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

H1 Collaboration

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 $0.000197 \leq x \leq 0.005$. The fraction of events containing charm and beauty quarks is determined 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. 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 $F_2^{c\bar{c}}$.

1 Introduction

Measurements of the charm (c) and beauty (b) contributions to the inclusive proton structure function F_2, have been made recently at HERA, using information from the H1 vertex detector, for values of the negative square of the four momentum of the exchanged boson $Q^2 > 150\ \mathrm{GeV}^2$ [1]. In this high Q^2 region a fraction of $\sim 18\%$ ($\sim 3\%$) of Deep Inelastic Scattering (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 $3.5 \le Q^2 \le 60\ \mathrm{GeV}^2$ and $0.000197 \le x \le 0.005$.

Events containing heavy quarks are distinguished from those containing only light quarks by reconstructing the displacement of tracks from the primary vertex, using precise spatial information from the H1 vertex detector. The long lifetimes of c and b flavoured hadrons lead to larger displacements than for light quark events. The charm structure function $F_2^{c\bar{c}}$ and the beauty structure function $F_2^{b\bar{b}}$, are obtained from the measured c and b cross sections after small corrections for the longitudinal structure functions $F_L^{c\bar{c}}$ and $F_L^{b\bar{b}}$. The measurements at low Q^2 benefit from increased statistics when compared to those at high Q^2. However, the low Q^2 region is experimentally more challenging because the final state does not have as large a transverse boost in the laboratory frame. The separation between b and c events is also difficult since although the c fraction is expected to be similar as at high Q^2, the b fraction is expected to be much smaller ($\sim 0.2\%$ at $Q^2 = 3.5\ \mathrm{GeV}^2$ [2, 3]).

Previous measurements of the open charm cross section in DIS at HERA have mainly been of exclusive D or D^* meson production [4–6]. From the D^* measurements the contribution of charm to the proton structure function, $F_2^{c\bar{c}}$, has been derived by correcting for the fragmentation fraction $f(c \to D^*)$ and the unmeasured phase space (mainly at low values of transverse momentum of the meson). The results are found to be in good agreement with pQCD predictions. The b cross section in DIS, in a similar kinematic region to the present analysis, has been measured for events containing a muon and an associated jet in the Breit frame in the final state [7, 8]. The measured cross sections are found to be higher than perturbative calculations at NLO.

2 Theoretical Description of Heavy Flavour Production in DIS

2.1 NLO QCD Calculations

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. 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 [9]. 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. A number of different approaches [10–12] 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.

Predictions for the charm and beauty cross sections may also be obtained from fits [13] to the HERA inclusive F_2 data based on CCFM evolution [14]. The heavy quarks are produced in the fixed flavour number scheme (FFNS) according to the PGF off-shell matrix elements (with $m_c = 1.5$ GeV and $m_b = 4.75$ GeV) convoluted with the CCFM k_T-unintegrated gluon density of the proton. The predictions are calculated using the Monte Carlo program CASCADE [15].

2.2 Monte Carlo Simulation

Monte Carlo simulations are used to correct the measured data for the effects of the finite detector resolution, acceptance and efficiency. The Monte Carlo program RAPGAP [16] is used to generate low Q^2 DIS events for the processes $ep \rightarrow eb\bar{b}X$ and $ep \rightarrow ec\bar{c}X$. The Monte Carlo program DJANGO [17] is used to generate light quark production. Both programs combine $\mathcal{O}(\alpha_s)$ matrix elements with higher order QCD effects modelled by the emission of parton showers. The heavy flavour event samples are generated according to the massive PGF matrix element with the mass of the c and b quarks set to $m_c = 1.5$ GeV and $m_b = 4.75$ GeV, respectively. In the heavy flavour event generation, the DIS cross section is calculated using the parton distribution functions (PDFs) from [21]. The light flavour event samples are generated with the LO PDFs from [18]. The partonic system for all generated events is fragmented according to the LUND string model implemented within the JETSET program [19]. The HERACLES program [20] calculates single photon radiative emissions off the lepton line, virtual and electroweak corrections. The Monte Carlo program PHOJET [22] is used to simulate the background contribution from photoproduction ($\gamma p \rightarrow X$).

The samples of events generated for the uds, c, and b processes are passed through a detailed simulation of the detector response based on the GEANT3 program [23], and through the same reconstruction software as is used for the data. A total of $\simeq 50$ million uds events, $\simeq 9$ million c events and $\simeq 1$ million b events were simulated to evaluate the cross sections, corresponding to luminosities of $87\ \mathrm{pb}^{-1}$, $163\ \mathrm{pb}^{-1}$ and $981\ \mathrm{pb}^{-1}$, respectively.

3 H1 Detector

The analysis is based on a low Q^2 sample of e^+p neutral current scattering events corresponding to an integrated luminosity of $57.4\ \mathrm{pb}^{-1}$, 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.

Only a short description of the H1 detector is given here; a full description may be found in [24]. A right handed coordinate system is employed at H1 that has its z-axis pointing in the proton beam, or forward, direction and x (y) pointing in the horizontal (vertical) direction.

Charged particles are measured in the central tracking detector (CTD). This device consists of two cylindrical drift chambers interspersed with z-chambers to improve the z-coordinate reconstruction and multi–wire proportional chambers mainly used for triggering. The CTD is situated in a uniform $1.15\,\mathrm{T}$ magnetic field, enabling momentum measurement of charged particles over the polar angular range $20^\circ < \theta < 160^\circ$ [1].

The CTD tracks are linked to hits in the vertex detector (central silicon tracker CST) [25], to provide precise spatial track reconstruction. The CST consists of two layers of double-sided silicon strip detectors surrounding the beam pipe, covering an angular range of $30^\circ < \theta < 150^\circ$ for tracks passing through both layers.

The track detectors are surrounded in the forward and central directions ($4^\circ < \theta < 155^\circ$) by a fine grained liquid argon calorimeter (LAr) and in the backward region ($153^\circ < \theta < 178^\circ$) by a lead–scintillating fibre calorimeter (SPACAL) [26] with electromagnetic and hadronic sections. These calorimeters provide energy and angular reconstruction for final state particles from the hadronic system. The SPACAL is used in this analysis to measure and identify the scattered positron. In addition, a planar drift chamber (BDC [27]) positioned in front of the SPACAL ($151^\circ < \theta < 178^\circ$), allows suppression of photoproduction background, where particles from the hadronic final state fake a positron signal.

Electromagnetic calorimeters situated downstream in the positron beam direction allow detection of photons and electrons scattered at very low Q^2. The luminosity is measured from the rate of photons produced in the Bethe-Heitler process $ep \rightarrow ep\gamma$.

4 Experimental Method

4.1 Event and Track Selection

The events are selected by requiring a compact electromagnetic cluster in the SPACAL associated with a track segment in the BDC to define the scattered positron candidate. The z position of the interaction vertex, reconstructed by one or more charged tracks in the tracking detectors, must be within ± 20 cm of the centre of the detector to match the acceptance of the CST. Photoproduction events are suppressed by requiring $\sum_i (E_i - p_{z,i}) > 35$ GeV. Here the sum is over all final state particles including the scattered positron and the hadronic final state (HFS). The HFS particles are reconstructed using a combination of tracks and calorimeter deposits [28], where E_i, $p_{x,i}$, $p_{y,i}$ and $p_{z,i}$ denote the energy and momentum components of the particles. The event kinematics, Q^2 and the inelasticity variable y, are reconstructed using the scattered positron. The Bjorken scaling variable x is obtained from $x = Q^2/sy$. In order to have good acceptance in the SPACAL, events are selected in the range $2 < Q^2 < 120\ \mathrm{GeV}^2$. The analysis is restricted to $0.07 < y < 0.7$ to ensure that the direction of the quark which is struck by the photon is mostly in the CST angular range. A further cut of $y < 0.63$ is imposed for events with $Q^2 < 18\ \mathrm{GeV}^2$ to reduce photoproduction background.

The triggers used in the analysis require a SPACAL energy deposit in association with a loose track requirement. Although these triggers are almost 100% efficient, not all events could be recorded, due to the large rate for low Q^2 events. Events were prescaled (randomly rejected)

[1] The angular coverage of each detector component is given for the interaction vertex in its nominal position.

at the first trigger level and an event downgrade, based on final state properties, was performed at the final trigger level. The prescales and event downgrades are largest for those events with an electron at low radius and low energy. In order to account for the prescales a weight is assigned to each Monte Carlo event. To account for the event downgrades a weight is assigned to each data event. The overall effect of the prescales and downgrades is a reduction of the the effective luminosity by a factor of about 13 for the lowest Q^2 bin and 1.3 for the highest. After applying the event weights and the inclusive selection detailed above the total number of events is about 2.6 million. The background from photoproduction events is estimated from the PHOJET Monte Carlo simulation. On average this background is 1.9% and does not exceed 8.6% in any x-Q^2 bin used in this analysis.

The primary event vertex in r–ϕ is reconstructed from all tracks (with or without CST hits) and the position and spread of the beam interaction region [1]. The impact parameter of a track, which is the transverse distance of closest approach (DCA) of the track to the primary vertex point, is only determined for those tracks which are measured in the CTD and have at least two CST hits linked (referred to as CST tracks). Only CST tracks with a transverse momentum > 0.5 GeV are included in the DCA and related distributions that are used to separate the different quark flavours. In the kinematic range of this measurement, the fraction of c (b) events that have at least one charged track, with transverse momentum > 0.5 GeV, within the angular range of the CST, originating from the decay of a heavy flavoured hadron, is expected to be 77% (94%), as determined from the Monte Carlo simulation. The efficiency to obtain a CST track from a CTD track is 76%, within the angular range of the CST. The information on the z-coordinate of the CST tracks is not used in the analysis presented in this paper.

In order to determine a signed impact parameter (δ) for each track, the azimuthal angle of the struck quark $\phi_{\rm quark}$ must be determined for each event. To do this, jets with a minimum p_T of 4 GeV, in the angular range $15^\circ < \theta < 155^o$, are reconstructed using the invariant k_T algorithm [29] in the laboratory frame using all reconstructed HFS particles. The angle $\phi_{\rm quark}$ is defined as the ϕ of the jet with the highest transverse momentum or, if there is no jet reconstructed in the event, as $180^\circ - \phi_{\rm elec}$, where $\phi_{\rm elec}$ is the azimuthal angle of the electron. Approximately 33% (55%) of c (b) events have $\phi_{\rm quark}$ 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 $\phi_{\rm quark}$ 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. It is found to be well described by the Monte Carlo simulation. Tracks with $|\delta| > 0.1$ cm are rejected from the analysis to suppress light quark events containing long lived strange particles.

The difference between the reconstructed to the true $\phi_{\rm quark}$ (defined as the azimuthal angle of the quark with highest transverse momentum) is estimated from the Monte Carlo simulation to have a resolution of about 5° for events with a reconstructed jet and 35° for the rest. The resolution of $\phi_{\rm quark}$ in the data was checked with events containing a reconstructed D^* meson, where the difference between the reconstructed D^* azimuthal angle and $\phi_{\rm quark}$ was found to be well described by the Monte Carlo simulation for events with and without a reconstructed jet.

4.2 Quark Flavour Separation

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.

Figure 2 shows the three significance distributions. The simulation gives a reasonable description of the data. In order to substantially reduce the uncertainty due to the resolution of δ and the light quark normalisation the content of the negative bins in the significance distributions are subtracted from the content of the positive. The subtracted distributions are shown in figure 3. It can be seen that the resulting distributions are dominated by c quark events, with an increasing b fraction with increasing significance. The light quarks contribute a small fraction for all values of significance.

The fractions of c, b and light quarks of the data are extracted in each x–Q^2 interval using a least squares simultaneous fit to the subtracted S_1, S_2 and S_3 distributions (as in figure 3) 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 give 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 normalisation constrains P_l.

The results of the fit to the complete data sample are shown in figure 3. The fit gives a good description of all the significance distributions. Since the same event may enter the S_1, S_2 and S_3 distributions, it was checked using a high statistics Monte Carlo simulation sample that this has negligible effect on the results of the fits with the present data statistics.

The results of the fit in each x–Q^2 interval are converted to a measurement of the 'reduced c cross section' defined from the differential cross section as

$$\tilde{\sigma}^{c\bar{c}}(x,Q^2) = \frac{\mathrm{d}^2\sigma^{c\bar{c}}}{\mathrm{d}x\,\mathrm{d}Q^2}\frac{xQ^4}{2\pi\alpha^2(1+(1-y)^2)}, \tag{1}$$

using:

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

where $\tilde{\sigma}(x,Q^2)$ is the measured inclusive reduced cross section from H1 [27] and 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. A bin centre correction δ_{BCC} is applied using a NLO QCD expectation for $\tilde{\sigma}^{c\bar{c}}$ to convert the bin averaged measurement into a measurement at a single x–Q^2 point. The NLO QCD expectation is calculated from the results of a fit similar to that performed in [30] but using the FFNS scheme to generate heavy flavours. A small correction ($\leq 2.6\%$) is applied, using the NLO QCD expectation, to the measurement of $\tilde{\sigma}(x, Q^2)$ which was taken at a lower centre of mass energy of $301\ \mathrm{GeV}$ than the data presented here. The cross section is defined so as to include a correction for pure QED radiative effects. Events that contain c hadrons via the decay of b hadrons are not included in the definition of the c cross section. The differential b cross section is evaluated in the same manner.

4.3 Systematic Errors

The systematic uncertainties on the measured cross sections are estimated by applying the following variations to the Monte Carlo simulation:

- A track efficiency uncertainty of 2% due to the CTD and of 1% due to the CST.
- An uncertainty in the δ resolution of the tracks is estimated by varying the resolution by an amount that encompasses the differences between the data and simulation (figures 1, 2). This was achieved by applying an additional Gaussian smearing in the Monte Carlo of 200 $\mu\mathrm{m}$ to 5% of randomly selected tracks and 25 $\mu\mathrm{m}$ to the rest.
- A 4% uncertainty on the hadronic energy scale.
- An error on the quark axis is estimated by shifting the quark axis by $2°(5°)$ for events with (without) a reconstructed jet.
- The uncertainty on the asymmetry of the light quark δ distribution is estimated by repeating the fits with the subtracted light quark significance distributions (figure 3) changed by $\pm 50\%$. The light quark asymmetry was checked to be within this uncertainty by comparing the asymmetry of Monte Carlo events to that of the data, in the region $0.1 < |\delta| < 0.5\ \mathrm{cm}$, where the light quark asymmetry is enhanced.
- The uncertainties on the various D and B meson lifetimes, decay branching fractions and mean charge multiplicities are estimated by varying the input values of the Monte Carlo simulation by the errors on the world average measurements. For the branching fractions of b quarks to hadrons and the lifetimes of the D and B mesons the central values and errors on the world averages are taken from [31]. For the branching fractions of c quarks to hadrons the values and uncertainties are taken from [32]. For the mean charged track multiplicities the values and uncertainties for c and b quarks are taken from MarkIII [33] and LEP/SLD [34] measurements, respectively.
- An uncertainty on the fragmentation function of the heavy quarks is estimated using the Peterson fragmentation function [35] with parameters $\epsilon_c = 0.058$ and $\epsilon_b = 0.0069$.
- An uncertainty on the QCD model used is estimated by using the CASCADE Monte Carlo.

- Uncertainties on the acceptance and bin centre correction due to the input structure functions used are estimated by reweighting the input $\tilde{\sigma}^{c\bar{c}}$ distribution by $x^{\pm 0.1}$ and $1 \pm 0.2\ln[Q^2/(10\ \mathrm{GeV}^2)]$ and $\tilde{\sigma}^{b\bar{b}}$ by $x^{\pm 0.3}$ and $1 \pm 0.4\ln[Q^2/(10\ \mathrm{GeV}^2)]$. The range of variation of the input structure functions was estimated by comparing to the measured values obtained in this analysis.

- An uncertainty on the photoproduction background is estimated by assigning $\pm 100\%$ of the expected number of events from the PHOJET simulation that enter the significance distributions.

Other sources of systematic error pertaining to the NC selection were also considered [27]: a 1.5% uncertainty on the luminosity measurement; an uncertainty on the scattered positron polar angle of $0.3\ \mathrm{mrad}$ and energy of 0.3–1.0% depending on the energy; a 0.5% uncertainty on the scattered positron identification efficiency; a 0.5–2% uncertainty on the positron track-cluster link efficiency; a $\leq 1\%$ uncertainty on the trigger efficiency and a 1% uncertainty on the cross section evaluation due to QED radiative corrections. The systematic error is larger for the b measurement than it is for the c because the b fraction is much smaller than the c fraction.

5 Results

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

$$\frac{\mathrm{d}^2\sigma^{c\bar{c}}}{\mathrm{d}x\,\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^4}[(1+(1-y)^2)F_2^{c\bar{c}} - y^2 F_L^{c\bar{c}}], \tag{3}$$

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.

The measurements of $F_2^{c\bar{c}}$ are shown in figure 4 as a function of x for fixed values of Q^2. The H1 data for $F_2^{c\bar{c}}$ are compared with the results extracted from D^* meson measurements by H1 [5] and ZEUS [6]. For the former, the values of $F_2^{c\bar{c}}$ are shown as the average of the extractions obtained using DGLAP or CCFM evolution and an additional systematic uncertainty of half the difference is added in quadrature. The measurements for $F_2^{c\bar{c}}$ from both the present analysis and the D^* extraction methods are in good agreement.

The $F_2^{c\bar{c}}$ data are compared with two predictions from NLO QCD (see section 2.1), from MRST [2] and CTEQ [3] both of which use the VFNS scheme and with predictions based on CCFM [14] parton evolution. The predictions provide a reasonable description of the present data.

The measurements of $F_2^{b\bar{b}}$ are shown in figure 5 as a function of x for fixed values of Q^2. This is the first measurement of $F_2^{b\bar{b}}$ in this kinematic range. The measurement at the lowest Q^2 value is consistent with zero and, therefore, the data are shown as a 95% confidence limit. The $F_2^{b\bar{b}}$ data are also compared with the two NLO VFNS QCD predictions and the CCFM prediction. The difference between the two NLO VFNS QCD calculations, which reaches a factor 2 at the lowest Q^2 and x, arises from the different treatments of threshold effects by

MRST and CTEQ. Within the current experimental errors these differences cannot be resolved. The b cross section measurements [7, 8], which have been made in a similar range of Q^2 and x to the present measurement with an additional requirement of a muon and a high p_T jet in the Breit frame in the final state, reported an excess when compared with NLO QCD predictions in the FFNS scheme and the predictions of CCFM. Calculations of final state cross sections using NLO QCD in the VFNS scheme are not yet available.

The measurements of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ are shown as a function of Q^2 in figure 6 and figure 7. The measurements show positive scaling violations which increase with decreasing x. The data are compared with the predictions of NLO VFNS QCD calculations from MRST and CTEQ. The present $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ data are generally well described by the calculations.

The measurements are shown in figure 8 in the form of the fractional contribution to the total ep cross section

$$f^{c\bar{c}} = \frac{\mathrm{d}^2\sigma^{c\bar{c}}}{\mathrm{d}x\,\mathrm{d}Q^2} / \frac{\mathrm{d}^2\sigma}{\mathrm{d}x\,\mathrm{d}Q^2}. \tag{4}$$

The b fraction $f^{b\bar{b}}$ is defined in the same manner. In the present kinematic range the value of $f^{c\bar{c}}$ is around 22% on average and increases slightly with increasing Q^2 and decreasing x. The value of $f^{b\bar{b}}$ is 0.8% on average and, in contrast to $f^{c\bar{c}}$, increases rapidly with Q^2. The NLO QCD predictions of MRST are found to describe the data reasonably well.

6 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 made 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 generally well described by predictions of perturbative QCD. This is the first measurement of $F_2^{b\bar{b}}$ in the low Q^2 kinematic regime. 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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References

[1] A. Aktas *et al.* [H1 Collaboration], Accepted by Eur. Phys. J. [hep-ex/0411046].

[2] A. D. Martin, R. G. Roberts, W. J. Stirling and R. S. Thorne, Eur. Phys. J. C **39** (2005) 155 [hep-ph/0411040].

[3] S. Kretzer, H. L. Lai, F. I. Olness and W. K. Tung, Phys. Rev. D **69** (2004) 114005 [hep-ph/0307022].

[4] C. Adloff *et al.* [H1 Collaboration], Z. Phys. C **72** (1996) 593 [hep-ex/9607012];

J. Breitweg *et al.* [ZEUS Collaboration], Phys. Lett. B **407** (1997) 402 [hep-ex/9706009];

C. Adloff *et al.* [H1 Collaboration], Nucl. Phys. B **545** (1999) 21 [hep-ex/9812023];

J. Breitweg *et al.* [ZEUS Collaboration], Eur. Phys. J. C **12** (2000) 35 [hep-ex/9908012].

[5] C. Adloff *et al.* [H1 Collaboration], Phys. Lett. B **528** (2002) 199 [hep-ex/0108039].

[6] S. Chekanov *et al.* [ZEUS Collaboration], Phys. Rev. D **69** (2004) 012004 [hep-ex/0308068].

[7] S. Chekanov *et al.* [ZEUS Collaboration], Phys. Lett. B **599** (2004) 173 [hep-ex/0405069].

[8] A. Aktas *et al.* [H1 Collaboration], Accepted by Eur. Phys. J. [hep-ex/0502010].

[9] E. Laenen, S. Riemersma, J. Smith and W. L. van Neerven, Nucl. Phys. B **392** (1993) 162;

E. Laenen, S. Riemersma, J. Smith and W. L. van Neerven, Nucl. Phys. B **392** (1993) 229.

[10] F. I. Olness and W. K. Tung, Nucl. Phys. B **308** (1988) 813;

M. A. G. Aivazis, J. C. Collins, F. I. Olness and W. K. Tung, Phys. Rev. D **50** (1994) 3102 [hep-ph/9312319];

M. A. G. Aivazis, F. I. Olness and W. K. Tung, Phys. Rev. D **50** (1994) 3085 [hep-ph/9312318];

M. Krämer, F. I. Olness and D. E. Soper, Phys. Rev. D **62** (2000) 096007 [hep-ph/0003035].

[11] R. S. Thorne and R. G. Roberts, Phys. Rev. D **57** (1998) 6871 [hep-ph/9709442];

R. S. Thorne and R. G. Roberts, Phys. Lett. B **421** (1998) 303 [hep-ph/9711223];

R. S. Thorne and R. G. Roberts, Eur. Phys. J. C **19** (2001) 339 [hep-ph/0010344];

M. Cacciari, M. Greco and P. Nason, JHEP **9805** (1998) 007 [hep-ph/9803400];

M. Cacciari, S. Frixione and P. Nason, JHEP **0103** (2001) 006 [hep-ph/0102134].

[12] M. Buza, Y. Matiounine, J. Smith and W. L. van Neerven, Phys. Lett. B **411** (1997) 211 [hep-ph/9707263];

A. Chuvakin, J. Smith and W. L. van Neerven, Phys. Rev. D **61** (2000) 096004 [hep-ph/9910250];

A. Chuvakin, J. Smith and W. L. van Neerven, Phys. Rev. D **62** (2000) 036004 [hep-ph/0002011].

[13] M. Hansson and H. Jung, "Status of CCFM: Un-integrated gluon densities," Proceedings of 11th International Workshop on Deep Inelastic Scattering (DIS 2003), St. Petersburg, Russia, April 2003. Edited by V.T. Kim and L.N. Lipatov. p488 [hep-ph/0309009].

[14] Nucl. Phys. B **296** (1988) 49;

S. Catani, F. Fiorani and G. Marchesini, Phys. Lett. B **234** (1990) 339;

S. Catani, F. Fiorani and G. Marchesini, Nucl. Phys. B **336** (1990) 18;

G. Marchesini, Nucl. Phys. B **445** (1995) 49 [hep-ph/9412327].

[15] H. Jung and G. P. Salam, Eur. Phys. J. C **19** (2001) 351 [hep-ph/0012143];

H. Jung, Comput. Phys. Commun. **143** (2002) 100 [hep-ph/0109102]; (see also http://www.desy.de/∼jung/cascade/).

[16] H. Jung, Comput. Phys. Commun. **86** (1995) 147; (see also http://www.desy.de/∼jung/rapgap.html).

[17] K. Charchula, G. A. Schuler and H. Spiesberger, Comput. Phys. Commun. **81**, 381 (1994); (see also http://www.desy.de/∼hspiesb/django6.html).

[18] M. Gluck, E. Reya and A. Vogt, Z. Phys. C **67** (1995) 433.

[19] T. Sjostrand, P. Eden, C. Friberg, L. Lonnblad, G. Miu, S. Mrenna and E. Norrbin, Comput. Phys. Commun. **135** (2001) 238 [hep-ph/0010017].

[20] A. Kwiatkowski, H. Spiesberger and H. J. Möhring, Comput. Phys. Commun. **69** (1992) 155.

[21] A. D. Martin, W. J. Stirling and R. G. Roberts, Phys. Rev. D **50** (1994) 6734 [hep-ph/9406315].

[22] R. Engel and J. Ranft, Phys. Rev. D **54** (1996) 4244 [hep-ph/9509373].

[23] R. Brun, R. Hagelberg, M. Hansroul and J. C. Lassalle, CERN-DD-78-2-REV.

[24] I. Abt *et al.* [H1 Collaboration], Nucl. Instrum. Meth. A **386** (1997) 310 and 348.

[25] D. Pitzl *et al.*, Nucl. Instrum. Meth. A **454**, 334 (2000) [hep-ex/0002044].

[26] T. Nicholls *et al.* [H1 SPACAL Group Collaboration], Nucl. Instrum. Meth. A **374** (1996) 149.

[27] C. Adloff *et al.* [H1 Collaboration], Eur. Phys. J. C **21** (2001) 33 [hep-ex/0012053].

[28] C. Adloff *et al.* [H1 Collaboration], Z. Phys. C **74** (1997) 221 [hep-ex/9702003].

[29] S. D. Ellis and D. E. Soper, Phys. Rev. D **48** (1993) 3160 [hep-ph/9305266];

S. Catani, Y. L. Dokshitzer, M. H. Seymour and B. R. Webber, Nucl. Phys. B **406** (1993) 187.

[30] C. Adloff *et al.* [H1 Collaboration], Eur. Phys. J. C **13** (2000) 609 [hep-ex/9908059].

[31] K. Hagiwara *et al.* [Particle Data Group Collaboration], Phys. Rev. D **66** (2002) 010001.

[32] L. Gladilin, “Charm hadron production fractions”, [hep-ex/9912064].

[33] D. Coffman *et al.* [MARK-III Collaboration], Phys. Lett. B **263** (1991) 135.

[34] D. Abbaneo *et al.* [LEP/SLD Heavy Flavour Working Group], LEPHF 2001-01; (available from http://lepewwg.web.cern.ch/LEPEWWG/heavy/).

[35] C. Peterson, D. Schlatter, I. Schmitt and P.M. Zerwas, Phys. Rev. D **27** (1983) 105.

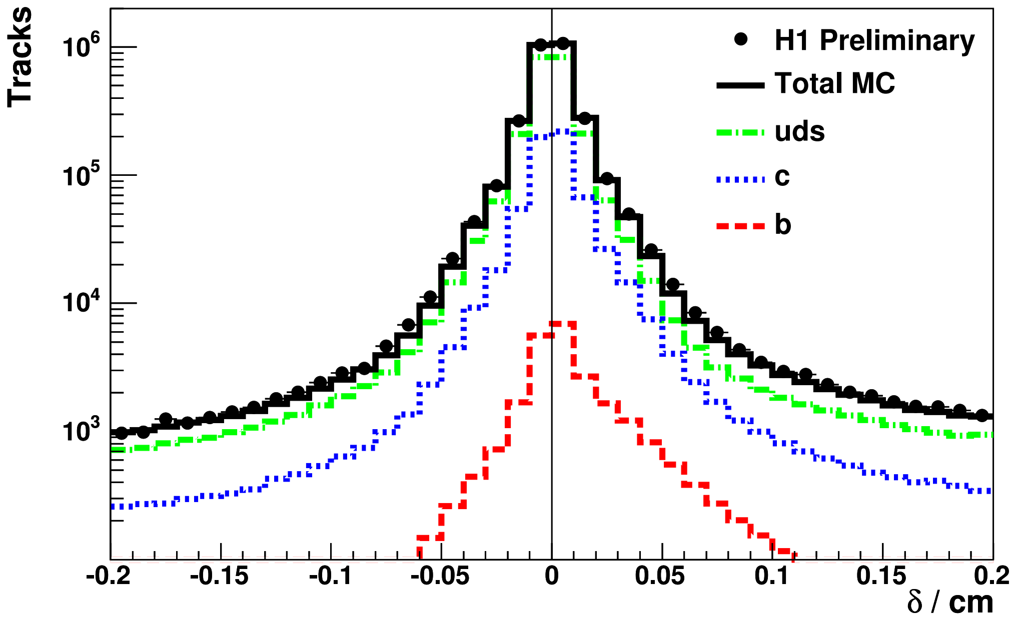

Figure 1: The signed impact parameter δ of a track to the primary vertex in the x–y plane. Included in the figure is the expectation from the Django Monte Carlo simulation for light quarks and the RAPGAP Monte Carlo simulation for c and b quarks. The contribution from the various quark flavours are shown after applying the scale factors obtained from the fit to the subtracted significance distributions of the data.

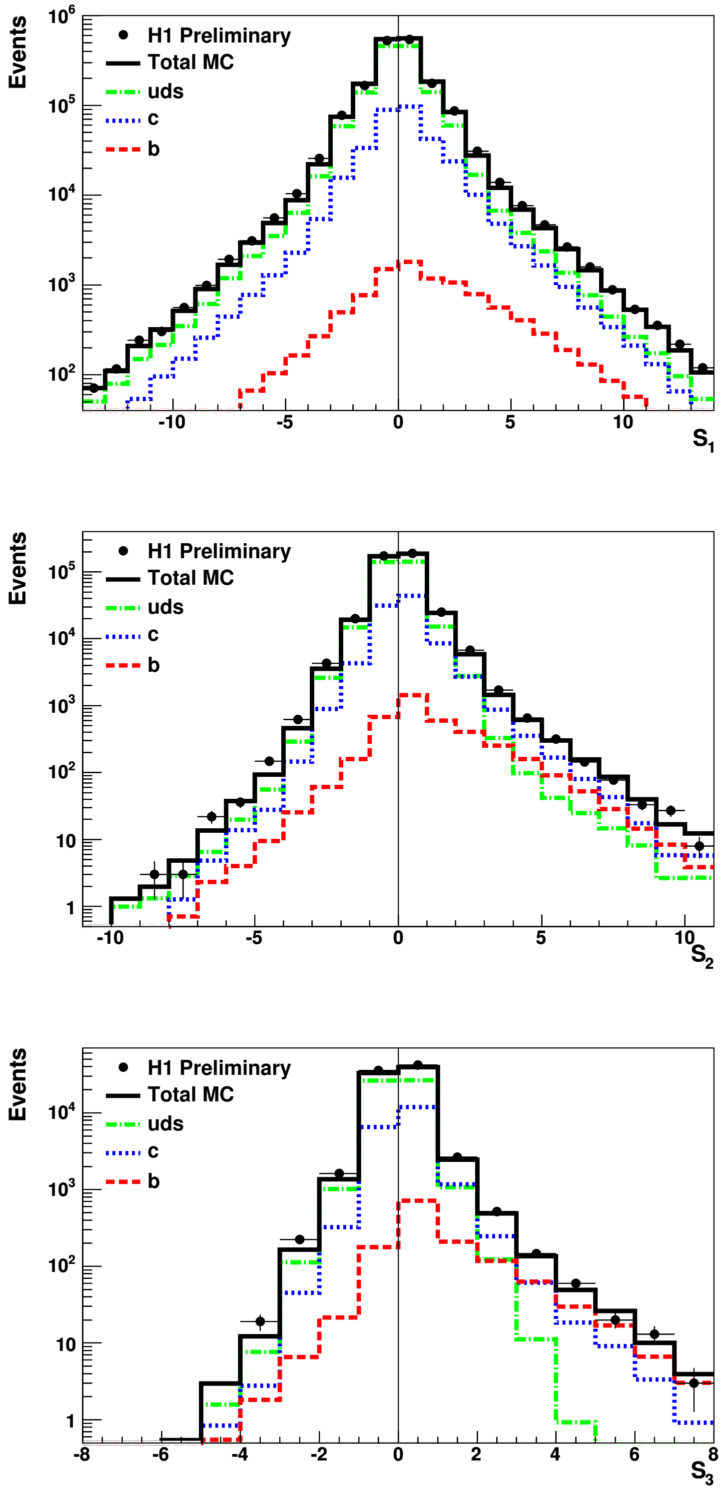

Figure 2: The significance $\delta/\sigma(\delta)$ distribution (a) of the highest absolute significance track (S_1), (b) of the track with the second highest absolute significance (S_2) and (c) of the track with the third highest absolute significance (S_3). Included in the figure is the expectation from the Django Monte Carlo simulation for light quarks and the RAPGAP Monte Carlo simulation for c and b quarks. The contribution from the various quark flavours are shown after applying the scale factors obtained from the fit to the subtracted significance distributions of the data.

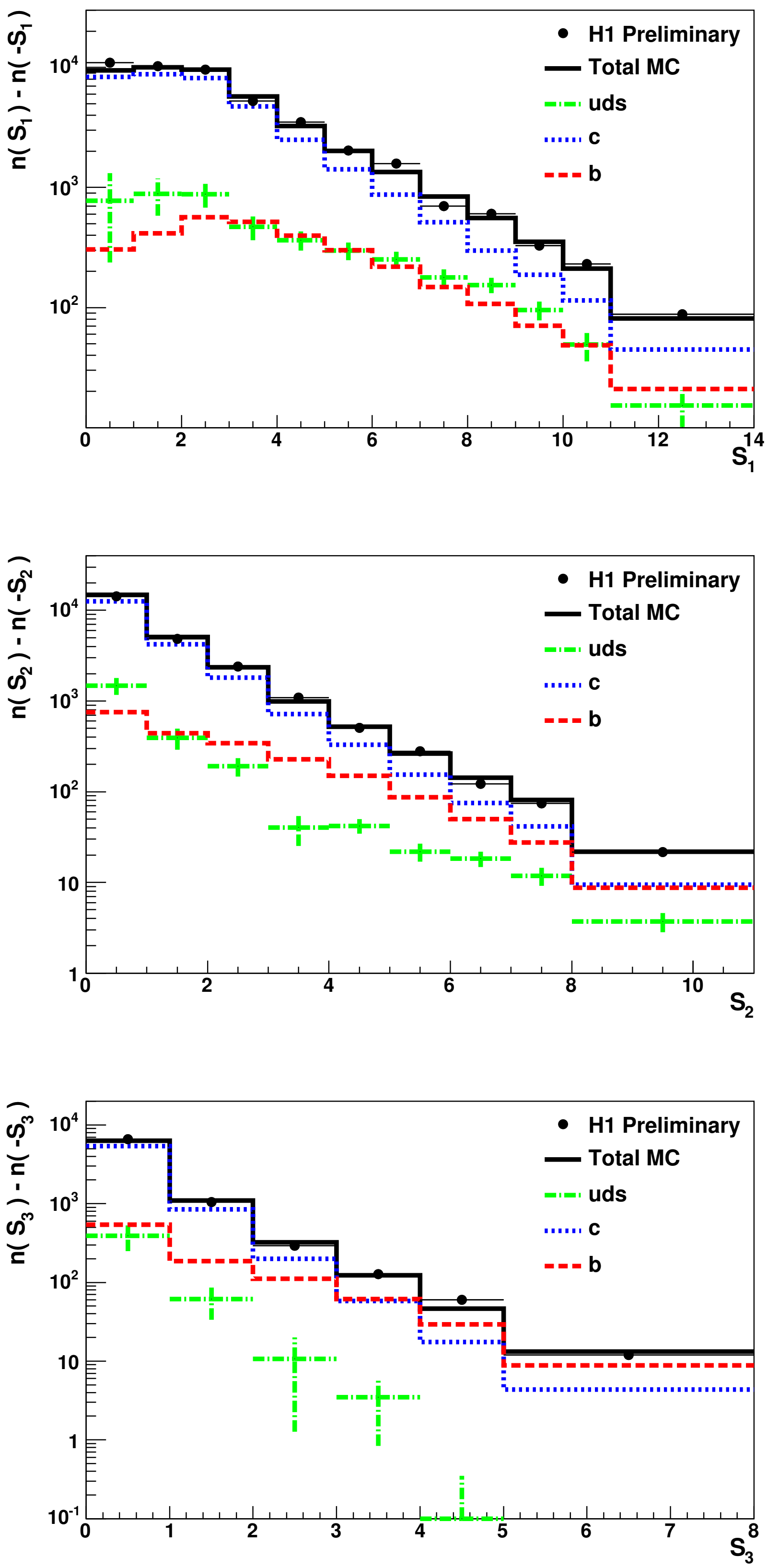

Figure 3: The subtracted distributions of (a) S_1, (b) S_2 (c) S_3. Included in the figure is the result from the fit to the data of the Monte Carlo distributions of the various quark flavours.

H1 PRELIMINARY

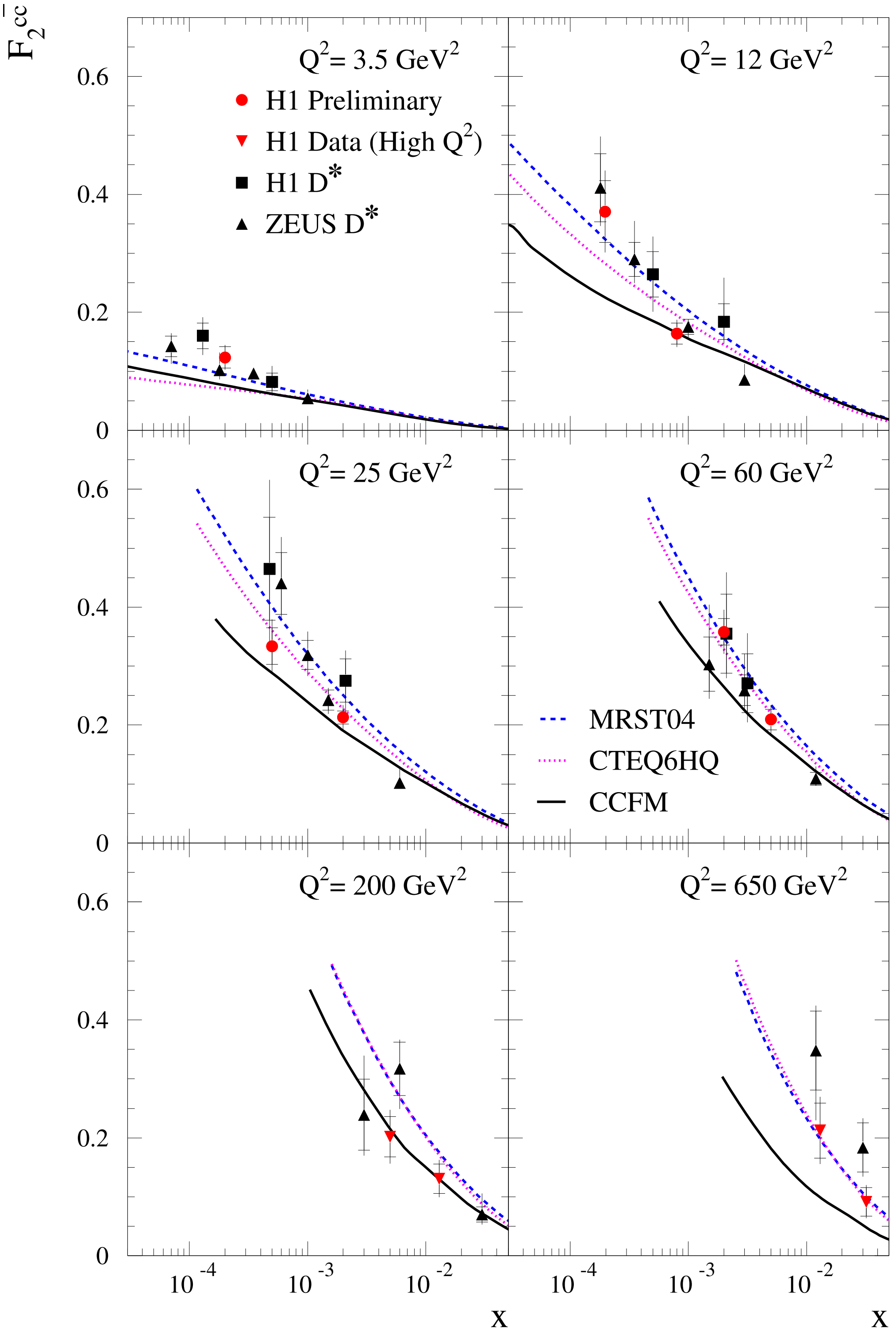

Figure 4: The measured reduced cross section $F_2^{c\bar{c}}$ shown as a function of x for 6 different Q^2 values. The inner error bars show the statistical error, the outer error bars represent the statistical and systematic errors added in quadrature. The measurements of $F_2^{c\bar{c}}$ from H1 at higher values of Q^2 [1], the measurements obtained from D^* mesons from H1 [5] and ZEUS [6] and the predictions of QCD are also shown.

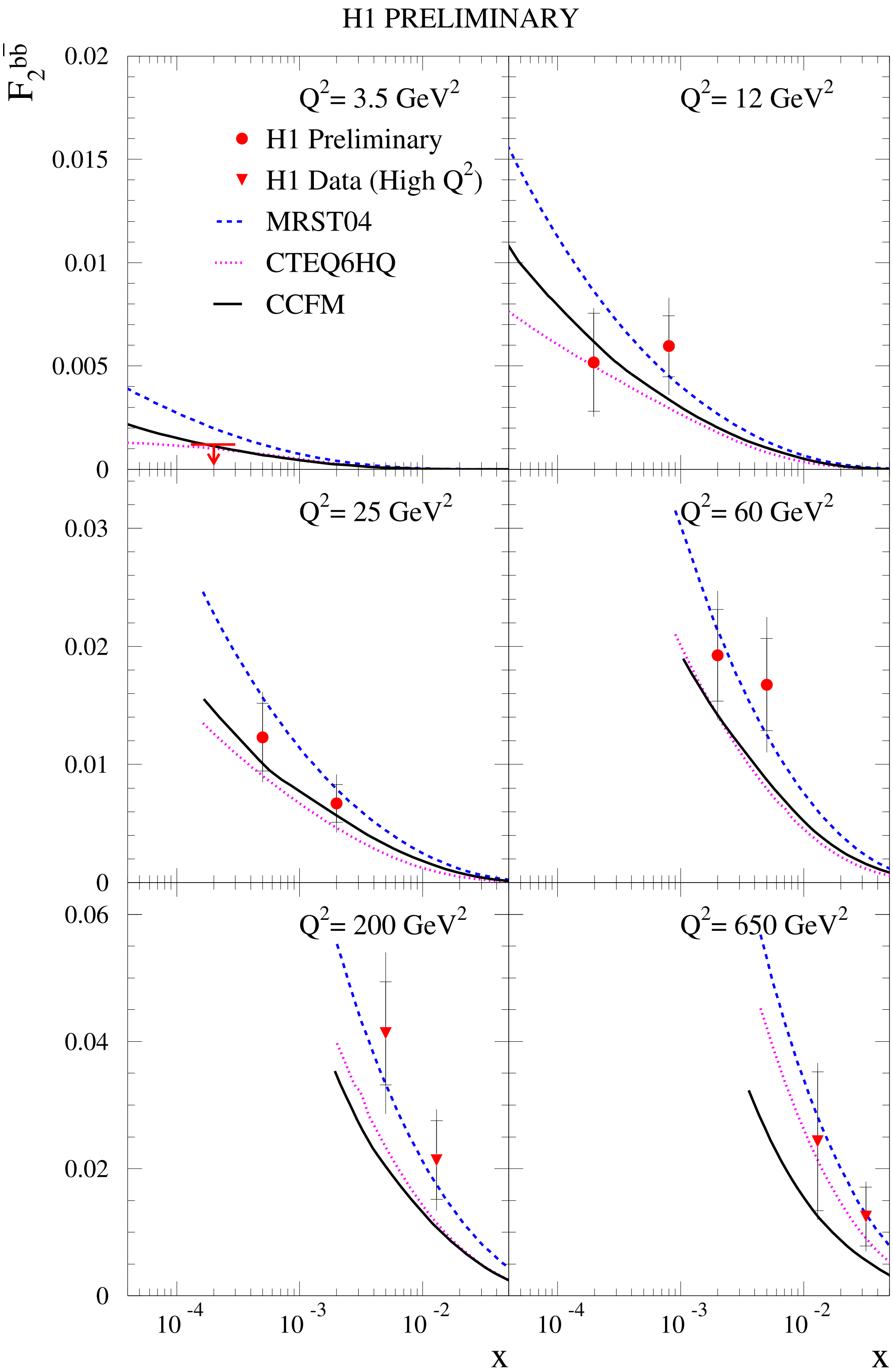

Figure 5: The measured reduced cross section $F_2^{b\bar{b}}$ shown as a function of x for 6 different Q^2 values. The inner error bars show the statistical error, the outer error bars represent the statistical and systematic errors added in quadrature. The measurements of $F_2^{b\bar{b}}$ from H1 at higher values of Q^2 [1] and the predictions of QCD are also shown.

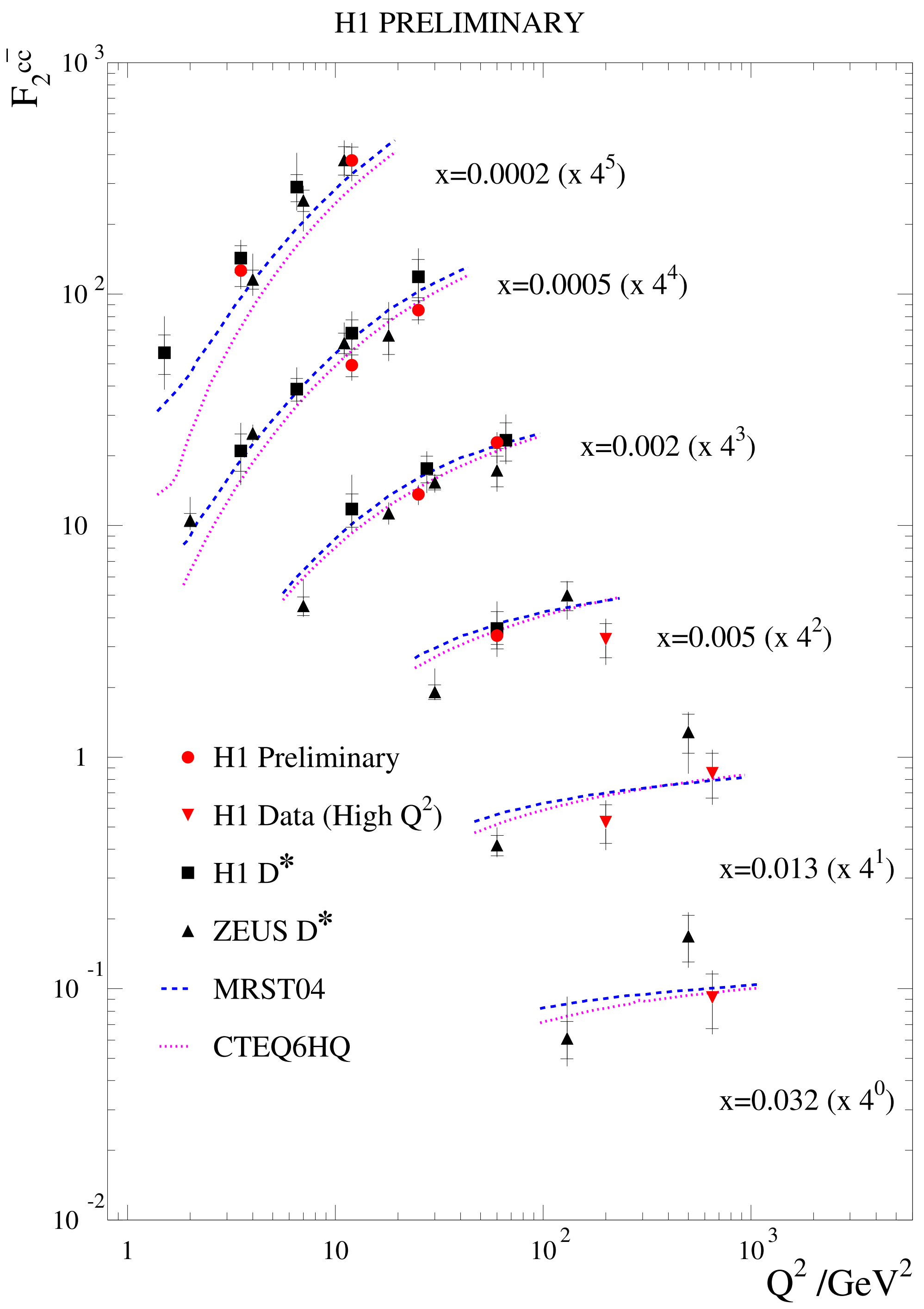

Figure 6: The measured $F_2^{c\bar{c}}$ shown as a function of Q^2 for various x values. The inner error bars show the statistical error, the outer error bars represent the statistical and systematic errors added in quadrature. The $F_2^{c\bar{c}}$ from H1 at higher values of Q^2 [1], the measurements of obtained from D^* mesons from H1 [5] and ZEUS [6] and the predictions of QCD are also shown.

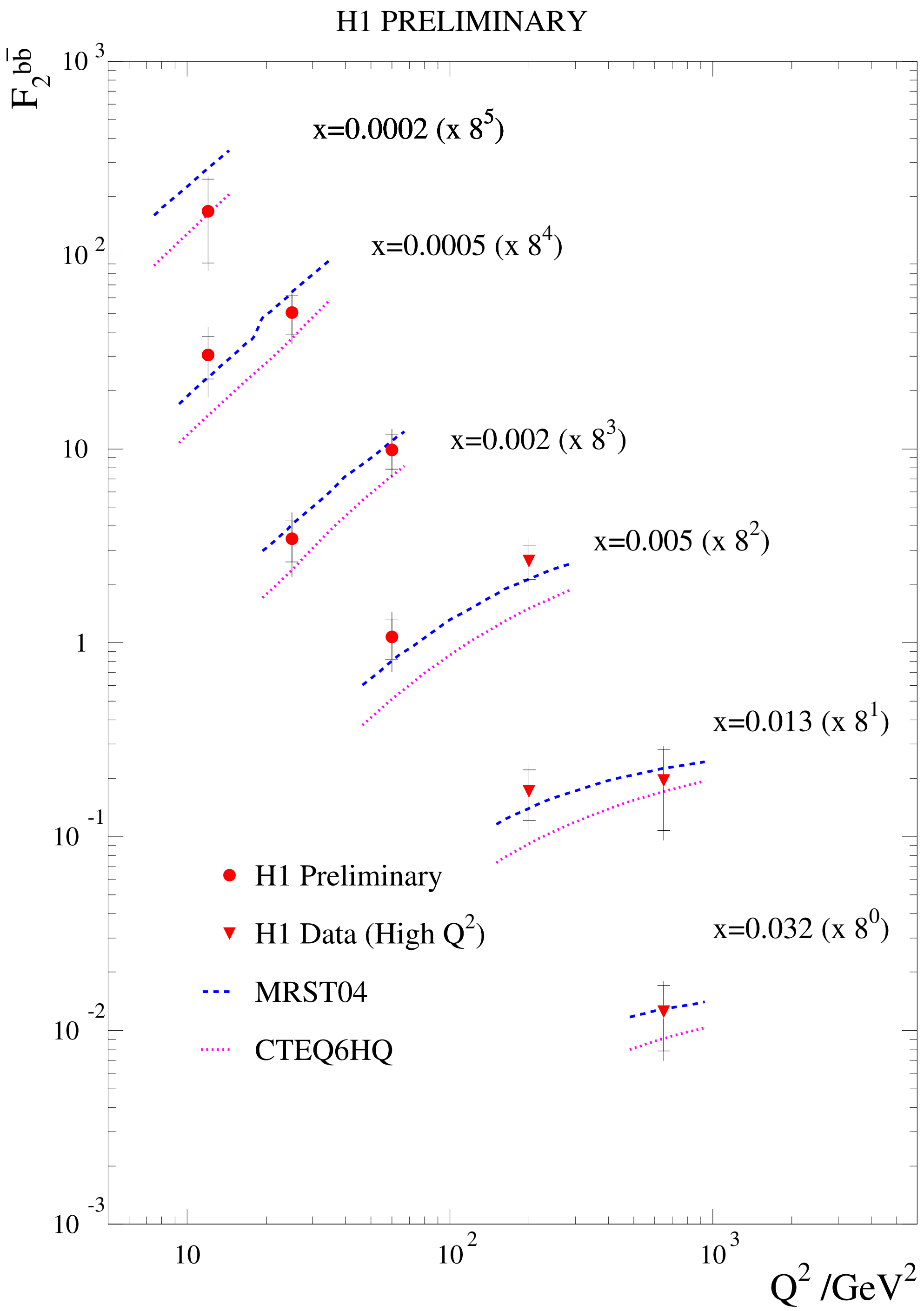

Figure 7: The measured $F_2^{b\bar{b}}$ shown as a function of Q^2 for various x values. The inner error bars show the statistical error, the outer error bars represent the statistical and systematic errors added in quadrature. The $F_2^{b\bar{b}}$ from H1 at higher values of Q^2 [1] and the predictions of QCD are also shown.

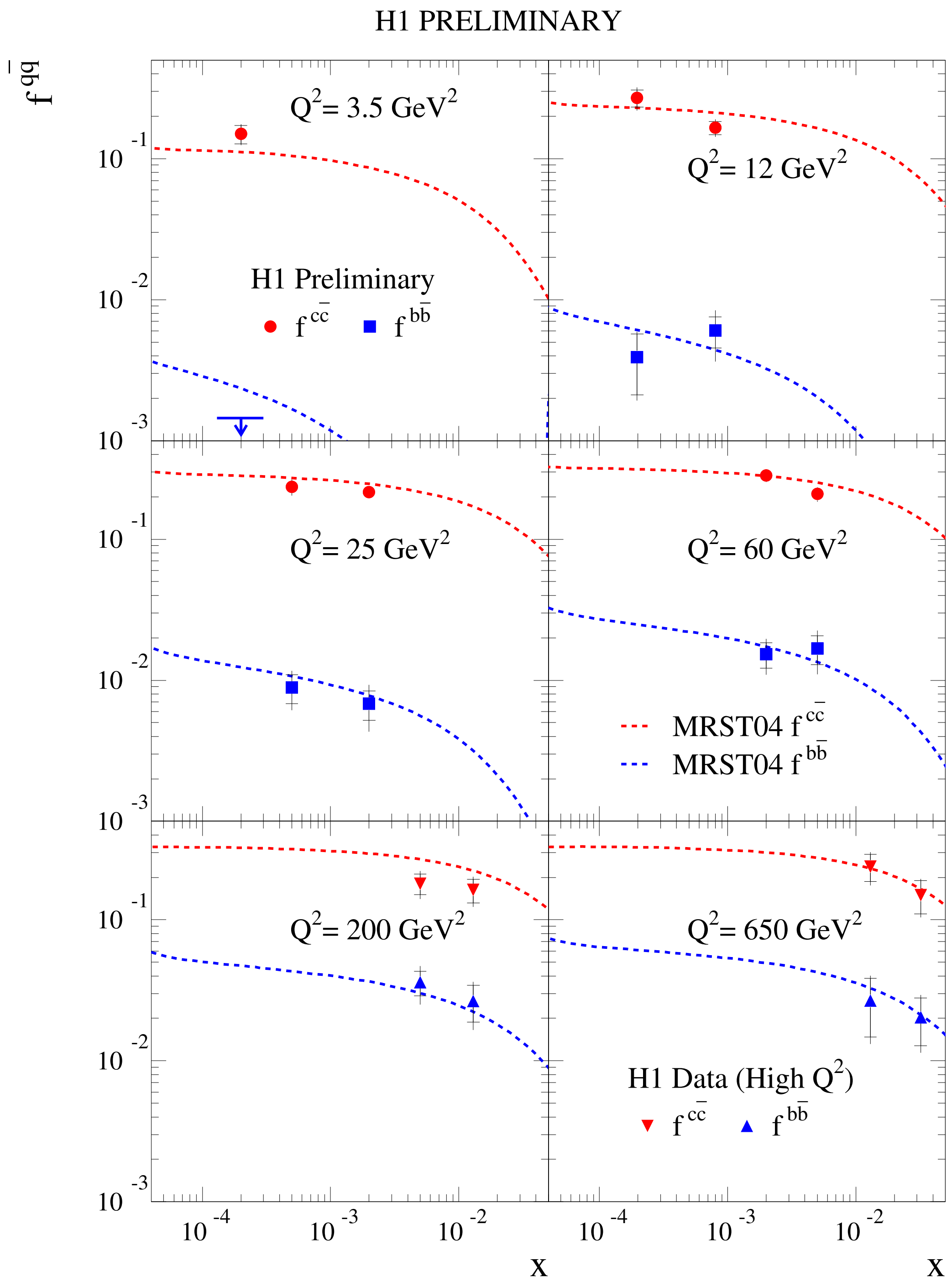

Figure 8: The contributions to the total cross section $f^{c\bar{c}}$ and $f^{b\bar{b}}$ shown as a function of Q^2 for 6 different x values. The inner error bars show the statistical error, the outer error bars represent the statistical and systematic errors added in quadrature. A prediction of NLO QCD is also shown.