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.

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 $p_{qz}^{in} = Q/2$ is back-scattered into the current hemisphere ($z < 0$) with $p_{qz}^{out} = -Q/2$ while the proton fragments into the opposite direction (remnant hemisphere, $z > 0$). The studies presented by the H1 and ZEUS collaborations investigate five event shapes which are confined to the current region: thrust with respect to the thrust axis ($\tau_C, \tau_m$), thrust and jet broadening with respect to the boson axis ($\tau, \tau_z; B, B_c$), jet mass ($\rho$) 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\footnote{The +1 denotes the proton remnant jet.}, exploiting the full phase space: the factorizable JADE ($y_{fJ}$) and the $k_t$ algorithm ($y_{kt}$).

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 Bjorken $x$ 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\footnote{A more sophisticated approach\cite{4} introduces for $p = 1$}

\[ P = 1.61 \frac{\mu_I}{Q} \left[ \alpha_0(\mu_I) - \alpha_s(Q) - 1.22 \left( \ln \frac{Q}{\mu_I} + 1.45 \right) \alpha_s^2(Q) \right] \]

with $\alpha_F$ being a $F$ dependent calculable coefficient. A simple form of $P \propto \text{const}/Q^p$ is not sufficient to describe the data\cite{5}. A more sophisticated approach\cite{4} introduces for $p = 1$

\[ \langle F \rangle = \langle F \rangle^{\text{pert}} + \langle F \rangle^{\text{pow}} = \langle F \rangle^{\text{pert}} + a_F \cdot P \]
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 $\tau$ and $B$. For a comparison to results from $e^+e^-$ annihilation see\cite{footnote:5}.

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

Similar fits have been performed by H1\cite{footnote:9} for the differential two-jet rates $y_{fJ}$ and $y_{kt}$, 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.
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

$$\frac{1}{\sigma_{tot}} \frac{d\sigma(F)}{dF} = \frac{1}{\sigma_{tot}} \frac{d\sigma^{pert}(F - a_F \mathcal{P})}{dF}$$  \hspace{1cm} (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 $y_{kt}$, 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 $\langle C_0, \alpha_s(M_Z) \rangle$ (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, 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 $y_{kt}$.

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

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 $\alpha_0 \approx 0.5 \pm 20\%$
can be deduced. With further progress in resummed predictions, a fruitful future lies ahead of us.

References

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