EVENT SHAPES AND POWER CORRECTIONS IN ep DIS AT HERA

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Deep-inelastic ep scattering data, taken with the H1 and ZEUS detectors at HERA, are used to study the means and distributions of the event shape variables thrust, jet broadening, jet mass, C-parameter and two kinds of differential two-jet rate. The data cover a range of the four-momentum transfer Q, taken to be the relevant energy scale, between 7 GeV and 141 GeV. The Q dependences are compared with second-order calculations of perturbative QCD. Power law corrections are applied to account for hadronization effects.

1 Introduction

Event shapes are observables designed to study the influence of the strong interaction on hadronic final states by characterizing deviations from the pencil-like structure to be expected within the framework of the quark parton model. Measurements have shown, however, that even at energies as high as the Z mass non-perturbative effects have to be taken into account. The search for a better theoretical understanding of these non-perturbative contributions has prompted a revival of interest in event shapes.[1]

2 The Measured Data

A suitable frame of reference to study event shapes in DIS is the Breit frame which maximizes the separation between the current jet from the struck quark and the proton remnant. In this frame, the exchanged gauge boson is purely space-like with four-momentum $q = \{0, 0, 0, -Q\}$. Within the framework of the quark parton model, the incoming quark with longitudinal momentum $p^{\rm in}_{q\,z} = Q/2$ is back-scattered into the current hemisphere ($z < 0$) with $p^{\rm out}_{q\,z} = -Q/2$ while the proton fragments into the opposite direction (remnant hemisphere, $z > 0$). The studies presented by the H1 and ZEUS collaborations[2,3] investigate five event shapes which are confined to the current region: thrust with respect to the thrust axis (τ_C, τ_m), thrust and jet broadening with respect to the boson axis (τ, τ_z; B, B_c), jet mass (ρ) and the C-parameter (C).

In order to keep these variables infrared-safe, the total energy in the current hemisphere has to exceed 20% (H1) or 6% (ZEUS) of the value expected from the quark parton model ($Q/2$). In addition, H1 has studied two kinds of differential two-jet rates, i.e. the transition value from $(2+1)$ to $(1+1)$ jets,[a] exploiting the full phase space: the factorizable JADE (y_{fJ}) and the k_t algorithm (y_{k_t}).

The analyzed data cover a kinematic range in Q from 7 GeV (9 GeV) up to 100 GeV (141 GeV) for H1 (ZEUS) and are integrated over the scaling variable Bjørken x in H1 whereas ZEUS employs a binning in x as well. Note that while unfolding the influence of the detector on the measured data ZEUS additionally corrects as proposed [4] for mass effects by assuming all hadrons to be massless (P scheme). This leads to differences for the means of the jet mass between ZEUS (ρ_0) and H1 (ρ) as shown in fig. 1. Thrust, jet broadening and the C-parameter are unaffected because they are derived from three-momenta and are in good agreement between the two collaborations.

3 Power Corrections to Mean Values

Hadronization effects on an event shape, generically labelled as F, are treated within the concept of power corrections which appear as additive terms to the perturbative predictions for the mean values and are proportional to $1/Q^p$ with exponents $p = 1$ ($p = 2$ for y_{k_t}):

$$\langle F \rangle = \langle F \rangle^{\text{pert}} + \langle F \rangle^{\text{pow}} = \langle F \rangle^{\text{pert}} + a_F \cdot \mathcal{P} \tag{1}$$

with a_F being a F dependent calculable coefficient. A simple form of $\mathcal{P} \propto \text{const}/Q^p$ is not sufficient to describe the data [2]. A more sophisticated approach [1] introduces for $p = 1$

$$\mathcal{P} = 1.61 \frac{\mu_I}{Q} \left[\overline{\alpha}_0(\mu_I) - \alpha_s(Q) - 1.22 \left(\ln \frac{Q}{\mu_I} + 1.45 \right) \alpha_s^2(Q) \right] \tag{2}$$

where the renormalization scale has been identified with Q and $\mu_I = 2$ GeV is the infrared-matching scale below which the strong interaction is parameterized by a non-perturbative parameter $\overline{\alpha}_0$ that corresponds to an average effective strong coupling in the infrared region.

The results of fits of $\overline{\alpha}_0$ and $\alpha_s(M_Z)$ according to eqs. 1 and 2 are summarized in fig. 2 in the form of contours of $\chi^2(\alpha_s, \overline{\alpha}_0) = \chi^2_{\text{min}} + 4$. For τ_C (τ_m) and C there is fair agreement whereas due to the different treatment of hadron masses in the correction procedure the jet masses ρ (ρ_0) differ. Performing

[a] The +1 denotes the proton remnant jet.

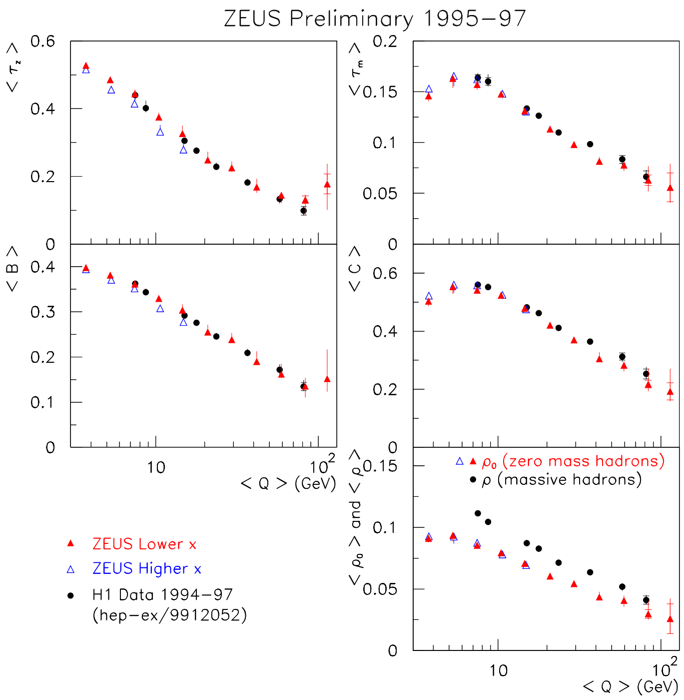

Figure 1: Comparison of unfolded event shape means as measured by H1 and ZEUS.

the fit simultaneously for two different regions in x as done by ZEUS is more problematic and leads to the larger discrepancies which are observed for τ and B. For a comparison to results from e^+e^- annihilation see [5].

On the right hand side of fig. 2 the influence of discrepancies [6] that have been observed for the two pQCD programs DISENT [7] and DISASTER++ [8] is demonstrated. DISASTER++ leads in general to a somewhat smaller $\overline{\alpha}_0$ and to slightly more consistent values of $\alpha_s(M_Z)$.

Similar fits have been performed by H1 [2] for the differential two-jet rates y_{fJ} and y_{k_t} both of which exhibit much smaller hadronization corrections than the other event shapes. In the case of y_{fJ} the suggested value of $a_{y_{fJ}} = 1$, i.e. the same as for thrust, can be excluded from the data. For the k_t algorithm the coefficient of the $p = 2$ power correction is not known and due to large correlations for a three parameter fit it can only be stated that the data are consistent with quadratic power law corrections.

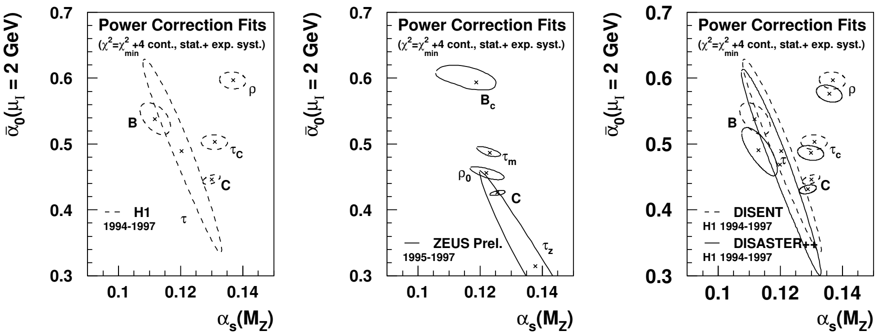

Figure 2: Comparison of power correction fits for H1 (left) and ZEUS data (middle), differences between the fits for H1 data using either DISENT or DISASTER++ (right).

4 Power Corrections to Distributions

If distributions in the event shapes confined to the current hemisphere are studied the power corrections can (except for B) be written as

$$\frac{1}{\sigma_{\rm tot}}\frac{d\sigma(F)}{dF} = \frac{1}{\sigma_{\rm tot}}\frac{d\sigma^{\rm pert}(F - a_F\mathcal{P})}{dF} \tag{3}$$

provided $\mu_I/Q \ll F$. The power term $\mathcal{P}$ is exactly the same as that of eq. 2. Fig. 3 shows fits of the next-to-leading order calculations for the distributions in C and y_{k_t}, with and without power correction, respectively. In general, these exercises lead to inconsistent results between the outcome of fits to the means and the distributions of the same observable, e.g. C gives for $(\overline{\alpha}_0,\ \alpha_s(M_Z))$ $(0.45, 0.130)$ from $\langle C\rangle$ and $(0.62, 0.131)$ from $d\sigma/dC$. A scheme for matching resummed and next-to-leading order distributions, which for ep DIS has only recently become available [6], may be necessary. Only in case of the differential two-jet rates, where hadronization corrections are smaller, can reasonable fits at sufficiently high Q be obtained while neglecting power corrections completely. An example is given in fig. 3 for y_{k_t}.

Including resummed predictions, the same techniques have been successfully applied in e^+e^- annihilation [5].

5 Conclusion

In summary, the power correction approach to hadronization appears to work well in ep DIS and e^+e^- annihilation, although some theoretical and experimental questions remain. An approximately universal value of $\overline{\alpha}_0 \approx 0.5 \pm 20\%$

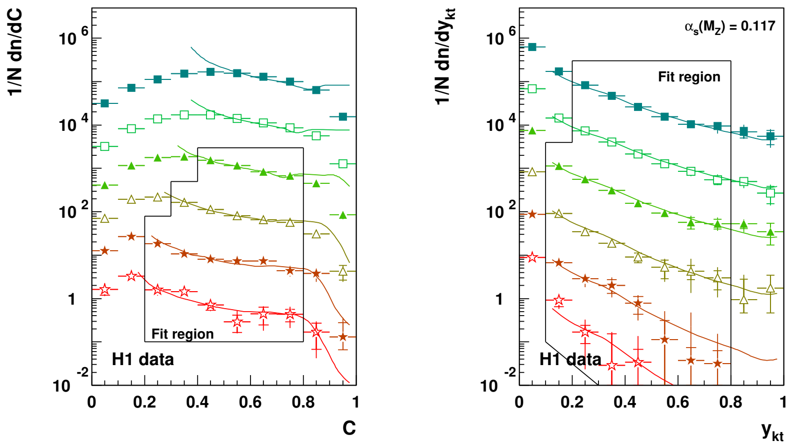

Figure 3: Fits of differential distributions for C with power correction (left) and for y_{k_t} without (right). The different symbols label the binning in Q with $\langle Q \rangle$ ranging from 15.0 GeV (■) up to 81.3 GeV ($\star$).

can be deduced. With further progress in resummed predictions, a fruitful future lies ahead of us.

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