Event shapes in deep inelastic $ep \to eX$ scattering at HERA

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Abstract. The study of energy flow in high energy particle collisions is a powerful tool for testing QCD predictions. Event shape variables extend this study to the non-perturbative region of QCD.

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INTRODUCTION

Hadronic final states in *ep* collisions at HERA provides a unique opportunity to test perturbative QCD predictions over a large range of the four-momentum transfer squared. Q^2 is the virtuality of the photon in the region where the experimental uncertainties and non-perturbative effects are expected to be reduced. However, understanding of the nature of the non-perturbative contribution, hadronization, is one of the most important subjects of high energy physics. Recent revival of interest in event shapes has been prompted by theoretical developments in the understanding of hadronization. This gives a chance to go beyond the phenomenological models of hadronization that are currently used in Monte Carlo event generators.

EVENT SHAPES

The event shapes studied at HERA by ZEUS[1] are thrust T, broadening B, jet mass M, and the C-parameter C. The measurements were performed in the kinematic range $80 < Q^2 < 2 \cdot 10^4\,\mathrm{GeV}^2$ and $0.0024 < x < 0.6$, in the current region of the Breit frame, in order to facilitate comparison with e^+e^- experiments.

According to the theoretical model of power corrections (PC) introduced by Y. Dokshitzer and B. Webber[2], event-shape values, $\langle F \rangle$, can be described as the sum of perturbative, $\langle F \rangle_{pert}$, and non-perturbative , $\langle F \rangle_{PC}$, terms. The perturbative contribution is then calculated using QCD next-to-leading-order (NLO) programs such as DISENT and DISASTER[3], while the non-perturbative term is an analytical function of two parameters $(\alpha_s, \overline{\alpha_0})$, where $\overline{\alpha_0}$ is an effective coupling. By fitting the measured Q^2 dependence of the mean event-shape values to the NLO + PC prediction, values for α_s and $\overline{\alpha_0}$ were extracted.

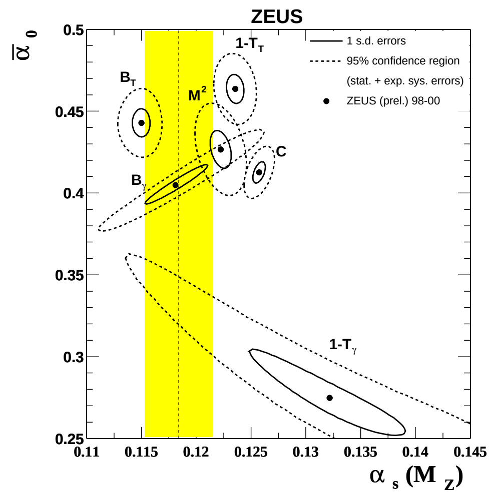


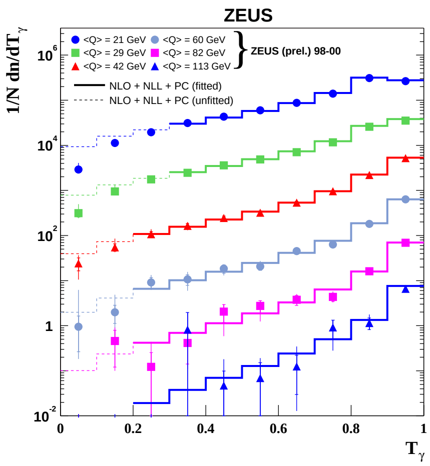
FIGURE 1. ZEUS extractions of α_s and $\overline{\alpha_0}$ shown in the $(\alpha_s,\overline{\alpha_0})$ plane from fits to the event-shape means. The experimental systematic errors were determined using the Hessian method which takes into account bin-by-bin correlations. The solid curve is the statistical plus experimental systematic 1 σ error contour; the dashed curve represents the 95% confidence limit for α_s and $\overline{\alpha_0}$. The shaded band is the world average of α_s.

The extraction of α_s and $\overline{\alpha_0}$ from each mean event-shape value provided values of α_s and $\overline{\alpha_0}$ that are consistent overall with each other and with the world average. Figure 1 shows the extracted values $(\alpha_s,\overline{\alpha_0})$ for each event-shape mean studied. There is a slight spread between most of the values and with the values extracted from thrust with respect to the photon axis in the Breit frame and broadening with respect to the thrust axis in the Breit frame.

The dispersion of the α_s and $\overline{\alpha_0}$ values could be due to higher-order terms that are not present in the NLO + PC calculations. Studying the differential event-shape distributions provides a way to analyze the effects of those higher-order terms. Due to the lack of convergence of the perturbative series for the differential distributions, the NLO + PC model used for the mean is not expected to describe the distributions. To study the event-shape distributions, a resummation[4] of the next-to-leading logarithm (NLL) is required. The effect of adding the PC terms to the NLO + NLL prediction cause a shift in the distributions.

Power-correction theory is not expected to be accurate in all regions of the event shape distributions because the lack of terms beyond NLO in the perturbative series causes a deficit of very broad events and an excess of strongly collimated events. Therefore, the predictions do not match the data at each end of the distributions. By studying the differential distributions, one can identify regions in phase space where the model is performing well, and restrict the fits to these regions. The missing higher-order, resummation terms still make small, but significant, contributions, even in this restricted phase space.

ZEUS has recently made measurements of the differential distributions. As described above, the NLO + NLL + PC predictions are fit to the measurements in a restricted range. The NLO + NLL + PC predictions are shown together with the measured distributions



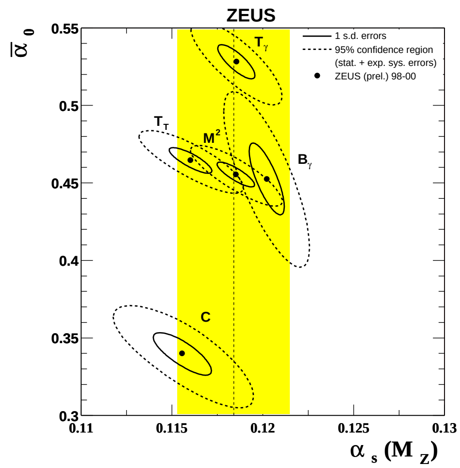


FIGURE 2. ZEUS measurement of T with respect to the photon axis in the Breit frame in different bins of Q^2 compared to the prediction of NLO + NLL + PC, as described in the text. Errors are shown. Solid lines for the prediction represent the fit range, and the dashed prediction line represents the region not fit to the data.

FIGURE 3. ZEUS extractions of α_s and $\overline{\alpha_0}$ shown in the (α_s,$\overline{\alpha_0}$) plane from fits to the event shape differential distributions. The experimental systematic errors were determined using the Hessian method, which takes into account bin-by-bin correlations. The solid curve is statistical plus experimental systematic 1 σ contour; the dashed curve represents the 95% confidence limit for α_s and $\overline{\alpha_0}$.

in Fig. 2, for the thrust distribution.

Based on the fits to the event-shape distributions, values for α_s and $\overline{\alpha_0}$ are extracted from each event shape. As with the values extracted from the measurement of the means, the values extracted from the measured distributions provide consistent values for α_s (see Fig. 3). The values extracted for $\overline{\alpha_0}$ are a little lower than for other experiments, and notably the ZEUS value from the C-parameter is lower.

To study further the non-perturbative region of QCD, it is possible to investigate event shapes which are more sensitive to higher-order effects. In particular, the study of dijet events provides a sample which is sensitive to $\mathscr{O}(\alpha_s^2)$ contributions. The out-of-plane momentum and jet rates are event shapes that are sensitive to these higher order effects. The out-of-plane momentum, K_{OUT}, is the sum of momentum out of the event plane formed by the two highest energy jets, and the jet rate, y_2, is the (2+1)-jet resolution defined by the k_T cluster algorithm[5] in the longitudinally invariant inclusive mode in the Breit frame. Figure 4 shows the distributions of the multijet event shape K_{OUT}. For these shapes, no fits were performed up to now since only lowest order K_{OUT} calculations are available. Figure 4 shows K_{OUT} in two Q^2 bins; the available LO + NLL + PC prediction[6] is in acceptable agreement with K_{OUT} data. For y_2, NLOJET[7] gives a good description of y_2 for higher values of Q.

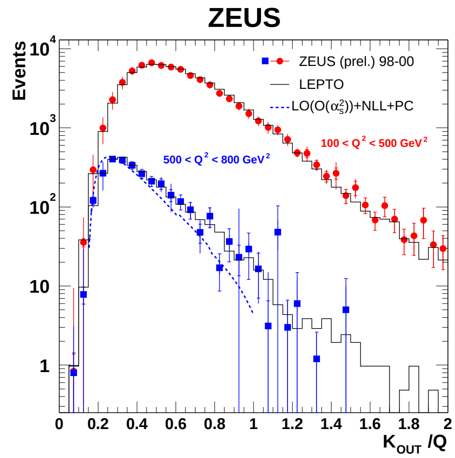


FIGURE 4. K_{OUT} distribution compared to LEPTO shown in bins of $100 < Q^2 < 500\,\mathrm{GeV}^2$ and $500 < Q^2 < 800\,\mathrm{GeV}^2$. The LO + NLL + PC calculation is shown in the higher Q^2 bin.

SUMMARY

Existing ZEUS event-shape measurements [1] are complemented by a new measurement of the means, using a larger data sample, and by measurements of differential distributions. For the kinematic ranges and cuts employed by this analysis, the NLO + PC calculation is unable to extract consistent results for all of the mean values and differential distributions of the event-shape variables. When matched NLL resummations are added to the model, good fits to the differential distributions are obtained that yield $\alpha_s(M_Z)$ values that are consistent with the world average. For the first time, ZEUS has measured a two jet event-shape variable, K_{OUT}.

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