Measurement of the Longitudinal Proton Structure Function with the ZEUS Detector at HERA

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The reduced cross sections for ep deep inelastic scattering have been measured with the ZEUS detector at HERA at three different centre-of-mass energies, 318, 251 and 225 GeV. From the reduced cross sections, measured double differentially in Bjorken x and the photon virtuality, Q^2, the proton structure functions F_L and F_2 have been extracted in the region $5 \times 10^{-4} < x < 0.007$ and $20 < Q^2 < 130$ GeV^2.

1 Introduction

The inclusive $e^{\pm}p$ deep inelastic scattering (DIS) cross section can, at low virtuality of the exchanged boson, Q^2, be expressed in terms of the two structure functions, F_2 and F_L, as

$$\frac{d^2\sigma^{e^{\pm}p}}{dxdQ^2} = \frac{2\pi\alpha^2 Y_+}{xQ^4}\left[F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)\right] = \frac{2\pi\alpha^2 Y_+}{xQ^4}\,\tilde{\sigma}(x,Q^2,y),$$

where α is the fine structure constant, x is the Bjorken scaling variable, y is the inelasticity and $Y_+ = 1 + (1-y)^2$. The quantity $\tilde{\sigma}$ is referred to as the reduced cross section. The kinematical variables are related via $Q^2 = xys$, where s is a centre-of-mass energy. The magnitude of F_L is proportional to the absorption cross section of longitudinally polarised virtual photons by protons, $F_L \propto \sigma_L$, while F_2 includes also the absorption cross section for transversely polarised virtual photons, $F_2 \propto (\sigma_T + \sigma_L)$. At low values of x, the ratio $R = F_L/(F_2 - F_L) \approx \sigma_L/\sigma_T$ gives the relative strengths of the two components. Within the DGLAP formalism, F_2 is dominated at low x by the $q\bar{q}$ sea distributions while the scaling violations of F_2 reflect the gluon distribution via a convolution with a splitting function. In contrast, the value of F_L is directly related to the gluon content regardless of the specific form of the scaling violation.

2 Experimental method

The values of F_2 and F_L were extracted at fixed x and Q^2 by fitting a straight line to the values of $\tilde{\sigma}$ against y^2/Y_+. The method relies on the relations $F_2(x,Q^2) = \tilde{\sigma}(x,Q^2,y=0)$ and $F_L(x,Q^2) = -\partial\tilde{\sigma}(x,Q^2,y)/\partial(y^2/Y_+)$, hence the need for data at fixed (x,Q^2) and different y. At HERA this was achieved by varying the centre-of-mass energy $\sqrt{s} = \sqrt{Q^2/xy}$.

Data were collected at $\sqrt{s} = 318$ GeV, $\sqrt{s} = 251$ GeV, and $\sqrt{s} = 225$ GeV, keeping the electron beam energy constant, $E_e = 27.5$ GeV, and varying the proton beam energy, E_p. Data were collected in 2006 and 2007 with $E_p = 920$, 575 and 460 GeV, referred to respectively as the HER (high-), MER (medium-) and LER (low-energy-running) samples. The corresponding integrated luminosities of the HER, MER and LER samples are 44.5, 7.1 and 13.9 pb^{-1}, respectively.

The event kinematics were evaluated based on the reconstruction of the scattered electron. At high y, the scattered electron tends to be low in energy and poorly separated from the hadronic final state which makes the measurement challenging. After the full event selection, the background consisted almost entirely of photoproduction events due to the misidentification of hadrons as electrons.

The reduced cross sections, $\tilde{\sigma}$, were measured from the HER, MER and LER samples in the kinematic region $0.09 < y < 0.78$ and $20 < Q^2 < 130$ GeV^2. The reduced cross sections in a given (x, Q^2) bin were calculated according to $\sigma(x, Q^2) = \frac{N_{\rm data} - N_{\rm MC}^{\rm bg}}{N_{\rm MC}^{\rm DIS}} \tilde{\sigma}_{\rm SM}(x, Q^2)$, where $\tilde{\sigma}_{\rm SM}(x, Q^2)$ is the Standard Model electroweak Born-level reduced cross section and $N_{\rm data}$, $N_{\rm MC}^{\rm bg}$ and $N_{\rm MC}^{\rm DIS}$ denote, respectively, the number of observed events in the data and the expected number of background and DIS events from the MC.

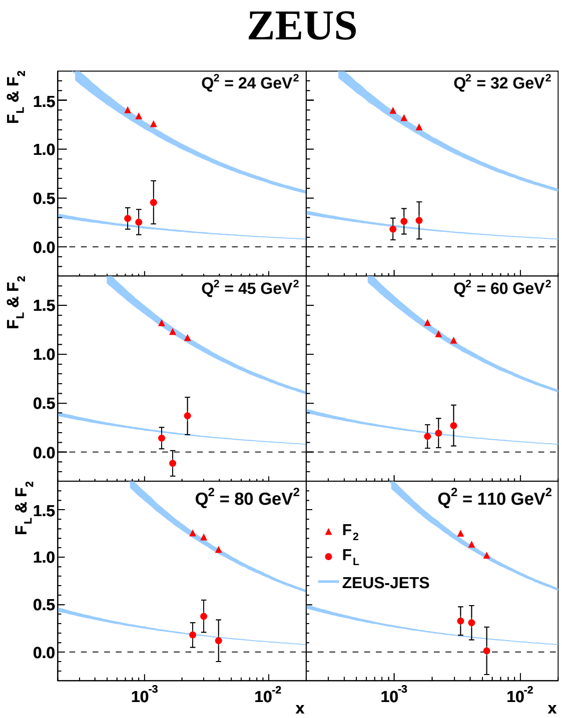

Figure 1: The points represent the ZEUS data for F_L (●) and F_2 (▲), respectively. The error bars on the data represent the combined statistical and systematic uncertainties. The predictions for F_L and F_2 using the ZEUS-JETS PDFs are also shown. The bands indicate the uncertainty in the predictions.

3 Extraction of F_L, F_2 and R

In order to extract F_L, F_2 and R, bins were chosen in y such that, for each of the 6 Q^2 bins, there were 3 values of x at which the reduced cross sections were measured from all three data sets. Thus 54 cross sections were measured and the structure functions were extracted by performing a simultaneous fit to these cross section values.

To extract F_L and F_2, 48 parameters were fit simultaneously: 18 F_2 and 18 F_L values for the 18 (x, Q^2) points; 3 relative normalisation factors for the HER, MER and LER data sets and 9 global shifts of systematic uncertainties. The results are shown in Fig. 1. More details can be found elsewhere [1].

Further fits to the data were performed to extract $F_L(Q^2)$ (evaluated for $y = 0.71$), $R(Q^2)$, and a single overall value of R for the full data set. Figures 2a and 2b show a comparison of the data with various predictions and models. All the models are consistent with the data. The overall value of R extracted from the fit is $R = 0.18^{+0.07}_{-0.05}$.

4 Summary

The first measurement of $F_L(x, Q^2)$ by the ZEUS collaboration is presented, as is the first measurement of $F_2(x, Q^2)$ at low x that does not include assumptions about F_L. The F_2 values are the most precise available from the ZEUS collaboration in the analysed kinematic region. The extraction of F_L and F_2 was based on the reduced double differential cross sections, $\tilde{\sigma}(x, Q^2)$, which were measured for $0.09 < y < 0.78$ and $20 < Q^2 < 130$ GeV^2 using data collected at $\sqrt{s} = 318$, 251 and 225 GeV. In addition, F_L and the ratio, $R = F_L/(F_2 - F_L)$, have been extracted as function of Q^2. An overall value of $R = 0.18^{+0.07}_{-0.05}$ was extracted for the entire kinematic region studied. A wide range of theoretical predictions agree with the measured F_L. The measurements provide strong evidence of a non-zero value of F_L.

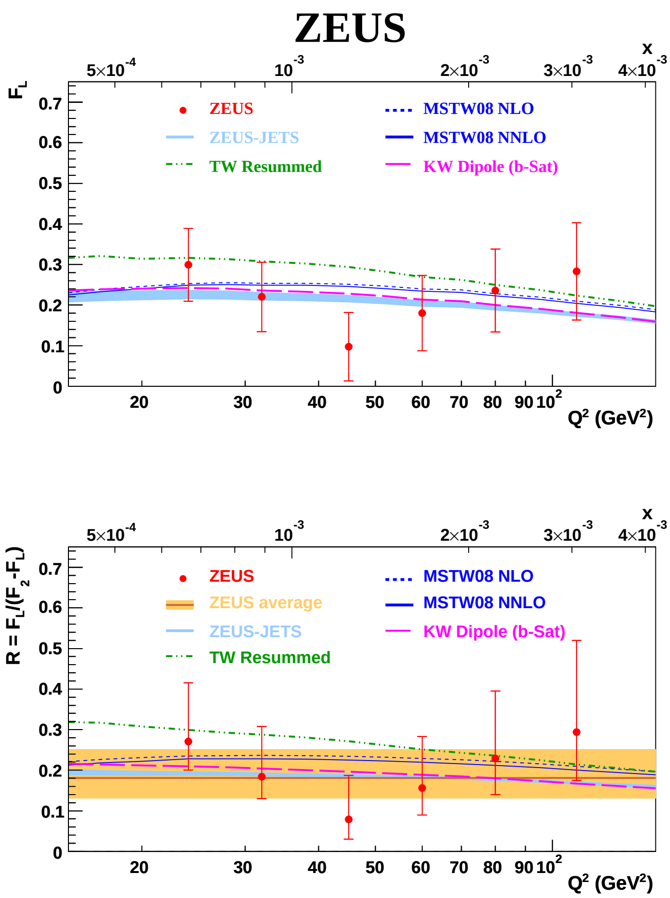

Figure 2: Values of (a) F_L and (b) R as a function of Q^2. The error bars on the data represent the combined statistical and systematic uncertainties. A $\pm 2.5\%$ correlated normalisation uncertainty is not included in the error bars. Various predictions and models are shown. The shaded band shown at (b) labelled ZEUS average represents the 68% probability interval for the overall R.

References

[1] ZEUS Collab., S. Chekanov et al. Phys. Lett. **B 682** 8-22 (2009)