Measurement of the Longitudinal Structure Function F_L at HERA with the ZEUS Detector

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The longitudinal structure function, F_L, was measured using data taken with the ZEUS detector at the ep collider HERA with two different proton beam energies, 920 GeV and 460 GeV. The structure function F_L was extracted using cross sections measured at fixed Bjorken x and momentum transfer squared Q^2, but different inelasticity y.

1 Introduction

The proton structure functions measured at HERA are a substantial input to the determination of the parton distribution functions (PDFs). The measurement of the longitudinal structure function F_L at small x is of high importance, as it is a more direct probe of the gluon density than deriving it from the scaling violation of the structure function F_2.

Ignoring xF_3, which is only important in the region of high Q^2, the $e^{\pm}p$ inclusive neutral current (NC) cross section for deep-inelastic scattering (DIS) of unpolarized beams can be written as

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

where $Y_+ = 1 + (1-y)^2$ and $\tilde{\sigma}$ is defined as the reduced cross section. F_L is extracted by measuring the cross section at fixed (x, Q^2) at two or more values of y which, via the relation $Q^2 = xys$, corresponds to different center-of-mass (CM) energies s. For two different CM energies (indicated by numerical indices) F_L can be extracted as

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

The maximum difference $\Delta y = y_2 - y_1$ at the same (x, Q^2) is desirable and translates to the largest possible difference in CM energies and measurements at the highest possible y. Using the energy and polar angle of the scattered electron, E'_e and θ_e, and the electron beam energy, E_e, y can be calculated as

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

High values of Δy can best be achieved by changing the proton beam energy. To extend the kinematic range to high y scattered electrons with low energy have to be identified.

To allow for a direct F_L measurement, in the period March to June 2007, HERA operated with two reduced proton beam energies of 460 GeV and 575 GeV. The measurement of F_L

performed by ZEUS using 32.8 pb^{-1} of data taken at nominal proton beam energy of 920 GeV, the so-called High Energy Running (HER), corresponding to center-of-mass energy squared $\sqrt{s} = 318$ GeV and 14 pb^{-1} of data taken at proton beam energy of 460 GeV, the so-called Low Energy Running (LER), with $\sqrt{s} = 225$ GeV is presented here.

2 Measurement strategy

Due to a different y range within a given (x, Q^2) bin the cross section measurment requires different strategies at different beam energies. In the LER, the cross section is measured at low s which corresponds to high y. At high y the energy of the scattered electron is low ($E'_e \approx 4$ GeV at $y = 0.85$). Identification and reconstruction of events with scattered electrons with very low energy is very challenging with the ZEUS detector.

Finding the low energy electrons and controling the efficiency is difficult and in addition a large background of photons and hadrons falsely identified as electrons in photoproduction (γp) events complicates the situation.

Suppression of background events coming from neutral particles (mostly photons) can in principle be achieved by requiring a matching track in the tracking detectors. However, the standard ZEUS tracking is limited to $\theta_e \lesssim 154°$. Since most of the γp background events occur at larger polar angles (close to the beam-pipe), it is crucial to extend this region. A new tool is used to define a corridor between the reconstructed vertex of the event and the position of the electron candidate in the calorimeter. Counting the hits in the tracking detectors within the corridor and comparing it to the number of the traversed layers allows to discriminate between charged and neutral particles up to $\theta_e \approx 168°$.

The remaining background was studied using the so-called '6m tagger'. This device is located approximately 6 m downstream from the interaction point in the electron direction. It has nearly 100% acceptance for forward scattered electrons within a window of few GeV. The events with a (fake) electron candidate in the main detector and a signal in the 6m tagger can be used to estimate the γp background. The measured rate of these events was used to normalize the γp Monte Carlo (MC)

In the HER, the cross section below $y \approx 0.4$ is needed for the F_L measurement. This corresponds to an energy of the scattered electron of above ≈ 15 GeV. At these energies the identification and reconstruction of the scattered DIS electron are standard ZEUS procedures and well understood. Typically, the electron is well separated from the hadronic system of the event and the contribution from the γp background is small.

3 Details of the analysis

Special triggers were developed to record events with low energy electrons. The reliability of these triggers was demonstrated in a previous ZEUS measurement of NC cross section at high y [2].

For offline event selection, the following criteria were applied for both HER and LER data sets:

- an electron candidate $E_e > 4$ GeV with an impact point on the rear ZEUS calorimeter outside of $R \approx 28$ cm;
- only electron candidates inside the extended acceptance of the ZEUS tracking system with sufficient number of hits within the corridor were accepted.

- 42 GeV $< \sum_{tot}(E - p_z)_i <$ 65 GeV, where the sum runs over energy deposits in the calorimeter;

- $|Z_{vtx}| <$ 30 cm, where Z_{vtx} is the position of the event vertex in the z direction;

4 Reduced cross sections and F_L

The kinematic variables were reconstructed using the energy and polar angle of the scattered electron. Bins were defined as rectangles in the (y, Q^2) plane to have good coverage at high y reaching down to $E'_e = 6$ GeV.

The reduced cross sections are extracted from

$$\tilde{\sigma}(x, Q^2) = \frac{N_{\text{data}} - N_{\text{MC}}^{\gamma p}}{N_{\text{MC}}^{\text{DIS}}} \tilde{\sigma}_{\text{SM}}(x, Q^2) ,$$

where N_{data}, $N_{\text{MC}}^{\gamma p}$ and $N_{\text{MC}}^{\text{DIS}}$ are the number of observed data events, number of expected γp events from MC and number of expected DIS events from the MC in a given bin, respectively. $\tilde{\sigma}_{\text{SM}}(x, Q^2)$ denotes the electroweak Born-level reduced cross section from the Standard Model (SM).

The sources of systematic uncertainties considered for the cross section measurement are electron finding efficiency, electron energy scale, normalization of the γp MC, $\sum_{tot}(E-p_z)_i$ threshold and position reconstruction of the electron.

The measurement of the reduced cross sections was done for 24 GeV$^2 < Q^2 <$ 110 GeV^2 and $0.1 < y < 0.8$ for both data sets which resulted in different coverage in x. The results are shown in Fig. 1 as a function of x at fixed Q^2 together with the predictions evaluated using the ZEUS-Jets PDF's with and without F_L. The measured values are slightly below the predictions in the whole range of x for both data sets. The expected turnover in the cross sections at lowest x (high y) due to F_L is not obvious in the data. Measurement at higher y (lower electron energies) is necessary to clarify the situation.

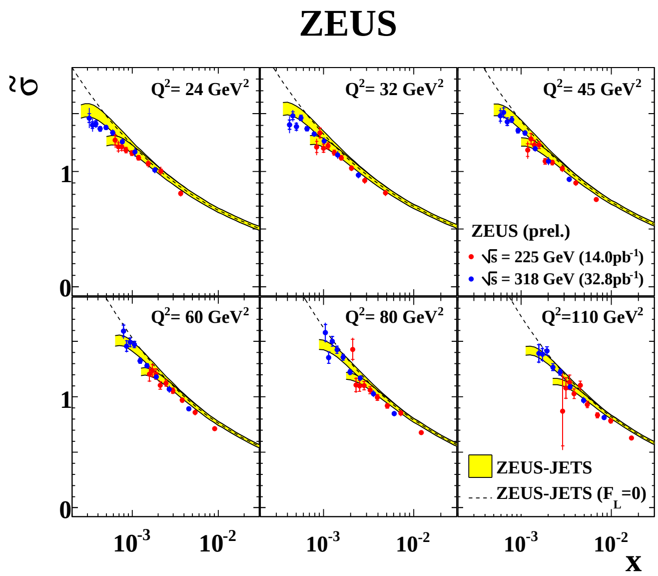

Figure 1: Measured reduced cross sections as a function of x for fixed values of Q^2 (points) compared to SM expectations evaluated using ZEUS-Jets PDFs with/without F_L (yellow band/dashed line).

The F_L was extracted using Eq. (1). A relative normalization uncertainty between the two datasets was considered as an additional source of the systematic uncertainty. This, together with the uncertainty in the energy scale, induced the largest systematic uncertainties in F_L.

The measurement of F_L was done in the kinematic range of 24 GeV^2 $< Q^2 <$ 110 GeV^2 and $6 \times 10^{-4} < x < 0.005$. The measured F_L is shown in Fig. 2 as a function of x at fixed Q^2. The inner error bars represent the statistical uncertainties and the outer error bars represent the statistical and systematic uncertainties added in quadrature. The SM prediction evaluated using the ZEUS-Jets PDFs [3] are also shown. The measured values of F_L are consistent with both the prediction using the ZEUS-Jets PDFs as well as with $F_L = 0$ within the uncertainties.

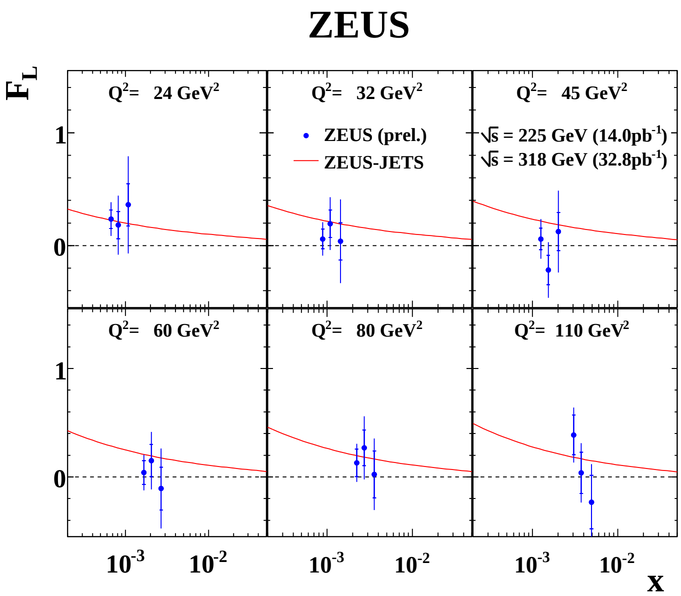

Figure 2: Measured F_L as a function of x for fixed values of Q^2 (points) compared to SM expectations evaluated using ZEUS-Jets PDFs (red line).

Improvements are planed which should reduce the uncertainties of the F_L measurement, such as adding the data set at the third proton beam energy, $E_p = 575$ GeV, and reducing the limit on reconstructed energy of scattered electron and thus reaching higher values of y.

References

[1] Slides:
`http://indico.cern.ch/contributionDisplay.py?contribId=97&sessionId=17&confId=24657`

[2] S. Shimizu for the ZEUS Collaboration, *ZEUS high-y Cross Section Measurement and Preparation for Low Energy Running*, in proceedings DIS2007 (2007)

[3] ZEUS Coll., S. Chekanov *et al.*, Eur. Phys. J. **C42** 1 (2005)