Measurement of the Longitudinal Proton Structure Function in Diffraction at the H1 Experiment

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The measurement of the inclusive and diffractive longitudinal proton structure function at low x and low Q^2 has been considered to be essential to complete the HERA ep programme has motivated a run at reduced $\sqrt{s}$ at the end of HERA. The theoretical interest in longitudinal structure functions is shortly motivated and basic principles of their direct measurements are outlined. A referenced simulation study anticipates the results that are awaited soon.

1. Introduction

The HERA accelerator, the only ep collider in the world, was a powerful instrument to provide experimental data to study a structure of the proton. At the highest centre-of-mass energy of 319 GeV, it detected collisions of electrons at 27 GeV and protons at 920 GeV in two experiments H1 and ZEUS.

Since the origin of its operation in 1992 until the end in 2007, diffractive processes have been observed at HERA. These are inelastic processes $e + p \rightarrow e + X + Y$ where the proton stays either intact or turns into a low mass state Y. These processes are characterised by a gap in rapidity between the final state X and the proton state Y. The presence of this gap is explained by the exchange of a phenomenological object with quantum numbers of vacuum, the so called *pomeron*. Approximately 10% of neutral current DIS processes are of diffractive nature.

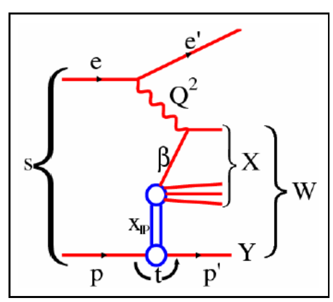

Fig. 1. Diffractive process.

Figure 1 shows a diffractive process. In diffraction, the kinematical variables $x_{\mathbb{P}}$ and β are introduced. The first one stands for the proton momentum fraction carried by the pomeron, the latter stands for the momentum fraction of the pomeron carried by the struck quark.

Experimentally, diffractive processes can be detected by demanding a *large rapidity gap* in the forward region (in the direction of protons). Another possibility is to detect the scattered proton in the diffractive processes where the proton remains intact far from the interaction point in detectors called *Roman pots*. The large rapidity gap method has the advantage of higher statistics. The Roman pots give a cleaner diffractive sample with less contribution from proton dissociation processes.

2. Physics Interest

2.1. Longitudinal Proton Structure Function F_L

The neutral current cross section in DIS is given by

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

where x, Q^2 are standard DIS variables and y can be obtained from

$$sxy = Q^2. \tag{2}$$

$Y_+ = 1 + (1-y)^2$ is a kinematical factor and F_2, F_L are two structure functions. The second term in (1) containing F_L can be neglected anywhere but at large y due to the presence of $\frac{y^2}{Y_+}$ factor. Since the kinematical variables are bound by equation (2) the longitudinal structure function plays an important role in low x physics.

In the Quark Parton Model, the longitudinal structure function F_L is zero since longitudinally polarised photons do not couple to spin 1/2 quarks [1]. In the lowest order DGLAP approximation of QCD, the longitudinal structure function is given by [2]

$$F_L(x) = \frac{\alpha_s}{4\pi}x^2\int_x^1 \frac{dz}{z^3}\left[\frac{16}{3}F_2(x) + 8\sum e_q^2(1-\frac{x}{z})zg(z)\right]. \tag{3}$$

Both quarks and gluons contribute. This equation reflects a strong relation between F_L and the gluon density at low x. Thus the knowledge of F_L gives a complementary determination of the gluon distribution $xg(x,Q^2)$, as can be easily seen from an approximate solution of the equation above [3]

$$xg(x) = 1.8\left[\frac{3\pi}{2\alpha_s}F_L(0.4x) - F_2(0.8x)\right] \simeq \frac{8.3}{\alpha_s}F_L(0.4x). \tag{4}$$

Presently, the gluon distribution at low x is determined indirectly from the Q^2 evolution of $F_2(x, Q^2)$. Obviously, this is model dependent and relies on DGLAP assumptions. The validity of DGLAP is questionable at low x, therefore a direct measurement of F_L is an important cross check of our understanding of parton distributions at low x.

2.2. Longitudinal Proton Structure Function in Diffraction F_L^D

Nothing is experimentally known about $F_L^D(x_{I\!P}, Q^2, \beta)$. According to our understanding, the diffractive cross section is dominated by a higher twist contribution arising from the exchange of longitudinally polarised photons at high β and low Q^2. The dominant role played by gluons in the diffractive parton densities points to a relatively large F_L^D. Assuming the validity of QCD hard scattering collinear factorisation for diffraction, this gluon dominance results in a leading twist F_L^D which is approximately proportional to the diffractive gluon density. A direct measurement of F_L^D would thus provide a powerful independent tool to verify our understanding of the gluon densities extracted indirectly in QCD fits from the scaling violations of F_2^D [4].

3. Measurement

3.1. Direct Measurement of F_L

In order to perform a direct measurement of the longitudinal proton structure function in DIS, at least two different centre-of-mass energies are needed. Looking at equation (1), one cannot distinguish the two structure functions at fixed x and Q^2 without varying y. Since the kinematics are constrained by (2), the only way to change y holding x and Q^2 fixed is to vary the squared centre-of-mass energy s. One would not consider the HERA *ep* programme as complete without having performed such a text book measurement. Thus low energy runs at HERA were proposed [5].

3.2. Direct Measurement of F_L^D

The measurement of the longitudinal proton structure function in diffraction is analogous. The diffractive cross section in terms of diffractive reduced cross section σ_r^D reads

$$\frac{\mathrm{d}^3\sigma^{ep\rightarrow eXY}}{\mathrm{d}x_{I\!P}\mathrm{d}\beta\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{\beta Q^4} Y_+ \sigma_r^D(x_{I\!P}, \beta, Q^2) \tag{5}$$

$$\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D, \tag{6}$$

where the diffractive kinematical variables are constrained by

$$s x_{I\!P} \beta y = Q^2. \tag{7}$$

Again, in order to distinguish the two structure functions $F_2^D(x_{I\!P}, Q^2, \beta)$ and $F_L^D(x_{I\!P}, Q^2, \beta)$ one needs to vary y. The low energy runs at HERA are necessary to directly measure the longitudinal proton structure function in diffraction F_L^D.

Combining the equations (6) for two different centre-of-mass energies, one can express the longitudinal structure function as follows

$$F_L^D = \frac{Y_+^{460} Y_+^{920}}{y_{460}^2 Y_+^{920} - y_{920}^2 Y_+^{460}} \left(\sigma_r^{D\,920} - \sigma_r^{D\,460} \right), \tag{8}$$

where the indices stand for different proton beam energies.

The large rapidity gap method was chosen to select the diffractive data sample for this measurement. The advantage of ∼10 times larger statistics than the Roman pots can provide is essential to decrease the statistical uncertainties. However, the Roman pots can serve as an important tool to check the cleanness of the diffractive sample.

Figure 2 shows a simulation of the measurement based on 100 pb^{-1} of data with a proton beam energy at 920 GeV and 10 pb^{-1} of data with proton beam energy at 400 GeV [6]. This value is similar to the final beam energies used (see section 3.3). The dominant errors arise from statistical uncertainties and from the uncertainties that are uncorrelated between the different beam energies. According to this simulation, it is possible to measure the F_L^D with such a precision so that the gluon densities extracted in QCD fits to F_2^D can be tested. It may also be possible to obtain results at high β, giving information on the higher twist contribution in that region.

3.3. Low Energy Runs at HERA

The final stage of HERA operation was devoted to the low energy runs. According to the simulations, at least 10 pb^{-1} of data with protons at 460 GeV are needed in order to perform a precise measurement of longitudinal structure functions F_L and F_L^D (combined with ∼100 pb^{-1} of 920 GeV proton data). At the time these data were being taken, a further strategy had to be decided; either to take more 460 GeV data, or to move to a different proton beam energy. Finally, an additional 7 pb^{-1} of data with protons at 575 GeV were taken. The three different centre-of-mass energies in total allow cross checks of the precision of the F_L and F_L^D measurement. All available low and middle energy data together with 100 pb^{-1} of 920 GeV proton data will be used.

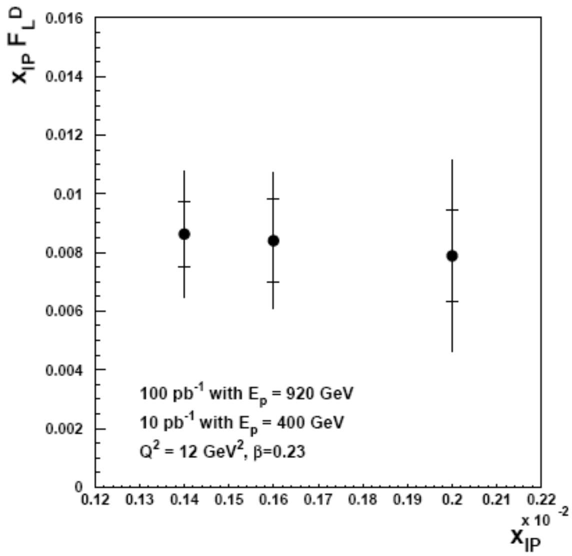

Fig. 2. Simulation of a longitudinal proton structure function in diffraction $F_2^D(x_{I\!P}, Q^2, \beta)$ based on two different proton beam energies. The outer error bars show the total error, the inner bars show the statistical uncertainties.

4. Conclusion

The latest data from the H1 experiment provide satisfactory statistics to carry out the F_L and F_L^D measurements. The basic aspects of the measurements have been described and the theoretical interests have been briefly introduced here.

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