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# Measurement of charm and beauty in DIS using the H1 Vertex Detector and Combination of $F_2^{c\bar{c}}$

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Recent measurements by the H1 experiment of the inclusive charm and beauty cross sections in deep inelastic $ep$ scattering at HERA are presented. The data were collected in the years 2006 and 2007 corresponding to an integrated luminosity of 189 $\text{pb}^{-1}$. The numbers of charm and beauty events are determined using variables reconstructed by the H1 vertex detector. The measurement of the inclusive charm cross section is combined with the result obtained using the reconstruction of $D^{*\pm}$ mesons in order to obtain a more precise measurement of the charm contribution $F_2^{c\bar{c}}$ to the proton structure function $F_2$ . The measurements are compared with QCD predictions.

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## 1. Introduction

In perturbative QCD (pQCD) calculations, the production of heavy quarks at HERA proceeds dominantly via the direct boson-gluon fusion (BGF) where the photon interacts with a gluon from the proton by the exchange of a heavy quark pair. Therefore, the measurements of processes involving heavy flavour production provide powerful tests of pQCD. Heavy quark production in *ep* collisions can be described in pQCD using different schemes. At energy scales significantly larger than the heavy quark mass, calculations may be performed in the zero mass variable flavour number scheme (ZMVFNS), where the heavy quarks are treated as massless partons in the proton. The fixed flavour number scheme (FFNS [1, 2]) applies close to the heavy quark production threshold and takes into account the heavy quark mass effects properly. In the latter scheme all quark flavours lighter than charm are treated as massless with massive charm (beauty) being produced dynamically in BGF. A consistent treatment of heavy quarks in pQCD over the full energy range should be provided through the calculation in the generalised mass variable flavour number scheme (MSTW [3, 4], CTEQ 6.6 [5], H1PDF 09 [6]).

Charm (beauty) production contributes to the total deep inelastic scattering (DIS) cross section by at most 30% (1%) at HERA. Charm and beauty quarks can be identified by making use of the long lifetime of heavy flavoured hadrons and/or the large mass of heavy quarks. Charm quarks are also tagged by reconstructing charmed hadrons e.g. $D^{*\pm}$ mesons. From the measured visible charm (beauty) cross section its contribution $F_2^{c\bar{c}}$($F_2^{b\bar{b}}$ ) to the proton structure function $F_2$ is extracted. When using the lifetime information, $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ are extracted simultaneously. By combining different analysis techniques, more precise tests of pQCD become possible.

## 2. Measurement of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ using Lifetime Information

In the presented analysis [7] events containing heavy quarks are distinguished from those containing only light quarks using variables that are sensitive to the longer lifetimes of heavy flavour hadrons. The most important of these variables are the transverse displacement of tracks from the primary vertex and the reconstructed position of a secondary vertex in the transverse plane. For events with three or more tracks in the vertex detector the reconstructed variables are used as input to an artificial neural network (NN). This method has better discrimination between $c$ and $b$ compared to previous methods [8, 9], which used only the transverse displacement of tracks from the primary vertex. The $c$, $b$ and light quark fractions in the data are extracted using a simultaneous fit of simulated reference distributions, obtained from Monte Carlo simulation, to the measured impact parameter and NN output distributions. The charm and beauty fractions are shown together with the MSTW [4] prediction in Fig. 1 (left). The reduced beauty cross section in DIS $\tilde{\sigma}^{b\bar{b}}$ is shown as a function of $x$ for different values of $Q^2$ in Fig. 1 (right). The measurements are compared with the NLO predictions of CTEQ [5] and MSTW [3, 4] and with predictions based on CCFM [10] parton evolution. The data are found to be generally well described by all the models within the experimental uncertainties. The charm structure function $F_2^{c\bar{c}}$ obtained using the lifetime information is shown in Fig. 2 (left) as a function of $x$ in different $Q^2$ bins. The measurement is compared to the prediction from the H1PDF09 [6]. Also the MSTW [3] prediction at NLO is shown. Within uncertainties, the data are well described by the QCD predictions.

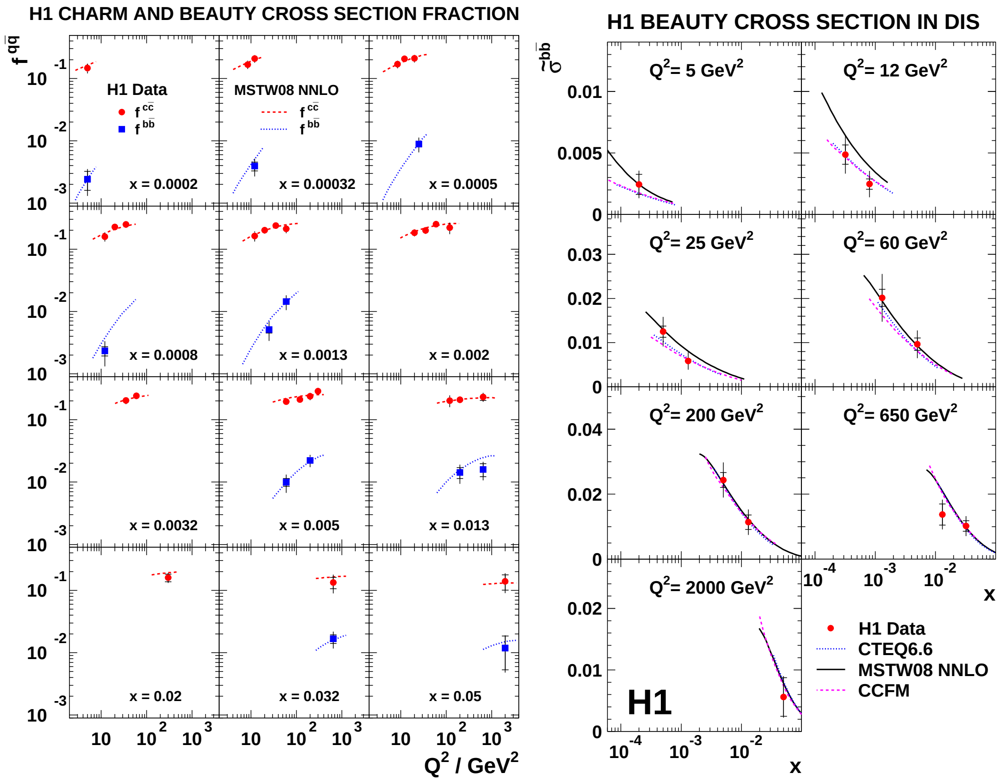


**Figure 1:** Left: the fractions of charm (circles) and beauty (squares) of the DIS cross section as a function of $Q^2$ in different $x$ bins. The measurements are compared to MSTW NNLO prediction for charm (dashed line) and beauty (dotted line) production. Right: beauty reduced cross section (circles) as extracted using the lifetime information compared to the predictions from MSTW NNLO (solid line), CTEQ (dotted line) and CCFM (dashed line).

## 3. Combination of $F_2^{c\bar{c}}$ with the results of $D^{*\pm}$ measurement

The charm structure function $F_2^{c\bar{c}}$ obtained using the vertex reconstruction from the HERA II data set is combined with that extracted from measured $D^{*\pm}$ meson cross sections at H1 [11]. In the combination procedure [12] the bin-to-bin correlations of systematic uncertainties of a single measurement as well as the cross-correlations of the systematic uncertainties of the different measurement methods are taken into account. The advantage of the combination of $F_2^{c\bar{c}}$ obtained by the different tagging methods is the cross-calibration of the combined measurement due to different independent sources of the experimental and theoretical systematic uncertainties.

The determination of $F_2^{c\bar{c}}$ via the measurement of $D^{*\pm}$ cross section strongly depends on the model used for the extrapolation to the full phase space [11]. HVQDIS [2] and CASCADE [13] models are used for the extrapolation. At high $x$ points in $5 < Q^2 < 100$ GeV$^2$ region the extrapolation factors of the two models differ almost by a factor of 2, therefore these points are excluded from the combination. Otherwise the differences of the extrapolation factors are small and the $F_2^{c\bar{c}}$ values obtained using the two models are averaged with the half-difference taken as a symmetric systematic uncertainty.

$F_2^{c\bar{c}}$ obtained via vertex reconstruction and $D^{*\pm}$ cross section measurements are derived at different central values of $x$ and $Q^2$. The $F_2^{c\bar{c}}$ values are interpolated to the common grid using the NLO calculation of Ref. [1]. The interpolation factors vary between 1% and at most 13%. In the kinematic regions where both measurements have similar precision, the uncertainty of combined $F_2^{c\bar{c}}$ is significantly reduced with respect to a single measurement. By reducing the uncertainty, the data become more sensitive to the different QCD predictions. The combined values of the $F_2^{c\bar{c}}$ are compared to the theoretical predictions in Fig. 2. The massive QCD calculation in FFNS [1] using the CTEQ5F3 parton densities describes the data best. The prediction from the MSTW08 [3] at NLO overestimates $F_2^{c\bar{c}}$, while the NNLO [4] prediction describes the data better at medium $Q^2$ and tend to overshoot the data at high $Q^2$ .

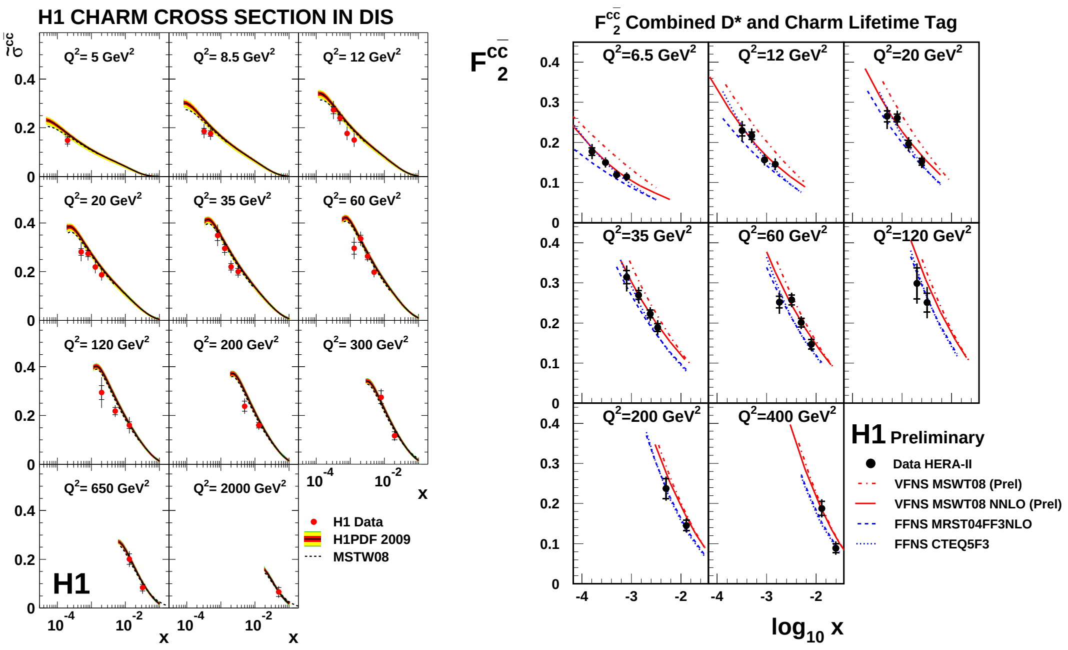


**Figure 2:** Left: the charm structure function (symbols) as obtained using the lifetime information compared to H1PDF09 (shaded band represents the experimental, model and parametrisation uncertainty) and MSTW NLO (dashed line). Right: the combined $F_2^{c\bar{c}}$ (symbols) compared to the theory curves: MSTW NLO (dash-dotted line) and NNLO (solid line); massive FFNS calculation using MRST04nlo PDFs (dashed line) and CTEQ5F3 (dotted line). The inner error bars represent the statistical uncertainty, the full error bar show the total uncertainty.

## 4. Conclusion

Measurements of the heavy flavour content of the proton in DIS at HERA have been presented. The extraction of the inclusive cross sections $F_2^{b\bar{b}}$ and $F_2^{c\bar{c}}$ is made using information from the H1 vertex detector. The cross sections are found to be well described by the predictions of perturbative QCD at NLO and NNLO within experimental uncertainties. The averaged $F_2^{c\bar{c}}$ obtained by combining the $D^{*\pm}$ measurement and the results of the displaced track analysis provides currently the most precise $F_2^{c\bar{c}}$measurement at HERA. Hence, more precise tests of perturbative QCD have become possible. The NLO calculation in fixed flavour number scheme describes the data best. The prediction from the PDF fit in NLO in variable flavour number scheme at NLO overestimates the charm contribution to the proton structure function at low $Q^2$, which is improved in the NNLO prediction.

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