Performance of the ATLAS Forward Calorimeter

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Calor2008

• Forward Calorimeter in ATLAS
• Forward Calorimeter in the 2003 Test Beam
• Test Beam Data Analysis & Results
  • Electron Linearity and Resolution
  • Hadron Weighting and Resolution
• Ongoing Analyses
• Summary
Forward Calorimeter (FCal) in ATLAS

- located in each endcap, 4.7 m from interaction point
- FCal1 (EM), FCal2,3 (hadronic)
- eta range (3.1 < |eta| < 4.9)
- electrodes lie parallel to beam pipe

<table>
<thead>
<tr>
<th>No. Readout Channels</th>
<th>LAr Gap (width [mm])</th>
<th>No. Electrodes</th>
<th>Main Absorber</th>
</tr>
</thead>
<tbody>
<tr>
<td>1008</td>
<td>0.269</td>
<td>12260</td>
<td>Cu</td>
</tr>
<tr>
<td>500</td>
<td>0.376</td>
<td>10200</td>
<td>W</td>
</tr>
<tr>
<td>254</td>
<td>0.508</td>
<td>8224</td>
<td>W</td>
</tr>
</tbody>
</table>

- goal is to provide good measurement of missing Et at high eta and to tag forward going jets (ex. Higgs vector boson fusion)
**FCal Test Beam**

- purpose was to measure the intrinsic response of the FCal, examine the performance under ATLAS conditions, examine the energy loss and showering near beam pipe (high eta)

- beams of electrons and hadrons with energies of (10 - 200) GeV were directed onto one of the final ATLAS FCals using the CERN SPS H6 beam line

- five impact points (angle adjusted to correspond to ATLAS)

- wide beam spot to ensure proper sampling across FCal face (6.5 cm diameter)

- ~1000 active readout channels
Test Beam Data Analysis: 4L Position

- minimal upstream material, fully contained showers
- measure the intrinsic response of the FCal
  - electromagnetic scale of calorimeter (ADC2GeV)
  - electron energy resolution
  - hadronic calibration scheme
  - hadron energy resolution
  - comparison of clustering algorithms
- signal pulse reconstructed using optimal filtering technique
- pedestals and noise calculated run-by-run, channel-by-channel
Test Beam Data Analysis: Clustering

- Cylinder clustering
  - project particle trajectory onto FCal front face using beam profile chamber (BPC) information (x, y)
  - cluster all cells within some radial distance from cluster center (8 cm radius for electrons, 16 cm radius for hadrons)
Electron Data Analysis

- cluster all cells within an 8 cm cylinder radius of the cluster center in FCal1
- fit electron energy peak with double Gaussian
  - main peak and high energy tail due to impact point dependence (particle strikes liquid argon or absorber)
- model the remaining pion background using pion data (at the same energy) to understand high energy pion tail under electron peak
Electron Energy Distributions

- Electron data
- Total fit
- Pion data

(no pion data)
Electron Linearity & Residual

- **Slope** = 12.07 ADC/GeV
- **Intercept** = -12.27 ADC

- fit ADC2GeV conversion factor for FCal1
- best fit slope: $12.07 \pm 0.07\text{stat} \pm 0.07\text{sys}$ ADC/GeV
- predictions:
  - FCal1 12.0 ADC/GeV
  - FCal2 6.1 ADC/GeV
  - FCal3 5.4 ADC/GeV

- linearity of response within $\pm 0.8\%$ across energies from 10 GeV to 200 GeV

![Graph showing linearity of response](image-url)
Electron Energy Resolution: 4L Position

Energy resolution function (noise subtracted)

\[ \frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b \]

- Stochastic term \( a = 28.53 \pm 1.0 \% \text{ GeV}^{1/2} \)
- Constant term \( b = 3.48 \pm 0.1 \% \)

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**Hadron Data Analysis**

- analysis of hadron data in 4L position similar to electron analysis
- energy deposited in FCal1+2+3 within a 16 cm cylinder cluster
- determine mean energy response and width of this variation by fitting energy distribution with a double Gaussian
- use electromagnetic scale, as predicted by models

Example:
- 200 GeV pions
- electromagnetic scale

- similar plots for other pion energies [10, 40, 60, 80, 100, 120, 150] GeV
Hadron Calibration

- FCal is a non-compensating calorimeter
- design a hadronic weighting scheme to calibrate hadronic energy deposition

Flat weighting
  - uses modular/longitudinal segmentation of calorimeter
  - 3 calibration constants (each module)
  - minimize energy resolution and require the beam energy equals mean reconstructed energy

Radial weighting
  - uses very fine transverse segmentation, and coarse longitudinal segmentation of calorimeter
  - Nx3 calibration constants (where N = number of radial slices from cluster center)
  - minimize energy resolution to extract calibration constants
Hadron Weights

Flat weights (FW)

- FCal1 FW
- FCal2 FW
- FCal3 FW

Beam Energy [GeV]

Radial weights (RW)

- FCal1 RW
- FCal2 RW
- FCal3 RW

Radial Distance from CC [cm]
Hadron Weights

Flat weights (FW)

- apply the flat weights extracted with the 200 GeV data...
Hadron Energy Distributions

- Pion data FW applied
- Total fit
Hadron Energy Resolution (FW): 4L Position

Energy resolution function (noise subtracted)

\[ \frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b \]

- Stochastic term \( a = 95.34 \pm 1.6 \, \% \, \text{GeV}^{1/2} \)
- Constant term \( b = 7.52 \pm 0.4 \, \% \)
Ongoing Analyses: Topological Clustering

- Topological clustering
  - Include cells in cluster based on the significance of their energy over their noise (calculated for each cell run-by-run)
  - Cluster seeded if cell energy/noise > 4σ
  - Cluster expands if neighboring cell energy/noise > 2σ
  - Cluster all neighboring cells if cell energy/noise > 0σ

- Testing seed/neighbor/cell configurations with comparisons to cylinder clustering

![Graph showing reconstructed σ/E (%) vs beam energy (GeV)]

- Stochastic term $a = 31.84 \pm 0.11$ (stat) % GeV$^{1/2}$
- Constant term $b = 3.31 \pm 0.02$ (stat) %

- Electrons
- Position 4L
- Topological clustering 4/2/0

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Ongoing Analyses: Inner Edge

- examine the energy loss and showering near beam pipe (high eta), and ensure this is correctly modeled in the Monte Carlo
- preliminary look a results with topological clustering 4/2/0 for 200 GeV electrons and pions
- mean reconstructed energy vs average beam impact position

**Electrons**
- Energy clustered in FCal1

**Hadrons**
- Energy clustered in FCal1+2+3 (flat weights applied)

[Graphs showing mean energy vs radial distance from beam pipe for electrons and hadrons at different positions (1, 2, 3, 4H).]
Summary

• the ATLAS forward calorimeter (FCal) has been studied using electron and hadron test beam data at a range of energies (10 GeV – 200 GeV)

• FCal intrinsic energy resolutions (4L position) using cylindrical clustering and flat weights:
  - Electron
    \[ \frac{\sigma_E}{E} = \frac{28.53\text{GeV}^{1/2}}{\sqrt{E}} \oplus 3.48\% \]
  - Hadron
    \[ \frac{\sigma_E}{E} = \frac{95.34\text{GeV}^{1/2}}{\sqrt{E}} \oplus 7.52\% \]

• ongoing analyses to investigate different clustering algorithms used in ATLAS, and energy loses and splashing due to the beam pipe

• references:
  - “Energy calibration of the ATLAS Liquid Argon Forward Calorimeter”, 2008 JINST 3 P02002
  - “Electron signals in the Forward Calorimeter prototype for ATLAS”, 2007 JINST 2 P11001
  - “The ATLAS Forward Calorimeters”, 2008 JINST 3 P02010
Additional Slides
Electron Systematic Uncertainties

- fitting technique (double Gaussian vs single Gaussian, pion modeling)
- cylinder cluster size (on avg 99% of energy within 8 cm cylinder)
- impact point dependence
- beam conditions
  - high energy electrons from secondary beam, polarity determined by H8 beamline (single polarity)
  - low energy electrons are from tertiary beam and are of mixed polarity
  - assign systematic uncertainties at 10 GeV of 0.9 % (and 20 GeV of 0.6 %)

- upstream energy losses due to presence of upstream detectors/material (losses nonlinear with beam energy)

Small effect 0.1-0.2%
Hadron Systematic Uncertainties

- largest systematic uncertainty from choice of flat weights applied to all energy points (recall: we used weights extracted with 200 GeV pion data)
  - instead apply weights from 100 GeV, 120 GeV, 150 GeV
  - stochastic term varied by $\sim1.6\%\,\text{GeV}^{1/2}$ and constant term varied by $\sim0.4\%$
- particle type ($\pi^+$ vs $\pi^-$)
  - there was an observable difference between data taken with $\pi^+$ beams vs $\pi^-$ beams
  - motivated use of CEDAR trigger (removes protons from pion beam)
• energy resolution of the two hadronic weighting schemes: flat weights and radial weights
• the use of the radial weighting technique improves the resolution and is under further study

![Graph showing the energy resolution comparison between flat weights and radial weights.]

\[ \frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b \]

Flat Weights

- \( a = 95.34 \% \text{ GeV}^{1/2} \)
- \( b = 7.52 \% \)

Radial Weights

- \( a = 70.0 \% \text{ GeV}^{1/2} \)
- \( b = 3.00 \% \)