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MEASUREMENTS OF THE PROTON STRUCTURE AT LOW Q^2

A. del Rocio Vargas Treviño[1]
Dortmund University, Experimental Physics E5
Otto-Hahn-Strasse 4, 44227 Dortmund, Germany

Measurements of the proton structure functions at low Q^2 are discussed. An extension of previous F_2 measurements to large values of x in the transition region from non-perturbative to perturbative QCD is presented, as well as several determinations of F_L.

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1 Introduction

Measurements of inclusive differential cross sections in deep inelastic scattering (DIS) have played a crucial role in the development of the understanding of perturbative quantum chromodynamics (pQCD).

The kinematics of inclusive DIS are usually described by the variables Q^2, the negative four-momentum-transfer, and x, the fraction of the proton's longitudinal momentum carried by the struck quark. The reduced cross section for electron-proton scattering in the one-photon approximation, which is valid for $Q^2 \leq 100$ GeV^2, is given by the expression:

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

where y is the inelasticity, given by $y \approx Q^2/sx$, and s is the centre-of-mass energy of the ep collision.

The proton structure function F_2 is the dominant contribution to the inclusive cross section, while F_L contributes only at high values of y. The experiments H1 and ZEUS at the HERA ep collider have shown that the Q^2 evolution of the proton structure function F_2 is well described by pQCD throughout a wide range in x and Q^2 [1]. However, at low Q^2, where the transition to photoproduction takes place, non-perturbative effects are observed [2] and the data can be only described by phenomenological models like Regge theory [3]. This note summarizes the results of new experimental methods used to investigate the behaviour of F_2 in the transition region. In addition, the determination of the proton structure function F_L is presented.

[1] E-mail address: vargas@mail.desy.de

2 F_2 Measurement at low Q^2

In order to study the transition region $Q^2 \approx 1\text{GeV}^2$, HERA has delivered positron-proton scattering data, in which the interaction vertex was shifted by about 70 cm in the proton beam direction. These "shifted vertex" runs allow larger positron scattering angles to be measured and hence lower values of Q^2 can be accessed. Early measurements in the transition region between non-perturbative and perturbative QCD were made by the H1 and ZEUS Collaborations using shifted vertex data [4].

The H1 Collaboration has presented a new measurement of the proton structure function F_2 in the transition region, $0.35 < Q^2 < 3.5$ GeV^2, using shifted vertex data taken in August 2000 [5]. This data sample is four times larger than that taken in initial shifted vertex run in 1995. An extension of the shifted vertex measurement to larger values of x at low Q^2 is possible by studying initial state radiative events (ISR). This analysis exploits the fact that the centre of mass energy $\sqrt{s}$ of the ep collision is reduced by the emission of the photon and therefore larger x values are accessed.

In contrast to the ZEUS ISR analysis [6], which will be discussed later, the new analysis introduced by H1 does not require the detection of the radiated photon. The energy of the incoming electron is reconstructed from energy and longitudinal momentum conservation, assuming that the photon is radiated collinearly with the electron beam [7]. Using the reduced incoming electron energy, the kinematic variables are reconstructed with the sigma method [8] which makes use of the scattered electron and the hadronic final state. In Fig. 1, the H1 ISR cross section measurement made using the shifted vertex data from 2000 are shown (closed points). The ISR analysis extends the previous shifted vertex measurement to values of x up to $5 \cdot 10^{-3}$. Previous ZEUS measurements which access the region $0.0045 < Q^2 < 0.65$ GeV^2 using a silicon strip tracking detector and an electromagnetic calorimeter very close to the beam pipe [2], are also shown in Fig. 1.

QED Compton (QEDC) events are another class of radiative processes which give access to high values of x in the region where only fixed target experiments have previously measured [9]. QEDC events are characterised by an exchanged photon with low virtuality and by an exchanged electron with high virtuality. The scattered electron and the radiated photon are reconstructed in the backward detectors and are back-to-back in the azimuthal plane. This analysis was done using data taken by H1 in 1997 [9] at the nominal vertex position. The reconstruction of the kinematics is possible for $0.5 < Q^2 < 7\text{GeV}^2$ and for $0.001 < x < 0.06$. This extension is achieved by introducing a detailed simulation of the hadronic final state at low masses which includes the resonance region [10], and through an improved understanding of the calorimeter noise. Fig. 2 shows the QEDC F_2 measurement together with previous measurements from H1, ZEUS and fixed target measurements.

3 F_L Determination

The first direct measurement of F_L at HERA was made by the ZEUS collaboration using ISR events in which the radiated photon is explicity detected [6]. As already discussed in the last section, the reduced energy of the incoming electron leads to a variation of the centre-of-mass energy and therefore y varies for fixed x and Q^2, such that F_L can be measured. Using a MC

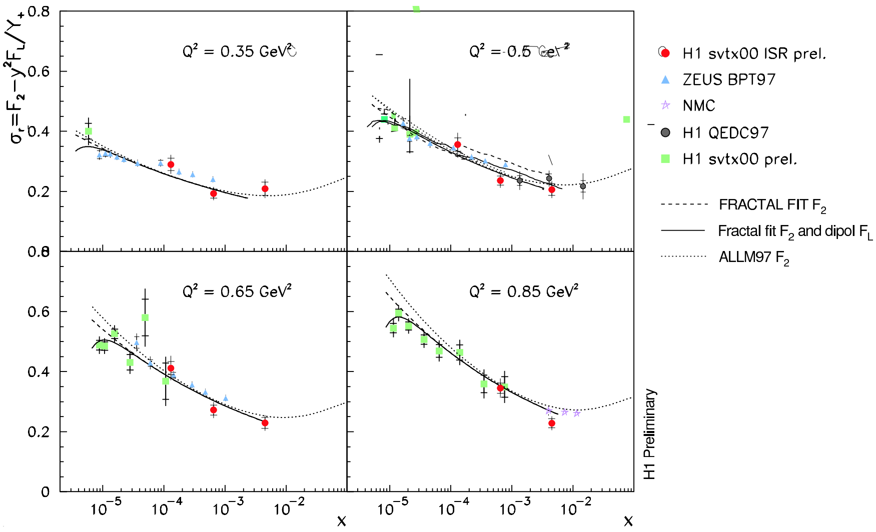

Fig. 1. Measured reduced cross section from non-radiative and ISR analyses, using shifted vertex data. Comparison with previous measurements from ZEUS and fixed target experiments are also shown.

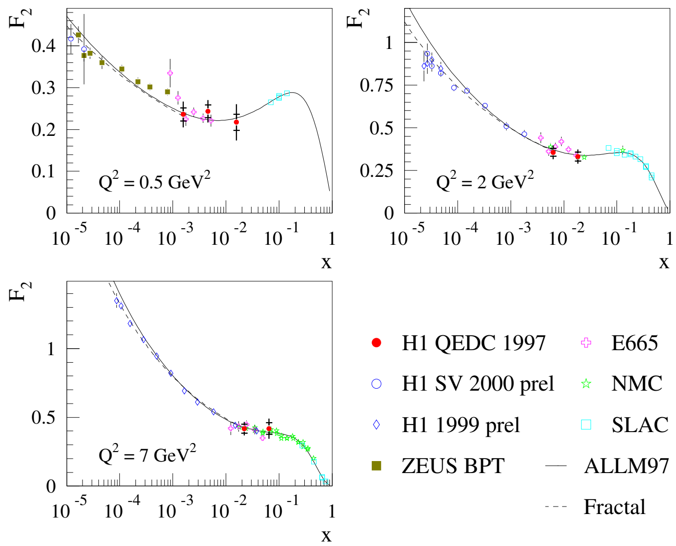

Fig. 2. F_2 measurement from QED Compton scattering by H1 (closed circles), compared with other measurements at HERA and with fixed target experiments. The inner error bars for the QEDC data represent the statistical errors and the total error bars the statistical and systematic errors added in quadrature.

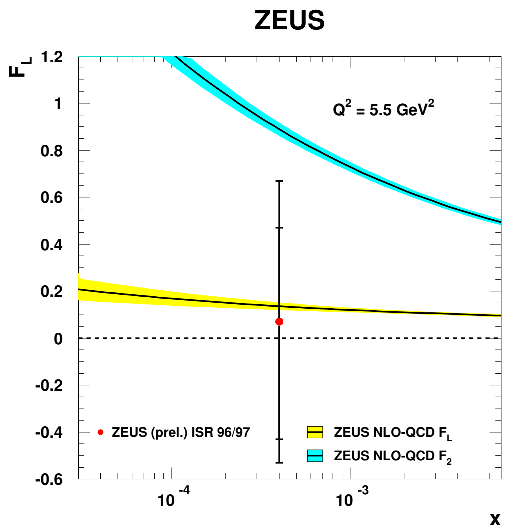

Fig. 3. F_L measurement. The inner error bars show the statistical uncertainties while the outer ones show the statistical and systematic uncertainties added in quadrature.

simulation where the F_L contribution is set to zero, the ratio of the number of background-substracted data events to the number of MC events as a function of y is studied leading to a determination of F_L. The measurement of F_L, made in a single bin defined by $1 < Q^2 < 30$ GeV^2 and $0.11 < y < 0.23$, is shown in Fig. 3 and is found to be compatible with NLO-QCD calculations within the large experimental uncertainties.

The H1 Collaboration has developed various methods for obtaining information about F_L. As can be seen from Fig. 1, the contribution from F_L is visible in the reduced cross section only at the lowest values of x, which correspond to the highest values of y up to 0.9. This means that the contribution from F_2 can be determined most precisely for y below 0.6 and then an extrapolation can be made into the high y region using the H1 QCD fit [11]. Finally the contribution from F_L can then be extracted at high y by taking the difference between the measured cross section and the extrapolated F_2 measurements. For low values of Q^2 the shape method for extracting of F_L is introduced [12]. This method assumes that the reduced cross section can be parametrized as

$$\sigma_{fit} = cx^{-\lambda} - \frac{y^2}{Y_+} F_L, \tag{2}$$

where c, λ and F_L are free parameters at each Q^2 value. The first term in Eq. (2) is the result of previous measurements, which show that $F_2(x, Q^2)$ behaves like $x^{-\lambda}$ at fixed Q^2 [13]. The results of the F_L extraction are shown in Fig. 4 as a function of Q^2, where the shape method was used for the extraction up to $Q^2 = 7.5$ GeV^2. The extracted F_L values are in good agreement with the GBW dipole model over the whole Q^2 range. The data show that F_L remains non-zero down to low Q^2 and that it is possible to distinguish between the different models in the low x region.

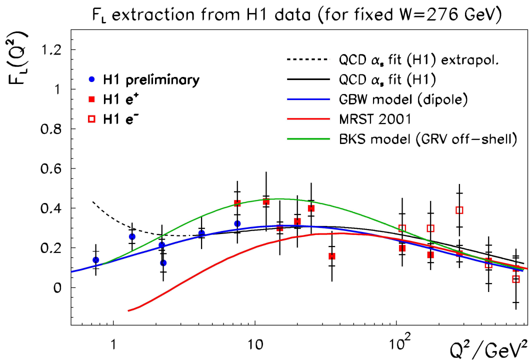

Fig. 4. $F_L(Q^2)$ at fixed $W = 276$ GeV. The full errors include the statistical uncorrelated and correlated systematic errors added in quadrature.

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