VALIDATION OF THE HADRONIC CALIBRATION OF THE ATLAS CALORIMETER WITH TESTBEAM DATA CORRESPONDING TO THE PSEUDORAPIDITY RANGE $2.5 < |\eta| < 4.0$

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The pseudorapidity region $2.5 < |\eta| < 4.0$ in ATLAS is a particularly complex transition zone between the endcap and forward calorimeters. A set-up consisting of 1/4 resp. 1/8 of the full azimuthal acceptance of the ATLAS liquid argon endcap and forward calorimeters has been exposed to beams of electrons, pions and muons in the energy range $E < 200\,\text{GeV}$ at the CERN SPS. Data have been taken in the endcap and forward calorimeter regions as well as in the transition region. This beam test set-up corresponds very closely to the geometry and support structures in ATLAS. Pion data have been analyzed using the standard local hadronic calibration scheme as forseen for the ATLAS calorimeter. In particular the weighting scheme to compensate for the different electron to pion response as well as corrections for dead material in the transition region have been extensively tested and compared to simulations based on GEANT 4 models.

Keywords: ATLAS, endcap calorimeter, testbeam, hadronic calibration

1. Introduction

The jet energy scale is one of the main systematic uncertainties in many physics studies foreseen with the ATLAS detector.[1] Top mass reconstruction or measurements of inclusive jet cross-sections are examples relevant for the first data taking phase. The energy reconstruction of hadronic showers is difficult due to non-compensation effects in the calorimeter system or energy deposits outside of the reconstructed calorimeter objects, leading to nonlinearities and the degradation of the energy resolution for hadrons. The local hadronic calibration is one of the simulation based calibration techniques in ATLAS to reconstruct the correct energy of pions. The goal of this study is a validation of the calibration strategy using the data of the ATLAS combined testbeam in the endcap and forward calorimeter region carried out in 2004.

2. Local hadronic calibration schema

The main goal of the local hadronic calibration[2,3] is to provide jet algorithms with constituents — calibrated clusters with energies corresponding to the corresponding stable particle energies. The key feature of the approach is to factorize corrections in several sequential steps to disentangle detector effects of different types and to correct them independently.

The starting point of the calibration is the topological clustering in the calorimeter cells which have been calibrated at the electromagnetic (*em*) scale. Cluster shape variables are then used to classify clusters as having electromagnetic or hadronic origin. Hadronic clusters have smaller cell energy densities and larger depth in the calorimeter in comparison to electromagnetic ones. The hadron-like clusters are subject to a cell weighting procedure to compensate for the lower response of the calorimeter to hadronic energy deposits, while clusters classified as electromagnetic are kept at the original scale. In the next step out-of-cluster corrections are applied for the lost energy deposited in calorimeter cells outside of reconstructed clusters, i.e. in the tails of hadronic or electromagnetic showers. Finally dead material corrections are applied on the cluster level to account for energy deposits outside of active calorimeter volumes, e.g. in the cryostat, the magnetic coil and calorimeter intermodular cracks.

3. Testbeam Setup and Data

The beam test in the particularly difficult forward region $2.5 < |\eta| < 4.0$ (the transition from the electromagnetic endcap calorimeter EMEC and hadronic endcap calorimeter HEC to the forward calorimeter FCal) was carried out in 2004[5] . The general view of testbeam setup is illustrated in Fig. 1.

The main elements of the setup are: beam instrumentation to measure the impact position and angle of beam particles, the liquid argon (LAr) cryostat with calorimeter modules and a tail-catcher to measure any leakage beyond the calorimeter modules. The setup can be moved horizontally by ± 30 cm perpendicular to the beamline, while the vertical bending magnet in the beamline allows a vertical deflection of the beam by ± 25 cm at the

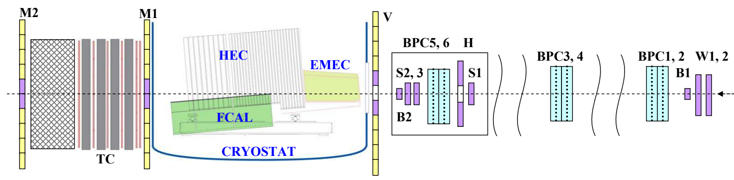

Fig. 1. Schematic view of the beam test set-up for the 2004 ATLAS combined test beam. Shown are the calorimeter modules in the cryostat and the beam instrumentation used: multiware proportional chambers (BPC), scintillation counters (S,B) and schintillator walls (V,W,M1,M2).

front face of the cryostat. The load in the LAr cryostat consists of the inner section of one EMEC module (in ϕ 1/8 of the full EMEC wheel), eight front wheel HEC modules (8/32 of the full wheel), eight rear wheel HEC modules (specially build) and the FCal modules corresponding to the first 2 samplings of one quadrant.

In the two run periods more than 4000 runs have been taken with electrons, pions or muons in the energy range $6\,\mathrm{GeV} \leq E \leq 200\,\mathrm{GeV}$ with about 80 million triggers in total. Energy scans have been taken at a standard set of impact points. In addition, horizontal and vertical scans have been done at fixed particle energies. To compare data with Monte-Carlo (MC) expectation the simulation code GEANT 4[5] (version 9.2) has been used. From the physics list for hadronic shower simulations available in GEANT 4 QGSP-BERTINI 2.6 has been used. For the reconstruction the standard ATLAS software rel.15.0.0 has been used.

4. Comparison of cluster moments in Data and MC

Typically a cluster moment of a certain degree n in an observable x defined for a cell constituent of the cluster is given by:

$$\langle x^n \rangle = \frac{1}{E_{\mathrm{norm}}} \times \sum_{\{i\,|E_i>0\}} E_i\, x^n, \quad E_{\mathrm{norm}} = \sum_{\{i\,|E_i>0\}} E_i. \tag{1}$$

Cluster moments could be used to quantify hadronic shower characteristics. Several typical moments describing the width and the length of hadronic shower as well as the average density of energy in the cluster, are used in the local hadronic calibration. The validation of these moments in the testbeam is very important in the context of understanding the hadronic shower simulation. Results for two of them, the depth of the shower in the calorimeter and the average cluster energy density, are presented in Fig. 2. In comparison to the data, the MC predicts slightly denser showers which start earlier in the calorimeter.

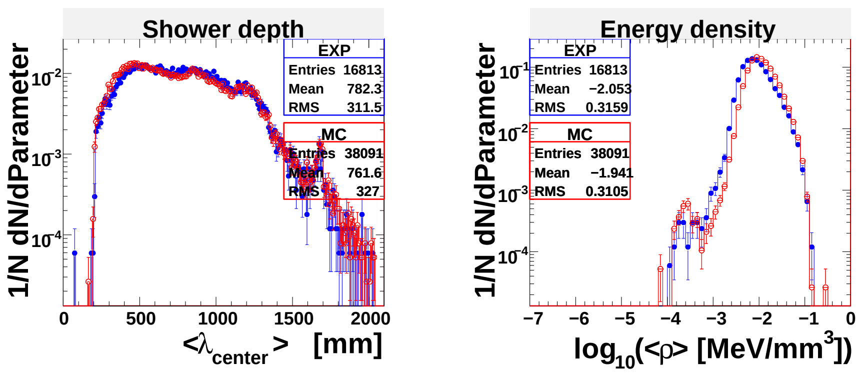

Fig. 2. Comparison of shower depth (left) and average cluster energy density (right) in data and MC for 200 GeV charged pions in the endcap region.

5. Linearity and energy resolution for pions

The figure 3 (left) shows the linearity before and after applying the local hadronic calibration. At the electromagnetic scale the energy is at the level of about 75% of the beam energy. This ratio increases with the beam energy due to the increasing electromagnetic fraction of the hadronic shower.

The Monte-Carlo predicts a 5% higher response than seen in the data due to a difference in the electromagnetic scale for hadrons given by the QGSP_BERT physics list. After applying the local hadronic calibration the linearity in the simulation is recovered within 2%, except at low energies. This holds also for the data, except for the difference due to the *em* scale.

The energy dependence of the energy resolution is shown in Fig. 3 (right). The simulation in comparison to data predicts a better resolution by about 20%. The resolution is improving just a little after applying the hadronic calibration in both, data and MC. This could be explained by the usage of standard ATLAS calibration constants rather than testbeam specific ones, not accounting for limited acceptance and difference in dead material description.

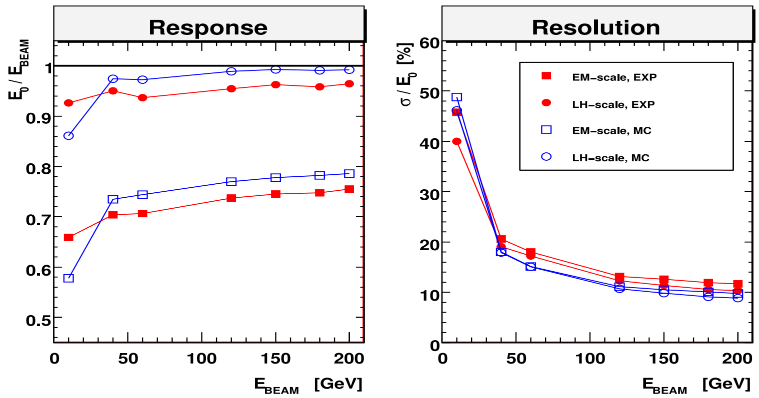

Fig. 3. Energy dependence of the response to pions (left) and the energy resolution (right) for data and MC before(*em* scale) and after applying the calibration.

6. Conclusion

The ATLAS local hadronic calibration procedure has been validated using ATLAS combined testbeam data in the endcap and forward region. Shower shape variables as well as linearity and energy resolution for pions have been studied. The results have been compared with MC simulations (GEANT 4 QGSP_BERT list). The simulation predicts a somewhat larger pion response at the electormagnetic scale, coupled with better energy resolution and more compact shower size than seen in the data. The local hadronic calibration recovers the linearity in simulations within 2%. But a new testbeam specific set (rather than ATLAS) of correction constants has to be applied to reach the full performance.

References

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