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Measurement of the Polarisation Dependence of the Total $e^- p$ Charged Current Cross Section

H1 Collaboration

Abstract

Data taken by the H1 detector, with longitudinally polarised left handed electrons in collision with unpolarised protons at HERA, are used to measure the total charged current cross section for $Q^2 > 400\,\mathrm{GeV}^2$ and inelasticity $y < 0.9$. The polarisation dependence of the total charged current cross section is compared with Standard Model expectations.

1 Introduction

In November 2004 the HERA machine began running for the first time with longitudinally polarised electron beams. This allows HERA to further constrain the parton densities of the proton through measurements of polarisation asymmetries [1], as well as continuing to test the Electroweak part of the Standard Model at the energy frontier.

The two contributions to deep inelastic scattering, neutral current (NC), $ep \to eX$, and charged current (CC) interactions, $ep \to \nu X$, can both be measured at HERA and provide complementary information on the Standard Model, which makes clear predictions of the polaristion dependence of these cross sections. Specifically, it predicts that the CC cross section should have a linear dependence on polarisation, and furthermore, the cross section for fully right handed electrons should be zero (similarly for fully left handed positrons). This follows from the nonexistence of right handed currents within the framework of the Standard Model.

In this paper we report on the first measurement of the total CC cross section for longitudinally polarised left handed electrons. The measurement is compared to unpolarised data and Standard Model expectations.

The data set presented here has a mean polarisation of $(-25.40 \pm 0.44)\,\%$ and an integrated luminosity of $(17.8 \pm 0.2)\,\mathrm{pb}^{-1}$. The incident electron beam energy is $27.6\,$GeV, whilst the unpolarised proton beam energy is $920\,$GeV. This yields a center-of-mass energy of $\sqrt{s} = 319\,$GeV. The measured cross sections are defined in terms of two of the kinematic variables Q^2, x, and y, where y quantifies the inelasticity of the interaction.

The leading order double differential CC cross section for $e^+p \to \bar{\nu}X$ can be written as

$$\frac{\mathrm{d}^2\sigma_{CC}}{\mathrm{d}x\,\mathrm{d}Q^2} = (1-P_e)\frac{G_F^2}{2\pi x}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 x\left[(u+c)+(1-y)^2(\bar{d}+\bar{s})\right] \quad , \tag{1}$$

where G_F is the Fermi coupling constant, M_W is the mass of the W boson, and u, c, $\bar{d}$, $\bar{s}$ are quark distribution functions of the proton. P_e is the degree of longitudinal polarisation and is defined as $P_e = (N_R - N_L)/(N_R + N_L)$ with N_R, and N_L the number of right and left handed electrons in the beam. It can be seen that the cross section has a linear dependence on the polarisation of the lepton beam. The cross section for left handed electrons is enhanced, whilst the cross section for right handed right is suppressed. For $P_e = +1$ the cross section is identically zero in the Standard Model.

2 Experimental Technique

The H1 detector components most relevant to this analysis are the LAr calorimeter, which measures the positions and energies of charged and neutral particles over the polar[1] angular range $4^\circ < \theta < 154^\circ$, and the inner tracking detectors which measure the angles and momenta

[1]The polar angle θ is defined with respect to the positive z axis. The forward direction is the region of increasing z and the direction of the incident proton beam.

of charged particles over the range $7^\circ < \theta < 165^\circ$. A full description of the detector can be found in [3].

At HERA transverse polarisation of the positron beam arises naturally through synchrotron radiation via the Sokolov-Ternov effect [4]. In 2000 pairs of spin rotators were installed in the beamline around the H1 detector allowing transversely polarised positrons to become longitudinally polarised. The polarisation is continuously measured using two independent polarimeters measuring the transverse polarisation: TPOL [5] and the longitudinal polarisation LPOL [6]. The luminosity weighted polarisation distribution is shown in figure 1 for the data and is reproduced in the Monte Carlo simulation.

In order to determine acceptance corrections and background contributions for the DIS cross section measurements, the detector response to events produced by various Monte Carlo generation programs is simulated in detail, and is described in [2].

The selection and analysis of deep inelastic scattering (DIS) processes with charged current (CC) interactions follows closely that of published unpolarised data [2] and is briefly described below. The CC events are identified as having missing transverse momentum, $P_{T,h}$, where $P_{T,h} = \sqrt{(\sum_i p_{x,i})^2 + (\sum_i p_{y,i})^2}$ and is summed over all particles of the hadronic final state.

The CC kinematic quantities can only be determined with the hadron method (h method) [7] using the relations

$$y_h = \frac{\Sigma}{2\,E_e} \qquad Q_h^2 = \frac{P_{T,h}^2}{1 - y_h} \qquad x_h = \frac{Q_h^2}{s\,y_h} \quad , \tag{2}$$

This method is influenced by particle losses in the beam pipe and fluctuations of the detector response to hadronic final state particles, and therefore has moderate precision.

NC interactions are also studied and provide an accurate and high statistics data sample with which to check the detector response. The selection of NC interactions is based mainly on the requirement of an identified scattered positron in the liquid argon (LAr) calorimeter with an energy $E_e' > 11\,\mathrm{GeV}$. The NC sample is used to carry out an *in-situ* calibration of the energy scale of hadronic final state particles using the analysis described in [2]. The calibration procedure is based on the balance of the transverse energy of the positrons with that of the hadronic final state. The procedure is found to give good agreement between data and simulation.

In addition NC events are used for studies of systematic uncertainties in the charged current analysis. The data are processed such that all information from the scattered positron is suppressed, the so-called *pseudo-CC* sample. This sample then mimics CC interactions allowing all efficiencies to be checked with high precision.

3 Measurement Procedure

Candidate CC interactions are selected by requiring $P_{T,h} > 12\,\mathrm{GeV}$. In order to ensure high efficiency of the trigger and kinematic resolution the analysis is futher restricted to the domain of $Q_h^2 \gtrsim 200\,\mathrm{GeV}^2$ and $0.03 < y_h < 0.85$. Finally, non-ep background is rejected by searching for typical cosmic ray and beam-induced background event topologies.

The good understanding of the detector can be seen in figures 2 and 3. In figure 2 the NC sample is compared to simulation and demonstrates the quality of the electromagnetic and hadronic calibration of the detector. In particular fig. 2d shows the ratio of transverse momentum of the scattered positron to that of the hadronic final state. This distribution is described by the simulation within the systematic uncertainty assigned to the hadronic calibration. Figure 3 shows relevant distributions of the CC sample compared to simulation. The contribution of background photoproduction processes is also shown and can be seen to have a large influence at low Q^2.

4 Results

The integrated charged current (CC) cross section of longitudinally polarised electrons in collision with protons is measured in the range $Q^2 > 400\,\mathrm{GeV}^2$ and $y < 0.9$. The value is:

$$\sigma_{CC}(P_e = -0.25) \quad = \quad 66.42\,\mathrm{pb} \pm 2.39\,\mathrm{pb}\ (\mathrm{stat}) \pm 2.99\,\mathrm{pb}\,(\mathrm{sys})$$

where the 1.2% luminosity normalisation uncertainty is included in the systematic error. The polarisation uncertainty, which does not directly enter in the cross section measurement, is shown in Fig. 4 as horizontal error bars.

The measurement of the unpolarised CC cross section based on the HERA-I data set with a luminosity of 16.4 pb^{-1} and measured in the same phase space region is:

$$\sigma_{CC}(P_e = 0) \quad = \quad 57.03\,\mathrm{pb} \pm 2.21\,(\mathrm{stat}) \pm 1.38\,(\mathrm{sys})$$

where the systematic error also includes the normalisation uncertainty of 1.8%.

The polarisation dependence of these cross sections shown in Fig. 4 agrees well with the Standard Model expectations based on the H1 PDF 2000 [9]. Also shown are the total cross sections and their polarisation dependence of the charged current interactions measured previously in positron-protron collisions [8].

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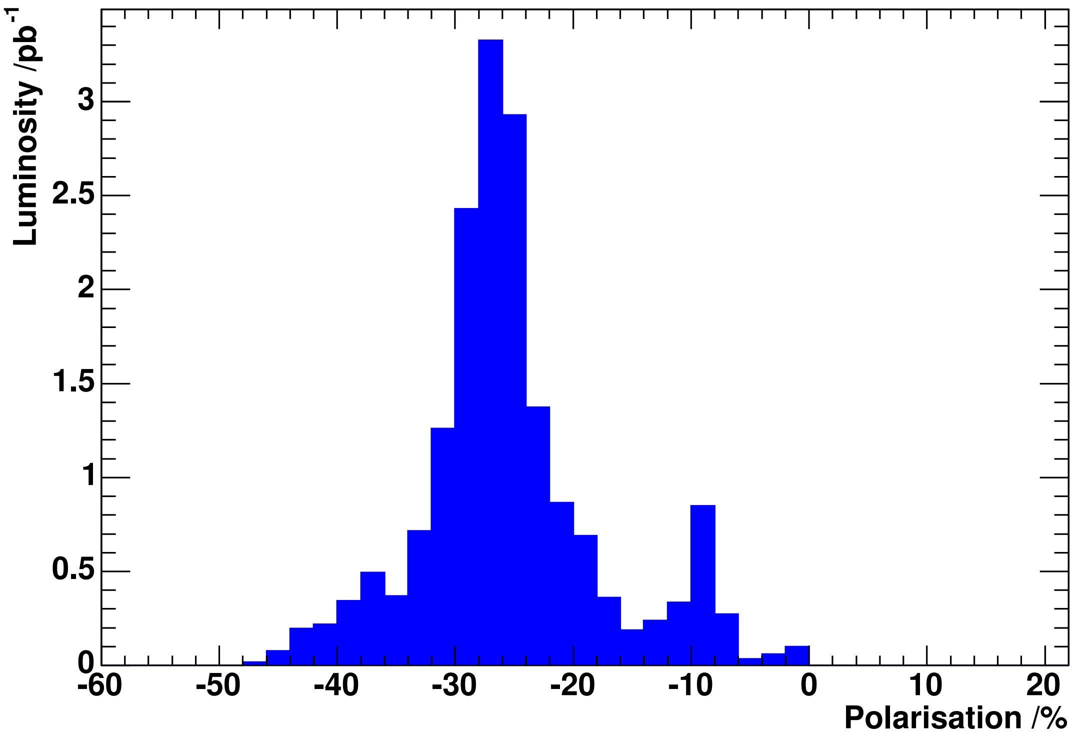

Figure 1: Distribution of luminosity versus polarisation P_e

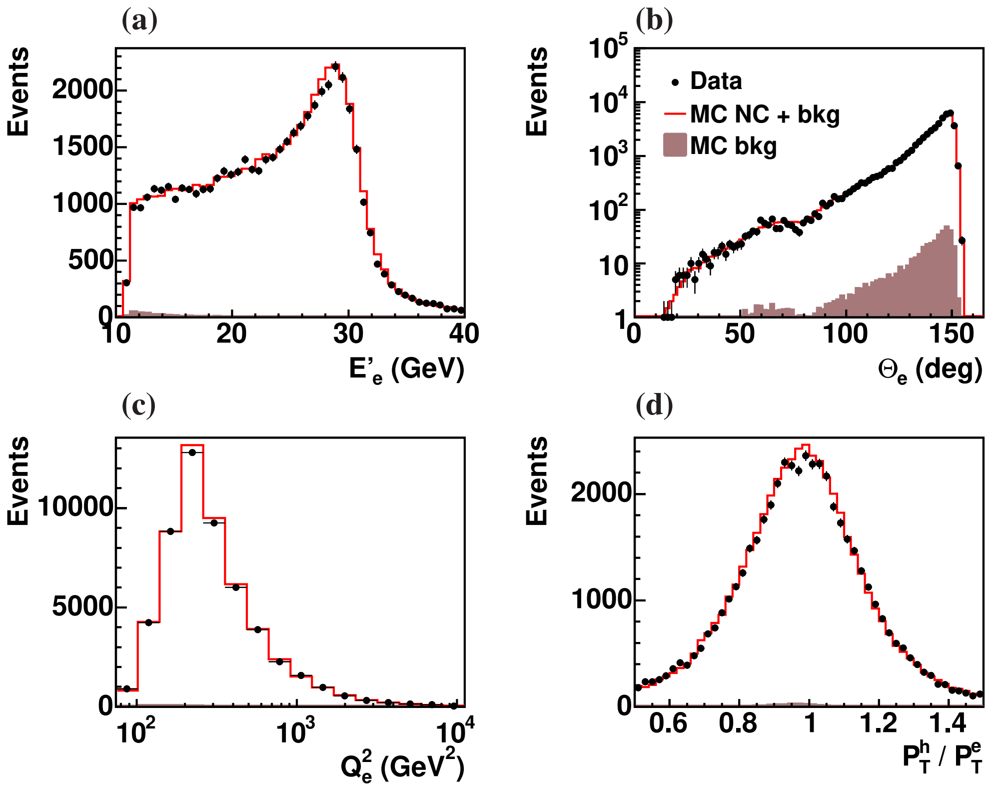

Figure 2: Distributions of E'_e (a), θ_e (b), Q^2 (c) and $P_{T,h}/P_{T,e}$ (d) of the NC data set.

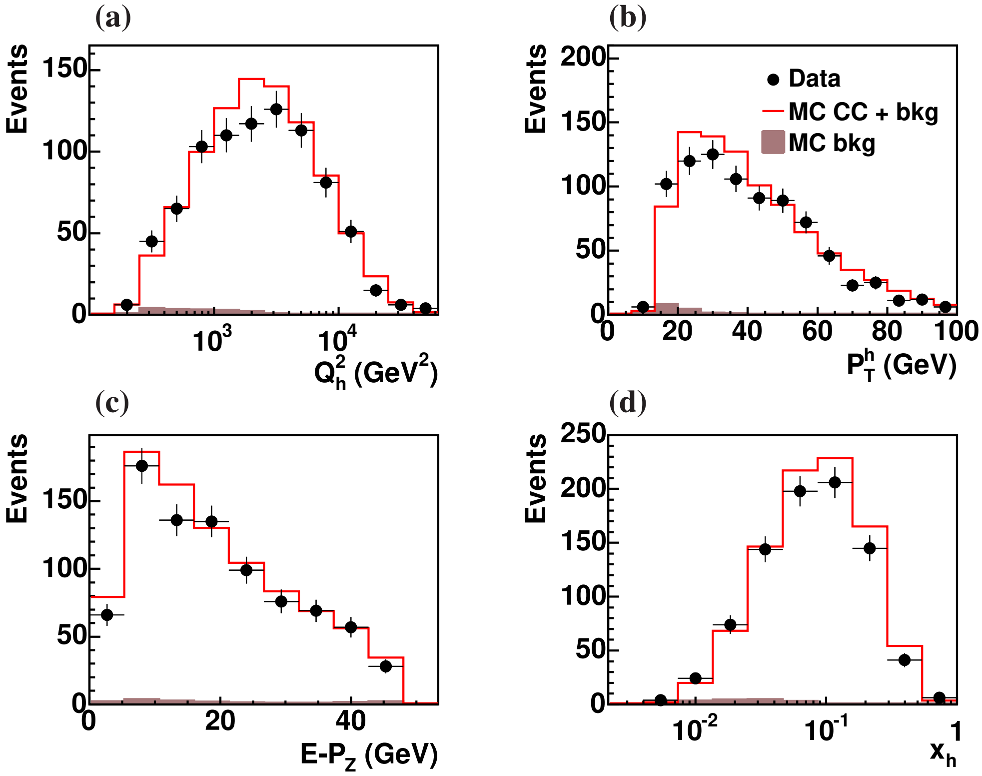

Figure 3: Distributions of Q^2_h (a), $P_{T,h}$ (b), $E_h - p_{z,h}$ (c) and x_h (d) of the CC data set.

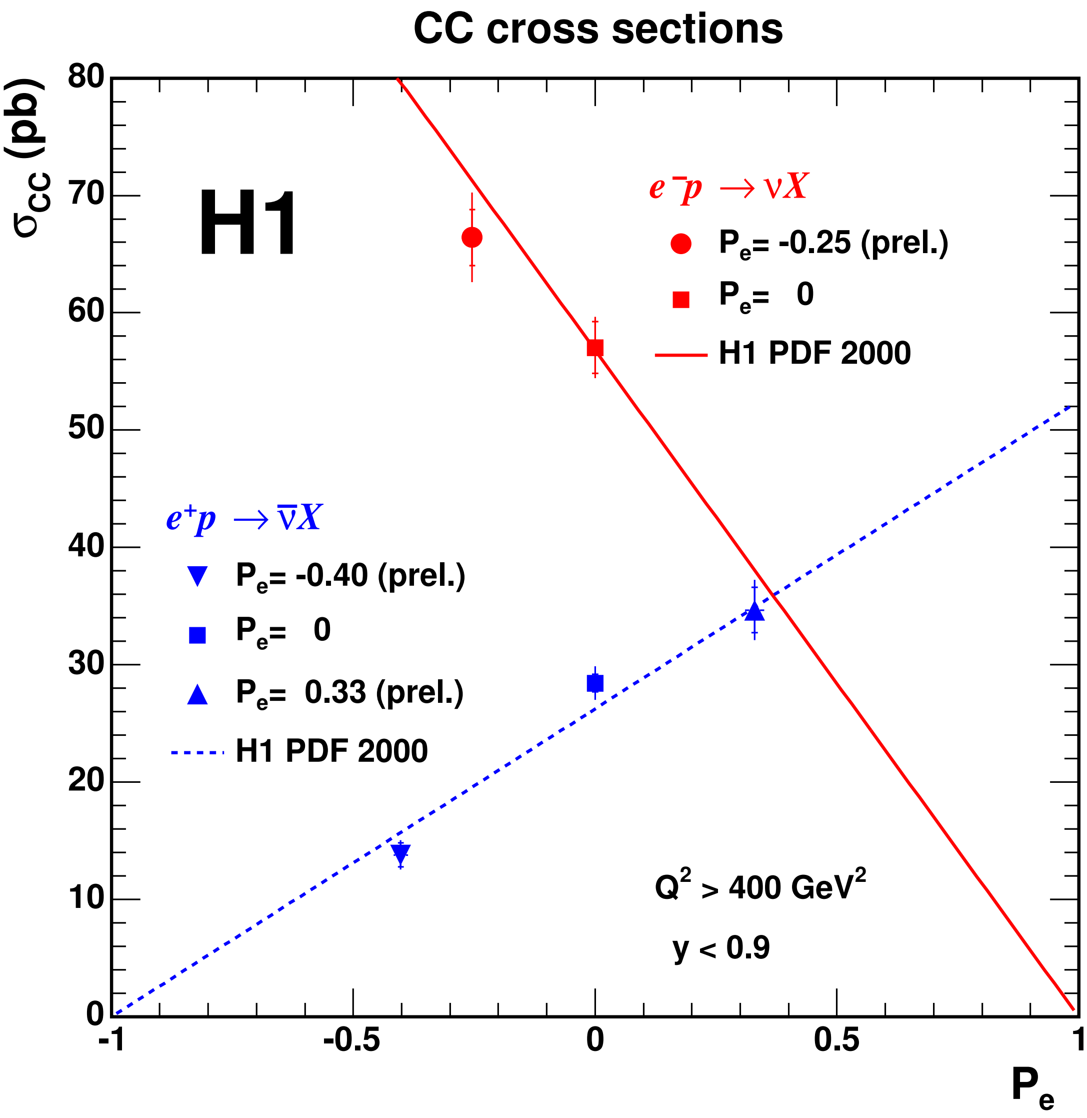

Figure 4: The dependence of the e^+p and e^-p CC cross section with the lepton beam polarisation P_e is shown. The data are compared to the prediction from the H1 PDF 2000 fit for polarised positrons (dashed line) and for polarised electrons (full line) .