Measurement of the Neutral Current DIS Cross Section at ZEUS

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Abstract. The ZEUS experiment at the ep collider HERA has performed a new measurement of the deep-inelastic scattering cross-sections with the data collected during the year 2006. The new measurement is optimised for the kinematic region of large values of the inelasticity \( y \) where several experimental challenges need to be overcome. The results were compared to the expectations of the Standard Model obtained with several parton density functions.

1. Introduction
The ep collider HERA has played a key role in the investigation of the proton structure. The ZEUS experiment performed a precise measurement of the neutral current (NC) deep-inelastic scattering (DIS) reduced cross sections using the data collected in 1996 and 1997 [1]. These data have served as the main ingredient in the extraction of parton distribution functions (PDFs). Presented here is a new measurement of the NC DIS cross section concentrating on the kinematic region of high value of inelasticity \( y \), based on 29.5 pb\(^{-1}\) of data collected in 2006. During this period, HERA was operating at center-of-mass (CM) energy 318 GeV, with proton and electron beam energies being 920 GeV and 27.5 GeV, respectively.

From March to June 2007, HERA operated with reduced proton beam energies of 460 GeV and 575 GeV. Distributions from these data sets are also presented.

2. DIS kinematics and NC cross section
The kinematics of lepton-proton scattering can be described in terms of the Bjorken scaling variable \( x \), the inelasticity \( y \) and the momentum transfer \( Q^2 \). The variables are related by \( Q^2 = xy s \), where \( s \) is the CM energy squared. Considering only the electro-magnetic interaction, the NC DIS reduced cross section at given \( x \) and \( Q^2 \) can be written in terms of proton structure functions \( F_2 \) and \( F_L \) as

\[
\hat{\sigma}(x,Q^2) \equiv \frac{xQ^4}{2\pi\alpha^2 Y_+} \int dxdQ^2 \sigma(x,Q^2) = F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2),
\]

where \( Y_+ = 1 + (1 - y)^2 \). The structure function \( F_2 \), which is sensitive to the total number of quarks and antiquarks in the proton, has the largest contribution to the cross section. The contribution of the longitudinal structure function \( F_L \) is only sizeable at large \( y \). Since large

\[^1\] In the following, the term “electron” is used to refer to both electrons and positrons.

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y corresponds to small \( x \), this is also the region where the contribution from gluons becomes important. In fact, in perturbative QCD, \( F_L \) is directly proportional to gluon density inside the proton.

Using measured energy and polar angle of the scattered DIS electron, \( E_e \) and \( \theta_e \), and the energy of the electron beam, \( E_B^e \), the inelasticity \( y \) is calculated as:

\[
y = 1 - \frac{E_e}{2E_B^e}(1 - \cos \theta_e).
\]

Thus, extending the measurement to high \( y \) requires going to smallest possible values of scattered electron energy. Therefore, the electron finding and reconstruction at low energies are the key issues in the high \( y \) measurement.

3. Event selection

For online event selection, two independent trigger logics were prepared to take events with low scattered electron energy. One of them requires a scattered electron with energy above 4 GeV. The other requires \( \sum_{\theta_i<165^\circ}(E-p_z)_i > 20 \) GeV, where the sum runs over energy deposits in the calorimeter. Both logics require in addition \( \sum_{\text{tot}}(E-p_z)_i > 30 \) GeV. Events satisfying at least one of the two logics are selected.

For offline event selection, the following criteria are applied:

- an electron candidate should be found in the calorimeter with energy \( E_e > 5 \) GeV with an impact point on the rear ZEUS calorimeter outside of 28 cm radius around the beampipe,
- for a candidate inside the acceptance of the ZEUS tracking system a track matched to the electron candidate is required,
- \( 38 \) GeV \( \leq \sum_{\text{tot}}(E-p_z)_i < 65 \) GeV,
- \( |Z_{vtx}| < 50 \) cm, where \( Z_{vtx} \) is the position of the event vertex in the \( z \) direction.

4. Background estimation

The main background for the measurement is photoproduction (\( \gamma p \)). In a \( \gamma p \) event the electron escapes through the beampipe and a photon or a hadron in the main detector is misidentified as a scattered electron. The contamination of the DIS sample with \( \gamma p \) events occurs especially at low electron energy.

The \( \gamma p \) background was studied using the 6m tagger which is a detector located downstream in the electron beam direction and has nearly 100% acceptance for electrons in the beam pipe in a few GeV window. The events with a (fake) electron in the main detector and a signal in the 6m tagger can be considered a pure \( \gamma p \) sample. These events were compared with the \( \gamma p \) Monte Carlo (MC) sample and an agreement was found except for normalization. The scale factor derived to account for this normalization was found to be 2.07.

The evaluation of the \( \gamma p \) scaling factor was checked using an enriched \( \gamma p \) sample without using 6m tagger, in which a low quality scattered electron was found (based on its shower shape). Again, the normalization factor was necessary for \( \gamma p \) MC to describe the data. The derived factor agrees with the one obtained using 6m tagger within 5%. By considering the imperfections of the \( \gamma p \) MC in describing the shape of distributions, the normalization uncertainty was evaluated to be \( \pm 10\% \).

The contamination of \( \gamma p \) in the cross section measurement was evaluated using the \( \gamma p \) MC scaled by the factor derived using 6m tagger.

\(^2\) In the ZEUS coordinate system, proton beam direction is the positive \( z \) direction.
5. Reduced cross sections

Kinematic variables are reconstructed using the energy and polar angle of the scattered electron. Bins are defined as rectangles in the \((y, Q^2)\) plane to have good coverage at high \(y\). In the region where reduced cross sections are extracted, the acceptance in every bin is above 60% and the \(\gamma p\) contamination is below 40%.

The reduced cross sections are measured as

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

where \(N_{\text{data}}\), \(N_{\gamma p}^{\text{MC}}\) and \(N_{\text{DIS}}^{\text{MC}}\) are the number of observed data events, number of expected \(\gamma p\) 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 are:

- electron finding efficiency (±10% of the inefficiency),
- electron energy scale (±2%),
- normalization of the \(\gamma p\) MC (±10%),
- \(\sum_{\text{tot}} (E - p_z)\) threshold (±2 GeV).

Amongst them, the uncertainty in the \(\gamma p\) MC normalization induced the largest effect to the cross sections at the highest \(y\) in the low \(Q^2\) region \((Q^2 \lesssim 50 \text{GeV}^2)\), giving \(\sim 5\%\) uncertainty. In addition to the sources above, all cross sections have an additional normalization uncertainty of 3.5% from the luminosity measurement.

**Figure 1.** Measured reduced cross sections as a function of \(x\) for fixed values of \(Q^2\) (points) compared to SM expectations evaluated using CTEQ5D (red line) and ZEUS-Jets (yellow band) PDFs.
The measurement was done for $0.1 < y < 0.8$ and $25 \text{ GeV}^2 < Q^2 < 1300 \text{ GeV}^2$. The measured reduced cross sections are shown in Fig. 1 as a function of $y$ for fixed values of $Q^2$. The SM predictions evaluated using CTEQ5D [2] and ZEUS-Jets [3] PDFs are also shown. The SM predictions are in good agreement with the measured cross sections.

6. HERA running with reduced beam energy
To separate $F_2$ and $F_L$, measurement of the cross section at the same $(x, Q^2)$ but two or more different values of $y$ should be measured (see Eq. (1)). This corresponds to measurement at different $s$, i.e. different beam energies. The ZEUS experiment has already performed a feasibility study for an $F_L$ measurement [4].

To allow for this measurement, from March to June 2007, HERA operated with reduced proton beam energies of 460 GeV and 575 GeV. The total amount of data collected by ZEUS during this period is about 14 pb$^{-1}$ and 7 pb$^{-1}$, respectively. The coverage of the $(y, Q^2)$ kinematic space for the first events taken while running with 460 GeV is shown in Fig. 2.

![ZEUS First Events](image)

Figure 2. The coverage of the $(y, Q^2)$ kinematic space for the first events taken while running with reduced proton beam energy of 460 GeV.

7. Conclusions
The new NC DIS cross section measurement extends the previous ZEUS measurement to the high $y$ region and demonstrates the feasibility of performing measurements with low energy electrons. In the kinematic region studied so far, the results are in good agreement with the SM predictions. Extension of the measurement to lower $Q^2$ and higher $y$, where the PDF uncertainties are larger, is planned.

The ZEUS experiment has collected data at lowered proton beam energies aiming for a direct $F_L$ measurement.

References
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