PRECISE MEASUREMENT OF JET ENERGIES WITH THE ZEUS DETECTOR

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ABSTRACT

A method to correct the jet transverse energy has been developed for the ZEUS detector which attains an uncertainty better than 3%. The procedure is based on a combination of tracking and calorimeter information that optimises the resolution of reconstructed kinematic variables. The selected calorimeter clusters and tracks are referred to as Energy Flow Objects (EFOs). The conservation of energy and momentum in neutral current deep inelastic $e^+p$ scattering events is exploited to determine the required energy corrections by balancing the scattered positron with the hadronic final state. The method has been applied to data and simulated events independently. The corrected EFOs are used as input to a $k_T$-cluster jet algorithm to reconstruct the jets and to determine kinematic variables. In addition, the corrected EFOs allow an improved measurement of the internal structure of a jet.


1 Introduction

Through studying jet production at the $ep$ collider, HERA, a wide variety of fundamental measurements are possible, such as the determination of the strong coupling constant, $\alpha_s$, or information on the gluon content of the photon. To make the measurements as significant as possible, jets have to be reconstructed, optimising the energy resolution and minimising the uncertainty of the absolute energy scale. The accurate reconstruction of jets at the ZEUS experiment generally relies on the precise determination of energies and angles of hits in the uranium-scintillator calorimeter (CAL). Before reaching the CAL, particles pass through approximately one radiation length of dead material in the central region of the detector mainly due to the solenoid magnet between the tracking detector and the CAL. The modelling of the energy lost by particles traversing the solenoid plays the most significant rôle in understanding the absolute energy scale between data and MC.

It has been shown that the energy scale of high-energy scattered positrons in the central part of the CAL is understood to within 1%. Similarly, the hadronic energy scale (i.e. the energy carried by particles in the neutral current (NC) final state, excluding the scattered positron) is known to within 2%, of which 1% comes from the uncertainty of the positron measurement. The uncertainty when specifically studying jet production (jets in the range of transverse energy, $E_T^{\text{jet}} \sim 10 - 100$ GeV) is not the same as the hadronic energy scale because the choice of algorithm and modelling of the jet structure can affect the result. The absolute energy scale uncertainty for jet production is currently known to within 3%, which contributes a roughly 15% error on a jet cross section measurement, due to the steeply falling $E_T^{\text{jet}}$ distribution.

This article describes a method capable of reducing the jet energy scale uncertainty to 1–2% as for the case of the electromagnetic and hadronic energy scale uncertainties. First, the reconstruction of Energy Flow Objects (EFOs) is introduced, which optimise the use of tracking and CAL information. Then, a method is outlined which exploits energy and momentum conservation in a high purity sample of NC events to correct the CAL-EFOs for energy loss in the dead material of the detector.
2 Jet energy correction method

2.1 Energy flow objects

The use of EFOs has been shown to improve the reconstruction of kinematic quantities. Clusters of cells are formed and combined with tracks originating from the primary vertex. In general, for low momentum particles, tracks provide a better measurement of the energy, whereas the CAL is better for high momentum particles. In the case of clusters not matched to a track (from, for example, neutral particles) or tracks not matched to a cluster (where the particle momentum is so small that it does not reach the CAL), the situation is clear. However, for clusters and tracks considered matched (or even many tracks matched to one cluster, etc.), a decision has to be made concerning which quantity (or quantities) to use. For a matched cluster-track system, the resolutions and ratio of energy to momentum are considered in the decision-making process. Using this procedure, a list of track-EFOs and CAL-EFOs is obtained. The track-EFOs are assumed to be an accurate measurement of the particle energy, whereas the CAL-EFOs are subject to energy-loss in the dead material in front of the CAL and must be corrected.

2.2 Sample of neutral current events

The conservation of energy and momentum in NC events can be exploited to determine the CAL-EFO energy-correction functions by balancing the momentum of the scattered positron with that of the hadronic final state. Using a method similar to that detailed below, the uncertainty in the ZEUS jet energy-scale has already been determined to within 3%. In order to reduce this uncertainty, the form of the function for energy loss, improving the samples of events chosen and using a larger data sample have been studied.

Two samples of events with high momentum transfer, $Q^2 > 100 \text{ GeV}^2$, were used to provide full angular coverage of the detector. A sample of events with high positron $p_T$ and a sample of events at high effective longitudinal momentum, $y$, were used. The kinematic variables of the positron were reconstructed using the double angle method, which, to first order, is independent of the absolute energy scale of the CAL. The hadronic final state four-vector was calculated from the EFOs reconstructed as above and its momentum components balanced with that of the scattered positron. Each correction for the
CAL-EFOs were parametrised as a function of energy. There parameters were determined for several bins of polar angle, $\theta$, (reflecting the detector geometry), by minimisation of the following quantity:

$$\sum_{\text{sample 1}} \min \left[ \left( \frac{p^\text{DA}_T - p^\text{had}_T}{p^\text{DA}_T} \right)^2, 0.2^2 \right] + \sum_{\text{sample 2}} \min \left[ \left( \frac{y^\text{DA} - y^\text{had}}{y^\text{DA}} \right)^2, 0.2^2 \right].$$

The minimisation was performed using the MINUIT package and correction factors obtained separately for data and MC. The difference between data and MC may arise from inadequate detail in the description of the dead material in front of the CAL and an inaccurate simulation of the hadronic energy loss process.

2.3 Energy correction functions

The CAL clusters were corrected for energy loss using the functional form, $f(E) = A/E^B$, where $E$ is the cluster energy and $A$ and $B$ are the correction factors to be determined in each angular region. The result of the fits for both data and HERWIG MC are shown in fig. 1. It can be seen that the data and MC show similar trends but differ in detail, justifying the need to perform the fits and apply the corrections separately for data and MC.

3 Results

To test the validity of the factors obtained, the correction functions were applied to an independent photoproduction MC sample, where the scattered positron is not detected in the CAL. Jet quantities were reconstructed using both EFOs with and without correction and the transverse energy, $E_{\text{JET}}^T$, compared to the “true” hadron-level, $E_{\text{HAD}}^T$ as shown in fig. 2. Before the EFOs are corrected, the deviation from the true value is roughly $10 - 15\%$ as shown in fig. 2b. After correction, as in fig. 2a, the transverse energies are significantly closer to the true values, demonstrating that the energy correction helps to reproduce the true quantities when applied to an independent MC sample. The extent to which hadron-level quantities in the data are reproduced and the size of the resulting energy scale uncertainty can be determined by comparing the correction in data and MC separately.
The results of applying the corrections to the same data and MC used to obtain the factors is shown in fig. 3. Here, instead of the $p_T$ of the hadronic final state, the transverse energy of the jet, $E_{Jet}^{T}$, which takes into account the extra uncertainties due to jet reconstruction and is closely related to $p_T^{HAD}$, is considered. As a function of the pseudorapidity of the jet, $\eta^{Jet} = -\ln[\tan(\theta/2)]$, the data and MC agree to within roughly 1%.

For the global kinematic quantities, $p_T$ and $y$, a similar trend was seen, i.e. the data and MC agreed to within $1 - 2\%$ in all parts of the kinematic region considered.

4 Conclusions

A method has been developed for correcting for energy lost in the dead material in front of the ZEUS calorimeter. The procedure relies on a combination of tracking and CAL information. The CAL energy correction is determined using
Figure 2: Fractional difference between hadron-level jet $E_T$ and that reconstructed with (a) corrected EFOs and (b) uncorrected EFOs as a function of the transverse energy. The shaded band shows the width of the distribution.

energy and momentum balanced NC events. A more accurate reproduction of the hadronic final state is obtained indicating that the absolute CAL energy scale is reproduced to within $1 - 2\%$ between data and MC.

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Figure 3: (a) Fractional difference of $E_{\text{jet}}^J$ and $p_T^{DA}$ for data and MC and (b) the difference, DATA–MC.

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