Prospects for F_L^D Measurements at HERA-II

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Abstract
The theoretical interest in the longitudinal diffractive structure function F_L^D is briefly motivated and possible measurement methods are surveyed. A simulation based on realistic scenarios with a reduced proton beam energy at HERA-II using the H1 apparatus shows that measurements are possible with up to 4σ significance, limited by systematic errors.

1 Introduction

In order to understand inclusive diffraction fully, it is necessary to separate out the contributions from transversely and longitudinally polarised exchange photons. Here, the formalism of [1] is adopted, where by analogy with inclusive scattering and neglecting weak interactions, a reduced cross section σ_r^D is defined,[1] related to the experimentally measured cross section by

$$\frac{d^3\sigma^{ep\to eXY}}{\mathrm{d}x_{I\!P}\,\mathrm{d}\beta\,\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{\beta\,Q^4} \cdot Y_+ \cdot \sigma_r^D(x_{I\!P}, \beta, Q^2)\,, \quad \text{where} \quad \sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D \tag{1}$$

and $Y_+ = 1 + (1-y)^2$. The structure function F_L^D, is closely related to the longitudinal photon contribution, whereas the more familiar F_2^D contains information on the sum of transverse and longitudinal photon contributions.

It is generally understood [2] that at high β and low-to-moderate Q^2, σ_r^D receives a significant, perhaps dominant, higher twist contribution due to longitudinally polarised photons. Definite predictions [3] exist for this contribution, obtained by assuming 2-gluon exchange, with a similar phenomenology to that successfully applied to vector meson cross sections at HERA. The dominant role played by gluons in the diffractive parton densities [1] implies that the leading twist F_L^D must also be relatively large. Assuming the validity of QCD hard scattering collinear factorisation [4], this gluon dominance results in a leading twist F_L^D which is approximately proportional to the diffractive gluon density. A measurement of F_L^D to even modest precision would provide a very powerful independent tool to verify our understanding of the underlying dynamics and to test the gluon density extracted indirectly in QCD fits from the scaling violations of F_2^D. This is particularly important at the lowest x values, where direct information on the gluon density cannot be obtained from jet or D^* data due to kinematic limitations and where novel effects such as parton saturation or non-DGLAP dynamics are most likely to become important.

Several different methods have been proposed to extract information on F_L^D. It is possible in principle to follow the procedure adopted by H1 in the inclusive case [5, 6], exploiting the decrease in σ_r^D at large y relative to expectations for F_2^D alone (see equation 1). This method may yield significant results if sufficient precision and y range can be achieved [7], though assumptions are required on the $x_{I\!P}$ dependence of F_2^D, which is currently not well constrained by theory. An alternative method, exploiting the azimuthal decorrelation between the proton and electron scattering planes caused by interference between the transverse and longitudinal photon contributions [8], has already been used with the scattered proton measured in the ZEUS LPS [9]. However, due to the relatively poor statistical precision achievable with Roman pots at HERA-I, the current results are consistent with zero. If the potential of the H1 VFPS is fully realised, this method may yet yield significant results in the HERA-II data [10]. However, if the necessary data are taken, the most promising possibility is to extract F_L^D by comparing data at the

[1]It is assumed here that all results are integrated over t. The superscript (3) usually included for $F_2^{D(3)}$ and other quantities is dropped for convenience.

same Q^2, β and $x_{I\!P}$, but from different centre of mass energies $\sqrt{s}$ and hence from different y values. The longitudinal structure function can then be extracted directly and model-independently from the measured data using equation 1. In this contribution, one possible scenario is investigated, based on modified beam energies and luminosities which are currently under discussion as a possible part of the HERA-II programme.

2 Simulated F_L^D Measurement

Given the need to obtain a large integrated luminosity at the highest possible beam energy for the remainder of the HERA programme and the fixed end-point in mid 2007, it is likely that only a relatively small amount of data can be taken with reduced beam energies. A possible scenario is investigated here in which 10 pb^{-1} are taken at just one reduced proton beam energy of $E_p = 400$ GeV, the electron beam energy being unchanged at 27.5 GeV. Since the maximum achievable instantaneous luminosity at HERA scales like the proton beam energy squared [11], this data sample could be obtained in around 2-3 months at the current level of HERA performance. It is assumed that a larger data volume of $100\ \mathrm{pb}^{-1}$ is available at $E_p = 920$ GeV, which allows for downscaling of high rate low Q^2 inclusive triggers.[2] The results presented here can be used to infer those from other scenarios given that the statistical uncertainty scales like $\sigma_r^{D\,400}/\sqrt{\mathcal{L}_{400}} + \sigma_r^{D\,920}/\sqrt{\mathcal{L}_{920}}$, where $\sigma_r^{D\,E_p}$ and $\mathcal{L}_{E_p}$ are the reduced cross section and the luminosity at a proton beam energy of E_p, respectively.

The longitudinal structure function can be extracted from the data at the two beam energies using

$$F_L^D = \frac{Y_+^{400}\,Y_+^{920}}{y_{400}^2 Y_+^{920} - y_{920}^2 Y_+^{400}} \left(\sigma_r^{D\,920} - \sigma_r^{D\,400}\right) \ , \tag{2}$$

where y_{E_p} and $Y_+^{E_p}$ denote y and Y_+ at a beam energy E_p. It is clear from equation 2 that the best sensitivity to F_L^D requires the maximum difference between the reduced cross sections at the two beam energies, which (equation 1) implies the maximum possible y at $E_p = 400$ GeV. By measuring scattered electrons with energies E_e' as low as 3 GeV [5], the H1 collaboration has obtained data at $y = 0.9$. This is possible with the use of the SPACAL calorimeter in combination with a measurement of the electron track in either the backward silicon tracker (BST) or the central jet chamber (CJC). For HERA-II running, the corresponding available range of scattered electron polar angle is $155^\circ < \theta_e' < 173^\circ$, which is used in the current study.[3] Three intervals in y are considered, corresponding at $E_p = 400$ GeV to $0.5 < y_{400} < 0.7$, $0.7 < y_{400} < 0.8$ and $0.8 < y_{400} < 0.9$. It is ensured that identical ranges in β, $x_{I\!P}$ and Q^2 are studied at $E_p = 920$ GeV by choosing the bin edges such that $y_{920} = y_{400} \cdot 400/920$. Since the highest possible precision is required in this measurement, the restriction $x_{I\!P} < 0.02$ is imposed, which leads to negligible acceptance losses with a typical cut on the forwardmost extent of the diffractive system $\eta_{\mathrm{max}} < 3.3$. The kinematic restrictions on E_e', θ_e' and $x_{I\!P}$ lead to almost no change in the mean Q^2, M_{X}^2 or $\beta \simeq Q^2/(Q^2 + M_{\mathrm{X}}^2)$ as either y or E_p are varied. In contrast, $x_{I\!P} = Q^2/(s\,y\,\beta)$ varies approximately as $1/y$. As is shown in figure 1, at the average $\beta = 0.23$, there is at least partial acceptance for all y bins in the range $7 < Q^2 < 30\ \mathrm{GeV}^2$, which is chosen for this study, leading to an average value of Q^2 close to $12\ \mathrm{GeV}^2$.

The simulation is performed using the RAPGAP [13] Monte Carlo generator to extract the number of events per unit luminosity in each bin at each centre of mass energy. The values of F_2^D and F_L^D, and hence $\sigma_r^{D\,920}$ and $\sigma_r^{D\,400}$ are obtained using an updated version of the preliminary H1 2002 NLO QCD fit [1].

[2]Alternative scenarios in which a smaller data volume at large E_p is taken in a short, dedicated run, could potentially lead to better controlled systematics at the expense of increased statistical errors.

[3]One interesting alternative running scenario [12] is to obtain data at $E_p = 920$ GeV with the vertex shifted by 20 cm in the outgoing proton direction, which would allow measurements up to $\theta_e' = 175^\circ$, giving a low Q^2 acceptance range which closely matches that for the $E_p = 400$ GeV data at the normal vertex position.

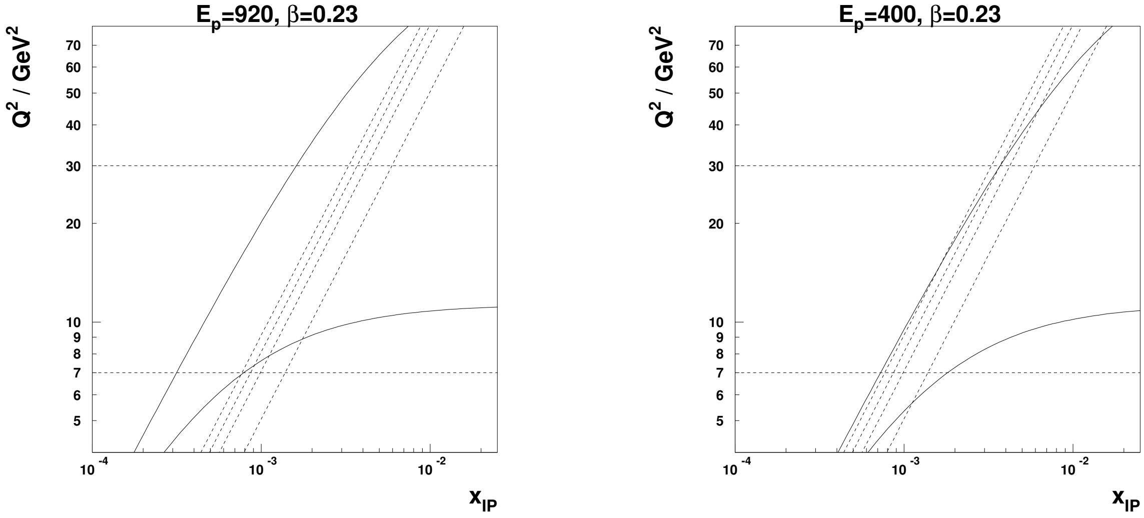

Fig. 1: Illustration of the kinematic plane in Q^2 and $x_{I\!P}$ at proton energies of 920 GeV and 400 GeV, with fixed $\beta = x/x_{I\!P} = 0.23$. The solid lines illustrate the experimental limits of $155^\circ < \theta'_e < 173^\circ$. The horizontal dashed lines illustrate the Q^2 range used for the simulation. The diagonal dashed lines illustrate the binning in y, corresponding at $E_p = 400$ GeV to $y = 0.9$ (leftmost line), $y = 0.8$, $y = 0.7$ and $y = 0.5$ (rightmost line).

The expected precision on F_L^D is obtained by error propagation through equation 2. The systematic uncertainties are estimated on the basis of previous experience with the H1 detector [1, 5]. At the large y values involved, the kinematic variables are most accurately reconstructed using the electron energy and angle alone. The systematic uncertainties on the measurements of these quantities are assumed to be correlated between the two beam energies. With the use of the BST and CJC, the possible bias in the measurement of θ'_e is at the level of 0.2 mrad. The energy scale of the SPACAL calorimeter is known with a precision varying linearly from 2% at $E'_e = 3$ GeV to 0.2% at $E'_e = 27.5$ GeV. Other uncertainties which are correlated between the two beam energies arise from the photoproduction background subtraction (important at large y and assumed to be known with a precision of 25%) and the energy scale for the hadronic final state used in the reconstruction of M_X and hence $x_{I\!P}$ (taken to be known to 4%, as currently). Sources of uncertainty which are assumed to be uncorrelated between the low and high E_p measurements are the luminosity measurement (taken to be $\pm 1\%$), the trigger and electron track efficiencies ($\pm 1\%$ combined) and the acceptance corrections, obtained using RAPGAP ($\pm 2\%$). The combined uncorrelated error is thus 2.4%. Finally, a normalisation uncertainty of $\pm 6\%$ due to corrections for proton dissociation contributions is taken to act simultaneously in the two measurements. Other sources of uncertainty currently considered in H1 measurements of diffraction are negligible in the kinematic region studied here.

y_{400}	y_{920}	$x_{I\!P}$	F_2^D	F_L^D	$\delta_{\rm unc}$	$\delta_{\rm norm}$	$\delta E'_e$	$\delta\theta'_e$	δM_X	$\delta\gamma p$	$\delta_{\rm syst}$	$\delta_{\rm stat}$	$\delta_{\rm tot}$
$0.5 - 0.7$	0.217 - 0.304	0.0020	15.72	3.94	34	6	8	2	7	0	36	20	41
$0.7 - 0.8$	0.304 - 0.348	0.0016	20.87	5.25	19	6	3	2	5	6	22	17	28
$0.8 - 0.9$	0.348 - 0.391	0.0014	24.47	6.16	14	6	6	1	2	13	21	13	25

Table 1: Summary of the simulation at $Q^2 = 12$ GeV and $\beta = 0.23$. The first three columns contain the y ranges used at $E_p = 400$ GeV and $E_p = 920$ GeV and the $x_{I\!P}$ values. The next two columns contain the values of the diffractive structure functions. These are followed by the uncorrelated ($\delta_{\rm unc}$) and proton dissociation ($\delta_{\rm norm}$) uncertainties and the correlated systematics due to the electron energy ($\delta E'_e$) and angle ($\delta\theta'_e$) measurements, the hadronic energy scale (δM_X) and the photoproduction background ($\delta\gamma p$), all in percent. The last three columns summarise the systematic, statistical and total uncertainties.

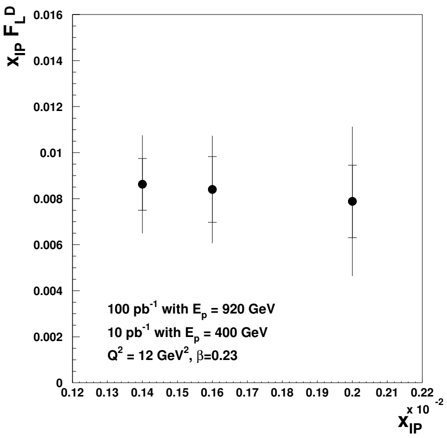

Fig. 2: Illustration of the simulated result for F_L^D, showing the three data points with statistical (inner bars) and total (outer bars) errors.

Full details of the simulated uncertainties on the F_L^D measurements are given in table 1. An illustration of the corresponding expected measurement, based on the F_L^D from the H1 2002 fit is shown in figure 2. The most precise measurement is obtained at the highest y, where F_L^D would be determined to be unambiguously different from its maximum value of F_2^D and to be non-zero at the 4σ level. Two further measurements are obtained at lower y values. The dominant errors arise from statistical uncertainties and from uncertainties which are uncorrelated between the two beam energies. Minimising the latter is a major experimental challenge to be addressed in the coming years.

Only one possible scenario has been investigated here, leading to a highly encouraging result at relatively low β, which would provide a very good test of the leading twist F_L^D and thus of the gluon density extracted in QCD fits to F_2^D. It may also be possible to obtain results at high β, giving information on the higher twist contributions in that region, for example by restricting the analysis to lower $x_{I\!P}$.

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References

[1] H1 Collaboration, paper 980 contributed to ICHEP 2002, Amsterdam (H1prelim-02-012).

[2] J. Bartels, J. Ellis, H. Kowalski, M. Wusthoff, Eur. Phys. J. **C7**, 443 (1999).

[3] A. Hebecker, T. Teubner, Phys. Lett. **B498**, 16 (2001).

[4] J. Collins, Phys. Rev. **D57**, 3051 (1998). Erratum ibid **D61** (2000) 019902.

[5] C. Adloff et al. [H1 Collaboration], Eur. Phys. J. **C21**, 33 (2001).

[6] H1 Collaboration, paper 4-083 contributed to EPS 2003, Aachen (H1prelim-03-043).

[7] A. Mehta, J. Phillips, B. Waugh, proceedings of the workshop ‘Future Physics at HERA’, DESY, 1996, ed. Ingelman, de Roeck, Klanner, pg 704.

[8] M. Diehl, proceedings of the XIth International Conference on Elastic and Diffractive Scattering, Blois, France, 2005 [hep-ph/0509107].

[9] S. Chekanov et al. [ZEUS Collaboration], Eur. Phys. J. **C38**, 43 (2004).

[10] L. Favart et al., ‘Proposal for Installation of a Very Forward Proton Spectrometer in H1 after 2000’, DESY-PRC 01/00.

[11] F. Willeke, ‘Issues for HERA Future Operation’, talk at the Workshop on the Future of Lepton-Nucleon Scattering, Durham, UK, 2001.

[12] M. Klein. Proceedings of the 12th International Workshop on Deep Inelastic Scattering (DIS 2004), Strbske Pleso, Slovakia, 2004.

[13] H. Jung, Comp. Phys. Commun. **86**, 147 (1995). See also http://www.desy.de/ jung/rapgap.html.