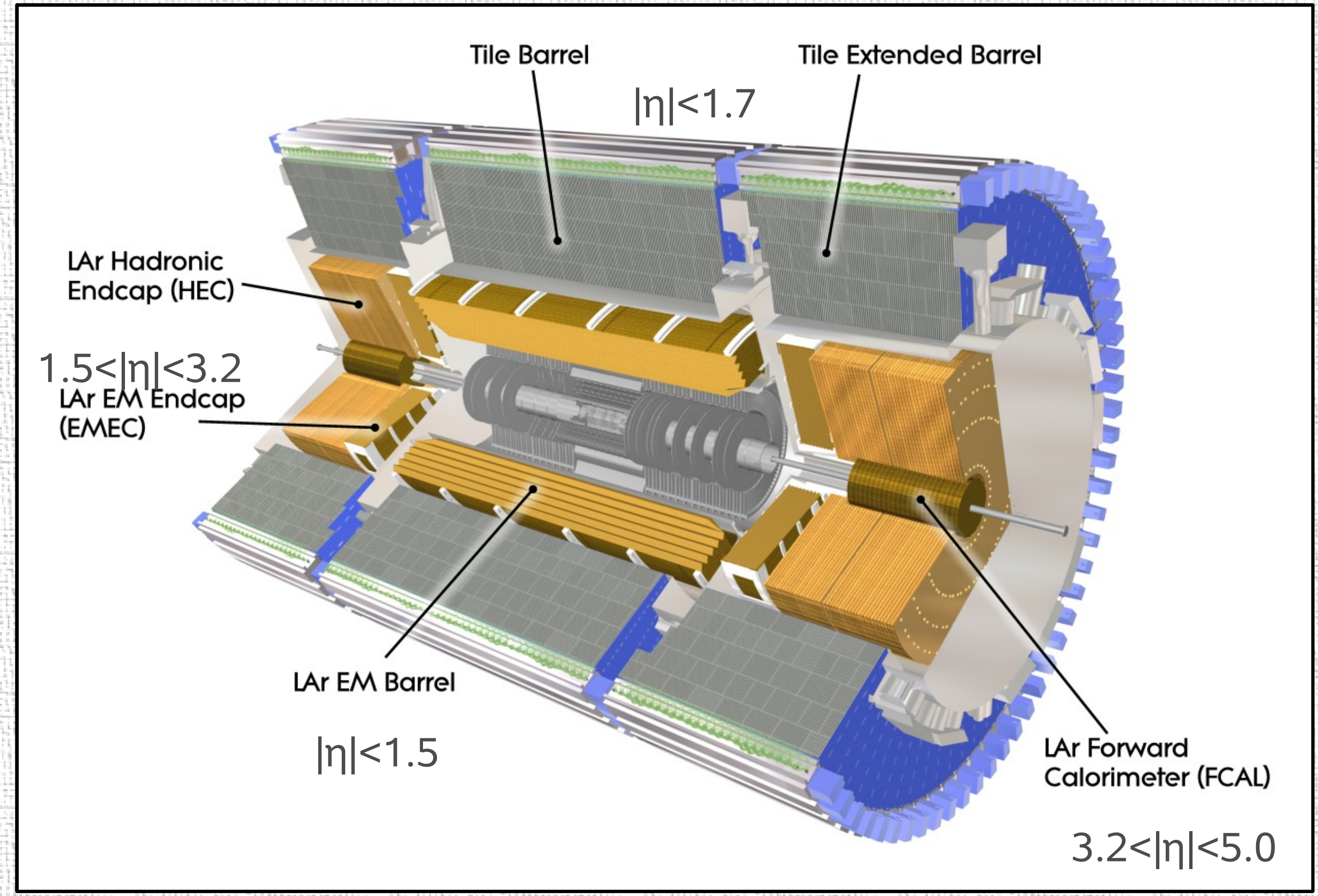
Overview of ATLAS Local Hadron Calibration

Gennady Pospelov, MPI München
for the ATLAS Hadronic Calibration group

CALOR08, 26-30 May 2008, Pavia, Italy

- ATLAS calorimeters
- global and local calibration approaches
- local hadron calibration steps:
  - weighting, out-of-cluster, dead material corrections
- performance
- summary

ATLAS calorimeters



Electromagnetic calorimeters:

acceptance	$\lvert\eta\rvert<3.2$
depth	~22X0
number of channels	173952
cluster noise	250 MeV
design goals	

$$\frac{\sigma(E)}{E}=\frac{10\,\%}{\sqrt{E}}\oplus\frac{0.3}{E}\oplus 0.7\,\%,\ E\ in\ GeV$$

$$nonlinearity<0.1\,\%$$

Hadron and forward calorimeters:

acceptance	$\lvert\eta\rvert<5.0$
number of channels	19000
absorption length	9.7 – 13 λ
design goal for jets	

$$\frac{\sigma(E)}{E}=\frac{50\,\%}{\sqrt{E}}\oplus 3\,\%,\ \lvert\eta\rvert<3$$

$$\frac{\sigma(E)}{E}=\frac{100\,\%}{\sqrt{E}}\oplus 5\,\%,\ 3<\lvert\eta\rvert<5$$

$$nonlinearity<2\,\%$$

- in ATLAS e/h > 1 for each sub-detector
- Hadron calibration accounts for invisible and escaped energy

Global and local calibration approaches

Calorimeter cells
(em scale)

- 0.1x0.1 fixed size tower building
- tower noise suppression

Calorimeter towers
(em scale)

- Jet finding algorithms
- K_T, Cone, ...

Uncalibrated Jets
(em scale)

- matching a truth particle jet with reco jet
- apply calibration function to all matched jet pairs.
  $w_{cell}=f(E_{cell}/V_{cell})$, $w_{jet}=f(E_{jet},\eta)$, ...
- H1-style, Pisa calibration, Pseudo H1

Calibrated Jets
(particle level)

- 3D topological cell clustering
  (noise suppression included)

Topo clusters
(em scale)

Local Hadron Calibration

Topo clusters
(HAD scale)

- Jet finding algorithms
- K_T, Cone, ...

Calibrated Jets
(particle level)

Final in-situ calibration
- $tt \rightarrow WbWb \rightarrow l\nu j_b jjj_b$, ...

Calibrated jets
(parton level)

Local Hadron Calibration Schema

Local Hadron Calibration is called to deal with non-compensating nature of hadron calorimeter.

3-d topological clusters with cells at em scale.	• starts with topological 3D clusters, which are efficient tool to suppress electronic and pile up noise
classify clusters as EM, HAD or Unknown	• classification to identify em/non-em part of the shower, relay on cluster calorimeter depth and cluster energy density
cluster calibration	• H1-style hadronic weighting of clusters classified as HAD
out-of-cluster correction	• correction for energy deposited in calorimeter cells outside of any cluster
dead material correction	• correction for energy losses in dead material in front and between calorimeter modules
calibrated clusters	

- Calibration is independent of any jet algorithm; defines the same hadronic scale for all signals (missing E_T, jets, τ's).
- Factorization of different effects (e/h, out-of-cluster, dead material...).
- Based on single pions simulation.

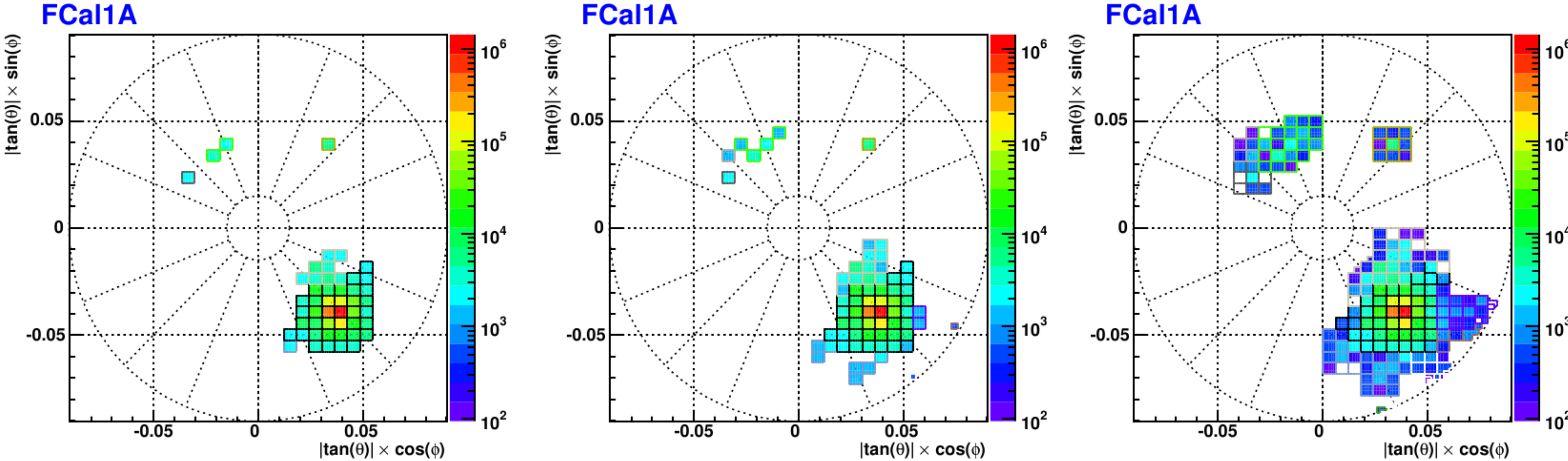
Cluster making algorithm

- form cluster around seed cells with $|E_{cell}| > S \cdot \sigma_{noise}$, S=4
- expand in 3D, add neighbours with $|E_{cell}| > N \cdot \sigma_{noise}$, N=2
- add perimeter cells with $|E_{cell}| > P \cdot \sigma_{noise}$, P=0
- Seed/Neighbour/Perimeter formula = 4/2/0 good for combined beam tests

Cluster splitting algorithm

- split clusters around local maxima with maxima threshold E>500MeV
- one cell can share energy between two clusters
- aim is to have one cluster per isolated $e^{\pm}, \mu, \gamma$, currently $N_{particle}/N_{clusters}$=1.6 in jet context

$|E_{cell}| > 4\sigma_{noise}$ $|E_{cell}| > 2\sigma_{noise}$ all cells



Calibration hits

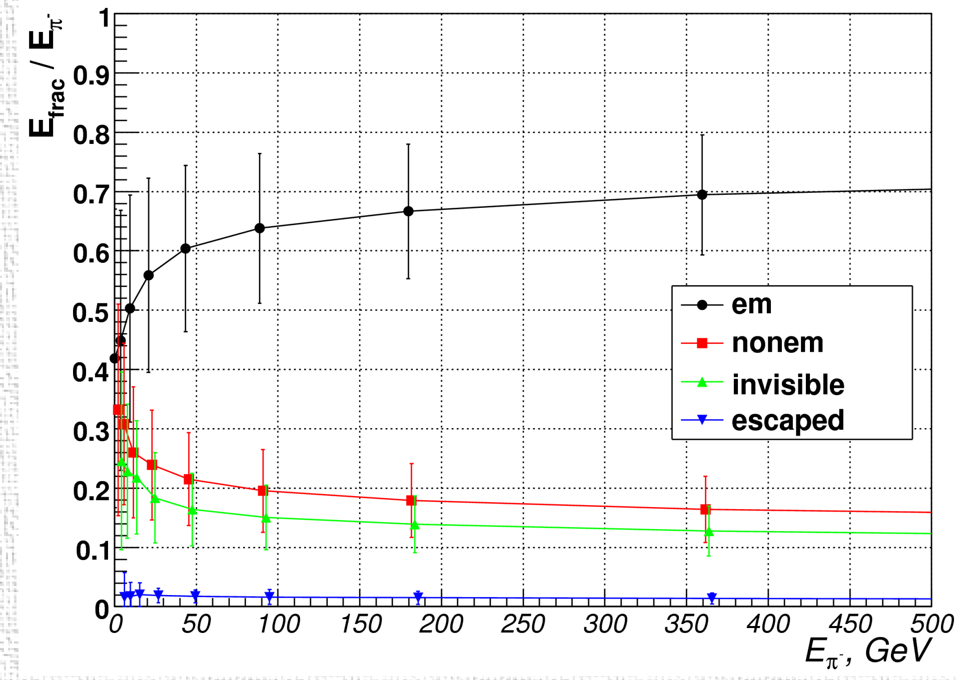
Calibration hits are implemented into ATLAS Geant4 simulation to save 4 energy categories:

EM ($e^{\pm}$, γ)	O(50%)
nonEM (dE/dX from $\pi^{\pm}$, $\mu^{\pm}$)	O(25%)
Invisible (nuclei excitation)	O(25%)
Escaped (ν)	O(2%)

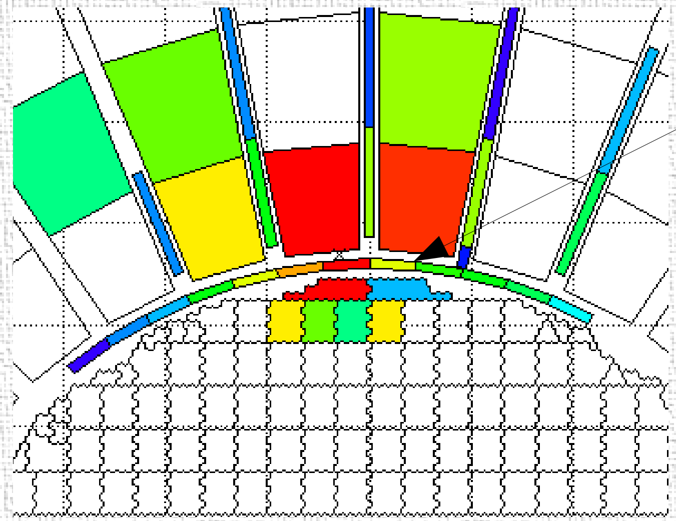
for each calorimeter cell:

active cells (LAr)
inactive cells (Absorber)
dead material cells
(i.e. virtual cells containing inactive material outside calorimeter cell volumes, with 0.1x0.1 typical granularity)

Total sum of *EM+nonEM+invisible+escaped* energies in all active/inactive/dead material calibration hits == total energy of generated primary particles.



Calibration energies depends on pion energy and are the subject of big fluctuation.



dead material calibration hit in the crack between HEC and FCAL

Classification

To identify EM and non-EM parts of the shower

Uses following shower shape variables (so-called cluster moments):

λ_{center} cluster barycenter depth in calorimeter
$<\rho_{cell}>$ average cell energy density

High average cell energy density and small calorimeter cluster depth denotes EM nature of the cluster.

4-dimensional phase space for clusters in

$|\eta|$, $E_{cluster}$, $\log10(\lambda_{center})$, $\log10(<\rho_{cell}>)$

is binned and filled with simulated pions in the energy range
$200MeV < E_{cluster} < 2TeV$

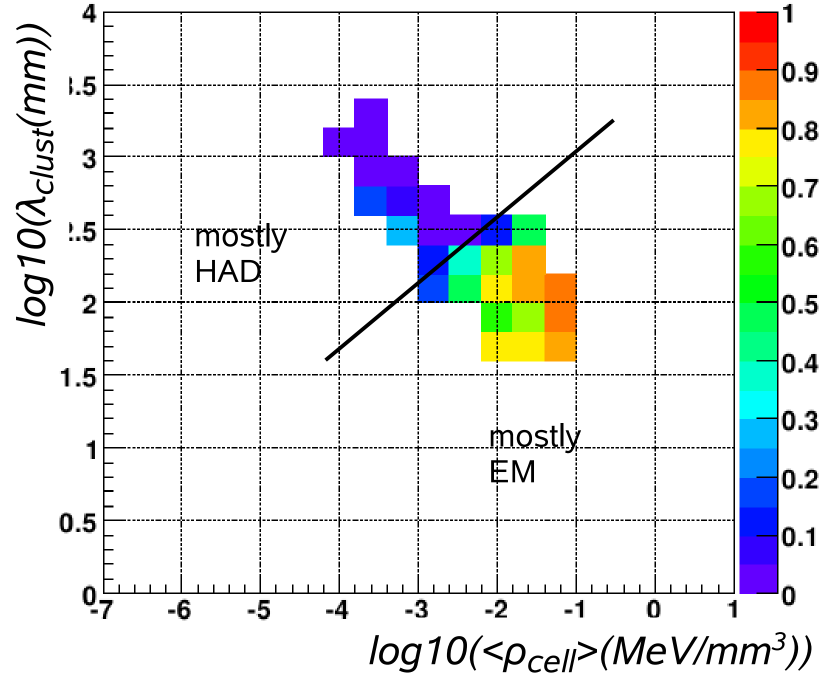


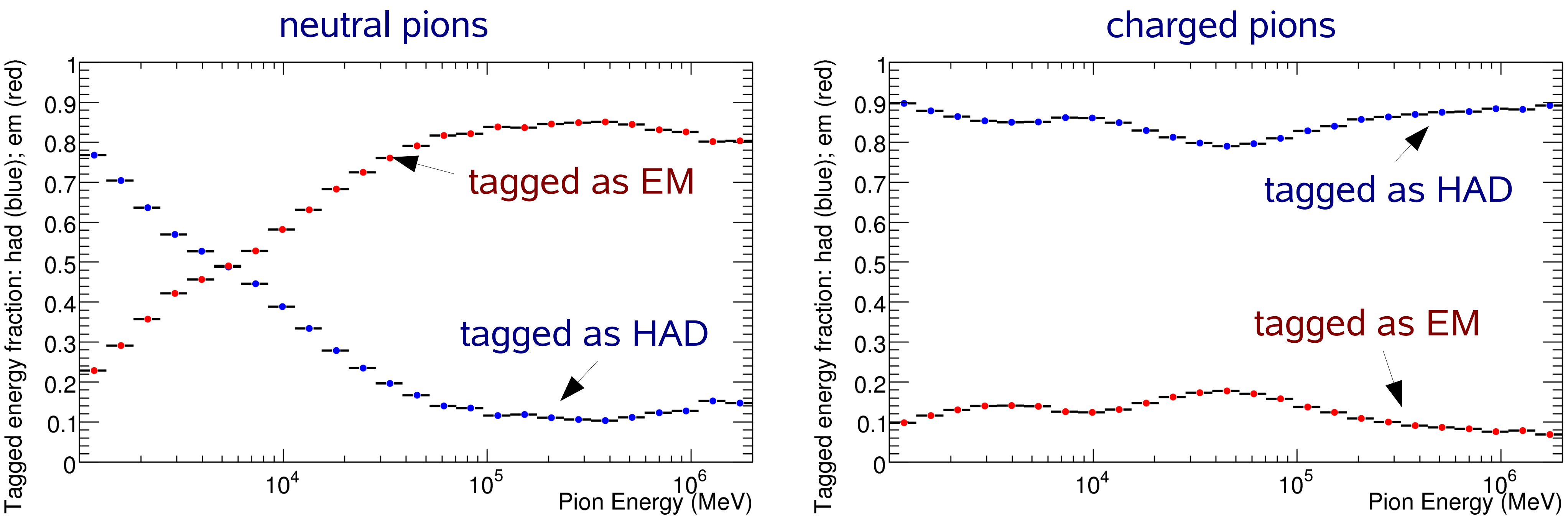
Table of probability for cluster to be EM
$2.0<|\eta|<2.2$, $4GeV \leq E_{cluster} < 16 GeV$

Fraction of neutral and charged pions in given phase-space bin *i* is used to calculate weight:

$$w_i = n^i_{\pi^0} / \left(n^i_{\pi^0} + 2 \ n^i_{\pi^\pm} \right)$$

At reconstruction stage cluster will be treated as hadronic if lookup value for *w <0.5 at a* given cluster phase-space point.

Classification performance



Energy fractions of single pions classified as electromagnetic / hadronic as a function of the pion energy averaged over all η and Φ.

Weighting

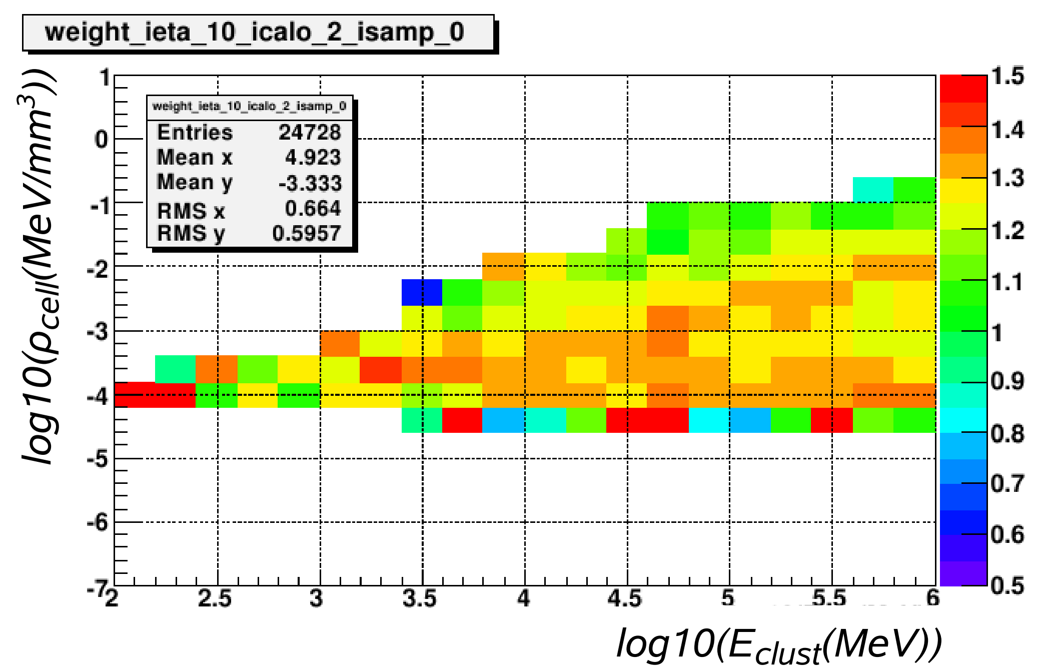
Cell weights are derived from true energy deposits in LAr+Absorber (calibration hits) and accounts for invisible energy.

$$E'_{cell} = w \cdot E_{cell},$$

$$w = \langle \underbrace{\left(E^{Em}_{cell} + E^{nonEm_{vis}}_{cell} + E^{nonEm_{invis}}_{cell} + E^{escaped}_{cell} \right)}_{\text{calibration hits}} / \underbrace{E^{reco}_{cell}}_{\text{cell signal at em scale (with noise and HV correction)}} \rangle$$

Weights are kept as a function of cluster energy $E_{cluster}$ and average cell energy density $\langle\rho_{cell}\rangle$, for different η regions and longitudinal sampling.

Weights are applied only to the clusters classified as hadronic.

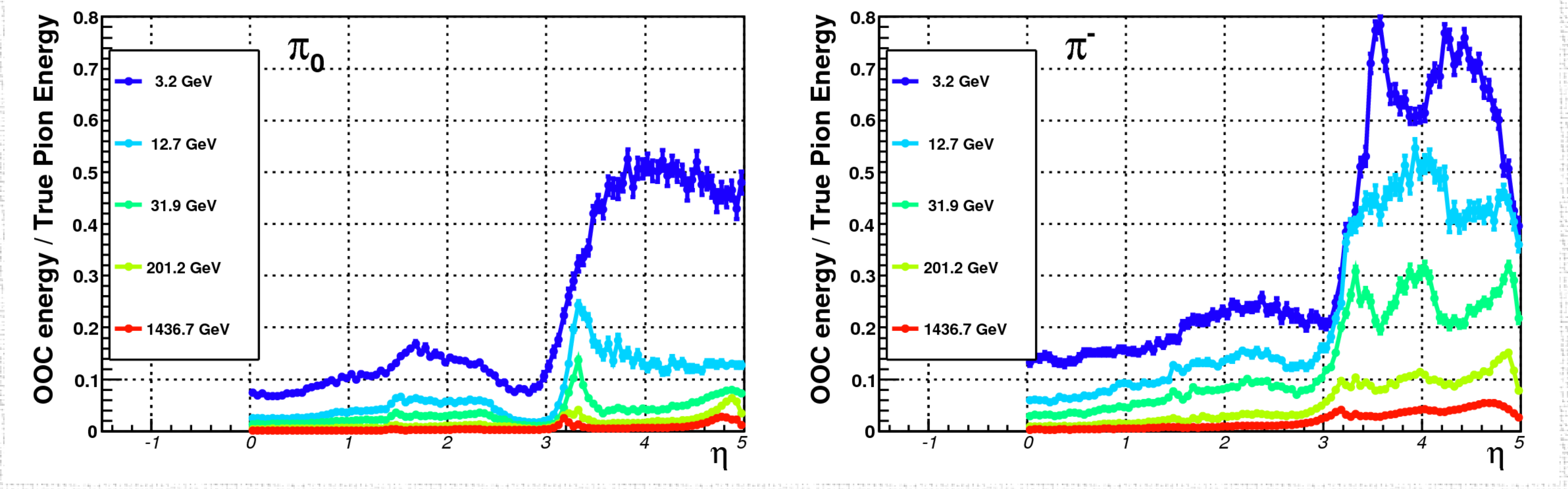


Hadronic cell weight table for 2.0<|η|<2.2, HEC layer 1

Out-Of-Cluster (OOC) correction

Accounts for energy deposited in cells which are not part of any cluster.

- derived from single pion simulation
- use calibration hits info
- figure shows the ratio of out-of-cluster energy for neutral (left) and charged (right) pions versus η.



- correction factor is $$\left(1+\frac{E_{ooc}}{E_{cluster}}\right)$$

OOC energy is stored in lookup tables

- $E_{cluster}$, $|\eta|$, $\lambda_{cluster}$ bins

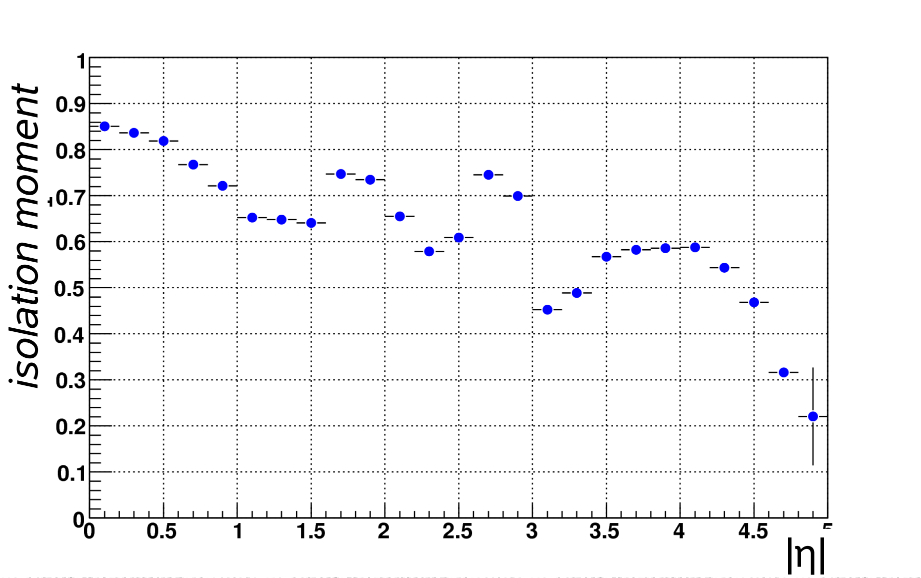
Out-Of-Cluster (OOC) correction

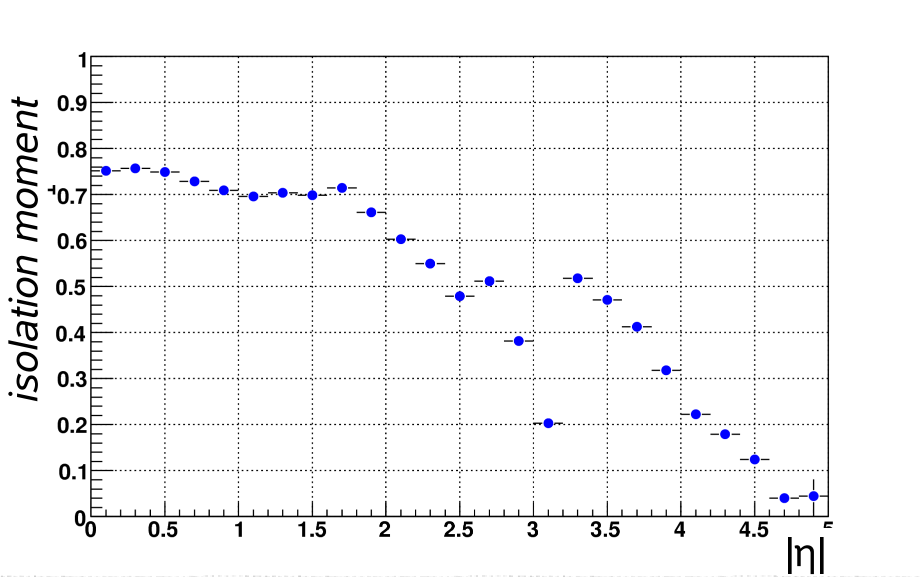
Over correcting problem

- OOC energy for one cluster could actually be deposited in another cluster.
- especially important for jets

Cluster isolation moment

- fraction of cells on the outer cluster perimeter that are not included in any other cluster





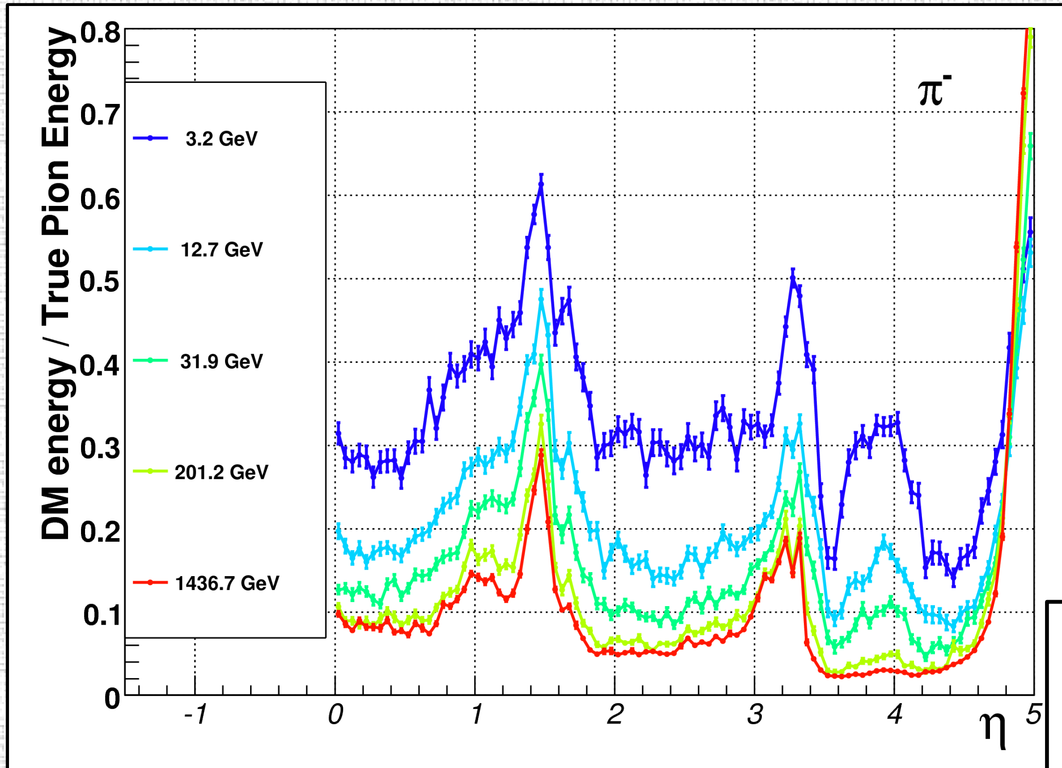
Level of isolation for clusters above 1GeV versus |η| for single charged pion (left) and tt sample (right).

Out-of-cluster correction final estimate

- it's a product of OOC correction from look-up table and cluster isolation moment

Correction is applied as a multiplicative factor to all cells in the cluster

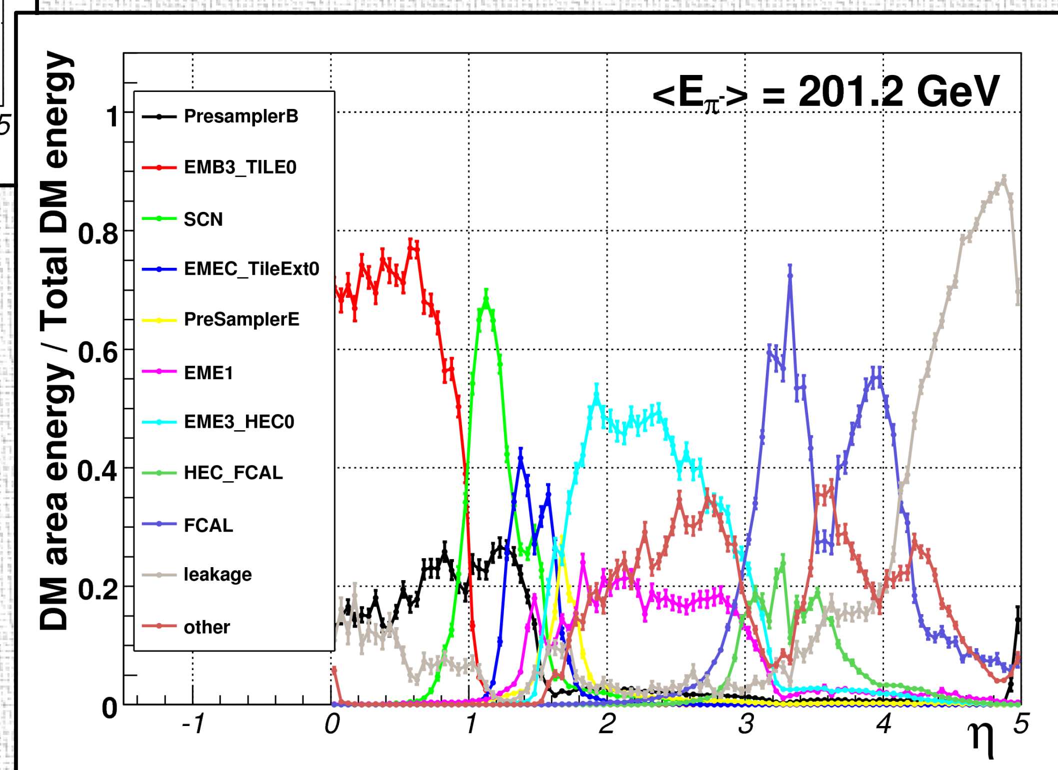
Dead material correction



Dead material (DM) correction accounts for energy deposited outside of active calorimeter volumes.

← Average ratio of DM energy (taken from calibration hits) to the beam energy versus |η| for charged pions at different energies.

Ratio of DM energy deposited in different detector parts ("DM regions") →



Dead material correction

- Correction is derived for each DM region separately using correlation of DM energy losses (MC) and cluster quantities calculated at electromagnetic scale.

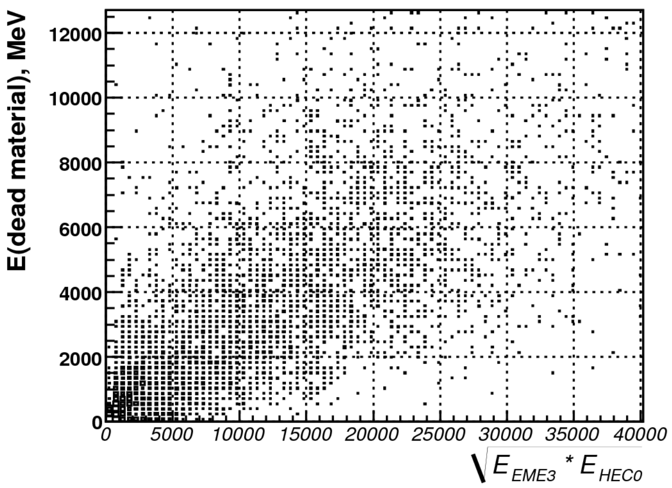
- Two major approaches:

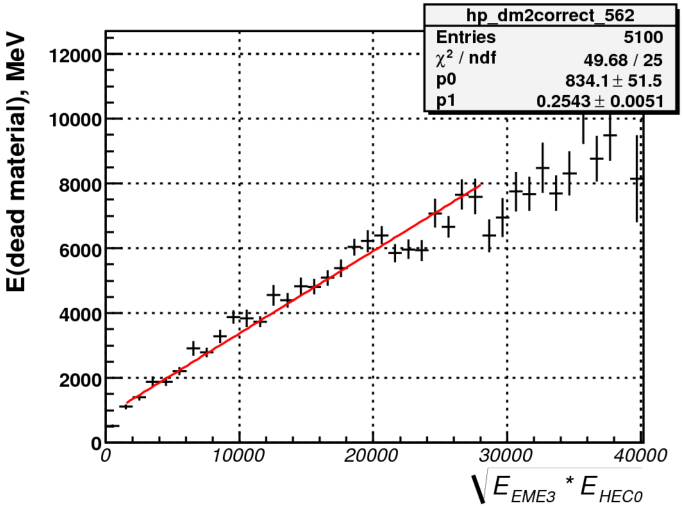
1. Parametrization of DM energy losses with the first order polynomial, e.g.

$$E^{DM}_{PreSampler} = a(em/nonem, E_{clust}, \eta_{clust}) + b(em/nonem, E_{clust}, \eta_{clust}) * E_{PreSampler}$$
$$E^{DM}_{EMB3\,TILE0} = a(em/nonem, E_{clust}, \eta_{clust}) + b(em/nonem, E_{clust}, \eta_{clust}) * \sqrt{(E_{EMB3} * E_{TILE0})}$$

2. Keeping <E_{DM}/E_{clust}> for intricate DM regions in look-up table: $E_{cluster}$, $|\eta|$, $\lambda_{cluster}$ bins.

- DM energy is then added to the cluster by increasing cluster cells weights.



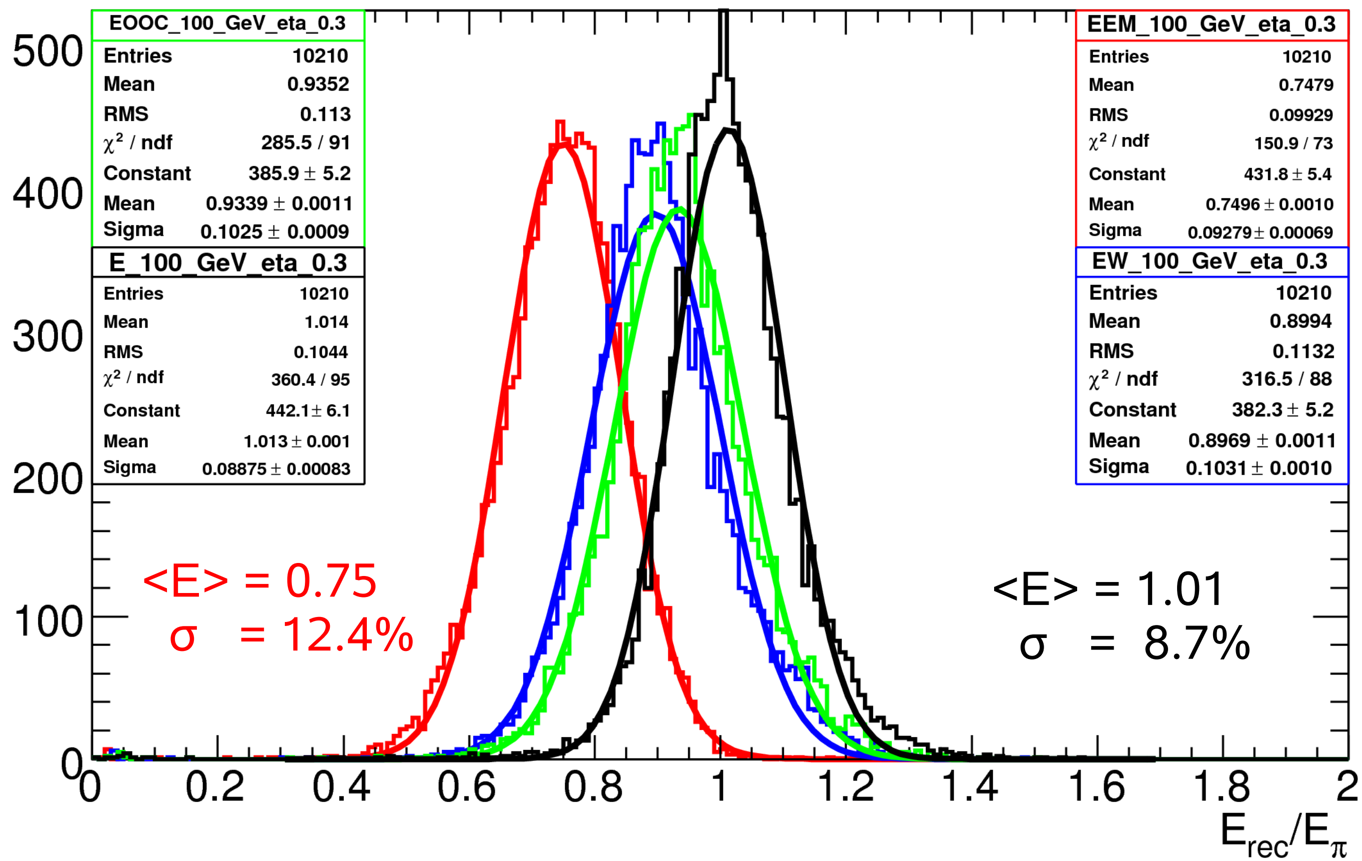


energy lost between EMEC and HEC as a function

$$\sqrt{E_{EME3} * E_{HEC0}}$$

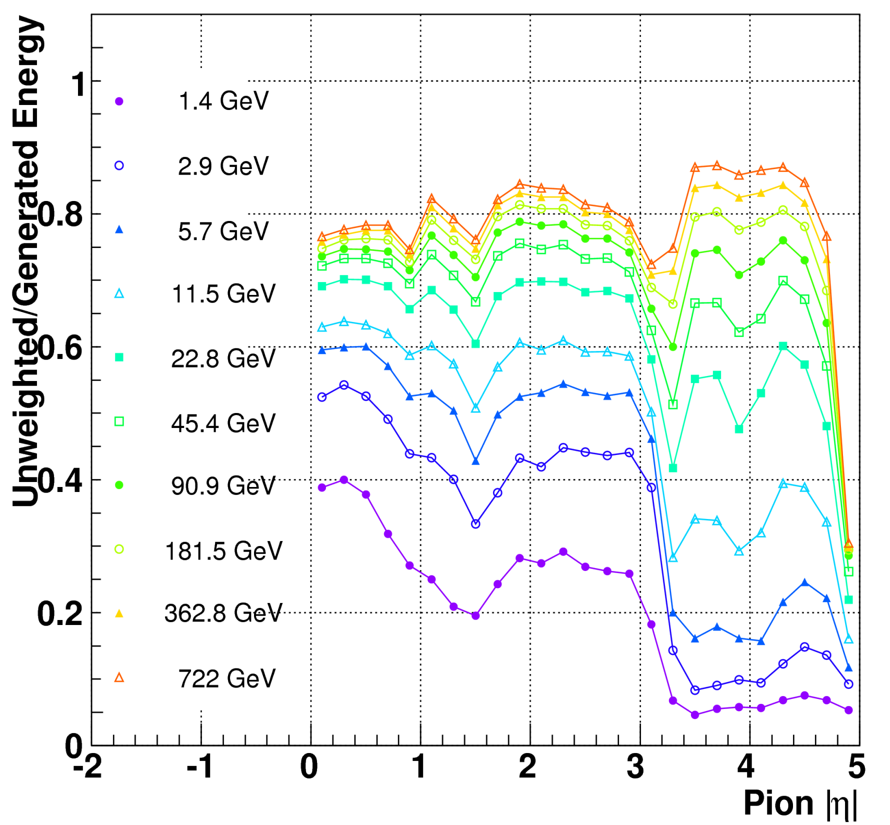
for clusters with $4.7 < \log 10(E_{clust}) < 5.1$

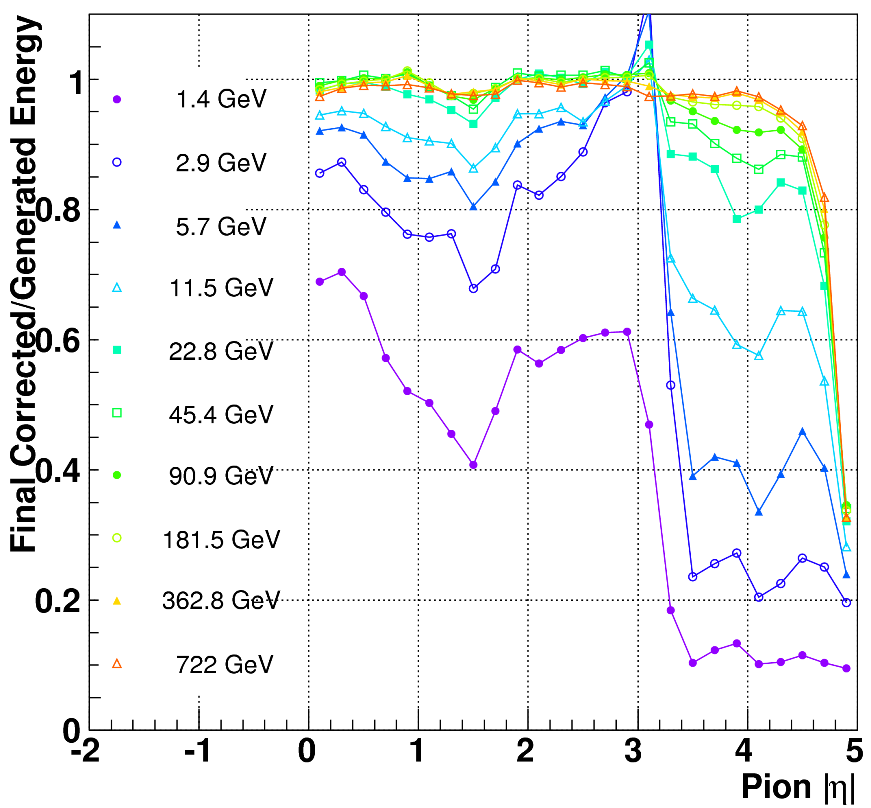
Performance for single pions



Ratio of reconstructed over simulated pion energy for 100 GeV single charged pion at η=0.3 at various stages of the calibration.
red: em-scale, **blue:** +weighted, **green:** +out-of-cluster, **black:** +dead material

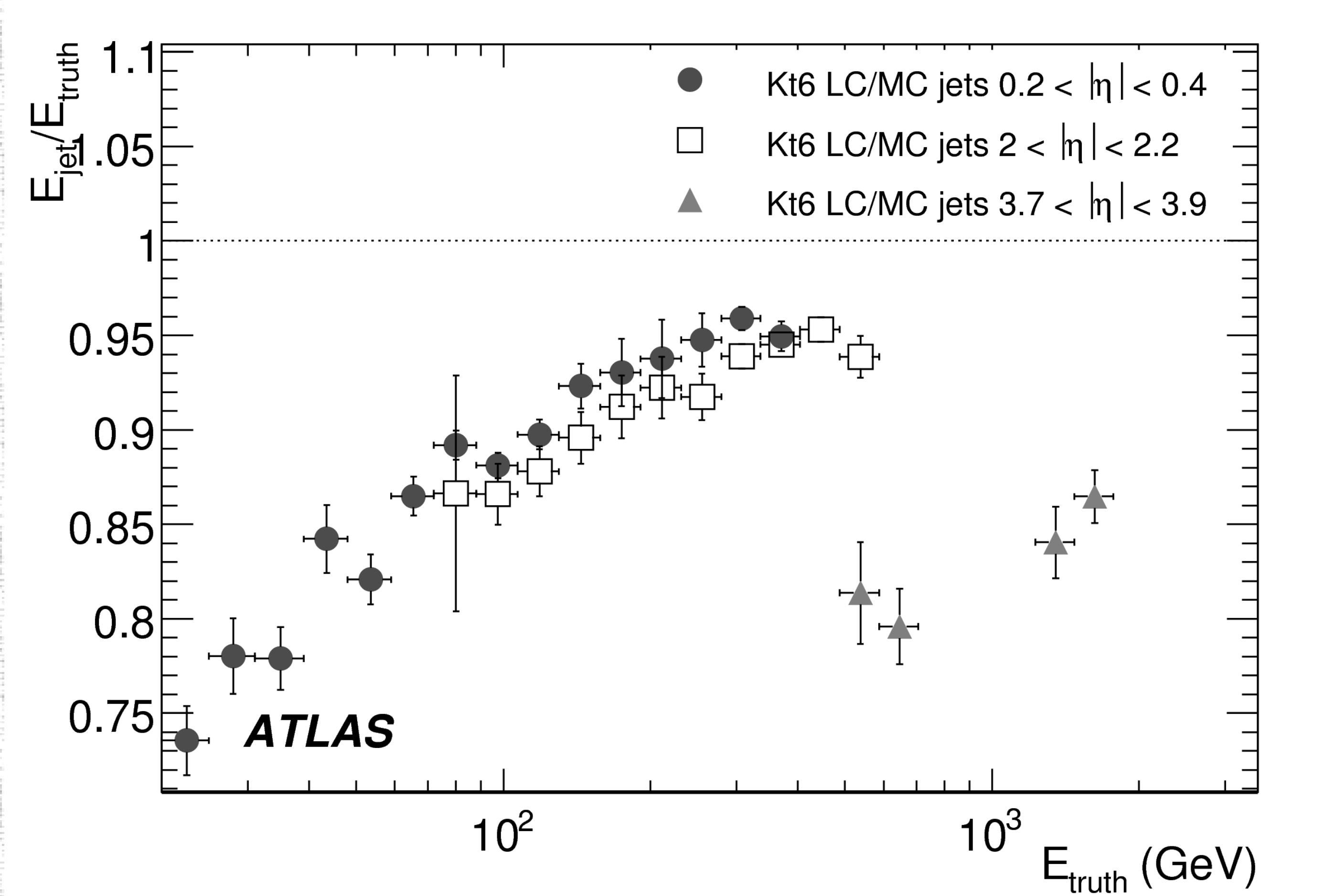
Performance for single pions





E_{reco}/E_{true} versus η for single pions at em-scale (left) and after weighting, out-of-cluster and dead material corrections (right).

Performance for jets



Linearity plot for Kt jets with R=0.6 calibrated with the local hadron calibration method using truth particle as reference.

The linearity is shown as a function of matched truth jet energy.

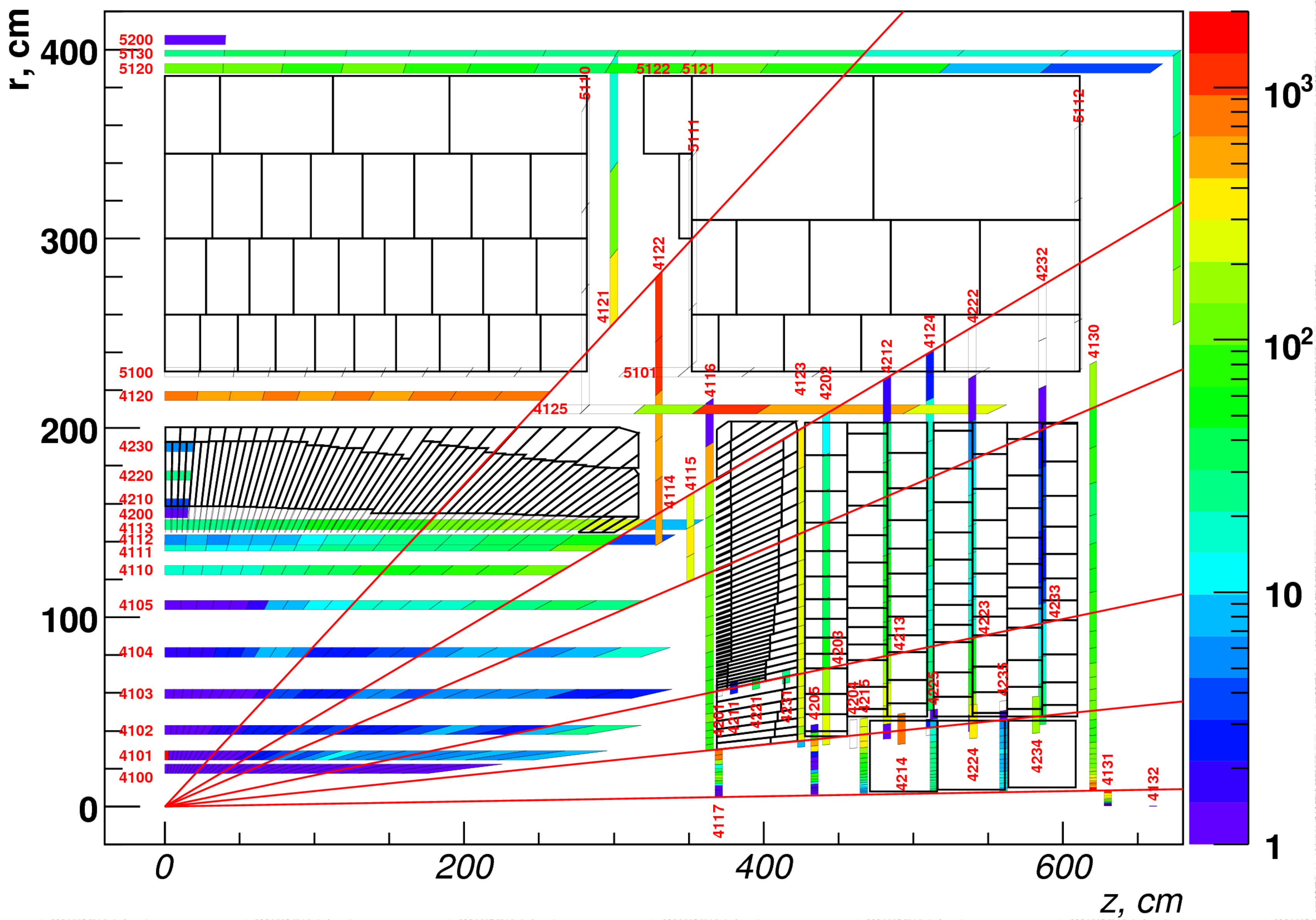
Main sources of remaining energy correction (P⊥~150GeV estimation):

- missclassification: hadronic energy deposits treated as electromagnetic and vice versa ~3%
- calorimeter inefficiency, when particle leaves signal below noise threshold ~3%
- jet effects, e.g. particles are bent out of jet cone by magnetic field ~2%

Summary

- Local Hadron Calibration is called to deal with non-compensating nature of hadron calorimeter.
- It consists of 4 steps:
  - cluster classification, weighting, out-of-cluster correction, dead material correction.
- Factorization of these effects simplifies the future validation.
- For single pions linearity on the level of ~2% for $|\eta|<1.0$ and $1.7<|\eta|<2.9$, energy resolution is improving by ~20% for $E_{\pi}>100$ GeV.
- Calibration provides jet algorithms with calibrated constituents and defines the same hadronic scale for all signals.
- Current jet scale provided by local hadron calibration is 8% off for di-jets with $P_{\perp}\sim150$GeV. This is explained by
  - misclassification (3%),
  - calorimeter inefficiency for low energetic pions (3%)
  - out-of-jet effects (2%).

backup



average energy deposited by 500 GeV single charged pions in dead material calibration hits