Thrust Analysis in Deep Inelastic Scattering

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Deep inelastic $e\,p$ scattering data are used to study the event shape variable thrust in the current hemisphere of the Breit frame over a large range of momentum transfer Q.

1 Introduction

Event shape variables like thrust T have been successfully used in e^+e^- experiments in order to extract the strong coupling constant $\alpha_s(Q)$ independent of any event topology (*e.g.* a jet definition). In deep inelastic $e\,p$ scattering (DIS) a similar analysis can be performed, provided the proton (target) fragmentation can be discarded. A particularly suited frame of reference to separate the current and target regions is the Breit frame. In the Breit system the purely space-like photon with four-momentum $q^\mu = \{0, 0, -Q; 0\}$ collides against the incoming quark with longitudinal momentum $p^{in}_{q\,z} = Q/2$. The outgoing quark is back-scattered into the current hemisphere with longitudinal momentum $p^{out}_{q\,z} = -Q/2$, while the proton fragments in the opposite target hemisphere. DIS event properties in the Breit current hemisphere should be similar and therefore comparable to those in e^+e^- collisions at a scale $Q = \sqrt{s_{e^+e^-}}$.

2 Data and Analysis Procedure

DIS events taken with the H1 detector at HERA (E_e = 27.5 GeV, E_p = 820 GeV, $\sqrt{s}$ = 300 GeV) are selected with the essential criteria listed in table 1. In the analysis only calorimetric information is used. The kinematic quantities Q^2 and $x = Q^2/(y\,s)$ used to perform the Breit frame transformation are calculated from the electron (E'_e, θ_e) and hadron (E_h, θ_h) measurements[a]:

$$Q^2 = 4\,E_e\,E'_e\,\cos^2\frac{\theta_e}{2}\,, \tag{1}$$

$$y = y_e = 1 - \frac{E'_e}{E_e}\,\sin^2\frac{\theta_e}{2} \qquad \text{for } y_e > 0.15\,, \tag{2}$$

$$y = y_h = \frac{\sum_h E_h\,(1-\cos\theta_h)}{2\,E_e} \qquad \text{for } y_e < 0.15\,. \tag{3}$$

[a] Polar angles θ are defined with respect to the proton direction.

Table 1: Event selection criteria

variable	$Q^2 = 20 \div 100$ GeV^2	$Q^2 = 200 \div 10,000$ GeV^2
lepton energy	$E'_e > 10$ GeV	
lepton polar angle	$157° < \theta_e < 173°$	$30° < \theta_e < 150°$
hadron polar angles	$5.7° < \theta_h < 170°$	
$E - p_z$ conservation	30 GeV $< \sum_h E_h\,(1 - \cos\theta_h) < 65$ GeV	
kinematic variables	$0.05 < y_e < 0.80$ and $0.05 < y_h$	

The data are corrected at the hadron level bin-by-bin for detector effects (acceptance, resolution, energy scale, ...) using the LEPTO 6.1 matrix element plus parton showers and colour dipole model Monte Carlo generators [1], which describe the data reasonably well. The Monte Carlo event selection is the same as for the data, but without any polar angle cuts on the hadrons.

3 Thrust Analysis in the Breit Current Hemisphere

Thrust is defined by

$$T_c \;=\; \max \frac{\sum_h |\,\mathbf{p}_h \cdot \mathbf{n}\,|}{\sum_h |\,\mathbf{p}_h\,|}\;, \tag{4}$$

where the sum extends over all hadrons $\mathbf{p}_h$ in the Breit current hemisphere and the maximum is with respect to the unit vector $\mathbf{n}$, *i.e.* the thrust axis $\vec{T}_c$.

The differential thrust distributions, shown in fig. 1, get more peaked towards high values $T_c \longrightarrow 1$ as Q^2 increases: The energy flow becomes more collimated.

The mean values of $\langle 1 - T_c \rangle$ vs Q, shown in fig. 2 a, exhibit a decrease with Q. For comparison, the e^+e^- data [2] show a slightly stronger Q dependence. Good agreement between $e\,p$ and e^+e^- results can be obtained by using an alternative definition of thrust T_t, calculated analogous to eq. (4), but taking all hadrons in the hemisphere defined by the $\vec{T}_c$ axis, see fig. 2 b. The difference between the two definitions $\langle 1 - T_c \rangle$ and $\langle 1 - T_t \rangle$ is most pronounced at low Q due to soft particle migration between the current and target hemispheres.

The Q dependence of $\langle 1 - T \rangle$ can be described by [3]

$$\langle 1 - T \rangle \;\simeq\; \langle 1 - T \rangle^{\rm pert} + \langle 1 - T \rangle^{\rm pow}\;, \tag{5}$$

$$\langle 1 - T \rangle^{\rm pert} \;=\; c_1\,\alpha_s(Q) + c_2\,\alpha_s^2(Q)\;, \tag{6}$$

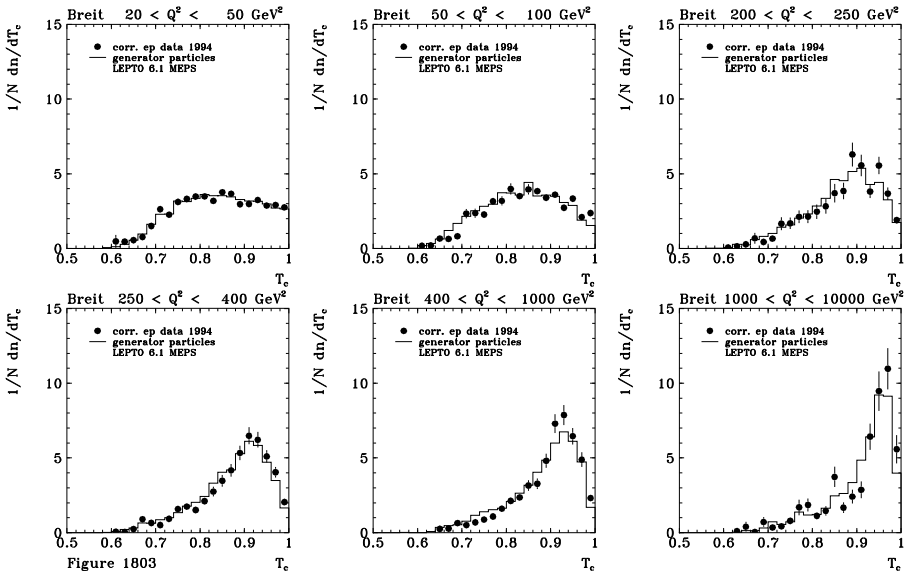

Figure 1: Differential thrust distributions $1/N\,dn/dT_c$ of H1 DIS $e\,p$ data (•) and Monte Carlo predictions (—) for various Q^2 values between 20 GeV^2 and 10,000 GeV^2

$$\langle 1-T\rangle^{\rm pow} \;=\; \frac{16\,\mu}{3\,\pi\,Q}\left[\bar{\alpha}_0(\mu)-\alpha_s(Q)-b_0\left(\ln\frac{Q}{\mu}+1\right)\alpha_s^2(Q)\right]\;. \qquad (7)$$

The perturbative part, eq. (6), represents the second order QCD prediction. The power or so-called 'hadronization' corrections, eq. (7) with $b_0 = (33-2\,N_{flavour})/6\,\pi$, contain a free parameter $\bar{\alpha}_0(\mu)$ to be evaluated at some scale $\Lambda \ll \mu \ll Q$ and are expected [3] to behave like $\propto Q^{-1}$. They may be due to a universal soft gluon phenomenon associated with the behaviour of the running coupling at small momentum scales. 'Universal' means that they could be expressible in terms of a few non-perturbative parameters with calculable process dependent coefficients.

The data of fig. 2 can be used to determine in a simultaneous fit $\alpha_s(Q)$ and the power corrections, *e.g.* DELPHI [2] obtains $\alpha_s(M_Z) = 0.117 \pm 0.002 \pm 0.008$ and $\bar{\alpha}_0 = 0.552 \pm 0.012$ for the e^+e^- experiments. For DIS $e\,p$, however, perturbative NLO calculations are not yet available. Present Monte Carlo event generators are not usable for such an analysis due to the non-unique modeling of partons in higher order (not well defined effective α_s^{eff} instead of *e.g.*

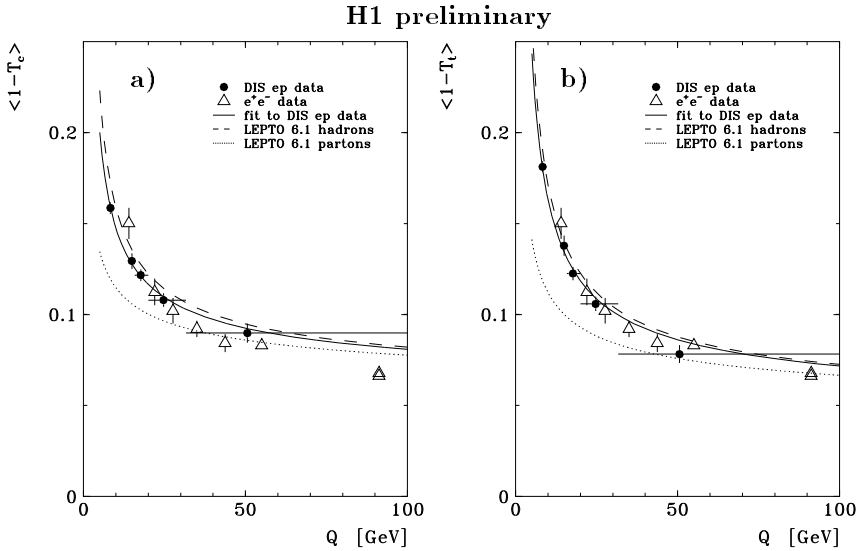

Figure 2: **a)** $\langle 1 - T_c \rangle$ vs Q and **b)** $\langle 1 - T_t \rangle$ vs Q. H1 DIS $e\,p$ data (• and —) are compared with e^+e^- data (△) and Monte Carlo predictions for hadrons (– –) and partons ($\cdots$)

$\alpha_s^{\overline{MS}}$). But one may get an idea of the amount of hadronization contributions, becoming less important at high values of Q, by comparing the data (or Monte Carlo) with the parton curves in fig. 2.

Conclusion Event shape analyses in deep inelastic $e\,p$ scattering offer another possibility to determine $\alpha_s(Q)$ as well as power corrections with a comparable or even better precision than e^+e^- experiments. The advantage is that a large Q range can be covered in a single experiment with high statistics.

References

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