RESULTS FROM PARTICLE BEAM TESTS OF THE ATLAS LIQUID ARGON ENDCAP CALORIMETERS

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A segment of the hadronic and electromagnetic liquid argon endcap calorimeters of the ATLAS experiment was subjected to electron, pion and muon beams in the energy range 6 GeV to 200 GeV at the CERN SPS, in a near ATLAS configuration. The beam test setup and the calibration of the readout electronics are described. Results on electromagnetic and hadronic shower signal reconstruction are presented.

1. Introduction

The ATLAS calorimeter [1] is designed to operate in the high luminosity environment of the Large Hadron Collider (LHC), and to provide an accurate measurement of the position and energy of electrons and photons, of the direction and energy of jets and of the missing transverse energy in an event, and to assist in particle identification. Previous independent beam tests of the liquid argon (LAr) electromagnetic endcap (EMEC) [2], hadronic endcap (HEC) [3] and forward calorimeters have provided standalone calibration information and production quality assessment. Further details of the HEC construction status and recent EMEC stand-alone beam test results can be found in [4] and [5] respectively.

During the summer of 2002, segments of the EMEC and HEC were subjected to electron, pion and muon beams in the energy range 6 GeV to 200 GeV at the CERN SPS, in a near ATLAS configuration (see Fig. 1). A total of 976 (183) cells were readout from the EMEC (HEC). Note that this

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beam test configuration does not exactly reproduce the ATLAS projective geometry; the beam was incident perpendicular to the face of the calorimeters, rather than tilted at an angle corresponding to particles coming from the LHC interaction point. This *non-pointing setup* has no major impact on the hadronic response. The goals of this test include the determination of the hadronic calibration constants in the ATLAS pseudorapidity region $1.6 < |\eta| < 1.8$, the development of hadronic energy reconstruction methods, and Monte Carlo simulation validation and extrapolation to jets.

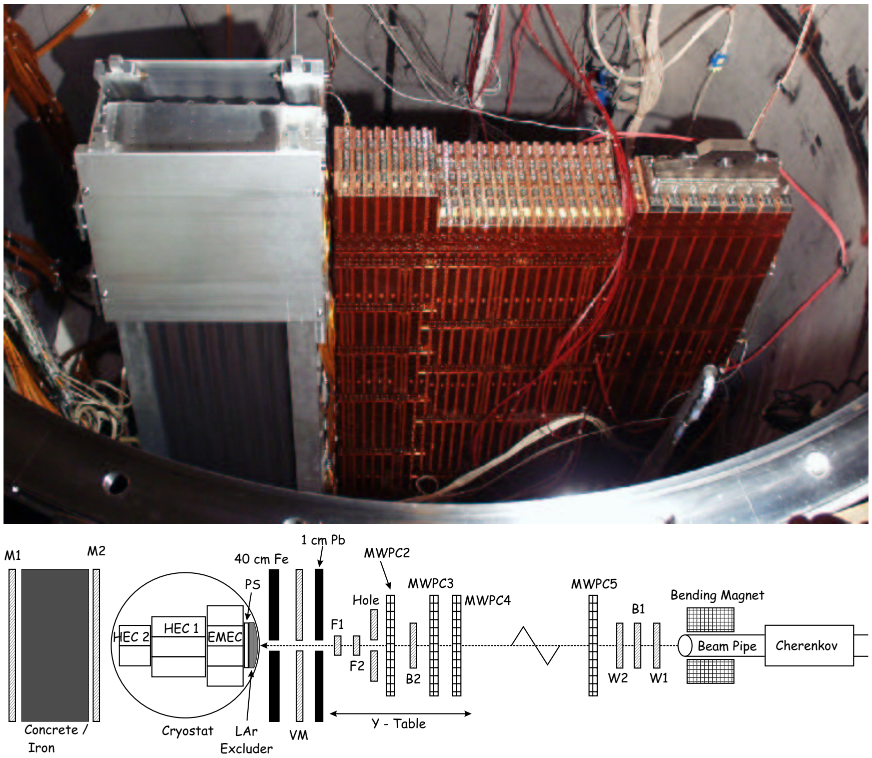

Figure 1. Top: View of the open cryostat, showing (from left to right) the EMEC module with the presampler, three front wheel HEC modules (HEC1), and two back wheel HEC modules (HEC2) of reduced longitudinal size. The beam enters from the left. Bottom: Schematic of the beam test setup, showing the modules in the cryostat and the instrumentation used. The beam enters from the right.

2. Signal Reconstruction and Calibration

The particle signal in a calorimeter cell is a current pulse of triangular shape of duration equal to the electron drift time (typically 450 ns), which is then shaped by a bipolar shaper (peaking time typically 50 ns). The resulting signal is sampled every 25 ns and digitized. Five time samples and the optimal filtering method [6] are used for amplitude reconstruction (more time samples were readout for pulse shape studies). This technique requires the knowledge of the particle signal shape for each cell, which can be obtained from calibration pulses and detailed knowledge of the difference between signal pulse shape and calibration pulse shape. Signal pulse shapes can be predicted from calibration pulses to about 1%. A study of calibration pulse heights then produces the required ADC to nA calibration for each cell.

The electronics noise σ_n (in nA) for each cell is obtained from the study of muon data or of time samples located outside the physics pulse time region. On an event by event basis, the total signal deposited in the calorimeters is estimated using a cell-based topological nearest neighbor clustering algorithm. Cells with a signal (current) $I > 4\sigma_\mathrm{n}$ are kept as seed cells for the clusters. Only cells with $|I| > 2\sigma_\mathrm{n}$ can be added to clusters. Clusters connected by cells with $|I| > 3\sigma_\mathrm{n}$ are eventually merged.

3. Response to Electrons

The EMEC electromagnetic (EM) scale $\alpha_\mathrm{em}^\mathrm{EMEC}$ for the non-pointing setup is required as reference for the hadronic calibration, and is obtained through the study of the EMEC response to electrons. The electron clusters signal exhibits an azimuthal angle-dependent modulation (of amplitude about 3% of the signal) characteristic of the EMEC accordion structure [2, 5]. This effect is well understood, and is corrected. Energy leaking out of clusters remains in the calorimeter and is therefore measurable: it is less than 3% for $E_\mathrm{beam} > 30$ GeV. For a given electron beam energy, the EMEC electromagnetic scale is estimated from $\alpha_\mathrm{em}^\mathrm{EMEC} = \left\langle \left(E_\mathrm{beam} - E_\mathrm{leak}\right)/I^\mathrm{EMEC} \right\rangle$, yielding $\alpha_\mathrm{em}^\mathrm{EMEC} = (0.430 \pm 0.001 \pm 0.009)$ MeV/nA. The second (systematic) error is due to signal shape uncertainties and η dependent corrections that have not been applied in this analysis. The EMEC linearity of response to electrons is better than ±0.5% (see Fig. 2). For each event, the reconstructed electron energy is then $E_\mathrm{reco} = E_\mathrm{em}^\mathrm{EMEC} = \alpha_\mathrm{em}^\mathrm{EMEC} I^\mathrm{EMEC}$. Figure 2 shows the intrinsic energy resolution, obtained after subtraction in quadrature of the corresponding clusters electronics noise; the latter is also shown. Fits to the data for various impact points on the calorimeter typically yield a sampling term of $(12.1 \pm 0.2)\%\sqrt{\mathrm{GeV}}$ (which is slightly worse than in the case of pointing stand-alone EMEC beam tests) and a constant term of $(0.4 \pm 0.1)\%$.

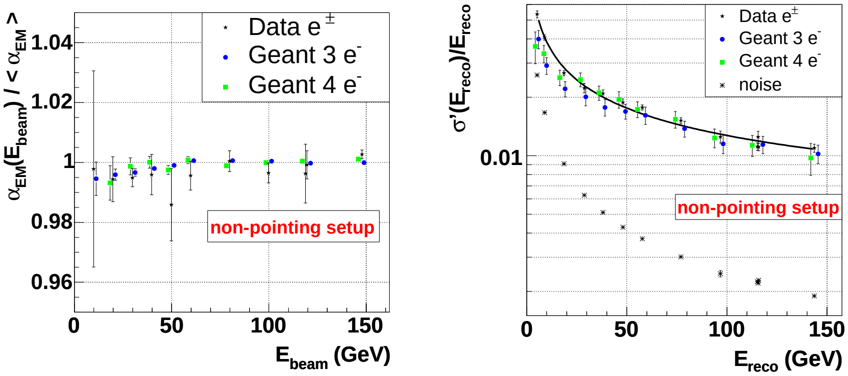

Figure 2. Left: Linearity of the electron response. Ratio of the EM scale $\alpha_{\mathrm{em}}^{\mathrm{EMEC}}$ over the average EM scale for different beam energies. Right: Energy dependence of the energy resolution of electrons. Shown are the electronics noise subtracted beam test data. The electronics noise contribution at various energies is also shown. The solid line shows the result of the fit to the data. For both plots, the data are compared to Monte Carlo simulation predictions [7].

4. Response to Pions

Both the EMEC and the HEC are non-compensating calorimeters. Corrections (weights) are required, over the EM scale constants. For the HEC, the EM scale is obtained from previous stand-alone beam tests (including a correction for a known calibration pulse shape change) and is found to be $\alpha_{\mathrm{em}}^{\mathrm{HEC}} = (3.27 \pm 0.03 \pm 0.03)$ MeV/nA. Various weighting methods are being investigated. Here we consider cluster weights as a function of its EM energy density. We have $E_{\mathrm{reco}} = E_{\mathrm{reco}}^{\mathrm{EMEC}} + E_{\mathrm{reco}}^{\mathrm{HEC}} = w^{\mathrm{EMEC}} E_{\mathrm{em}}^{\mathrm{EMEC}} + w^{\mathrm{HEC}} E_{\mathrm{em}}^{\mathrm{HEC}}$. The weights should be obtained from simulations. As this is not yet available, the (H1) form $w = C_1 \exp(-C_2 \rho_{\mathrm{em}}) + C_3$ is considered where $\rho_{\mathrm{em}} = E_{\mathrm{em}}/V_{\mathrm{cluster}}$ is the cluster energy density. To test this ansatz, a sample of 30 GeV pions with no energy deposited in the HEC is considered. This is of course a biased sample, but it allows the test to be performed without the need for simulation results (except for part of the lateral energy leakage). Weight estimates can then be obtained on an event by event basis from $w^{\rm EMEC} = \left(E_{\rm beam} - E_{\rm leak}\right)/E_{\rm em}^{\rm EMEC}$. Figure 3 shows that the energy density dependence of $w^{\rm EMEC}$ agrees with the chosen form, and that the resulting improvement of the energy resolution is large.

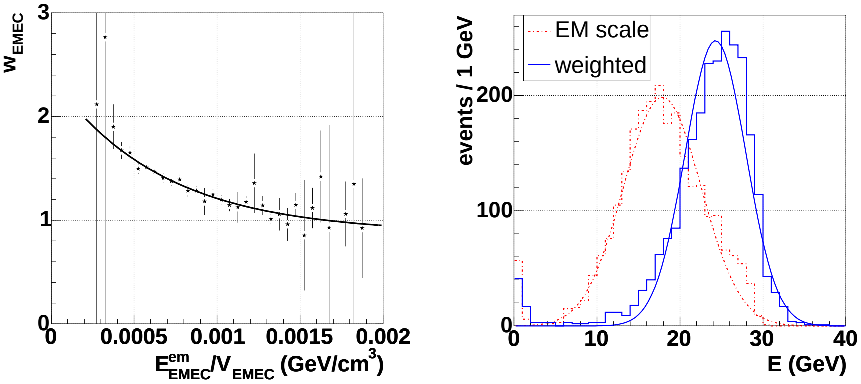

Figure 3. Sample of 30 GeV pions fully contained in the EMEC. Left: Ratio (hadronic weight) of the true energy over the energy measured on the EM scale as a function of the cluster energy density. The line shows the result of the fit. Right: Reconstructed energy distributions before (broken histogram and line) and after (solid histogram and line) weighting.

The final weights are obtained through the minimization of

$$\sum_{\rm events}\left[\frac{E_{\rm beam} - E_{\rm leak} - E_{\rm reco}^{\rm EMEC}\left(\rho_{\rm em}^{\rm EMEC}, C_j^{\rm EMEC}\right) - E_{\rm reco}^{\rm HEC}\left(\rho_{\rm em}^{\rm HEC}, C_j^{\rm HEC}\right)}{\sigma_{\rm n}^{\rm total}}\right]^2$$

where $\sigma_{\rm n}^{\rm total}$ includes the clusters electronics noise $\sigma_{\rm n}$ and the electronics noise contribution to the leakage estimate. The results are $E_{\rm reco}$ dependent C_j coefficients that then allow to obtain, on an event by event basis, the relevant cluster weights. Figure 4 shows the resulting intrinsic energy resolution for pions, obtained after subtraction of the corresponding clusters electronics noise in quadrature; the latter is also shown. A fit to the data shown on Fig. 4 yields a sampling term of $(84.6 \pm 0.3)\%\sqrt{\rm GeV}$ and a constant term of zero within errors. The energy range available is not big enough to avoid any correlation between the sampling and constant term, but nevertheless the reduction of the constant term, after the correction for leakage, gives some indication of the effectiveness of the weighting approach in achieving a good level of compensation. Weighting was also attempted at cell level and yielded similar results.

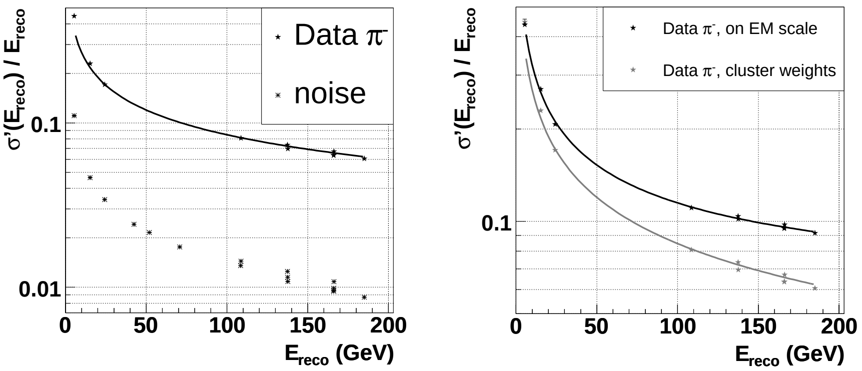

Figure 4. Energy dependence of the energy resolution for pion data using the cluster weighting approach. The electronics noise has been subtracted in quadrature. Lines are the results of fits. Left: Also showing the noise contribution (lower points). Right: Also showing the worse energy resolution obtained using the EM scale (top curve).

An e/h ratio of 1.56 ± 0.01 is obtained from $\langle E_{\rm reco}/(E_{\rm em}^{\rm EMEC} + E_{\rm em}^{\rm HEC}) \rangle$. This is an effective e/h ratio since the calorimeter is of a composite nature.

5. Conclusions

A segment of the hadronic and electromagnetic liquid argon endcap calorimeters of the ATLAS experiment was subjected to electron, pion and muon beams in the energy range 6 GeV to 200 GeV at the CERN SPS, in a near ATLAS configuration. The electronics calibration method to be used in ATLAS was successfully tested. The first steps toward an hadronic calibration strategy were explored, including topological clustering and cluster or cell weighting as a function of energy density. Remaining calibration tasks to investigate include the use of validated Monte Carlo simulations in obtaining the weights and the study of jet reconstruction and particle identification in jets.

During the summer of 2004 a combined EMEC-HEC-FCAL setup will be beam tested at CERN in an ATLAS configuration of the pseudorapidity region $2.8 < |\eta| < 3.2$, where FCAL is the forward ATLAS calorimeter. This has required the construction of special mini-HEC modules to fit in the test cryostat, and of cold and warm tail catchers. The focus of this test is the study of the hadronic energy reconstruction when the deposited energy is shared among all three calorimeters.

References

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