Test of the ATLAS Pion Calibration scheme in the ATLAS Combined Test Beam

CALOR08
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The 2004 ATLAS Combined test beam
Pion calibration techniques
Performance on simulation and data

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on behalf of the Combined Test Beam and Hadron Calibration ATLAS groups
2004 ATLAS Combined Test Beam

I LAr/Pb EM barrel module with accordion shape

particle ID (select $\pi$) by track reconstruction (reject e, $\mu$)

3 iron/scintillator modules stacked vertically (along $\varphi$)

Cryo-stat

Calo coverage
$\eta$: (-1.6, 1.6)
$\varphi$: (-0.15, 0.15)

$\lambda_{int}$ @ $\eta = 0.45$

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Data and Monte Carlo Samples

pions shot “centrally” at (φ=0, η=0.45)

<table>
<thead>
<tr>
<th>#ev after sel</th>
<th>Energy (GeV)</th>
<th>Particle</th>
<th>Proton fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>~8000</td>
<td>20</td>
<td>$\pi^+$</td>
<td>0 %</td>
</tr>
<tr>
<td>~15000</td>
<td>50</td>
<td>$\pi^+$</td>
<td>41 %</td>
</tr>
<tr>
<td>~7000</td>
<td>100</td>
<td>$\pi^+$</td>
<td>59 %</td>
</tr>
<tr>
<td>~5000</td>
<td>180</td>
<td>Select $\pi^+$ from e$^+$ run</td>
<td>75 %</td>
</tr>
</tbody>
</table>

Monte Carlo Simulation

- Simulate pions and protons in energy range (15, 230) GeV
- Geant 4.7 QGSP_BERT with consistent description of fully combined test beam set-up
- Divided into two statistically independent samples for calculating corrections and applying them
- ~$4 \cdot 10^6$ events in total

proton fraction measured by TRT
Pion in ATLAS Calo

7 layers

Back
Middle
First

Cryostat
Back
Middle
Front

Presampler

LAr
EM
Cal

Tile
Had
Cal

Incoming hadron

Dead material
Correct

Leakage
Out of cluster

Signal definition
(Clusters)

Invisible energy

Weight

Had Calib

Correct

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Calibration techniques

Local Hadron Calib. (LH)
(See G Pospelov’s talk)

- Classified Cluster
- Cell en. density, $\eta$, $E_{\text{clus}}$
- Cluster position
- Parametrization

Calibrated clusters used to form calibrated jets

Layer Correlation Calib. (LC)

- $E_{\text{LAYER}} =$ clustered energy in LAYERs
- Hadronic and Em energy deposits have different fluctuation properties
- Variables sensitive to fluct. to compensate and improve resolution
- Calibrated layer energies technically extendable to jets, need to calibrate jet itself

**Signal definition**

- Invisible energy
- Out of cluster Leakage
- Dead material

**Corrections**

- All values from 2 sigma Gaussian fit to energy

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Local Had Calib Linearity - Simulation

pure $\pi^+$ beam

EM scale: $\sim 75\%$ of $E_{beam}$

Dead Material recovers remaining $\sim 10\%$

Out of clus: small

Weighting recovers $\sim 10\%$

Expect linearity recovered within 2\% for $E_{beam} > 20$ GeV
Local Had Calib Resolution - Simulation

pure $\pi^+$ beam

Dead material is dominant effect

Expect improvement by 11% to 40% in relative resolution
**Layer Correlation Calibration (LC)**

**Signal:** clustered energy in LAYERs

**Corrections:** function of linear comb of LAYER energies with largest expected fluctuations

- Weight \( E^{\text{LAYER}} \) to recover \( E^{\text{inv}} \)
  - Include out of clus. corr

- Derive from simulated samples with \( E_{\text{beam}} \) in (15,230) GeV
  - No \( E_{\text{beam}} \) dep

- Dead material estimate
  - Para for upstream loss + leakage

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LC Linearity - Data and Simulation

consistent $\pi^+-p$ mix in data and simulation

Remaining dead material adds ~2%

EM scale: ~75% of $E_{\text{beam}}$

Data - sim. agreement is within 2% at all stages

Linearity is recovered within 3%
LC Resolution - Data and Simulation

Calibration improves relative resolution by 17% to 21% (expect 17 to 24%)

Simulation underestimates data relative resolution by 10% to 25%
G4.9 improves resolution description (see P. Speckmayer’s talk)

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Local vs Layer: Linearity (Data)

Linearity recovered at 2% to 5% level in both

EM scale taken from LC method: slight difference with LH due to different reco version

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Conclusions

- A simulation-based technique for hadronic signal calibration (LH) was applied to pion energy reconstruction in 2004 ATLAS combined test beam for $E_{\text{beam}}$ in (20 GeV, 180 GeV). A novel technique based on layer correlation (LC) was also used.

- Pion linearity is recovered within 2 to 5% by both approaches in good agreement between data and simulation. Weighting and dead material effect have similar impact.

- Relative energy resolution is expected to improve (by 20-30% to 40% in LH/LC). LC actually achieves 17 to 21% improvement. Simulation underestimates data resolution by 10 to 25%. Dead material effects are dominant.

- Data-sim. discrepancies at EM scale kept at all stages: simulation performance is limiting factor.
Back-up
ATLAS Calorimeters @ Test beam 04

3 Tilecal iron scintillator stacked modules

Dead mat: 0.6 $\lambda_{\text{int}}$ @ $\eta=0.45$

8.2 $\lambda_{\text{int}}$ @ $\eta=0.45$

Coverage:
Phi (-0.15,0.15), Eta (-1.6,1.6)

1.3 $\lambda_{\text{int}}$ @ $\eta=0.45$

1 LAr/Lead EM barrel module with accordion shape
Weighting performance:
Average (Simulation)
pions only

On average weighted energy reproduces energy deposited in calorimeter within 1 to 2%
Weighted energy follows deposited energy more closely than em scale: smaller spread → better agreement on event-by-event basis.

Weighting Performance: Spread (Simulation) pions only
Dead Material effects in LH

(simulation - pion only)

(e) dead material: relative difference
Layer correlation Calibration: more details

Basic idea: hadronic and em energy deposits have different fluctuation properties. Variables sensitive to fluctuations can compensate and provide resolution improvement.

- Derive weight by principal analysis technique
  - Calorimeter energy layers (sum of topoclusters) make an N dimensional vector \((E_1, ... E_N)\)
  - Calculate covariance matrix between layer energies and diagonalize it
  - Derive Layer Energies Components (LEC) \((E_{Eig0}, ..., E_{EigN})\) along new basis of covariance matrix eigenvectors

- Build weights
  - One weight table per layer obtained as function of first 2 LECs \(w(E_{Eig0}, E_{Eig1}) = \langle E_{tot,k}/E_{rec,k} \rangle\) for all events in given bin
  - Superpose various fixed energy samples to avoid beam energy dependence
Effect of LC Calibration

Data/simulation ratios are not varying significantly from em to had scale.

LC Calibration does not introduce distortions sizeable in the initial EM description.

Uncertainties on em and had ratios are assumed to be fully correlated.

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Data-Simulation Ratios in LC

Linearity described at 2% level

Simulation underestimates data relative resolution by 10% to 25%

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• $\bar{E}_{eig0} \approx \text{"Difference between Tile and LAr"}$
• $\bar{E}_{eig1} \approx \text{"Difference between Tile second (middle) layer and Tile first layer"}$
• $\bar{E}_{eig2} \approx \text{"Total Energy"}$
• $\bar{E}_{eig3}$ to $\bar{E}_{eig6} \approx \text{"Individual layers"}$