HEAVY FLAVOUR PRODUCTION AT HERA

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Results from the study of the production of charm quarks in positron-proton collisions at HERA are reviewed. Charm is identified in the H1 and ZEUS detectors in the form of D^0, D^*, J/ψ or $\psi(2S)$ mesons.

1 Introduction

Charm is produced in positron-proton collisions at HERA predominantly as a $c\bar{c}$ pair in the current system. Production can occur in inelastic collisions, in which colour is transferred from the proton so that the proton breaks up, or in diffractive interactions, in which no colour is transferred and the proton can remain intact (elastic interaction) or dissociate.

Models for the direct inelastic production of charm are based on the photon-gluon fusion mechanism, where the positron radiates a photon which participates in the hard interaction with a gluon from the proton to form a $c\bar{c}$ pair. The hard interaction is calculable in perturbative QCD, and the production is clearly sensitive to the gluon content of the proton. To achieve a colourless J/ψ state at least one further gluon must be involved in the interaction. In the colour-singlet model [1,2] the radiation of a gluon from a $c(\bar{c})$ line to form a colourless $c\bar{c}$ state is part of the hard interaction, whilst in the colour-octet model [3] the transition from the coloured $c\bar{c}$ state produced in the hard sub-process proceeds non-perturbatively.

Charm is also produced in collisions in which the photon does not participate directly in the hard sub-process, but is 'resolved', that is, a parton from the photon is involved leaving a spectator photon-remnant. The resolved photon contribution is significant in photo-production, that is where the exchanged photon has a negative mass-squared of $Q^2 \approx 0$, but not in Deep Inelastic Scattering (DIS) where $Q^2 > 1\,\mathrm{GeV}^2$.

The results presented are based upon data recorded by the H1 [4] and ZEUS [5] detectors during 1994 and 1995, when positrons with energy 27.5 GeV and protons of energy 820 GeV were collided head-on in HERA.

2 D^* Production in Photo-production

D^* mesons are identified by the decay $D^{*+} \rightarrow D^0\pi^+$. The transverse momentum, p_t, of the D^* is restricted to 2.5 (3.0) GeV by H1 [6] (ZEUS [7]) when looking at the decay $D^0 \rightarrow K^-\pi^+$ and 4.0 GeV for $D^0 \rightarrow K^-\pi^+\pi^+\pi^-$. The kinematic region is restricted further by requiring the laboratory rapidity to be between -1.5 and 1.0. Events with $Q^2 > 4\ \mathrm{GeV}^2$ are rejected by insisting that the scattered electron is not found in the main part of the detector.

The differential cross-section $d\sigma(ep \rightarrow D^*X)/dp_t^{D^*}$ is shown in figure 1(a). The data are compared to both massive [9] and massless [10] charm NLO QCD calculations. Both agree well with the data with the massless approach giving slightly better agreement. The cross-section measurements are found to be insensitive to the choice of parton density parameterizations.

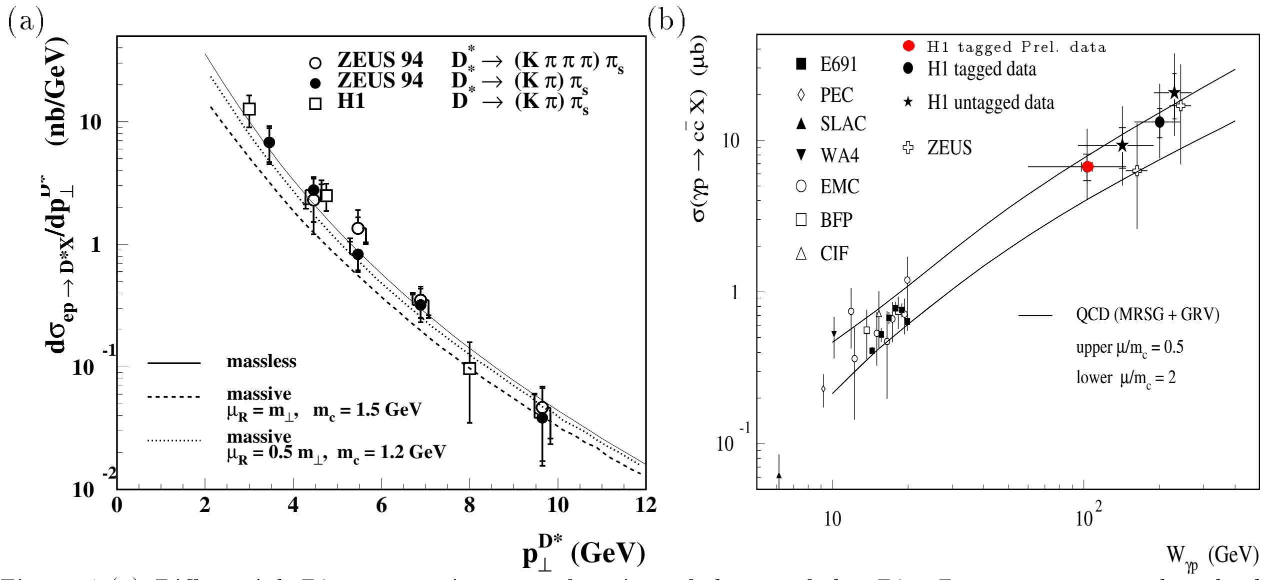

Figure 1:(a) Differential D^* cross-section as a function of the p_t of the D^*. Data are compared to both the massive [9] and massless [10] NLO QCD calculations. (b) Total charm photo-production cross-section as a function of $W_{\gamma p}$, including results from fixed-target experiments [8], and predictions of NLO QCD calculations [9] with MRSG [11] and GRV-G HO [12] parton density parameterizations. H1 'tagged' events refer to those where the scattered e^+ was detected in the low angle electron tagger.

The result for the cross-section $\sigma(\gamma p \to c\bar{c}X)$ is shown in figure 1(b) where the inner error bars represent the combined statistical and systematic errors, and the outer error bars include the large uncertainty in the extrapolation which arises due to the possible choices of parton density parameterizations. The prediction of a NLO QCD calculation [9] is shown for two extreme values of the renormalization scale as indicated. A strong rise of the photo-production cross-section of charm with $W_{\gamma p}$, with respect to earlier results from lower energy collisions, is observed.

3 D^* and D^0 Production in DIS

The production of D^* in events in which the scattered electron has been identified in the main dectector have been studied. The ZEUS (H1 [13]) results for $D^{*+} \to D^0\pi^+$ are restricted to $5\ (10) < Q^2 < 100\,\mathrm{GeV}^2$. In addition results are obtained using direct D^0 production. In both cases the D^0 decays to $K^-\pi^+$. Extrapolating from the visible D cross-sections to the full $c\bar{c}$ cross-sections introduces less uncertainty than in the photo-production case.

Good agreement is seen between the data and both LO and NLO [14] QCD calculations. Figures 2(a) and 2(b) show the differential $ep \to D^*X$ cross-section as a function of the D^* p_t and η respectively. The upper limit on the contribution from the charm sea within the proton to the cross-section is found to be less than 5% at the 95% confidence level [13].

ZEUS 1994 Preliminary

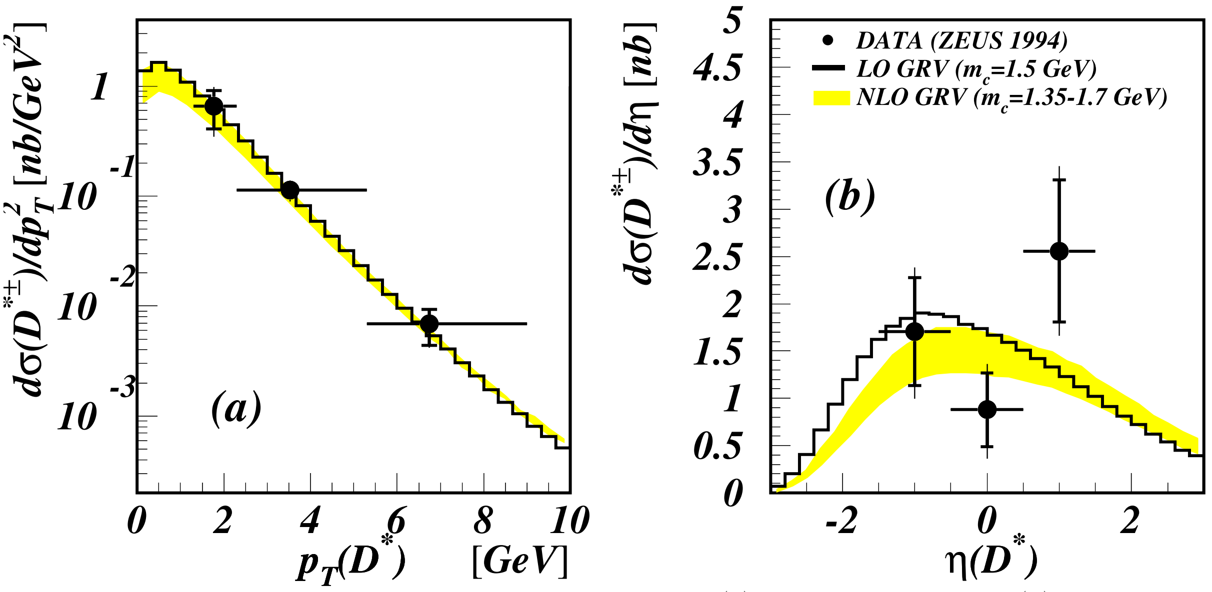

Figure 2:Differential $ep \to D^* X$ cross-section as a function of (a) the p_t of the D^* and (b) the η of the D^*. Preliminary results from the 1994 ZEUS data are compared to both LO and NLO [14] QCD calculations.

4 Inelastic J/ψ Photo-production

J/ψ mesons are identified by their decays to lepton pairs. The cross-section measurements are restricted to the range in z ($\equiv E_{J/\psi}/E_\gamma$ in the proton rest frame) between 0.3 and 0.9 where the contributions from diffractive production and resolved photon events are small. For comparison with NLO QCD calculations in the colour-singlet model, cross-section determinations are restricted to the kinematic region $p_t(J/\psi) > 1$ GeV.

Figure 3(a) shows the direct inelastic photo-production cross-section of J/ψ as a function of $W_{\gamma p}$ for $z < 0.8$, with predictions from NLO QCD calculations based on various proton structure parameterizations and with a LO QCD calculation. A strong rise in the cross-section with $W_{\gamma p}$ is observed which, in the model used, reflects the rising gluon content of the proton towards low x. The results are not sensitive enough to distinguish between different parameterizations of the gluon content of the proton.

As can be seen in figure 3(b), the differential cross-section in z is also well reproduced by the calculation based on the colour-singlet model, but contains no indication of the sharp rise towards high z which is predicted in the colour-octet model if the normalization is chosen to fit the CDF data [17].

5 ψ(2S) Photo-production

Clear signals for ψ(2S) are seen by searching for the decay to $J/\psi\ \pi^+\pi^-$, where the J/ψ subsequently decays to a pair of leptons (figures 4(a), 4(b) and 4(c)), or to a pair of leptons

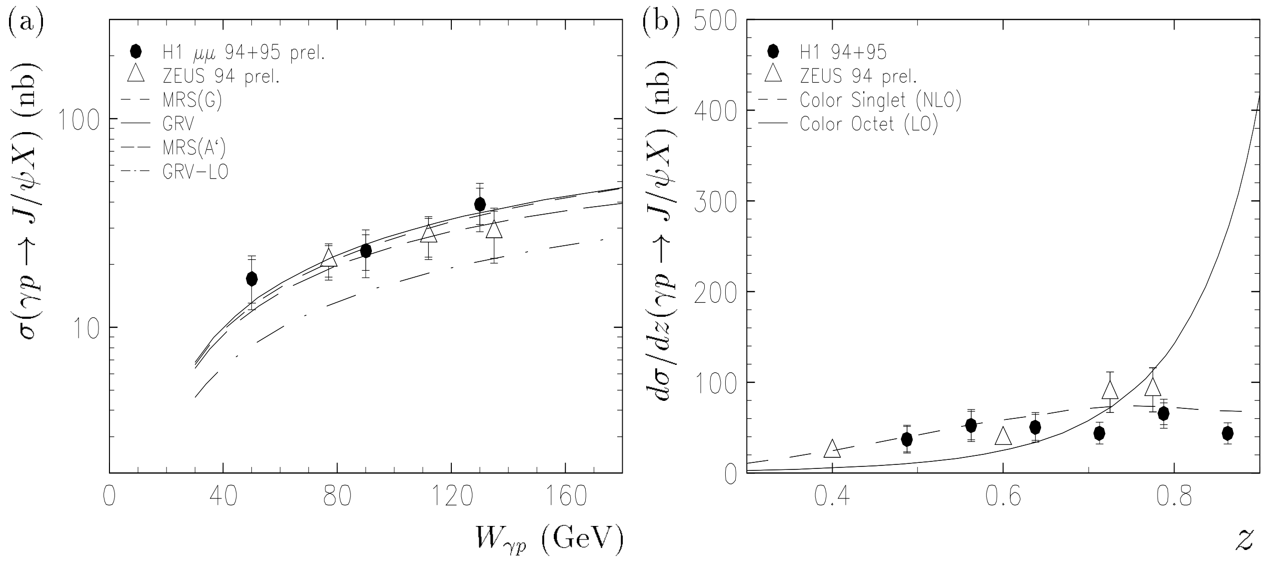

Figure 3:(a) Direct photo-production cross-sections for J/ψ, compared to NLO and LO QCD calculations in the colour-singlet model [2] based on the parton density parameterizations MRSG [11], GRV [15], MRSA′ [16]. Inner error bars statistical, outer total. (b) Differential photo-production cross-section for J/ψ in the variable z, compared to predictions of the colour-singlet and colour-octet models [3].

(figure 4(d)). In both channels the leptons can be either electrons or muons. By insisting that no further particles are identified the acceptance is limited to the kinematic region $z > 0.95$ and $Q^2 < 4\,\mathrm{GeV}^2$.

The ratio for the photo-production cross-sections $\sigma(\psi(2S))/\sigma(J/\psi)$ has be measured by H1 to be 0.15 ± 0.05 at $W_{\gamma p} = 80\,\mathrm{GeV}$ using the decay $\psi(2S) \to J/\psi\ \pi^+\pi^-$. Using the decay $\psi(2S) \to l^+l^-$, but without a cut on z, ZEUS measure the ratio to be 0.21 ± 0.02 (the error is statistical only). The ratio appears energy independent when comparing to measurements from other experiments [18] at $W_{\gamma p} < 20$ GeV.

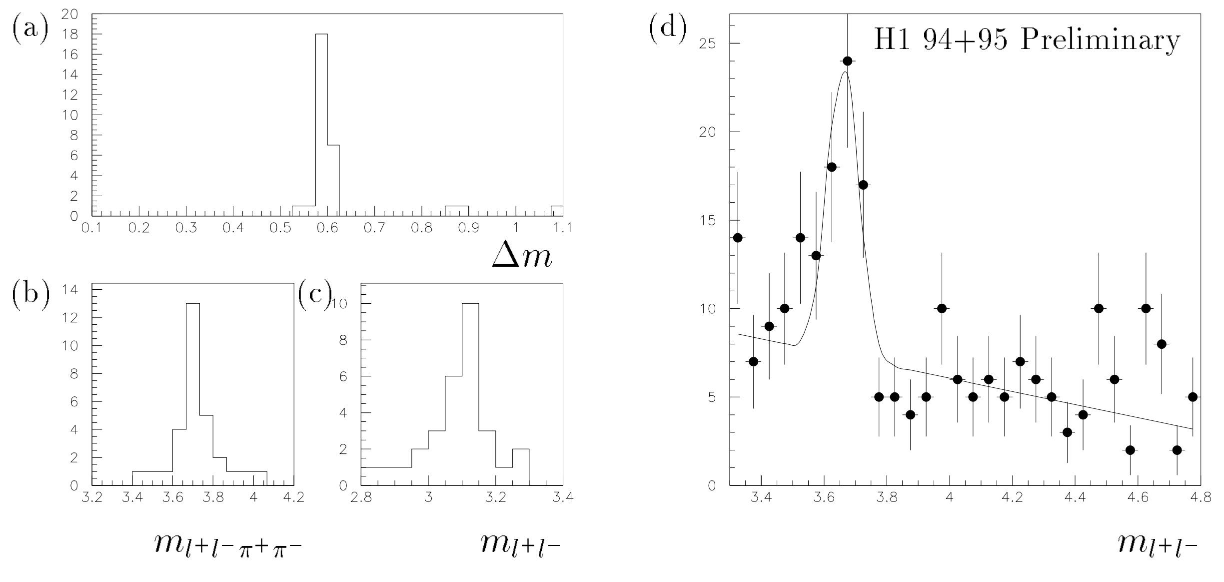

Figure 4:The distribution of (a) $\Delta M \equiv M_{l^+l^-\pi^+\pi^-} - M_{l^+l^-}$, (b) $M_{l^+l^-\pi^+\pi^-}$ and (c) $M_{l^+l^-}$ for the decay $\psi(2S) \to J/\psi\ \pi^+\pi^-$. (d) The distribution for $M_{l^+l^-}$ for the decay $\psi(2S) \to l^+l^-$. All masses are in GeV.

6 Conclusions

The production of charm quarks in e^+p-collisions at HERA has been studied by identifying charm in the form of D, D^*, J/ψ and $\psi(2S)$ mesons. All photo-production cross-sections are found to rise steeply with increasing $W_{\gamma p}$. This characteristic is well described by models based on perturbative QCD in which the rise reflects the increase in the gluon content of the proton towards low x.

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