Measurement of the Structure of the Proton at HERA

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Abstract

A combination of the reduced $e^{\pm}p$ cross section, previously measured by H1 and ZEUS, has been performed and leads to well constrained QCD fits of the parton densities in the proton. These results, as well as the high-Q^2 neutral current deep inelastic scattering cross sections are presented. First direct measurements of the longitudinal structure function F_L are also reported.

Key words: HERA, H1, ZEUS, F_2, xF_3, F_L, PDF, NC,
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1. Introduction

HERA, running from 1992 until 2007, was the only electron-proton[1] ($e^{\pm}p$) collider in the world, providing head-on collision data for two multi-purpose detectors, H1 and ZEUS. Studies of neutral current (NC, $e^{\pm}p \rightarrow e^{\pm}X$, mediated by γ and Z^0 bosons) and charged current (CC, $e^{\pm}p \rightarrow \tilde{\nu_e}(\nu_e)X$, mediated by $W^{\pm}$ bosons) deep inelastic scattering (DIS) processes, performed by both collaborations, allowed for a substantial increase in the understanding of pQCD and parton density functions (PDFs). First analyses using the full luminosity of ≈ 1 fb^{-1} are about to be finalized. This paper points to the most recent measurements of the F_L and xF_3 structure functions, as well as to the first combination of reduced ep cross sections measured separately by H1 and ZEUS and to common QCD PDF fits, resulting in much more precise picture of the structure of the proton.

2. Deep Inelastic Scattering at HERA

The kinematics of DIS can be described using three variables: the momentum transfer, Q^2, the Bjorken scaling variable, x and the inelasticity, y ($Q^2 = sxy$, where s is the

[1] Unless it is stated otherwise, terms *electron* and *positron* are used interchangeably.

center-of-mass collision energy squared). The electroweak (EW) Born-level reduced cross section for the $e^{\pm}p$ NC interaction can be written as:

$$\tilde{\sigma}_r^{e^{\pm}p} = \frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+}\frac{d^2\sigma_{NC}^{\pm}}{dxdQ^2} = \tilde{F}_2(x,Q^2) \mp \frac{Y_-}{Y_+}x\tilde{F}_3(x,Q^2) - \frac{y^2}{Y_+}\tilde{F}_L(x,Q^2). \qquad (1)$$

where $Y_{\pm} = 1 \pm (1-y)^2$. The generalized structure functions $\tilde{F}_2(x,Q^2)$, $x\tilde{F}_3(x,Q^2)$ are directly related to quark distributions. Scaling violation of $\tilde{F}_2$ at small-x, as well as the longitudinal structure function $\tilde{F}_L(x,Q^2)$, are directly related to the gluon density in the proton. At high Q^2, $x\tilde{F}_3$ provides information on valence quark densities.

3. HERA combined NC cross sections and PDF fits

The H1 and ZEUS collaborations have both used their data to perform reduced cross section and F_2 measurements as well as NLO QCD PDF fits [1] [2]. As these measurements are limited by systematic effects, both data sets have now been combined (Fig 1 left) using a 'theory-free' Hessian fit such, that both experiments 'calibrate' each other [3]. This results in a common data set with reduced systematic uncertainties, which is then used as input to the HERAPDF0.1 fit (Fig 1 right). The new PDFs [4] are of impressive precision as compared to the fit of each dataset alone, as well as to the global parton analyses [5] [6].

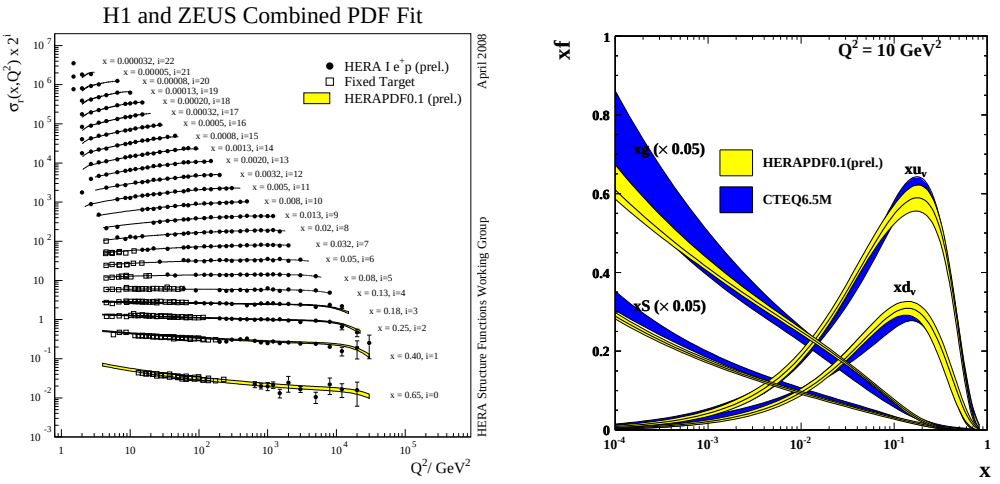

Figure 1. LEFT: HERA combined NC reduced cross section σ_r as a function of Q^2 at different x values. The predictions of the HERAPDF0.1 fit are superimposed. RIGHT: HERAPDF0.1 PDFs at $Q^2 = 10\text{GeV}^2$ compared to the PDFs from CTEQ6.5M.

4. Neutral and Charged Currents at HERA II

Exploiting the full luminosity ($\approx 175\text{pb}^{-1}$) for a given lepton-beam charge, and polarization, precise measurements of high-Q^2 NC and CC cross sections in e^-p collisions

are performed [7] [8], allowing for the direct observations of the effects of the weak interactions in DIS. The structure function $x\tilde{F}_3$ is obtained from the difference of e^+p (from previous data) and e^-p scattering cross sections (Fig. 2 left). All results agree very well with SM predictions and provide strong constraints at the EW scale (on e.g. u and d quark couplings to the Z boson).

5. First direct measurements of the longitudinal structure function F_L

The first direct measurements of F_L are performed using dedicated runs with three proton beam energies (920, 575, 460 GeV). The longitudinal structure function $F_L(x, Q^2)$ is then extracted at fixed (x, Q^2) as the slope of σ_r versus y^2/Y_+ [9,10]. The F_L values obtained by H1 are presented in (Fig. 2 right) as a function of Q^2. The data are consistent with the SM predictions evaluated by the MSTW and CTEQ groups, confirming the applicability of the DGLAP evolution framework at low Bjorken x.

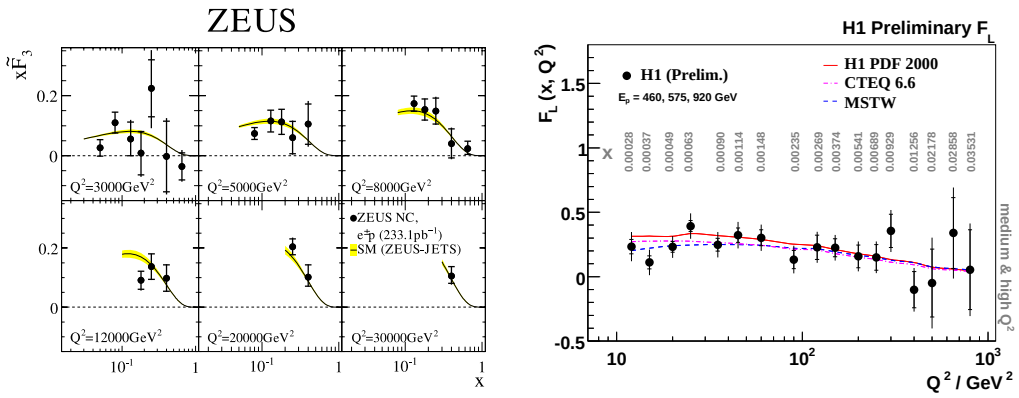

Figure 2. LEFT: The structure function $x\tilde{F}_3$ plotted as a function of x in bins of Q^2. RIGHT: The F_L structure function shown as a function of Q2 at the given values of x.

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