$F_2^{c\bar{c}}$ at HERA

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Abstract. The charm contribution $F_2^{c\bar{c}}$ to the proton structure function $F_2$ has been measured by the two experiments ZEUS and H1 at the electron-proton collider HERA, in a wide $x$ and $Q^2$ range. Charm has been tagged by different techniques: by the reconstruction of particular charmed mesons in the final state, $D^*$, $D^0$, $D^+$, $D_s$, or by the inclusive measurement of the displacement of the charm decay products with respect to the event vertex. The data are compared with next-to-leading order QCD predictions.

1. Introduction
At HERA, in deep inelastic electron-proton scattering (DIS), charm quarks are produced mainly via boson-gluon fusion, in which the virtual photon interacts with a gluon from the proton. From the total cross section for charm production in DIS the charm contribution to the proton structure function $F_2$ can be extracted and compared to NLO QCD predictions. Since those predictions are sensitive to the gluon density of the proton, the measurement can help in constraining it.

2. Charm cross section measurement
The charm contribution to the proton structure function, $F_2^{c\bar{c}}$, has been measured at HERA by the two Collaborations ZEUS [1, 2, 3, 4] and H1 [5, 7, 6], in a wide kinematic region in $x$ (0.00002 \lesssim x \lesssim 0.03) and in the photon virtuality, $Q^2$ (1 < $Q^2$ < 1000 GeV$^2$).

Charm production at HERA can be tagged in different ways. The so-called golden mode is the reconstruction of a $D^*(2010)$ meson through its decay $D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$. Other charmed mesons can also be reconstructed: the most copiously produced are $D^0$, $D^\pm$, $D_s$. The production cross section of these mesons can be measured in a defined kinematic region, and the charm cross section can then be extracted by an extrapolation to the full phase space. This cross section is then used to evaluate the reduced cross section and $F_2^{c\bar{c}}$. Both the ZEUS and H1 Collaborations have used this method to extract $F_2^{c\bar{c}}$ from $D$ mesons cross sections. Charm tagging with mesons gives a clean signature of charm production, but the extrapolation to the total charm cross section can be large, especially in the low $Q^2$ region [1].

An alternative method to tag charm production takes advantage of the long lifetime of the charmed particles, by identifying tracks having impact parameter, $\delta$, significantly displaced from the event vertex, or by reconstructing secondary vertices from the meson decay products. This second method can also be used to enhance the signal to background ratio, for example in the production of $D^+$ mesons (fig. 1). The distribution of the impact parameter significance in an inclusive DIS data sample is shown in fig. 2, together with the contributions coming separately.
Figure 1. The $D^+$ mass peak, reconstructed from the decay $D^+ \rightarrow K^-\pi^+\pi^+$, and with the request that the secondary vertex reconstructed from the $D^+$ decay products is displaced by more than three standard deviations from the event vertex.

Figure 2. The distribution of the impact parameter significance, $\delta/\sigma(\delta)$, of the track with second highest absolute significance ($S_2$). Included in the figure is the expectation from the Monte Carlo simulation for light flavours, charm and beauty quarks, after the fit to the data.

from beauty, charm and light flavour background. A clear asymmetry of the significance distribution for heavy flavours can be seen, and the fraction of charm and beauty in the data can be extracted by fitting the distribution with the different flavour components. This method has been used by the H1 Collaboration to obtain some of the results presented here.

The advantage of the second method is that the kinematic region for the measurement of charm production is significantly enlarged, and therefore the extrapolation needed for the measurement of $F_2^{c\bar{c}}$ is strongly reduced.

3. Theoretical predictions

The program HVQDIS [8] is used to calculate theoretical predictions for $D$ meson production cross sections at NLO in perturbative QCD. It was used by the ZEUS and H1 Collaborations to extrapolate the measured cross section for a particular $D$ meson final state to $F_2^{c\bar{c}}$. In this program, the production of heavy flavours is described using the fixed flavour number scheme (FFNS), in which the charm quark is not an active flavour in the proton PDF, but is generated dynamically in the hard subprocess. The ZEUS and H1 measurements of $F_2^{c\bar{c}}$ extracted in this way should therefore be compared with NLO QCD predictions evaluated in the FFNS.

4. Results

The results for $F_2^{c\bar{c}}(x, Q^2)$ are shown in fig. 3. In the figure the ZEUS and H1 measurements, obtained from charmed meson reconstruction, are compared with the H1 results from inclusive lifetime measurements. The agreement between the experiments is good, validating the two different analysis procedures. The data rise with increasing $Q^2$, with the rise becoming steeper at lower $x$, demonstrating the property of scaling violation in charm production.

The data are also compared with perturbative QCD predictions at NLO. Two different parameterisations of the proton PDF have been used for the NLO QCD calculations, in order to check the sensitivity of the predictions to different gluon densities. The PDFs used were CTEQ5F3 [9] and MRST2004FF3 [10], extracted mainly from inclusive scattering data. The charm data are in general well described by NLO QCD. The two PDFs show differences in the
low $x$ region, demonstrating that the data have the power to constrain the gluon density of the proton.

5. Conclusions
The charm contribution to the proton structure function, $F_2^{cc\bar{c}}$, has been measured by the two experiments ZEUS and H1 at HERA. Charm has been tagged by reconstructing a particular charmed meson in the final state, or using the long lifetime of the charm decay products. The data and the NLO QCD predictions have been found to be in good agreement. NLO QCD predictions based on different PDFs show differences in the low $x$ region, demonstrating that the data have the power to constrain the gluon density of the proton.

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