414: New Jet Physics Results at HERA

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Abstract. New results on event shapes, jet profiles and the strong coupling constant α_s from dijet rates at HERA are presented.

1 Event shapes

Measurements of event shape variables like thrust T_C, jet mass ρ_C and jet broadening B_C provide information about perturbative and non-perturbative aspects of QCD. They have been measured for momentum transfers Q between 7 and 100 GeV by the H1 collaboration [1]. They are defined in the current hemisphere of the Breit frame by[1]:

$$T_C := \max \frac{\sum_i |\mathbf{p}_i \cdot \mathbf{n}_T|}{\sum_i |\mathbf{p}_i|} \qquad B_C := \frac{\sum_i |\mathbf{p}_{Ti}|}{2\sum_i |\mathbf{p}_i|} \qquad \rho_C := \frac{M^2}{Q^2} = \frac{(\sum_i \mathbf{p}_i)^2}{Q^2} \qquad (1)$$

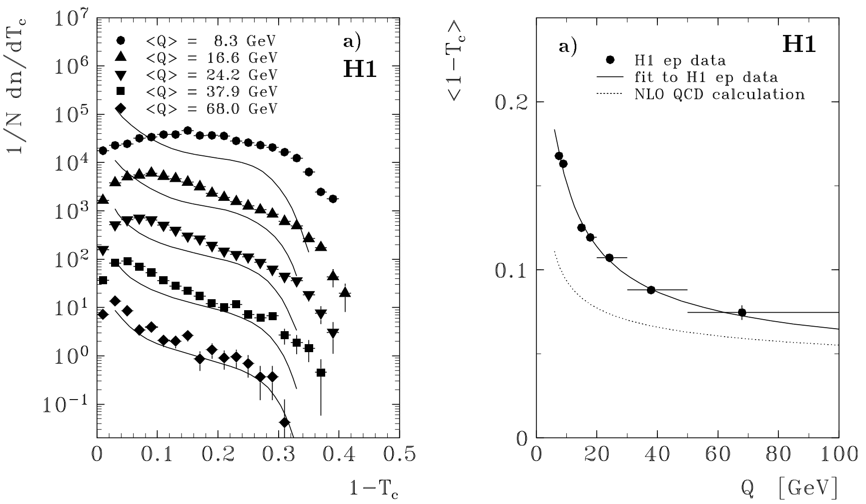

Fig. 1. Left: The differential thrust distribution compared to a NLO calculation. The spectra for $\langle Q \rangle = 8.3-68$ GeV are multiplied by factors of 10^n.Right: $\langle 1-T_C \rangle$ as function of Q. The H1 data are compared to a NLO calculation and a fit inspired by power corrections.

As example the mean value and the differential thrust distribution of $1-T_C$ is shown in Fig.1. A spherical (pencil-like) configuration corresponds to $1-T_C = 1/2$ (0). The energy flow along the event shape axis becomes more collimated as Q increases. The mean values of the event shape variables can be expressed by a perturbative part calculable to $\mathcal{O}(\alpha_s^2)$ of the strong coupling α_s using next-to-leading order (NLO) programs [2, 3] and a non-perturbative

[1] The summation of the four-vector $p_i = (E_i, \mathbf{p}_i)$ extends over all objects (energy depositions, hadrons or partons). For the thrust calculation the unit vector $\mathbf{n_T}$ is chosen such that the normalized longitudinal momentum sum is maximal.

contribution suppressed by $\sim 1/Q$ which can be expressed as a function of only one free non-perturbative effective coupling parameter $\bar{\alpha_0}$ [4]. α_s and $\bar{\alpha_0}$ can be simultaneously fitted to the data corrected for detector effects without assuming any fragmentation model (see Fig.1 for $\langle 1-T_C\rangle$). The power corrections are large at low Q, but become less important with increasing Q. For $\langle Q\rangle = 68$ GeV the perturbative contribution alone reproduces the shape of the data for $(1-T_C) > 0.03$. The fit results are summarized in Tab.1. The uncertainties on α_s and $\bar{\alpha_0}$ are due to the accuracy of the QCD calculation and to the choice of different possible scales. All investigated shape variables lead to consistent values for α_s and within 20% for $\bar{\alpha_0}$.

Observable	a_F	$\bar{\alpha_0}(\mu_I = 2\mathrm{GeV})$	$\alpha_s(m_Z)$
$\langle 1-T_C\rangle$	1	$0.497 \pm 0.005^{+0.070}_{-0.036}$	$0.123 \pm 0.002^{+0.007}_{-0.005}$
$\langle B_C\rangle$	2	$0.408 \pm 0.006^{+0.036}_{-0.022}$	$0.119 \pm 0.003^{+0.007}_{-0.004}$
$\langle \rho_C\rangle$	1/2	$0.519 \pm 0.009^{+0.025}_{-0.020}$	$0.130 \pm 0.003^{+0.007}_{-0.005}$

Table 1. Fit results of the event shape analysis.

2 Jet shapes

The internal structure of jets provides useful information on the transition of a parton to the complex aggregate of hadrons. The jet shape is defined as the average fraction of the transverse energy (E_T) of the jets inside an inner cone r concentric to the outer jet cone with radius R:

$$\Psi(r) = \frac{1}{N_{\mathrm{jet}}} \sum_{\mathrm{jets}} \frac{E_T(r)}{E_T(R)} \quad , \quad E_T(r) = \int_0^r dr' dE_T(r')/dr' \tag{2}$$

where N_{jet} is the total number of selected jets. By definition $0 < \Psi < 1$ and $\Psi(R) = 1$. The steepness of the rise of Ψ describes the collimation of the jet. ZEUS has measured Ψ for jets with $\eta \in [-1, 2]$ selected with the CDF-cone algorithm [5] ($R = 1$) in the laboratory frame in a DIS sample with $Q^2 > 100$ GeV^2 and has compared them to jets in other reactions. In most cases the current jet recoiling from the scattered electron will be selected.

The jet shape Ψ corrected for detector effects for jets with $E_T > 37$ GeV is shown in Fig. 3. 90% of the jet E_T is contained in a cone with $r = 0.4$ around the jet axis. This is very similar to jets produced in e^+e^- collisions [7]. Jets in $p\bar{p}$ collisions from CDF (D0) [8, 9] are broader. This might be explained by a larger fraction of jets initiated by quarks in e^+e^- and ep collisions compared to $p\bar{p}$ collisions. Since the laboratory frame plays not the same rôle for e.g. $p\bar{p}$ and ep collisions, one has, however, to be careful about strong conculsions. The shapes of jets produced in neutral (NC) or charged current (CC) reactions are very similar. H1 has reported on jet shapes measurements in a dijet sample for NC DIS in the kinematic region defined by: $10 < Q^2 < 100$ GeV^2, $y_{el} > 0.15$ and $E_{el} > 11$ GeV. Jets are defined using the CDF-cone algorithm ($R = 1$) requiring $E_T > 5$ GeV in the Breit frame and $-1 < \eta_{lab} < 2$ in the laboratory frame. As is shown in Fig.2 jets get narrower with increasing E_T. In the ZEUS measurement no significant η dependence is found. In the phase space region chosen by H1, jets get less collimated towards the proton remnant direction.

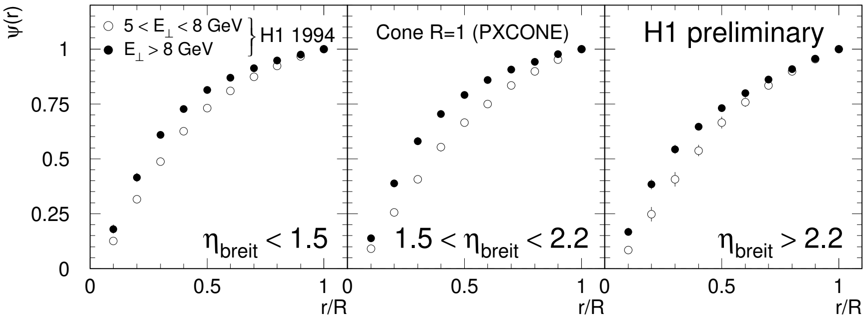

Fig. 2. The average jet profile for some η and E_T regions in the Breit frame in a dijet sample for NC DIS events with $10 < Q^2 < 100$ GeV^2. Syst. and stat. errors are added in quadrature. For large η the jets get further in the target region.

3 Determination of the strong coupling

The cross-section for events with two jets in the central part of the detector is proportional to α_s. Since at large x and Q^2 the parton densities are rather well known, it can be predicted by a NLO QCD calculation [2, 3]. The measurement of the ratio of dijet events to all events allows therefore $\alpha_s(Q^2)$ to be extracted. Jets are defined by the JADE algorithm [10] with a resolution parameter m_{ij}^2/W^2 where m_{ij} (W^2) is the invariant mass of a particle pair (total hadronic final state). Only the kinematic range of high x and Q^2 is considered to reduce the uncertainties from hadronisation and to avoid the region where higher order gluon emissions become important. Also the region towards the target is excluded. Inspired by the potential to measure the behaviour of α_s over a large span of Q^2, jet studies have focused on the determination of α_s right from the beginning of HERA data analysis [12, 13]. Since these early measurements used a NLO calculation [14] which could not fully match the experimental jet definition [15], H1 [16] has now updated the α_s value obtained before[2]. The α_s values extracted at HERA are shown in Fig. 3. For increasing Q^2, $\alpha_s(Q^2)$ decreases as predicted by the renormalisation group equation. A fit to the data for $\alpha_s(m_Z^2)$ yields:

$$\text{H1 94/95}: \quad \alpha_s(m_z^2) = 0.115 \pm 0.003\ (\text{stat})^{+0.008}_{-0.011}\ (\text{sys}) + 0.006\ (\text{rec})$$
$$\text{ZEUS 94}: \quad \alpha_s(m_z^2) = 0.117 \pm 0.005 (\text{stat})^{+0.004}_{-0.005}\ (\text{sys}_{\text{exp}}) \pm 0.007\ (\text{sys}_{\text{th}})$$

The dominant experimental errors stem from the uncertainty on the energy scale for hadrons, the model dependence of assigning jets to partons and the phenomenological description of the hadronisation process. Furthermore the renormalisation scale and the input parton density systematically influence the result. H1 has also given an error for the dependence on the recombination scheme (rec). The obtained value is compatible with the world average and has reached a competitive precision.

[2] The ZEUS result does not change when using the new NLO calculations [17].

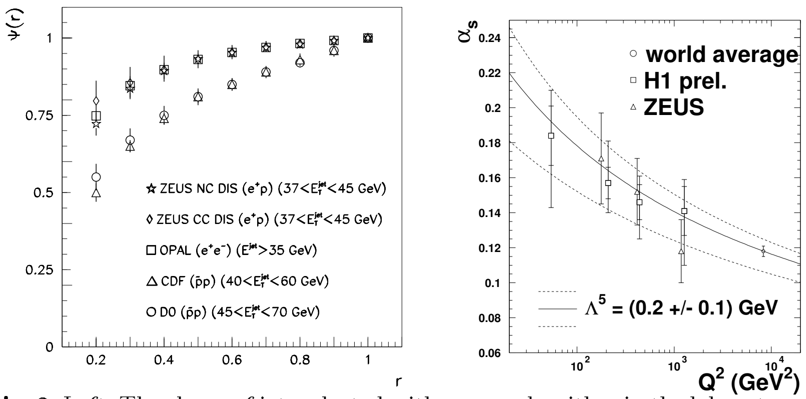

Fig. 3. Left: The shape of jets selected with a cone algorithm in the laboratory frame for DIS CC and NC events with $Q^2 > 100$ GeV^2, compared to jets in e^+e^- and $p\bar{p}$ events. Right: The strong coupling α_s in function of Q^2 as determined from the dijet rates. Shown are the HERA data together with the world average for $\alpha_s(m_Z^2)$ [11]. The lines give the expectation for $\Lambda^5 = 0.2 \pm 0.1$ GeV (for 5 flavours).

4 Forward jets

The DGLAP approximation for QCD evolution is expected to fail in the region of small x. A possible signature of this incomplete approximation is an enhanced production of 'forward jets' [18]. They are characterized by E_T of the order of Q^2 and $x_{\rm jet} = E_{\rm jet}/E_p$ as large and x as small as kinematically possible[3]. The first requirement suppresses the strongly ordered DGLAP evolution. For $x_{\rm jet}/x$ large, the forward jet is separated by a large η interval from the struck quark such that the phase space of parton emission between the two is enlarged. For this kinematical configuration the $\alpha_s \ln x_{\rm jet}/x$ terms are expected to become so large that their resummation should lead to a sizeable increase of the cross-section.

First measurements have been presented by H1 [20, 21]. A strong rise of the cross-section with decreasing x has been observed. The interpretation in terms of BFKL was however hindered due to large model dependences of hadronisation effects [22]. The ZEUS collaboration has reported on a new measurement of the forward jet cross-section [23] corrected for detector effects (see Fig. 4). The behaviour of the data is well described by the ARIADNE Monte Carlo [24] with an unsuppressed gluon radiation pattern while LEPTO [25] based on the $\mathcal{O}(\alpha_s)$ QCD matrix element and leading log parton showers cannot account for the steep rise towards small x. The NLO prediction from MEPJET [2] fails to describe the data at small x and agrees with an analytical calculation [19] (Born-BFKL) where only the quark box coupling to the photon in addition to the gluon leading to the forward jet is considered. If the full LO BFKL resummation is included, the cross-section rises towards low x, but overshoots the data. Since these analytical calculations do not include a jet algorithm, no firm conclusion can be drawn.

[3] $E_{\rm jet}$ (E_p) denotes the energy of the forward jet (proton).

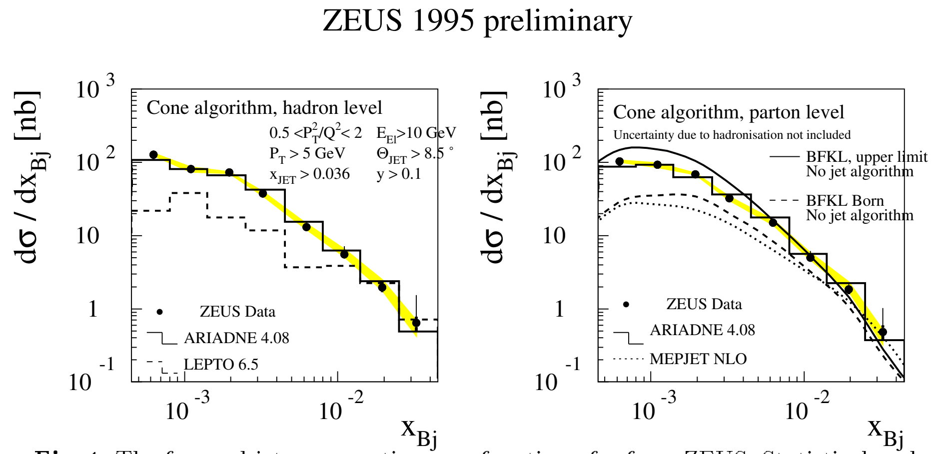

Fig. 4. The forward jet cross-section as a function of x from ZEUS. Statistical and systematic errors are added in quadrature. The shaded bands give the uncertainty of the hadronic energy scale. Left: The data corrected for detector effects are compared to expectations from ARIADNE and LEPTO. Right: The data also corrected for hadronisation effects compared to ARIADNE and the NLO predictions for jets [2] and the BFKL and Born graph calculations for parton cross sections [19].

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