Jet Reconstruction and Calibration in the ATLAS Calorimeters

On behalf of ATLAS collaboration

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Outline

- **Introduction**
- **ATLAS Calorimetry**
  - Characteristics
  - Response uniformity
- **ATLAS reconstruction and calibration strategy**
  - Preclustering and noise suppression
  - Jet clustering
  - Calibration to particle level
- **In Situ processes**
- **Conclusions**

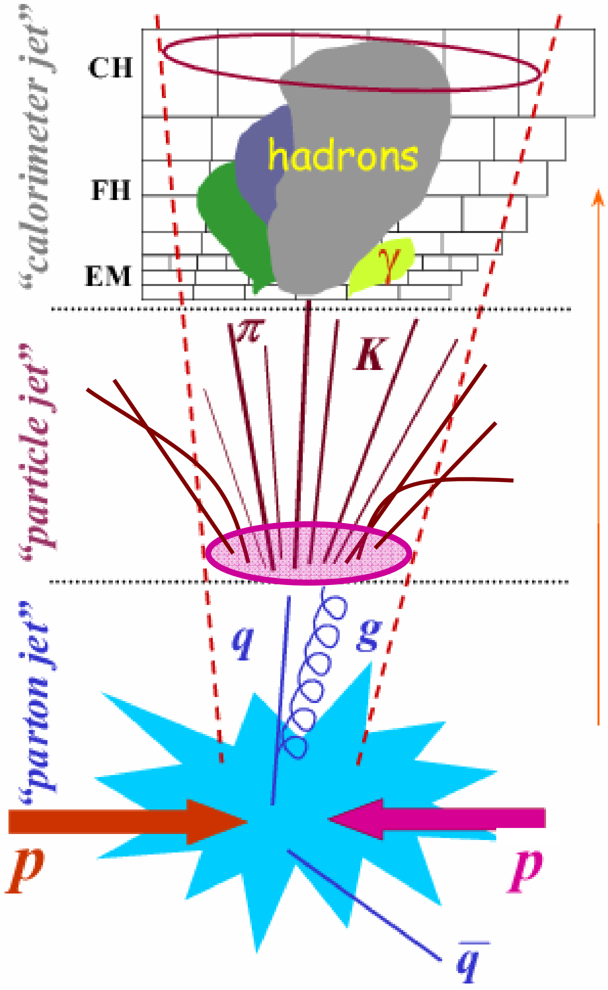
• From **partons** to **signals**

Various effects play a role in the chain:

Partons → Calorimeter signals

- **Physics**:
  - Parton shower & fragmentation
  - Underlying events
  - Initial State Radiation & Final State Radiation
  - Pileup form minimum bias events
- **Detector**:
  - Non compensation
  - Dead material
  - Electronic noise
  - Energy leakage
- **Clustering**:
  - Out of “cone” energy losses

Strategy: disentangle as much as possible physics and detector effects



• Atlas Calorimeters

LAr
Electromagnetic
calorimeter

barrel

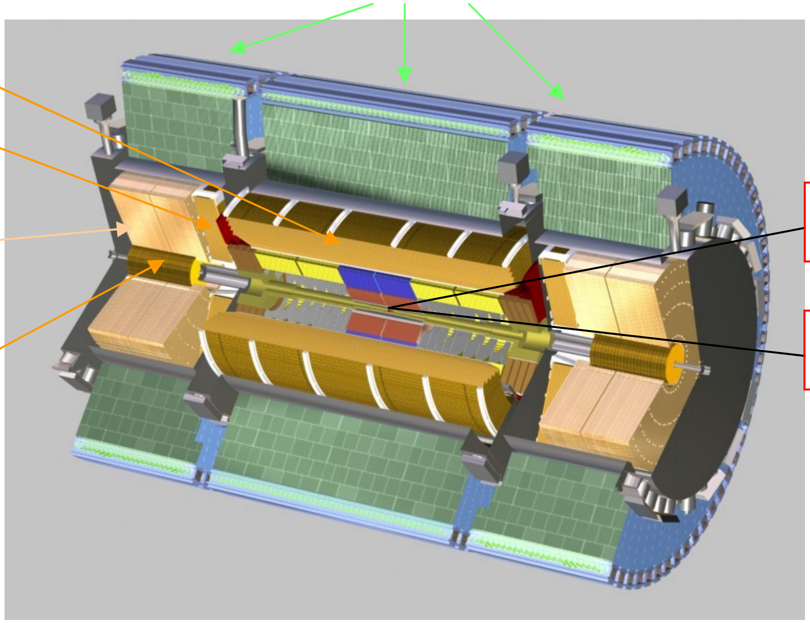
endcap

LAr EndCap
Hadronic
calorimeter

LAr Forward
Calorimeter

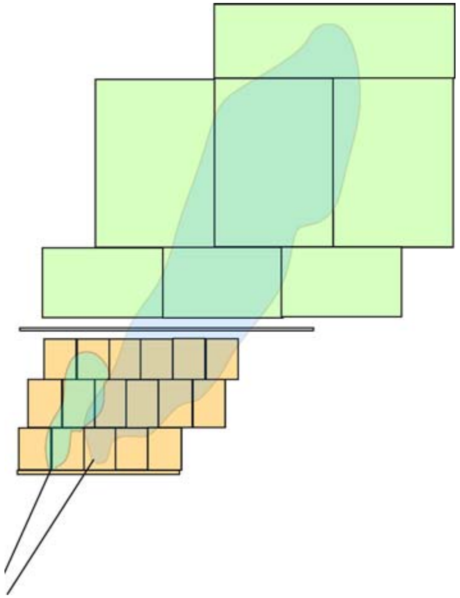
Barrel **Tile**

Hadronic calorimeter



η = 1.5

η = 3.2

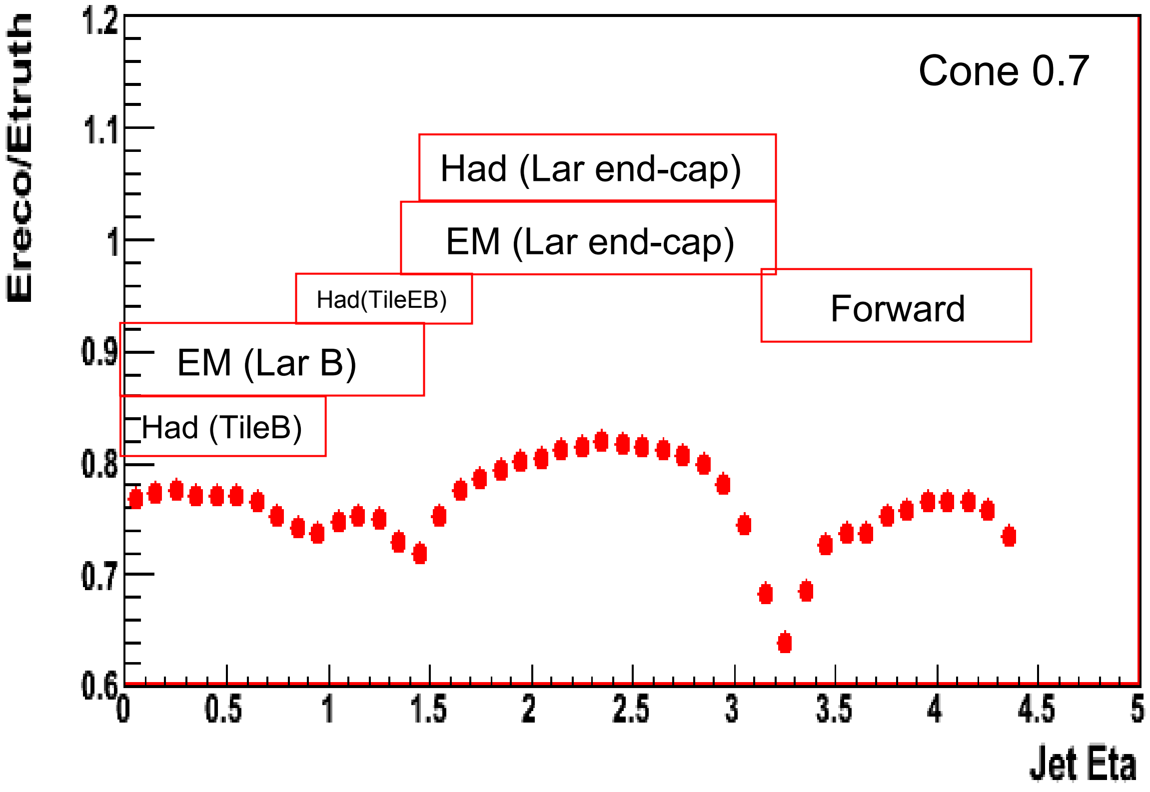


large eta coverage up to $|\eta| \sim 5$

fine lateral & longitudinal granularity

- Calorimeter non-compensation e/h ~1.3 – 1.5 (depend on calorimeter)
- Extensive test beam program to validate detector simulation (see talks of the Test Beam session)

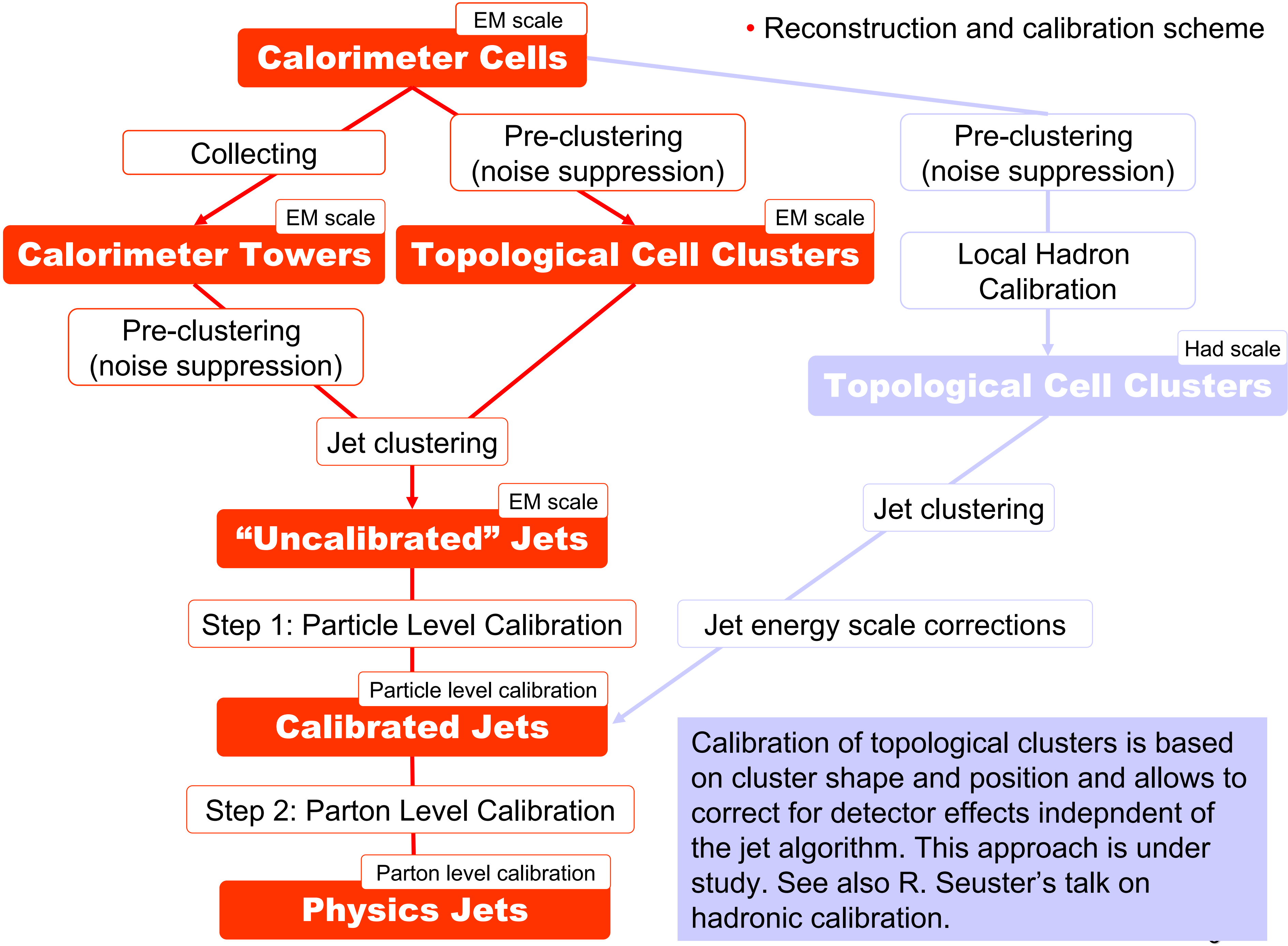
Jet Response Uniformity



Jet energy calibrated at **EM scale /** normalized to **MC truth energy**

Calorimeter response depends on:
- dead material and gaps
- level of non-compensation

- Reconstruction and calibration scheme



EM scale

Calorimeter Cells

Collecting

Pre-clustering (noise suppression)

EM scale

Calorimeter Towers

EM scale

Topological Cell Clusters

Pre-clustering (noise suppression)

Jet clustering

EM scale

“Uncalibrated” Jets

Step 1: Particle Level Calibration

Particle level calibration

Calibrated Jets

Step 2: Parton Level Calibration

Parton level calibration

Physics Jets

Pre-clustering (noise suppression)

Local Hadron Calibration

Had scale

Topological Cell Clusters

Jet clustering

Jet energy scale corrections

Calibration of topological clusters is based on cluster shape and position and allows to correct for detector effects indepndent of the jet algorithm. This approach is under study. See also R. Seuster’s talk on hadronic calibration.

• **Preclustering** and **Noise Treatment**

Start with cells calibrated at EM scale

Three methods:

- Build and precluster **projective towers**:
  - Sum energy of cells in towers of $\Delta\eta\times\Delta\varphi = 0.1 \times 0.1$
  - **Compensate towers with negative energy with its positive neighbors.**

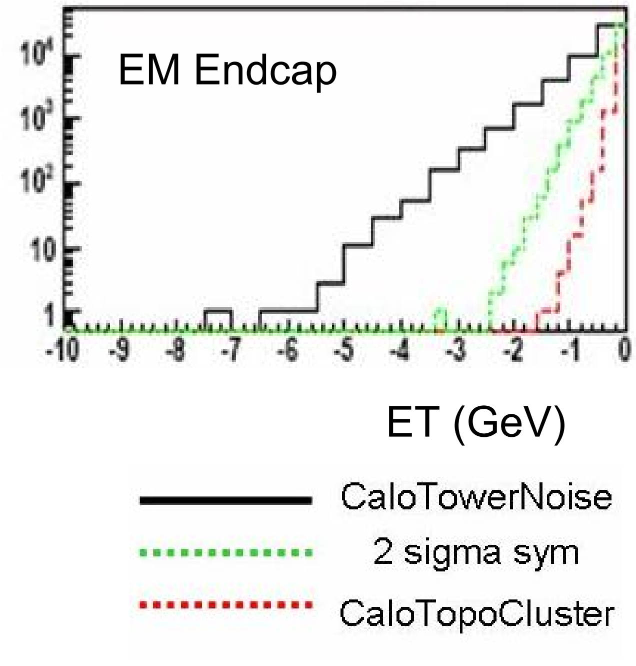
  (default option)

- Build **topological cell clusters**:
  - Nearest-neighbor clustering cells around a seed with significant signal (4σ,2σ,0σ noise)
  - Clusters = EM shower or hadronic sub-showers
  - **Removes cells with insignificant signals (unclustered).**

  (under study)

- Select cells with **2σ symmetric cut**:
  - **Removes all cells with |E|< 2σ noise.**

Negative energy left in preclusters



Jet clustering

- For jet clustering three typical algorithms are used:

Seeded Cone algorithms

- Collect **neighbors** around a **seed** in a radius R (+ split/merge)
  - **Cone 0.7**: R = 0.7
    To avoid fragmentation loss for low Pt jets.
  - **Cone 0.4**: R = 0.4
    Necessary at high luminosity and to separate overlapping jets (high Pt resonance disintegration).

Kt algorithm

- Algorithm that merges particles based on **radial distance** and **transverse momentum** (D parameter “Jet Size” =1)

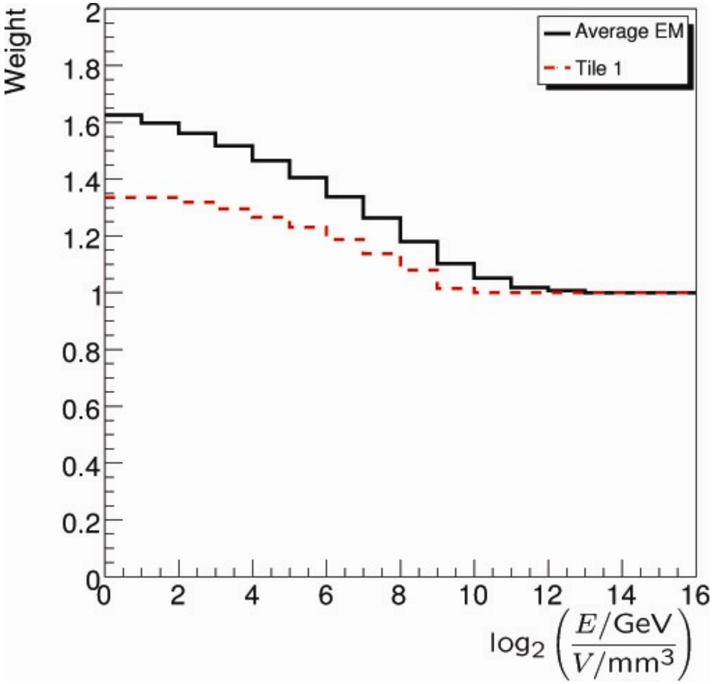
- Study **detector** and **physics effects** for the 3 cases

• Jet energy **calibration** to **particle level**

Calibration aim: Energy resolution minimization with linearity constraint
Correct for dead material and non compensation

- **Jet calibration** – various strategies:
  - Apply **weight** to **each cell**.
  - Apply **weight** to **calorimeter layers**. Simple and fast but less performant.

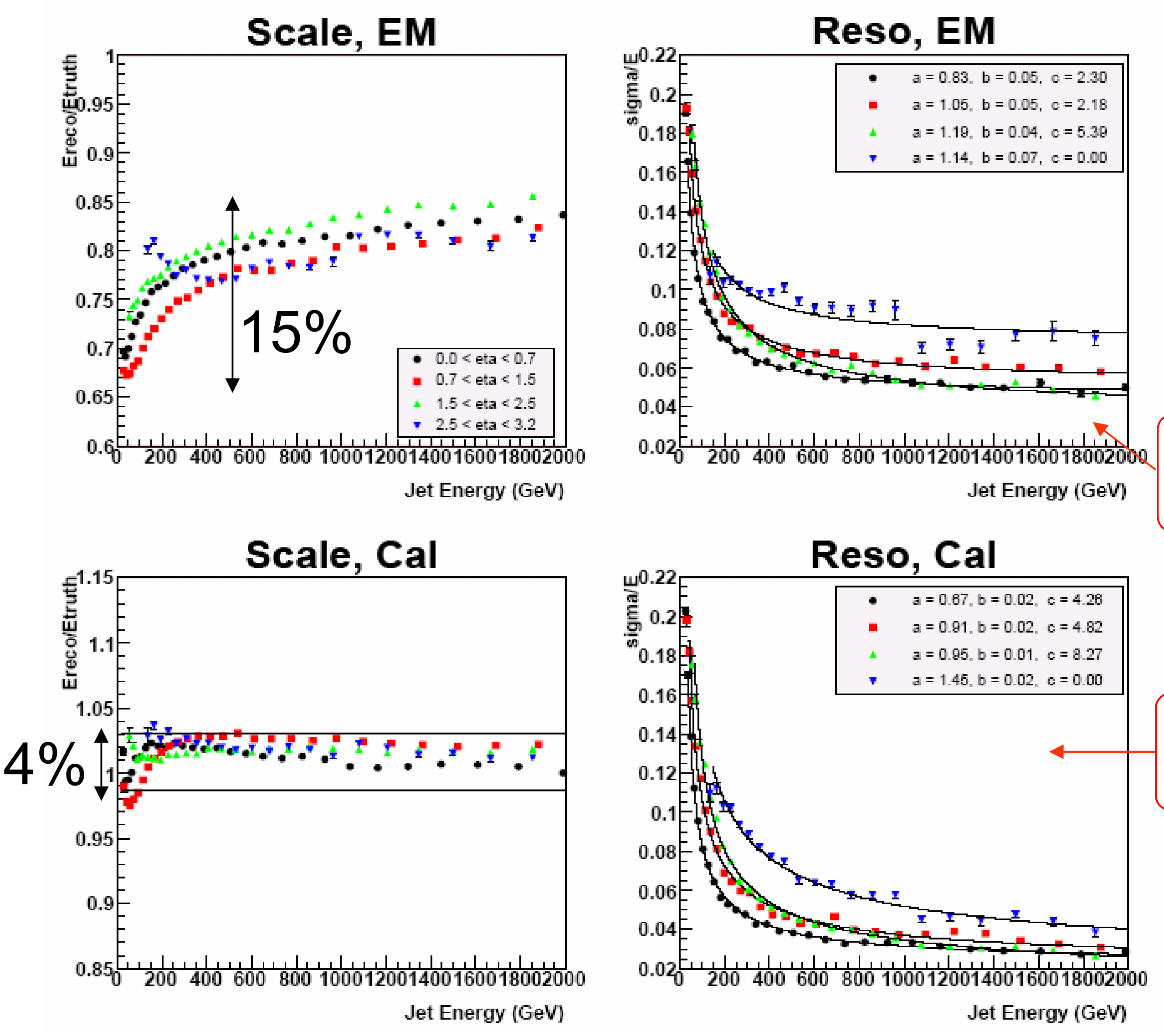
  Different ways to take into account eta and jet energy dependence and additional correction for dead material.



- **Default calibration**:
- $E_{rec} = \sum_i W(Ecell_i / V_i, \text{sampling})Ecell_i$
- A factor R(ET,η) = ETrec/ETMC is applied to correct for residual non linearities and for algorithm effects.

Detector description by MC is validated with an extensive CTB program

Jet **energy resolution** 1



- Cell energy weight
- Cone 0.7
- For |η|<0.7:
- Before calibration:

$$\frac{\sigma(E)}{E} = \frac{83\%}{\sqrt{E(GeV)}} \oplus 5\% \oplus \frac{2.3}{E(GeV)}$$

- After calibration:

$$\frac{\sigma(E)}{E} = \frac{67\%}{\sqrt{E(GeV)}} \oplus 2\% \oplus \frac{4.3}{E(GeV)}$$

- Linearity ±2% E>30 GeV

• **In situ** physics processes

- In situ physics processes provides a way to **calibrate** the jets to **parton level** and **validate** the **MC** simulation, specially the **physics effects**:

Dijets

- Cross calibrate the detector

Gamma / Z (→ ll) + jet

- Parton level calibration, jet clustering, UE studies...
- Well understood EM reference recoiling against hadronic system
- Large statistics available at $L=10^{33}cm^{-2}s^{-1}$:
    - pT range from 20 GeV to 60 GeV: Z(→ll)+jet ~2Hz and γ+jet ~ 0.1 Hz
    - pT range > 60 GeV: (expected threshold for single γ) γ+jet ~2Hz and Z+jet ~ 0.1 Hz

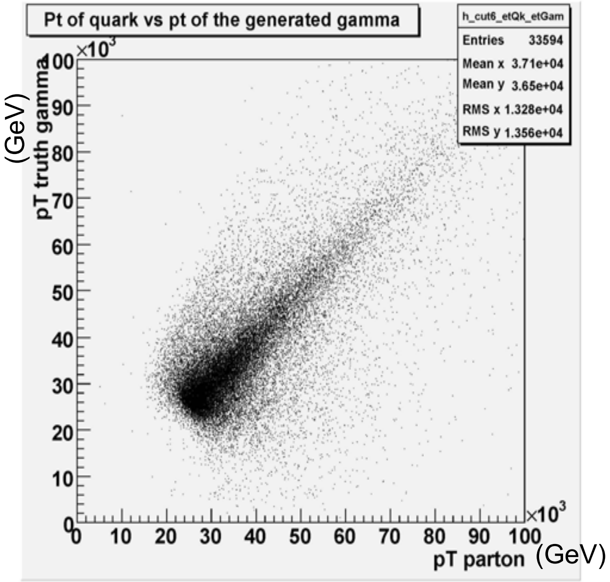
W → jet jet

- Parton level calibration
- Resonance with precisely known mass decaying into two jets
- Statistics ($L=10^{33}cm^{-2}s^{-1}$): few hundred per day (depending on b-tagging)

In situ – **Gamma + jet** 1

- Two complementary Methods:
  - **Pt balance**:
    - Calculated from the **leading recoiling jet** and **photon**.
    - Sensitive to out of cone showering, gluon radiation, UE and detector effects.
    - Relative jet clustering studies

$$\boxed{\Delta p_t = \frac{p_t^{jet} - p_t^{\gamma}}{p_t^{\gamma}}}$$



  - **Missing Et projection**:
    - Vector sum of everything in the calorimeter. Sensitive to particle response only.
    - **Recoil of complete hadronic system against the photon**

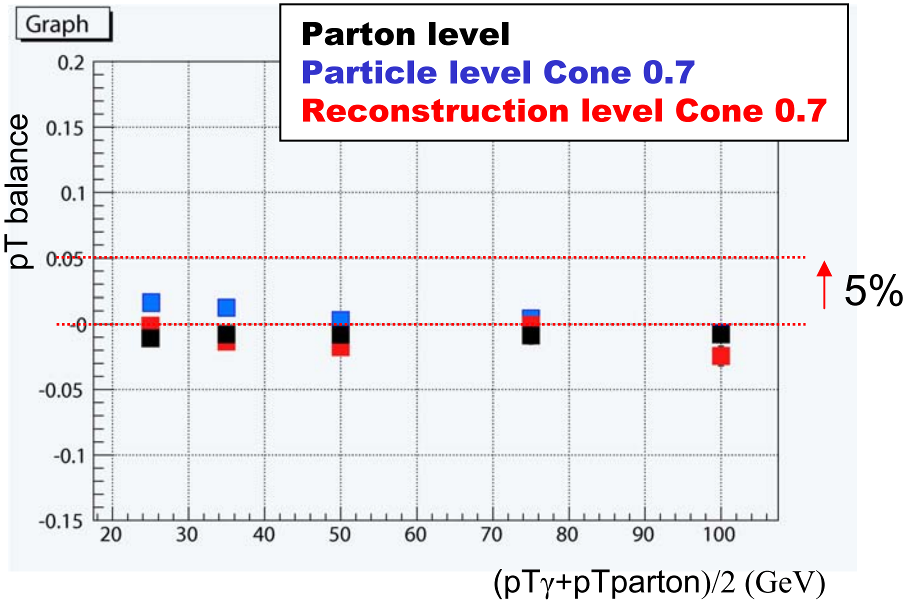
$$\boxed{R = 1 + \frac{\vec{E}_t^{miss} \cdot \vec{E}_t^{\gamma}}{\vec{E}_t^{\gamma} \cdot \vec{E}_t^{\gamma}}}$$

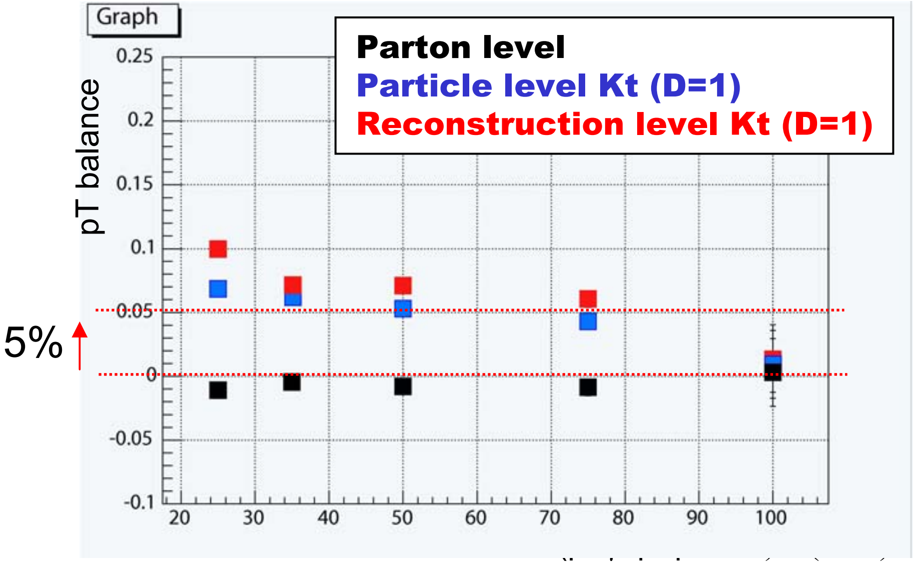
$$\boxed{\vec{E}_t^{miss} = -\sum_{calo} \vec{E}_t^{calo}}$$

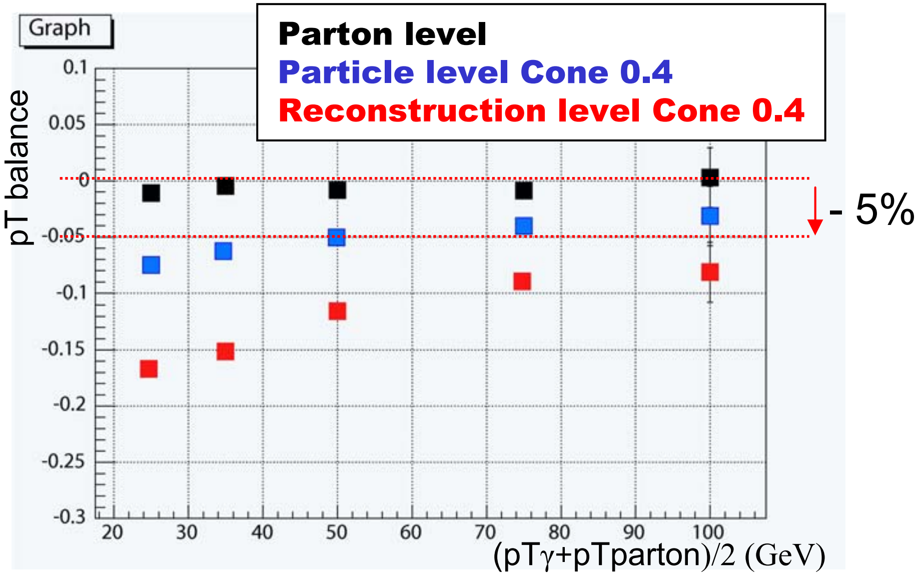
• In situ - **Gamma + jet** 2

- Most probable values of the Pt balances
- Differences between cone algorithms

Compare this results with real data

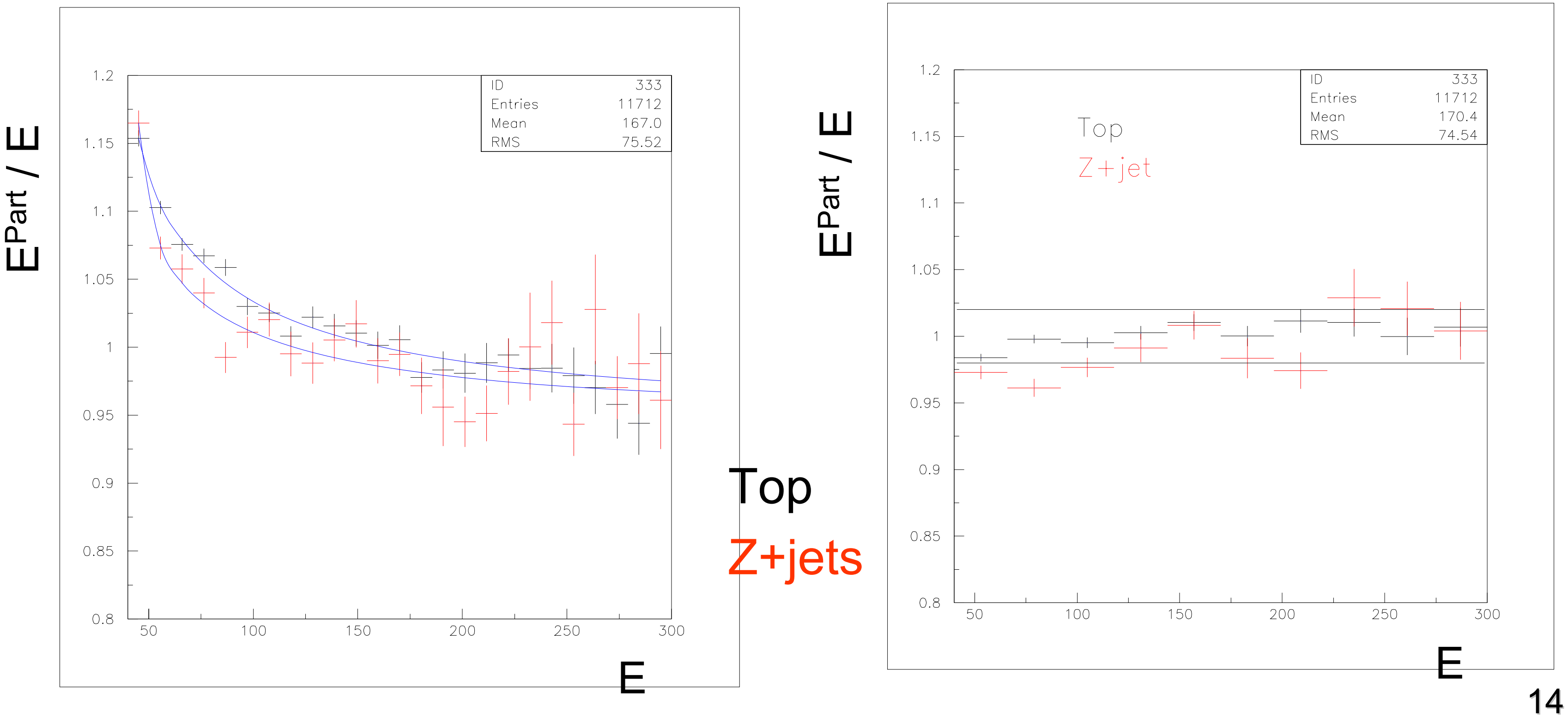






In Situ – **W → j j**

- W mass well defined
- Use W → j j in ttbar events to calibrate jets at parton level
- Use Cone 0.4 for efficient jet reconstruction in busy event environment
- $M_W^{PDG} = M_W^{rec} \sqrt{(\alpha_1 \alpha_2)}$, $\alpha_i = E_i^{part}/E_i^{jet}$
- This calibration can be applied to events with similar jet type (q, g). E.g. Z + jet.

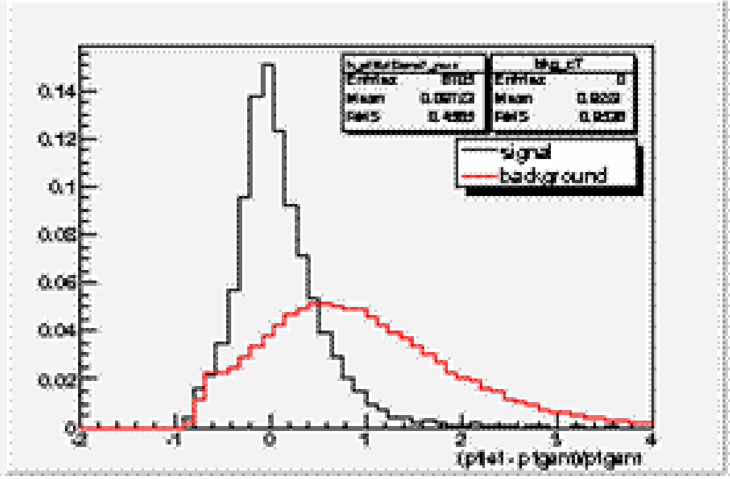


Conclusions

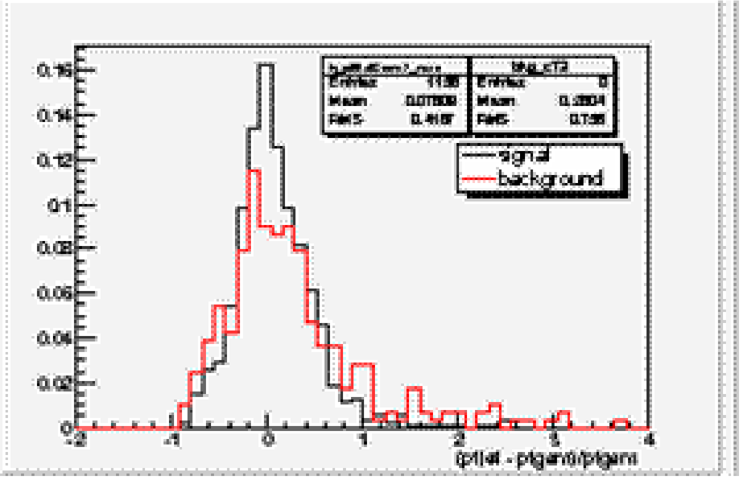
- Different strategies for signal reconstruction and jet energy calibration are being studied.
- Strategy for first data is being designed.
  - Analysis of in situ information is being prepared.
  - Validation / measurement of important factors (fragmentation, UE...) must be done with data.

- **Backup slides**

• γ+jet 6: Dijet background



Default CBNT cuts: S/B~10%
Efficiency γ ~ 90%



Optimised cuts: S/B~30%
Efficiency γ ~ 15%

Data sample Athena 7.2.0 DC1 data

low pT sample <ET>~30 GeV

Mean **(-0.6, 0.6) window**	**Cone 0.4**	**Cone 0.7**	**kT**
Signal	**-13 ± 0.8%**	**2 ± 0.9%**	**1 ± 0.9%**
Background	**-15 ± 2%**	**1 ± 2%**	**-1 ± 2%**

statistical error

remaining jet background ≈ π^0

C. Deluca. Rome Workshop

Calibrating to Particle Jet

2 step procedure

1. Calibrated energy is calculated as:

$$E_{Raw} = \sum_{s} Ecell_s$$

$$E_{\mathrm{Rec}} = \sum_{s} w(Ecell, CellPosition)\,Ecell_s$$

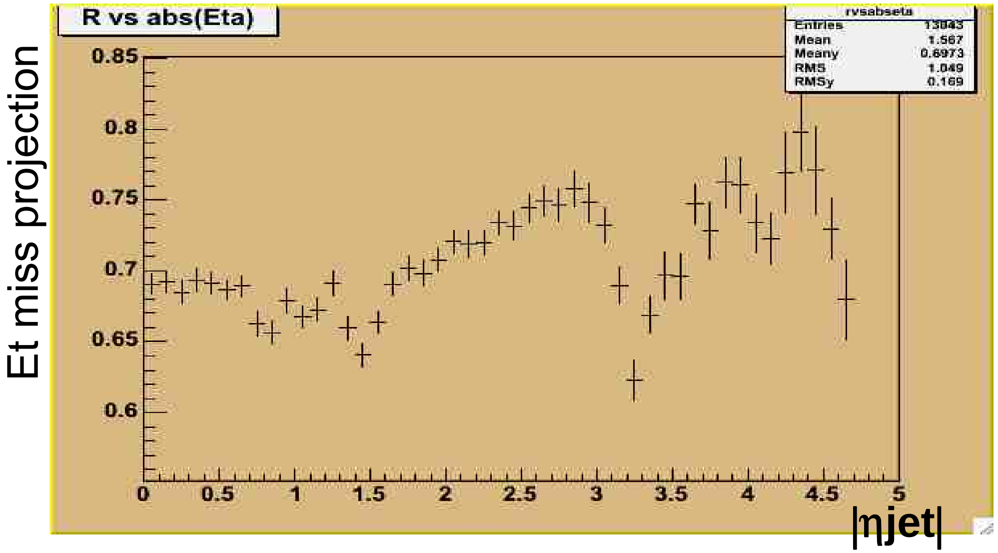
Cell weighting

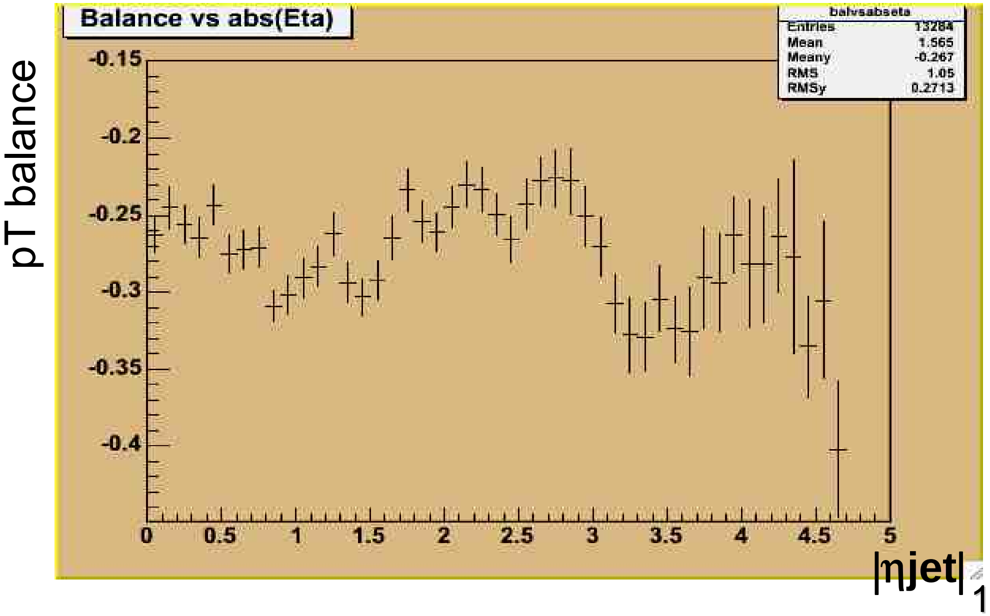
the *w(Ecell,CellPosition)* coefficients are obtained by minimizing the energy resolution to the MC truth with the linearity constraint. Same weights are used for different algorithms.

2. A factor $R(E_T,\eta) = E_T rec/E_T MC$ is applied to correct for residual non linearities and for algorithm effects.

• In situ – **Z + jet**

- EM scale
- Pt balance flatter in eta
- E, R and out-of-cone showering increase with η





Check that MC reproduce data behavior

- Atlas Calorimeters – **Response uniformity**