F_L MEASUREMENTS AT HERA

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The motivation for an F_L measurement at HERA is briefly reviewed, as are existing measurements. The precision and kinematical coverage which could be achieved by the H1 and ZEUS experiments in a future low energy run of HERA are then presented.

1. Introduction

A major element of the HERA program is the study of parton distributions at small-x. In this kinematic regime, the dynamics stem primarily from the creation and annihilation of virtual gluons. These fluctuations are not understood in detail theoretically, and any data which can shed light on this topic is valuable. The measurement of F_L is particularly interesting since it is a more direct probe of the gluon density than the structure function F_2. A dedicated measurement of F_L would also allow for a model-independent determination of F_2 at small-x.

In leading order pQCD [1],

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

At small x, the gluon density is expected to be much larger than the quark density, and should therefore be the dominant contribution to F_L (this is not necessarily the case at small Q^2).

The experiments measure cross sections. The unpolarized neutral current cross section can be written in terms of structure functions as follows:

$$\frac{d^2\sigma(e^{\mp}p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} \left[Y_+ F_2(x,Q^2) - y^2 F_L(x,Q^2) \pm Y_- x F_3(x,Q^2) \right]$$

where $Y_{\pm} = \left(1 \pm (1-y)^2\right)$. The structure function F_3 can be extracted by measuring the cross section separately for electron-proton and positronproton scattering, and is a major focus of the HERA II program. Its contribution to the cross section is negligible at small Q^2 and will be ignored in the following. For not too large y, the contribution to the cross section from F_L is small, and F_2 can be extracted reliably. To separately measure F_2 and F_L, it is necessary to fix (x, Q^2) and measure the cross section at different y. I.e., different center-of-mass energies are necessary (recall that the center-of-mass energy squared is, ignoring masses, $s = Q^2/xy$).

Due to limited space, the predictions for F_L will not be described here. A detailed discussion can be found in the contribution from Robert Thorne (these proceedings).

2. Existing HERA Data

The contribution from F_L is most pronounced at high y, and it is therefore interesting to focus on the highest-y data available. These are from the H1 collaboration. As an example [2], Fig. 1 shows the reduced cross section

$$\sigma_r = F_2 - y^2 F_L / Y_+$$

as a function of x for different Q^2. Note the striking turnover of the cross section at the smallest values of x. These data can be consistently fit with the NLO DGLAP equations by H1 assuming no saturation of the parton densities. The turn-over at small x is interpreted as arising from the negative contribution of F_L to the cross section. However, the MRST and CTEQ groups have trouble fitting the H1 data at low Q^2 within the NLO DGLAP framework (these groups are also simultaneously fitting additional data) [3].

The H1 collaboration has employed three techniques to estimate F_L from the measured cross sections:

Subtraction Method In this method [4], F_2 is measured in the low y region where the contribution from F_L is negligible. NLO DGLAP is then used to extrapolate F_2 to higher Q^2 and therefore higher y. This extrapolated F_2 is then compared to the measured cross section to evaluate the contribution of F_L.

Derivative Method In this method [2], the quantity $\frac{\partial \sigma_r}{\partial \ln y}|_{Q^2}$ is evaluated in the data. The derivative is expected to be dominated by the F_L term because of the y^2 factor. The contribution from F_2 is estimated and subtracted to extract F_L.

Shape Method Here [5], F_2 is parametrized as $F_2 = ax^{-\lambda}$ and $F_L = C$ at high y, and the contributions are separately fit.

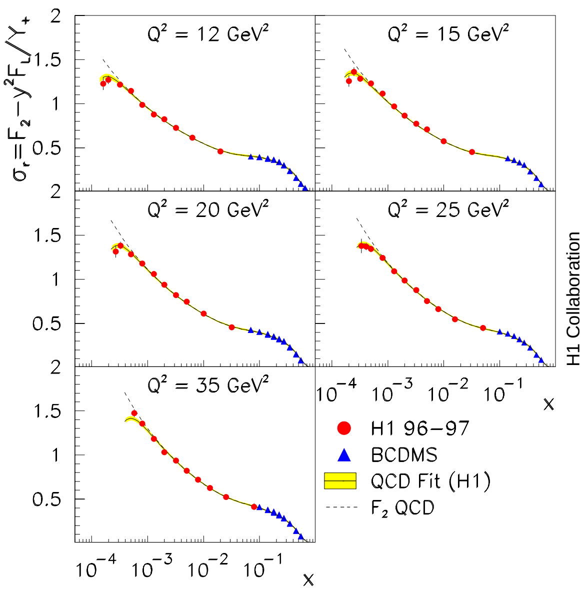

Figure 1. Neutral current reduced cross section measurements from the H1 Collaboration.

H1 results on F_L extraction using these techniques can be found in the talk of Max Klein (these proceedings).

The ZEUS Collaboration has performed a measurement of F_L using events where the incoming electron has radiated a high energy photon, thereby effectively reducing the center-of-mass energy [6]. The initial state radiation events provide a broad band beam and are therefore in principle interesting. However, the measurement is difficult and limited in precision.

3. Measuring F_L with different beam energies

The standard technique for measuring F_L is to measure cross sections at two or more beam energies and compare the cross sections at fixed (x, Q^2). With this data,

$$F_L(x, Q^2) = \frac{\sigma_r(x, Q^2, y_1) - \sigma_r(x, Q^2, y_2)}{y_2^2/Y_{2,+} - y_1^2/Y_{1,+}} ,$$

where $y_{1,2}, Y_{1,2;+}$ are the corresponding y, Y_+ values for the two beam energies. This type of data also allows for an assumption free measurement of F_2. The precision of the measurement is maximized by having the largest possible difference $y_2 - y_1$ for the same (x, Q^2). This requires the largest possible difference in beam energies, and measurements as near to $y = 1$ as possible. Given that

$$y = 1 - \frac{E'_e}{2E_e}(1 - \cos\theta_e) \ ,$$

where E_e, E'_e are the incident and scattered electron energies, and θ_e is the scattering angle, it is advantageous to keep the electron beam energy high while pushing to the smallest scattered electron energies as possible. For the accelerator, this implies that the proton beam energy should be reduced to its minimum while still producing reasonable luminosity. For the experiments, pushing the electron identification and reconstruction to small energies is a major challenge because of triggering issues, and photoproduction and other backgrounds. The running scenario currently under discussion foresees a data set of 10 pb^{-1} with a proton beam energy $E_p = 460$ GeV. Such a run would require approximately three months, including accelerator setup times [7].

3.1. *Measurement with the H1 detector*

The H1 measurement would rely on the rear calorimeter, SPACAL, which has fine segmentation and good energy resolution, to identify the electron and measure its energy. A track measured in the backward silicon tracker is required to remove photons and determine the charge and scattering angle. The central tracker provides the event vertex. With these tools, H1 has demonstrated that measurements down to $E'_e = 3$ GeV are possible with backgrounds under control. A simulation of the F_L measurement [8] gives uncertainties on F_L ranging between $\delta F_L = 0.05$ and 0.1, about evenly divided between statistical and systematic uncertainties. The expected precision and measurement range are shown in Fig. 4.

3.2. *Measurement with the ZEUS detector*

The ZEUS measurement would principally rely on the rear calorimeter, RCAL, to recognize and measure the electron, and the central tracking detector to measure the event vertex, although other subdetectors such as the hadron-electron-separator could also be made use of. A track in the central detector will likely be required to control the photoproduction background in the high-y sample. The photoproduction background can be evaluated using the '6m tagger', located approximately 6 meters downstream from the interaction point in the electron direction. ZEUS anticipates reaching

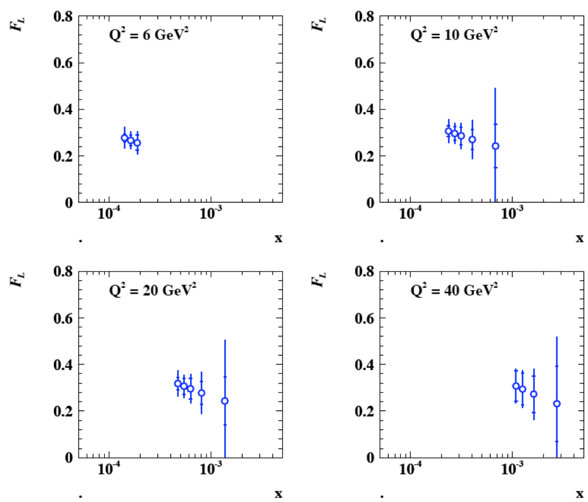

Figure 2. Simulation of the range and precision which can be attained for an F_L measurement with the H1 detector, assuming $L = 30$ pb^{-1} at $E_P = 920$ GeV and $L = 10$ pb^{-1} at $E_P = 460$ GeV.

scattered electron energies as low as 4 GeV, albeit with rather large backgrounds at high-y. A simulation of the F_L measurement typically gives uncertainties of $\delta F_L = 0.15$ over the full kinematic range. The uncertainty is dominated by the photoproduction background uncertainty at low Q^2, whereas the statistical uncertainty dominates at higher Q^2. The expected precision and measurement range are shown in Fig. 5.

To quantify the results in terms of a single number, a Bayesian analysis of the full simulated data was performed by ZEUS, assuming that the quantity $r = F_L/F_2$ is constant. The actual value varied between 0.2 and 0.3 in the simulation. The estimated precision on this quantity was determined to be $\delta r \leq 0.025$. This can be compared to expectations for r averaged over the same kinematic range from different PDF sets: $r = 0.25$, CTEQ5D; $r = 0.30$, MRST2002(LO); $r = 0.18$, MRST2004(NLO); $r = 0.18$ MRST2004(NNLO).

4. Discussion

The measurement of F_L is a must for HERA. This view is shared by both the H1 and ZEUS experiments, and both collaborations have requested that the necessary low energy run takes place before the end of HERA running. The measurement is technically difficult, and will require a long fight with backgrounds and systematic uncertainties. The detectors, particularly ZEUS, are not optimal for the measurement. However, the anticipated precision is still very interesting. A note: although the F_L measurement is the prime motivation for the low energy run, many additional interesting results are expected to come out, such as structure function measurements at higher x, F_L in diffraction, etc. Both collaborations therefore look forward to a low energy run with great anticipation.

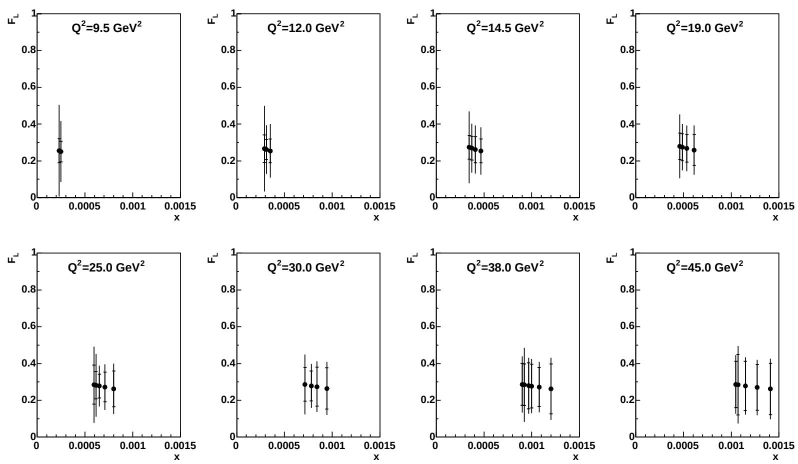

Figure 3. Simulation of the range and precision which can be attained for an F_L measurement with the ZEUS detector, assuming $L = 30$ pb^{-1} at $E_P = 920$ GeV and $L = 10$ pb^{-1} at $E_P = 460$ GeV.

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