# Introduction to Hadronic Calibration in ATLAS

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# This Talk: Overview

- Preliminaries
- ATLAS Environment
- ATLAS Detectors
- Calorimeters
- Local Hadronic Calibration
- Jet Reconstruction and Calibration
- Missing Et Reconstruction and Calibration
- Hadronic Final State Trigger Calibration
- Detector Simulation Tool
- Reconstruction Software Tools
- Important Issues For This Workshop

# This Talk [1]

- Preliminaries
  - why this talk?
  - what do we mean with hadronic calibration?
  - hadronic calibration models
- ATLAS Environment
  - jet signatures
  - missingEt signatures
  - underlying event
  - pile-up
- ATLAS Detectors
  - calorimeters
  - dead material

# This Talk [2]

- Calorimeters
  - physics requirements
  - hadronic showers
  - electronic noise
  - Monte Carlo validation
- Local Hadronic Calibration
  - clusters and cluster classification
  - hadronic weighting
  - out-of-cluster and dead material corrections
- Jet Reconstruction and Calibration
  - jet reconstruction overview
  - jet ingredients
  - jet finding algorithms
  - from electromagnetic energy scale to jet energy scale
  - calibration approaches
  - special jets

# This Talk [3]

- Missing $E_t$ Reconstruction and Calibration
  - missing $E_t$ ingredients
  - fake MET and calibration
- Hadronic Final State Trigger Calibration
  - trigger levels
  - event filter
- Detector Simulation Tools
  - GEANT4 in ATLAS
  - calibrationHits

# This Talk [4]

- Reconstruction Software Tools
  - relevant Event Data Models in Athena
  - *Event Summary Data* vs *Analysis Object Data*
- Important Issues For This Workshop
  - how to obtain relevant calibrations
  - how to validate hadronic signals
  - how to assess robustness and quality of hadronic calibrations
  - calibration feedback from real data

# Preliminaries

# Preliminaries: Why This Talk?

- First attempt to collect material for "educational" purposes
  - Common and solid basic set of educational transparencies
    - To be used by EVERYBODY in future talks
  - Need to be updated in a reasonable fashion
    - Reflect latest evolution and new models under consideration
  - Transferred to Wiki
    - Extend and transfer to educational Hadronic Final State Wiki as soon as possible
    - Should be basis for description of hadronic final state reconstruction in upcoming papers
      - Can even imagine to provide a collection of text fragments at various levels of detail for use in future papers
- Some educational material guidelines
  - Avoid too many technical details
    - But be sufficiently explicit and descriptive
  - Need material and review by experts
    - More frequently initially
    - We need the experts to support this **Thanks!**
  - Need feedback from clients
    - Understand usefulness to avoid waste of time

# Preliminaries: Meaning of Hadronic Calibration

- Calibration of signals generated by hadronic final state objects
  - generated by single particles like $\pi^{\pm}$, $K$ , $n$, $p$, …
  - … or particle jets, $\tau$ (hadronic decays), etc.
- Input is electromagnetic energy scale signal
  - most basic signal calibration
  - does not mean perfect calibration for electrons or photons
- First calibration reference is incoming particle energy
  - calibration of detector signal characteristics
    - e.g. calibrating out particle type depending signal variations depending on detector technology
  - corrections for energy losses in inactive detector regions
    - e.g. upstream dead material losses
  - corrections for signal degradations by reconstruction algorithms
    - e.g. cell selection in calorimeters by noise suppression, jet finder inefficiencies, …
- Extension to parton level calibration
  - physics object oriented final calibration
    - e.g. calibrate out particle level inefficiencies (losses in magnetic field, etc.)
    - Correct accidental contributions from background activity (underlying event, pile-up)
  - can use real data only or simulations
    - e.g. in-situ calibration using balanced hadronic systems or resonances

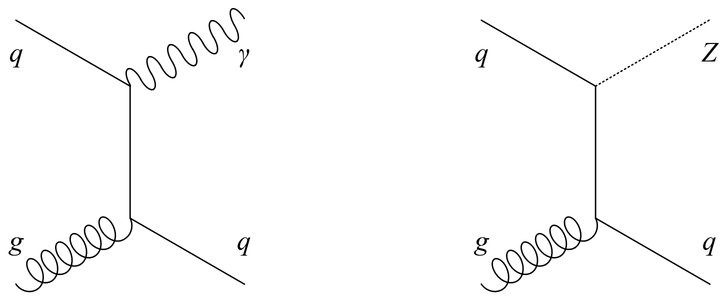
# Preliminaries: Hadronic Calibration Models

- Model I: Physics object based (**Global**):
  - first reconstruct hadronic final state objects like jets and missing Et using calorimeter signals on fixed electromagnetic energy scale
    - accepting the fact that these may be more than 30% too low in non-compensating calorimeters!
  - then calibrate the jets in-situ using physics events
    - feedback calibration to calorimeter signals for missing Et calculation
    - real data approach with limited use of simulations
  - a priori use “MC Truth” in simulations for normalization
    - uses full physics simulations to determine hadronic calorimeter calibration
    - some direct bias due to choice of physics final state and jet reconstruction
- Model II: Detector-based objects (**Local**):
  - reconstruct calorimeter final state objects like cell clusters first and calibrate those using a local normalization and corrections (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
    - no direct physics object bias, but strong dependence on simulations for determining local calibration functions
- Both models have been used in ATLAS so far!

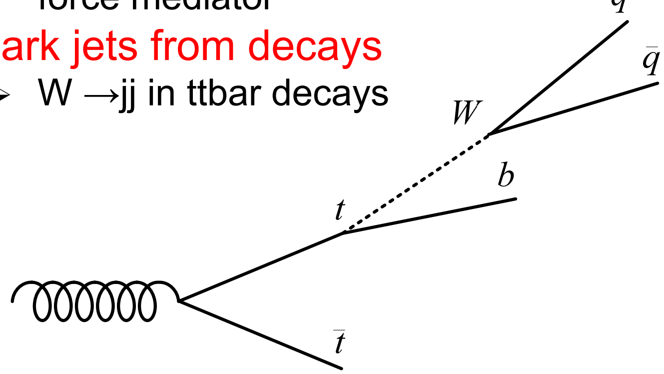
# The ATLAS Environment

# ATLAS Environment: Jet Signatures

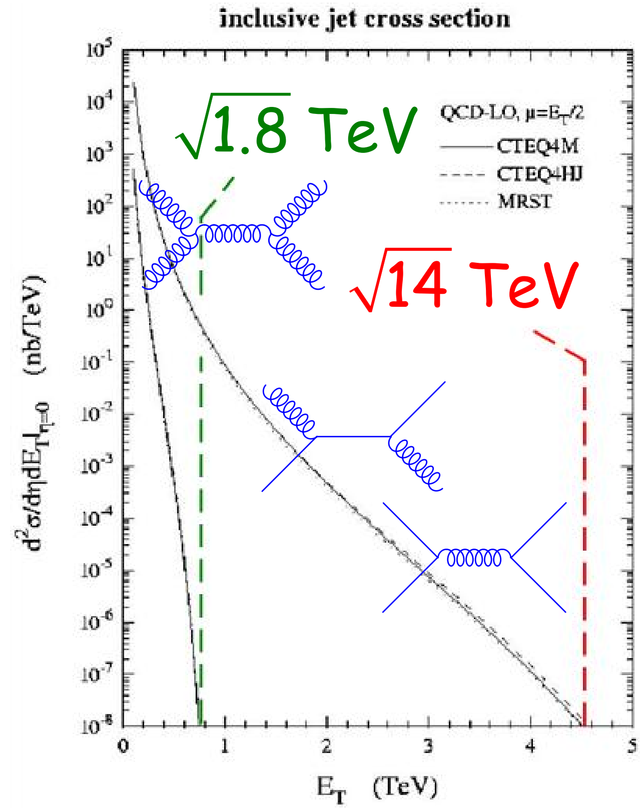
- Jets at LHC
  - gluon jets from parton scattering
    - mostly in (lower Pt) QCD 2→2 processes
  - quark jets from parton scattering
    - high end Pt in QCD 2→2 processes
    - dominant prompt photon channel, Z+jet, …




    - final state in extra dimension models with graviton force mediator
  - quark jets from decays
    - W →jj in ttbar decays



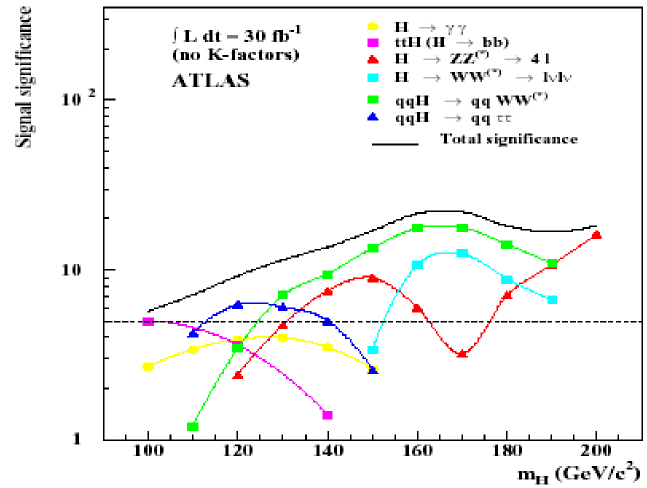

    - end of long decay chains in SUSY and exotic (ultra-heavy) particle production, like leptoquarks

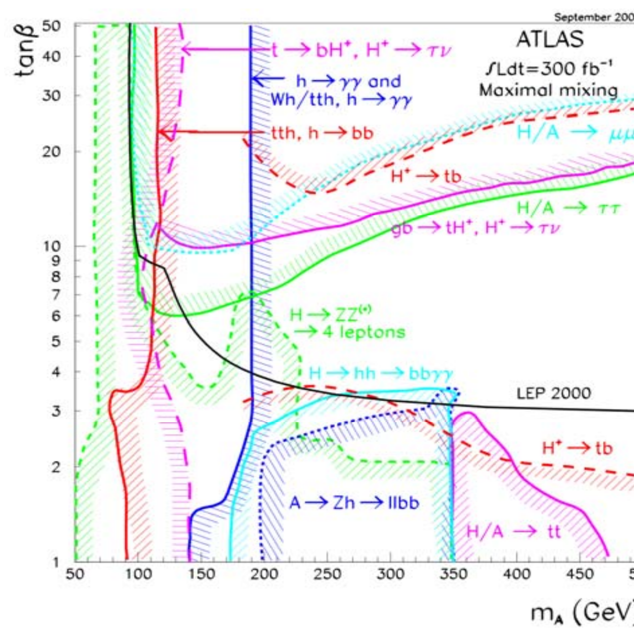



Multitude of "jet flavours" generated in *pp* collisions at LHC
→ expect corresponding variety of jet shapes with (possibly) specific calibrations!

# ATLAS Environment: MissingEt Signatures

- Standard model physics
  - Decays involving leptons:
    - W→$\ell\nu$, Z→$\nu\nu$
    - $\tau\to\pi^{\pm}+(0..3)\,\pi^0+\nu_\tau$, $\tau\to 3\pi^{\pm}+\pi^0+\nu_\tau$, $\tau\to e(\mu)+\nu_{e(\mu)}+\nu_\tau$
  - Heavy quarks and Higgs final states:
    - W in semi-leptonic b decays;
    - W in t decay chain
    - W, Z, $\tau$ in Higgs decays
- Beyond Standard Model
  - MSSM extension and SUSY
    - MSSM: h/A→$\tau\tau$
    - Lightest SUSY Particle (LSP) similar $\nu$ (neutral, stable, weakly interacting), escapes detection
    - Exclusive SUGRA features neutralino decay chains with final states:
      - LSP + leptons (moderate $\tan\beta$)
      - LSP + heavy quarks (moderate $\tan\beta$)
      - LSP + $\tau\tau$ (large $\tan\beta$)
  - Exotics
    - Technocolor particles decay to WZ
    - Excited quarks and heavy quark resonances
    - Leptoquark decays
    - W',Z' decays to W,Z and combinations
    - particles escaping in extra dimensions

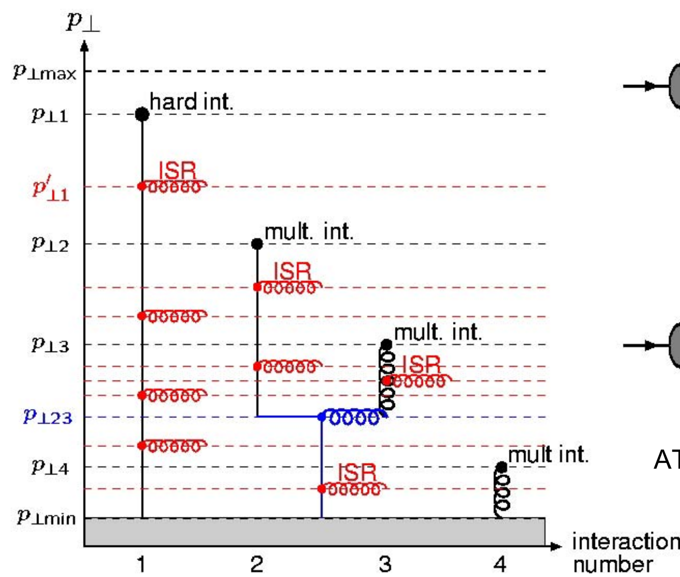


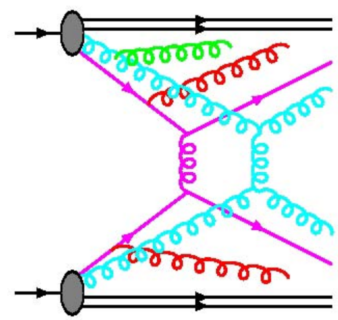



# ATLAS Environment: Underlying Event

- Distortion of hadronic final state signals (1)
  - Underlying event
    - collisions of partons from both p remnants
      - in-time collisions produce (soft) particles
      - some correlation with hard scatter
      - generates Et flow "perpendicular" to hard scatter → experimental estimates?
    - background to jet and missing Et signals
      - Et balanced → distorts missing Et resolution
      - generates Et flow around hard scatter → signal shift (up) for jets
      - fake jets not related to hard scatter
      - Et flow in transverse region in QCD 2→2 processes estimates activity

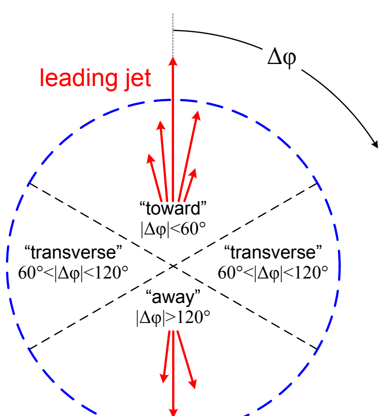
Interleaved Multiple Interactions

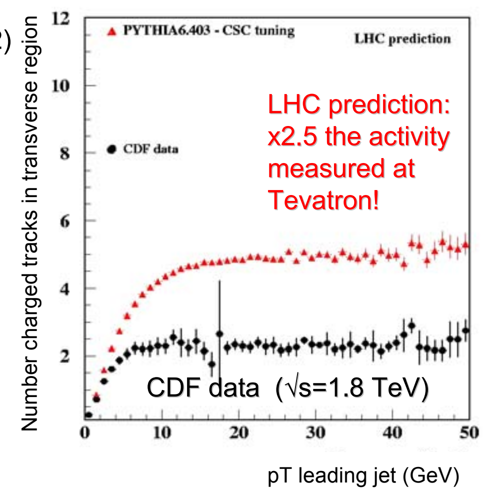


A.Moraes, ATLAS-UK SM Mtg Sept. 2005

CDF data: Phys.Rev, D, **65** (2002)

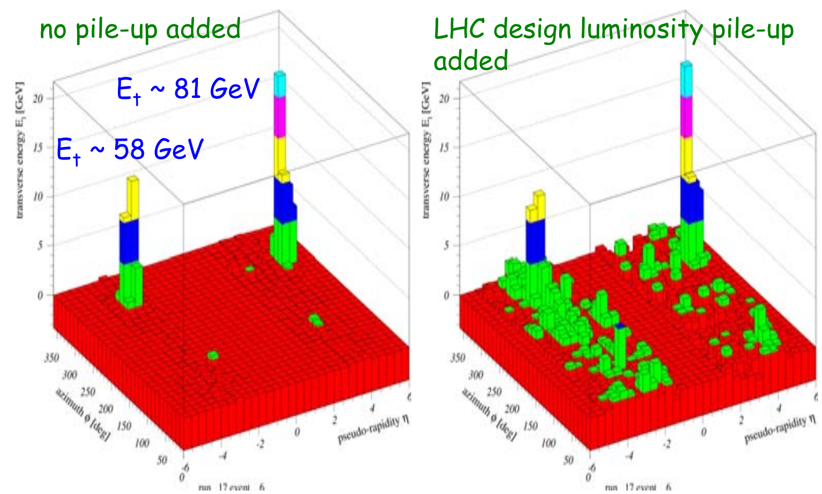


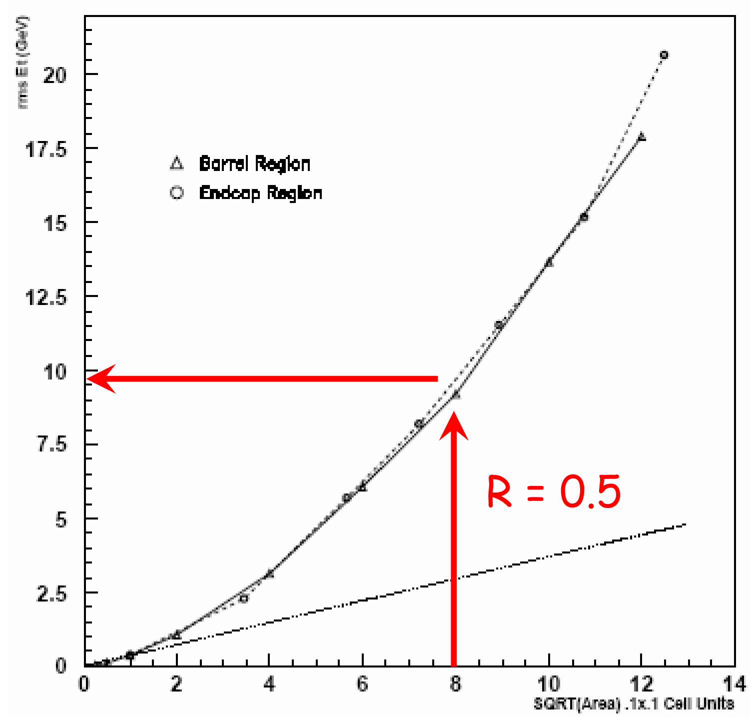




A.Moraes, HERA-LHC Workshop, DESY, March 2007

# ATLAS Environment: Pile-up

- Distortion of hadronic final states (2)
  - Pile-up
    - Minimum/zero bias (MB) collisions
      - same (non-perturbative) QCD dynamics as UE
      - no correlation with hard scatter
    - Depends on instantaneous luminosity
      - average ~25 statistically independent collisions/bunch crossing @ $10^{34}$, 2.5 @$10^{33}$, 0.025 @ $10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$…
    - Jet signals
      - signal bias ~ jet area;
      - signal fluctuations ~10 GeV RMS (Et) for R=0.5 cone jets @ $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
    - Missing Et
      - signal bias depending on calculation strategy
      - major resolution contribution

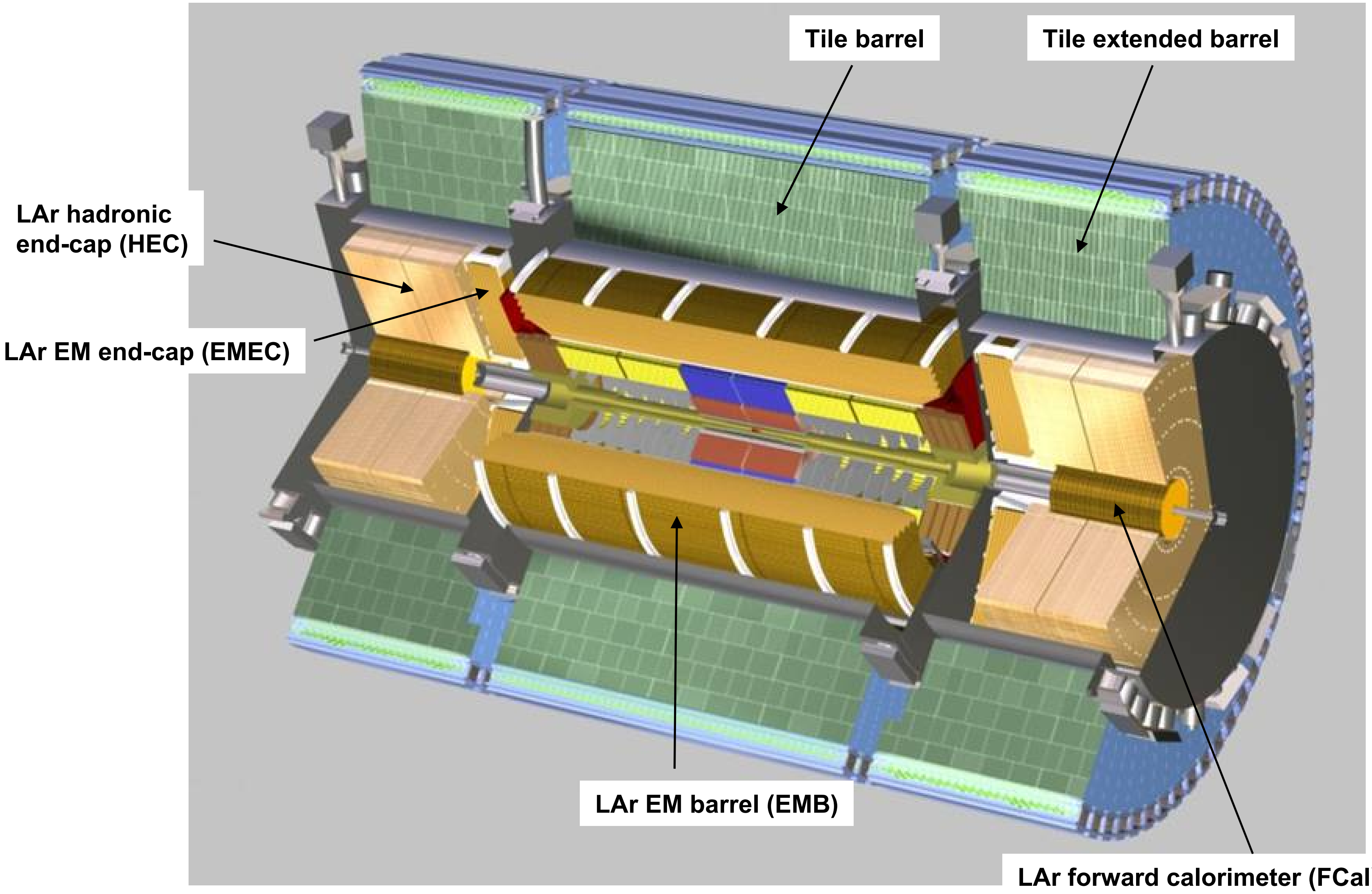


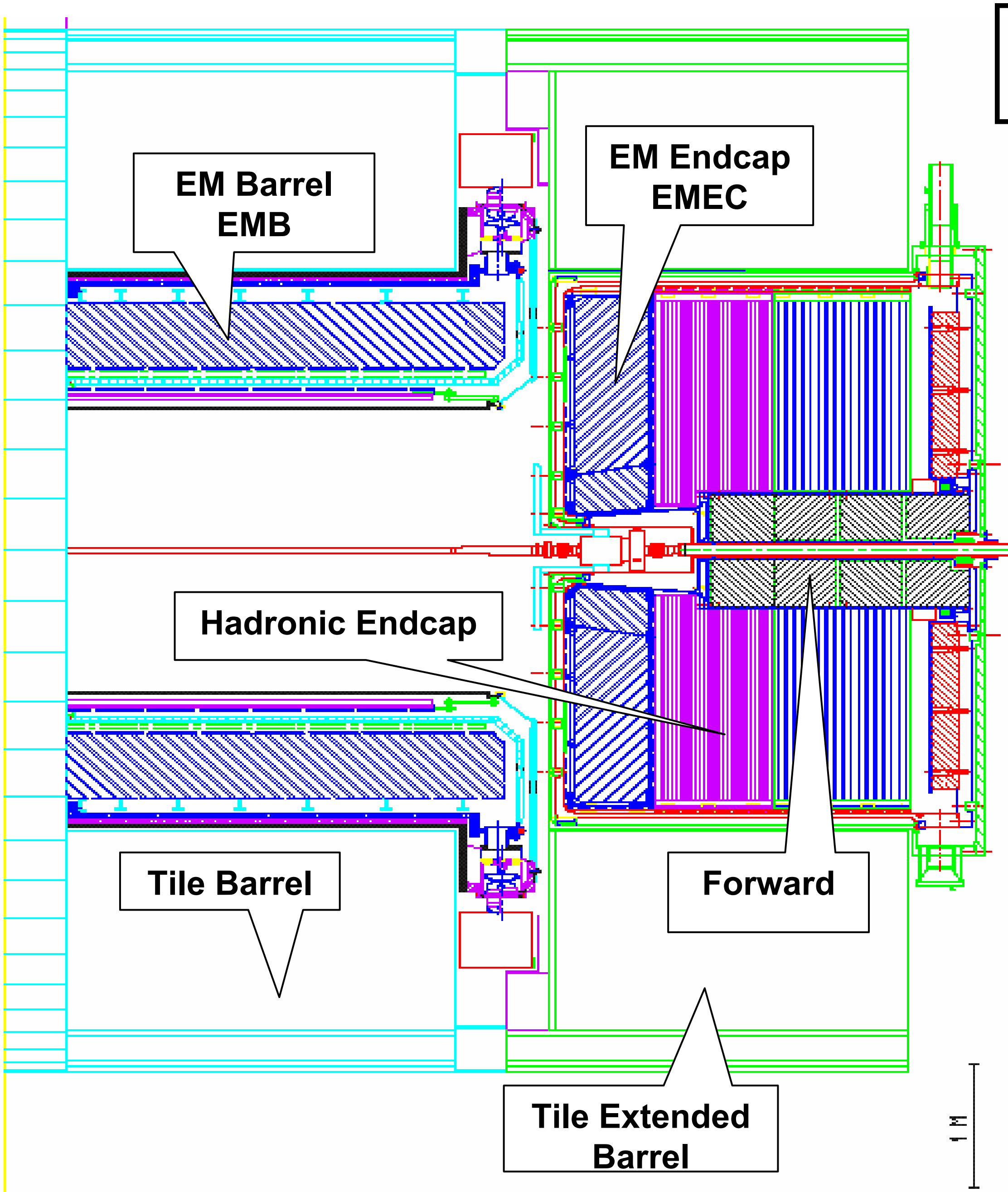




P. Savard et al., ATLAS-CAL-NO 084/1996

# The ATLAS Calorimeters

# ATLAS Detectors: Calorimeters






# 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
varied techniques
many overlap regions

# Calorimeters: Physics Requirements

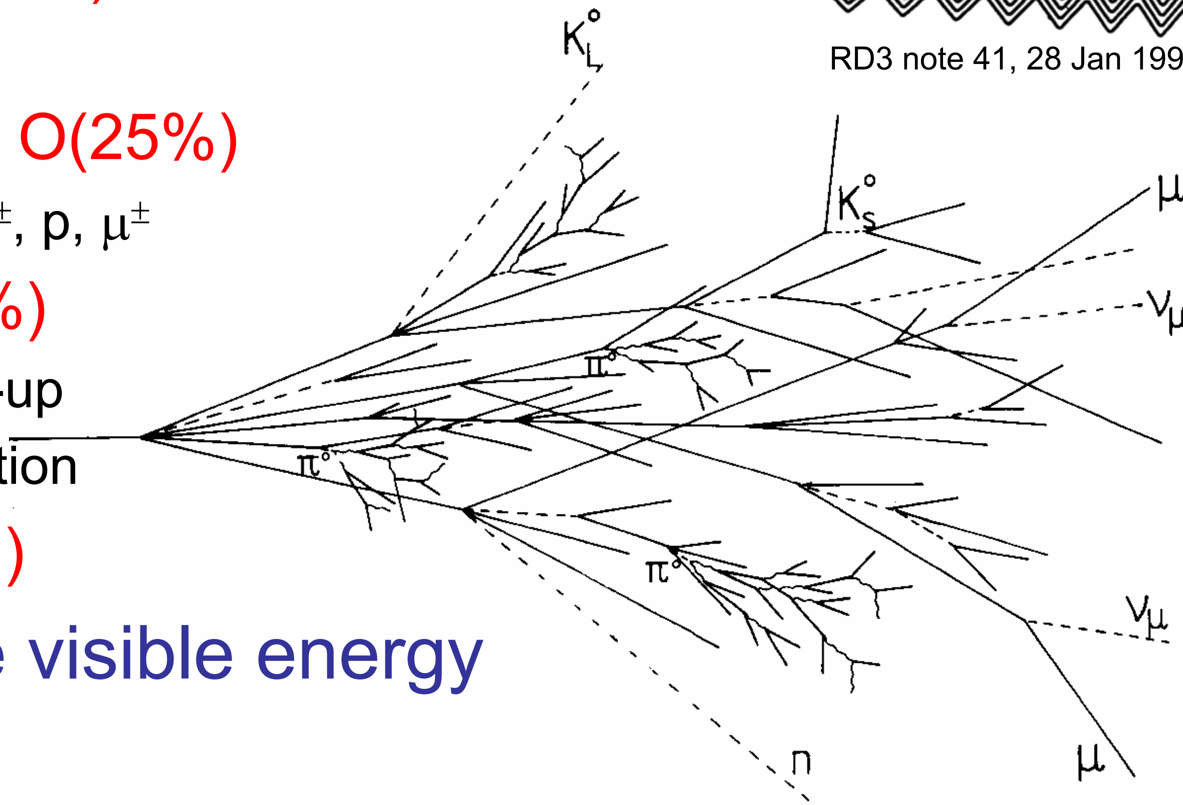
- EM Calorimeters
  - Benchmark channels $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow eeee$ require high resolution at $E \approx 100$ GeV and coverage to low $E_T$
  - b-physics: e reconstruction down to GeV range
  - Dynamic range: mip to $Z' \rightarrow ee$ at a few TeV
  - Design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

# Calorimeters: Hadronic Showers

- More complex than EM showers
  - visible EM O(50%)
    - $e^{\pm}$, $\gamma$, $\pi^o \rightarrow \gamma\gamma$
  - 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

# Calorimeters: Hadronic Showers

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

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

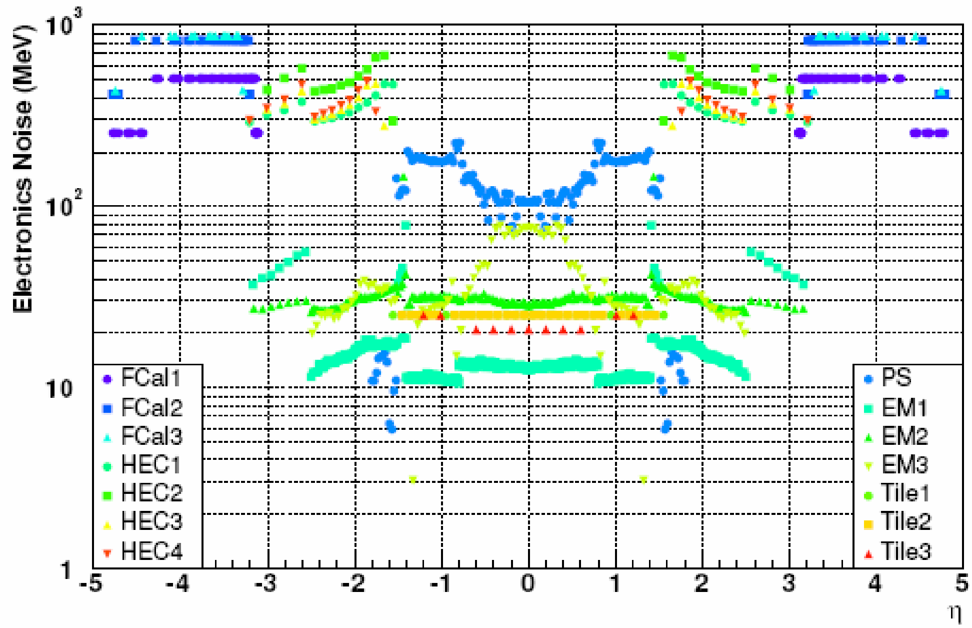
$$0.80 \le m \le 0.85$$
$$E_0 \approx 1 \text{ GeV for } \pi^{\pm}$$
$$E_0 \approx 2.6 \text{ GeV for p}$$

  - 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

# Calorimeters: Signal Noise (Incoherent)

- Electronic noise
  - unavoidable basic fluctuation on top of each calorimeter cell signal, typically close to Gaussian (symmetric)
  - ranges from ~10 MeV (central region) to ~850 MeV (forward) per cell
  - independent of physics collision environment
  - coherent noise contribution in cells generated in the calorimeter and/or in the readout electronics typically much smaller than incoherent cell electronic noise
    - “fake” pile-up noise avoided

Electronic Noise in Calorimeter Cells

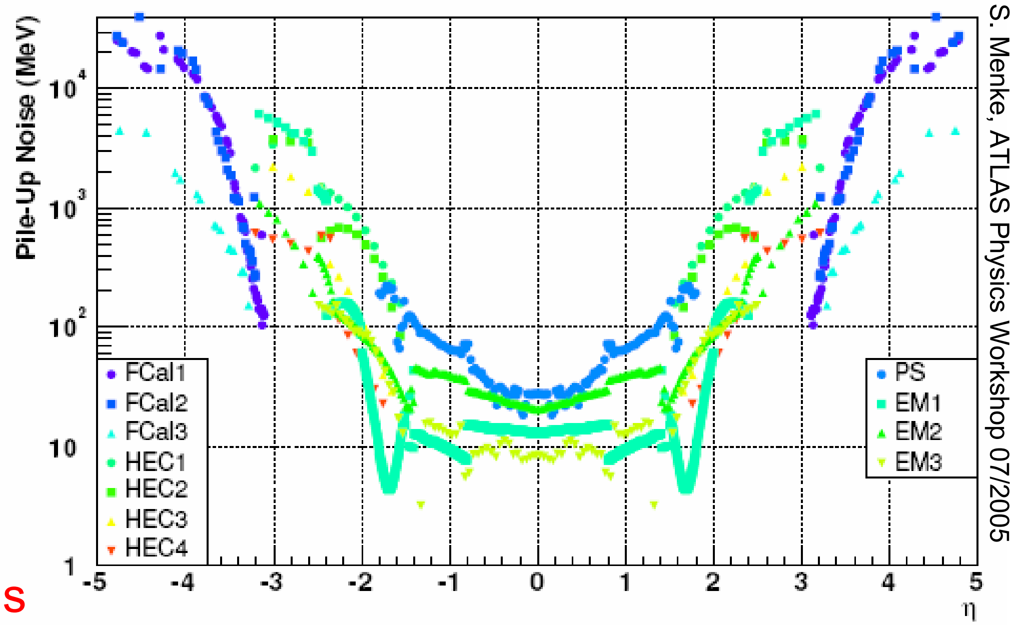



S. Menke, ATLAS Physics Workshop 07/2005

# Calorimeters: Signal Noise (Coherent)

- Pile-up noise
  - Generated by (many) minimum bias events (MB) in physics collisions → depends on instantaneous luminosity (see earlier discussion)
  - illuminates basically the whole calorimeter
  - Major contribution to out-of-time signal history due to calorimeter shaping functions (total of ~625 MB/triggered event affect the signal @ $10^{34}\text{cm}^{-2}\text{s}^{-1}$)
    - slow charge collection in LAr calorimeters (~500ns) versus high collision frequency (25ns bunch crossing to bunch crossing) generates signal history in detector
  - Introduces asymmetric cell signal fluctuations from ~10 MeV (RMS, central region) up to ~4 GeV (RMS, forward) similar to coherent noise
    - “real” showers generated by particles in pile-up event introduce cell signal correlation leading to (large) coherent signal fluctuations

Pile-up Noise in Calorimeter Cells



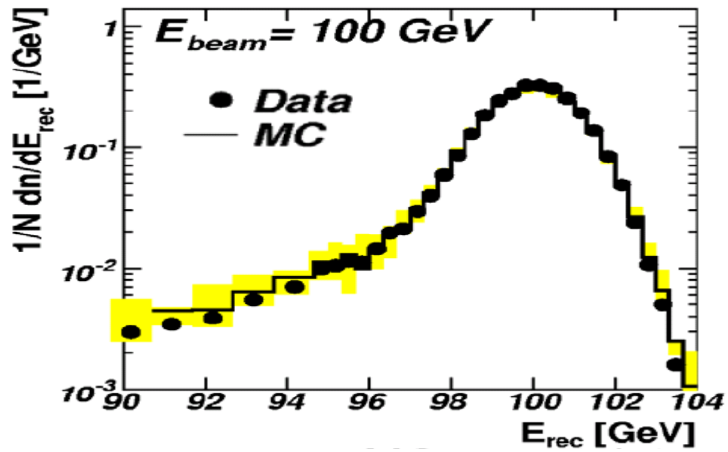
# Calorimeters: Monte Carlo Validation [1]

- 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, $\pi$, p, $\mu$
    - beam test data crucial
  - follow GEANT4 package evolution
    - feedback to GEANT4 developers
  - recent GEANT4 review, 16-20 April 2007, CERN
    - agenda: http://indico.cern.ch/conferenceDisplay.py?confId=14946
    - LHC Physics talk by Tancredi Carli

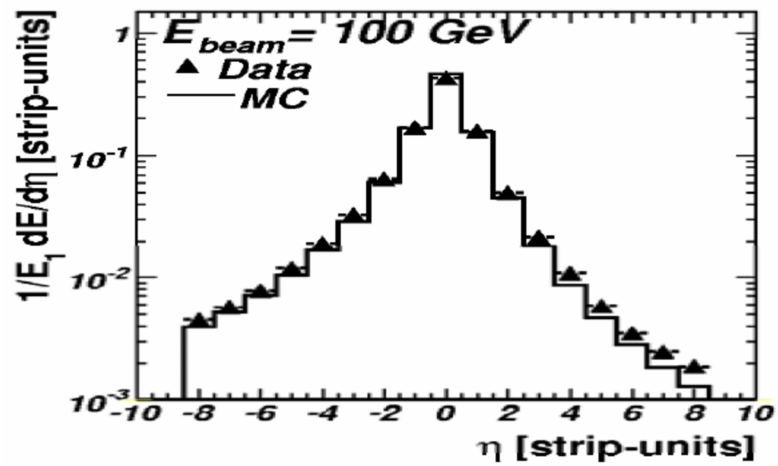
# Calorimeters: Monte Carlo Validation [2]

- Examples (taken from Tancredi Carli's talk at GEANT4 Review 2007/04/16)

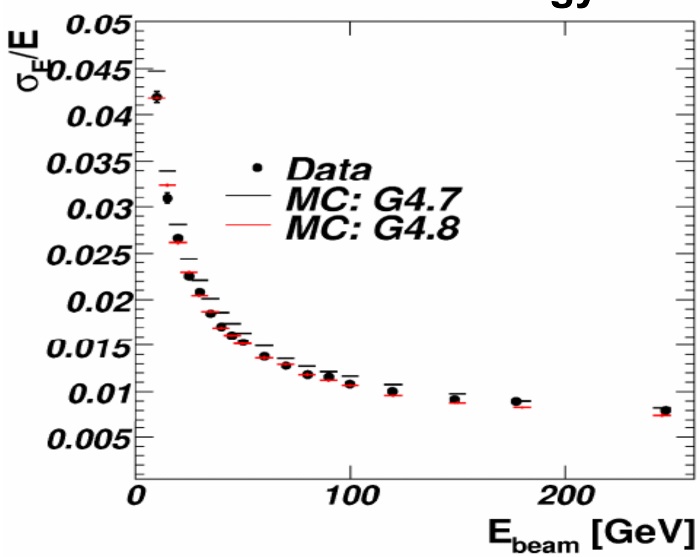
**Barrel electron total response**



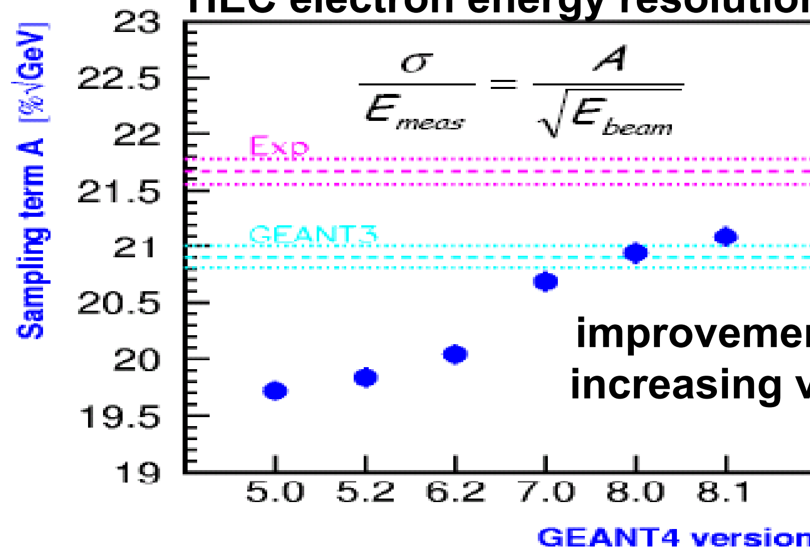

**Barrel electron radial profile**




**Barrel electron energy resolution**




**HEC electron energy resolution**

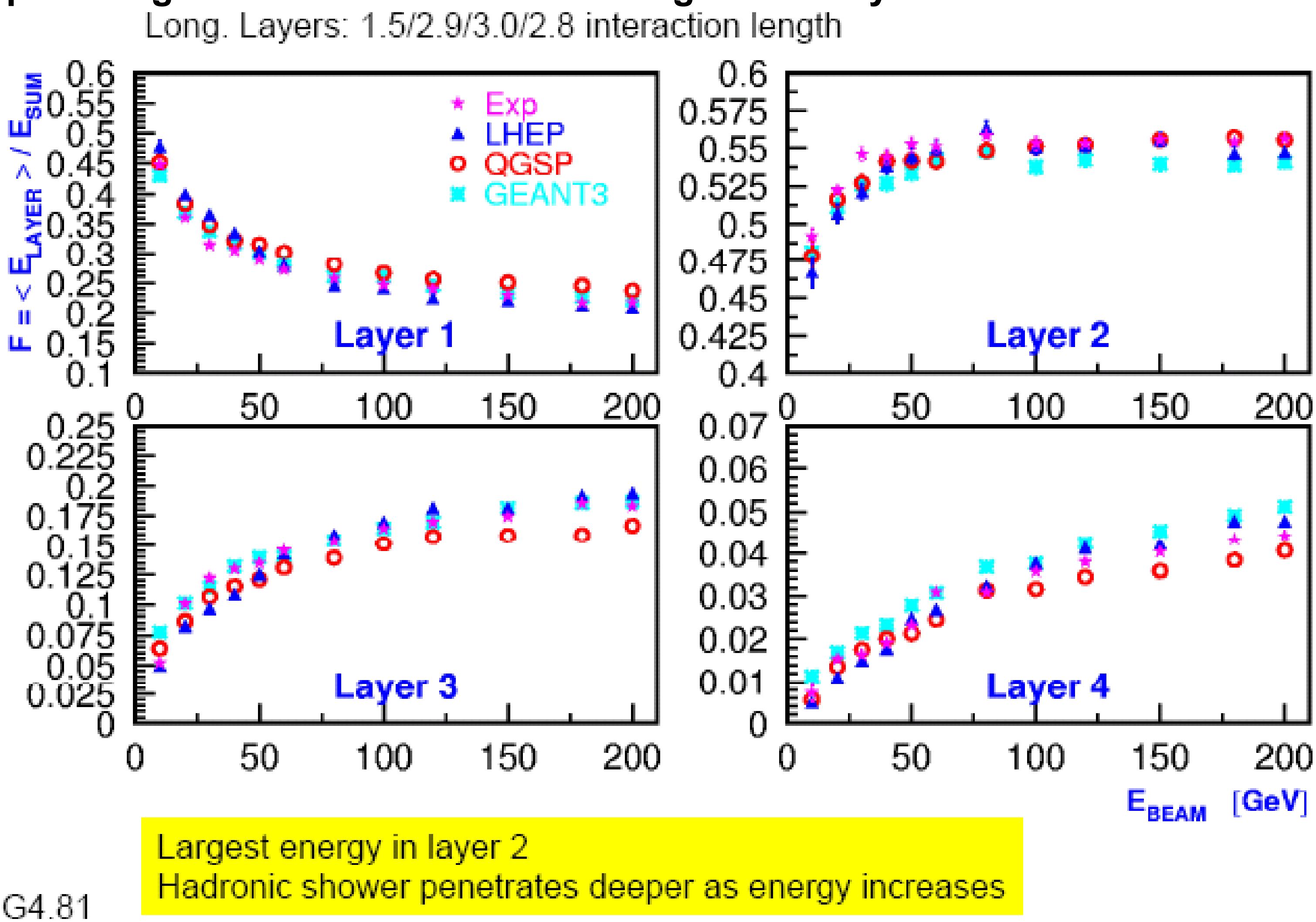



**improvements with increasing version#**

# Calorimeters: Monte Carlo Validation [3]

- Examples (taken from Tancredi Carli's talk at GEANT4 Review 2007/04/16)

**pion longitudinal fractions in HEC longitudinal layers**



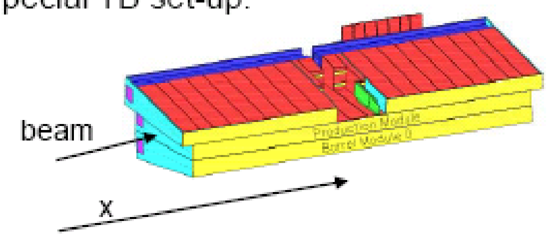

Largest energy in layer 2
Hadronic shower penetrates deeper as energy increases

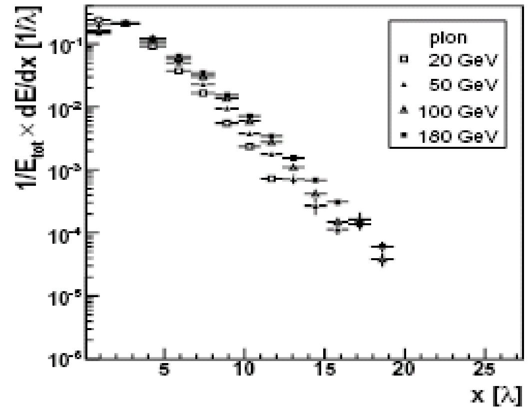
# Calorimeters: Monte Carlo Validation [4]

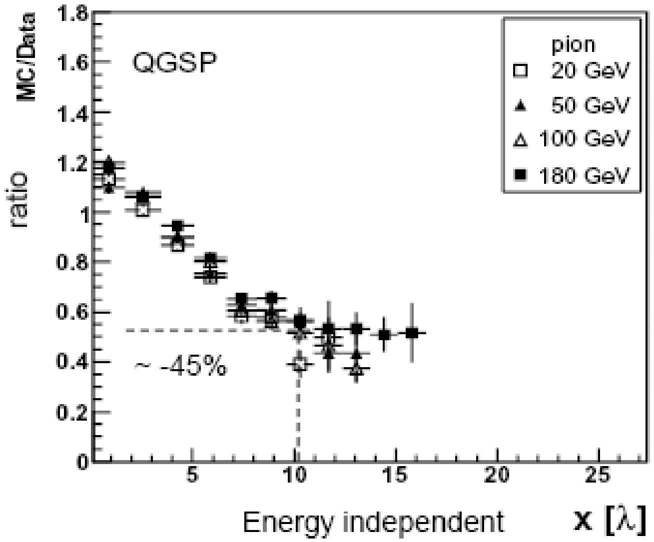
- ❑ Examples (taken from Tancredi Carli's talk at GEANT4 Review 2007/04/16)

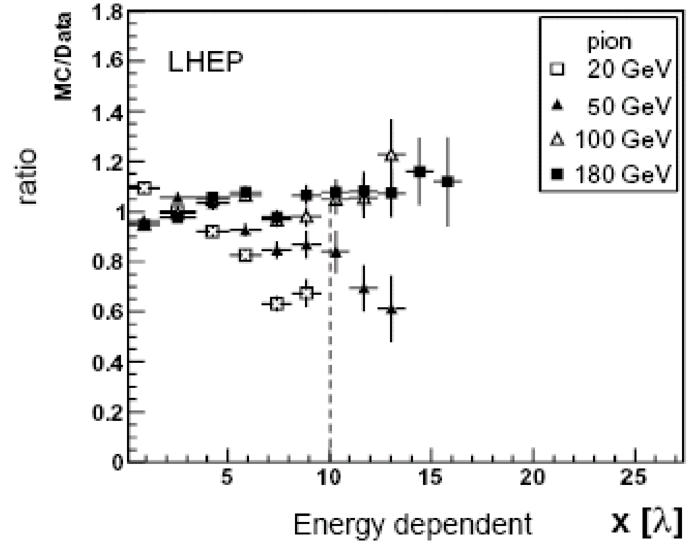
## Atlas Tile: Pion Shower Profile

Special TB set-up:



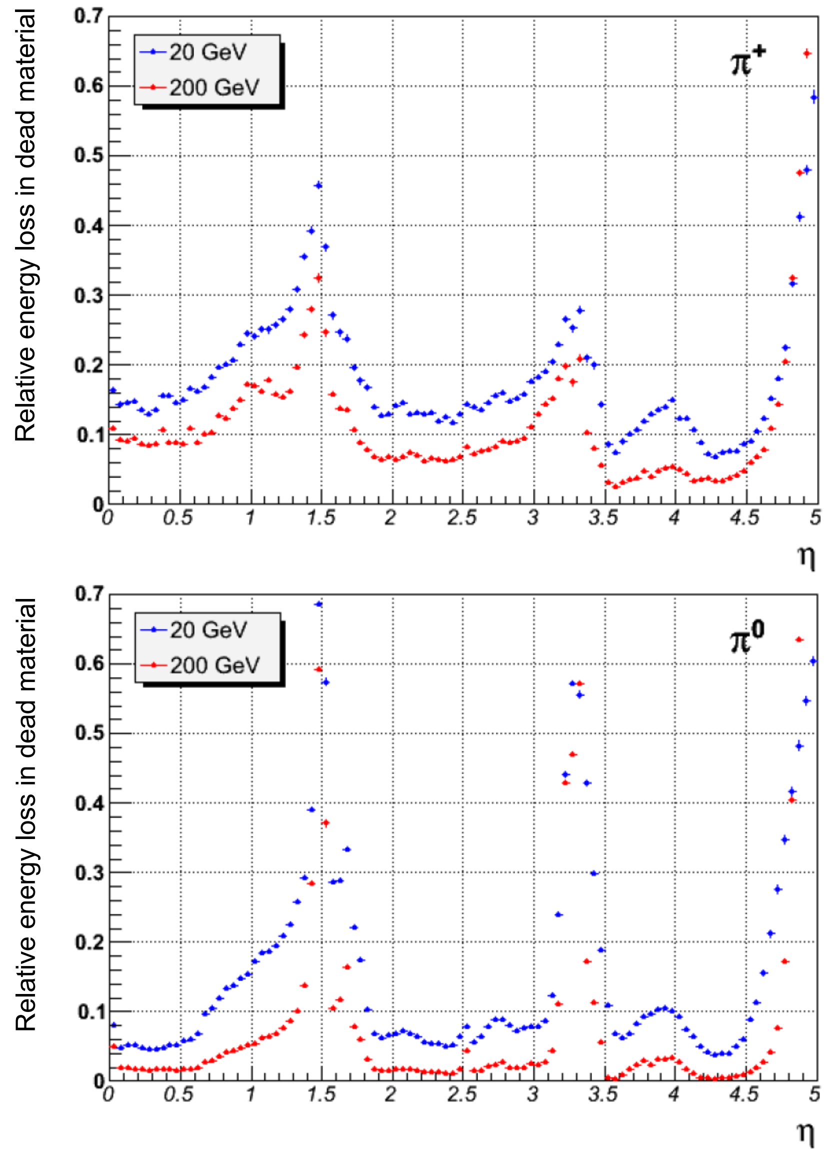




- QGSP predicts too short showers.
- LHEP describes shower profile at high energies quite well.

# ATLAS Detectors: Dead Material

- Dead material
  - Energy losses not directly measurable
    - Signal distribution in vicinity can help
  - Introduces need for signal corrections up to O(10%)
    - Exclusive use of signal features
    - Corrections depend on electromagnetic or hadronic energy deposit
  - Major contributions
    - Upstream materials
    - Material between LArG and Tile (central)
- Cracks
  - dominant sources for signal losses
    - $|\eta|\approx1.4$-$1.5$
    - $|\eta|\approx3.2$
  - Clearly affects detection efficiency for particles and jets
    - already in trigger!
    - Hard to recover jet reconstruction inefficiencies
  - Generate fake missing Et contribution
    - Topology dependence of missing Et reconstruction quality



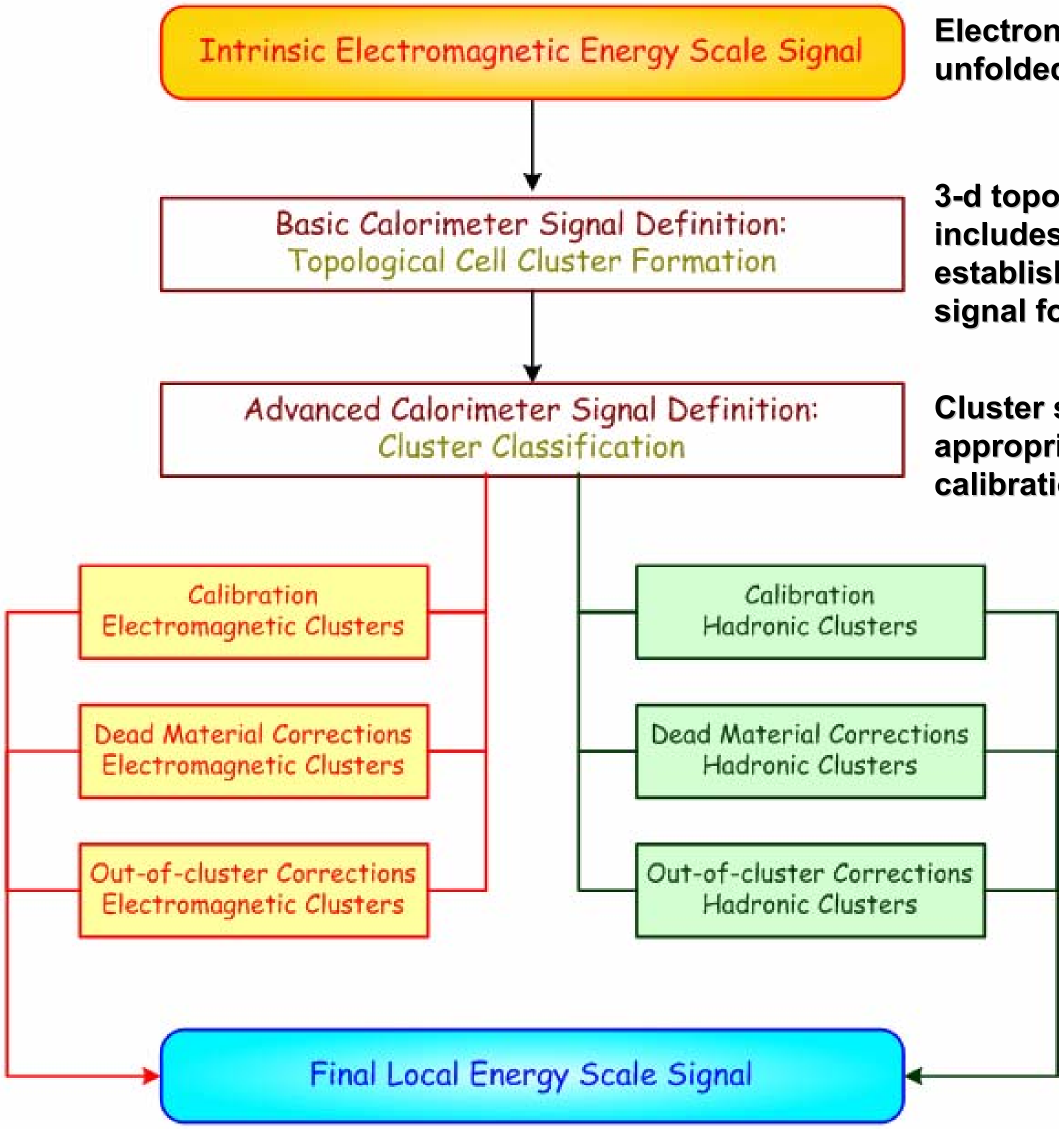

Guennadi Pospelov, ATLAS T&P Week March 2007

# Local Hadronic Calibration

# Local Hadronic Calibration: Basic Ingredients

- Clusters
  - group of calo cells forming basic energy deposit
- Cluster classification
  - classify clusters as EM, hadronic, or unknown
- Hadronic weighting
  - obtain and apply weights to cells in clusters
- Dead material correction
  - some energy is deposited in upstream material
- Out-of-cluster correction
  - some energy is deposited in cells outside clusters

# Local Hadronic Calibration: Flow




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

**3-d topological cell clustering includes noise suppression and establishes basic calorimeter signal for further processing**

**Cluster shape analysis provides appropriate classification for calibration and corrections**

**Cluster character depending calibration (cell signal weighting for HAD, to b developed for EM)**

**Apply dead material corrections specific for hadronic and electromagnetic clusters, resp.**

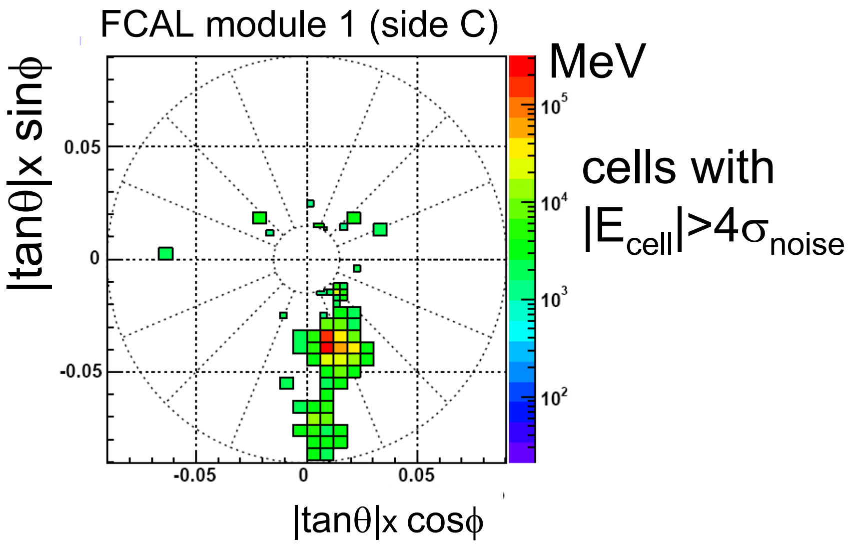
**Apply specific out-of-cluster corrections for hadronic and electromagnetic clusters, resp.**

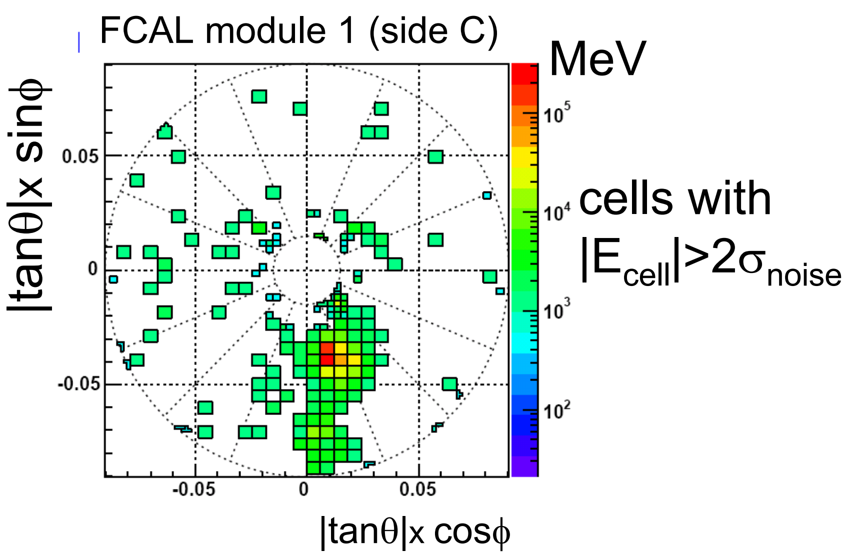
# Local Hadronic Calibration: Clusters

- 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

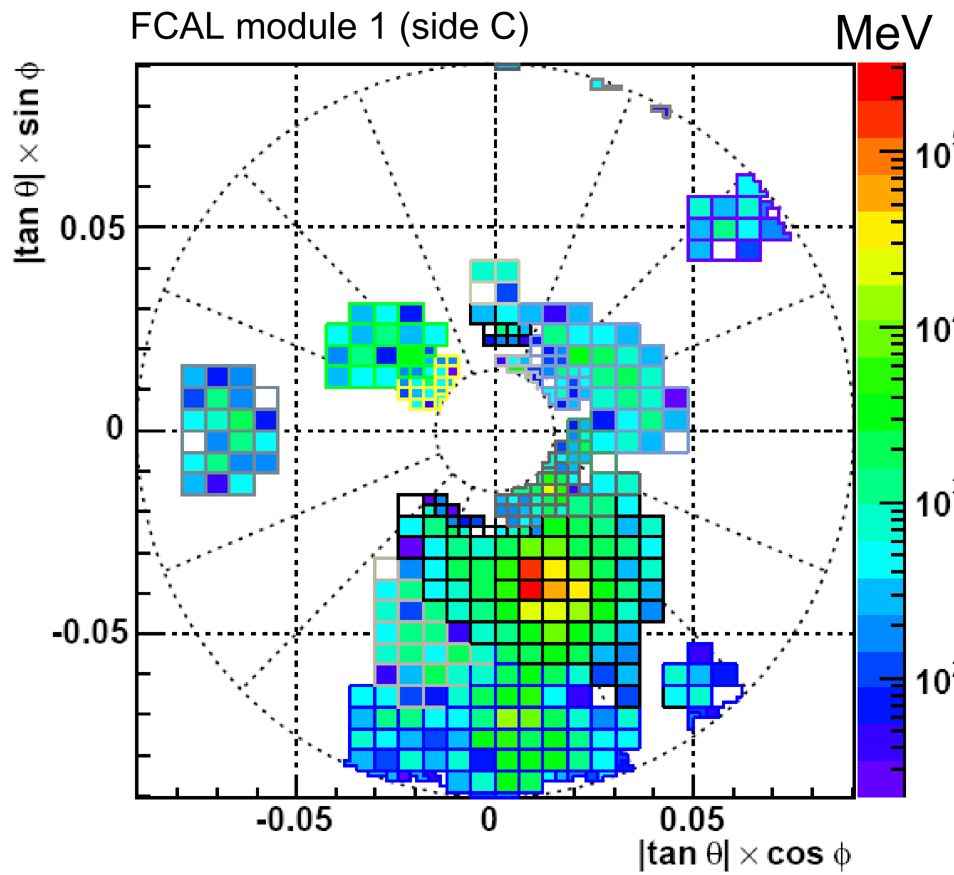
# Local Hadronic Calibration: Clusters

Sven Menke



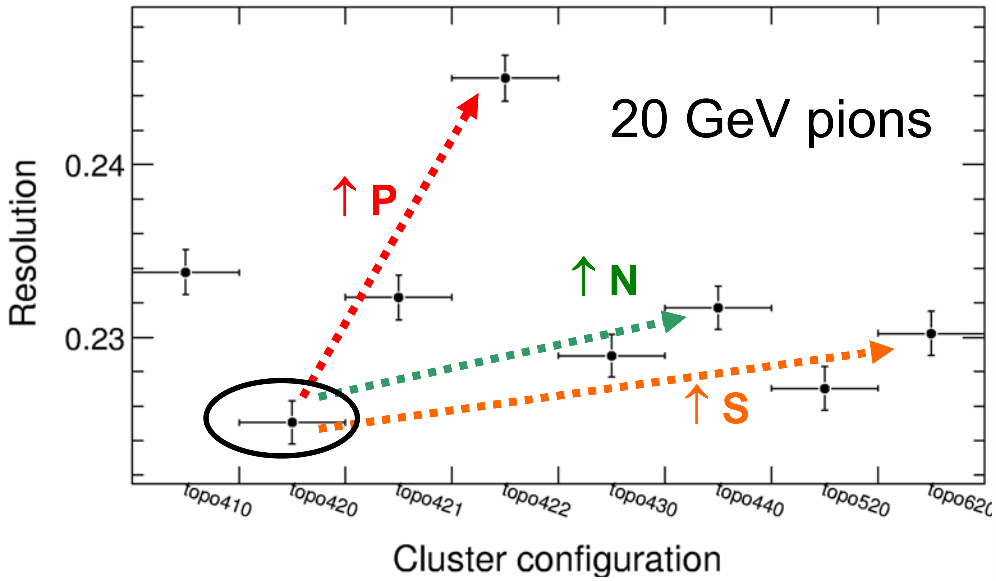




- Topological clustering
  - 4,2,0 clusters in FCal
    - jets with $p_T$ > 50 GeV

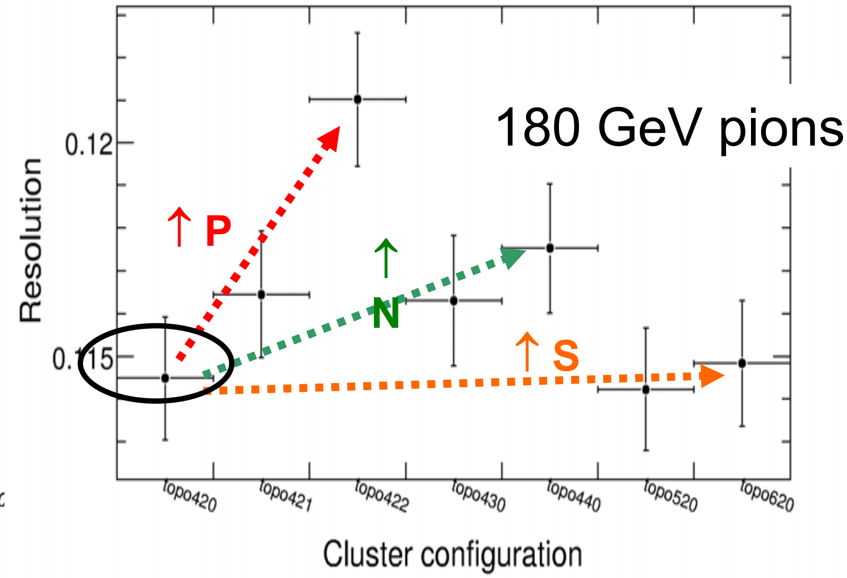


# Local Hadronic Calibration: Clusters

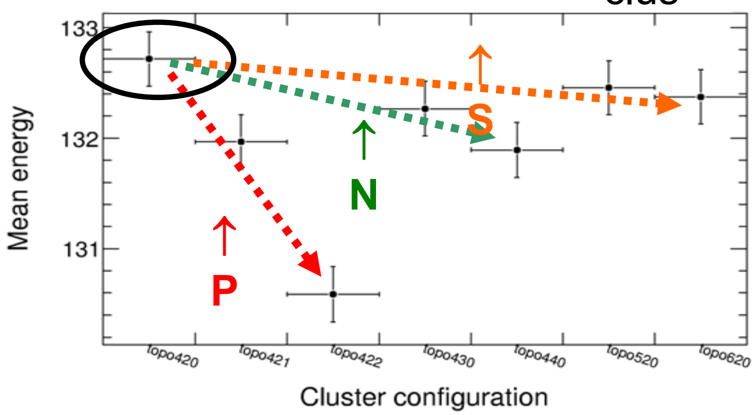
Resolution of Sum $E_{clus}$




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

# Local Hadronic Calibration: Clusters

- 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
  - Additional secondary maxima in hadronic and strip layers included if not shadowed by maxima in EM layers given above
  - maxima threshold set to $E$ > 500 MeV
  - one cell can share energy between two clusters
- Aim at one cluster per isolated $e^{\pm}$, $\gamma$, $\pi^{\pm}$
  - Presently ~1.6 particles/cluster in jet context

# Local Hadronic Calibration: Cluster Classification

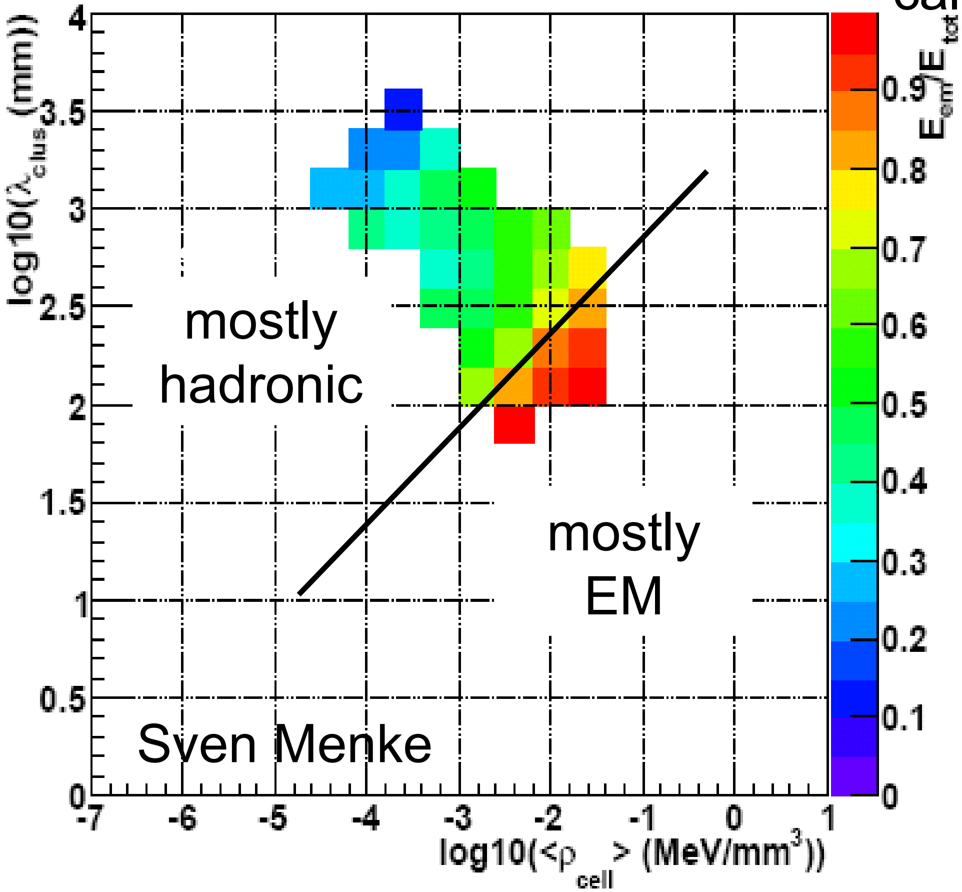
- Cluster classified as EM, hadronic, unknown
- Use MC single pions (charged and neutral)
- EM fraction method
  - Select EM clusters using the correlation of
    - $F_{EM} = E_{EM}/E_{tot}$ from MC single $\pi^{\pm}$ calibration hits
    - shower shape variables in single $\pi^{\pm}$ MC events
      - $\lambda$ = cluster barycenter depth in calo
      - $\rho$ = energy weighted average cell density
  - Implementation
    - keep $\mu_F$ and $\sigma_F$ in bins of $|\eta|$, $E$, $\lambda$, $\rho$ of clusters
    - for a given cluster
      - if $E < 0$, then classify as unknown
      - lookup $\mu_F$ and $\sigma_F$ from the observables $|\eta|$, $E$, $\lambda$, $\rho$
      - cluster is EM if $\mu_F + \sigma_F > 90\%$, hadronic otherwise

## ❑ EM fraction method: example

$2.0 < |\eta| < 2.2$

$4 \text{ GeV} < E_{clus} < 16 \text{ GeV}$

mean of $F_{EM}$ from calibration hits




other method using three cluster shape observables has also been investigated (P. Stavina)

# Local Hadronic Calibration: Cluster Classification

- Phase-space pion counting method
  - Classify clusters using the correlation of
    - shower shape variables in single $\pi^{\pm}$ MC events
      - $\lambda$ = cluster barycenter depth in calo
      - $\rho$ = energy weighted average cell density
    - .

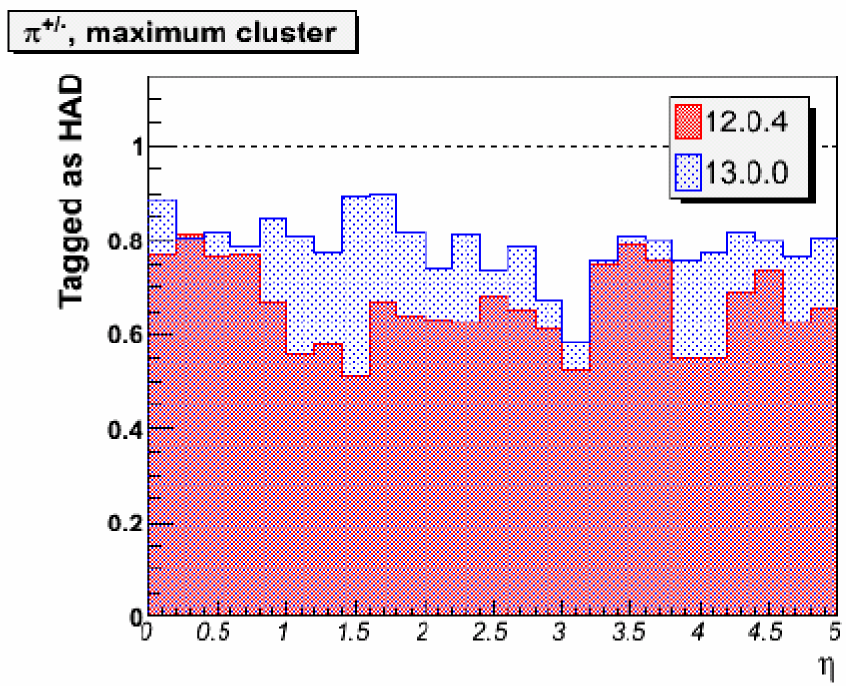
$$F \equiv \frac{\varepsilon\left(\pi^0\right)}{\varepsilon\left(\pi^0\right) + 2\varepsilon\left(\pi^-\right)}$$

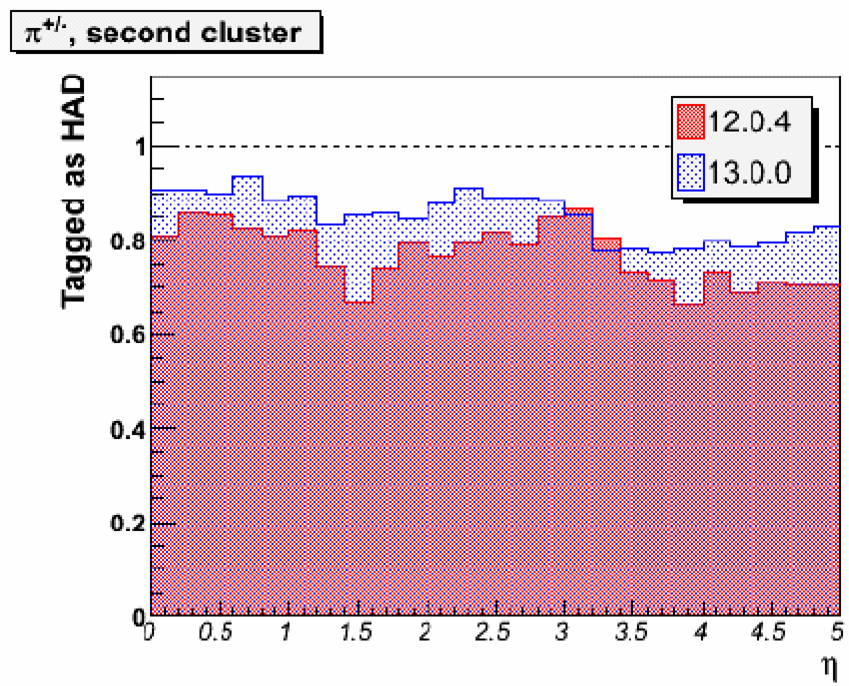
$$\varepsilon\left(X\right) = \frac{N\left(X\right) \text{ producing a cluster in a given } \eta, E, \lambda, \rho}{N\left(X\right) \text{ total}}$$

  - Implementation
    - keep *F* in bins of $\eta$, *E*, $\lambda$, $\rho$ of clusters
    - for a given cluster
      - if *E* < 0, then classify as unknown
      - lookup *F* from the observables $|\eta|$, *E*, $\lambda$, $\rho$
      - cluster is EM if *F* > 50%, hadronic otherwise

# Local Hadronic Calibration: Cluster Classification

- Phase-space pion counting method performs better
  - probability of charged pion clusters to be tagged as hadronic as a function of charged pion $\eta$
    - 12.0.4 = EM fraction method, 13.0.0 = phase-space method

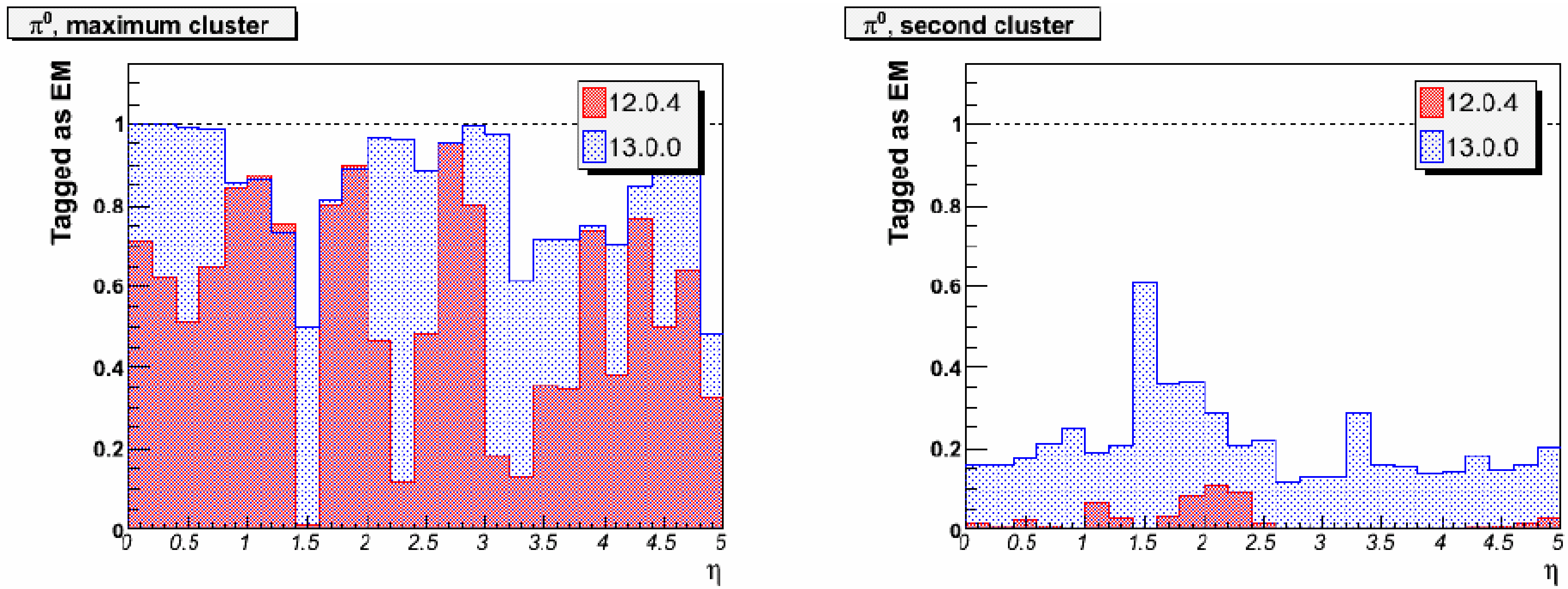



Genadi Pospelov, T&P week, 20 March 2007

# Local Hadronic Calibration: Cluster Classification

- Phase-space pion counting method performs better
  - probability of neutral pion clusters to be tagged as EM vs neutral pion η
    - 12.0.4 = EM fraction method, 13.0.0 = phase-space method




Genadi Pospelov, T&P week, 20 March 2007

# Local Hadronic Calibration: Hadronic Weighting

- Use simulated single pions from 1 to 1000 GeV, uniform in $\eta$ in full ATLAS
  - Reconstruct and classify clusters
  - Using calibration hits, obtain

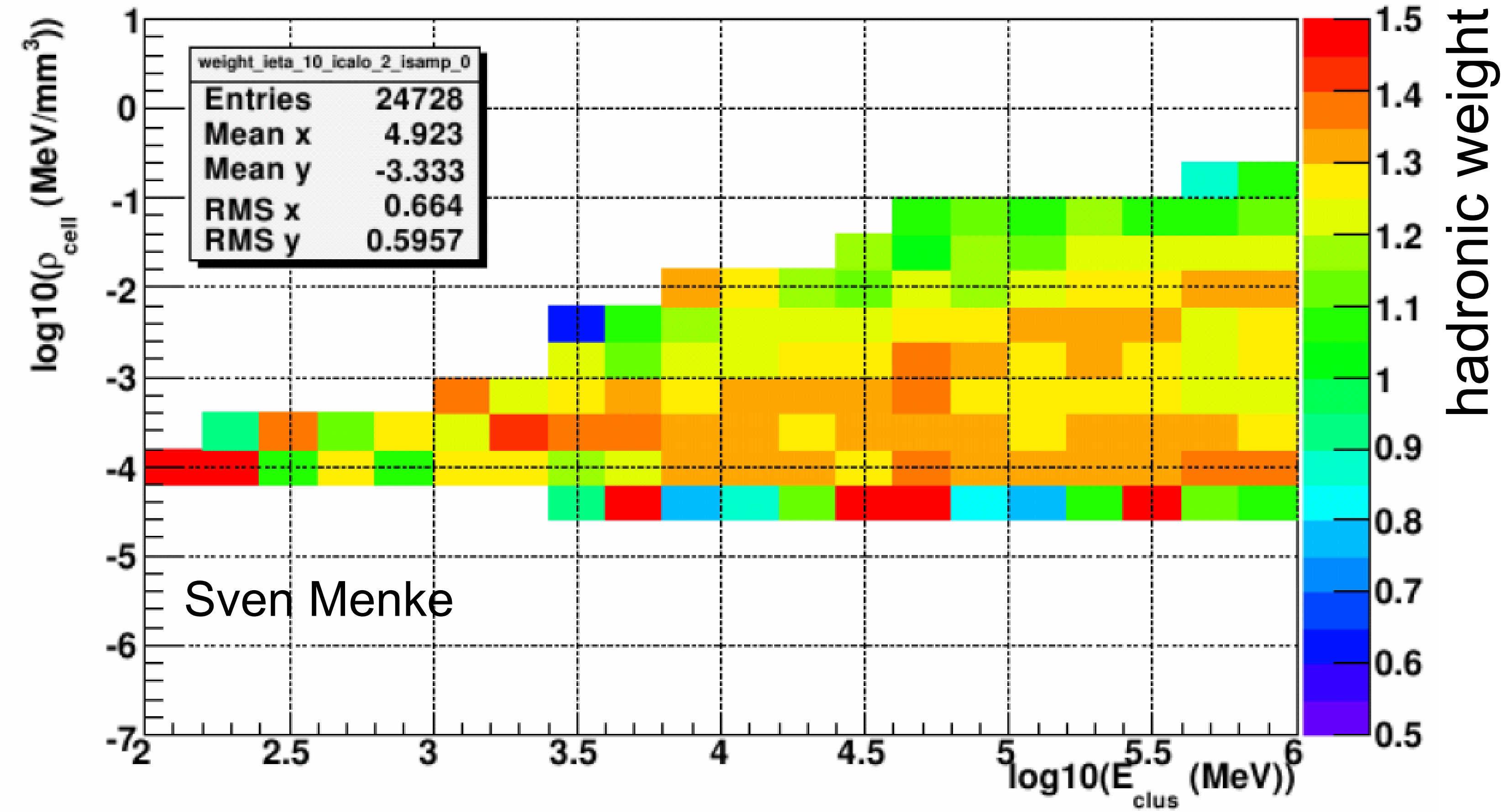
$$w = \left\langle \left( E_{cell}^{Em} + E_{cell}^{nonEm_{vis}} + E_{cell}^{nonEm_{invis}} + E_{cell}^{escaped} \right) \Big/ E_{cell} \right\rangle$$

  - Ecell is the reconstructed cell signal on electromagnetic energy scale
    - contains noise and HV corrections!
  - keep $w$ as a function of $\log(E_{cluster})$, $\log(|\rho_{cell|}| = |E_{cell}|/V_{cell})$ 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 $|\eta_{cluster}|$, $\log(E_{cluster})$, $\log(\rho_{cell})$

# Local Hadronic Calibration: Hadronic Weighting

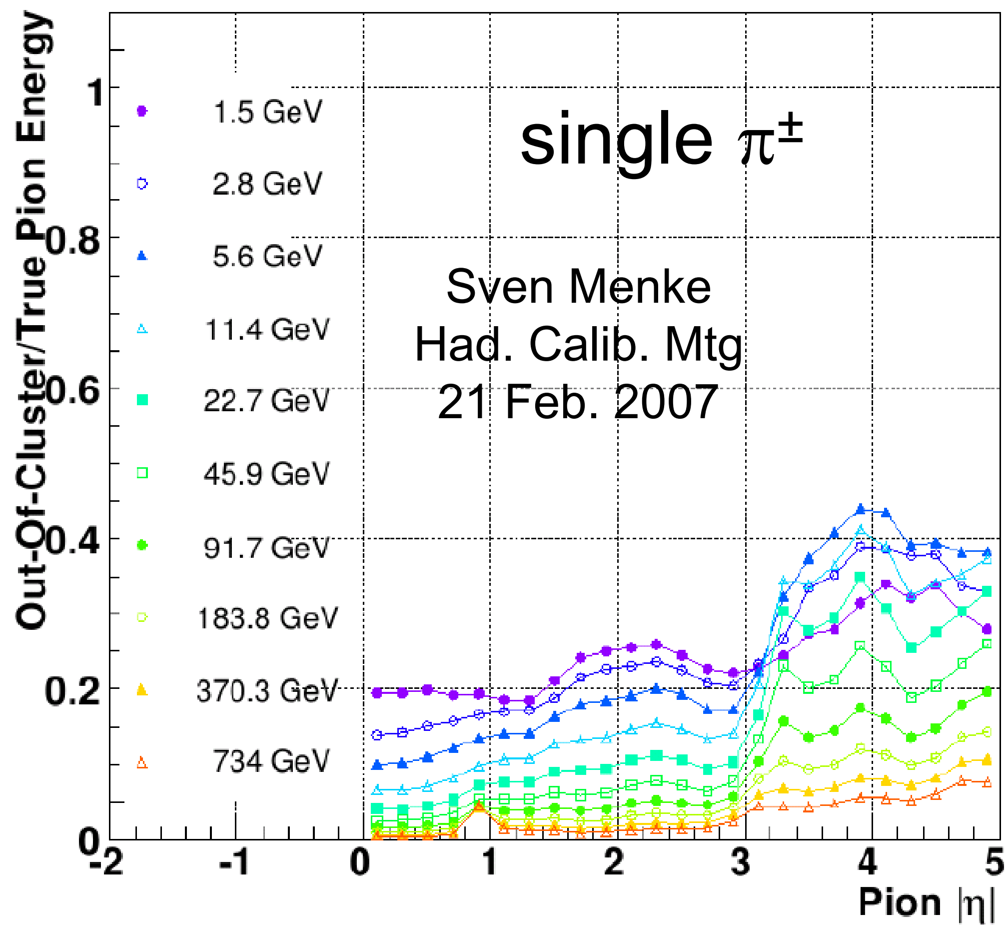
## ❑ Example

- ❖ 2.0 < |η| < 2.2, HEC layer 1



# Local Hadronic Calibration: Out-of-cluster Correction

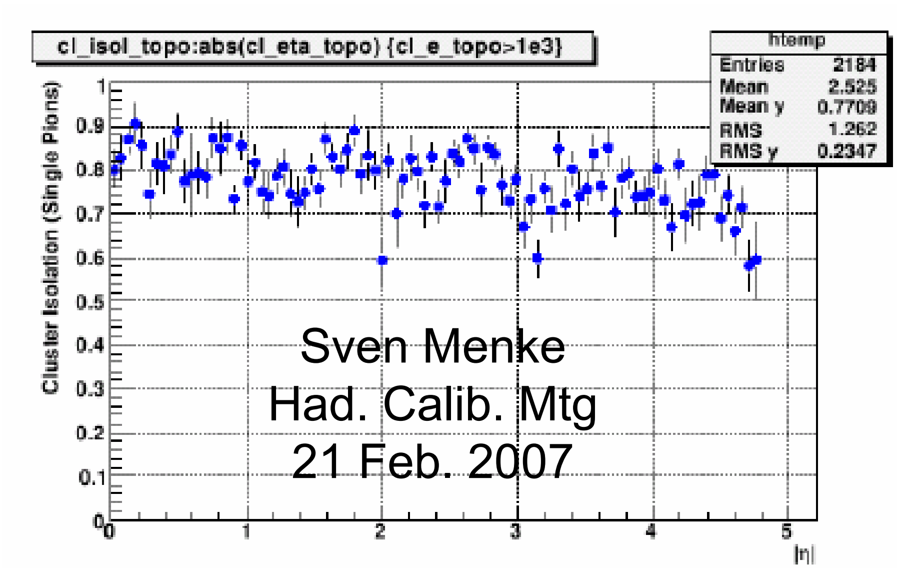
- Consider a cluster produced by a single pion
  - some energy is deposited in nearby cells not part of the cluster
    - use calib hits
- Correction factor is $\left(1+\frac{E_{OOC}}{E_{cluster}}\right)$
- Keep lookup table from $\pi^{\pm}$
  - $|\eta|$, $E$, $\lambda$ bins

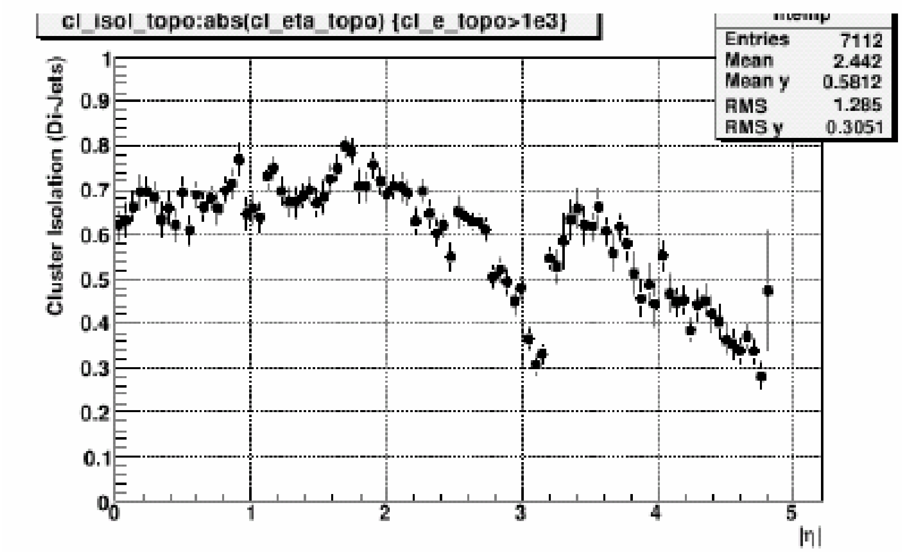


# Local Hadronic Calibration: Out-of-cluster Correction

- Need to avoid over correcting
  - out-of-cluster energy for one cluster could actually be deposited in another cluster
    - especially important for jets!
- Isolation moment
  - The fraction of calo cells neighbouring (2D) the cluster but not part of any other clusters in each sampling is determined
  - Sampling energy weighted averages are calculated
- Out-of-cluster correction estimate is the product of
  - out-of-cluster correction from lookup table
  - isolation moment
- This correction is applied as a multiplicative factor to all the cells in the cluster

# Local Hadronic Calibration: Out-of-cluster Correction



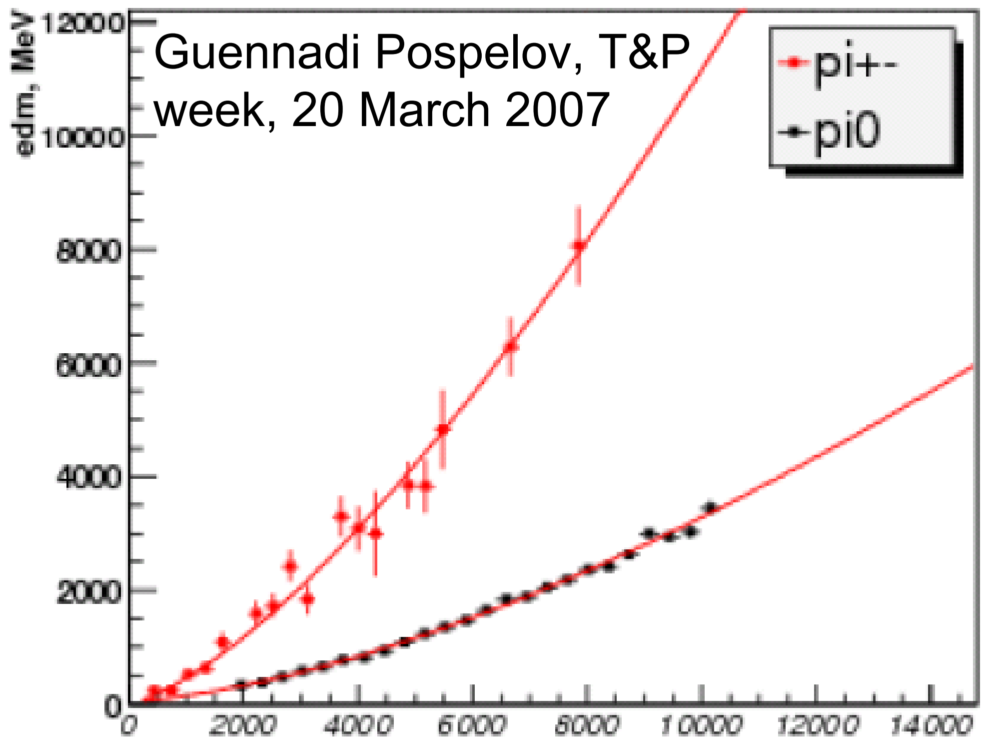




- Isolation moment of clusters depends on the physics sample
  - single pions
    - most clusters isolated
  - di-jets
    - less isolation

# Local Hadronic Calibration: Dead Material Corrections

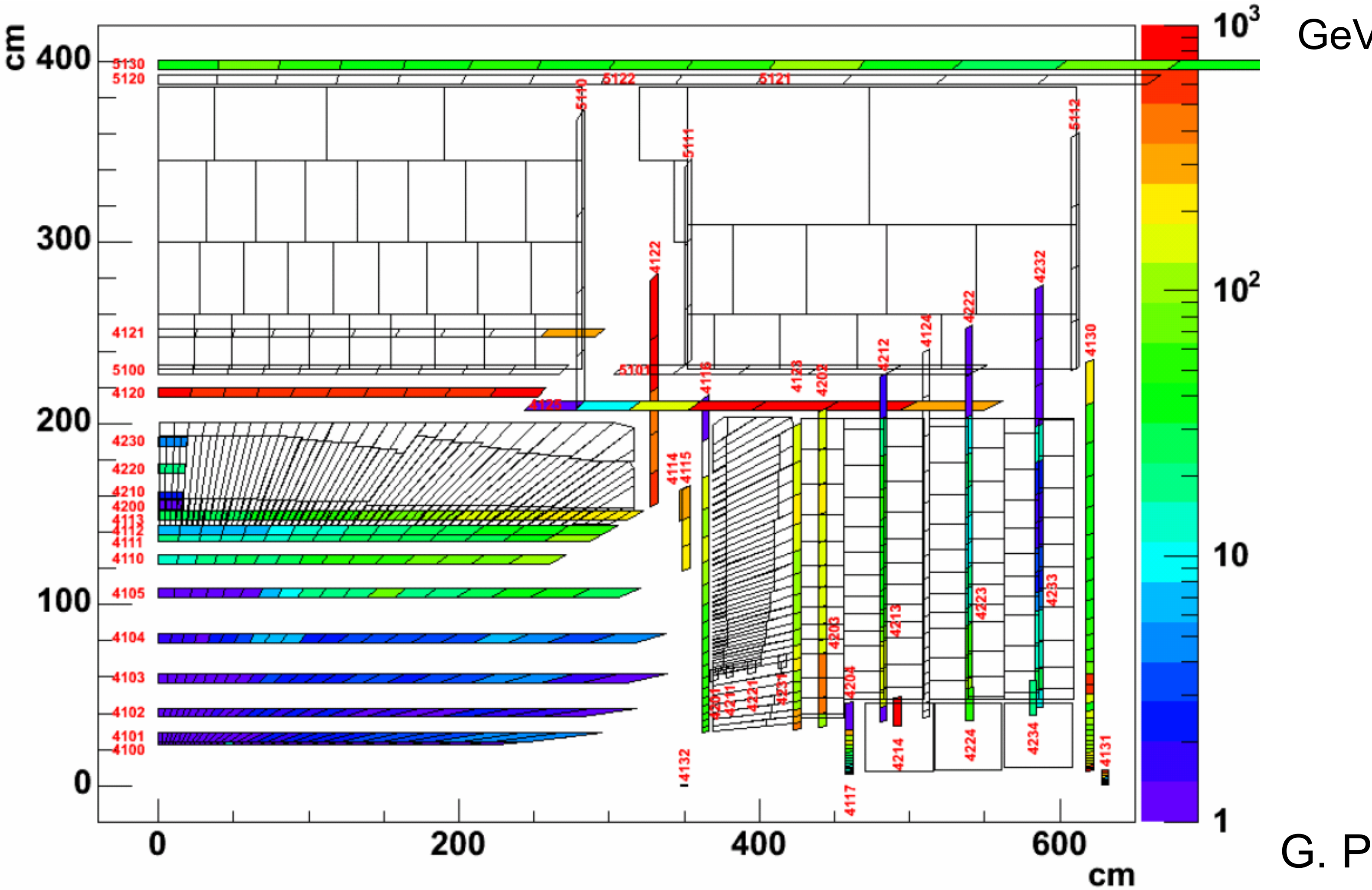
- Some energy is deposited in DM: correlate
  - energy deposited in DM (MC) near the cluster
  - functions of cluster cells energy (EM scale)
- Consider each DM region separately

- For example consider the energy in the DM between the barrel presampler and the first sampling as a function of the geometrical mean of the cluster presampler energy and first sampling energy



# Local Hadronic Calibration: Dead Material Corrections

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

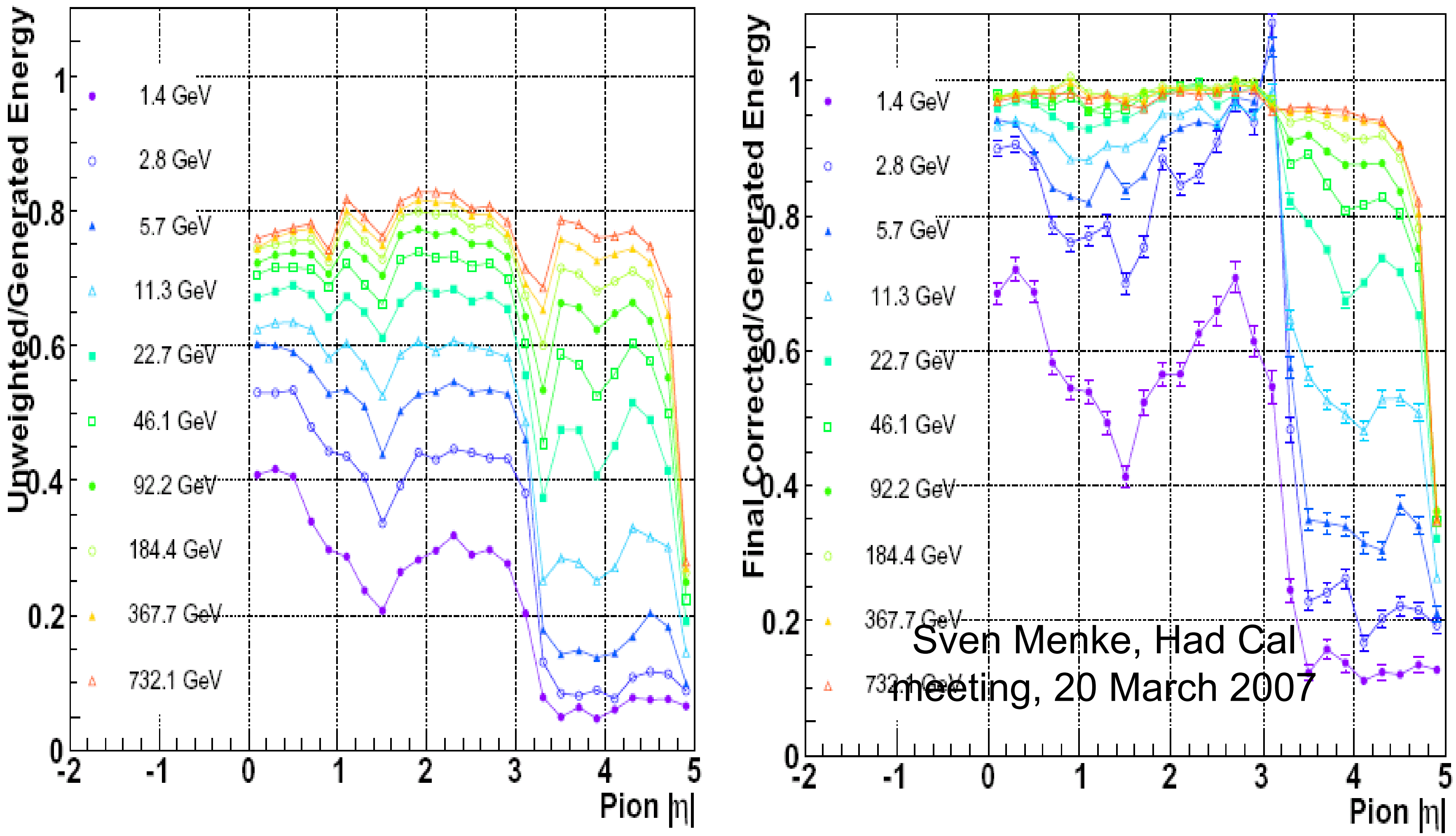



G. Pospelov

# Local Hadronic Calibration: Performance

- Performance on single charged pions

E(EM scale) / E(true) E(all corrections) / E(true)

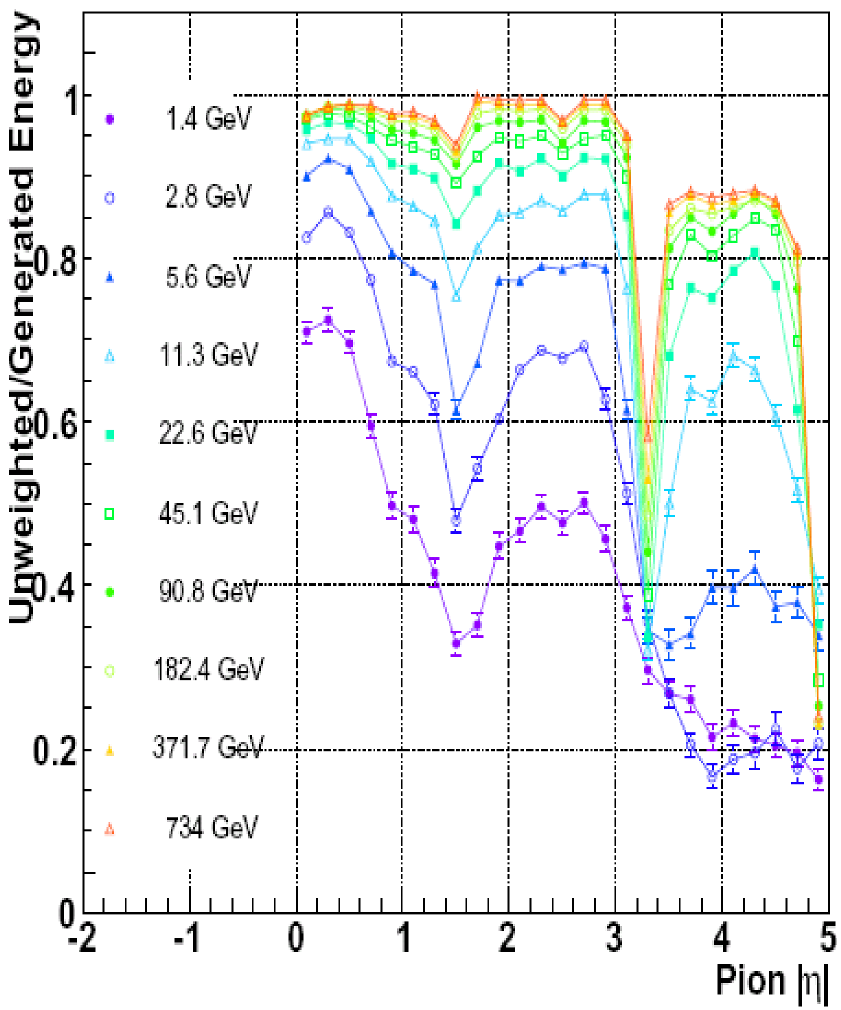



Sven Menke, Had Cal meeting, 20 March 2007

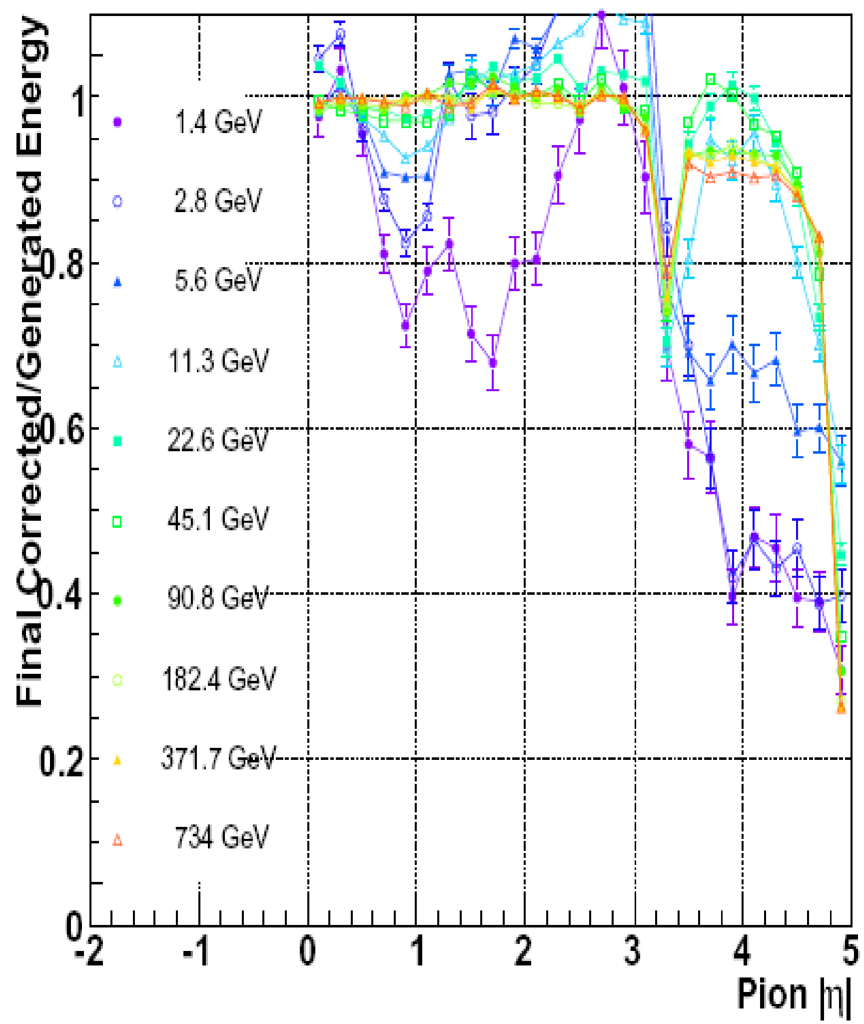
# Local Hadronic Calibration: Performance

- Performance on single neutral pions

E(EM scale) / E(true)



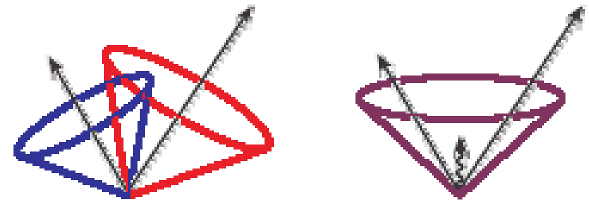

E(all corrections) / E(true)



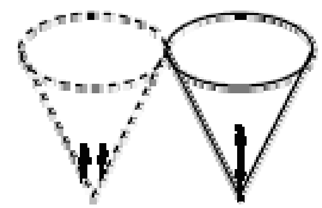
# Jet Reconstruction & Calibration

# Jet Algorithm Choices: Guidelines for ATLAS

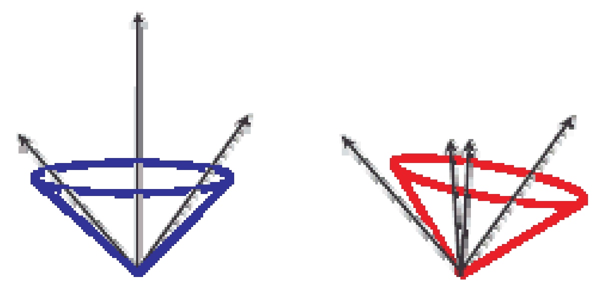
- Initial considerations
  - Jets define the hadronic final state of basically all physics channels
    - Jet reconstruction essential for signal and background definition
    - Applied algorithms not necessarily universal for all physics scenarios
  - Which jet algorithms to use?
    - Use theoretical and experimental guidelines collected by the Run II Tevatron Jet Physics Working Group
      - J.Blazey et al., hep-ex/0005012v2 (2000)
- Theoretical requirements
  - Infrared safety
    - Artificial split due to absence of gluon radiation between two partons/particles
  - Collinear safety
    - Miss jet due to signal split into two towers below threshold
    - Sensitivity due to Et ordering of seeds
  - Invariance under boost
    - Same jets in lab frame of reference as in collision frame
  - Order independence
    - Same jet from partons, particles, detector signals



infrared sensitivity
(artificial split in absence of soft gluon radiation)



collinear sensitivity (1)
(signal split into two towers below threshold)



collinear sensitivity (2)
(sensitive to $E_t$ ordering of seeds)

# Jet Algorithms: Experimental Requirements

- Detector technology independence
  - Jet efficiency should not depend on detector technology
    - Final jet calibration and corrections ideally unfolds all detector effects
- Minimal contribution from spatial and energy resolution to reconstructed jet kinematics
  - Unavoidable intrinsic detector limitations set limits
- Stability within environment
  - (Electronic) detector noise should not affect jet reconstruction within reasonable limits
    - Energy resolution limitation
    - Avoid energy scale shift due to noise
  - Stability with changing (instantaneous) luminosity
    - Control of underlying event and pile-up signal contribution
- "Easy" to calibrate
  - Small algorithm bias for jet signal
- High reconstruction efficiency
  - Identify all physically interesting jets from energetic partons in perturbative QCD
  - Jet reconstruction in resonance decays
    - High efficiency to separate close-by jets from same particle decay
    - Least sensitivity to boost of particle
- Efficient use of computing resources
  - Balance physics requirements with available computing
- Fully specified algorithms only
  - Absolutely need to compare to theory at particle and parton level
  - Pre-clustering strategy, energy/direction definitions, recombination rules, splitting and merging strategy if applicable

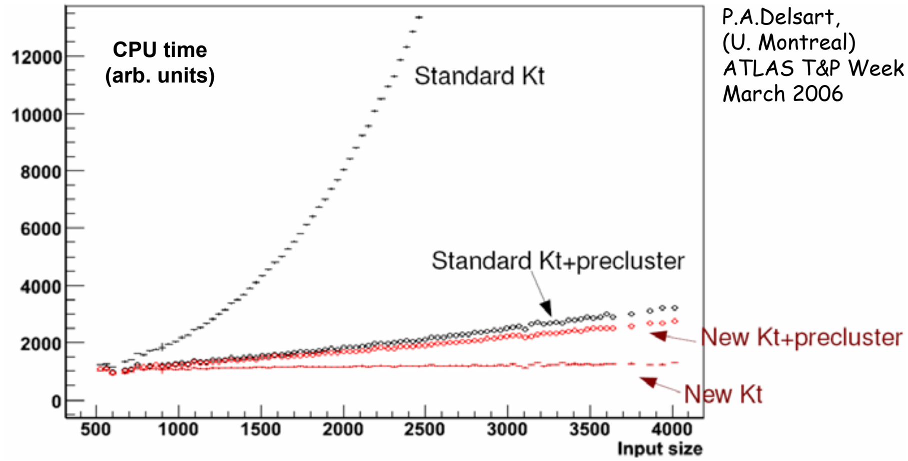
# Jet Finders in ATLAS: Implementations [1]

- General implementation
  - All jet finders can run on all *navigable* ATLAS data objects *providing a 4-momentum* through the standard interface
  - Tasks common to different jet finders are coded only once
    - Different jet finders use the same tools
  - Default full 4-momentum recombination
    - Following Tevatron recommendation
- Cone jets
  - Seeded fixed cone finder
    - Iterative cone finder starting from seeds
    - Free parameters are: seed Et threshold (typically 1 GeV) and cone size R
    - Needs split and merge with overlap fraction threshold of 50%
  - Seedless cone finder
    - Theoretically ideal but practically prohibitive
      - Each input is a seed
      - New fast implementation in sight: G.P.Salam & Gregory Soyez, *A practical seedless infrared safe cone jet algorithm*,arXiv:0704.0292
    - No split and merge needed
  - MidPoint cone
    - Seeded cone places seeds between two large signals
    - Still needs split and merge

# Jet Finders in ATLAS: Implementations [2]

## Dynamic Angular Distance Jet Finders

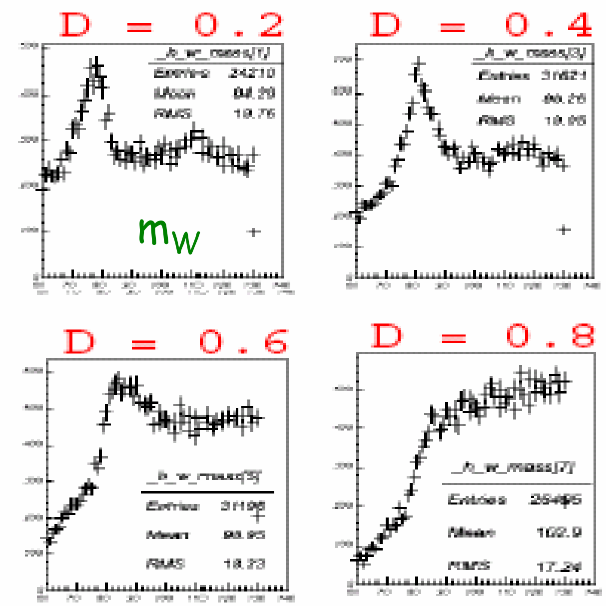
- Kt algorithm
  - Combines protojets if relative Pt is smaller than Pt of more energetic protojet
  - No seeds needed
  - Fast implementation available → no pre-clustering to reduce number of input objects needed anymore




- "Aachen" algorithm
  - Similar to Kt, but only distance between objects considered (no use of Pt)
- Optimal Jet Finder
  - Based on the idea of minimizing a test function sensitive to event shape
  - Uses unclustered energy in jet finding

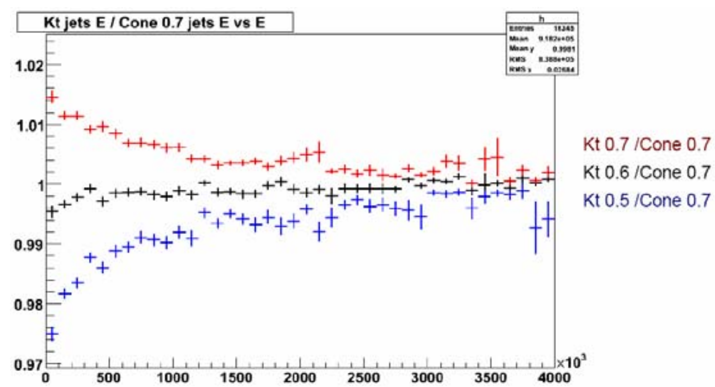
# Jet Finders in ATLAS: Algorithm Parameters

- Adjust parameters to physics needs
  - Mass spectroscopy W →jj in ttbar needs narrow jets
    - Generally narrow jets preferred in busy final states like SUSY
    - Increased resolution power for final state composition
  - QCD jet cross section measurement prefers wider jets
    - Important to capture all energy from the scattered parton
- Common configuration
  - ATLAS, CMS, theory
    - J.Huston is driving this
  - Likely candidate two-pass mid-point
    - Chosen on the base of least objections
    - Some concerns about properties (esp. infrared safety)
    - Second pass should reduce problem with missing signal




N.Godbhane, JetRec Phone Conf. June 2006

| Algorithm | Cone Size R | Distance D | Clients |
|---|---|---|---|
| Seeded Cone | 0.4 | | W mass spectroscopy, top physics |
| Kt | | 0.4 | |
| Seeded Cone | 0.7 | | QCD, jet cross-sections |
| Kt | | 0.6 | |




P.-A. Delsart, JetRec Phone Conf. June 28, 2006

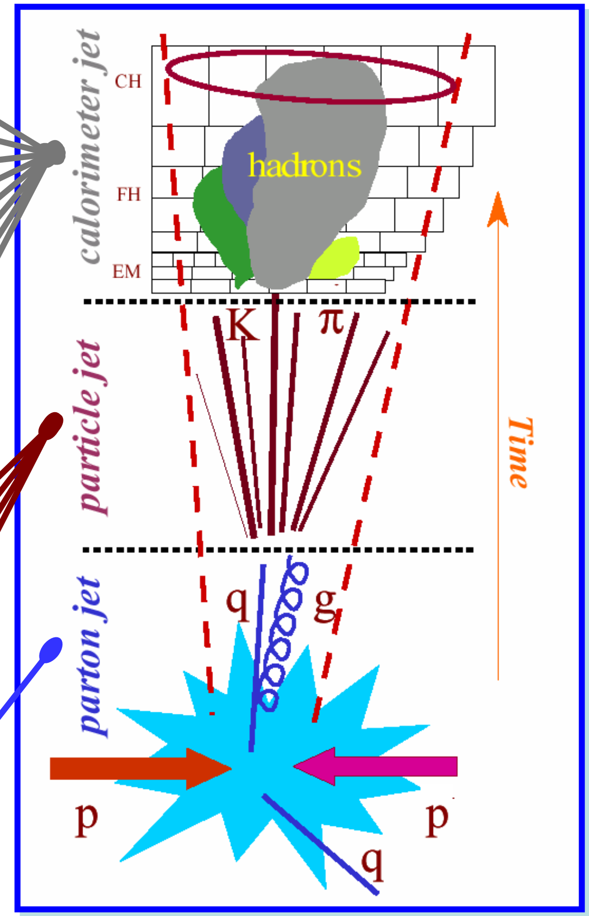
# ATLAS Jet Reconstruction and Calibration

- Contributions to the jet signal:

longitudinal energy leakage
detector signal inefficiencies (dead channels, HV…)
pile-up noise from (off-time) bunch crossings
electronic noise
calo signal definition (clustering, noise suppression ,…)
dead material losses (front, cracks, transitions…)
detector response characteristics (e/h ≠ 1)
jet reconstruction algorithm efficiency

jet reconstruction algorithm efficiency
added tracks from in-time (same trigger) pile-up event
added tracks from underlying event
lost soft tracks due to magnetic field

physics reaction of interest (parton level)




- Try to address reconstruction and calibration through different levels of factorization

# ATLAS Calorimeter Jets: Tower Jets

**CaloCells** (em scale)

↓ Tower Building ($\Delta\eta\times\Delta\varphi=0.1\times0.1$, non-discriminant)

**CaloTowers** (em scale)

↓ Tower Noise Suppression (cancel E<0 towers by re-summation)

**ProtoJets** (E>0,em scale)

↓ Jet Finding (cone R=0.7,0.4; $k_t$)

**Calorimeter Jets** (em scale)

↓ Jet Based Hadronic Calibration ("H1-style" cell weighting in jets etc.)

**Calorimeter Jets** (fully calibrated had scale)

↓ Jet Energy Scale Corrections (noise, pile-up, algorithm effects, etc.)

**Physics Jets** (calibrated to particle level)

→ In-situ Calibration (underlying event, physics environment, etc.) → **Refined Physics Jet** (calibrated to parton level)

- Collect all electromagnetic energy cell signals into projective towers
  - ideal detector geometry, grid $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$
  - No explicit use of longitudinal readout granularity in jet finding
  - "Uncalibrated" electromagnetic energy scale input signals
- Cancel noise by re-summation of these towers
  - Towers with E<0 are added to near-by towers with E>0 until the resulting protojet has E>0 (all cells are kept!)
- Run jet finding on the protojets
  - Results are "uncalibrated" electromagnetic energy scale calorimeter tower jets
- Apply cell level calibration
  - Retrieve all cells used in the jet
  - Apply cell level calibration weights depending on cell energy density and cell location
  - Results are hadronic energy scale jets with e/h>1 and dead material corrections applied
  - The jets are defined by the seeded cone algortihm with R=0.7
- Additional corrections for residual Et and $\eta$ dependencies of the reconstructed jet energy, and since recently also for jet algorithm depedencies, are applied
  - Results are physics jets calibrated at particle level
- More corrections determined from in-situ calibration channels
  - $W\rightarrow jj$ provides mass constraint for calibration
  - Photon/Z+jet(s) balance well measured electromagnetic systems against the jet
  - Care required with respect to calibration biases by specific physics environment
    - No color coupling between W and rest of event, for example

calorimeter domain

jet reconstruction domain

physics analysis domain

P. Loch, University of Arizona, created: March 14, 2006, last change: September 18, 2006

# Determination of “H1-style” Calibration Weights

- Cone QCD jets with R = 0.7 from J1…J8 production
  - Covers wide kinematic range ~10 GeV to few TeV
- For calorimeter tower jet…
  - Find matching truth jet
  - Extract cells from tower jet
  - Fit cell signal weights $w_i$ with constraint

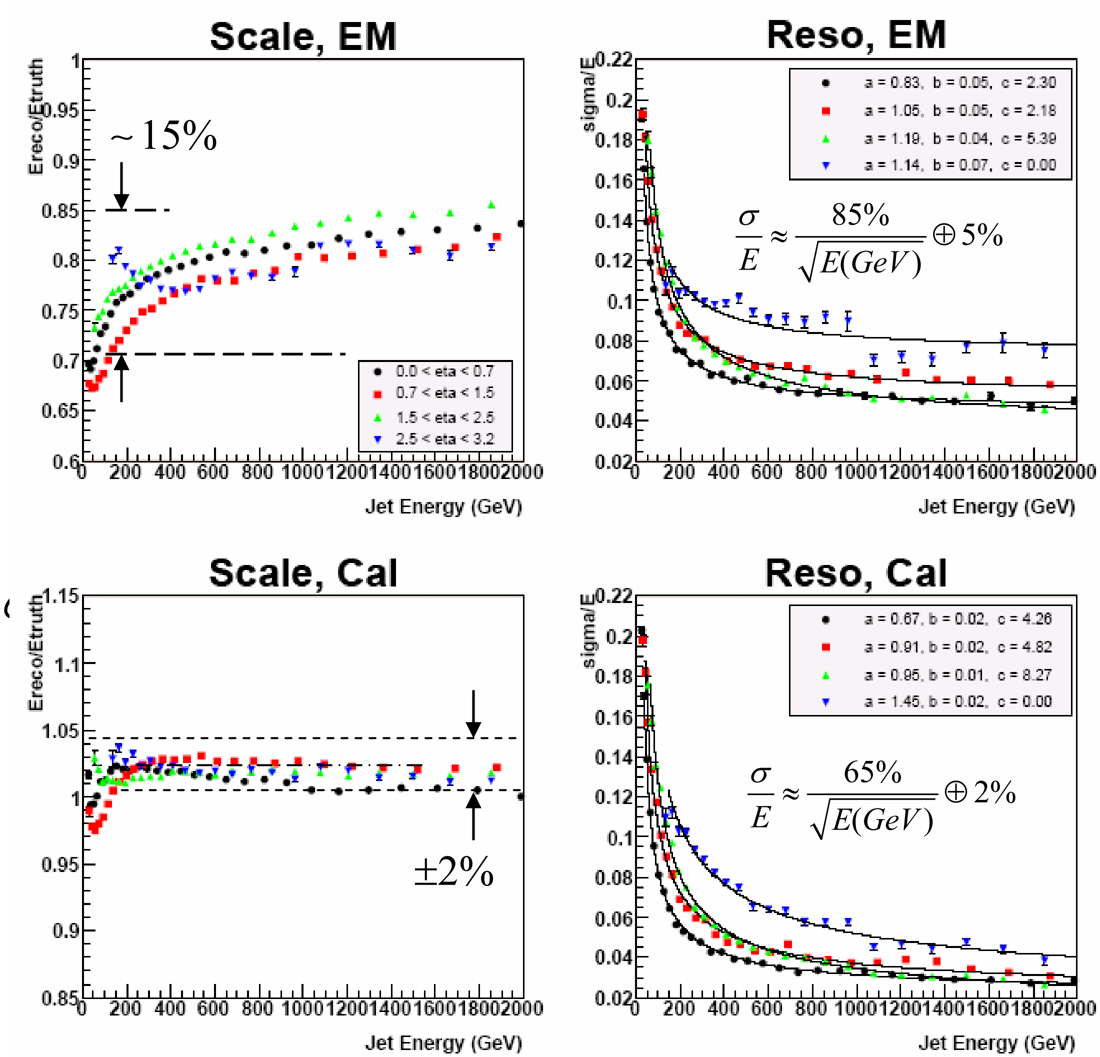
$$E_{jet}^{reco} = \sum_{cells \in jet} w_i(\rho, s_{cell}) \cdot E_{cell} \equiv E_{jet}^{truth}, \text{ with } \rho_i \leq \rho < \rho_{i+1}$$

  - Correct residual (Et,η)-dependent signal variations after cell signal weights are fixed
    - This is done for all other tower and “uncalibrated” topojets as well
- All done within Athena (JetCalib package)
  - Can be used for all kinds of calibration fits
  - Jets from other algorithms or parameters corrected this way

# Tower Jet Features: Performance

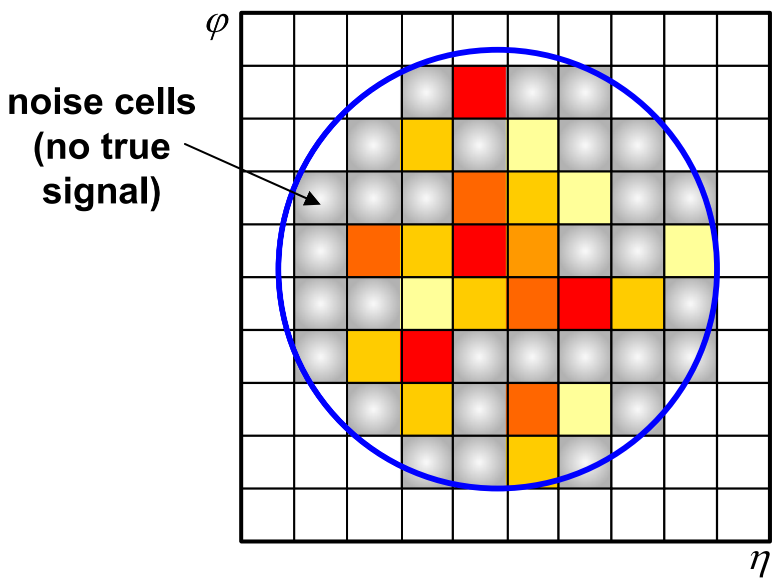
- QCD di-jets
  - "H1" motivated cell calibration
  - apply (Et,η) dependent overall jet energy corrections to adapt for other jet algorithms
  - Clearly only possible to derive from MC
    - Choice of normalization/truth reference is particle jet pointing into same direction as tower jet
    - Low factorization level as calibration merges dead material corrections and jet algorithm driven corrections into the signal weighting functions
    - Somewhat high maintenance load
      - Requires re-fitting with every new round of simulations
    - Also limitations due to definition of truth reference
      - Fluctuations at particle level folded into fit
- Successfully applied in many physics analysis
  - It has been a baseline for a long time
  - It will be a good benchmark in the near future

Chiara Roda HCP 2006



# Tower Jet Features: Some Limitations

- Too many non-signal cells included in jet
  - (quasi)projective towers feature longitudinal summing and (large) fixed area
    - Non-discriminative cell signal summation
  - Relatively large noise contribution
    - non-optimal performance!

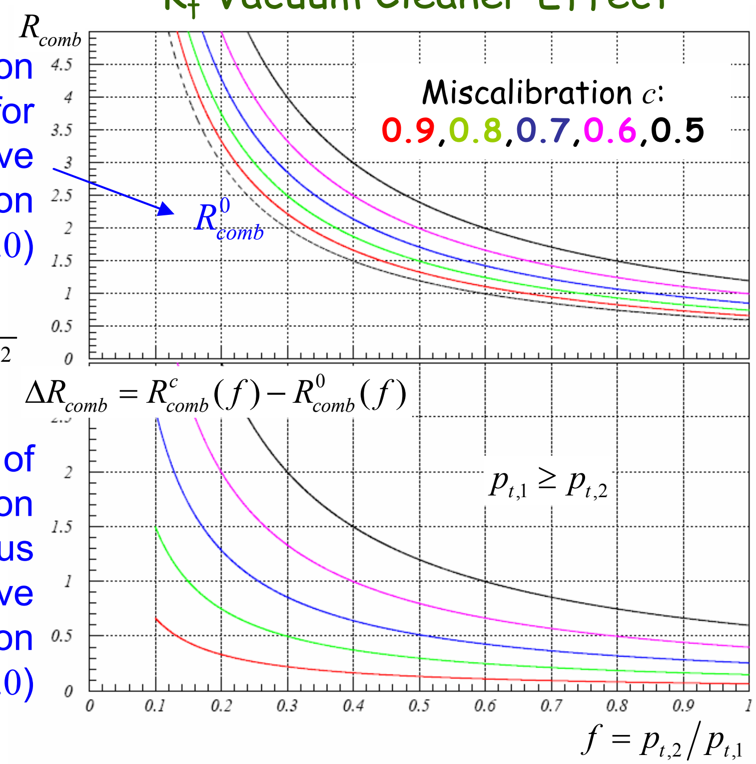



$$R_{comb} = \sqrt{\Delta\eta^2 + \Delta\varphi^2}$$

"$K_t$ Vacuum Cleaner Effect"

combination radius for perfect relative calibration ($c = 1.0$)

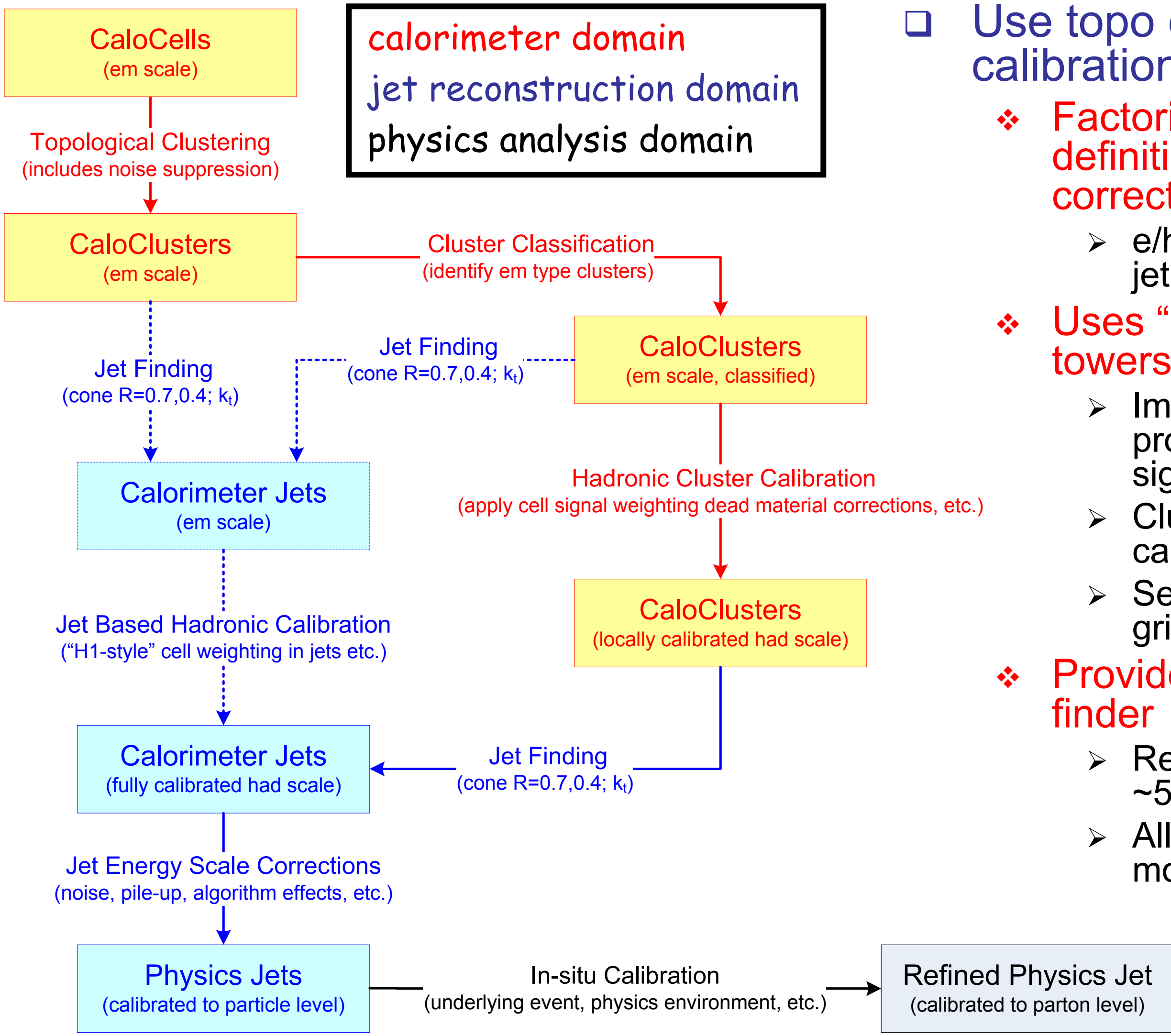
change of combination radius for various levels of relative mis-calibration ($c \neq 1.0$)




Width up to which two protojets are combined by the Kt algorithm as function of the Pt ratio $f$ of the lower energetic protojet to the higher energetic one, for various levels of relative mis-calibration $c$

- Uncalibrated input
  - Relative miscalibration between towers >30% possible
    - Electromagnetic energy scale only!
  - Especially problematic for Kt
    - Jets can get very big due to miscalibration

# Calorimeter Cluster Jets

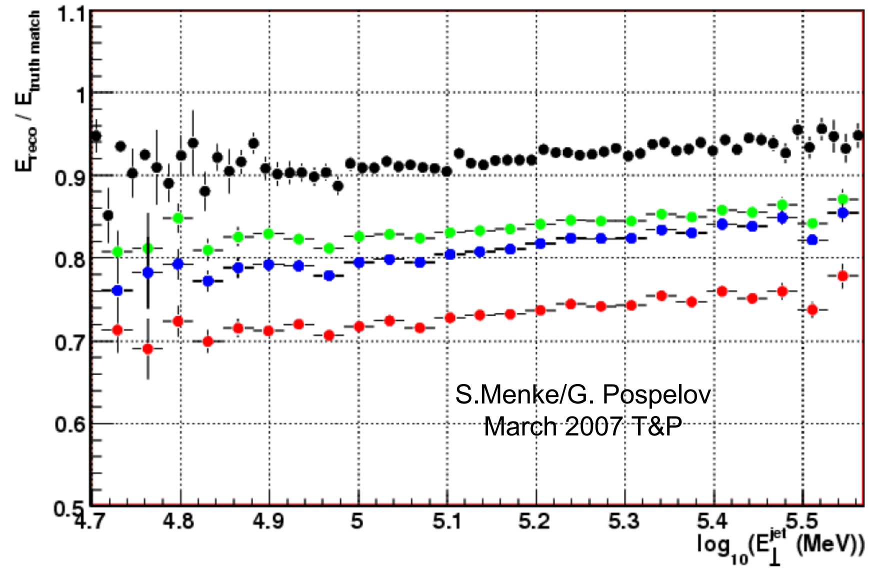


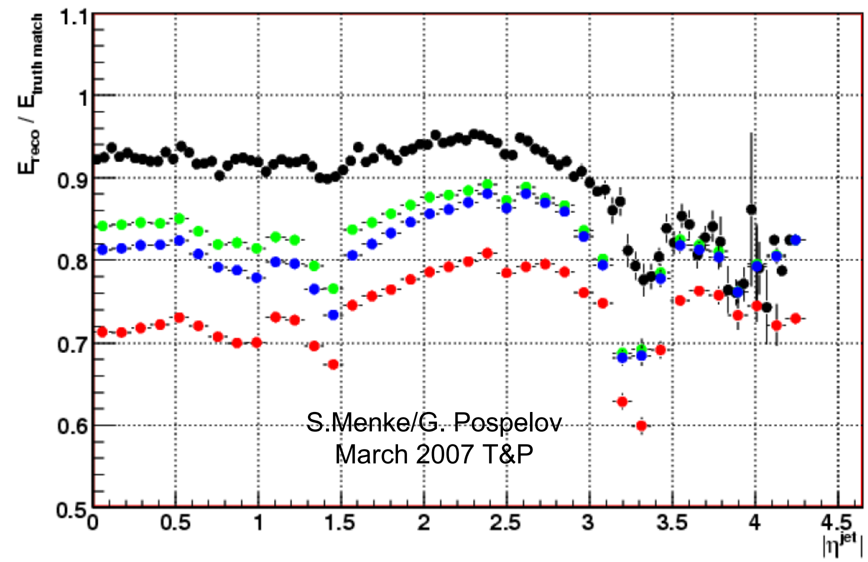

- Use topo cluster with local hadronic calibration
  - Factorizes hadronic calibration, signal definition corrections, dead material corrections
    - e/h corrected at the detector level, no jet context needed
  - Uses "3-d energy blobs" rather than towers
    - Implied noise suppression → cluster provide signal of (constant) minimum significance over fluctuations
    - Clusters are freely located in calorimeter
    - Seed splitting due to fixed geometry grid like for tower jets less likely
  - Provides better calibrated input to jet finder
    - Relative mis-calibration much smaller, ~5% at most
    - Allows possible input selection to be more comparable with particle jets

P. Loch, University of Arizona, created: March 14, 2006, last change: September 18, 2006

# Calorimeter Cluster Jets: Performance [1]

- Apply local hadronic calibration to jets
  - QCD di-jets
    - C4 sample
  - Flat response in Et within +/- 2%
    - ~50-400 GeV range
  - Rapidity dependence ok up to $|\eta|\approx2.7$
    - likely em scale calibration problem in FCal
    - Dead material correction in
- Indicators
  - All calibrations and corrections derived from single particle signals alone
    - no jet context bias at all
  - Achieved high level of factorization (!!)
    - classification, weighting, dead material and out-of-cluster corrections are mutually independent derived and applied
    - all energy scale dependent observables used in look-up or parametrized functions are calculated on the electromagnetic energy scale
  - Still missing
    - calibrations for electromagnetic clusters
    - jet context driven energy scale corrections
      - Dead material losses impossible to correct at cluster level
      - Jet algorithm efficiency corrections like out-of-cone

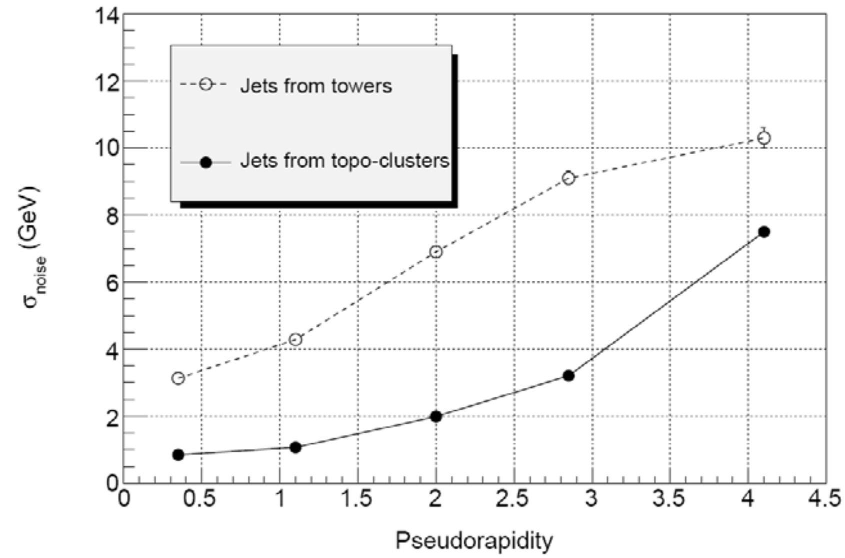


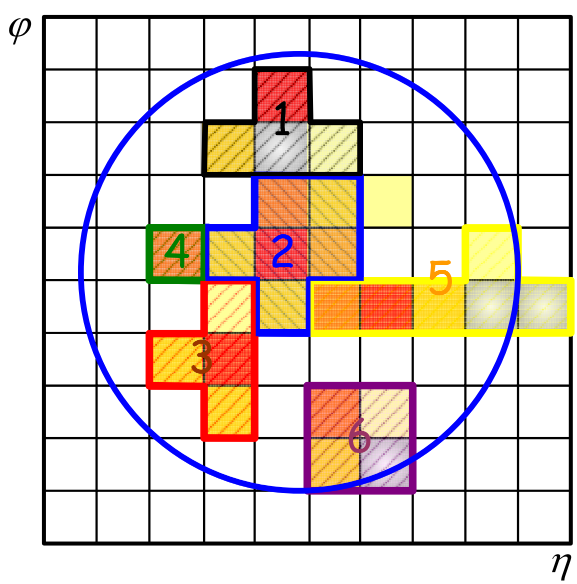



# Calorimeter Cluster Jets: Performance [2]

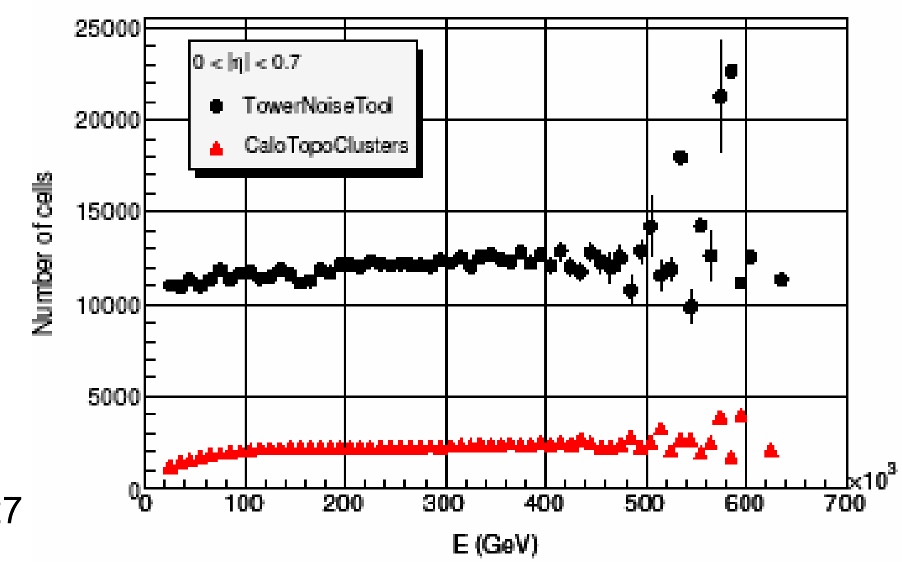
- Noise in jets
  - Only electronic noise studied so far
    - Need to understand the effect in pile-up scenario
  - clear indication of significant improvement
    - Expect due to "active" noise suppression in calorimeter signal
    - Much smaller number of cells contributing to jet signal

Noise in Calorimeter Jets vs Jet Rapidity




Number Cells in Calorimeter Jets vs Jet Energy



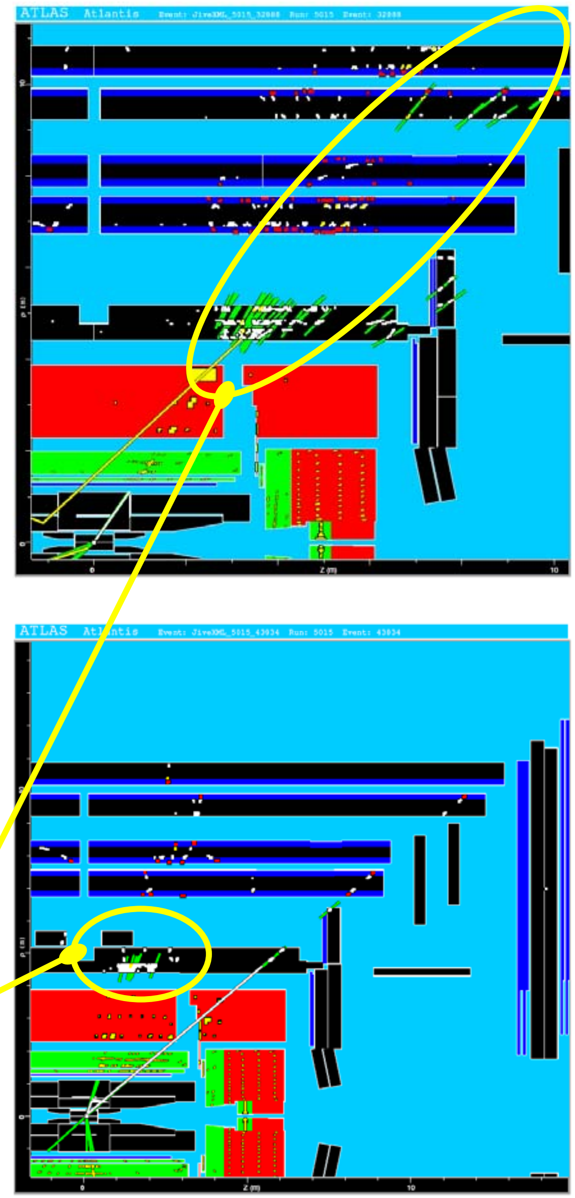

I.Vivarelli, Calorimeter Calibration Workshop, September 2006

# Calorimeter Cluster Jets: Preliminary Summary

- Present observations with respect to jet calibration
  - All calibrations and corrections derived from single particle simulations alone
    - No jet context bias at all in application of calibration
  - Achieving high level of factorization
    - Classification, signal weighting, dead material and out-of-cluster corrections are mutually independent derived and applied
    - All signal dependent observables used in look-up tables and/or parametrized functions are calculated on the electromagnetic energy scale
      - Least biased cluster signal is input to everything
  - Control of systematics
    - Factorization allows addressing systematic uncertainties at various levels of the reconstruction chain somewhat independently
    - More controlled scenario
      - Understanding relative importance of individual contributions
      - Prioritized signal quality improvement possible
- Available variables
  - Missing jet energy scale corrections can use a wealth of jet shape and cluster shape variables
    - Jet and cluster moments, cluster classification, can help to use jet composition jet-by-jet for calibration refinement and energy resolution improvement
  - Mostly uncovered territory so far

# Calorimeter Cluster Jets: Refinements

- still missing
  - Calibration for electromagnetic clusters
    - Only specific dead material corrections so far
    - Calibrations expected very soon
  - Jet context driven energy scale corrections
    - Dead material energy losses impossible to correct in cluster context need larger signal object volume
      - Far away from signal cluster
    - Jet algorithm inefficiency corrections
      - Loss of energy due to jet clustering algorithm application (*out-of-cone*,…)
      - Leakage losses for very high energetic jets or jets close to cracks

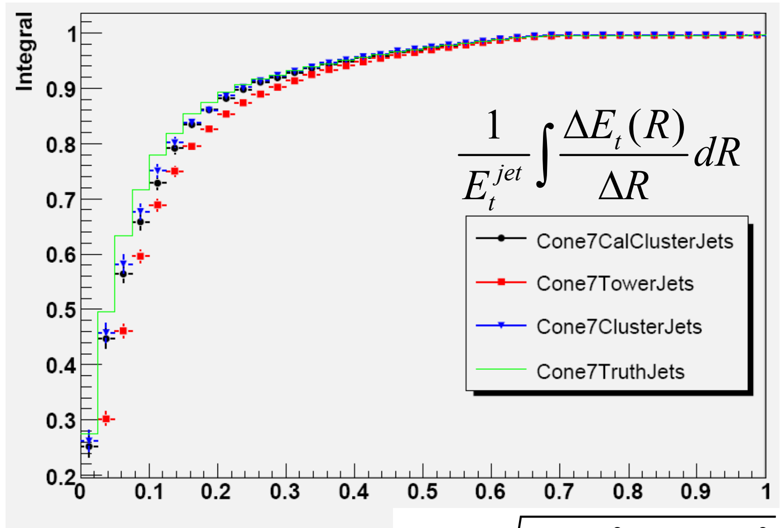


Frank Paige, ATLAS T&P Week February 2006

# Calorimeter Cluster Jets: More Refinement

- Using jet and cluster shapes
  - Wealth of shape information can be used for refined jet calibration
    - Jet and cluster moments, and cluster classification, can help to measure jet composition
    - Allow for jet-by-jet calibration refinements
      - Expect energy resolution improvements
  - Typical variables to consider
    - Energy sharing between EM and HAD calorimeter in jet
    - Jet energy fraction classified as electromagnetic at cluster level
    - Energy in clusters with significant deviations of principal axis from vertex extrapolated direction
      - Hints on magnetic field effect → charged pion/hadron contribution to jet
    - ...
  - Definitively some uncovered territory here!

Integrated Radial Jet Profile



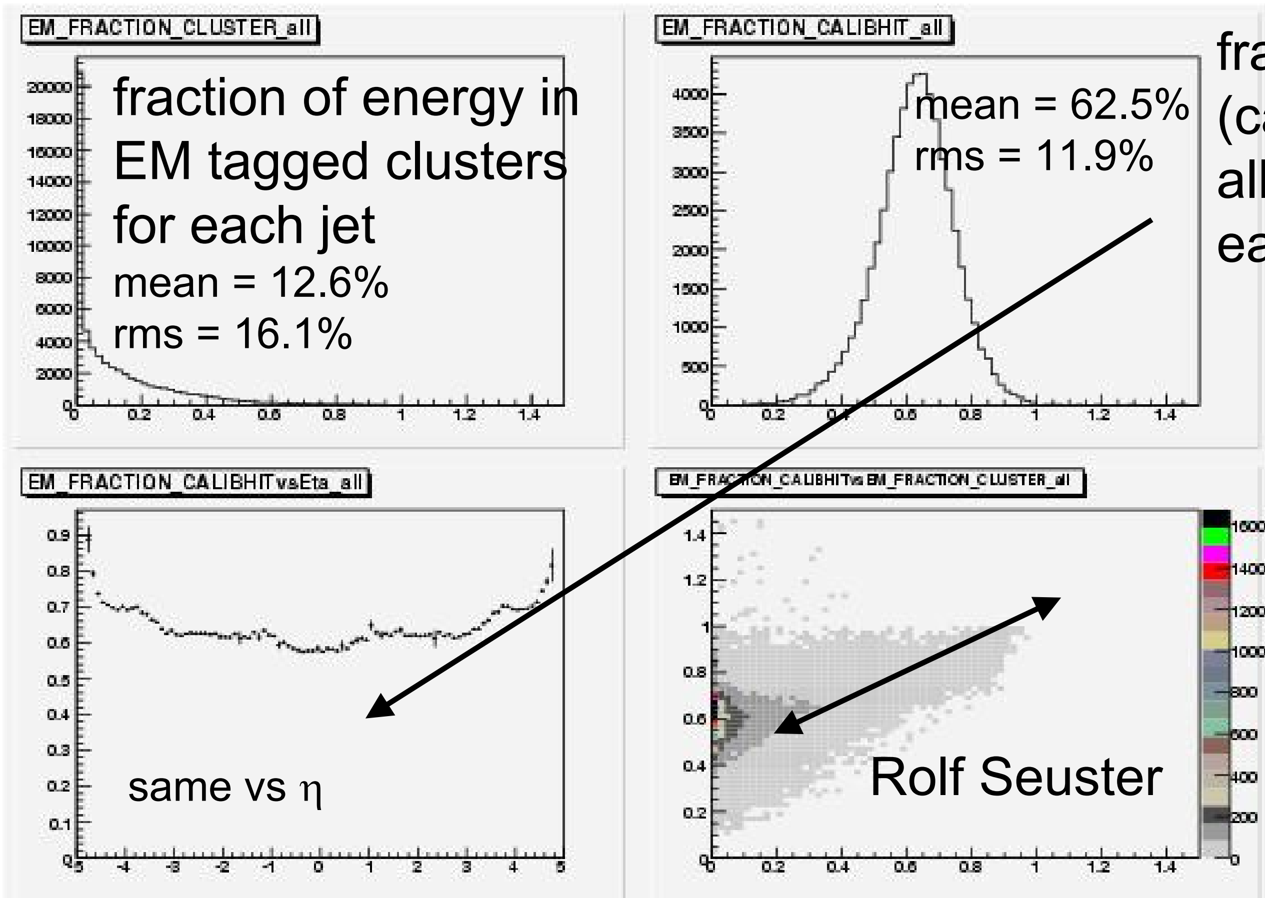

$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$$

Locally calibrated narrow cone TopoCluster Jets (R=0.7) with matched tower and truth jets

# Monitoring Cluster Classification in Jets

- very useful tools for assessing the validity of cluster classification

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

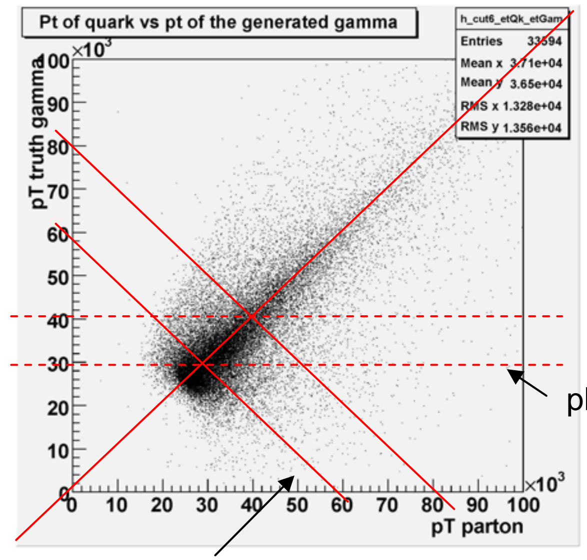
cluster classification works in the right direction!

# Tower Jets: Alternative Calibrations

- Alternative calibrations can be applied to tower and cluster jets
  - No significant performance differences in general
  - Final recommendation for jet calibration and jet signal basis needs ATLAS collision data
    - Input signals very likely topological clusters
- Modified cell signal weighting (Pisa)
  - use jet energy together with cell signal in weighting functions
    - Fully parametrized weighting functions
- Sampling energy based (Chicago)
  - Use weighted sampling energy sums in jets
    - Weights are parameterized as function of the calorimeter sampling energy and the fraction of energies in the EM and HAD calorimeters in a given jet
    - Few numbers, does not need cells
    - Not quite optimal but fast and a good candidate for HLT jet calibration
- Pseudo-H1 weighting (Wisconsin/BNL)
  - Similar to default cell level weighting scheme for tower jets
  - Some factorization
    - Cell weights are determined from particle jets in QCD with only relevant particles handed to detector simulation (no full event simulation)
    - Allows some factorization with respect to clusterization effects and avoids particle level jet finding biases

# Parton Level Calibration: Photon/Jet Balance

- Use in-situ calibration events
  - Pt balance Z+jet(s), photon+jet(s)
    - Affected by ISR/FSR, underlying event
      - Needs modeling to understand average balance
    - Some handles studied
      - Transverse Et flow




S.Jorgensen, CCW San Feliu Sept. 2006

**Mean transverse energy per η x φ = 0.1 x 0.1 :**

| | |
|---|---|
| Tower (RMS of el.noise ~140 MeV) | 16.17 ± 0.03 MeV |
| Recon tower protojet (tower preclusters after noise treatment) | 16.84 ± 0.03 MeV |
| Recon topocluster protojet (topoclusters) | 12.52 ± 0.02 MeV |
| Particle protojet (Σ particles per tower) | 19.91 ± 0.02 MeV |

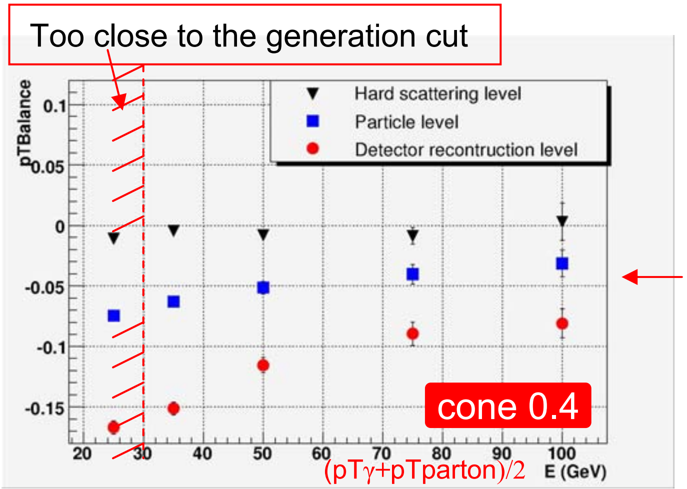
EM scale

3 GeV in cone 0.7

- Average UE level ~10% RMS of el.noise (very sensitive to noise suppression)

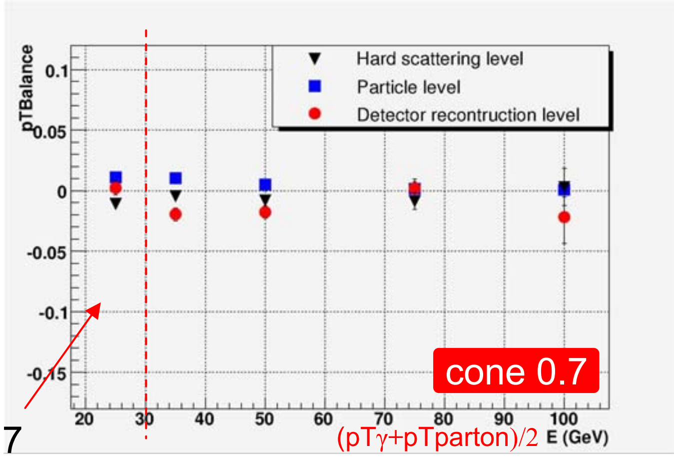
# Parton Level Calibration: Jet Algorithms in Pt Balance

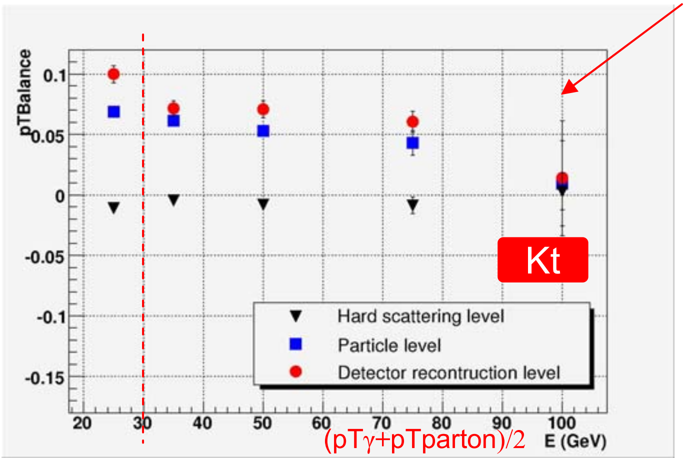
Slide from S.Jorgensen, CCW San Feliu Sept. 2006




• Cone 0.4 collects only the core of the jet

• Leakage out of cone and UE compensate in cone 0.7




• Excess of energy in Kt jets (D=1) due to UE and noise

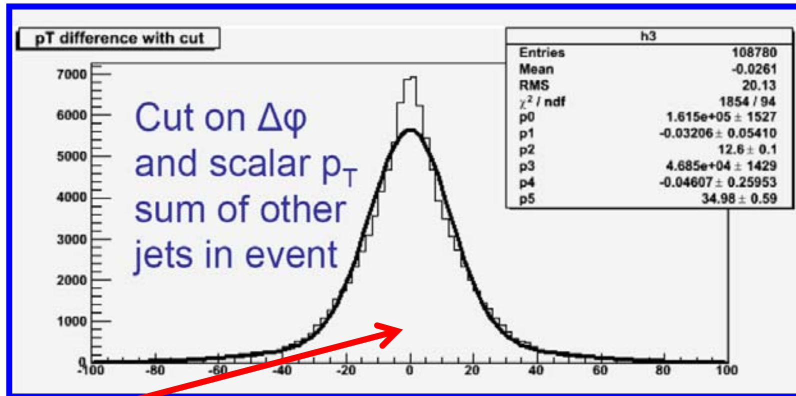
Differences between recon and particle levels related to the standard H1 weighting (calibrated for cone 0.7)

• Biases on pT balance MOP for the different jet algorithms:

| **Algorithms** | **Cone 0.7** | **Cone 0.4** | **Kt** (D=1) |
|---|---|---|---|
| **Parton level** | -1 - 0% | -1 - 0% | -1 - 0% |
| **Particle level** | 1 - 0% | -6 - -3% | 6 - 1% |
| **Recon level** | -2 - 0% | -15 - -7% | 7 - 2% |

# Parton Level Calibration: Extraction of Calibration

- Jet calibration using module or sampling weights (coarse) from data




- Double Gaussian likelihood:

$$L = N_1 \exp\left\{-\frac{1}{2}\left(\frac{p_T^{\gamma} - p_T^{Jet}}{\sigma_1}\right)^2\right\} + N_2 \exp\left\{-\frac{1}{2}\left(\frac{p_T^{\gamma} - p_T^{Jet}}{\sigma_2}\right)^2\right\}$$

- Jet pT:

$$p_T^{Jet} = \frac{E_{Calib}^{Jet}}{\cosh\left(\eta^{Jet}\right)}$$

**M. Hurwitz (U Chicago) et al., priv. comm. September 2006**

- Calibrated jet energy:

$$E_{Calib}^{Jet} = \left(A1 + A2\ln\left(E^{gj}\right)\right)E_{EM}^{Jet} + \left(B1 + B2\ln\left(E^{gj}\right)\right)E_{Had}^{Jet}$$

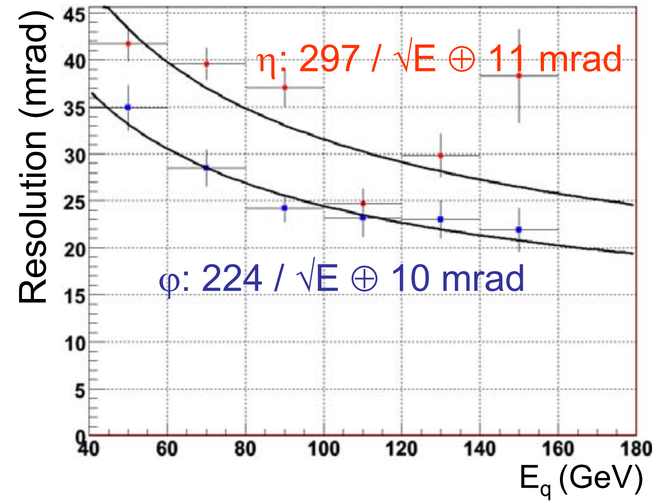
- Energy used in calibration formula:

$$E^{gj} = p_T^{\gamma}\cosh\left(\eta^{Jet}\right)$$ *iterative estimate if no photon!*

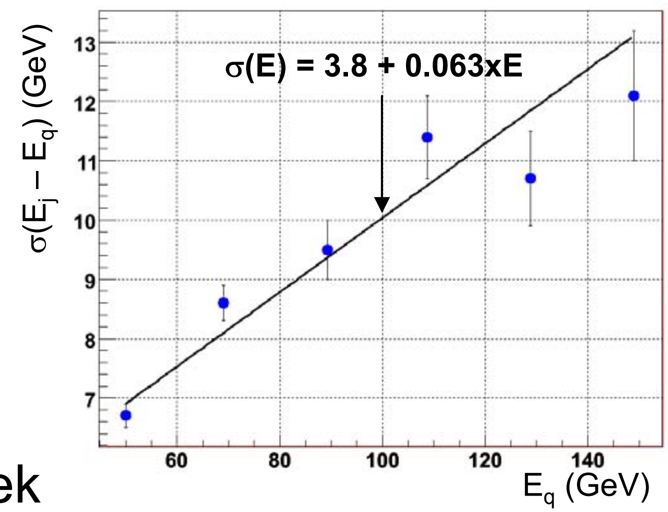
# Parton Level Calibration: W Mass Constraint

- Apply template method to W mass reconstruction in W→jj
  - use very high statistics sample W→qq from Pythia
    - Need only parton level
    - Tested with 1.2M Pythia ttbar events with $m_t$ = 175 GeV
  - Smear quark 4-momentum kinematics
    - Energy resolution
    - Angular resolution
    - Energy correlation
    - Use fully simulated jets for guidance for smearing parameters
  - Fill template histograms with smeared quark kinematics
    - Use various energy scale ($\alpha$) and resolution ($\beta$) parameters
  - Fit each template to $m_{jj}$ from data and find best ($\alpha$,$\beta$) parameter set
    - Data can be experimental data, ATLFAST, parametrized and full simulation

Smearing of quark angles:



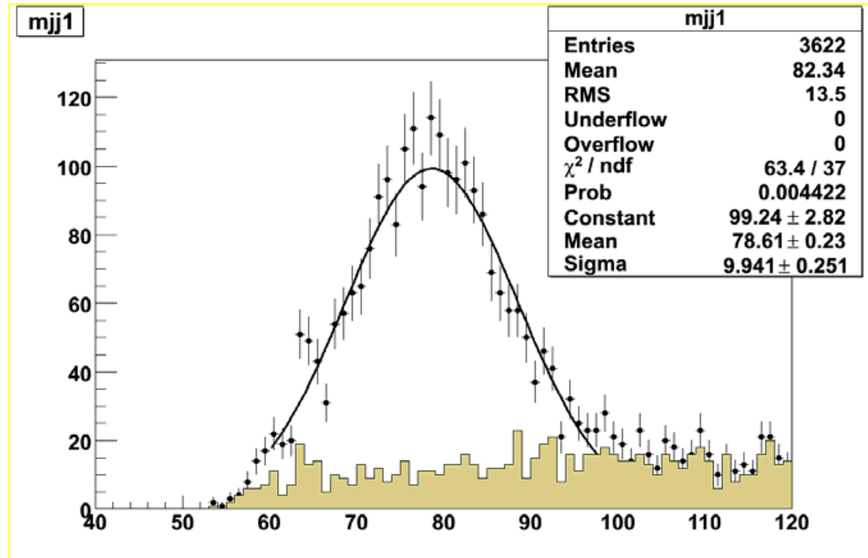

Smearing of quark energies:

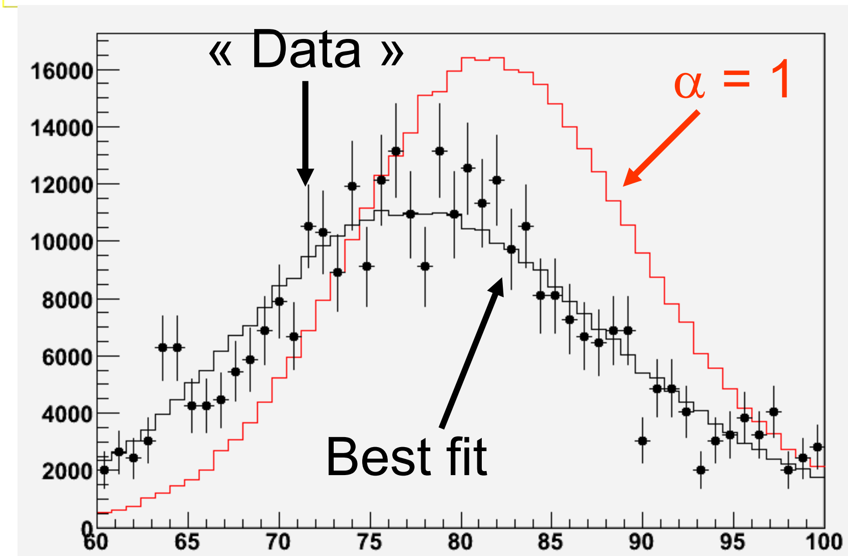



Jerome Schwindling, October 2006 T&P week

# Parton Level Calibration: Template Performance

- Apply to W mass reconstruction
  - Select 60 < mjj < 100 GeV
  - $\alpha$ fit yields espected value (here ~0.93)
    - Expectation from direct $E_{jet}$ and $E_q$ comparisons
  - $\beta$ fit yields ~1.45
    - Expectation closer to 1
    - Some indication of sensitivity to background and underlying event
- Best fit with simple templates describes (fully simulated) data very well



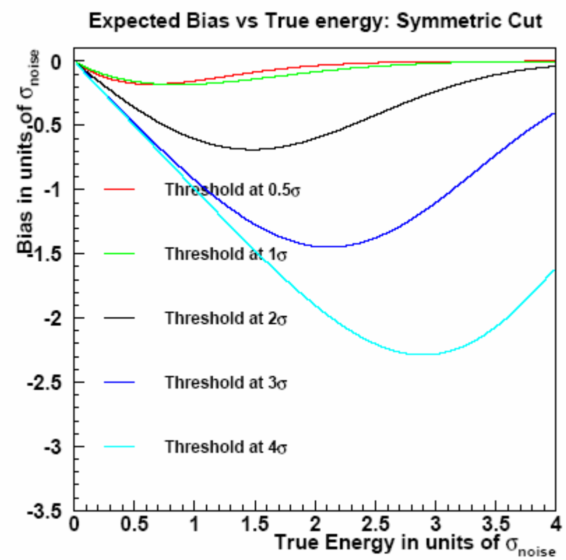




Jerome Schwindling, October 2006 T&P week

# Missing Et Reconstruction

# Missing Et Reconstruction: Intro

- Best missing Et reconstruction
  - Use all calibrated calorimeter cells
  - Use all calorimeter cells with true signal
  - Use all reconstructed particles not fully reconstructed in the calorimeter
    - e.g. muons from the muon spectrometer




K. Cranmer, in talk by S. Menke, ATLAS Physics Workshop 07/2005

- Calorimeter issues
  - About 70-90% of all cells have no true or significant signal
  - Applying symmetric or asymmetric noise cuts to cell signals
    - Reduces fluctuations significantly
    - But introduces a bias (shift in average missing Et)
  - Topological clustering applies more reasonable noise cut
    - Cells with very small signals can survive based on the signals in neighbouring cells
    - Still small bias possible but close-to-ideal suppression of noise

# Missing Et Reconstruction: Default Strategy Overview

- Default missing Et calculation

MET_RefFinal

=

MET_Calib + MET_Cryo + MET_Muon

| MET_Calib | MET_Cryo | MET_Muon |
| --- | --- | --- |
| **Calorimeter Cells**<br>$\lvert E_{cell}\rvert > 2\sigma_{noise}$<br>calibrated with weights from jet calibration<br>"H1" style jet calibration | **Cryostat Losses EMB/Tile**<br>correction factors from reconstructed seeded cone tower jets with $\Delta R = \Delta\eta\times\Delta\varphi \leq 0.7$<br>based on cone tower jets | **MuonBoy**<br>$\lvert\eta\rvert\leq 2.7$<br>best match/good quality required<br>$p_t$ from external spectrometer |
| **Calorimeter Cells**<br>in TopoClusters ($4\sigma/2\sigma/0\sigma$)<br>calibrated with weights from jet calibration<br>"H1" style jet calibration | **Cryostat Losses EMB/Tile**<br>correction factors from reconstructed seeded cone topocluster jets with $\Delta R = \Delta\eta\times\Delta\varphi \leq 0.7$<br>based on cone cluster jets | **MOORE**<br>$\lvert\eta\rvert\leq 2.7$<br>best match/good quality required<br>$p_t$ from external spectrometer |
| **Calorimeter Cells**<br>in TopoClusters ($4\sigma/2\sigma/0\sigma$)<br>cluster based calibration/dead material correction<br>local hadronic calibration | | |
| **Calorimeter Cells**<br>in e±, $\gamma$, $\tau$, jets, unused TopoClusters, outside<br>weights from physics object calibration<br>refined calibration | | |
| **Calorimeter Cell Clusters**<br>TopoClusters ($4\sigma/2\sigma/0\sigma$)<br>cluster based calibration/dead material correction<br>local hadronic calibration | | |

highlighted boxes indicate the default configuration

# Missing Et Reconstruction: Calorimeter Cells

- MET_Calib contribution
  - Reconstruction
    - Based on calorimeter cells with refined calibration from physics objects
    - each cell belongs to one or no physics object
    - Each cell contributes to MET according to the final calibration of this object
  - Calibration is directly derived from physics object calibration
    - Prioritized cell contribution (default):
      1. Cells in electrons
      2. Cells in photons
      3. Cells in taus
      4. Cells in jets
      5. Cells in muons
      6. Cells in unused TopoClusters
      7. *Cells outside of TopoClusters (to be studied)*

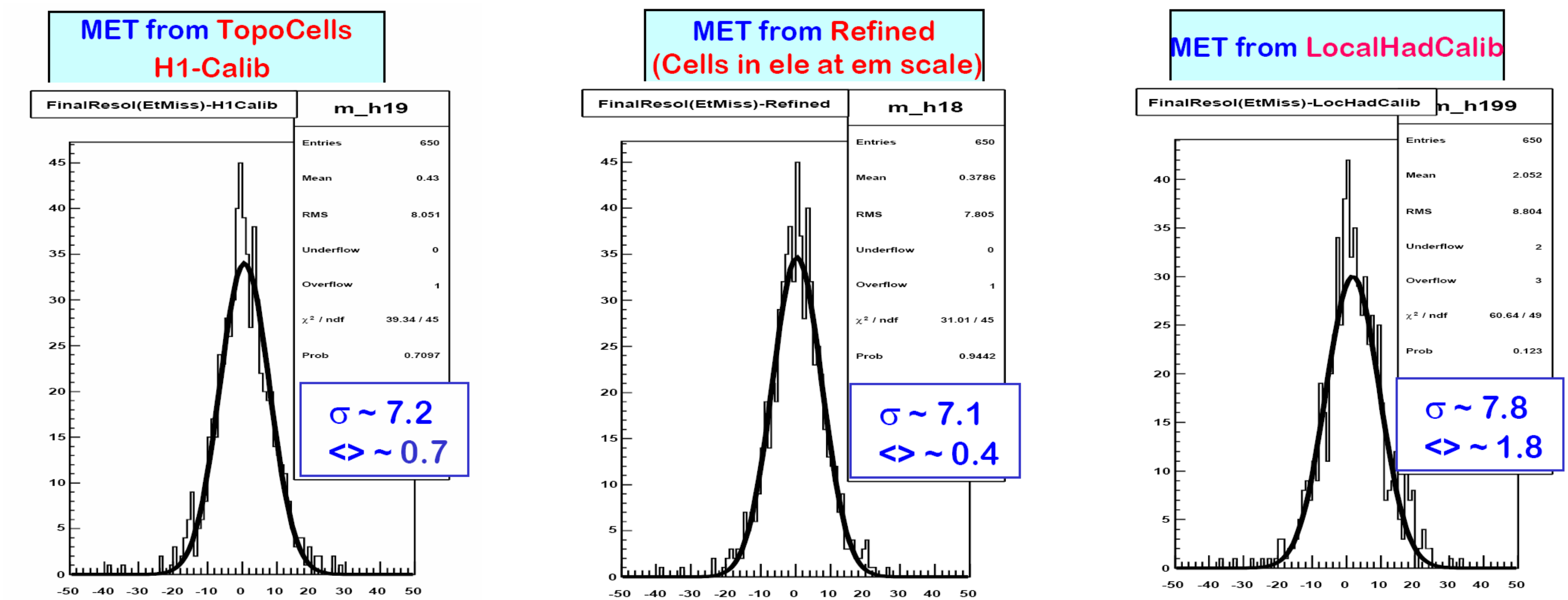
# MET Reconstruction: Dead Material & Muons

- MET_Cryo contribution
  - Based on jet energy correction for dead material
    - Not needed when using calibrated TopoClusters
      - Dead material corrections intrinsic to local calibration scheme
    - Empirically determined from cone jets in QCD
      - Correction $\sim \sqrt{E_{EMB3} \cdot E_{TILE0}}$
  - Calibration related to jet calibration
- MET_Muon contribution
  - Uses reconstructed high quality muons
    - MuonBoy with Pt from external spectrometer
    - MOORE with Pt from external spectrometer

# MET Performance

- Snapshot of MET performance 02/2007
  - Sensitive to signal details
  - Constantly monitored to follow signal definition and calibration evolution
    - A big job – now includes physics objects refined calibrations!

## MET resolution in $Z\rightarrow\tau\tau$




D.Cavalli, ATLAS LArG Week February 2007

# HLT Hadronic Calibration

# HLT Hadronic Calibration: Jet trigger menu

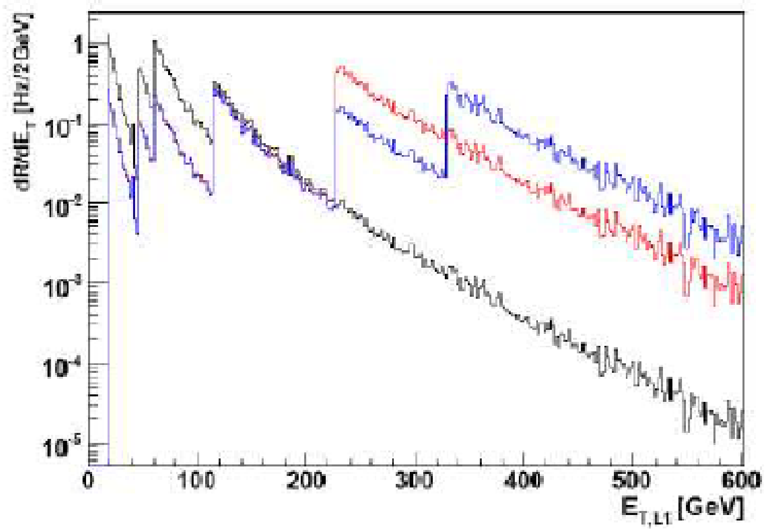
- Design menu to optimally sample jet spectrum for cross section measurements and efficiency determination
- Example of menu for LVL1:

Pre-scale factors for different jet triggers

| threshold [GeV] | $10^{31}$ | $5*10^{32}$ | $2*10^{33}$ |
|---|---|---|---|
| 18 -> J33 | 2000 | 452000 | 1.920.00 |
| 46 -> J70 | 63 | 15000 | 60000 |
| 60 -> J90 | 7 | 1620 | 6700 |
| 114 -> J160 | 1 | 60 | 247 |
| 228 -> J300 | 1 | 1 | 13 |
| 328 -> J410 | 1 | 1 | 1 |
| unprescaled rate | 6 Hz | 13 Hz | 9.8 Hz |

4j90
3j90+j160 (backup for merged jets in 4j90)

Note: Trigger names used here correspond to threshold needed for 95% efficiency w/r to offline




- Thresholds cover wide energy range: needs appropriate calibration for energies up to 400 GeV

P. Conde Muíño, LIP (18 Apr 07) 2

# HLT Hadronic Calibration: $\tau$, MET trigger menus

| Selection | L1 Rate (Hz) | L2 Rate (Hz) | EF Rate (Hz) | $W \rightarrow \tau\nu$ ($p_t^{vis} > 12$) | $Z \rightarrow \tau\tau$ ($p_t^{vis} > 12$) |
|---|---|---|---|---|---|
| tau10 | 9700 | 2960 | 1482 | 43.6% | 45.5% |
| tau10i | 9197 | 2894 | 522 | 30.0% | 36.0% |
| tau15 | 2574 | 864 | 401 | 31.6% | 35.3% |
| tau15i | 2213 | 796 | 161 | 24.3% | 29.2% |
| tau20i | 1053 | 344 | 99 | 19.8% | 25.4% |
| tau25i | 493 | 159 | 58 | 13.8% | 20.1% |
| tau35i | 184 | 48 | 23 | 6.5% | 11.5% |

Table 2: J0-J3 event rates at $\mathcal{L} = 10^{31}\text{cm}^{-2}\text{s}^{-1}$

Few thresholds: could calibrate around threshold

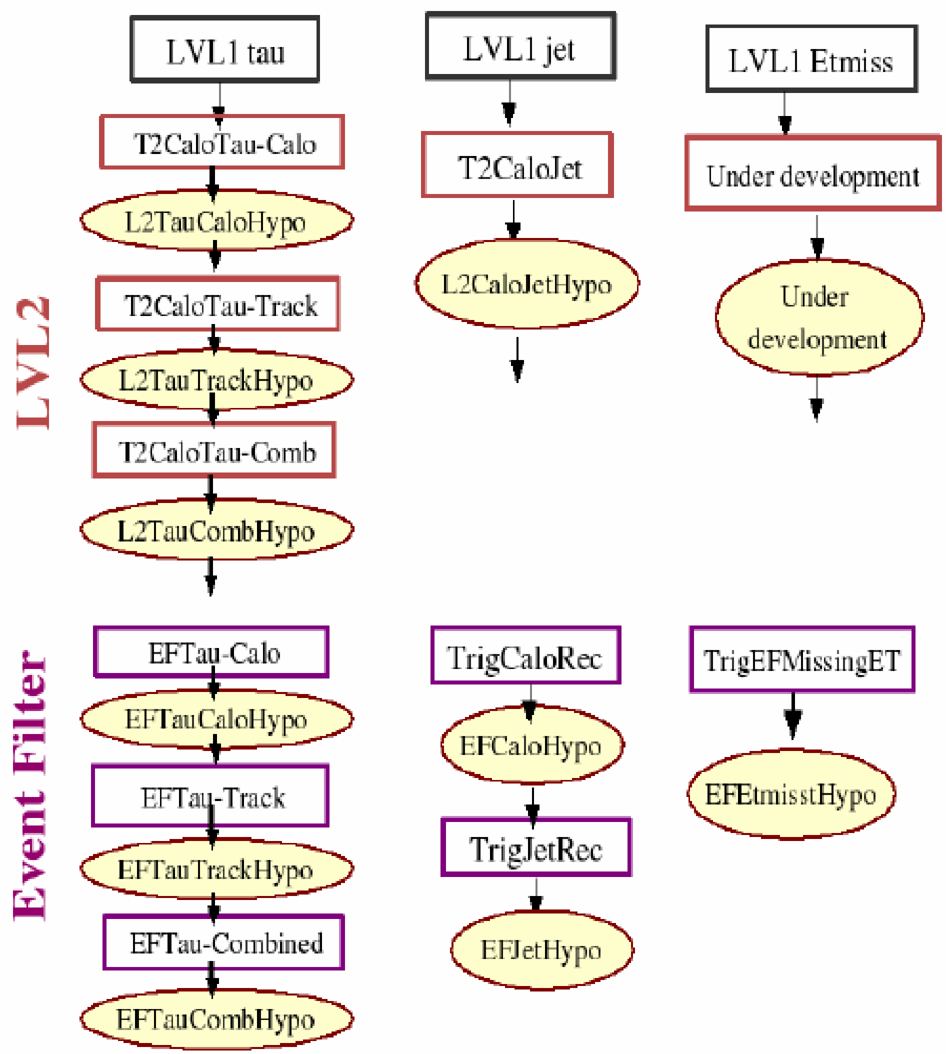
For SUSY: combined signatures missing $E_T$+ taus or missing $E_T$+ jets. Example:

| Selection | L1 Rate (Hz) | L2 Rate (Hz) | EF Rate (Hz) | $W \rightarrow \tau\nu$ ($p_t^{vis} > 12$) |
|---|---|---|---|---|
| tau15i | 2213 | 796 | 161 | 24.3% |
| + MET 20 | 521 | 171 | 40 | 16.6% |
| + MET 30 | 114 | 39 | 9 | 8.6% |
| + MET 40 | 27 | 6.7 | 1.3 | 3.2% |

Table 3: J0-J3 event rates at $\mathcal{L} = 10^{31}\text{cm}^{-2}\text{s}^{-1}$

P. Conde Muíño, LIP (18 Apr 07) 3

# HLT Hadronic Calibration: Jet/MET/τ trigger slice overview




- Strong timing constraints:
  - LVL2: ~1ms
  - Event Filter: ~1s
- Robustness & reliability are very important
- Multi-threaded environment at LV2:
  - Needs additional tests
- Hypothesis algorithms applied after each reconstruction step
- LVL2: seeded by LVL1
  - Reconstructs small window around LVL1 signal
- EF: seeded by LVL2 or full event access

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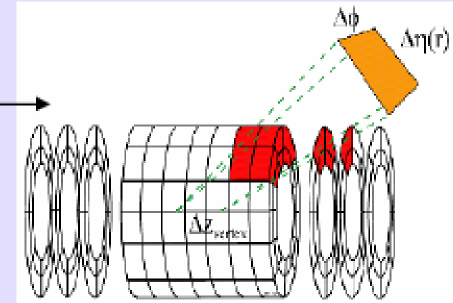
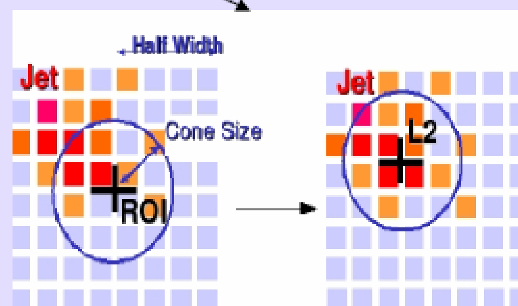
# HLT Hadronic Calibration: LVL2 Jet/τ, EF MET




- Jets/Taus: reconstruct only a RoI (1.4x1.4 in η,Φ) around LVL1 signal
- Jets: iterative cone algorithm R=0.4
  - Calculate energy weighted η,Φ (3 iterations)
- Taus: cluster = energy in the RoI (0.2x0.2 in η,Φ)
- LVL2 jets/EF missing $E_T$:
  - Data unpacking time may be too large
  - Considering 3 possible granularities:
    - Cells (default)
    - FEB-base (software implemented, performance under study)
      - Sums to be calculated at the ROD!
    - LVL1 Trigger Towers

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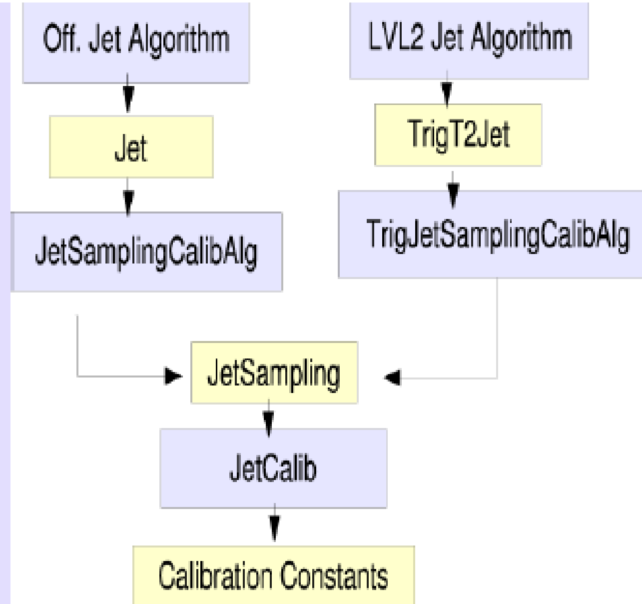
# HLT Hadronic Calibration

Jets/taus: use same procedure: Sampling method

- More robust & faster than other methods
- Common tools for both algorithms
- Re-use when possible offline tools:
  - LVL2:
    - Strong timing constraints
    - 3 possible unpacking modes

    needs special treatment!
  - EF:
    - Same environment/algorithms as offline
    - Tools can be reused.
    - Study RoI effects




Weights obtained with the JetCalib package

Missing $E_T$:

- 3 unpackign strategies: needs special calibration
- Sampling method not valid (dependence on $E_{jet}$)
- We need to define the proper calibration strategy

# Calorimeter Simulation

# Calorimeter Simulation

- GEANT4 based
  - Most recent version GEANT4.8
  - Features very detailed descriptions of all ATLAS detector geometries and inactive structures
    - Includes cryostats, internal and external supports
  - Hadronic shower model evolutions are followed by ATLAS
    - Main activity for Hadronic EndCap (A.Kiryunin,MPI)
    - Validation in combined testbeam 2004 (T.Carli et al.,CERN)

# Calibration Hits

- Use of GEANT4 for hadronic calibration
  - Local hadronic calibration requires local normalization for cell signals
    - Access to “true” deposited energy at cell level in the simulation → **CalibrationHits**
    - Allows to establish the (average) ratio between the simulated signal and the corresponding energy deposit
    - Inverse of this ratio is basis of cell signal calibration weights
  - Dead material corrections
    - Require collection of energy not deposited in instrumented calorimeter regions
    - Uses the same CalibrationHit infrastructure
  - Leakage estimates
    - Requires recording energy escaping the calorimeter

# Energy Desposits

- Particle and Process dependencies
  - Energy is classified by particles and shower processes
    - **Electromagnetic**: electrons, positrons, photons (possible signal contribution)
    - **Ionizing**: all other charged particles, including muons (possible signal contribution)
    - **Escaping**: energy carried by non-interacting particles, mostly neutrinos (no signal contribution)
    - **Invisible**: energy lost (or gained) in inelastic hadronic interactions, mostly nuclear binding energies (no signal contribution in ATLAS calorimeters)
      - "late" photons (outside of signal time window) from nuclear de-excitations
      - Slow neutrons
    - Very helpful in understanding shower models and the signal source they represent
  - Deposit is also classified by location
    - Anywhere inside the unit cell volume (possible signal contribution)
    - Inside active material in the unit celll (full signal contribution)
    - Inside dead material not belonging to any unit cell (no signal contribution)

# Energy Deposits: Use In Calibration

- Recall hadronic signal weights

$$w = \left\langle \left( E^{Em}_{cell} + E^{nonEm_{vis}}_{cell} + E^{nonEm_{invis}}_{cell} + E^{escaped}_{cell} \right) \Big/ E_{cell} \right\rangle$$

$$c^{em} \cdot A\left( \left[ E^{Em}_{cell} \oplus E^{nonEm_{vis}}_{cell} \right]_{active}, t, \vec{\varepsilon}, \ldots \right)$$

Reconstructed em scale signal

Escaped energy (no signal contribution)

Invisible energy (no signal contribution)

Ionization energy (charged hadron & muon signal contribution)

Electromagnetic energy (electron,positron,photon signal contribution)

**Electromagnetic shower branch**

**Purely hadronic shower branch**

# Calibration Hits: Use For Sampling Fractions

- Calibration hits can be used to calculate sampling fractions from simulations
  - Allow to relate signal component to its specific source within the context of the applied model
    - Signal contribution from electromagnetic deposit can be understood independently from signal contribution from hadronic (ionization) deposit in complex hadronic showers

Generates signal

$$S = \frac{E_{vis}}{E_{dep}} = \frac{E^{em}_{dep,act} + E^{ion}_{dep,act}}{\underbrace{E^{em}_{dep,act} + E^{em}_{dep,inact}}_{E^{em}_{dep}} + \underbrace{E^{ion}_{dep,act} + E^{ion}_{dep,inact}}_{E^{ion}_{dep}} + \underbrace{E_{inv,act} + E_{inv,inact}}_{E_{inv}} + \underbrace{E_{esc,act} + E_{esc,inact}}_{E_{esc}}} \quad (2)$$

In case of electrons, positrons and photons $E_{inv} \approx 0$, $E_{esc} \approx 0$, and $E^{ion}_{dep} \approx 0$, except the small contributions discussed above. The electron sampling fraction $S_e$ is then in very good approximation given by

$$S_e = \frac{E^{em}_{dep,act}}{E^{em}_{dep,act} + E^{em}_{dep,inact}}, \quad (3)$$

**Tiny photo-nuclear component in electromagnetic showers generates hadronic deposits**

(article by Leltchouk, Loch, Pospelov, Seligman et al. in prep.)

# Calibration Hits: Signal Ratios

- Directly calculate e/h, e/$\pi$, e/$\mu$ from simulations
  - Again limited by implemented shower models
  - Calculate from calibration hits:

$$f_{em} = \frac{E^{em}_{dep}}{E_{dep}}, \quad f_{ion} = \frac{E^{ion}_{dep}}{E_{dep}}, \quad f_{inv} = \frac{E_{inv}}{E_{dep}}, \quad \text{and} \quad f_{esc} = \frac{E_{esc}}{E_{dep}}.$$

    - Can be done at cell level, within a sampling, for the whole calorimeter
  - Calculate signal ratios from fractions
    - Again possible within any implemented geometrical or readout boundary

$$S_h = \frac{E^{ion}_{dep,act}}{\underbrace{(f_{ion} + f_{inv} + f_{esc})\, E_{dep}}_{E_{dep} - E^{em}_{dep}}} = \frac{E^{ion}_{dep,act}}{(1 - f_{em})\, E_{dep}}$$

$$\begin{aligned} S_\pi &= \left[ S_e E^{em}_{dep} + S_h \left( E_{dep} - E^{em}_{dep} \right) \right] / E_{dep} \\ &= S_e f_{em} + S_h (1 - f_{em}) \end{aligned}$$

$$\boxed{\frac{e}{\pi} = \frac{E_{vis}(e)}{E_{vis}(\pi)} = \frac{S_e E_{dep}}{S_\pi E_{dep}} = \frac{1}{f_{em} + (1 - f_{em})\, S_h / S_e} = \frac{1}{f_{em} + (1 - f_{em})\,(e/h)^{-1}}}$$

- Many more response details can be studied!

# Reconstruction Software

# Calorimeter Event Data Model [1]

- CaloCell
  - Contains electromagnetic scale signal, time, gain indicator, signal quality indicator
  - Provides location and other geometry information through a detector description element
    - Filled once from geometry data base
- CaloTower
  - Projective cell towers of fixed size in $\Delta\eta$ and $\Delta\varphi$
    - Electromagnetic towers in LAr calorimeter only are $\Delta\eta \times \Delta\varphi = 0.025 \times 0.025$ in $|\eta|<2.5$
    - Hadronic (combined) towers are $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$ in $|\eta|<5$ and use the whole calorimeter system
  - Cells are collected into towers without any selection

# Calorimeter Event Data Model [2]

## CaloCluster

- Data object used in two clustering algorithms
  - Sliding Window for electrons and photons
  - Topological clustering for whole final state
- Cluster contains links to cells forming it
  - Cell can contribute with kinematic weights
- Cluster kinematics can be modified cell energy sum
  - Cluster level corrections should be reflected back into cell weights
  - Meaning sum of cell energies should always be sum of weghted cell energies
    - Note that is not necessarily true for cluster 4-momentum: direction calculation only uses E>0 cells while cluster can contain E<0 cells as well
- Cluster has wealth of additional information
  - CaloClusterMoments mostly related to shape and cluster location

# Calorimeter Data In ESD

- Event Summary Data
  - CaloCell
    - One collection “AllCalo” with all cells
    - Persistent CaloCompactCell for storage optimization
  - CaloCluster (topo only)
    - One collection with uncalibrated 4/2/0 for hadronic final state physics
    - One collection with calibrated 4/2/0 (same clusters, but fully locally calibrated)
    - One collection with 6/3/3 clusters for photons and electrons
  - CaloTower
    - No persistent representation in ESD
    - Recreation on the fly if required for jets
    - Only tower grid information is stored for electromangetic and combined towers

# Calorimeter Data Objects in AOD

- Analysis Object Data
  - CaloCluster now available in AOD
    - 4/2/0 fully calibrated (local hadronic calibration) and 6/3/3 topological clusters
      - Excellent basis for application of jet finders at this level
  - But cluster information content is stripped down with respect to ESD
    - Cell links are severed
    - Needs back navigation to ESD to access cells
      - Not turned on in general AOD production
    - Only selected cluster variables available
      - Includes uncalibrated energies in samplings
    - Only selected moments available
      - Important moments for classification and hadronic calibration are kept

# This Workshop