Precision measurements of α_s at HERA[1]

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Abstract. Recent determinations of $\alpha_s(M_Z)$ from the H1 and ZEUS Collaborations using inclusive-jet cross-section measurements in neutral current deep inelastic scattering at high Q^2 are presented. A combined value of $\alpha_s(M_Z) = 0.1198 \pm 0.0019$ (exp.) ± 0.0026 (th.) was obtained from these measurements. The determinations of α_s at various scales clearly show the running of the coupling from HERA jet data alone and in agreement with the prediction of QCD.

1. Introduction

The strong coupling constant, α_s, is one of the fundamental parameters of QCD. However, its value is not predicted by the theory and must be determined experimentally. The success of perturbative QCD is strengthened by precise and consistent determinations of the coupling from many diverse phenomena such as τ decays, event shapes, Z decays, etc. At HERA, many precise determinations of α_s have been performed from a variety of observables based on jets and on structure functions. A summary of the determinations of $\alpha_s(M_Z)$ done by the H1 and ZEUS Collaborations is shown in Fig. 1a. The values are consistent with each other and in good agreement with the HERA-2004 [1] and world-2006 [2] averages. New determinations of $\alpha_s(M_Z)$, recently published by the ZEUS [3] and H1 [4] Collaborations, are presented. The new HERA-2007 $\alpha_s(M_Z)$ combined value is also presented.

2. Determinations of $\alpha_s(M_Z)$ from the H1 and ZEUS Collaborations

New determinations of α_s have been recently published by the H1 [4] and ZEUS [3] Collaborations. These determinations have been performed from the measurements of inclusive-jet cross sections in neutral current (NC) deep inelastic scattering (DIS) at high Q^2. The procedure to determine α_s from jet observables used by ZEUS is based on the α_s dependence of the calculations and takes into account the correlation with the parton distribution functions (PDFs). The method consists of performing next-to-leading-order (NLO) calculations using sets of PDFs for which different values of $\alpha_s(M_Z)$ were assumed in the fits. A parameterisation of the α_s dependence of the theory for the given observable is obtained and then the value of $\alpha_s(M_Z)$ is extracted from the measured cross section using such a parameterisation. This procedure handles correctly the α_s dependence of the calculations and preserves the correlation with the PDFs. A similar method is used by the H1 Collaboration.

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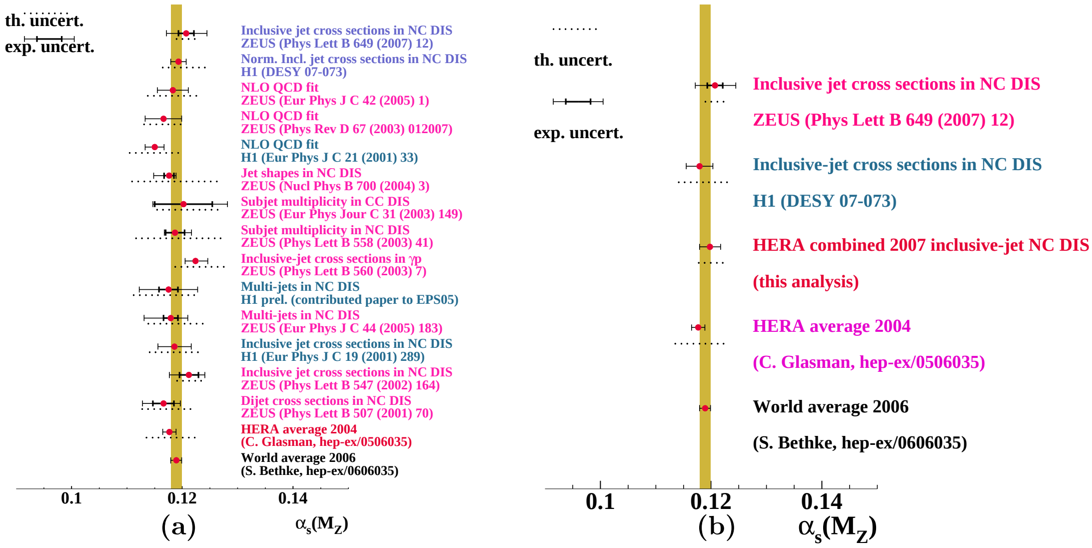

Figure 1. $\alpha_s(M_Z)$ determinations from the ZEUS and H1 Collaborations. The HERA combined 2007 $\alpha_s(M_Z)$ and the HERA-2004 and world-2006 averages are also shown.

The new determinations of $\alpha_s(M_Z)$ focus on obtaining the most precise values. ZEUS has determined a value of $\alpha_s(M_Z)$ with the aim of decreasing the theoretical uncertainties. From the measured cross section as a function of Q^2 for $Q^2 > 500$ GeV^2, the value [3]

$$\alpha_s(M_Z) = 0.1207 \pm 0.0014 \text{ (stat.) } {}^{+0.0035}_{-0.0033} \text{ (exp.) } {}^{+0.0022}_{-0.0023} \text{ (th.)}$$

has been determined. The experimental uncertainty is dominated by the jet energy scale and amounts to 2%. The theoretical uncertainties comprise the terms beyond NLO, which are the dominant contribution, and the uncertainties due to the proton PDFs and hadronisation effects. This value of $\alpha_s(M_Z)$ is very precise, with a total uncertainty of 3.6% and a contribution of only 1.9% from the theoretical uncertainty. This minimisation of the theoretical uncertainty comes from the optimisation of the phase-space region selected by ZEUS: the theoretical uncertainties arising from terms beyond NLO and the PDFs decrease as Q^2 increases.

The H1 Collaboration has extracted the value [4]

$$\alpha_s(M_Z) = 0.1193 \pm 0.0014 \text{ (exp.)}^{+0.0050}_{-0.0034} \text{ (th.)}$$

from the normalised double-differential inclusive-jet cross sections in the region $150 < Q^2 < 15000$ GeV^2. In this way, a region of phase space is selected for which experimental uncertainties are well under control. Furthermore, the use of a normalised cross section allows a partial cancellation of correlated uncertainties. The experimental uncertainties are dominated by the jet energy scale and the model dependence of the correction factors. This analysis also gives a very precise value of $\alpha_s(M_Z)$, with a total uncertainty of 4.3%, and a contribution of only 1.2% from the experimental uncertainty. The advantage of using normalised cross sections can be appreciated by comparing this determination with that obtained from using double-differential inclusive-jet cross sections in the same Q^2 range: $\alpha_s(M_Z) = 0.1179 \pm 0.0024 \text{ (exp.)}^{+0.0059}_{-0.0043} \text{ (th.)}$. Another test was done by restricting Q^2 to the range between 700 and 5000 GeV^2. The result, $\alpha_s(M_Z) = 0.1171 \pm 0.0023 \text{ (exp.)}^{+0.0034}_{-0.0014} \text{ (th.)}$, benefits from a significant decrease of the theoretical uncertainties at the expense of an increase in the experimental uncertainty. This trend is compatible with the result obtained by ZEUS.

The energy-scale dependence of α_s has been tested by both Collaborations. ZEUS has determined α_s from the measured inclusive-jet cross section as a function of the jet transverse energy in the Breit frame, $E_{T,\mathrm{B}}^{\mathrm{jet}}$, at different values of $E_{T,\mathrm{B}}^{\mathrm{jet}}$ [3]. H1 has tested the energy-scale dependence of α_s by determining the coupling from the normalised inclusive-jet cross sections both as a function of $E_{T,\mathrm{B}}^{\mathrm{jet}}$ and Q. In all cases, the results (see Fig. 2) show a decrease of α_s as the energy scale increases and are in good agreement with the running of α_s as predicted by QCD over a large range of the scale. Figure 3a shows a compilation of all the available measurements of α_s as a function of the energy scale at HERA. The values of α_s at different scales determined from jet observables have been combined [1] (see Fig. 3b): the running of α_s is observed from HERA jet data alone.

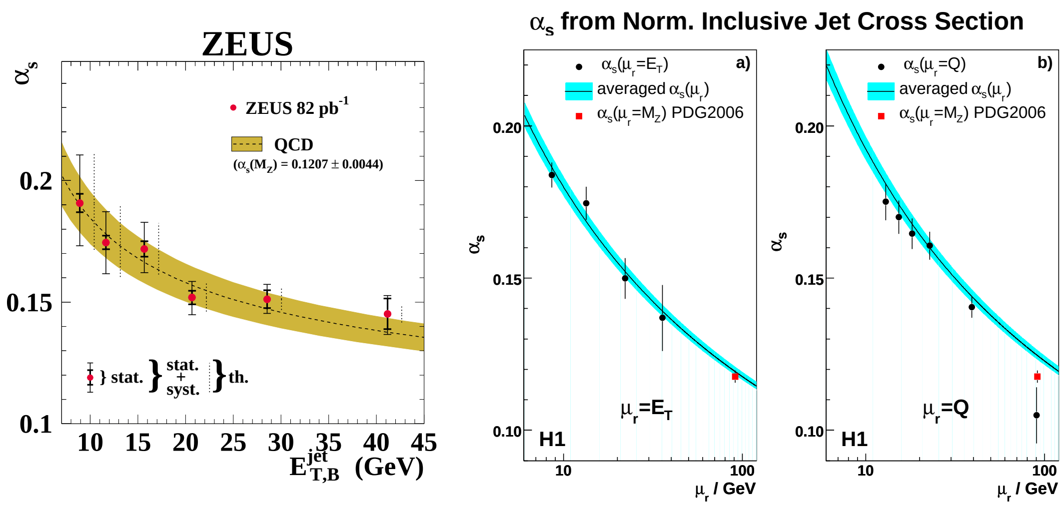

Figure 2. α_s determinations from the ZEUS and H1 Collaborations as a function of the scale.

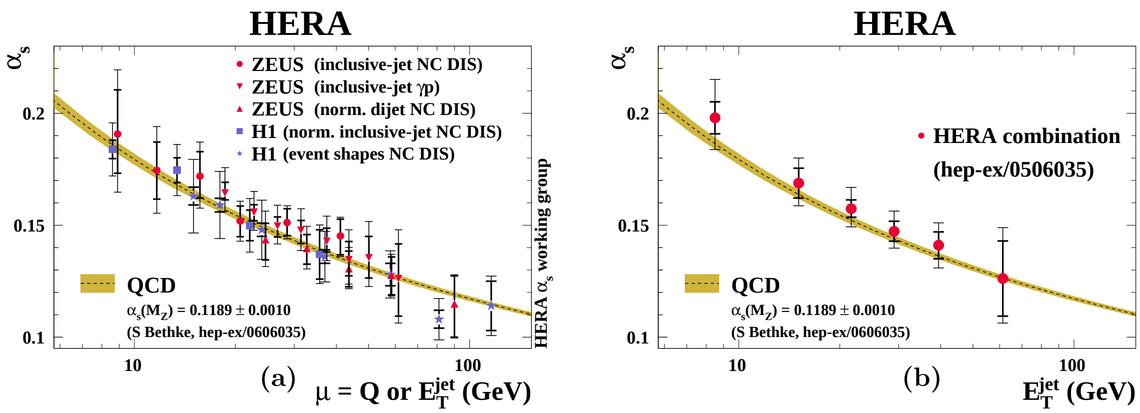

Figure 3. (a) α_s determinations from the H1 and ZEUS Collaborations as a function of the scale. (b) HERA combined values of α_s as a function of $E_{T,\mathrm{B}}^{\mathrm{jet}}$.

3. HERA combined 2007 $\alpha_s(M_Z)$

A combined analysis of H1 and ZEUS data has been performed to obtain a value of $\alpha_s(M_Z)$. For this, only those measurements which yield the most precise α_s values, namely inclusive-jet cross sections in NC DIS at high Q^2, were used. A simultaneous fit to the actual cross-section

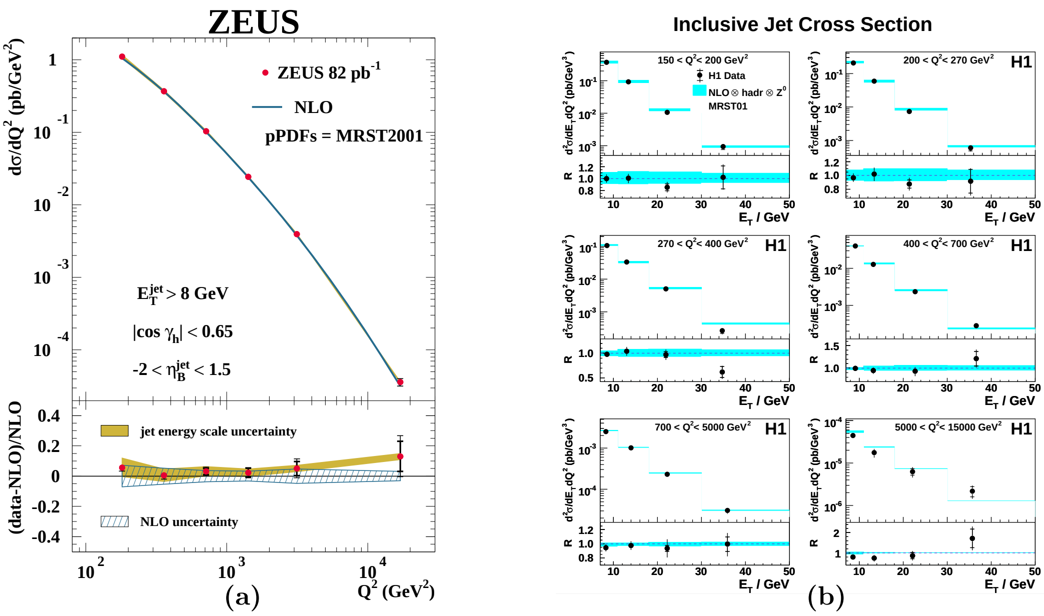

Figure 4. (a) Inclusive-jet single-differential cross-section $d\sigma/dQ^2$ as a function of Q^2 by ZEUS. (b) Inclusive-jet double-differential cross-section $d^2\sigma/dE_{T,\mathrm{B}}^{\mathrm{jet}}dQ^2$ by H1.

measurements, instead of combining α_s values as it was done for the HERA-2004 average, was performed. The data sets used in the fit are shown in Fig. 4.

The simultaneous fit was done to 24 H1 data points in the range $150 < Q^2 < 15000$ GeV^2 and 6 ZEUS data points in the range $125 < Q^2 < 100000$ GeV^2. The NLO calculations used were based on the MRST2001 PDF sets. The renormalisation and factorisation scales were set to $E_{T,\mathrm{B}}^{\mathrm{jet}}$ and Q, respectively. The experimental uncertainty on the combined α_s value amounts to 0.0019 and was obtained using the Hessian method, which fits the sources of systematic uncertainties such as the energy scale, luminosity, model dependence, etc. The sources of systematic uncertainty were treated as correlated for measurements within one experiment, but as uncorrelated between the two experiments. It was checked that the model dependence, which in principle could be correlated between experiments, had very little effect whether it was treated as correlated or uncorrelated. The theoretical uncertainty coming from terms beyond NLO was estimated using the method of Jones et al. [5], and gives the largest contribution. The other sources of theoretical uncertainty considered were: PDFs (0.0010), factorisation scale (0.0010) and hadronisation (0.0004). Therefore, the HERA combined 2007 $\alpha_s(M_Z)$ value is

$$\boxed{\alpha_s(M_Z) = 0.1198 \pm 0.0019\ (\mathrm{exp.}) \pm 0.0026\ (\mathrm{th.})}\ (\mathrm{HERA\ combined\ 2007}).$$

This combined value is shown in Fig. 1b together with the individual values obtained by both collaborations, the HERA-2004 ($0.1186 \pm 0.0011(\mathrm{exp.}) \pm 0.0050(\mathrm{th.})$) and the world-2006 ($0.1189 \pm 0.0010$) averages. The measurements are consistent with each other and with the world average. The HERA-2004 average, which combined many determinations of α_s, had a very small experimental uncertainty, but the theoretical uncertainty was large. The HERA 2007 combined $\alpha_s(M_Z)$ has a much smaller theoretical uncertainty, due to the combination of measurements in which the theoretical uncertainties are well under control, at the expense of a slight increase in experimental uncertainty. However, the total uncertainty of the new combined value, 2.7%, is smaller than that of the HERA-2004 average. This value of $\alpha_s(M_Z)$ is very competitive with the most recent result from LEP [6].

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