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Running at Low Proton Beam Energies

H1 Collaboration

Expression of Interest submitted to the DESY Physics Research Committee, PRC 11/05

Abstract

The H1 Collaboration is interested in a run with reduced proton beam energy of about three months duration in order to measure the inclusive and the diffractive longitudinal structure functions at low x and Q^2 from data corresponding to an integrated luminosity of about 10 pb^{-1} . This run has been considered to be essential to complete the HERA ep programme, which is largely devoted to the understanding of a gluon dominated high density system of partons. It is proposed to be performed in the year 2007.

1 Introduction

For 13 years HERA has been operated at the highest accessible centre-of-mass energy $\sqrt{s}$ above 300 GeV, with $s = 4E_eE_p$, in order to explore the region of highest momentum transfers Q^2 and high transverse scales. This exploration is not completed and in fact interesting hints have been observed for new physics [1], which deserve clarification with high luminosity.

Following the request of the PRC to consider the running period 2006/07, H1 has decided to express its firm interest in a run with lowered proton beam energies, which is discussed in this paper. This run is devoted to a complementary measurement at low x and thus provides important information on the theory [2] of a high density gluon dominated system of partons. The two main physics subjects are a measurement of the longitudinal structure function $F_L(x, Q^2)$ and of the diffractive longitudinal structure function $F_L^D(x_{IP}, Q^2, \beta)$. A reduced beam energy run could allow, moreover, to measure the energy dependence of vector meson and total cross sections and to extend the kinematic range of inclusive F_2 measurements towards larger x.

It has long been known that variation of s allows direct access to the longitudinal photon induced part of the scattering cross section. Such a measurement requires very high accuracy as the longitudinal structure function generally has only a small influence on the cross section and where it is noticable, at large inelasticity y, the experimental background from photoproduction is large and the electron identification a challenge. Since 1993, H1 has been pursuing extensive upgrade projects of the backward detector region [SPACAL (installed 95), BDC (95), BST (96 and 06), BPC (02), CIP (02)], which were endorsed by the PRC and directed to precision measurements at low x, including a new luminosity measurement system (02) and a new forward proton tagging system [VFPS(04)] for diffractive events. H1 is thus now able to trigger on and to identify low energy scattered electrons, $E'_e > 3$ GeV, corresponding to an inelasticity y up to about 0.9, and to measure the cross section at the per cent level of accuracy in a large part of the low Q^2 region. HERA has upgraded the luminosity performance. A meaningful low proton beam run can thus be performed in a few months running time.

2 Physics Interest

2.1 The Longitudinal Structure Function F_L

The inclusive, deep inelastic electron-proton scattering cross section at low Q^2

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

is defined by two proton structure functions, F_2 and F_L, with $y = Q^2/sx$, $Y_+ = 1 + (1-y)^2$ and $f(y) = y^2/Y_+$. These two basic quantities have so far not been properly disentangled at HERA and the cross section has basically been taken as a measure for F_2 with some assumptions on F_L, or *vice versa* at large y [3]. Any DIS experiment has attempted to unfold these functions as they yield independent information on the structure of the proton. The prospects to measure F_L at HERA are much better than at fixed target experiments due to the estimated large size of F_L. Without the textbook measurement of $F_L(x,Q^2)$ one can not consider the HERA *ep* programme to be completed.

The two functions reflect the transverse and the longitudinal polarisation state of the virtual photon probing the proton structure, i.e. $F_T = F_2 - F_L$ and F_L, respectively. In the Quark Parton Model F_L is zero since longitudinally polarised photons do not couple to spin 1/2 quarks [4]. In the DGLAP approximation of perturbative QCD, to lowest order, the longitudinal structure function is given by [5]

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

with contributions from quarks and from gluons. At low x $F_L(x,Q^2)$ thus essentially determines the gluon distribution $xg(x,Q^2)$ as can be illustrated solving this equation approximately [6]

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

Presently the gluon distribution at low x is constrained indirectly by the Q^2 evolution of $F_2(x,Q^2)$. However, this relies on the DGLAP theory assumption which becomes questionable at low x. Data on $F_L(x,Q^2)$ represent a direct measure of xg and thus they provide an important cross check of the whole understanding of low x physics. Specifically the extraction of xg from $\partial F_2/\partial \ln Q^2$ has to be consistent at higher orders perturbation theory [7, 8] with that from $F_L(x,Q^2)$.

The Q^2 evolution is not uniquely governed by xg, recent fits from MRST and CTEQ deviating much in the relative contributions from quarks and gluons to this evolution. The additional constraint from $F_L(x,Q^2)$ closes the circle: data on F_2, $\partial F_2/\partial \ln Q^2$ and F_L constrain the theory completely and uniquely determine the sea quark and the gluon distribution at low x.

An alternative approach to low x physics is based on the colour dipole model (CDM). In this approach, the two polarisation states of the virtual photon lead to cross sections which are uniquely related by the longitudinal and transverse wavefunctions, i.e. with the CDM describing F_2 there exist testable predictions [9, 10] for F_L.

2.2 The Diffractive Longitudinal Structure Function F_L^D

A further strong motivation for a low energy run is a first measurement of the diffractive longitudinal structure function $F_L^D(x_{IP}, Q^2, \beta)$, describing events of the type $ep \to eXp$, where the proton loses a fraction x_{IP} of its longitudinal momentum to a colourless exchange (a pomeron), of which a momentum fraction $\beta = x/x_{IP}$ is carried by the struck quark. Nothing is experimentally known about F_L^D. It is generally understood [11] that at high β and low Q^2, the diffractive cross section receives a significant, perhaps dominant, contribution due to longitudinally polarised photons. Definite predictions [12] exist for this contribution, obtained by assuming two gluon exchange, with a similar phenomenology to that successfully applied to vector meson and DVCS cross sections at HERA. The dominant role played by gluons in the diffractive parton densities [13] implies that F_L^D must also be relatively large. Assuming the validity of QCD hard scattering collinear factorisation for diffraction [14], this gluon dominance results in a leading twist F_L^D which is approximately proportional to the diffractive gluon density, similarly to equation 2. A measurement of F_L^D would thus 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.

3 Low Energy Run Assumptions

It is possible to extract the longitudinal structure function directly from two or more cross section measurements at fixed x and Q^2 by varying y, which is possible by changing s. Since $s = 4E_eE_p$ one may vary the electron or proton beam energy or both. The sensitivity to F_L is proportional to y^2, see Eq. 1. As at large y and low Q^2 the inelasticity is given by $y \simeq 1 - E_e'/E_e$, reducing the electron beam energy would require to lower the scattered electron energy below the 2 GeV trigger threshold. Moreover, a reduction of the electron beam energy affects the scattered electron angle, θ_e, stronger than a reduction of the proton beam energy would do [1]. The advantage of making a relative cross section measurement when reducing E_p consists in a maximum cancellation of systematics. It has therefore been decided, as in previous investigations of such a run [18], to chose to lower E_p.

In a recent HERA note [19] estimates were given for the expected performance of a low proton beam energy run. Reducing the proton beam energy the luminosity is diminished approximately $\propto E_P^{-2}$. Including an initial setup and luminosity tuning time of three weeks, within 96 days a luminosity of 15 pb^{-1} is expected to be delivered at 460 GeV which for the simulations is taken to correspond to about 10 pb^{-1} of data collected by H1. There are arguments to run at more than one reduced energy to extend the range of x of the F_L data and provide valuable systematic cross checks. There are also arguments to restrict this measurement to just one setting because of the set-up time and because the luminosity for the diffractive data will be crucial. At this stage this question is not evaluated further and simulations are restricted to one data set of 10 pb^{-1} of reduced proton beam energy, keeping E_e unchanged.

4 Cross Section Measurement

The extraction of the two structure functions F_2 and F_L requires the DIS cross section to be measured as accurately as possible in a range of y from about 0.1 to the largest possible values. At large y and low Q^2 the scattering kinematics at HERA resemble those of a fixed target scattering experiment: the electron scattered off quarks at very low x ("at rest") is scattered through a small angle. It is accompanied by part of the hadronic final state which is related to the struck quark. Since high inelasticities y demand to identify scattered electrons down to a few GeV of energy, there is a considerable background from hadrons or photons, e.g. from the $\pi_0 \rightarrow \gamma\gamma$ decay. These particles usually stem from photoproduction in which the scattered electron escapes in the electron beam direction. Removal of this background is possible by requiring a track to be associated to the energy cluster in the SPACAL, which rejects photons, and by measuring its charge, which on a statistical basis allows the remaining part of the background to be removed, as was demonstrated with the BST and the CJC [3].

The most relevant uncertainties of the low x electron measurement as assumed in this simulation are: for E_e' the scale uncertainty varies between 0.2% at the kinematic peak, $E_e \simeq E_e'$ and 2% at 2 GeV; for θ_e an uncertainty between 0.2 mrad in the BST region and 1 mrad in the BPC/CJC region; a photoproduction background uncertainty of at most 4% at $y = 0.9$ and negligible for $y < 0.65$; radiative corrections are much reduced with the energy momentum conservation requirement ($E - p_z$ cut) and controlled to an uncertainty of 0.5%, and a relative uncorrelated cross section uncertainty of 1%.

Figure 1 shows a simulated measurement of F_L based on data sets at 920 GeV and 460 GeV proton beam energy. For the assumed size of the gluon density, based on H1 NLO QCD fits, F_L can be measured to 5-6 standard deviations. Such a measurement has been estimated at the HERA-LHC Workshop to improve the knowledge of the gluon distribution at low x by an amount which is comparable to the improvements obtained at medium x by adding HERA jet data to the

[1] It has been proposed [15] to access F_L with radiative events, in which effectively E_e is lowered by Bremsstrahlung from the incoming electron beam. This method has been tried by both H1 [16] and ZEUS [17] but appears to be systematics and statistics limited, preventing a significant measurement of $F_L(x, Q^2)$.

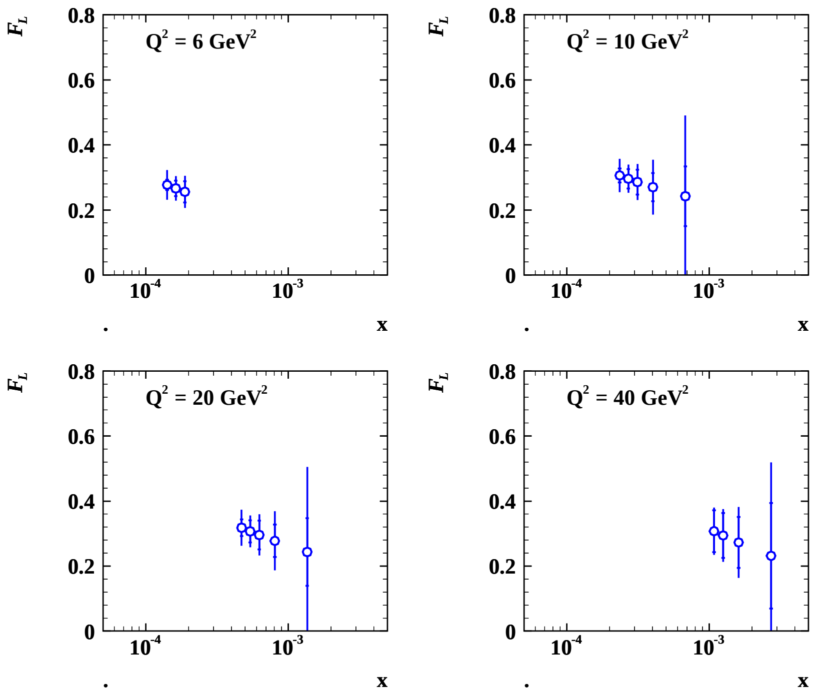

Figure 1: Simulation of a measurement of the longitudinal structure function $F_L(x, Q^2)$ based on data at 920 GeV (30 pb^{-1}) and 460 GeV (10 pb^{-1}). The inner error bars show the statistical accuracy and the total error bars represent the total uncertainty taking into account correlations of systematic effects and adding both uncertainties in quadrature.

inclusive cross section data [21]. The expected accuracy is of significant interest to distinguish between different theoretical predictions [20]. Further details on the $F_L(x, Q^2)$ measurement and its simulation are given in [18, 22].

The result of the simulated extraction of F_L^D from a set of 920 GeV and 400 GeV data [2] is shown in Figure 2. Diffractive events are assumed to be identified via the rapidity gap. Since once again, many systematic effects cancel, such a measurement is rather accurate determining F_L^D to 3 sigma accuracy, taking the gluon density from the H1 diffractive NLO QCD fit prediction. The very forward proton spectrometer (VFPS) will provide useful additional information on the t dependence and the diffractive event selection. Further details on a future F_L^D measurement are given in [23].

5 Concluding Remarks

The H1 Collaboration has always considered a low energy run to be an essential part of its physics programme [24]. Over the years the experimental uncertainties have been much reduced, largely due to upgraded instrumentation, and the HERA luminosity has been raised. It thus now becomes possible to pursue a low energy run in order to directly measure the inclusive and the diffractive longitudinal structure functions, which are essential ingredients for the development of the theory of parton dynamics at low x. The H1 Collaboration thus expresses its firm interest in a run at low E_p of an integrated luminosity of the order of $10\,\text{pb}^{-1}$, with 'HV on', which has been estimated to take three months including set-up time. This plan for H1 is subject to confirmation in 2006, depending on the results of searches for physics beyond the standard model.

[2] For the diffractive study instead of 460 GeV a proton energy of 400 GeV was used which is of no significant influence for the result.

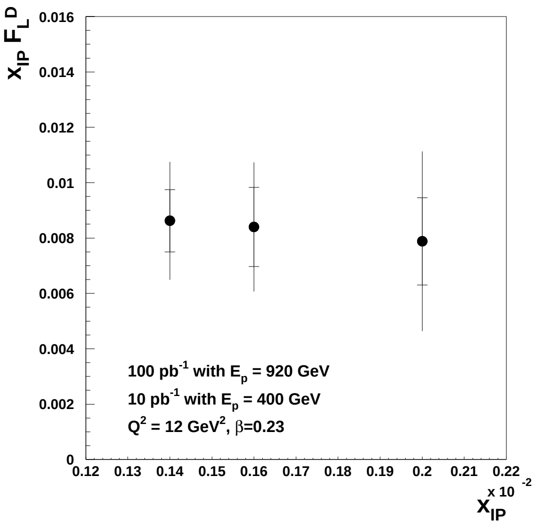

Figure 2: Simulation of a measurement of the diffractive longitudinal structure function $F_L^D(x_{IP}, Q^2, \beta)$ based on data at 920 GeV (100 pb^{-1}) and 400 GeV (10 pb^{-1}). The inner error bars show the statistical accuracy and the total error bars represent the total uncertainty taking into account correlations of systematic effects and adding both uncertainties in quadrature.

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