# QCD analysis with determination of $\alpha_s$ based on HERA inclusive and jet data

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**Abstract.** An NLO QCD analysis with simultaneous determination of the proton parton densities and strong coupling constant $\alpha_s(M_Z)$ is presented. The analysis is based on the same combined H1 and ZEUS inclusive DIS measurements as the HERAPDF1.5 fit, together with jet measurements provided by both the H1 and ZEUS collaborations. The inclusion of jet data in the analysis significantly reduces the correlation between the gluon parton density function and the strong coupling constant, improving the precision of the gluon PDF and providing an accurate unbiased determination of $\alpha_s(M_Z)$.

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## INTRODUCTION

The H1 and ZEUS collaborations recently reported results obtained by a fit of the Parton Density Function (PDF) using combined H1 and ZEUS inclusive DIS HERA II data [1]. This analysis presents an NLO QCD fit to determine the PDFs simultaneously with the strong coupling constant $\alpha_s(M_Z)$. The strong correlation between the gluon density function and the strong coupling constant in the inclusive DIS cross section has been significantly reduced by the inclusion of the H1 and ZEUS jet data in the fit.

The following H1 and ZEUS jet data sets are used:

- **H1** high $Q^2$ DIS normalised inclusive jet data (HERA I+II) [2],
- **H1** low $Q^2$ DIS inclusive jet data (HERA I) [3],
- **ZEUS** high $Q^2$ DIS inclusive jet data (HERA I, 96/97) [4],
- **ZEUS** high $Q^2$ DIS inclusive jet data (HERA I, 98-00) [5]

together with the combined NC and CC DIS cross sections for $e^+p$ and $e^-p$ scattering from the HERA I and HERA II running periods [1].

In the following the fit using only inclusive DIS data is referred to as HERAPDF1.5f. If the four above mentioned jet data sets are used simultaneously with the inclusive DIS data the fit is called the HERAPDF1.6 fit.

## THEORETICAL PREDICTIONS

For the prediction of the inclusive DIS cross sections the QCDNUM 17 program [6] has been used. The factorisation and renormalisation scales were chosen as $\mu_f = \mu_r = \sqrt{Q^2}$. Heavy quarks are treated as massive using the Thorne-Roberts variable flavour number scheme [7].

The NLO cross sections of jet production were calculated using the NLOJET++ program [8] together with the FASTNLO [9] interface which convolutes the matrix elements with the fitted PDFs. For the jet data the factorisation and renormalisation scales follow the choice used in the relevant publications, the combination of $Q^2$ and transverse jet energy $E_T$ measured in the Breit frame.

The uncertainty coming from the model assumptions has been evaluated in the same way as for HERAPDF1.0 [10]. It includes variation of the following model parameters: strangeness fraction at the starting scale $f_s$, charm mass $m_c$, beauty mass $m_b$ and minimum $Q^2$ of the data points considered in the fit $Q^2_{min}$. Also the hadronization uncertainty for each of the jet data samples is taken into account.

The renormalisation and factorisation scales are separately varied by a factor of 2 up and down simultaneously for all the data sets. The simultaneous variation of the scales for all jet data sets yields larger uncertainties than the variation of the individual data sets and thus has been preferred as the more conservative approach. The renormalisation scale variation is the dominant source of the final model error.

## PARAMETRIZATION

At the starting scale $Q_0^2 = 1.9$ GeV$^2$ the PDFs are parametrised as follows:

$$
\begin{aligned}
xg(x) &= A_g x^{B_g} \cdot (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g} \\
xu_v(x) &= A_{u_v} x^{B_{u_v}} \cdot (1-x)^{C_{u_v}} \cdot (1 + D_{u_v} x + E_{u_v} x^2) \\
xd_v(x) &= A_{d_v} x^{B_{d_v}} \cdot (1-x)^{C_{d_v}} \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}} \cdot (1-x)^{C_{\bar{U}}} \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}} \cdot (1-x)^{C_{\bar{D}}}
\end{aligned}
$$

The parameters $A_g$,$A_{u_v}$, $A_{d_v}$ are constrained by the sum rules. It is assumed that $B_{\bar{U}} = B_{\bar{D}}$, $C'_g = 25$, $A_{\bar{U}} = A_{\bar{D}}(1 - f_s)$, where $f_s$ is the strangeness fraction. Including all the above constraints results in a 14-parameter fit, while further parameters are considered when evaluating the parametrisation uncertainty.

## FIT USING FIXED STRONG COUPLING $\alpha_s = 0.1176$

In Figure 1 the HERAPDF1.6 PDFs are shown. The fit has been performed using the fixed $\alpha_s$ value $\alpha_s = 0.1176$. There is very little difference in the size of PDF uncertainties when the jet data are included in the fit, as compared to the HERAPDF1.5f case, however the high-$x$ gluon uncertainty is somewhat reduced.

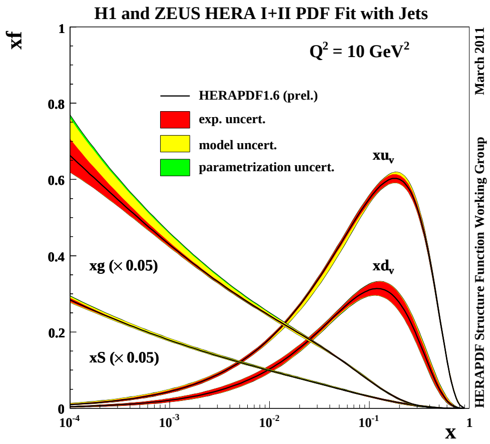


**FIGURE 1.** HERAPDF1.6 fit with fixed $\alpha_s$ value ($\alpha_s = 0.1176$)

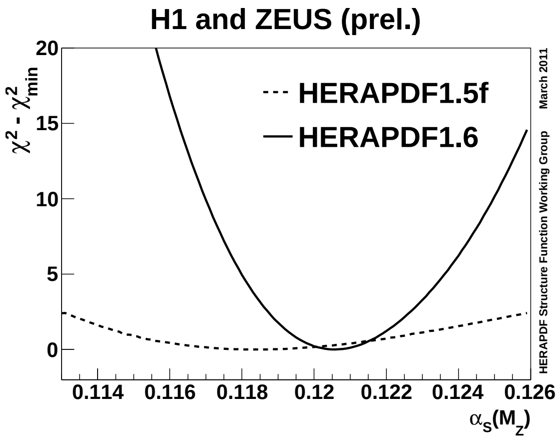


**FIGURE 2.** $\Delta\chi^2$ as a function of the value of $\alpha_s(M_Z)$ in the PDF fit for HERAPDF1.5f (dashed line) and HERAPDF1.6 (solid line).

## DETERMINATION OF $\alpha_s$

The HERAPDF1.6 fit and the HERAPDF1.5f fit were also performed with the strong coupling $\alpha_s(M_Z)$ treated as a free parameter. The HERAPDF1.6 fit determines the value of $\alpha_s(M_Z)$ as

$$\begin{aligned}\alpha_S(M_Z) = 0.1202 \;&\pm\; 0.0013(\mathrm{exp}) \\ &\pm\; 0.0007(\mathrm{model/param}) \pm 0.0012(\mathrm{hadr})^{+0.0045}_{-0.0036}(\mathrm{scale}).\end{aligned}$$

The HERAPDF1.5f fit does not give a good determination of $\alpha_s(M_Z)$ because the correlation between the gluon PDF and $\alpha_s(M_Z)$ is too strong when inclusive data alone are used. This is illustrated in Figure 2, where the $\chi^2$ for both the HERAPDF1.5f and the HERAPDF1.6 fits with free $\alpha_s$ are shown as a function of $\alpha_s(M_Z)$. The HERAPDF1.5f fit shows a shallow minimum, while the HERAPDF1.6 fit with the additional jet data provides a strong constraint on the $\alpha_s$ value.

In Figure 3 the HERAPDF1.5f and HERAPDF1.6 fits obtained using $\alpha_s(M_Z)$ as a free parameter are shown for $Q^2 = 10$ GeV$^2$. The gluon density has a very large uncertainty for the HERAPDF1.5f fit with free $\alpha_s(M_Z)$, but this uncertainty is dramatically reduced for the HERAPDF1.6 fit with free $\alpha_s(M_Z)$. The PDF uncertainty introduced by freeing $\alpha_s$ affects only the gluon PDF as can be seen by comparing HERAPDF1.6 with free $\alpha_s$ (Figure 3) and HERAPDF1.6 with fixed $\alpha_s$ (Figure 1).

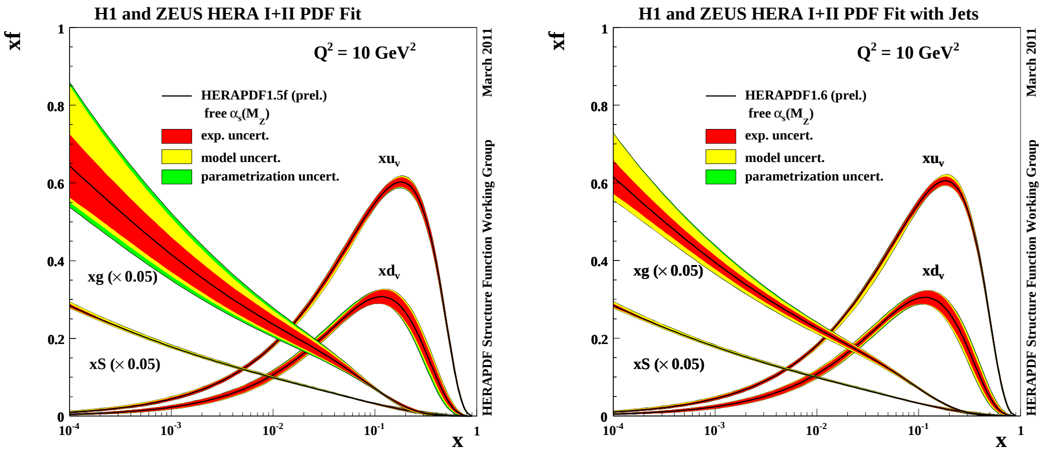


**FIGURE 3.** PDFs obtained by a fit to the HERAPDF1.5f and HERAPDF1.6 data sets and $\alpha_s$ treated as a free parameter.

## SUMMARY

The impact of jet measurements on the determination of PDFs and the strong coupling $\alpha_s$ has been studied. The jet cross section measurements from the H1 and ZEUS experiments are included in the PDF fit to the combined H1 and ZEUS NC and CC cross section measurements based on the HERA I and HERA II data samples. For the fit with fixed $\alpha_s$ very little improvement is observed.

The impact of the jet data on the QCD analysis is more significant when using the strong coupling $\alpha_s$ as a free parameter in the fit. The addition of the jet cross sections into the PDF fit reduces significantly the strong correlation between the gluon distribution and the $\alpha_s$ allowing a determination of the strong coupling with small experimental uncertainty.

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