Measurement of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ at Low and High Q^2 using the H1 Vertex Detector

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Abstract. Measurements are presented of inclusive charm and beauty cross sections in e^+p collisions at HERA for values of photon virtuality $3.5 \leq Q^2 \leq 60$ GeV^2 and of the Bjorken scaling variable $0.0002 \leq x \leq 0.005$ using a method based on the impact parameter, in the transverse plane, of tracks to the primary vertex, as measured by the H1 vertex detector. Values for the structure functions $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ are obtained and presented together with recently published high Q^2 measurements [1]. This is the first measurement of $F_2^{b\bar{b}}$ in this kinematic range. The results are found to be compatible with the predictions of perturbative quantum chromodynamics and with previous measurements of $F_2^{c\bar{c}}$.

Keywords: H1, structure function, charm, beauty, heavy quarks
PACS: 13.85.Hd, 14.65.Dw, 14.65.Fy

1. INTRODUCTION

Measurements of the charm (c) and beauty (b) contributions to the inclusive proton structure function F_2 have been made recently in Deep Inelastic Scattering (DIS) at HERA, using information from the H1 vertex detector, for values of the negative square of the four momentum of the exchanged boson $Q^2 > 150$ GeV^2 [1]. In this high Q^2 region a fraction of $\sim 18\%$ ($\sim 3\%$) of DIS events contain c (b) quarks. It was found that perturbative QCD (pQCD) calculations at next-to-leading order (NLO) gave a good description of the data. In this paper a similar method is employed, using data from the same running period, to extend the measurements to the range $3.5 \leq Q^2 \leq 60$ GeV^2 and $0.000197 \leq x \leq 0.005$. Events containing heavy quarks can be distinguished from light quarks events by the long lifetimes of charm and beauty hadrons, which lead to displacements of tracks from the primary vertex.

In the framework of NLO QCD analyses of global inclusive and jet cross section measurements the production of heavy flavours is described using the variable flavour number scheme (VFNS) which aims to provide reliable pQCD predictions over the whole kinematic range in Q^2 [2, 3]. At values of $Q^2 \simeq M^2$ the effects of the quark mass must be taken into account and the heavy flavour partons are treated as massive quarks. The dominant LO process in this region is photon gluon fusion (PGF) and the NLO diagrams are of order α_s^2 [4, 5]. As Q^2 increases, in the region $Q^2 \gg M^2$, the heavy flavour quark may be treated as a massless parton in the proton. Different approaches have been developed which deal with the transition from the heavy quark mass effects at low Q^2 to the asymptotic massless parton behaviour at high Q^2.

2. EXPERIMENTAL METHOD

The analysis is based on a low Q^2 sample of e^+p neutral current scattering events corresponding to an integrated luminosity of 57.4 pb^{-1}, taken in the years 1999-2000, at an ep centre of mass energy $\sqrt{s} = 319$ GeV, with a proton beam energy of 920 GeV. The low Q^2 events are selected in a similar manner to that described in [6].

In order to determine a signed impact parameter (δ) for each track, the azimuthal angle of the struck quark ϕ_{quark} must be determined for each event. To do this, jets with a minimum p_T of 4 GeV, in the angular range $25^\circ < \theta < 155^\mathrm{o}$, are reconstructed exploiting the invariant k_T algorithm [7, 8] in the laboratory frame using all reconstructed hadronic final state (HFS) particles. The angle ϕ_{quark} is defined as the ϕ of the jet with the highest transverse momentum or, if there is no jet reconstructed in the event, as $180^\circ - \phi_{\mathrm{elec}}$, where ϕ_{elec} is the azimuthal angle of the scattered electron. Approximately 33% (55%) of c (b) events have ϕ_{quark} reconstructed from a jet, as determined from a Monte Carlo simulation.

If the angle between the quark axis and the line joining the primary vertex to the point of DCA is less than 90°, δ is defined as positive, and is defined as negative otherwise. Tracks with azimuthal angle outside $\pm 90^\circ$ of ϕ_{quark} are rejected. The δ distribution, shown in FIGURE 1, is seen to be asymmetric with positive values in excess of negative values indicating the presence of long lived particles. Tracks with $|\delta| > 0.1$ cm are rejected from the analysis to suppress light quark events containing long lived strange particles.

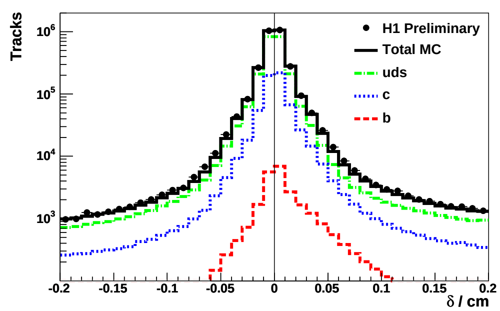

FIGURE 1. The distribution of the signed DCA δ of a track to the primary vertex in the x–y plane.

The method used in [1] to distinguish between the c, b and light quark flavours has been modified in the present analysis because here the fraction of b quarks is smaller. The quantities S_1, S_2 and S_3 are defined as the significance ($\delta/\sigma(\delta)$) of the track with the highest, second highest and third highest absolute significance, respectively, where $\sigma(\delta)$ is the error on δ. Distributions of each of these quantities are made. The events contributing to the S_2 distribution also contribute to the S_1 distribution. Similarly, those contributing to the S_3 distribution also contribute to the S_2 and S_1 distributions. Events in which S_1 and S_2 have opposite signs are excluded from the S_2 distribution. Events in which S_1, S_2 and S_3 do not all have the same sign are excluded from the S_3 distribution.

The fractions of c, b and light quarks of the data are extracted in several x–Q^2 intervals using a least squares simultaneous fit to the subtracted S_1, S_2 and S_3 distributions and the total number of inclusive events before any CST track selection. The c, b and uds

Monte Carlo simulation samples are used as templates. The Monte Carlo c, b and uds contributions in each x–Q^2 interval are scaled by factors P_c, P_b and P_l, respectively to obtain the best fit to the observed subtracted S_1, S_2, S_3 and total distributions. Only the statistical errors of the data and Monte Carlo simulation are considered in the fit. The fit to the subtracted significance distributions mainly constrains P_c and P_b, whereas the overall normalization constrains P_l. The fit gives a good description of all the significance distributions, with values of $P_c = 1.34 \pm 0.06$, $P_b = 1.43 \pm 0.17$ and $P_l = 1.16 \pm 0.01$.

The results of the fit in each x–Q^2 interval are converted to a measurement of the 'reduced c cross section' using:

$$\tilde{\sigma}^{c\bar{c}}(x,Q^2) = \tilde{\sigma}(x,Q^2)\frac{P_c N_c^{\mathrm{MCgen}}}{P_c N_c^{\mathrm{MCgen}} + P_b N_b^{\mathrm{MCgen}} + P_l N_l^{\mathrm{MCgen}}}\delta_{\mathrm{BCC}}, \tag{1}$$

where $\tilde{\sigma}(x,Q^2)$ is the measured inclusive reduced cross section from H1 [6], N_c^{MCgen}, N_b^{MCgen} and N_l^{MCgen} are the generated number of c, b and light quark events from the Monte Carlo in each bin, respectively, δ_{BCC} is a bin centre correction. The differential b cross section is evaluated in the same manner.

The structure function $F_2^{c\bar{c}}$ may be evaluated from the reduced cross section expression:

$$\tilde{\sigma}^{c\bar{c}} = F_2^{c\bar{c}} - \frac{y^2}{1+(1-y)^2}F_L^{c\bar{c}}, \tag{2}$$

where the longitudinal structure function $F_L^{c\bar{c}}$ is estimated from the NLO QCD expectation. The structure function $F_2^{b\bar{b}}$ is evaluated in the same manner.

3. RESULTS

The measurements of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ are shown as a function of x for various Q^2 values in FIGURE 2. In the lowest Q^2 bin $F_2^{b\bar{b}}$ is shown as a limit because it is consistent with zero. The data are compared with the results extracted from D^* meson measurements by H1 [9] and ZEUS [10] obtained using a NLO program based on DGLAP evolution to extrapolate the measurements outside the visible D^* range. The data are also compared with two VFNS predictions of NLO QCD from MRST [2] and CTEQ [3]. The predictions provide a reasonable description of the present data.

4. CONCLUSION

The differential charm and beauty cross sections in deep inelastic scattering are measured at low Q^2 using a technique based on the impact parameters of tracks from decays of long lived c and b hadrons. The measurements are done using all events containing tracks with vertex detector information. The cross sections and derived structure functions $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ are found to be well described by predictions of perturbative QCD.

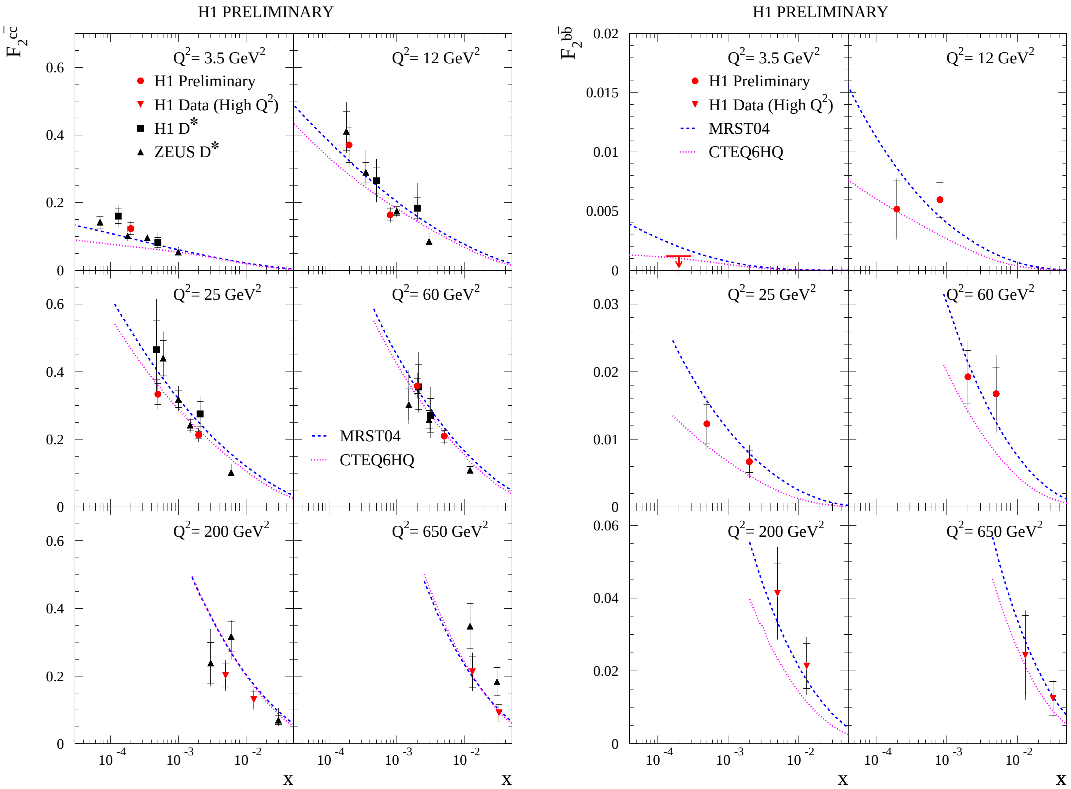

FIGURE 2. The measured $F_2^{c\bar{c}}$(left) and $F_2^{b\bar{b}}$ (right) shown as a function of x for various Q^2 values. The inner error bars show the statistical error, the outer error bars represent the statistical and systematic errors added in quadrature. The $F_2^{c\bar{c}}$and $F_2^{b\bar{b}}$ from H1 at higher values of Q^2 [1], the measurements of obtained from D^* mesons from H1 and ZEUS [9, 10] and the predictions of QCD are also shown.

This is the first measurement of $F_2^{b\bar{b}}$ in the low Q^2 kinematic region. The charm and beauty cross sections contribute on average 22% and 0.8% of the total *ep* cross section in this kinematic range.

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