PERFORMANCE OF THE ATLAS LIQUID ARGON FORWARD CALORIMETER IN BEAM TESTS

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A beam test of three final ATLAS Forward Calorimeter modules (FCal) is described. The data were taken at CERN in the summer of 2003, using electron and hadron beams with energies from 10 to 200 GeV. The response of the FCal to single electrons and hadrons is derived.

1. The ATLAS Forward Calorimeter

ATLAS is one of two general purpose detectors that will take data at the Large Hadron Collider at CERN, starting in 2008. The experimental programme includes searches for the Higgs Boson and searches for supersymmetry. For the former, in certain mass regions, the tagging of energetic forward jets is important, For the latter, calorimetric hermeticity is crucial. The ATLAS Liquid Argon Forward Calorimeter (FCal) is designed primarily for the detection of jets, either tagging jets, or jets that would otherwise escape detection and degrade the resolution on missing transverse energy. The ATLAS FCal is a liquid argon calorimeter that is integrated into the endcap cryostat that also houses the electromagnetic and hadronic endcap calorimeters, extending the calorimetric coverage from $|\eta|$ of about 3.1 to 4.9. This region of the detector is close to the beam pipe, where the particle flux from minimum bias events places severe constraints on the calorimeter design. In particular, liquid argon gaps must be very narrow, to avoid problems due to positive ion buildup that would distort the electric field in the gap, degrading the detector performance.[2] Since constructing very narrow LAr gaps in a parallel plate structure is difficult, this constraint is accommodated by use of an electrode structure with thin annular LAr gaps

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*On behalf of the ATLAS Forward Calorimeter Group oriented parallel to the beamline. Individual gaps are formed by a structure consisting of a copper tube, acting as the cathode, and an absorber rod acting as the anode. This rod is positioned concentrically, and electrically isolated, by a helically-wound radiation hard plastic (PEEK) fibre. The FCal consists of three modules: the FCal1, FCal2 and FCal3, which sit one behind another inside a support tube that forms a structural part of the endcap cryostat. The FCal1, which sits closest to the interaction point, is designed for EM calorimetry. It has copper anode rods, and the 12,260 electrodes are positioned within a copper matrix made of a stack of copper plates with precision drilled holes to accept the electrode tubes. The FCal2 and FCal3 modules are designed for hadronic calorimetry and are made primarily of tungsten, with 10,200 and 8224 electrodes, respectively. A copper skeleton is used, consisting of electrode tubes installed between two endplates. The space between the tubes is filled with specially formed tungsten alloy slugs and the anode rods are made of pure tungsten. The LAr gaps in the FCal1, 2 and 3 are 250 μm, 375 μm and 500 μm, respectively.

In each module, electrodes are positioned within the absorber matrix in an hexagonal array, with a spacing optimized for energy resolution. This leads to a detector with a fine lateral segmentation that can be exploited in the energy reconstruction.[3] The module structure is illustrated in figure 1, which shows a schematic partial view of the front face of the FCal1 module alongside a photo of the rear face of the FCal3 module. For high voltage distribution and signal readout, electrodes are ganged together in groups of 4, 6, or 9 on the FCal1, FCal2 and FCal3, respectively, using interconnect

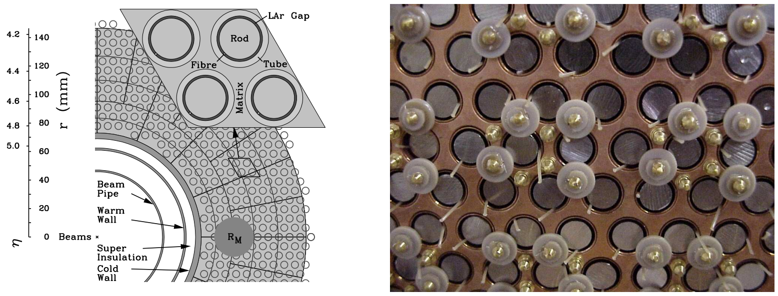

Fig. 1. Forward calorimeter electrode arrangement. The left-hand plot shows a schematic view of a portion of the front face of the FCal1, also illustrating a single electrode group and indicating the size of the Molière radius in this device. The right-hand figure shows a photograph of the rear (non-readout) face of a hadronic (FCal3) module. Also visible are PEEK retention washers and the ends of the PEEK fibres.

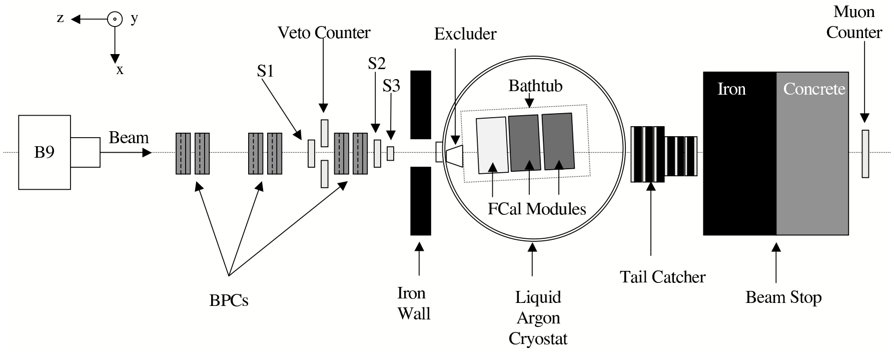

Fig. 2. Beamline instrumentation used for FCal calibration testbeam

boards at the readout face of each calorimeter module, which are installed onto pins inserted in the ends of the anode rods. For most channels, four such groups are summed on a transformer summing board before the signals are sent to the cryogenic feedthrough.

2. Forward Calorimeter Beam Test

Beam test data were taken using the three production FCal modules for the C-side of ATLAS. The tests were done in the H6 beamline at CERN, with electron and hadron beams of energies from 10 to 200 GeV. Because the support tube that houses them in ATLAS was not available, the modules were placed on a purpose-built stand. The FCal readout used prototype electronics, with 25 sampling of the shaped signals, as in ATLAS. Signal reconstruction was done with the optimal filtering method[4] as will be the case in ATLAS.

The beamline instrumentation is illustrated in figure 2. Coincidence of the three scintillators, $S1$, $S2$ and $S3$ was used for triggering. Three stations of beam positioning chambers (BPCs) provided tracking information. Additional counters provided other information for use in offline analysis, for example, for beam-cleaning similar to that employed previously.[5]

Electron energy reconstruction was done by summing the energy of all cells within an 8 cm radius cylinder centred on the beam particle impact point, which was reconstructed using information from the BPCs. Noise contributions were accounted for by using knowledge of the average noise for each channel, run-by-run, obtained from analysis of random-triggered events. For each energy sum, a noise sum over the same channels was also performed, allowing the noise contribution, which varied from 12.5 to 15.5 ADC counts, to be removed when fitting the resolution function. Signal shapes are non-Gaussian due to the calorimeter response being dependent on the impact point relative to the closest electrode;[5] this effect is the dominant contribution to the constant term in the resolution function. Energy spectra are fitted with a double-Gaussian, which provides a good description of the signal, and a contribution for residual hadron contamination, the shape of which is taken from the analysis of hadron data taken at the same energy. The response linearity and resolution are shown in figure 3. The response is linear to within 0.5%. The linearity fit yields the EM scale factor for the FCal1. Previous measurements of the relative response of FCal1 and FCal2 prototypes,[5] along with simulations, set the EM scales for the FCal2 and FCal3, which are needed as the starting point for hadronic calibration. The result of a fit to the energy resolution, using the function $\sigma_E/E = a/\sqrt{E} \oplus b$, is overlaid. The fit values for the sampling and constant terms agree well with the results of the prototype tests, and with expectations for ths design.

For pions, the energy sum was done within a 16 cm radius cylinder. After correcting for the relative EM scales of the three modules, the total hadronic energy is summed using a flat weighting technique, with one weight per module.Weights were derived from the 200 GeV sample by minimizing the resolution with the constraint that the average reconstructed energy equal the beam energy. Noise was dealt with as described earlier and varied between 5 and 6 GeV. The reconstructed energy for 200 GeV pions is shown in figure 4, alongside a plot of the corresponding noise-subtracted energy resolution. Overlaid, in each case, are results of an alternative weighting scheme, also used in past analyses,[3,6] which exploits the fine transverse

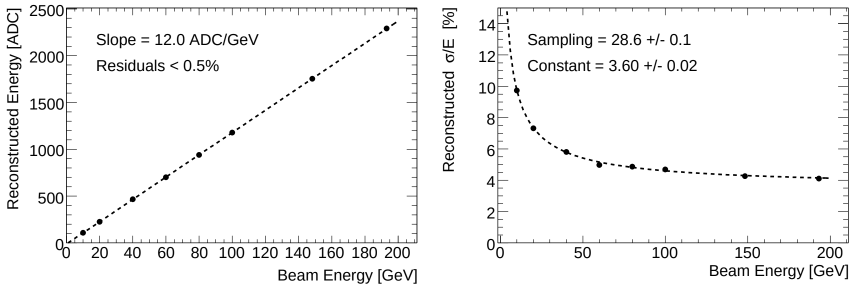

Fig. 3. ATLAS Forward Calorimeter performance for electrons: linearity and resolution.

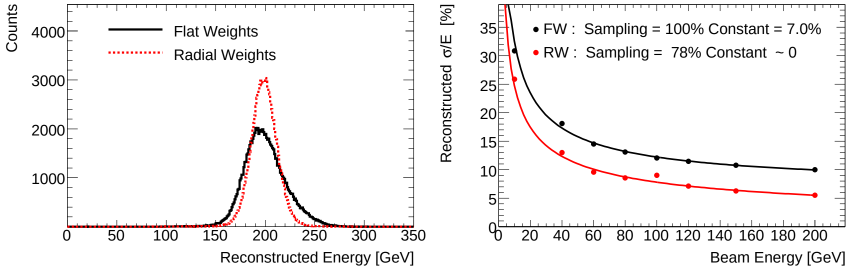

Fig. 4. ATLAS Forward Calorimeter performance for hadrons.

segmentation of the FCal modules. In this "radial weighting" scheme, cell energies at the appropriate EM scale are summed using weights that are a function of the radial distance from the beam impact point. The results of the resolution fits are shown on the plot; the potential improvement, with radial weighting, is apparent. However, the ATLAS requirement of $100\%{\cdot}\mathrm{GeV}^{1/2}/\sqrt{E} \oplus 10\ \%$ is achievable with the simpler technique.

For all results, the statistical uncertainties are relatively small, while the systematics remain under investigation.

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