# QCD NLO analysis of inclusive, charm and jet data (HERAPDF 1.7)

*Krzysztof Nowak* on behalf of the H1 and ZEUS Collaborations

DESY, Notkestraße 85, 22607 Hamburg, Germany

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A preliminary global NLO QCD analysis of the HERA data is presented. The following data sets are used in this analysis: the NC and CC inclusive DIS cross sections obtained from preliminary combination of the measurements from H1 and ZEUS based on HERA I and HERA II data at the nominal proton beam energy, the preliminary combined inclusive NC DIS cross sections at reduced proton beam energies, the inclusive jet cross sections from H1 and ZEUS and the preliminary combined HERA results on the charm contribution $F_2^{c\bar{c}}$ to the proton structure.

## 1 Introduction

Electron-proton collisions performed at the HERA collider provide a perfect environment for precise determination of parton density functions (PDFs) of the proton. They are determined by global fitting groups which base their fits on measurements performed at HERA as well as proton-antiproton data from Tevatron and fixed-target data from various experiments. The HERAPDF fitting group restricts used data to measurements based only on HERA data.

Both the H1 and ZEUS collaborations have performed PDF fits based on solely their data [1, 2]. The precision in the PDF determination has been improved by the combination of the H1 and ZEUS data collected in the period 1994-2000, resulting in the HERAPDF 1.0 fit [3]. The preliminary combination of the high statistics H1 and ZEUS data collected in years 2004-2007 was used in a more precise QCD analysis, named HERAPDF 1.5 [4]. The inclusion of the preliminary combined charm contribution $F_2^{c\bar{c}}$ to the proton structure in the PDF analysis has been used for the determination of the charm mass model parameter $m_c^{model}$ for the different heavy flavour treatments in the evolution code [5]. Finally, several H1 and ZEUS results on inclusive jet production were used together with combined inclusive DIS data in the QCD analysis for a simultaneous determination of the PDFs and the strong coupling constant $\alpha_S(M_Z)$, termed HERAPDF 1.6 [6]. This document presents an analysis combining all these developments in a single fit which will be referred to as HERAPDF 1.7. In addition fit uses data collected during last months of HERA operation taken with reduced proton beam energy. This analysis tests the internal compatibility of different HERA data sets.

## 2 Data Sets

The QCD analysis presented in this document is based on four main components:

- **Preliminary combined H1 and ZEUS Neutral and Charged Current high $Q^2$ data**, which is crucial for the determination of PDFs. The combination of H1 and ZEUS measurements provide the most precise data spanning over the wide kinematic range $0.045 < Q^2 < 30000$ GeV$^2$ and $6 \times 10^{-5} < x < 0.65$. This data alone allows for the determination of PDFs with high precision, as was shown in [4].

- **Preliminary combined H1 and ZEUS data measured at reduced proton beam energy** measured in the last few months of HERA operation provide additional constrain on PDFs in the low $Q^2$ and low $x$ region [7].

- **Preliminary combined H1 and ZEUS measurement of $F_2^{c\bar{c}}$ structure function**, which is directly sensitive to $m_c^{model}$ parameter related to mass of the charm quark (for more detailed discussion see [5]).

- **Inclusive jet results in DIS from H1 and ZEUS:** high $Q^2$ DIS normalised inclusive jet data (HERA I+II) from H1 [8], low $Q^2$ DIS inclusive jet data (HERA I) from H1 [9], high $Q^2$ DIS inclusive jet data (HERA I, 96/97) from ZEUS [10] and high $Q^2$ DIS inclusive jet data (HERA I, 98-00) from ZEUS [11]. The inclusion of the jet data allows for a simultaneous determination of the strong coupling constant $\alpha_s(M_Z)$ and PDFs as has been demonstrated in [6]. It also leads to a small uncertainty reduction for the high-$x$ gluon PDF.

All previously mentioned data sets have been already used as input to QCD analyses performed by HERAPDF fitting group. In this presentation we use all of them simultaneously in order to demonstrate the high level of consistency between different areas of HERA-based studies.

# 3 Theoretical predictions

For the inclusive DIS cross sections, for both the nominal and reduced proton beam energies, the QCDNUM 17 program [12] is used. The factorisation and renormalisation scales are chosen as $\mu_f = \mu_r = \sqrt{Q^2}$. Heavy quarks are treated as massive at threshold using the Thorne-Roberts general mass variable flavour number scheme [13], which also provided prediction for the $F_2^{c\bar{c}}$. The Thorne-Roberts program is used in its *optimal* version rather than *standard* which was previously used in HERAPDF fits. The *optimal* scheme is preferred due to a smooth threshold transition (see [14]).

The predictions for jet cross sections are calculated using the NLOJET++ program [15]. The fast convolution of the matrix elements with PDFs and $\alpha_s$ is preformed by the FASTNLO program [16]. Renormalisation and factorisation scale choices follow those in the relevant publications, using a combination of $Q^2$ and transverse jet energy measured in the Breit frame $E_T$.

Value of the $m_c^{model}$ parameter is taken as $m_c^{model} = 1.5$ GeV which is obtained to be optimal for Thorne-Roberts scheme in [5]. The strong coupling constant is fixed to value of $\alpha_s(M_Z) = 0.119$, which is obtained from a fit with free $\alpha_s(M_Z)$. The other model parameters and uncertainties due to the assumptions made follow closely approach described in HERAPDF 1.0 publication [3].

# 4 PDF parametrisation

The parametrisation of PDFs at the starting scale of $Q_0^2 = 1.9$ GeV$^2$ follows the general approach taken in the previous HERAPDF fits. Five PDFs are parametrised, including gluon ($g$), valence quarks ($u_v$, $d_v$) and sea quarks ($\bar{U}$, $\bar{D}$) taking following functional form:

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

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The parameters $A_g, A_{u_v}, A_{d_v}$ are constrained by quark counting and momentum 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 at the starting scale $Q_0$ (assumed to be $f_s = 0.31$). The inclusion of these constraints results in a 13-parameter fit, while further parameters are considered when evaluating the parametrisation uncertainty. Assumption on the starting scale $Q_0$ lead to additional parametrisation uncertainty which is taken into account as well.

The parametrisation used in this study is slightly different from the parametrisation used for HERAPDF 1.6 where 14 free parameters were considered. In addition to the parameters introduced here, a non-vanishing linear term $D_{u_v} x$ is allowed which is considered as part of the parametrisation uncertainty in this study.

# 5 Results

The inclusion of all the previously used HERA data into a single fit allows a determination of PDFs with a very good precision. The resulting fit is called HERAPDF 1.7. In figure 1 HERAPDF1.6 (a) and HERAPDF1.7 (b) are shown evaluated at the scale $Q^2 = 10$ GeV$^2$. In Fig. 1 (b) also HERAPDF 1.6 is plotted as a reference.

Overall only small differences are observed for the quark PDFs. HERAPDF 1.7 exhibits slightly higher parametrisation uncertainties, particularly visible for $u_v$ in the mid-$x$ range between $10^{-2}$ and $10^{-1}$ which previously was assigned to model uncertainty. This is a direct consequence of a transition from 14-parameters fit to 13-parameters fit which was discussed earlier.

HERAPDF 1.7 has a significantly steeper gluon distribution. This is due to use of *optimal* rather than *standard* Thorne-Roberts scheme together with increased $m_c^{model}$ value. The effect is reduced by the usage of higher $\alpha_s(M_Z)$ value which in general lead to a more gentle slope of gluon distribution. Also the experimental uncertainties are slightly reduced for HERAPDF 1.7 fit.

The usage of all previously studied data sets in a simultaneous fit is an important exercise to verify the consistency of all used HERA measurements. The study proves the high level of consistency between data sets, particularly if optimal values of model parameters like $m_c^{model}$ and $\alpha_s(M_Z)$ are used.

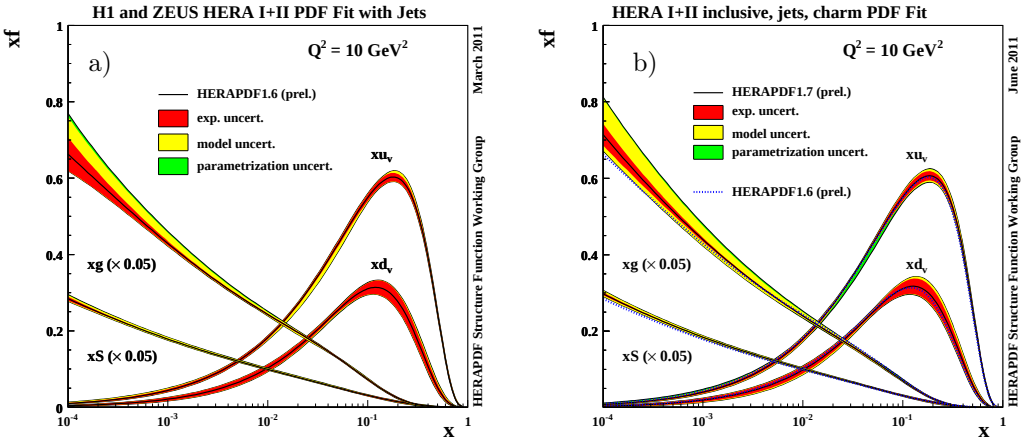


Figure 1: Gluon ($g$), valence quarks ($u_v$ and $d_v$) and sea quarks ($S = \bar{U} + \bar{D}$) parton density functions at $Q^2 = 10$ GeV with their experimental, model and parametrisation uncertainties for HERAPDF 1.6 (a) and HERAPDF 1.7 (b) fits.

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