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Combined Measurement of the Inclusive e^+p Scattering Cross Sections at HERA for Reduced Proton Beam Energy Runs and Determination of Structure Function F_L

H1 and ZEUS Collaborations

Abstract

A combination of the inclusive deep inelastic cross sections measured by the H1 and ZEUS Collaborations for ep scattering with nominal and reduced proton-beam energies, $E_p = 920$ GeV, $E_p = 460$ GeV and 575 GeV, is presented. The combination method used takes the correlations of systematic uncertainties into account, resulting in improved accuracy. From the combined data the proton structure function, F_L, is extracted in the region of $2.5 \leq Q^2 \leq 800$ GeV^2.

1 Introduction

At low absolute four momentum transfer squared, Q^2, the neutral current deep-inelastic scattering (DIS) cross section is defined by the two structure functions, F_2 and F_L. In its reduced form the cross section can be written as

$$\sigma_r(x, Q^2) = F_2(x, Q^2) - f(y)F_L(x, Q^2), \qquad f(y) = \frac{y}{1 + (1 - y)^2}. \tag{1}$$

Here x is the Bjorken-x variable and y is the inelasticity of the process. The structure function F_2 has the dominant contribution to the cross section, while F_L is only visible at large values of y. Measurements of the reduced cross sections at fixed (x, Q^2) and different y would allow to extract F_2 and F_L simultaneously. For this purpose, the HERA collider undertook reduced proton-beam energy runs with E_p = 460 GeV and E_p = 575 GeV at the end of its operation. These data were used by the H1 and ZEUS collaborations to perform the first measurements of F_L [1,2].

In this note a combined measurement of the DIS cross sections at the reduced proton-beam energies is presented. The combination is based on the method developed in [3,4] and used previously for the combination of the H1 and ZEUS data collected at E_p = 820 GeV and E_p = 920 GeV [5]. The combined cross sections at reduced and nominal E_p are used to extract F_L.

2 Data Sets

Input data for the combination are the ZEUS measured cross sections at E_p = 460, 575 and 920 [2], preliminary H1 measurements at reduced E_p using SpaCal [6] and LAr calorimeter [7] as well as published H1 measurement at E_p = 920 GeV [4,8]. The data cover wide range in $2.5 \leq Q^2 \leq 800$ GeV^2 and $0.85 \leq y \leq 0.1$.

Both H1 and ZEUS collaborations use electron method for kinematic reconstruction which has optimal resolution at high y. The systematic errors arise from electromagnetic and hadronic energy scales, detector alignment, background subtraction and electron reconstruction efficiency.

3 Procedure

For the combination a χ^2 minimisation method is used. The combination procedure allows to average H1 and ZEUS data taking into account correlations due to systematic uncertainties. Before the combination, data are corrected to a common x, Q^2 grid. Swimming corrections are based on HERAPDF1.0 parameterisation for the structure functions F_2 and F_L.

4 Combination Results

To extract F_L, cross sections measured at two or more available proton beam energies in the same x, Q^2 binning are required.

At $y < 0.35$ the sensitivity of the cross section to the structure function F_L is small, therefore the data sets for all E_p are averaged in this kinematic domain. This allows to reduce relative normalization uncertainty among the data sets.

The cross-section average for the low energy combination is shown in figure 1 for all Q^2 bins and in figure 2 for the Q^2 bins were both H1 and ZEUS measurements contribute to the average.

5 Extraction of F_L

Extraction of the structure function F_L is performed using the offset method. The central values are obtained fitting cross sections with statistical uncertainties only. The total uncertainty on F_L is calculated performing the fit with each of the systematic errors separately, and adding the difference to the total error, together with the uncorrelated part.

The structure function F_L is measured as a slope of a linear fit of $\sigma_r(x, Q^2, f(y))$ versus $f(y)$. For illustration, these fits are shown for $Q^2 = 32$ GeV^2 bin in figure 3. The measured structure function F_L is shown in figure 4. The measurements are compared to the prediction of the HERAPDF1.0 fit.

The range in x covered by the measurements for each Q^2 value is limited and for this range variation of F_L is expected to be small. The measurements are therefore averaged for each Q^2 bin to obtain more compact representation of the data. This average is performed using total uncertainties: the systematic errors have strong y depencence and hence neighbouring in x F_L points are to a large extend uncorrelated. The averaged structure function F_L is shown in figure 5 and it is compared to HERAPDF1.0 prediction. The region were both H1 and ZEUS measurements are present is zoomed in figure 6.

6 Conclusions

An averaging of the reduced proton beam energy DIS cross-section measurements by the H1 and ZEUS collaborations is reported. The average allows to represent the results by a single dataset with reduced total uncertainty. The averaged cross sections are used to extract the structure function F_L

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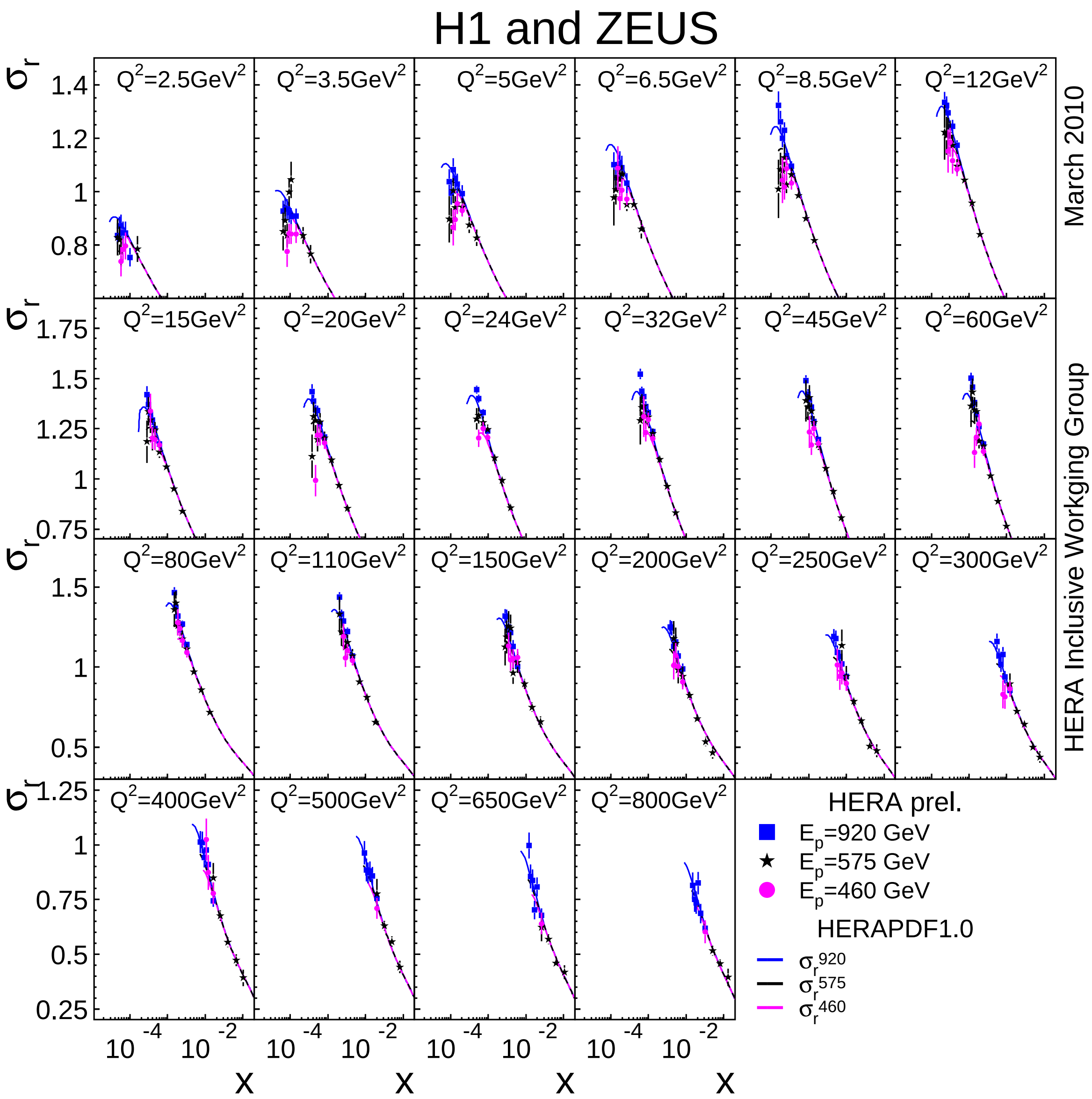

Figure 1: Reduced average H1 and ZEUS cross section for $2.5 \leq Q^2 \leq 800$ GeV^2 taken at different proton beam energies E_p of 920 GeV (full boxes), 575 GeV (stars) and 460 GeV (full circles). The error bars show total experimental uncertainties. Theoretical predictions of reduced cross section are shown as solid lines for 920 GeV (blue), 575 GeV (black) and 460 GeV (magenta). Theoretical expectations are derived from HERAPDF1.0 fit.

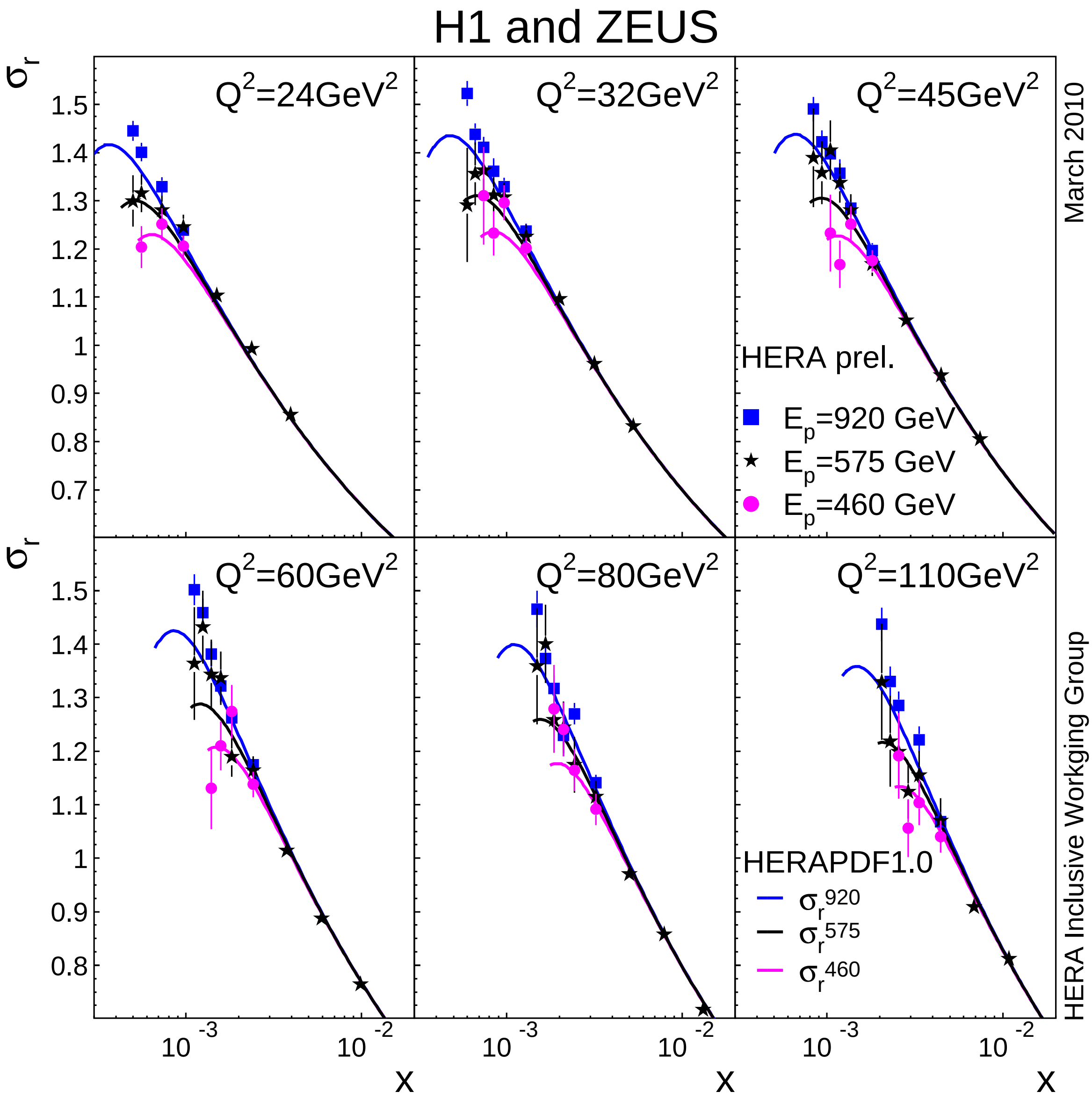

Figure 2: Reduced average H1 and ZEUS cross section for bins were both H1 and ZEUS measurements are present taken at different proton beam energies E_p of 920 GeV (full boxes), 575 GeV (stars) and 460 GeV (full circles). The error bars show total experimental uncertainties. Theoretical predictions of reduced cross section are shown as solid lines for 920 GeV (blue), 575 GeV (black) and 460 GeV (magenta). Theoretical expectations are derived from HERAPDF1.0 fit.

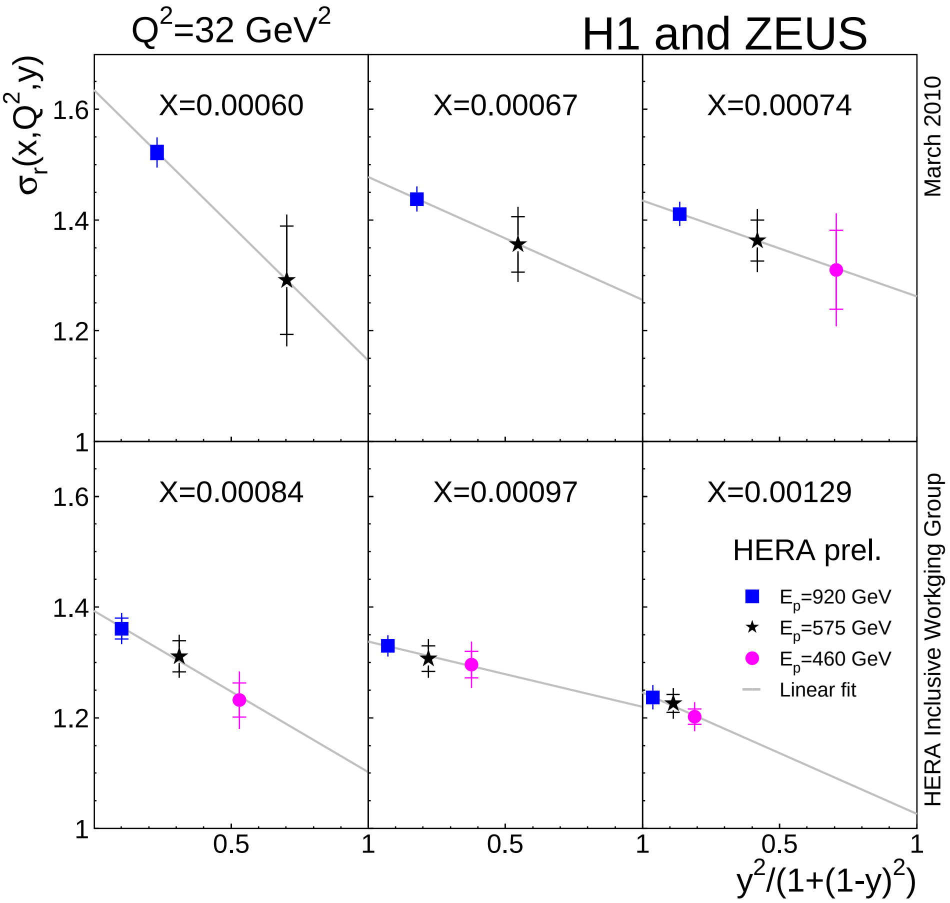

Figure 3: The reduced cross section $\sigma(x, Q^2, f(y))$ measured at $Q^2 = 32$ GeV^2 and different x valies as a function of $f(y)$. The full boxes represent data at $E_p = 920$ GeV, stars represnt data at $E_p = 575$ GeV and full circles represent data at $E_p = 460$ GeV. The inner error bars are the statistical uncertainties and the full error bars are the total uncertainties. The lines show the linear fits used to determine F_L.

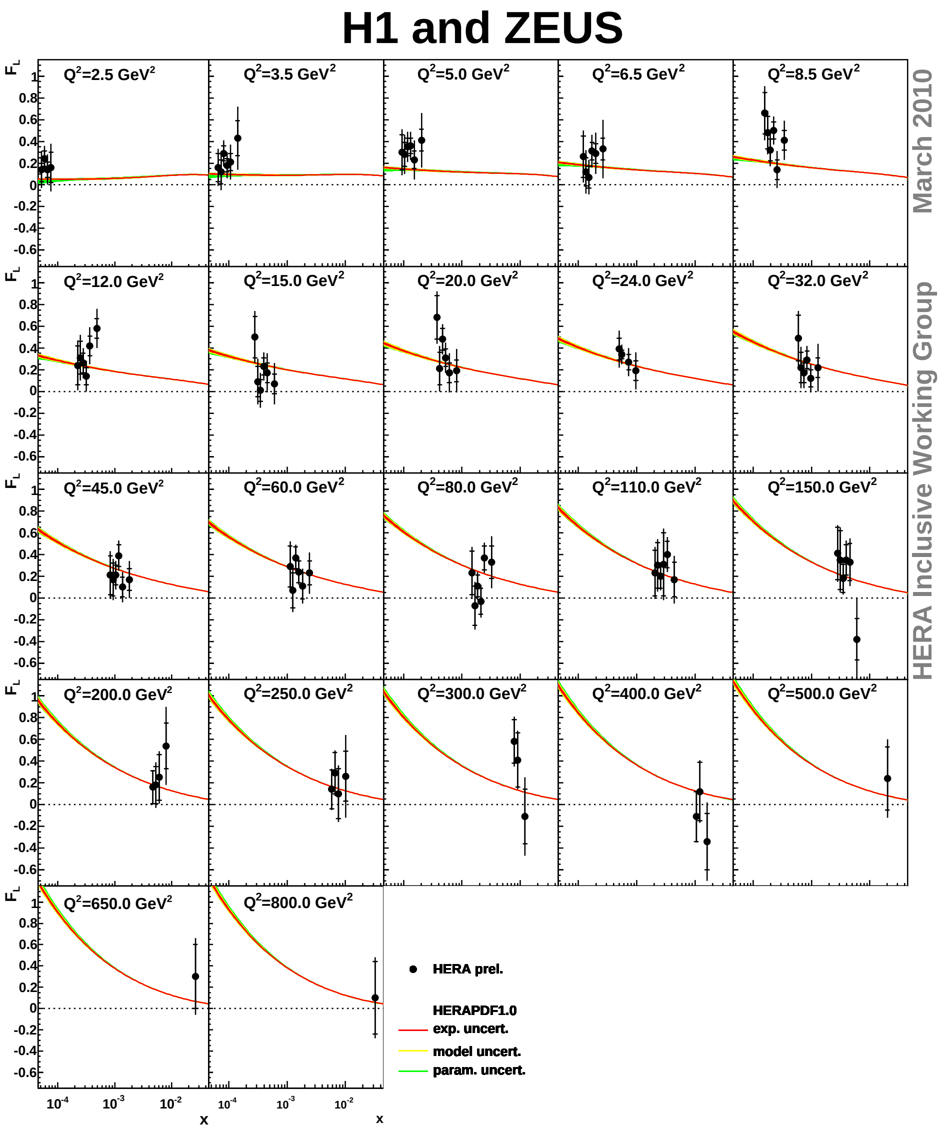

Figure 4: The structure function F_L measured a s function of x at fixed values of Q^2 obtained from the combined H1 and ZEUS cross-section data. The inner error bars are the statistical uncertainties and the full error bars are the total uncertainties. The line represents a QCD prediction based on HERAPDF1.0 fit with parameterization (green) model (yellow) and experimental (red) uncertainties.

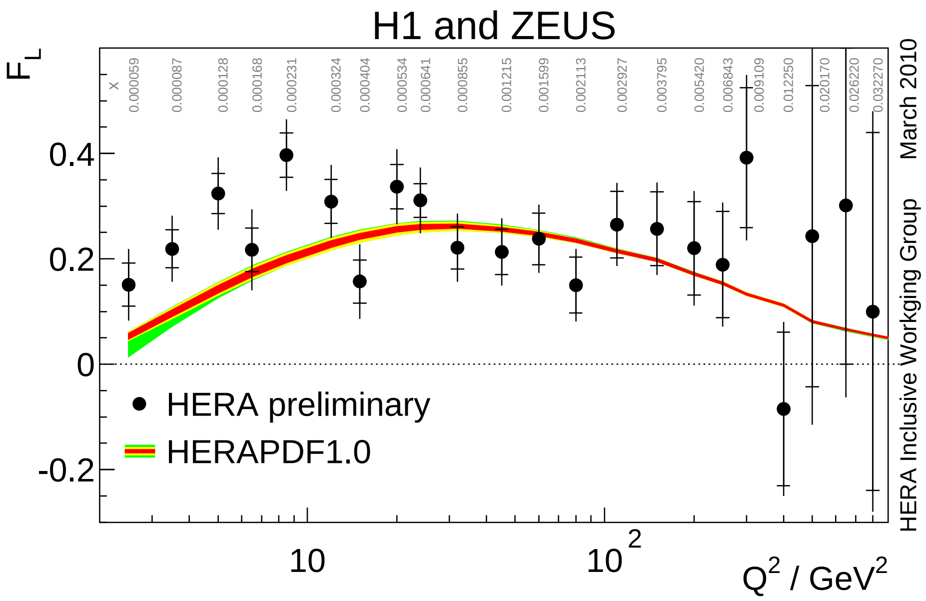

Figure 5: The structure function F_L averaged in x at given valie of Q^2 using combined H1 and ZEUS cross-section data. The resulting x values of the averaged F_L measurements are given in the figure for each point in Q^2. The inner error bars are the statistical uncertainties and the full error bars are the total uncertainties. The band represents a QCD prediction based on HERA-PDF1.0 fit with parameterization (green) model (yellow) and experimental (red) uncertainties.

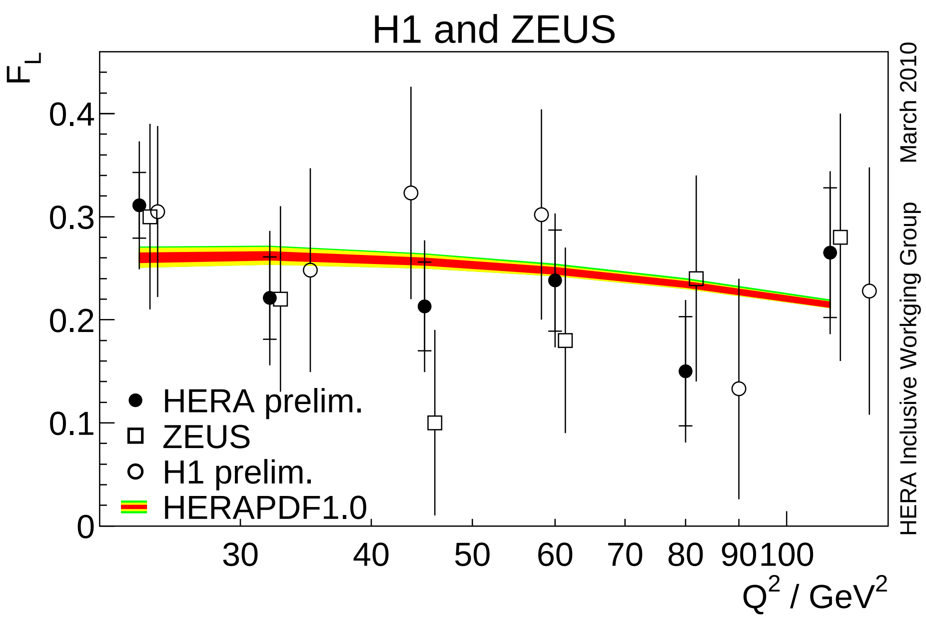

Figure 6: H1 and ZEUS average structure function F_L (full circles) compared to the individual measurements of the H1 (open circles) and ZEUS (open boxes) collaborations. The inner error bars are the statistical uncertainties and the full error bars are the total uncertainties. The band represents a QCD prediction based on HERAPDF1.0 fit.