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Event Shapes and Power Corrections in ep DIS

H1 Collaboration

Abstract

Deep-inelastic ep scattering data, taken with the H1 detector at HERA, are used to analyze the event shape variables thrust, jet broadening, jet mass, C parameter and two kinds of differential two-jet rate over a large range of the four-momentum transfer Q between $7\ \mathrm{GeV}$ and $100\ \mathrm{GeV}$. Here, Q is taken to be the relevant energy scale for these processes. The Q dependence of the mean values is matched with second order calculations of perturbative QCD applying power law corrections proportional to $1/Q^p$ to account for hadronization effects. The concept of these power corrections is investigated by fitting simultaneously a non-perturbative parameter $\overline{\alpha}_{p-1}$ and the strong coupling constant α_s.

Abstract: 157k
Parallel sessions: 3
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1 INTRODUCTION

Due to asymptotic freedom, perturbative QCD is a powerful theoretical tool for the investigation of strong interactions in hard scatterings. Given, however, the precision of today's measurements over a large range of energy, deviations proportional to $1/Q^p$ are observed, where Q represents the energy available in the hard interaction. The energy scale relevant here is given by the four-momentum transfer q of the scattered lepton as $Q := \sqrt{-q^2}$ and ranges from $7\,\mathrm{GeV}$ up to $100\,\mathrm{GeV}$. Depending on the sensitivity of the observable on long-distance, non-perturbative effects, these power corrections may be sizable. In case of event shapes they are typically proportional to $1/Q$. More inclusive quantities, e.g. the total cross section of $e^+e^- \to \mathrm{hadrons}$, where Q can be identified with the center of mass energy $\sqrt{s}$, exhibit much smaller corrections with e.g. $p = 4$.

One possibility to account for the non-perturbative formation of hadrons out of quarks and gluons is to invoke phenomenological models implemented in Monte Carlo generators. As a drawback, one has to deal with several models, each involving a large number of tunable parameters. Alternatively, analytical formulae either inspired by a simple tube model [1] or by a recent approach initiated by Dokshitzer and Webber [2] may be employed. A first study of event shapes and analytically parameterized power corrections in ep deep-inelastic scattering (DIS) was published in [3]. The results presented here are based on the substantially improved and extended analysis in [4].

2 EVENT SHAPE VARIABLES

The investigated event shapes are two kinds of $1-$thrust, τ and τ_C, the jet broadening B, the jet mass ρ, the C parameter and two kinds of differential two-jet rate, y_{fJ} and y_{k_t}, with y denoting the maximal value for which, neglecting the proton remnant, two jets can still be resolved in an event. All of these infrared and collinear safe variables are defined in the Breit frame of reference, see fig. 1. Except for the two jet observables y_{fJ} and y_{k_t}, they exploit the property of this frame to maximally separate the current quark jet from the proton remnant and are evaluated from objects in the current hemisphere alone, which constitutes an analogue to one half of an e^+e^- event. They are normalized to the total momentum or the total energy in the current hemisphere; precise definitions follow below. In the case of the y variables, the jet algorithms, i.e. the factorizable JADE and the k_t algorithm [6], implicitly isolate the proton remnant.

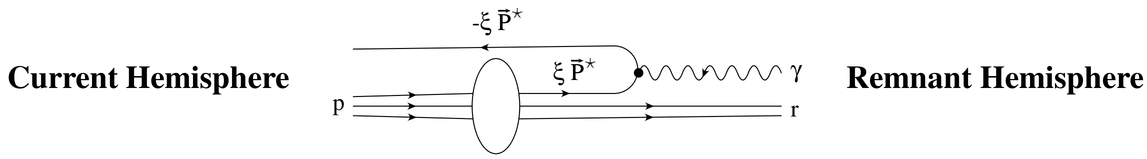

Figure 1: Diagram of an ep collision in the quark-parton-model as seen in the Breit frame.

1. **Event shapes employing the boson axis $\vec{q}^{\,\star}$ as event axis $\vec{n}$:**
   $1-$thrust:

$$\tau := 1 - \frac{\sum\limits_{i\in\mathrm{CH}} |\vec{p_i}^{\star} \cdot \vec{n}|}{\sum\limits_{i\in\mathrm{CH}} |\vec{p_i}^{\star}|} = 1 - \frac{\sum\limits_{i\in\mathrm{CH}} |p^{\star}_{li}|}{P^{\star}} \tag{1}$$

   jet broadening:

$$B := \frac{\sum\limits_{i\in\mathrm{CH}} |\vec{p_i}^{\star} \times \vec{n}|}{2\sum\limits_{i\in\mathrm{CH}} |\vec{p_i}^{\star}|} = \frac{\sum\limits_{i\in\mathrm{CH}} |p^{\star}_{ti}|}{2P^{\star}} \tag{2}$$

2. **Event shapes without reference to the boson axis as event axis:**
   $1-$thrust_C:

$$\tau_C := 1 - \max_{\vec{n},\vec{n}^2=1} \frac{\sum\limits_{i\in\mathrm{CH}} |\vec{p_i}^{\star} \cdot \vec{n}|}{\sum\limits_{i\in\mathrm{CH}} |\vec{p_i}^{\star}|} = 1 - \frac{\sum\limits_{i\in\mathrm{CH}} |\vec{p_i}^{\star} \cdot \vec{n}_T|}{P^{\star}} \tag{3}$$

   jet mass:

$$\rho := \frac{\left(\sum\limits_{i\in\mathrm{CH}} p^{\star}_i\right)^2}{4\left(\sum\limits_{i\in\mathrm{CH}} E^{\star}_i\right)^2} = \frac{M^2}{4E^{\star 2}} \tag{4}$$

   C parameter:

$$C := 3(\lambda_1\lambda_2 + \lambda_2\lambda_3 + \lambda_3\lambda_1) \tag{5}$$

   with $\lambda_i\,, i = 1, 2, 3$ being the eigen values of the momentum tensor

$$\Theta^{\star}_{jk} := \frac{\sum\limits_{i\in\mathrm{CH}} \frac{p^{\star}_{j_i} p^{\star}_{k_i}}{|\vec{p}^{\star}_i|}}{\sum\limits_{i\in\mathrm{CH}} |\vec{p}^{\star}_i|} \tag{6}$$

3. **Event shapes employing jet algorithms:**
   Distance measures between objects, y_{ij}, and with respect to the remnant, y_{ir}, for the factorizable JADE algorithm

$$y_{ij} := \frac{2E^{\star}_i E^{\star}_j (1 - \cos\theta^{\star}_{ij})}{Q^2} \tag{7}$$

$$y_{ir} := \frac{2E^{\star}_i x E^{\star}_p (1 - \cos\theta^{\star}_i)}{Q^2} \tag{8}$$

   and the k_t algorithm

$$y_{ij} := \frac{2\min(E_i^{\star 2}, E_j^{\star 2})(1 - \cos\theta^{\star}_{ij})}{Q^2} \tag{9}$$

$$y_{ir} := \frac{2E_i^{\star 2}(1 - \cos\theta^{\star}_i)}{Q^2}\,. \tag{10}$$

   y_{fJ} and y_{k_t} denote the transition values $(2+1) \to (1+1)$ jets.

3 POWER CORRECTIONS

According to [2], the energy dependence of any event shape mean $\langle F\rangle$ can be written as the sum of a perturbative part $\langle F\rangle^{\mathrm{pert}}$ and a power suppressed contribution $\langle F\rangle^{\mathrm{pow}}$. Identifying for simplicity the renormalization scale μ_R with Q, the perturbative part, evaluated to $\mathcal{O}(\alpha_s^2)$ using DISENT [7], is given by

$$\langle F\rangle^{\mathrm{pert}} = c_{1,F}(x,Q)\,\alpha_s(Q) + c_{2,F}(x,Q)\,\alpha_s^2(Q)\,. \tag{11}$$

Note that in contrast to e^+e^- annihilation, a second quantity, e.g. the Bjørken scaling variable $x := -q^2/(2P\cdot q)$ with P being the four-momentum of the incoming proton, is necessary to fix the DIS kinematics. Therefore, the coefficients explicitly depend on x as well. Here, x varies between $\approx 10^{-3}$ and ≈ 0.5.

Anticipating power corrections proportional to $1/Q$, in the case of $\langle y_{k_t}\rangle$ $1/Q^2$, the simplest ansatz would be $\langle F\rangle^{\mathrm{pow}} = \lambda/Q$ or $\langle F\rangle^{\mathrm{pow}} = \mu/Q^2$. However, fits to λ or μ alone are not able to describe the data satisfactorily. If $\alpha_s(M_Z)$ is also included in the fit it tends to unacceptable values owing to strong correlations, see table 1. Given the x dependence of $\langle F\rangle^{\mathrm{pert}}$, one could assume that $\langle F\rangle^{\mathrm{pow}}$ should be a function of x as well. Yet, for corrections with power $p = 1$ this is not expected [8].

This calls for the more elaborate approach of [2], relating infrared divergences in the perturbative expansion to the power corrections. Assuming the existence of a well-behaved effective strong coupling even at scales below the infrared matching scale μ_I of $\approx 2\,\mathrm{GeV}$, one can deduce the relative size of the corrections $\mathcal{P}/Q$ to the means of different event shapes at the expense of introducing a new non-perturbative parameter $\overline{\alpha}_0$:

$$\mathcal{P} = a_F\mathcal{M}'\frac{16\mu_I}{3\pi}\left[\overline{\alpha}_0(\mu_I) - \alpha_s(Q) - \frac{23}{6\pi}\left(\ln\frac{Q}{\mu_I} + 1.45\right)\alpha_s^2(Q)\right], \tag{12}$$

where a_F is a calculable F dependent coefficient. To resolve ambiguities a refinement to two-loop level leads to another global factor, the *Milan factor* $\mathcal{M}$, where $\mathcal{M}' = 2\mathcal{M}/\pi \approx 1.14$ [9].

Figs. 2–5 show the unfolded differential distributions in comparison to perturbative QCD as well as the power correction fits except for y_{k_t}.

The results of the two-parameter fits to this approach are compiled in table 2 and fig. 6. The universal non-perturbative parameter $\overline{\alpha}_0(\mu_I = 2\,\mathrm{GeV})$ is confirmed to be $\approx 0.5 \pm 20\%$ for the means of τ, B, τ_C, ρ and C, which are sizably affected by hadronization. The spread in $\alpha_s(M_Z)$, however, is uncomfortably large. In contrast to earlier analyses of B, a reasonable fit is obtained if the revised coefficient a'_B [10] is included.

Both y observables exhibit small negative hadronization corrections. For y_{fJ} a power correction with $p = 1$ and $a_{y_{fJ}} = 1$ was proposed at the DIS95 conference [11], which has not been reconsidered in recent publications. From the emerging very low values for both, $\overline{\alpha}_0(\mu_I = 2\,\mathrm{GeV})$ and $\alpha_s(M_Z)$, one can rule out $a_{y_{fJ}} = 1$. Turning the argument around, a reasonable fit can be achieved with $a_{y_{fJ}} = -1/4$, see fig. 7, while presupposing the validity of eq. 12. For y_{k_t} fits with $p = 1$ do not work properly in accordance with the expectation of a power $p = 2$. Unfortunately, the coefficients a_F are not yet calculable for that case. A fit neglecting hadronization effects is presented in fig. 8.

The influence of various sources of systematic uncertainties are visualized in fig. 9 for the C parameter.

4 SUMMARY AND CONCLUSIONS

The improved and extended analysis of event shape means in ep DIS supports the concept of power corrections according to eq. 12. However, the uncomfortably large spread of values gained for $\alpha_s(M_Z)$ leaves room for further progress.

As in e^+e^- annihilation, it would be very interesting to compare the above results with power corrections to event shape distributions. To that goal, resummed calculations are awaited for.

Acknowledgements

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H1 Preliminary								
$\langle F \rangle$	$\alpha_s(M_Z)$	$\lambda/\,\mathrm{GeV}$	χ^2_n	$\kappa/\%$	$\alpha_s(M_Z)$	$\mu/\,\mathrm{GeV}^2$	χ^2_n	$\kappa/\%$
$\langle \tau \rangle$	0.132	-0.04	0.6	-99	0.131	-0.23	0.6	-89
$\langle B \rangle$	0.120	0.53	0.8	-92	0.128	3.07	1.7	-68
$\langle \tau_C \rangle$	0.157	-0.15	1.3	-99	0.154	-0.57	1.1	-86
$\langle \rho \rangle$	0.165	-0.09	0.5	-99	0.161	-0.27	0.4	-87
$\langle C \rangle$	0.161	-1.39	2.0	-99	0.152	-4.84	1.0	-85
$\langle y_{fJ} \rangle$	0.114	-0.08	1.6	-97	0.112	-0.28	1.7	-82
$\langle y_{k_t} \rangle$	0.122	-0.45	1.6	-99	0.105	1.33	1.6	-93

Table 1: Results of two-parameter fits of $\alpha_s(M_Z)$ and simple λ/Q respectively μ/Q^2 power corrections for the event shape means. κ denotes the correlation coefficient between the two fit parameters.

H1 Preliminary					
$\langle F \rangle$	a_F	$\overline{\alpha}_0(\mu_I = 2\,\mathrm{GeV})$	$\alpha_s(M_Z)$	χ^2/n	$\kappa/\%$
$\langle \tau \rangle$	1	$0.480 \pm 0.028\ ^{+0.048}_{-0.062}$	$0.1174 \pm 0.0030\ ^{+0.0097}_{-0.0081}$	0.5	-97
$\langle B \rangle$	$1/2 \cdot a'_B$	$0.491 \pm 0.005\ ^{+0.032}_{-0.036}$	$0.1106 \pm 0.0012\ ^{+0.0060}_{-0.0057}$	0.7	-58
$\langle \tau_C \rangle$	1	$0.475 \pm 0.003\ ^{+0.044}_{-0.048}$	$0.1284 \pm 0.0014\ ^{+0.0100}_{-0.0092}$	1.3	$+19$
$\langle \rho \rangle$	$1/2$	$0.561 \pm 0.004\ ^{+0.051}_{-0.058}$	$0.1347 \pm 0.0015\ ^{+0.0111}_{-0.0100}$	1.2	$+7$
$\langle C \rangle$	$3\pi/2$	$0.425 \pm 0.002\ ^{+0.033}_{-0.039}$	$0.1273 \pm 0.0009\ ^{+0.0104}_{-0.0093}$	0.9	$+63$
$\langle y_{fJ} \rangle$	1	0.258 ± 0.004	0.104 ± 0.002	1.9	-61

Table 2: Results of two-parameter fits of $\overline{\alpha}_0(\mu_I = 2\,\mathrm{GeV})$ and $\alpha_s(M_Z)$ according to the power correction approach initiated by Dokshitzer and Webber for the event shape means. The uncertainties are statistical and total systematic except for y_{fJ} where a coefficient $a_{y_{fJ}}$ different from 1 is anticipated. κ denotes the correlation coefficient between the two fit parameters.

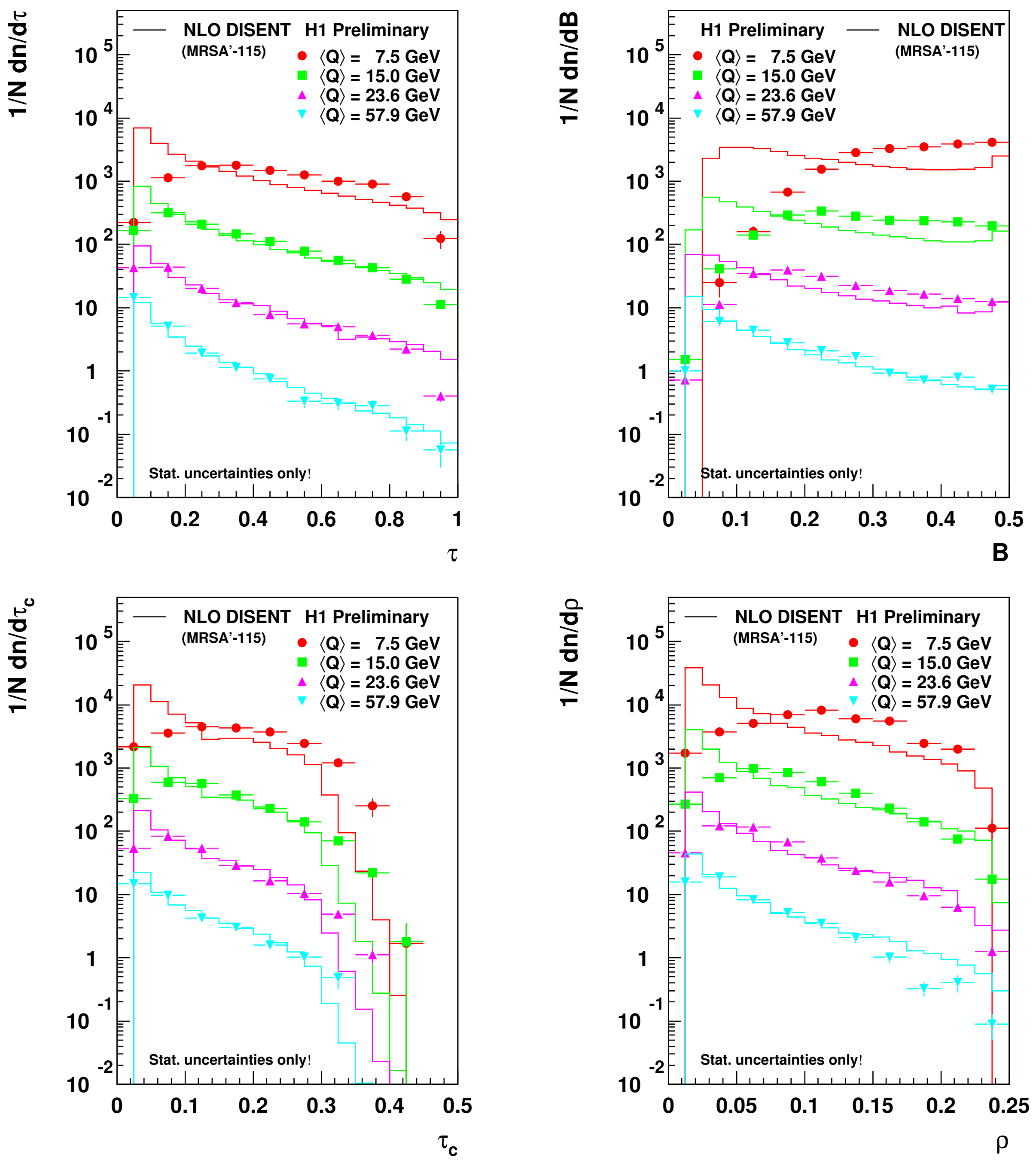

Figure 2: Normalized differential distributions of the event shapes τ, B, τ_C and ρ corrected for detector effects. H1 data (full symbols) are compared with DISENT 0.1 NLO calculations (full lines) for four out of eight investigated bins in Q. The spectra for $\langle Q \rangle = 7.5$–$57.9\,\mathrm{GeV}$ are multiplied by factors of 10^n, $n = 0, 1, 2, 3$. The error bars represent statistical uncertainties only. Note that the range corresponding to the left-most data bin was omitted in the normalization.

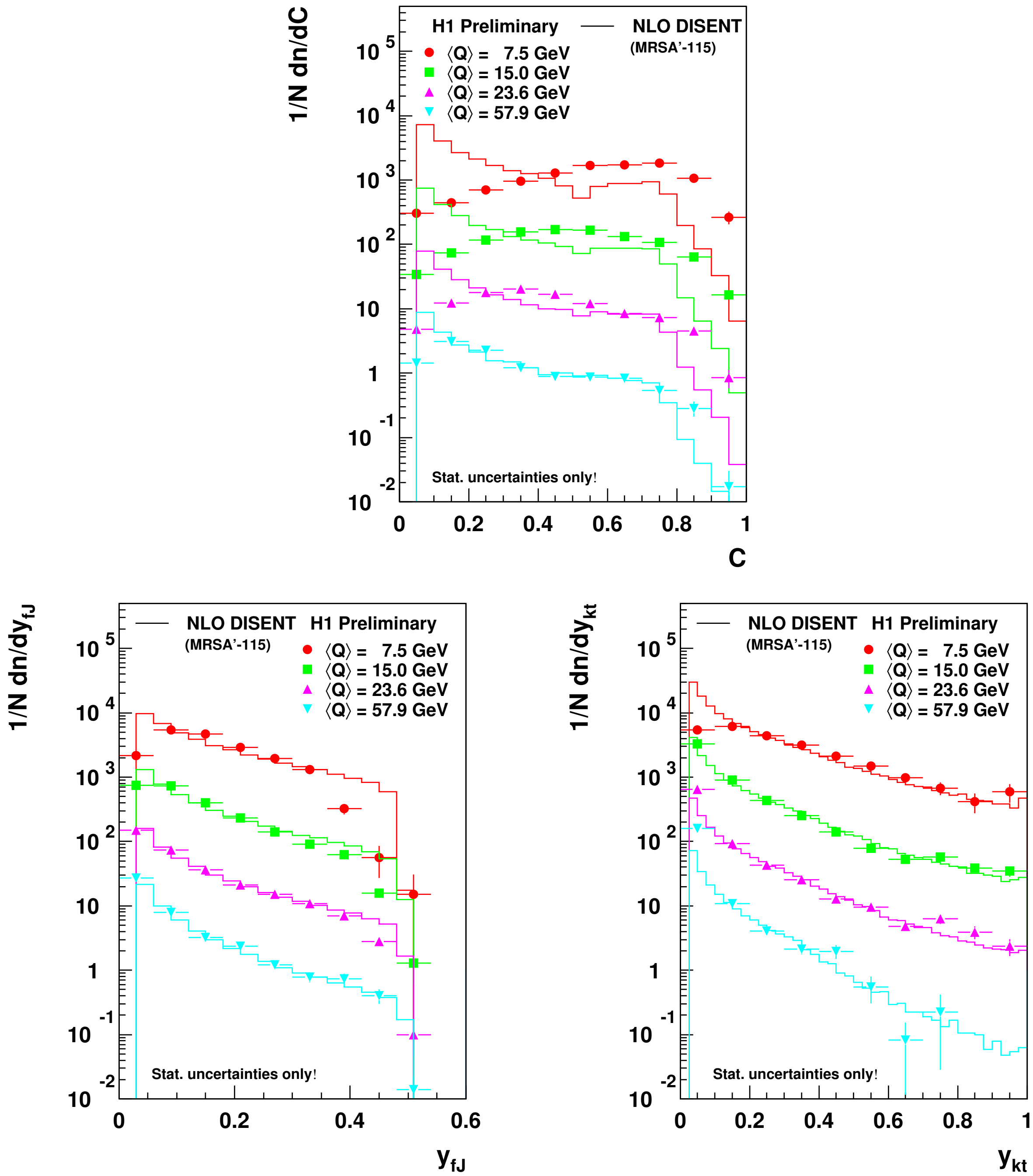

Figure 3: Normalized differential distributions of the event shapes C, y_{fJ} and y_{k_t} corrected for detector effects. H1 data (full symbols) are compared with DISENT 0.1 NLO calculations (full lines) for four out of eight investigated bins in Q. The spectra for $\langle Q \rangle = 7.5$–$57.9\,\mathrm{GeV}$ are multiplied by factors of 10^n, $n = 0, 1, 2, 3$. The error bars represent statistical uncertainties only. Note that the range corresponding to the left-most data bin was omitted in the normalization.

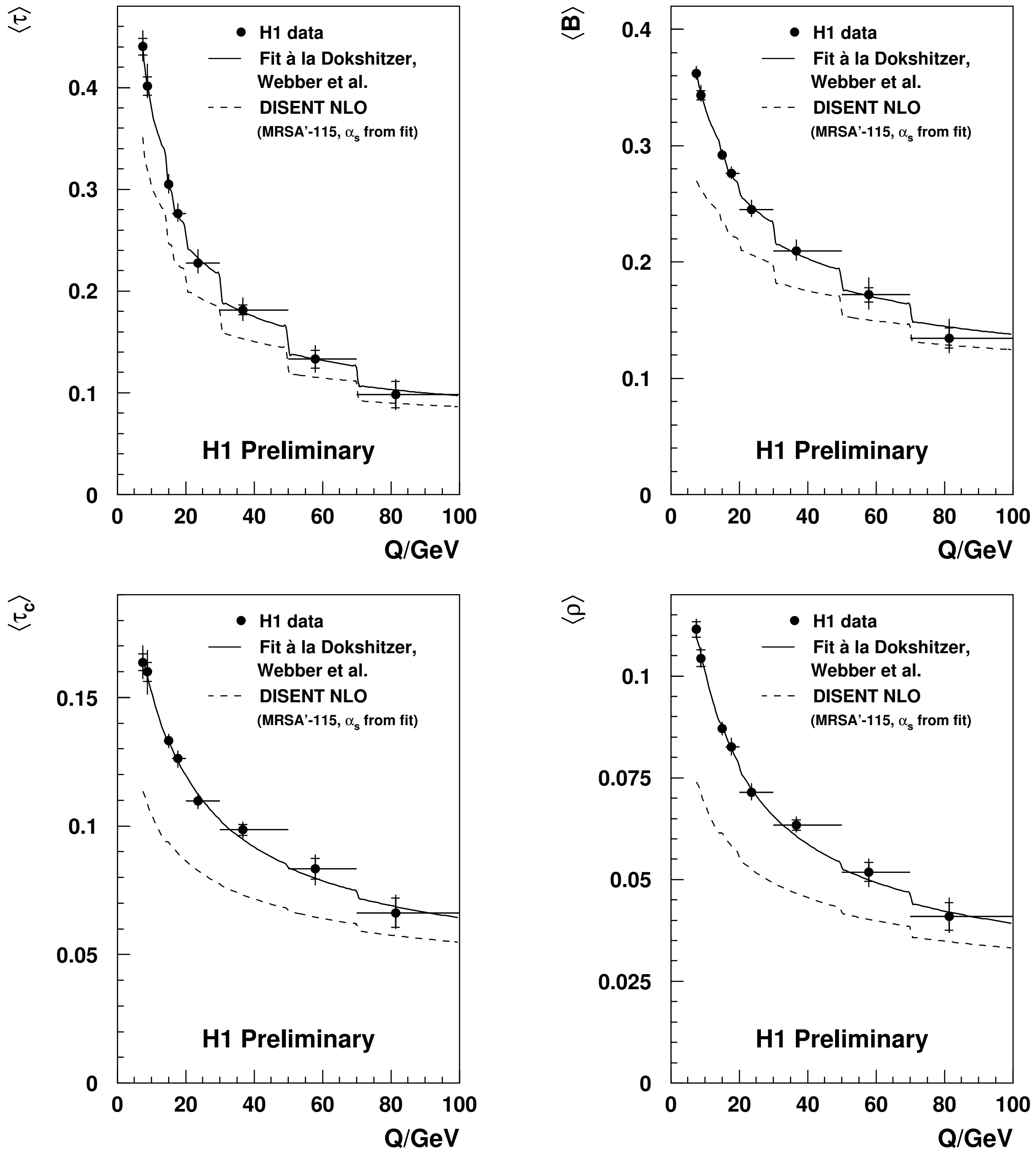

Figure 4: Corrected means (full symbols) of τ, B, τ_C and ρ as a function of Q. The inner error bars represent the statistical uncertainty, the outer ones the total statistic and systematic uncertainty. The full line corresponds to a power correction fit according to the approach initiated by Dokshitzer and Webber. Taking $\alpha_s(M_Z)$ from the fit the NLO prediction of DISENT 0.1 (dashed line) is shown for comparison.

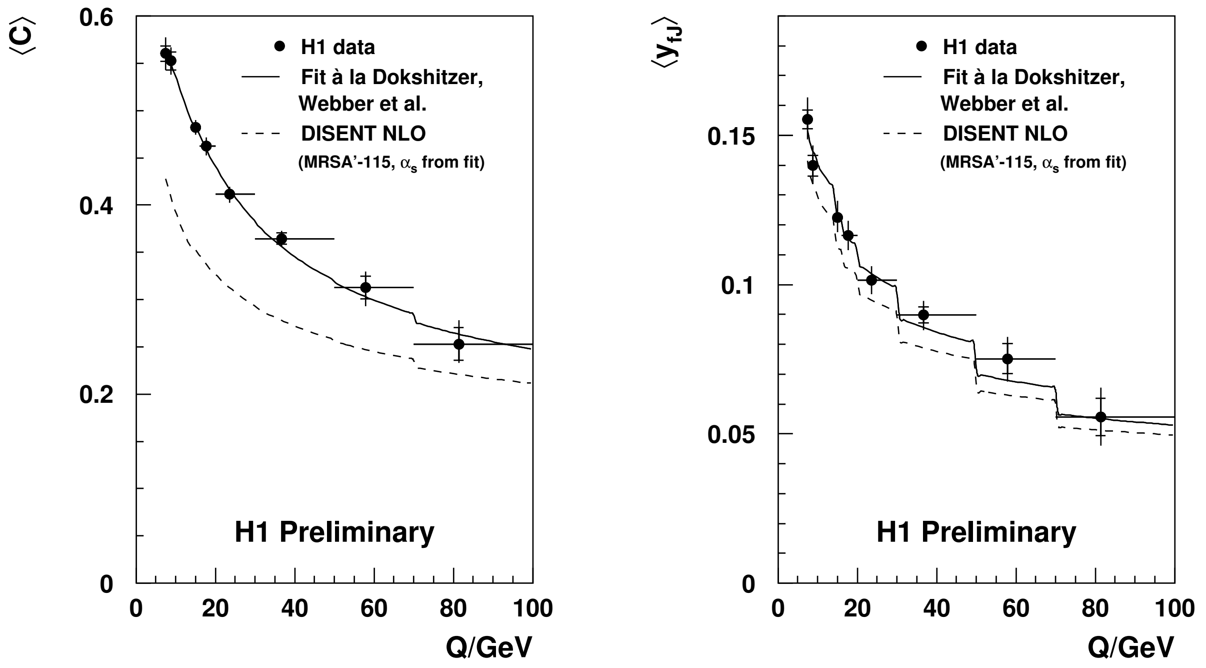

Figure 5: Corrected means (full symbols) of C and y_{fJ} as a function of Q. The inner error bars represent the statistical uncertainty, the outer ones the total statistic and systematic uncertainty. The full line corresponds to a power correction fit according to the approach initiated by Dokshitzer and Webber. Taking $\alpha_s(M_Z)$ from the fit the NLO prediction of DISENT 0.1 (dashed line) is shown for comparison.

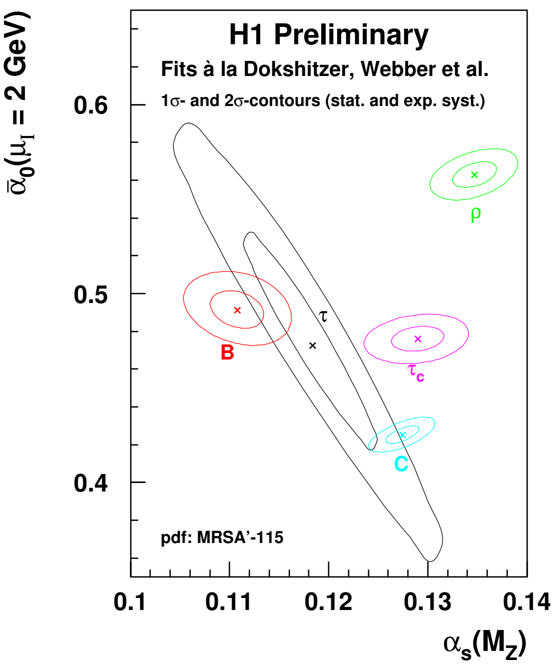

Figure 6: Results of two-parameter power correction fits for the means of τ, B, τ_C, ρ and C in the form of 1σ- and 2σ-contours in the $(\alpha_s, \overline{\alpha}_0)$-plane including statistical and experimental systematic uncertainties.

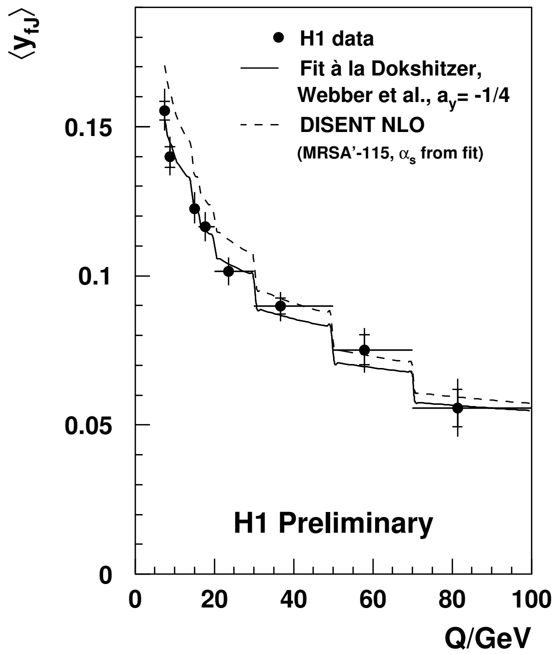

Figure 7: Corrected means (full symbols) of y_{fJ} as a function of Q. The inner error bars represent the statistical uncertainty, the outer ones the total statistic and systematic uncertainty. The full line corresponds to a power correction fit according to the approach initiated by Dokshitzer and Webber with $a_{y_{fJ}}$ set to $-1/4$. Taking $\alpha_s(M_Z)$ from the fit the NLO prediction of DISENT 0.1 (dashed line) is shown for comparison.

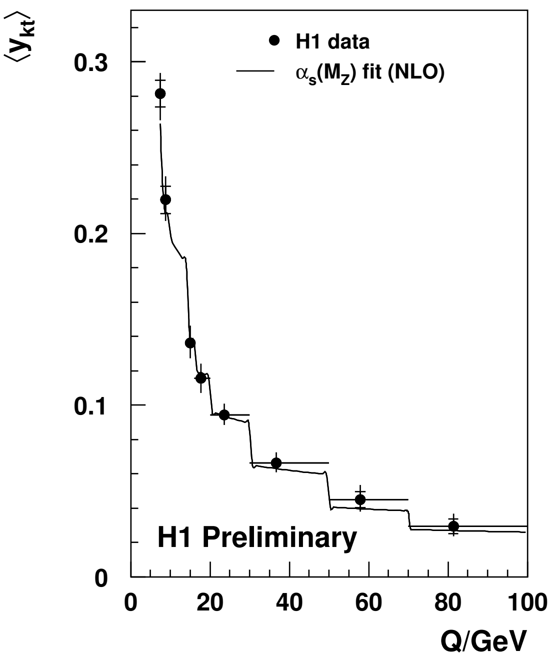

Figure 8: Corrected means (full symbols) of y_{k_t} as a function of Q. The inner error bars represent the statistical uncertainty, the outer ones the total statistic and systematic uncertainty. The full line corresponds to a fit of $\alpha_s(M_Z)$ using the NLO prediction of DISENT 0.1 and assuming that power corrections are negligible.

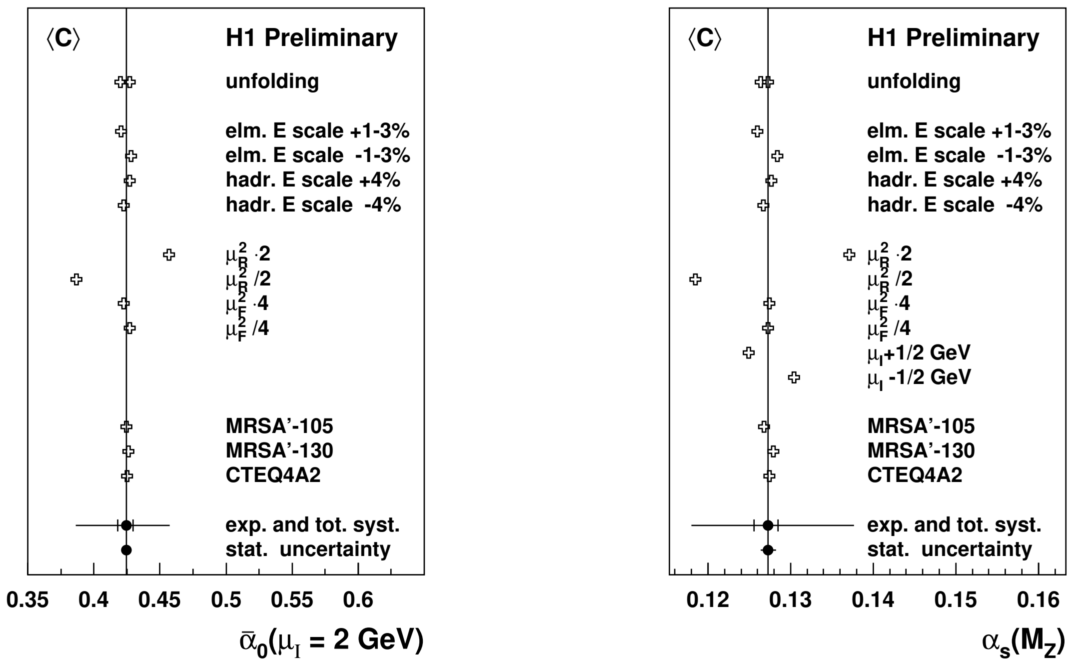

Figure 9: Systematic uncertainties of $\overline{\alpha}_0(\mu_I = 2\,\mathrm{GeV})$ (left) and $\alpha_s(M_Z)$ (right) for C.