PROSPECTS FOR A MEASUREMENT OF F_L AT HERA WITH THE ZEUS DETECTOR

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Presented is the Monte Carlo feasibility study of the measurement of the longitudinal proton structure function $F_L(x, Q^2)$ with the ZEUS detector at HERA. Data sets assumed are 10 pb^{-1} at proton beam energy of 460 GeV and 30 pb^{-1} at proton beam energy of 920 GeV. Prospects on achievable precision of F_L measurement are discussed.

1. Introduction

Measurement of proton structure functions at HERA gives a substantial input to studying parton distribution functions (PDFs). In this respect, the measurement of the longitudinal structure function F_L at small-x is of high importance, as it is a more direct probe of gluon density than deriving it from the scaling violation of the structure function F_2.

Ignoring xF_3, which is negligible in the region of Q^2 considered for the F_L measurement ($Q^2 \leq 50$ GeV^2), the unpolarized $e^{\pm}p$ inclusive neutral current cross section measured at HERA can be written as

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

where $Y_+ = 1 + (1-y)^2$ and σ_r is the so-called reduced cross section. Extraction of F_L can be done by measuring the cross section at two or more beam energies and compare the reduced cross section at the same (x, Q^2). For two beam energies, one gets

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

where the numerical indices indicate the y and Y_+ values corresponding to the two different beam energies.

For the highest precision measurement the maximum possible difference $y_2 - y_1$ at the same (x, Q^2) should be achieved. This requires the largest possible difference in beam energies and measurements at highest possible y. Using the energy and angle of scattered electron E'_e and θ_e and the electron beam energy E_e, y is calculated as

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

To reach high values of y it is advantageous to change the proton beam energy and keep the electron beam energy while pushing to smallest scattered electron energy possible. A Monte Carlo based study has been performed to evaluate the kinematic region where F_L can be measured and achievable precision of the ZEUS F_L measurement. The study was based on the running scenario of HERA as: 10 pb^{-1} of data with proton beam energy being lowered to 460 GeV, and 30 pb^{-1} of data with nominal proton beam energy of 920 GeV.

2. Electron finding and background rejection

Identifying and reconstructing of events with scattered electrons with very low energy is the biggest challenge for the F_L measurement with the ZEUS detector. We have evaluated fesibility to measure cross sections with such low energies of scattered electron, $E'_e = 4$ GeV. This allows to reach up to $y = 0.85$ in low energy running (LER).

The most serious difficulties of the electron finding at small energies are, on one hand, understanding the efficiency of electron reconstruction algorythm, and, on the other hand, controlling the large background of photons and hadrons falsly identified as electrons in photoproduction events. For understanding this background a so-called '6m tagger' can be used. This device is located approximately 6 meters downstream from the interaction point in the electron direction. The 6m tagger has nearly 100% acceptance for scattered electrons in Bethe-Heitler events within a restricted energy window of a few GeV. As much as 25% of the photoproduction background events can be rejected directly using the 6m tagger.

Further suppression of background from photoproduction events can be achieved by requiring a matching track in the central tracking detector (CTD). The maching track requirement limits the measurement to scattering angles $\theta_e < 168^\circ$, thereby limiting the minimum Q^2 of the measurement to $Q^2 \approx 9.5$ GeV^2.

3. Details of the study

The study was performed using the full ZEUS Monte Carlo simulation. A full data analysis was pursued, including an evaluation of systematic errors. The sources of systematic uncertainty considered (with the uncertainty value in brackets) were:

- normalization of the photoproduction background (10%)
- electron finding efficiency (10% of inefficiency)
- energy scale (1% at high energy increasing to 2% at 4 GeV)
- luminosity (2% correlated and 1% uncorrelated)

Radiative corrections were also investigated but found negligible.

The results are summarized in Fig. 1. Note that only the error bars are relevant – the value of F_L was fixed to $F_L = 0.2F_2$ for the purpose of producing this plot. The statistical errors, represented by the inner error bars, are at the level of $\delta F_L = 0.04$ at $Q^2 = 9.5$ GeV^2, and increase to about $\delta F_L = 0.15$ at $Q_2 = 45$ GeV^2. The systematic uncertainties, on the other hand, are largest at the smaller Q^2 values, primarily due to the photoproduction background, and range from $\delta F_L = 0.20$ to below 0.10. The result is that the total uncertainty does not change very much as a function of Q^2, and is about $\delta F_L = 0.15$ per data point. In this analysis, 33 simulated data points were measured. This is considered to be a realistic estimate of the number of measurements ZEUS should be able to extract.

To quantify the sensitivity to F_L from the data set such as the one presented in Fig. 1 we have performed an analysis on the expected precision to which we could measure tha ratio

$$r = F_L/F_2$$

To simplify the analysis of the simulated data sets, it was assumed that r is a constant. The actual value of r in the MC varied from 0.3 for the smallest Q^2 bin to 0.2 in the highest Q^2 bin. The measured value of r was determined together with the F_2 values in each data bin using a Bayesian analysis with a flat prior for r, $P_0(r) = 1$ for $0 \leq r \leq 1$ and $P_0(r) = 0$ elsewhere. All systematic effects were taken into account. The extracted precision on r is $\delta r \leq 0.025$. This can be compared to expectations for r averaged over the same kinematic range from different PDF sets: $r = 0.25$ for CTEQ5D; $r = 0.30$ for MRST2002(LO); $r = 0.18$ for MRST2004(NLO); $r = 0.18$ for MRST2004(NNLO).

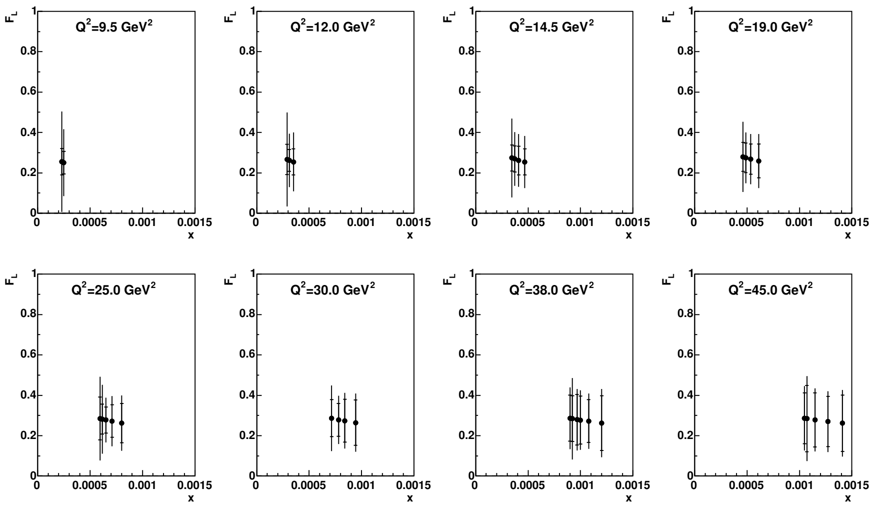

Figure 1. Result of the full Monte Carlo simulation of range and precision of the ZEUS F_L measurement. The value of F_L is fixed to $F_L = 0.2F_2$.

4. Discussion

Assuming a HERA run with proton beam energy lowered to 460 GeV and accumulating 10 pb^{-1} of data, the range and precision of the F_L measurement in the ZEUS experiment are moderate. However, there is room for improvement. The range of the measurement can be extended to lower Q^2 by dropping the track match requirement and using the information from other subdetectors (such as hadron-electron separator) for background suppression. Extending to higher Q^2 is only limited by the statistical uncertainty given by the size of the accumulated data sample in low energy running. The improvement in precision can be achieved by better understanding electron finding efficiency at low energies. An eventual direct inclusive measurement of the photoproduction background using 6m tagger can reduce the largest contribution to systematic uncertainty at high-y.

Considering the importance of the measurement, the ZEUS collaboration has requested that the necessary low energy run takes place before end of HERA running[1].

References

1. ZEUS Collaboration, *Expression of Interest submitted to the DESY Physics Research Comittee* PRC 05/06