SETTING THE JET ENERGY SCALE FOR THE ZEUS CALORIMETER

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A much improved determination of the transverse energy of jets has been carried out in ZEUS, using a correction procedure based on two independent methods. The first is based on a combination of tracking and calorimeter information which optimises the resolution of reconstructed kinematic variables. The conservation of energy and momentum in neutral current deep inelastic e^+p scattering events is exploited to determine the energy corrections by balancing the kinematic quantities of the scattered positron with those of the hadronic final state. The method has been independently applied to data and simulated events. The second method uses calorimeter cells as inputs to the jet algorithm. Simulated events are then used to provide a correction for the energy loss due to inactive material in front of the calorimeter. A detailed comparison of the jet transverse energy and the transverse energy of tracks in a cone around the jet provides the final correction. This procedure relies on an accurate simulation of charged tracks and so is less reliant on simulating the energy loss of neutral particles in inactive material. Final comparisons of the data and simulated events for both methods allow an uncertainty ±1% to be assigned to the jet energy scale.

1. Introduction

The energy scale uncertainty of the calorimeter (CAL) coupled with differences between data and Monte Carlo (MC) simulations has traditionally been the dominant systematic uncertainty in jet measurements from the ZEUS collaboration. Energy scale uncertainties of $\pm(3-5)\%$, lead to uncertainties of $\sim \pm(10-20)\%$ in the cross-section measurements[1].

The HERA accelerator collides positrons of 27.5 GeV with protons of 820 (or 920) GeV leading to heavily boosted final states. Neutral current deep inelastic scattering events with high momentum transfer, Q^2, provide both interesting physics and the opportunity to study and calibrate the CAL energy scale. Quark-parton model type events, in which the positron scatters off a quark in the proton producing a final state jet back-to-back with the scattered

positron, have been selected. After setting the electromagnetic energy scale, as discussed in section 2, a comparison of the scattered positron energy with that of the hadronic jet allows the determination of the uncertainty on the hadronic energy scale as discussed in the rest of this paper.

2. Electromagnetic energy scale uncertainty

The electromagnetic energy scale has been studied in detail[2] by taking the ratio of the energy of the scattered positron measured in the calorimeter, E_e, with the track momentum or the electron energy reconstructed via the double angle (DA) method, E_{DA}. The DA method predicts the electron energy from the angular information of the scattered positron and the hadrons and is, therefore, to first order, independent of the absolute energy scale of the CAL[3]. The difference between the energy ratio in data and MC is shown in figure 1. The agreement is within $\sim \pm 1\%$.
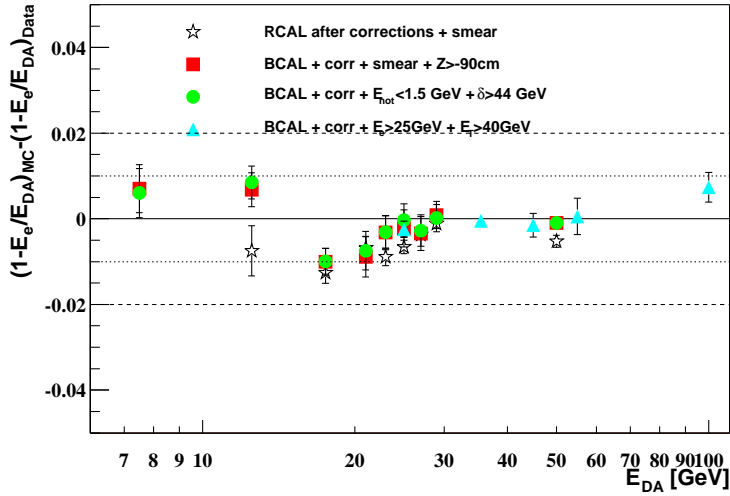

Figure 1. Difference between data and MC of the energy scale for scattered positrons as a function of the energy, E_{DA}.

3. Jet energy scale uncertainty

Due to inactive material between the interaction point and the CAL, jets need to be corrected for the energy loss. Typically, 20% of the jet's transverse energy is lost and is the major factor to be accounted for in order to produce an accurate determination of the uncertainty in the jet energy scale. Two different methods for correction have been developed.

3.1. *Method 1*

The first method uses energy flow objects (EFOs) to reconstruct the final state in which a combination of tracking and calorimeter information is used[4]. Clusters of cells are formed and combined with tracks originating from the primary vertex and a decision made on whether to use the cluster or track. In the case of isolated clusters or tracks, the decision is trivial. For a matched cluster-track system, the resolutions of each object and ratio of energy to momentum are considered. Using this procedure, a list of track-EFOs and CAL-EFOs was obtained, where the track-EFOs are assumed to be an accurate measure of the particle energy and the CAL-EFOs are subject to energy loss in the inactive material and must, therefore, be corrected.

The conservation of energy and momentum in NC events was exploited to determine the CAL-EFO energy-correction functions by balancing the momentum of the scattered positron with that of the hadronic final state[5,6,7]. Two samples of events were used, both with $Q^2 > 100$ GeV^2; one sample had high positron p_T and the other sample had high y. The variable y is the fraction of the lepton energy transferred to the proton in its rest frame and is a measure of the effective longitudinal momentum. Using the two samples, full angular coverage of the detector was achieved. The kinematic variables of the positron were reconstructed using the DA method. 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. The CAL-EFOs were corrected for energy loss as a function of the cluster energy in several angular regions (reflecting the detector geometry). The difference between p_T and y for the hadronic system and scattered positron was minimised and correction factors obtained separately for data and ARIADNE[9] and HERWIG[8] MC simulations as shown in figure 2. It can be seen that the data and MC show similar

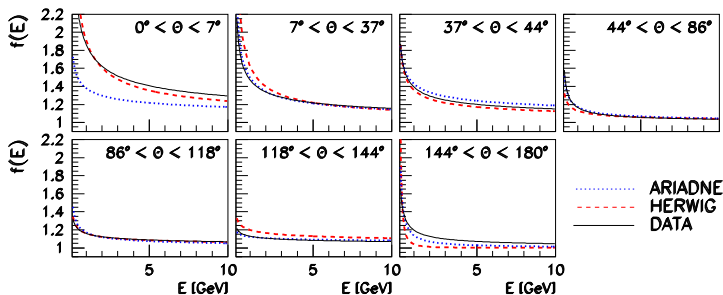

Figure 2. Energy corrections as a function of cluster energy in bins of θ. The corrections are shown separately for data (solid line) and HERWIG MC (dashed line) and ARIADNE MC simulations (dotted line).

trends but differ in detail, justifying the need to perform the fits and apply the corrections separately for data and MC.

To test the validity of the procedure, 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_T^{jet}, compared to the hadron-level, E_T^{HAD} as shown in figure 3. Using calorimeter cells as shown in
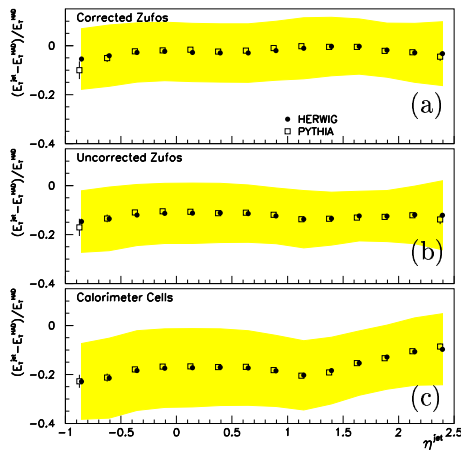

Figure 3.   Fractional difference between hadron-level jet E_T and that reconstructed with (a) corrected EFOs, (b) uncorrected EFOs and (c) calorimeter cells as a function of the transverse energy. The shaded band shows the width of the distribution.

figure 3c, the deviation from the true value is 20% which is reduced to $10-15\%$ when using EFOs due to the use of tracking information as shown in figure 3b. After correction, as in fig. 3a, 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. To determine the jet energy scale uncertainty, the difference between data and MC after the application of these corrections was considered; this is discussed in section 3.3.

3.2. Method 2

In the second method jets are reconstructed using calorimeter cells and a correction for energy loss is derived from MC simulation[10]. The reconstructed jet energies are corrected on average to the value of the jets from hadrons as a function of transverse energy and in regions of pseudorapidity. The correction factors are applied to both data and MC events. After this procedure
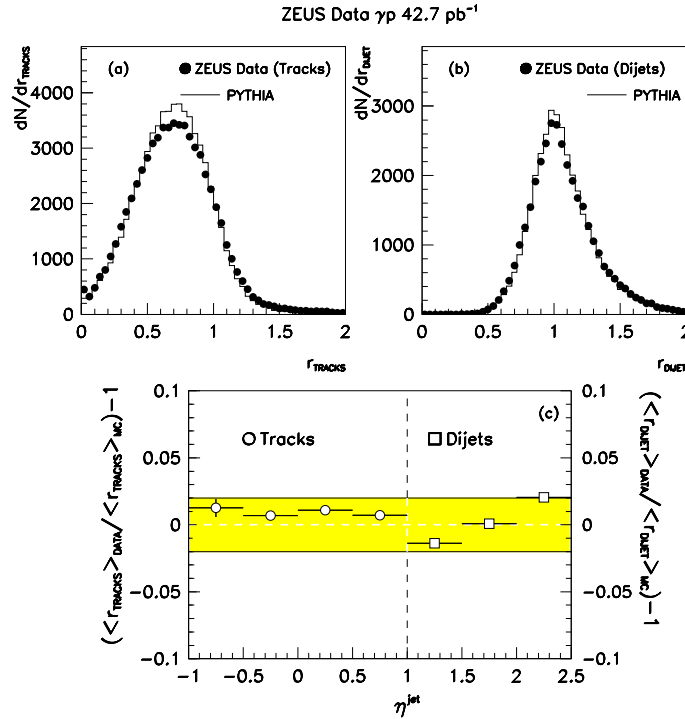
Figure 4. Comparison of (a) r_{TRACKS} and (b) r_{DIJET} for data (points) and MC simulation (histogram) and (c) the difference between data and MC as a function of pseudorapidity.

the calorimetric jets in the data and MC simulation are compared by utilising tracking information in a cone around the jets. The ratio r_{TRACKS} of the jet transverse energy, E_T^{jet}, and transverse energy of tracks in a cone around the jet axis is shown for data and MC in figure 4a. This quantity can only be calculated within a certain angular region corresponding to good acceptance for the central tracking chamber. For a jet outside this region, the ratio, r_{DIJET}, of its transverse energy to that of a central jet was calculated; this is shown in figure 4b. The mean value in data and MC for these ratios was found in different regions of pseudorapidity of the jet, η^{jet}; the difference between data and MC is shown in figure 4c. The MC agrees with the data to within $\pm 2\%$; this deviation is then used as a further correction. This procedure relies on the accurate simulation of charged tracks and so is less reliant on simulating the energy loss of neutral particles in inactive material. This jet-correction procedure was applied to an independent sample of neutral current DIS events. As for method 1, the ratio of the transverse momentum of the positron and hadronic jet was calculated and the difference between data and MC determined.

3.3. *Jet energy scale uncertainty*

The jet energy scale uncertainty is shown in figure 5 as a function of pseudo-rapidity (for method 1) and transverse energy (for method 2). The difference between data and MC is within $\pm 1\%$.
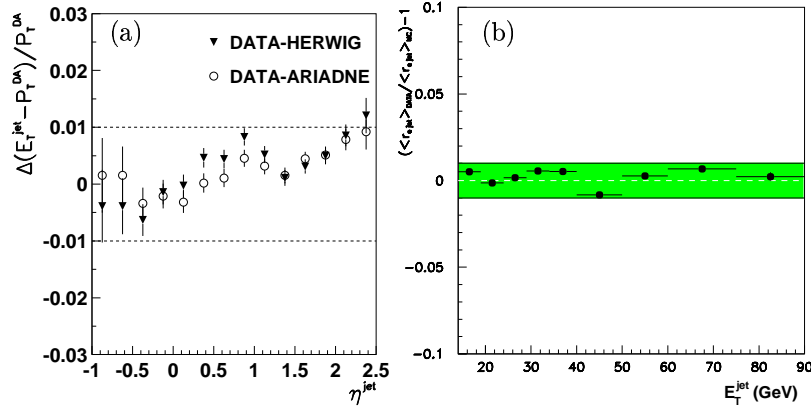

Figure 5. Jet energy scale uncertainty as a function of (a) η^{jet} and (b) E_T^{jet}.

4. Conclusions

Two independent methods have been developed for correcting jet energies for energy loss in inactive material in the detector. Both methods give an improved reconstruction of the hadronic final state and understanding of the jet energy scale. The uncertainty of the jet energy scale for $E_T^{\mathrm{jet}} > 10$ GeV is $\pm 1\%$. This leads to uncertainties in measured cross sections of $\sim \pm 5\%$, significantly smaller than current theoretical uncertainties.

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