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THE CALIBRATION OF THE H1 LIQUID ARGON CALORIMETER

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ABSTRACT

The calibration of the Liquid Argon (LAr) Calorimeter of the H1 detector at HERA is briefly described. Based on a high statistics sample of neutral current events uncertainties on the electromagnetic and the hadronic energy scales of $0.7\% - 3\%$ and 2%, respectively, have been achieved. To further improve on the knowledge of the hadronic energy scale a new software weighting method was developed, which when applied to CERN test beam data shows clear progress in terms of scale uncertainties, energy resolution and linearity.

1 Introduction

The H1 LAr–Calorimeter is one of the main components of the H1 experiment [1], one of two omni–purpose detectors at the *ep* collider HERA. It consists of an electromagnetic (EMC) and a hadronic section (HAC). The EMC is built as a stack of absorber boards with a lead kernel of 2.4 mm and argon gaps of 2.35 mm, leading in total to 30784 cells with a transverse size of $10 - 100\,\mathrm{cm}^2$. Its depth varies between 20 and 30 radiation lengths. The HAC is built out of 19 mm thick stainless steel absorber material intercepted by a double argon gap of $2 \times 2.4\,\mathrm{mm}$. The number of hadronic cells amounts to 13568 with a transverse size of $50 - 2000\,\mathrm{cm}^2$. The total depth (including the EMC) amounts to 4.5 in the central region and up to 8 interaction lengths in the forward region. The high granularity of the calorimeter enables the use of software weighting methods to achieve approximate compensation.

2 Energy Calibration using neutral current ep–events

For the electron energy measurement the calorimeter is calibrated with respect to the primary lepton energy, E_{beam}, exploiting the kinematic constraints of deep inelastic neutral current (NC) events[1]. The measurement of the electron scattering angle Θ_e and the angle of the hadronic final state[2] γ allows an absolute calibration by comparison of the calorimetric energy E_{Cal} with the so called double angle prediction: $E_{DA} = (2 \cdot E_{beam} \sin\gamma)/(\sin\gamma + \sin\theta_e - \sin(\gamma + \theta_e))$. The achieved energy scale uncertainty is $0.7\,\% - 3.0\,\%$ depending on the scattering angle. The upper value of $3.0\,\%$ is due to limited statistics. The achieved improvement has an important impact for the physics analysis. The systematic error of the F_2 structure function measurement decreased for low x and low Q^2 ($x \sim 10^{-2}$, $Q^2 \sim 300\,\mathrm{GeV}^2$) from 7% to 4% and for high x and high Q^2 ($x \sim 0.4$, $Q^2 > 3000\,\mathrm{GeV}^2$) from 20% to 15%.

The calibration of the hadronic energy scale is based on the fact that in NC events the transverse momentum of the lepton $p_{t,e}$ must be balanced by the transverse momentum of the hadronic final state $p_{t,h}$. This allows to adjust the unknown hadronic energy scale with respect to the known electromagnetic energy scale (calibrated before). The momentum balance calibration is done relative to Monte Carlo in order to take into account detector effects. The achieved energy scale uncertainty is 2%.

[1] To calibrate the electromagnetic energy scale with NC events several methods are used [2]. In this contribution the so called DA–method is described in more detail.

[2] The angles are measured with respect to the incident proton beam direction.

3 Software Weighting Method

The task of a software weighting method applied in the energy reconstruction on the non–compensating H1 LAr–Calorimeter is to distinguish between electromagnetically and hadronically deposited energies in a hadronic shower and to weight these depositions such, that the signal ratio of electrons and hadrons reaches unity. This is possible since the high granularity of the H1 LAr–Calorimeter allows the recognition of electromagnetic and hadronic energy deposition patterns.

Starting from the electromagnetic energy E_0, the final reconstructed energies E_{rec} are obtained by weighting factors ω on a cell by cell basis. Depending on the energy of so called hadronic objects 3), different weighting methods are used to determine the weight ω for a cell. A hadronic object is defined by the sum of energy depositions in a cylinder around the largest energy deposition with a radius of 25 cm (50 cm) in the EMC (HAC). If energy depositions are not associated to a hadronic object a new hadronic object is determined arround the largest energy deposition of the remaining depositions. This is iterated until all energy depositions in an event are assigned.

For cells associated to a hadronic object above 10 GeV an iterative weighting method is applied. The weighting factors ω depend on the energy E_{cone} in a cone 4) of opening angle of 10 degrees around the most energetic cluster[3] and the cell energy density $\rho = E_0/V$ (V is the cell volume)[4] and were determined using simulated jet-data. They are given by

$$\omega(\rho, E_{cone}) = C_1 \cdot \exp\left(-C_2 \cdot \rho\right) + C_3 \tag{1}$$

with the parameter functions $C_1(E_{cone})$, $C_2(E_{cone})$ and $C_3(E_{cone}, \Theta_{cone})$. After applying the weighting factors to the cell energies the cone energy E_{cone} is determined. With this new E_{cone} the weighting factors are recalculated according to eq.1. This iteration is repeated until the energy in the cone changes by less than 0.2%. A detailed description of this method can be found in 5). For hadronic objects with an energy below 7 GeV constant weighting factors are applied (EMC: ω = 1.353, HAC: ω = 1.608). In the intermediate region between 7 and 10 GeV both methods contribute to the weight ω such that a

[3] A cluster is defined as a group of interrelated cells.

[4] In an event, cones are built until no cluster is left outside a cone.

smooth transition from the simple corrections factors to the iterative weighting is achieved.

4 Development of an Alternative Weighting Procedure

The new alternative weighting sheme (AW) [6] aims in contrast to the H1 standard weighting to reconstruct the correct hadronic energy not only in average per event, but also per cell. Special attention is put to low energies.

4.1 Determination of the weighting factors

The weighting factors of the AW procedure, which depend again on ρ and E_{cone}, were developed with simulated pion events (GEANT3.21, GHEISHA), used to calibrate modules of the H1 LAr–Calorimeter. The momenta of the simulated pions were: 0.5, 0.75, 1, 1.5, 2, 3, 5, 6, 7, 10, 15, 20 and 25 GeV [7]. This set of pion events (83051 events) was used in the following way to determine the weighting factors seperately for EMC and HAC:

1. For each cell, which survives a noise cut and belongs to the cone with the highest energy E_{cone} in a simulated pion event, the energy E_{dep} truly deposited inside the cell and its cell energy density $\rho = E_0/V$ are determined.
2. The mean values of E_0 and E_{dep} are determined in a two-dimensional grid of $\rho = E_0/V$ and E_{cone} with bins which are scaled logarithmically to take low cone energies and low cell energy densities properly into account.
3. These mean values $(\langle E_0\rangle_{\rho,E_{cone}},\langle E_{dep}\rangle_{\rho,E_{cone}})$ are used to determine the weighting factor for each $\rho - E_{cone}$–bin:

$$\omega(\rho, E_{cone}) = \frac{\langle E_{dep}\rangle_{\rho,E_{cone}}}{\langle E_0\rangle_{\rho,E_{cone}}} = \frac{\sum_j^{N_{cell}^{bin}} E_{dep,j}/N_{cell}^{bin}}{\sum_j^{N_{cell}^{bin}} E_{0,j}/N_{cell}^{bin}}\,, \tag{2}$$

   where N_{cell}^{bin} is the number of cells in a $\rho - E_{cone}$–bin. The sums in eq.2 run over cells, which do belong to a ρ–E_{cone}–bin.

4.2 Weighting procedure

The AW procedure does not use hadronic objects. The weighting is done by multiplying the cell energies E_0, which survive the noise cut and belong to a cone with $E_{conus} > 0.250\,\mathrm{GeV}$, with the corresponding weight. This weight is determined by a two dimensional linear interpolation of the values $\omega(\rho, E_{cone})$ in the grid.

4.3 Results

The AW procedure was cross checked using CERN test beam data [6]. Fig.1a) and b) show for the AW procedure the reconstructed energy in a cell E_{rec} over E_0 for 3 and 20 GeV simulated π–events as a function of the cell energy density . Also shown is the ratio of the truly deposited energy in a cell E_{dep} over E_0. The AW procedure is able to reconstruct the energies deposited in the cells in an excellent way. Fig.1c) and d) show for simulated π–events in the CERN test beam setup the resolutions and the linearities achieved with the H1 standard weighting compared to the AW procedure. The AW method is compatible in resolution with the standard weighting, does, however, achieve much better linearities (1-3%) for $1 < P_\pi < 25\,\mathrm{GeV}$ [5] (H1 standard weighting: 3-12%). Furthermore the reconstructed energy distributions of the AW method do have less aberration from the gaussian form. Reconstructing measured 20 GeV pion data from the CERN test beam data finally shows that the AW procedure results in a better energy resolution (new: $(13.1 \pm 0.2)\%$ old: $(14.7 \pm 0.3\%)$).

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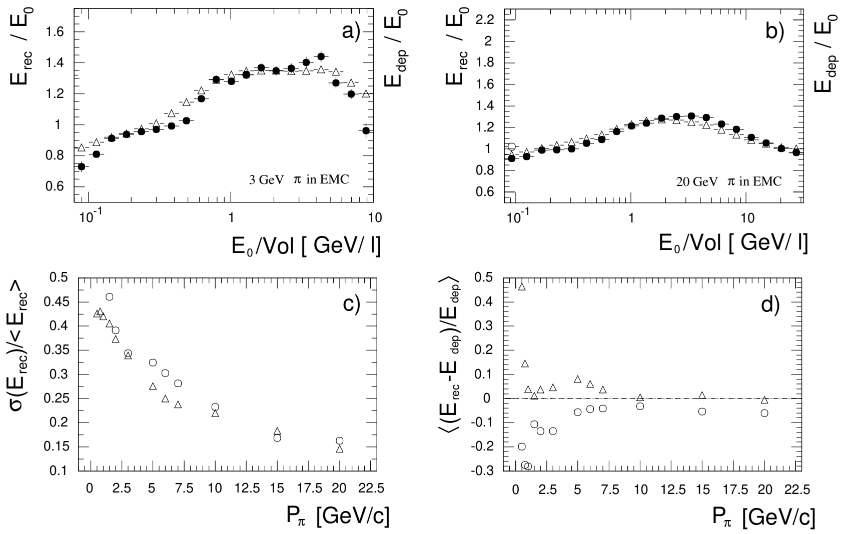

Figure 1: *a) and b)* E_{rec}/E_0 *for 3 and 20 GeV simulated pions for a CERN test beam setup in EMC in dependency of* E_0/V *for the AW procedure* ($\triangle$). *Shown also is* E_{dep}/E_0 ($\bullet$). *Plot c) is showing the resolution and plot d) the linearity* $\langle(E_{rec} - E_{dep})/E_{dep}\rangle$ *of the reconstructed energy in dependency of the incident pion momentum for both weightings (H1 standard* ($\circ$)*)) for simulated pions in a CERN test beam setup.*