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Jet Energy Scale and Calibration Framework

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UChicago Argonne LLC

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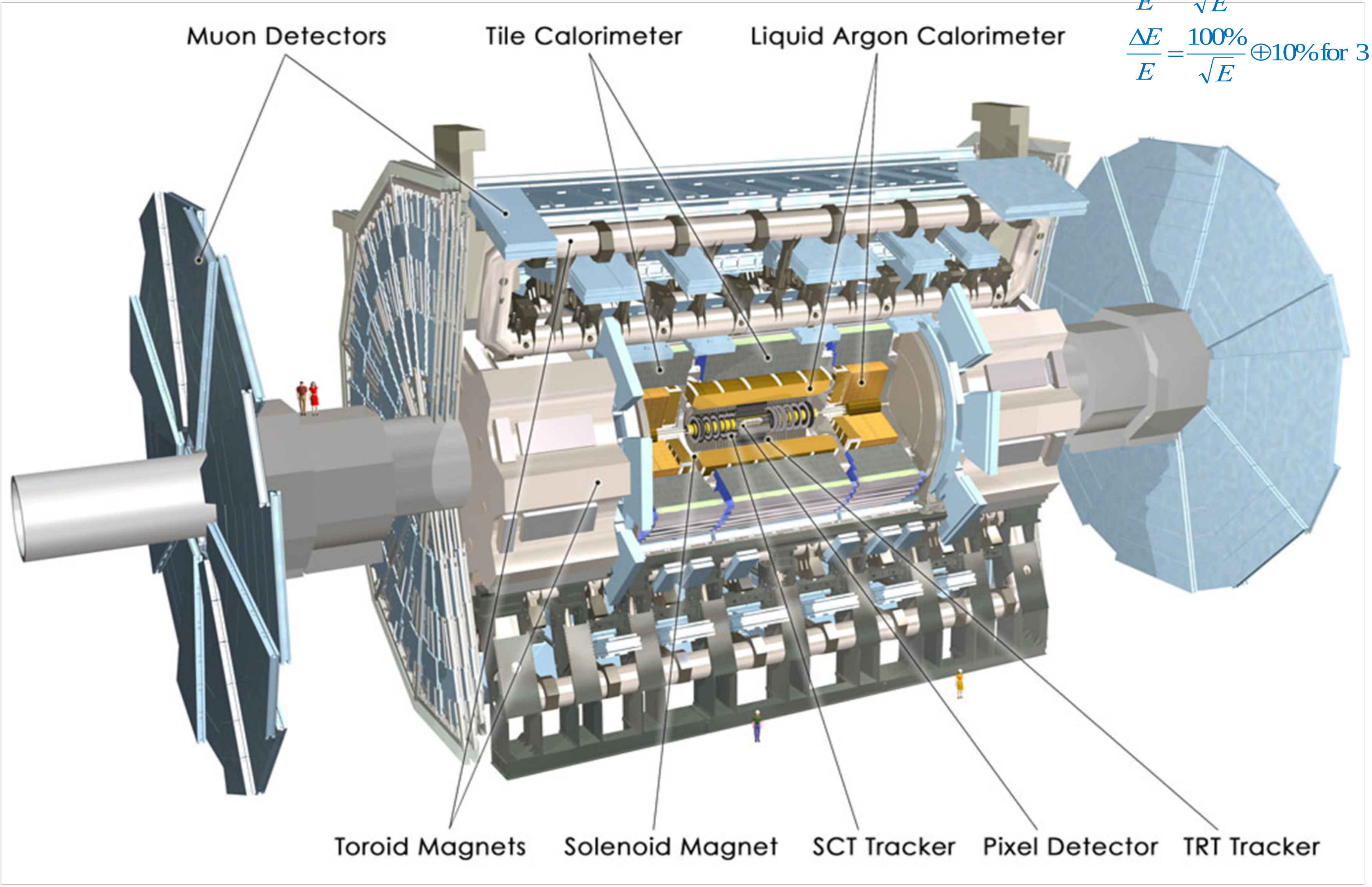
The ATLAS Detector

$$\frac{\Delta E}{E} = \frac{50\%}{\sqrt{E}} \oplus 3\% \text{ for } |\eta| < 3$$

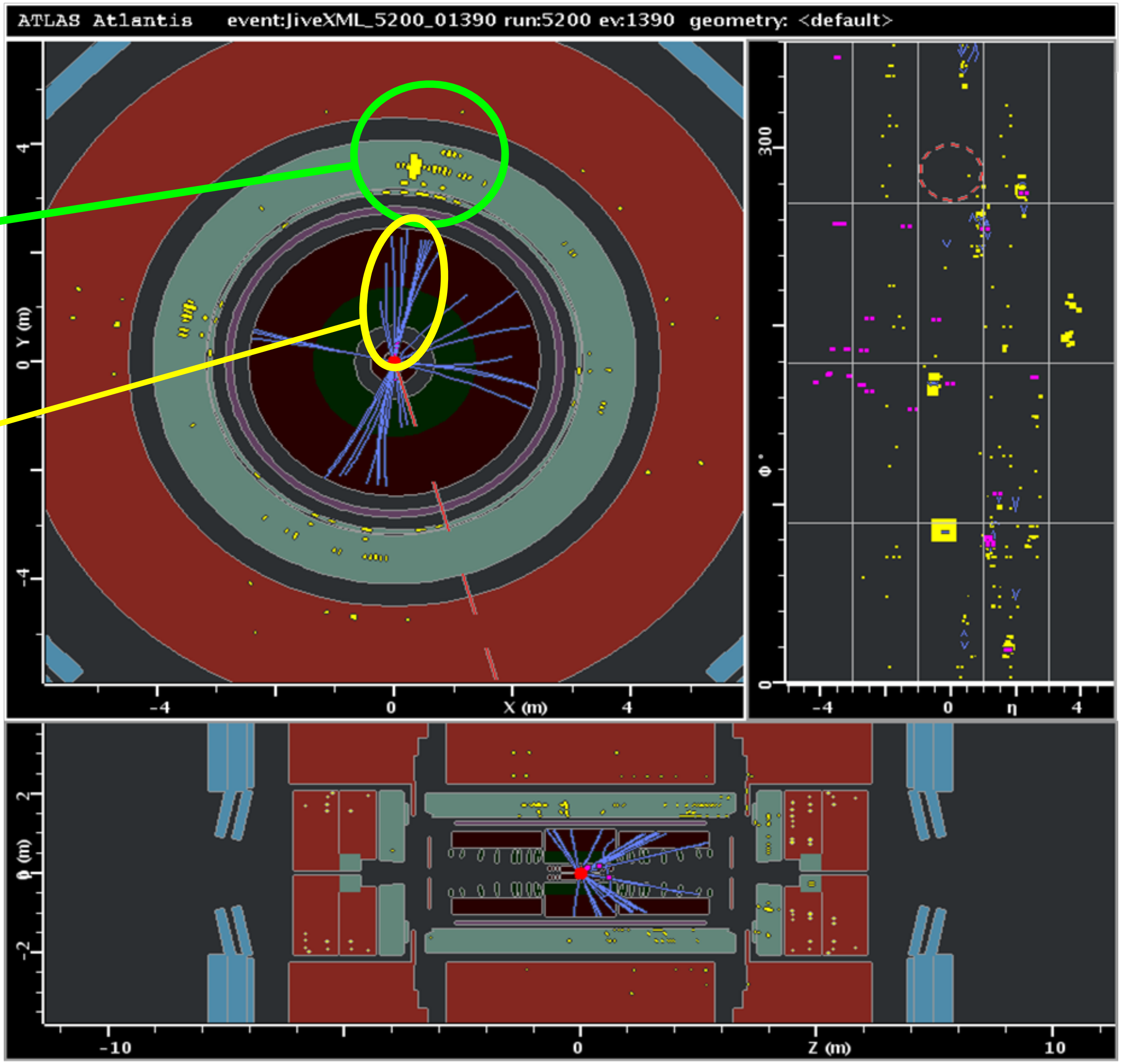
$$\frac{\Delta E}{E} = \frac{100\%}{\sqrt{E}} \oplus 10\% \text{ for } 3 < |\eta| < 5$$



How we detect products from interaction

Charged and neutral components seen in calorimeter

Charged component seen in tracker

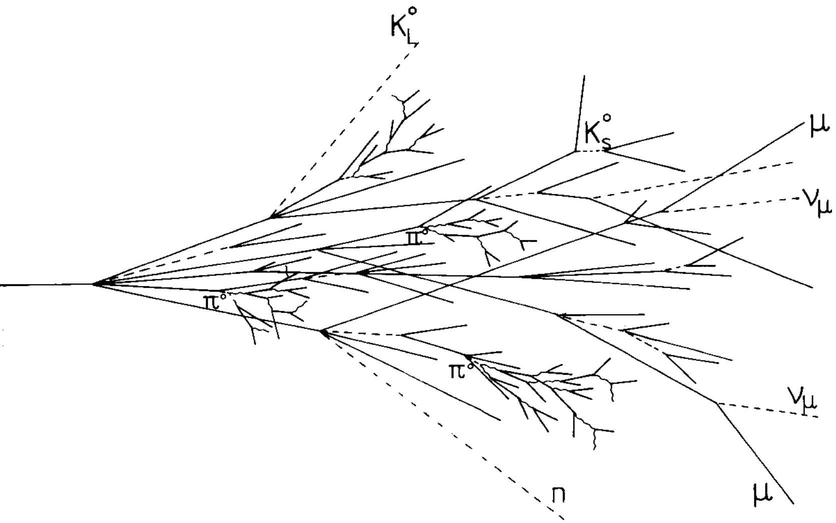


Jet Finding algorithms will return jets out of signals in the calorimeters

Why do we need a jet calibration?

- Different response electrons/hadrons. For hadrons:
  - Visible EM energy ~ 50%
  - Visible non-EM energy ~ 25%
  - In-visible energy ~ 25%
  - Escaped energy ~ 2%

Main reason for non compensation



- Detector DEAD material and GAPs

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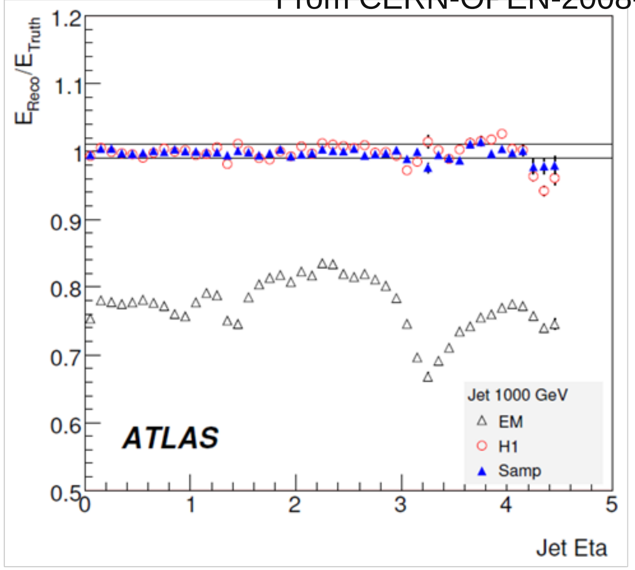
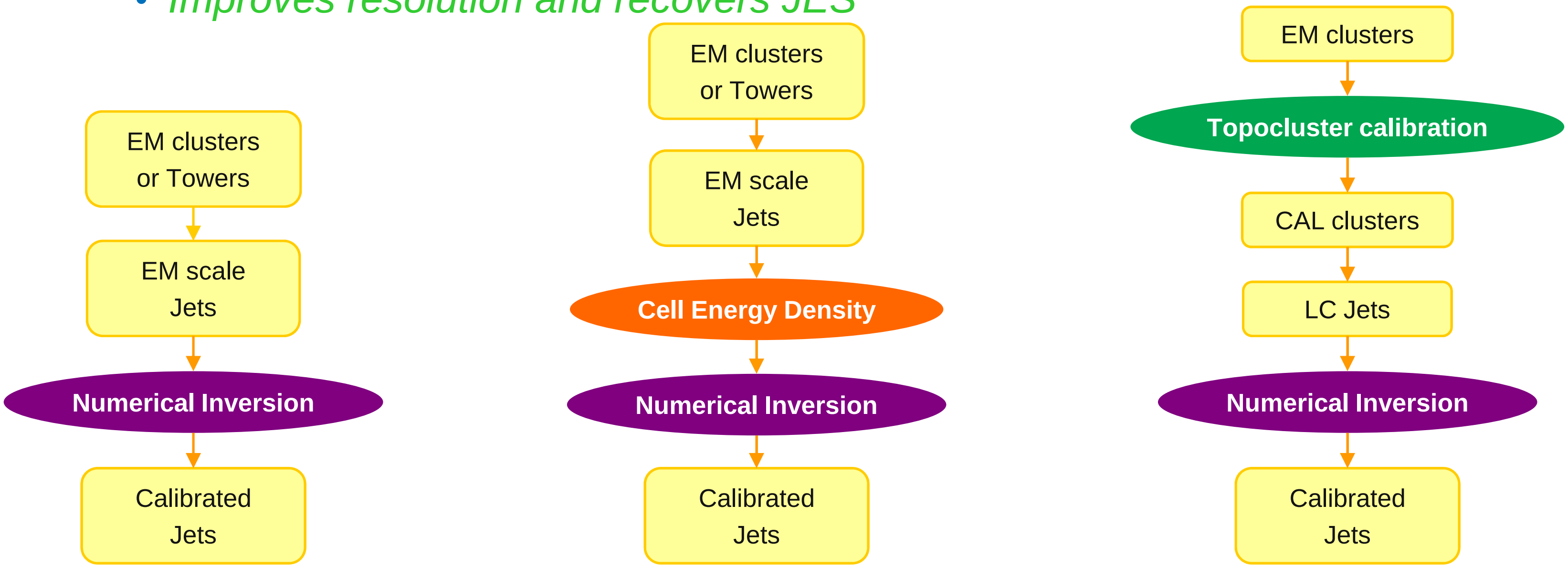


- Other corrections:
  - Energy not included in the Jet Finding algorithm
  - Additional energy due to underlying and pile-up events

Initial Jet Calibration proposed for ATLAS

- Three methods are being proposed for initial calibration all based on **Monte Carlo**:
  - Numerical inversion:
    - *Recovers the Jet Energy Scale (JES)*
  - Cell energy density + Num. Inversion:
    - *Improves resolution and recovers JES*
  - Topocluster calibration + Num. Inversion:
    - *Improves resolution and recovers JES*



Monte Carlo truth jets

- Following corrections attempt to calibrate the measured jets to particle truth
- How we define truth?
  - Particle-in-cone (PIC):
    - *Define a jet with the MC truth particles that fall around the measured jet cone*
  - Nearest-truth-jet (NTJ):
    - *Run Jet Finder over MC truth particles*
    - *Match the nearest-truth-jet to the reconstructed jet*

Numerical Inversion

Cell Energy Density (H1-style)

- Where is this important?
  - Underlying event
  - Out-of-cone energy

Part of these corrections are including on the calibration when using nearest-truth-jet

Numerical Inversion

- Restores linearity within 1-2%
- Only depends on Jet E_T

STEP 1

$$\left\langle \frac{E}{E^{NTJ}} \right\rangle = f\left(E_T^{NTJ}\right) = \sum_{i=0}^{4} \frac{a_i}{\ln\left(E_T^{NTJ}\right)^i}$$

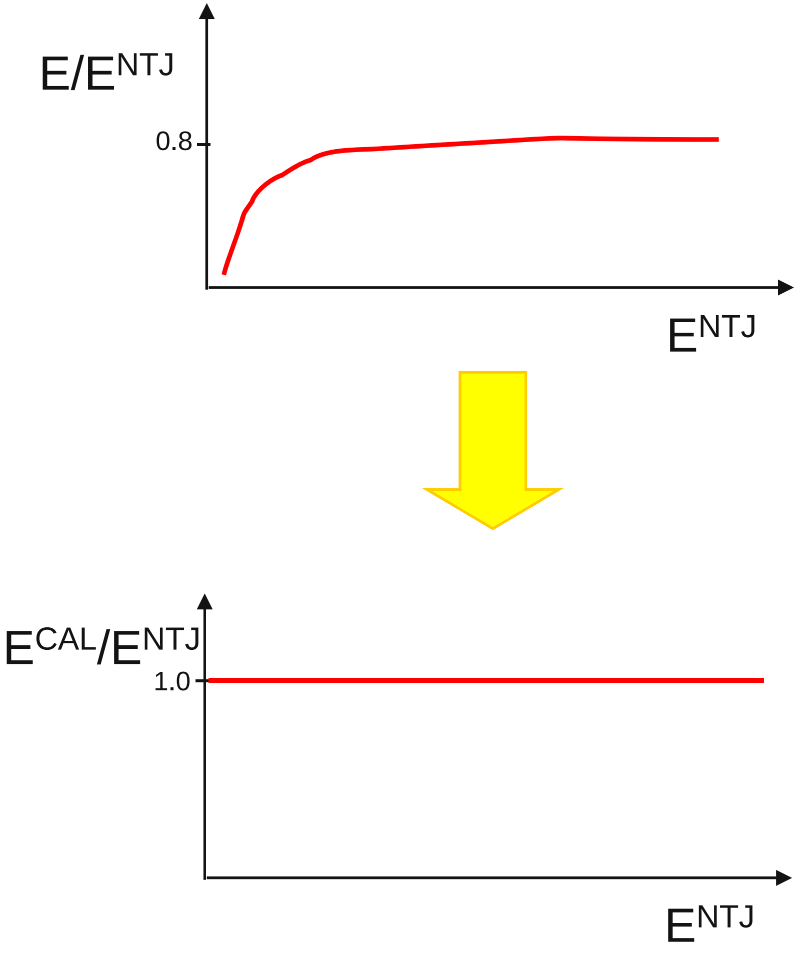
$$E \approx E^{INV} = E^{NTJ} f\left(E_T^{NTJ}\right)$$

STEP 2

$$\left\langle \frac{E}{E^{NTJ}} \right\rangle = g\left(E_T^{INV}\right) = \sum_{i=0}^{4} \frac{a_i}{\ln\left(E_T^{INV}\right)^i}$$

$$\boxed{E^{CAL} = E \frac{1}{g\left(E_T\right)}}$$

- Correction calculated independently for each pseudorapidity η

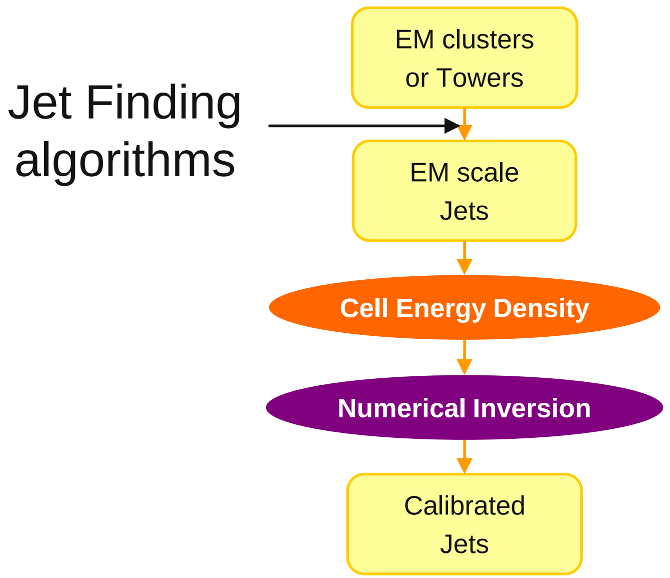


Global Calibration: H1 Cell energy density based calibration

ATL-COM-PHYS-2009-162

- Basis:
  - Electro-magnetic showers are more dense, energy concentrated in smaller region
  - Hadronic showers are broader, energy is spread in a larger volume

- Mechanism:
  - Apply a different weight depending on the **energy density** of the cell



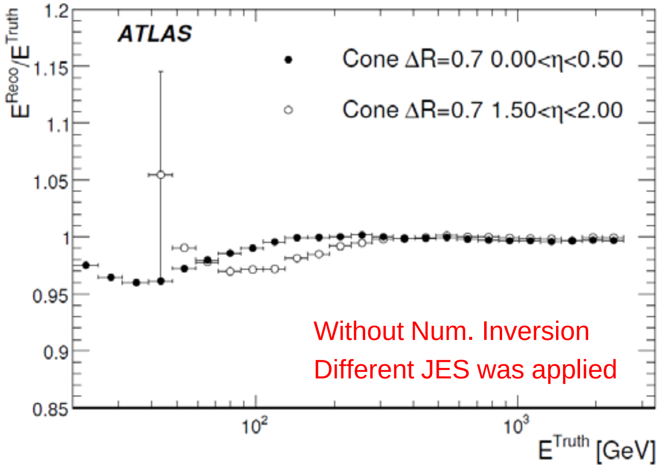
Global Calibration: H1 Cell energy density based calibration

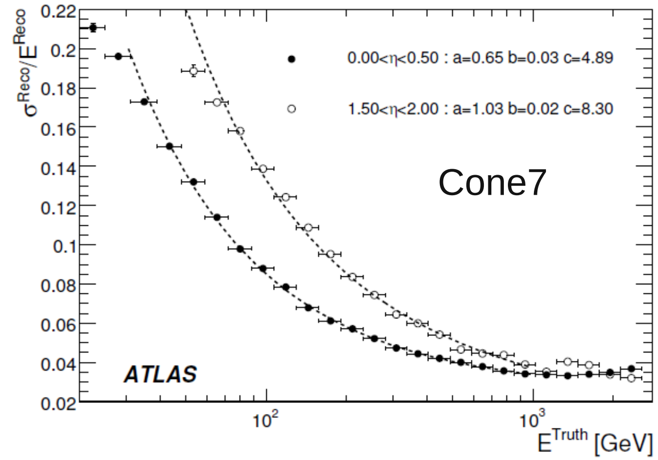
- Using MC di-jet event calculates the weights
- Cells are classified according to its e/v in 16 bins
- Weights parameterized as function of the e/v bins using a 4th degree polynomial function
- Calibrated energy is calculated as:

$$E^{CAL} = \sum_{cells} w_i\left(\ln\frac{e_i}{v_i}\right)e_i$$

- Requiring that the weights w_i minimize the following function:

$$\chi^2 = \frac{1}{n}\sum_{i=1}^{n}\left[\left(\frac{E^{CAL}}{E^{NTJ}}-1\right)^2\right]$$





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Local Hadron Calibration

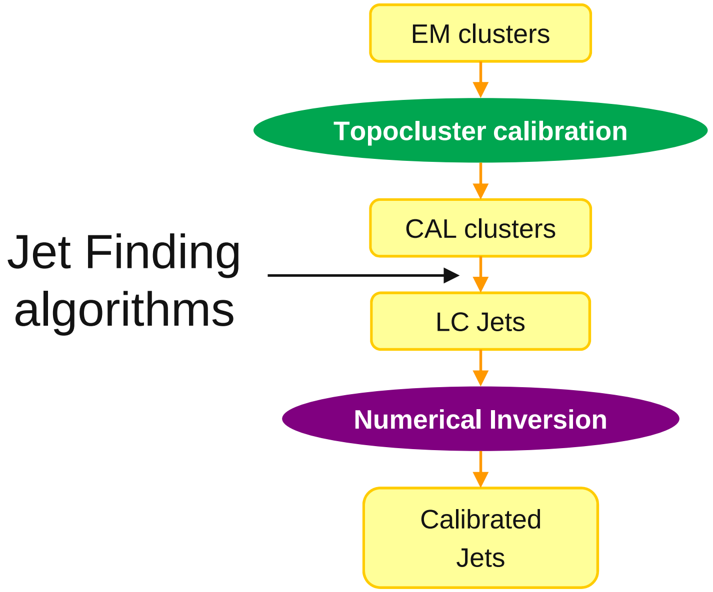
ATL-LARG-PUB-2009-001

- Calibrate topological clusters before they are part of the jet

- Classifies EM clusters depending on cluster parameters into:
  - Electro-magnetic: no weights
  - Hadronic: cell weighting

Try to separate $e^{\pm}$, γ and π^0 from $\pi^{\pm}$

Classification based on **MC** predictions for π^0 and $\pi^{\pm}$



- Apply calibration to the cells of Hadronic Clusters
- Apply out-of-cluster corrections
- Apply dead material corrections

Local Calibration : Cluster classification

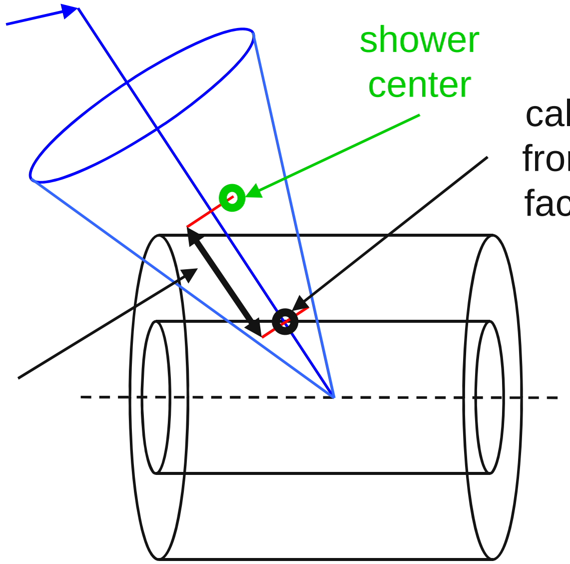
- G4 simulation of neutral and charged single pions
- For each cluster calculate the so called cluster moments:

$$\langle\rho\rangle = \frac{\sum_{\{i|E_i>o\}} E_i\rho}{\sum_{\{i|E_i>o\}} E_i}$$

$$|\eta|$$

$$E_{cluster}$$

$$\lambda_{center}$$



- Classify clusters in bins of

$$\begin{cases} |\eta| \\ E_{cluster} \\ \log_{10}(\lambda_{center}) \\ \log_{10}(\langle\rho\rangle) - \log_{10}(E_{cluster}) \end{cases}$$

- Count the number of simulate neutral and charged pions in each bin of the grid and calculate :

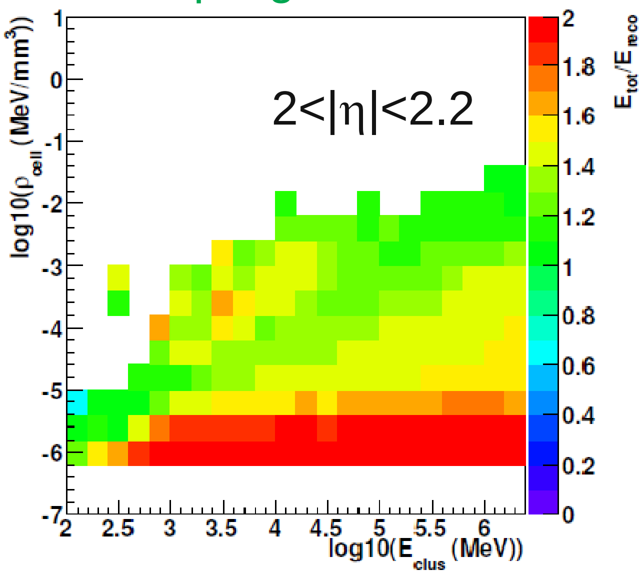
$$w_i = \frac{n_i^{\pi^0}}{n_i^{\pi^0} + 2n_i^{\pi^\pm}}$$

A cluster is classified as EM if it falls in a bin with weight w_i>0.5

Local Calibration: Apply weights to Hadronic Clusters

- Cells from clusters classified as Hadronic will be weighted under certain conditions
- Correction depends on:
  - Cell energy density
  - |η| of the cell center
  - Cluster energy

2nd sampling of TileBarrel



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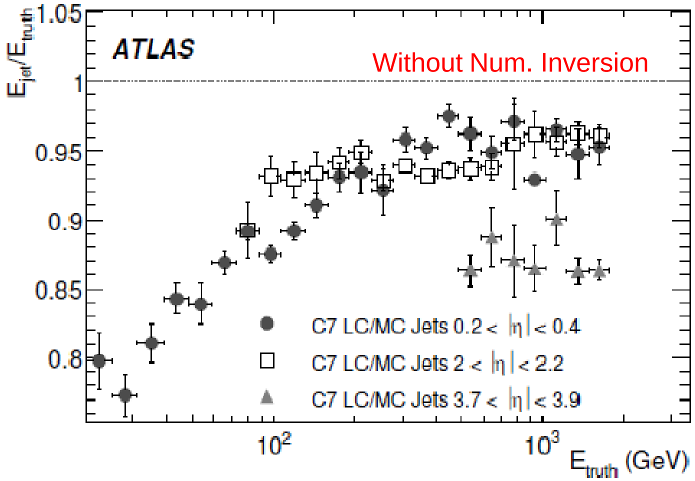

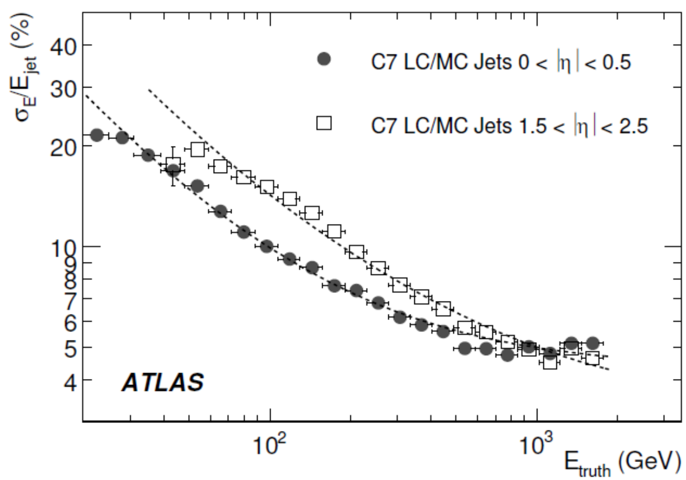

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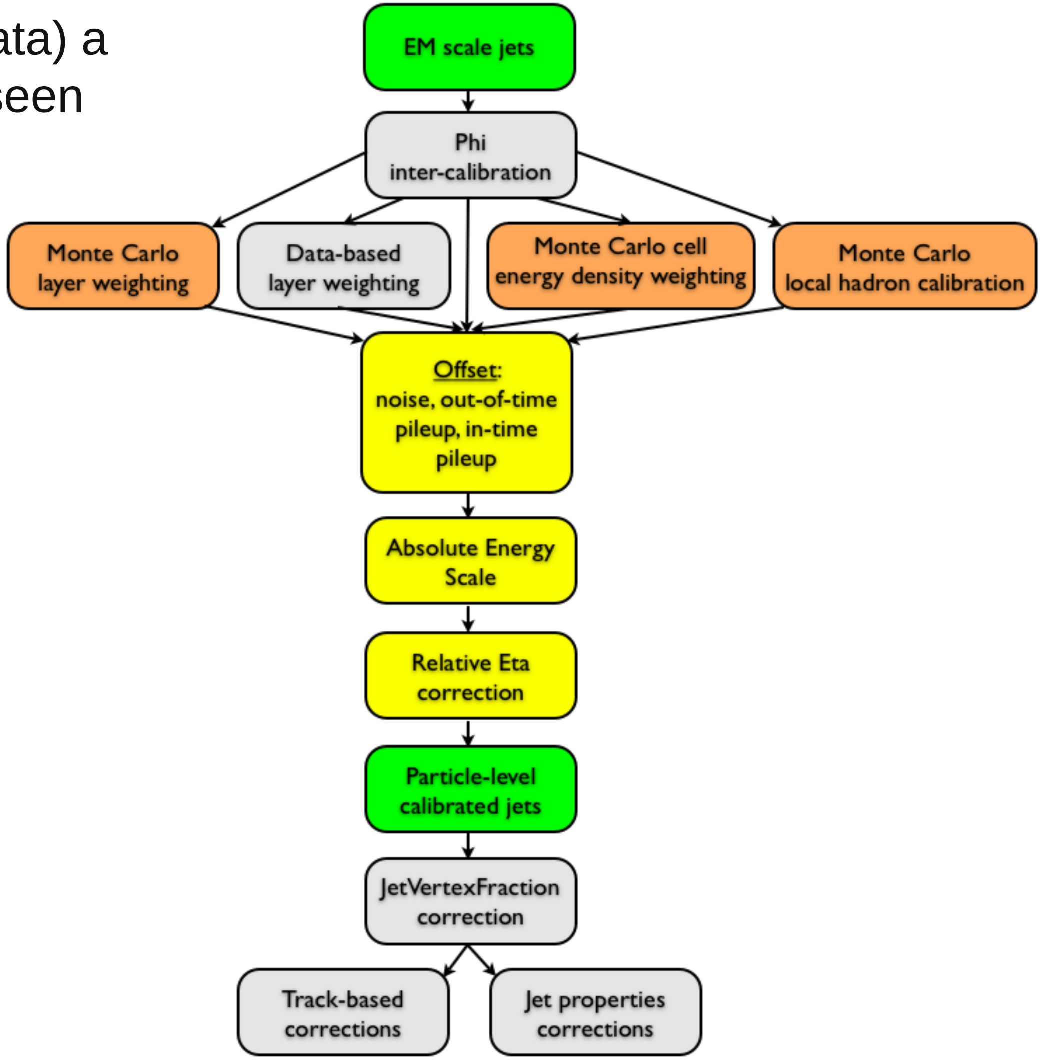
Other corrections: MC and data-driven

- In medium term (once we have data) a more complete calibration is foreseen



Other corrections: MC and data-driven

- Corrections
  - Dead material corrections : H1 and Local Hadron implement dead material corrections
    - *Merged in the calibration algorithm is difficult to establish the real impact of these corrections*
  - PileUp corrections
    - *In time pile-up : Approaching similar methods to DØ and CDF*
    - *Out-of-time pile-up: This is a new issue at the LHC, the impact is uncertain*
  - Track fraction and EM fraction corrections
    - *Both important to validate the whole process*
- Closure or are we doing everything properly?
  - Gamma+jets
  - MPF
  - Z+jets
  - Pt balance
  - ttbar

We are exploring also to use these channels for in-situ calibration procedures : see Jet calibration task force meetings

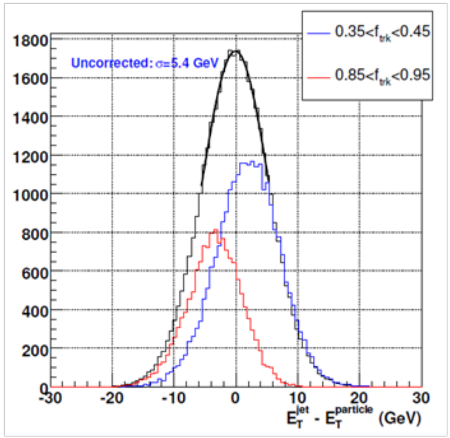
Improving resolution after JES: Monte Carlo based

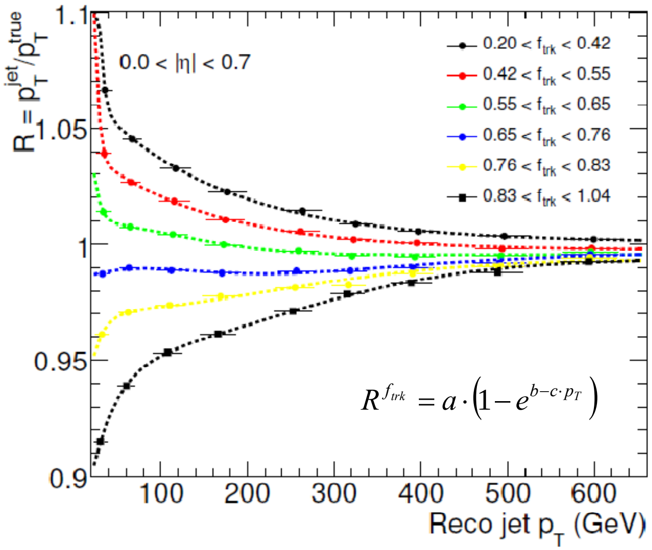
- Track energy fraction f_{trk}

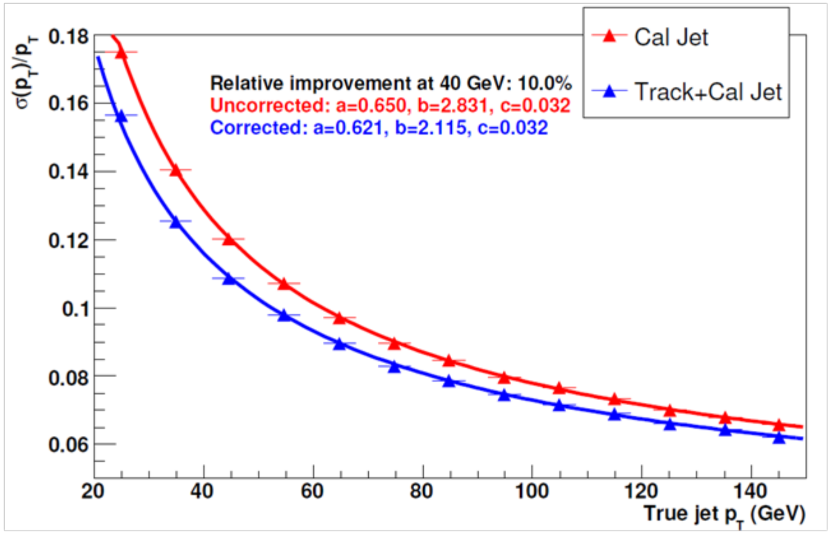
$$f_{trk} = \frac{\sum p_T^{trk}}{p_T^{jet}}$$

Improves jet energy resolutions without changing the JES

$|\eta| < 0.7$ and $40GeV < p_T < 200GeV$







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Check of Jet Calibration with data

- Dijet balancing vs Relative EM fraction
  - When calibration is correct we should expect perfect p_T balance independent of the distribution of the jet energy

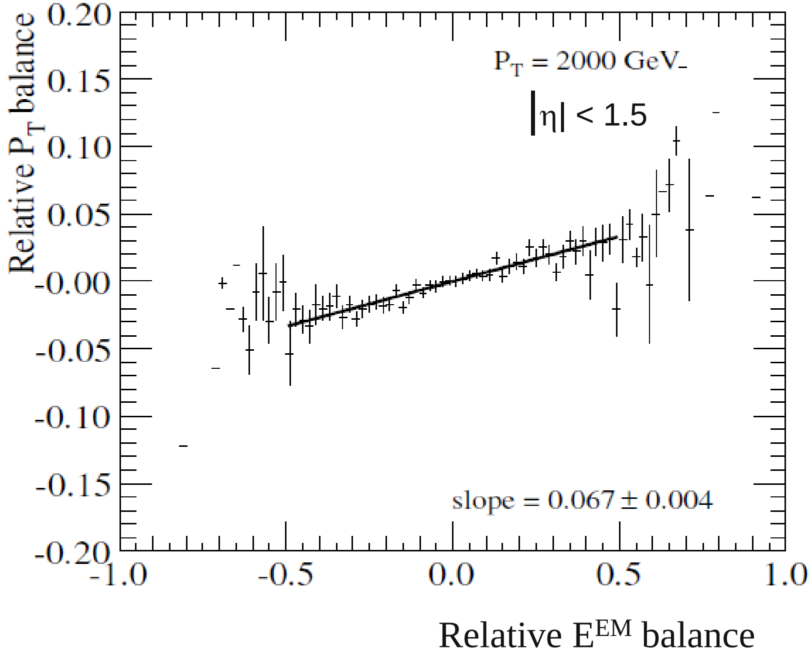
$$\text{Relative } p_T \text{ balance} = 2\left(\frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}}\right)$$

$$\text{Relative } E^{EM} \text{ balance} = \left[\frac{\mathrm{E}^{\mathrm{EM}}}{E^{tot}}\right]_1 - \left[\frac{\mathrm{E}^{\mathrm{EM}}}{E^{tot}}\right]_2$$

$p_{T,1}$ and $p_{T,2}$ are the 2 leading jets

$$\Delta\phi_{12} > 2.9$$

$$p_{T,3} \leq 0.10 \times \frac{p_{T,1} - p_{T,2}}{2}$$



How do you know which calibration has been applied?

- Data access keys of Jet Collections in ESD/AOD/DPD… :
  - Cone4H1TopoJets
    - ***Input to the jet finder:*** *Topological clusters at EM scale*
    - ***Jet Finder:*** *Cone algorithms with R=0.4*
    - ***Calibration:*** *H1 → Global calibration, cell energy density + Numerical Inversion (or alternative JES correction)*
  - Cone7H1TowerJets
    - ***Input to the jet finder:*** *Projective towers at EM scale*
    - ***Jet Finder:*** *Cone algorithms with R=0.7*
    - ***Calibration:*** *H1 → Global calibration, cell energy density + Numerical Inversion (or alternative JES correction)*
  - Kt4LCTopoJets
    - ***Input to jet finder:*** *Calibrated to Hadronic scale topoclusters*
    - ***Jet Finder:*** *Kt algorithms with R=0.4*
    - ***Calibration:*** *Local calibration, hadronic topoclusters calibration + JES*

Link to Documentation

- CSC book
  - CERN-OPEN-2008-020 : http://arxiv.org/abs/0901.0512
- Twiki JetEtMiss:
  - https://twiki.cern.ch/twiki/bin/view/AtlasProtected/JetEtMiss
- Twiki Jet Reconstruction and Calibration Task Force:
  - https://twiki.cern.ch/twiki/bin/view/AtlasProtected/JetEtMiss
- Global Calibration: Cell Energy Density
  - https://twiki.cern.ch/twiki/bin/view/AtlasProtected/CellEnergyDensityCalibration
  - ATL-COM-PHYS-2009-162: http://cdsweb.cern.ch/record/1170925?ln=en
- Local Calibration: Topocluster calibration
  - ATL-LARG-PUB-2009-001: http://cdsweb.cern.ch/record/1112035?ln=pl
- Numerical Inversion
  - https://twiki.cern.ch/twiki/bin/view/AtlasProtected/MCInitialPtAndEtaCorrection
  - ATL-COM-PHYS-2009-163: http://cdsweb.cern.ch/record/1171280?ln=en