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HERAPDF1.5LO PDF Set with Experimental Uncertainties

H1 and ZEUS Collaborations

Abstract

This note presents the HERAPDF1.5 PDF set evolved to leading order (LO) α_s using DGLAP evolution equations. This LO PDF is particularly useful for Monte Carlo event generators, based on LO matrix elements plus parton showers.

1 Introduction

Parton densities evolved to leading order (LO) in α_s are essential for the proper simulation of parton showers (PS) and underlying event properties in LO+PS Monte Carlo (MC) event generators.

In the light of the imminent restart of the LHC with upgraded proton energy beams, new tunes for the underlying events and minimum bias are needed using various MC generators. Since the higher energies at the LHC will cover measurements to lower values of the Bjorken-x variable, the HERAPDF PDF sets with its special emphasis on the small-x structure functions and its validity at small scales is important for equipping the MC generators with accurate PDFs that enable precise predictions of the underlying event properties and also for minimum bias events and the simulation of pile-up events.

In this note we present the HERAPDF1.5 LO set based on the same settings as used for the HERAPDF1.5 NLO PDF set [1], with the exception of the use of the LO DGLAP splitting kernel and, correspondingly, of a different value for the strong coupling constant.

2 Technical Description of the HERAPDF1.5 LO PDF set

The framework used in this QCD analysis is based on the HERAFitter project [2], with evolution code as implemented in the QCDNUM package [3]. The results were cross checked by an independent framework referred to as the ZEUS Fitter [4]. The QCD fit settings are adopted from the previous HERAPDF fits to preliminary combined H1 and ZEUS HERA I+II data of inclusive deep-inelastic scattering used to extract HERAPDF1.5 NLO [1] and NNLO PDF [5] sets. The experimental uncertainties of data are treated in the same way as in the HERAPDF1.5 NLO and NNLO fits.

The PDFs parametrised at the starting scale of the evolution[1] of $Q_0^2 = 1.9$ GeV^2 are the valence distributions xu_v and xd_v, the gluon distribution xg, and the $x\bar{U}$ and $x\bar{D}$ distributions, where $x\bar{U} = x\bar{u}$, $x\bar{D} = x\bar{d} + x\bar{s}$. The following functional form is used to parametrise them and is identical to the HERAPDF1.5 NLO set:

$$xu_v(x) = A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + E_{u_v} x^2) \quad (1)$$

$$xd_v(x) = A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}} \quad (2)$$

$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}} \quad (3)$$

$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}} (1-x)^{C_{\bar{D}}} \quad (4)$$

$$xg(x) = A_g x^{B_g} (1-x)^{C_g} \,. \quad (5)$$

where the normalization parameters ($A_{u_v}; A_{d_v}; A_g$) are constrained by quark counting and momentum sum rules. The B exponents for the quark sea and valence distributions, respectively, are set equal, $B_{\bar{U}} = B_{\bar{D}}$ and $B_{u_v} = B_{d_v}$. The strange quark distribution at the starting scale is assumed to be a constant fraction of $\bar{D}$, $x\bar{s} = f_s x\bar{D}$, chosen to be $f_s = 0.31$ such that $\bar{s} \approx \bar{d}/2$.

[1] chosen to be below the charm mass threshold as required by the QCDNUM package

In addition, to ensure that $x\bar{u} = x\bar{d}$ as $x \to 0$, $A_{\bar{U}} = A_{\bar{D}}(1 - f_s)$. This yields the same 13 free parameters as in the NLO fit.

The PDFs are evolved using the DGLAP evolution equations at LO with the squared renormalisation and factorisation scales set to the squared momentum transfer of the NC or CC interaction, Q^2. The value for $\alpha_s(M_Z)$ has been chosen to be 0.13, which yields the best level of agreement between data and the fit[2].

As for previous HERAPDF PDF sets, the analysis is performed accounting for the charm and beauty quark masses in the Thorne-Roberts (TR) Variable Flavour Number Scheme [8].

The experimental uncertainties on the PDFs are determined using the $\Delta\chi^2 = 1$ criterion leading to uncertainties with a confidence level of 68%. The χ^2 is defined as in [9]:

$$\chi^2 = \sum_i \frac{\left[\mu_i - m_i\left(1 - \sum_j \gamma_j^i b_j\right)\right]^2}{\delta_{i,\mathrm{unc}}^2 m_i^2 + \delta_{i,\mathrm{stat}}^2 \mu_i m_i \left(1 - \sum_j \gamma_j^i b_j\right)} + \sum_j b_j^2 \qquad (6)$$

where m_i is the theoretical prediction and μ_i is the measured cross section at point i, (Q^2, x, s) with the relative statistical and uncorrelated systematic uncertainty $\delta_{i,\mathrm{stat}}$, $\delta_{i,\mathrm{unc}}$, respectively. The values γ_j^i denote the relative correlated systematic uncertainties and b_j their shifts with a penalty term $\sum_j b_j^2$ added.

3 QCD Fit Results and Comparisons

The LO QCD fit to the preliminary combined H1 and ZEUS HERA I+II data [1] yields a reasonable total χ^2 of 762 for 664 degrees of freedom, slightly worse than the NLO χ^2 of 736. The choice of $\alpha_s(M_Z) = 0.13$ was motivated through a scan procedure, where the data were refit with other choices of the strong coupling and the best value in terms of quality of fit was chosen. The resulting PDF distribution plots for the starting scale as well as for momentum transfers of 10, 100 and 10000 GeV^2 can be found in Figs. 1-4. They are presented together with uncertainty bands reflecting the experimental uncertainties transferred from the data to the PDFs. In line with the restricted purpose of the LO sets, no further model or theoretical uncertainties were evaluated.

Figures 5-9 show LO cross section predictions obtained from the fitted PDFs, overlayed on the data used in the fits, for the neutral current and charged current e^+p and e^-p differential measurements. Good agreement is achieved.

The LO PDF set has been formatted to match the LHAPDF style, similarly to what was done for the HERAPDF1.5 NLO set, compatible with the LHAPDFv5 grid style. The LHAPDF grid contains 21 members with member 0 representing the central fit, while members $1-20$ correspond to the experimental uncertainties on the PDFs. The 20 error PDFs should be treated two by two as the up and down excursions for each of the 10 eigenvectors defined by the number of free PDF parameters in the fit, such that the symmetric error is calculated as the quadratic sum of the difference between the up and down eigenvectors divided by two. If asymmetric errors are desired equation 43 of [10] may be used.

[2] This value agrees with the value used by the CTEQ LO set [6] of $\alpha_s(M_Z) = 0.12978$, which is different from the value chosen by the MSTW LO set [7] of $\alpha_s(M_Z) = 0.136$.

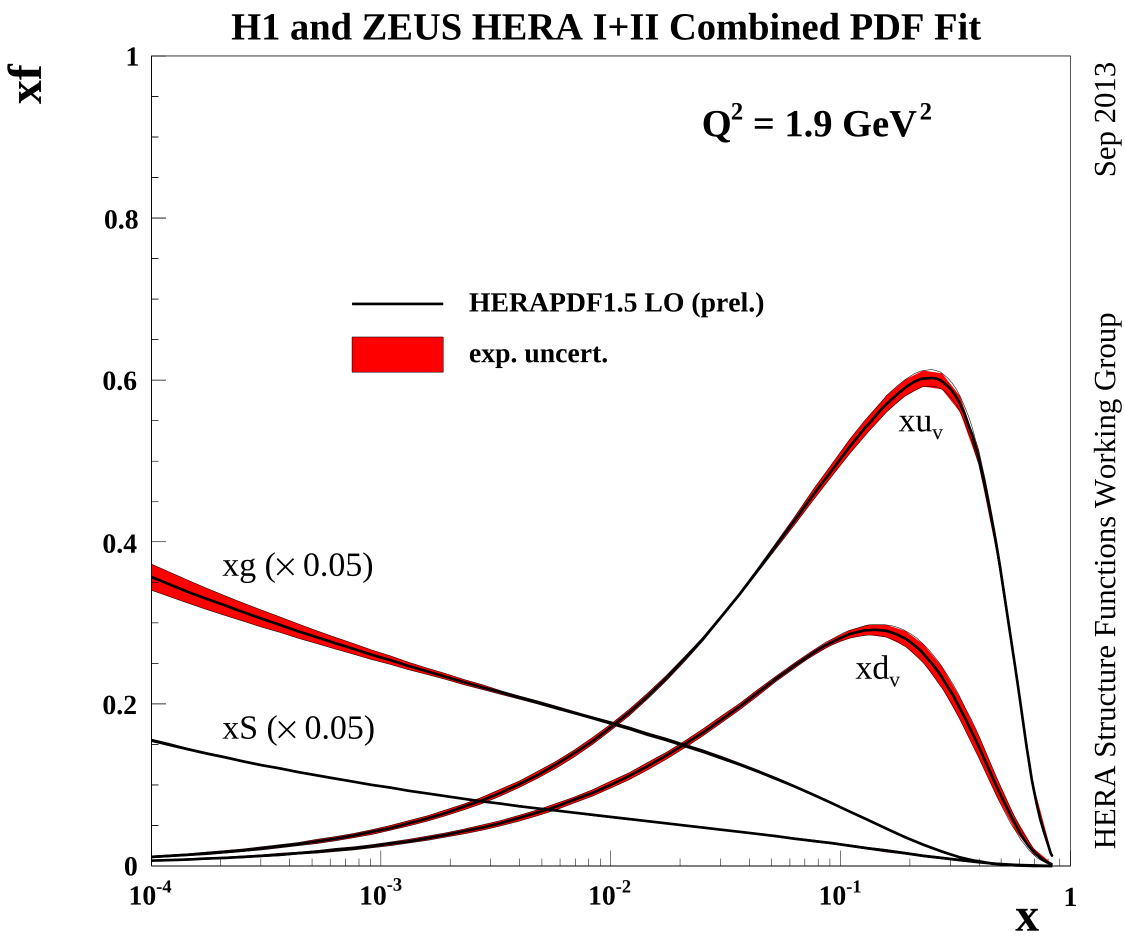

Figure 1: Summary of LO PDFs at $Q^2 = 1.9$ GeV^2 .

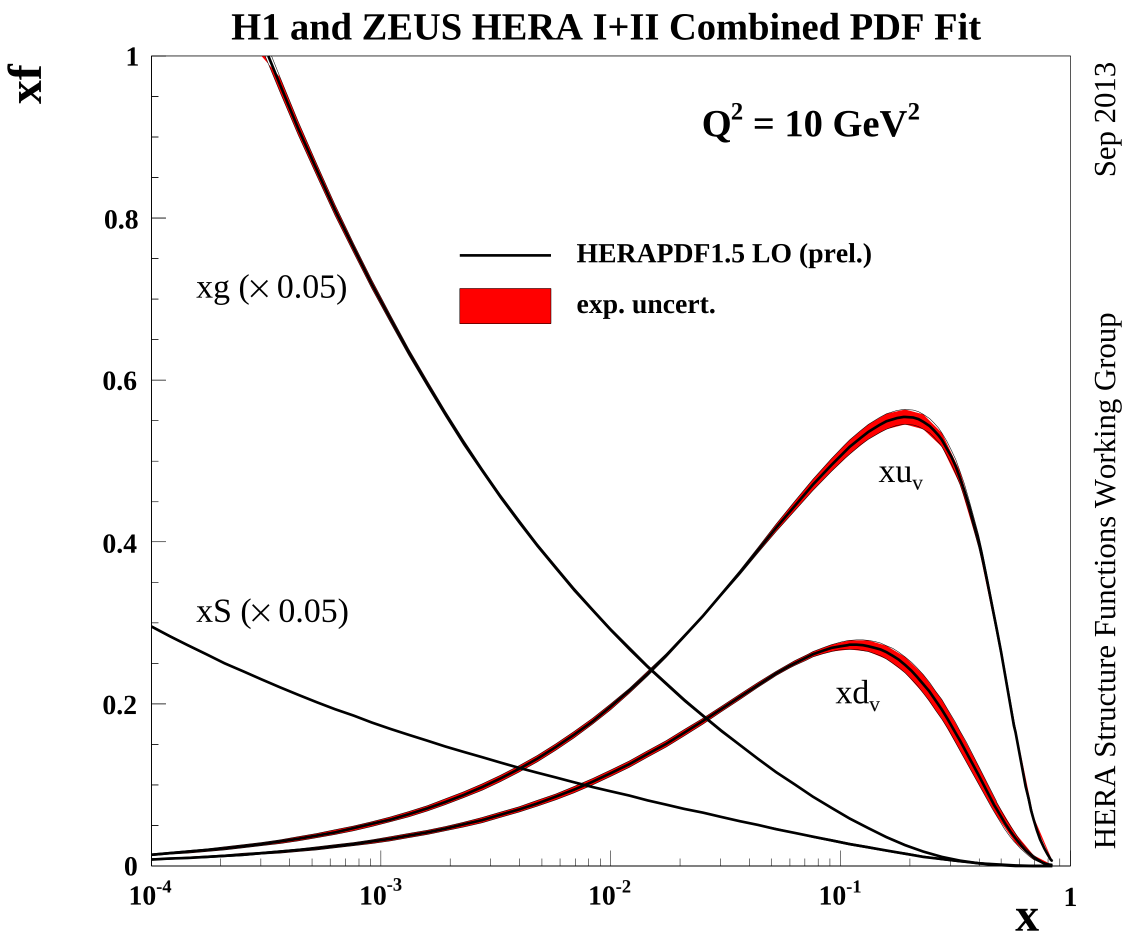

Figure 2: Summary of LO PDFs at $Q^2 = 10.0~\mathrm{GeV}^2$.

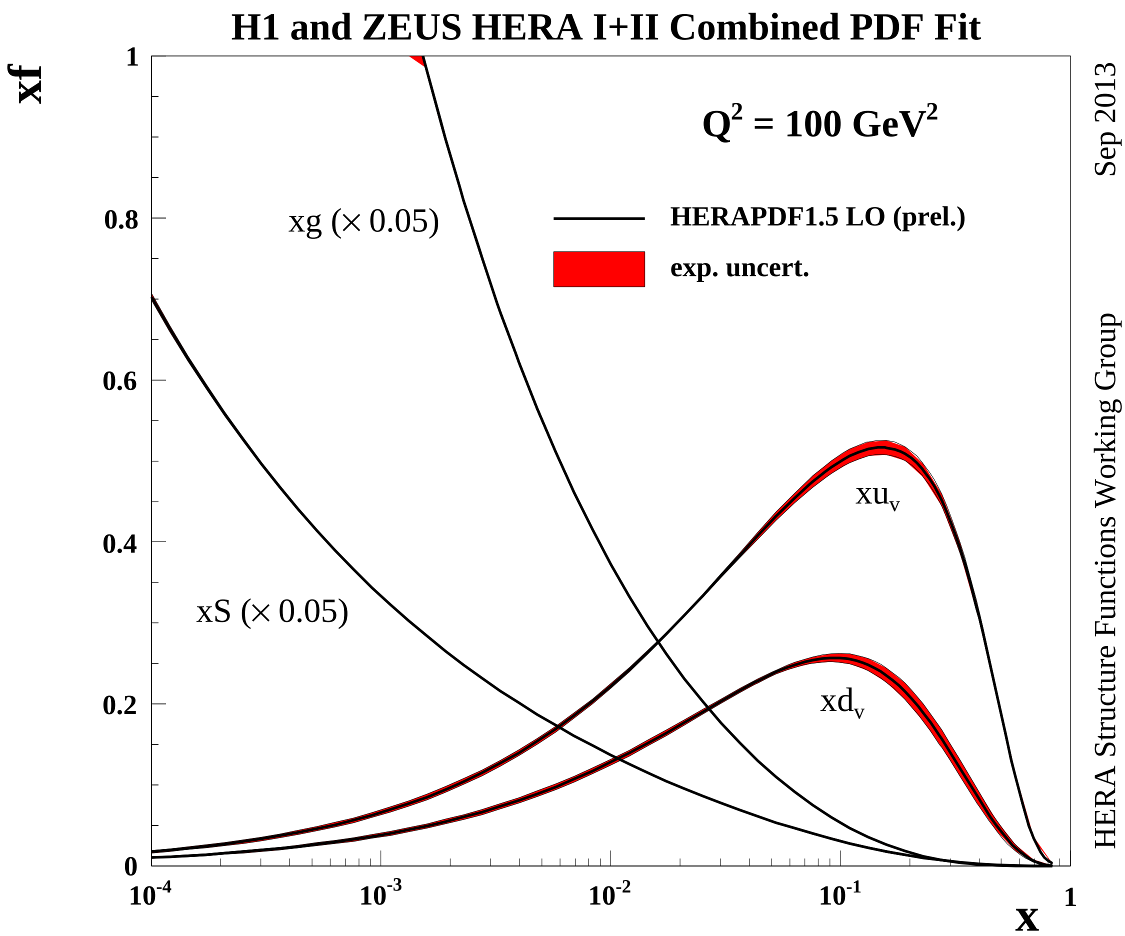

Figure 3: Summary of LO PDFs at $Q^2 = 100\ \mathrm{GeV}^2$.

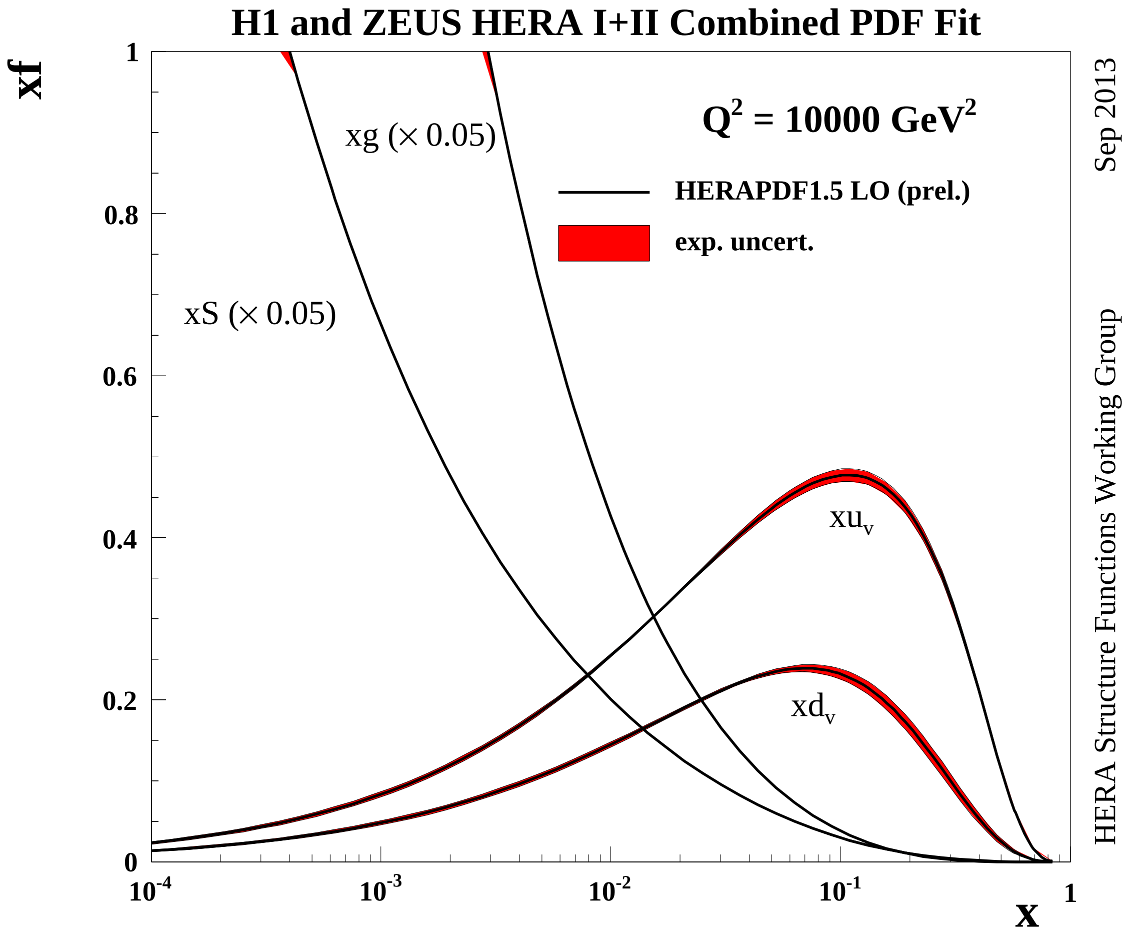

Figure 4: Summary of LO PDFs at $Q^2 = 10000\ \mathrm{GeV}^2$.

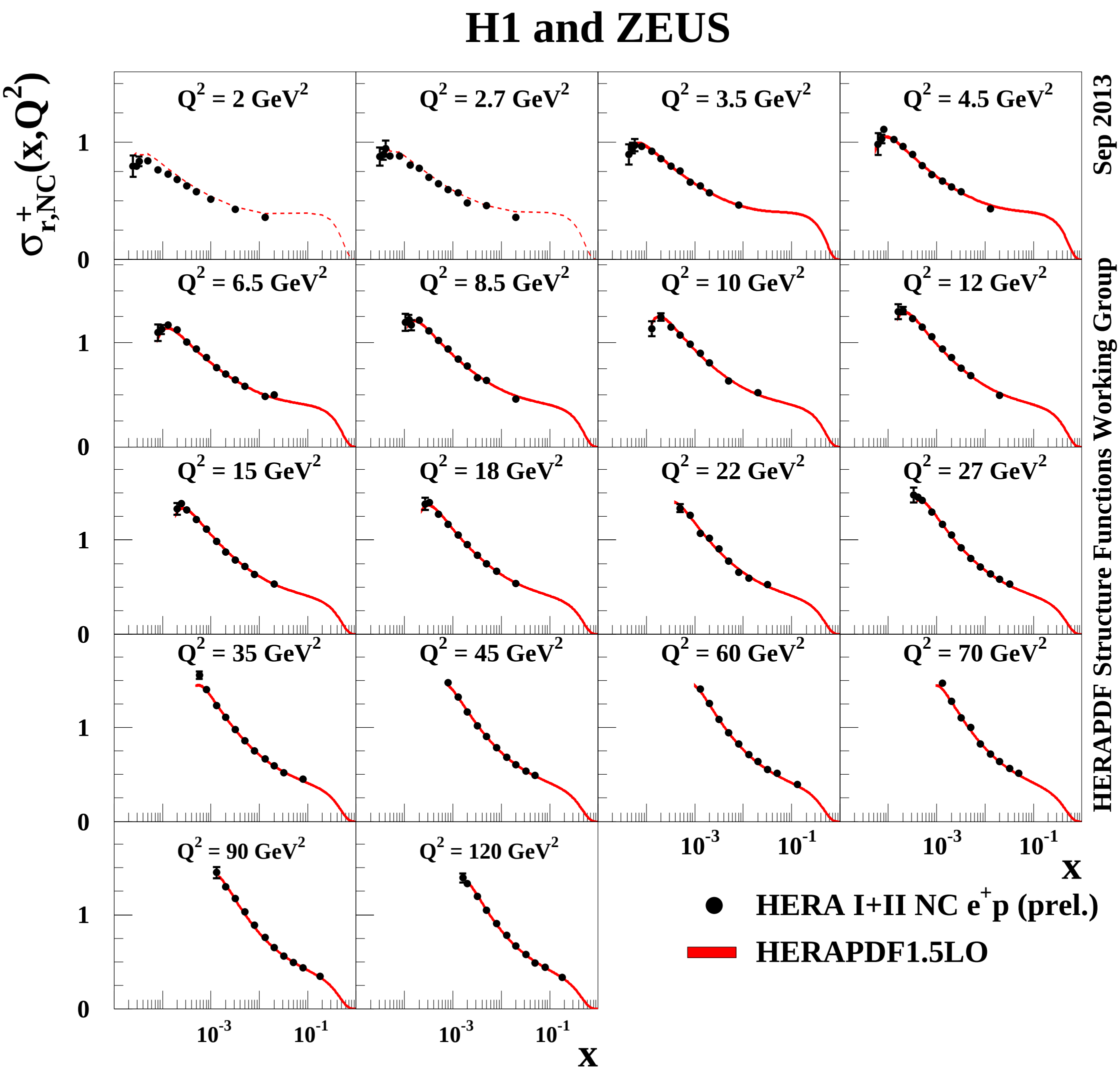

Figure 5: Neutral current e^+p differential cross section measurements (data points, part I, for lower Q^2 bins) compared to predictions based on the HERAPDF1.5 LO PDF set with experimental uncertainties included in the predictions (contious bands). The dashed line indicates predictions for regions not included in the fit.

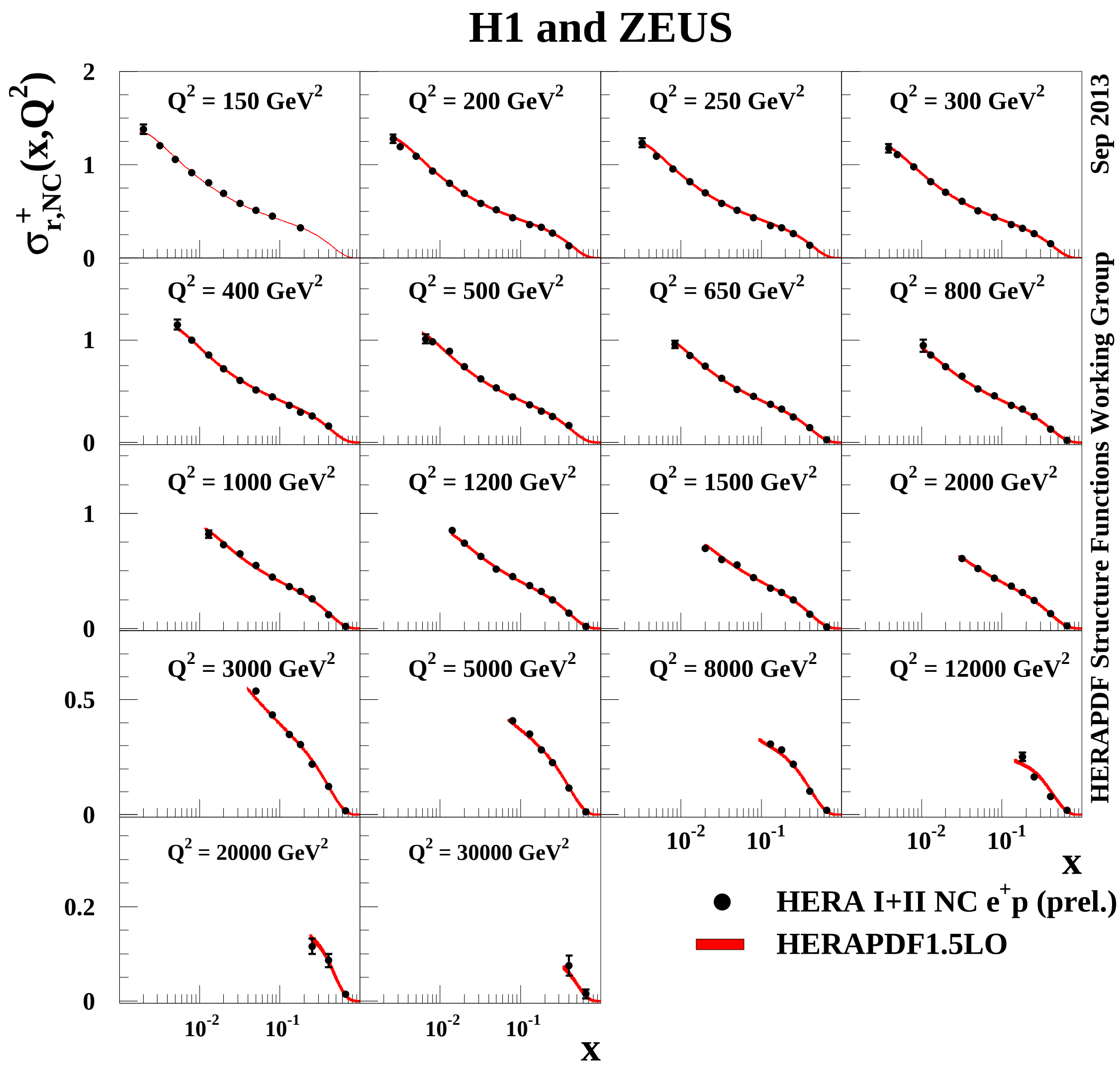

Figure 6: Neutral current e^+p differential cross section measurements (data points, part II, for higher Q^2 bins) compared to predictions based on the HERAPDF1.5 LO PDF set with experimental uncertainties included in the predictions (continous bands).

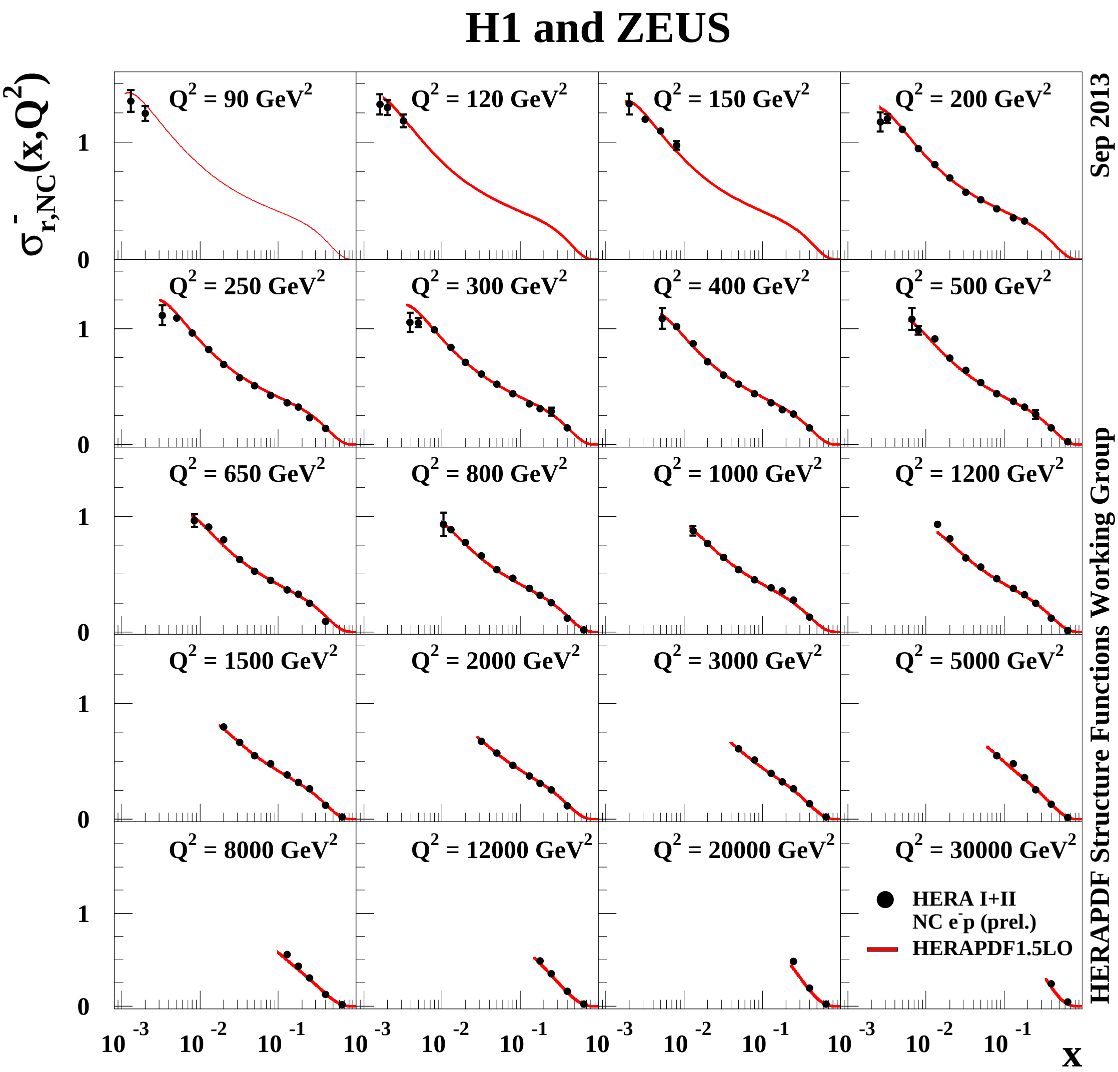

Figure 7: Neutral current e^-p differential cross section measurements (data points) compared to predictions based on the HERAPDF1.5 LO PDF set with experimental uncertainties included in the predictions (continous bands).

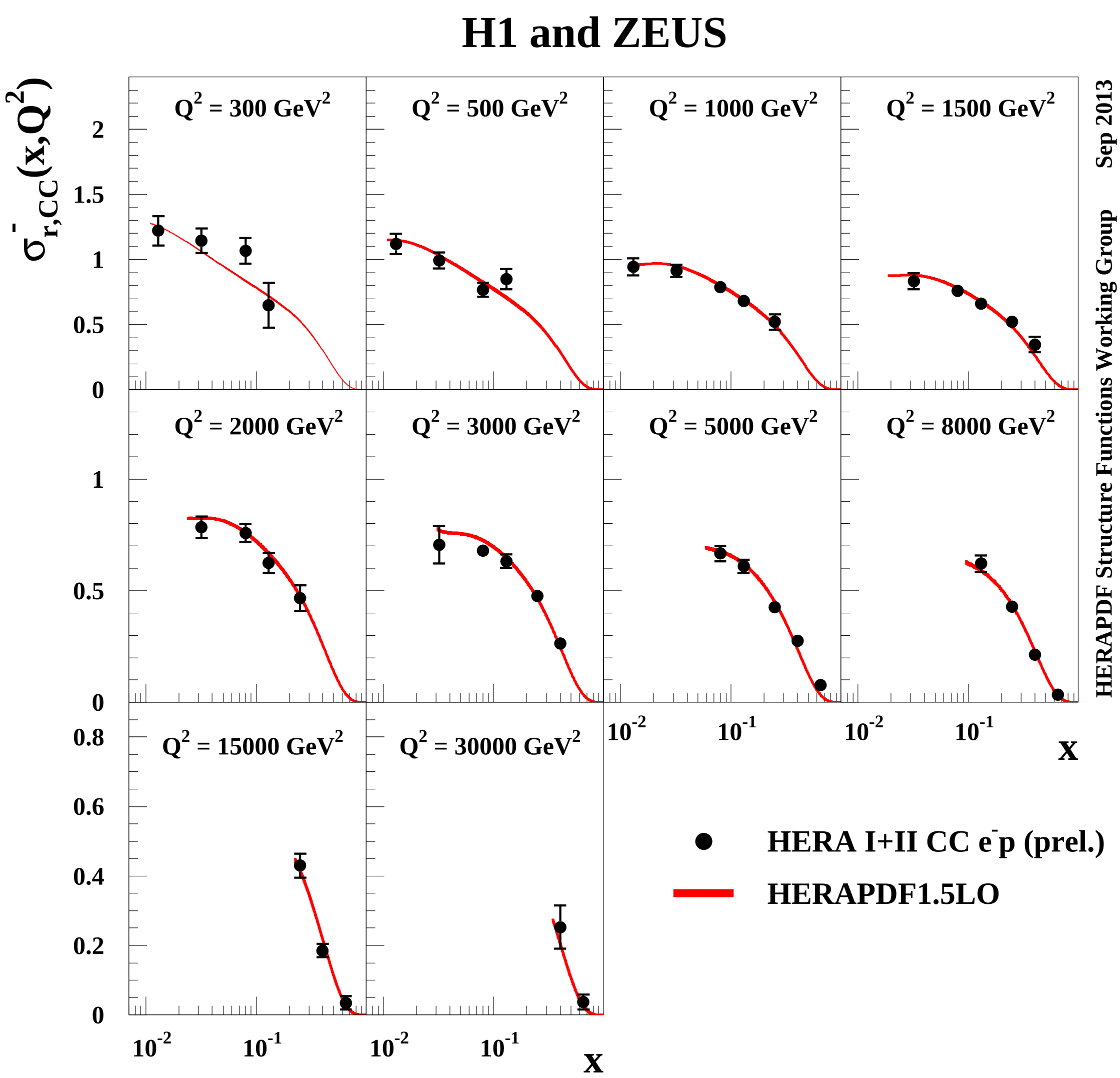

Figure 8: Charged current e^-p differential cross section measurements (data points) compared to predictions based on the HERAPDF1.5 LO PDF set with experimental uncertainties included in the predictions (continous bands).

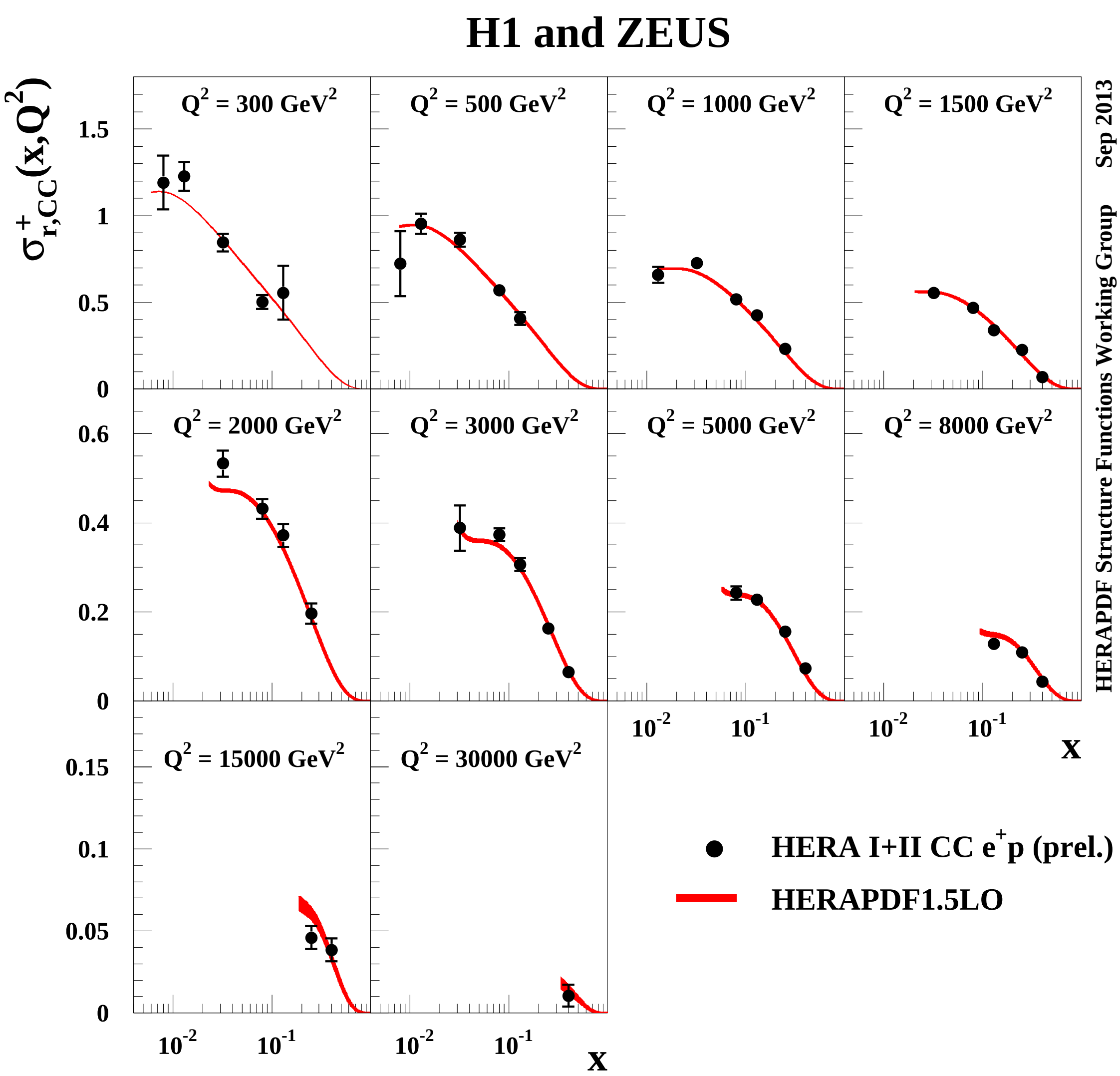

Figure 9: Charged current e^+p differential cross section measurements (data points) compared to predictions based on the HERAPDF1.5 LO PDF set with experimental uncertainties included in the predictions (continous bands).

4 Summary

We have extracted a HERAPDF1.5 LO PDF set based on the preliminary HERA I+II H1 and ZEUS combined NC and CC measurements, providing experimental uncertainties. The fit describes the data reasonably well. The set has been formatted to match the LHAPDF style, similarly to what was done for the HERAPDF1.5 NLO set, compatible with the LHAPDFv5 grid style.

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