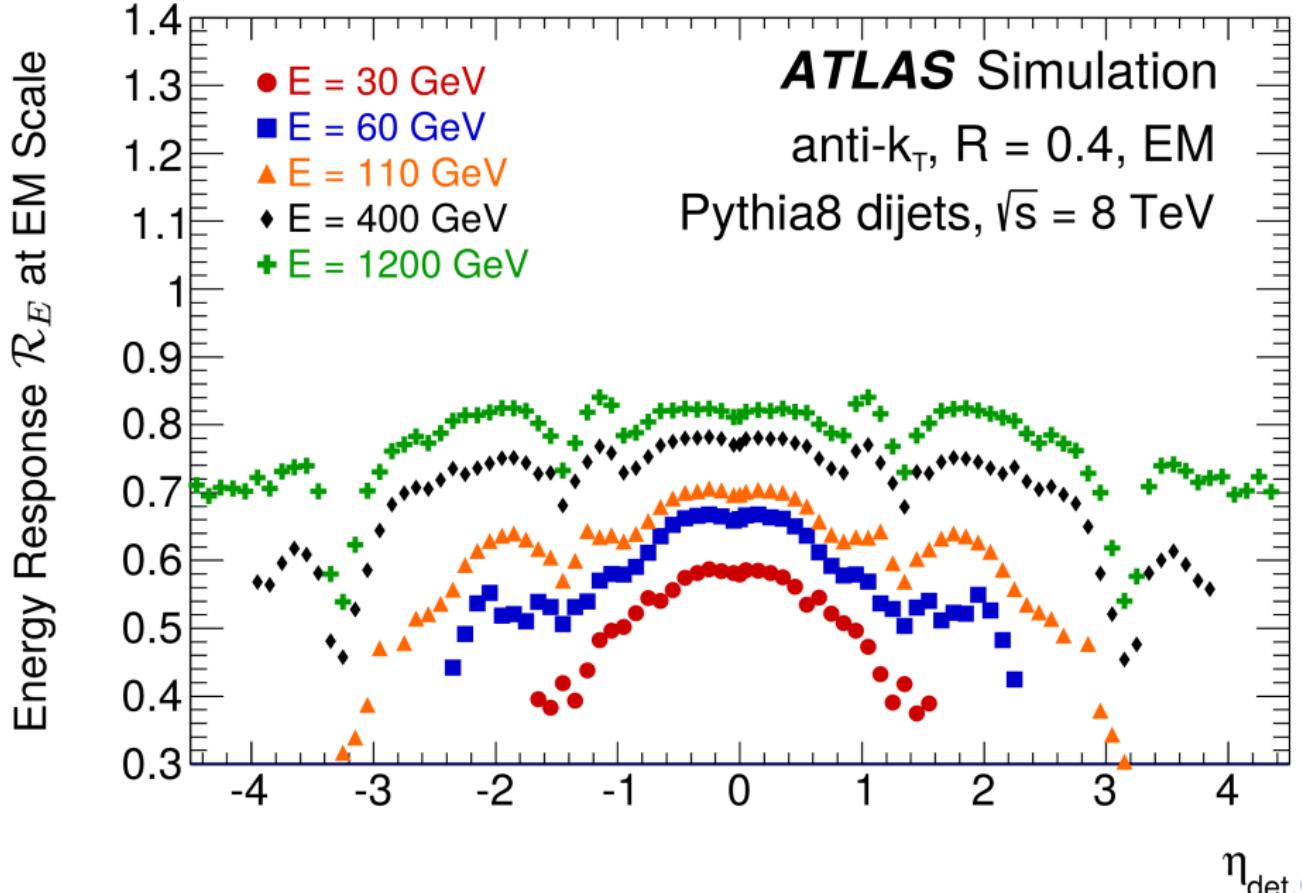
Jet energy : Monte Carlo absolute calibration

After the reconstruction, jets are calibrated to the energy scale of truth jets in order to compensate for detector-and reconstruction-based limitations:

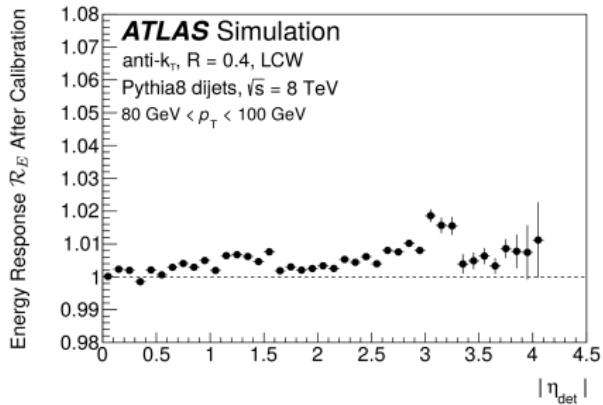
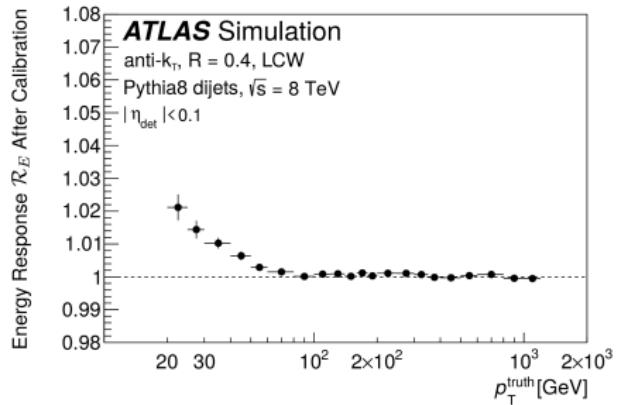
- Calorimeter non-compensation: correction for the different scales of the energy measured from hadronic and EM showers.
- Dead material: energy lost in inactive areas of the detector.
- Leakage: showers reaching the outer edge of the calorimeters.
- Out of calorimeter jet: energy of particles which are included in the truth jet but not in the reco jet.
- Energy deposits below noise thresholds: correction needed for particles which do not form clusters and shower parts falling outside the topo-clusters.
- Pileup: additional energy deposits from particles from multiple pp collisions in the same/different bunch crossings.

All stages correct the 4-momentum, scaling the jet energy and mass.

MC calibration



MC calibration



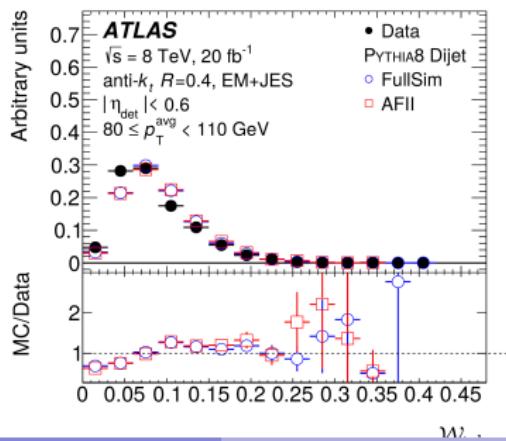
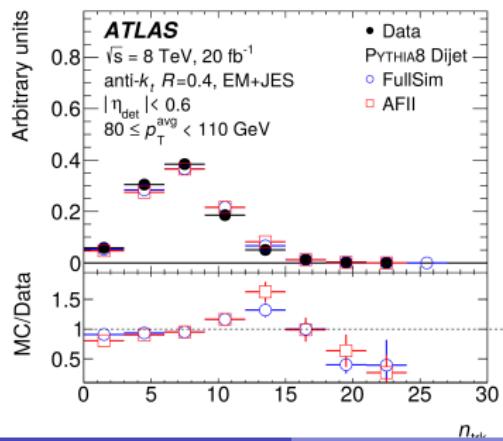
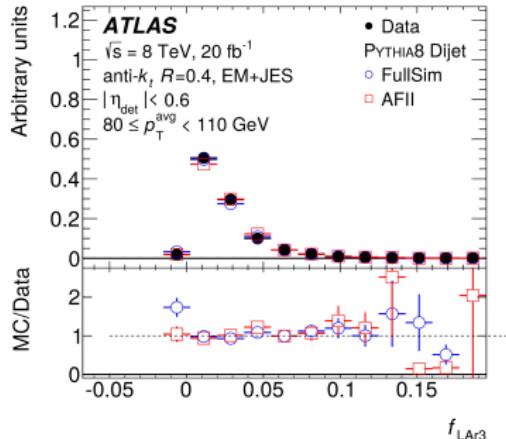
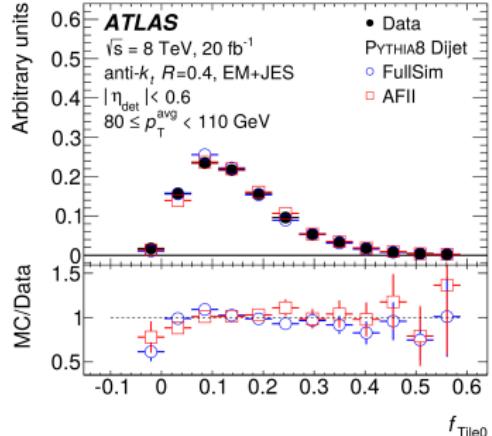
GSC calibration

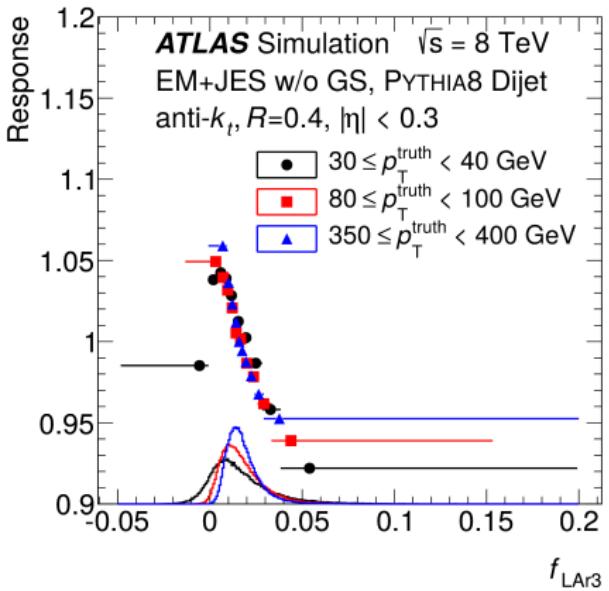
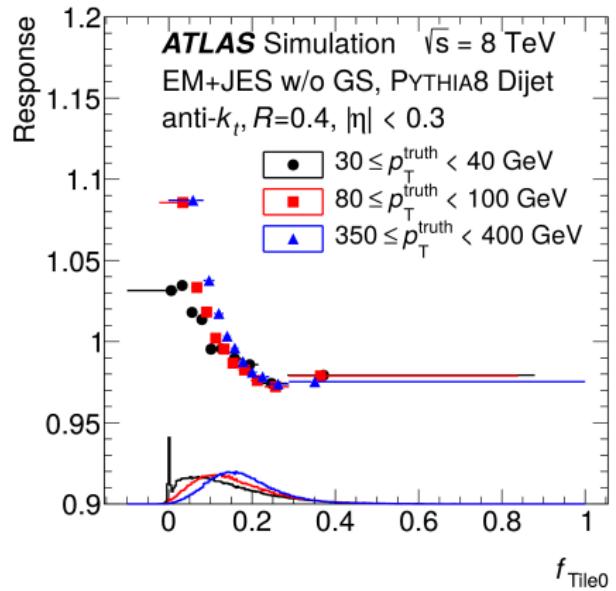
The GSC improves the resolution leaving unaffected the average energy response by applying a series of independent multiplicative corrections to:

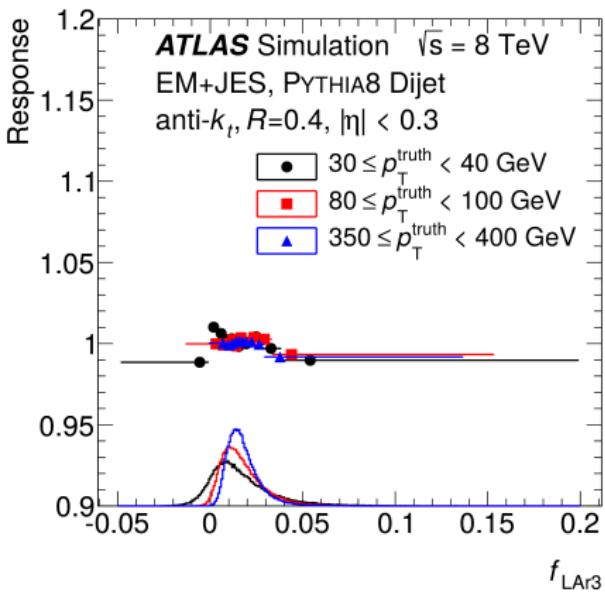
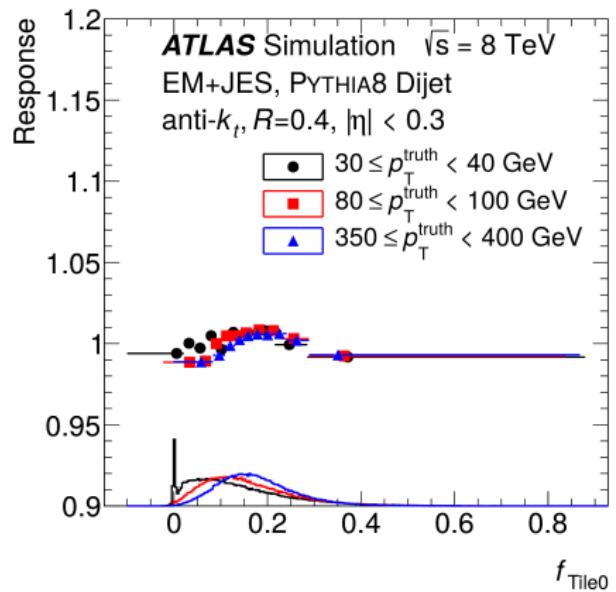
- reduce the JES flavour dependence (quark- vs. gluon-jets);
- adjust the energy loss due to punch-through (hadronic energy deposited beyond the calorimeter system);
- adjust for calorimeter non-compensation (differences in detector response to hadrons vs. leptons and photons)

The 5 (5+1) stages of the GSC applied to EM (PFlow) jets are:

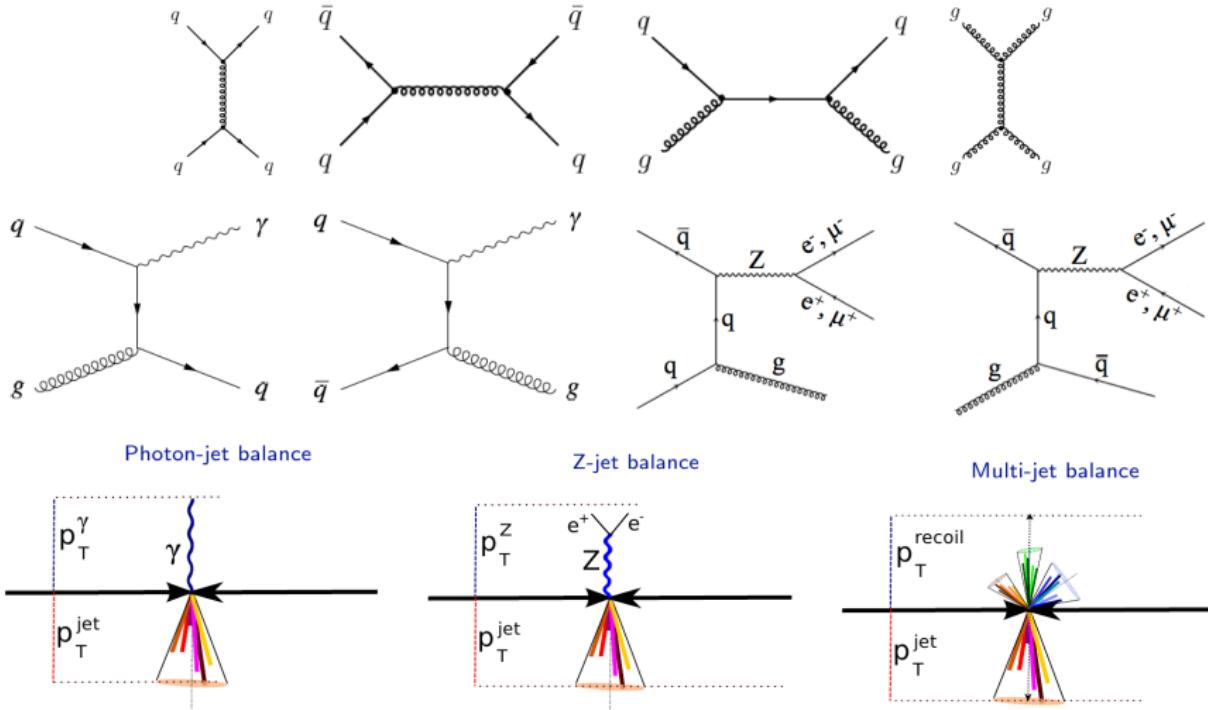
- f_{charged} : jet pT fraction measured from ghost-associated tracks;
- $f_{\text{Tile}0}$: jet energy fraction measured in the 1st layer of the Tile calorimeter;
- $f_{\text{LAr}3}$: jet energy fraction measured in the 3rd layer of the EM LAr calorimeter;
- n_{trk} : number of tracks ghost-associated with the jet;
- w_{trk} : average p_T weighted transverse distance in the $\eta - \phi$ plane between the jet axis and all ghost-associated tracks;
- n_{segments} : number of muon segments ghost-associated with the jet.



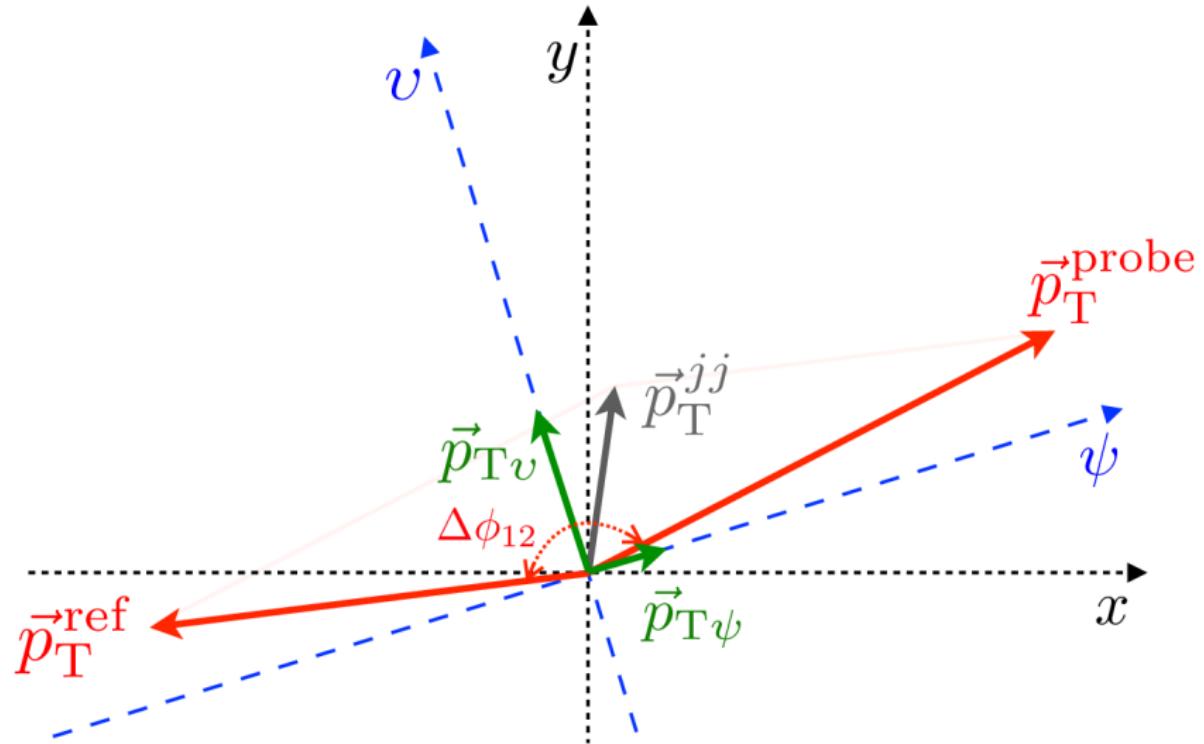




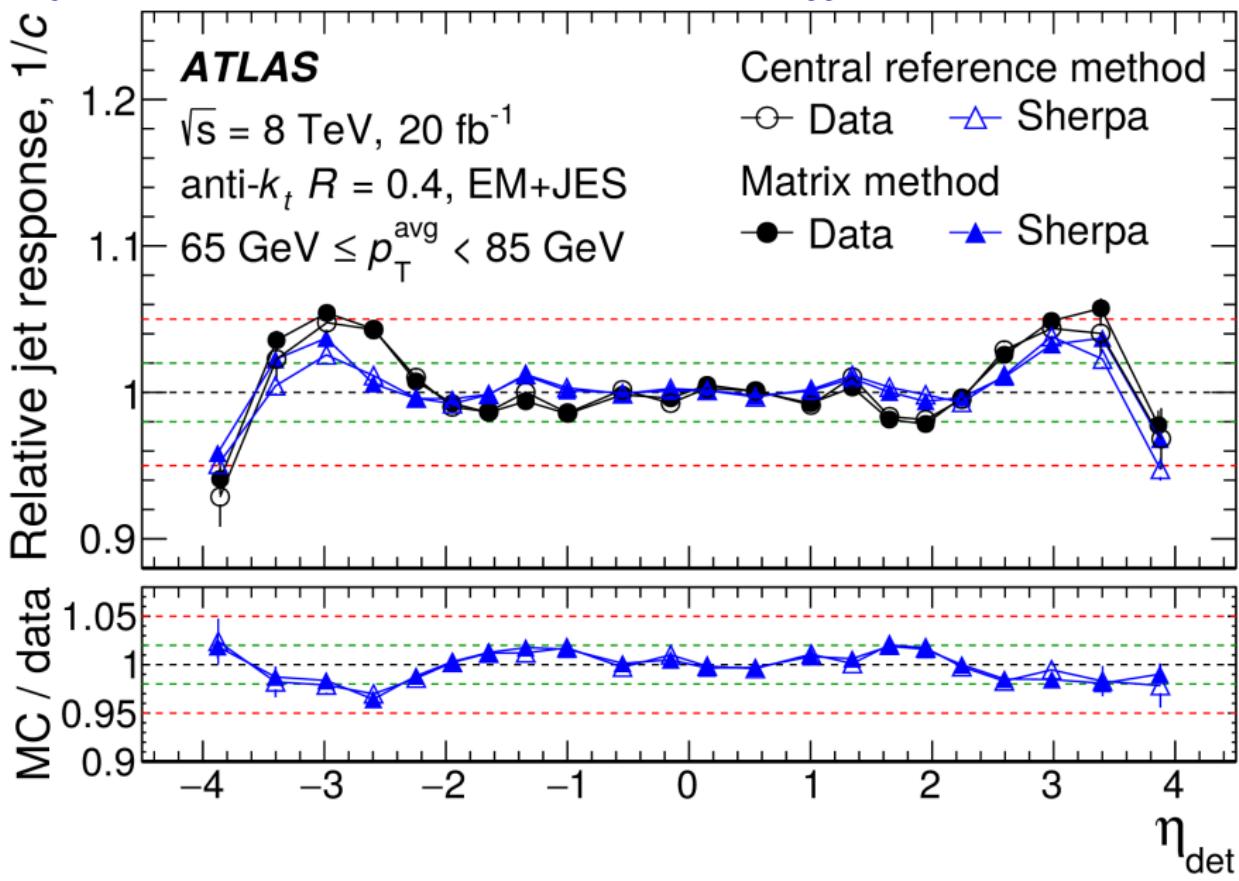
Calibration in situ



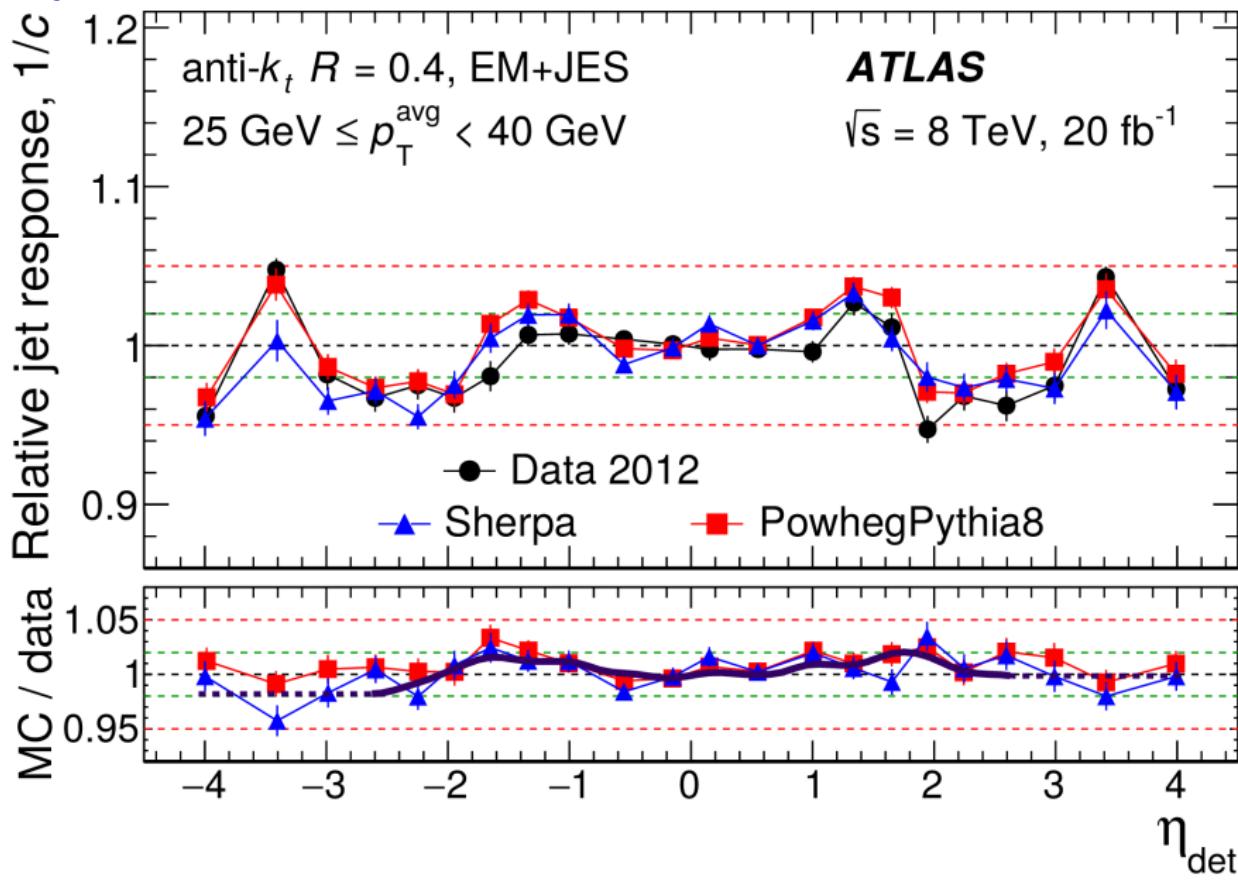
Dijet intercalibration



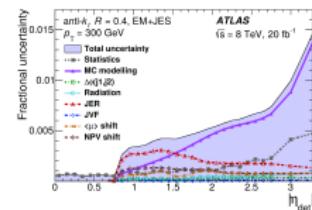
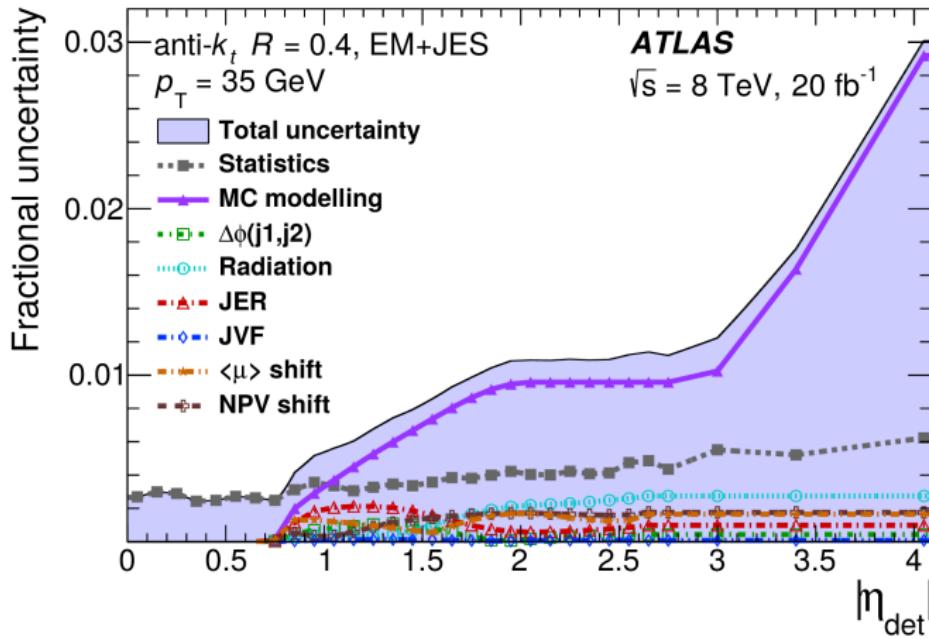
Dijet intercalibration: matrix vs single reference



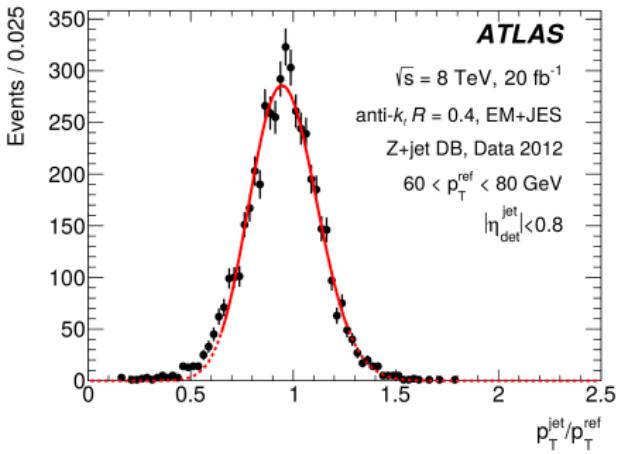
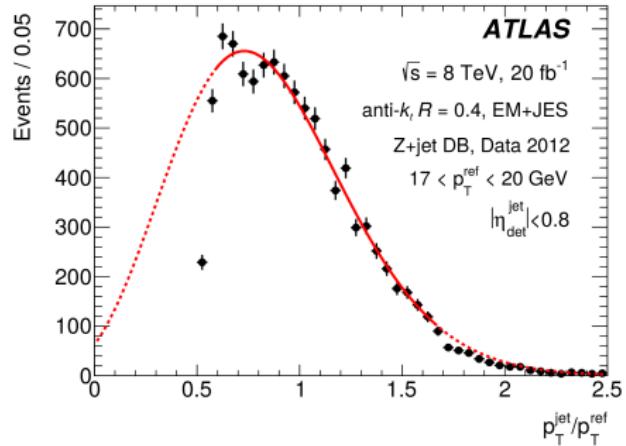
Dijet intercalibration calibration factors



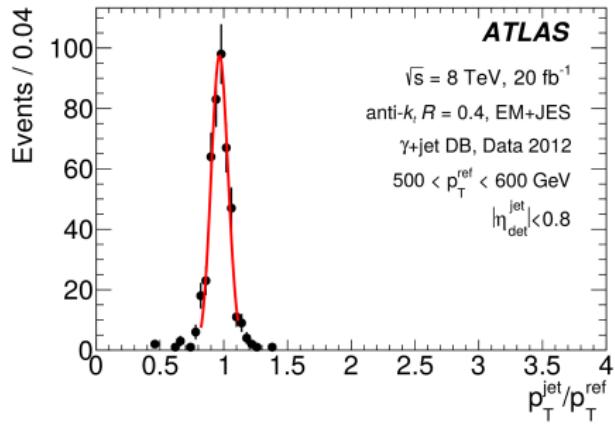
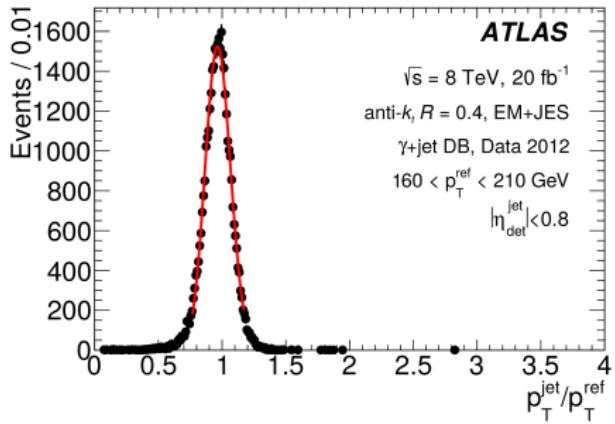
Dijet intercalibration uncertainties



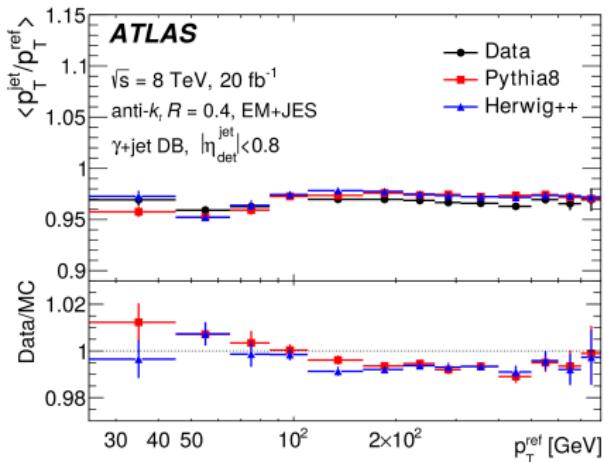
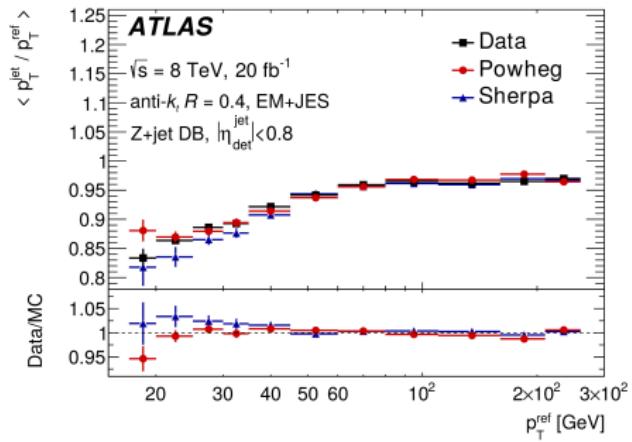
Direct balance Zjet



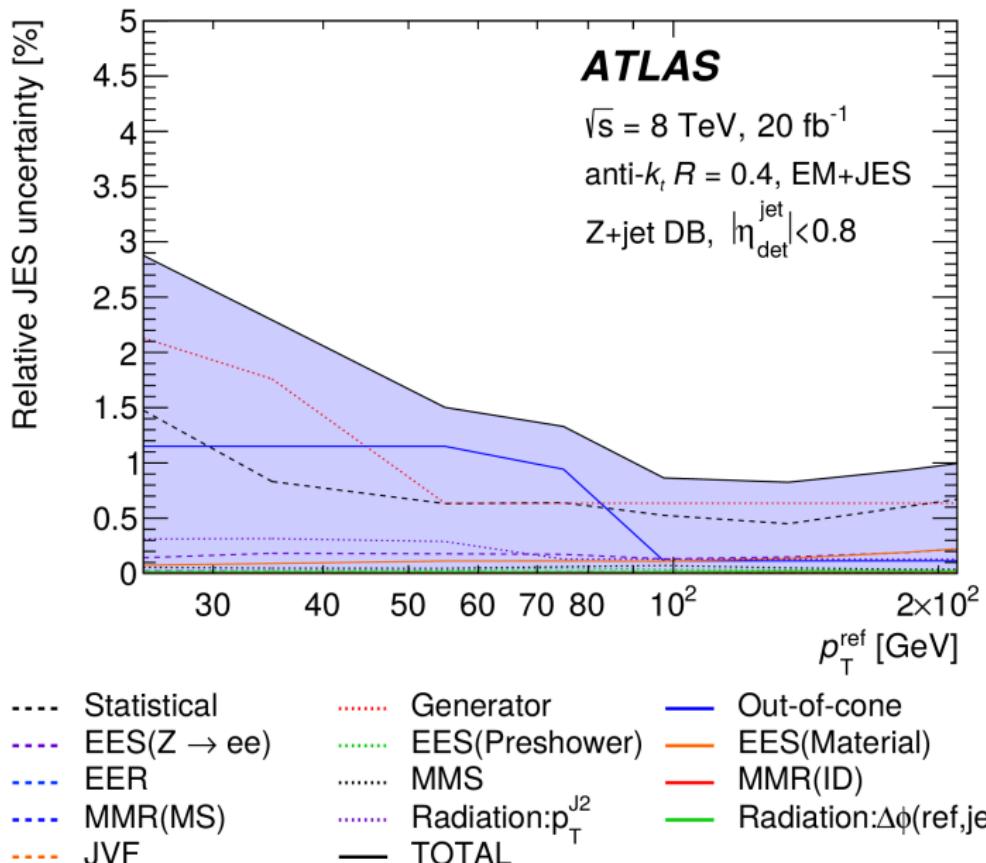
Direct balance Gjet



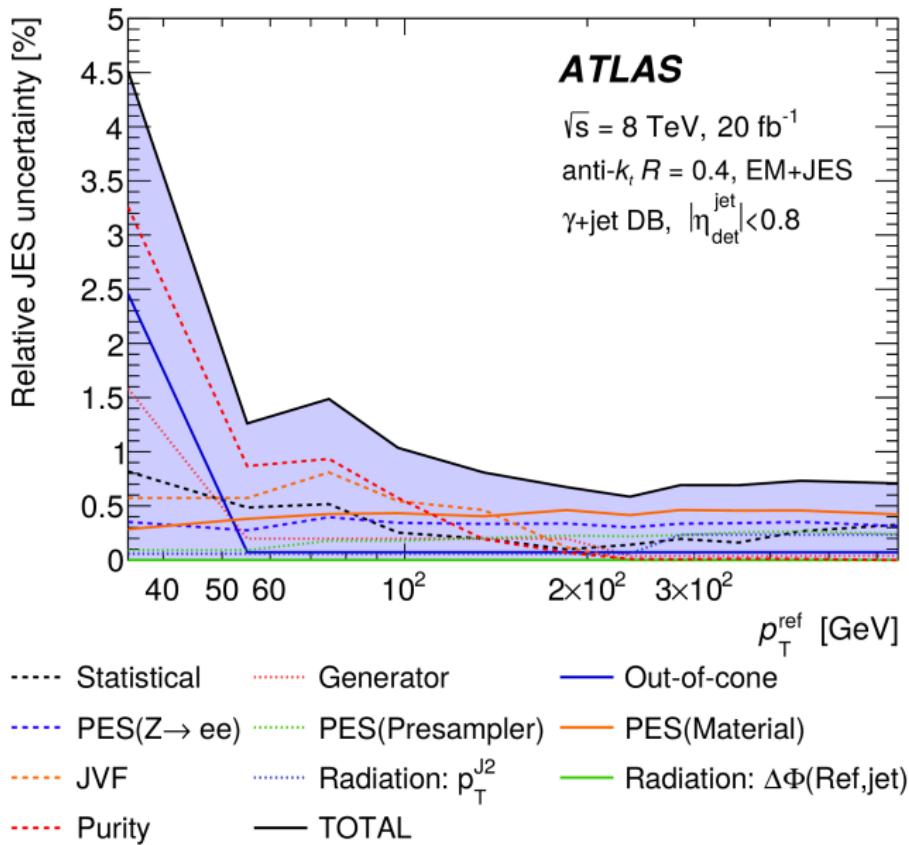
Direct balance response



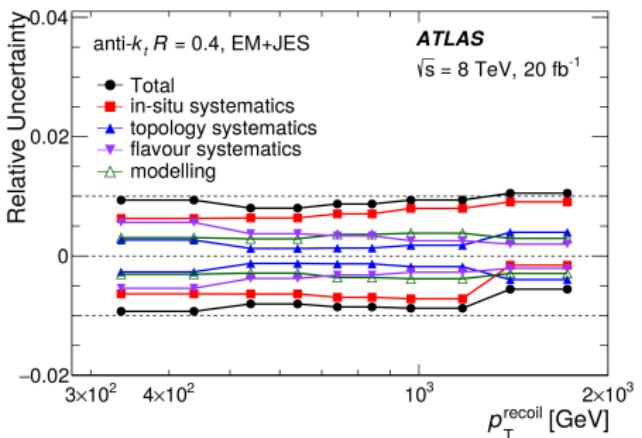
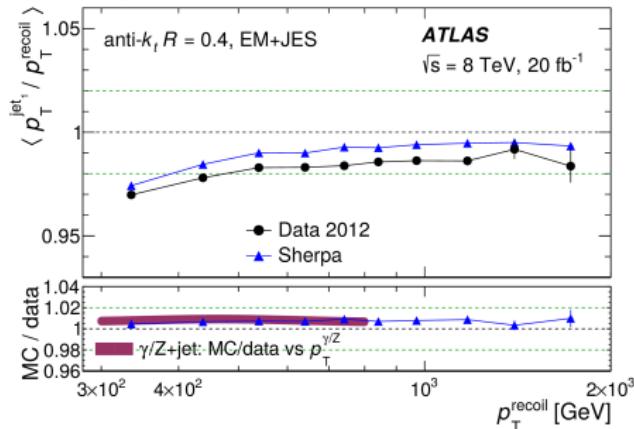
Direct balance uncertainty



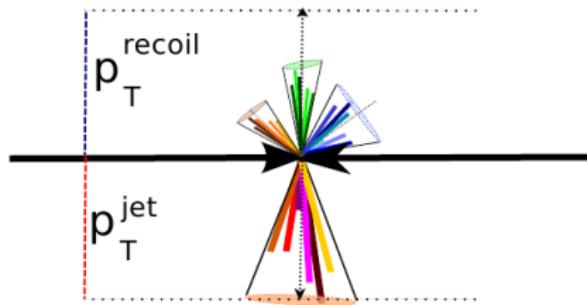
Direct balance uncertainty



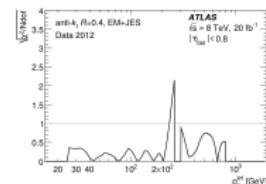
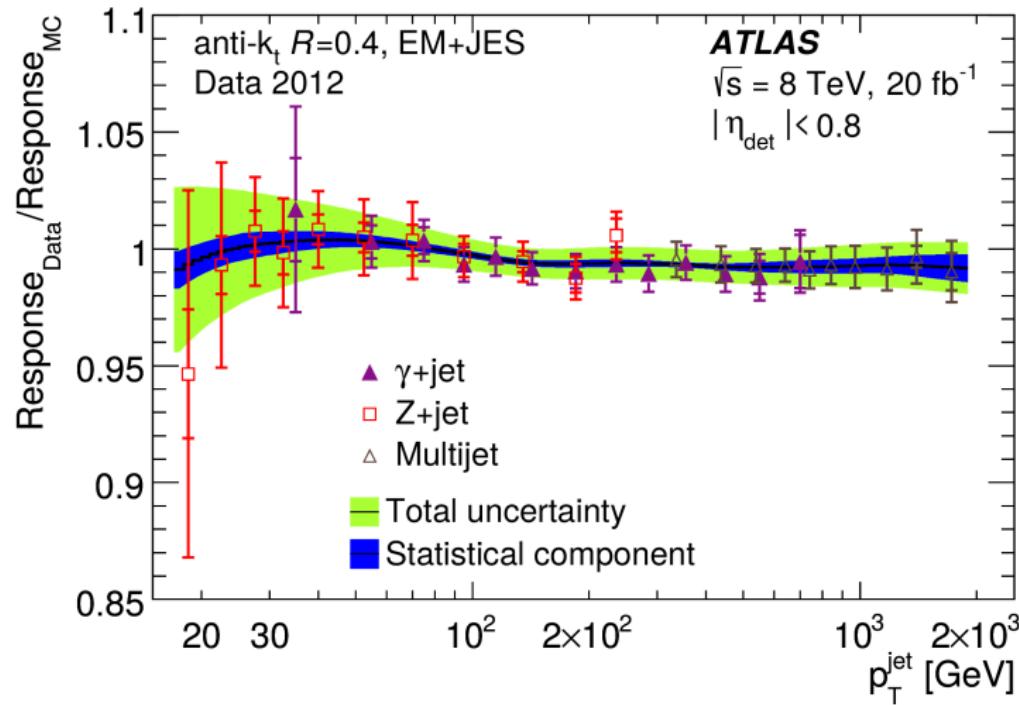
Multi-jet balance



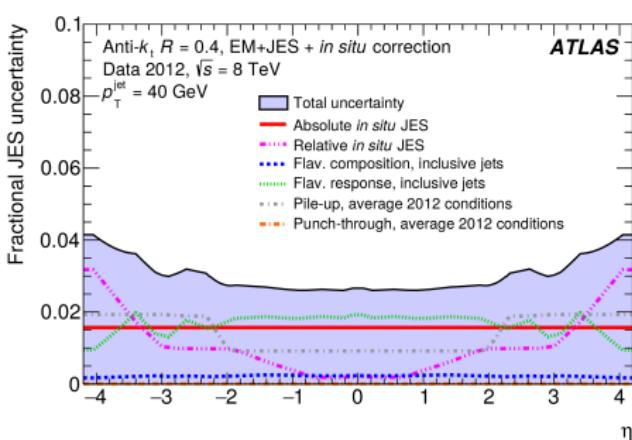
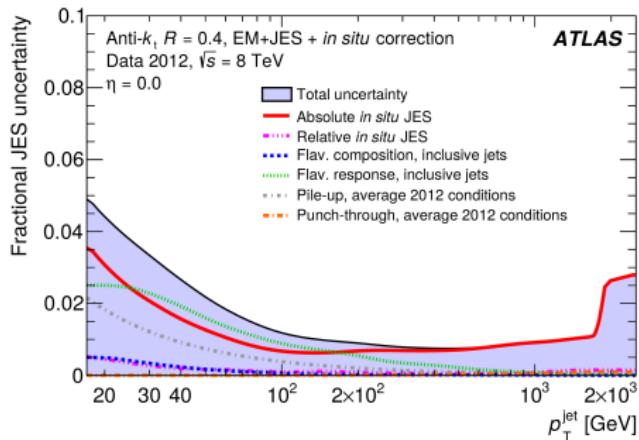
Multi-jet balance



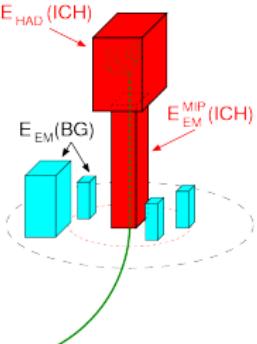
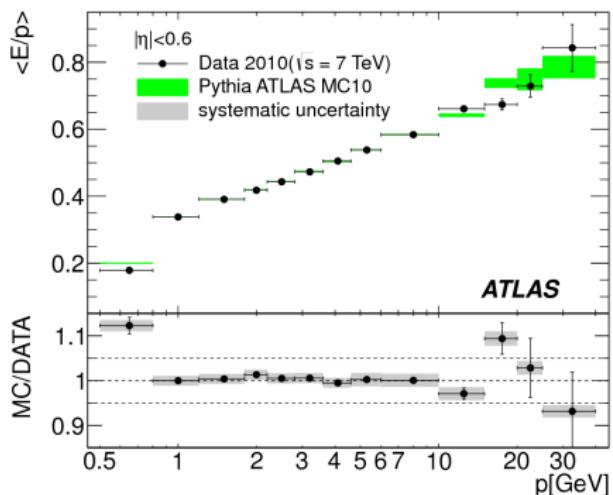
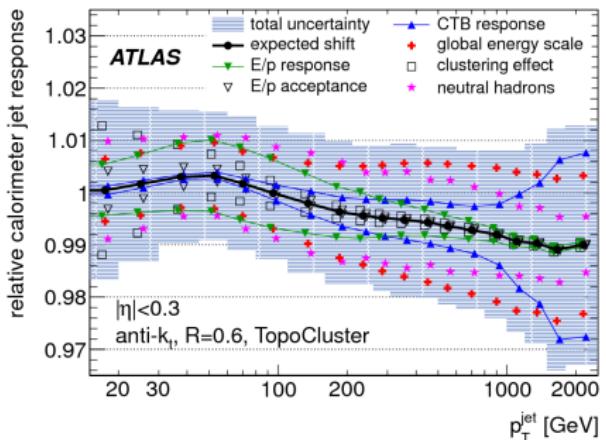
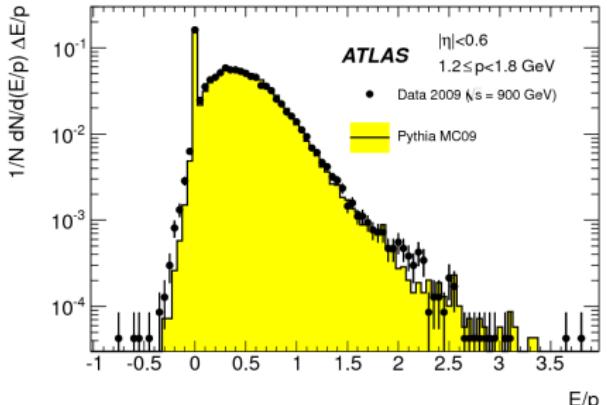
Combination



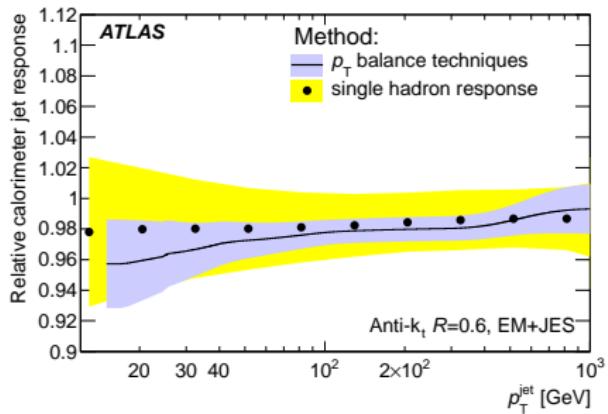
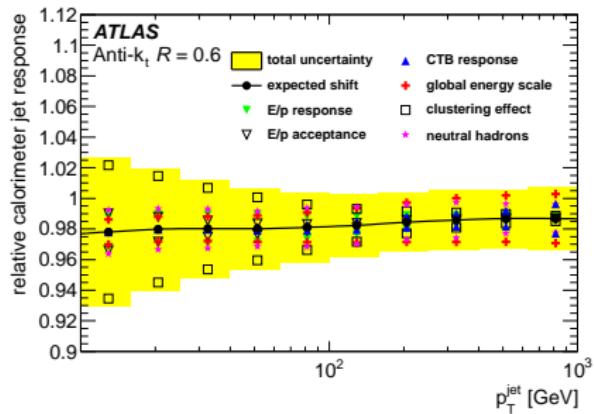
Final JES precision



Final JES precision single particles



Single hadron response vs p_T balance

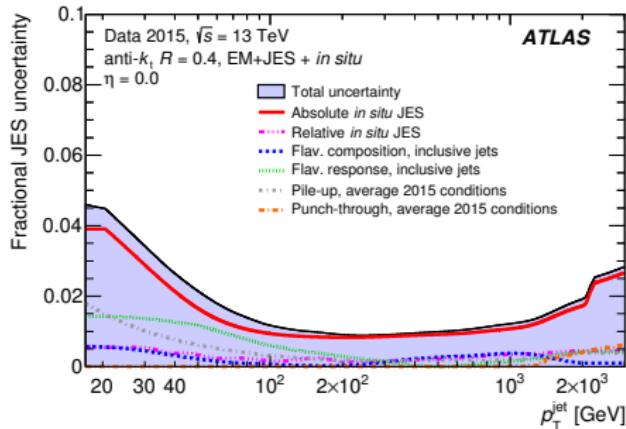
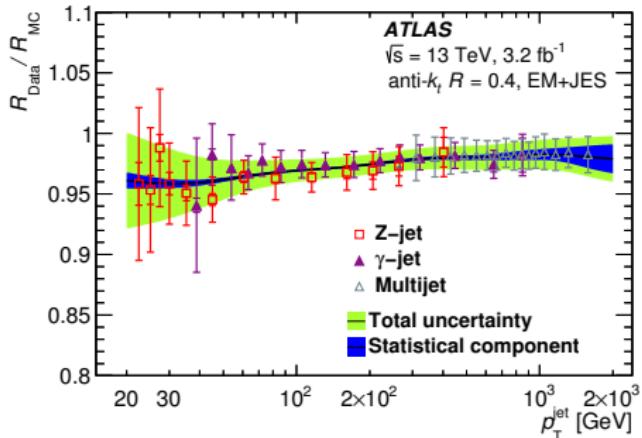


Final JES precision

Name	Description	Category
Z+jet		
e E-scale material	Material uncertainty in electron energy scale	det.
e E-scale presampler	Presampler uncertainty in electron energy scale	det.
e E-scale baseline	Baseline uncertainty in electron energy scale	mixed
e E-scale smearing	Uncertainty in electron energy smearing	mixed
μ E-scale baseline	Baseline uncertainty in muon energy scale	det.
μ E-scale smearing ID	Uncertainty in muon ID momentum smearing	det.
μ E-scale smearing MS	Uncertainty in muon MS momentum smearing	det.
MC generator	Difference between MC generators	model
JVF	JVF choice	mixed
$\Delta\phi$	Extrapolation in $\Delta\phi$	model
Out-of-cone	Contribution of particles outside the jet cone	model
Subleading jet veto	Variation in subleading jet veto	model
Statistical components	Statistical uncertainty	stat./meth.
γ +jet		
γ E-scale material	Material uncertainty in photon energy scale	det.
γ E-scale presampler	Presampler uncertainty in photon energy scale	det.
γ E-scale baseline	Baseline uncertainty in photon energy scale	det.
γ E-scale smearing	Uncertainty in photon energy smearing	det.
MC generator	Difference between MC generators	model
$\Delta\phi$	Extrapolation in $\Delta\phi$	model
Out-of-cone	Contribution of particles outside the jet cone	model
Subleading jet veto	Variation in subleading jet veto	model
Photon purity	Purity of sample in γ +jets	det.
Statistical components	Statistical uncertainty	stat./meth.
Multijet balance		
α selection	Angle between leading jet and recoil system	model
β selection	Angle between leading et and closest subleading jet	model
MC generator	Difference between MC generators (fragmentation)	mixed
p_T asymmetry selection	Asymmetry selection between leading and subleading jet	model
Jet p_T threshold	Jet p_T threshold	mixed
Statistical components	Statistical uncertainty	stat./meth.

Jet energy scale uncertainties

arXiv:1703.10485



- $\sim 1\%$ precision in the 80–1000 GeV range
- around 4% in the very low- p_T region
- similar results at 7,8 TeV and for CMS