Future Measurement of the Longitudinal Proton Structure Function at HERA

L. Bauerdick[a], A. Glazov[b], M. Klein[b]
[a] DESY, Notkestraße 85, D-22607 Hamburg, Germany
[b] DESY-IfH Zeuthen, Platanenallee 6, D-15738 Zeuthen, Germany

Abstract: A study is presented of a possible future measurement of the longitudinal structure function $F_L(x, Q^2)$ with different proton beam energies at HERA.

1 Introduction

In the one-photon exchange approximation, the deep inelastic inclusive scattering (DIS) cross section is given by the expression

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

Here Q^2 is the squared four-momentum transfer, x is the Bjorken scaling variable and $y = Q^2/sx$ the inelasticity variable with $s = 4E_eE_p$ the centre of mass energy squared of the collision. The two form factors F_2 and F_L are related to the cross sections σ_T and σ_L of the scattering of transversely and longitudinally polarized virtual photons off protons. In the Quark Parton Model F_2 is the sum of quark and antiquark distributions in the proton weighted with the electric quark charges squared while F_L is predicted to be zero for spin 1/2 partons [1]. In Quantum Chromodynamics (QCD) F_L aquires a non zero value due to gluon radiation which is proportional to the strong coupling constant α_s [2] with possibly sizeable higher order corrections in QCD perturbation theory [3]. Measurements of F_L, expressed as the structure function ratio

$$R = \frac{F_L}{F_2 - F_L} = \frac{\sigma_L}{\sigma_T}, \tag{2}$$

were performed by various fixed target lepton-hadron scattering experiments at x values larger than 0.01 [4, 5].

A measurement of the longitudinal structure function at low x at HERA is important for a number of reasons:

- At lowest x the cross section measurement can not be uniquely interpreted as a determination of F_2 because the F_L contribution to the cross section becomes sizeable, see eq.1.

- A measurement of F_L and of F_2 represents an important test of QCD which uniquely describes the decomposition of the cross section into the F_2 and the F_L part based on a common set of parton distributions and NLO corrections [6]. In particular, the scaling violations of F_2 which at low x determine the gluon distribution are predicted to be in accord with F_L which is directly given by xg.

- The lowest Q^2 behaviour of F_2 is related to F_L or R: a hard input distribution leads to $R = 6.2\alpha_s(Q^2)/\pi$, independently of x while a soft distribution ,which implies approximate double logarithmic scaling of F_2, leads to a dependence of R on $\ln 1/x$ [7], see also [8].

- The F_L measurements are performed at lowest possible x where BFKL dynamics may show up. This may not affect F_2 in a sizeable way but may lead to F_L values predicted to be different by a factor of 2 from the standard DGLAP expectation [9].

The question is how precise one may hope to perform this measurement. This can be studied now more reliably than previously [10, 11] since the systematics of that measurement is better defined. This paper documents a study to measure F_L with a set of different proton beam energies. Similar conclusions were reached during this workshop in [12]. Data at lower electron beam energies E_e may be useful for systematic cross checks. Access to F_L with lowered electron energy, however, is even more complicated as about two times lower scattered electron energies have to be measured than with maximum E_e. Further information on R may be obtained from radiative events as originally proposed in [13].

2 Cross Section Measurement

A measurement of the longitudinal structure function requires to access the lowest possible scattered electron energies E_e' which approximately define y as $1 - E_e'/E_e$. The measurement accuracy improves with rising y like $1/y^2$, see eq.1. The kinematic range of the F_L measurement is a band in the Q^2, x plane of a y interval, between about 0.5 and 0.85, with a low Q^2 limit given by the maximum accepted polar angle of the scattered electron $\theta_e \simeq 177^o$ and a large Q^2 limit around 100 GeV^2. A measurement performed at several beam energy settings appropriately chosen permits to cover an x range at fixed Q^2 of about one order of magnitude. The smallest x values can be covered using highest energy data by the method introduced by H1 [14] which subtracts the F_2 contribution to the cross section assuming that F_2 is accurately described by NLO QCD.

The following sources of systematic errors of the high y cross section measurement were considered:

- The uncertainty of the scattered electron energy: using the kinematic peak and the π_0 mass reconstruction, the double angle method and Compton events one may assume a scale uncertainty of 0.5% which implies a cross section error of about 0.7% at high y.

- The polar angle measurement can be as accurate as 0.5 mrad, even independently of the event vertex reconstruction with hadron tracks, based on drift chambers and Silicon trackers. The resulting cross section uncertainty amounts to about 0.6%.

- The photoproduction background may cause an error of 2% which assumes a 10% control of the background. This should be possible using the electron tagger systems, the hadronic backward calorimeter sections and reducing the π_0 background part with tracking in front of calorimeters.
- At high y the radiative corrections are large [15] if the kinematics is reconstructed with the scattered electron. These get reduced due to possible track requirements or $E - p_z$ cuts which allows to study the effect of the radiative corrections. Moreover, with hadron calorimetry in backward direction one may use as well the hadronic final state to reconstruct the kinematics which then is much less affected by radiative effects. Altogether an uncertainty of 1% may remain.
- Various detector and analysis efficiencies give rise to an estimated uncertainty of 2%.
- At low E_e' the electron identification becomes difficult. For $E_e' \geq 6.5$ GeV an error of 1% has been achieved by the H1 Collaboration [14]. Refined cluster algorithms considering the highest energy cluster and the next high energy cluster can be employed and information on hadron deposition in the calorimeters be used. Here we assume an error of 1%.

Altogether it can be expected that a 3% cross section error is achievable owing to the large statistics envisaged for this measurement. This represents an improvement by a factor of 2 of the H1 result obtained at $y \simeq 0.7$ with data taken in 1994.

3 Longitudinal Proton Structure Function F_L

The estimated systematic cross section errors were converted into F_L measurement errors, see fig.1 (open points), which are typically 0.08 in absolute. At each Q^2 two or three rather precise F_L measurements can be obtained at different x for the set of energies considered. Some of the bins are accessed with more than one beam energy combination. The beam energies finally chosen should include smallest and largest possible proton beam energies because of the measurement accuracy and x range. An important parameter of the measurement accuracy is the minimum electron energy E_e' which was assumed to be 5 GeV. No use was made in the analysis of a possible reduction of the F_L errors by the cross calibration of the measurement results at low y where the sensitivity to F_L is negligible.

At lowest x information on F_L can be obtained using the F_2 subtraction method [14]. The result of a corresponding study for the highest beam energy is illustrated in fig.1 (closed points). The assumptions on the cross section error were those as described above. In the standard method two independent cross section measurements have to be combined. Here errors have to be considered from one data set only, i.e. those from the large and the low y region. These partially are compensating with the exception of the electron energy miscalibration. This, however, leads to a very distinguished departure of F_2 at low y from any possible QCD behaviour. Therefore it can be constrained further in the required QCD analysis of F_2 giving finally rise to an estimated 1.5% accuracy of the extrapolated F_2. Finally, the uncertainty of the QCD fit to F_2 and its extrapolation to high y were estimated to leave a residual 2% error of the subtracted F_2 cross section part.

The subtraction method can of course be applied to all data sets. The data at the present HERA energies have shown already that the QCD assumption on F_2 will be justified for the lower energy data since these are limited to relatively larger x, at fixed Q^2. The estimated F_L errors of the subtraction method and of the data comparison method are similar which should enable important systematic cross checks since the subtraction method depends on one energy data set only while the standard method uses at least two. These were not used here for any possible error reduction which would have been difficult to model.

4 Conclusions

A measurement of the longitudinal proton structure function can be performed at HERA with runs at ≥ 4 different proton energies with luminosities per beam of about 10 pb^{-1}. Such a dedicated measurement series is estimated to determine F_L for Q^2 values between about 4 and 100 GeV^2 with systematic errors of $\simeq 0.08$ for one order of magnitude in x at given Q^2. This accuracy is challenging but the measurement is of fundamental theoretical interest.

References

[1] C.G. Callan and D. Gross, Phys.Rev.Lett. **22**(1969)156;

[2] G.Altarelli and G.Martinelli, Phys.Lett.**B76**(1978)89;

[3] E.B. Zijlstra and W. van Neerven, Nucl.Phys. **B383**(1992)525;

[4] A.Bodek, Contribution to the Proceedings of the 4th International Conference on Deep Inelastic Scattering, Rome, April 1996, to appear, and references cited therein;

[5] A.Milstaijn, NMC Collaboration, Contribution to the Proceedings of the 4th International Conference on Deep Inelastic Scattering, Rome, April 1996, to appear;

[6] J. Blümlein and S. Riemersma, these proceedings;

[7] F.J. Yndurain, FTUAM 96-12(1996), Nucl.Phys.to be published;

[8] R.S. Thorne, these proceedings;

[9] R. Peschanski and G. Salam, these proceedings;

[10] J. Blümlein et al., Proc. HERA Workshop 1987, ed. by R. Peccei, Vol.1, p.67;

[11] A.M. Cooper-Sarkar et al; Proc. HERA Workshop 1987, ed. by R. Peccei, Vol.1, p.235 and Proc. HERA Workshop 1991, ed. by W. Buchmüller and G. Ingelman, Vol.1, p.155;

[12] H. Blaikley, M. Cooper-Sarkar and S. Dashu, Contribution to this workshop;

[13] M.W. Krasny, W. Placzek and H. Spiesberger, Proc. HERA Workshop 1991, ed. by W. Buchmüller and G. Ingelman, Vol.1, p.171;

[14] H1 Collaboration, *Determination of the Longitudinal Structure Function F_L at Low x at HERA*, Contributions to the Rome and Warsaw Conferences, 1996, to be published;

[15] D.Yu. Bardin et al., these proceedings;

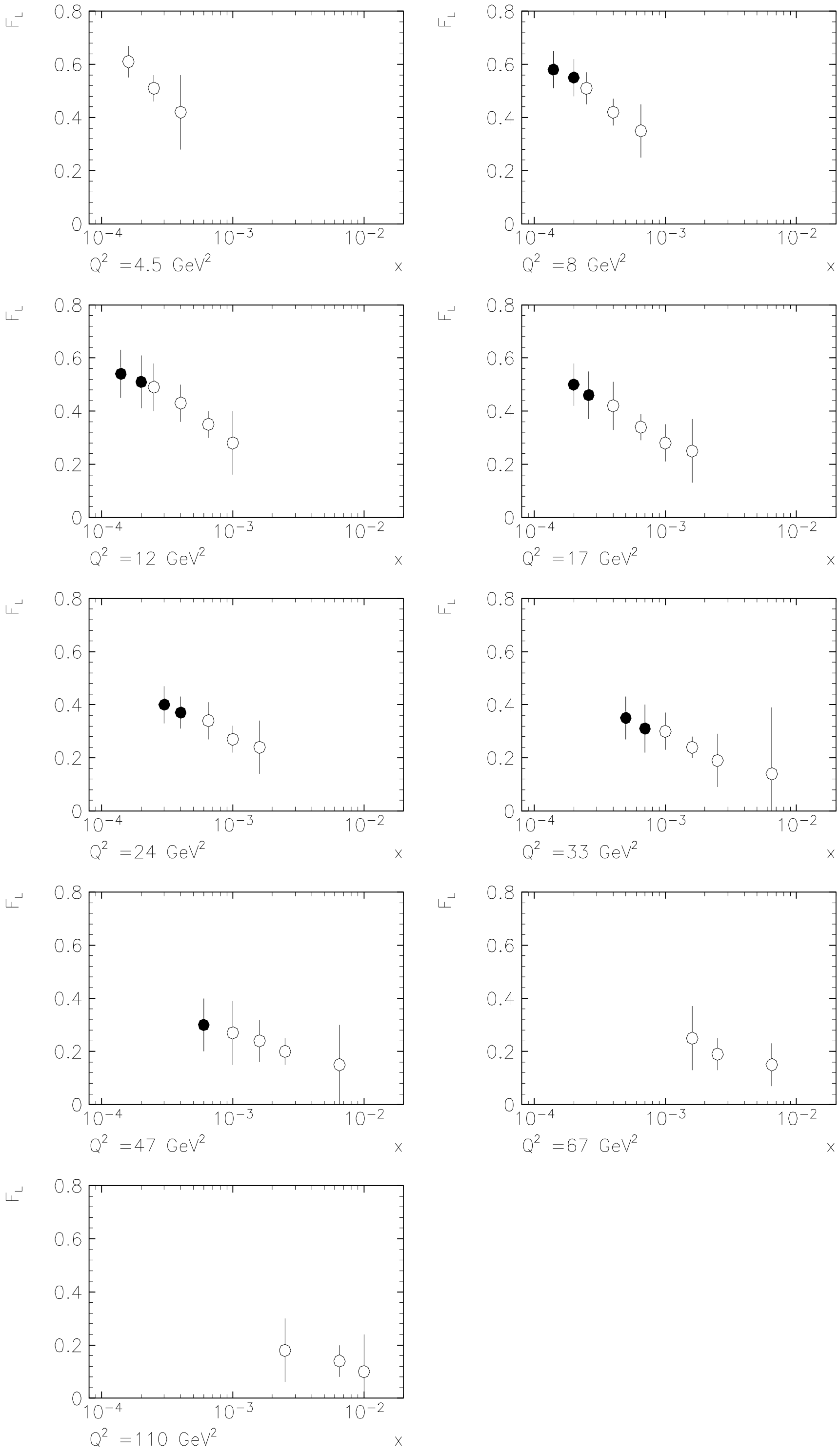

Figure 1: Estimated total accuracy of a measurement of the longitudinal structure function $F_L(x, Q^2)$ simulating data for an electron beam energy of 27.5 GeV and proton beam energies of 250, 350, 450 and 820 GeV with luminosities of 10 pb^{-1} per beam energy setting (open points). The closed points at lowest x represent the result of a simulation study using the method to determine F_L after subtraction of F_2. These points are based on the highest energy data set.