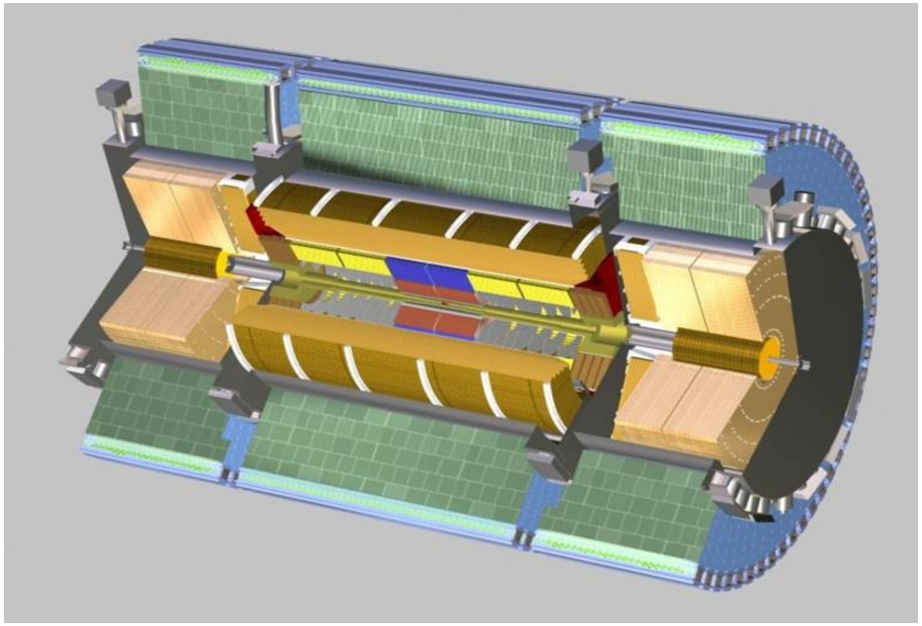
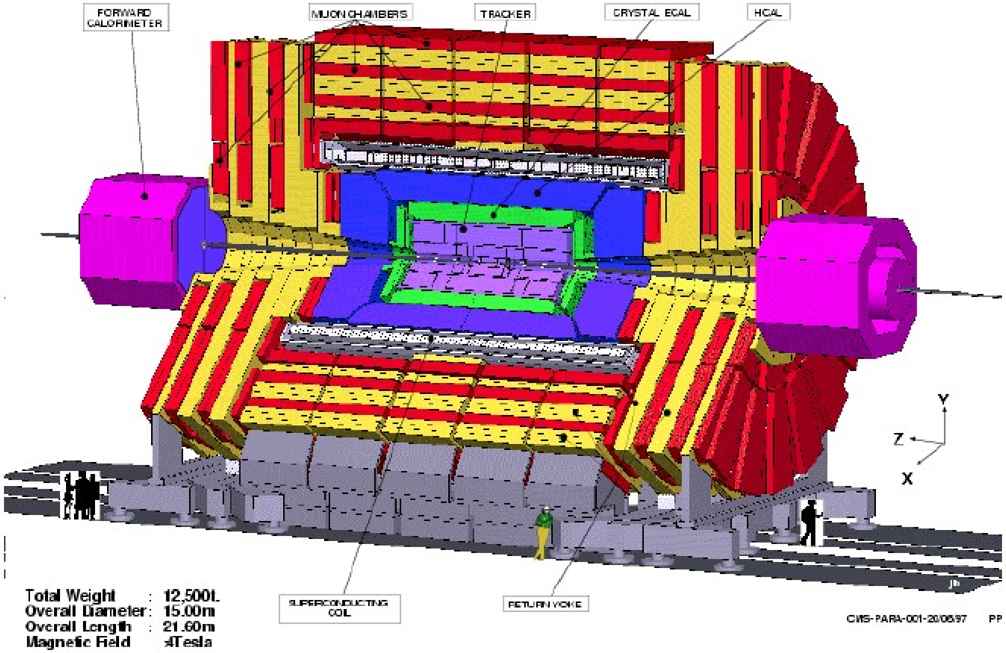
Off-line software compensation of the calorimeter response to hadron energy (hadronic calibration)

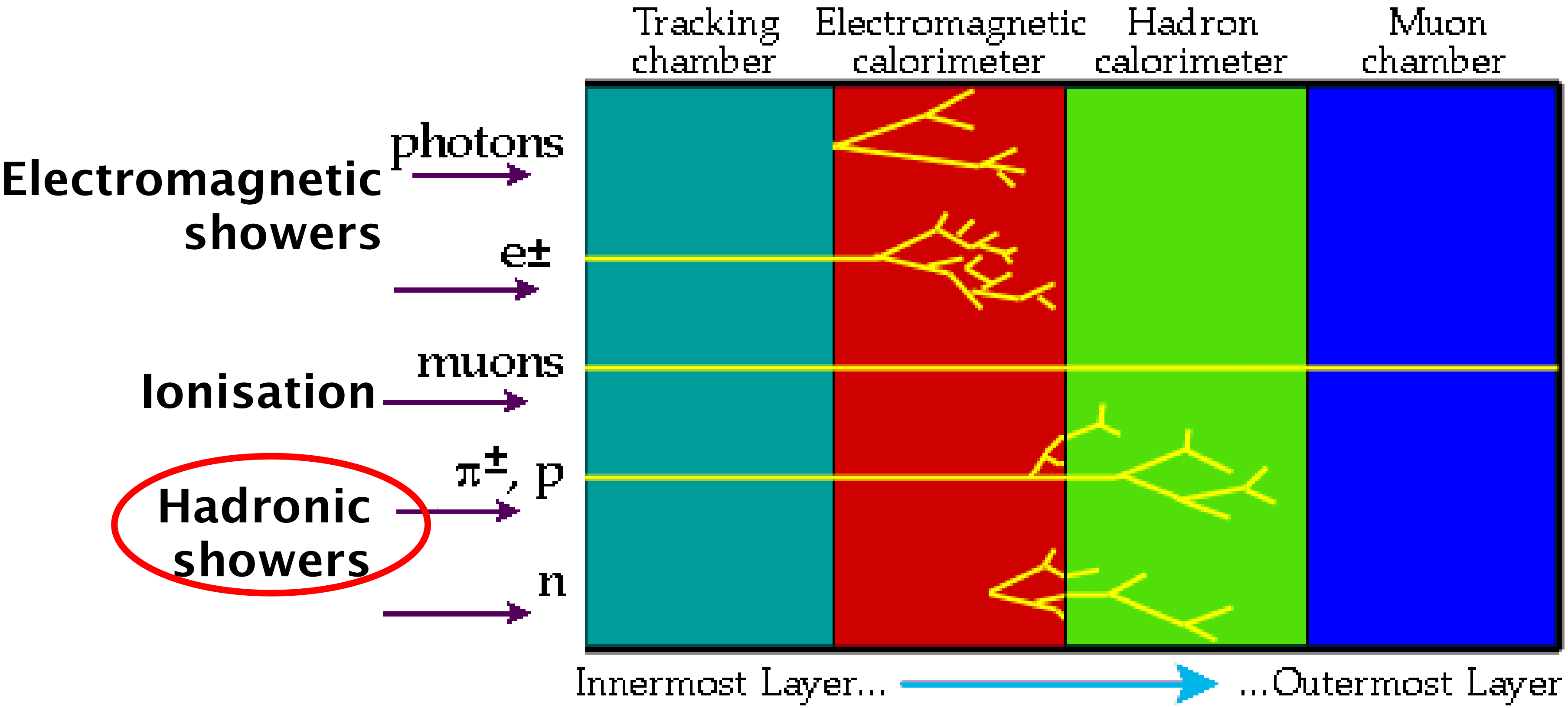




Elin Bergeaas Kuutmann
Stockholm University

LHC detector school – calorimetry session

A brief reminder: Detection principles



Electrons generally shower earlier than hadrons.
Hadronic showers reach deeper into the calorimeter

Image from www.particleadventure.org

Calibrating a calorimeter

Simplified calibration scheme:

- Expose the calorimeter to electrons of known energy
- Compare the read-out to the initial energy

Now the calorimeter is calibrated on the *electromagnetic scale*

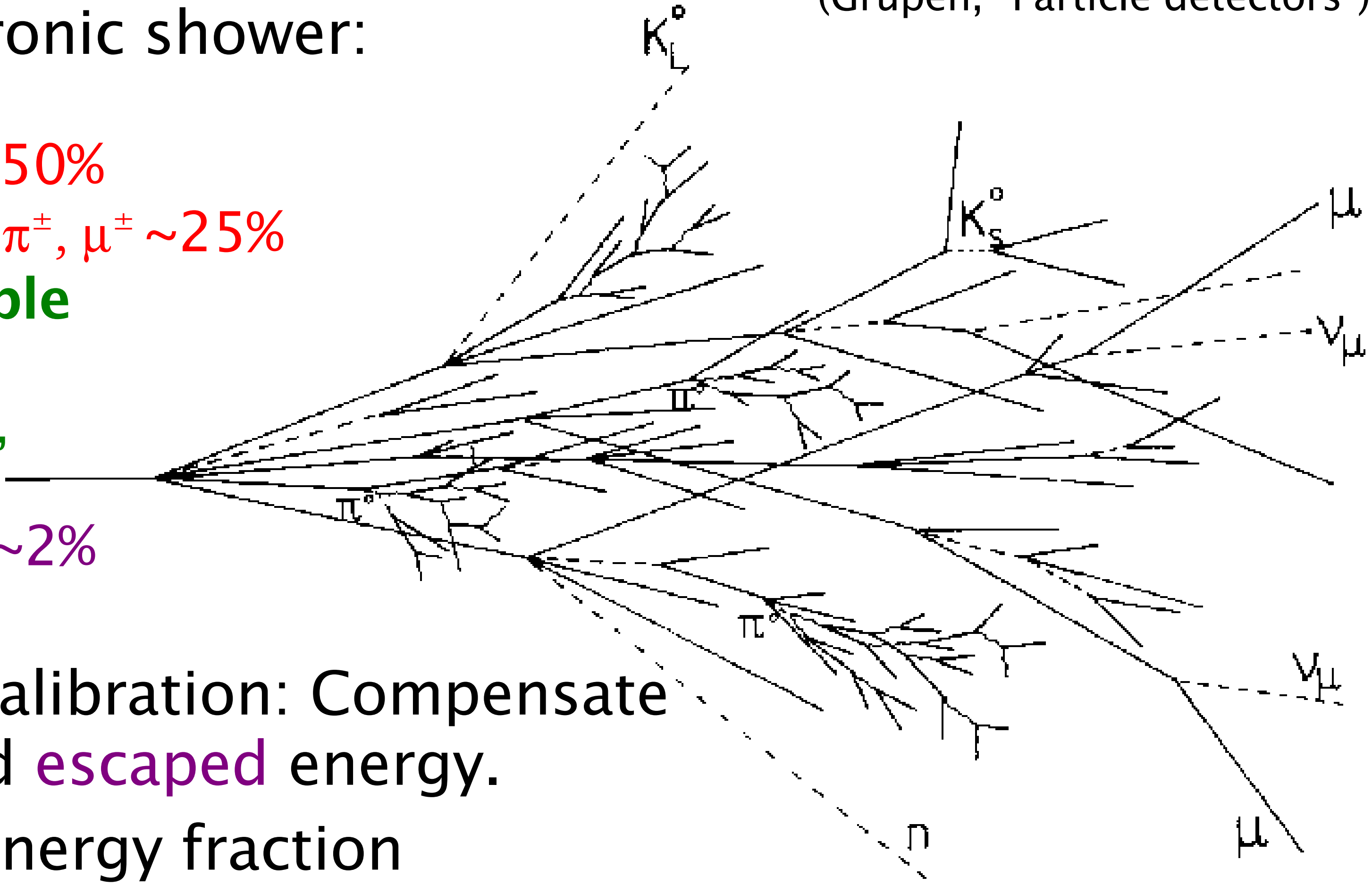
... so why do we need hadronic calibration?

---> Because of *invisible energy!*

Hadronic shower

Contents of a hadronic shower:

- Visible energy
  from $e^{\pm}$; $\pi^0 \rightarrow \gamma\gamma$; ~50%
  ionisation from p, $\pi^{\pm}$, $\mu^{\pm}$ ~25%
- Hadronic **invisible** energy ~25%
  (nuclear excitations, break-ups)
- Escaped energy ~2%
  (mainly ν, some μ)


(Grupen, “Particle detectors”)

Aim of hadronic calibration: Compensate for invisible and escaped energy.

Electromagnetic energy fraction *increases* with increasing hadron energy due to production of π^0's in the shower

Heavy event-by-event fluctuations

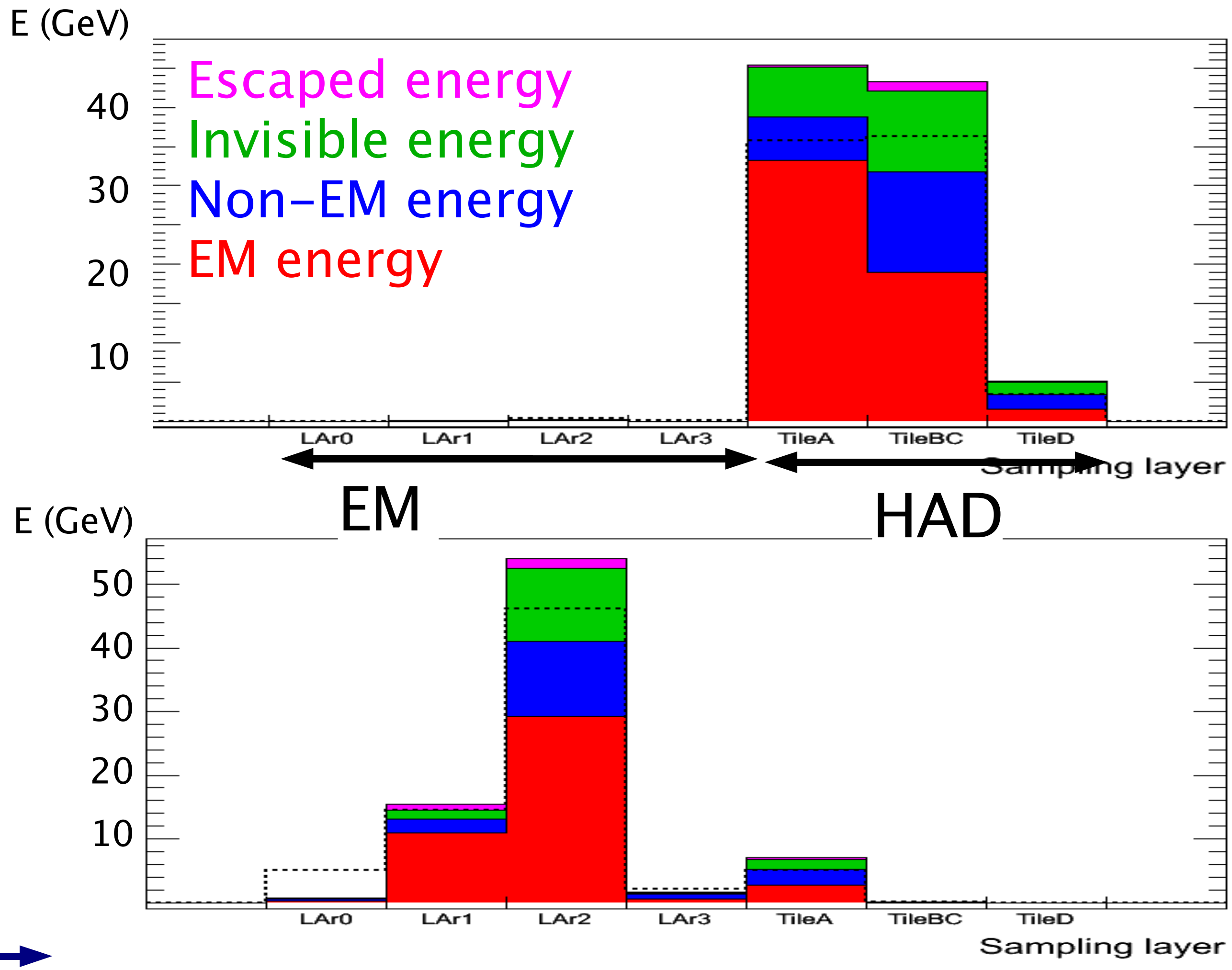
Compensate for the invisible energy

some strategies

- Change the calorimeter (make it *compensating*):
  - Increase the response to the hadronic part of the shower: Hydrogen in the active material (organic material, e.g. plastic)
  - Decrease the response to the EM part of the shower: High–*Z* absorber (^{238}U)
- Apply weighting factors to the energy read–out (off–line compensation)
  - Sometimes the best option, because of problems with intrinsically compensating calorimeters.
    Example: D0 integration time

Off-line hadronic calibration: the challenges

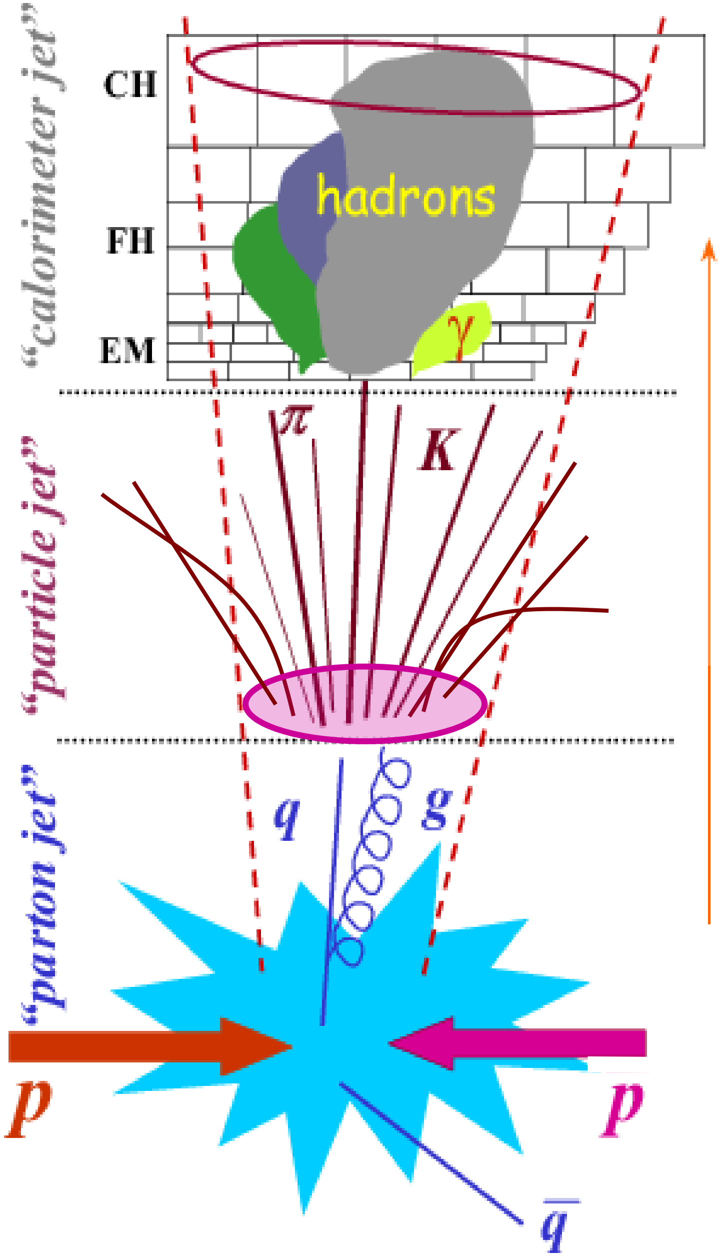
- Weight the hadronic energy, without disturbing the EM energy
- Visible fraction of the hadronic shower is energy dependent
- Energy fluctuations



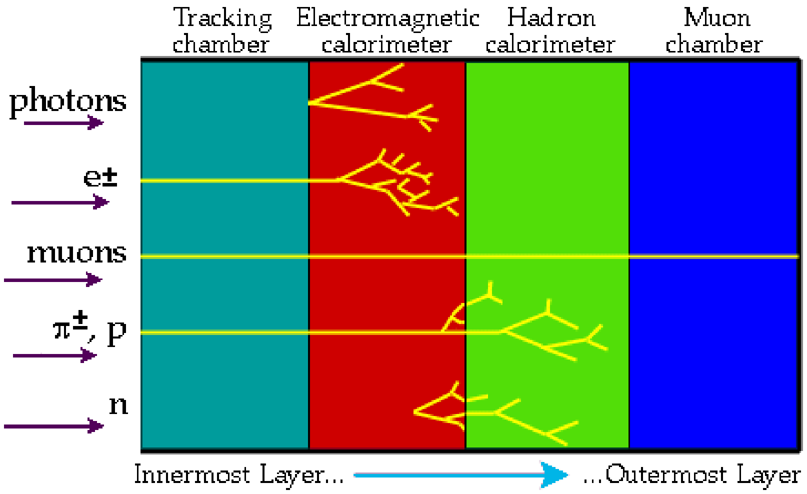
2 different events of 100 GeV pions in the ATLAS barrel calorimeter (simulation)

Off-line calibration: some strategies

- “Simple” calibration:
  one weight for each longitudinal segment
- Local calibration:
  first calibrate clusters (calo energy blobs) and then use the clusters to form physics objects (jets, electrons...)
- Global calibration:
  first form physcis objects (jets...), then calibrate by matching them to simulated objects of the same kind
- Layer correlation of energy deposits (not covered here, ask Karl-Johan)



“Simple calibration”



- Most calorimeters are divided into at least two parts: EM and HAD
- Electrons deposit most of their energy in the EM part.
- Apply corrections: $C_{\mathrm{EM}} \approx 1, C_{\mathrm{HAD}} > 1$ (these can be energy dependent)
- The EM energy scale is preserved, while the hadronic energy is weighted

Pro: Easy and simple (often used in test-beams)

Con: Correct energy on average only. No handling of event-by-event fluctuations

Local off-line hadronic compensation (1)

principal overview

- EM showers are denser than hadronic ones
  --> Use the energy density to separate the hadrons from electrons/photons
- Cluster the energy depositions, so that each cluster contains the energy of one particle
  --> An estimate of the particle energy
- Apply the corrections cellwise event–by–event
  --> Improves the resolution by handling the fluctuations

Local off-line hadronic compensation (2)

make the weights

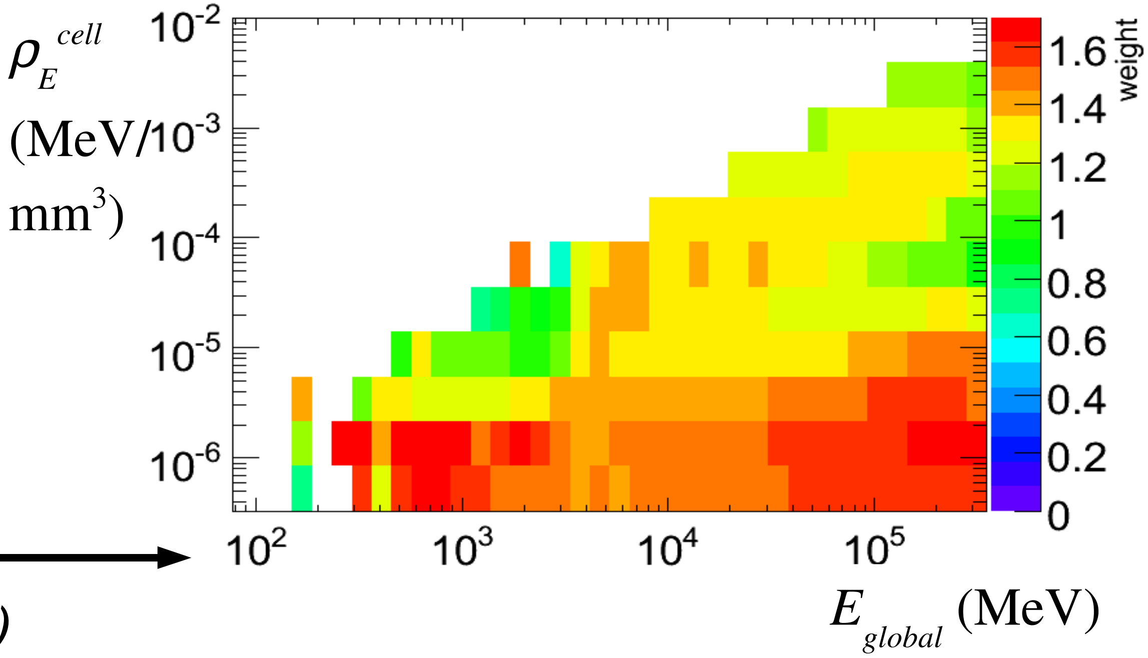
- Derive the weights from simulation of single pions:

$$w_i = E_i^{\text{true}} / E_i^{\text{reco}}$$

- Parametrise with cell energy density, cluster energy, sampling layer and η.

- Apply corrections for each calorimeter cell

$$E_i^{\text{weighted}} = w_i \cdot E_i^{\text{reco}}$$



(Weights for first HAD layer, ATLAS)

Local off-line hadronic compensation (3)

full chain step by step

Modular corrections:

- Start from EM level calibration
- Make **topological clusters** out of the calolorimeter cell energy signals (suppresses noise)
- **Classify clusters**: EM, hadronic or unknown (improves resolution, leaves electromagnetic objects undisturbed)
- Correct for the invisible hadronic energy loss on cell level in hadronic clusters using **weights** derived from simulated single pions
- Correct for **“unclustered” energy** in calorimeters
- Correct for losses in **“dead” material** (cryostat, cracks etc)
- (Apply jet corrections...)

Global calibration ("H1 style" in ATLAS)

- Start with an object (jet, ...) which is calibrated on the EM scale
- Find a matching "truth" object (from simulation)
- Extract calorimeter cell energy signals E_i
- Derive cell signal weights $w_i(\rho_i, s_i)$

  (where ρ_i is the cell energy density and s_i the sampling layer)

  such that $$E^{weighted}_{object} = \sum_{i \in object} w_i(\rho, s_i) \cdot E_i \equiv E^{truth}_{object}$$

- Apply the weights cellwise to the same type of object

The global scheme is **default** for ATLAS jets

Local or global method? (A comparison)

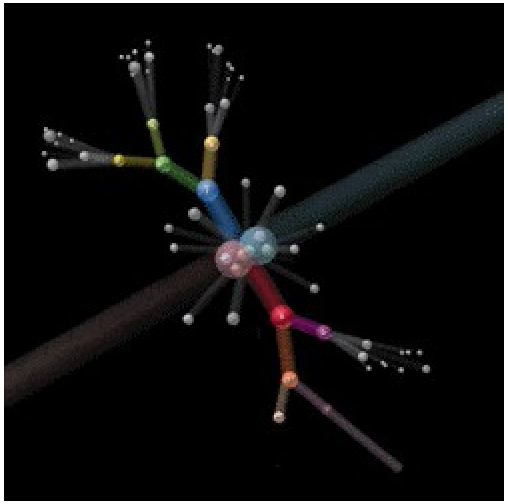
Local:

- Modular corrections: correct one effect at the time. Debugging much easier.
- Relies on pion MC simulations
- Additional jet corrections still needed for ATLAS

Global:

- Corrects for all effects in one step. Harder to spot problems if such occur.
- Relies on jet simulation
- Works nicely in ATLAS simulation

In-situ calibration (comparison with known physics processes) needed for the final calibration



Summary

- Off–line hadronic calibration is needed in non–compensating calorimeters (such as the calos of ATLAS and CMS)
- Hadronic calibration is complicated due to
  - invisible energy
  - event–by–event fluctuations
  - energy dependence in the visible energy content
- A clever calibration scheme leaves the electromagnetic objects undisturbed, and weight the hadronic objects on an event–by–event basis

References

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A. Bhatti: *Jet Energy Scale in CMS*, 8 June 2006

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http://indico.fnal.gov/conferenceDisplay.py?confId=1965

Back-up

The calorimeter system of ATLAS

LAr Barrel – LAr / Pb
  $|\eta| < 1.5$

EMEC – LAr / Pb

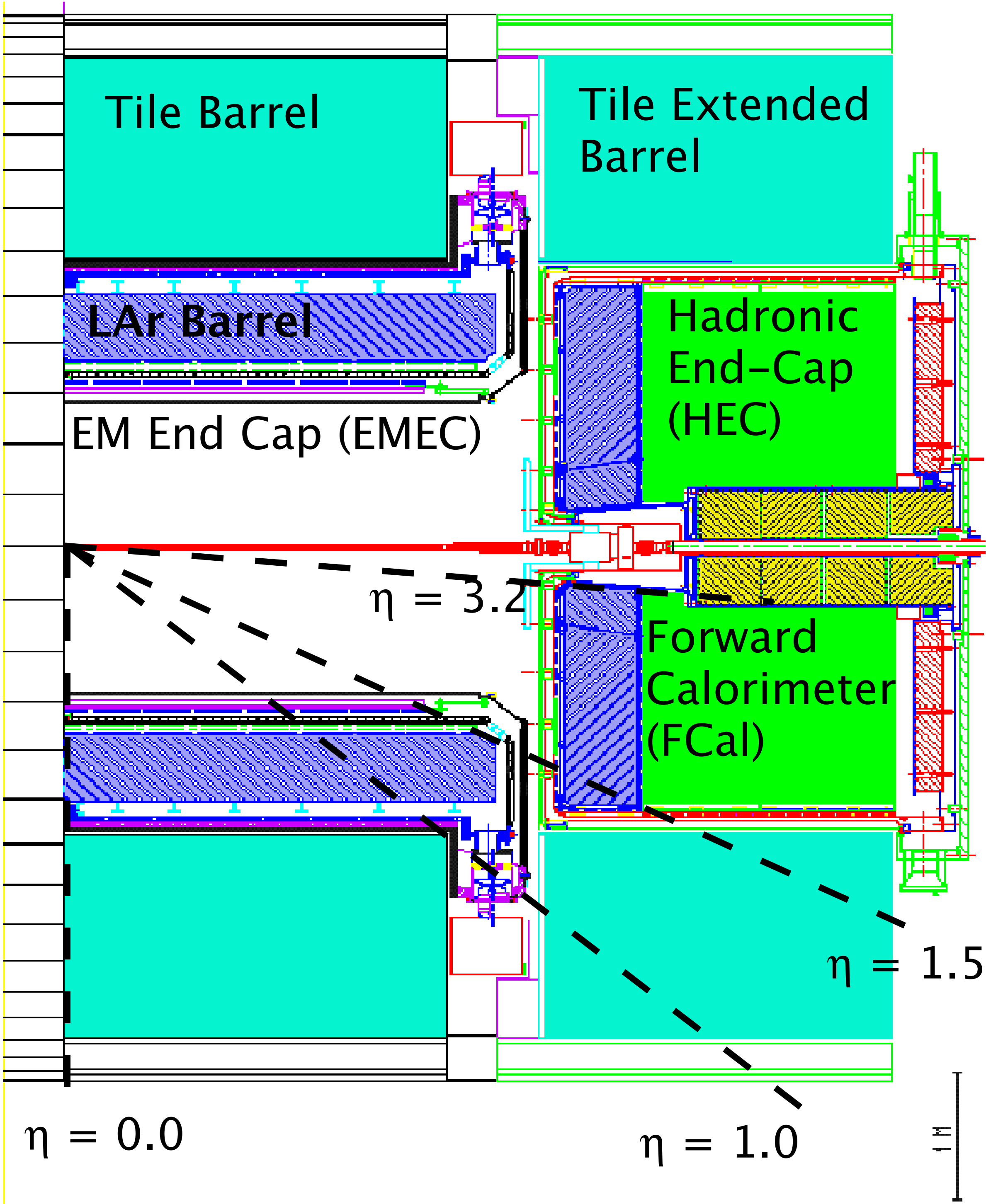
Tile – Scintillators / Fe

HEC – LAr / Cu

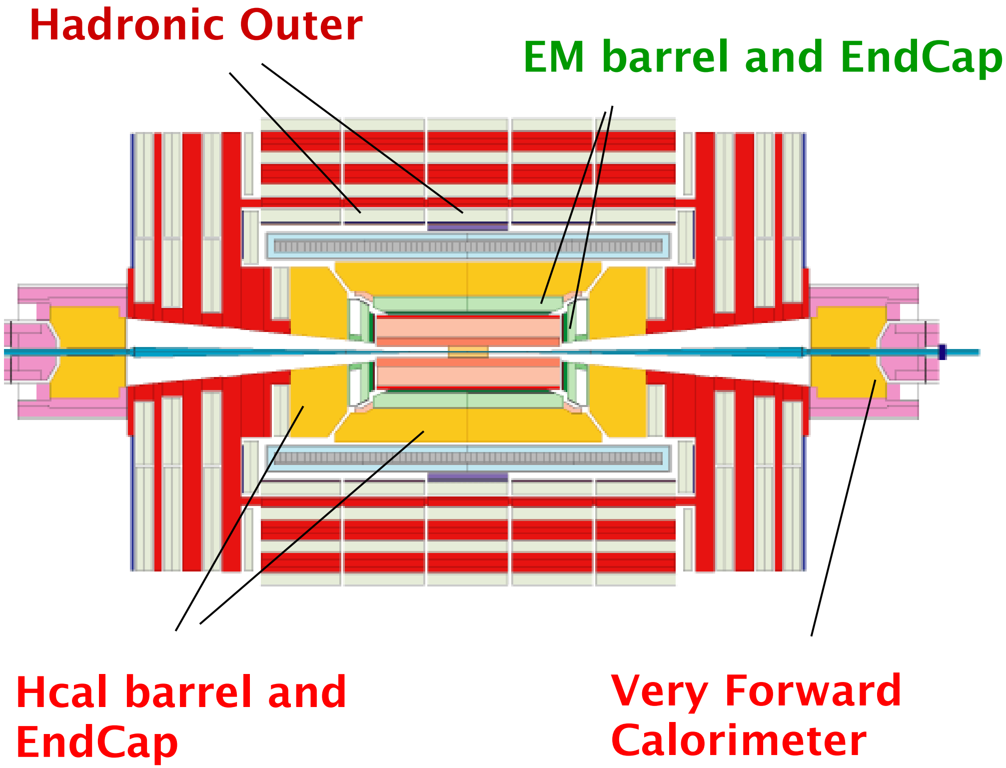
FCal – LAr / Cu or W

Directions:

- z–axis along beam pipe
- ϕ – azimuthal angle
- $\eta = -\ln(\tan(\theta/2))$ pseudorapidity



The calorimeter system of CMS



EM calorimeter $|\eta| < 3$:

$PbW0_4$ crystals. 1 longitudinal section/preshower 1.1 λ

Central Hadronic $|\eta| < 1.7$:

Brass/scintillator +WLS
5.9 + 3.9 λ ($|\eta| = 0$)

Endcap Hadronic $1.3 < |\eta| < 3$:

Brass/scintillator +WLS
2 or 3 longitudinal sections 10λ

Forward $2.9 < \eta < 5$:

Fe/quartz fibers

This slide from CALOR 2006

(A. Bhatti: *Jet Energy Scale in CMS*, 8 June 2006)