Physics at the LHC

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November 13, 2019


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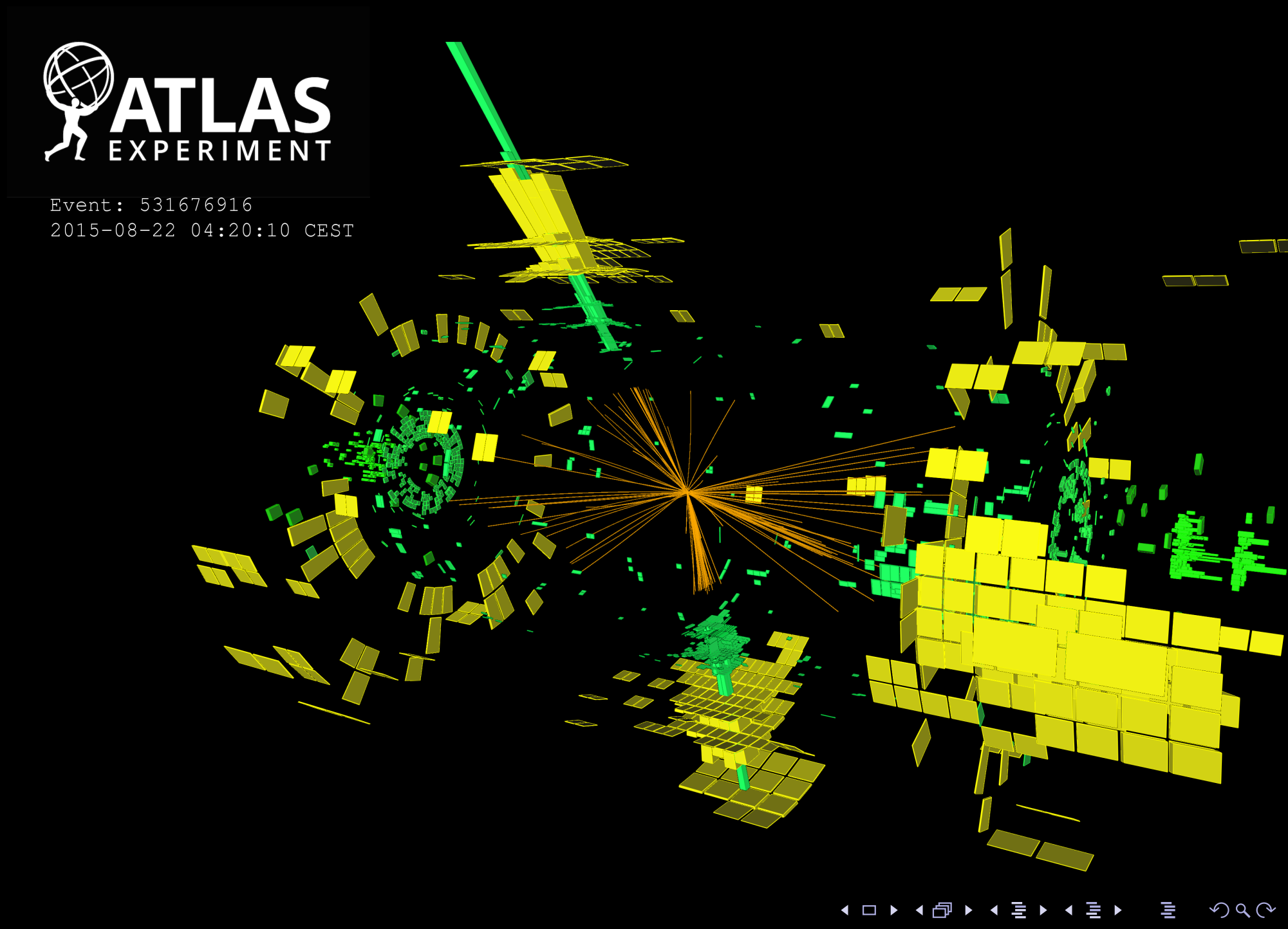
ATLAS
EXPERIMENT
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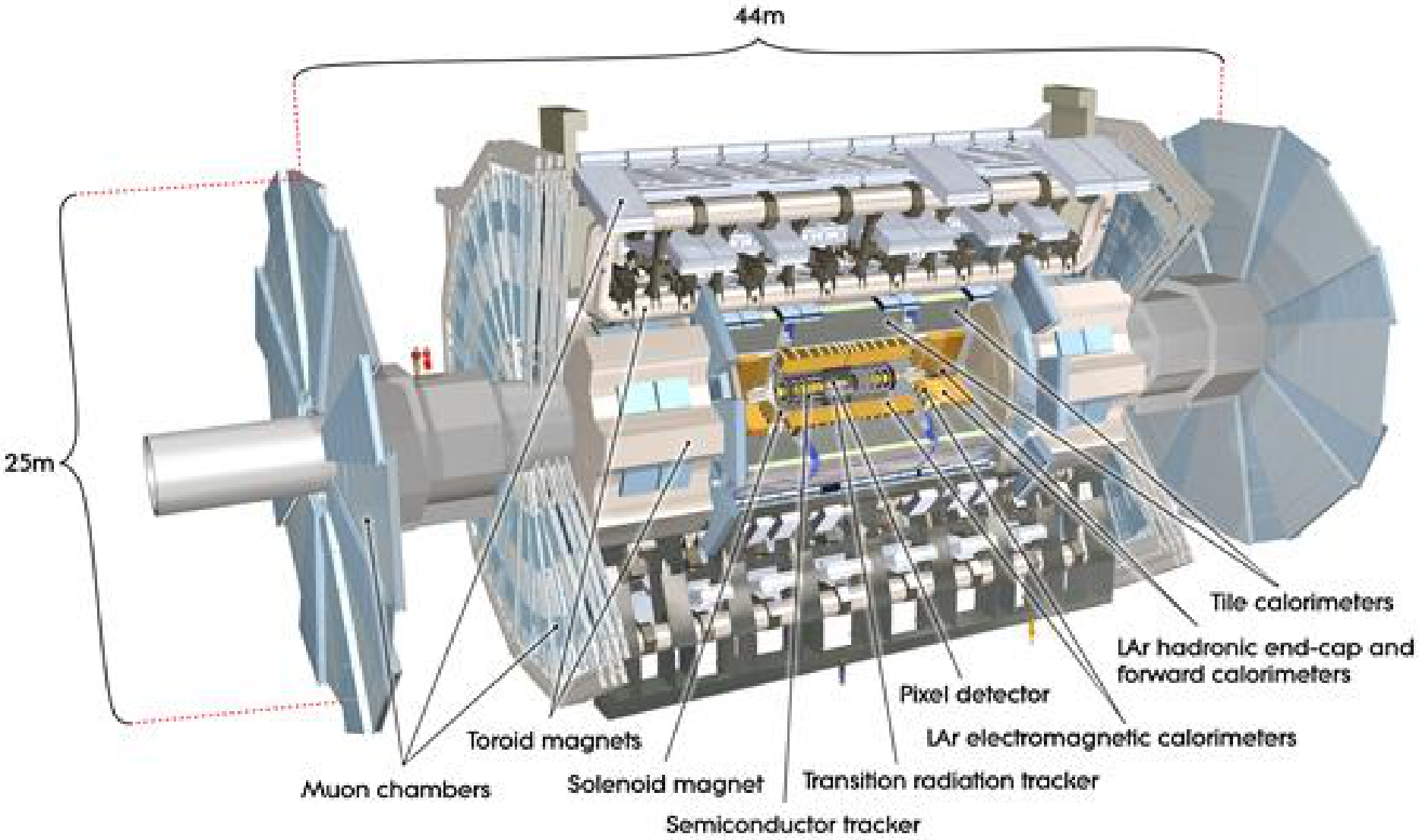
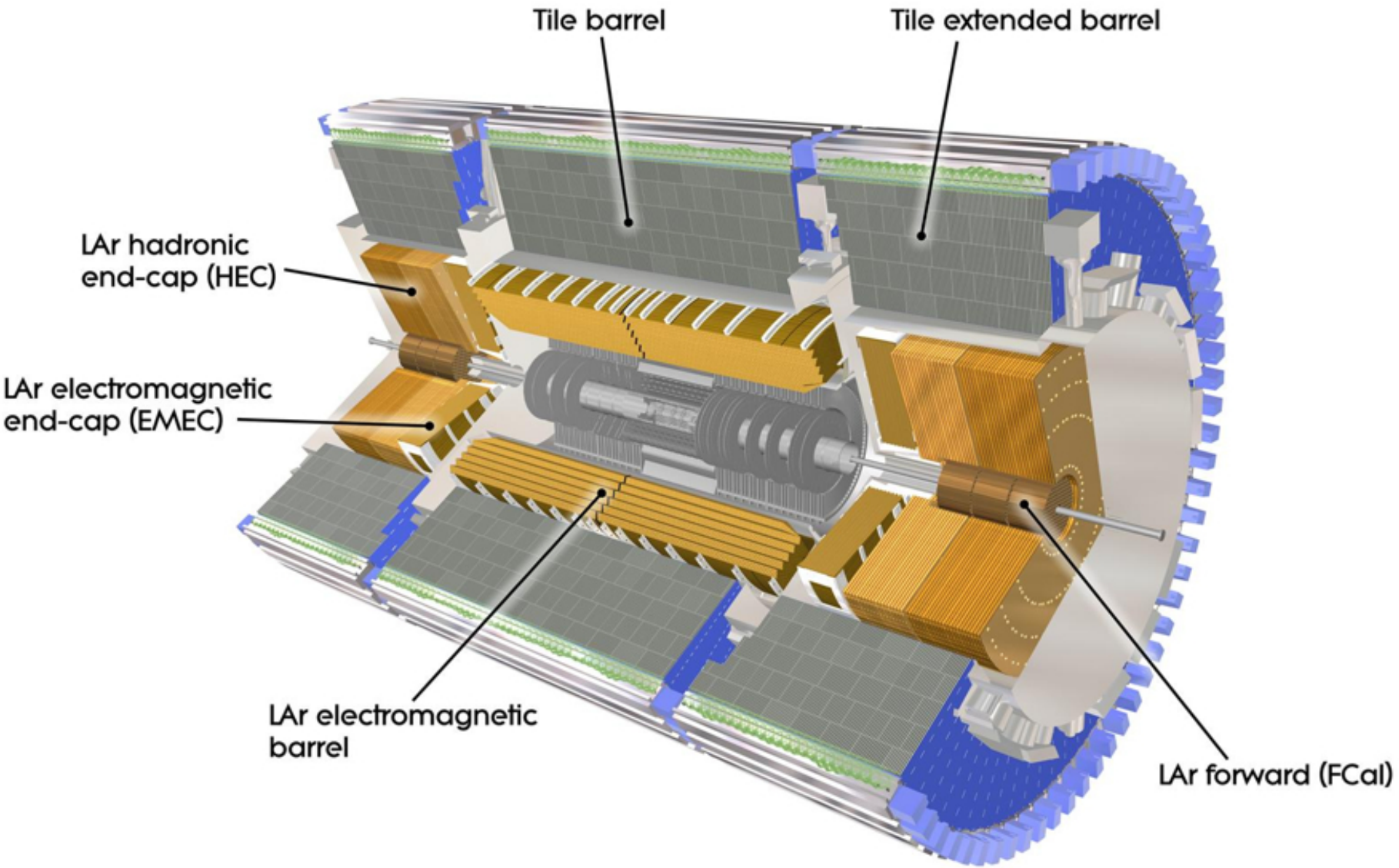
Outlook

- ATLAS detector
  - Calorimeters : electromagnetic and hadronic
- Jet definition, reconstruction and calibration
  - jet algorithms, infra-red stability, pileup, 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

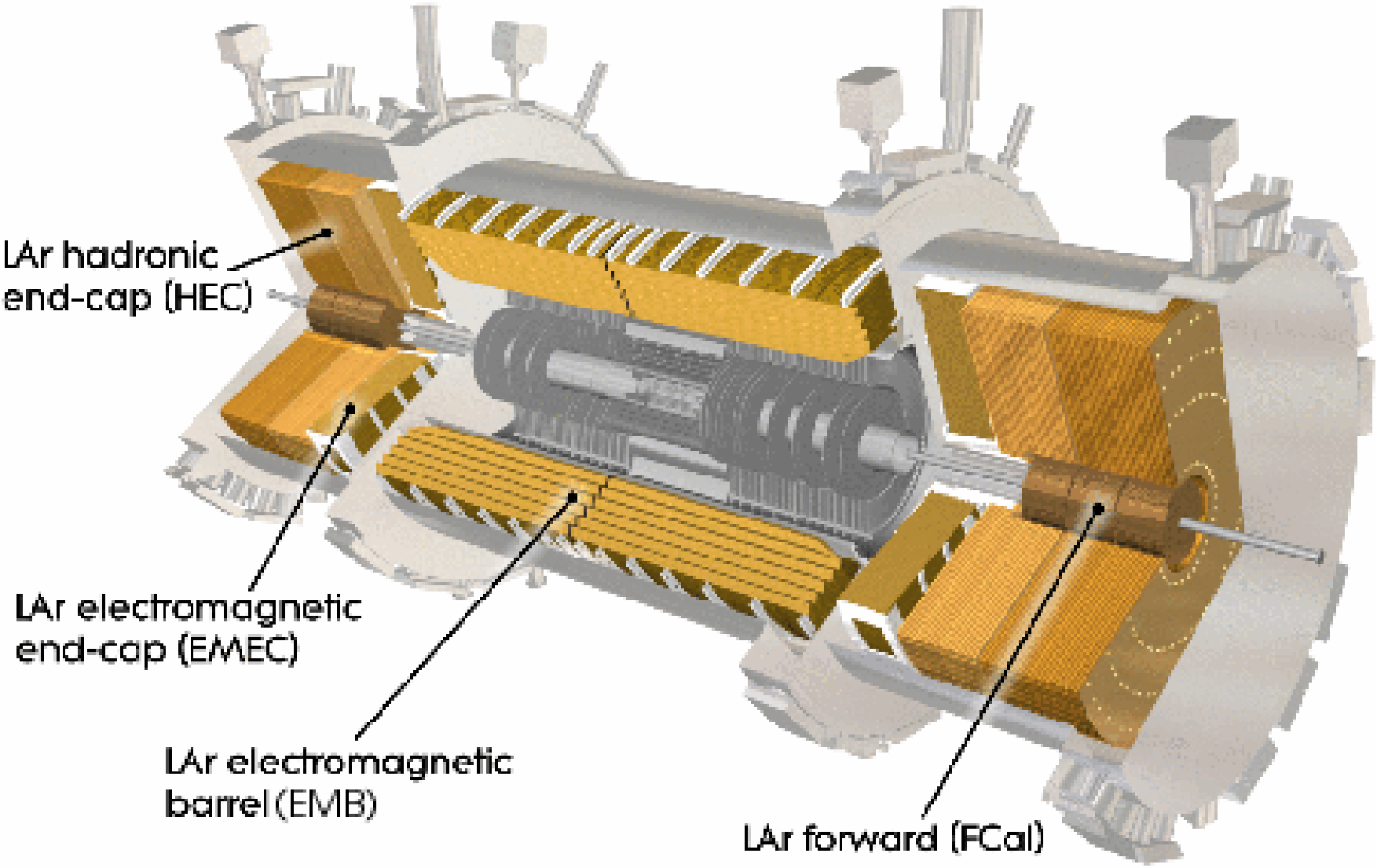
ATLAS detector



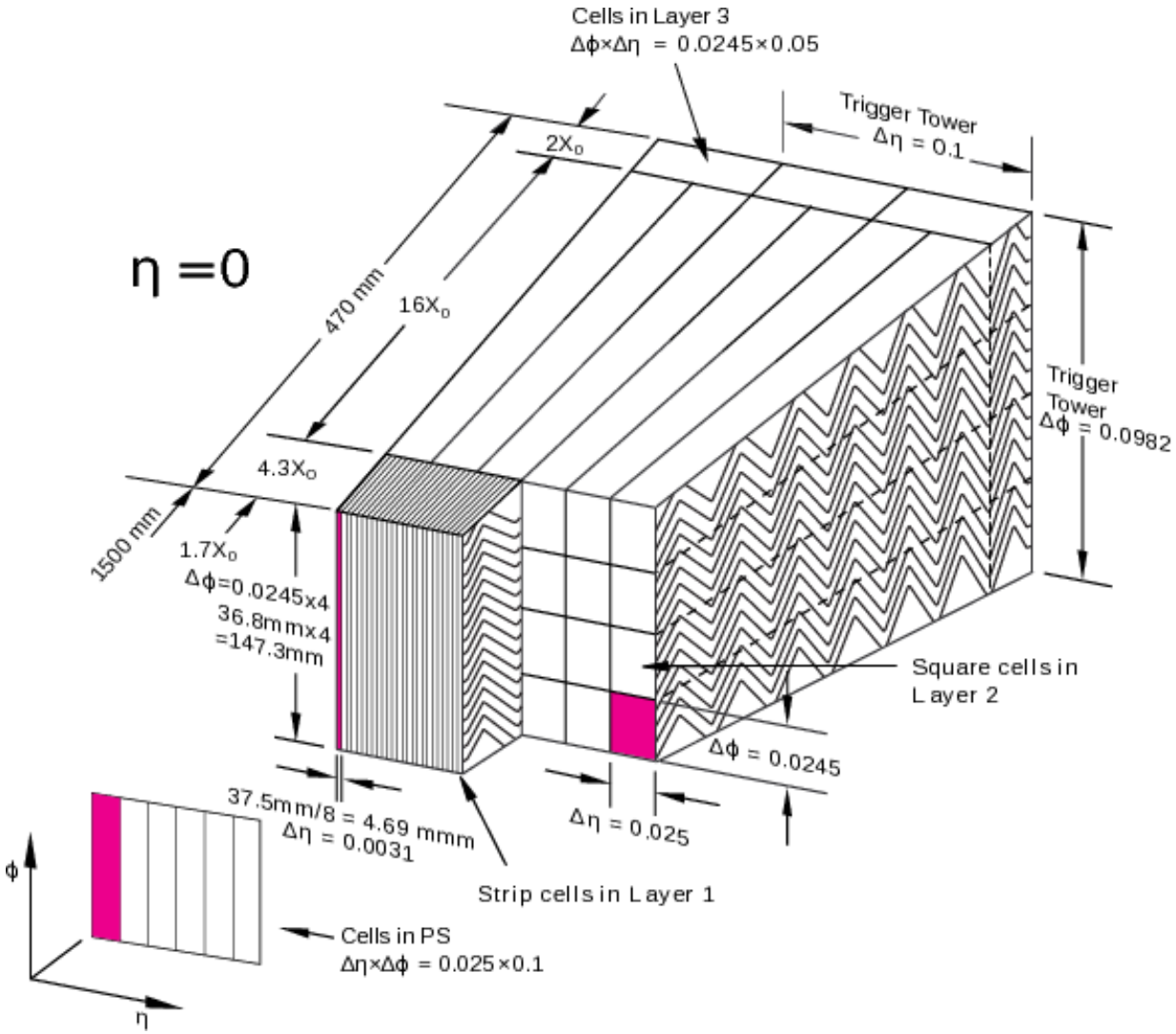
ATLAS Calorimeters

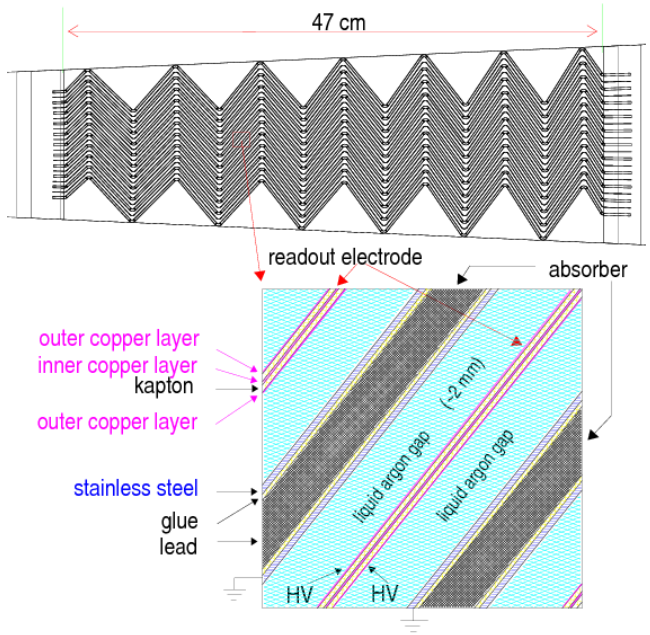


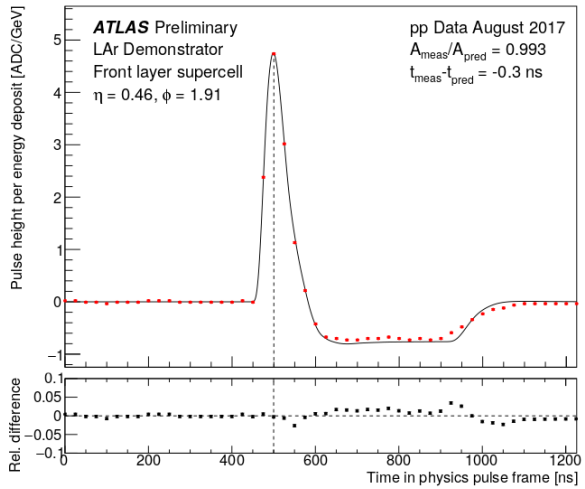
LAr Calorimeter



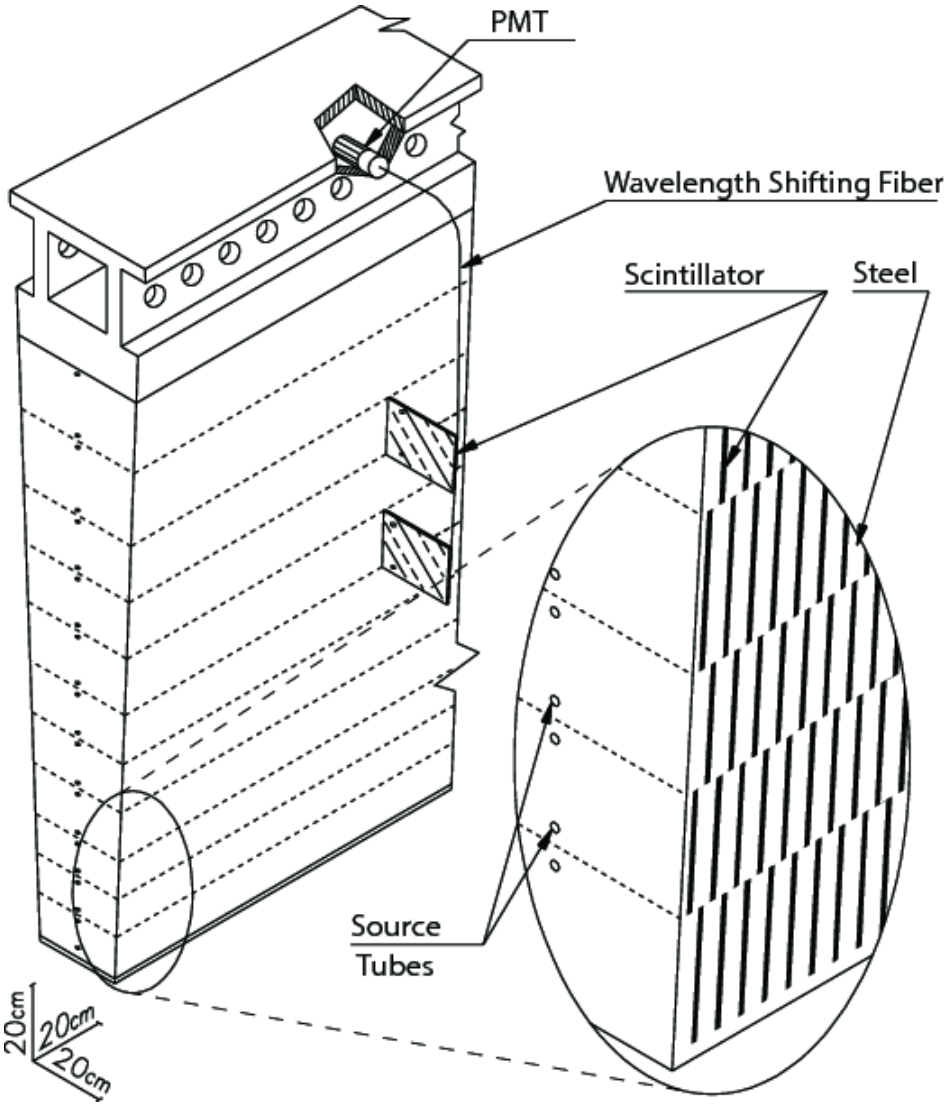
LAr Calorimeter

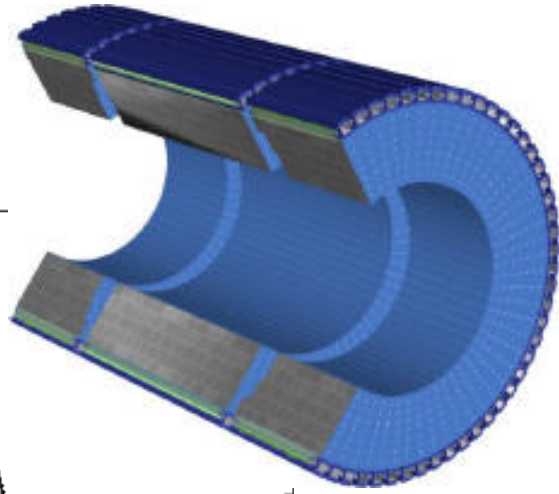


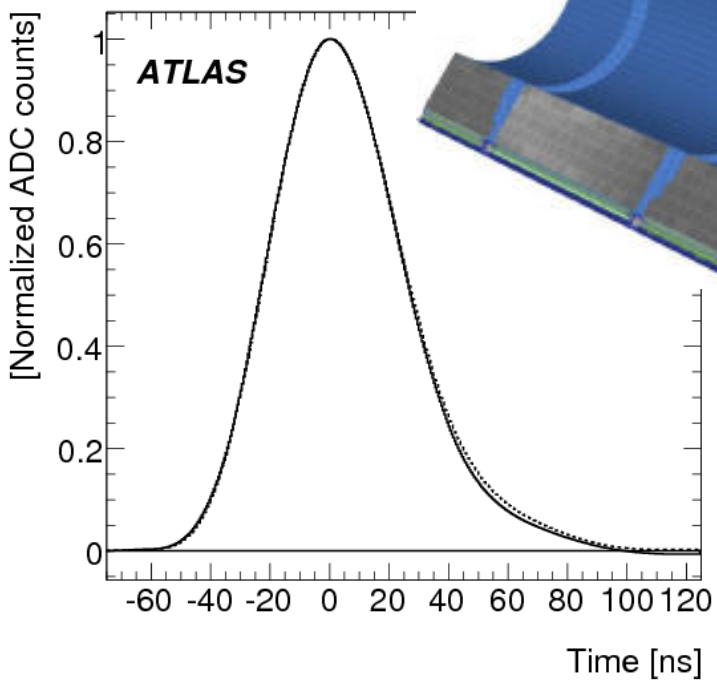


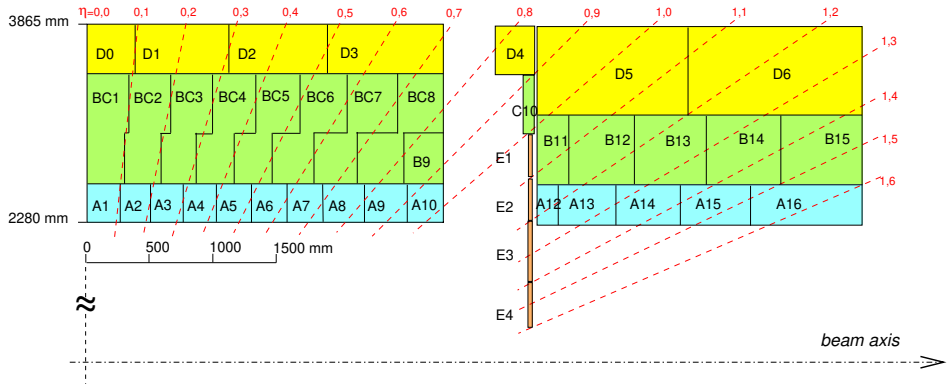


Tile Calorimeter



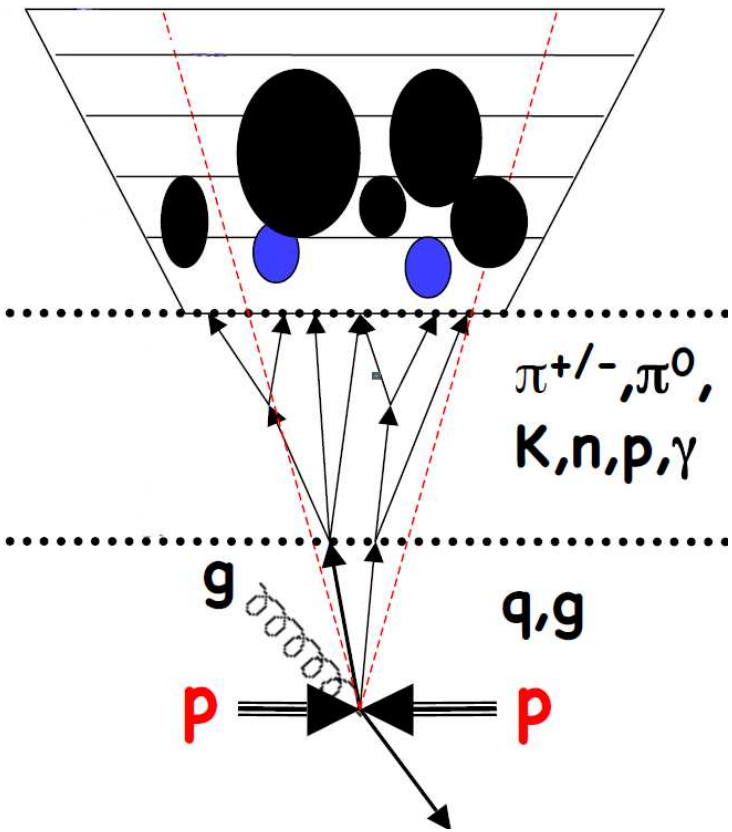






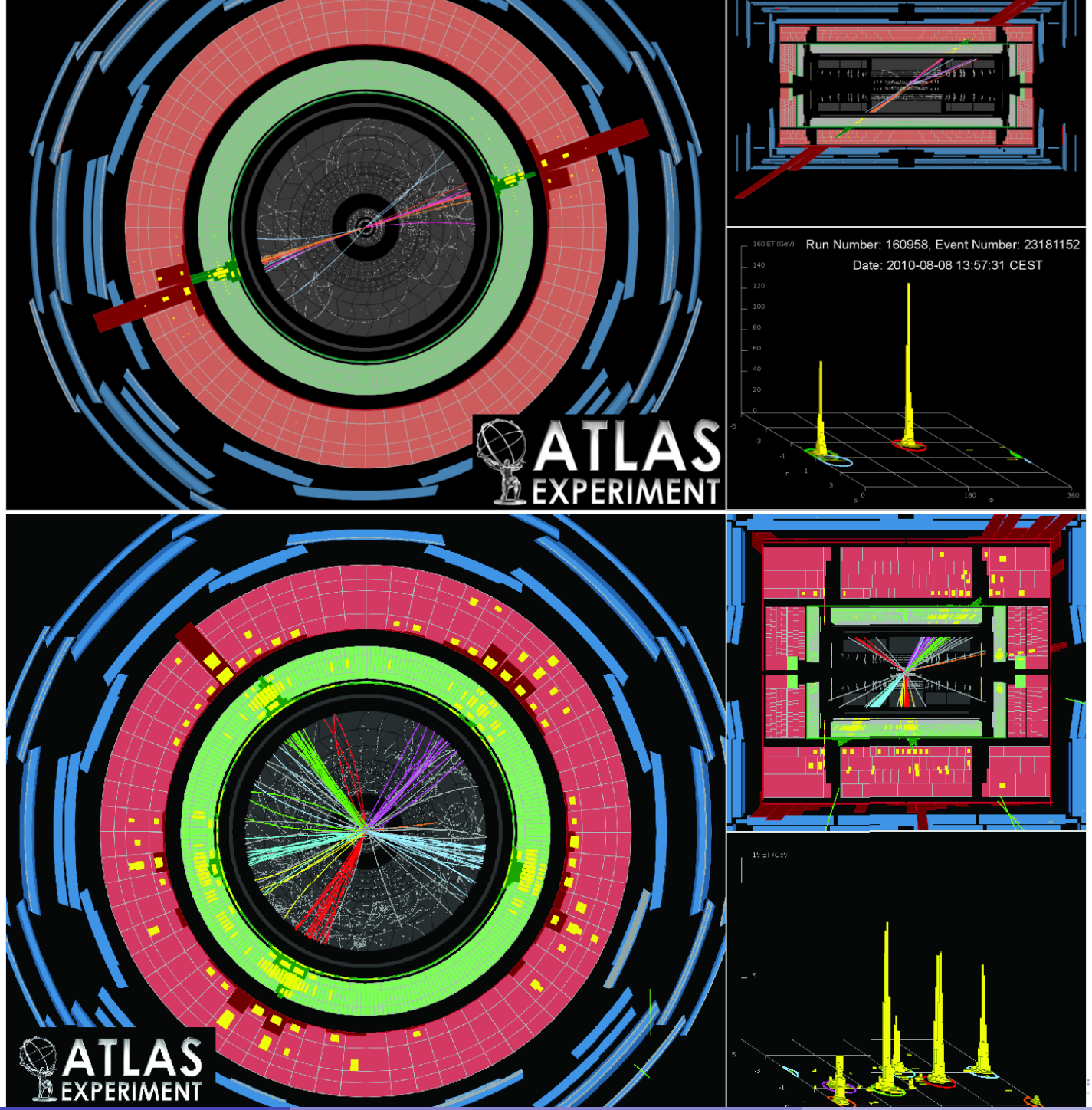
Tile Calorimeter

Hadron jet



- JET is a collimated spray of energetic hadrons
- HEP phenomena involving strong force $\rightarrow$ quarks/gluons
- partons fragment and hadronise into particles
- parton $\leftrightarrow$ jet (both ambiguous)
- Jet algorithm : set of rules to group constituents together

A good algorithm can be applied to experimental objects (cells, clusters, towers) AND fixed order calculations (LO, NLO, NNLO,...) AND parton shower MCs providing a common ground for the description of different types of events.


ATLAS
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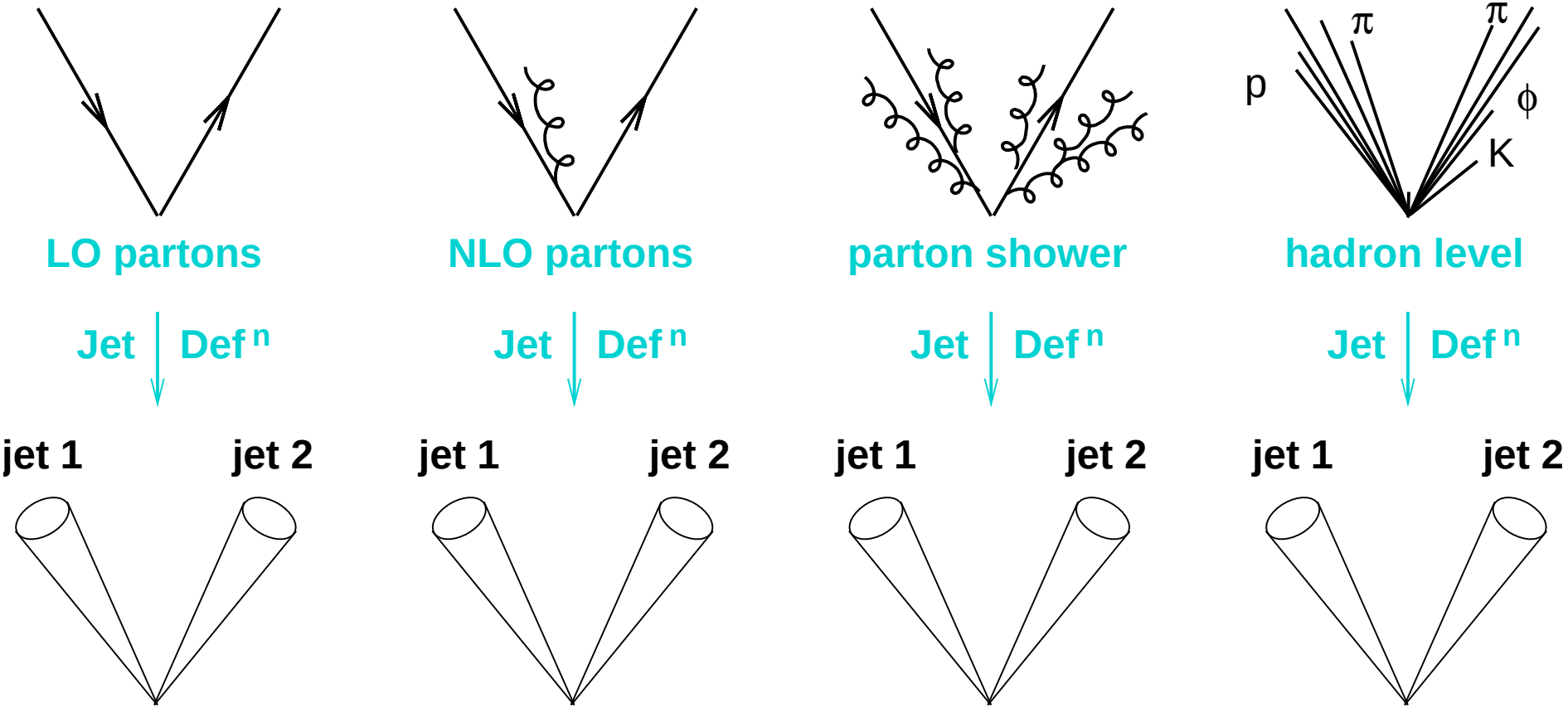
ATLAS
EXPERIMENT

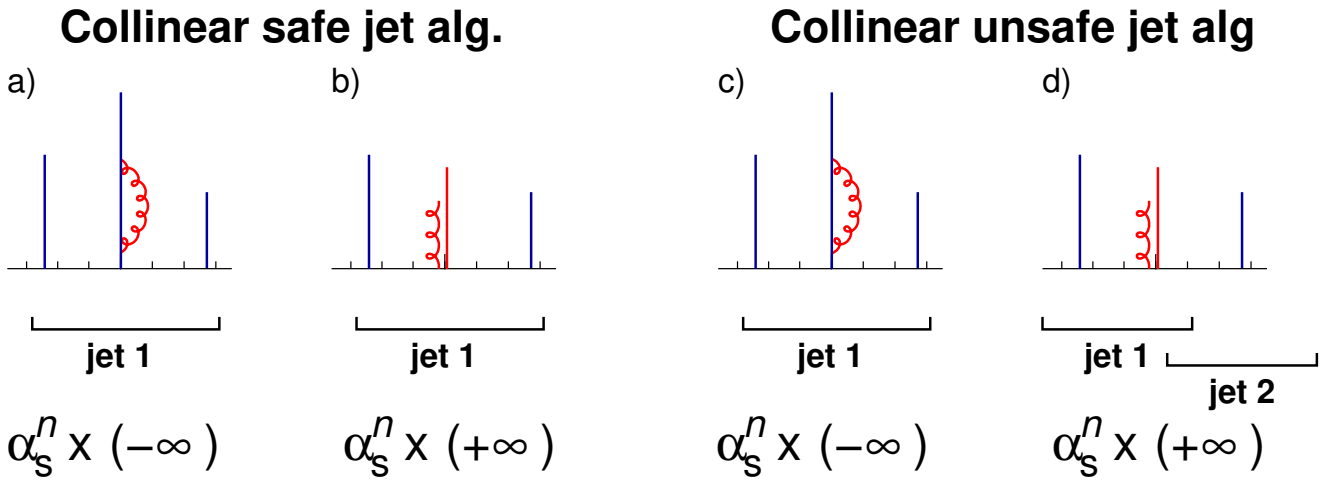
Jets as proxies to initiating partons



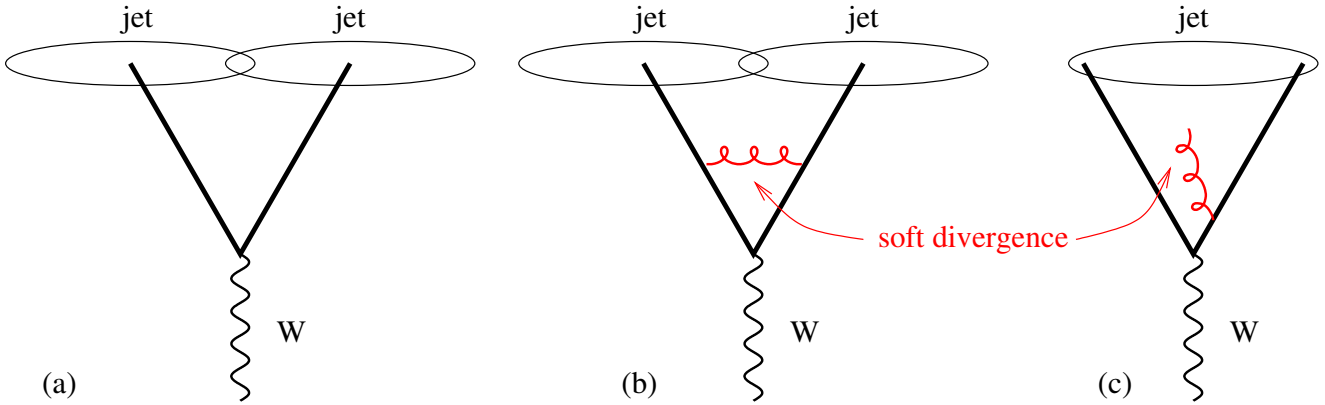
Jets should be stable against theory (radiation, underlying event, hadronisation) and experiment (noise, pile-up) effects

Jet algorithm : IRC safety

EPJC(2010)67:637



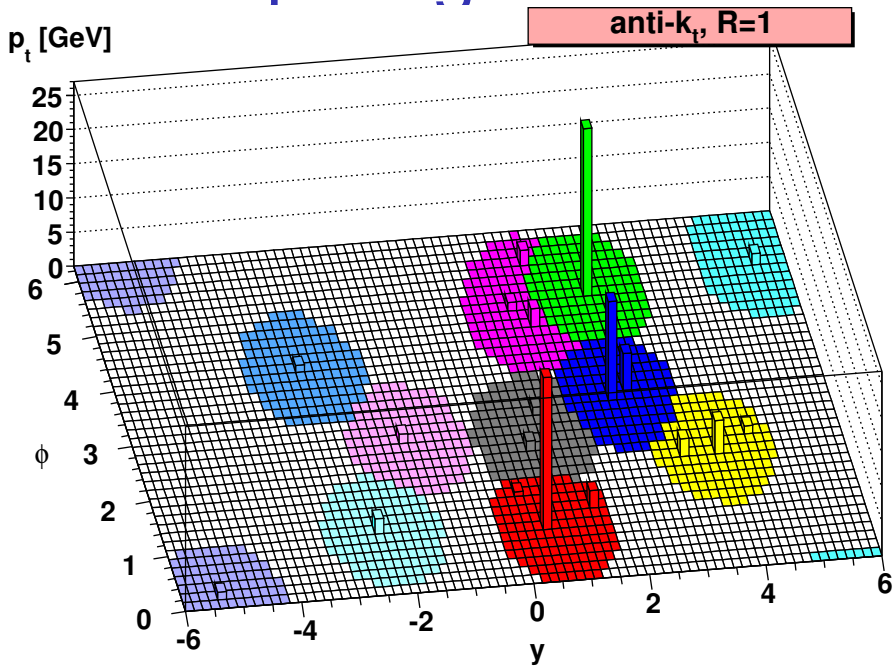
iterative cone-progressive removal alg

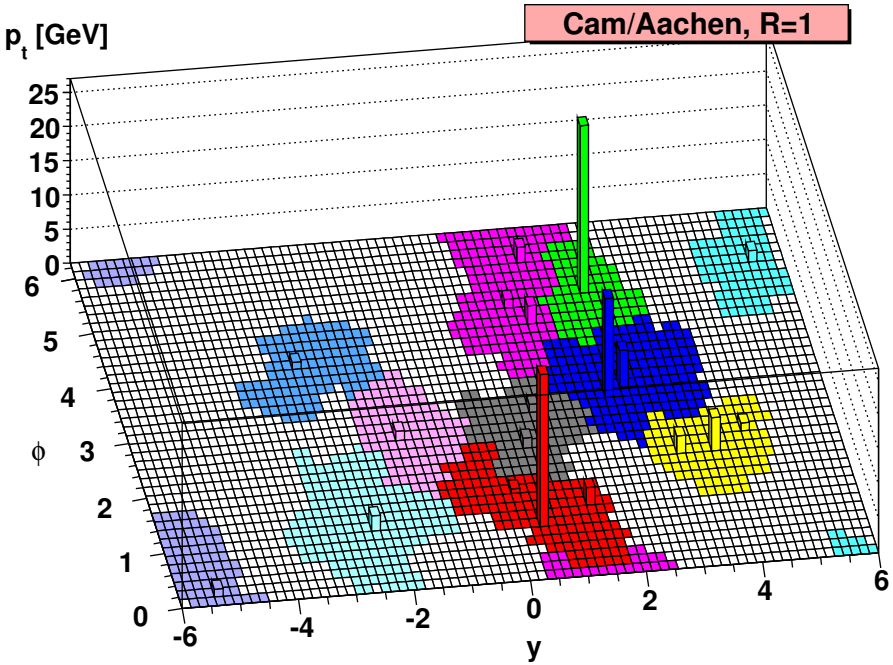


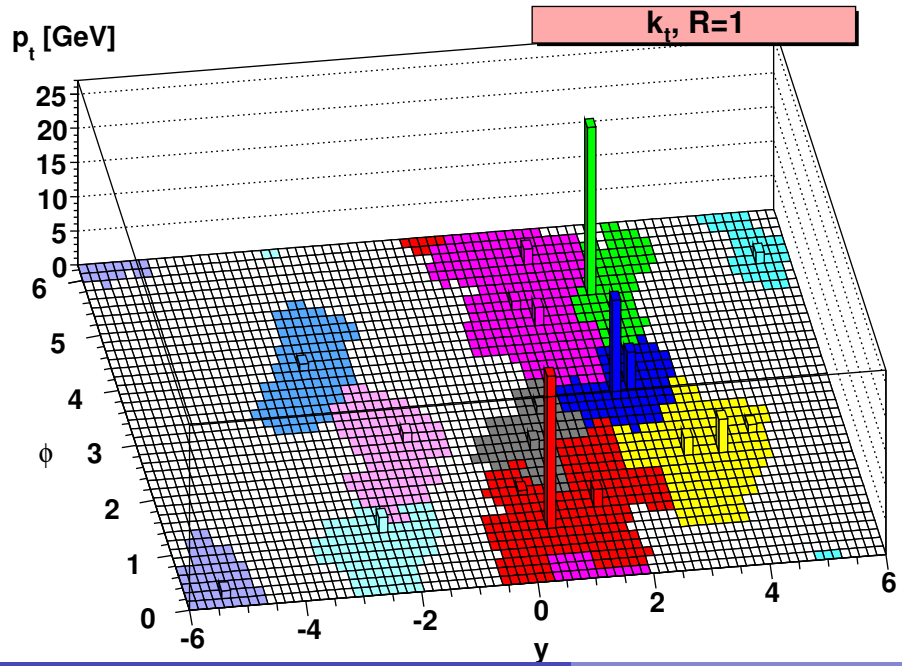
iterative cone-split/merge alg

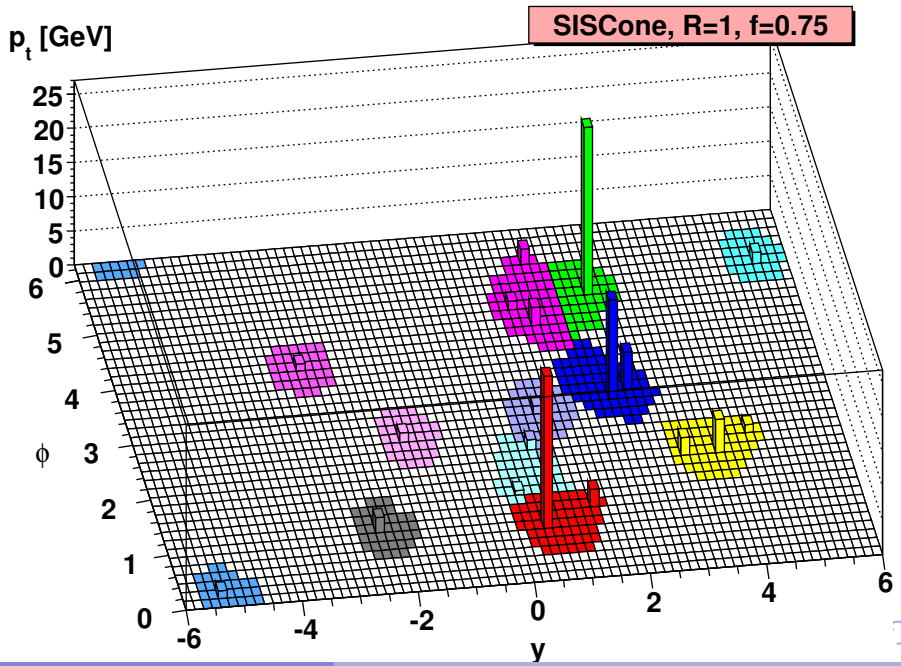
Different jet algorithms

EPJC(2010)67:637

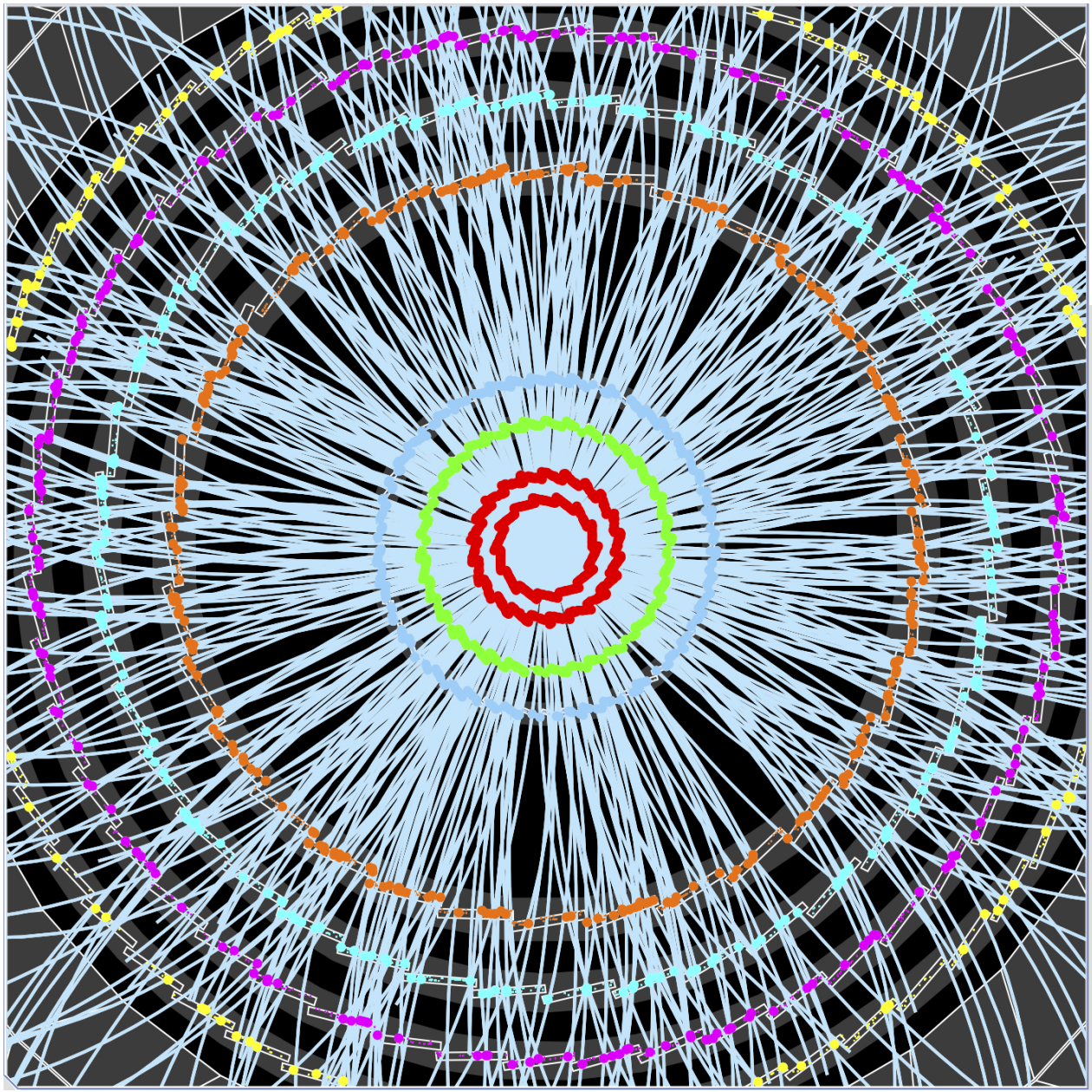


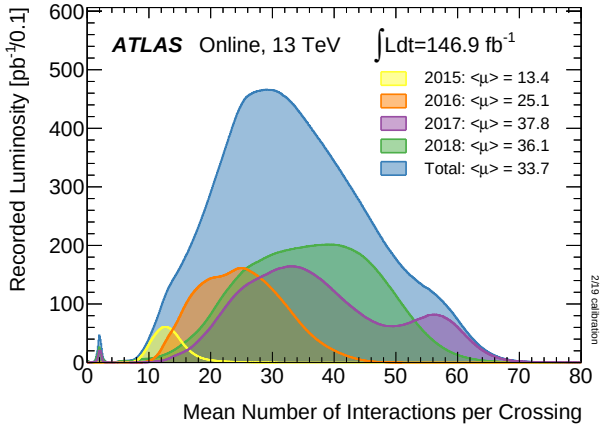


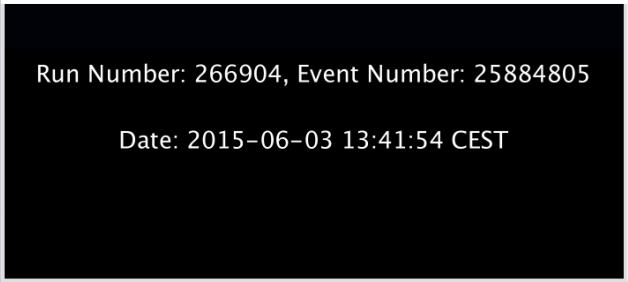


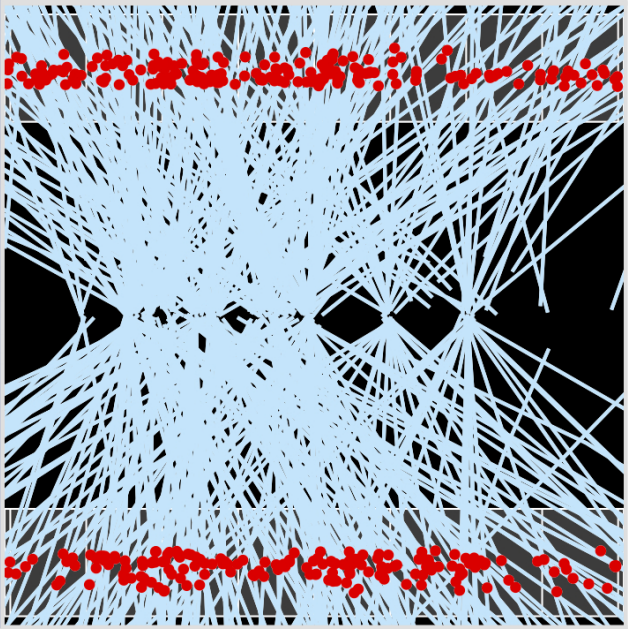


Pileup $N_{PV} = 17$

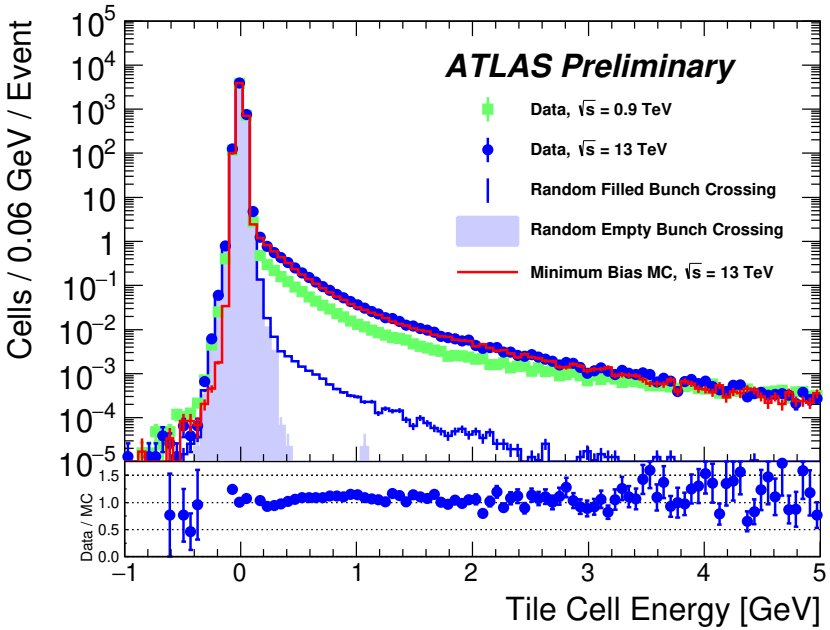


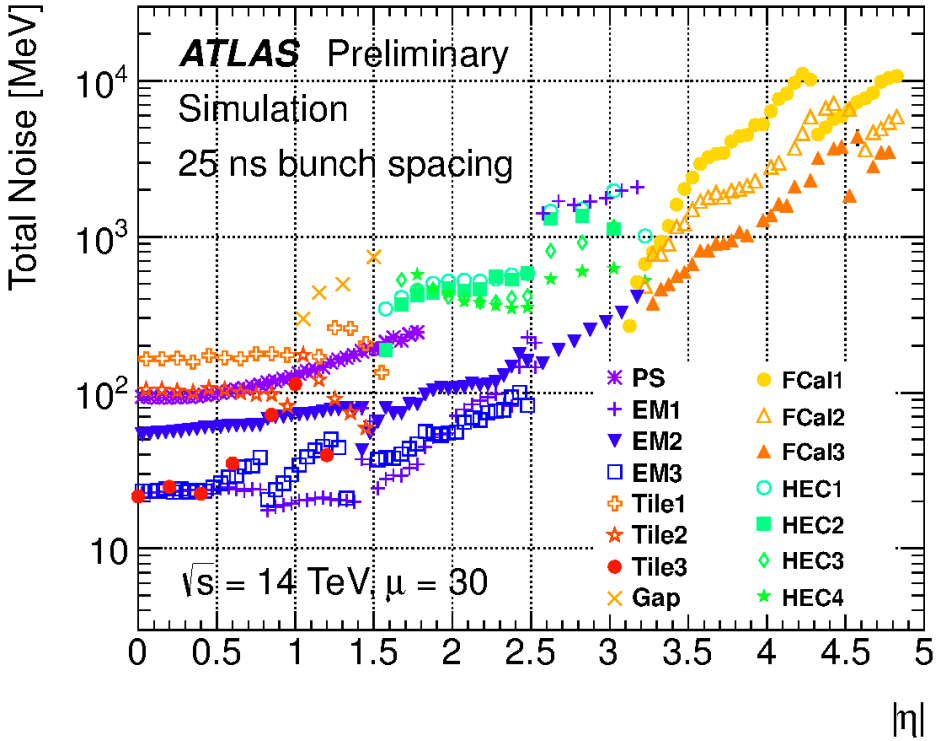


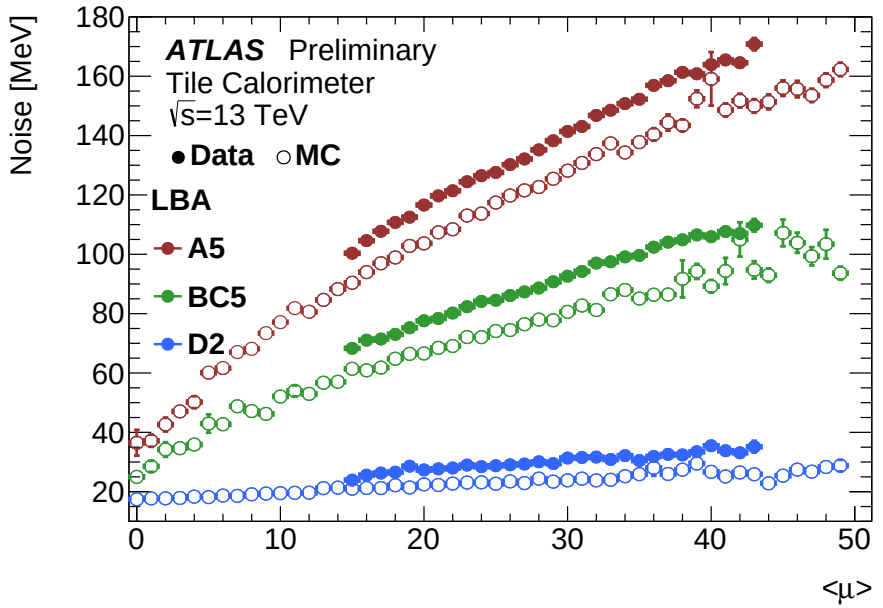




Physics noise in calorimeter

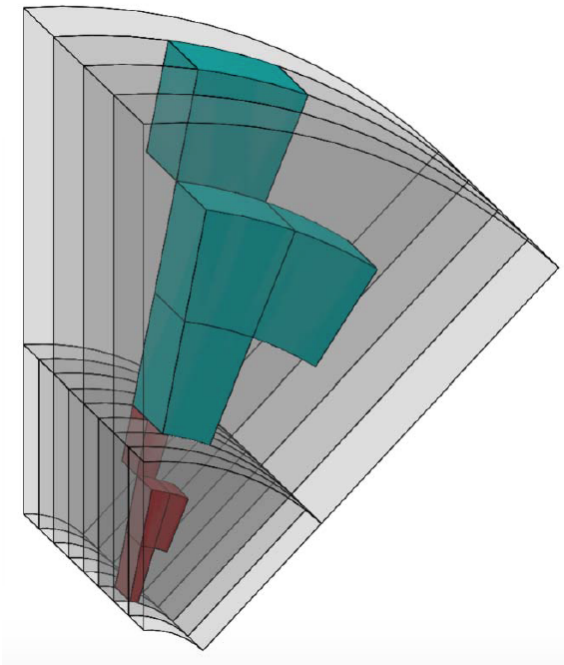






Topological clustering

- 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



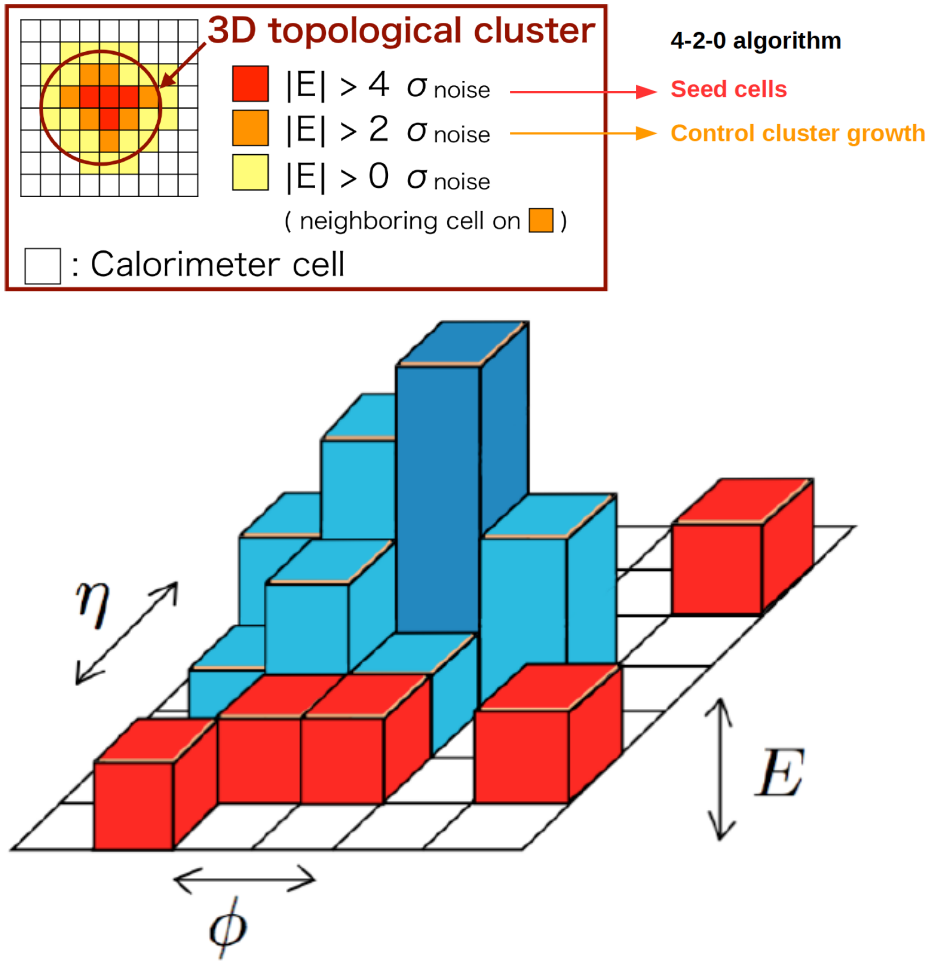


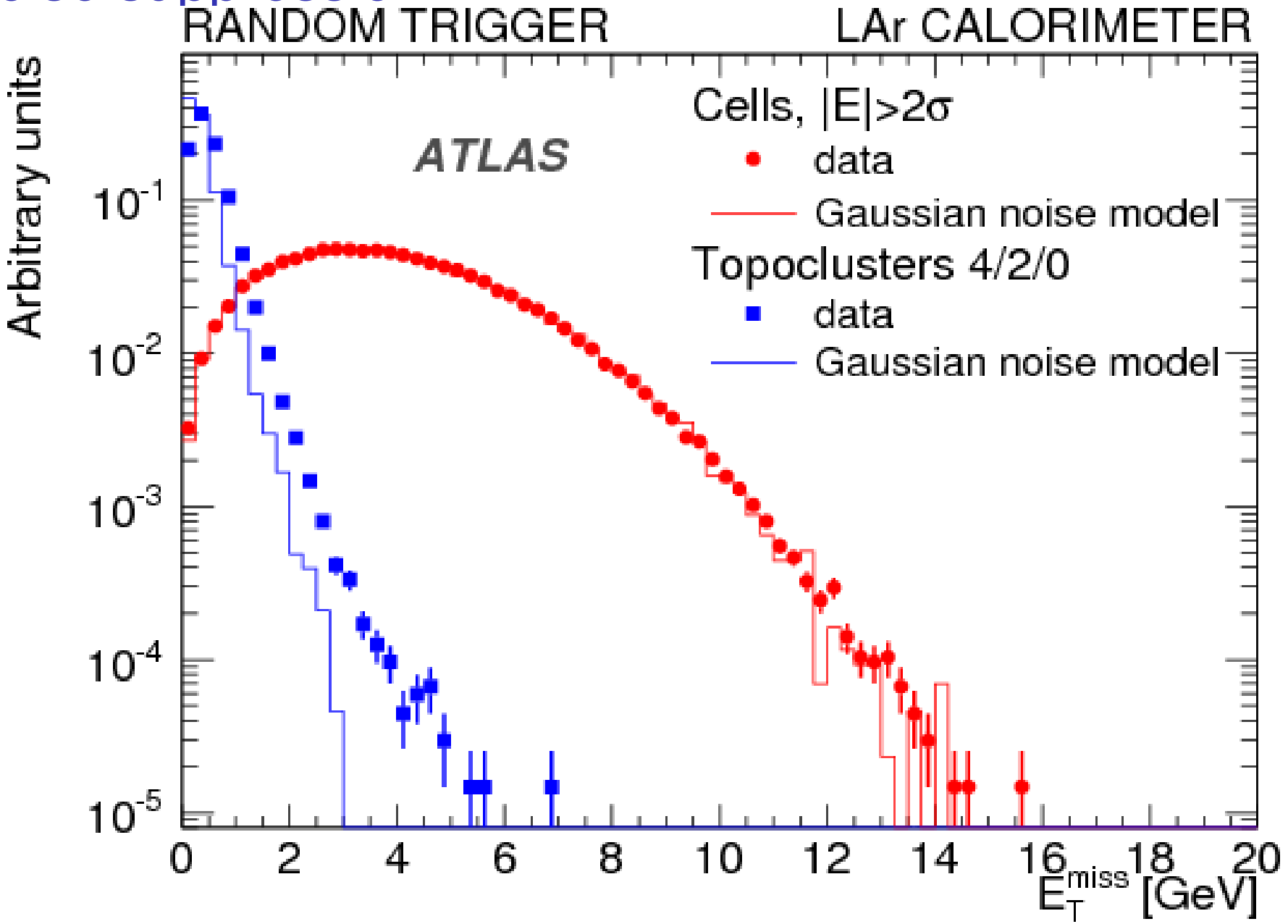
Illustration of a topological cluster:

dark blue seed cell

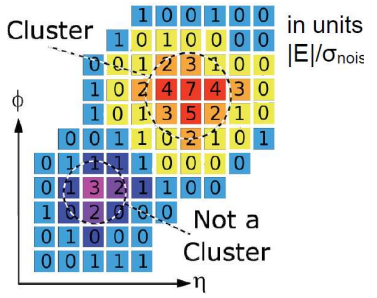
light blue selected adjoint and neighboring cells

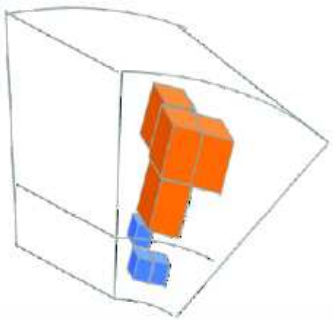
red rejected cells

Noise suppression



Jet reconstruction & calibration





EM-scale jets → **Origin correction** → **Jet area-based pile-up correction** → **Residual pile-up correction**

Jet finding applied to topological clusters at the EM scale.

Changes the jet direction to point to the hard-scatter vertex. Does not affect E.

Applied as a function of event pile-up p_T density and jet area.

Removes residual pile-up dependence, as a function of μ and N_{PV}.

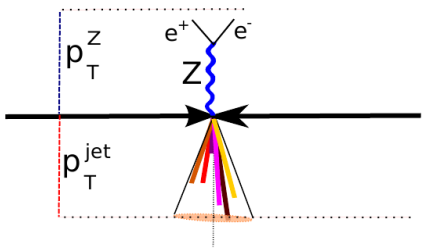
Absolute MC-based calibration → **Global sequential calibration** → **Residual *in situ* calibration**

Corrects jet 4-momentum to the particle-level energy scale. Both the energy and direction are calibrated.

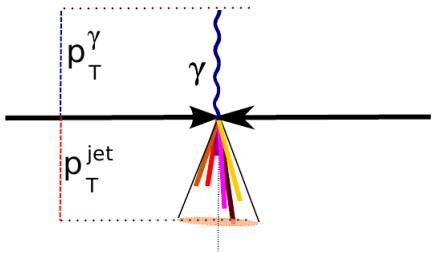
Reduces flavor dependence and energy leakage effects using calorimeter, track, and muon-segment variables.

*A residual calibration is derived using in situ measurements and is applied **only to data**.*

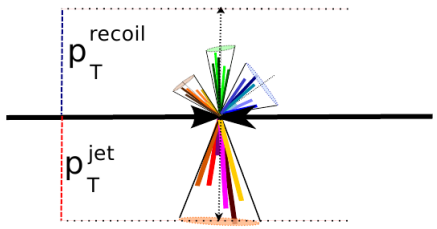
Z-jet balance



Photon-jet balance



Multi-jet balance

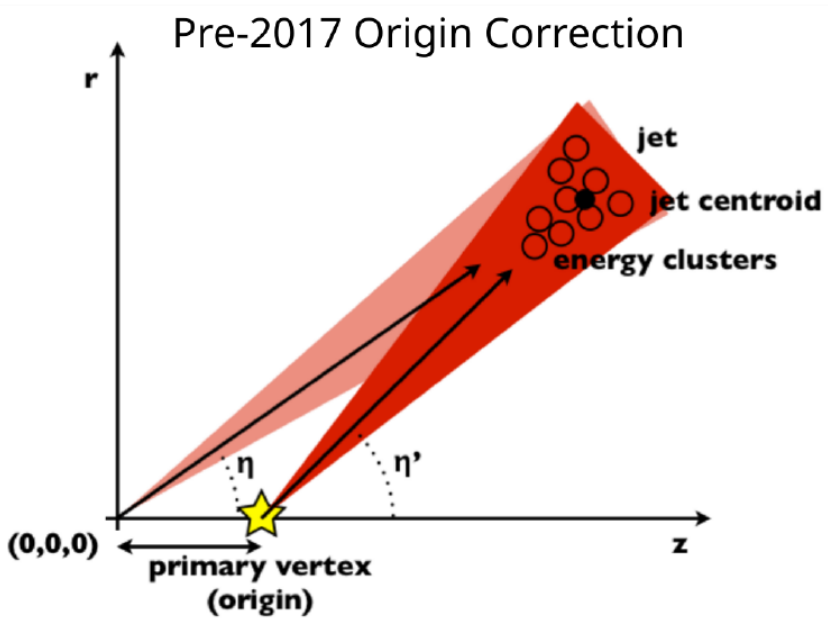


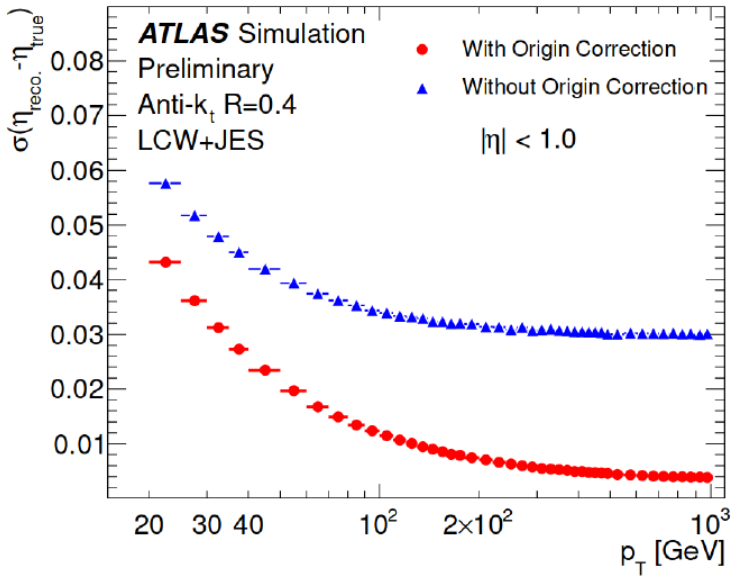
Applied to data →

Applied to simulation →

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 $(\sigma(\eta_{\text{reco}} - \eta_{\text{truth}}))$:

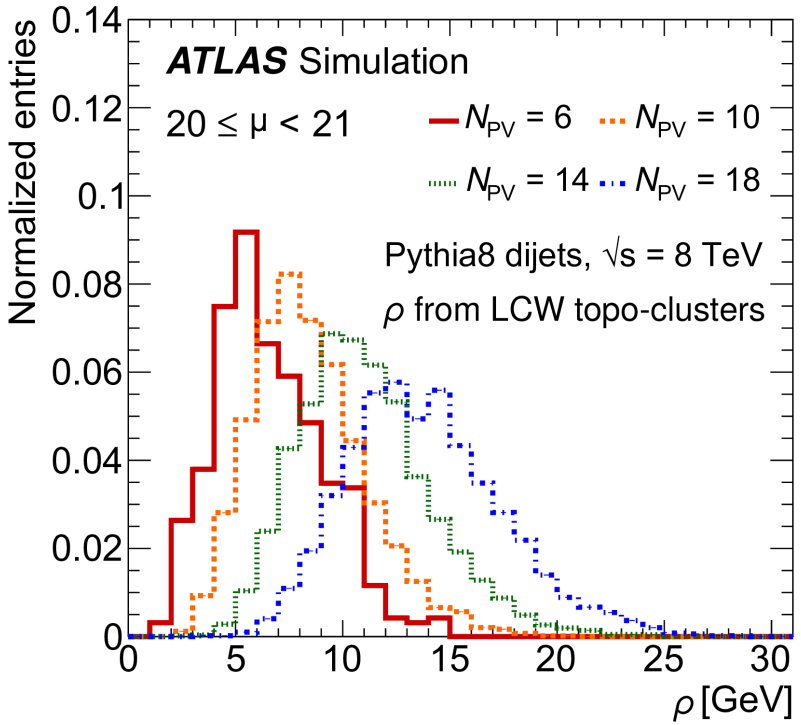




Pileup correction

- 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)
  $\rho = median(p_T \times A)$
- Determined event-by-event using kt jets with R = 0.4 (more sensitive to soft radiation);

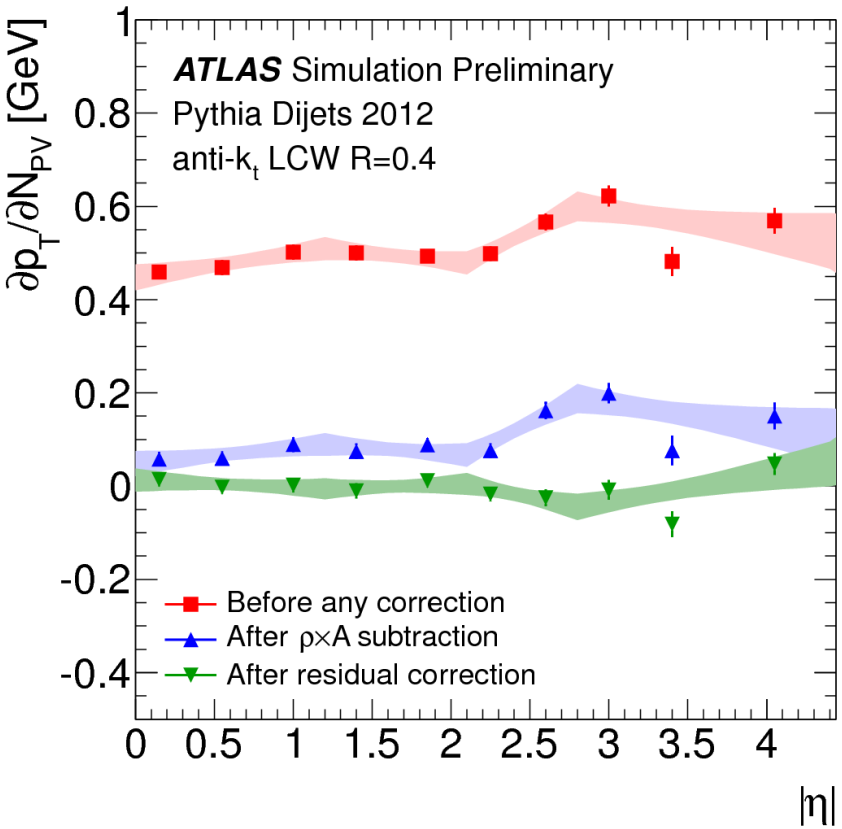
$$p_T^{\text{corr}} = p_T^{\text{reco}} - \rho \times A - \dots$$

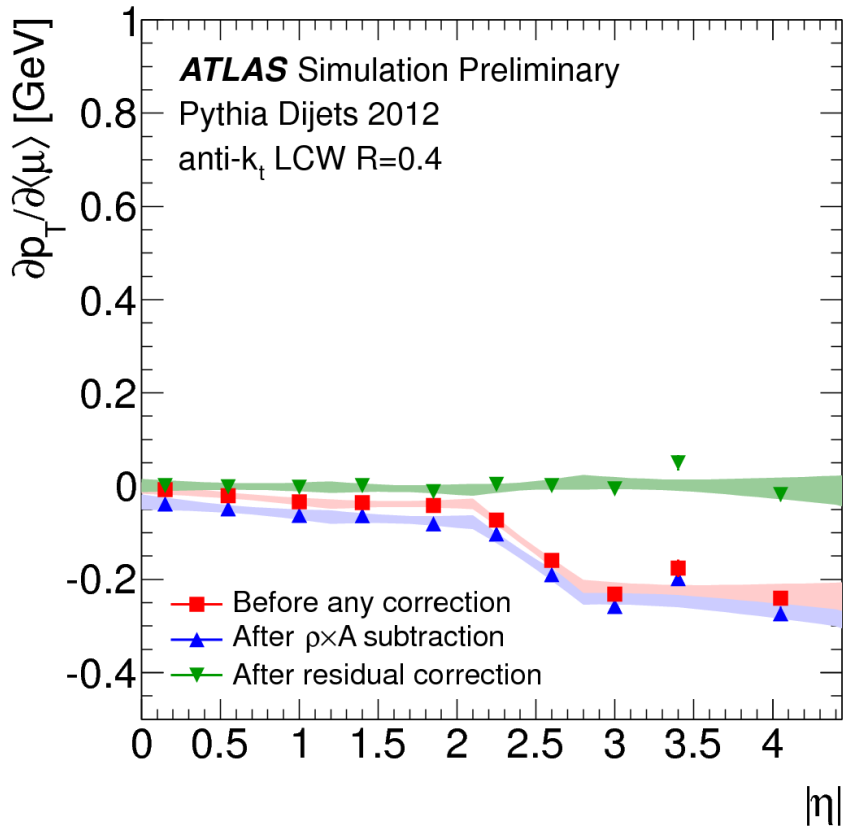


Pileup residual correction

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

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





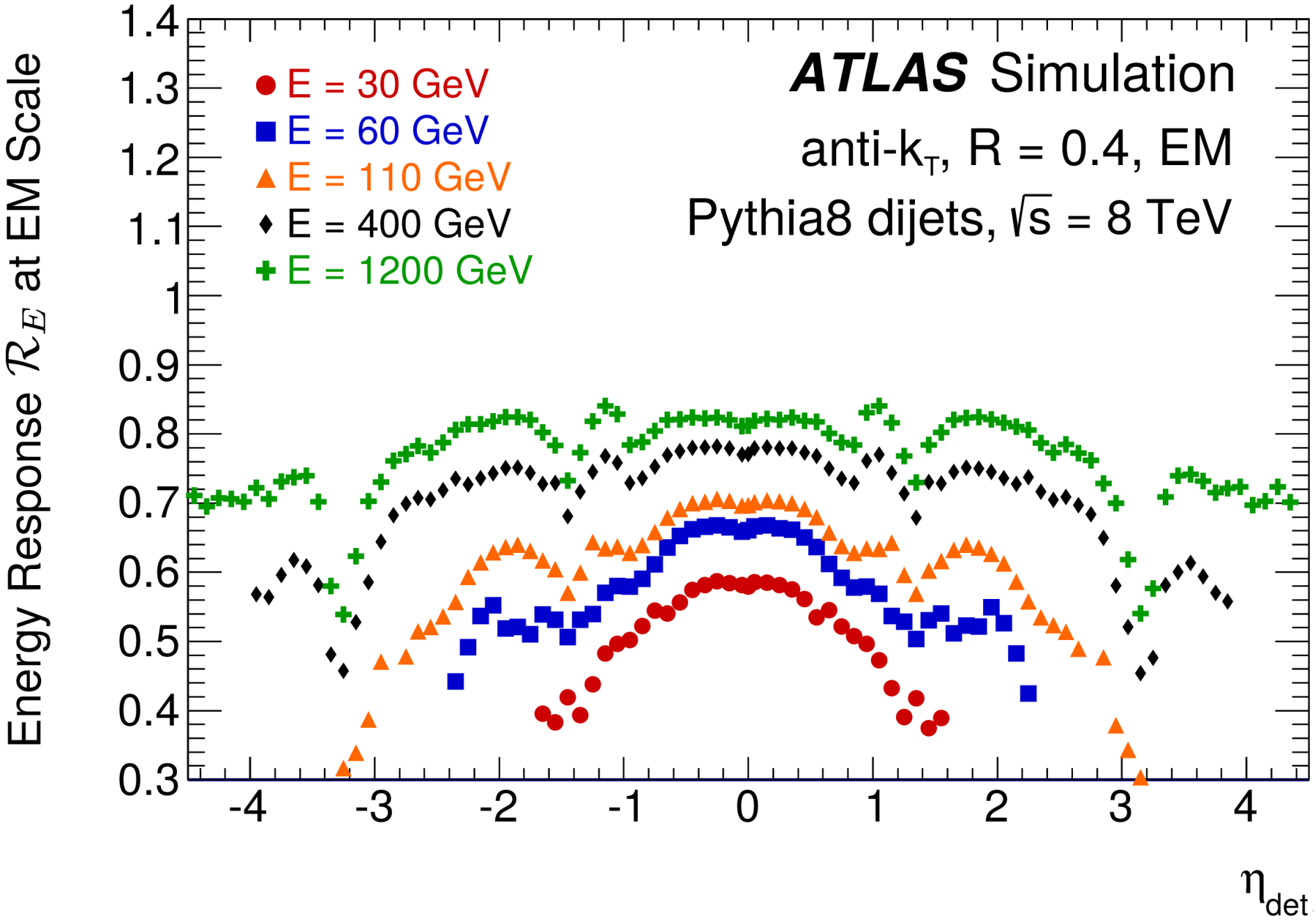
Jet energy : Monte Carlo absolute calibration

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

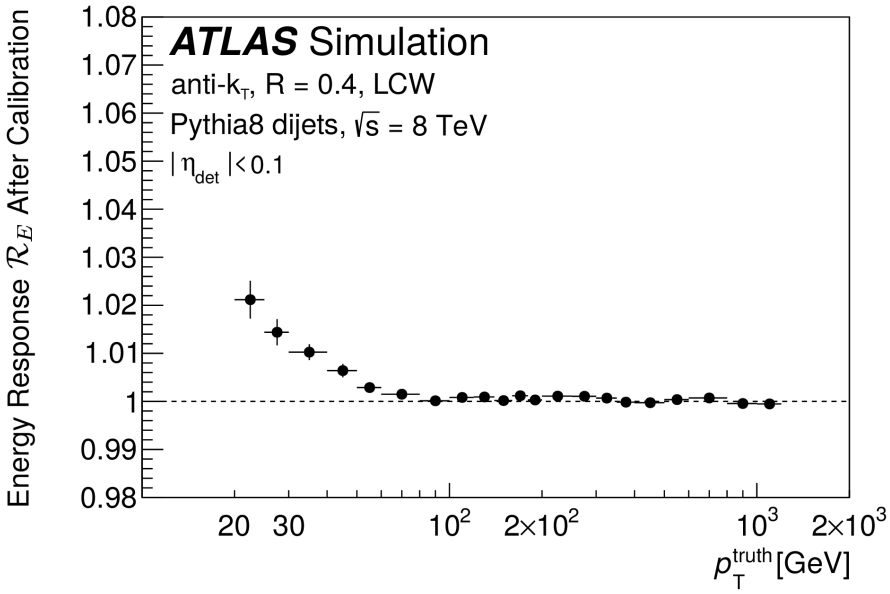
- Calorimeter non-compensation: correction for the different scales of the energy measured from hadronic and EM showers.
- Dead material: energy lost in inactive areas of the detector.
- Leakage: showers reaching the outer edge of the calorimeters.
- Out of calorimeter jet: energy of particles which 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.

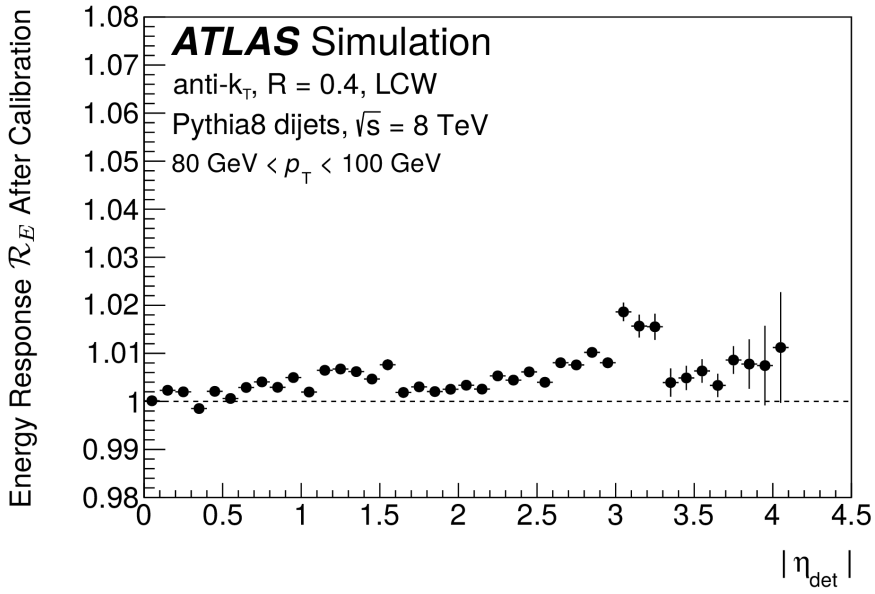
All stages correct the 4-momentum, scaling the jet energy and mass.

MC calibration



MC calibration





GSC calibration

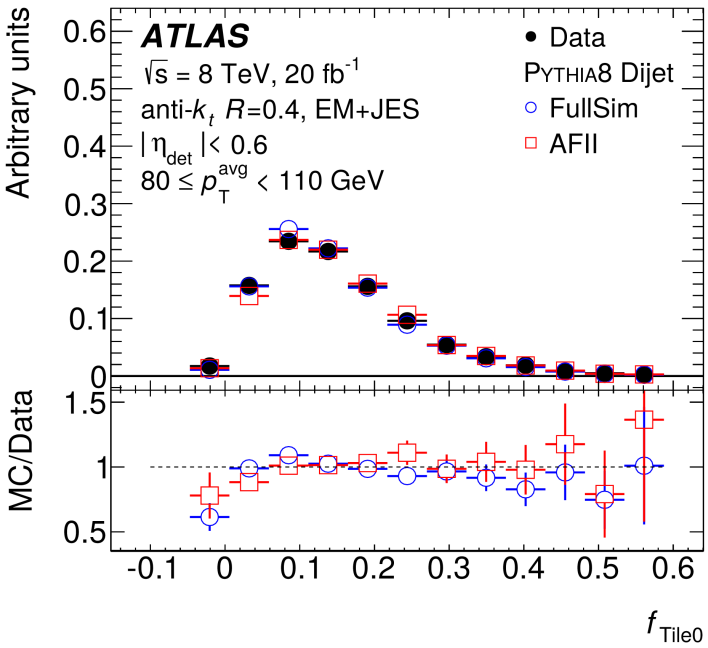
The GSC improves the resolution leaving unaffected the average energy response by applying a series of independent multiplicative corrections to:

- 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_{Tile0}: jet energy fraction measured in the 1st layer of the Tile calorimeter;
- f_{LAr3}: 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.

GCS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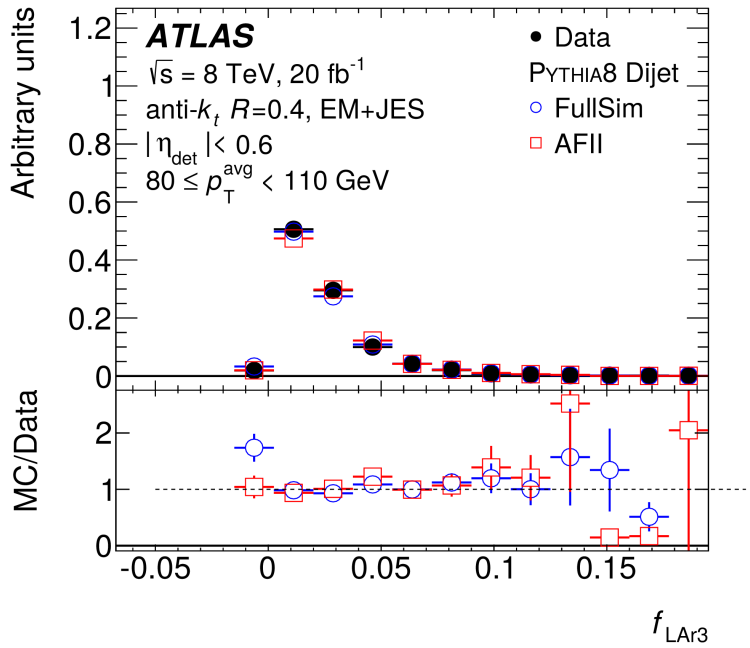
√s = 8 TeV, 20 fb-1
anti-kt R=0.4, EM+JES
| ηdet |< 0.6
80 ≤ pTavg < 110 GeV
Data
Pythia8 Dijet
FullSim
AFII
Arbitrary units
MC/Data
fTile0


ATLAS
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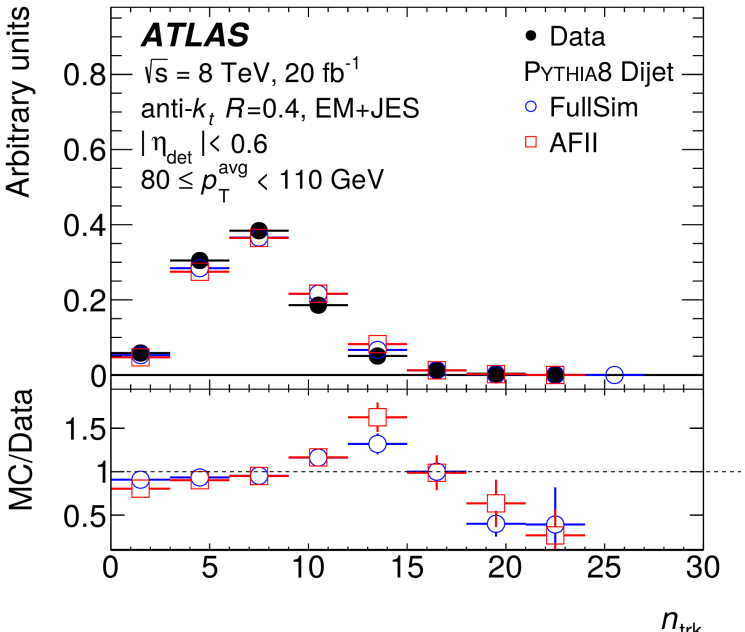
anti-kt R=0.4, EM+JES
| ηdet |< 0.6
80 ≤ pTavg < 110 GeV
Data
Pythia8 Dijet
FullSim
AFII
Arbitrary units
MC/Data
fLAr3


ATLAS
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anti-kt R=0.4, EM+JES
| ηdet |< 0.6
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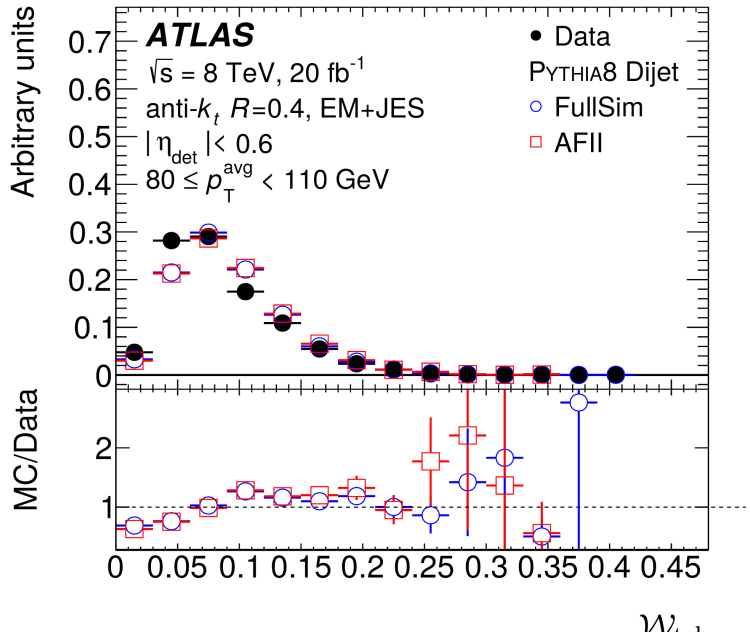
Data
Pythia8 Dijet
FullSim
AFII
Arbitrary units
MC/Data
ntrk


ATLAS
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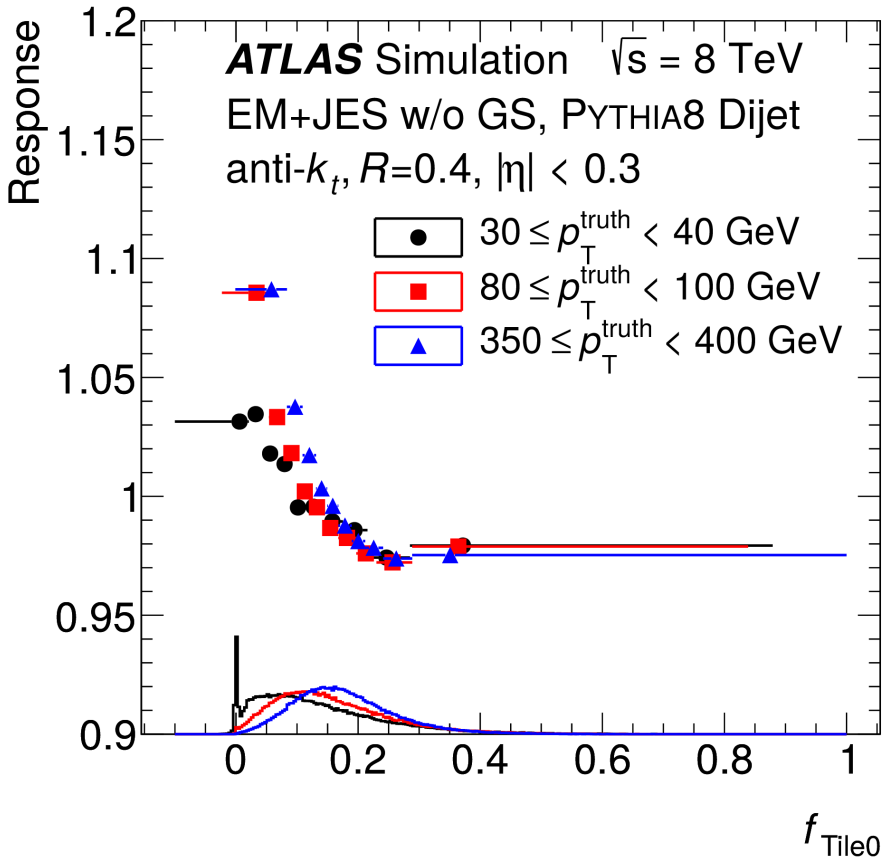
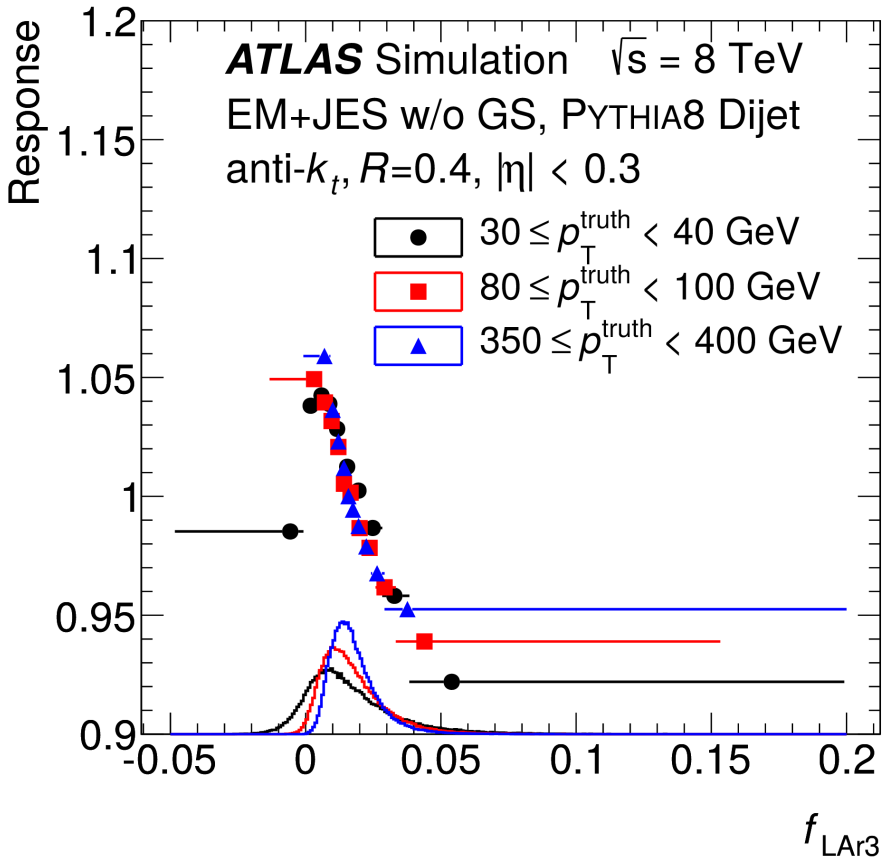
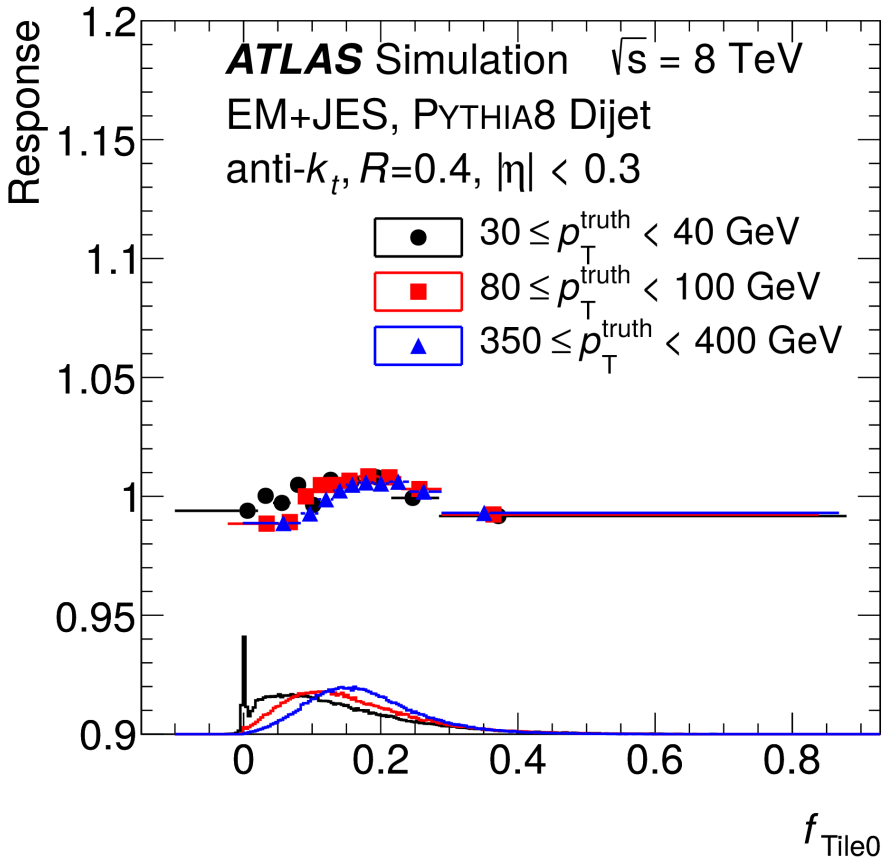
anti-kt R=0.4, EM+JES
| ηdet |< 0.6
80 ≤ pTavg < 110 GeV
Data
Pythia8 Dijet
FullSim
AFII
Arbitrary units
MC/Data

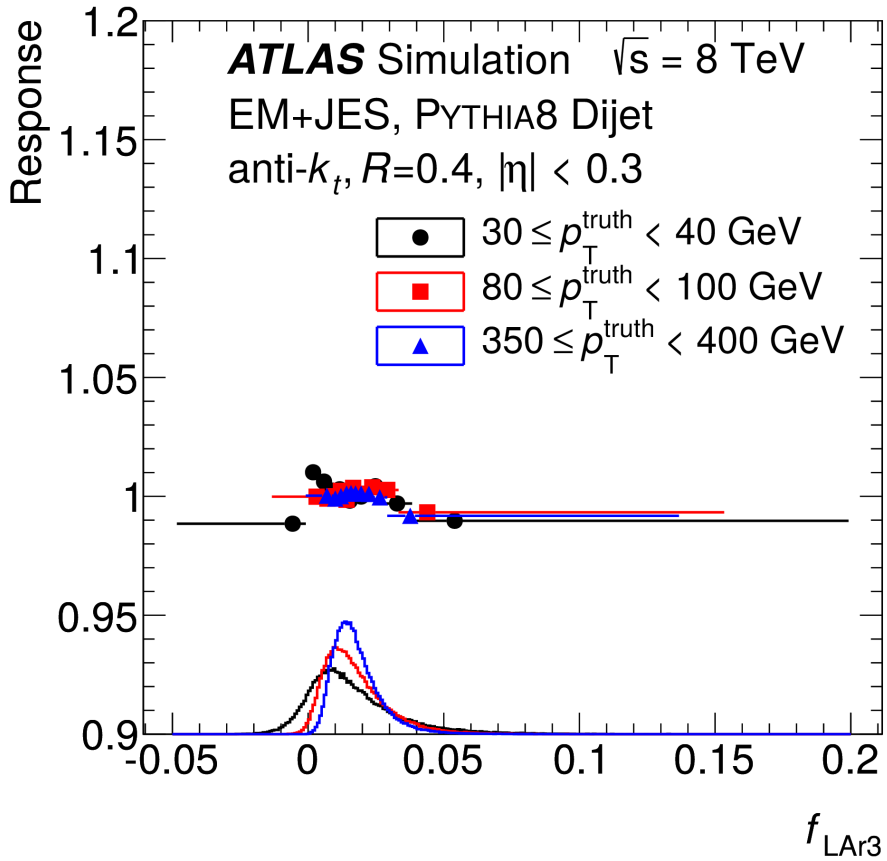
GCS


ATLAS Simulation √s = 8 TeV
EM+JES w/o GS, PYTHIA8 Dijet
anti-k_t, R=0.4, |η| < 0.3
$30 \le p_T^{truth} < 40$ GeV
$80 \le p_T^{truth} < 100$ GeV
$350 \le p_T^{truth} < 400$ GeV
Response
f_{Tile0}


ATLAS Simulation √s = 8 TeV
EM+JES w/o GS, PYTHIA8 Dijet
anti-k_t, R=0.4, |η| < 0.3
$30 \le p_T^{truth} < 40$ GeV
$80 \le p_T^{truth} < 100$ GeV
$350 \le p_T^{truth} < 400$ GeV
Response
f_{LAr3}

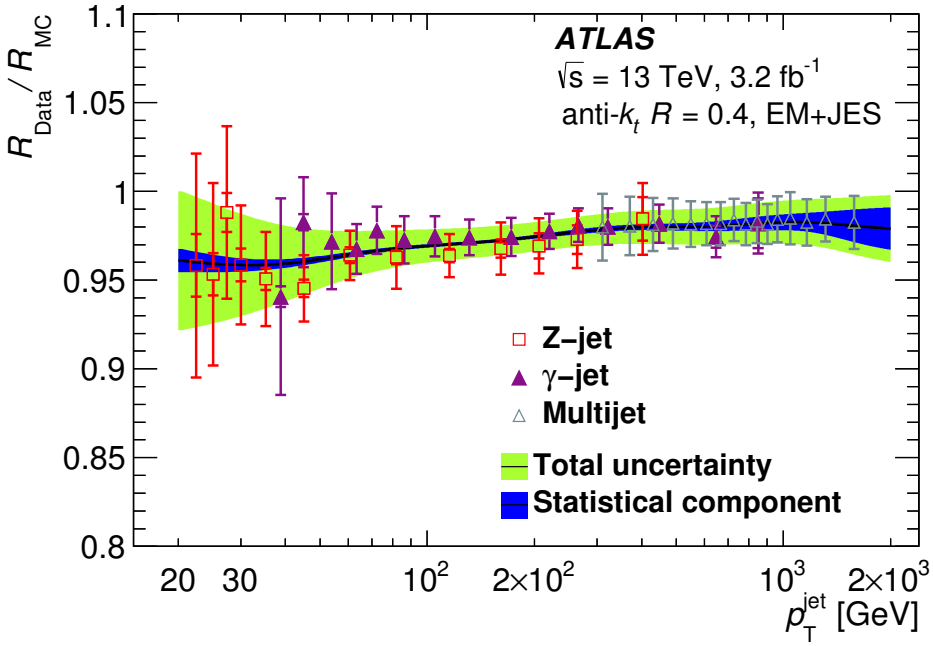
GCS

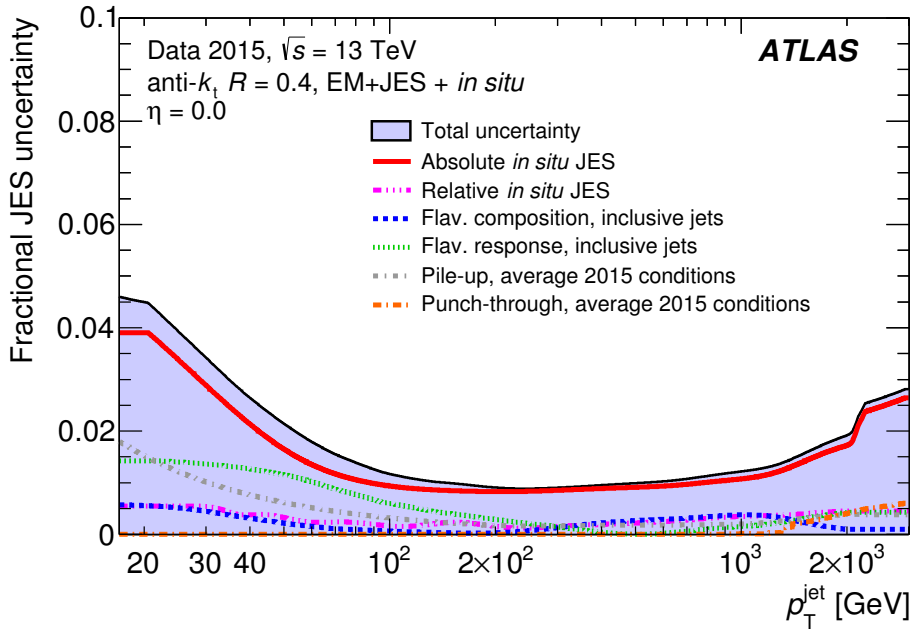

Response
1.2
1.15
1.1
1.05
1
0.95
0.9
ATLAS Simulation √s = 8 TeV
EM+JES, PYTHIA8 Dijet
anti-k_t, R=0.4, |η| < 0.3
30 ≤ p_T^truth < 40 GeV
80 ≤ p_T^truth < 100 GeV
350 ≤ p_T^truth < 400 GeV
0
0.2
0.4
0.6
0.8
f_Tile0


Response
1.2
1.15
1.1
1.05
1
0.95
0.9
ATLAS Simulation √s = 8 TeV
EM+JES, PYTHIA8 Dijet
anti-k_t, R=0.4, |η| < 0.3
30 ≤ p_T^truth < 40 GeV
80 ≤ p_T^truth < 100 GeV
350 ≤ p_T^truth < 400 GeV
-0.05
0
0.05
0.1
0.15
0.2
f_LAr3

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