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First Measurement of the Polarisation Dependence of the Total Charged Current Cross Sections

H1 Collaboration

Abstract

Data taken with the H1 detector, for longitudinally polarised positrons in left and right handed states 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. The data are used to obtain an extrapolated total charged current cross section for a fully left handed positron beam. This extrapolation is found to be consistent with the expectations of the Standard Model.

1 Introduction

In Autumn 2003 the HERA accelerator started operation of the second phase of its Deep Inelastic Scattering (DIS) programme. The ep collision data collected since then has been taken with longitudinally polarised positrons for the first time. The polaristion of the lepton beam 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 DIS, neutral current (NC), $ep \rightarrow eX$, and charged current (CC) interactions, $ep \rightarrow \nu X$, 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 left handed positrons should be zero (similarly for fully right handed electrons). This follows from the nonexistence of right handed currents within the framework of the Standard Model.

In this paper we report on new measurements of the total CC cross section for two values of lepton beam polarisation. The measurements are compared to Standard Model expectations and a linear fit to the data is performed. The fit is extrapolated to that of a fully left handed polarised positron beam.

For the analysis presented here, two independent data samples with right and left handed polarised positrons are used. For convenience, they are named hereafter as the R and L data sets, respectively. The R data set has a mean polarisation of $33.0 \pm 2.0\,\%$ and an integrated luminosity of $15.3 \pm 0.4\,\mathrm{pb}^{-1}$. The corresponding numbers for the L data set are $-40.2 \pm 1.5\,\%$ and $21.7{\pm}0.6\,\mathrm{pb}^{-1}$. In both data sets the incident positron 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 $e^+p \rightarrow \bar{\nu}X$ can be written as

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

where G_F is the Fermi coupling constant, M_W is the mass of the W boson, and $\bar{u}$, $\bar{c}$, d, 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 positrons 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 right handed $(+)$ positrons is enhanced, whilst the cross section for left handed $(-)$ positrons 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 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

$$y_h = \frac{\Sigma}{2\,E_e} \qquad Q^2_h = \frac{P^2_{T,h}}{1-y_h} \qquad x_h = \frac{Q^2_h}{s\,y_h} \quad , \tag{2}$$

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 $E'_e > 11$ 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. For the hadronic energy scale a conservative uncertainty of 3% is assigned.

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.

[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.

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 2,3,4 and 5. In figure 2 the NC R sample is compared to simulation and demonstrates the electromagnetic calibration of the detector. Figure 3 shows relevant distributions of the CC R 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. Figure 4 shows the same NC distributions for the L sample. The simulation provides a good description of the data. In particular fig. 4d 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. The details of the analysis are not identical for the measurements of the right and left handed cross sections, in particular the supression of photoproduction background.

4 Results

The integrated polarised CC cross sections are measured in the range $Q^2 > 400\,\mathrm{GeV}^2$ and $y < 0.9$. The values are:

$$\sigma_{CC}(P_e = +0.33) = 34.67\,\mathrm{pb} \pm 1.94\,\mathrm{pb}\ (\mathrm{stat}) \pm 1.66\,\mathrm{pb}\ (\mathrm{sys})$$
$$\sigma_{CC}(P_e = -0.40) = 13.80\,\mathrm{pb} \pm 1.04\,\mathrm{pb}\ (\mathrm{stat}) \pm 0.94\,\mathrm{pb}\ (\mathrm{sys})$$

The measurement of the unpolarised CC cross section based on the HERA-I data set [2] with a luminosity of 65.2 pb^{-1} and measured in the same phase space region is:

$$\sigma_{CC}(P_e = \quad 0.00) = 28.44\,\mathrm{pb} \pm 0.77\,\mathrm{pb}\ (\mathrm{stat}) \pm 1.22\,\mathrm{pb}\ (\mathrm{sys})$$

These are to be compared to Standard Model expectations using the H1PDF 2000 fit which yields $\sigma_{CC} = 34.91\,\mathrm{pb}$ for $P_e = +0.33$, $\sigma_{CC} = 26.25\,\mathrm{pb}$ for $P_e = 0.00$, and $\sigma_{CC} = 15.70\,\mathrm{pb}$ for $P_e = -0.40$. The measurements are shown in fig. 6 compared to the Standard Model expectations.

A linear fit to the polarisation dependence of the measured cross sections was performed. The fit took into account the correlated systematics between the measurements and is also shown in fig. 6. The fit provides a reasonable description of the data with a $\chi^2 = 2.45$. The fit extrapolated to the point $P_e = -1.0$ yields a cross section of:

$$\sigma_{CC}(P_e = -1.00) = -3.7\,\mathrm{pb} \pm 2.4\,\mathrm{pb}\ (\mathrm{stat}) \pm 2.7\,\mathrm{pb}\ (\mathrm{sys})$$

This extrapolated cross section expectation is consistent with the Standard Model prediction of a zero cross section.

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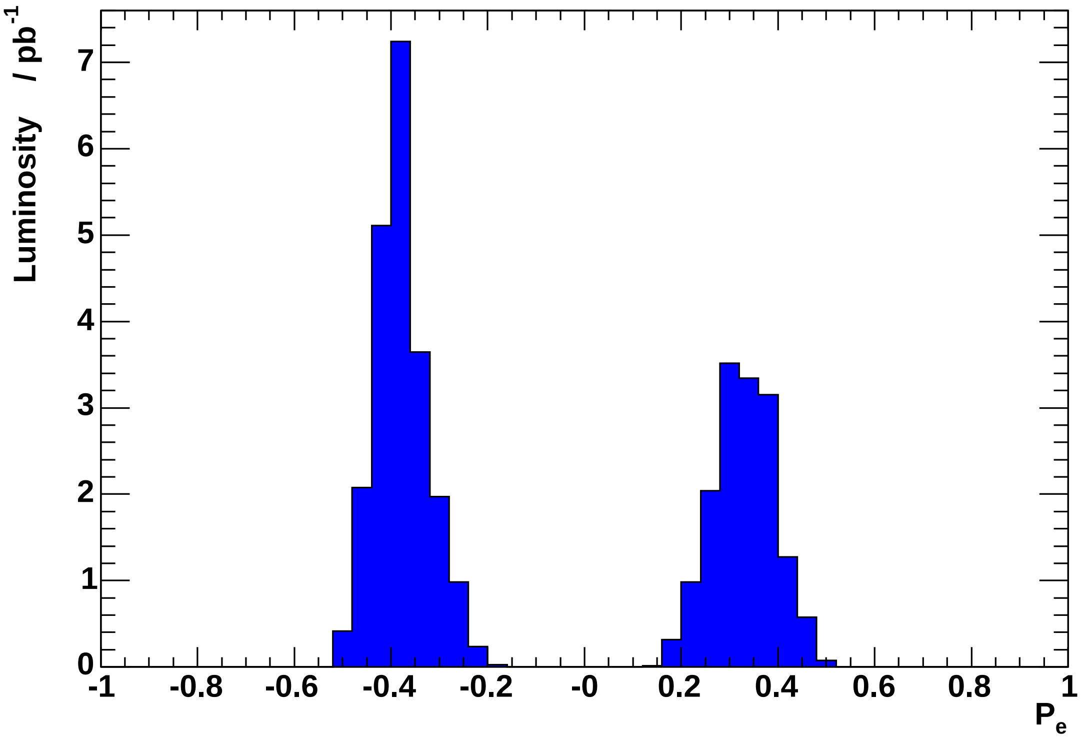

Figure 1: Distribution of luminosity versus polarisation P_e

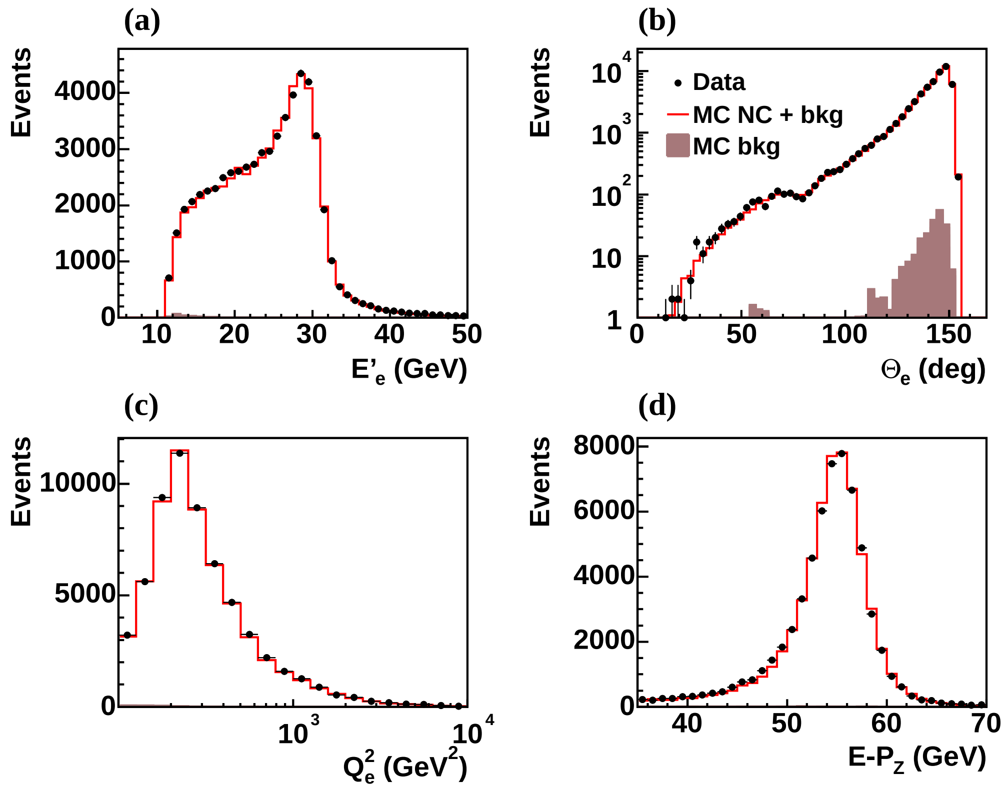

Figure 2: Distributions of E'_e (a), θ_e (b), Q^2 (c) and $E - p_z$ (d) of the NC R data set.

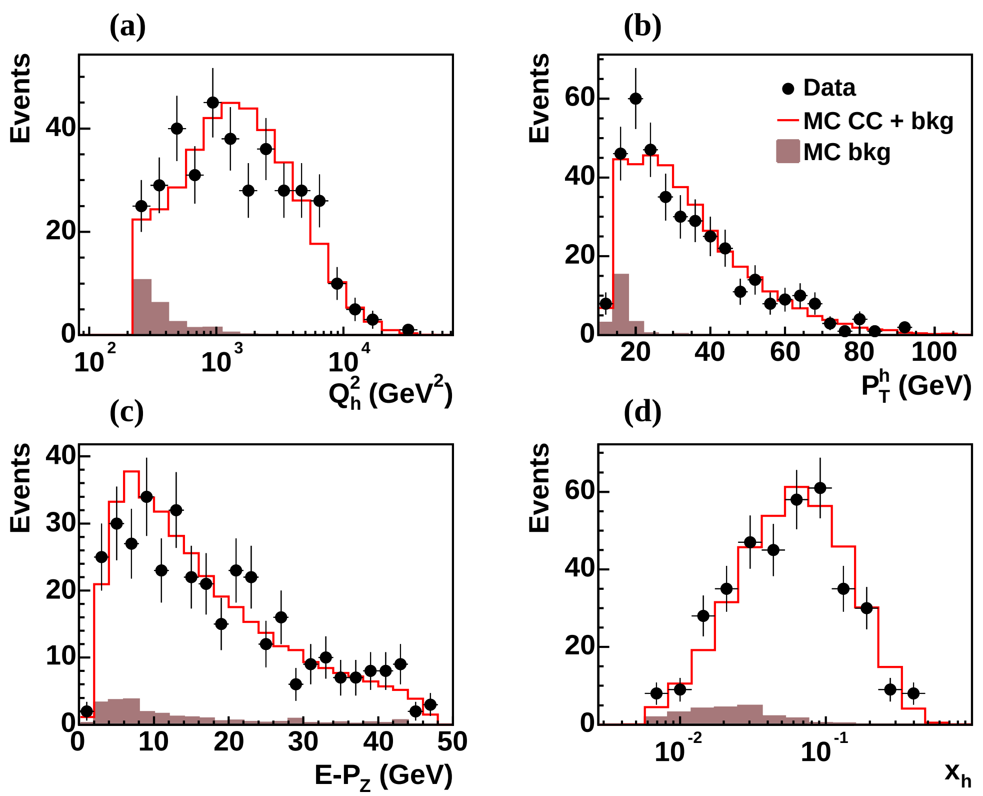

Figure 3: Distributions of Q_h^2 (a), $P_{T,h}$ (b), $E_h - p_{z,h}$ (c) and x_h (d) of the CC R data set.

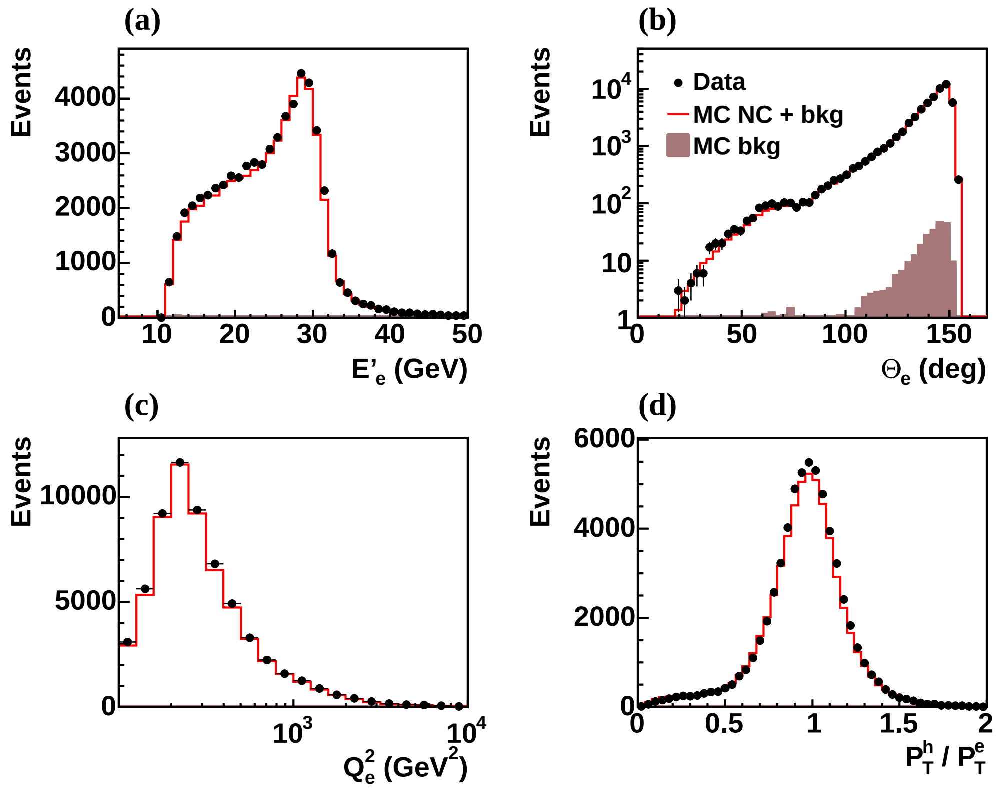

Figure 4: Distributions of E'_e (a), θ_e (b), Q^2 (c) and $P_{T,h}/P_{T,e}$ (d) of the NC L data set.

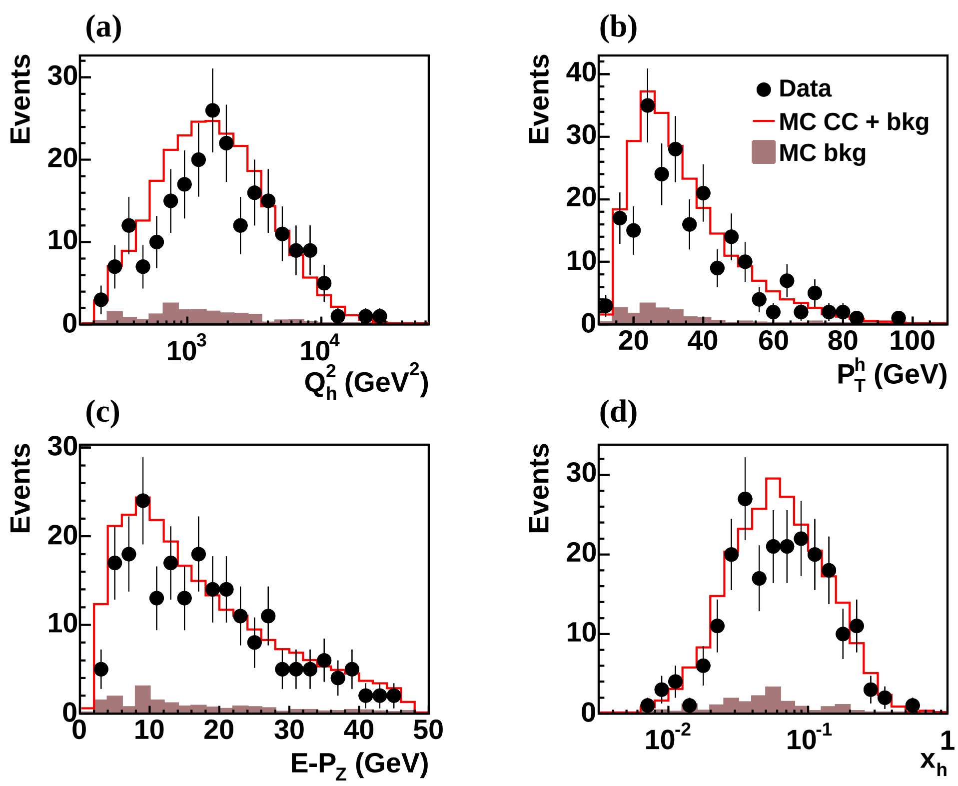

Figure 5: Distributions of Q_h^2 (a), $P_{T,h}$ (b), $E_h - p_{z,h}$ (c) and x_h (d) of the CC L data set.

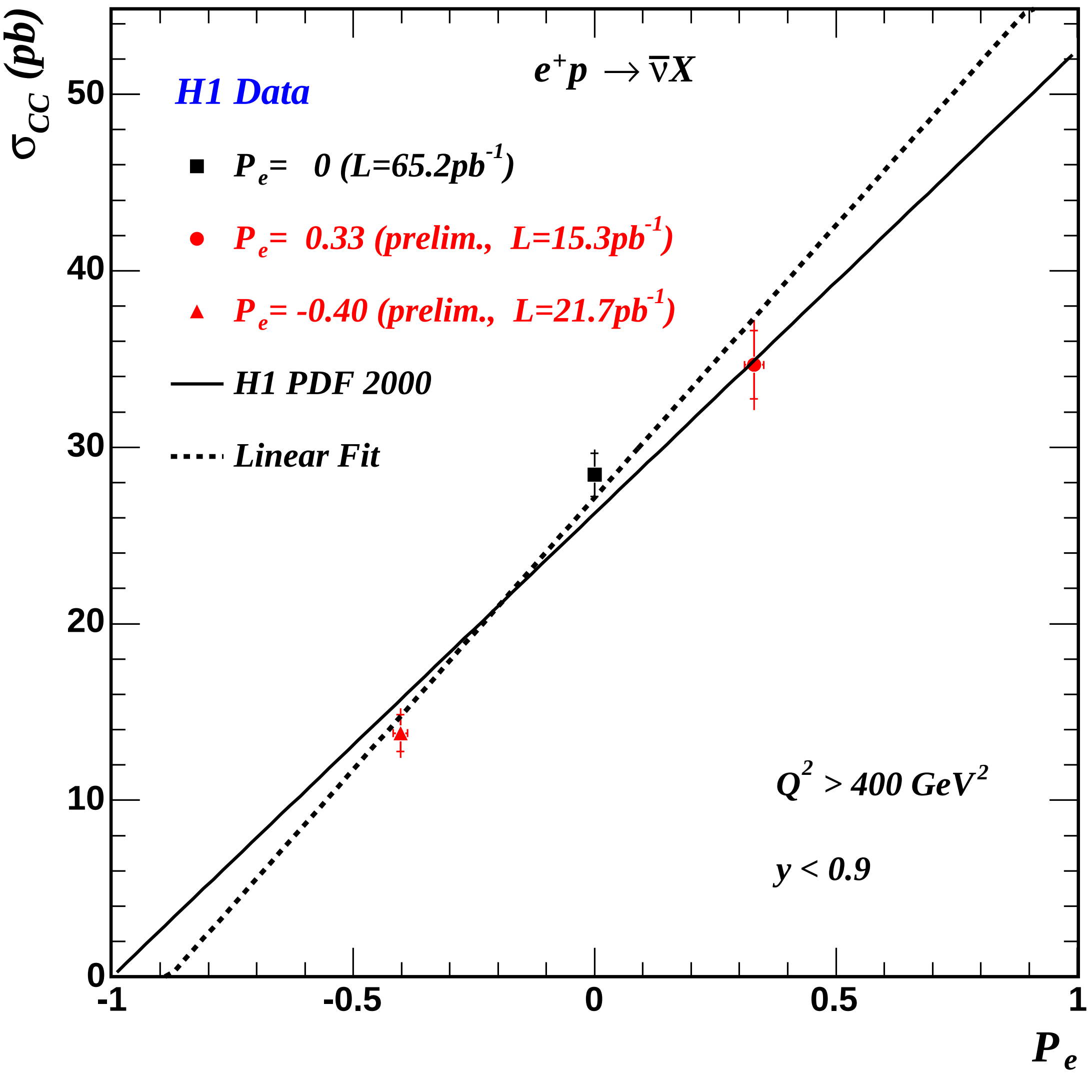

Figure 6: The dependence of the e^+p CC cross section with the lepton beam polarisation P_e is shown. The data are compared to the prediction from the H1 PDF 2000 fit (full line). The dashed line shows the result of a linear fit to the data with $\chi^2/n.d.f = 2.45$.