Local Hadronic Calibration

Energy calibration strategy for ATLAS Calorimeters

ATLAS Hadronic Calorimeter
Calibration Group

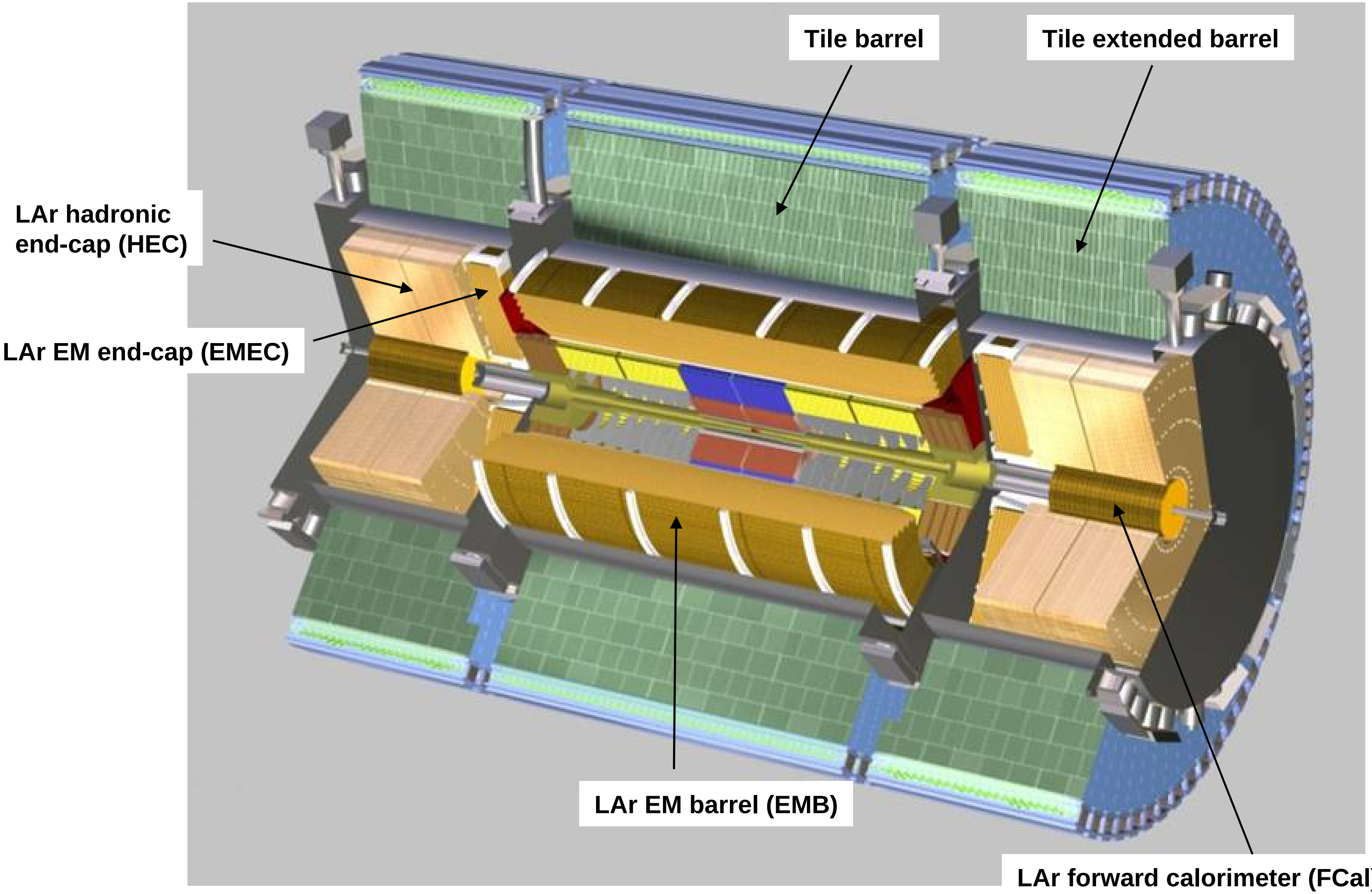
3rd ATLAS Physics Workshop
in North America
Boston, July 26-28, 2006

Previous Calorimeter Calibration workshops:
Munich, May 2-3, 2006
CERN, July 14-15, 2005
Tatranská Štrba, December 1-4, 2004

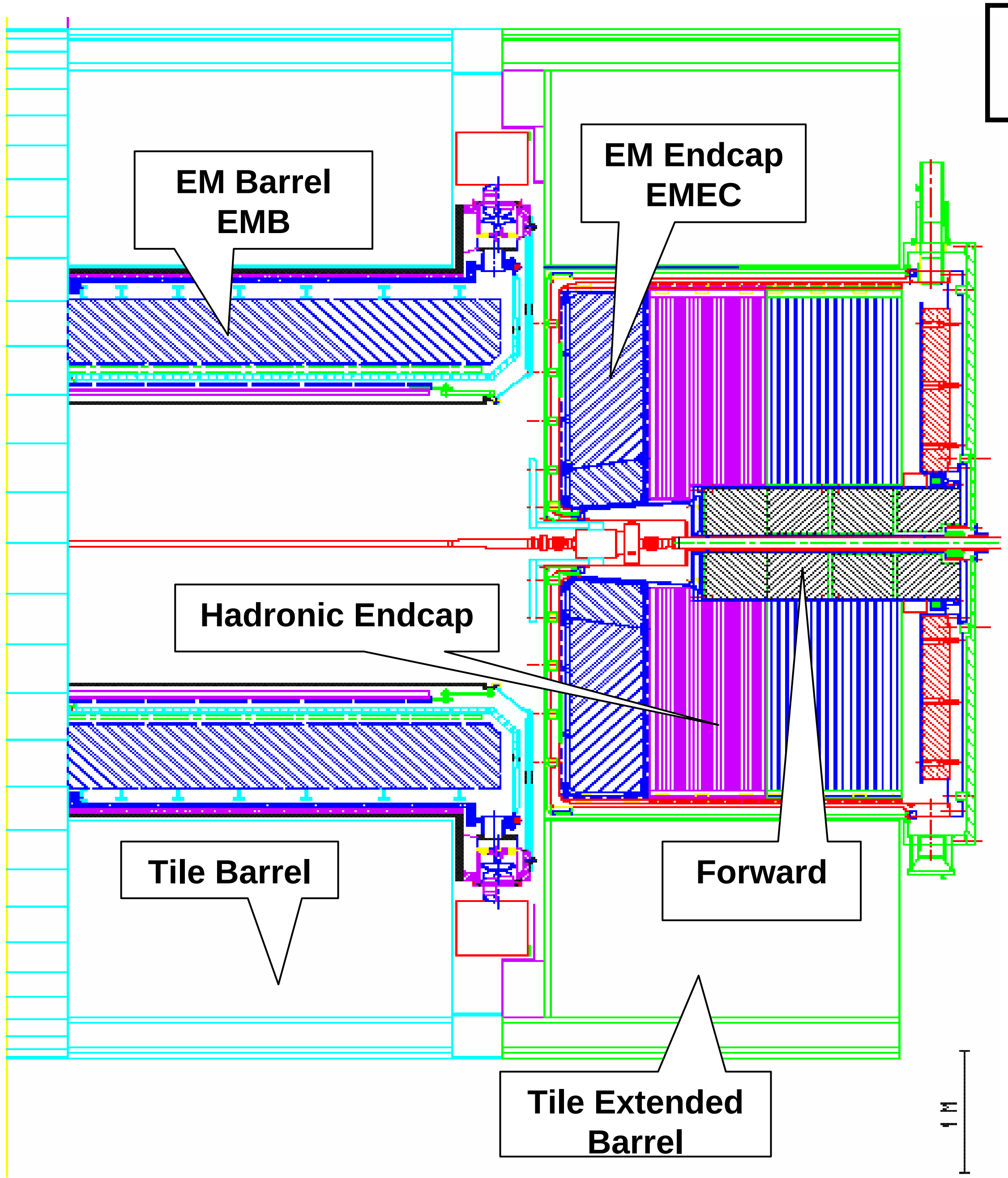
Next workshop:
Barcelona, September 5-8, 2006

Michel Lefebvre
Physics and Astronomy
University of Victoria

ATLAS LAr and Tile Calorimeters



LAr Calorimeters



- EM Barrel
  - $|\eta| < 1.4$
- EMEC
  - $1.375 < |\eta| < 3.2$
- Tile
  - $|\eta| < 1.7$
- HEC
  - $1.5 < |\eta| < 3.2$
- FCal
  - $3.2 < |\eta| < 4.9$

Varied granularity, techniques; many overlap regions

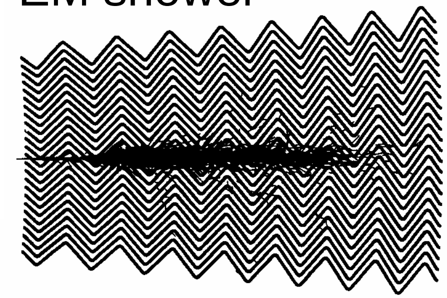
Design Physics Requirements

- EM Calorimeters
  - Benchmark channels $H \to \gamma\gamma$ and $H \to ZZ \to eeee$ require high resolution at $\approx$ 100 GeV and coverage to low E_T
  - b-physics: e reconstruction down to GeV range
  - Dynamic range: mip to $Z' \to ee$ at a few TeV
  - Design goals for $|\eta| < 2.5$
    - $\sigma(E)/E = 8\text{-}11\ \%/\sqrt{E} \oplus 0.2\text{-}0.4/E \oplus 0.7\%$
    - Linearity better that 0.1%
- Hadron and Forward Calorimeters
  - Benchmark channels $H \to WW \to$ jet jet X and Z/W/t require good jet-jet mass resolution
  - Higgs fusion $\to$ good forward jet tagging
  - EtMiss $\to$ calibration, jet resolution, linearity
  - Design goals
    - $\sigma(E)/E = 50\%/\sqrt{E} \oplus 3\%$ for $|\eta| < 3$
    - $\sigma(E)/E = 100\%/\sqrt{E} \oplus 5\%$ for $3 < |\eta| < 5$

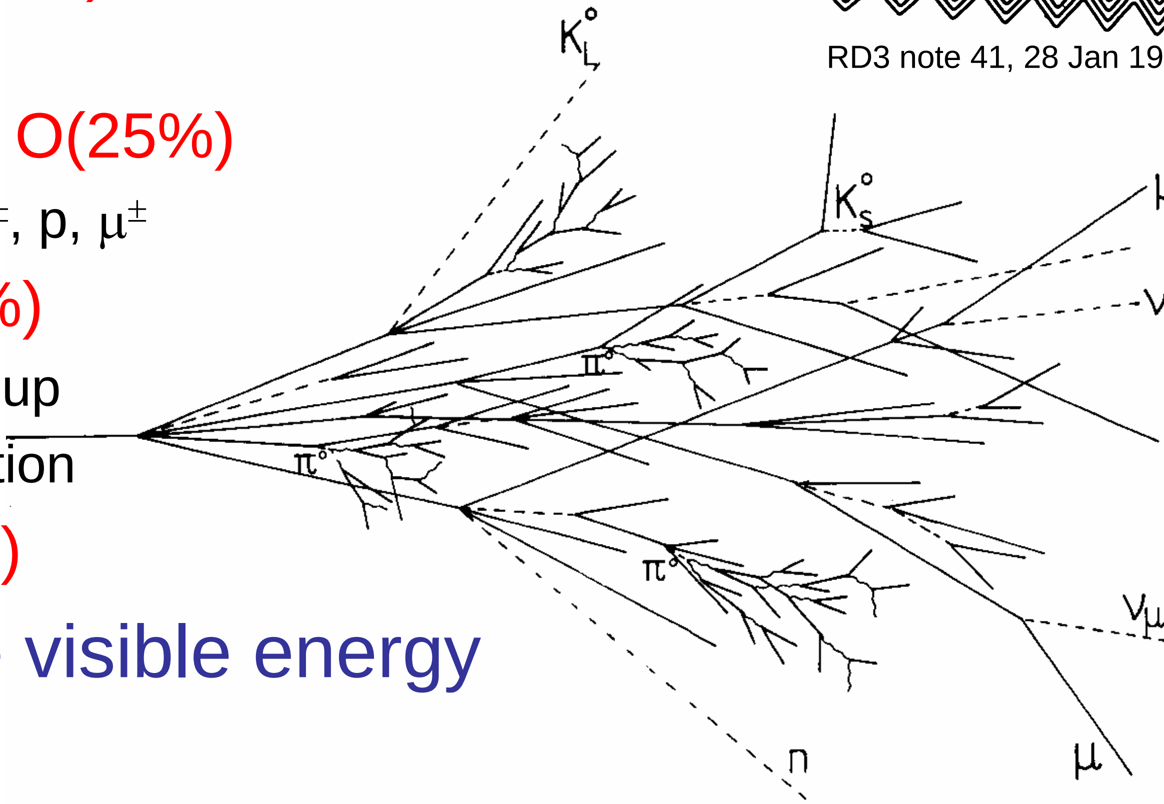
Hadronic Showers

- More complex than EM showers
  - visible EM O(50%)
    - $e^{\pm}$, γ, $\pi^{o} \rightarrow \gamma\gamma$
  - visible non-EM O(25%)
    - ionization of $\pi^{\pm}$, p, $\mu^{\pm}$
  - invisible O(25%)
    - nuclear break-up
    - nuclear excitation
  - escaped O(2%)
- Only part of the visible energy is sampled

EM shower



RD3 note 41, 28 Jan 1993



Grupen, Particle Detectors

Hadronic Shower

- Each component fraction depends on energy
  - visible non-EM fraction decreases with *E*
  - pion (and jets) response non linear with *E*

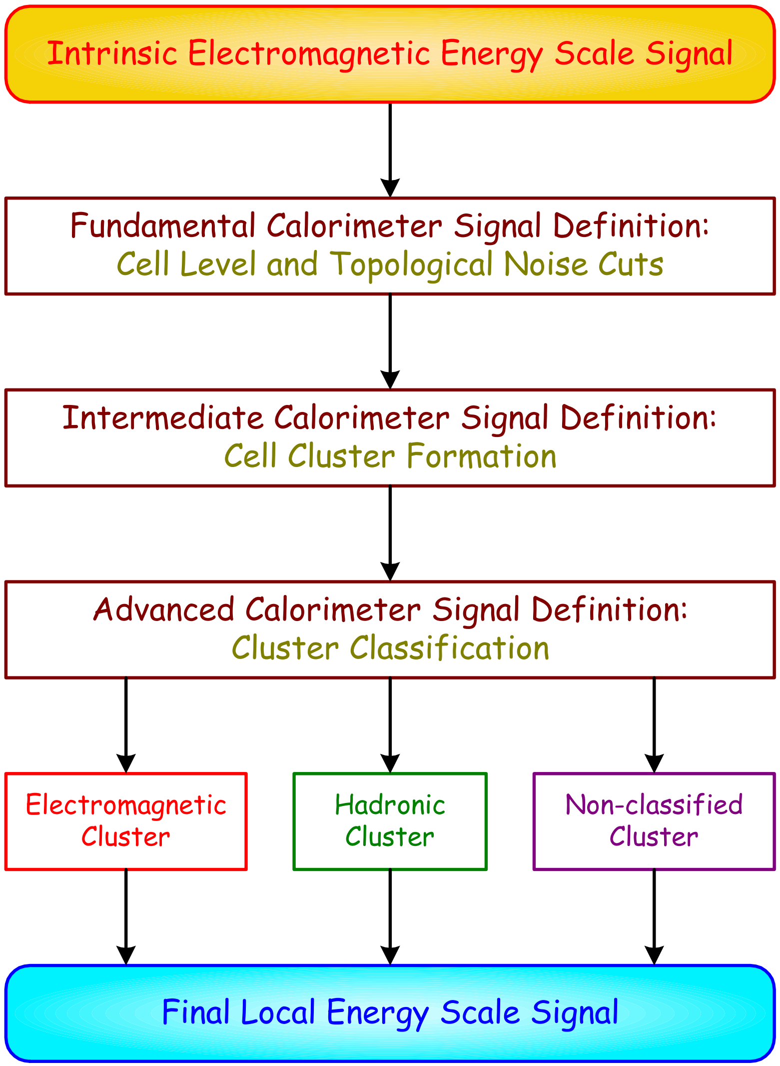
$$"\pi/e" = 1 - (1 - \text{h/e})\left(\frac{E}{E_0}\right)^{m-1}$$

$0.80 \le m \le 0.85$
$E_0 \approx 1$ GeV for $\pi^{\pm}$
$E_0 \approx 2.6$ GeV for p

  - in ATLAS, e/h > 1 for each sub-detector
    - “e” is the intrinsic response to visible EM
    - “h” is the intrinsic response to visible non-EM
    - invisible energy is the main source of e/h > 1
- Large fluctuations of each component fraction
  - non-compensation amplifies fluctuations
- Hadronic calibration attempts to
  - provide some degree of software compensation
  - account for the invisible and escaped energy

Local Calorimeter Calibration Flow

P. Loch



Electronic and readout effects unfolded (nA->GeV calibration)

Detector noise suppression algorithms (optional, can be absorbed into cluster formation algorithm)

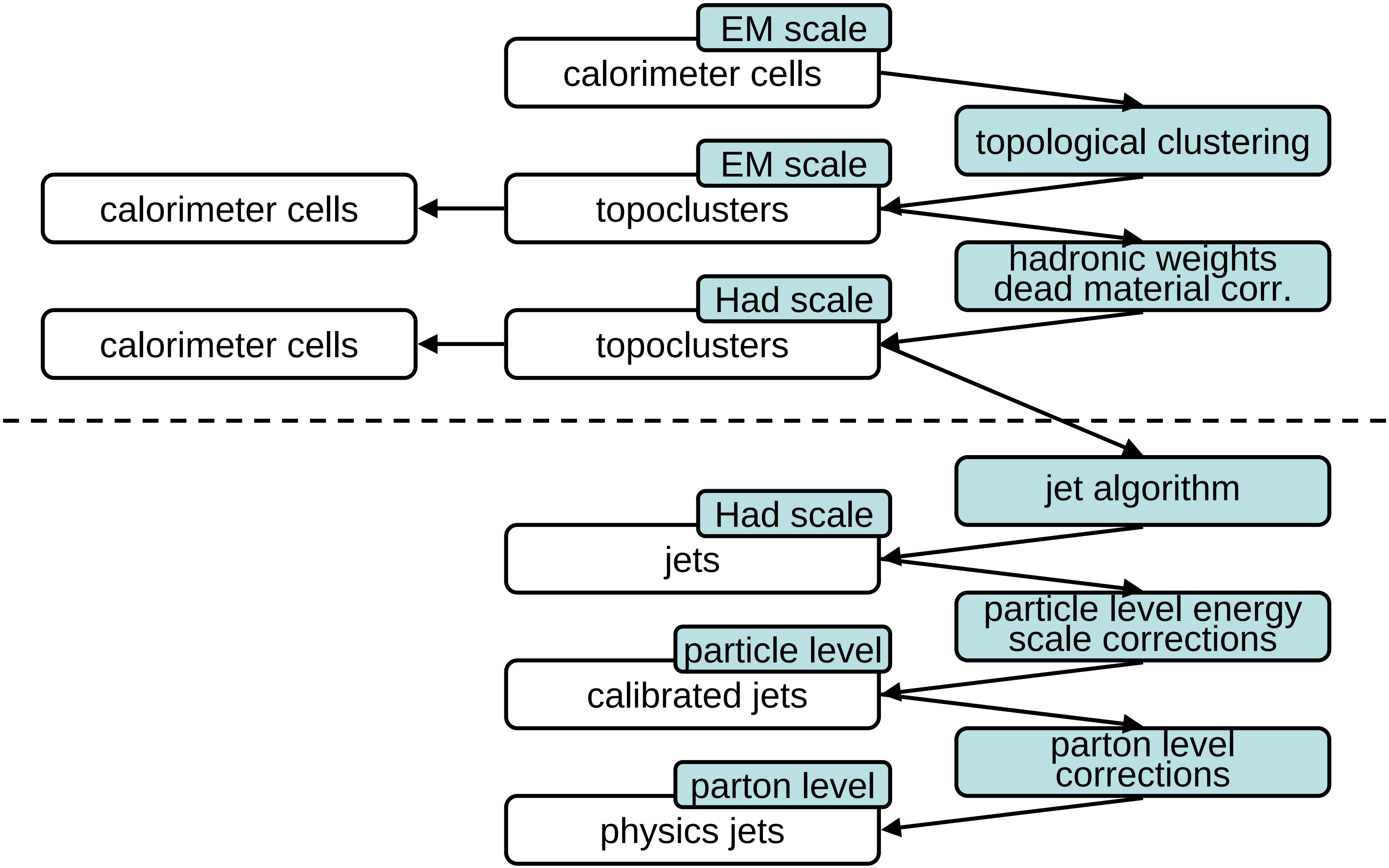
Cluster formation in calorimeter regions (2D->3D->spanning regions)

Simple cluster shape analysis -> classification

Apply cluster type specific calibration functions, dead material and crack corrections

Best estimate for general energy flow in event -> re-calibrate smallest readout units (cells)!

Local Hadronic Calibration

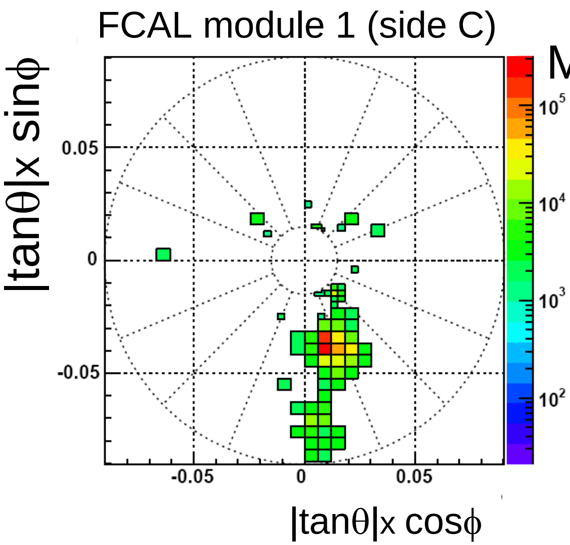


Clustering

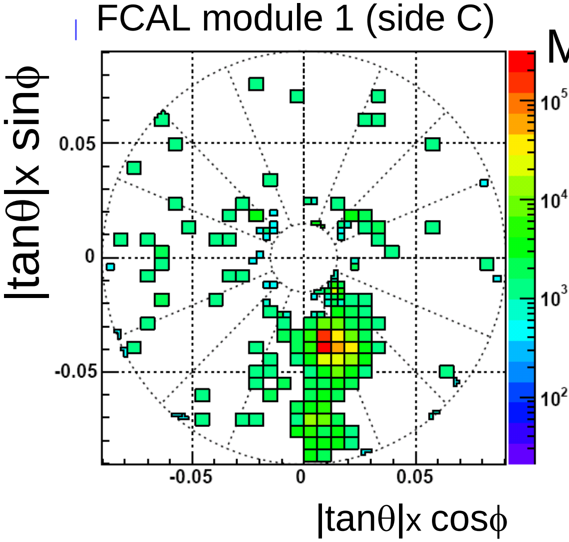
- Topological clustering
  - identify energy deposits in topologically connected cells
    - use cell signal significance criteria based on $\sigma_{noise} = \sigma_{electronic} \oplus \sigma_{pileup}$
    - over the full calorimetry
    - correlated signals automatically taken into account
  - offers noise suppression
- Seed, Neighbour, Perimeter cells (S,N,P)
  - 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)
  - (S,N,P) = (4,2,0) good for combined beam tests

Clustering

Sven Menke

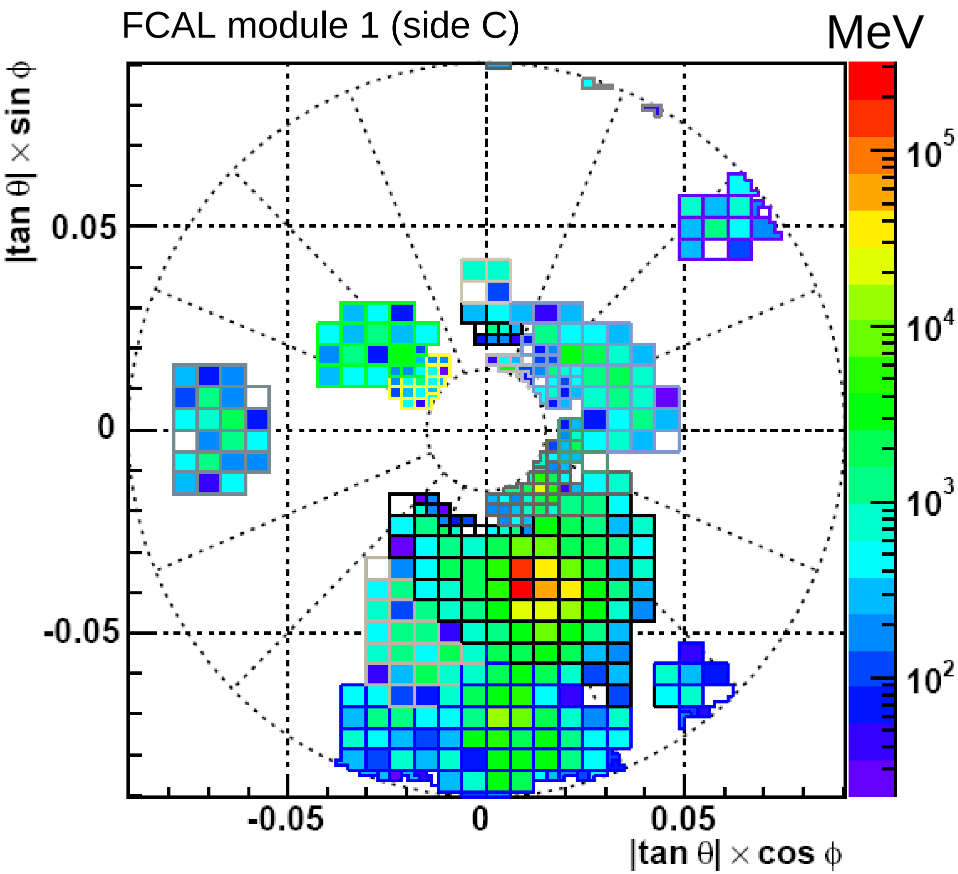


cells with $|E_{cell}|>4\sigma_{noise}$



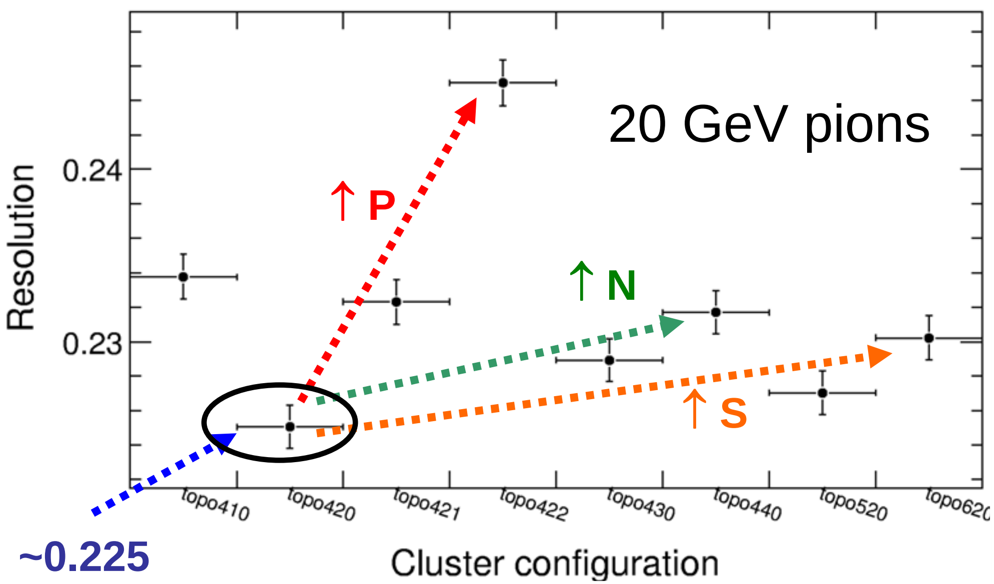
cells with $|E_{cell}|>2\sigma_{noise}$

- Topological clustering
  - 4,2,0 clusters in FCal
    - jets with p_T > 50 GeV

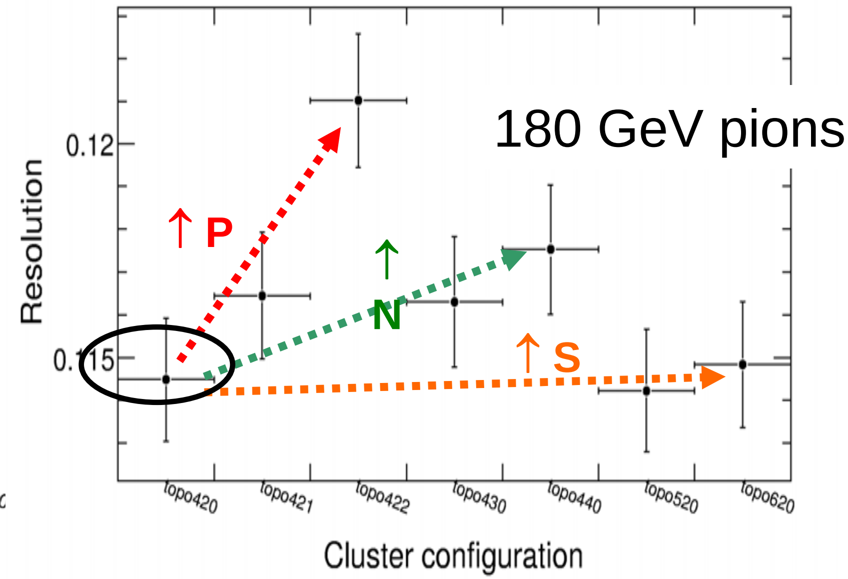


Topocluster Threshold Tuning

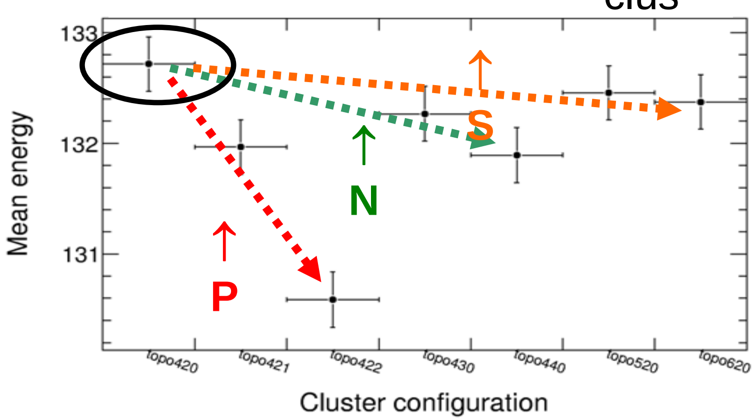
Resolution of Sum E_{clus}



Resolution of Sum E_{clus}



Mean of Sum E_{clus}



4,2,0 performs in the best way, beam test pions $\eta = 0.45$

Speckmayer, Carli

Cluster Splitting

- Energy deposited by nearby sources can have overlapping clusters
  - split clusters (Sven Menke)
- Cluster splitter looks for local maxima in cluster
  - sought only in EM layers 2 and 3, and FCAL layer 0
  - maxima threshold set to $E > 500$ MeV
    - this is for nightlies and 12.0.2; Recent fixes improve bahaviour for jets in inner wheel and forward regions.
  - one cell can share energy between two clusters
- Aim at one cluster per isolated $e^{\pm}$, γ, $\pi^{\pm}$

Cluster Classification

- Cluster classified as EM, hadronic, unknown
- Select EM clusters using the correlation of
  - $F_{EM} = E_{EM}/E_{tot}$ from MC single π Calibration hits
  - shower shape variables in single π MC events
    - λ = cluster barycenter depth in calo
    - ρ = energy weighted average cell density
- Current implementation (Sven Menke)
  - keep μ_F and σ_F in bins of η, E, λ, ρ of clusters
  - for a given cluster
    - if E < 0, then classify as unknown
    - lookup μ_F and σ_F from the observables η, E, λ, ρ
    - cluster is EM if $\mu_F + \sigma_F > 90\%$, hadronic otherwise

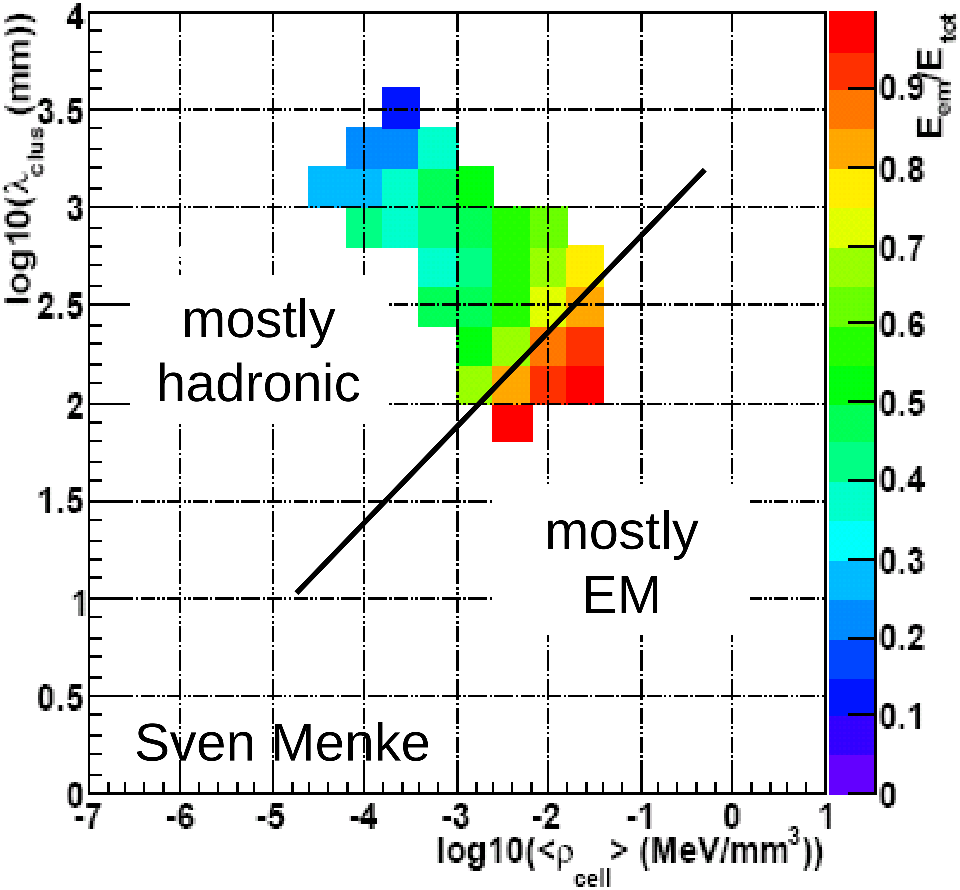
Cluster Classification

- Example

2.0 < |η| < 2.2

4 GeV < E_{clus} < 16 GeV

F_{EM} from calibration hits



other method under development using three cluster shape observables (P. Stavina)

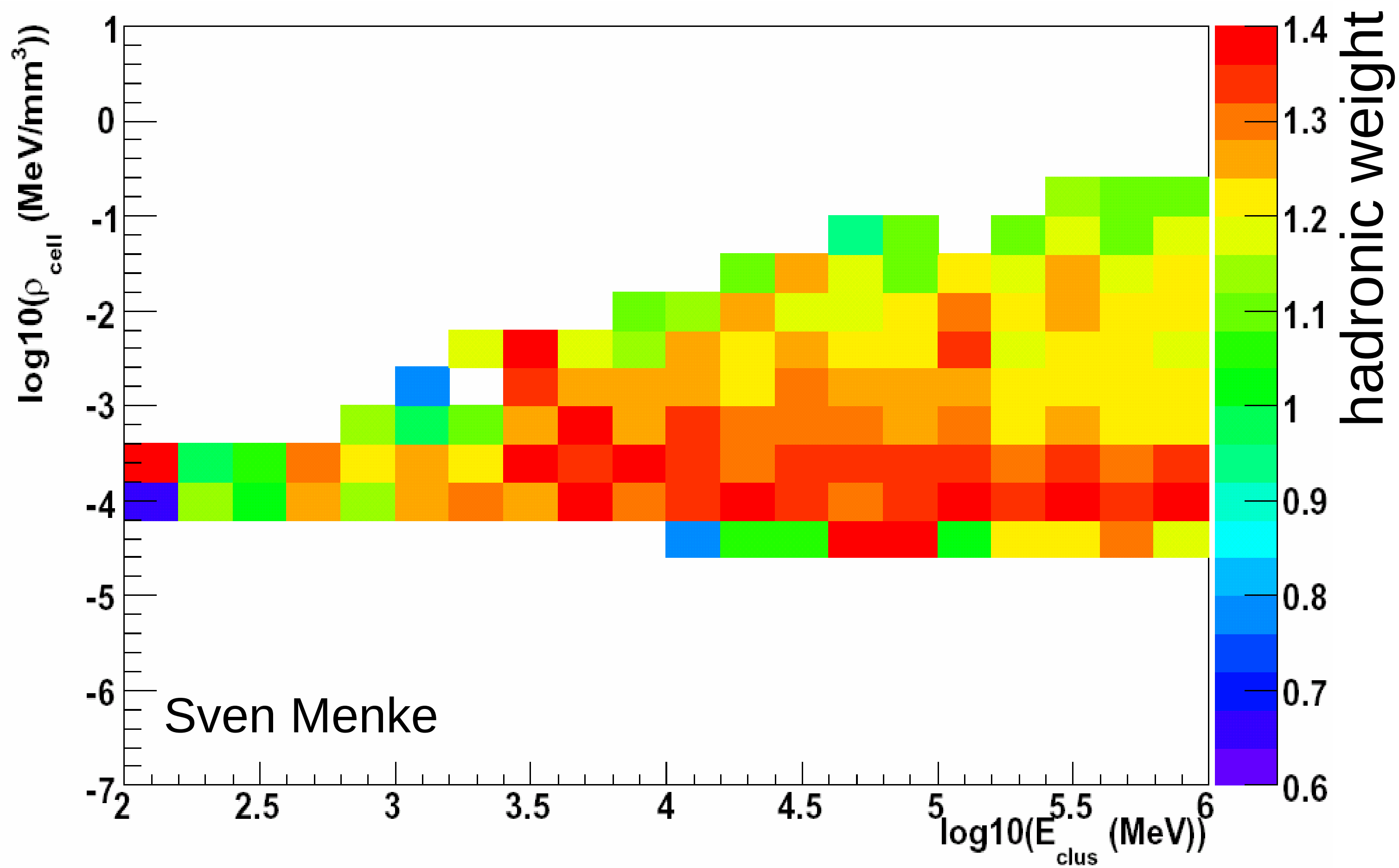
Hadronic Weighting

- Use simulated single pions from 1 to 1000 GeV, uniform in η in full ATLAS
  - Reconstruct and classify clusters
  - Let $R = E_{tot}/E^{reco}$, where E_{tot} is from calib hits
  - keep $W = \mu_R$ as a function of $\log(E_{cluster})$, $\log(\rho_{cell})$ for bins in $|\eta_{cluster}|$ and cell sampling depth
    - average performed over all non-EM clusters, all events
- For a given cell in a hadronic cluster
  - lookup W in bins of $|\eta_{cluster}|$, $\log(E_{cluster})$, $\log(\rho_{cell})$
- Results: weighting works for $E_{clus} > 10$ GeV
  - need more work for the FCal classification and W

Hadronic Weighting

Example

- $2.0 < |\eta| < 2.2$, HEC layer 0

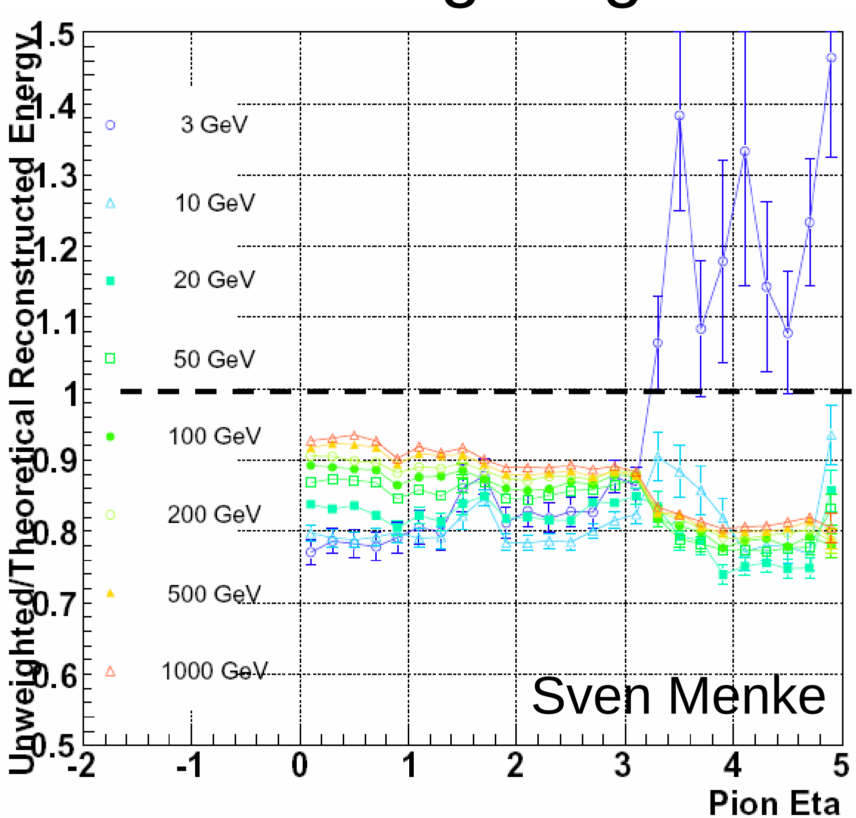


Hadronic Weighting

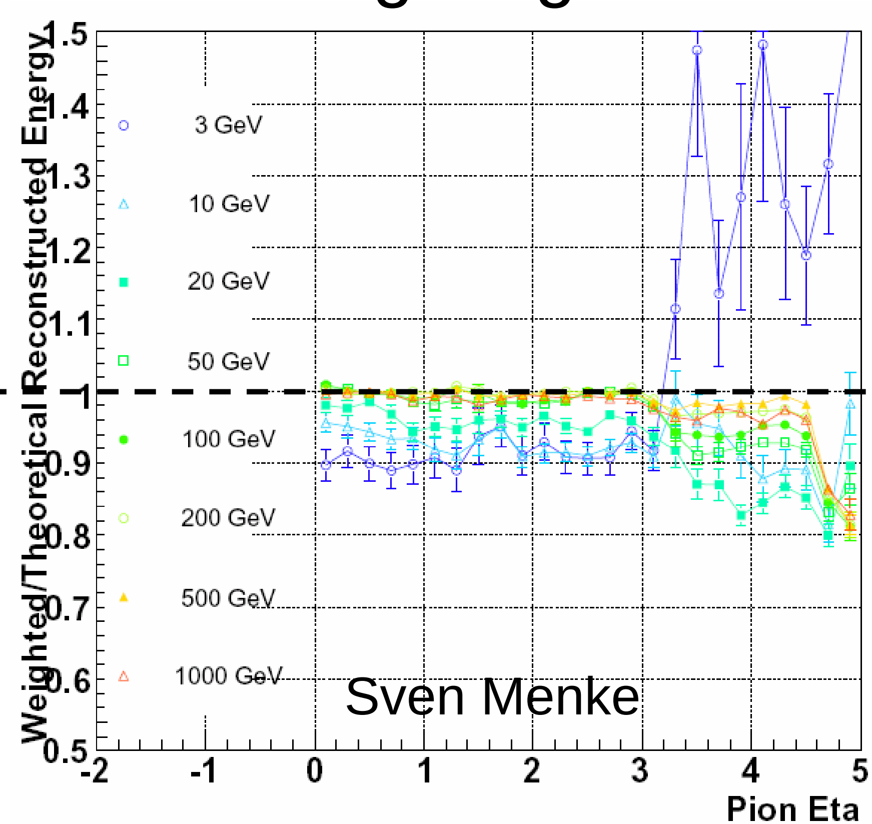
Weighting single pions: mean response

- do not include presampler and gap scintillators
- mean is improved for all energies

before weighting



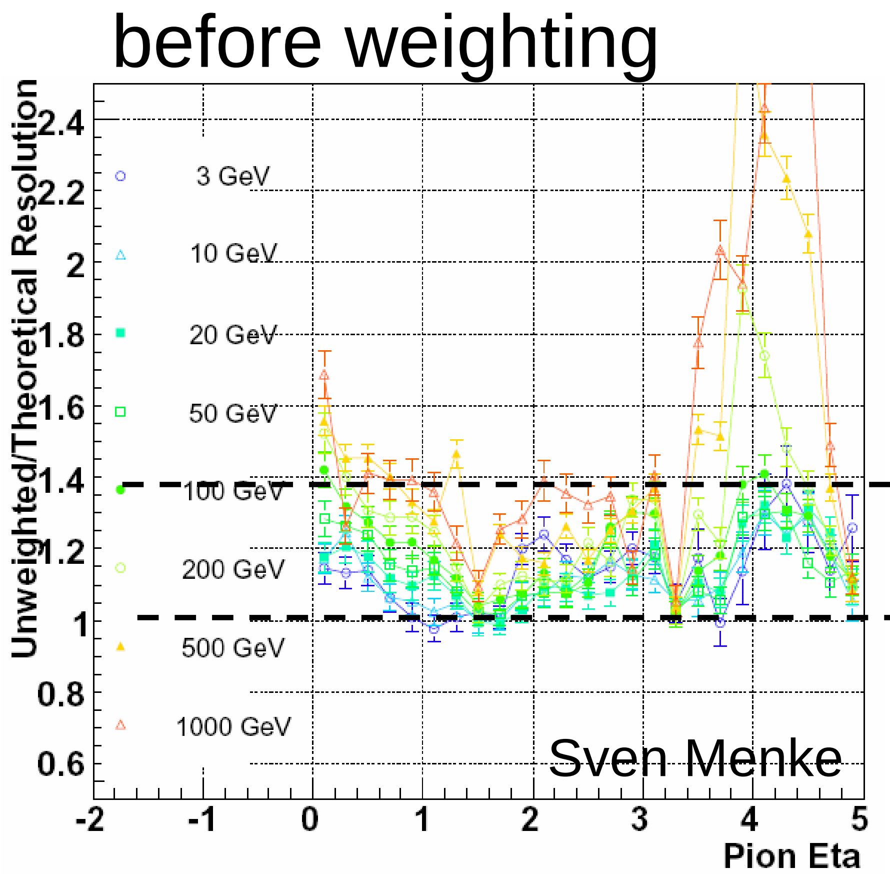
after weighting

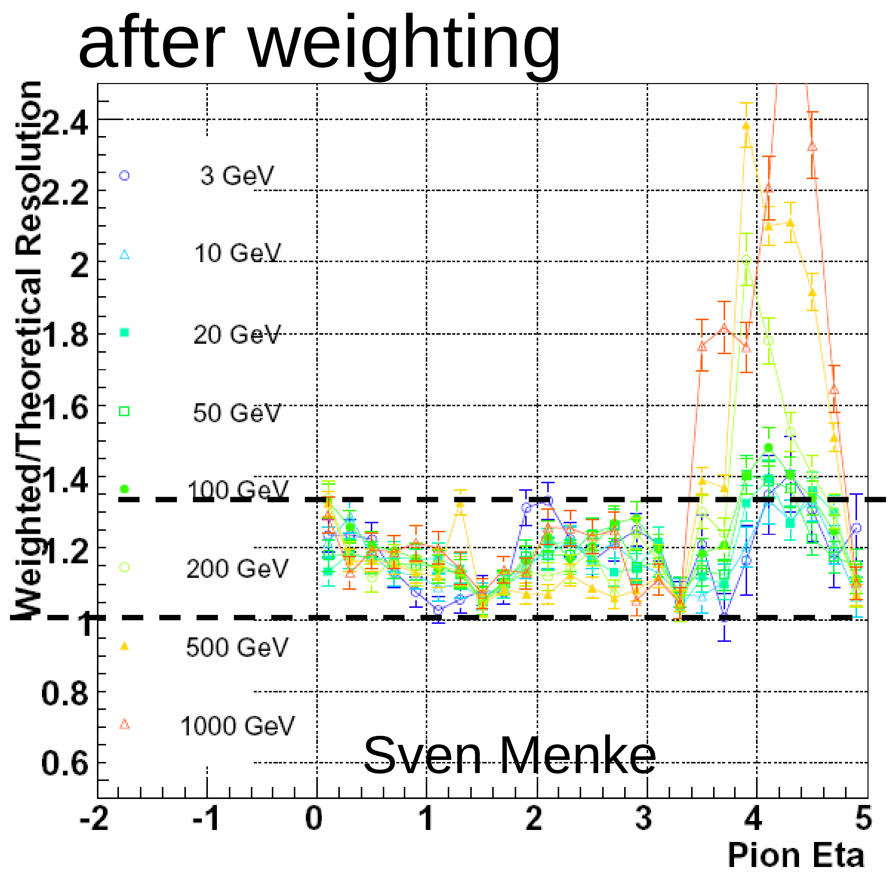


Hadronic Weighting

Weighting single pions: resolution

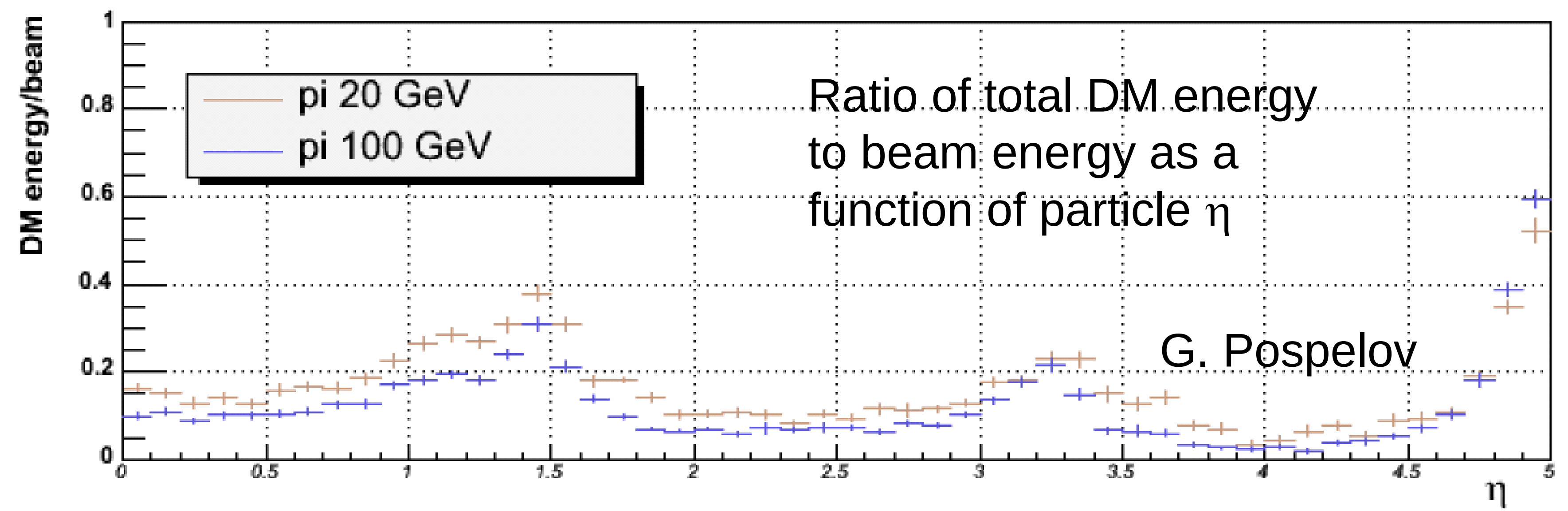
- do not include presampler and gap scintillators
- resolution is improved for *E* > 50 GeV





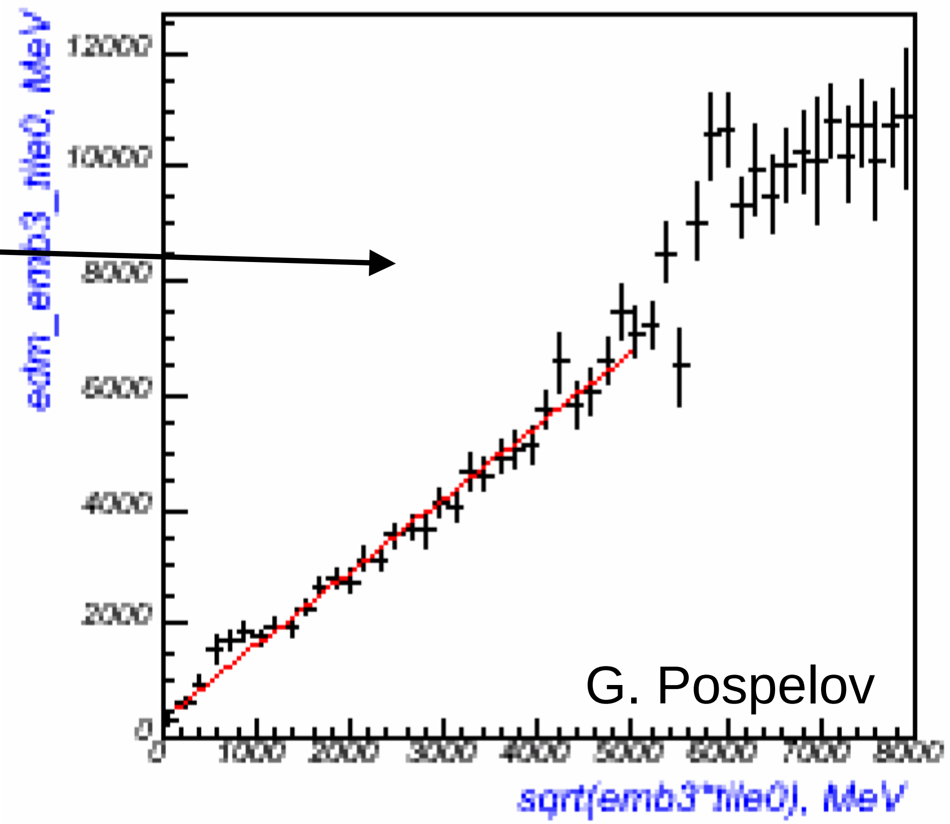
Dead Material Corrections

- Estimate cluster energy correction from dead material (DM) region
  - Correlate energy deposits in DM area (from calib hits) with functions of the reconstructed energies in cluster cells in samplings close to the DM area
  - 76000 6D (η, φ, ...) bins in 53 DM areas



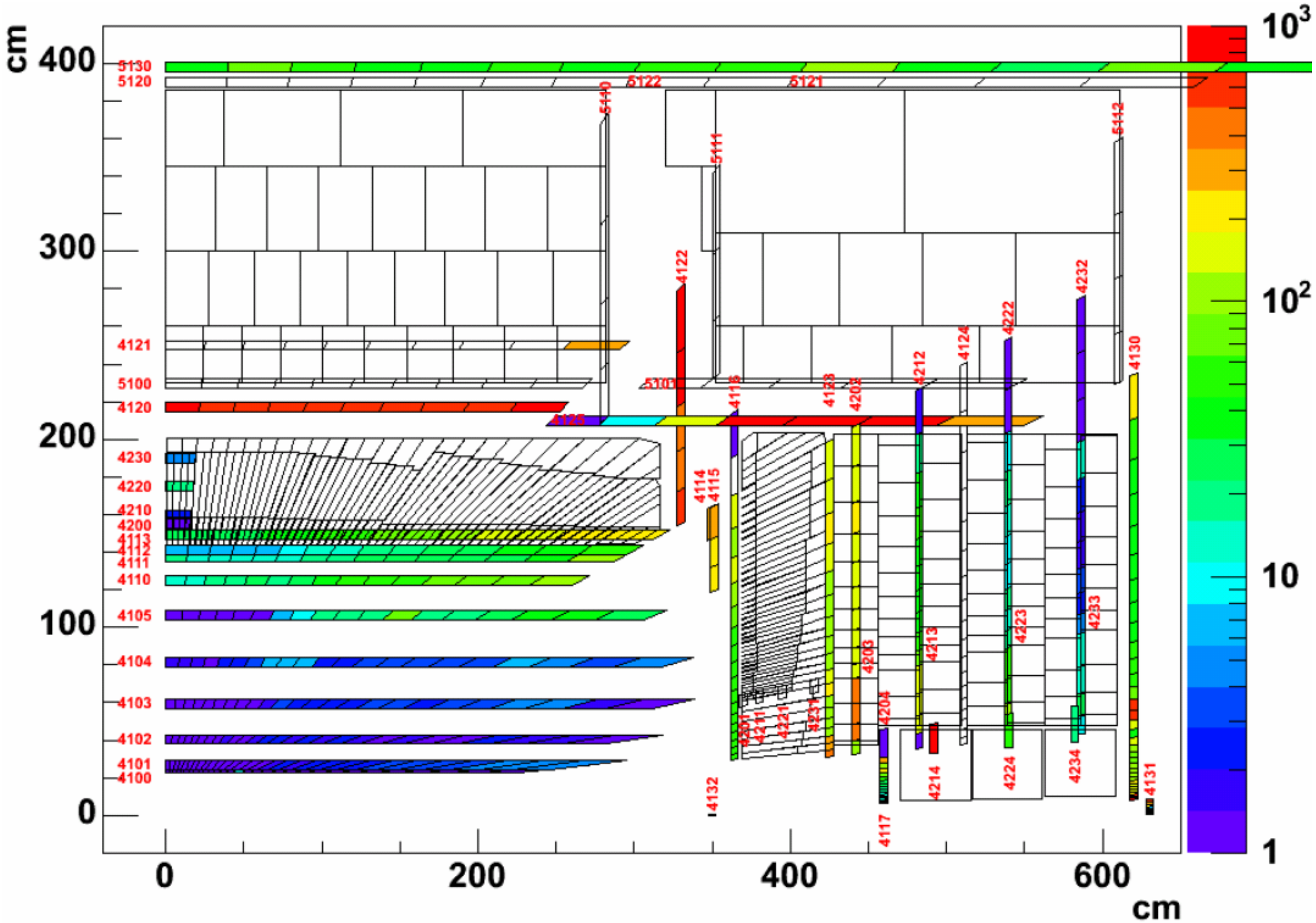
Dead Material Corrections

- For example, the energy between the tile and the LAr barrel (calib hits) correlates with the geometrical mean of the barrel back layer and the tile layer 0
- DM corrections are sought for energy deposited in DM in front and behind clusters, but not laterally outside the cluster



Dead Material Corrections

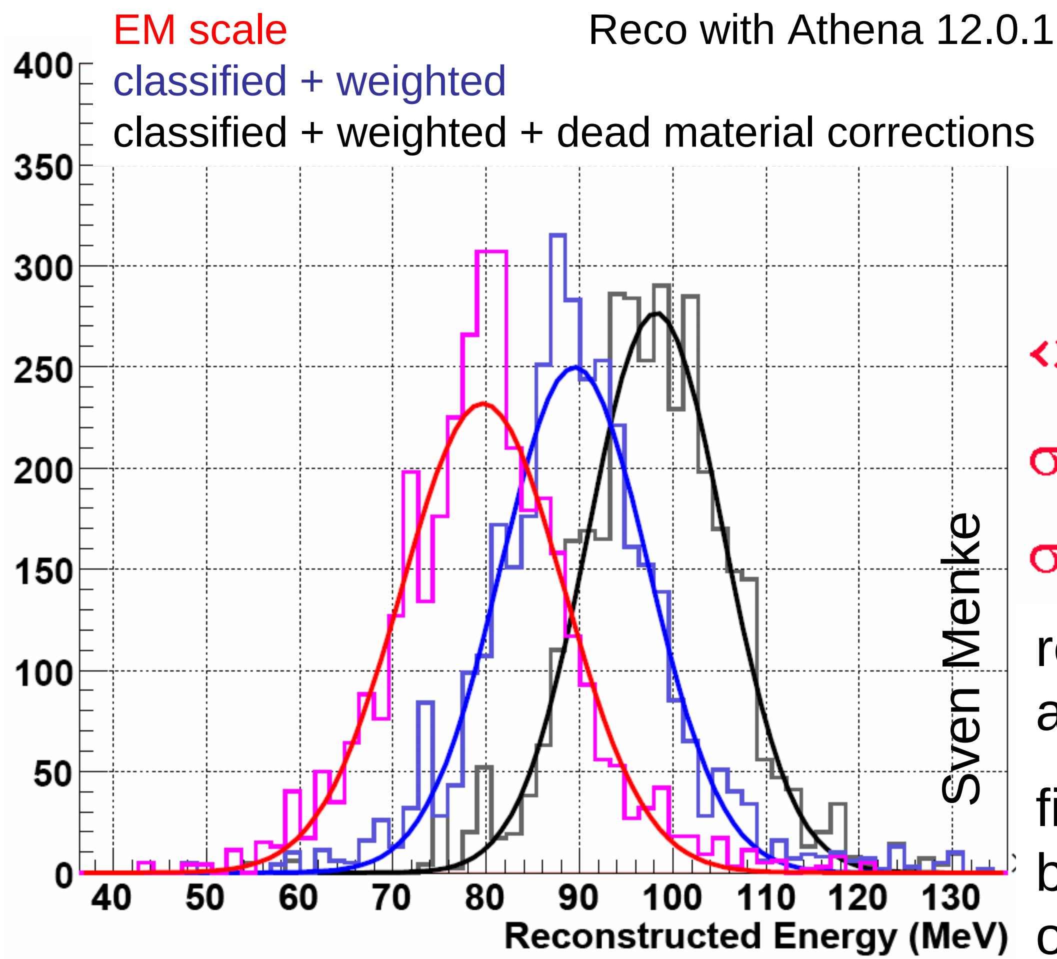
- Average energy in dead material deposited by 500 GeV single pion showers
- Generated flat in |η| < 5. Energy summed in phi in this plot.



G. Pospelov

Application: simulated single pions

- Apply single π weights to non-EM clusters
- Plot sum of energies for clusters around the true π direction within $\Delta R < 1$



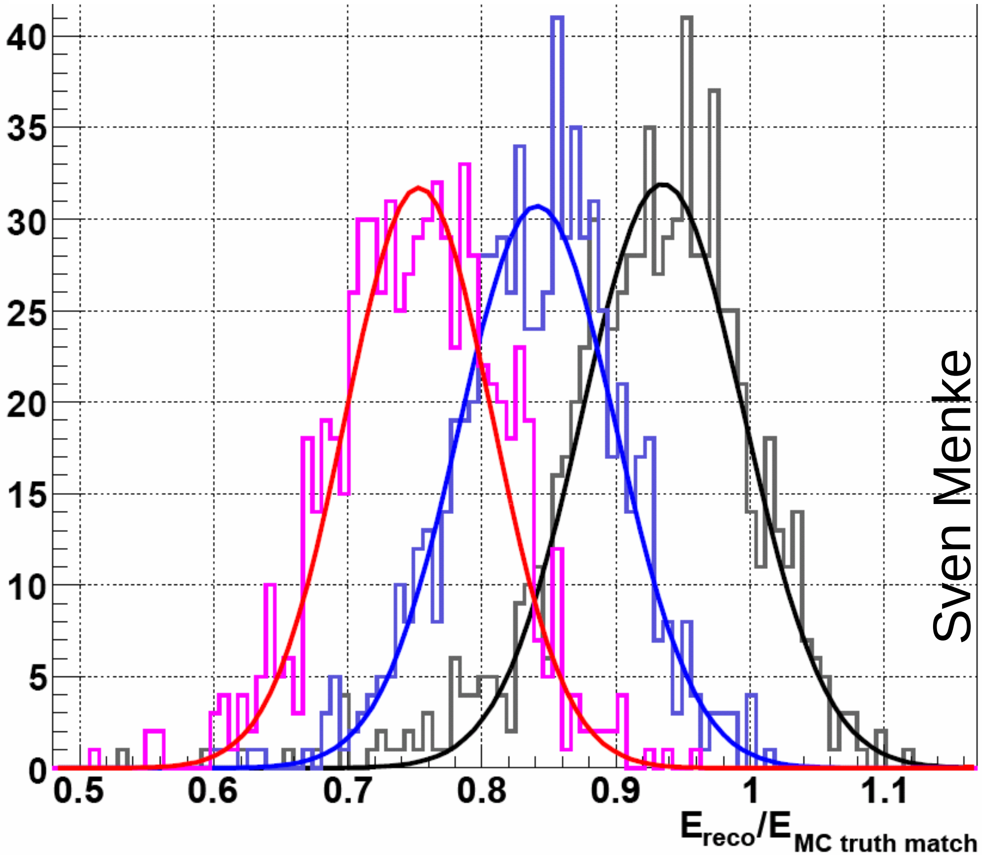
	EM	W	W+DM
<>(GeV)	79.9	89.5	98.2
σ (GeV)	8.7	7.9	7.3
σ/<>(%)	10.9	8.8	7.4

response and resolution improve at each step

final response only 1.8% from beam energy → small residual out of cluster correction

Application: simulated di-jet

- Apply single π weights to non-EM clusters
- Plot E/E_{truth} of two highest E_T jets with $|\eta|$~0.3



- Jets made with k_T algorithm, D parameter for k_T = 0.6)
- average energy for two highest E_T jets ~ 150 GeV, with rms ~ 40 GeV

	EM	W	W+DM
<>(GeV)	0.753	0.841	0.935
σ (GeV)	0.055	0.058	0.060
σ/<>(%)	7.3	6.9	6.5

response and resolution improve at each step

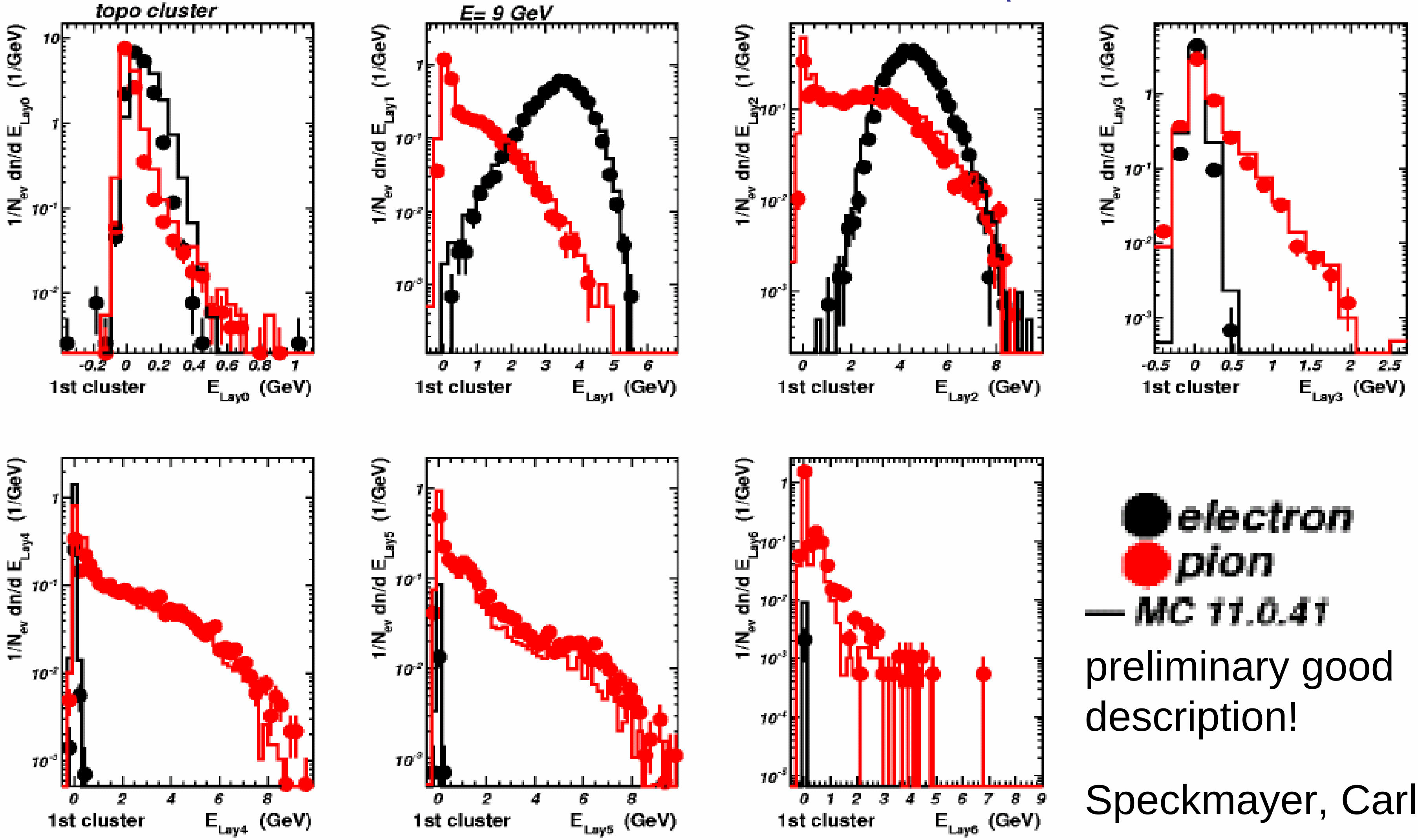
final response is 6.5% from MC truth match → small out of jet correction

Monte Carlo Validation

- Monte Carlo based calibration
  - MC must be able to reproduce data properties
- Activities
  - validate GEANT4 physics lists and detector description
  - compare basic observables for e, π, μ
    - $0.2 < \eta < 1.8$
    - $2 < E < 180$ GeV
- Aim at using weighting and dead material corrections on data from 2004 combined test beam (also 2002?)

Monte Carlo Validation

- Energy distributions in barrel layers
- combined test beam 2004, 9 GeV e^- and π^- at $\eta = 0.45$



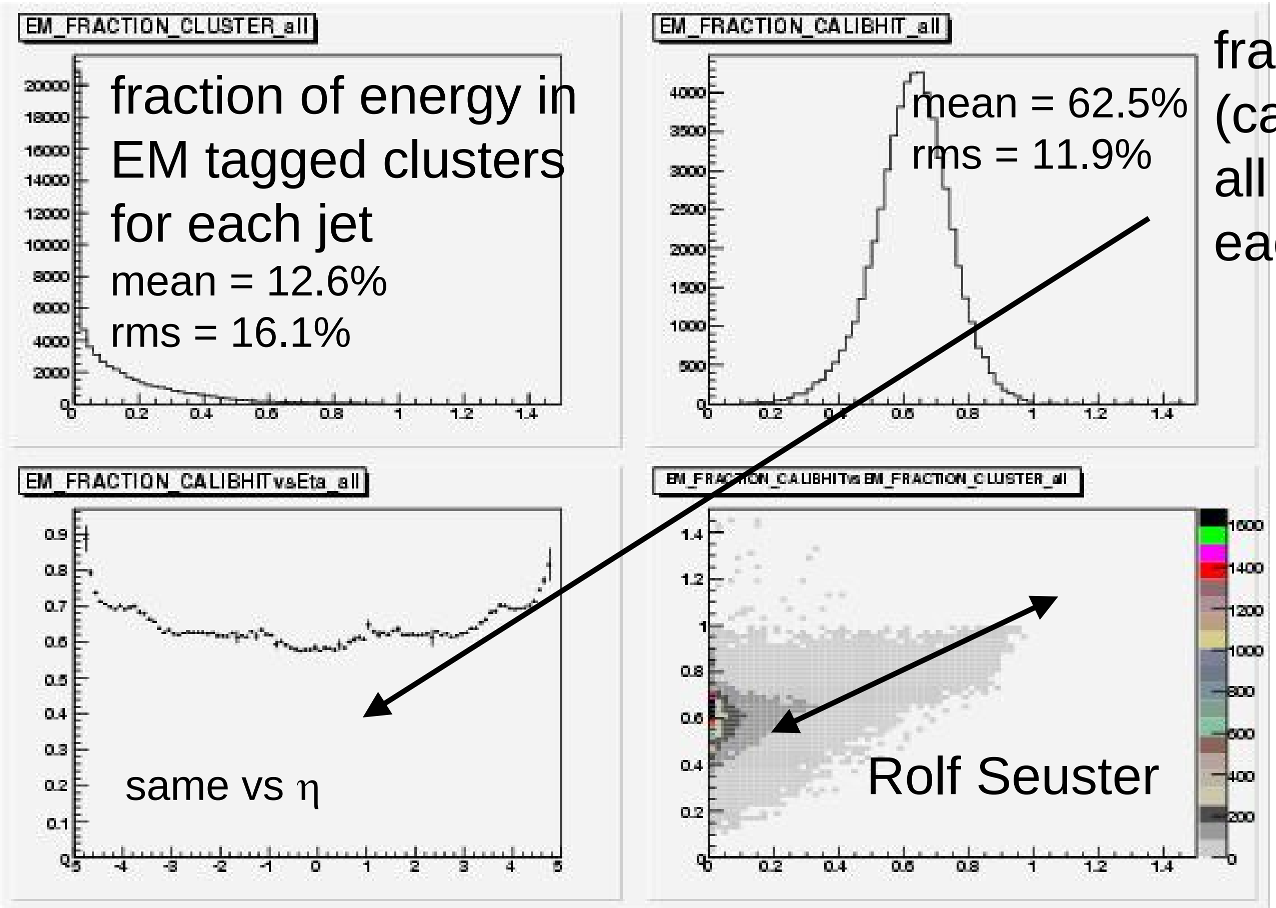
preliminary good description!

Speckmayer, Carli

Monitoring Cluster Classification in Jets

- very useful tools for assessing the validity of cluster classification, updated version now in CVS

14.2k events, 58k jets, J5 (280 < p_T < 560 GeV) with calib hits,
ConeCluster jets *R*=0.7 build from CaloCalTopoCluster. 12.0.1.



fraction of EM energy (calib hits) deposited in all cells of all clusters for each jet

correlation between two top plot variables

cluster classification works in the right direction!

Plans and Ongoing Work

- Cluster classification
  - re-produce single particle (pion/electron) samples with 12.0.2, compare different options, performance on jets
- Weighting
  - extend and understand weight application to J1-J7 di-jets, more work on low energy, test different weighting approaches on pions, jets, CTB04
- Dead material correction
  - re-run simulation with improved calibration hits, develop corrections for uncovered areas (HEC and FCAL), improve DM-cluster assignment, validate and try on single particles and jets
- Towards CDC
  - Close contact with jet-E_T^{miss} for final in-situ calibration: use calibrated clusters to make jets, use single particle weights in J1-J7 di-jets samples, study the performance for ttbar, build feedback loop on in-situ calibration and impact of detector imperfections

Conclusions

- We have a local hadronic calibration scheme in place and results can be tested up to jet and E_T^{miss} reconstruction
- Validation and improvement efforts are ongoing on many fronts
- Next milestone: ATLAS Calorimeter Calibration Workshop, Costa Brava, 5-8 Sep 2006!