EVENT SHAPE STUDIES AT HERA

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Recent progress on the study of power corrections applied to event shape variables in deep inelastic \(ep\) scattering is discussed.

1 Introduction

Event shape variables in deep inelastic scattering allow to study QCD properties of the final state. Recent results based on high statistics data by the ZEUS and H1 collaborations at HERA are discussed with emphasis on power law hadronisation effects.

A suitable frame of reference with optimal separation between the current jet and the proton remnant is the Breit system, where the spacelike \(\gamma/Z\) with momentum \(Q\) collides head-on with an incoming quark of momentum \(Q/2\). The quark is back-scattered into the current hemisphere, while the proton fragments into the remnant hemisphere (QPM picture). Event shapes studied in the current region are: thrust \(\tau\) and \(\tau_c\), broadening \(B\), \(C\) parameter and jet mass \(\rho\) and \(\rho_0\). H1 also investigates two-jet rates, the transitions from \((2 + 1)\) to \((1 + 1)\) jets, in the whole phase space: \(y_{fJ}\) for a factorisable JADE and \(y_{kt}\) for the \(k_t\) jet algorithm. The analyses of both experiments are very similar. The kinematic range covers \(Q = 7 − 140\) GeV. ZEUS distinguishes two \(x\)-bins at low \(Q < 18\) GeV. The data are unfolded to the hadron level, where H1 takes the true masses and ZEUS assumes massless hadrons. This difference affects jet masses and two-jet rates.

2 Power corrections to mean values of event shapes

The mean value of an event shape variable \(F\) can be expressed as

\[
\langle F \rangle = \langle F \rangle_{\text{pert}} + a_F \mathcal{P}.
\]  

(1)

The perturbative part \(\langle F \rangle_{\text{pert}}\) is calculated in \(\mathcal{O}(\alpha_s^2)\) using DISENT. The program DISASTER++ yields consistent but somewhat higher mean values, at most a few percent for \(\langle B \rangle\) at low \(Q\). These discrepancies have no influence on the conclusions.

Hadronisation is treated within the concept of power corrections with a calculable coefficient \(a_F\) and a universal function

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

One expects a \(1/Q\) behaviour (except for \(y_{kt}\)), which is multiplied by terms involving the strong coupling \(\alpha_s\) and a non-perturbative effective coupling \(\bar{\alpha}_0(\mu_I)\), defined at an infrared matching scale \(\mu_I = 2\) GeV.

The \(Q\) dependences of the event shape means are well described by this ansatz. Results of fits to \(\bar{\alpha}_0\) and \(\alpha_s(M_Z)\) are shown as
correlations in figs. 1 and 2, the renormalisation scale uncertainties (not shown) exceed the experimental errors by far. For the non-perturbative parameter one finds a universal value of $\alpha_0 \simeq 0.5 \pm 20\%$ for most observables. ZEUS reports that fits to $\langle B \rangle$ and $\langle \tau_z \rangle$, resulting in a large spread (see fig. 1), are especially sensitive to experimental systematics and exhibit a significant $x$-dependence at low $Q$. In general, power corrections do not depend on $x$; such terms may, however, arise for $\langle B \rangle$.

The H1 analysis, presented in fig. 2, demonstrates the strong influence of the treatment of hadrons on the jet masses $\rho$ and $\rho_0$. A correction to massless hadrons, $\rho_0$, leads to a more consistent interpretation of power corrections. The spread of $\alpha_s(M_Z)$ is considerable for both experiments, suggesting that higher order QCD contributions are missing. This is supported by large scale uncertainties.

The energy dependence of the H1 mean two-jet rates are shown in fig. 3. They exhibit much smaller hadronisation corrections than the other variables. For the JADE algorithm $\langle y_{fJ} \rangle$ the conjectured coefficient $a_{fJ} = 1$ leads to an unphysically low value of $\alpha_0$ and is excluded by the data. Instead a small negative hadronisation contribution is preferred. In case of the $k_t$ algorithm no firm power correction prediction exists except of a $1/Q^2$ dependence for $\langle y_{kt} \rangle$, very different from the other event shapes. Such a behaviour is supported by the H1 data, a $1/Q^2$ shape can be ruled out. An experimental determination of the unknown parameters, $a_{kt}$ and $\alpha_1$, together with $\alpha_s$, suffers from large correlations. In view of the existing data more theoretical work on the jet rates is needed.

### 3 Power corrections to spectra

Power corrections to event shape spectra lead to a shift of the pQCD prediction

$$
\frac{1}{\sigma_{\text{tot}}} \frac{d\sigma(F)}{dF} = \frac{1}{\sigma_{\text{tot}}} \frac{d\sigma_{\text{pert}}(F - aF \mathcal{P})}{dF},
$$

(3)
Figure 4. Fits to differential distributions of the $C$ parameter including power corrections and the two-jet rates $y_J$ and $y_{kt}$ applying pQCD without hadronisation corrections. The H1 data cover a $\langle Q \rangle$ range from 15 GeV (top) to 81.3 GeV (bottom).

provided $\mu_I/Q < F < F_{\text{max}}$. The shift $\alpha_F^P$ amounts to exactly the same value as for the mean values. The event shape distributions at $Q > 14$ GeV can be well described by eq. (3) within restricted regions, as shown in fig. 4. However, the fit values of $\pi_0$ and $\alpha_s(M_Z)$ are, in general, inconsistent (larger) to those from fits to the means. For example $(\pi_0, \alpha_s(M_Z)) = (0.45, 0.130)$ from $\langle C \rangle$ and $(0.62, 0.131)$ from $d\sigma/dC$. It is hoped that resummed QCD calculations will improve the applicability of power corrections to DIS event shape spectra.

The analysis of mean values lead to small hadronisation corrections for the two-jet rates. In fact, at sufficiently high energies $Q$, the jet rate spectra can be reasonably well described by pQCD alone, i.e. neglecting power corrections or hadronisation contributions completely. This is shown in fig. 3 for $d\sigma/dy_{J\ell}$ and $d\sigma/dy_{kt}$, using 0.116 and 0.118, respectively, for the strong coupling constant.

Summary

Event shape studies of deep inelastic scattering provide very useful information to get a better understanding of the interplay between perturbative and non-perturbative QCD. The basic concept of approximate universal power corrections is generally supported by the HERA experiments, yielding a common parameter $\pi_0 \simeq 0.5 \pm 20\%$. However, there remain several open questions. The quality of the data requires further theoretical progress concerning the jet rates and $x$-dependence of power corrections and resummed QCD calculations.

References

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