ATLAS Calorimeter Calibration: strategies and progress

ATLAS Canada Review

10 December 2004

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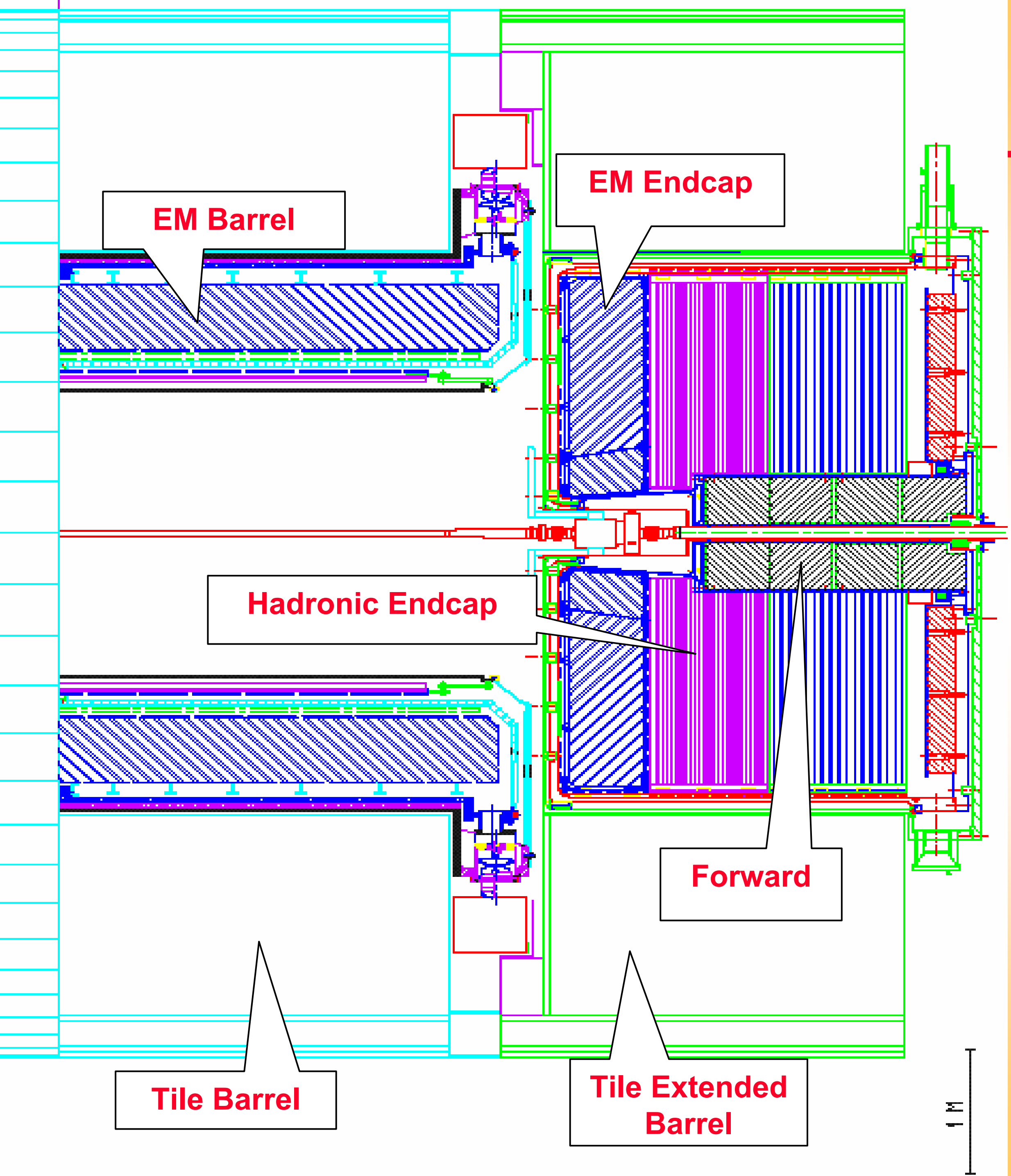
Driving physics requirements

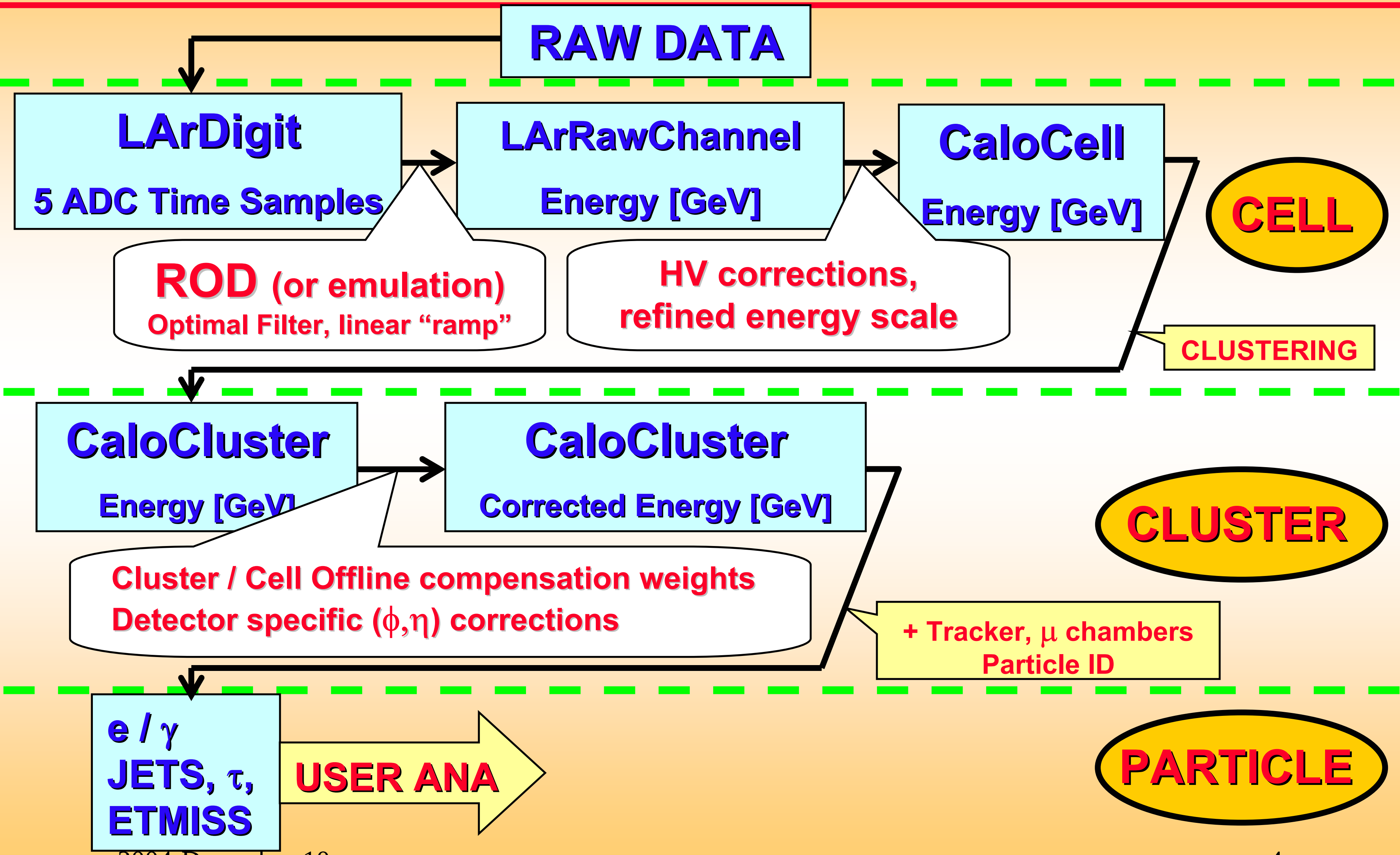
- **EM Calorimeters**
  - Benchmark channels H $\rightarrow \gamma\gamma$, H $\rightarrow$ eeee need high resolution O(100 GeV) range, coverage to low E_T
  - Z'$\rightarrow$ ee to few TeV range
  - b-physics: e down to GeV range
    - Design goals for $|\eta| < 2.5$: $\sigma(E)/E = 8\text{-}11\ \%/\sqrt{E} \oplus 200\text{-}400\ \text{MeV}/E \oplus 0.7\ \%$
      - Electronics + Pileup noise $\approx$ 200-400 MeV/E
      - Constant term < 1%
      - Linearity better than 0.1%
- **Hadron and forward Calorimeters**
  - Benchmark channels: Higgs with W $\rightarrow$ jet jet, Z/W/top need good jet-jet mass resolution
  - Higgs fusion, forward physics: good forward jet tagging
  - E_{TMISS} : jet resolution, linearity
    - Design goals:
      - $50\%\ \sqrt{E} \oplus 3\%$ for $|\eta| < 3$
      - $50\%\ \sqrt{E} \oplus 10\%$ for $3 < |\eta| < 5$



LAr Calorimeters

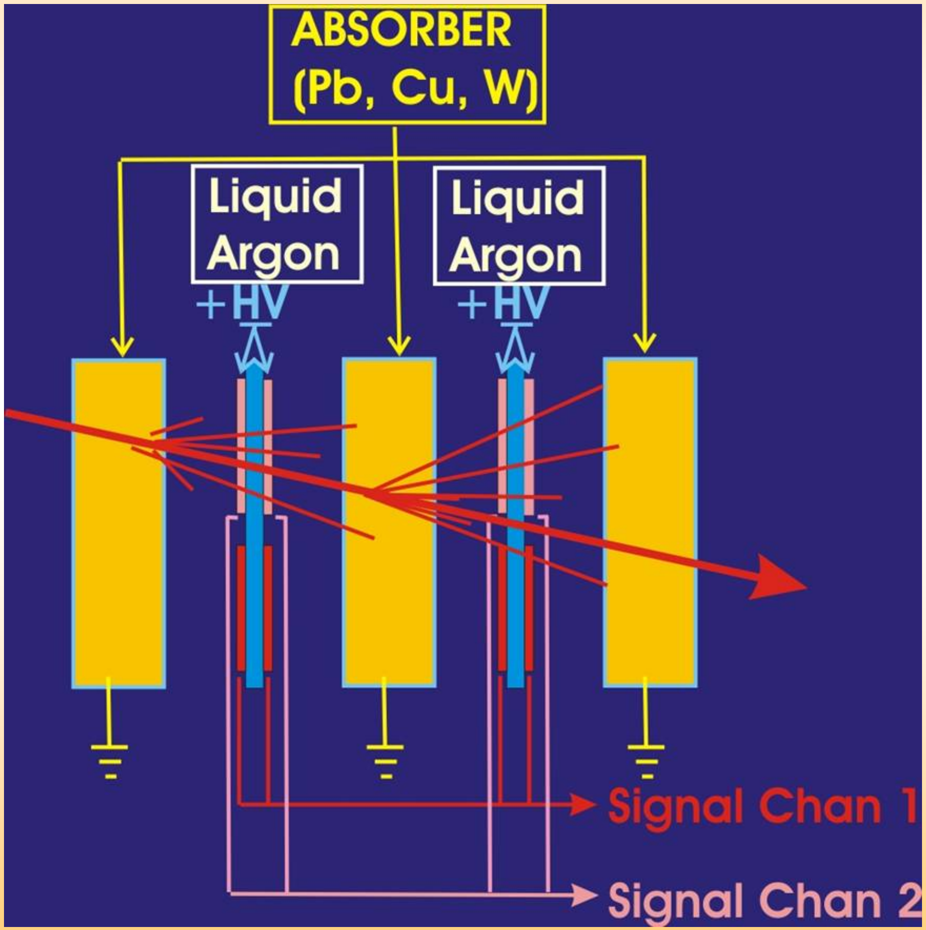
- **EMB:**
  - |η| < 1.5
- **EMEC**
  - 1.4 < |η| < 3.2
- **HEC**
  - 1.5 < |η| < 3.2
- **FCAL**
  - 3.1 < |η| < 4.9

Data and corrections flow

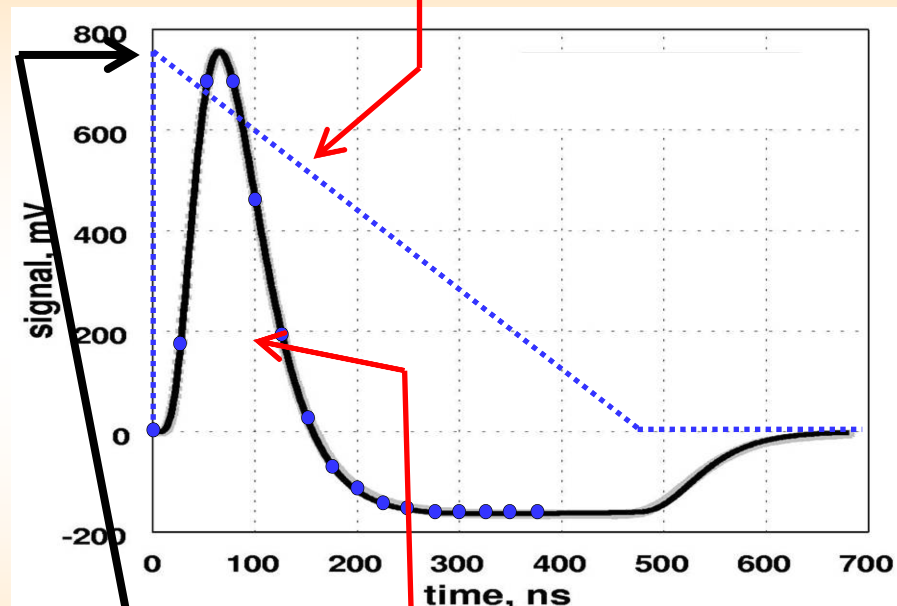


Electronics chain: “physics”

“Toy LAr Calo”



Ionization Signal



After Shaping

Measure:

$I_0 \propto E_{vis} \propto E_{tot}$

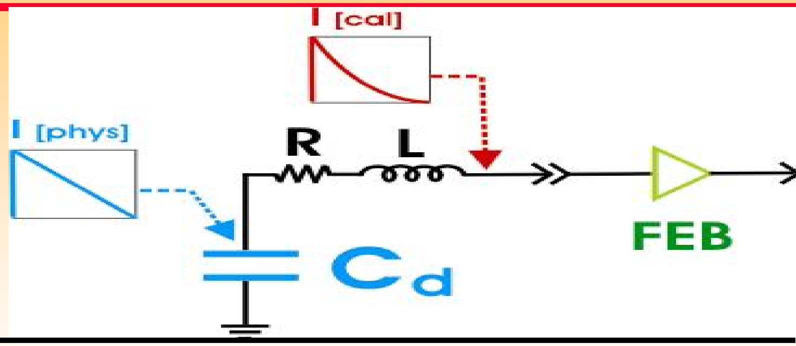
Cell reconstruction steps

- "Physics" pulse height reconstruction
  - Get the height ADC in ADC counts, "ADC[Phys]"
    - LAr: use optimal filter "OFC" in ROD or offline
- Now need to convert to current [μA] ...
  - Can use channel-to-channel calibration pulser system
    - Correct for calibration ↔ physics pulse height differences for same injection current
  - Intended LAr electronics calibration chain:
    - ADC[Phys] → ADC[Cal] → Current in μA (calib board)

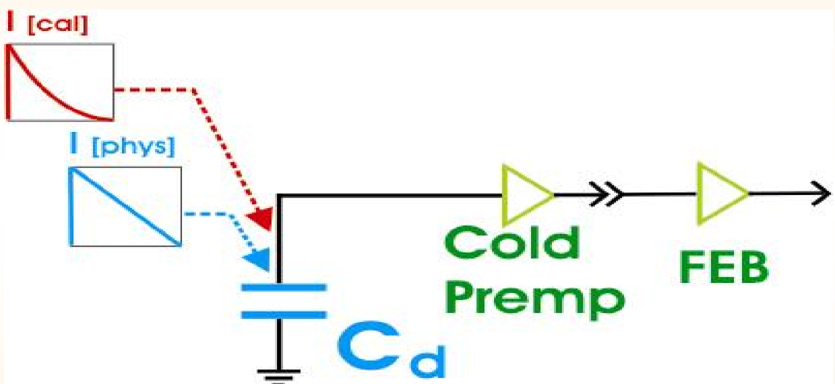
  - Still need: μA → MeV (from testbeam, MC, ...)
  - Alternative, if channel response uniform enough, can convert directly ADC[Phys] → MeV (from testbeam)
- Current developments using 2004 testbeam data
  - Including: McPherson, Wielers, Vincter + MPI and Arizona colleagues

All LAr detectors have calibration pulser system

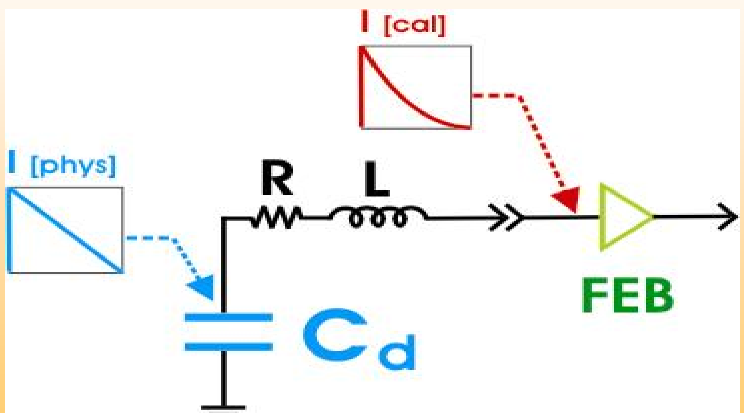
- **EM**
  - Inject on summing boards

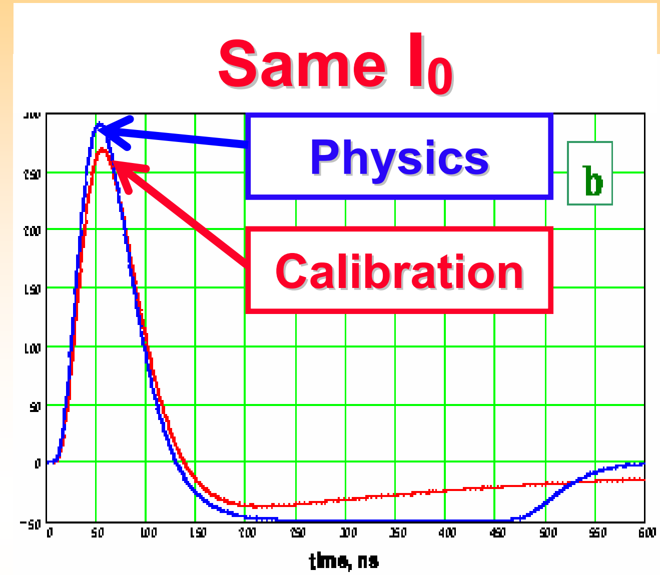


- **HEC**
  - Inject at calo pads



- **FCAL**
  - Inject on FEB backplane



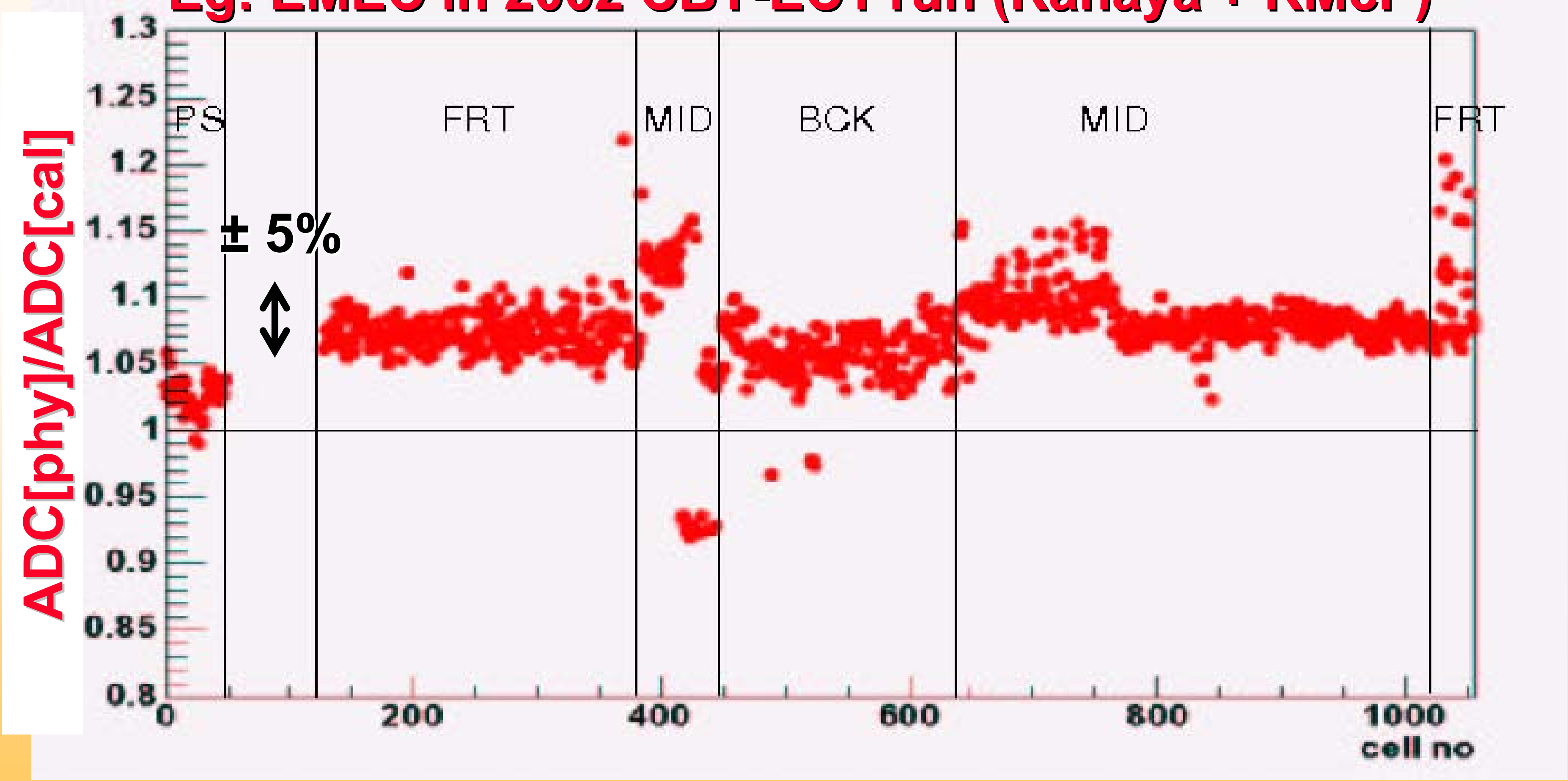


- **To use calibration system:**
  - Understanding ADC[phys]/ADC[cal] for fixed I_0 is key

Zero'th calibration (ancient history)

- **Inject calibration pulse with known current into channel to measure ADC → μA**
  - ⇒ Doesn't work well enough because of cell-to-cell differences in ADC[Phys]/ADC[Cal] for fixed current.

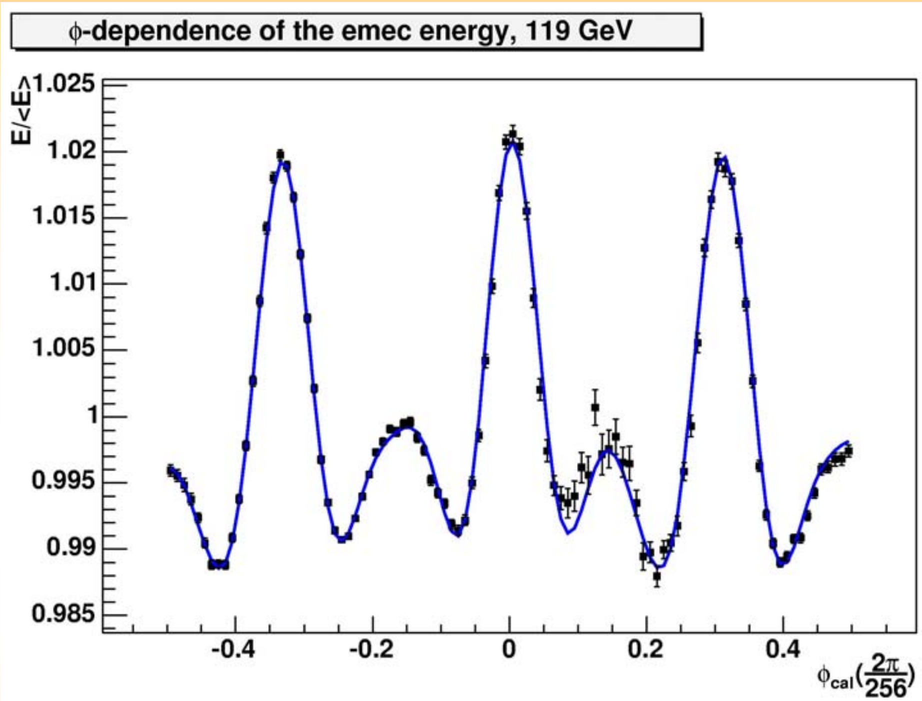
Eg: EMEC in 2002 CBT-EC1 run (Kanaya + RMcP)

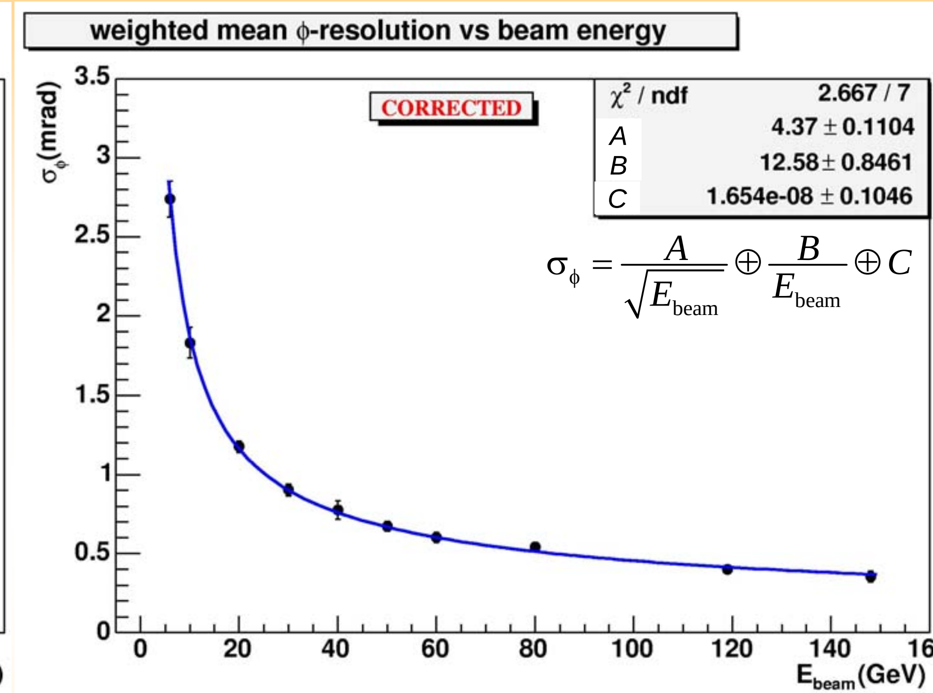


EM: Current channel reconstruction

- Use simple electronics model (LC, maybe RC, + tdrift ...)
- Extract parameters of model
  - Calibration pulse only: Milano, MPI
    - Then must "line up" with physics pulse in time
  - Fit calibration ↔ physics pulse shape : LAPP, Victoria
    - Time domain or FFT methods
- Use predicted physics pulse + autocorr ⇒ OFC
  - Normalize: OFC on physics pulse computes height of corresponding calibration pulse with same I0 ⇒ ADC[cal]
- Then use calibration (ramp) runs ADC[cal] ⇒ DAC ⇒ R ⇒ μA
- Then μA ⇒ MeV from MC (or testbeam)
- Accuracy / channel uniformity: O(0.5%)

Calorimeter Reco/Calibration





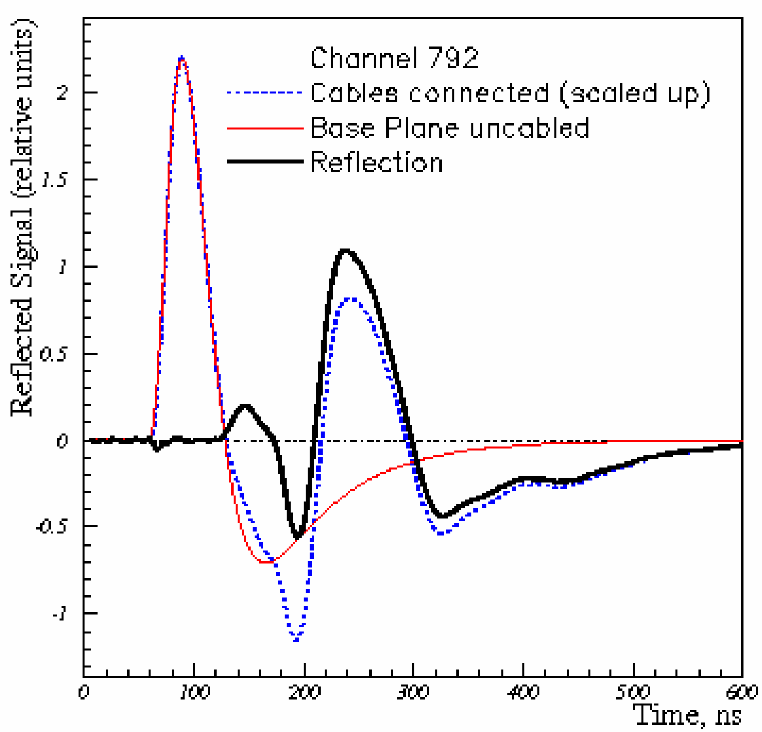
- **Example of electron response phi-modulation correction, and resulting phi-resolution**
  - Results shown here from T. Ince, R. Keeler

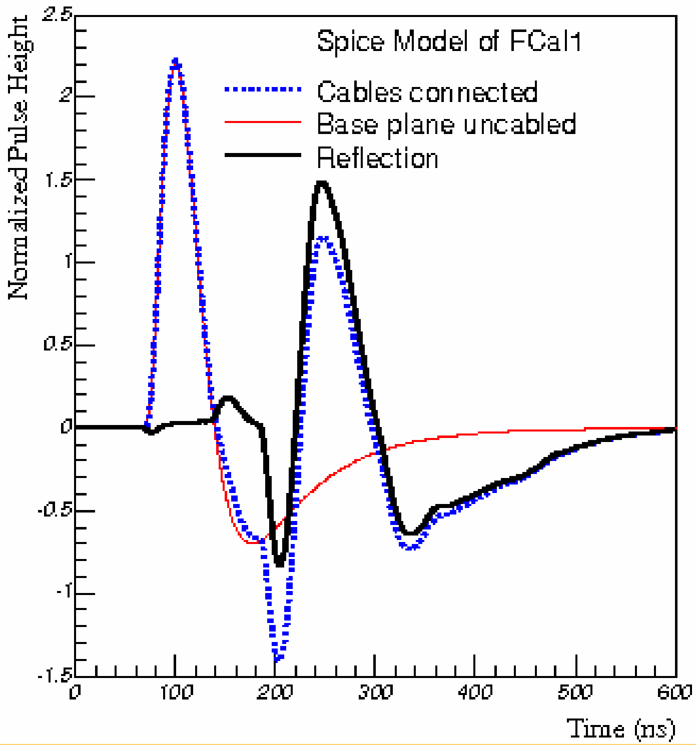
HEC: Current channel reconstruction

- Have several techniques, all of which use some "lab measurements" of some circuit parameters, and all use only calibration pulse
  - Full model fit (18 poles / 9 zeros) time consuming
  - Simplified model fit (9 poles / 3 zeros) used for most testbeams
  - NR method fits only for calibration chain parameters
- Use predicted physics pulse shape + autcorr ⇒ OFC
  - Normalize: OFC on physics pulse computes height of actual pulse
- Then use calibration (ramp) runs which are corrected for ADC[phys]/ADC[cal] to give
  - ADC[phys] ⇒ μA
- Then μA ⇒ MeV from MC (or testbeam)
- Accuracy / channel uniformity: O(1%)

FCAL: Current channel reconstruction
(Arizona, Carleton, Toronto)

- Use direct physics pulse shape accumulation from beam data
- measured physics pulse shape + OFC ⇒ OFC
  - Normalize: OFC on physics pulse computes height of actual pulse
- Then ADC[phys] ⇒ MeV from MC (or testbeam)
  - i.e. do not use the calibration system directly (yet)
- Accuracy : O(few %)
- Calibration system used for FEB stability monitoring
  - Investigations in progress about use of reflection pulse



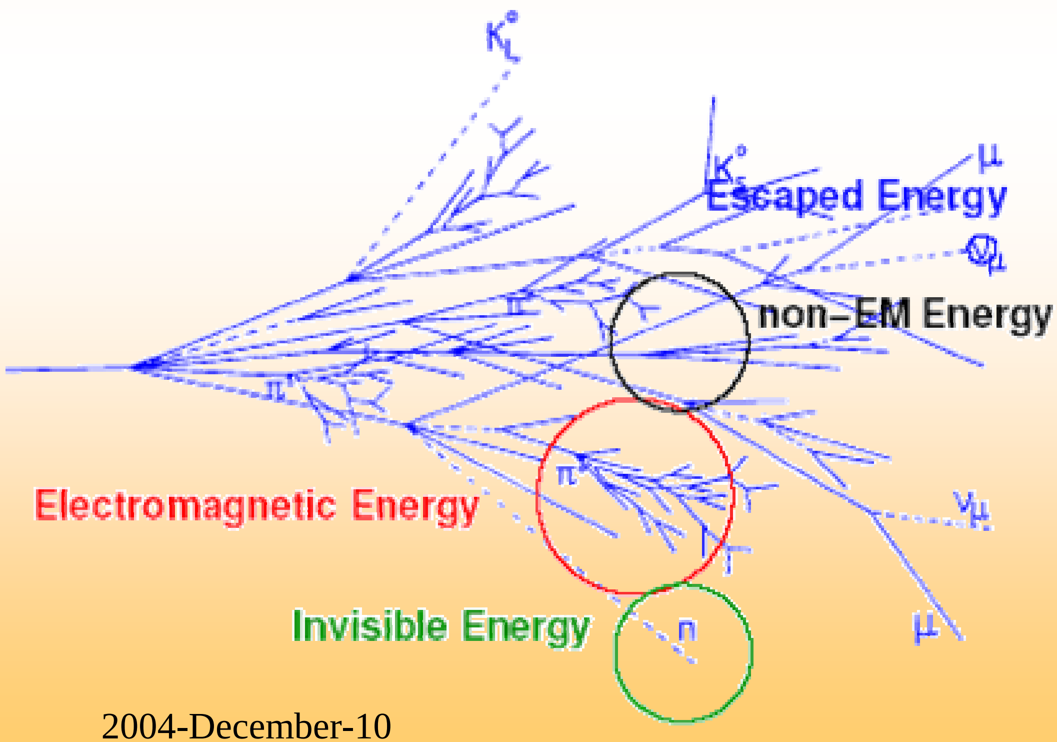


Calorimeter Reco/Calibration

- **Historically split into two communities**
  - e/γ
    - Used fixed $\Delta\eta x \Delta\phi$ cell indows (3x3, 3x5, 5x7, ...) to reconstruct shower core
    - Apply corrections for shower tails, detector effects (ϕ, η)
  - Jets, τ, ETmiss
    - Direct building of jets from cells (sometimes 2D "towers")
    - Jet energy corrections ... (constant tuning ...)
- **Unpleasant side effects**
  - Difficult (impossible) to get best e/γ in hadronic events
  - Jet energy scale corrections (very) sensitive to MC tunes, ...
- **New initiative (following in part from 2002 EMEC/HEC TB)**
  - Move ATLAS calorimeters to cluster-based reconstruction
    - Part of cluster benchmark is that it should contain e/γ objects
  - Apply cluster or cell "energy density" weights for offline compensation corrections in hadronic energy deposition
    - Weight calculation algorithms under most intense study now

Hadronic Energy Reconstruction

- **Hadronic shower consists of**
  - EM energy (eg $\pi^0 \to \gamma\gamma$) : O(50%)
  - Visible non-EM energy (eg dE/dX) : O(25%)
  - Invisible non-EM energy (eg nuclear breakup) : O(25%)
  - Escaped energy (eg ν) : O(2%)



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

Hadronic Calibration Models

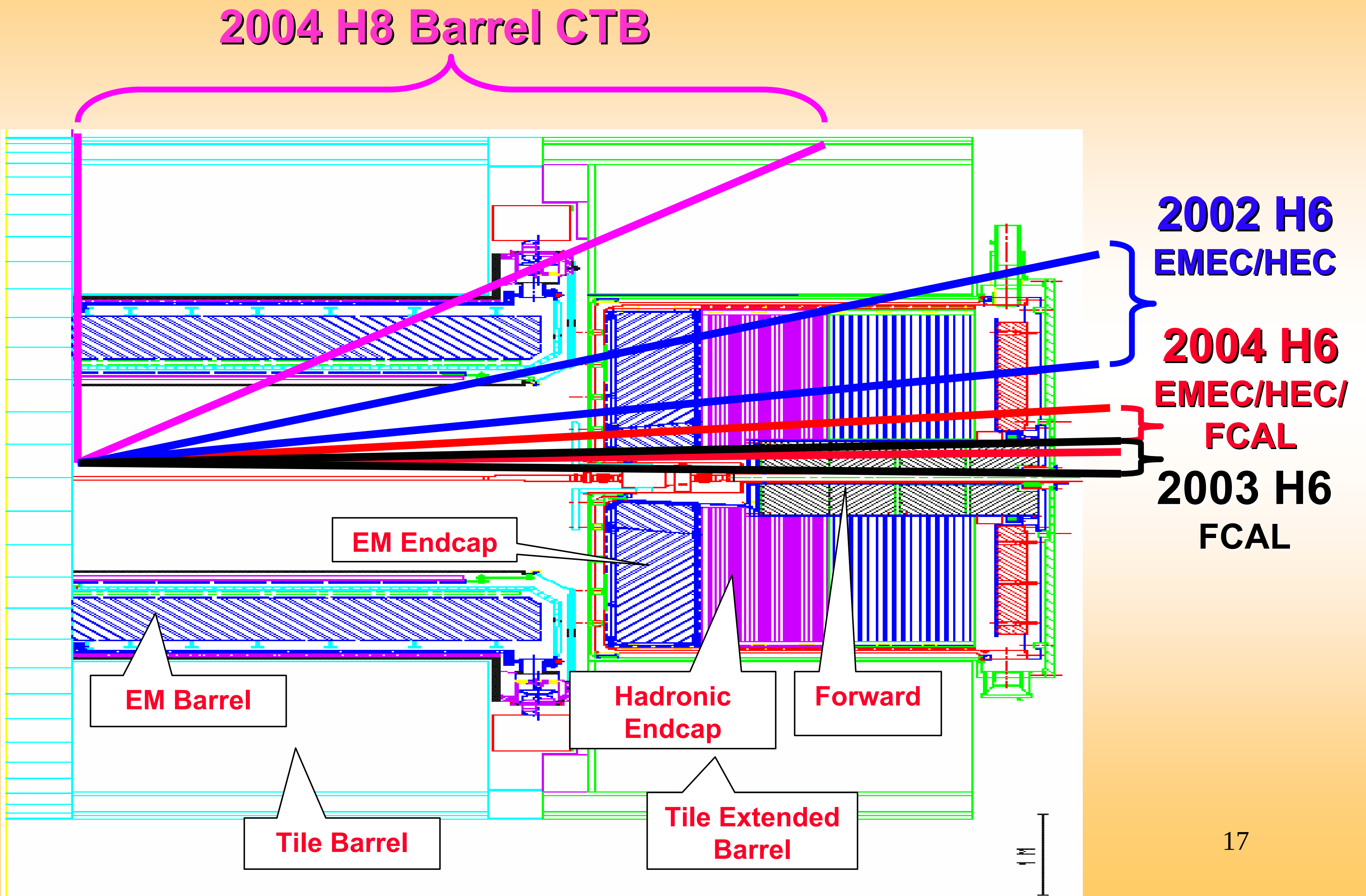
- **Model I : Physics object based:**
  - first reconstruct hadronic final state physics objects (jets, missing Et) using calorimeter signals on a fixed (electromagnetic) energy scale (accepting the fact that these are ~30% too low, typically);
  - then calibrate the jets in situ using physics events
  - a priori using “MC Truth” in simulations for normalization (presently studied approach in ATLAS)
    - 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**
  - 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 we are studying it’s applicability to ATLAS

Model II: Local Calorimeter Calibration Algorithm Flow

P. Loch

Intrinsic Electromagnetic Energy Scale Signal	**Electronic and readout effects unfolded (nA->GeV calibration)**
Fundamental Calorimeter Signal Definition: Cell Level and Topological Noise Cuts	**Detector noise suppression algorithms (optional, can be absorbed into cluster formation algorithm)**
Intermediate Calorimeter Signal Definition: Cell Cluster Formation	**Cluster formation in calorimeter regions (2D->3D->spanning regions)**
Advanced Calorimeter Signal Definition: Cluster Classification	**Simple cluster shape analysis -> classification**
Electromagnetic Cluster / Hadronic Cluster / Non-classified Cluster	**Apply cluster type specific calibration functions, dead material and crack corrections**
Final Local Energy Scale Signal	**Best estimate for general energy flow in event -> re-calibrate smallest readout units (cells)!**

Test-bench : combined calo beam tests



Cluster/cell weighting formalism

- Cluster (or cell) weights are used for energy reco

$$E_{\text{reco}}\left(C_j\right)=\sum_{\substack{\text{cells or}\\ \text{clusters}}} w\left(C_j, A_k\right) E_{\text{em}}$$

  - weights depends on some parameters C_j and some observables A_k

- Parameters should be obtained from (validated!) MC
- First look at parameters can be obtained from TB data through the minimization of

$$\chi^2=\sum_{\text{events}} \frac{\left[E_{\text{beam}}-E_{\text{leak}}-E_{\text{reco}}\left(C_j\right)\right]^2}{\left(\sigma_{\text{leak}}^2+\sigma_{\text{reco}}^2\right)}$$

  - leakage outside the cluster/cell (but in the calorimeter) can be parameterized from the data
  - leakage outside the detector must be parameterized from MC

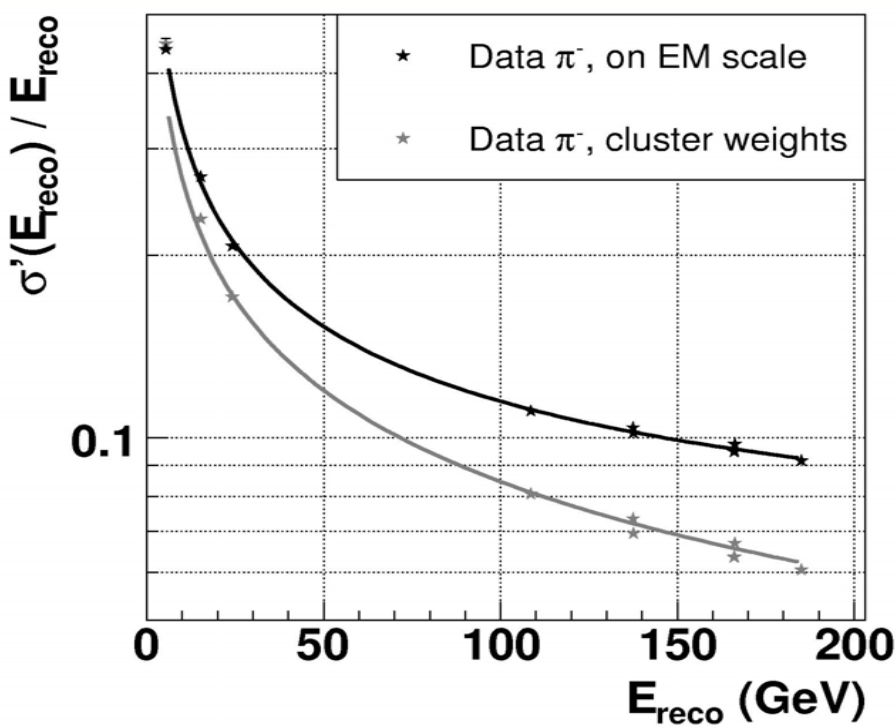
First look: beam energy dependent cluster weights

- Consider 3D topological clusters
- Use cluster energy density as observable
- Use simple weight function, à la H1

$$E_{\text{reco}}\left(C_j^{\text{E}}, C_j^{\text{H}}\right) = \sum_{\substack{\text{EMEC}\\ \text{clusters}}} w^{\text{E}}\left(C_j^{\text{E}}, \rho\right) E_{\text{em}}^{\text{EMEC}} + \sum_{\substack{\text{HEC}\\ \text{clusters}}} w^{\text{H}}\left(C_j^{\text{H}}, \rho\right) E_{\text{em}}^{\text{HEC}}$$

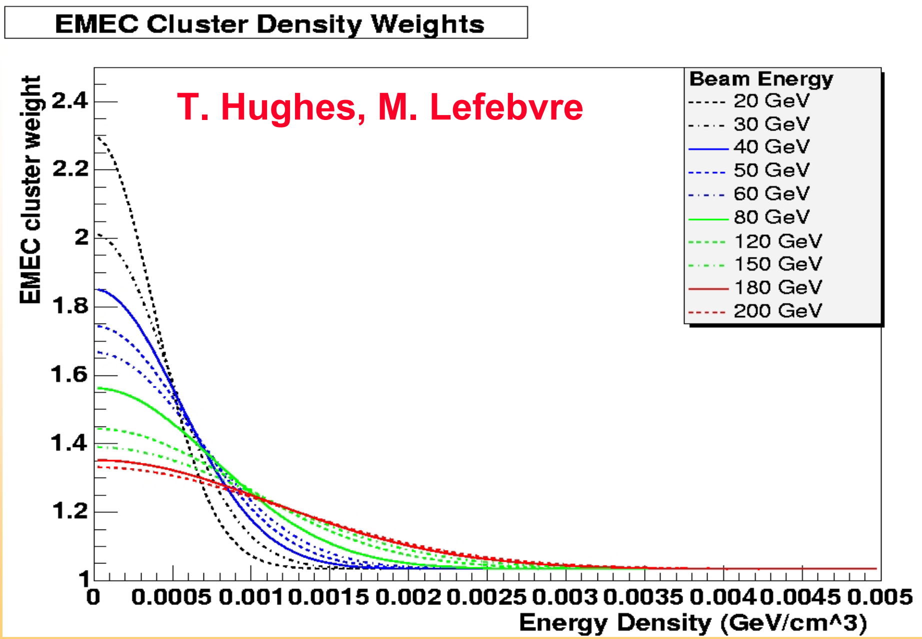
$$w\left(C_j, \rho\right) = C_1 \exp\left(-C_2 \rho\right) + C_3$$

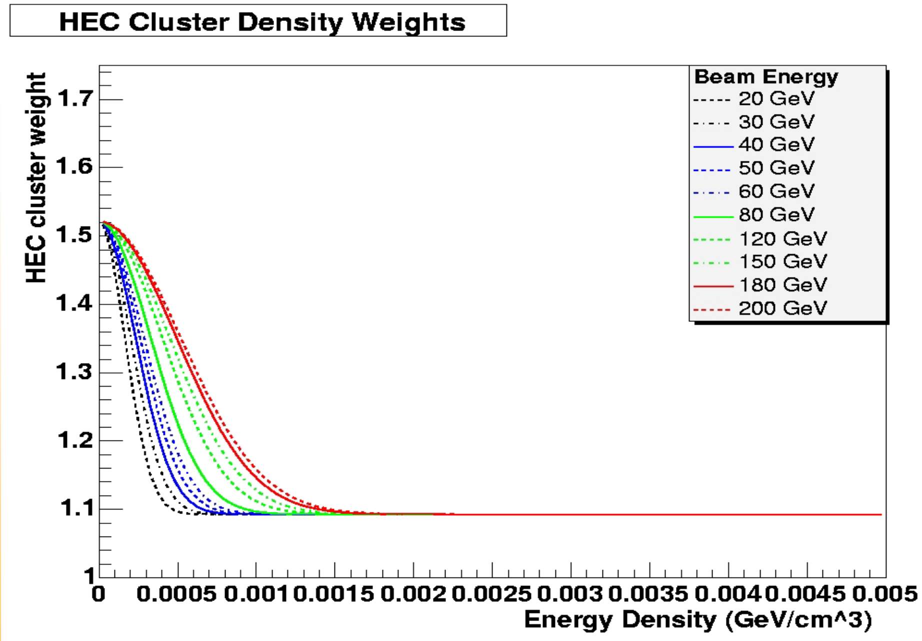
- Significant improvement of energy resolution
  - Results published [NIM A531 (2004) 481-514] uses fixed C2 values
  - Electronics noise subtracted in quadrature



Current work: beam energy independent cluster weights (Victoria)

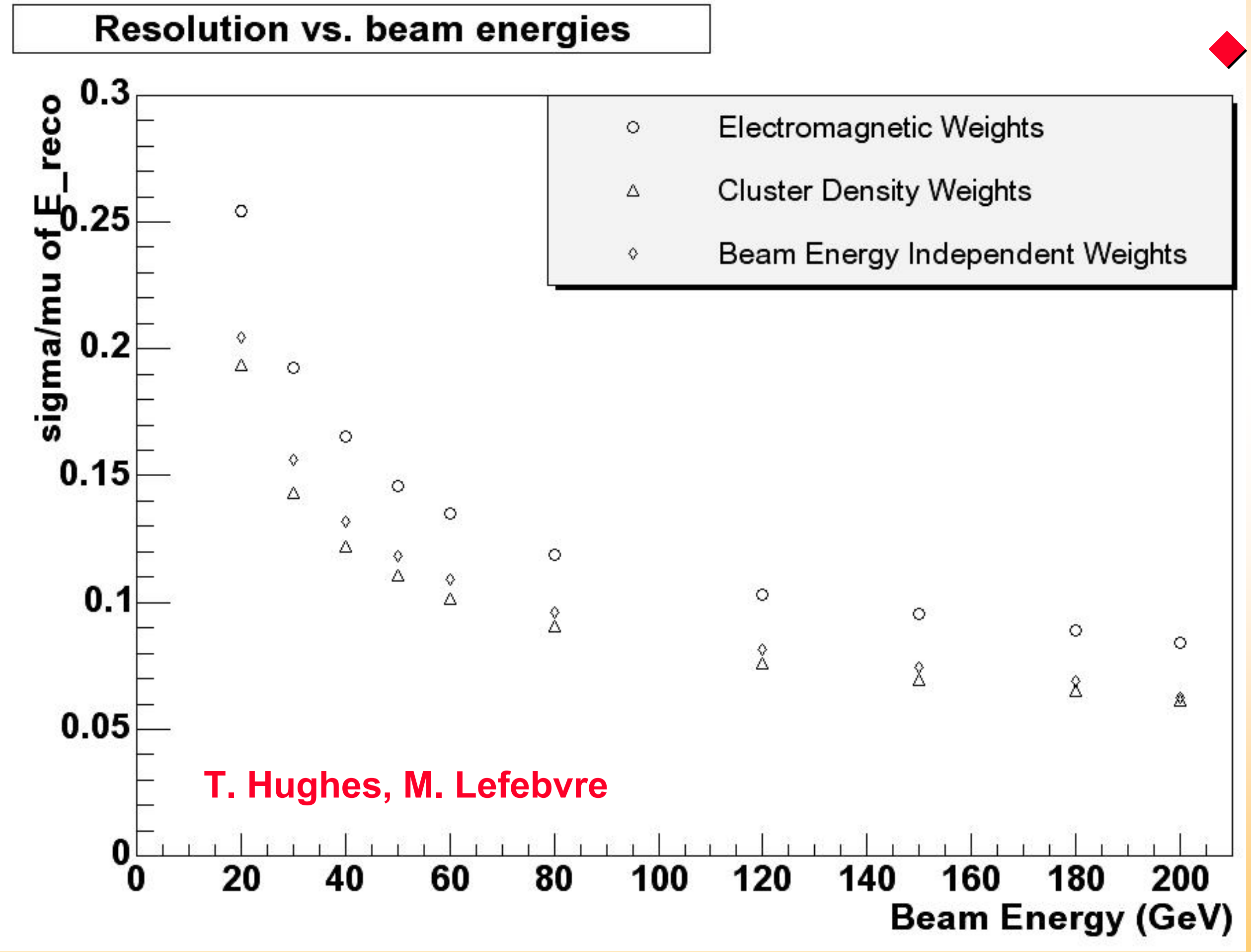
- **The knowledge of the beam energy must be taken out!**
- **First look at beam energy independent cluster weights**
  - Use beam energy to produce weight parameterization
  - Estimate beam energy using cluster energy
  - In general one pion corresponds to many clusters
  - Use $w\left(C_j,\rho\right)=C_1\exp\left(-C_2\rho^2\right)+C_3$





Current work: beam energy independent cluster weights

- As expected the energy resolution is degraded somewhat, especially at low energy



- Linearity of response is not affected by the removal of the knowledge of the beam energy

Cell weights

- **Weights can also be applied at cell level**
  - thought to be more flexible and more adapted to ATLAS
- **cell weights can depend on cluster observables**
  - energy and energy density
  - cluster shape
  - distance of cell from shower axis
  - etc.
- **Initial attempts (NIM) only used energy density**
  - results comparable to cluster weights
- **Recent attempts includes more observables and MC**

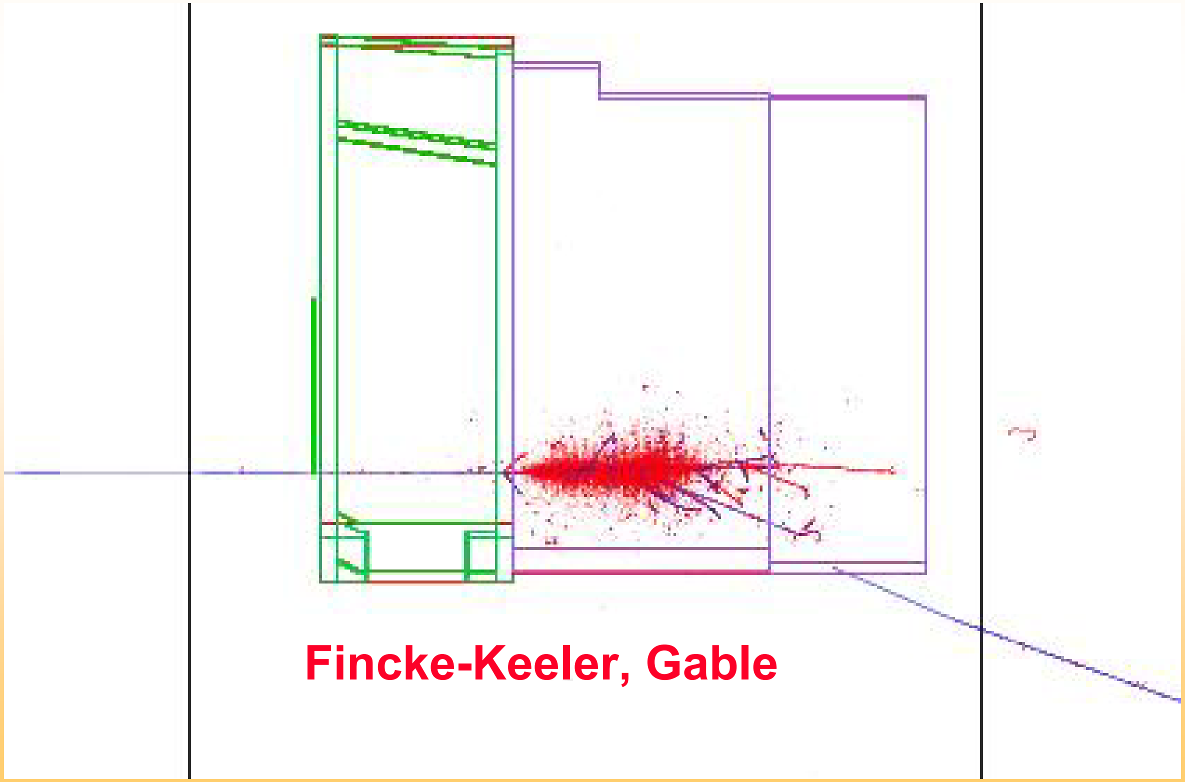
$$E_{\text{cell}}^{\text{reco}} = wE_{\text{cell}}$$

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

Cell weights

- **Large Canadian effort on the MC front**
  - taken responsibility of one package: LArG4TBEmecHec
  - implementing access to MC truth within the Athena framework
- **TB MC in Athena will very shortly allow direct comparison (≈same code!) of data and MC**

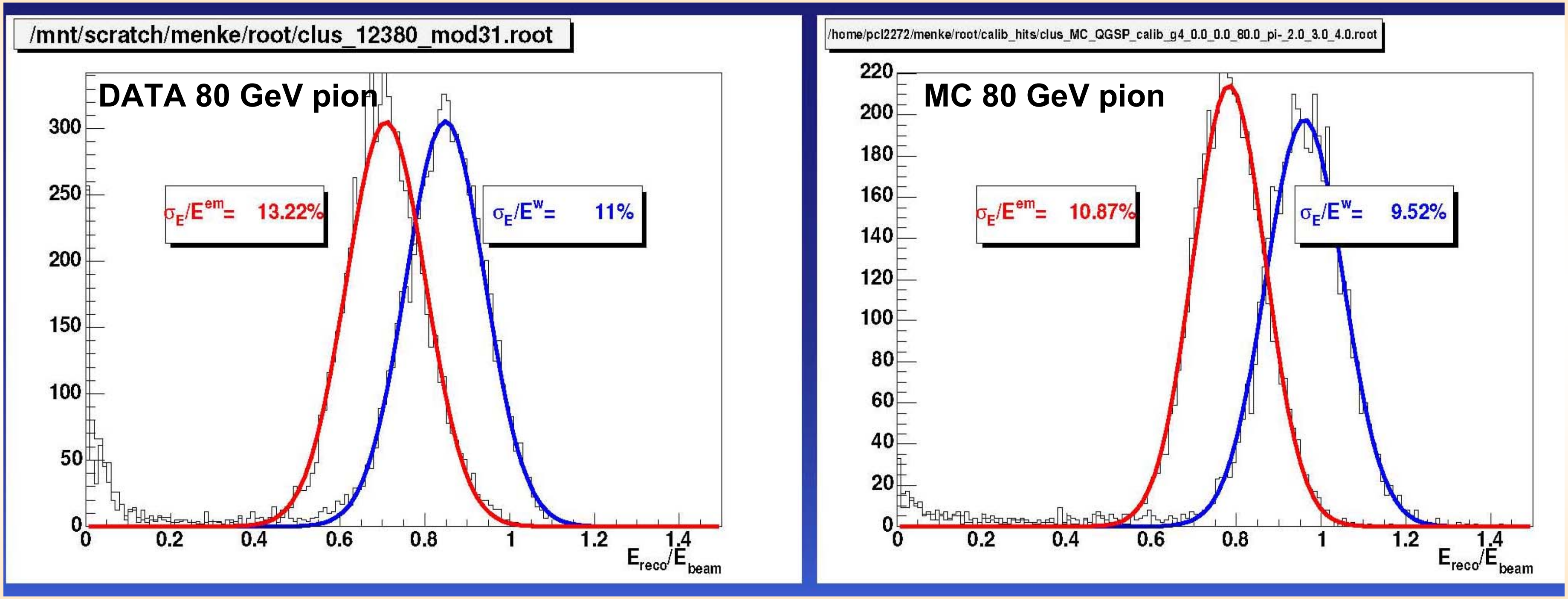
100 GeV pion (charged tracks) in the 2002 EMEC-HEC beam test setup



Fincke-Keeler, Gable

Cell weights

- **Initial work on cell weighting promising...**
  - weights obtained from MC only



- **... but still work in progress**
  - understand data/MC differences
  - understand bias in reconstructing EM showers
  - energy linearity

EMEC-HEC-FCAL TB Monte Carlo

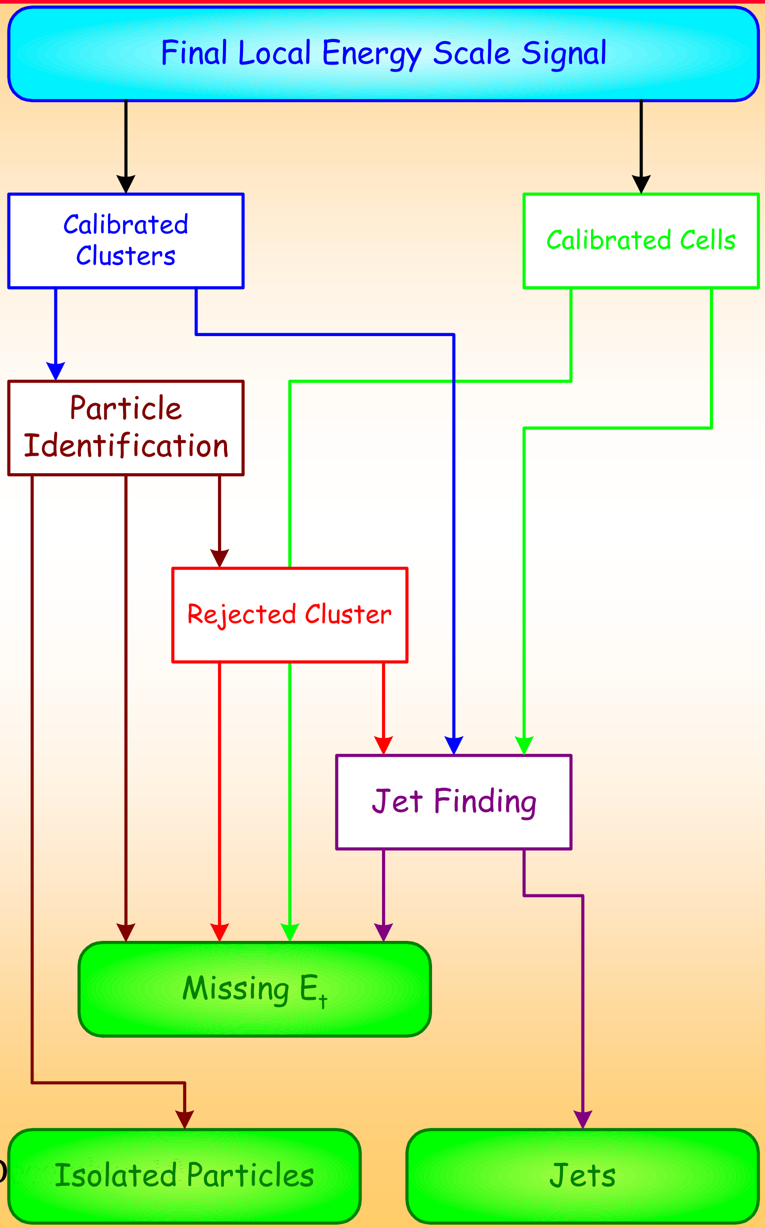
- **Very first (2004/12/08) visualization of 2004 EMEC-HEC-FCAL TB MC using Athena!**

100 GeV pion (charged tracks) in the 2004 EMEC-HEC-FCAL beam test setup

Fincke-Keeler, Gable, Khakzad

From local energy scale signal to physics objects

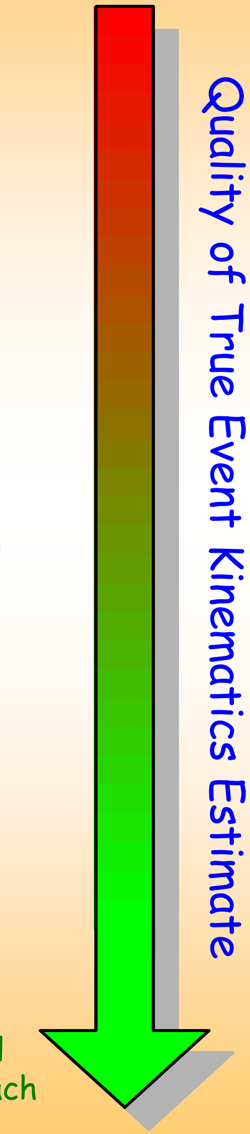
P. Loch



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…)



More activities

- **2002 EMEC-HEC data being made persistent**
  - allow data and MC to be analysed within the same framework
  - need to analyze this data again with MC input
- **2004 EMEC-HEC-FCAL TB analysis**
  - important (and complicated!) forward region
- **Combine effort across all TB**
  - 2002 EMEC-HEC, 2003 FCAL, 2004 EMEC-HEC-FCAL and Barrel Wedge
  - effort started in jets/tau/etmiss reconstruction
- **Combine calorimetry and tracking**
  - could start with muon+calo
- **Recent relevant meetings**
  - Calor2004, Mar 2004, Perugia
  - ATLAS Calorimeter Calibration Workshop, Dec 2004, Štrba
  - Many calibration, detector performance and physics meetings