Global Sequential (GS) Calibration in ATLAS

Journées Jeunes Chercheurs 2010
Ethic étapes Lac de Maine
Angers, France
21-27th Novembre 2010

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- ATLAS at LHC
- Brief introduction to jets reconstruction and calibration
- Global Sequential (GS) Calibration description
- Performance of the GSC
- GS validation with Data
- Monte Carlo based systematics
- Ongoing work

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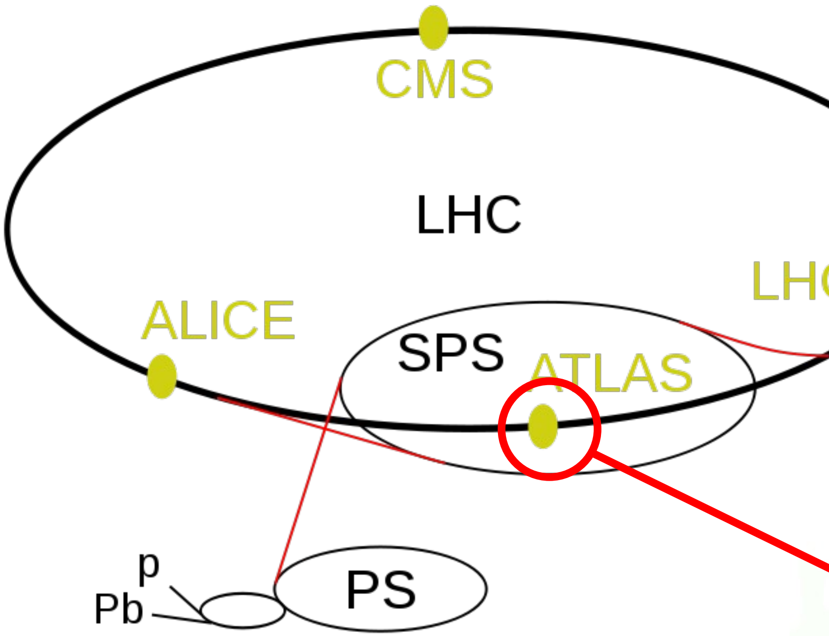
[2] Columbia/ Caltech

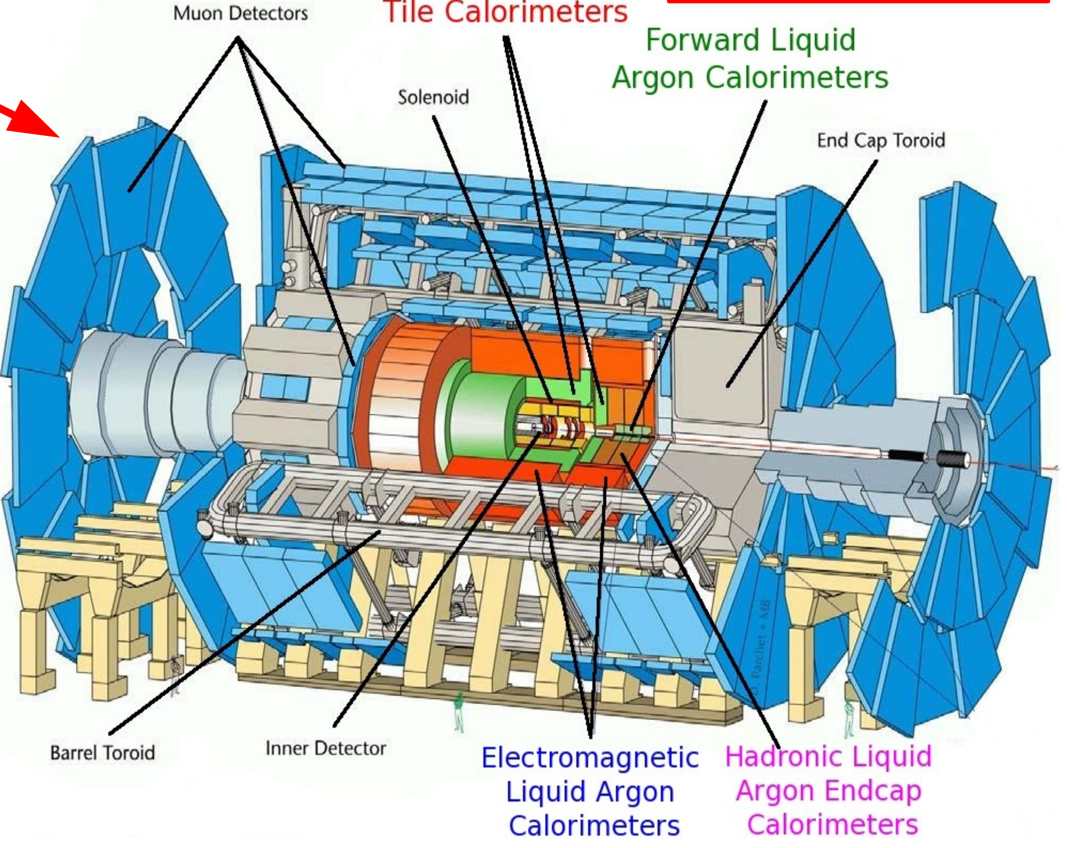
[3] SLAC

ATLAS (A Toroidal LHC ApparatuS)



The **Large Hadron Collider (LHC)** is the world's largest and highest energy particle accelerator. It holds the new world record for the highest-energy man-made particle collisions with 3.5 TeV per beam.

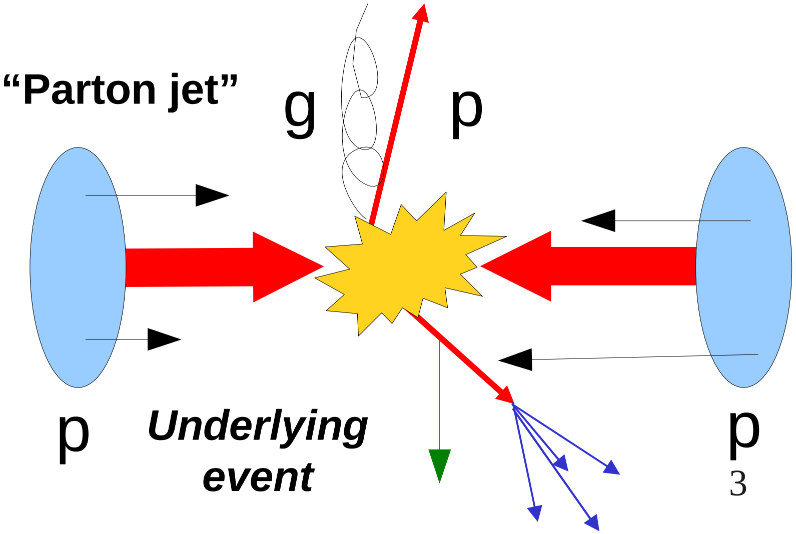
ATLAS characteristics:
- Overall length = 42 m
- Diameter = 22 m
- Weight = 7000 tons



- **ATLAS** is one of the six detectors at LHC. It consists of a series of concentric cylinders around the interaction point.
- Divided into 4 major parts: the Inner Detector, the calorimeters, the muon spectrometer and the magnet systems.
- It is in the calorimeters where the collision particles deposit their energy. We consider in this study only calorimeter **jets.**

But...What is a jet?

- Initial p-p collision produces outgoing partons (**quarks and gluons**).



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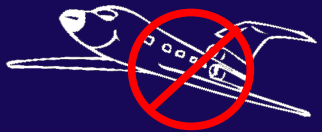

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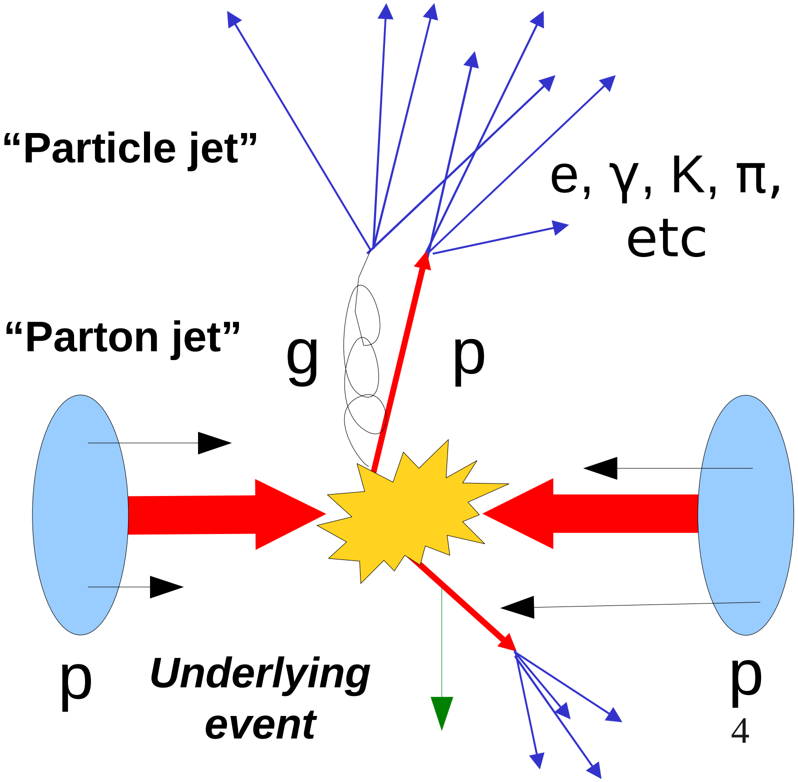
- Fragmentation, hadronization and decay produce neutral and charged particles. The particles in this bunch have correlated kinematic properties.



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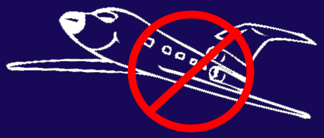

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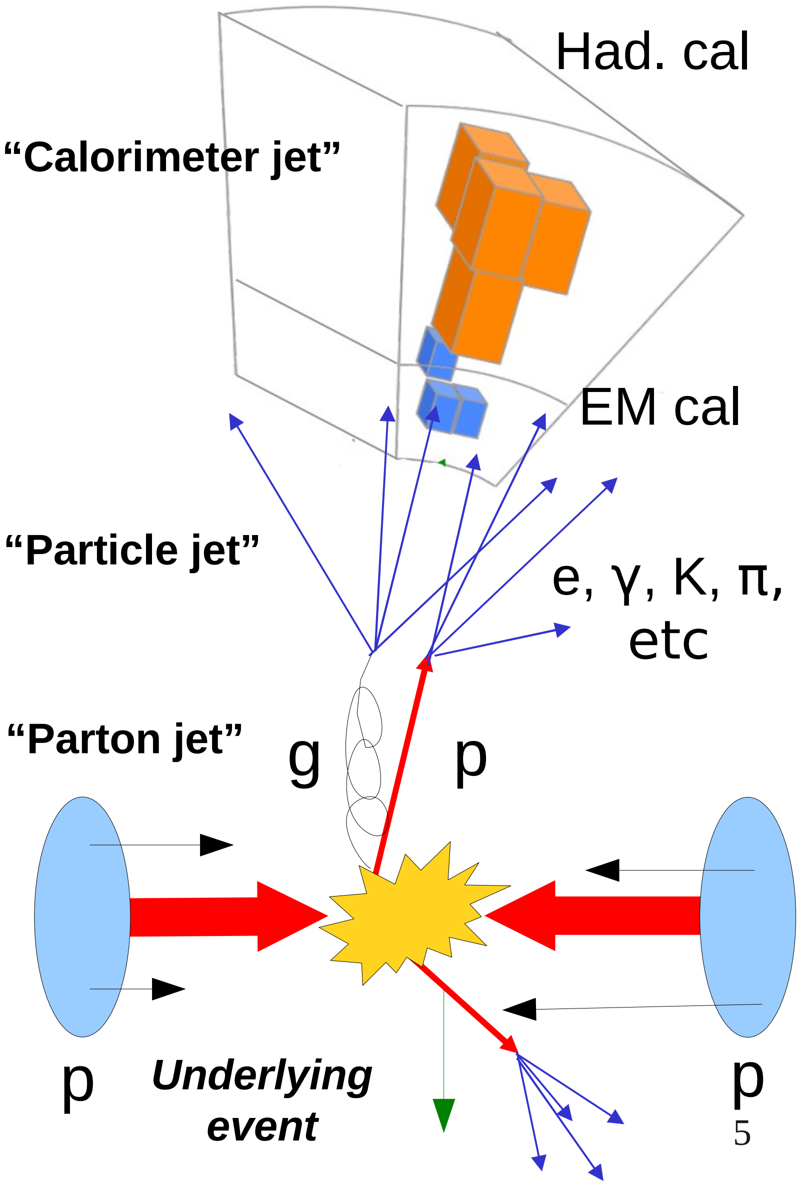
- Fragmentation, hadronization and decay produce neutral and charged particles. The particles in this bunch have correlated kinematic properties.

- Resulting **interacting particles**: electrons, photons, and hadrons (and their antiparticles) deposit energy in the calorimeter. The **non-interacting particles** (mostly neutrinos) do not generate an observable signal.



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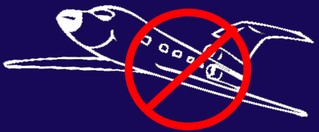

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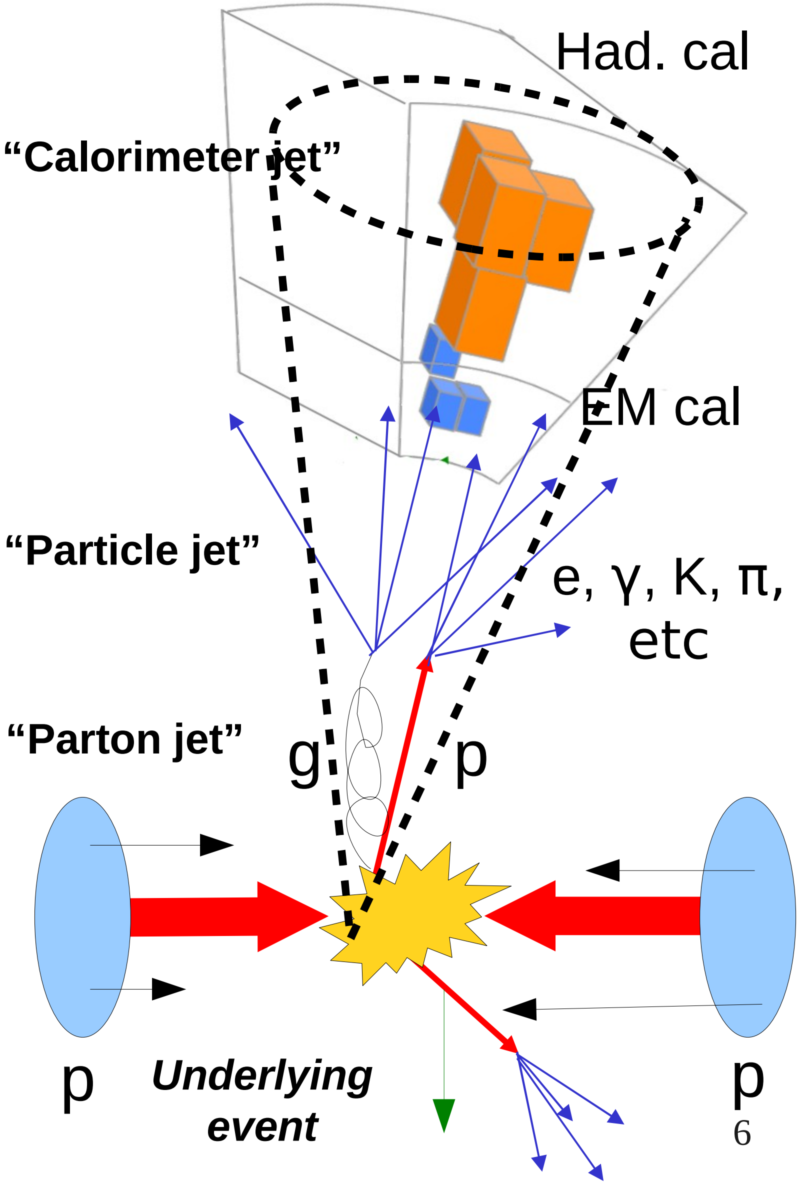
- Fragmentation, hadronization and decay produce neutral and charged particles. The particles in this bunch have correlated kinematic properties.
- Resulting **interacting particles**: electrons, photons, and hadrons (and their antiparticles) deposit energy in the calorimeter. The **non-interacting particles** (mostly neutrinos) do not generate an observable signal.
- **A jet is the combination of these elements**. This combination is made using different jet algorithms of reconstruction (k_T, Anti k_T (**default**), Cone algorithms). A jet algorithm can be applied at both levels:

  - Particle level: generator particles as input.

  - Calorimeter level: calorimeter towers and 3D topological clusters as input.



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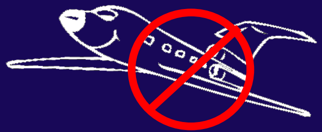
But...What is a jet?



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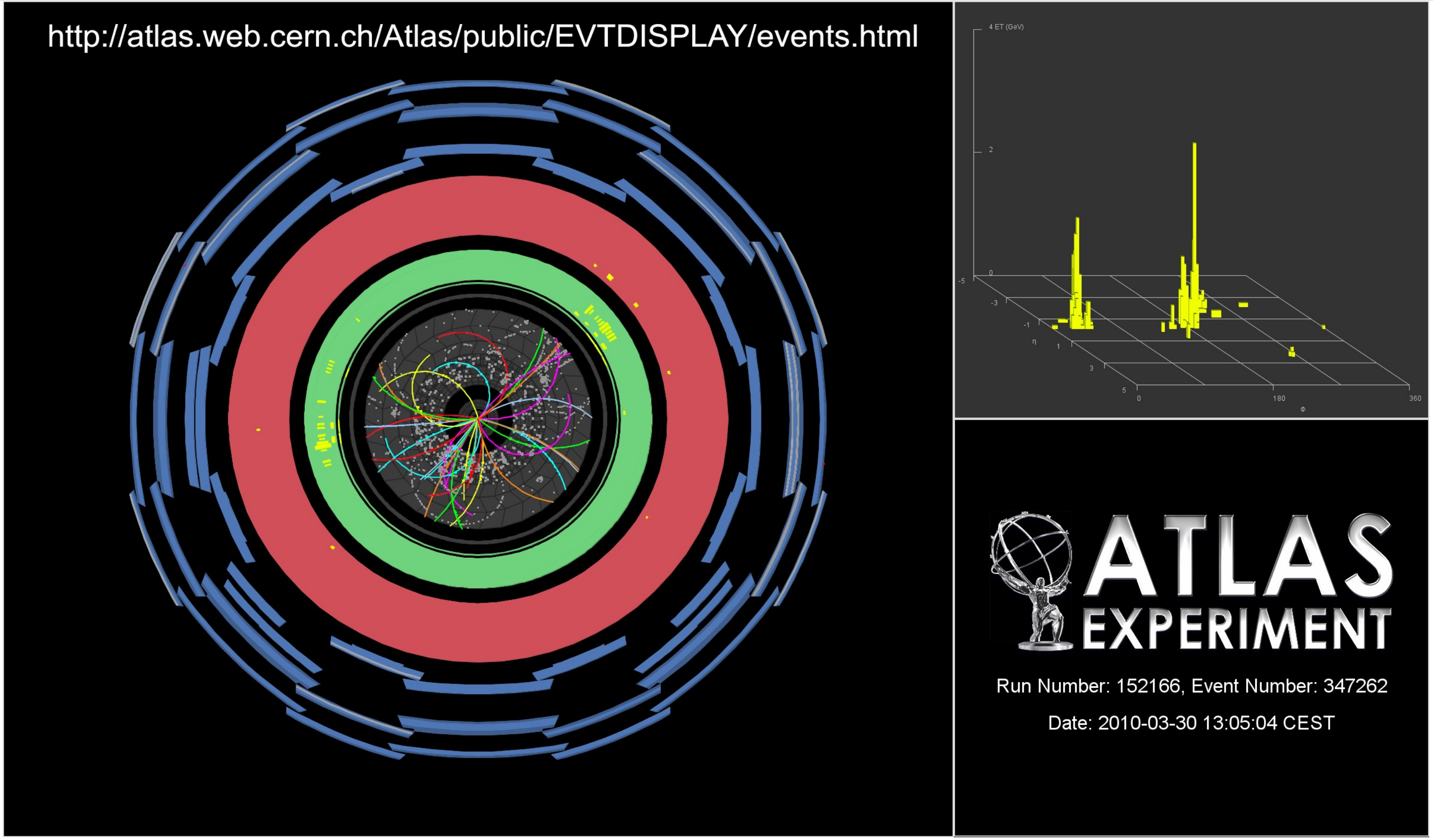


http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

Run Number: 152166, Event Number: 347262

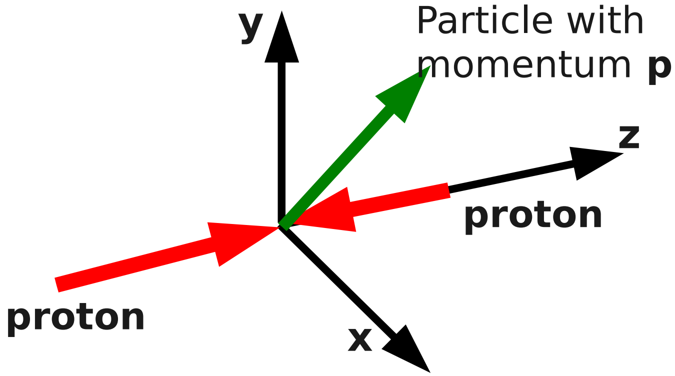
Date: 2010-03-30 13:05:04 CEST

Jet production cross section is very large at LHC, and many analysis depend on them:

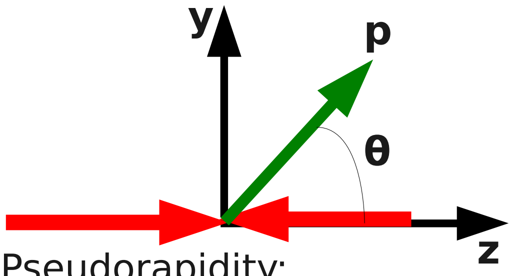
- Top quark physics, Higgs, susy ...
- QCD jets are the background for many analysis.

The ATLAS Calorimeters

But first, some useful definitions:



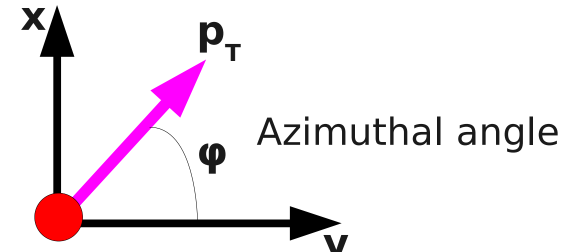
y-z plane:



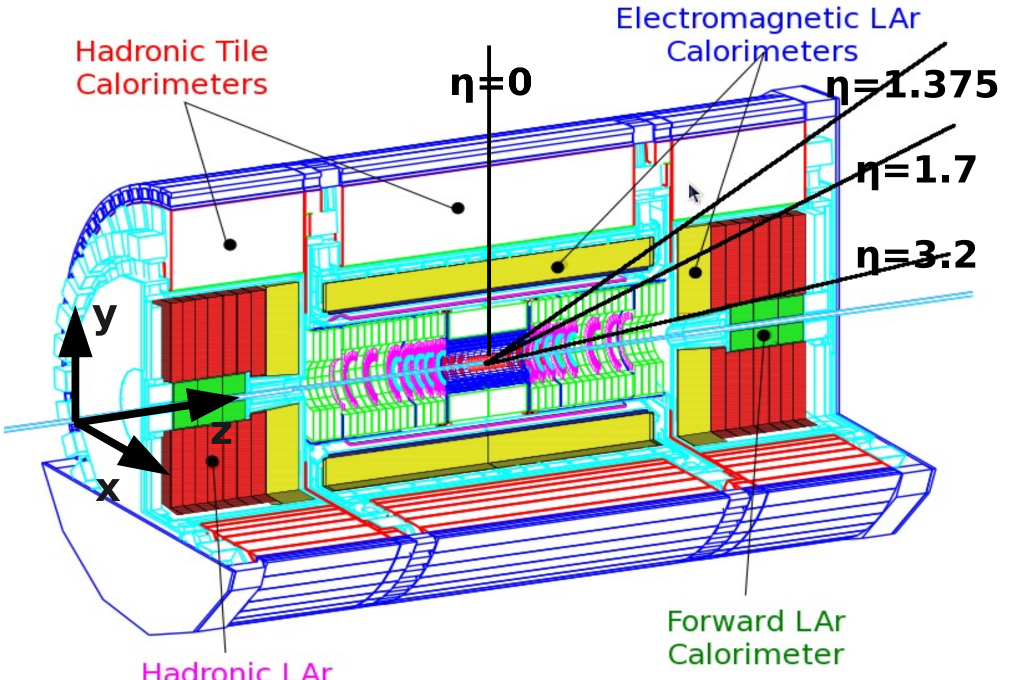
Pseudorapidity:

$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right],$$

y-x plane:



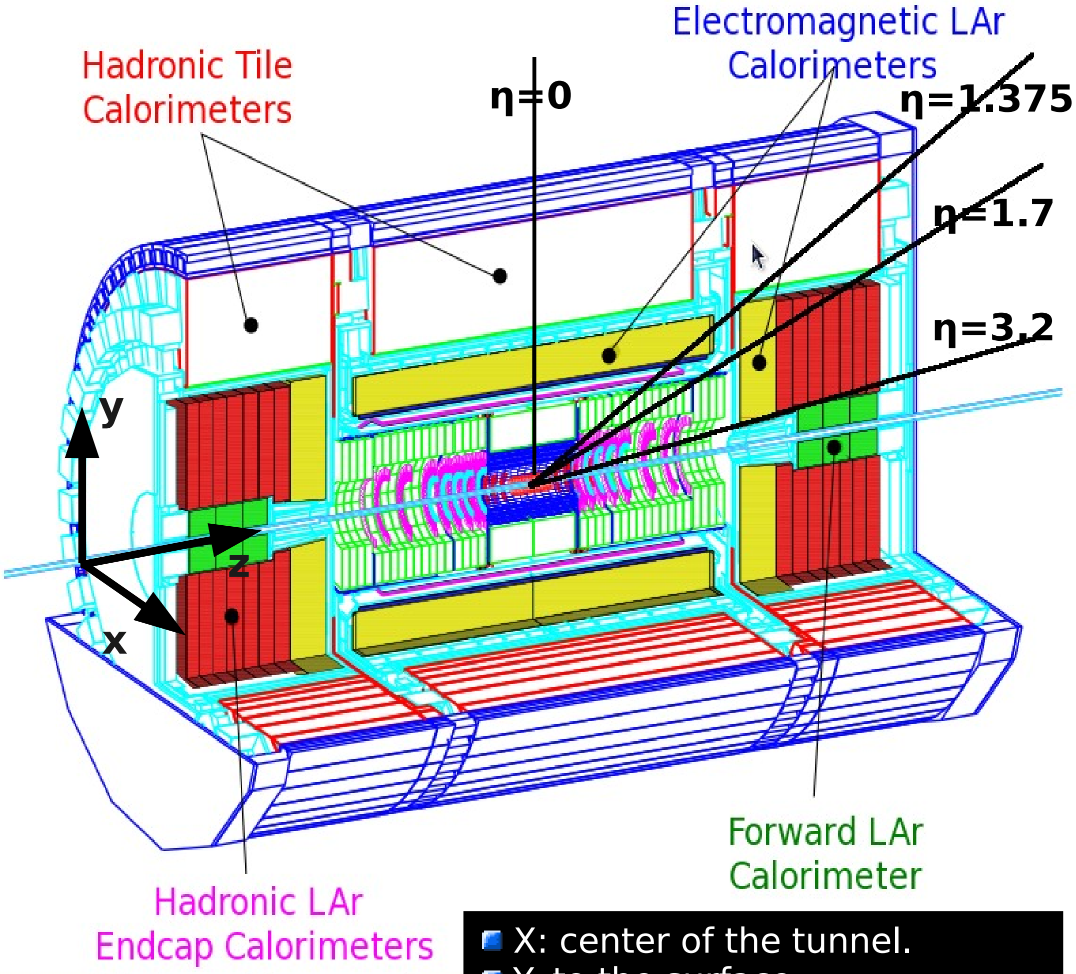
Transverse momentum:
$p_T = p\mathrm{Sin}(\theta)$



- X: center of the tunnel.
- Y: to the surface.
- Z: beam direction

The ATLAS Calorimeters

And now the calorimeters:



- X: center of the tunnel.
- Y: to the surface.
- Z: beam direction

Electromagnetic (EM) calorimeters |η| < 3.2
- Pb/LAr
- 3 longitudinal sections

Hadronic Tile calorimeters |η| < 1.7
- Fe/scintillator
- 3 longitudinal sections

Hadronic EndCap 1.5 < η < 3.2
- Cu/LAr
- 4 longitudinal sections

Forward calorimeter 3.2 < η < 4.9
- EM Cu/LAr – HAD W/Lar
- 3 longitudinal sections

- Divided in layers
- Varied granularities
- Varied technologies
- Overlap/crack regions

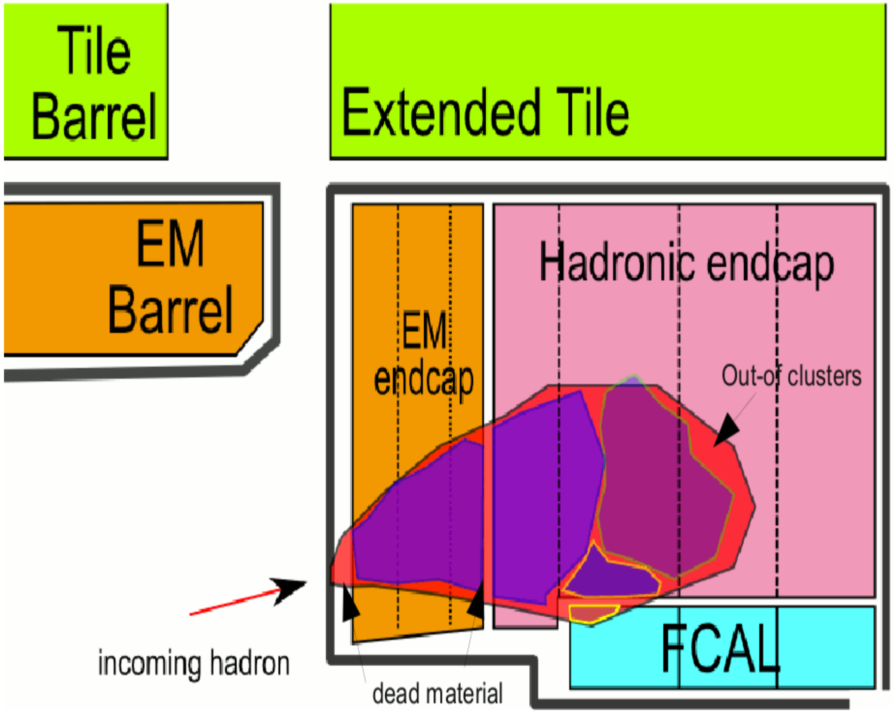
Why do we need to calibrate the jets in ATLAS?

Mainly to correct for calorimeter effects:

- **Non compensation (e/h >1)**
  - Hadrons generate smaller signal than electrons and photons.
- **Dead material**
  - Particles lose energy in dead material before reaching the EM calorimeter, or end up in non instrumented regions.
- **Magnetic field bending**
  - Some particles are bent out of the reconstructed jet by the tracker magnetic field.

Other effects are also implied:

- **Energy lost due to jet algorithm efficiency.**
- **Energy added by underlying event and/or pile up.**
- **Energy lost due to calorimeter signal definition.**



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Université Blaise Pascal

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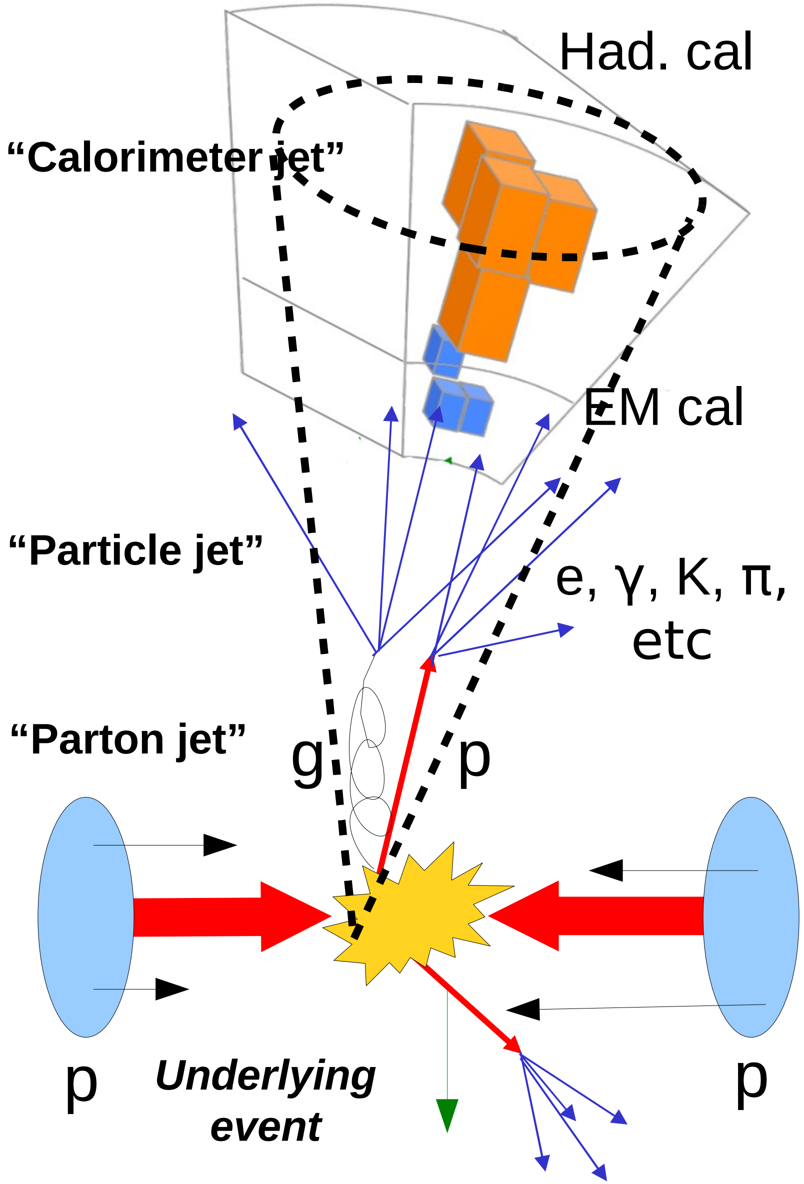


As a consequence:

- The energy deposited ($E_{calorimeter}$) does not correspond to the initial energy carried by the particles ($E_{particle}$), i.e. the response ($R=E_{calorimeter}/E_{particle}$) of the calorimeter is different from one.

- We need to calibrate to bring the calorimeter response $E_{calorimeter}/E_{particle}=1$ (Jet Energy Scale)

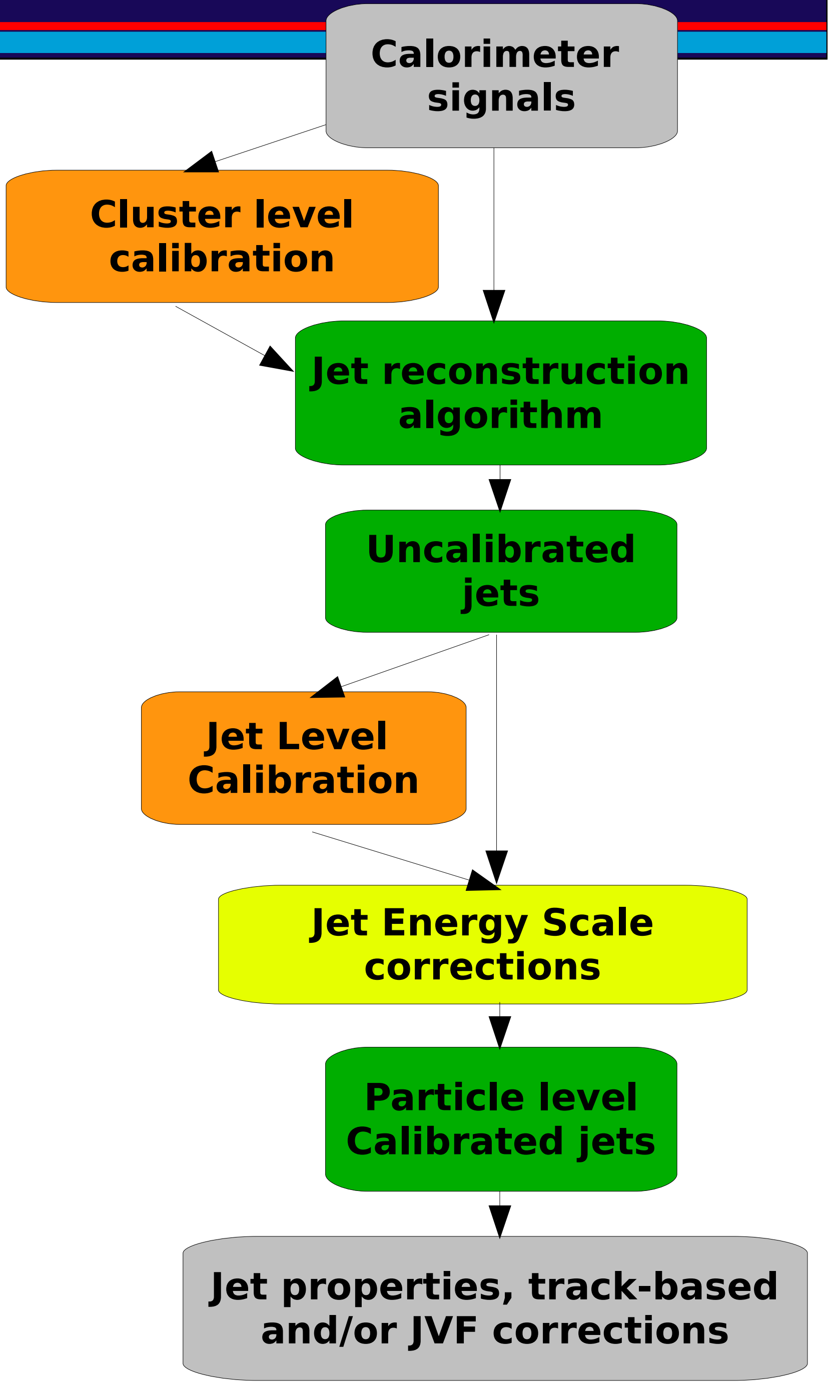
- Another goal of the jet calibration is to achieve an optimal jet energy resolution.

From uncalibrated to calibrated jets

There is no universal model for jet calibration. ATLAS has developed several schemes of calibration basically at two levels:

- **Jet level:** First find jet, then calibrate, then other corrections required are applied.
  - **Global Cell Weighting (GCW) or H1-Style.**
  - **EM+JES:** It's the default in ATLAS.
- **Cluster level:** Calibrate calorimeter signals, then find jet, then other corrections required are applied.
  - **Local Cell Weighting (LCW).**

The calibration schemes mentioned above are MC based, but there are other "**data only**" calibration methods under development and validation rigth now.



Calorimeter signals

Cluster level calibration

Jet reconstruction algorithm

Uncalibrated jets

Jet Level Calibration

Jet Energy Scale corrections

Particle level Calibrated jets

Jet properties, track-based and/or JVF corrections

Global Sequential (GS) Calibration

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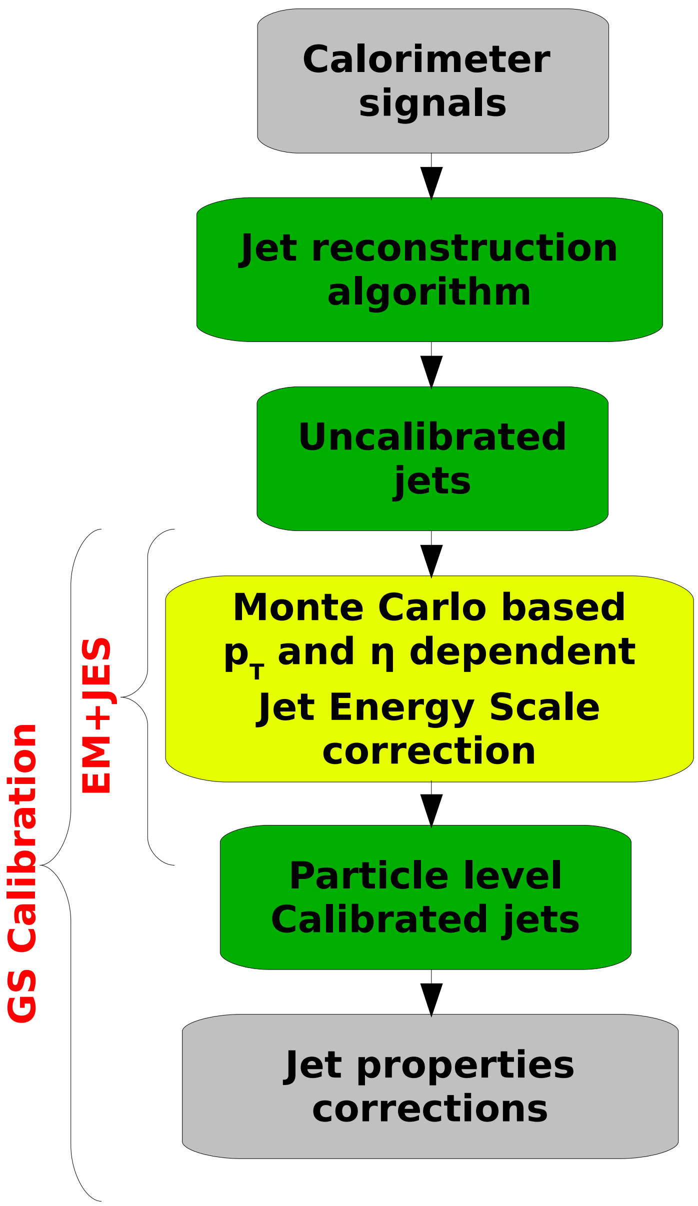


Calorimeter signals

Jet reconstruction algorithm

Uncalibrated jets

Monte Carlo based p_T and η dependent Jet Energy Scale correction

Particle level Calibrated jets

Jet properties corrections

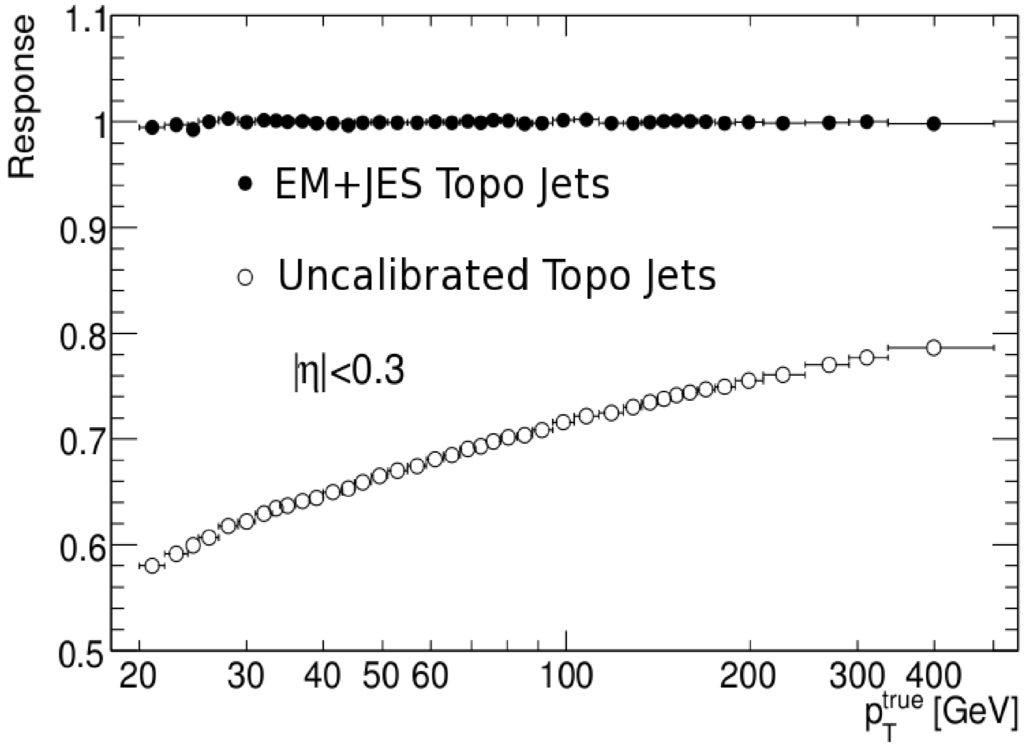
EM+JES

GS Calibration

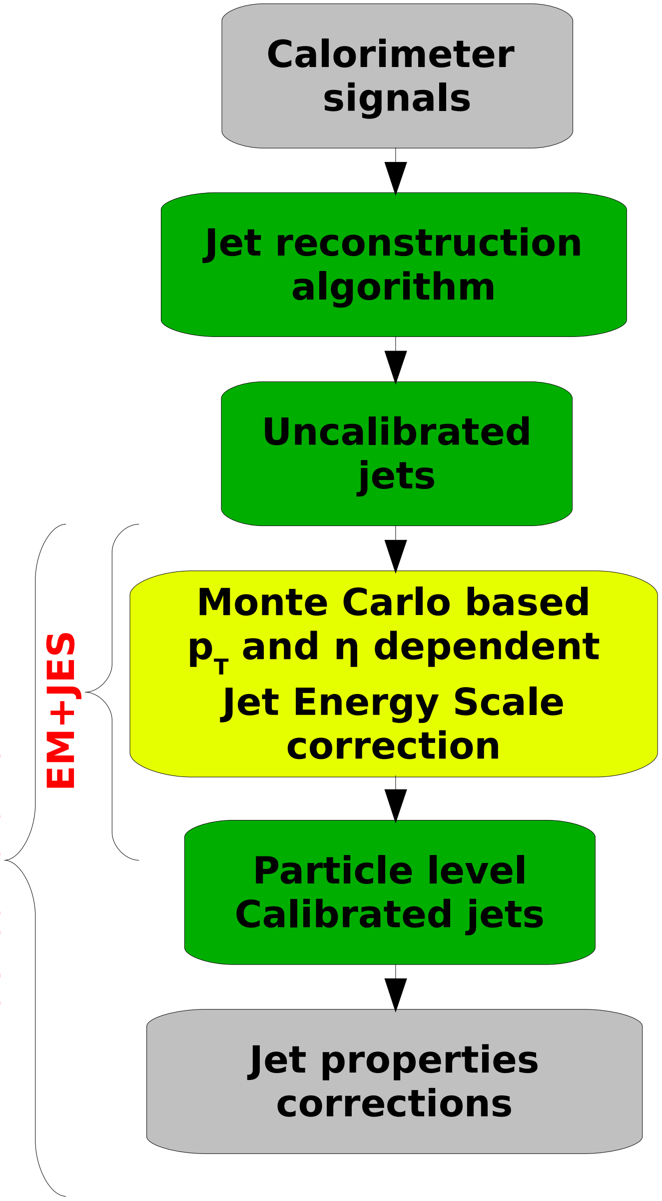
GS Calibration is a **jet level Monte Carlo based calibration,** divided in two steps:

First step: Jet Energy Scale correction:

- We use the EM+JES calibration (**default in ATLAS**) which parametrize the response as a function of p_T^{reco} and η.
- The application of EM+JES coefficients brings the response equal to 1.



Global Sequential (GS) Calibration



Calorimeter signals

Jet reconstruction algorithm

Uncalibrated jets

Monte Carlo based p_T and η dependent Jet Energy Scale correction

Particle level Calibrated jets

Jet properties corrections

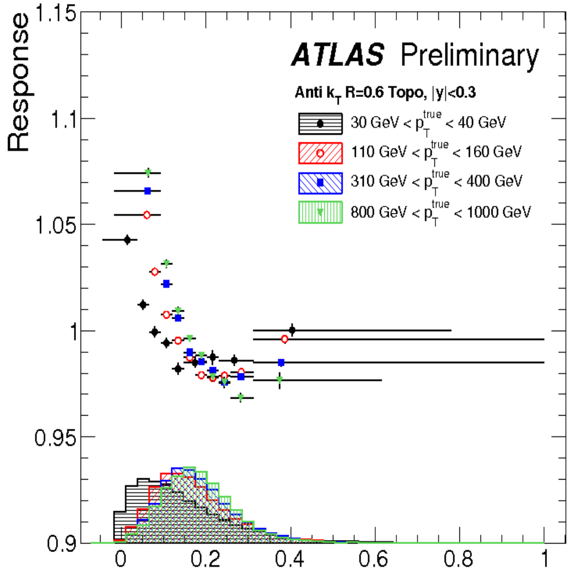
EM+JES

GS Calibration

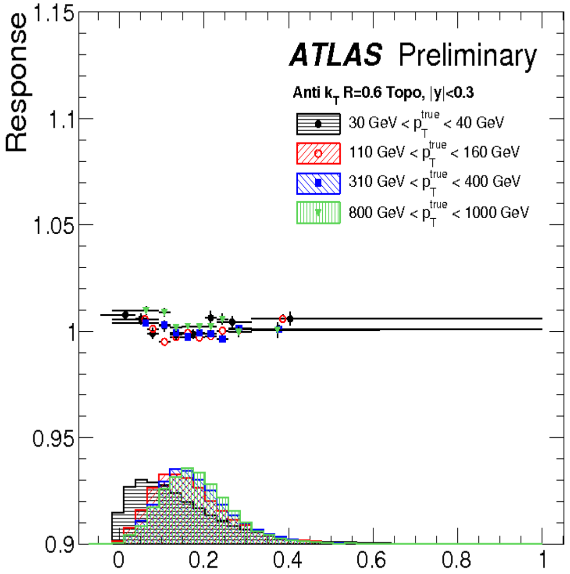
GS Calibration is a **jet level Monte Carlo based calibration,** divided in two steps:

Second step: Improvement of jet resolution (σR/R):

- GS parametrize the response as a function of p_T^{reco} and η and one jet property (in the example below: fraction of jet energy deposited in 1st layer of tile calorimeter).
- The application of GS coefficients improve the resolution, but keeping the response to 1.
- Once one correction is applied, start procedure over again with new variables to achieve optimal performance

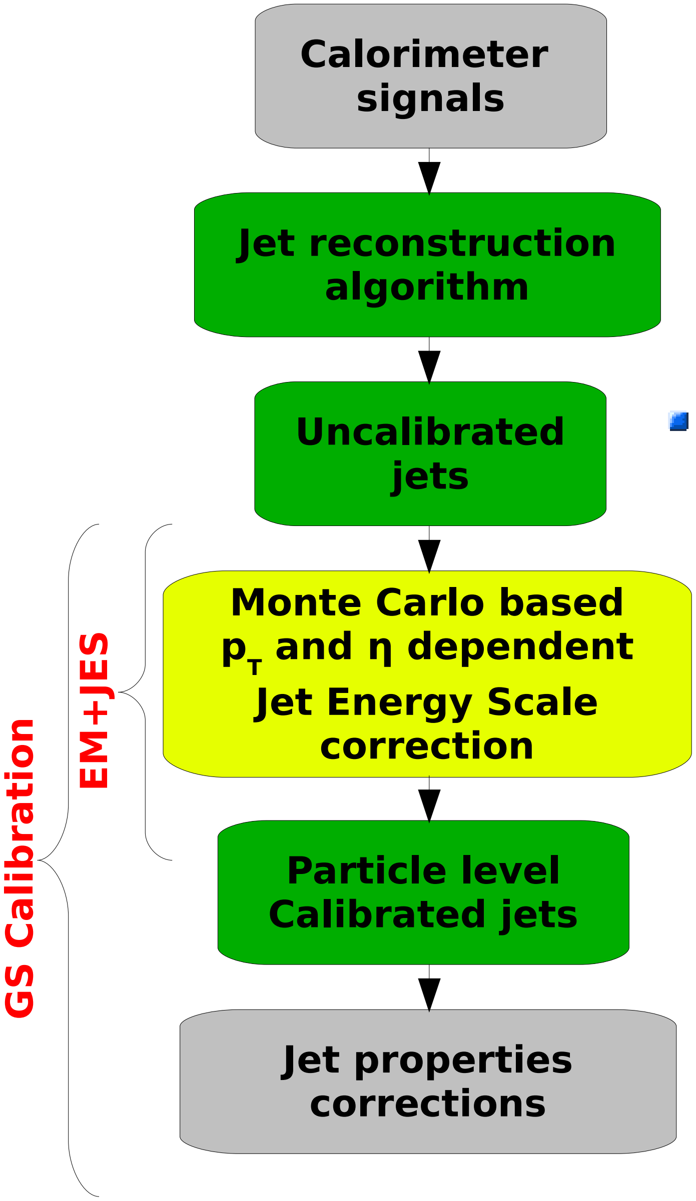


Before correction



After correction

Global Sequential (GS) Calibration



Calorimeter signals

Jet reconstruction algorithm

Uncalibrated jets

Monte Carlo based p_T and η dependent Jet Energy Scale correction

Particle level Calibrated jets

Jet properties corrections

GS Calibration is a **jet level Monte Carlo based calibration,** divided in two steps:

Second step: Improvement of jet resolution (σ_R/R):

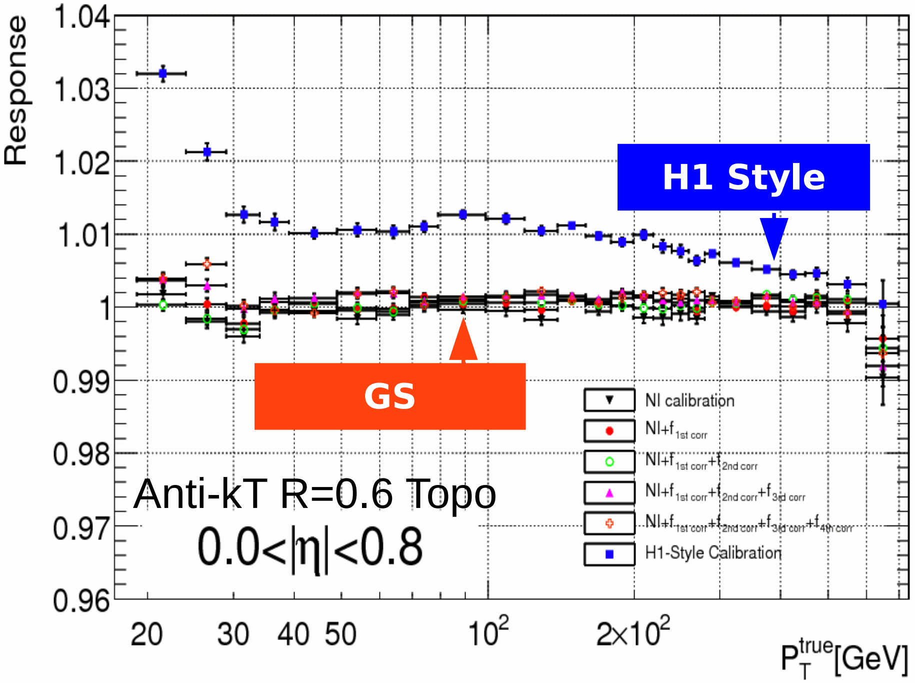
- Corrections are not very sensitive to pile-up.
- Corrections can be calculated/validated using data.
- Corrections are applied sequentially and their number depends on the jet η.

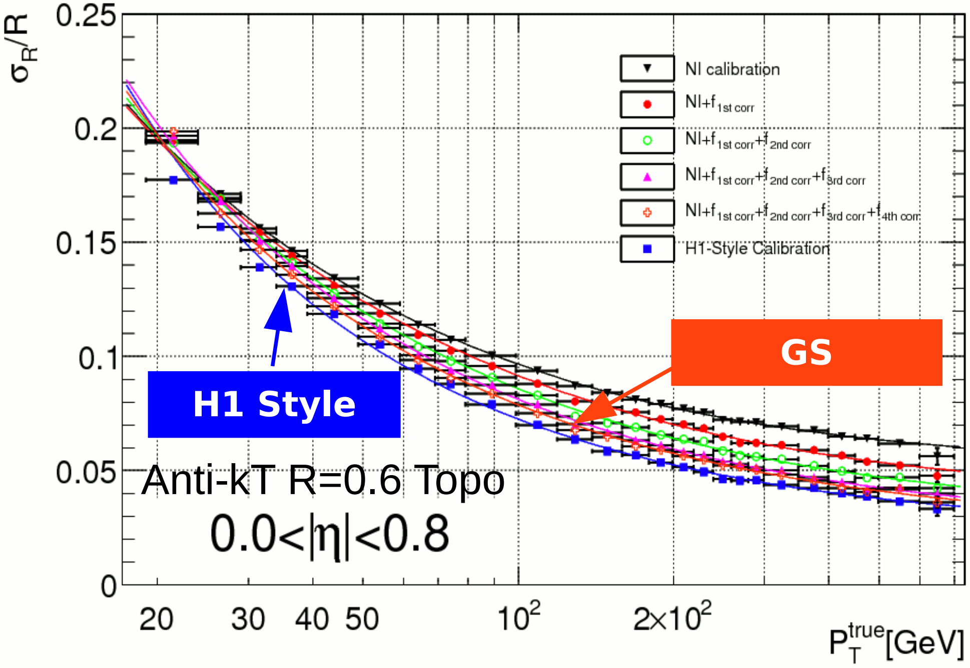
$\lvert\eta\rvert$ region	Correction 1	Correction 2	Correction 3	Correction 4
$[0, 1.2]$	f_{tile1}	f_{em3}	$f_{\mathrm{presampler}}$	width
$[1.2, 1.3]$	f_{tile1}			width
$[1.3, 1.4]$	f_{tile1}			width
$[1.4, 1.7]$	f_{tile1}	f_{hec0}		width
$[1.7, 3.0]$		f_{hec0}		width
$[3.0, 3.2]$		f_{em3}		width
$[3.2, 3.4]$		f_{em3}		
$[3.4, 3.5]$		f_{em3}		width
$[3.5, 3.8]$	f_{fcal1}			width
$[3.8, 4.4]$	f_{fcal1}			

* f correspond to the fractional jet energy deposited in the corresponding calorimeter layer. Width refers to the jet width.

GSC performance Anti-k_T R=0.6 Topo

Response=$E_{calorimeter}/E_{particle}$





- Corrections keep the response close to 1, at the level of 0.5%.
- The jet energy resolution improves after each correction.
- Resolution is comparable to the Global Cell Weighting (GCW or H1-Style) calibration (one of the calibration schemes existent in ATLAS).

GS Validation with Data

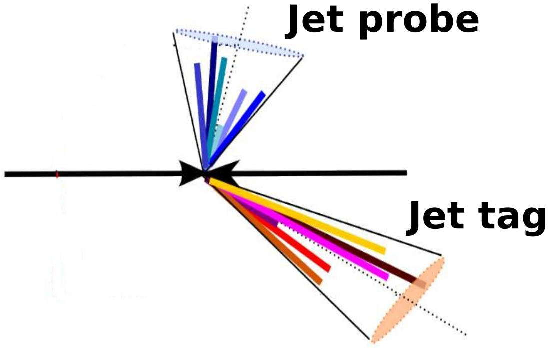
In Monte Carlo:

Response=$E_{calorimeter}/E_{particle}$

In Data:

- We do not have particle level information.
- We need to use di-jet balance techniques in order to calculate the calorimeter response.

GS Validation with Data



- Di-jet are events used to determine the GS calibration response functions R(xi) (xi : input variables).

- Asymmetry of di-jet system can be directly related with the response (R):

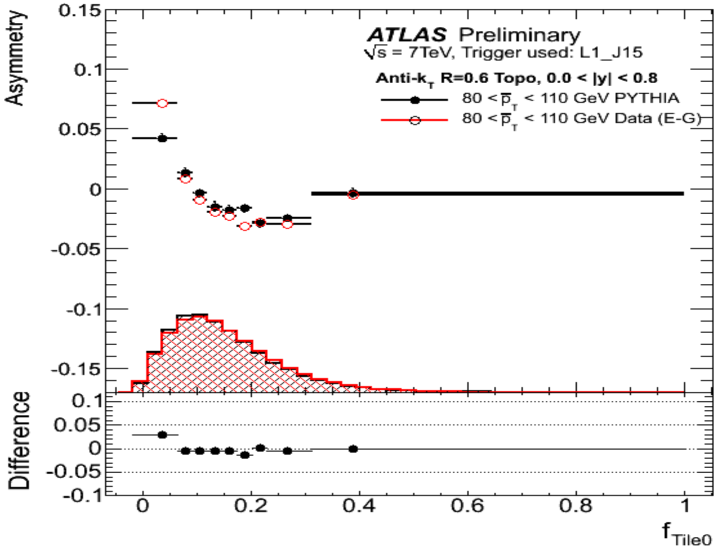
$$A(x) = \frac{p_T^{\text{probe}}(x) - p_T^{\text{tag}}}{p_T^{\text{probe}}(x) + p_T^{\text{tag}}} \Rightarrow \langle R(x) \rangle = \frac{1 + \langle A(x) \rangle}{1 - \langle A(x) \rangle}$$

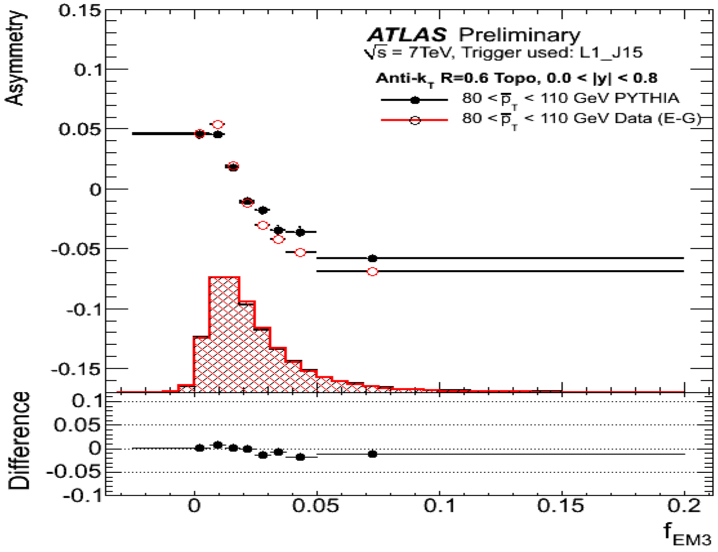
- Imbalance in the event mainly due to:
  - - Calorimeter effects
  - - Imbalance at the truth level jet

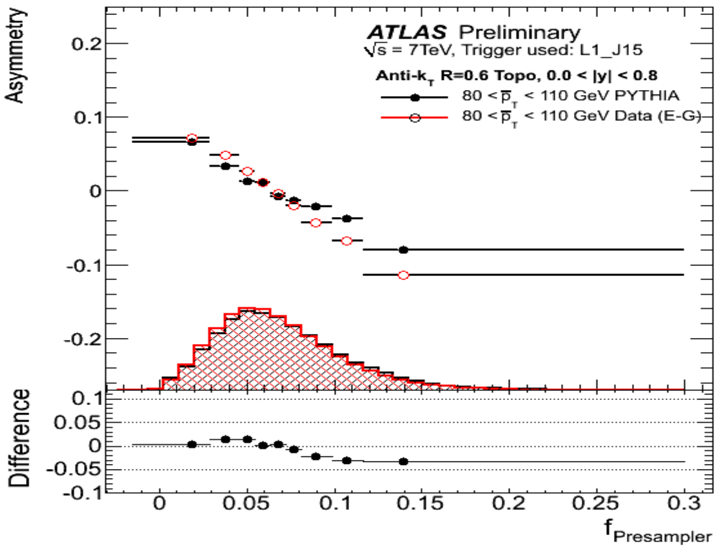
- It can be shown that the two effects can be decoupled for small asymmetries:

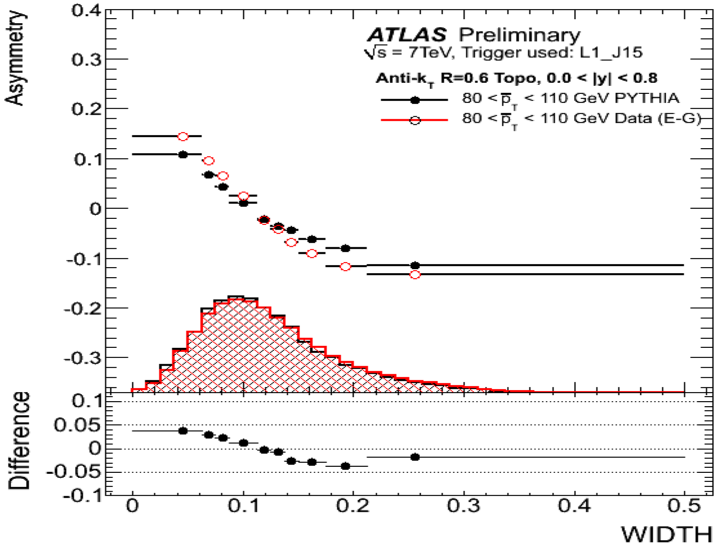
$A \rightarrow A(x) - A_{truth}(x)$ where $A_{\text{truth}} = \frac{p_{T,\text{truth}}^{\text{probe}} - p_{T,\text{truth}}^{\text{tag}}}{p_{T,\text{truth}}^{\text{probe}} + p_{T,\text{truth}}^{\text{tag}}}.$

GS Validation with Data









- Reminder

$$A(x) = \frac{p_T^{\text{probe}}(x) - p_T^{\text{tag}}}{p_T^{\text{probe}}(x) + p_T^{\text{tag}}}$$

- So far good MC/Data agreement in asymmetry vs f_{Tile0}, f_{EM3} and f_{HEC0} (also in others η and p_T regions).

- WIDTH and $f_{Presampler}$ not well described by MC.

- Validation has been made up to 800 GeV in pT in the central region of the detector.

GS Validation with Data

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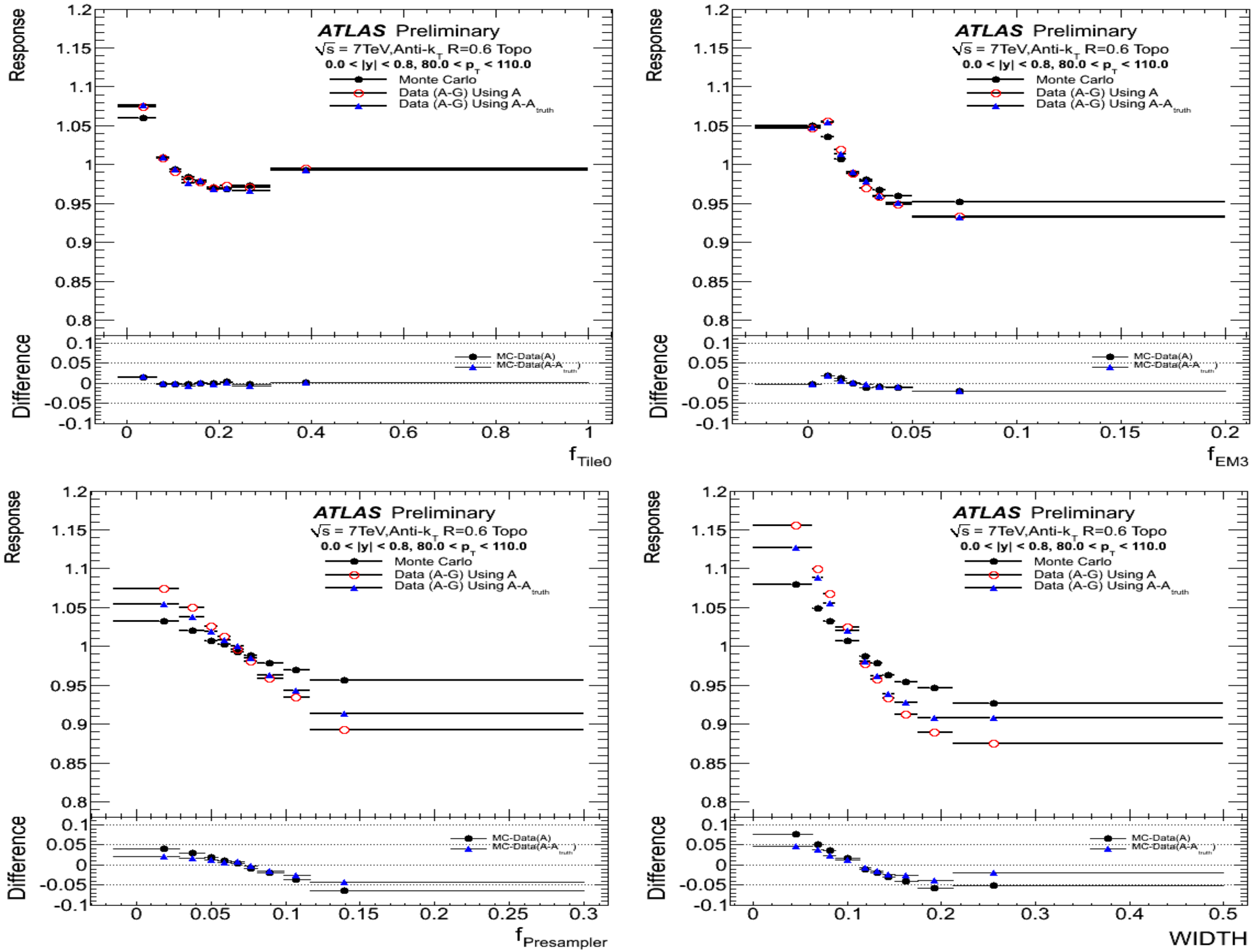


- Reminder

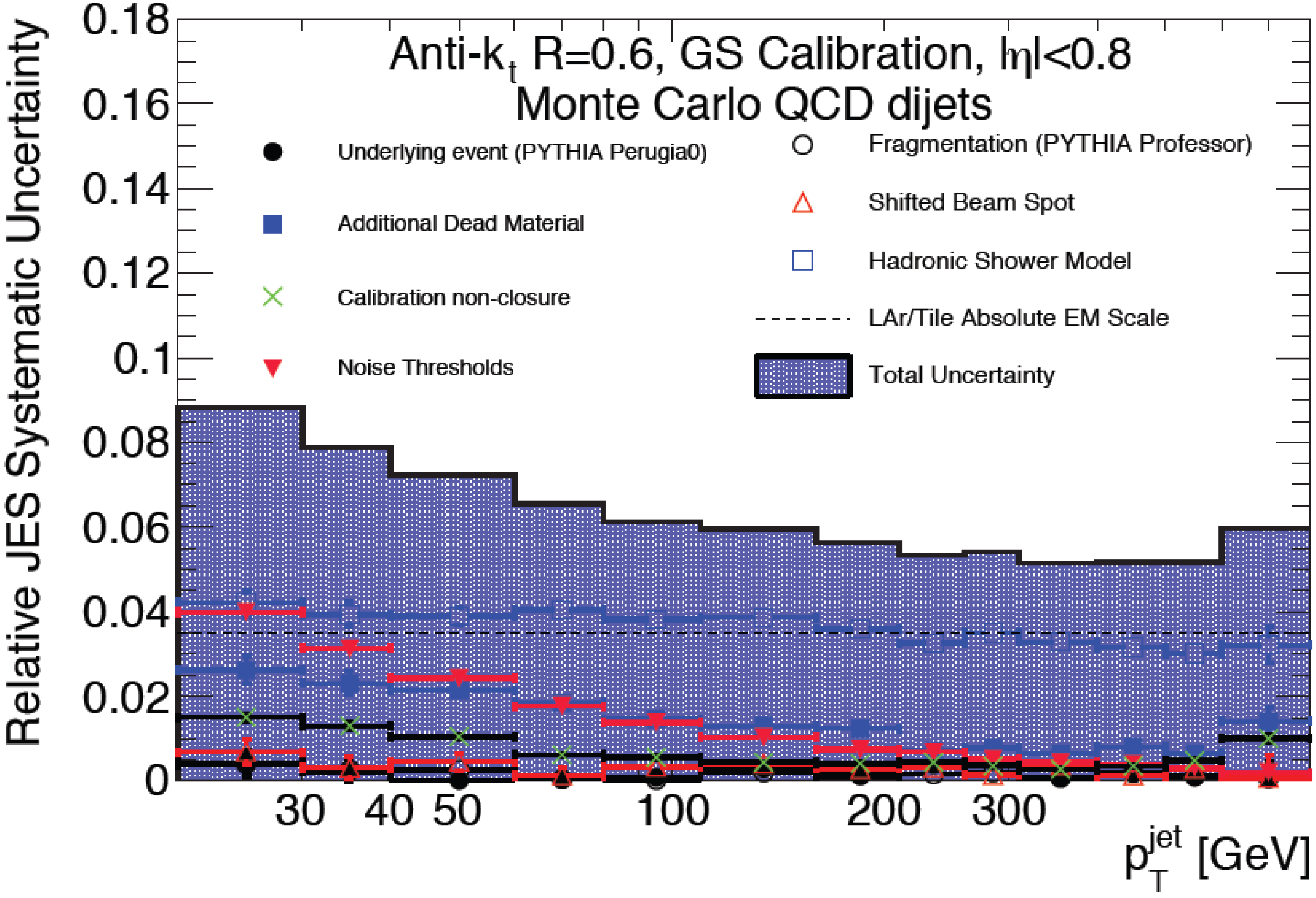
$$\langle R(x)\rangle = \frac{1+\langle A(x)\rangle}{1-\langle A(x)\rangle}$$

- Using A(data)
- Using A(data)-A_{truth}(MC)

- Good MC/Data agreement in the Response vs f_{Tile0}, f_{EM3} and f_{HEC0}.

- Statistics accumulated by ATLAS in the last month will allow us to calculate the GS coefficients in some p_T and η regions using only data.

Monte Carlo based systematics in GS



- The figure shows the Monte Carlo (MC) based derived systematics. Those were calculated using MC samples with different description of the interactions and the detector geometry than the sample used to derive the GC corrections.
- Similar results where obtained in other η regions.
- Systematics due to MC/Data differences in corrections and due to imbalance at the truth level are under study.

Conclusions and future work

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- The Global Sequential (GS) Calibration uses few properties of the jet to achieve good performance.

- The GS corrections are applied sequentially (then if one of them is not well understood it can be eliminated). A systematic uncertainty can be assigned to each one of the corrections.

- Direct validation of corrections in data can help cross-check the calibration:

  - It has shown good MC/Data agreement for f_{EM3} and f_{Tile0} in the central region and for f_{HEC0} in the EndCap region of the detector.
  - On the other hand, $f_{Presampler}$ and WIDTH are not well described by MC.

- We are now concentrated on the calculation of the systematic uncertainties associated to MC/Data differences in corrections and to the imbalance at the truth level.

Some bibliography

- D. Lopez, E.W. Hughes and A. Schwartzman, “A simple pT and η-Dependent Monte Carlo-Based Calibration”, ATL-PHYS-INT-2009-077.

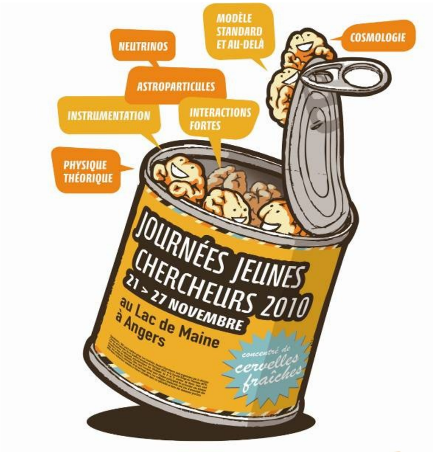
- DLM, E.W. Hughes and A. Schwartzman, “Jet Energy Resolution Improvement After Calibration Using Longitudinal Calorimeter Segmentation in ATLAS”, ATL-PHYS-INT-2009-051.

- D. Lopez, E.W. Hughes and A. Schwartzman, “A Sequential Multi-Variate Jet Calibration Based On Global Properties of the Jet Structure”, ATL-COM-PHYS-2010-058.

- Public studies with data: ATLAS collaboration, ATLAS-CONF-2010-053.

- Twiki with updated information: https://twiki.cern.ch/twiki/bin/view/Main/ResultsGSC

Backup



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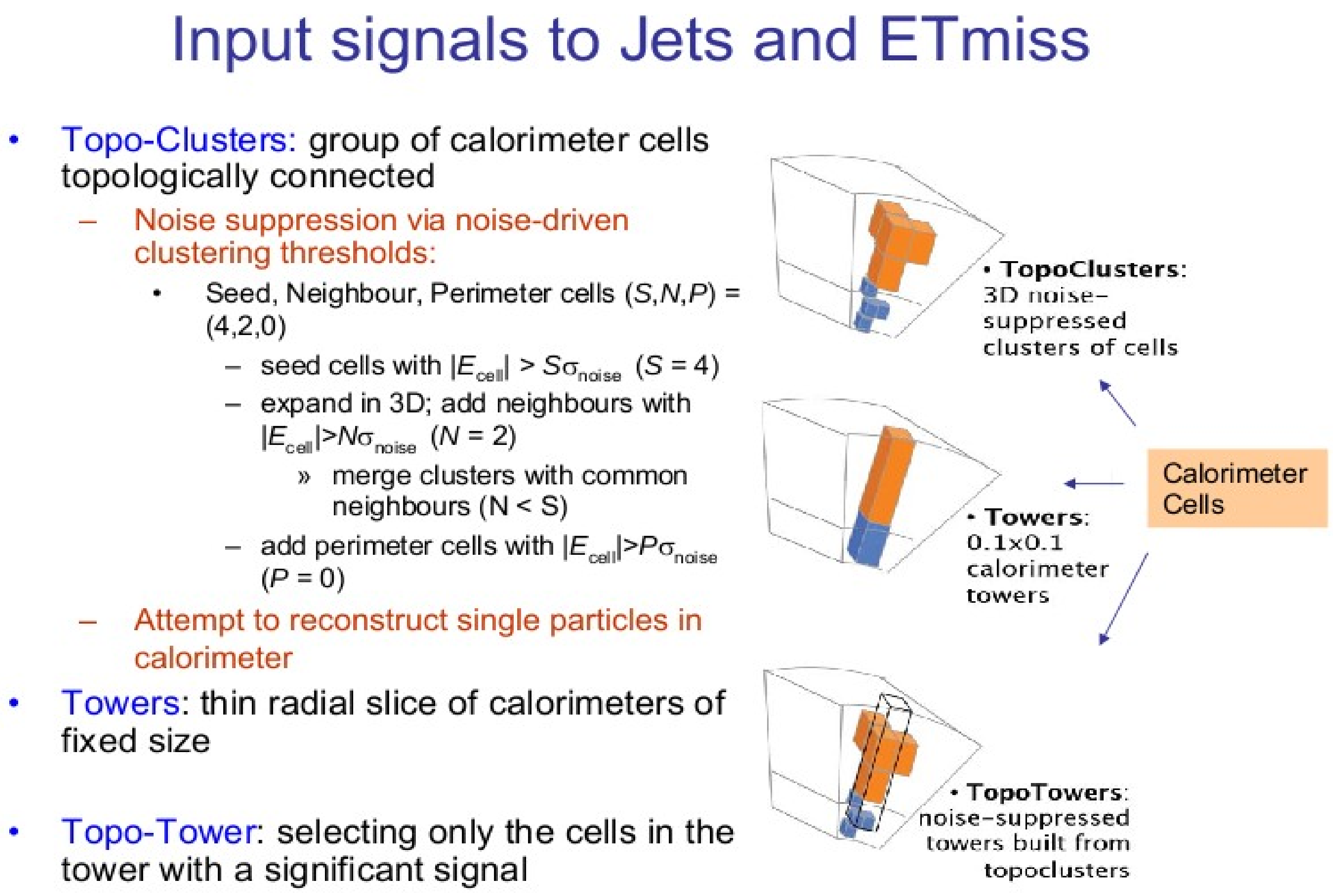
Inputs to Jets and ETmiss



Input signals to Jets and ETmiss

- Topo-Clusters: group of calorimeter cells topologically connected
  - – Noise suppression via noise-driven clustering thresholds:
    - Seed, Neighbour, Perimeter cells (*S*,*N*,*P*) = (4,2,0)
      - – seed cells with $|E_{cell}| > S\sigma_{noise}$ ($S = 4$)
      - – expand in 3D; add neighbours with $|E_{cell}| > N\sigma_{noise}$ ($N = 2$)
        - » merge clusters with common neighbours (N < S)
      - – add perimeter cells with $|E_{cell}| > P\sigma_{noise}$ ($P = 0$)
  - – Attempt to reconstruct single particles in calorimeter
- Towers: thin radial slice of calorimeters of fixed size
- Topo-Tower: selecting only the cells in the tower with a significant signal

• **TopoClusters**: 3D noise-suppressed clusters of cells

Calorimeter Cells

• **Towers**: 0.1x0.1 calorimeter towers

• **TopoTowers**: noise-suppressed towers built from topoclusters

Taked from Silvia Resconi, HCP2009 Evian November 2009

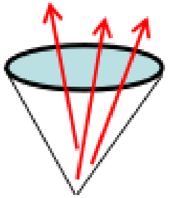
Jet Algorithms

Jet Algorithms

"Cone" algorithms:

Geometrically motivated jet finders:

- Seeded fixed cones (R=0.4,0.7)
  - Collect particles or detector signals into fixed sized cone of chosen radius R



$$R = \sqrt{\Delta\eta^2 + \Delta\varphi^2}$$

  - Basic parameters are seed p_T threshold and cone size
- Seedless fixed cones (R=0.4,0.7)
  - No seeds
  - Collect particles around any other particle into a fixed cone of chosen radius

All Cone algorithms require a split-merge procedure to define non overlapping exclusive jets.

"Cluster" algorithms:

Start from particles or detector signals and perform an iterative pair-wise clustering to build larger objects.

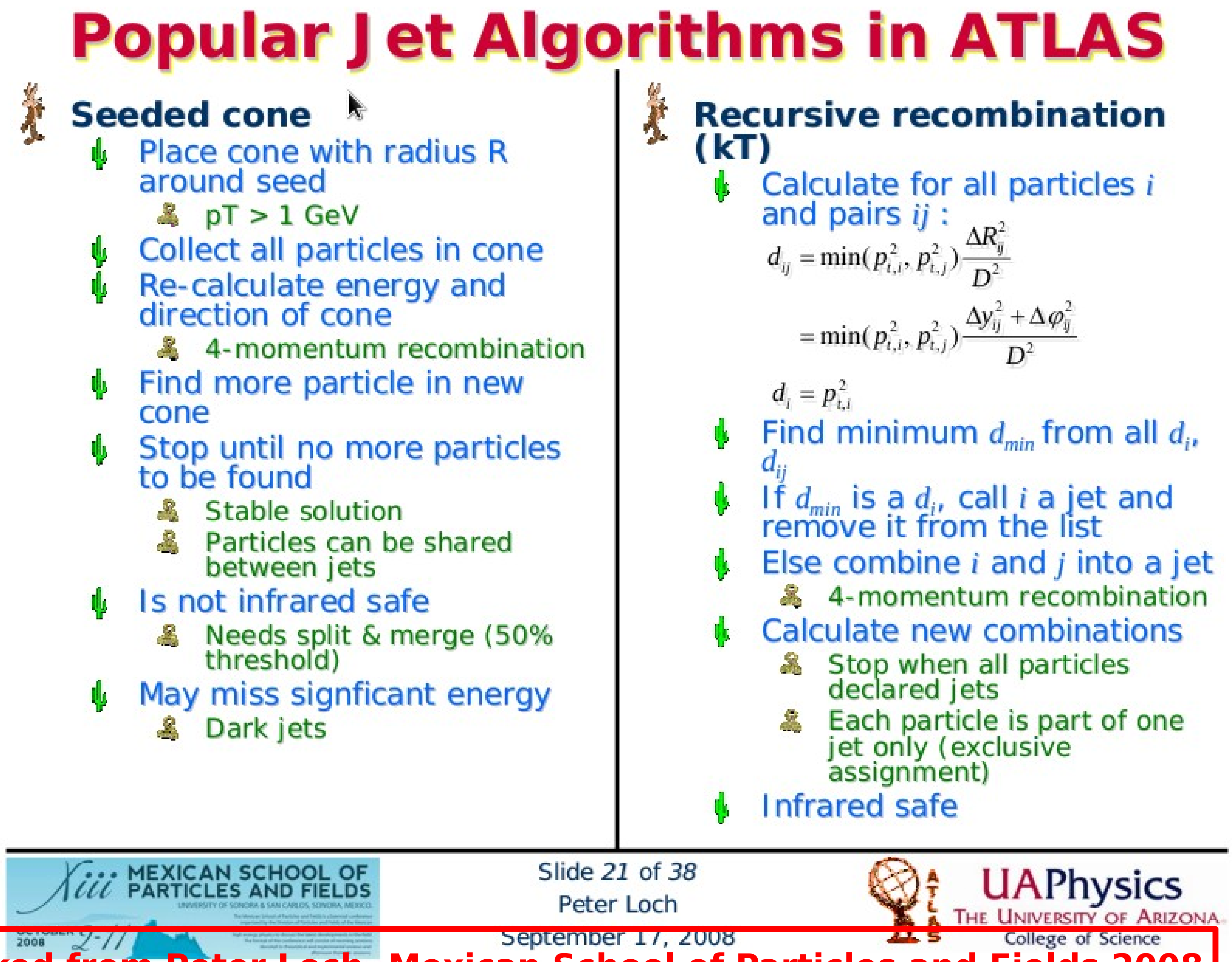
Attempt to undo QCD parton fragmentation:

- kT: with clustering sequence using p_T and distance parameter (start from the softer components)
- Anti-kT using p_T and distance parameter with inverted sequence (start from the harder components)

- ATLAS recently has decided to adopt the AntiKt algorithm as default (D=0.4)

Taked from Silvia Resconi, HCP2009 Evian November 2009

Jet Algorithms



Popular Jet Algorithms in ATLAS

Seeded cone

- Place cone with radius R around seed
  - pT > 1 GeV
- Collect all particles in cone
- Re-calculate energy and direction of cone
  - 4-momentum recombination
- Find more particle in new cone
- Stop until no more particles to be found
  - Stable solution
  - Particles can be shared between jets
- Is not infrared safe
  - Needs split & merge (50% threshold)
- May miss signficant energy
  - Dark jets

Recursive recombination (kT)

- Calculate for all particles i and pairs ij :

$$d_{ij} = \min(p_{t,i}^2, p_{t,j}^2)\frac{\Delta R_{ij}^2}{D^2}$$

$$= \min(p_{t,i}^2, p_{t,j}^2)\frac{\Delta y_{ij}^2 + \Delta\varphi_{ij}^2}{D^2}$$

$$d_i = p_{t,i}^2$$

- Find minimum d_{min} from all d_i, d_{ij}
- If d_{min} is a d_i, call i a jet and remove it from the list
- Else combine i and j into a jet
  - 4-momentum recombination
- Calculate new combinations
  - Stop when all particles declared jets
  - Each particle is part of one jet only (exclusive assignment)
- Infrared safe

XIII MEXICAN SCHOOL OF PARTICLES AND FIELDS
UNIVERSITY OF SONORA & SAN CARLOS, SONORA, MEXICO
OCTOBER 2-11 2008

Slide 21 of 38
Peter Loch
September 17, 2008

UAPhysics
THE UNIVERSITY OF ARIZONA
College of Science

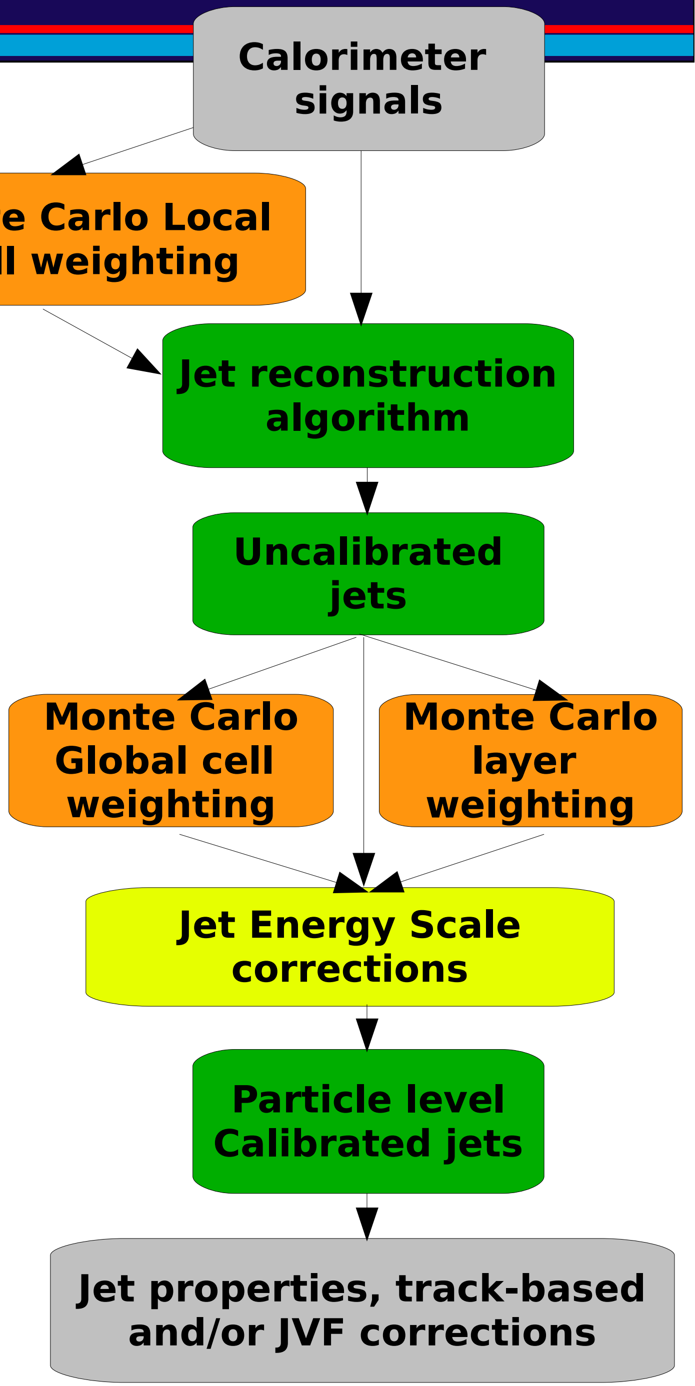
Taked from Peter Loch, Mexican School of Particles and Fields 2008

From uncalibrated to calibrated jets

There is no universal model for jet calibration. ATLAS has developed several schemes of calibration basically at two levels:

- **Jet level:** First find jet, then calibrate, then other corrections required are applied.
  - **Global Cell Weighting (GCW) or H1-Style:** calibrate using weights applied to cell signals in the jet. Weights are function of cell location and cell signal density.
  - **EM+JES:** calibrate using constants applied as a function of p_T and η of the jet. **It's the default in ATLAS**.
- **Cluster level:** Calibrate calorimeter signals, then find jet, then other corrections required are applied.
  - **Local Cell Weighting (LCW):** calibrate the topological cluster using weights calculated depending on the type of topological cluster it is (an electromagnetic or an hadronic cluster).

There are other “data only” calibration methods under development and validation rigth now.



Calorimeter signals

Monte Carlo Local Cell weighting

Jet reconstruction algorithm

Uncalibrated jets

Monte Carlo Global cell weighting

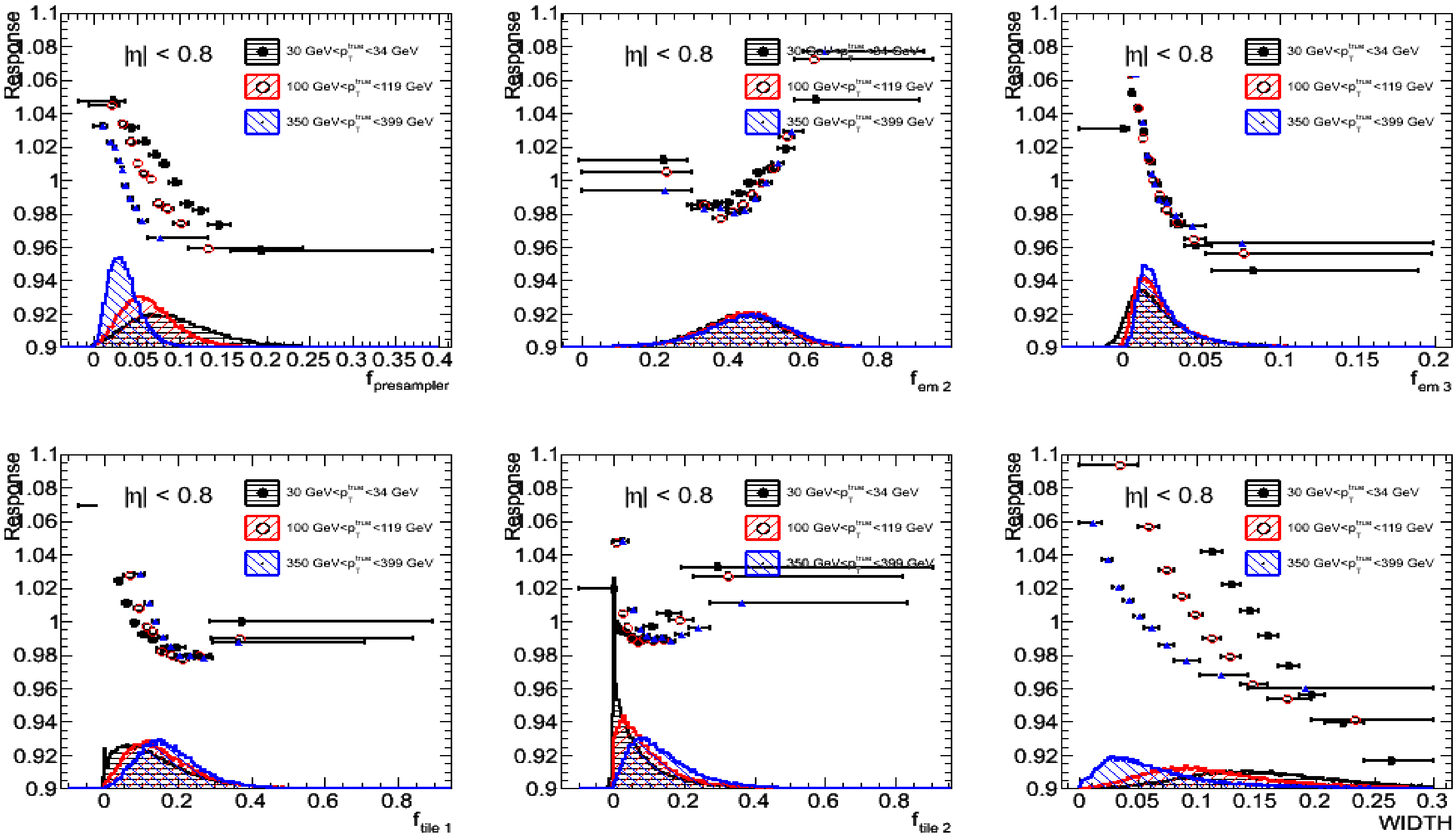
Monte Carlo layer weighting

Jet Energy Scale corrections

Particle level Calibrated jets

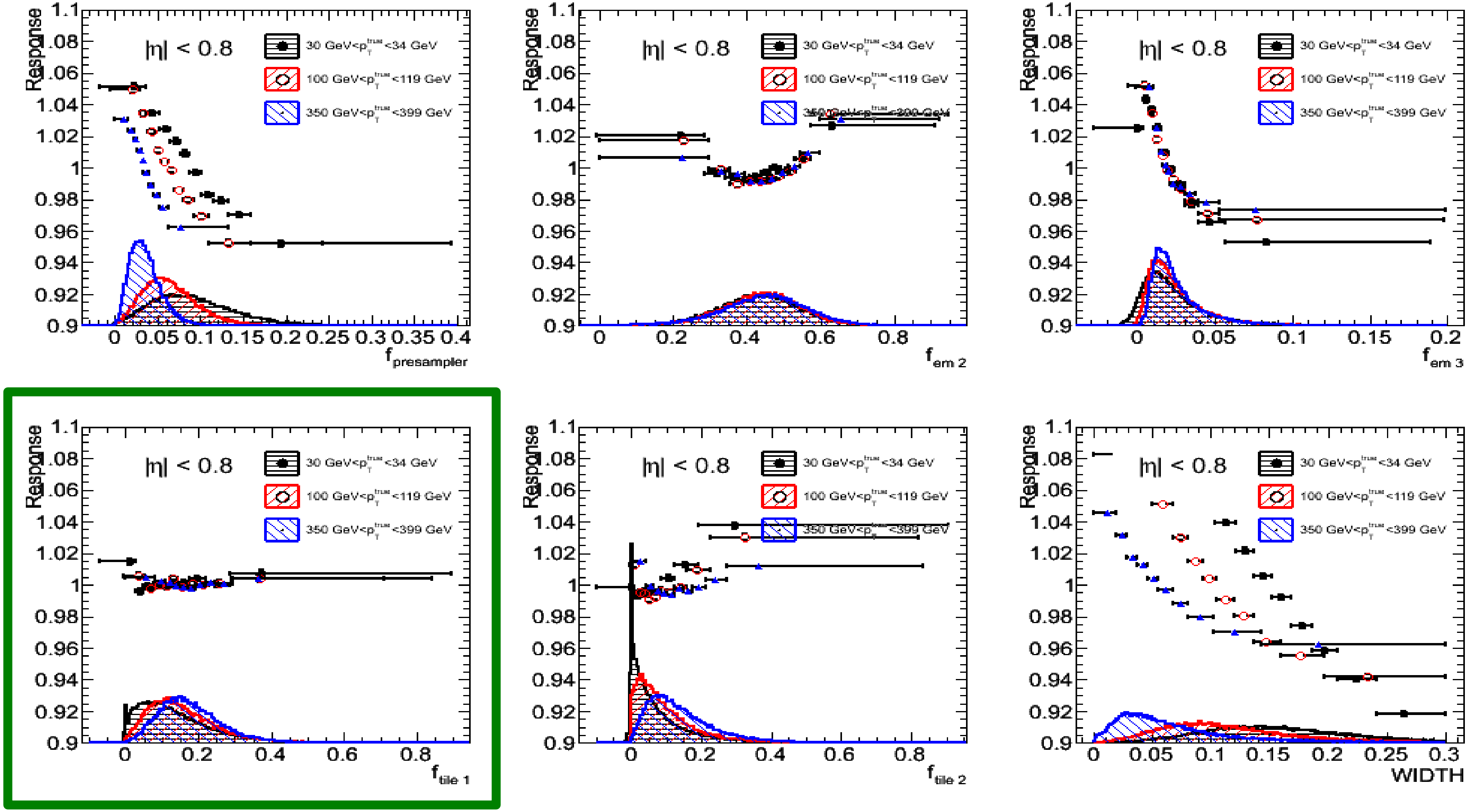
Jet properties, track-based and/or JVF corrections

Response as function of the properties after EM+JES



- For **Anti-kT R=0.6 Topo** jets in |η|<0.8 region

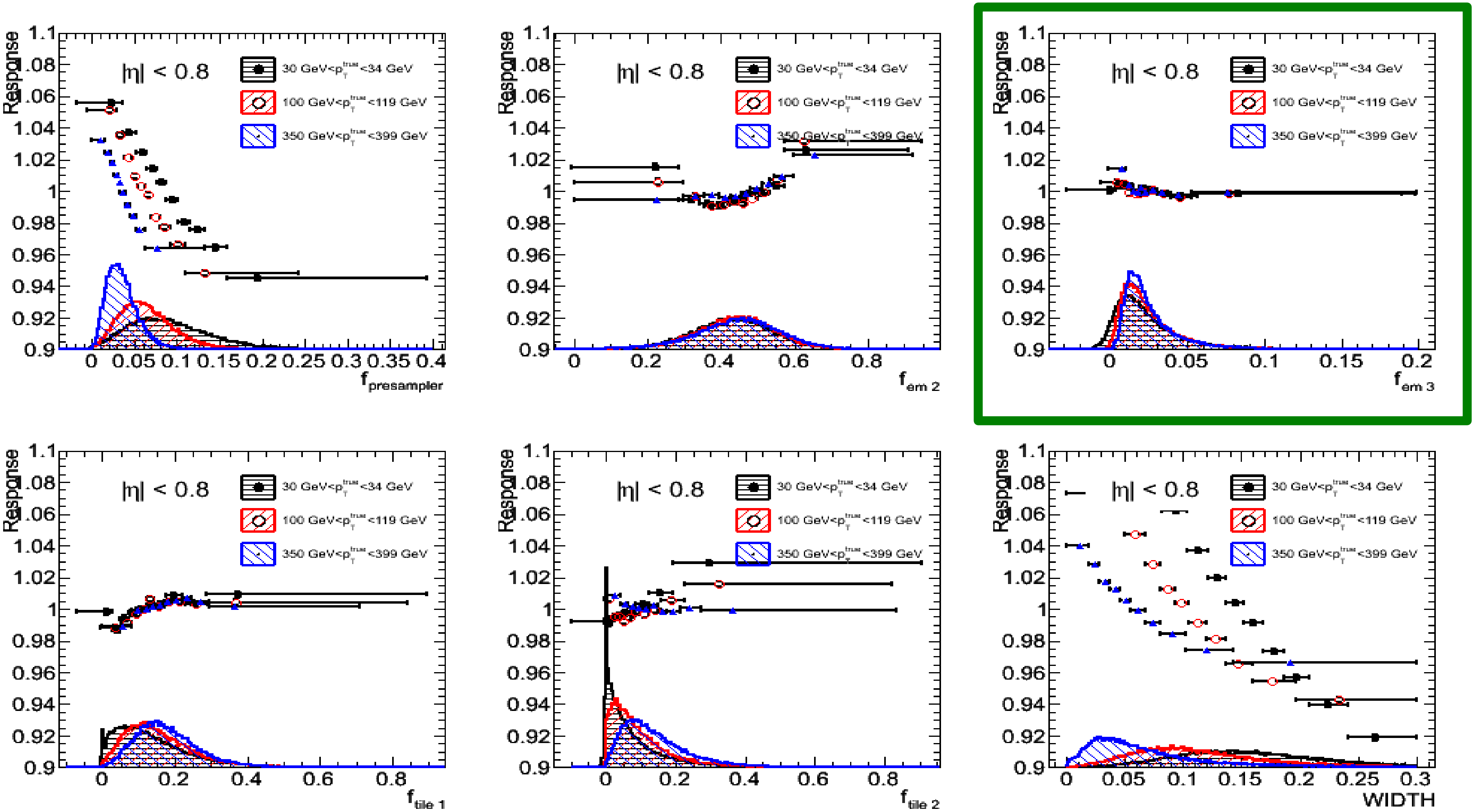
Response as function of the properties after GS 1^{st} level



- For **Anti-kT R=0.6 Topo** jets in |η|<0.8 region
- Response ~1, within 2%

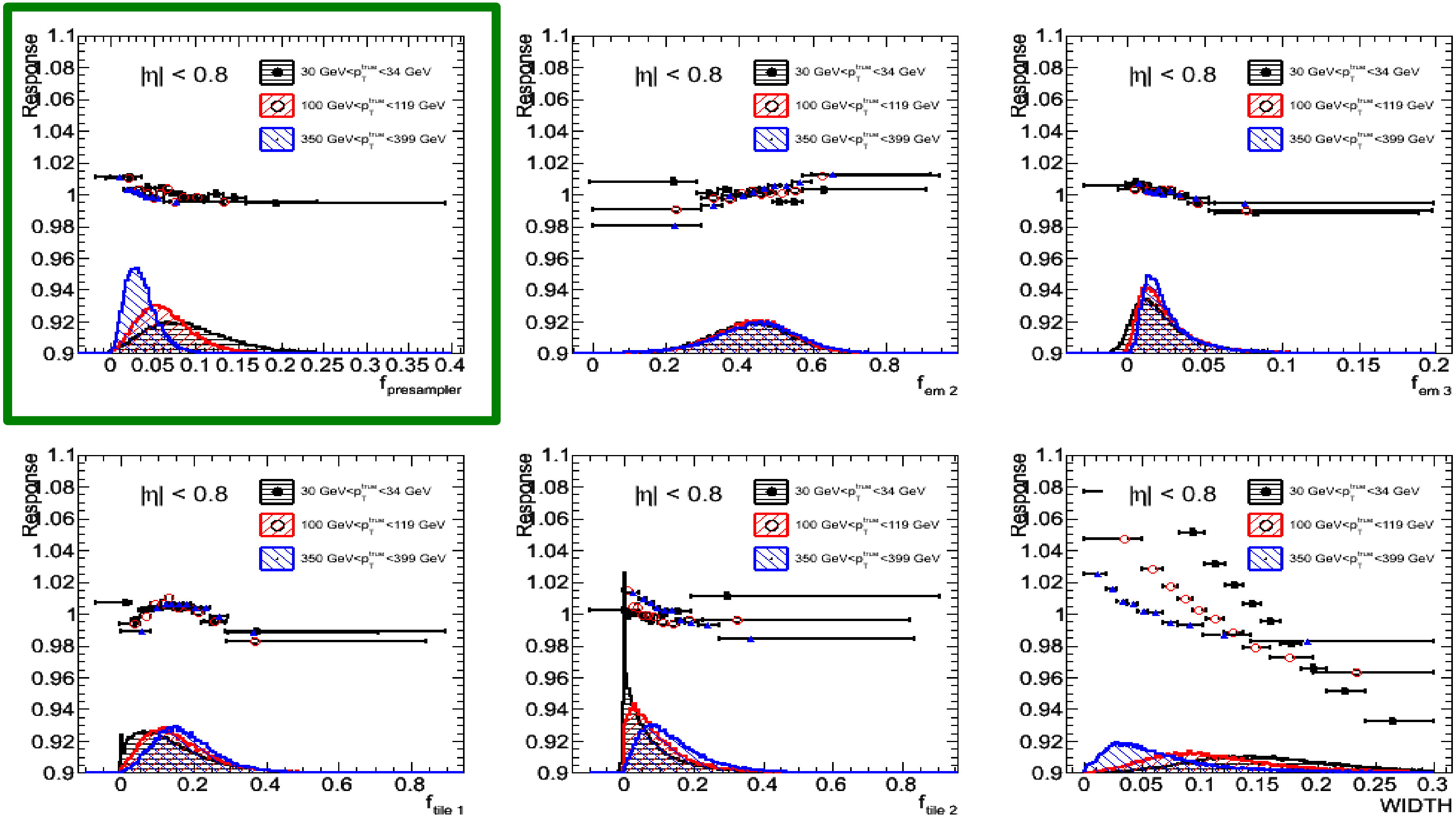
Response as function of the properties after GS 2nd level

Journées Jeunes Chercheurs 2010
Angers, France. 21-27th Novembre 2010



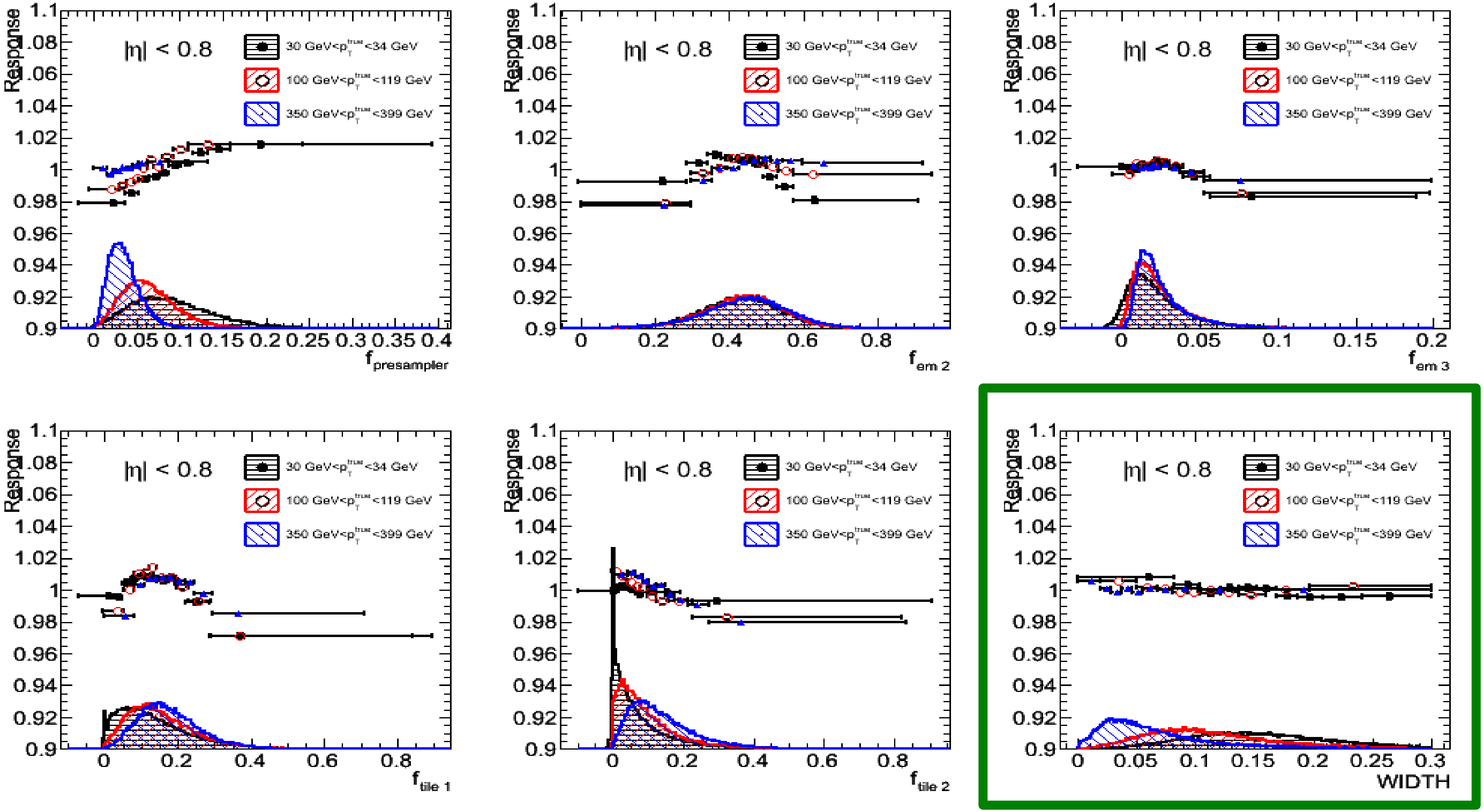
- For **Anti-kT R=0.6 Topo** jets in |η|<0.8 region
- Response ~1, within 2%

Response as function of the properties after GS 3rd level



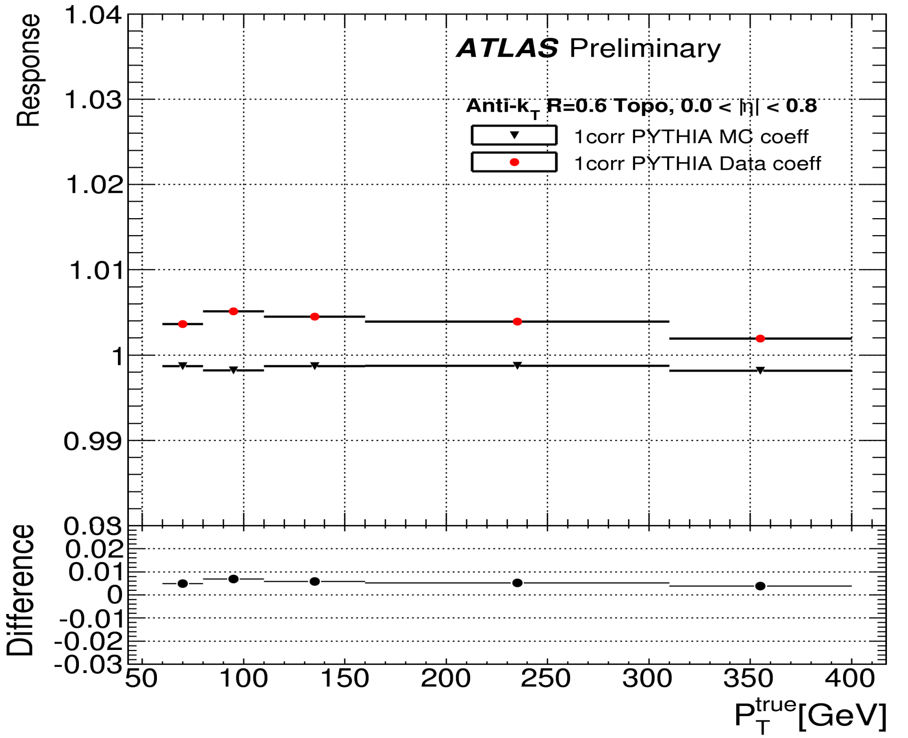
- For **Anti-kT R=0.6 Topo** jets in |η|<0.8 region
- Response ~1, within 2%

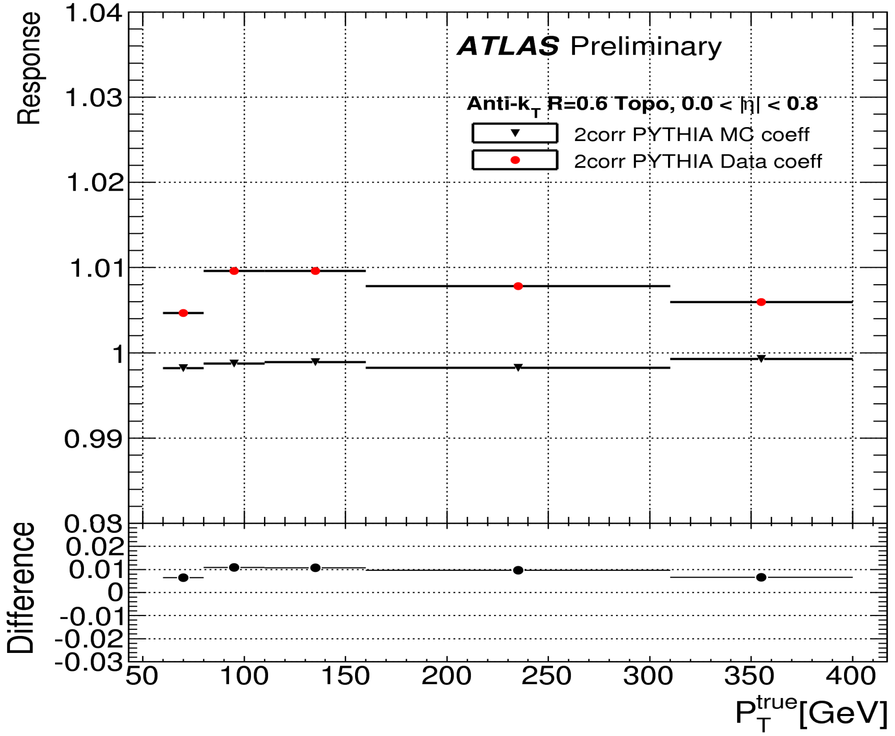
Response as function of the properties after GS 4th level



- For **Anti-kT R=0.6 Topo** jets in |η|<0.8 region
- Response ~1, within 2%

MC Response (E_{reco}/E_{truth}) vs p_T^{truth} $0.0<|\eta|<0.8$





Applying MC derived correction to MC
Applying Data derived correction to MC

- Up to second correction (f_{Tile0} and f_{EM3})

- The difference is a contribution to the systematic uncertainty coming from MC/Data differences.