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Citation: AIP Conference Proceedings **1722**, 210004 (2016); doi: 10.1063/1.4944232
View online: http://dx.doi.org/10.1063/1.4944232
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New Measurement of Inclusive Deep Inelastic Scattering Cross Sections at Hera

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Abstract. A combined measurement is presented of all inclusive deep inelastic cross sections measured by the H1 and ZEUS collaborations in neutral and charged current unpolarised $e^{\pm}p$ scattering at HERA. The H1 and ZEUS collaborations collected total integrated luminosities of approximately 500 pb^{-1} each, divided about equally between $e^{+}p$ and $e^{-}p$ scattering. They include data taken at electron (positron) beam energy of 27.5 GeV and proton beam energies of 920, 820, 575 and 460 GeV corresponding to centre-of-mass energy of 320, 300, 251 and 225 GeV respectively. This enabled the two collaborations to explore a large phase space in Bjorken x and negative four-momentum-transfer squared, Q^2. The combination method takes the correlations of the systematic uncertainties into account, resulting in improved accuracy.

INTRODUCTION

Deep inelastic scattering (DIS) of electrons on protons at HERA has been central to the exploration of proton structure and quark–gluon interaction dynamics as prescribed by perturbative Quantum Chromodynamics (QCD). HERA operated at a centre-of-mass energy of up to $\sqrt{s} \approx 320$ GeV. This enabled the two collaborations, H1 and ZEUS, to explore a large phase space in x and Q^2. The kinematic range for neutral current (NC) interactions was $0.045 \leq Q^2 \leq 50000$ GeV^2 and $6 \cdot 10^{-7} \leq x$ for values of the inelasticity, $y = Q^2/(sx)$, between 0.005 and 0.95.

The kinematic range for charged current (CC) interactions was $200 \leq Q^2 \leq 50000$ GeV^2 and $1.3 \cdot 10^{-2} \leq x \leq 0.40$ for values of y between 0.037 and 0.76. HERA was operated in two phases: HERA I, from 1992–2000, and HERA II, from 2002–2007. It was always operated with an electron beam energy of $E_e = 27.5$ GeV. For most of HERA I and II, the proton beam energy was $E_p = 920$ GeV, resulting in the highest centre-of-mass energy of $\sqrt{s} = 320$ GeV. The total luminosity collected by both H1 and ZEUS was aproximately 500 pb^{-1}, divided about equally between $e^{+}p$ and $e^{-}p$ scattering. In HERA I, each experiment collected about 100 pb^{-1} of $e^{+}p$ and 15 pb^{-1} of $e^{-}p$ data. The HERA I data was the basis of a combination published previously [1]. The paper presented now is based on the combination of all published H1 and ZEUS measurements from both HERA I and II on inclusive DIS in NC and CC reactions. This includes data taken at $\sqrt{s} = 320$, 300, 251 and 225 GeV, corresponding to proton beam energies of $E_p = 920$, 820, 575 and 460 GeV. The HERA II measurements were made with polarised beams, but individually averaged to obtain cross sections for unpolarised beams used as inputs to the combination.

COMBINATION OF THE MEASUREMENTS

The combination of the data was performed with the HERAverager [3] and HERAfitter [4] tools.

9th International Physics Conference of the Balkan Physical Union (BPU-9)
AIP Conf. Proc. 1722, 210004-1–210004-4; doi: 10.1063/1.4944232

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Averaging Data Points

The averaging of the data points was performed using the HERAverager tool which is based on a χ^2 minimisation method [2]. This method assumes that there is one and only one correct value for the cross section of each process at each point of the phase space. These values are estimated by optimising a vector, $\boldsymbol{m}$. The χ^2 function used takes into account the correlated and uncorrelated systematic uncertainties of the H1 and ZEUS cross-section measurements and allows for shifts of the data to accomodate the correlated uncertainties. For a single data set, *ds*, the χ^2 is defined as:

$$\chi^2_{\exp,ds}(m,b) = \sum_i^{ds} + \sum_j^{b} = \sum_i \frac{\left[m^i - \sum j\gamma_j^{i,ds} m^i bj - \mu^{i,ds}\right]^2}{\delta^2_{i,d,stats}\mu^{i,ds}\left(m^i - \sum j\gamma_j^{i,ds} m^i b_j\right) + \left(\delta_{i,ds,uncor} m^i\right)^2} + \sum_j b_j^2 \qquad (1)$$

where $\mu^{i,ds}$ is the measured value at the point i and $\gamma_j^{i,ds}$, $\delta_{i,d,stats}$ and $\delta_{i,ds,uncor}$ are the relative correlated systematic, relative statistical and relative uncorrelated systematic uncertainties, respectively. For the reduced cross-section measurements, $\mu^{i,ds} = \sigma_r^{i,ds}$, i runs over all points on the ($x_{Bj,grid}$, Q^2_{grid}) plane for which a measurement exists in *ds*. The components b_j of the vector $\boldsymbol{b}$ represent correlated shifts of the cross sections in units of sigma of the respective correlated systematic uncertainties; the summations over j extend over all correlated systematic uncertainties.

Common $\sqrt{s}$ Values and (x, Q^2) Grids

The data were taken with several E_p values and the double-differential cross sections were published by the two experiments for different reference $\sqrt{s}$ and (x_{Bj}, Q^2) grids. In order to average a set of data points, the points had to

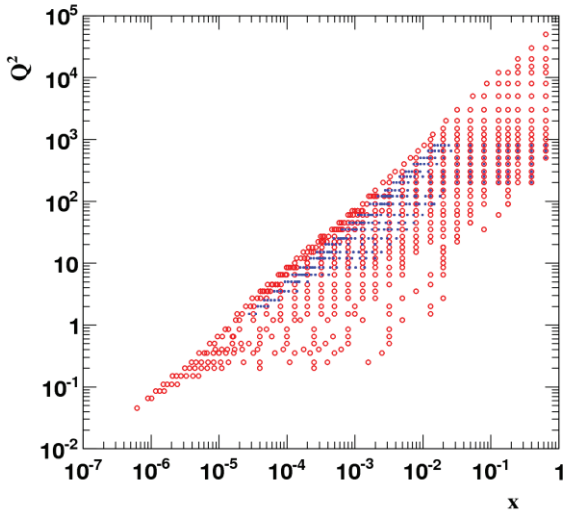

FIGURE 1. The points of the two grids for $\sqrt{s_{com,1}}$ = 318 GeV (big open circles) and $\sqrt{s_{com,2}}$ =252 GeV as well as $\sqrt{s_{com,3}}$ = 225 GeV (small filled squares) are shown. The latter grid has a finer binning in x in accordance with its special structure in y.

be translated to common $\sqrt{s_{com}}$ values and common ($x_{Bj,grid}$, Q^2_{grid}) grids. Three common centre-of-mass values, $\sqrt{s_{com,i}}$, with $\sqrt{s_{com,1}}$ = 318 GeV (E_p = 820 GeV and E_p = 920 GeV), $\sqrt{s_{com,2}}$ = 252 GeV (E_p = 575 GeV) $\sqrt{s_{com,3}}$ = 225 GeV (E_p = 460 GeV) were chosen to combine data. An exception was made for data with E_p = 820 GeV or E_p = 920 GeV which were not translated to $\sqrt{s_{com,1}}$ if $y \geq 0.35$. Such data were kept separately at $\sqrt{s}$ =301 and 319

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GeV, respectively. Two common ($x_{Bj,grid}$, Q^2_{grid}) grids were chosen, one for data at $\sqrt{s_{com,1}}$ and one for data at $\sqrt{s_{com,2}}$ and $\sqrt{s_{com,3}}$. The two grids have a different structure in y such that the translation corrections are minimised. Figure 1 depicts the grids. Over most of the phase space, it was ensured that separate measurements from the same data set were not translated to the same grid point.

Combination Procedure

The combination procedure is iterative. Each iteration has a first step, in which the data are translated to the common $\sqrt{s}$ values and (x, Q^2) grids and a second step, in which they are averaged. In the first iteration, the fits to provide the predictions needed for the translation were performed on the uncombined data. Starting with the second iteration, the fits were performed on combined data. The process was stopped after the third iteration. An investigation showed that further iterations did not induce significant changes in the resulting averaged cross sections.

Procedural Uncertainties

Procedural uncertainties are introduced by the choices made for the combination. Three kinds of such uncertainties were considered: multiplicative versus additive treatment of systematic uncertainties, correlations between systematic uncertainties on different data sets and pull distribution of correlated systematic uncertainties, [5].

COMBINED INCLUSIVE $e^{\pm}p$ CROSS SECTIONS

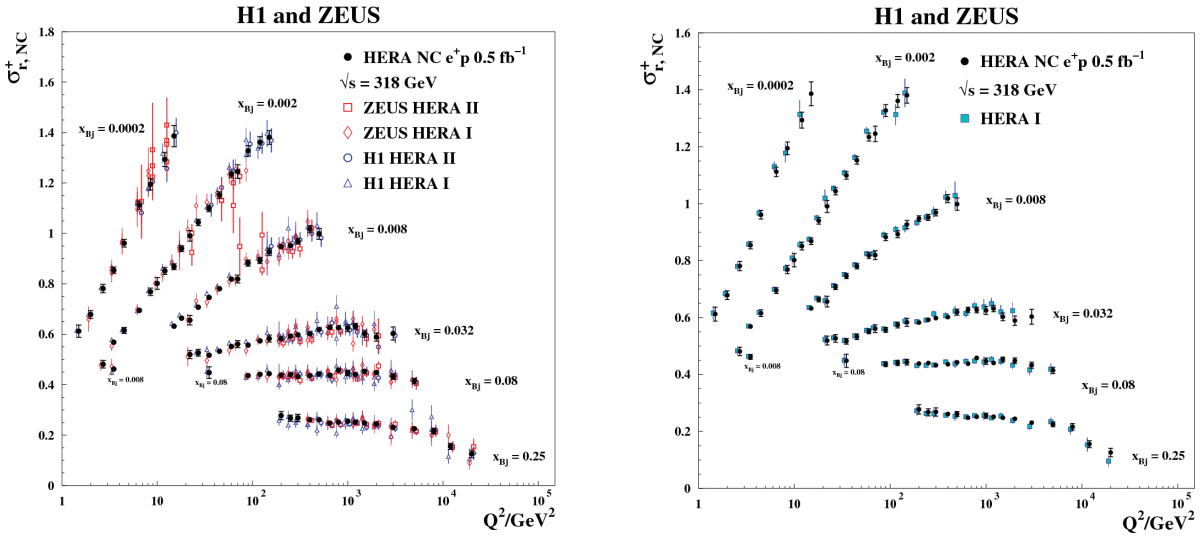

FIGURE 2. The combined HERA data for the inclusive NC e^+p reduced cross sections as a function of Q^2 for six selected values of x_{Bj} compared to the individual H1 and ZEUS data. The individual measurements are displaced horizontally for better visibility. Error bars represent the total uncertainties, (a). The combined HERA data for the inclusive NC e^+p reduced cross sections as a function of Q^2 for six selected values of x_{Bj} compared to the results from HERAI alone. The two measurements are displaced horizontally for better visibility. Error bars represent the total uncertainties, (b).

The new values supersede those published previously [1]. The total uncertainties are below 1.5 % over the Q^2 range of $3 \leq Q^2 \leq 500\text{GeV}^2$ and below 3 % up to $Q^2 = 3000$ GeV^2. Cross sections are provided for values of Q^2 between $Q^2 = 0.045$ GeV^2 and $Q^2 = 50000$ GeV^2 and values of x_{Bj} between $x_{Bj} = 6 \times 10^{-7}$ and $x_{Bj} = 0.65$. The events have a minimum invariant mass of the hadronic system, W, of 15 GeV. In Fig. 2 (a), the individual and the combined reduced cross sections for NC e^+p DIS scattering are shown as a function of Q^2 for selected values of x_{Bj}.

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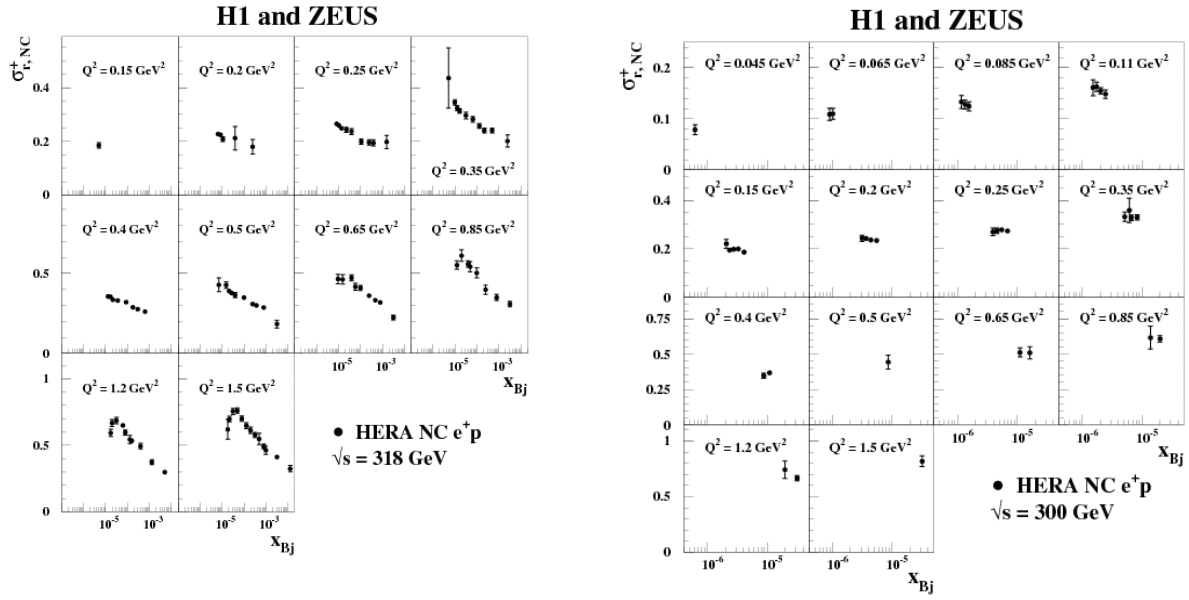
The improvement due to combination is clearly visible. In Fig 2 (b), a comparison between the new combination and the combination of HERA I data alone is shown. The improvement is especially significant at high Q^2.



(a) (b)

FIGURE 3. The combined HERA data for the inclusive NC e^+p reduced cross sections at $\sqrt{s}$ = 318 GeV at very low Q^2. Error bars represent the total uncertainties (a). The combined HERA data for the inclusive NC e^+p reduced cross sections at $\sqrt{s}$ = 300 GeV at very low Q^2. Error bars represent the total uncertainties (b).

The combined NC e^+p data for very low Q^2 with proton beam energies of 920 and 820 GeV are shown in Fig. 3 (a) and (b). These data were taken during the HERA I period, but due to the systematic shifts introduced by the combination with HERA II data, the numbers are not always the same as in the old HERA I combination.

CONCLUSIONS

The result of a combination of all inclusive deep inelastic cross sections measured by the H1 and ZEUS collaborations in neutral and charged current unpolarised $e^{\pm}p$ scattering at HERA was presented. The combination based on a total luminosity of about 1 fb^{-1} of data produced cross section measurements of very high precision which are one of the legacies of the HERA experiments.

ACKNOWLEDGMENTS

I thank all colleagues who were involved in obtaining the results presented here.

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