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Combination of H1 and ZEUS Deep Inelastic ep Scattering Cross Section Measurements and NLO-QCD analysis

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Deep inelastic scattering cross section measurements previously published by the H1 and ZEUS collaborations are combined. The procedure takes into account the systematic error correlations in a coherent approach, leading to a significantly reduced overall cross section uncertainty by cross calibrating the various data sets. The analysis is based on data with momentum transfers $Q^2 > 0.045$ GeV^2 collected by the H1 and ZEUS collaborations between the years 1995 and 2000. This combined HERA-I data set, of neutral and charged current inclusive cross sections for e+p and e-p scattering, is used as the sole input for a next-to-leading order (NLO) QCD parton distribution function (PDF) fit. The consistent treatment of systematic uncertainties in the joint data set ensures that experimental uncertainties on the PDFs can be calculated without need for an increased χ^2 tolerance. This results in PDFs with greatly reduced experimental uncertainties compared to the separate analyses of the ZEUS and H1 experiments. Model uncertainties, including those arising from parametrization dependence, are also carefully considered.

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1. Introduction

Deep inelastic scattering (DIS) at HERA has been crucial to the exploration of proton structure and quark-gluon interaction dynamics. The analysis reported here presents the combination of the published H1 and ZEUS measurements from the HERA I data taking period, from 1994 to 2000, in neutral (NC) and charged current (CC) $e^{\pm}p$ scattering corresponding to the total integrated luminosity of about 200 pb^{-1} for $e^{+}p$ and 30 pb^{-1} for $e^{-}p$. The combination of the H1 and ZEUS data provides the most accurate measurements of DIS inclusive cross-sections over an extended kinematic range of $0.045 < Q^2 < 30000$ GeV^2 and $6 \times 10^{-5} < x < 0.65$. These combined cross-sections are then used as a sole input into a QCD analysis to extract new proton's parton densities (HERAPDF0.2) which are reported here as well.

2. Combination of the H1 and ZEUS Cross-Sections

Prior combination of the data, all points are moved to a common (x, Q^2) grid, as well as to a common centre of mass energy, so that sets obtained with a proton energy beam of 820 GeV where moved to the 920 GeV proton beam energy. The combination of data uses the χ^2 minimisation method and it takes into account the correlated systematic uncertainties for the H1 and ZEUS cross-section measurements [1]. So that, for a single data set the χ^2 is defined as

$$\chi^2_{\rm exp}(\mathbf{m},\mathbf{b}) = \sum_i \frac{\left[m^i - \sum_j \gamma^i_j m^i b_j - \mu^i\right]^2}{\delta^2_{i,\rm stat}\,\mu^i\left(m^i - \sum_j \gamma^i_j m^i b_j\right) + (\delta_{i,\rm uncor}\, m^i)^2} + \sum_j b^2_j \,. \tag{2.1}$$

Here μ^i is the measured value at a point i (corresponding to a (x, Q^2) point) and γ^i_j, $\delta_{i,\rm stat}$ and $\delta_{i,\rm uncor}$ are relative correlated systematic, relative statistical and relative uncorrelated systematic uncertainties, respectively. The function $\chi^2_{\rm exp}$ depends on the true values m^i for the measurements and the shifts b_j of the correlated systematic error sources. Several data sets providing a number of measurements are represented by a total χ^2 function, which is built from the sum of the $\chi^2_{\rm exp}$ functions for each data set. All the NC and CC cross-section data from H1 and ZEUS are combined in one simultaneous minimisation, so that the resulting shifts of correlated systematic uncertainties propagate coherently to both CC and NC data.

All systematic uncertainties are treated multiplicatively. However, an alternative combination method is checked, for which only normalisation uncertainties are considered multiplicatively while all other uncertainties are treated additively. The difference between these averaging methods is taken as a procedural error and it has a typical size below 0.5% for the low Q^2 data and reaching few percents for high Q^2 .

Since the H1 and ZEUS collaborations use similar methods for detector calibration and employ similar Monte Carlo simulation models for radiative corrections, for the hadronic Þnal state simulation and for photoproduction background subtraction, possible correlations could occur. To investigate this effect, 12 pairs of sources of systematic uncertainty of common origin are identified. It is found that only two systematic sources contribute significantly, the photoproduction background ($\delta_{\gamma p}$) and the hadronic energy scale (δ_{had}), and are considered as additional procedural uncertainties with typical values below 0.5%, but larger at high $y > 0.5$ for $\delta_{\gamma p}$ and low y for δ_{had}. The combination procedure results into averaging the 1402 data points into unique 741 cross-section measurements with 110 source of correlated systematic and 3 procedural uncertainties.

3. QCD Analysis

The new combined data is used as a sole input into a QCD fit analysis to extract the proton's PDFs [1]. The HERA measurements are at $W^2_{min} = 300$ GeV^2 and $x_{max} = 0.65$, so that the target mass corrections and higher twist contributions are believed to be small. In addition, to restrain to the region where perturbative QCD is valid, only data above $Q^2 = 3.5$ GeV^2 is used in the central fit. The fit procedure consists first in parametrising PDFs at a starting scale $Q^2_0 = 1.9$ GeV^2, chosen to be below the charm mass threshold. The PDFs are then evolved using DGLAP evolution equations at NLO in the $\overline{MS}$ scheme with the renormalisation and factorisation scales set to Q^2 scale and the stong coupling $\alpha_s(M_Z) = 0.1176$ [2]. The QCD predictions for the structure functions are obtained by convoluting the PDFs with the calculable NLO coefficient functions. In this analysis, the coefficient functions have been calculated using an improved theoretical scheme of general mass variable favour of Thorne and Roberts [3]. In this analysis the following PDFs are parametrised: xu_v, xd_v, xg and $x\bar{U}$, $x\bar{D}$, where $x\bar{U} = x\bar{u}$, $x\bar{D} = x\bar{d} + x\bar{s}$. The following standard functional form is used to parametrise PDFs

$$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2), \tag{3.1}$$

with the normalisation parameters, A_{uv}, A_{dv}, A_g, constrained by the sum-rules. The B parameters $B_{\bar{U}}$ and $B_{\bar{D}}$ are set equal, $B_{\bar{U}} = B_{\bar{D}}$, such that there is a single B parameter for the sea distributions. The strange quark distribution is already present at the starting scale and is assumed here that, $x\bar{s} = f_s x\bar{D}$ at Q^2_0. The strange fraction is chosen to be $f_s = 0.31$ which is consistent with determinations of this fraction using neutrino induced di-muon production. In addition, to ensure that $x\bar{u} \to x\bar{d}$ as $x \to 0$, $A_{\bar{U}} = A_{\bar{D}}(1-f_s)$. Only the parameters that significantly contribute to χ^2 are left to vary. Additional requirements for the central fit are that all PDFs are positive definite and the valence quark approximation $d_v > \bar{d}$ is satisfied at large x. The best fit results in a total of 10 free parameters.

The model uncertainties are evaluated by varying the input assumptions. So that, the variation of the starting scale and of the Q^2_{min} are considered as model uncertainties, as well as the variations of the heavy quark masses which are set to the standard values of $m_c = 1.4$ GeV and $m_b = 4.75$ GeV for the central fit. The variation of f_s is also considered as a model uncertainty.

Besides the model uncertainties, an attempt is made to quantify uncertainties related to the PDF parameterisation. This dependence is assessed by considering all possible combinations for 11 parameter fits with D and E non-zero, which in fact do not represent a significant improvement in fit quality compared to the central fit. In addition, the criteria that all PDFs should be positive or that $d_v > \bar{d}$ at high x are no longer imposed for these fits. The parametrisation uncertainty is estimated as an envelope which is formed as a maximal deviation at each x value from the central fit of these 11 parameter fits.

The consistency of the input data set and its small systematic uncertainties enable us to calculate the experimental uncertainties on the PDFs using the χ^2 tolerance $\Delta\chi^2 = 1$. In addition, the role of correlated systematic uncertainties is no longer crucial since these uncertainties are relatively small. For HERAPDF0.2, the 110 systematic uncertainties are added in quadrature, and the 3 procedural sources of uncertainty are offset, which is the most conservative choice to estimate the experimental uncertainty. The resulting χ^2 per degree of freedom for the central fit is found to be 574/582.

[1] The program QCDNUM [4] has been used.

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4. Results

Figure 1 shows the extended kinemtaic range available to HERA combined cross section measurements as compared to the fixed target data. The line corresponds to the HERAPDF0.2 predictions which agrees very well with all data. On the right hand side, the summary plot for the HERAPDF0.2 is shown, displaying the gluon, sea and valence distributions at $Q^2 = 10$ GeV^2. It can be observed that at this scale the errors of the sea and gluon distributions in the low x region are dominated by the model uncertainties, of which the largest one is Q_0^2. At high x, the dominant uncertainty is the PDF parametrisation, as expected. The precision of the HERAPDF0.2, which includes the experimental, model and parametrisation uncertainies, is impressive for the low-x sea and gluon. However, further investigation to assess the PDF parametrisation uncertainty is needed by exploring various functional forms that could affect the low-x region.

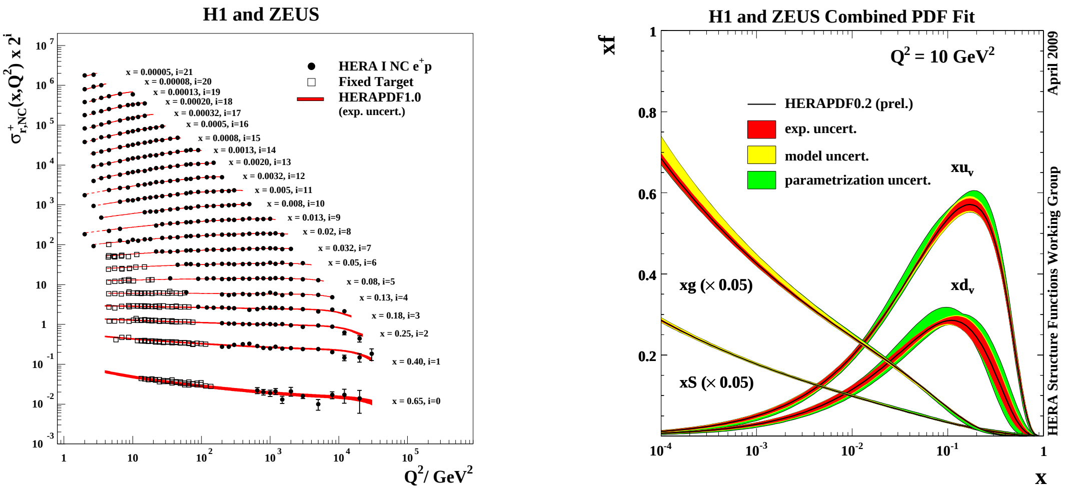

Figure 1: Figure shows on the left hand side the extended kinematic range of the HERA data compared to fixed target results, together with the fit line from HERAPDF0.2. On the right hand side the summary plot for the HERAPDF0.2 at the $Q^2 = 10$ GeV^2 is shown: gluon, sea (which are scaled by a factor of 0.05) and the valence distributions. The errors include the experimental (red), model (yellow) and the PDF parametrisation (green) uncertainties.

5. Summary

It this proceedings the combination of the published HERA I H1 and ZEUS cross section measurements was presented followed by the NLO QCD analysis of this new data to extract HERAPDF0.2 set based on an improved theoretical predictions which includes the heavy flavour treatment. The consistent treatment of systematic uncertainties in the joint data set ensures that experimental uncertainties on the PDFs can be calculated without need for an increased χ^2 tolerance. Model uncertainties and PDF parametrisation dependencies have also been carefully considered and included in the total uncertainty estimate.

References

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[3] R. S. Thorne code, revised in 2008.
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