DESY Summer Student Programme 2010

Analysis of the Inclusive $e^{\pm}p$ Scattering Cross Section at low values of four momentum transfer.

Alexander Bylinkin

supervised by

Alexander Glazov

Abstract

Theoretical analysis of the inclusive *ep* scattering cross section using data collected by the H1 experiment at HERA during the years of operation 2003-2007 with proton beam energies of E_p = 920 GeV, E_p = 820 GeV, E_p = 575 GeV and E_p = 460 GeV is presented. The kinematic range of the measurement covers low squared four-momentum transfers, 0.2 GeV^2 $< Q^2 <$ 150 GeV^2, small values of Bjorken x, $2.9 \times 10^{-5} < x < 0.01$, and extended high inelasticity up to $y = 0.85$. The new measurements are used to test λ fit model applicable in this low Q^2 and low x kinematic domain. The dependence of the parameter λ of this model on Q^2 is found and the improved model is presented.

1 Introduction

Deep inelastic lepton-nucleon scattering (DIS) plays pivotal role in determining the structure of proton. The electron[1]-proton collider HERA covers a wide range of the squared four-momentum transfers, Q^2, and Bjorken x. Accurate measurements of the DIS cross section performed using data at proton beam energies of $E_p = 820$ GeV and $E_p = 920$ GeV and lepton beam energy of $E_e = 27.5$ GeV obtained by the H1 [1–5] and ZEUS [6–14] experiments, as well as combination of their analyses [15], allow to study perturbative Quantum Chromodynamics (QCD) with unprecedented precision.

At low Q^2, the scattering cross section is defined by the two structure functions, F_2 and F_L. In a reduced form, the cross section is

$$\sigma_r(x, Q^2) \equiv \frac{Q^4 x}{2\pi\alpha^2 \left[1 + (1-y)^2\right]} \cdot \frac{\mathrm{d}^2\sigma}{\mathrm{d}x\,\mathrm{d}Q^2} = F_2(x, Q^2) - \frac{y^2}{1-(1+y)^2} F_L(x, Q^2) \,. \tag{1}$$

Here α is the fine structure constant and $0 \leq y \leq 1$ is the process inelasticity which is related to the Q^2, x and the centre-of-mass energy squared $s = 4E_e E_p$ as $y = Q^2/sx$. The two structure functions are related to the cross sections for the scattering of the longitudinally and transversely polarised photons off protons σ_L and σ_T

$$F_L(x, Q^2) = \frac{Q^2}{4\pi^2\alpha}(1-x) \cdot \sigma_L \,, \tag{2}$$

$$F_2(x, Q^2) = \frac{Q^2}{4\pi^2\alpha}(1-x) \cdot (\sigma_L + \sigma_T) \,, \tag{3}$$

which is valid to very good approximation at low x. This relation implies that $0 \leq F_L \leq F_2$.

In the quark-parton model, F_2 is given by the charge squared weighted sum of the quark densities while F_L is zero due to helicity conservation. In QCD, the gluon emission gives rise to non-vanishing F_L. Measuring F_L therefore gives an additional handle on the gluon density and provides a check of the QCD picture.

Using the ratio $R(x, Q^2)$ defined as

$$R = \frac{\sigma_L}{\sigma_T} = \frac{F_L}{F_2 - F_L}, \tag{4}$$

the reduced cross section in equation 1 can be also written as

$$\sigma_r = F_2(x, Q^2) \cdot \left[1 - f(y) \cdot \frac{R}{1+R}\,, \right] \tag{5}$$

where $f(y) = y^2/(1 + (1-y)^2)$.

The contribution of the structure function F_L to the scattering cross section is only significant at large values of y. For low values of y, the reduced DIS neutral current scattering cross section is well approximated by the structure function F_2. Kinematically, for low Q^2, large values of y correspond to low energies of the scattered lepton. Selecting of F_L-sensitive high y events is thus complicated due to large hadronic background. In addition, to disentangle contributions of F_2 and F_L in a model independent way, measurements at different values of s are required.

The measurements are then used to test several phenomenological models. The phenomenological models include the power-law dependence of F_2 at low x [16]

[1]The name electron in the text is used to denote both electrons and positrons

2 Theoretical Analysis

The H1 cross-section data for $E_p = 460, 575, 820$ and 920 GeV are used for phenomenological analysis discussed in the next section. The fits are applied to the combined reduced cross-section measuremets accounting for correlations between the data points.

2.1 λ Fit

The increase of the structure function F_2 for $x \to 0$ can be approximated by a power law in x, $F_2 = c(Q^2)x^{-\lambda(Q^2)}$. This parametrisation is shown to model the ep data rather well for $x < 0.01$ [16].

The H1 measurements are not of the structure function F_2 but of the reduced cross section σ_r. In the analysis of [1], the fit was performed to σ_r represented as

$$\sigma_r(Q^2, x) = c(Q^2)x^{-\lambda(Q^2)}\left[1 - \frac{y^2}{1+(1-y)^2}\frac{R}{1+R}\right] \tag{6}$$

It is assumed for all Q^2 bins that $R = 0.25$ and the only free parameters of the fit, termed λ fit, are $c(Q^2)$ and $\lambda(Q^2)$.

Fitting is done in the following way. For each Q^2-bin the values of the reduced cross section are taken with their uncorrelated and statistic errors added quadratically. Then the fitting function, depending on two free parameters, $c(Q^2)$ and $\lambda(Q^2)$, is called, and the values of these parameters are returned.

The second step is to evaluate systematic uncertainties. To do this correlated errors are considered. Total number of correlated errors for each point is equal to 69. So, all the values of the cross section are shifted according to its correlated error of a certain number. Thus, we get new 69 different values of the parameters $c(Q^2)$ and $\lambda(Q^2)$. Then the deviations of these new values from the initial one are added quadratically and the square root is taken. So, the values of the systematic uncertainties are evaluated.

The parameters obtained in the fits are shown in figure 1. The parameter λ exhibits an approximately linear increase as a function of $\ln Q^2$ for $Q^2 \geq 2$ GeV^2. For lower Q^2, the variation of λ deviates from that linear dependence. The normalisation coefficient $c(Q^2)$ rises with increasing Q^2 for $Q^2 < 2\,\text{GeV}^2$ and is consistent with a constant behaviour for higher Q^2, as in [16].

Closer inspection of the fits reveals that the quality of them is not very good with a total $\chi^2/\,n_{\text{dof}} = 538/350$ when the uncertainties are given by the statistical and uncorrelated systematic uncertainties added in quadrature. Largest contribution to χ^2 arises from $1 < Q^2 < 10\,\text{GeV}^2$ kinematic domain. In order to investigate this behaviour, the parameterisation of the structure function F_2 is extended by one parameter

$$F_2(x, Q^2) = c(Q^2)x^{-\lambda(Q^2)+\lambda'(Q^2)\ln x} \tag{7}$$

to allow for deviations from a single power law. This fit returns significantly improved $\chi^2/\,n_{\text{dof}} = 405/326$, the obtained parameters λ and λ' are shown in figure 2. From this figure, it is remarkable to observe that the parameter λ is consistent with a constant behaviour $\lambda = 0.25$. The two parameters λ and λ' are strongly correlated since for each Q^2 bin the data span over a limited range in x. Therefore, fits are performed, termed λ' fits, in which $\lambda = 0.25$ is fixed while c and λ' are floated. The quality of such fits is better compared to the original λ fit with total $\chi^2/n_{\rm dof} = 464/350$. A comparison of the λ' with the H1 reduced cross-section data is given in figures 4-5. The fitted parameters c and λ' are shown in figure 3. The parameter λ' is negative and shows a constant behaviour for $Q^2 < 5$ GeV^2, a smooth transition and a linear rise in $\ln Q^2$ for $Q^2 > 20$ GeV^2.

The λ and λ' fits are compared to the H1 data in figure 6 for $Q^2 \geq 2$ GeV^2. For this comparison, the measured cross sections are corrected to the structure function F_2 assuming $R = 0.25$. For low Q^2 kinematic domain, the λ' fit shows softer increase towards low x compared to the λ fit. This behaviour is reversed for higher Q^2 values.

3 Summary

The combined H1 data were subjected to phenomenological analyses. The rise of the structure function F_2 towards low x were examined using power-law fits.The power-law exponent λ was found to be approximately constant for $Q^2 \leq 2$ GeV^2 and exhibit a linear increase as a function of $\ln Q^2$ for higher Q^2 values. Closer inspection of the fits revealed, however, decrease of the fit quality for $1 \leq Q^2 \leq 10$ GeV^2 range. A parameterisation which allowed Q^2 dependent $\ln x$ correction to a fixed power-law $\lambda = 0.25$ provided a better description of the data with the same number of parameters. This study suggests that the structure function F_2 may deviate from a power law as a function of x at small x and small Q^2 and exhibit a softer rise.

References

[1] F. Aaron *et al.* [H1 Collaboration], Eur. Phys. J. **C63**, 625 (2009), [0904.0929].

[2] F. Aaron *et al.* [H1 Collaboration], Eur. Phys. J. **C64**, 561 (2009), [0904.3513].

[3] C. Adloff *et al.* [H1 Collaboration], Eur. Phys. J. **C13**, 609 (2000), [hep-ex/9908059].

[4] C. Adloff *et al.* [H1], Eur. Phys. J. **C19**, 269 (2001), [hep-ex/0012052].

[5] C. Adloff *et al.* [H1 Collaboration], Eur. Phys. J. C **30**, 1 (2003), [hep-ex/0304003].

[6] J. Breitweg *et al.* [ZEUS Collaboration], Phys. Lett. **B407**, 432 (1997), [hep-ex/9707025].

[7] J. Breitweg *et al.* [ZEUS Collaboration], Phys. Lett. B **487**, 53 (2000), [hep-ex/0005018].

[8] J. Breitweg *et al.* [ZEUS Collaboration], Eur. Phys. J. **C7**, 609 (1999), [hep-ex/9809005].

[9] S. Chekanov *et al.* [ZEUS Collaboration], Eur. Phys. J. C **21**, 443 (2001), [hep-ex/0105090].

[10] J. Breitweg *et al.* [ZEUS Collaboration], Eur. Phys. J. C **12**, 411 (2000), [Erratum-ibid. C**27** (2003) 305, [hep-ex/9907010].

[11] S. Chekanov *et al.* [ZEUS Collaboration], Eur. Phys. J. **C28**, 175 (2003), [hep-ex/0208040].

[12] S. Chekanov *et al.* [ZEUS Collaboration], Phys. Lett. **B539**, 197 (2002), [Erratum-ibid. B**552** (2003) 308], [hep-ex/0205091].

[13] S. Chekanov *et al.* [ZEUS Collaboration], Phys. Rev. D **70**, 052001 (2004), [hep-ex/0401003].

[14] S. Chekanov *et al.* [ZEUS Collaboration], Eur. Phys. J. **C32**, 1 (2003), [hep-ex/0307043].

[15] F. Aaron *et al.* [H1 and ZEUS Collaborations], JHEP **1001**, 109 (2010), [0911.0884].

[16] C. Adloff *et al.* [H1 Collaboration], Physics Letters B **520**, 183 (2001), [hep-ex/0108035].

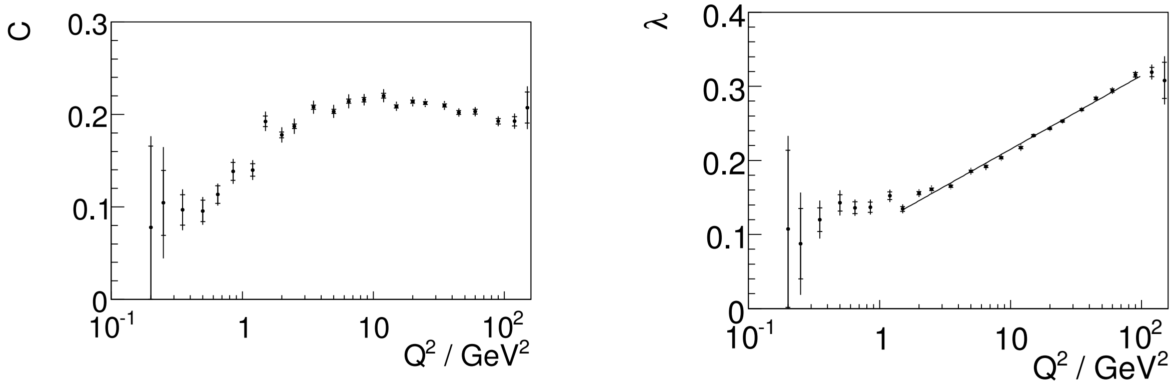

Figure 1: Coefficients c and λ, as defined in equation 6, determined from a fit to the H1 data as a function of Q^2. The inner error bars represent statistical uncertainties. The outer error bars contain systematics. The line in b) is from a straight-line fit for $Q^2 \geq 2$ GeV^2.

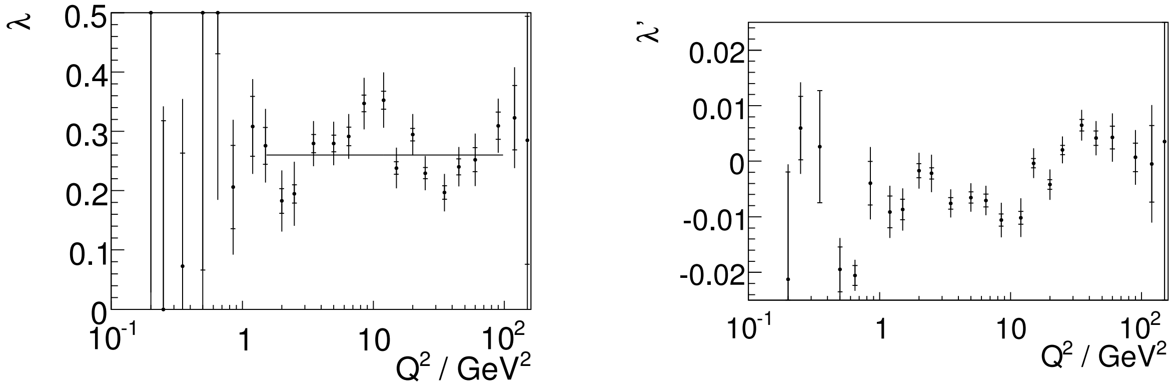

Figure 2: Coefficients λ and λ', as defined in equation 7, determined from a fit to the H1 data as a function of Q^2. The inner error bars represent statistical uncertainties. The outer error bars contain systematics. The line in b) is from a constant fit for $Q^2 \geq 2$ GeV^2.

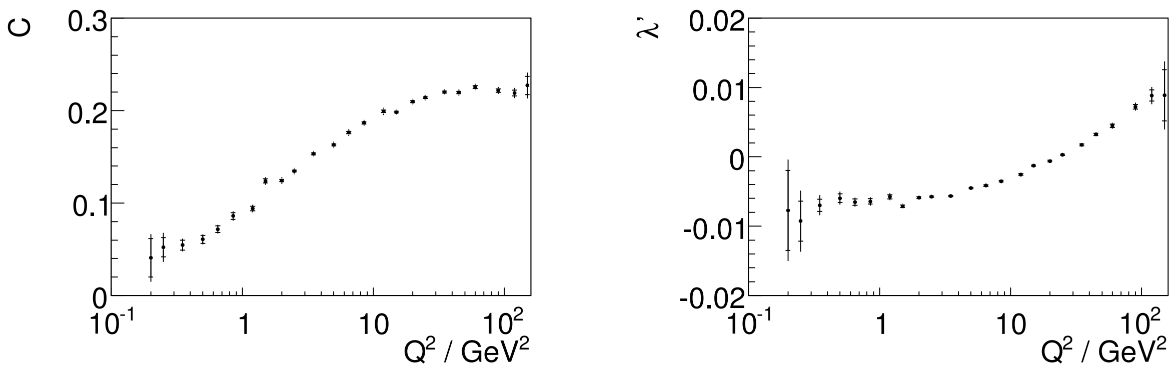

Figure 3: Coefficients c and λ', as defined in equation 7, determined from a fit to the H1 data as a function of Q^2 with fixed $\lambda = 0.25$. The inner error bars represent statistical uncertainties. The outer error bars contain systematics.

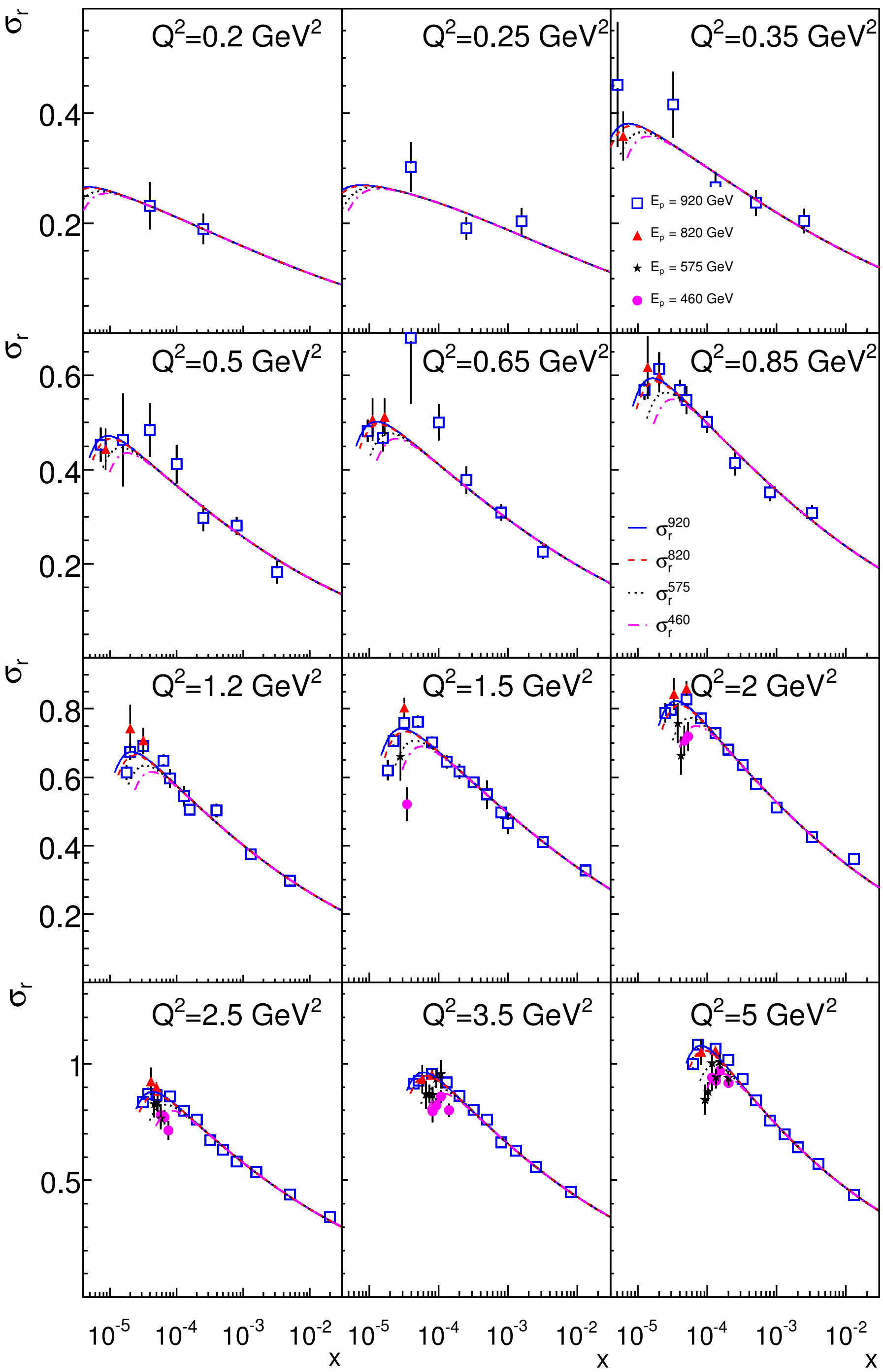

Figure 4: Reduced cross section σ_r as a function of x calculated for different Q^2 bins. The H1 data for different centre-of-mass energies as indicated by the legend are compared to the λ' fit result shown by lines.

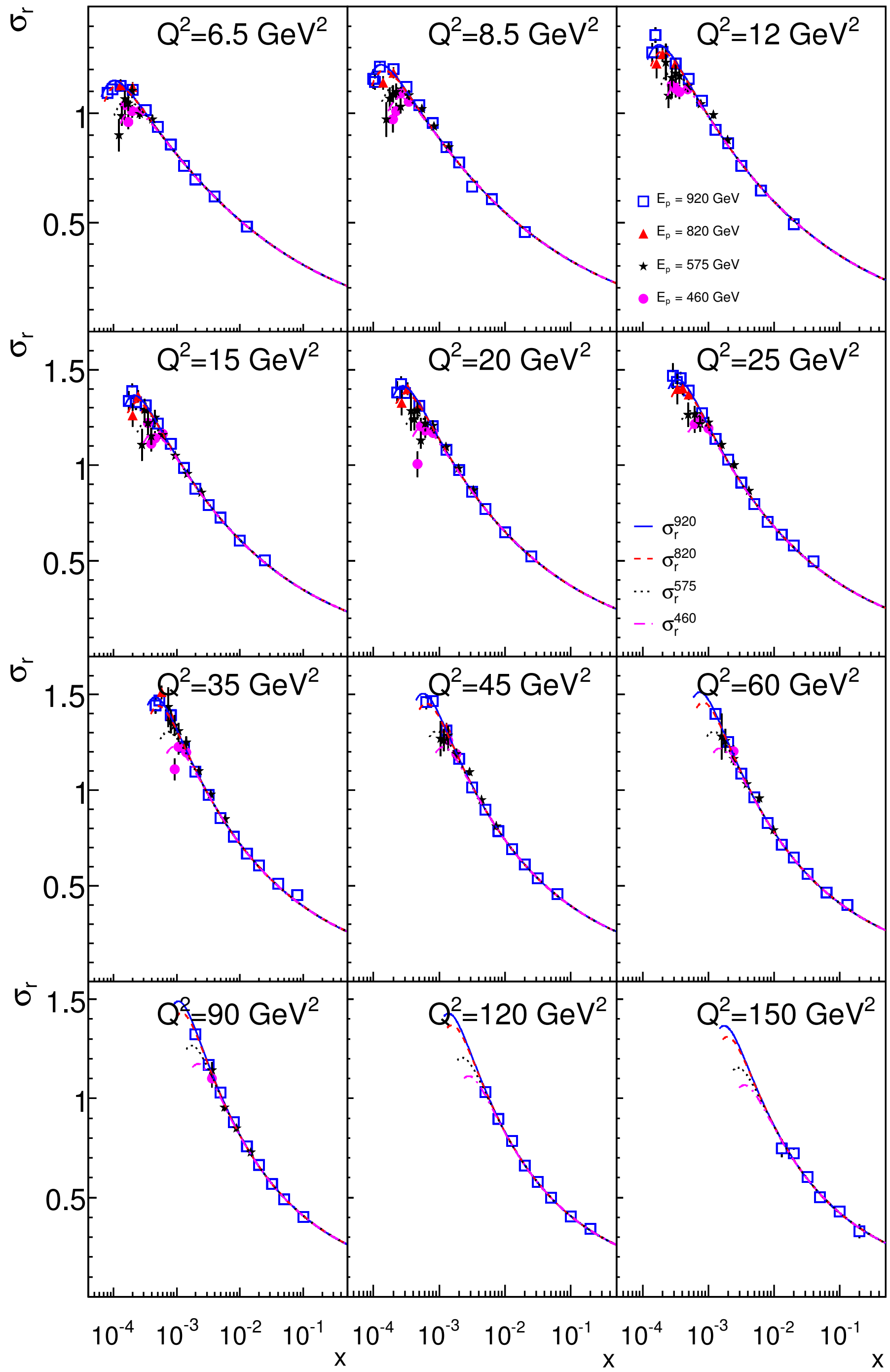

Figure 5: Figure 4 continued.

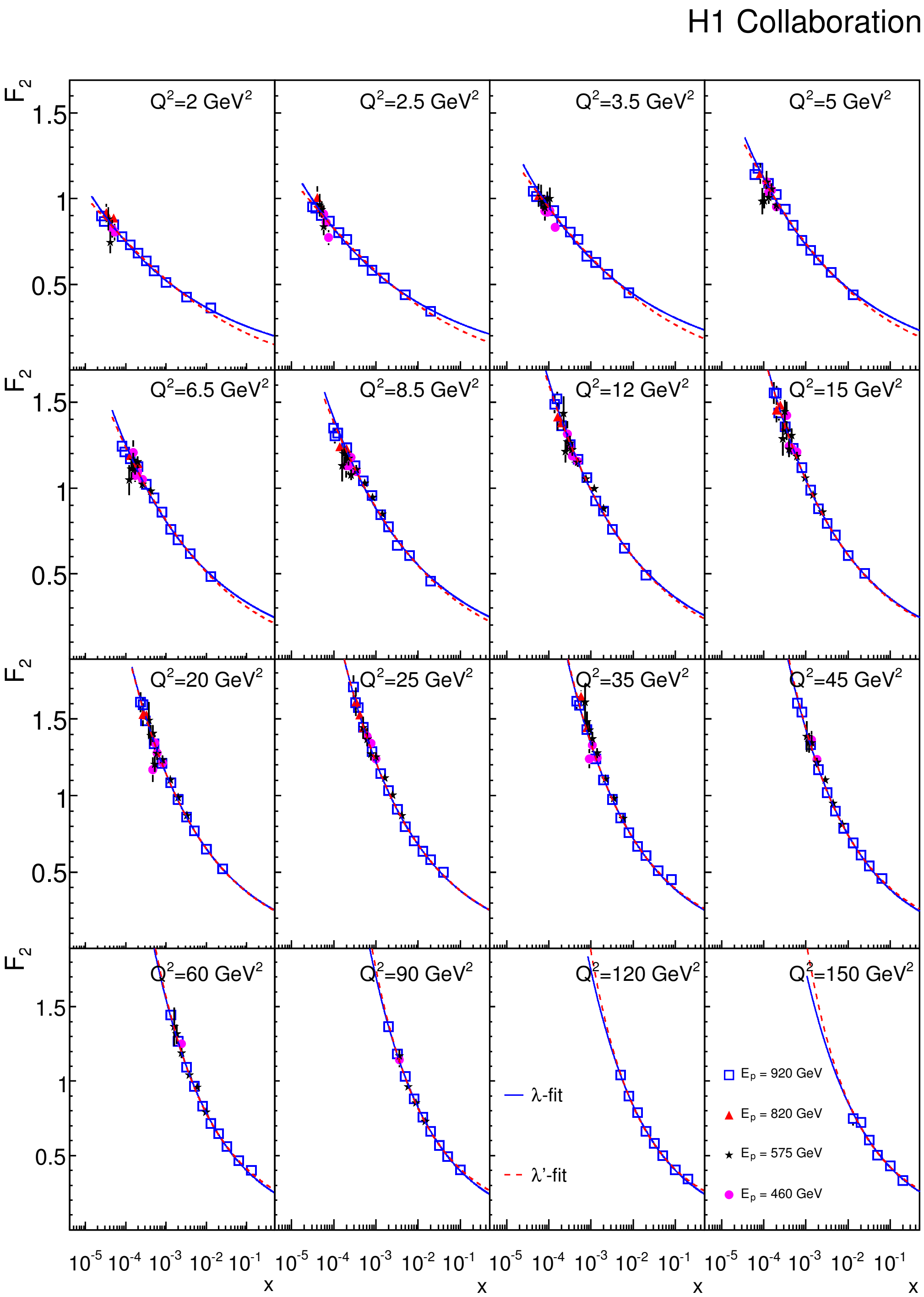

Figure 6: Structure function $F_2(x, Q^2)$ as a function of x calculated from the reduced cross section using $R = 0.25$ for different Q^2 bins. The H1 data for different centre-of-mass energies as shown by the legend are compared to the λ and λ' fit results.