JET SHAPES AND DETERMINATIONS OF α_s FROM HADRONIC FINAL STATES IN DEEP INELASTIC SCATTERING AT HERA

MARC WEBER
Institut für Hochenergiephysik, Universtät Heidelberg, Schröderstraße 90, D–69120 Heidelberg, Germany

Recent results from the study of hadronic final states in deep inelastic scattering at HERA are reviewed. Jet shapes from neutral and charged current interactions at HERA are compared to those from e^+e^- annihilation and $p\bar{p}$ collisions. The (2+1) jet event rate distributions $R_{2+1}(Q^2)$ and y_2 are measured using the modified JADE jet algorithm. The value of the strong coupling constant α_s is determined from a comparison with QCD predictions in next–to–leading order. An analysis of event shape distributions in terms of next–to–leading order QCD calculations and power corrections is presented.

1 Introduction

In the HERA storage ring at DESY, 27.5 GeV electrons collide with 820 GeV protons, corresponding to a centre–of–mass energy of $\sqrt{s} = 300$ GeV. The collisions are recorded by the H1 and ZEUS detectors. The study of the hadronic final state in ep collisions at HERA provides exciting possibilities of improving the current understanding of QCD models in a complex scattering process and of testing next–to–leading order (NLO) QCD predictions precisely. In $O(\alpha_s^0)$, deep inelastic (DIS) ep scattering is characterized by the two independent variables x and Q^2, where x is related to the struck quark's share of the proton momentum and Q^2 is the magnitude of the exchanged boson's 4–momentum squared. Experimentally, final states with (1+1) jet topologies have been observed. The notation '+1' refers to the proton remnant jet. A study of the shape of energetic (quark) jets in such a topology is presented below. QCD corrections to $O(\alpha_s)$, namely QCD–Compton scattering ($\gamma^* q \to qg$) and Boson–Gluon–Fusion ($\gamma^* g \to q\bar{q}$), give rise to events with (2+1) partons. Thus measurement of the corresponding rate of (2+1) jet events, or alternatively of event shape variables, provides a natural tool to determine the size of the strong coupling constant α_s as is discussed in this contribution. The results presented here are based on data collected in the years '94 to '96.

2 Jet shapes

The study of jet shapes provides information on the substructure of jets related to both hard QCD radiation and the non–perturbative fragmentation process. The comparison of the shape of quark and gluon induced jets is of particular interest. The ZEUS collaboration have selected energetic (quark) jets in neutral (NC) and charged (CC) current interactions using a cone jet finder with cone radius $R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 1$ [1]. The variable $\Psi(r)$ corresponds to the average fraction of the transverse energy contained in a subcone of radius $r < R$. Its distribution is shown in figure 1. Also shown in the figure are jet shape distributions as measured in e^+e^-

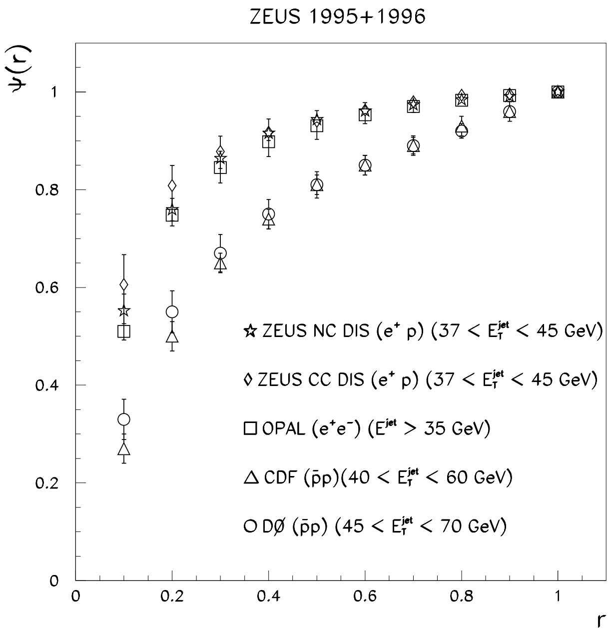

Figure 1: Jet shapes measured in DIS at HERA, in e^+e^- annihilations at LEP and in $p\bar{p}$ collisions at the TEVATRON.

annihilations at LEP and in $p\bar{p}$ collisions at the TEVATRON. The different jet samples are selected with comparable criteria. The jets in e^+e^- annihilations are predominantly quark jets whereas those in $p\bar{p}$ collisions are mostly gluon induced. The figure shows that the shape of CC and NC jets in DIS at HERA are very close to that in e^+e^- annihilations, in spite of their very different environment and production processes. However their shapes differ considerably from that of jets in $p\bar{p}$ collisions. This observation strongly suggests that gluon jets are broader than quark jets as is expected due to their larger colour charge.

3 (2+1) jet event rates

Given a good understanding of the structure of jets at HERA, we proceed to study the production rates of (2+1) jet events. We compare measured jet rates with QCD predictions in NLO and finally extract values of the strong coupling constant α_s. The jets are found with the modified JADE algorithm. The algorithm is applied to calorimeter clusters and is run in the laboratory frame. Compared to the version used in e^+e^- experiments, the algorithm is modified in two respects: the cluster due to the scattered electron is removed and an additional pseudo cluster is formed which allows for the proton remnant particles escaping undetected through the beam pipe.

3.1 'Integrated' (2+1) jet event rate $R_{2+1}(Q^2)$

Firstly, we present a recent measurement [2] of $R_{2+1}(Q^2)$, the rate of (2+1) jet events as a function of Q^2, at *fixed* jet resolution parameter $y_{cut} = m_{ij}^2/W^2 = 0.02$. Here m_{ij} is the mass of any pair of clusters i, j under consideration, and W^2 is the hadronic mass squared. The variable $R_{2+1}(Q^2)$ is commonly called the *integrated* jet event rate. This measurement is similar in spirit to the study of $R_3(s)$ combining measurements of e^+e^- annihilation experiments at different centre–of–mass energy squared s. Widely different values of Q^2 are accessible simultaneously at HERA.

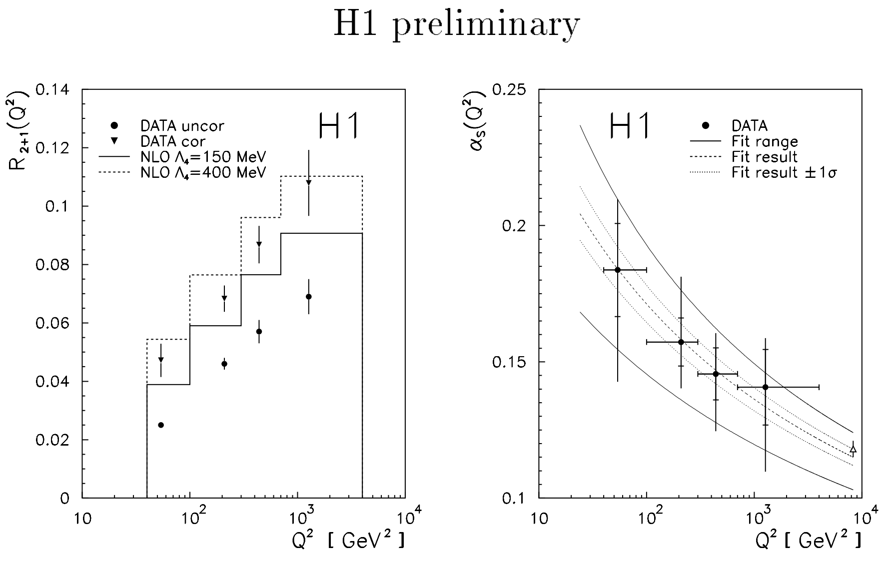

Figure 2: The measured (2+1) jet event rate $R_{2+1}(Q^2)$ compared to NLO QCD calculations (left). The values of $\alpha_s(< Q^2 >)$ determined from the fit of NLO calculations to the corrected data (right). The inner error bar corresponds to the statistical error. The sum of inner and outer error bars corresponds to the statistical and systematical error added in quadrature.

This measurement differs from earlier ones by using largely increased data samples, improved versions of Monte Carlo programs and second generation NLO programs. In figure 2 (left) the experimental $R_{2+1}(Q^2)$ distributions are compared with QCD predictions in NLO. The triangles show $R_{2+1}(Q^2)$ corrected for detector and hadronisation effects using Monte Carlo models. The full points show the uncorrected distribution. Note that the corrections are considerable. This is expected to change with the selection of more 'jetty' events as soon as even larger data samples become available. Comparing the NLO predictions for the different values of $\alpha_s(M_Z)$ corresponding to $\Lambda^{(4)}_{\overline{MS}} = 150$ and 400 MeV, a strong sensitivity to the value of α_s is observed. In each bin, the value of α_s with the renormalization scale set to the mean Q^2 of the bin is extracted. The extracted $\alpha_s(< Q^2 >)$ are shown in figure 2 (right). The figure is consistent with the 'running' of α_s as a function of the renormalization scale as predicted by the renormalization group equation. The uncertainties can be understood in the following sense: at low Q^2, the jet structure of the events is less pronounced and systematic errors dominate; at high Q^2, in contrast, the statistical error is sizable with only a few hundred events contributing to the bin highest in Q^2. Averaging over the four bins we obtain $\alpha_s(M_Z) = 0.115 \pm 0.003\ (stat.)\ ^{+0.008}_{-0.011}\ (syst.) + 0.006\ (recomb.\ scheme)$. Important sources of uncertainty included in the systematic error are: the precision of the hadronic energy scale of the calorimeter; the model dependence of the data correction; the knowledge of the parton densities and the (large) renormalization scale dependence. The last error given considers the change of the extracted α_s when the P scheme is used to recombine clusters to jets.

3.2 'Differential' (2+1) jet event rate y_2

Secondly, we study the variable y_2, the (2+1) jet event rate *differential* in the jet resolution parameter [3]. For a fixed value of Q^2, y_2 and R_{2+1} are related by $-\frac{dR_{2+1}}{dy_{cut}} = -\frac{1}{N_{tot}} \cdot \frac{dN_{2+1}}{dy_{cut}} \approx \frac{1}{N_{tot}} \cdot \frac{dN}{dy_2}$. Here y_2 is averaged over the range $200 < Q^2 < 10,000\ \mathrm{GeV}^2$. Thus it provides information complementary to the $R_{2+1}(Q^2)$ distribution evaluated at a fixed value of the resolution parameter y_{cut}.

In figure 3 the corrected differential (2+1) jet event rate y_2 is compared to QCD predictions in NLO calculated with the NLO program MEPJET. Again the sensitivity to α_s is seen. The full line corresponds to the fitted value of $\alpha_s(M_Z)$ of $0.118 \pm 0.002\ (stat.)\ ^{+0.007}_{-0.008}\ (syst.)\ ^{+0.007}_{-0.006}\ (theor.)$. It agrees well with the corrected data and provides a nice consistency check of QCD.

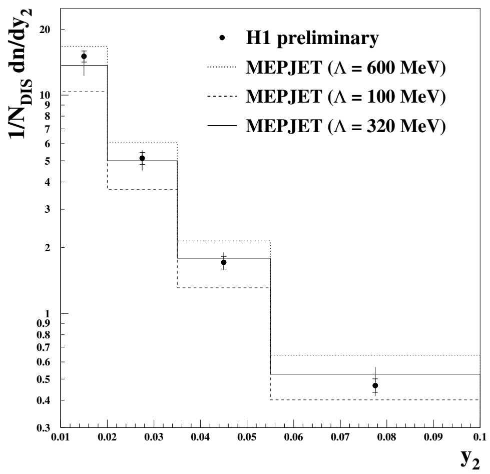

Figure 3: The corrected differential (2+1) jet event rate y_2 compared to the NLO QCD predictions of MEPJET obtained for different values of $\Lambda^{(4)}_{\overline{MS}}$.

4 Event shape variables and power corrections

The study of event shape variables, as opposed to that of jets, provides an alternative approach to the understanding of the hadronic final states.

In figure 4 the (preliminary) mean values of thrust, T_z and T_c, jet broadening B_c, the C_c parameter, and of the jet masses ρ_E and ρ_q are shown for different ranges of Q^2. A preceding analysis of the variables T_z, T_c, B_c and ρ_q based on a smaller data sample has been published in[4]. The value of a given variable is calculated from the particles detected in the current hemisphere in the Breit frame. This offers the advantage of optimum separation from the proton remnant.

The experimental distributions are corrected for the effects of detector resolution and acceptance but not for hadronisation effects. The prediction of QCD in NLO are also shown. They differ considerably from the data but the differences generally decrease with increasing Q^2 where the event shape is more pencil–like and where hadronisation corrections become smaller.

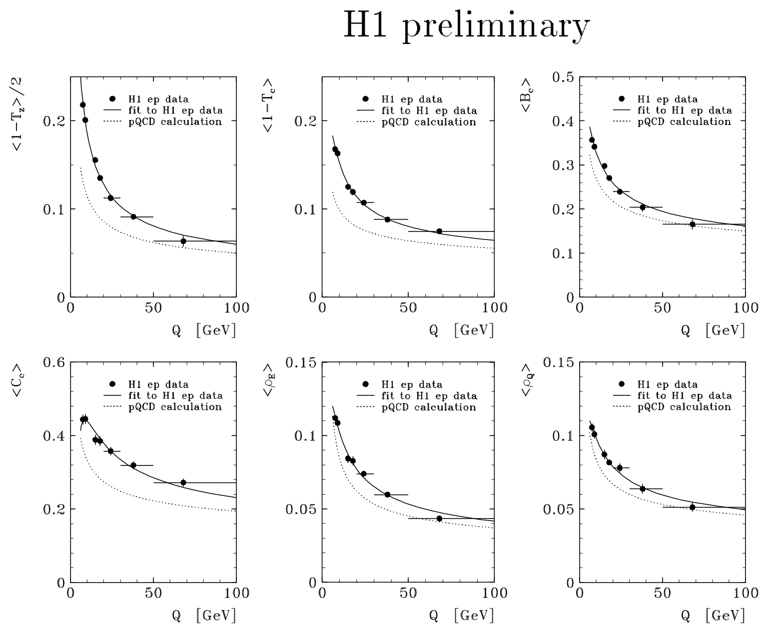

Figure 4: Mean values of event shape spectra for different values of Q^2.

Motivated by this observation, a power correction fit of $\langle O\rangle = \langle O\rangle^{pert} + \langle O\rangle^{pow}$ is performed. Here O represents any of the observables discussed; $\langle O\rangle^{pert}$ corresponds to the NLO prediction shown in the Figure and depends on α_s (and the parton densities) only; $\langle O\rangle^{pow}$ is a power correction term proportional to $1/Q$ for all variables (with the exception of B_c) which depends only on an effective strong coupling $\bar{\alpha}_0$ and which takes into account non–perturbative corrections. The power correction fit of α_s and $\bar{\alpha}_0$ is shown as the full line in the figure and describes the data very well. The extracted values of $\bar{\alpha}_0$ of ~ 0.5 with a spread of typically $\pm 20\%$ support the approximately universal character of $\bar{\alpha}_0$. The fit values of $\alpha_s(M_Z)$ cover the range of $0.115 - 0.137$. With the large range of Q^2 covered, HERA is the ideal place for this kind of analysis. The experimental errors of these measurements are small compared to the theoretical uncertainties. The latter are dominated by the renormalization scale ambiguity.

5 Summary

There is impressive progress in the study of the hadronic final state in deep inelastic scattering at HERA. Many new analyses profit from the use of the greatly increased data samples, from the advent of flexible, second–generation NLO programs and from the continuously improving Monte Carlo models. As an illustration the most recent (preliminary) values of $\alpha_s(M_Z)$ as discussed above are compiled in figure 5. The precision of these measurements is starting to be competitive. With the analysis of the large '97 data sample and the anticipated further refinement of the analysis methods, an even greater understanding of the hadronic final state at HERA is to be expected.

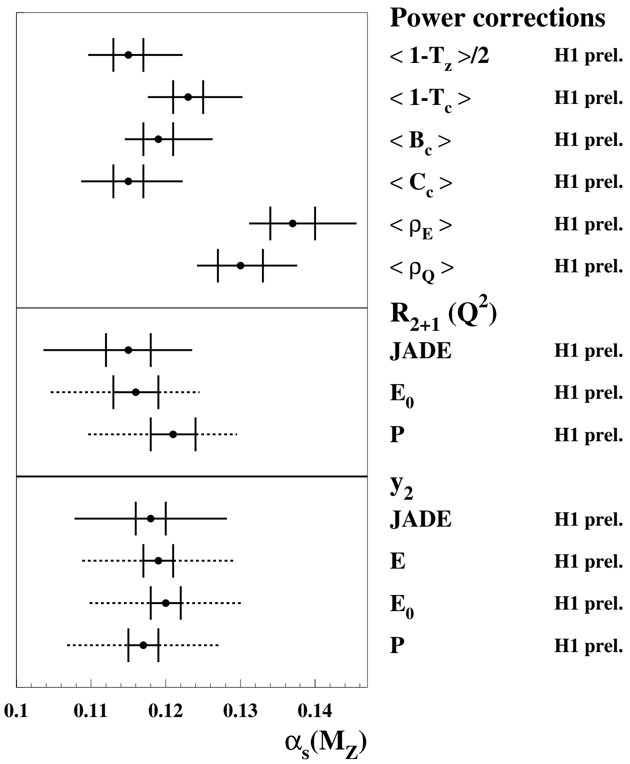

Figure 5: Assembly of α_s determinations from hadronic final states. The inner error bars reflect the statistical error of the measurements. The sum of inner and outer error bars corresponds to the statistical and systematical error added in quadrature. The systematic error bars (shown as dashed lines) for some of the jet algorithms have not been determined explicitly but were estimated using the respective analyses with the JADE algorithm.

Acknowledgments

It is a great pleasure to thank the organizers for a highly instructive, inspiring and well organized conference. This work was supported by the Bundesministerium für Forschung, Wissenschaft und Technologie under contract number 7HD27P.

References

1. ZEUS Collaboration, J. Breitweg, DESY 98–038 (March 1998), subm. to The European Physical Journal.
2. H1 Collaboration, *'Multi–jet Event Rates in Deep Inelastic Scattering and Determination of the Strong Coupling Constant'*, to be subm. to The European Physical Journal.
3. H1 Collaboration, *'Differential (2+1) Jet Event Rates and Determination of α_s in Deep Inelastic Scattering at HERA*, to be subm. to The European Physical Journal.
4. H1 Collaboration, C. Adloff et al., Phys. Lett. B406 (1997) 256.