Precision Measurements of α_s at HERA[1]

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Abstract. The precision measurements of the strong coupling constant, α_s, and its energy-scale dependence carried out at HERA by the H1 and ZEUS Collaborations are reviewed. An average value of

$$\overline{\alpha}_s(M_Z) = 0.1186 \pm 0.0011\,(\text{exp.}) \pm 0.0050\,(\text{th.})$$

is obtained from these measurements. The combined HERA determinations of the energy-scale dependence of α_s clearly show the running of α_s from jet data alone and are in agreement with the running of the coupling as predicted by QCD.

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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 by experiment. Many precise and consistent determinations of α_s from diverse phenomena underlie the success of perturbative QCD (pQCD). At HERA, α_s has been determined from many observables, which include jet cross sections and structure functions, by the H1 and ZEUS Collaborations. All the available determinations [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11] are shown in Fig. 1a. They are in good agreement with each other and are consistent with the current world average ($(\overline{\alpha}_s(M_Z))^{WA} = 0.1182 \pm 0.0027$ [12]). These determinations, most of which come from observables which involve jet algorithms, lead to determinations of α_s some of which are as precise as those from more inclusive measurements. The uncertainty in these determinations is dominated by the theoretical contributions, which amount to 4% for jet cross sections and fits of structure functions and 8% for the internal structure of jets, whereas the experimental uncertainties amount to $\sim 3\%$.

AVERAGING THE α_S DETERMINATIONS FROM HERA

To make a proper average of all these diverse measurements, the correlation among the different determinations has to be taken into account. The experimental contribution to the uncertainty due to that of the energy scale of the jets, which is the dominant source in the jet measurements, is correlated among the determinations from each experiment.

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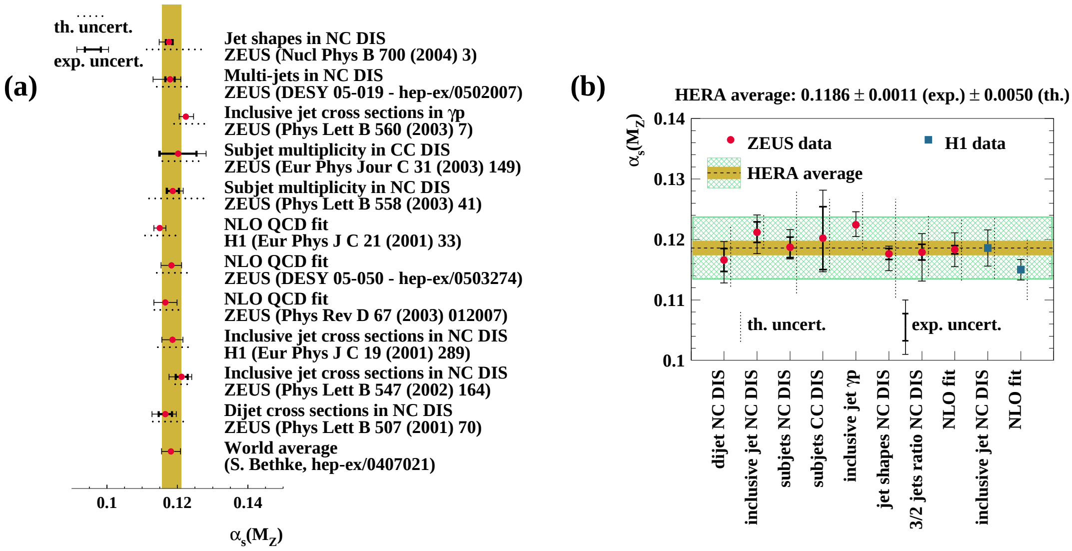

FIGURE 1. (a) Summary of $\alpha_s(M_Z)$ determinations at HERA compared with the world average; (b) $\alpha_s(M_Z)$ determinations at HERA compared with the HERA average.

On the theoretical side, the uncertainty coming from the proton parton distribution functions (PDFs) is certainly correlated whereas that coming from the hadronisation corrections is only partially correlated. The uncertainty coming from the terms beyond NLO is correlated up to a certain, a priori unknown, degree; since these uncertainties are dominant, special care must be taken in the treatment of these uncertainties when making an average of the HERA determinations.

Several methods have been used to obtain an average value of α_s from the HERA measurements and its uncertainty. Using a naive method in which all uncertainties are assumed to be uncorrelated, the average value and its uncertainty are:

$$\overline{\alpha}_s(M_Z) = 0.1188 \pm 0.0020 \; (\mathrm{ZEUS} + \mathrm{H1}).$$

The second method used is that developed by M. Schmelling [13] to average correlated data when correlations are present but hard to quantify. In this method, an error-weighted average and an optimised correlation error were obtained from the error covariance matrix by assuming an overall correlation factor between the total errors of all measurements; the overall factor was determined by the condition that the overall χ^2/dof is equal to unity. First, an error-weighted average was done separately for the ZEUS and H1 measurements, and then the two averages were combined:

$$\overline{\alpha}_s(M_Z) = 0.1196 \pm 0.0060 \; (\mathrm{ZEUS}) \qquad \text{and} \qquad \overline{\alpha}_s(M_Z) = 0.1166 \pm 0.0053 \; (\mathrm{H1}),$$

$$\overline{\alpha}_s(M_Z) = 0.1188 \pm 0.0057 \; (\mathrm{ZEUS} + \mathrm{H1}).$$

The averages from the ZEUS and H1 determinations are compatible within the uncertainties. The uncertainty of the combined average is $\sim 5\%$. This procedure gives rise to relatively large uncertainties when there are large correlations among some of the measurements, as it is the case here. To overcome this effect, the method has been repeated by restricting to the most accurate measurements [14]. The result of applying the procedure to those measurements with a total error $\Delta\alpha_s(M_Z) < 0.006$ [2, 3, 5, 6, 9] is:

$$\overline{\alpha}_s(M_Z) = 0.1192 \pm 0.0047 \; (\Delta\alpha_s^i < 0.006) \; (\mathrm{ZEUS} + \mathrm{H1}).$$

Finally, a more reliable, but conservative, approach has been used in which the known correlations from the determinations of α_s coming from the same experiment were taken into account ("correlation method"). The theoretical uncertainties arising from the terms beyond NLO were assumed to be (conservatively) fully correlated. Error-weighted averages were obtained separately for the ZEUS and H1 measurements:

$$\overline{\alpha}_s(M_Z) = 0.1200 \pm 0.0023 \; (\mathrm{exp.})^{+0.0058}_{-0.0049} \; (\mathrm{th.}) \; (\mathrm{ZEUS}),$$

$$\overline{\alpha}_s(M_Z) = 0.1160 \pm 0.0016 \; (\mathrm{exp.})^{+0.0048}_{-0.0049} \; (\mathrm{th.}) \; (\mathrm{H1}).$$

A HERA average was obtained by using the error-weighted average method on the ZEUS and H1 averages, assuming the experimental uncertainties to be uncorrelated and taking the overall theoretical uncertainty as the linear average of its contribution in each experiment. As a result, the average of the HERA measurements and its uncertainty are:

$$\overline{\alpha}_s(M_Z) = 0.1186 \pm 0.0011 \; (\mathrm{exp.}) \pm 0.0050 \; (\mathrm{th.}) \; (\mathrm{ZEUS} + \mathrm{H1}).$$

This average, together with the individual values considered, is shown in Fig. 1b. It is found to be in good agreement with the current world average, which does not include any of these determinations. The results of applying Schmelling's and the correlation methods are very similar, giving confidence on the average obtained and its estimated uncertainty.

ENERGY-SCALE DEPENDENCE OF α_S

The H1 and ZEUS Collaborations have tested the pQCD prediction for the energy-scale dependence of the strong coupling constant by determining α_s from the measured differential jet cross sections at different E_T^{jet} [1, 2, 3, 9]. Figure 2a shows the determinations of the energy-scale dependence of α_s as a function of E_T^{jet} from H1 and ZEUS. The determinations are consistent with the running of α_s as predicted by pQCD over a large range in E_T^{jet}.

The determinations of $\alpha_s(E_T^{\mathrm{jet}})$ from H1 and ZEUS at similar E_T^{jet} have been combined using the correlation method explained above. The combined HERA determinations of the energy-scale dependence of α_s are shown in Fig. 2b, in which the running of α_s from HERA jet data alone is clearly observed.

SUMMARY

A comprehensive average of α_s and its energy-scale dependence from HERA data has been performed taking into account the known correlations in each experiment and assuming conservatively that the theoretical uncertainties arising from the terms beyond NLO are fully correlated. The HERA average is

$$\overline{\alpha}_s(M_Z) = 0.1186 \pm 0.0011 \; (\mathrm{exp.}) \pm 0.0050 \; (\mathrm{th.}).$$

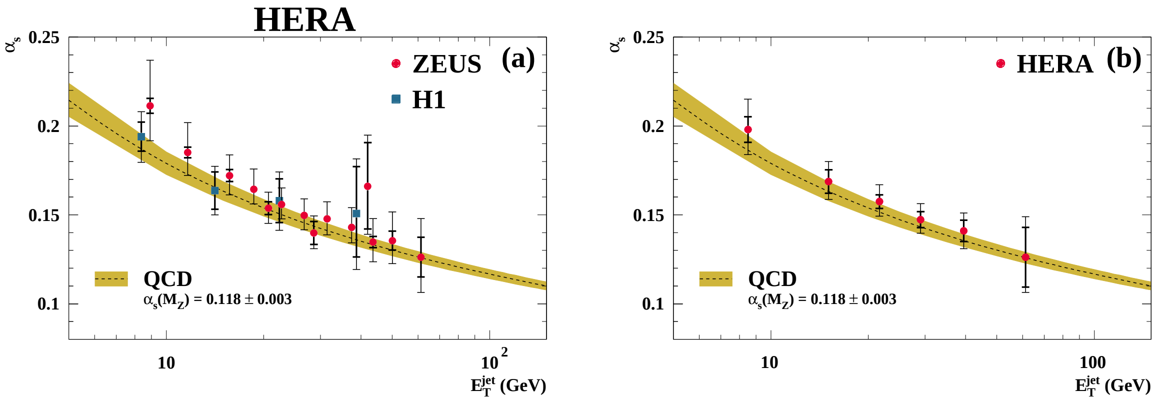

FIGURE 2. (a) α_s as a function of E_T^{jet} from H1 and ZEUS; (b) combined α_s as a function of E_T^{jet} from HERA jet data. In both figures, the QCD prediction for the running of α_s is also shown. In (a), the inner error bars display the statistical uncertainties and the outer error bars display the systematic and theoretical uncertainties added in quadrature. In (b), the inner (outer) error bars show the experimental (theoretical) uncertainties.

The experimental uncertainty of this average is $\sim 0.9\%$ and the theoretical uncertainty amounts to $\sim 4\%$. There is still room for improvement when the next-to-NLO (NNLO) calculations needed for the determination of the PDFs are included and when the NNLO calculations needed for jet-based observables are finished.

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