Romanian Reports in Physics, Vol. 65, No. 2, P. 420–426, 2013

MEASUREMENT OF THE INCLUSIVE ELECTRON (POSITRON) +PROTON SCATTERING CROSS SECTION AT HIGH INELASTICITY y USING H1 DATA*

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Received September 12, 2012

Abstract. This report presents the measurements of the inclusive neutral current $e^{\pm}p$ scattering cross section using data collected by the H1 experiment at HERA during the years 2003 to 2007 with proton beam energies E_p of 920, 575 and 460 GeV. The kinematic range of the measurement covers low absolute four-momentum transfers squared, 1.5 GeV^2 < Q^2 < 90 GeV^2, small values of Bjorken x, $2.9 \cdot 10^{-5} < x < 0.01$, and extends to high inelasticity up to $y = 0.85$.

Key words: deep inelastic scattering, cross section, neutral current.

1. INTRODUCTION

Deep inelastic lepton-nucleon scattering (DIS) plays a pivotal role in determining the structure of the proton. The electron-proton collider HERA covers a wide range of absolute four-momentum transfer squared, Q^2, and of Bjorken x. Previous measurements of the DIS cross section, performed by the H1 and ZEUS collaborations, using data at proton beam energies of E_p = 820 GeV and E_p = 920 GeV and a lepton beam energy of E_e = 27.6 GeV, as well as their combination, have enabled studies of perturbative Quantum Chromodynamics (QCD) with unprecedented precision. These measurements are complemented here with new data including the data taken at E_p = 460 GeV and E_p = 575 GeV.

This paper reports new measurements of the DIS cross section at low Q^2 and high y values, using data collected by the H1 collaboration in the years 2003 to 2007 [1]. The data samples are taken with dedicated high y and low Q^2 triggers. Methods relying on data are used to determine the hadronic background

* Paper presented at the 8th General Conference of Balkan Physical Union, July 5–7, 2012, Constanta, Romania.

contribution. The first data sample consists of a new cross-section measurement for the nominal proton beam energy of E_p = 920 GeV for $8.5 \leq Q^2 \leq 90$ GeV^2 with an increased integrated luminosity of 97.6 pb^{-1} compared to [2]. The second new data sample at E_p = 920 GeV covers the region $2.5 \leq Q^2 \leq 12$ GeV^2 using a dedicated silicon tracker for the measurement of the charge of backward scattered particles. This analysis is based on an integrated luminosity of 5.9 pb^{-1}. Two further data samples correspond to the measurements at reduced proton beam energy, E_p = 575 GeV and E_p = 460 GeV, covering the kinematic domain of $1.5 \leq Q^2 \leq 90$ GeV^2 with integrated luminosities of 5.9 pb^{-1} and 12.2 pb^{-1}, respectively.

At low Q^2, the scattering cross section is defined by the two structure functions, F_2 and F_L. In a reduced form, the double differential cross section is given by:

$$\sigma_r\left(x,Q^2\right)=\frac{Q^4 x}{2\pi\alpha^2\left[1+\left(1-y^2\right)\right]}\frac{\mathrm{d}^2\sigma}{\mathrm{d}x\mathrm{d}Q^2}=F_2\left(x,Q^2\right)-\frac{y^2}{1+\left(1-y^2\right)}F_L\left(x,Q^2\right). \quad (1)$$

Using the ratio $R(x, Q^2)$, defined as:

$$R=\frac{\sigma_L}{\sigma_T}=\frac{F_L}{F_2-F_L}, \quad (2)$$

the reduced cross section in equation 1 can also be written as:

$$\sigma_r=F_2\left(x,Q^2\right)\left[1-f\left(y\right)\frac{R}{1+R}\right], \quad (3)$$

where

$$f\left(y\right)=y^2/1+\left(1-y^2\right). \quad (4)$$

2. CONTROL DISTRIBUTIONS

Data and MC distributions of the scattered electron energy, polar angle, E-P_z, and of the kinematic variables y, Q^2, x for events passing all analysis cuts are presented in Fig. 1 for E_p = 460 GeV data set included in the analysis. The MC distributions are normalised to the integrated luminosity and corrected for selection efficiency differences. The control distributions illustrate the considerable level of background for low E'_e, that is estimated from the data. The DIS simulation uses the H1PDF2009 set of parton distributions [2]. There is a good overall agreement observed between the measurements and predictions.

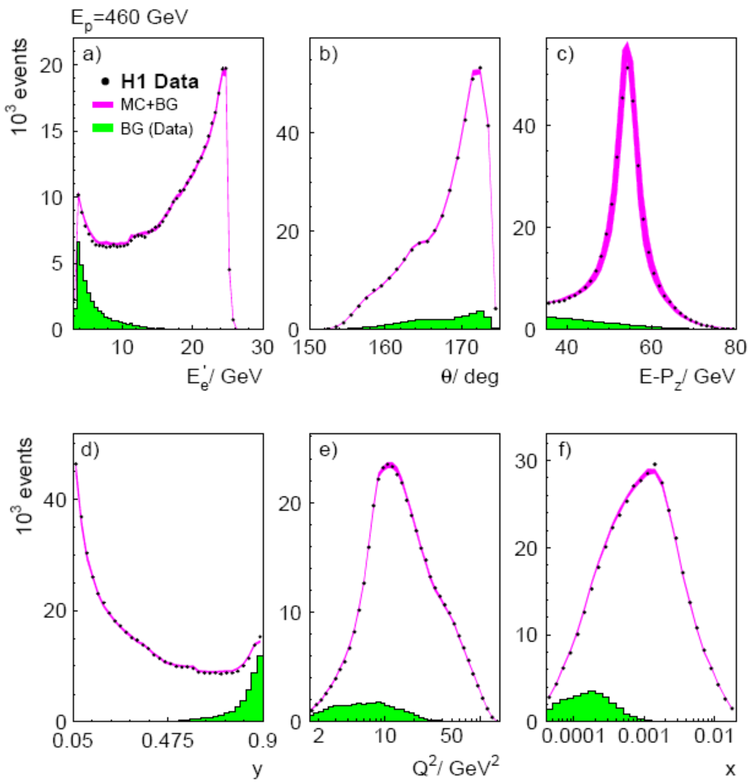

Fig. 1 – Distributions of the scattered electron energy, polar angle, E-P_z, and of the kinematic variables y, Q^2, x for events passing all analysis cuts from E_p = 460 GeV sample. Data are shown as dots with statistical errors, the shaded histograms show the data driven estimation of the background and the shaded bands represent the simulation of DIS signal with statistical and systematic uncertainties added in quadrature.

3. CROSS SECTION DETERMINATION

3.1. METHOD

At low Q^2 the contributions to the NC scattering process are completely dominated by photon exchange with negligible differences between the e^+p and e^-p scattering cross sections. The background determination at high y is based on the measured lepton-candidate charge. In order to reduce the sensitivity to the background charge asymmetry, the cross section is determined for a charge symmetric data sample for the medium Q^2 CJC E_p = 920 GeV and the low Q^2 BST E_p = 920 GeV samples. The reduced cross section is calculated in this case for each x, Q^2 bin as:

$$\sigma_r\left(x,Q^2\right)=\frac{N_{sig}^{e-p}+N_{sig}^{e+p}\dfrac{\zeta^{e-p}}{\zeta^{e+p}}}{N_{sigMC}^{e-p}\dfrac{\zeta^{e-p}}{\zeta_{sigMC}^{e-p}}+N_{sigMC}^{e+p}\dfrac{\zeta^{e+p}}{\zeta_{sigMC}^{e+p}}}\sigma_r^{MC}\left(x,Q^2\right). \quad (5)$$

Here $\zeta^{e\pm p}\left(\zeta_{MC}^{e\pm p}\right)$ is the integrated luminosity for the data (MC), $N_{sigMC}^{e\pm p}$ is the number of signal events in the MC and $\sigma_r^{MC}\left(x,Q^2\right)$ is the value of the reduced cross section in the MC.

3.2. RESULTS

$$\sigma_r\left(x,Q^2\right)=\frac{N_{sig}^{e+p}}{N_{sigMC}^{e+p}\dfrac{\zeta^{e+p}}{\zeta_{MC}^{e+p}}}\sigma_r^{MC}\left(x,Q^2\right). \quad (6)$$

Equation 5 is rather insensitive to the uncertainty of the background charge asymmetry $\kappa^{\pm}$ since for $y \geq 0.56$, the total background is estimated as $N_{BG}=\kappa_{-}N_{+}^{e-p}+\kappa_{+}N_{-}^{e+p}\left(\zeta^{e-p}/\zeta^{e+p}\right)$. The statistical accuracy of equation 5 is limited by the sample with the smaller luminosity, therefore the data taking strategy was tuned to obtain e^+p and e^-p samples of about equal size.

For the E_p = 460 GeV and E_p = 575 GeV samples, the absence of e^-p data does not allow for usage of equation 5, and a more standard cross section determination formula is used as

These cross sections are therefore more sensitive to the uncertainty in $\kappa^{\pm}$.

The medium Q^2 CJC E_p = 920 GeV and low Q^2 BST E_p = 920 GeV samples extend the published H1 measurements to high y and for them the same mixed $(Q^2, x) - (Q^2, y)$ binning is adapted as used in [3]. The E_p = 460 GeV and E_p = 575 GeV samples are used to measure the structure function F_L. For this measurement, an optimal binning is in (Q^2, y) with the y boundaries of the bins adjusted so that the corresponding $x = Q^2/(4E_e E_p y)$ values agree for different E_p. This binning is given in Table 1. Bin centres are calculated as an arithmetic average of the bin boundaries. Apart from the E_p = 460 GeV and E_p = 575 GeV samples, the binning is also employed in the reanalysis of the published H1 data at E_p = 920 GeV for the F_L measurement. The purity and stability [3] of the cross section measurements are typically above 70% at highest y reducing to about 50% at lowest y.

The cross-section measurements are shown in Fig. 3. The new data cover the range between 1.5 GeV^2 and 90 GeV^2 in Q^2 reaching values of inelasticity y as high as 0.85.

For the E_p = 920 GeV sample, the new data can be compared to the previous H1 results [2, 3]. For the high y region, the precision of the new data is significantly better than that of the previous H1 result, apart from the global normalisation uncertainty that is larger for the new result. This uncertainty is significantly reduced by combining the H1 measurements.

3.2. COMBINATION OF DATA

For the proton beam energy E_p = 920 GeV, the new data cover a phase space similar to previous H1 results [2, 3] which are based on HERA-I data, collected in the years 1994 to 2000. Therefore the data are combined, following the procedure described in [3].

Four data sets are considered in this combination: the combined H1 results from HERA-I [1, 2], reported for E_p = 820 GeV and E_p = 920 GeV, and the two new data sets, medium Q^2 CJC E_p = 920 GeV and low Q^2 BST E_p = 920 GeV. The systematic uncertainties are assumed to be uncorrelated between the HERA-I and HERA-II measurements, apart from a 0.5% overall normalisation uncertainty due to the theoretical uncertainty on the Bethe-Heitler process cross section used for the luminosity measurement. In total, there are 46 independent sources of systematic uncertainty. For $Q^2 \geq 12$ GeV^2, the new data extend the kinematic coverage towards high $y > 0.6$. At low $y < 0.6$ and for all values of y at low Q^2 , there a sizable region of overlap. The data show very good compatibility, with $\chi^2/\ n_{dof}$ = 15.4/36. At low y, the previous H1 data from [2, 3] have a higher precision than the new result. In particular, the global normalisation uncertainty was significantly smaller: about 1% at HERA-I compared to 3% at HERA-II. Therefore, in the combination, the new HERA-II data are effectively normalised to the HERA-I result and their global normalisation uncertainties are reduced significantly. Table 1 lists those few systematic sources of the HERA-II analyses, which are noticeably altered by the averaging procedure. All alterations stay within one standard deviation of the estimated error.

The systematic errors of the HERA-I data are not significantly affected by the combination. At low y, the gain in the combined data precision compared to the HERA-I result is small. The uncertainties are reduced by at most 5% of their size and the shift of central values does not exceed 0.2%. At high y, however, there is a significant gain in the precision achieved by the data combination. For the region $2.5 \leq Q^2 < 12$ GeV^2 and y = 0.8, for example, the accuracy of the E_p = 920 GeV data is improved by about a factor of two. For medium Q^2 , $12 \leq Q^2 \leq 35$ GeV^2 , the new high y measurements, corresponding to E_p = 920 GeV, exceed the accuracy of the HERA-I data, corresponding to E_p = 820 GeV, by a factor 1.5 to 2.

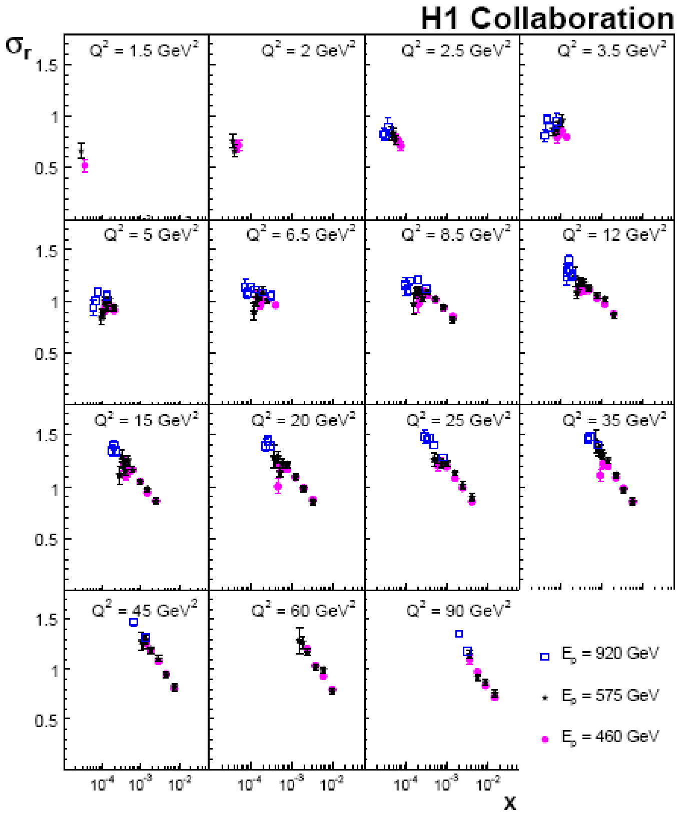

Fig. 3 – Results on the reduced cross section σ_r as determined from the E_p = 920 GeV, E_p = 575 GeV and E_p = 460 GeV samples. The error bars represent statistical and systematic uncertainties added in quadrature.

Table 1

Shifts of the central values and reduction of the uncertainty of the systematic error sources in the combination of the medium Q^2 CJC E_p = 920 GeV and low Q^2 BST = 920 GeV data sets with HERA-I data, expressed as fractions of the original uncertainty

Systematic Source	Shift in σ	Uncertainty in σ
E_e°	–0.25	0.85
Θ_e	0.14	0.84
ζ_{CJC}	0.03	0.96
ζ_{BST}	–0.30	0.37

The E_p = 920 GeV measurement at HERA-I was limited to $y \leq 0.6$. The E_p = 460 GeV and E_p = 575 GeV data sets are measured using an identical grid of (Q^2, x) bin centres. At low y, the influence of the structure function F_L is small. Therefore the two data sets are combined for all (Q^2, x) points satisfying

$y_{460} = Q^2 /(4E_e$ 460 GeV $x) < 0.35$ after a small correction of the cross-section values to E_p = 575 GeV. At higher y the measurements are kept separately but they are affected by the combination procedure. The data show good compatibility, with χ^2 / n_{dof} = 17.2/27.

4. CONCLUSIONS

A measurement is presented of the inclusive double differential cross section for neutral current deep inelastic $e\pm p$ scattering at small Bjorken x and low absolute four-momentum transfers squared, Q^2. The measurement extends to high values of inelasticity y. The data were collected with the H1 detector for the proton beam energy of E_p = 920 GeV, in the years 2003 to 2006, and for E_p = 575 GeV and E_p = 460 GeV, in 2007. The integrated luminosities of the measurements are 103.5 pb^{-1}, 5.9 pb^{-1} and 12.2 pb^{-1} for the E_p = 920 GeV, E_p = 575 GeV and E_p = 460 GeV data samples, respectively. The data at E_p = 920 GeV significantly improve the accuracy of the cross-section measurements at high y when compared to the previous H1 data.

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

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