Hadronic Final State Reconstruction

- Local hadronic calibration
- Jet and EtMiss
  - reconstruction
  - calibration
  - validation

2nd ATLAS Physics
Workshop in North America
Toronto, August 1-2, 2005

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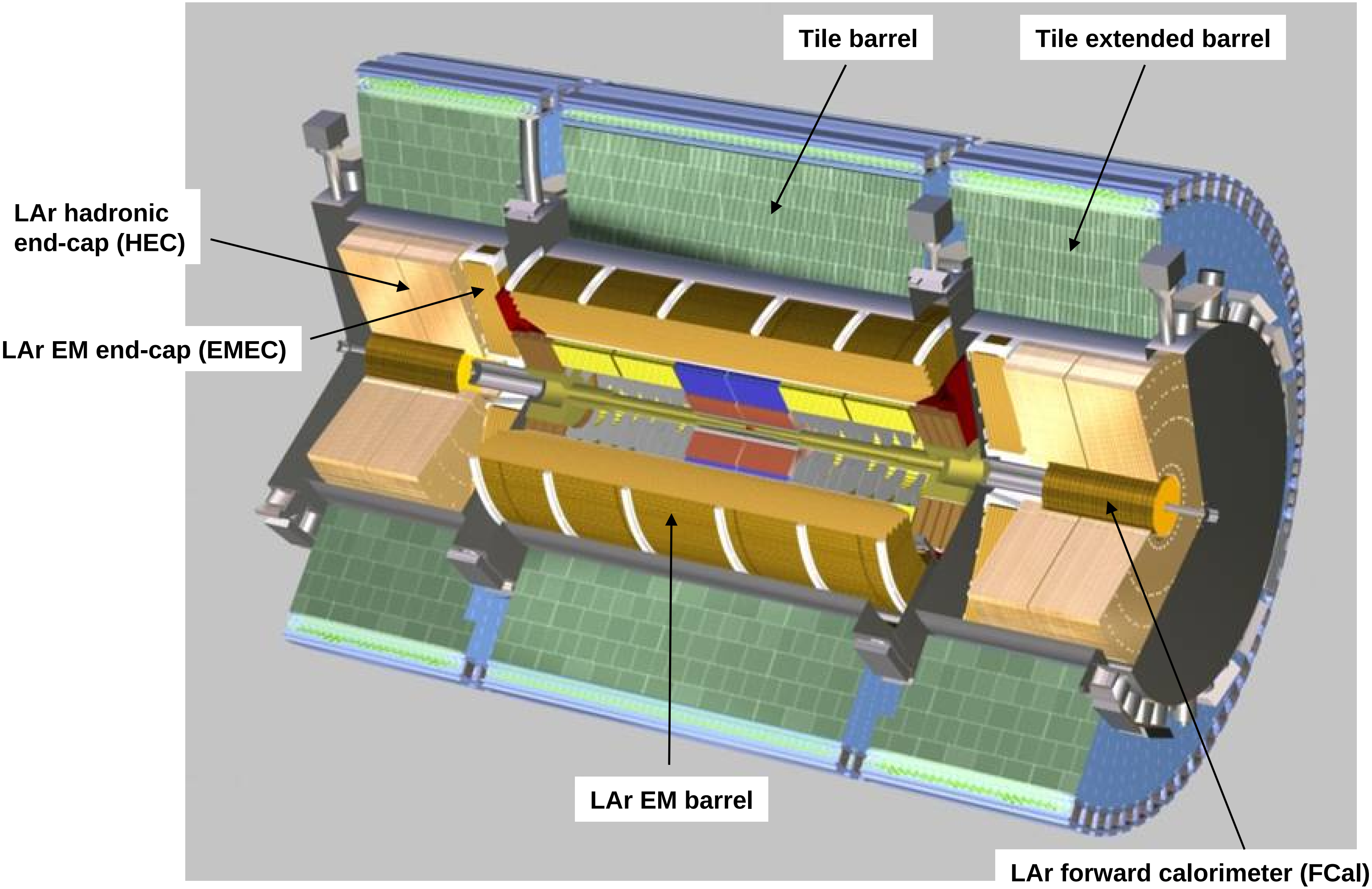
Recent Calorimeter Calibration workshops:

CERN, July 14-15, 2005
Tatranská Štrba, December 1-4, 2005

ATLAS LAr and Tile Calorimeters



Tile barrel

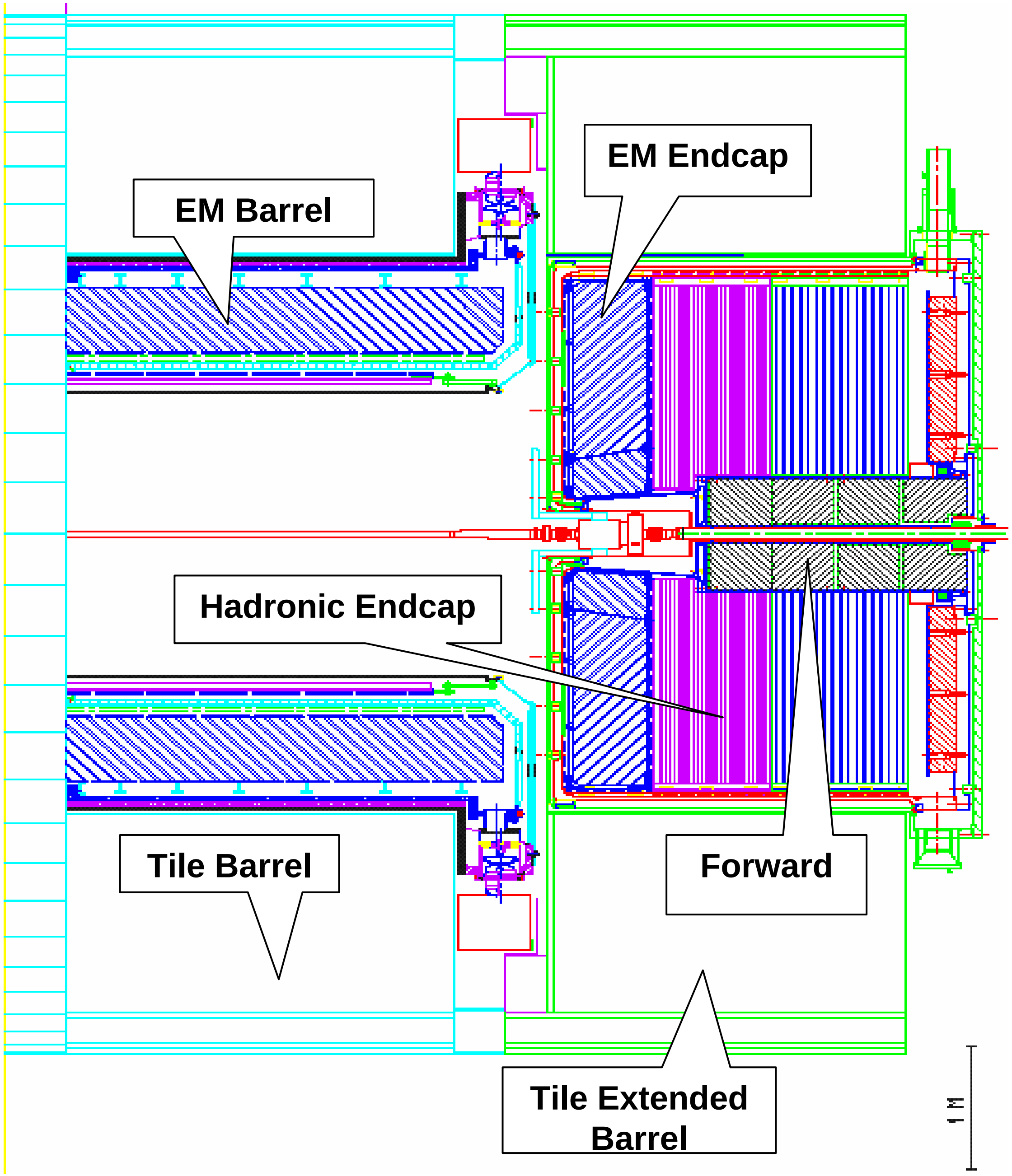
Tile extended barrel

LAr hadronic end-cap (HEC)

LAr EM end-cap (EMEC)

LAr EM barrel

LAr forward calorimeter (FCal)



LAr Calorimeters

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

Varied granularity, techniques; many overlap regions

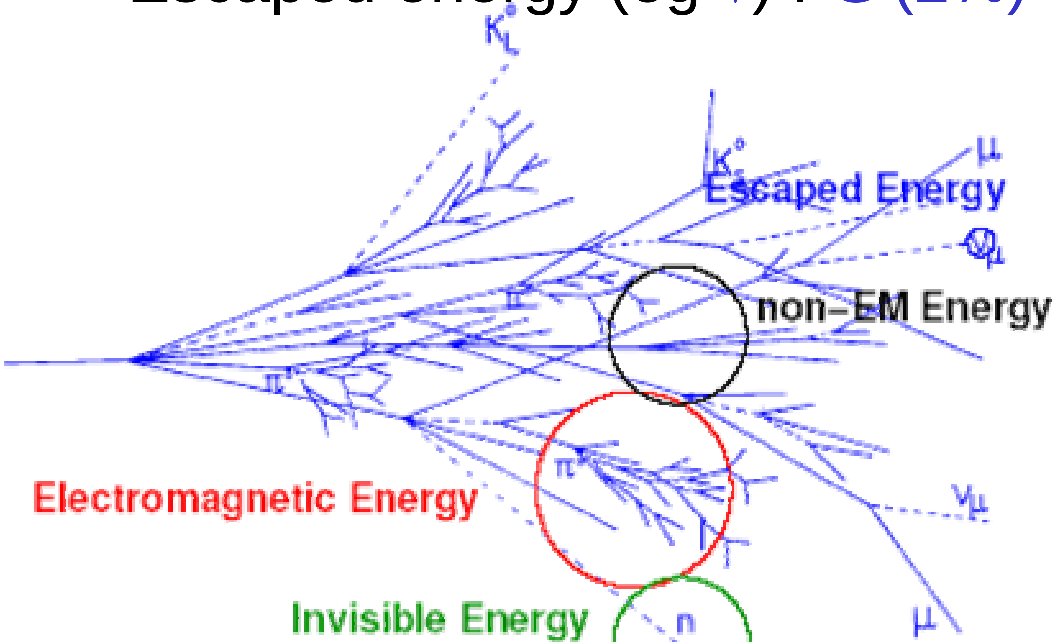
Design Physics Requirements

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

Hadronic Showers

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

energy dependent... and large fluctuations



main source of "non-compensation"

Goals:

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

Calibration Strategy

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

Linearity in energy response

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

+

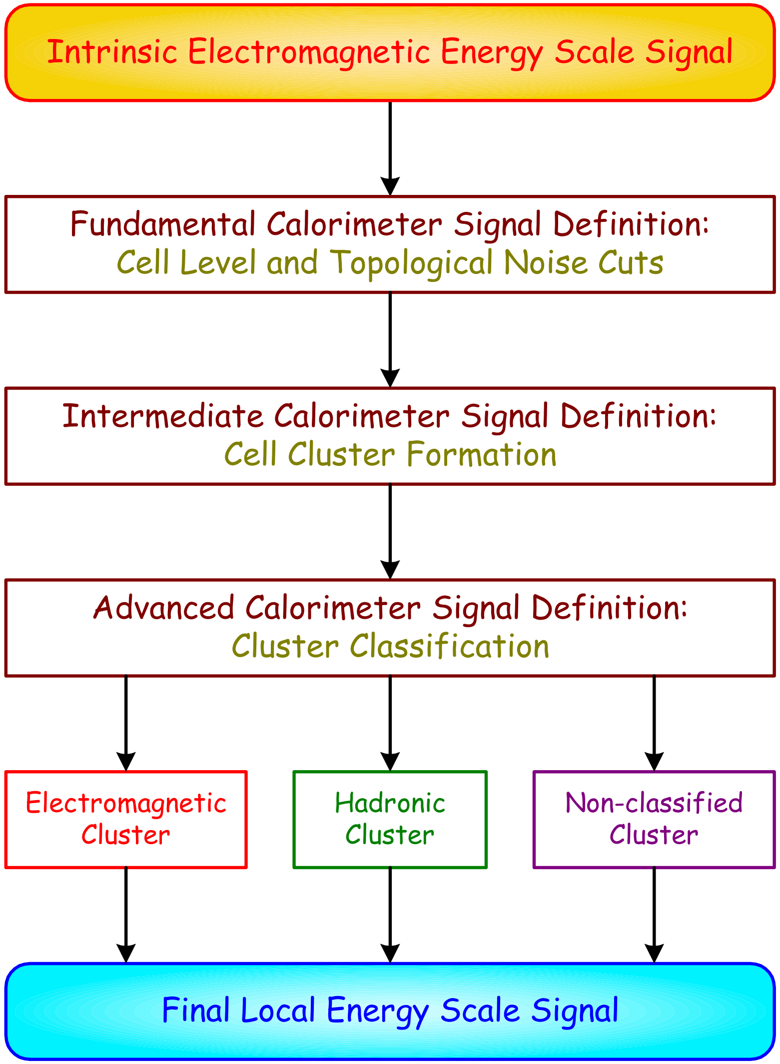
Optimal Resolution

Hadronic Calibration Models

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

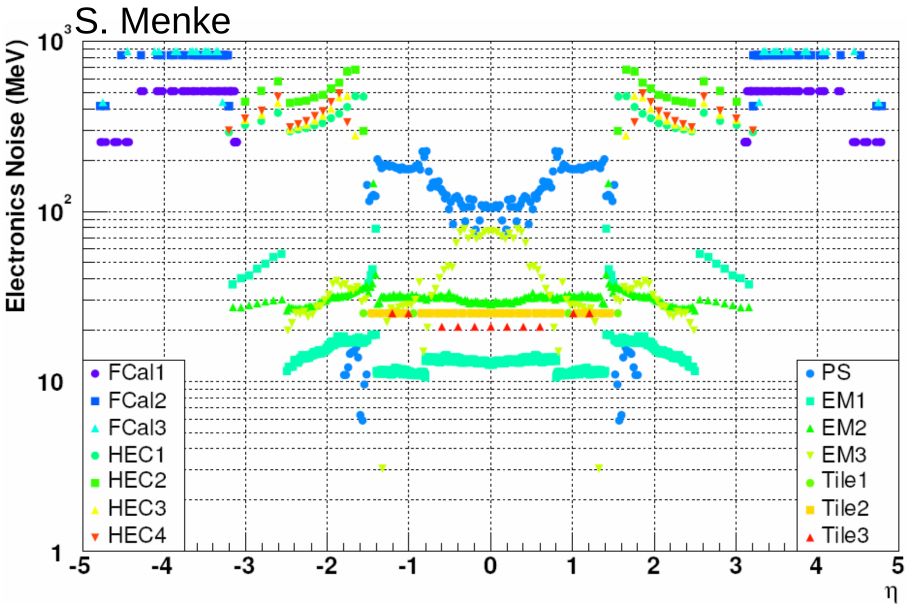
Apply cluster type specific calibration functions, dead material and crack corrections

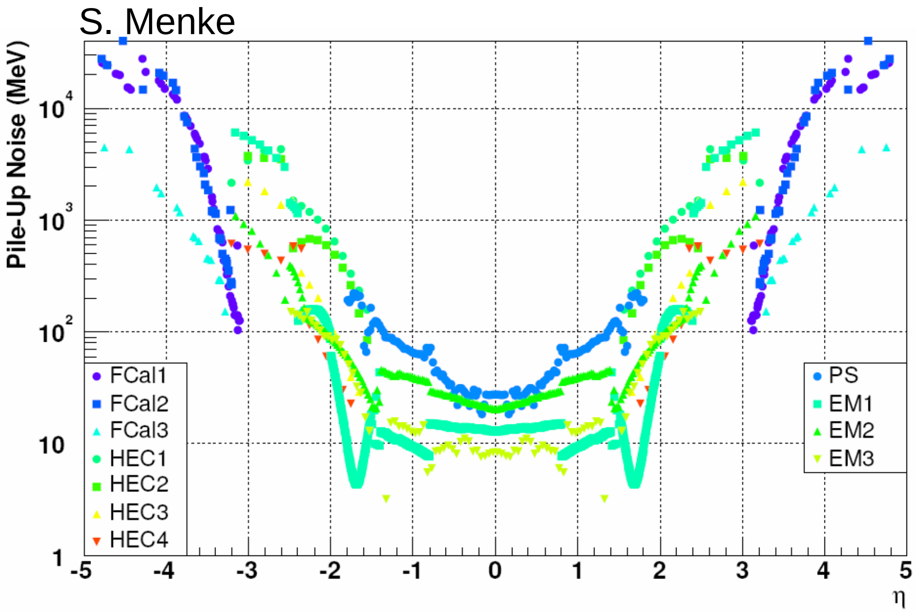
Final Local Energy Scale Signal

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

Noise Suppression

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

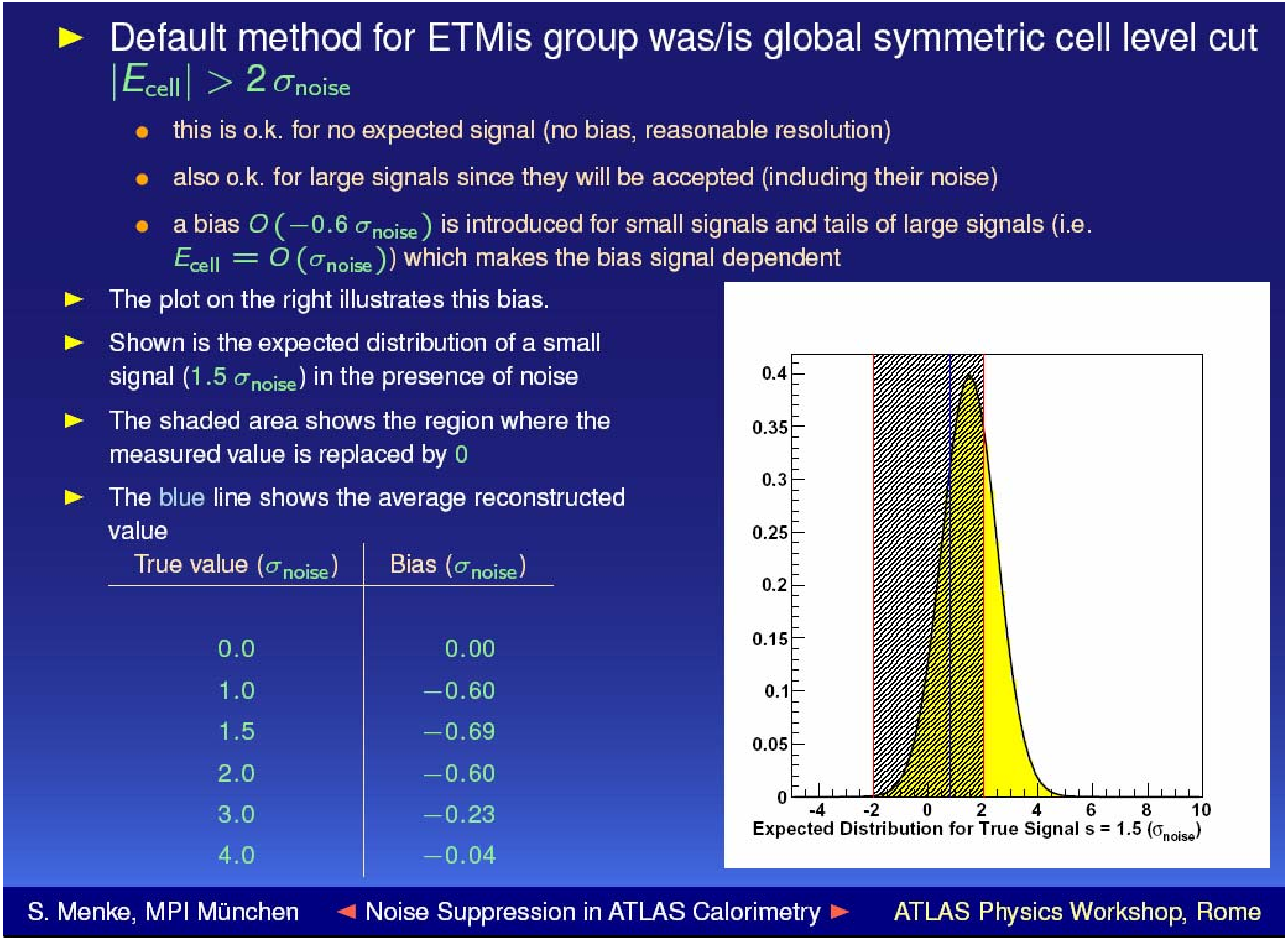

S. Menke


S. Menke

Noise Suppression Methods

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

Noise Suppression Methods $|E_{cell}| > 2\ \sigma_{noise}$



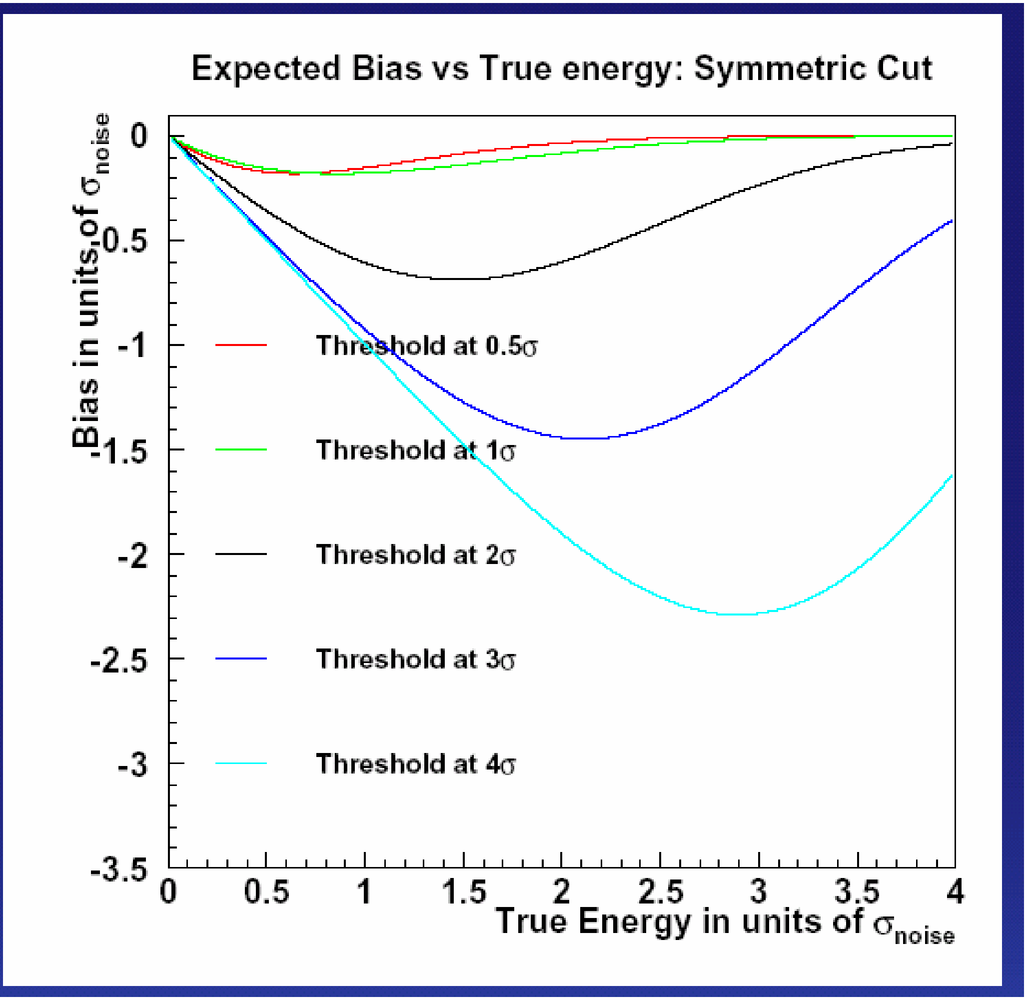
- Default method for ETMis group was/is global symmetric cell level cut $|E_{cell}| > 2\,\sigma_{noise}$
  - this is o.k. for no expected signal (no bias, reasonable resolution)
  - also o.k. for large signals since they will be accepted (including their noise)
  - a bias $O(-0.6\,\sigma_{noise})$ is introduced for small signals and tails of large signals (i.e. $E_{cell} = O(\sigma_{noise})$) which makes the bias signal dependent
- The plot on the right illustrates this bias.
- Shown is the expected distribution of a small signal ($1.5\,\sigma_{noise}$) in the presence of noise
- The shaded area shows the region where the measured value is replaced by 0
- The blue line shows the average reconstructed value

True value (σ_{noise})	Bias (σ_{noise})
0.0	0.00
1.0	−0.60
1.5	−0.69
2.0	−0.60
3.0	−0.23
4.0	−0.04

S. Menke, MPI München ◄ Noise Suppression in ATLAS Calorimetry ► ATLAS Physics Workshop, Rome

Noise Suppression Methods $|E_{cell}| > N\ \sigma_{noise}$

- Kyle Cramner made this nice plot showing the bias from a $N\sigma$ symmetric cut for various N as a function of the signal
  - bias is always negative
  - worst bias for $\text{Signal} = O(N\sigma_{\text{noise}})$
  - magnitude of bias is larger for larger N



CalibrationHits

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

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

    total
  - clearly need MC validation strategy

Hadronic Weights

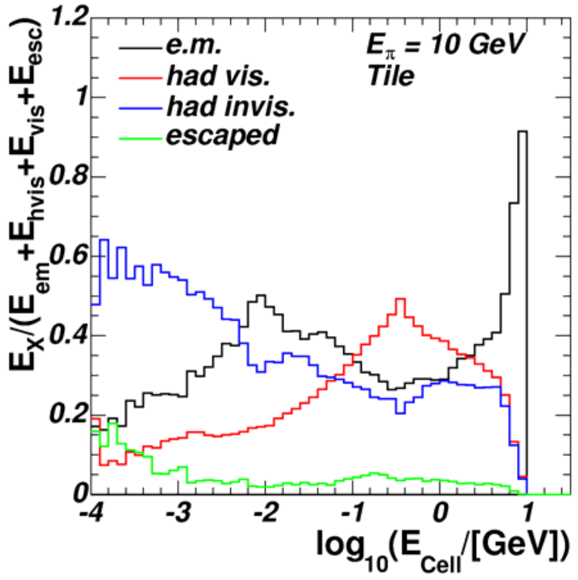
- Set initial hadronic energy scale
- Cell weights in general depend on cluster observables
  - energy and energy density
  - cluster moments
- Initial attempts (2002 EMEC-HEC) only used energy density
  - weights obtained from data
  - see Tucson workshop
- Current efforts based on CalibrationHits
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

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

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

Example: MC Weighting functions for π in Tile and LAr EM Barrel (CTB2004) (F. Spanò)

PRELIMINARY!



Energy Fractions:

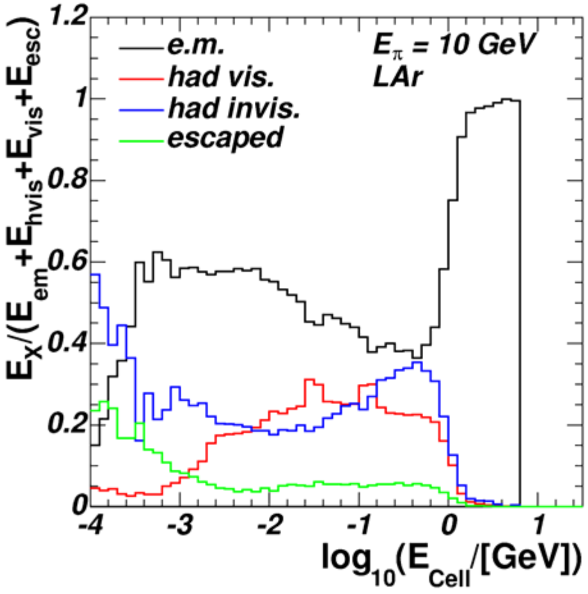
E_X/E_{total}

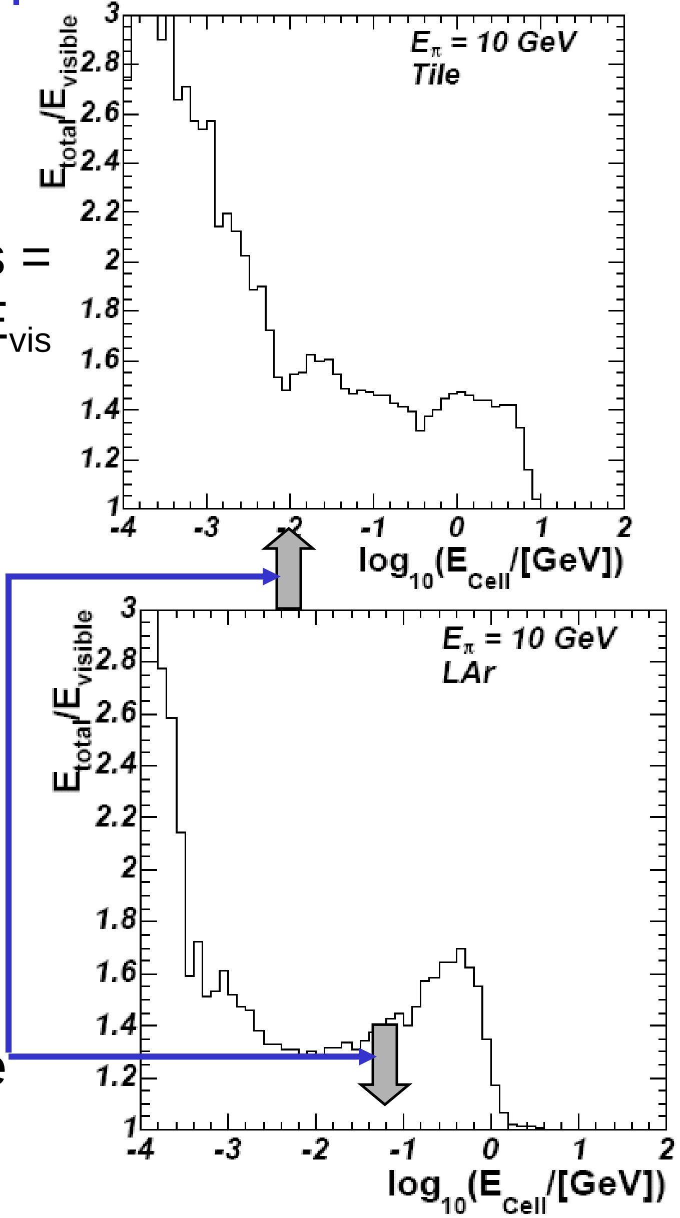
Weights = E_{total}/E_{vis}

η=0.35

E_{beam}=10 GeV

Typical noise level

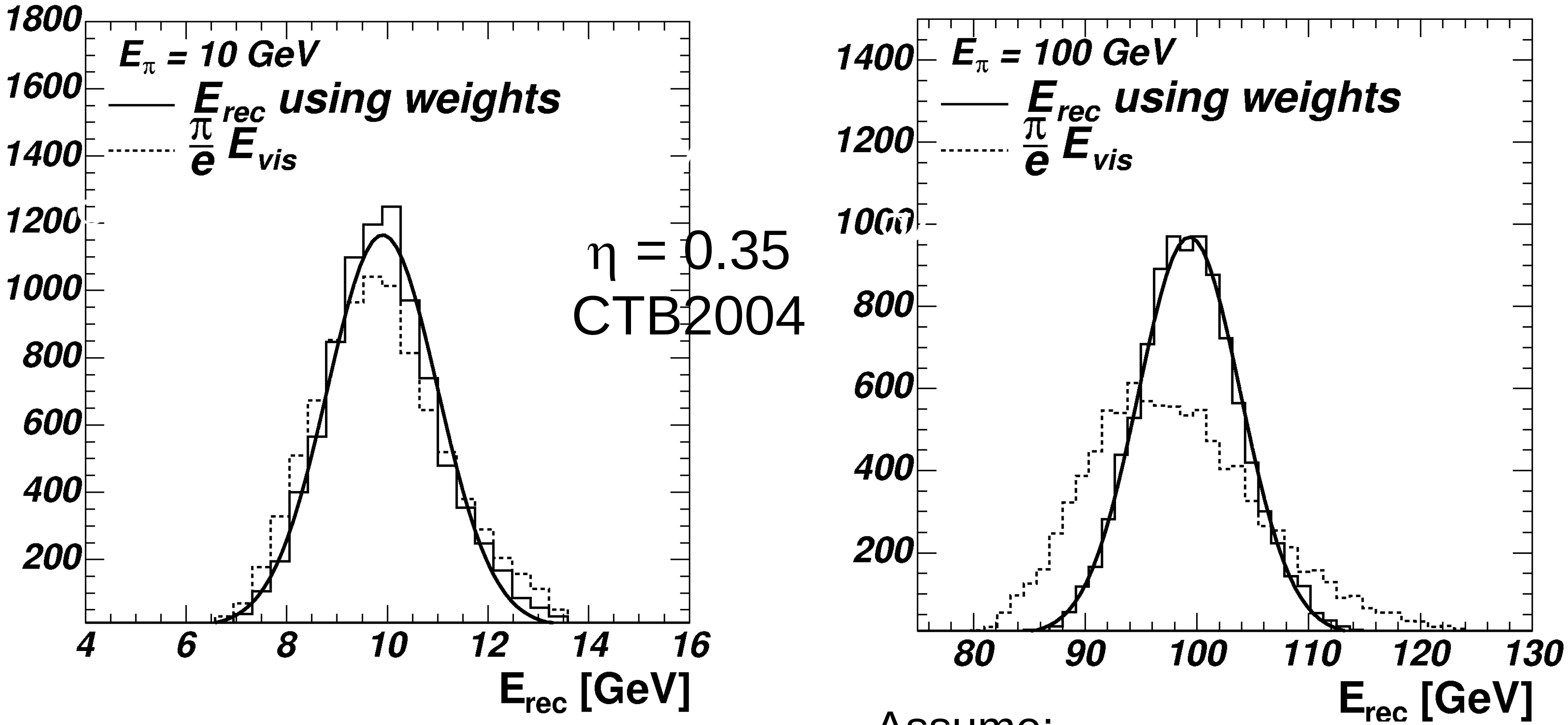




Example: Apply MC weights to MC Events

PRELIMINARY!

(F. Spanò)



η = 0.35

CTB2004

- Compare with simple “π/e” rescaling
- Linearity restored; need to improve resolution at low energy

Assume:

- perfect detector,
- perfect dead material knowledge,
- beam energy knowledge

Hadronic Weights: Tasks

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

Hadronic Weights: Tasks

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

Software Framework Status

All in place (or almost in place) in Athena to use beam test data and simulation

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

Local Hadronic Calibration: outlook

Personal views...

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

Jet Reconstruction

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

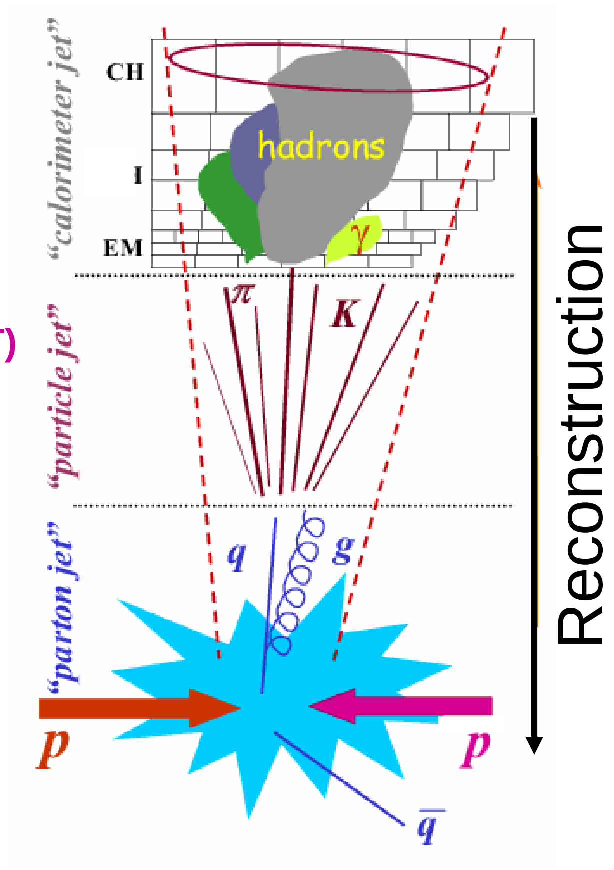
Jet Calibration

(See discussion chaired by J. Proudfoot, C. Roda at last hadronic calibration workshop)

Reconstructed Jet (with cone, or KT)

MC particle Jet (with cone, or KT)
fragmentation functions, detector description and response

Parton Jet



We apply the calibration algorithm to take the scale of the Reconstructed jet from the EM scale to the MC jet scale (compensation).

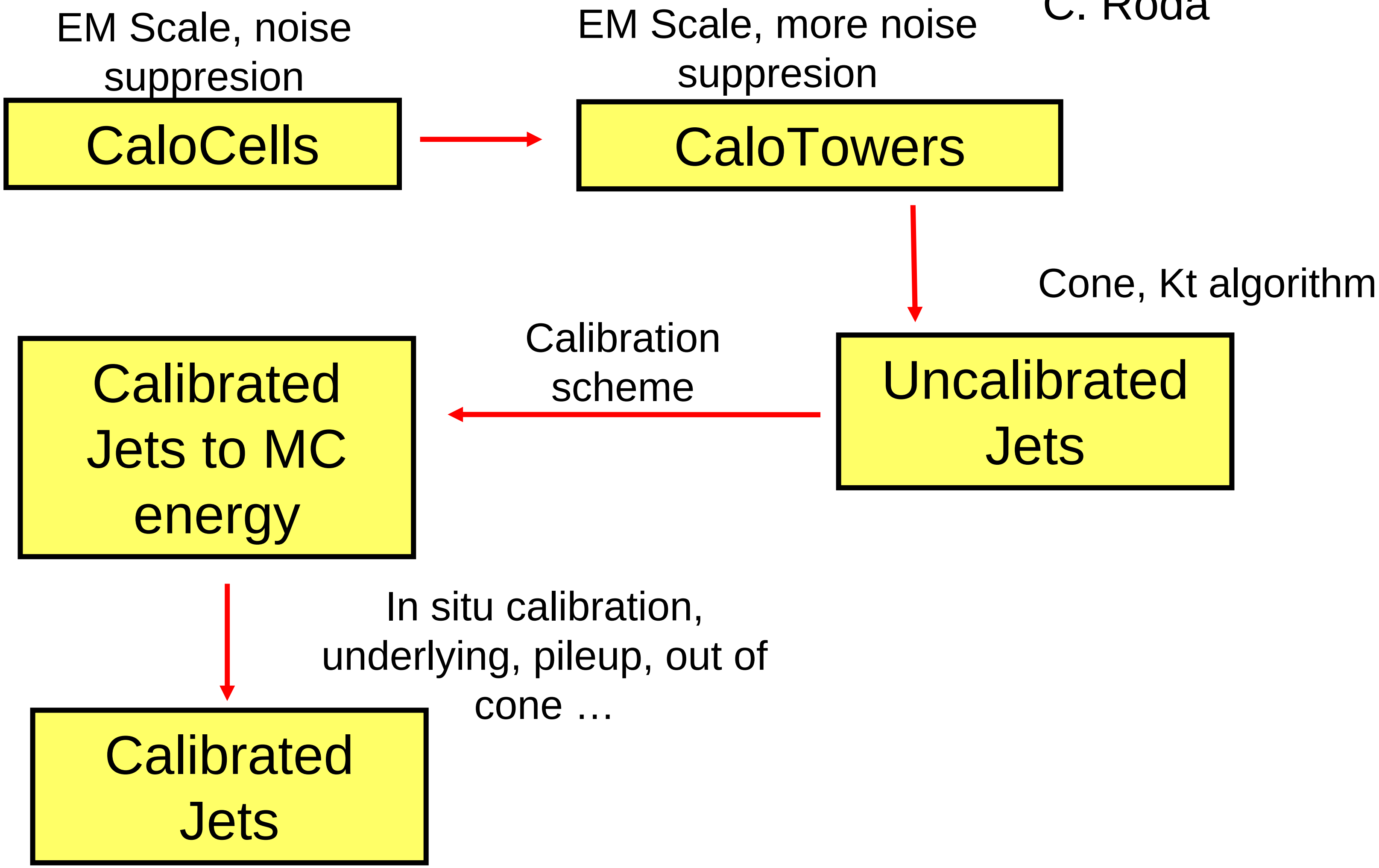
- does not correct for all algorithm effets (out of cone energy, ...)
- processes other than hard scatter contribute to jet energy: underlying event, noise, pileup.

Jet Calibration: status

- Three calibration methods have been developed independently (A.Gupta, F.Paige & S. Padhi, I.Vivarelli & C.Roda).
  - implemented in Athena
  - jets are calibrated to a MC truth based on MC particles
  - use E(jet), not Et(jet)
  - weights obtained by minimizing energy resolution with linearity constraint
  - the quality of the calibration is assessed by looking at the linearity and energy resolution before and after calibration in the different η regions
  - they differ with regards to noise suppression technique, the quantities used to obtain E_{reco}, the weight functions
- An approach based on TopoCluster classification is also being investigated (B. Mellado et al.)
  - needs to be integrated with the local hadronic calibration effort

Present flow of Jet Calibration

J. Proudfoot,
C. Roda



EM Scale, noise suppresion

CaloCells

EM Scale, more noise suppresion

CaloTowers

Cone, Kt algorithm

Uncalibrated Jets

Calibration scheme

Calibrated Jets to MC energy

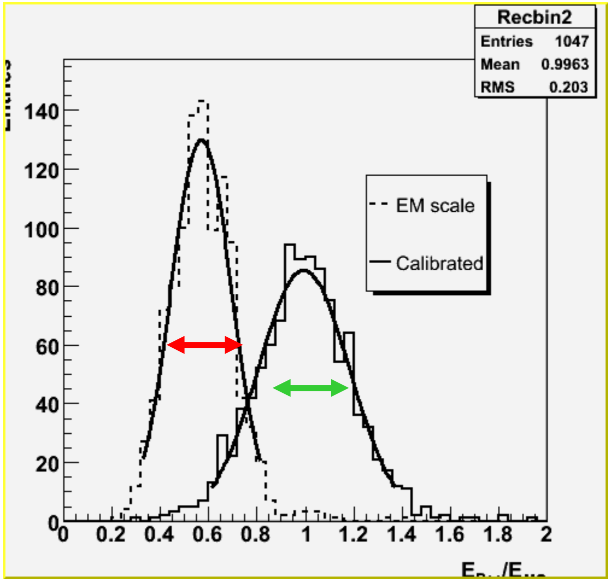
In situ calibration, underlying, pileup, out of cone …

Calibrated Jets

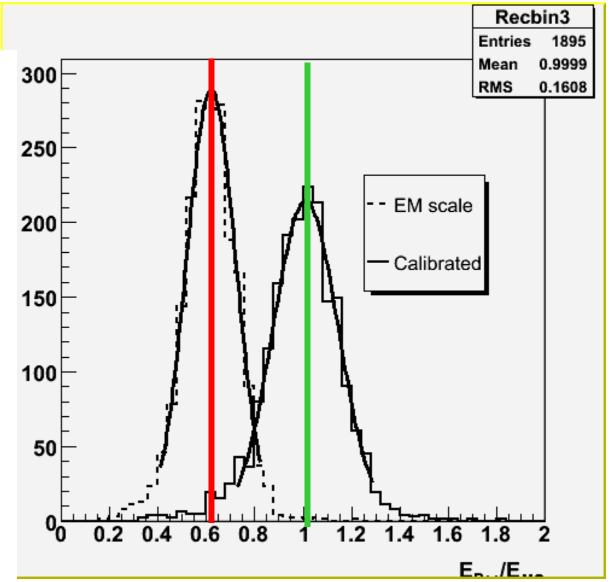
Evaluation of linearity and resolution

F. Paige?

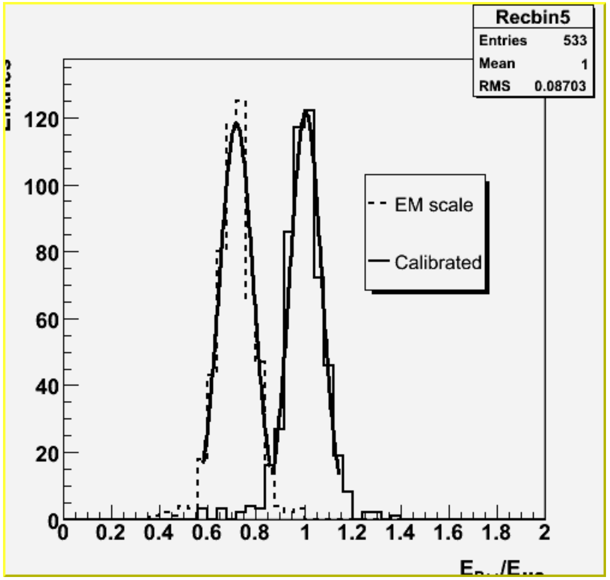
33 – 38 GeV



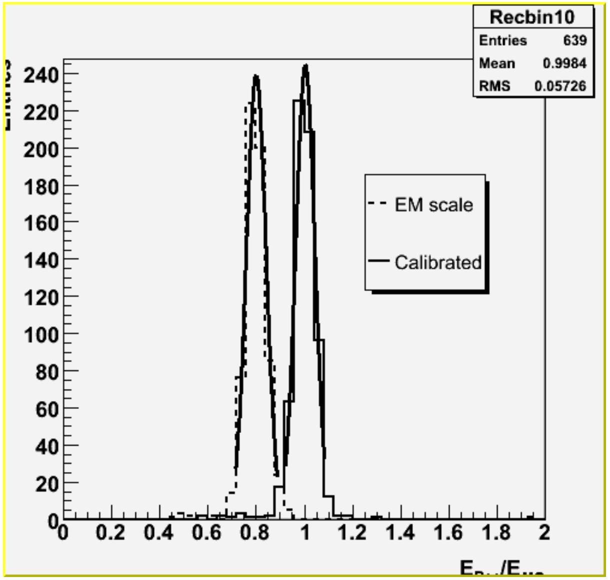
45 - 55 GeV



130 - 150 GeV



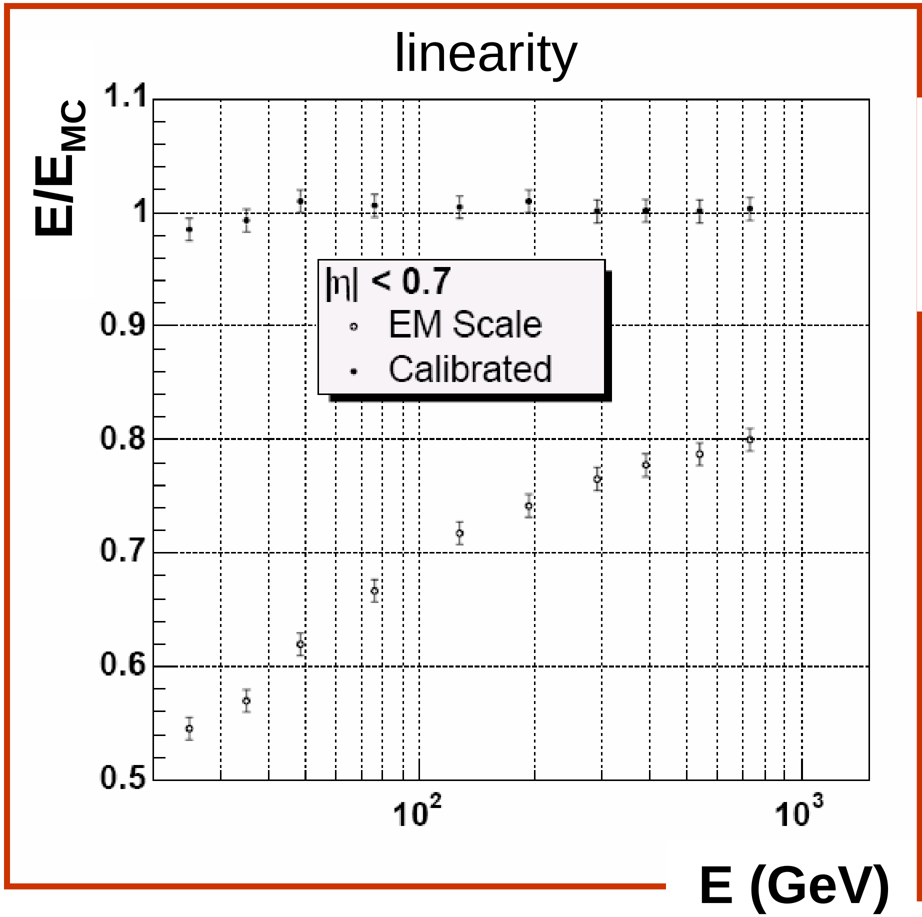
750 - 850 GeV



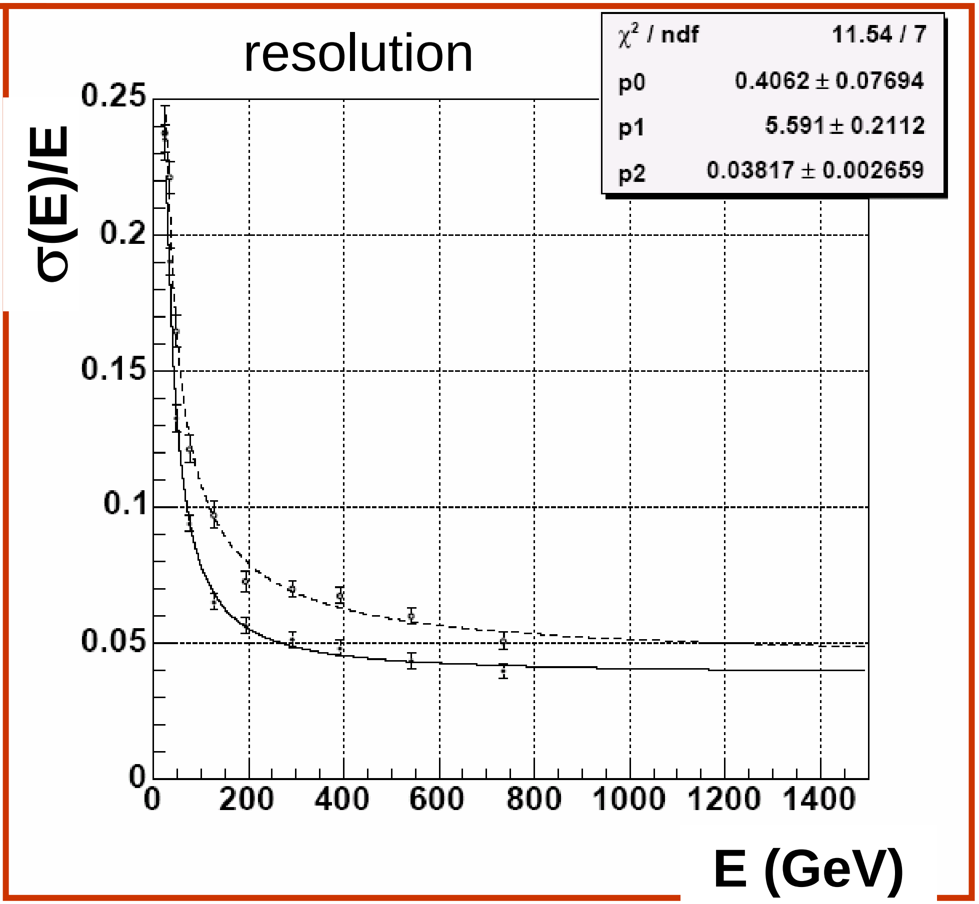
Example Jet Calibration

- weights on cells in TopoClusters (JetCellECSTool)
- use cell position, energy and MC true total jet energy
- Rome sample, $\eta < 0.7$
- electronics noise included

Chiara Roda and Iacopo Vivarelli



linearity



resolution

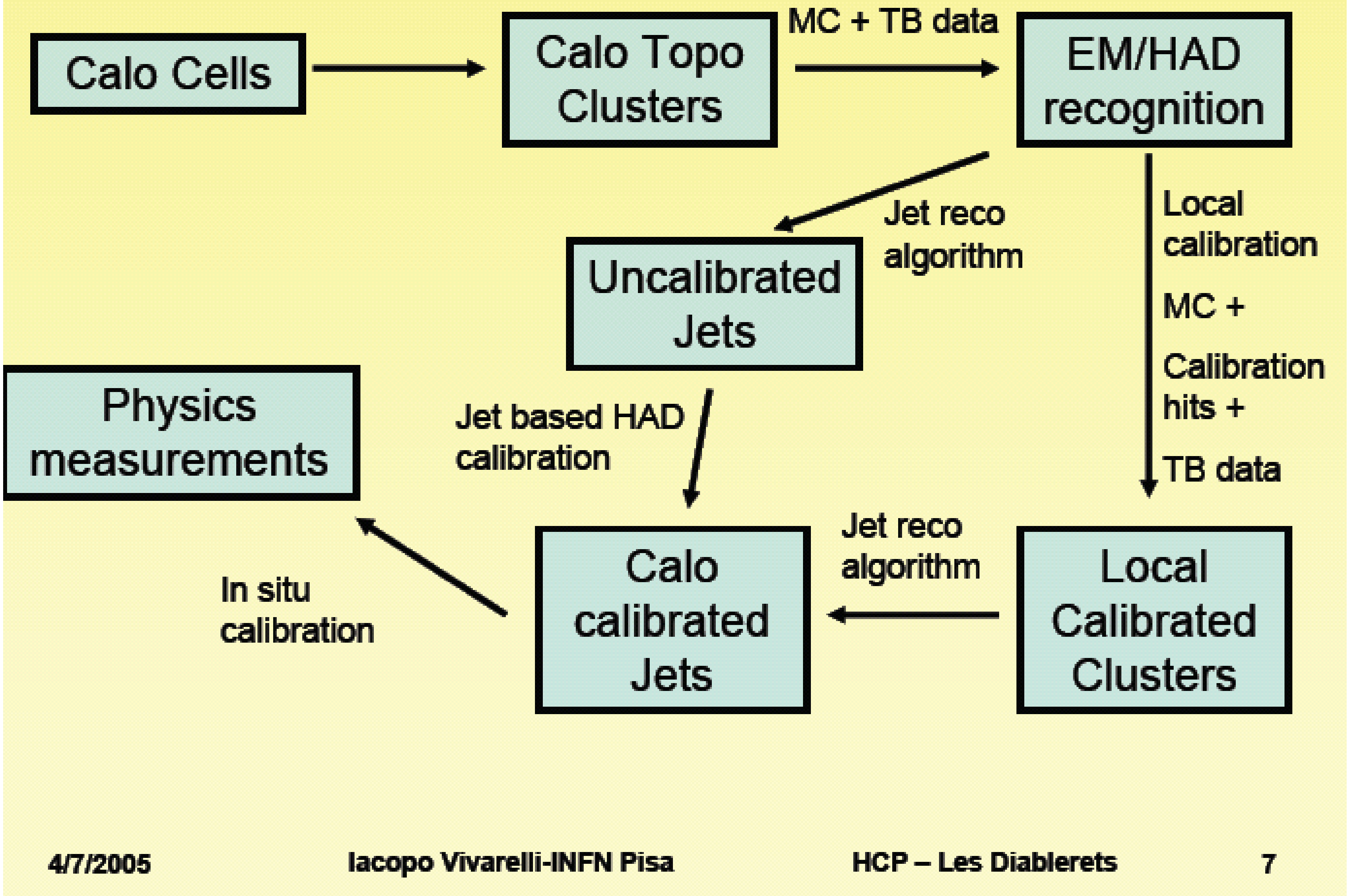
In-situ Jet Energy Scale Calibration

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

In-situ Jet Calibration

- p_T balance in γ/Z + jet events
  - see Rome Workshop talk by Caroline Deluca
  - potentially large statistics
- M_W constraint in top events
  - see Rome Workshop talk by Dominique Pallin
  - good for top mass reconstruction?...for other processes?
- Control samples?

Toward integration with HadronCalibration



Calo Cells

Calo Topo Clusters

MC + TB data

EM/HAD recognition

Jet reco algorithm

Uncalibrated Jets

Local calibration

MC +

Calibration hits +

TB data

Physics measurements

Jet based HAD calibration

In situ calibration

Calo calibrated Jets

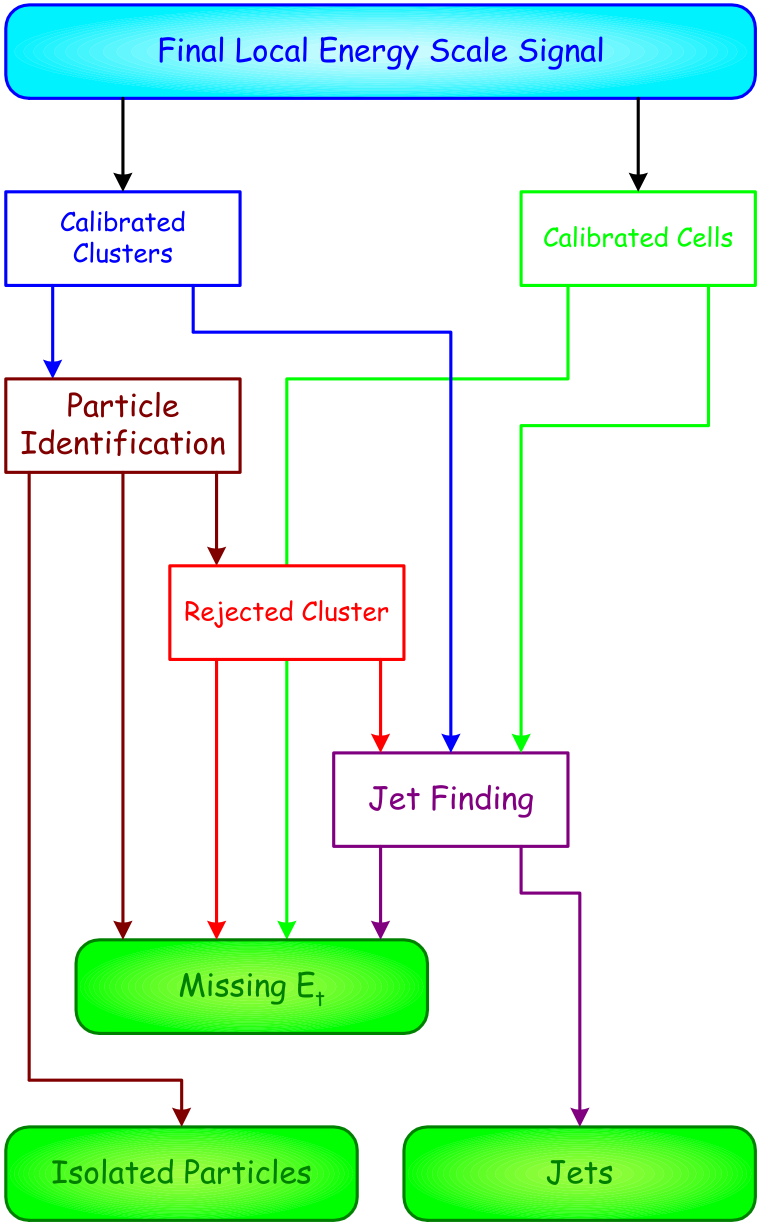
Jet reco algorithm

Local Calibrated Clusters

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

From local energy scale signal to physics objects

P. Loch



Final Local Energy Scale Signal

Calibrated Clusters

Calibrated Cells

Particle Identification

Rejected Cluster

Jet Finding

Missing E_t

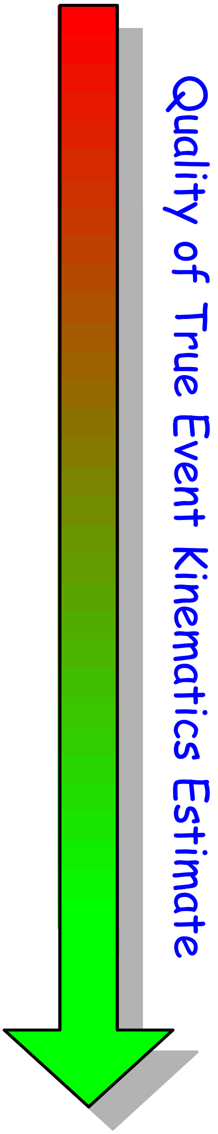
Isolated Particles

Jets

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…)



Quality of True Event Kinematics Estimate

Jets: Tasks

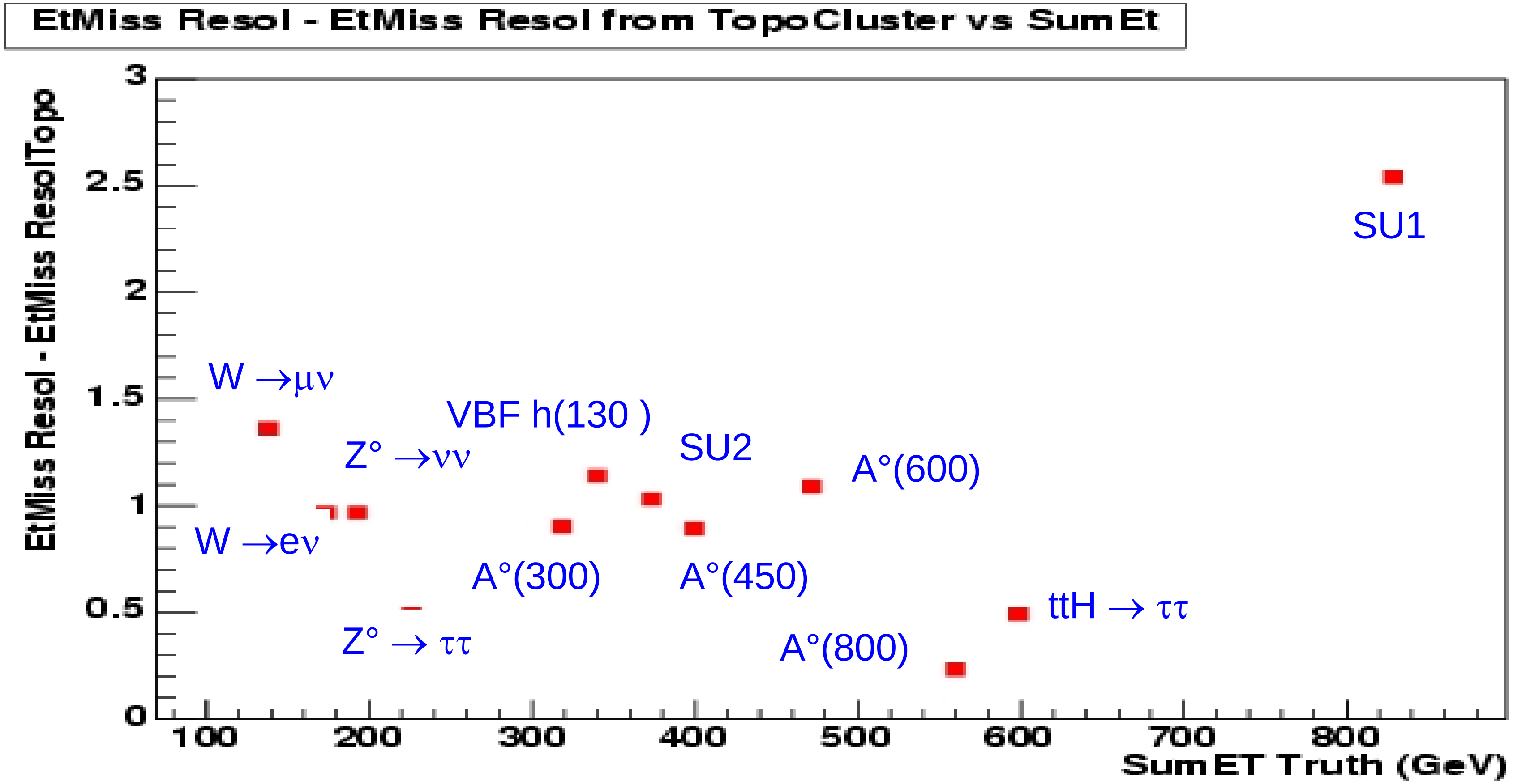
- Jet reconstruction algorithms
  - compare in detail the performance of the various algos (at EM energy scale); may need new algos
  - try using locally calibrated TopoClusters
  - develop methods for jet algorithm validation
    - are obvious jets being missed?
- Jet calibration studies (to MC jet)
  - should be easy to switch from one method to another
  - need to investigate effect of pileup and underlying event
  - systematic study of effects of electronics noise
- Jet energy scale calibration (to parton)
  - follow up with in-situ calibration
- Establish control samples
- At which level should electrons and muons in jets be treated?
  - at the event view!?

EtMiss Reconstruction

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

S. Resconi, ETmiss Performance in 10.0.1:

difference between EtMiss Resolution from all Cells with $|E_{cell}| > 2\sigma$ (noise) and EtMiss Resol from TopoCluster Cells (4/2/0) vs SumET Truth

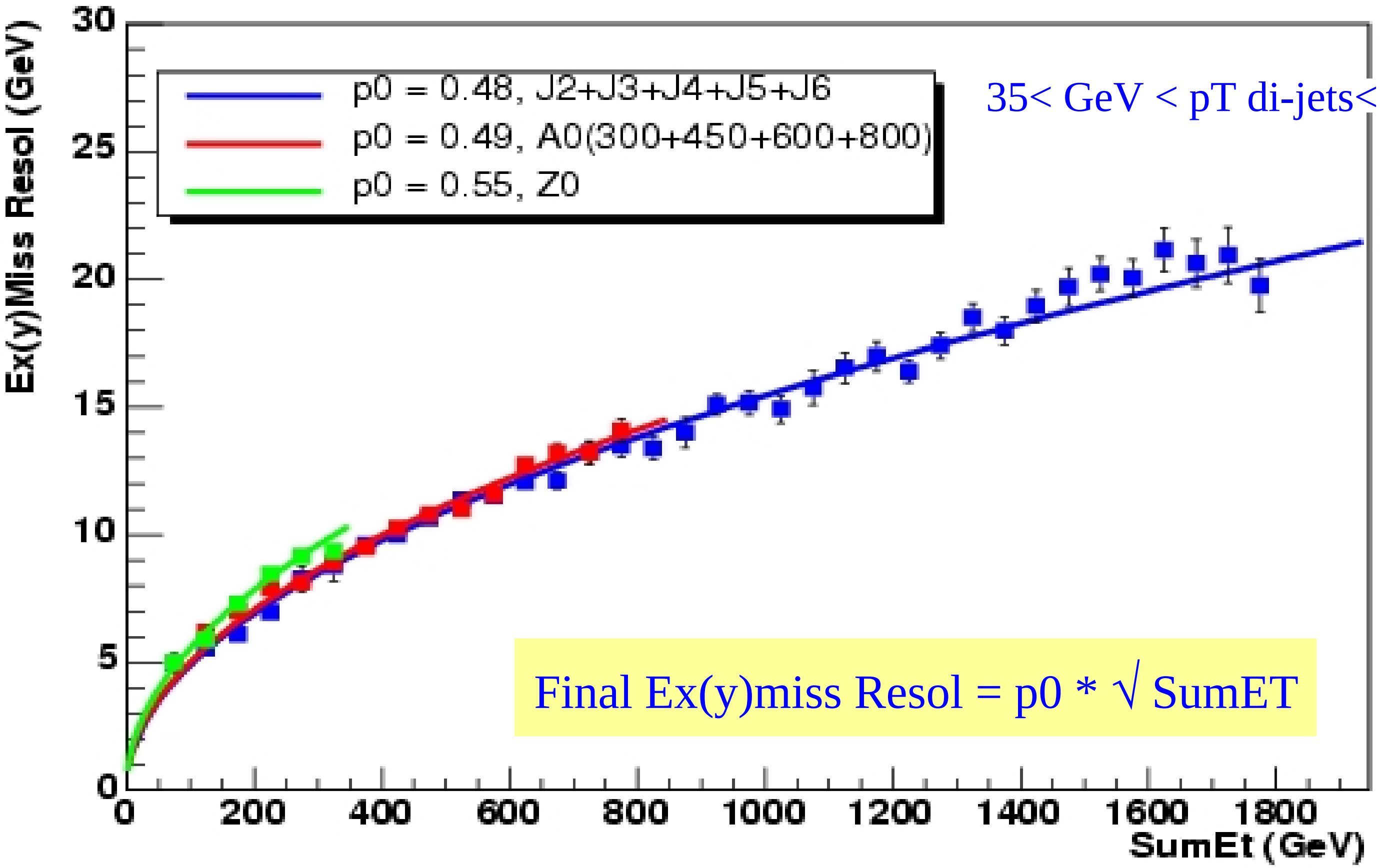


Final EtMiss Resol = σ fit (MET_Truth (NonInt) – MET_Final)

Resolution from TopoCluster always improves ⇒ better noise suppression

S. Resconi, Rome Workshop: ETmiss Performance in 10.0.1:

Ex(y)Miss Resol from TopoCluster vs SumET



35< GeV < pT di-jets< 1120 GeV

Final Ex(y)miss Resol = p0 * √ SumET

In TDR: p0 ~ 0.46 (Z° → ττ , A°→ ττ)

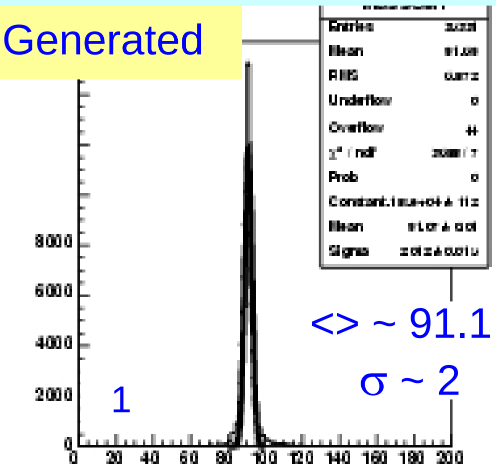
current H1-style calibration is not optimal for low energy region,

⇒ **needed a Topocluster based calibration to improve results**

S. Resconi: Commissioning: Z° → ττ → lept-had channel study

ττ invariant mass reconstruction from τ decay products

Generated

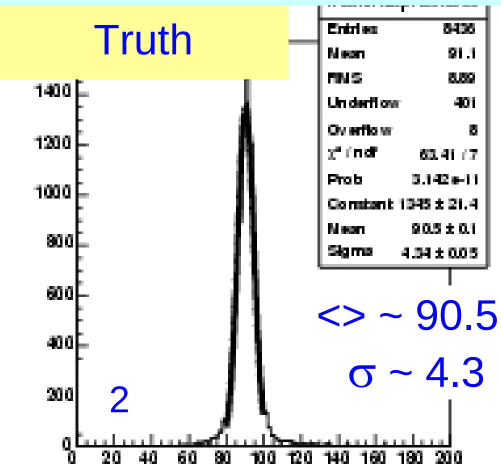


<> ~ 91.1

σ ~ 2

1

Truth

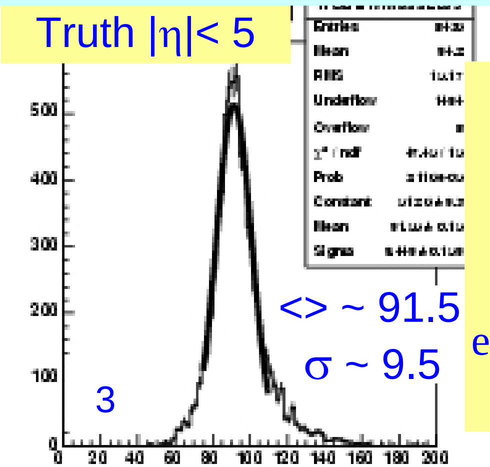


<> ~ 90.5

σ ~ 4.3

2

Truth |η|< 5



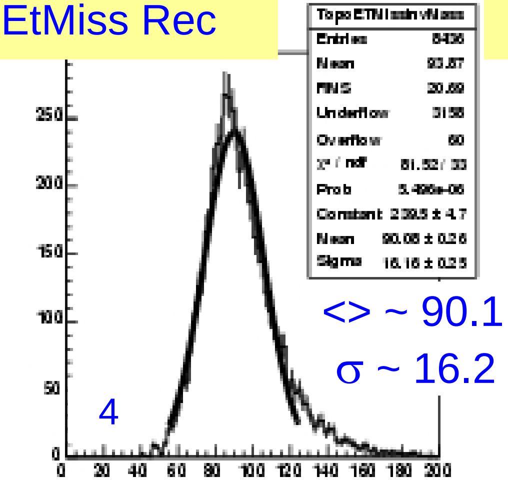
<> ~ 91.5

σ ~ 9.5

3

p_T(lept) > 15 GeV,
$p_T(\tau)$ > 15 GeV,
$\Delta\phi < 2.7$,$\Delta\phi > 3.6$
to kill back-to-back
evts causing large tails

EtMiss Rec

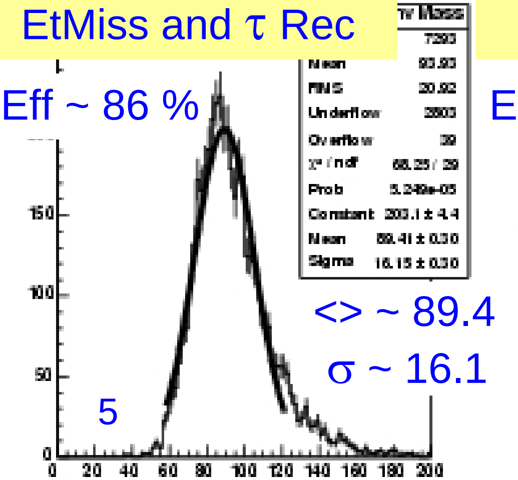


<> ~ 90.1

σ ~ 16.2

4

EtMiss and τ Rec



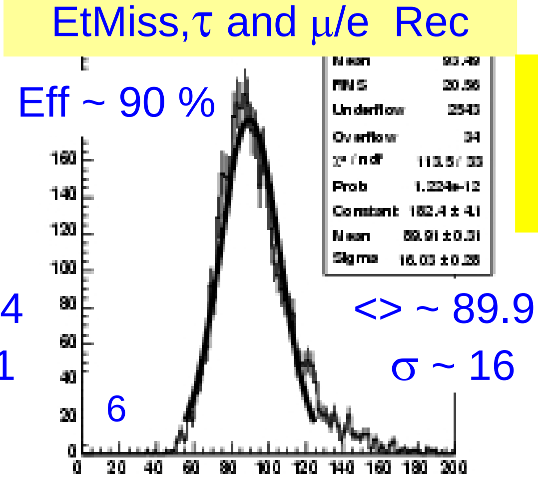
Eff ~ 86 %

<> ~ 89.4

σ ~ 16.1

5

EtMiss,τ and μ/e Rec



Eff ~ 90 %

<> ~ 89.9

σ ~ 16

6

G3-H1 τ calib
in 10.0.1
corr fact =1.12

Main contributions to the width :

(2) Assumption on τ-decay prod directions , (3) Coverage effect , (4) EtMiss Resol

Truth matching of reconstructed τ , μ, e

EtMiss: Tasks

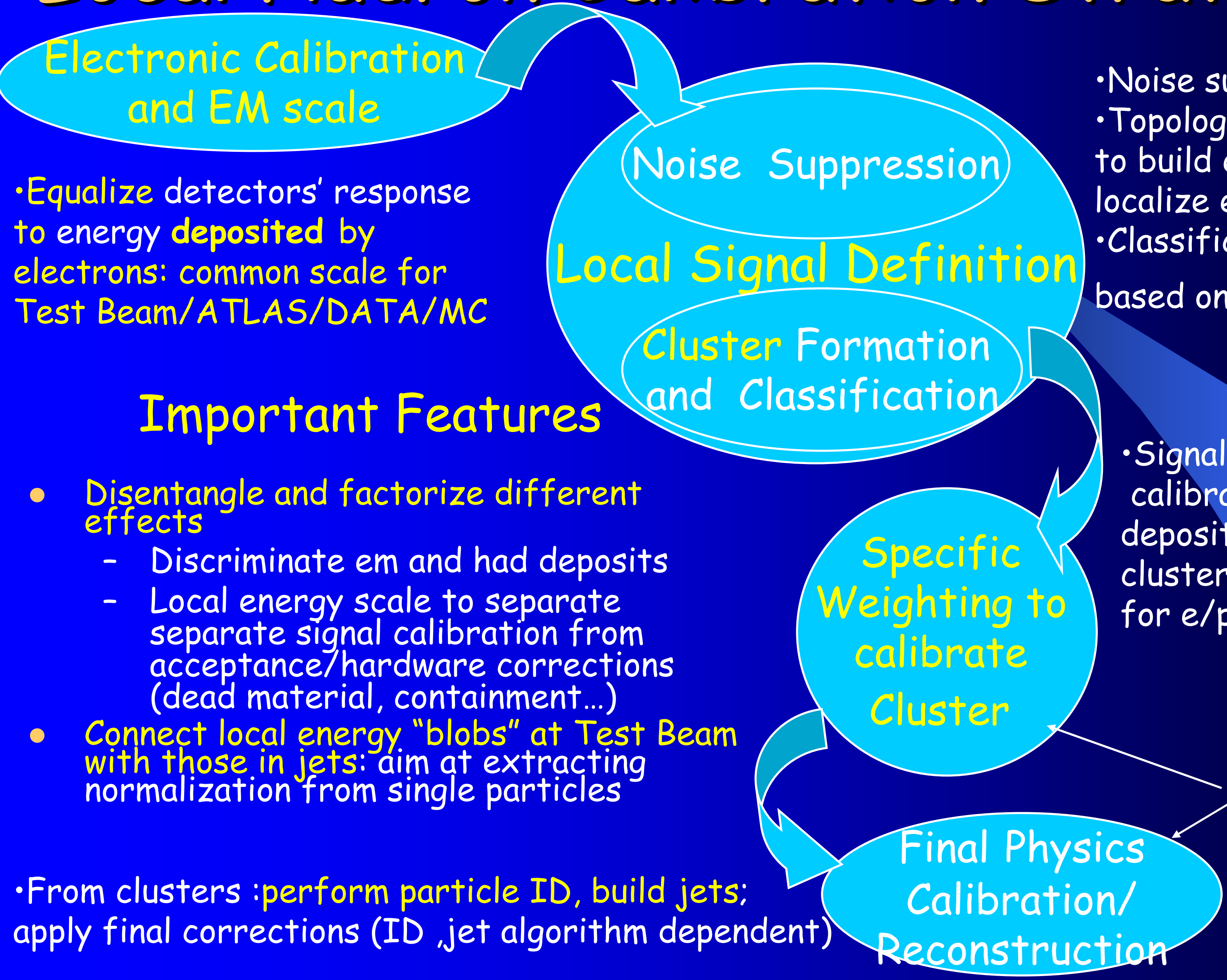
- EtMiss monitoring
  - with minimum bias events
  - time variations, luminosity changes
- Further develop EtMiss calibration/validation methods
- Need to try again with (locally) calibrated TopoClusters
- Further work required to understand the effect (and treatment) of dead regions on EtMiss
- Develop object-based EtMiss reconstruction (one for each event view?)

A few more comments...

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

Please let me know of any mistakes you may find
in this talk, especially regarding credits!

Local Hadron Calibration Strategy



Electronic Calibration and EM scale

•Equalize detectors' response to energy **deposited** by electrons: common scale for Test Beam/ATLAS/DATA/MC

Local Signal Definition

Noise Suppression

Cluster Formation and Classification

•Noise suppression
•Topological correlations to build energy blobs i.e. localize energy deposit
•Classification in e.m., had

based on cluster shape

Important Features

- Disentangle and factorize different effects
  - Discriminate em and had deposits
  - Local energy scale to separate separate signal calibration from acceptance/hardware corrections (dead material, containment…)
- Connect local energy "blobs" at Test Beam with those in jets: aim at extracting normalization from single particles

Specific Weighting to calibrate Cluster

•Signal Weighting: calibrate local energy depositions of had. clusters to compensate for e/pi

Correct for acceptance and Dead Mat

Final Physics Calibration/ Reconstruction

•From clusters :perform particle ID, build jets; apply final corrections (ID ,jet algorithm dependent)

Noise Suppression Methods and Jets

- Ambreesh Gupta looked at Jet reconstruction for 3 different noise treatments with 100 k events from Rome samples J1-J8
  - the plots show how much negative energy is kept by each treatment in each detector region
  - `JetTowerNoiseTool` keeps largest amount of negative energy
  - `CaloTopoClusterMaker` keeps smallest amount of negative energy
  - global symmetric 2 σ_{noise} cut keeps slightly more than `CaloTopoClusterMaker`