THE JET CALIBRATION IN THE H1 LIQUID ARGON CALORIMETER

C. SCHWANENBERGER

Deutsches Elektronen-Synchrotron DESY, Notkestraße 85,
D-22607 Hamburg, Germany
E-mail: schwanen@mail.desy.de

ON BEHALF OF THE H1 COLLABORATION

The jet calibration of the Liquid-Argon-Calorimeter of the H1 Detector at HERA is described. In the measurement of high jet transverse energies systematic uncertainties as low as 2% can be reached in deep inelastic scattering with a high photon virtuality (Q^2) and in photoproduction. Furthermore, the concept of a new energy weighting scheme of H1 is presented. First applications with a high Q^2 neutral current deep inelastic scattering sample show that the resolution of the balance in transverse momentum between the hadronic system and the electron is improved.

1. Introduction

In the H1 Experiment[1] at HERA a Liquid Argon (LAr) Calorimeter is used to measure the energies of particles emerging from the interaction of 27.5 GeV positron (or electron) and 920 GeV (or 820 GeV) proton beams over an angular range of $4^o \leq \theta \leq 154^o$.[a]

The H1 Liquid Argon Calorimeter[2] is a non-compensating sampling calorimeter which is divided into 8 self supporting wheels each built out of 8 octants in the barrel part or two half shells in the forward part. It consists of electromagnetic and outer hadronic sections. In the electromagnetic modules lead is used as absorber material which adds up to 20 – 30 radiation lengths (X_0). The hadronic part is built out of stainless steel absorber plates which corresponds to a total of 4.5 – 8 interaction lengths (λ) including the electromagnetic section.

[a]H1 uses a right-handed coordinate system, where the direction of the proton beam defines the positive z-direction. The polar angle θ is measured with respect to this direction.

2. Calorimeter Calibration using H1 Physics Data

Knowledge of the LAr calorimeter energy scale can be improved using neutral current (NC) deep inelastic scattering (DIS) physics data in off-line analysis. With the increased amount of data collected in the past years the precision in this calibration method has reached the design level.

2.1. *Energy calibration with DIS data*

The over-constrained kinematics of NC DIS events at HERA allow the prediction of the energy E_e of the scattered electron[b] from the electron beam energy E_{e-beam}, the scattering angle of the electron θ_e and the effective angle of the final state θ with the double angle method (DA)[3]:

$$E_e(\theta_e, \theta) = \frac{2 \cdot E_{e-beam} \cdot \sin\theta}{\sin\theta_e + \sin\theta - \sin(\theta_e + \theta)} \quad . \tag{1}$$

The remaining final state can be a hadronic shower (DIS-DA) or a photon (QED-Compton-DA). Using the predicted energies E_e, position dependent calibration factors for the electromagnetic scale are derived.

The hadronic energy scale can be adjusted using the known electron energy. The scale correction factors for the electromagnetic and hadronic sections are obtained wheelwise from the ratio of transverse momenta of the calibrated electron and the hadronic final state.

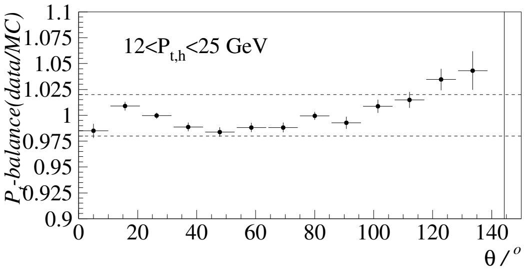

Figure 1. The ratio of data and Monte Carlo prediction for the p_t-balance ratio as a function of the mean hadronic scattering angle θ, for NC DIS with high momentum transfer Q^2 and for hadronic transverse momenta between 12 and 25 GeV.

The uncertainty of the hadronic energy scale is defined by the difference between the correction factors in data and Monte Carlo simulation. As can be seen in Fig. 1, the uncertainties are below 2% in a wide angular range of

[b]If not particularly emphasized, *electron* can mean either an electron or a positron.

calorimeter acceptance. Larger deviations can be found in the backward part where mostly low energy hadrons are accepted and where energy leakage occurs due to the missing hadronic section in the most backward wheel.

2.2. *Dijet Data in Photoproduction*

The calibration procedure obtained from DIS data is applied to the measurement of the dijet cross section in photoproduction.[4] The comparison of the ratio of the transverse energy of the highest energy jet $E_{t,\mathrm{max}}$ and the transverse energy of the rest[c] $E_{t,\mathrm{rest}}$ for data and Monte Carlo simulations indicates the quality of the hadronic calibration. This ratio is shown in Fig. 2 (a) as a function of the highest energy jet. The ratio of $E_{t,\mathrm{max}}/E_{t,\mathrm{rest}}$ in data and simulations, which is shown in Fig. 2 (b), is consistent with uncertainties of the hadronic energy scale below 2%.[d] Detailed studies[5] demonstrate that at large transverse momentum these scale uncertainties are independent of the angular distribution and the mass of the jets as well as of different data selections such as direct, resolved or diffractive processes.

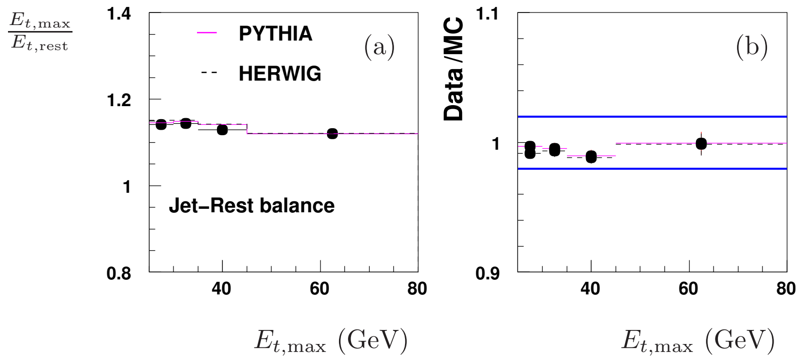

Figure 2. (a) The ratio of the transverse energy of the highest energy jet and the transverse energy of the rest for data and two different Monte Carlo simulations as a function of the transverse energy of the highest energy jet. (b) The ratio of data and Monte Carlo prediction.

In order to illustrate the impact of these uncertainties on a cross section measurement, the relative difference between the measured and the theoretical cross sections[6] is given in Fig. 3, as a function of x_γ, the longitudinal momentum fraction of the photon taken by the interacting parton. The correlated

[c]The *rest* is given by the energy of the second jet plus remaining energies in the event.
[d]This ratio is larger 1 due to the bias from the selection of the jet of highest E_t and losses for $E_{t,\mathrm{rest}}$ in the beam pipe.

errors due to the uncertainty in the calorimeter energy scales are shown as a shaded band. Fig. 3 shows that the assumed scale uncertainties in the next-to-leading order QCD calculation are the dominant source of uncertainties in the comparison of data and theory.

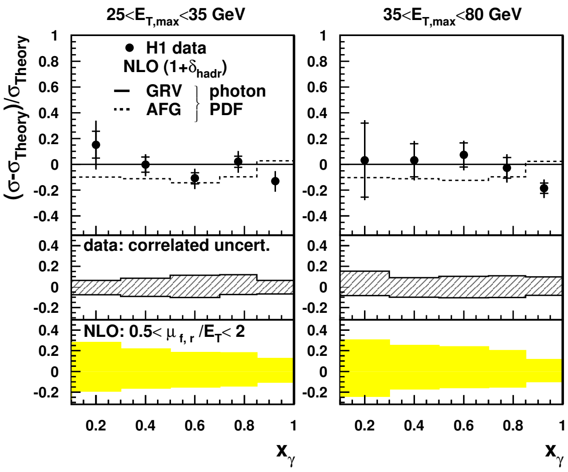

Figure 3. The x_γ dependence of the relative difference of the measured dijet cross sections ($Q^2 < 1\,\mathrm{GeV}^2$) from the NLO prediction, with hadronization corrections applied (here σ_{Theory}). The symbol σ stands for $d\sigma/dx_\gamma$. Figures a) and b) show the relative difference for a lower $E_{t,\max}$ and a higher $E_{t,\max}$ region respectively. The inner error bars denote the statistical error, the outer error bars denote all statistical and uncorrelated systematic errors of the data added in quadrature. The correlated systematic errors are shown in the middle plots as a shaded band. The bands in the lower plots show the renormalization and factorization scale uncertainties of this NLO prediction.

3. Towards a New Energy Weighting Scheme

Because the H1 LAr calorimeter is non-compensating, a software weighting method[7] is applied for the energy reconstruction. In order to overcome some deficits in the low energy regime of the current energy weighting scheme a new weighting procedure was studied using CERN test beam data[8].

The reconstructed energy $E^i_{\rm rec}$ in a calorimeter cell i is derived from the measured cell energy E^i_0 by

$$E^i_{\rm rec} = \omega\ (\ E^i_0/\,Vol^i, E_{\rm group}\ ) \cdot E^i_0 \quad . \tag{2}$$

The weighting factor ω depends on the deposited energy density $E^i_0/\,Vol^i$ (Vol^i being the cell volume) which is different for an electromagnetic and a hadronic deposition, and on the total energy to be reconstructed (energy of the group of selected clusters $E_{\rm group}$). The latter accounts for the fact that both the relative difference between the energy response to electrons and to pions[e] and the fluctuation of the electromagnetic component in the hadronic shower[f] depend on the energy.

The weighting factors ω are tabulated and derived wheelwise, separately for the electromagnetic and the hadronic parts of the whole calorimeter, using a more detailed simulation of single pions as standard for H1 physics analyses.[9] Furthermore, noise corrections are applied. The method is valid from the highest energies down to the noise level. For the final calibration real DIS data are used: the p_t-balance is adjusted wheelwise to $p_t^{\text{had}}/p_t^e \to 1$.

Fig. 4 depicts the change in the p_t-balance distribution if either the current (a) or the new (b) energy weighting scheme is applied. In the current energy weighting scheme there are too many entries for large p_t^{had}/p_t^e values which originate from neutral pions. In the new energy weighting scheme there are fewer entries in the tails of this distribution. Furthermore, the shape is more Gaussian-like and the resolution is somewhat improved.

The jet energy dependence of the p_t-balance is also given in Fig. 4. In the new energy weighting scheme an improvement of the hadronic energy response at small jet energies can be observed (c) and the agreement between data and Monte Carlo simulation is very good (d).

4. Conclusions

It has been discussed how physics data from electron proton scattering can be used for the jet calibration of the LAr Calorimeter. In analyses of photoproduction and NC DIS with high momentum transfer Q^2, the calibration uncertainties are of the order 2%.

A new software weighting scheme was discussed. First applications in DIS with high Q^2 show an improvement in the hadronic energy response at low jet energies. Using this energy weighting scheme, the distribution of the p_t-balance between the hadronic system and the electron gets more Gaussian-like compared to the current weighting.

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[e]For instance, at an energy of 10 GeV, the response to electrons is a factor 1.35 larger than the response to pions.
[f]This is due to neutral pion production in nuclear reactions in the hadronic component of the shower.

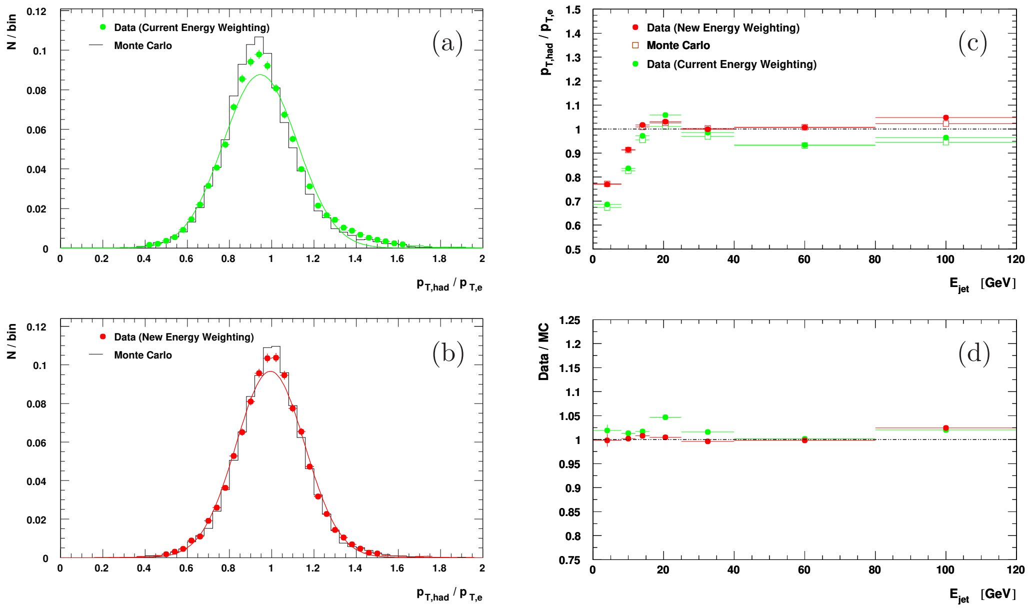

Figure 4. Distribution of p_t-balance for the current (a) and a new energy weighting (b). The data are compared to the Monte Carlo simulation prediction (histogram) and to a Gaussian fit (curve). (c) Mean p_t-balance ratio as a function of the jet energy. Data (dark points) and Monte Carlo simulation prediction (dark squares) in the new energy weighting scheme are compared to data (light points) and Monte Carlo simulation prediction (light squares) in the current energy weighting scheme. (d) The ratio of data and Monte Carlo prediction in the new (dark points) and the current (light points) energy weighting scheme as a function of the jet energy.

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