Overview of Hadronic Calibration Strategies

- Hadronic calibration models
  - local hadronic calibration
  - noise suppression
  - hadronic weights
- Jets and EtMiss

Jet/EtMiss/Tau Workshop
Victoria, December 1-2, 2005

Previous Calorimeter Calibration workshops:
CERN, July 14-15, 2005
Tatranská Štrba, December 1-4, 2004

Next workshops:
Munich, May 2-3, 2006
Barcelona, September 5-8, 2006

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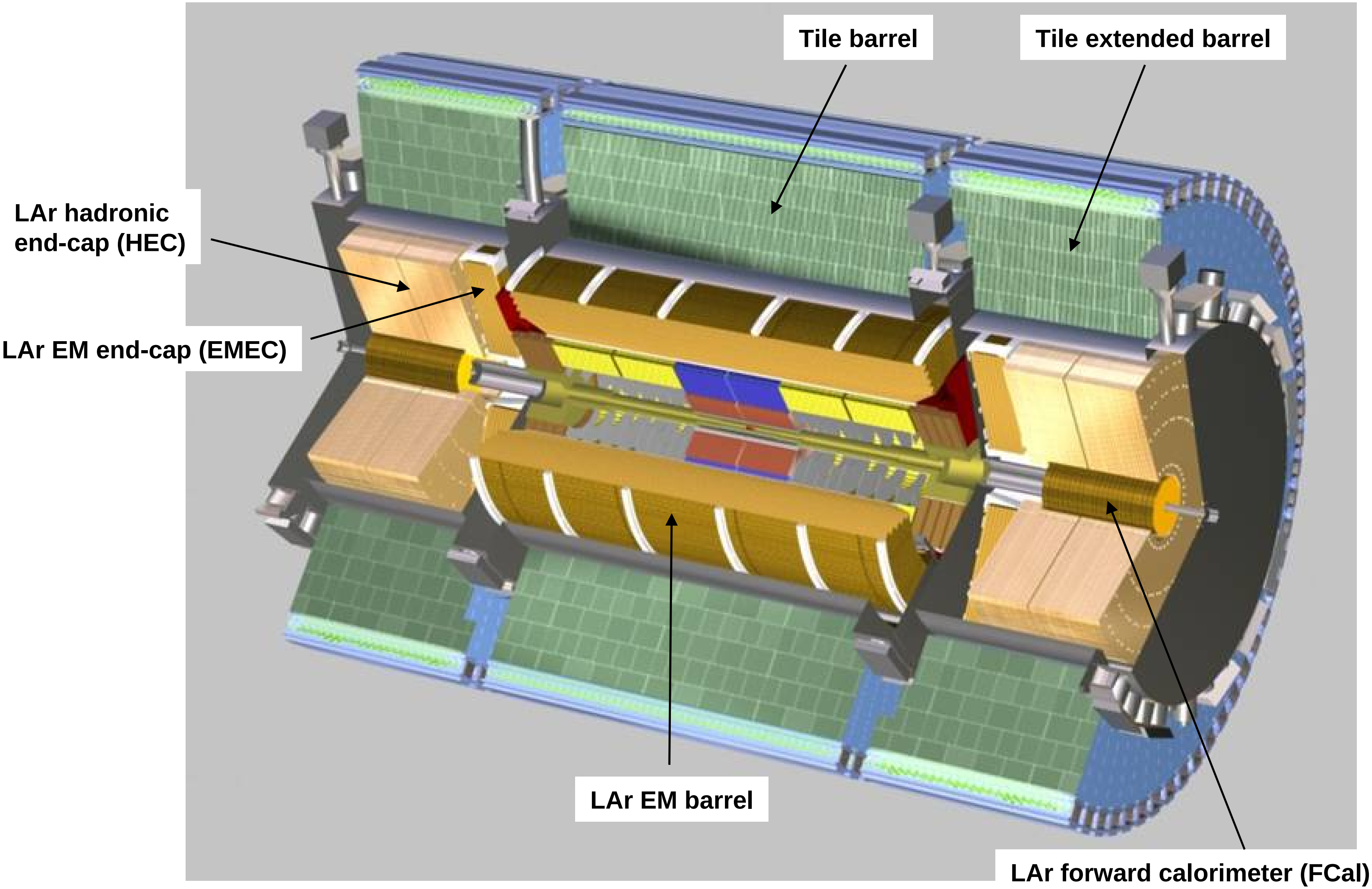
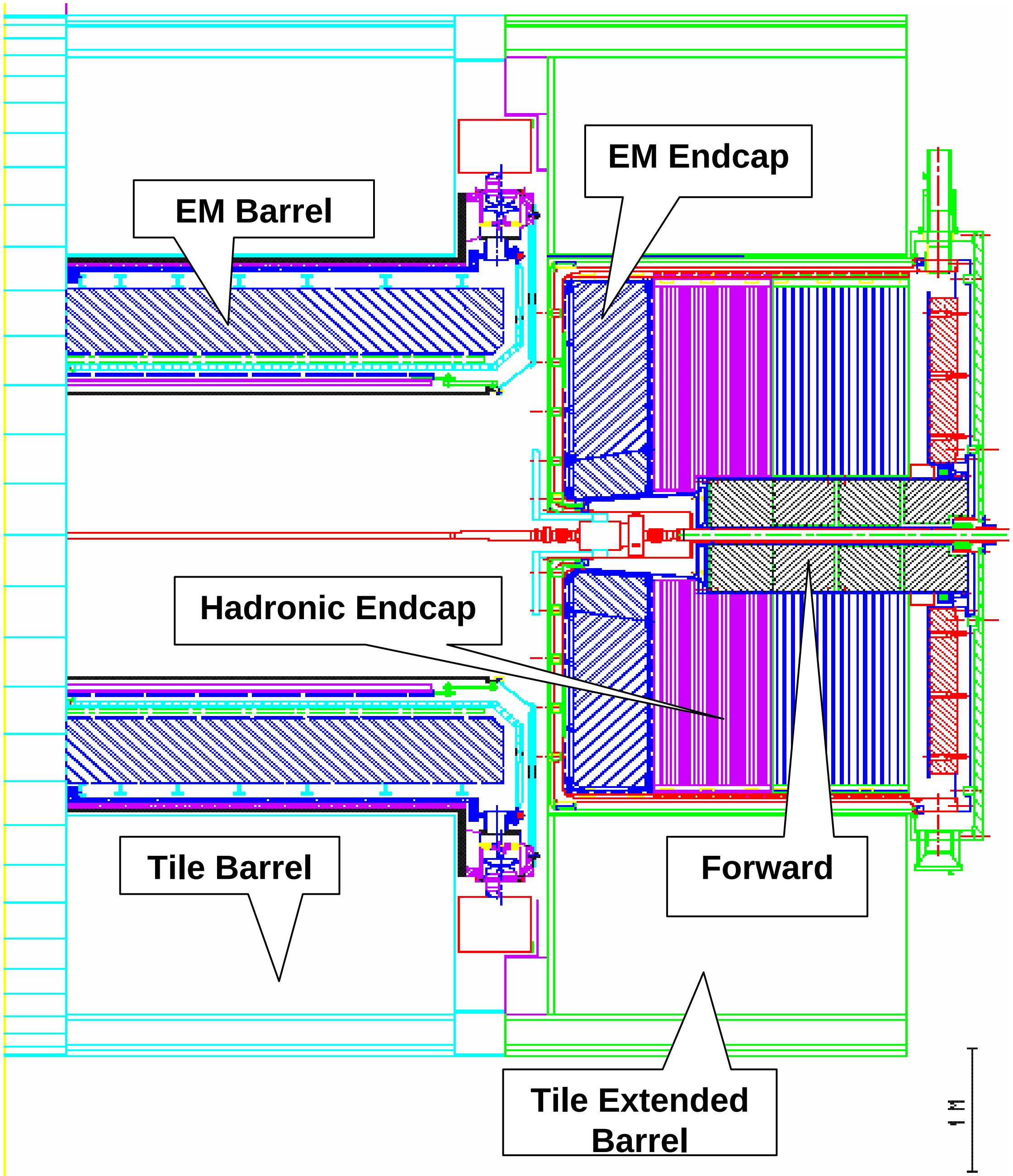
ATLAS LAr and Tile Calorimeters



LAr Calorimeters



- EM Barrel
  - |η| < 1.4
- EMEC
  - 1.375 < |η| < 3.2
- Tile
  - |η| < 1.7
- HEC
  - 1.5 < |η| < 3.2
- FCal
  - 3.2 < |η| < 4.9

Varied granularity, techniques; many overlap regions

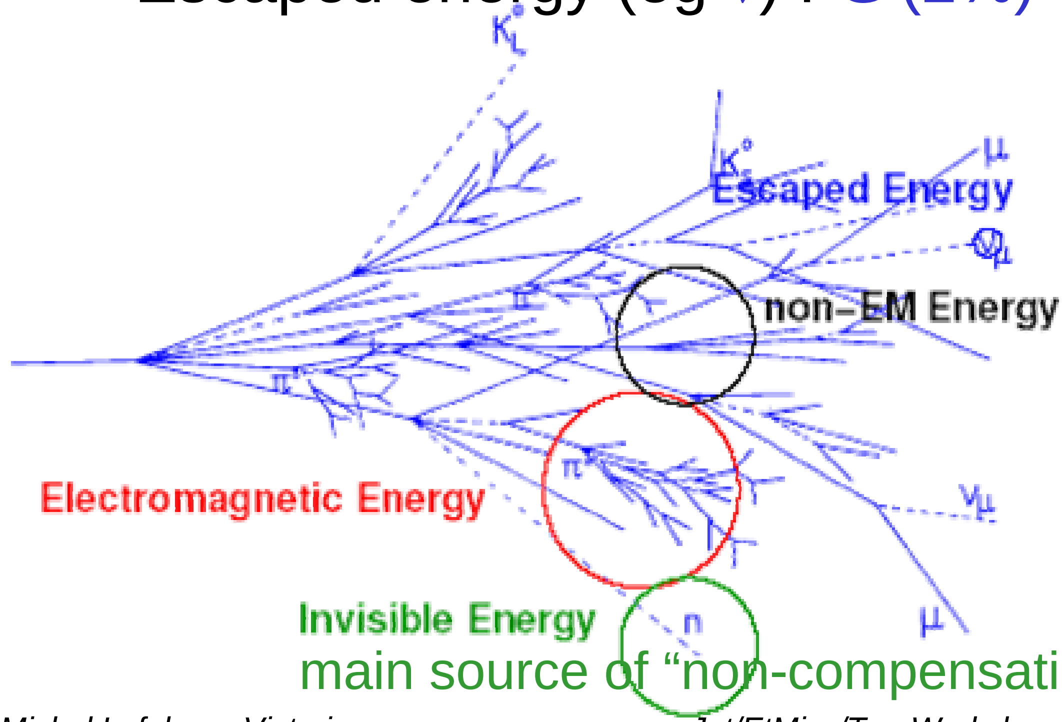
Design Physics Requirements

- EM Calorimeters
  - Benchmark channels H → $\gamma\gamma$ and H → ZZ → eeee require high resolution at ≈ 100 GeV and coverage to low E_T
  - b-physics: e reconstruction down to GeV range
  - Dynamic range: mip to Z' → 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 → WW → jet jet X and Z/W/t require good jet-jet mass resolution
  - Higgs fusion → good forward jet tagging
  - EtMiss → 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

- EM energy (eg $\pi^0 \to \gamma\gamma$) : *O*(50%)
- Visible non-EM energy (eg dE/dX from $\mu^\pm$, $\pi^\pm$,) : *O*(25%)
- Invisible non-EM energy (eg nuclear breakup and excitation) : *O*(25%)
- Escaped energy (eg ν) : *O*(2%)

energy dependent... and large fluctuations



main source of "non-compensation"

Goals:

- Event-by-event offline compensation of hadronic energy deposition
- Improve linearity and resolution

Calibration Strategy

- Local : calibration scheme to recover invisible (and escaped) energy (compensation) based on nature of localized energy deposits in calorimeters and aimed at
  - Being generally applicable
  - Minimizing
    - bias towards physics channels
    - systematic uncertainties ← Factorize dead material, leakage, etc…
  - Inter-calibrating sub-calorimeters
- Global: physics objects based calibration. Use full detector to correct analysis dependent effects (fragmentation, jet algorithms, b-jets, min bias events…)

Linearity in energy response

$(E_{rec}/E_{True}=1)$

\+

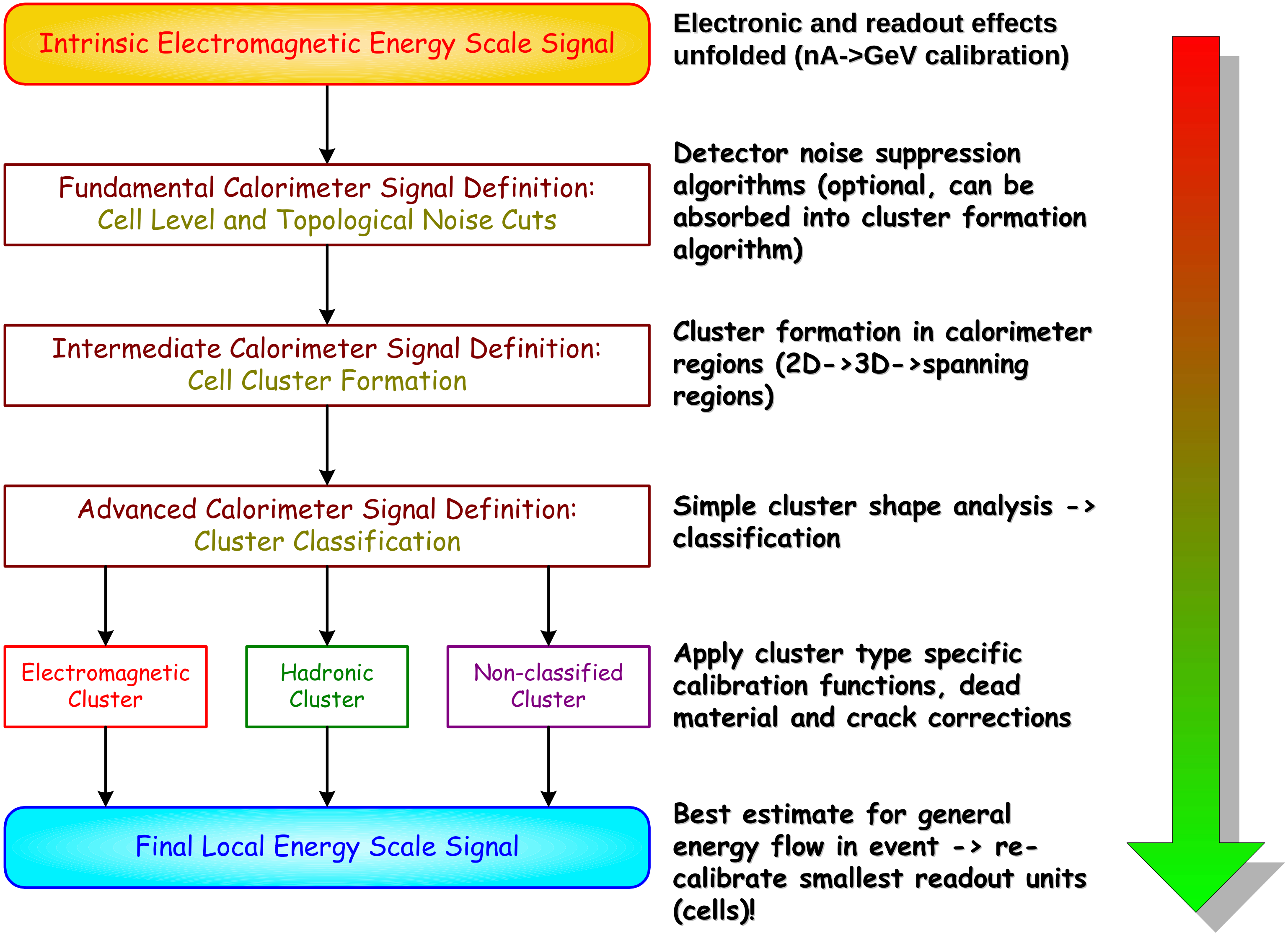
Optimal Resolution

Hadronic Calibration Models

- Model I : Physics object based (Global):
  - first reconstruct hadronic final state physics objects (jets, missing Et) using calorimeter signals on a fixed (electromagnetic) energy scale (accepting the fact that these are ~30% too low, typically);
  - then calibrate the jets in situ using physics events
  - a priori using “MC Truth” in simulations for normalization
    - Model I is currently the most common approach in ATLAS physics studies. It is somewhat fragile, sensitive to fragmentation modeling, jet finding, etc.
- Model II : Detector-based objects (Local)
  - reconstruct calorimeter final state objects (clusters) first and calibrate those using a “local” normalization (reference local deposited energy in calorimeter)
  - reconstruct physics objects in this space of calibrated calorimeter signals
  - apply higher level corrections for algorithm inefficiencies determined in situ or a priori, as above
    - Model II has been the focus of our testbeam analysis, and it’s applicability to ATLAS is under investigation

Local Calorimeter Calibration Algorithm 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

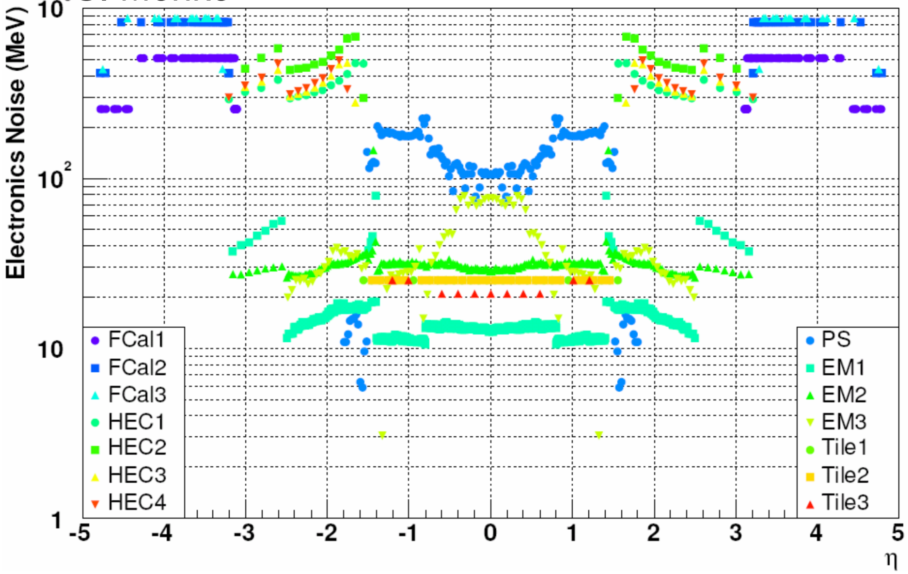
Apply cluster type specific calibration functions, dead material and crack corrections

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

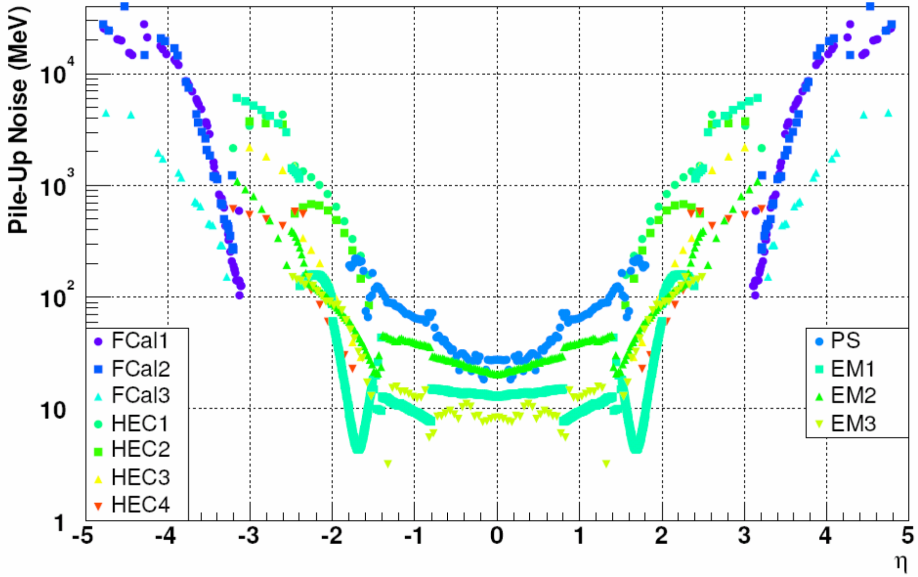
Noise Suppression

- see Rome Workshop talk by Sven Menke
- Sources of uncertainty in calorimeter cell signal:
  - intrinsic detector resolution
  - electronic noise (10 to 900 MeV)
  - pileup noise (4 MeV to 40 GeV @ 10^{34} $cm^{-2}s^{-1}$)

S. Menke



S. Menke



Noise Suppression Methods

- $|E_{cell}| > 2\ \sigma_{noise}$ (EtMiss group)
  - well understood bias (K. Cranmer)
- JetTowerNoiseTool (F. Paige)
  - use in jet reconstruction
  - clever way of grouping towers before making jets such that negative energy towers are "cancelled" by nearby positive towers
- CaloTopoClusterMaker (S. Menke)
  - group cells which are topological neighbours
  - tries to account for the fact that true energy deposits are correlated
- LocalNoiseSuppressionTool (K. Cranmer)
  - Use Bayes theorem to decide whether or not a cell contains signal
- Studies have been performed (including B. Mellado et al, D. Cavalli & S. Resconi, A. Gupta)
  - EtMiss: events with only electronic noise, $Z \rightarrow \nu\nu$, $Z \rightarrow \tau\tau$
  - Jets

CalibrationHits

- hadronic weights to be produced using MC truth
- CalibrationHits
  - energy depositions in the detector (active and inactive parts) and in “dead” material (cryostat, etc.)
  - each energy deposition is classified:
    - Visible EM
    - Visible Non-EM
    - Invisible hadronic
    - Escaped

E_{reco} is based on the visible energy in the active material only, corrected for the dE/dx sampling ratio

total

  - clearly need MC validation strategy

Hadronic Weights

- Set initial hadronic energy scale
- Cell weights in general depend on cluster observables
  - energy and energy density
  - cluster moments
- Initial attempts (2002 EMEC-HEC) only used energy density
  - weights obtained from data
  - see Tucson workshop
- Current efforts based on CalibrationHits
  - requires best possible detector description
  - requires best possible modeling of physics processes

$$E_{\text{cell}}^{\text{reco}} = wE_{\text{cell}}$$

$$w = \frac{E_{\text{cell}}^{\text{em}} + E_{\text{cell}}^{\text{non-em vis}} + E_{\text{cell}}^{\text{non-em invis}} + E_{\text{cell}}^{\text{escaped}}}{E_{\text{cell}}^{\text{em}} + E_{\text{cell}}^{\text{non-em vis}}}$$

Hadronic Weights: ongoing work

- Beam test data (2002 – 2004)
  - MC validation
  - CalibrationHits validation and production
  - use OFC’s to produce cell noise, and fill database
  - cluster classification
  - use calibration hits an further explore weighting schemes
    - cluster moments
    - multi-dimensional weights
    - dead material correction (for dead material inside clusters!)
    - using weights must not rely on knowledge of beam energy

Hadronic Weights: ongoing work

- Full ATLAS simulation

see Kai's talk

  - expand weighting schemes to all calorimeter areas
  - understand the effect of pileup on the calibration scheme
    - how does the local calibration strategy perform in the presence of pileup?
  - develop robust methods for the production of hadronic cell weights
    - can be quickly performed
    - resides in the repository, not in a private directory!
  - develop methods for quick jet energy scale validation
    - use of transverse W mass spectrum in ttbar or similar
  - dead material corrections: local hadronic calibration vs jet and EtMiss calibration

Software Framework Status

All in place in Athena to use beam test data and simulation

- Reconstruction
  - Signal reconstruction with OFC's
  - Cluster split/merge tools
  - Cluster moments
  - Noise tools
- GEANT4 simulation
  - Beam test setups and geometries
  - CalibrationHits

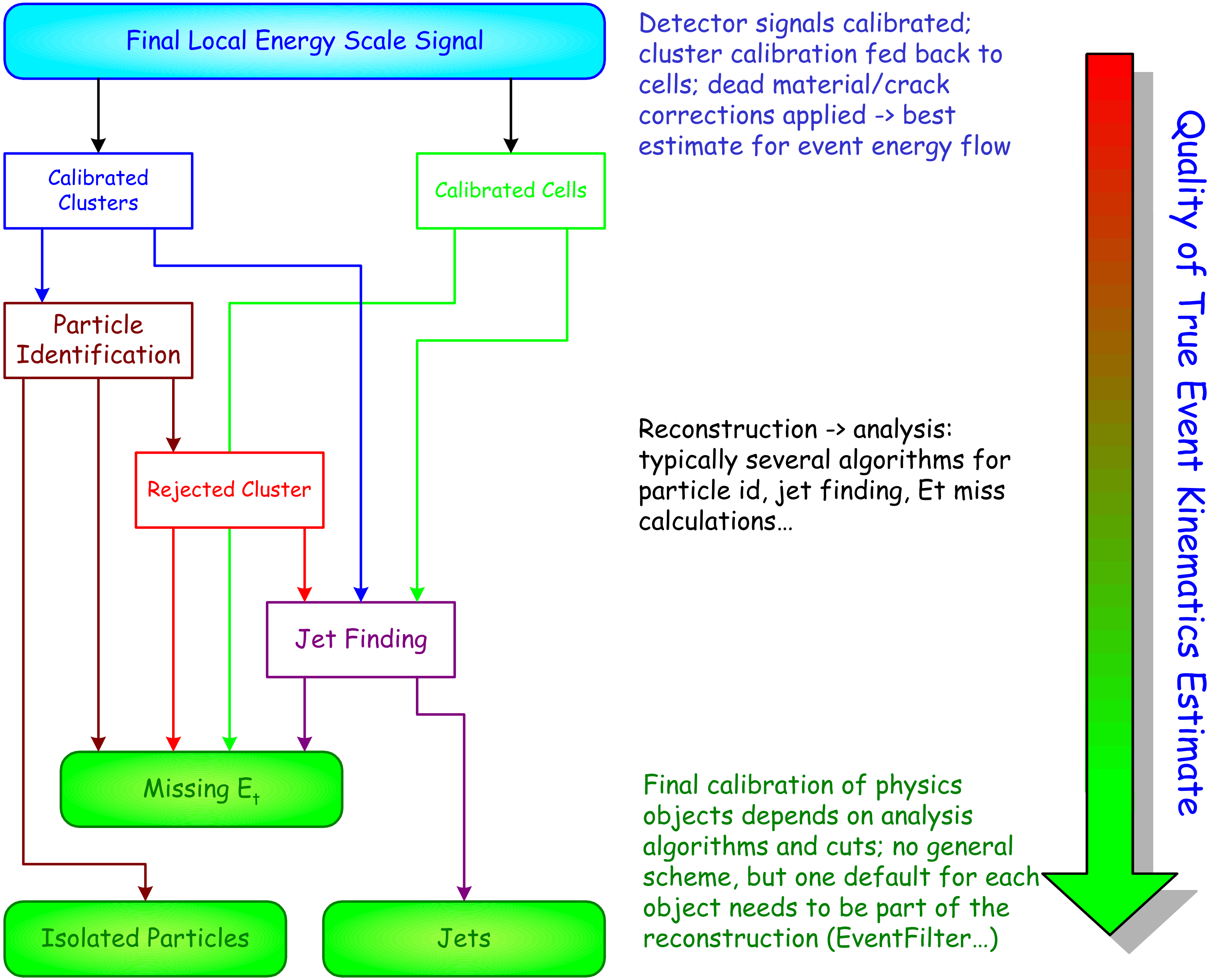
Local Hadronic Calibration: outlook

Personal views...

- the local calibration scheme (cells in TopoClusters) is very promising
- how independent from pileup can the validity of the local calibration be?
- It may well turn out that it local calibration makes a difference mainly in a limited part of the calorimeter where the readout cells are small
- It should be kept as simple as possible; it may not be practical to have cell weights depending on more than two (cell or cluster) parameters
- tables may turn out to be more adequate than parameterizations

From local energy scale signal to physics objects

P. Loch



Detector signals calibrated; cluster calibration fed back to cells; dead material/crack corrections applied -> best estimate for event energy flow

Reconstruction -> analysis: typically several algorithms for particle id, jet finding, Et miss calculations…

Final calibration of physics objects depends on analysis algorithms and cuts; no general scheme, but one default for each object needs to be part of the reconstruction (EventFilter…)

Jet Reconstruction

- Currently, Jets can be reconstructed from collections of
  - MC particles
  - Calorimeter Towers see Peter's talk
  - Calorimeter TopoClusters
  - Tracks
- Same algorithms applied to any collection
- Currently, four jet reconstruction algorithms are implemented in Athena: **see Rolf's talk**
  - Cone → Simple (geometrically motivated) and fast.
  - KT → Theoretically accurate. Somewhat slower. Harder to calibrate.
  - Seed-less cone → Theoretically accurate
    - Not much used due to speed issues in present implementations.
  - Midpoint

Jet Calibration: status

- Calibration methods (not using local hadronic calibration) have been developed independently (A.Gupta, F.Paige & S. Padhi, I.Vivarelli & C.Roda).

see Sanjay's talk

  - implemented in Athena
  - jets are calibrated to a MC truth based on MC particles
  - use E(jet), not Et(jet)
  - weights obtained by minimizing energy resolution with linearity constraint
  - the quality of the calibration is assessed by looking at the linearity and energy resolution before and after calibration in the different η regions
  - they differ with regards to noise suppression technique, the quantities used to obtain E_{reco}, the weight functions
- Approaches based on TopoCluster classification and local hadronic weights are being investigated
  - see Kai's talk

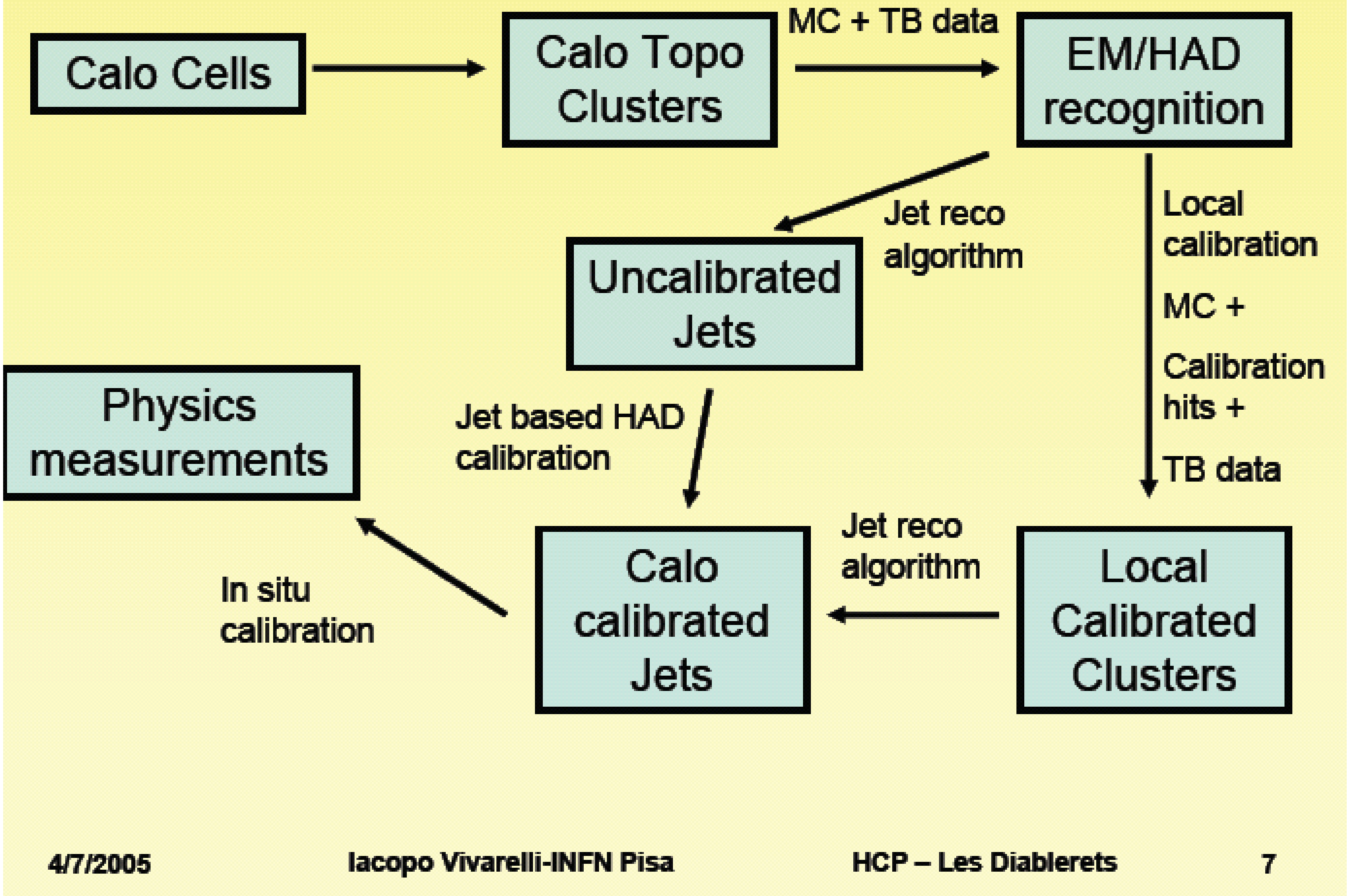
In-situ Jet Energy Scale Calibration

- Calibration of jet energy scale
  - in general this is process dependent
  - need to define clearly what “calibrating” means
    - to parton jet!
    - should correct for out of cone, underlying event
  - try to separate
    - detector effects: response, showering, coverage
    - physics effects: fragmentation, gluon radiations
  - should be after and on top of local hadronic calibration
    - one could argue that the local hadronic calibration coupled to the jet reconstruction should give a decent “light jet” energy scale, so that “light jet” energy scale corrections should be small
  - need to define clearly where/when are the pileup and noise bias effects taken into account

In-situ Jet Calibration

- p_T balance in γ/Z + jet events
  - see Rome Workshop talk by Caroline Deluca
  - potentially large statistics
- M_W constraint in top events
  - see Rome Workshop talk by Dominique Pallin
  - good for top mass reconstruction?...for other processes?
- E/p constraint from $\tau^{\pm} \rightarrow \pi^{\pm} \nu$ in $Z \rightarrow \tau\ \tau$
  - see Jiansen’s talk
- Control samples?

Toward integration with HadronCalibration



Calo Cells

Calo Topo Clusters

MC + TB data

EM/HAD recognition

Jet reco algorithm

Uncalibrated Jets

Local calibration

MC +

Calibration hits +

TB data

Jet based HAD calibration

Physics measurements

In situ calibration

Calo calibrated Jets

Jet reco algorithm

Local Calibrated Clusters

4/7/2005 Iacopo Vivarelli-INFN Pisa HCP – Les Diablerets 7

Jets: Tasks

- Jet reconstruction algorithms
  - compare in detail the performance of the various algos (at EM energy scale); may need new algos
  - try using locally calibrated TopoClusters
  - develop methods for jet algorithm validation
    - are obvious jets being missed?
- Jet calibration studies (to MC jet)
  - should be easy to switch from one method to another
  - need to investigate effect of pileup and underlying event

    see Doug's talk
  - systematic study of effects of electronics noise
- Jet energy scale calibration (to parton)
  - follow up with in-situ calibration
- Establish control samples
- At which level should electrons and muons in jets be treated?
  - at the event view!? See Rob Duxfield's talk JetRec phone meeting 30 Nov 2005

EtMiss Reconstruction

- see Rome workshop talk by S. Resconi
- A lot of work has been done at the cell level
- New results show that using TopoClusters (instead of cells) improves EtMiss performance, both shift and resolution (good noise suppression)
- Need to try again with (locally) calibrated TopoClusters
- Further work required to understand the effect (and treatment) of dead regions on EtMiss
- Preliminary results from Rome samples show that $Z^\circ \rightarrow \tau\tau \rightarrow \ell$ j EtMiss can be used for in-situ EtMiss calibration/validation
- Object-based reconstruction (see Bruce’s talk)

EtMiss: more work...

- EtMiss monitoring
  - with minimum bias events
  - time variations, luminosity changes
- Further develop EtMiss calibration/validation methods
- Need to try again with (locally) calibrated TopoClusters
- Further work required to understand the effect (and treatment) of dead regions on EtMiss

A few more comments...

- In our resources deployment we need to find a balance between two requirements:
  - the need for adequate calorimeter calibration on day-1
  - the need for the calibration framework to eventually reach the best possible performance
    - adaptable, robust
    - can be maintained and monitored
- Large (but very interesting!) task
  - cannot be done by one person
  - perhaps our biggest challenge is one of coordination
    - lots of expertise, lots of work already done
    - working groups: need well defined tasks, goals and milestones