Jets and Event Shape Studies in *ep*-collisions at HERA

R. PÖSCHL
LAL, Groupe H1,
91898 Orsay Cedex, France
On behalf of the H1 and ZEUS collaborations

The results of complementary tests of perturbative QCD in DIS at large centre-of-mass energies at HERA are presented. The analysis of event shape variables allows for the investigation of approaches to understand aspects of non-perturbative QCD such as the formation of the hadronic final state. The strong coupling constant, α_s, is extracted from both inclusive jet cross sections and dijet rates and is found to be competitive with the world average.

1 Introduction

The hadronic final state in deep inelastic ep scattering (DIS), i.e. $ep \to eX$, provides a rich testing ground for studies of QCD. The HERA ep collider offers the unique possibility to investigate QCD over several orders of magnitude in the virtuality, Q^2, of the exchanged boson. Figure 1 displays the DIS process as viewed in the Breit-Frame of reference. In zeroth order the

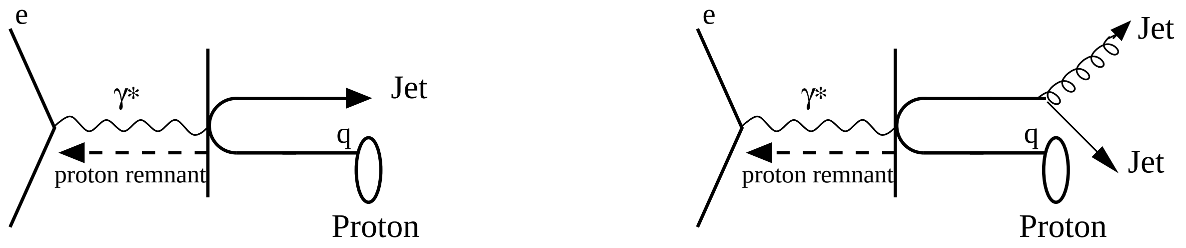

Figure 1: Deep inelastic scattering with (right) and without (left) QCD corrections as viewed in the Breit-Frame. The QCD corrections lead to final state jets with non-zero E_t.

scattered quark leaves the interaction collinear with the direction of the incoming photon. The radiation of a gluon (Fig. 1), or the process $\gamma^\star g \to q\bar{q}$, however, generates a non-zero transverse momentum of the final state gluon or quarks, resulting in distinct properties of the hadronic final state as exploited in high statistics analyses from the H1 and ZEUS collaborations presented in this article.

2 Event Shapes in DIS

In event shape studies, the complete set of hadronic final state particles is used to calculate proper observables which are sensitive to QCD corrections to the inclusive process. The analyses in the Breit-Frame of the thrust $\tau_m(\tau_c)$, measured with respect to the thrust axis, the C-Parameter and the jet mass ρ (ρ_0) permits the direct comparison of event shapes in DIS to event shapes in time-like e^+e^--events. The thrust $\tau(\tau_z)$ and the jet broadening $B(B_c)$ given by

$$\tau(\tau_z) = 1 - \frac{\sum p_{z,h}}{\sum |p_h|} \qquad (1) \qquad\qquad B(B_c) = \frac{\sum p_{t,h}}{\sum |p_h|} \qquad (2)$$

are measured with respect to the boson axis and are therefore specific to DIS. The sum runs over the longitudinal and transverse momenta of the hadronic final state particles projected onto the axis of the incoming boson. From Eqs. 1 and 2 and Fig. 1 it is easy to see that the defined variables are zero in case of lowest order DIS and different from zero in the higher order case including the hadronization step.

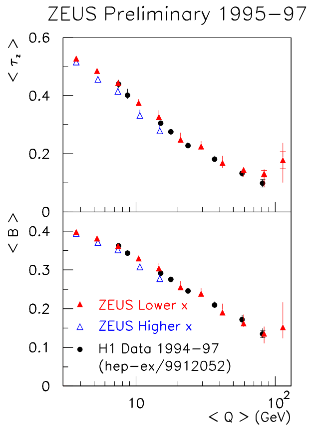

Figure 2: Means of different event shape variables as a function of $\langle Q \rangle$ as measured by the H1 and ZEUS collaborations.

The measured distributions of the mean values of $\langle \tau_z \rangle$ and $\langle B \rangle$ are shown in Fig. 2 [1,2]. The slope of the distributions with $\langle Q \rangle$ indicates that the events get more collimated with increasing boson virtuality. Here the results of the H1 and ZEUS collaborations agree within errors which is also for the variables not shown in Fig. 2. The ZEUS collaboration investigates the x-dependence of the event shape variables, where x is known as the fractional momentum of the interacting parton with respect to the incident proton momentum. Perturbative QCD up to $\mathcal{O}(\alpha_s^2)$ is not sufficient to describe the measured means of the event shape variables [1,2] and non-perturbative effects such as hadronization have to be considered. The mean of any event shape variable, $\langle \mathcal{F} \rangle$, may thus be decomposed into a perturbatively calculable part and a part which contains the non-perturbative physics

$$\langle \mathcal{F} \rangle = \langle \mathcal{F} \rangle^{pert.} + \langle \mathcal{F} \rangle^{npert.}. \tag{3}$$

In the analyses presented here hadronization is treated conceptually by attributing power corrections [3] to soft gluon phenomena. In this framework, the non-perturbative part $\langle \mathcal{F} \rangle^{npert.}$ can be written as

$$\langle \mathcal{F} \rangle^{npert.} = a_F \cdot 1.61 \frac{\mu_I}{Q} \left[\bar{\alpha}_0(\mu_I) - \alpha_s(Q) - 1.22 \left(\ln \frac{Q}{\mu_I} + 1.45 \right) \alpha_s(Q) \right], \tag{4}$$

with an additional enhancement a'_B in case of the jet broadening [4] which might also depend on x. Note the free parameter $\bar{\alpha}_0$ which takes soft gluon effects into account and can be interpreted as the mean of α_s in the region $0 < \mu_I < 2\,\mathrm{GeV}$. Good fits to the data of Fig. 2 are obtained using $\bar{\alpha}_0$ and α_s as free parameters [2,1]. The results on $\alpha_s, \bar{\alpha}_0$ obtained by the H1 and ZEUS collaborations are displayed in Fig. 3 together with the $\chi^2_{min} + 4$ (Fig. 3 a) and $\chi^2_{min} + 4(1)$ error ellipses (Fig. 3 b).

The α_s of the two analyses are broadly consistent with each other and with the world average although the large spread reveals the need for higher order corrections. The resulting $\bar{\alpha}_0$ of both analyses suggest an universal value of 0.5 ± 0.1 for the event shape variables $\tau_m(\tau_c)$, C and ρ_0. The H1 analysis as shown in Fig.3 b) demonstrates the influence of the treatment

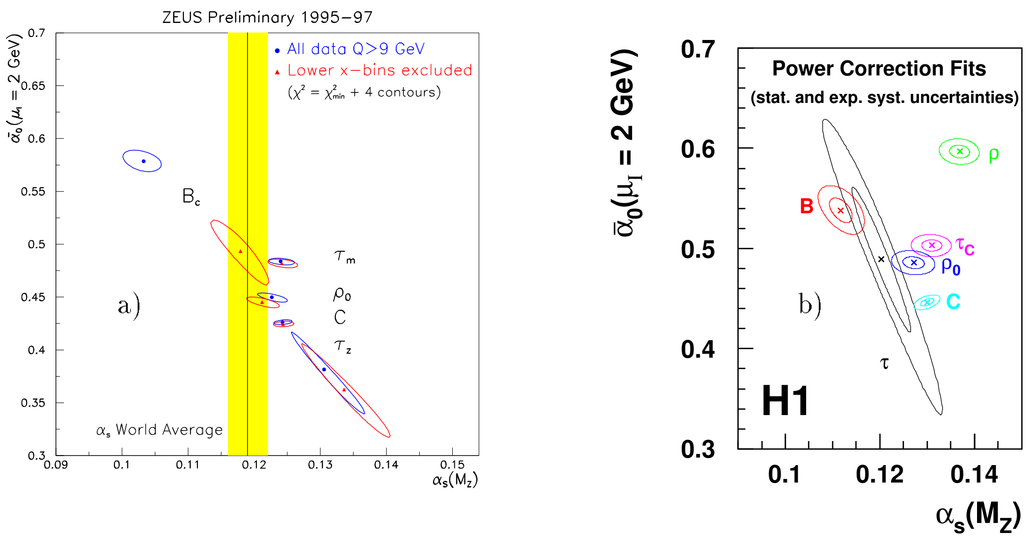

Figure 3: Results of power correction fits to the mean values of the event shape variables.

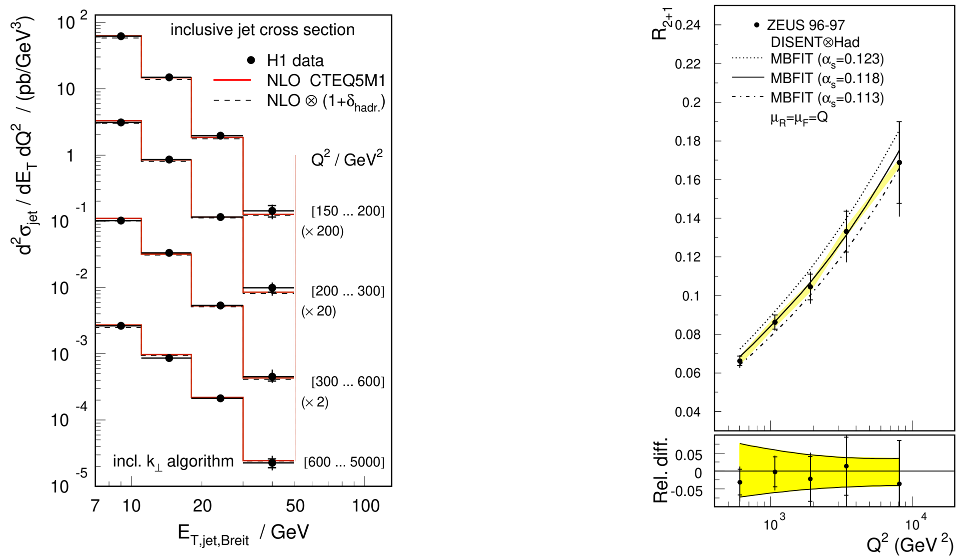

Figure 4: Inclusive jet cross section (left) and dijet rates (right) used in independent determinations of α_s by the H1 and ZEUS collaborations, respectively

of hadrons on the jet masses ρ and ρ_0 where the assumption of massless hadrons (ρ_0) leads to a more consistent interpretation of power corrections. The fit results on $B(B_c)$ differ between the both experiments although the measurement as shown in Fig. 2 is in good agreement. As already indicated in Fig. 2 the ZEUS collaboration splits the data into two x ranges and the resulting $\bar{\alpha}_0$ values obtained for the B-Parameter indicate a strong x-dependence in contrast to the weak dependence seen in Fig. 2. The fit results on $\tau(\tau_z)$ exhibit large uncertainties and strong correlations between $\alpha_s, \bar{\alpha}_0$, making the interpretation of the result quite difficult.

3 α_s and Gluon Density from Jet Cross Sections

As indicated in Fig. 1 the radiation of gluons leads to final state jets with non-zero transverse momentum E_t. In DIS high E_t jets are, in first order α_s, produced by the Boson-Gluon Fusion process and the QCD-Compton process. The resulting jet cross section can be expressed in a power series of the strong coupling constant:

$$\sigma_{jet} = \sum \alpha_s^n \sum_{i=q,G} \mathrm{C}_{i,n} \otimes \mathrm{pdf}_i . \tag{5}$$

Here the $\mathrm{C}_{i,n}$ denote the matrix elements which can be calculated in perturbative QCD and pdf_i denotes the parton density of a parton of type $i = q, G$ (q=quark, G=gluon). It is discussed in [6] that fundamental quantities such as α_s or the pdf can be determined for $Q^2 > 150\,\mathrm{GeV}^2$ by means of a QCD analysis due to the small uncertainties of NLO-QCD ($\mathcal{O}\ (\alpha_s^2)$) predictions in this phase space region.

Two complementary approaches have been used for the extraction of α_s by H1 [6] and ZEUS [7] each with slightly different advantages. Jets were defined by using the inclusive k_t-algorithm. The inclusive jet cross section as shown in Fig. 4 (left) was proven to have small uncertainties from the hadronization step. The partial cancellation of pdf uncertainties when using dijet rates, Fig. 4 (right), leads to small uncertainties from the pdf.

Both measurements are compared to NLO-QCD calculations corrected for hadronization effects. The results on α_s are

$$\alpha_s(M_Z) = 0.1186 \pm 0.0007\ (\mathrm{stat.}) \pm 0.0030\ (\mathrm{exp.}) \pm 0.0051\ (\mathrm{th.}) \tag{6}$$

from inclusive jet cross sections [6] and

$$\alpha_s(M_Z) = 0.1166 \pm 0.0019\ (\mathrm{stat.})^{+0.0024}_{-0.0033}\ (\mathrm{exp.})^{+0.0057}_{-0.0044}\ (\mathrm{th.}) \tag{7}$$

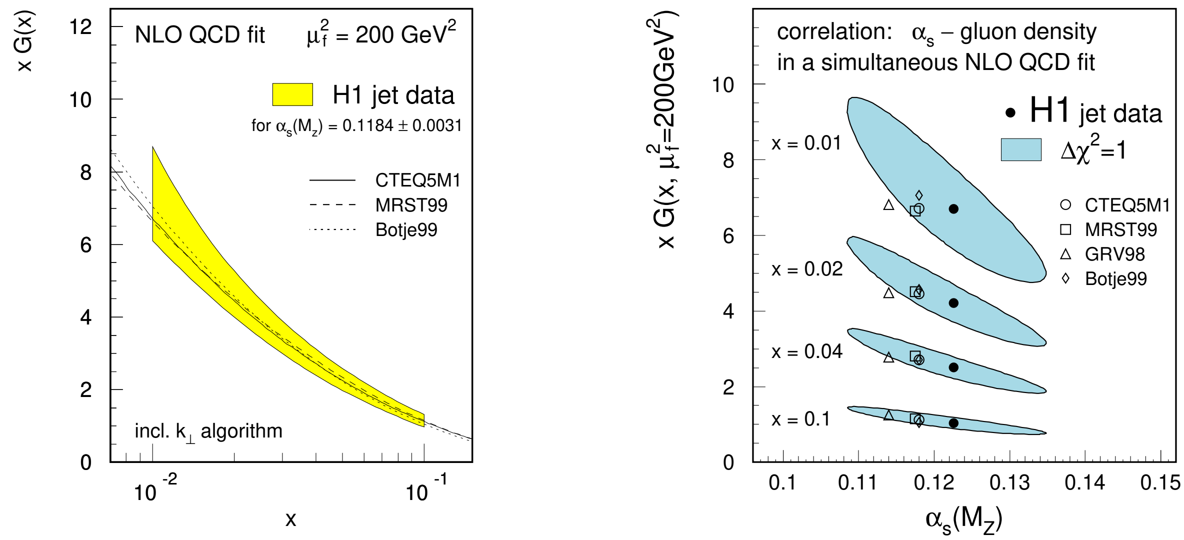

Figure 5: Left: The gluon density $xG(x)$ as determined from DIS Data including jet cross sections for a fixed value of α_s. The error band includes the combined experimental and theoretical uncertainties. Right: Results of a simultaneous fit of α_s and the gluon density in the proton to H1 jet and inclusive DIS data. The central fit results (black points) are displayed together with their $\chi^2_{min} + 1$ error ellipses

from dijet rates [7]. The results both agree with the current world average [5] $\alpha_s(M_Z) = 0.1184 \pm 0.0031$. Note, that the experimental errors are much smaller than the theoretical uncertainties, of which the pdf uncertainties dominate [6].

The extraction of α_s needs the pdf as external input. On the other hand, using the best knowledge of α_s, the jet cross-sections can be used to extract the quark and gluon densities in the proton. While the quark densities can be well constrained by using inclusive DIS data [8], jet cross sections are particularly sensitive to the gluon density. Figure 5 (left) shows the determination of the gluon density in the proton where the current world average for α_s was used as input. A more independent test of QCD can be performed by fitting α_s and the quark and gluon densities simultaneously. Figure 5 (right) displays the result in the form of a correlation plot of α_s versus the gluon density. The obtained values agree with those from global fits by various other groups within the errors given by the $\chi^2_{min} + 1$ error ellipses. The large eccentricities of the ellipses demonstrate that the result is sensitive to the product $\alpha_s \cdot G(x)$ while the size of the uncertainties, however, indicates that the precision of the measurement is still limited. The determination of the fundamental quantities will benefit from NNLO-calculations and/or the analysis of three-jet events for which the upcoming HERA II running promises sufficient statistics.

References

1. ZEUS Collaboration, *XXXth International Conference on High Energy Physics, July 2000, Contributed Paper No. 420.*
2. H1 Collaboration, C. Adloff et al., *Eur. Phys. J.* C **14**, 255 (2000) *and addendum.*
3. Yu.L. Dokshitzer and B.R. Webber, *Phys. Lett.* B **352**, 451 (1995).
4. Yu.L. Dokshitzer in Proceedings *XXIX International Conference on High Energy Physics*, Vancouver, Canada, 1998;
   Yu.L. Dokshitzer, G Marchesini and G.P. Salam *Eur. Phys. J. direct* C **3**, 1 (1999).
5. S. Bethke, *Eur. Phys. J.* G **26**, R27 (2000).
6. H1 Collaboration, C. Adloff et al., *hep-ex/0010054, accepted by Eur. Phys. J. C., 10/00.*
7. ZEUS Collaboration, J. Breitweg et al., *Phys. Lett.* B **507**, 70 (2001).
8. H1 Collaboration, C. Adloff et al., *Eur. Phys. J.* C **13**, 609 (2000)
   H1 Collaboration, C. Adloff et al., *Eur. Phys. J.* C **19**, 269 (2001).