VALIDATION OF THE LOCAL HADRONIC CALIBRATION SCHEME OF ATLAS WITH COMBINED BEAM TEST DATA IN THE ENDCAP AND FORWARD REGIONS OF ATLAS

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The local hadronic calibration developed for the energy reconstruction and the calibration of jets and missing transverse energy in ATLAS, has been validated using data obtained during combined beam tests of the ATLAS endcap and forward calorimeters. The analysis has been performed using special sets of calibration weights and corrections obtained with the GEANT4 simulation of a detailed beam test setup.

Keywords: ATLAS; Hadronic calibration; Beam tests; Simulations.

1. Introduction

For many physics processes studied with the ATLAS detector[1] at the Large Hadron Collider (LHC) at CERN, it is very important to have accurate measurements of the energy of jets and of the missing transverse energy. A lot of efforts were done by the ATLAS collaboration to develop methods of the hadronic calibration for the calorimeter system, allowing to reconstruct true energies of hadrons. Such techniques have to correct for the invisible energy due to the non-compensating nature of ATLAS calorimeters, for the energy losses in regions not instrumented with read-out and for energy losses due to unavoidable (at LHC conditions) threshold cuts in the signal reconstruction. The local hadronic calibration (LC) is one of the calibration schemes used in ATLAS. The subject of this talk is the validation of this scheme with data obtained during combined beam tests of modules of the ATLAS endcap and forward calorimeters.

2. Local Hadronic Calibration

The local hadronic calibration scheme is described in detail in Ref. 2. The input for this calibration are three-dimensional topological clusters[3] reconstructed at electromagnetic (EM) scale[a]. The calibration starts by classifying clusters as mostly electromagnetic or mostly hadronic depending on cluster shape variables and on the cluster energy. The following LC steps are applied: 1) weighting of the cluster energy to account for the non-compensating nature of the calorimeters, 2) out-of-cluster corrections to correct for lost energy deposits inside the calorimeter due to the noise thresholds, 3) dead material corrections to compensate for energy deposits in materials outside of active calorimeter volumes. LC-weights and corrections are determined from detailed Monte Carlo (MC) simulations.

3. Beam Test of ATLAS Endcap and Forward Calorimeters

A combined setup of modules of the ATLAS electromagnetic and hadronic endcap calorimeters and the forward calorimeter was exposed to beams of charged pions, electrons and muons in the H6 beamline at the CERN SPS in 2004.[4] Beams covered a zone corresponding to the ATLAS pseudorapidity region of $2.5 < |\eta| < 4.0$. To validate the local hadronic calibration, data from energy scans with charged pions in two impact points were used. These two points represented the endcap region ($\eta \simeq 2.75$ in ATLAS) and the forward region ($\eta \simeq 3.6$ in ATLAS). Scans covered the range of the beam energies (E_{BEAM}) from 10 to 200 GeV.

4. Simulations

The GEANT4 toolkit[5] (version 9.2) was used to simulate the response of the beam test setup to beam particles. Two sets of MC samples were produced. The first set contained simulations of energy scans with charged pions in studied impact points. This set was used to compare MC predictions with available experimental data. The second set of MC samples was used to derive weights and correction coefficients for the local hadronic

[a]This scale correctly measures the energy deposited in calorimeters by EM showers.

calibration. It contained simulations of charged and neutral pions with energies distributed in the interval from 1 to 400 GeV logarithmically flat and with uniform coverage of the front face of the calorimeter modules. From the standard physics lists available for the hadronic shower simulation in GEANT4,[6] two physics lists QGSP-BERT and FTFP-BERT were used.

5. Results

Results of the validation of the local hadronic calibration, presented in this contribution, are based on the analysis of the energy response and resolution for charged pions in the endcap and forward regions. The reconstructed energy is defined as the sum of energies of all clusters in an event. Gaussian curves are fitted to the reconstructed energy distributions in the interval $\pm 3\sigma$ around the peak value E_0. The parameters E_0 and σ from this fit are used to determine the response (E_0/E_{BEAM}) and the resolution (σ/E_0). Results are presented for the EM-scale and for the LC-scale after application of QGSP-BERT-based corrections only.

The energy dependencies of the response in the endcap region are shown at the top of Fig. 1 for both experimental data and simulations. The bottom of this figure presents the ratio of the simulated response and the experimental response: $R = (E_0/E_{\mathrm{BEAM}})_{\mathrm{MC}}/(E_0/E_{\mathrm{BEAM}})_{\mathrm{Data}} = E_0^{\mathrm{MC}}/E_0^{\mathrm{Data}}$, as a function of the beam energy. The non-linear response at EM-scale indicates the non-compensating nature of the endcap calorimeters. For $E_{\mathrm{BEAM}} \geq 40\,\mathrm{GeV}$, QGSP-BERT overestimates the experimental response by 2%, while FTFP-BERT overestimates data by 4%. The response at LC-scale is rather stable for $E_{\mathrm{BEAM}} \geq 60\,\mathrm{GeV}$, where it is close to 1.0 for data and QGSP-BERT-based simulations. The agreement between data and MC predictions is better at LC-scale than at EM-scale.

To assess the systematic uncertainty of the local hadronic calibration, the EM-scale difference between data and simulations should be factored out. This can be achieved by analysing the double ratio of the energy response. It is determined as the ratio of the parameters R, obtained at LC- and at EM-scale ($R_{\mathrm{LC}}/R_{\mathrm{EM}}$). This double ratio equals to 0.987 and 0.990 for QGSP-BERT and FTFP-BERT physics lists, respectively. Its deviation from unity by $1.0 - 1.3\%$ can be considered as the uncertainty of the local hadronic calibration for charged pions in the endcap region.

The energy resolution at EM-scale for pions in the endcap region decreases with the beam energy from $(44.6 \pm 0.2)\%$ at $10\,\mathrm{GeV}$ down to $(11.29 \pm 0.04)\%$ at $200\,\mathrm{GeV}$, for the data. The two physics lists give close results and predict a too good resolution compared to experimental values

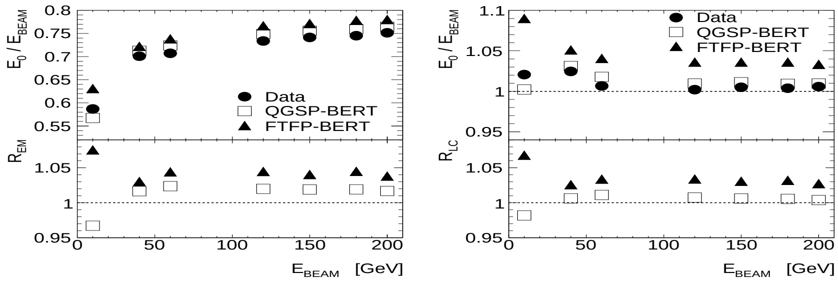

Fig. 1. Top: Response for pions in the endcap region at EM-scale (left) and at LC-scale (right) as a function of the beam energy. Bottom: Ratio between simulations and experimental data for the pion response.

by $10 - 15\%$. The improvement of the energy resolution after application of the local hadronic calibration is about $5 - 15\%$ for data and simulations. The weighting step improves the energy resolution at higher beam energies, while out-of-cluster corrections improve it at lower energies. The improvement of the energy resolution at LC-scale with respect to EM-scale is slightly better for simulations than for experimental data.

The energy dependencies of the response in the forward region are presented in Fig. 2 for experimental data and for simulations. The non-linear response at EM-scale reflects the non-compensation of the forward calorimeter. FTFP-BERT describes the experimental response at EM-scale rather well. QGSP-BERT underestimates the response by $3-8\%$. The application of QGSP-BERT-based LC-weights and corrections yields an overestimate of the experimental response by $3-4\%$. A good agreement between experimental response and the response predicted by FTFP-BERT at EM-scale becomes worse at LC-scale.

As for the endcap region, the double ratio of the response in the forward region is also analysed. Results obtained for the two physics lists are very similar. The double ratio is smaller than 1.0, and the deviation from unity is up to 3%. This is taken as the uncertainty of the local hadronic calibration for charged pions in the forward region.

The pion energy resolution at EM-scale varies with the beam energy between $(44.1 \pm 0.3)\%$ at 10 GeV and $(12.23 \pm 0.03)\%$ at 200 GeV, for the data in the forward region. The two physics lists give similar results and predict worse energy resolution at EM-scale compared to experimental values by $5-15\%$ (for $E_{\rm BEAM} \geq 40\,{\rm GeV}$). After applying LC-weights and corrections the resolution in general improves by $10 - 25\%$ for both data and simula-

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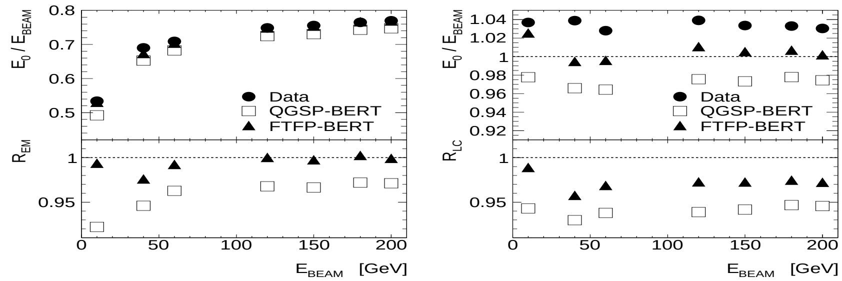

Fig. 2. Top: Response for pions in the forward region at EM-scale (left) and at LC-scale (right) as a function of the beam energy. Bottom: Ratio between simulations and experimental data for the pion response.

tions. The local hadronic calibration significantly improves the agreement between experimental and predicted values of the resolution, especially for the FTFP-BERT physics list.

6. Conclusions

The local hadronic calibration scheme, an advanced method for reconstructing hadronic signals in the ATLAS calorimeter system, is validated with data obtained during beam tests of modules of the ATLAS endcap and forward calorimeters. The scheme allows to reconstruct the initial energy of charged pions in the endcap region with uncertainties below 1.5%. In the forward region the uncertainty of the response is about 3%. One of the important features of the local hadronic calibration is a significant improvement of the energy resolution in all studied calorimeter regions.

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