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Latest results from HERA and their impact on the LHC

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Summary. — The H1 and ZEUS Collaborations at the HERA electron-proton collider are publishing their final analyses based on the full collected statistics and on the combination of their data sets. These results are an important input for the determination of the proton structure to be used for the predictions of proton-proton processes at the LHC. The most recent results obtained at HERA on inclusive, jet and heavy flavour cross-section and their impact on the determination of the proton structure are discussed. The proton parton distribution functions determined using the HERA data as sole input are presented. Predictions for cross-sections at the LHC based on these PDFs are shown.

PACS 13.60.Hb – Total and inclusive cross sections (including deep-inelastic processes).

1. – Introduction

After the end of the data taking at the electron-proton collider HERA in June 2007, the two Collaborations H1 and ZEUS are finalising their analyses using the full available data statistics. The main goal of the analyses is a deeper understanding of QCD and in particular of the proton parton distribution functions (PDFs). The best possible determination of the proton PDFs is a hot topic at the moment due to their impact on the predictions of cross-sections at the LHC. The HERA data cover a kinematic region in Bjorken x corresponding to the rapidity plateau for the LHC processes. Therefore a precise measurement of the proton PDFs in the HERA region provides through DGLAP evolution accurate PDFs for the LHC regimes.

The cross-sections of inclusive neutral- (NC) and charged-current (CC) deep inelastic $e^{\pm}p$ scattering (DIS) interactions provide an accurate determination of the valence- and the sea-quark content of the proton, as well as of the gluon. A further improvement of the understanding of the proton PDFs comes from other more exclusive QCD processes, like

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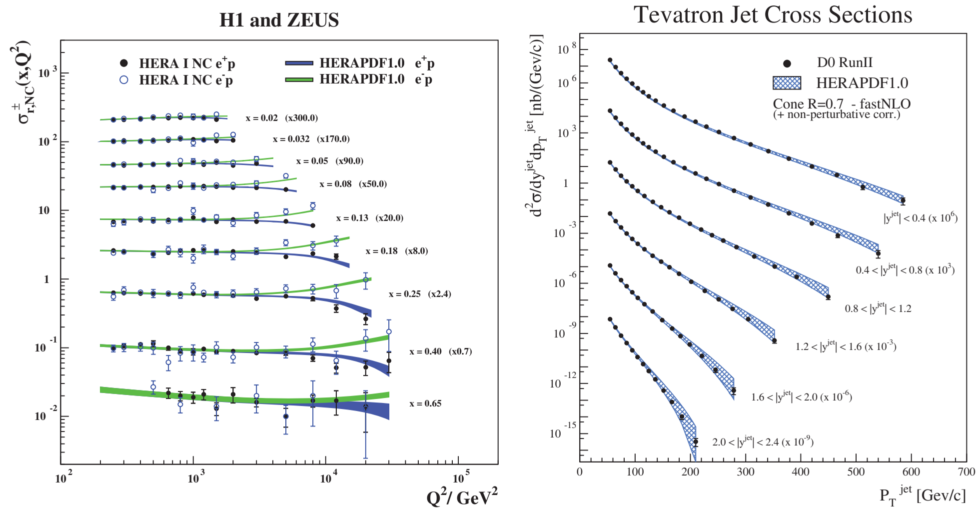

Fig. 1. – Left: HERAI combined NC cross-sections for e^-p and e^+p interactions. Right: jet production at D0 compared with theoretical predictions obtained using HERAPDF1.0.

jet and heavy flavour production. The study of such processes allows on the one hand to test theoretical predictions based on fits from inclusive data only. On the other hand, as also those measurements are reaching a very high precision, they can provide important input to the QCD fits. For this reason, the H1 and ZEUS Collaborations are combining their results in order to achieve the best possible precision of the measurements. In this paper a selection of the most recent H1 and ZEUS combined results is illustrated.

2. – Inclusive measurements

Inclusive NC and CC DIS cross-sections are measured at HERA to investigate the proton structure and to determine the proton PDFs. A combination of the H1 and ZEUS inclusive cross-sections based on the data collected between 1994 and 2000 (HERAI running) has been published [1].

The combination of the data sets was done using a χ^2 minimisation method [1]. The χ^2 function takes into account the correlated systematic uncertainties for cross-section measurements thus achieving a reduction of the systematic uncertainties in addition to the statistical. The combined cross-sections are everywhere significantly more precise than the individual measurements. The total uncertainty of the combined measurements is typically smaller than 2% for $3 < Q^2 < 500\,\mathrm{GeV}^2$ and reaches 1% for $20 < Q^2 < 100\,\mathrm{GeV}^2$, where Q^2 is the negative four-momentum squared of the intermediate boson. In fig. 1 (left) the combined HERAI NC cross-sections are shown separately for the e^-p and the e^+p data samples, and compared to theoretical predictions based on the HERAPDF1.0 PDF set (described below).

The HERAI combined H1 and ZEUS inclusive cross-sections were used as the sole input to extract the HERAPDF1.0 PDF set [1]. The data at low x determine the sea-quark and the gluon distributions while the large-x data constrain the up and down valence quark distributions. Due to the accuracy of the input data, the HERAPDF1.0 PDFs have a precision of the order of a percent in the medium-x region, which corresponds

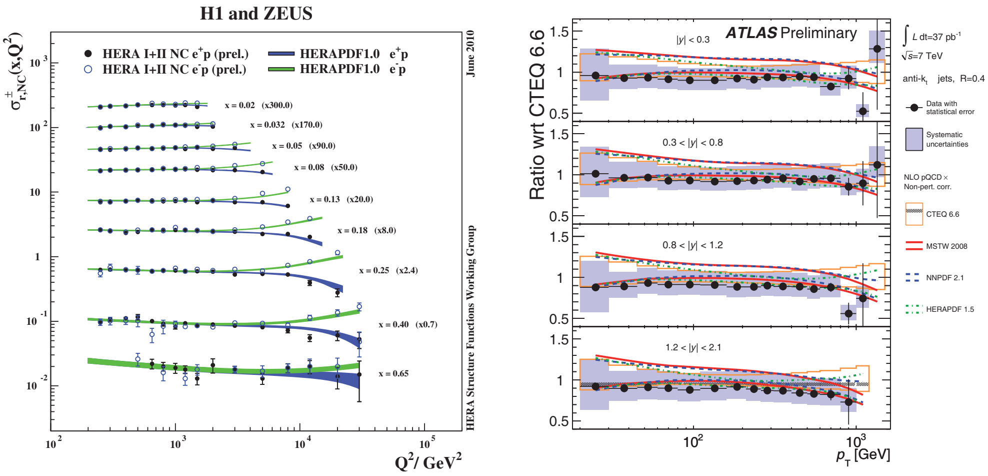

Fig. 2. – Left: HERAI+II combined NC cross-sections for e^-p and e^+p interactions. Right: ATLAS inclusive jet double-differential cross-sections as a function of the jet p_T in different central regions of rapidity $|y|$.

to the rapidity plateau region for the LHC measurements. To test the goodness of the PDFs in a kinematic region not covered by the data used to extract them, theoretical predictions for jet production at the Tevatron were produced. The description of the data obtained for, *i.e.* jet production at D0 [2] is good, as shown in fig. 1 (right).

The statistical precision of the combined HERAI data is limited in the high-x and high-Q^2 regions. The precision of the data in this region can be significantly improved by adding to the combination the NC and CC cross-sections measured using the data collected in the HERAII running period (2003–2007). This corresponds to a three-fold increase in the overall statistics and roughly a 10-fold increase in the e^-p data sample.

The combination of the HERAI and a partial [3, 4] HERAII data sample has been recently released as preliminary result [5]. The only missing data are the ZEUS NC e^+p cross-sections for HERAII [6] which were released after this combination was performed.

The improved precision of the HERAI+II combined data is clearly visible when fig. 1 (left) is compared to fig. 2 (left), where the HERAI and HERAI+II NC cross-sections are shown. The uncertainties are visibly reduced in the high-x and high-Q^2 regions. The data are compared with theoretical predictions based on the HERAPDF1.0, which describe the data well.

The HERAI+II combined cross-sections have been used as the sole input to extract the HERAPDF1.5 PDF set [7]. Predictions based on the HERAPDF1.5 are compared to jet cross-sections measured at ATLAS [8] in fig. 2 (right). The predictions based on the HERA data alone are able to describe well jet production at ATLAS.

3. – Jet and heavy flavour production

Although very precise proton PDFs can be obtained by using only inclusive NC and CC cross-section measurements, the study of jet and heavy flavour production can improve the picture. In this section two recent results obtained using jet and charm data in the PDF fits are discussed.

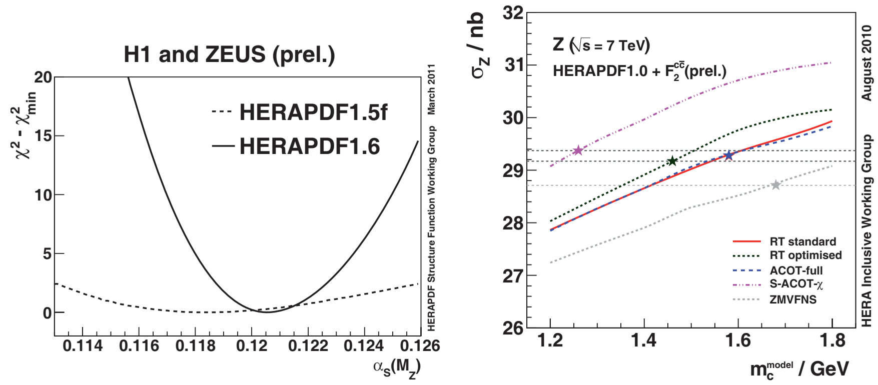

Fig. 3. – Left: $\Delta\chi^2$ distribution as a function of $\alpha_s(M_Z)$ for the fit to the inclusive (HERAPDF1.5f) and inclusive+jet data samples (HERAPDF1.6). Right: Z production cross-section at the LHC for $\sqrt{s} = 7\,\text{TeV}$ as a function of m_c^{model}.

3˙1. *Jet production and* α_s. – The data sample used for the extraction of the HERAPDF1.5 PDF set was enlarged to include jet cross-section measurements [9], and the PDF set HERAPDF1.6 was extracted [10]. The use of jet cross-sections allows the simultaneous determination in the fit of the PDFs and of the strong coupling constant, α_s. This was not possible in the previous fits for the extraction of the HERAPDF1.0 and 1.5, as the correlation between the gluon PDF and $\alpha_s(M_Z)$ is too strong when inclusive data alone are used.

A new parameterisation of the PDFs was introduced in order to allow a greater flexibility in the gluon density. This helps to avoid a parameterisation bias when more data which are sensitive to the gluon distribution, like jet production, are included. The fit to the NC and CC data included in HERAPDF1.5, but using the new PDF parameterisation, is referred to as HERAPDF1.5f.

The α_s dependence of the fits to the inclusive and the inclusive+jet data is well illustrated in fig. 3 (left), where the χ^2 of the HERAPDF1.5f and HERAPDF1.6 with free α_s is shown as a function of $\alpha_s(M_Z)$. The HERAPDF1.5f fit shows a shallow minimum, while the HERAPDF1.6 fit with the addition of the jet data provides a strong constraint on α_s.

3˙2. *Charm production*. – The combined H1 and ZEUS measurement of the charm contribution to the proton structure function F_2, $F_2^{c\bar{c}}$ [11], was used to investigate the PDF fit formalism, in particular the role of the charm mass parameter in the different models [12] used by different groups of fitters. In each model, the onset of the heavy quarks is controlled by the parameters $m_{c,b}^{\text{model}}$. The charm data are sensitive to the value of m_c^{model} and to the scheme used for the treatment of heavy quarks in the PDF fits.

For each of the different heavy-flavour schemes, a fit to the combined $F_2^{c\bar{c}}$ data together with the published combined HERAI data was performed. In each implementation an optimal value of m_c^{model} was determined as that corresponding to the best description of the data. The obtained optimal values for m_c^{model} show a sizable spread, from 1.26 to 1.68 GeV. However, the description of the data is satisfactory in each of the schemes as long as the optimal charm mass parameter is used.

PDFs obtained from fits with different m_c^{model} were used to predict W and Z production cross-sections at the LHC. A sizable spread in the predictions was observed for each model when m_c^{model} was varied between 1.2 and 1.8 GeV, as well as when considering different schemes at a fixed value of m_c^{model}. This spread is significantly reduced when the optimal value of m_c^{model} is used in each model, as shown in fig. 3 (right).

The inclusion of the $F_2^{c\bar{c}}$ measurements therefore helps to reduce in a model-independent way the uncertainties on the W and Z production cross-sections at the LHC due to the heavy flavour treatment in the PDF fit.

4. – Conclusions

The ZEUS and H1 Collaborations are combining their data in order to achieve the best possible precision in the measurement of inclusive neutral- and charged-current DIS cross-sections, jets and heavy flavour processes. Precise sets of parton distribution functions have already been published using the data collected in the HERAI data-taking period. Now a better precision is provided by including the latest HERA data and by improving the fit also with the help of jets and heavy flavour measurements. A precise input for the determination of the proton PDFs for cross-section predictions at the LHC is provided.

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