PROCEEDINGS OF SCIENCE

Combination of Inclusive $e^{\pm}p$ Cross-Section Measurements at HERA

Oleksii TURKOT* **on behalf of the H1 and ZEUS collaborations**
DESY
E-mail: olexii.turkot@gmail.com

The H1 and ZEUS collaborations have published their final measurements of inclusive deep inelastic scattering. These results have been combined for neutral and charged current unpolarised $e^{\pm}p$ cross sections at proton beam energies of 920, 820, 575 and 460 GeV. Correlations of systematic uncertainties were taken into account, resulting in significantly improved precision.

XXII. International Workshop on Deep-Inelastic Scattering and Related Subjects
28 April - 2 May 2014
Warsaw, Poland

*Speaker.

PoS(DIS2014)043

1. Introduction

Inclusive cross sections of deep inelastic electron[1]-proton scattering at HERA are an importand input for the determination of quark and gluon momentum distributions in the proton. A centre-of-mass energy of up to $\sqrt{s} = 319$ GeV allowed two collaborations, H1 and ZEUS, to cover a wide phase space in Bjorken x and Q^2 (photon virtuality) in their measurements. The kinematic range for neutral current (NC) processes was $0.045 \leq Q^2 \leq 50000$ GeV^2 and $6 \cdot 10^{-7} \leq x$, for inelasticity, $y = Q^2/(sx)$, of $0.005 \leq y \leq 0.95$. The kinematic range for charged current (CC) processes was $200 \leq Q^2 \leq 50000$ GeV^2 and $1.3 \cdot 10^{-2} \leq x \leq 0.4$, for inelasticity of $0.037 \leq y \leq 0.76$.

HERA collider was operated in two phases: HERA I, during 1992-2000, and HERA II, during 2002-2007. The electron beam energy was $E_e \simeq 27.5$ GeV and there were four different proton beam energies of $E_p \simeq 920$, 820, 575 and 460 GeV. Both experiments, H1 and ZEUS, collected aproximately 0.5 fb^{-1} of the luminosity, divided almost equally between e^+p and e^-p scattering. A previously published combination [1] was based on HERA I data, which had only 100 pb^{-1} of e^+p and 15 pb^{-1} of e^-p data. The combination presented now includes all published H1 [2–9] and ZEUS [10–23] measurements from HERA I and HERA II on inclusive DIS in NC and CC reactions.

Two packages have been used for the data combination: HERAFitter [24] for swimming data points to a common (Q^2,x) grid and HERAverager [25] for combining. The correlations in systematic uncertainties and global normalisations are taken into account and one coherent data set is obtained. The two experiments used different detectors, methods of kinematic reconstruction, and experimental approaches. Therefore, in addition to improved statistics, combining of the data gives a significant improvement in precision.

2. Combination of the Measurements

The data were taken at different centre-of-mass energies and the cross sections were calculated in different (Q^2,x) grids. Thus, the first step of combination is translating each data point to a common $\sqrt{s}_{com}$ and a common (Q^2_{grid}, x_{grid}) grid. Three common centre-of-mass values, $\sqrt{s}_{com,i}$, with $\sqrt{s}_{com,1} = 318$ GeV ($E_p = 920$ GeV and $E_p = 820$ GeV), $\sqrt{s}_{com,2} = 252$ GeV ($E_p = 575$ GeV), and $\sqrt{s}_{com,3} = 225$ GeV ($E_p = 460$ GeV) were chosen to combine data. An exception was made for data with $E_p = 820$ GeV which was kept at $\sqrt{s} = 301$ GeV if $y \geq 0.35$. Two common (Q^2_{grid}, x_{grid}) grids were used, one for $\sqrt{s}_{com,1}$ (and $\sqrt{s} = 301$ GeV in case of $y \geq 0.35$) and one for $\sqrt{s}_{com,2}$ and $\sqrt{s}_{com,3}$. The translation scale factors, SF, were calculated as ratios of the predicted double differential cross sections in the actual $\sqrt{s}$,(Q^2, x) and the common $\sqrt{s}_{com,i}$,(Q^2_{grid}, x_{grid}) grids. The predictions were obtained by performing the fits to the data with HERAFitter tool. For $Q^2 \geq 3$ GeV^2, a QCD fit within the DGLAP formalism was performed, and for $Q^2 \leq 4.9$ GeV^2 a fit using the fractal model [2, 26] was obtained. For overlaping region 3 GeV$^2 \leq Q^2 \leq 4.9$ GeV^2, the linear average of the scale factors was used.

The second step of combination is averaging data points within common grids. For this, the HERAverager [25] tool was used. It uses a χ^2-minimisation method, based on the assumption that there is only one correct value for the cross section for each process at each point of the phase space,

[1] Here and afterwards "electron" refers to both electrons and positrons, if not otherwise stated.

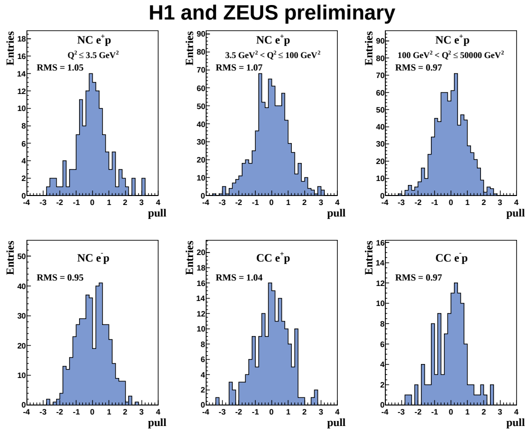


Figure 1: Distribution of pulls p for NC and CC e$^+$p and e$^-$p data samples. There are no entries outside the histogram ranges. RMS gives the root mean square of each distribution calculated as $\overline{p^2}$.

described in detail in [2]. The used χ^2 function takes into account the correlated and uncorrelated systematic uncertainties and for a single data set ds is defined as

$$\chi^2_{exp,ds}(\mathbf{m},\mathbf{b}) = \sum_{i,ds} + \sum_{j,b} = \sum_i \frac{[m^i - \sum_j \gamma^i_j m^i b_j - \mu^i]^2}{\delta^2_{i,stat}\mu^i(m^i - \sum_j \gamma^i_j m^i b_j) + (\delta_{i,uncorr} m^i)^2} + \sum_j b_j^2, \tag{2.1}$$

where $\mathbf{m}$ is the vector of averaged, or "true" values of cross sections, $\mathbf{m}$ represents the shifts with respect to the correlated systematic uncertainties, μ^i is the measured value at a point i, and γ^i_j, $\delta_{i,stat}$ and $\delta_{i,uncorr}$ are the relative correlated systematic, relative statistical and relative uncorrelated systematic uncertainties, respectively.

The final step is the estimation of procedural uncertainties, taking into account the possible influence of different evaluations of relative systematics uncertainties (by default they are proportional to the "true" values $\mathbf{m}$, and for variation all except the normalization uncertainties are treated proportional to μ^i), and possible correlations between the H1 and ZEUS estimations of the photoproduction background and hadronic energy scales. The typical values of procedureal uncertainties are below 1 %, reaching the few-percents level for low-Q^2, high-Q^2 and reduced proton beam energy data.

3. Results

About 0.5 fb^{-1} of luminosity for both e$^+$p and e$^-$p data were combined into one coherent data set. In total, 2927 data points were combined to 1307 cross-section values and showed good consistency, with $\chi^2/n_{dof} = 1685/1620$. For measured points, k, contributing to averaged point i of (Q^2_{grid}, x_{grid}) grid, pulls $p^{i,k}$ were defined as $p^{i,k} = \frac{\mu^{i,k} - \mu^{i,ave}(1 - \sum_j \gamma^{i,k}_j b_{j,ave})}{\sqrt{\Delta^2_{i,k} - \Delta^2_{i,ave}}}$, where $\Delta_{i,k}$ and $\Delta_{i,ave}$ are the statistical and uncorrelated systematic uncertainties added in a quadrature for the point k and the average, respectively. The distribution of pulls shows no tensions for all processes, as can be seen in Figure 1.

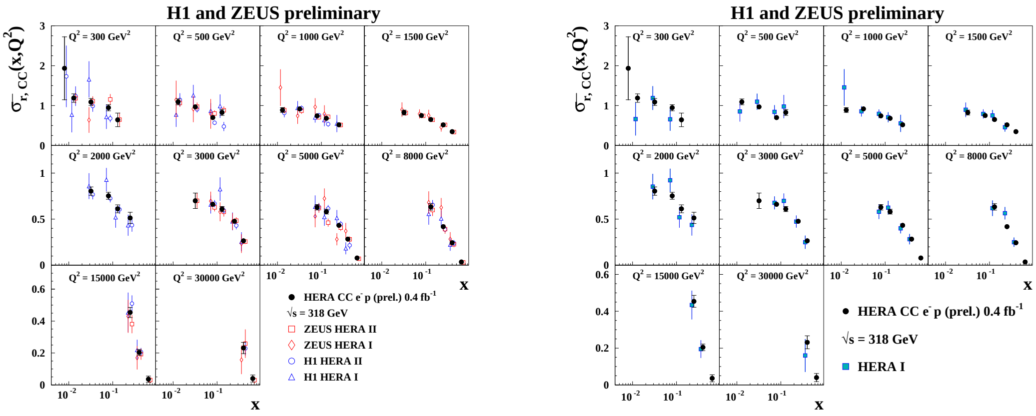


Figure 2: HERA combined CC e^{-}p reduced cross section as a function of x for 10 Q^2 bins compared to the separate H1 and ZEUS data wich were the input to the averaging procedure (left) and comparison of this combined results to the same results using HERA I data only (right) . The individual measurements are displaced horizontally for better visibility. Errors bars represent the total uncertainties.

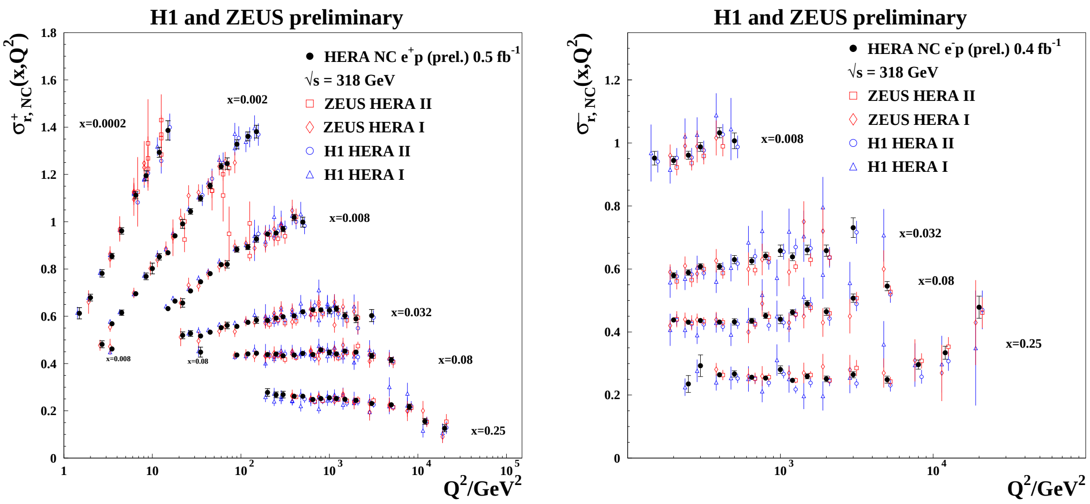
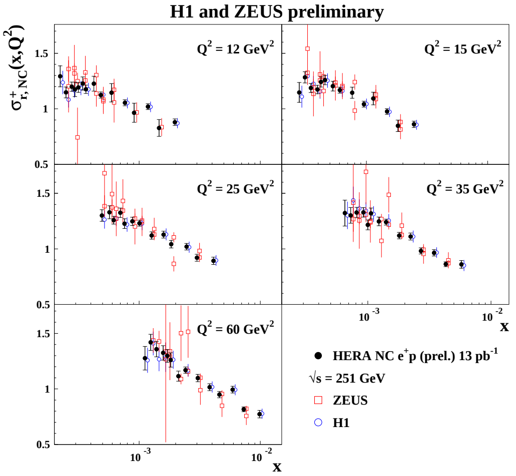


Figure 3: HERA combined NC e^{+}p (left) and e^{-}p (right) reduced cross section as a function of Q^2 for six selected x bins compared to the separate H1 and ZEUS data wich were the input to the averaging procedure. The individual measurements are displaced horizontally for better visibility. Errors bars represent the total uncertainties.

Figure 2 shows the averaged CC reduced cross sections together with the input data from H1 and ZEUS for e^{-}p scattering and a comparison of this average to the same results using HERA I data only. Significant improvement in precision and a better phase-space coverage is clearly seen. Figure 3 represents the averaged NC e^{+}p and e^{-}p reduced cross sections for selected x values. In Figure 4 example Q^2 bins are shown for NC e^{+}p cross sections for the data with lowered proton beam energies. The averaging leads to a significant uncertainty reduction, as can be seen in all figures.



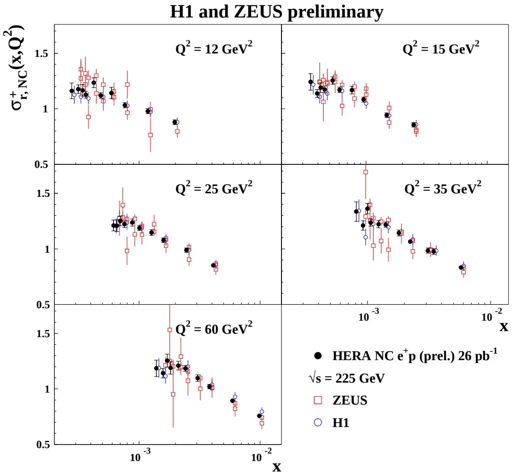


Figure 4: HERA combined NC e^+p reduced cross section at $E_p = 575$ GeV (left) and at $E_p = 460$ GeV (right) as a function of x for five selected Q^2 bins compared to the separate H1 and ZEUS data which were the input to the averaging procedure. The individual measurements are displaced horizontally for better visibility. Errors bars represent the total uncertainties.

4. Summary

A combination of all inclusive deep inelastic cross sections measurements by the H1 and ZEUS experiments in neutral and charged current unpolarised $e^{\pm}p$ scattering was presented. The data showed a good consistency and a total luminosity of about 1 fb^{-1} data was averaged into one data set. All correlations of systematic uncertainties were taken into account, resulting in cross section measurements of very high precision.

References

[1] H1 and ZEUS Collaboration, JHEP **1001** (2010) 109 [arXiv:0911.0884].

[2] H1 Collaboration, Eur. Phys. J. **C63** (2009) 625 [arXiv:0904.0929].

[3] H1 Collaboration, Eur. Phys. J. **C64** (2009) 561 [arXiv:0904.3513].

[4] H1 Collaboration, Eur. Phys. J. **C13** (2000) 609 [hep-ex/9908059].

[5] H1 Collaboration, Eur. Phys. J. **C19** (2001) 269 [hep-ex/0012052].

[6] H1 Collaboration, Eur. Phys. J. **C30** (2003) 1 [hep-ex/0304003].

[7] H1 Collaboration, JHEP **1209** (2012) 061 [arXiv:1206.7007].

[8] H1 Collaboration, Eur. Phys. J. **C74** (2014) 2814 [arXiv:1312.4821].

[9] H1 Collaboration, Eur. Phys. J. **C71** (2011) 1579 [arXiv:1012.4355].

[10] ZEUS Collaboration, Phys. Lett. **B407** (1997) 432 [hep-ex/9707025].

[11] ZEUS Collaboration, Phys. Lett. **B487** (2000) 53 [hep-ex/0005018].

[12] ZEUS Collaboration, Eur. Phys. J. **C7** (1999) 609 [hep-ex/9809005].

[13] ZEUS Collaboration, Eur. Phys. J. **C21** (2001) 443 [hep-ex/0105090].

[14] ZEUS Collaboration, Eur. Phys. J. **C12** (2000) 411, [Erratum-ibid. **C27** (2003) 305], [hep-ex/9907010].

[15] ZEUS Collaboration, Eur. Phys. J. **C28** (2003) 175 [hep-ex/0208040].

[16] ZEUS Collaboration, Phys. Lett. **B539** (2002) 197, [Erratum-ibid. **B552** (2003) 308], [hep-ex/0205091].

[17] ZEUS Collaboration, Phys. Rev. **D70** (2004) 052001 [hep-ex/0401003].

[18] ZEUS Collaboration, Eur. Phys. J. **C32** (2003) 1 [hep-ex/0307043].

[19] ZEUS Collaboration, Eur. Phys. J. **C62** (2009) 625 [arXiv:0901.2385].

[20] ZEUS Collaboration, Eur. Phys. J. **C61** (2009) 223 [arXiv:0812.4620].

[21] ZEUS Collaboration, Phys. Rev. **D87** (2013) 052014 [arXiv:1208.6138].

[22] ZEUS Collaboration, Eur. Phys. J. **C70** (2010) 945 [arXiv:1008.3493].

[23] ZEUS Collaboration, to be published in Phys. Lett. B (2014) [arXiv:1404.6376].

[24] https://www.herafitter.org/HERAFitter/

[25] https://wiki-zeuthen.desy.de/HERAverager/

[26] T. Lastovicka, Eur. Phys. J. **C24** (2002) 529 [hep-ph/0203260].