PROCEEDINGS OF SCIENCE

D* (+jets) in Deep Inelastic Scattering and Photoproduction

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New results on charm quark production at HERA in an increased phase space in deep-inelastic scattering and photoproduction are discussed. Single & double-differential cross section distributions are compared to next-to-leading order QCD calculations as well as to MC@NLO in the photoproduction regime. The charm contribution to the proton structure, $F_2^{c\bar{c}}(x,Q^2)$, is determined with different experimental techniques and finally combined.

35th International Conference of High Energy Physics - ICHEP2010,
July 22-28, 2010
Paris France

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PoS(ICHEP 2010)153

1. Introduction

HERA was the unique electron-proton (ep) machine colliding 27.5 GeV electrons (positrons) with 920 GeV protons providing a center-of-mass energy of $\sqrt{s} = 318$ GeV The charm quark production in ep scattering is dominated by the boson-gluon-fusion (BGF) process ($\gamma p \rightarrow c\overline{c}$). This production process is directly sensitive to the gluon density in the proton and allows its universality to be tested. There are two different kinematic regions of charm quark production distinguished by the four-momentum transfer squared (Q^2) of the exchanged photon: The photoproduction regime with $Q^2 \lesssim 2$ GeV^2 and the deep-inelastic scattering (DIS) regime with $Q^2 \gtrsim 5$ GeV^2. Due to the presence of a hard scale (m_c, Q^2 or p_T) perturbative Quantum Chromodynamics (pQCD) can be applied. If one of the other scales is much bigger than the mass, charm quarks can be treated as massless ("massless scheme"), otherwise the mass needs to be taken into account ("massive scheme"). The latter assumes no charm quark content of the proton.

2. D$^{*\pm}$ Cross Section Measurements in Photoproduction & DIS

Events containing charm quarks are efficiently identified reconstructing D^* mesons by the mass difference method. The new result [1] in the photoproduction regime covers the kinematic region of $Q^2 < 2$ GeV^2 and $0.1 < y < 0.8$ of the inelasticity of the scattering process. The $D^{*\pm}$ mesons have been tagged by the H1 Fast Track Trigger [2]. They are selected if they have a $p_T(D^*) > 2.1$ GeV and $|\eta(D^*)| < 1.5$. The results make use of the full available data set corresponding to $L = 93$ pb^{-1}. Additional jets are reconstructed with the inclusive k_T algorithm in the laboratory frame and are selected if they have a $p_T(Jet) > 3.5$ GeV. With the additional constraints given by the jets the reconstruction of the longitudinal momentum fraction of the photon x_γ taking part in the hard interaction is possible. Thus the phase space can be divided into a region enriched

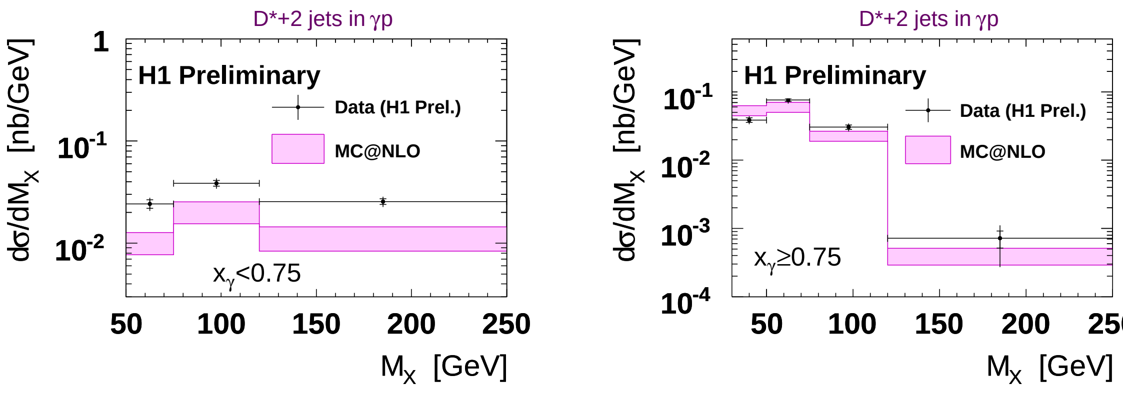

Figure 1: $D*+2$ jet cross section as a function of the invariant mass of the proton and photon side M_X for low $x_\gamma < 0.75$ (a) and high $x_\gamma > 0.75$ (b). The data are compared to the prediction by MC@NLO [3] using the CTEQ66 proton PDF [4].

with resolved photons ($x_\gamma < 0.75$), where a parton of the photon interacts with the proton and a region dominated by direct processes ($x_\gamma > 0.75$). It is found that the invariant mass M_X of the proton and photon remnants for the direct region is described by MC@NLO (Fig. 1(b)), while the resolved part is too low in normalization (Fig. 1(a)). Especially low x_γ is sensitive to the photon

parton density function (PDF).
D^* production in DIS has been measured for $0.02 < y < 0.7$ in two regimes of photon virtuality: $5 < Q^2 < 100$ GeV^2 and $100 < Q^2 < 1000$ GeV^2. Both analyses use the full HERAII data set corresponding to an integrated luminosity of about 350 pb$^-1$. In the lower Q^2 region the visible phase space of the D^* meson is restricted to $p_T(D^*) > 1.25$ GeV and $|\eta(D^*)| < 1.8$ [5].

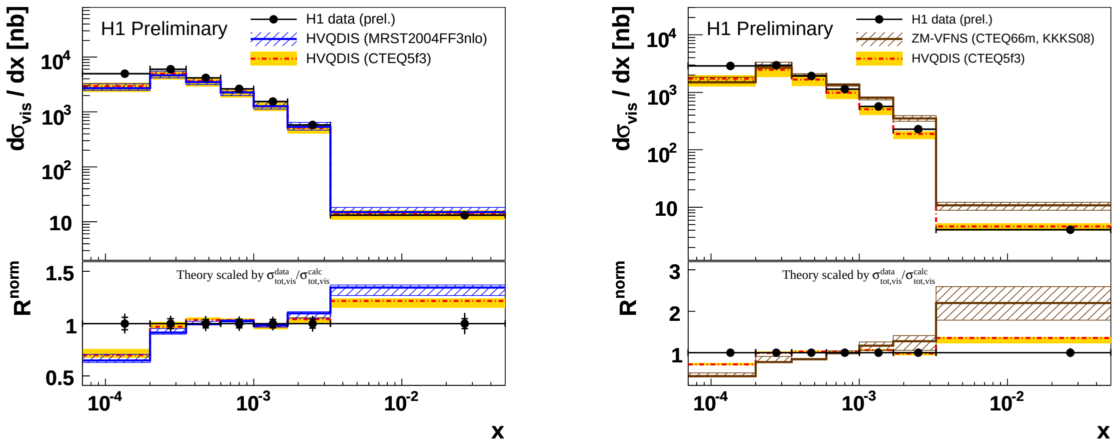

Figure 2: $D*$ cross section as a function of x (a) compared to the NLO QCD calculation (HVQDIS) using two different proton PDFs: MRST2004FF3nlo [7] or CTEQ5f3 [8]. (b) shows the $D*$ data for $p_T^* > 2$ GeV compared to the massless (ZM-VFNS) and massive NLO QCD calculation.

This measurement yields currently the largest phase space coverage at HERA for an inclusive D^* cross section measurement. The Data are reasonably well described using the NLO calculation HVQDIS [6] in the massive scheme (FFNS). However the slope in Bjørken x is not well described (Fig. 2a)). An additional transverse momentum cut in the photon-proton rest frame of $p_T^*(D^*) > 2$ GeV is applied. In order to allow comparisons with the massless NLO calculation (ZM-VFNS) [9] using the CTEQ66 proton parton density function (PDF) together with the fragmentation function KKKS08 [9]. The massless calculation fails completely to describe the x distribution (Fig. 2(b)), whereas the data are reasonably well described by the massive NLO QCD calculation provided by HVQDIS.
The D^* cross section result at high Q^2 [10] is restricted to a visible phase space of $p_T(D^*) > 1.5$ GeV and $|\eta(D^*)| < 1.5$. It is found that the NLO calculation HVQDIS describes the data reasonably well (Fig. 3). An additional cut $p_T^*(D^*) > 2$ GeV has been applied to compare

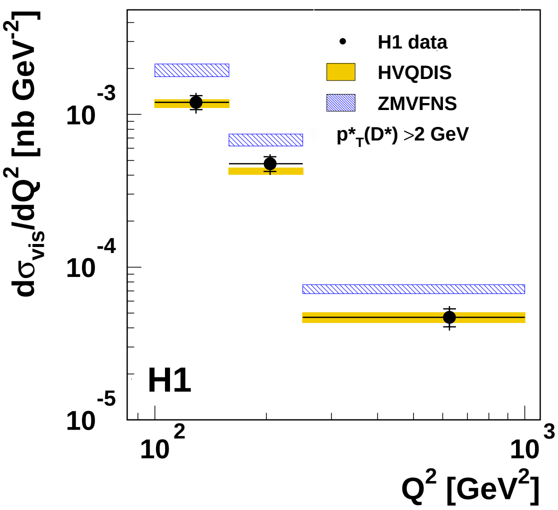

Figure 3: $D*$ cross section at high Q^2 compared to the massive (HVQDIS) and massless (ZM-VFNS) NLO QCD calculation.

with the massless NLO calculation ZM-VFNS. Like in the medium Q^2 regime it fails to describe the data (Fig. 3).

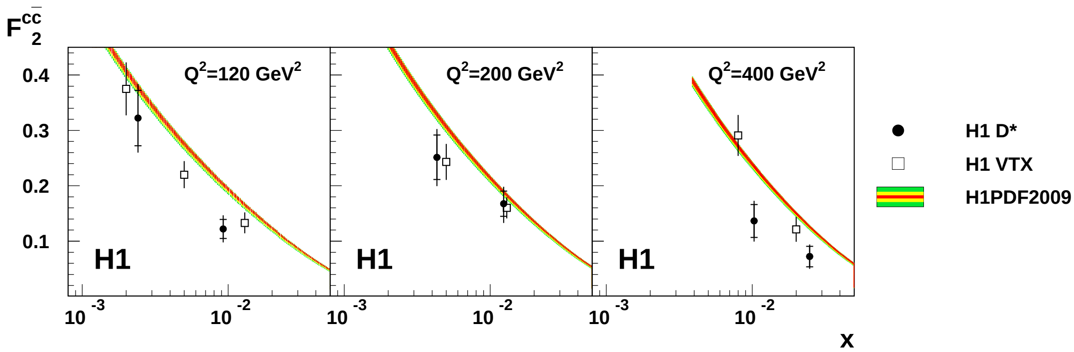

Figure 4: Charm contribution to the proton structure from D^* cross sections together with the H1 results using lifetime information. Data are compared to the H1 PDF fit H1PDF2009.

3. Measurement & Combination of $\mathbf{F_2^{c\bar{c}}(x,Q^2)}$

Different experimental techniques can be applied to measure the charm contribution, $F_2^{c\bar{c}}(x,Q^2)$, to the proton structure. Either the inclusive D^* cross section measurements, semi-leptonic decays or the inclusive lifetime technique where the precise track information of the H1 Silicon Vertex Detector is deployed. However, both techniques rely on the extrapolation of the measured cross sections to the full phase space. Published H1 results [10] of $F_2^{c\bar{c}}(x,Q^2)$ at high Q^2 (Fig. 4) are reasonable described by the H1 PDF fit H1PDF2009 [12]. The data are also in agreement with the H1 inclusive lifetime results [11]. An improvement in the precision of the data is obtained by the combination of different $F_2^{c\bar{c}}(x,Q^2)$ measurements. The results at high Q^2 and a H1 Preliminary result on $F_2^{c\bar{c}}(x,Q^2)$ at medium Q^2 [13] are combined with a published measurement using variables reconstructed with the H1 Silicon Vertex Detector [11]. This measurement uses a dataset corresponding to $L = 189$ pb^{-1}. The typical reduction of the systematic error is 25%. The combined data [14] are compared to various NLO QCD calculations

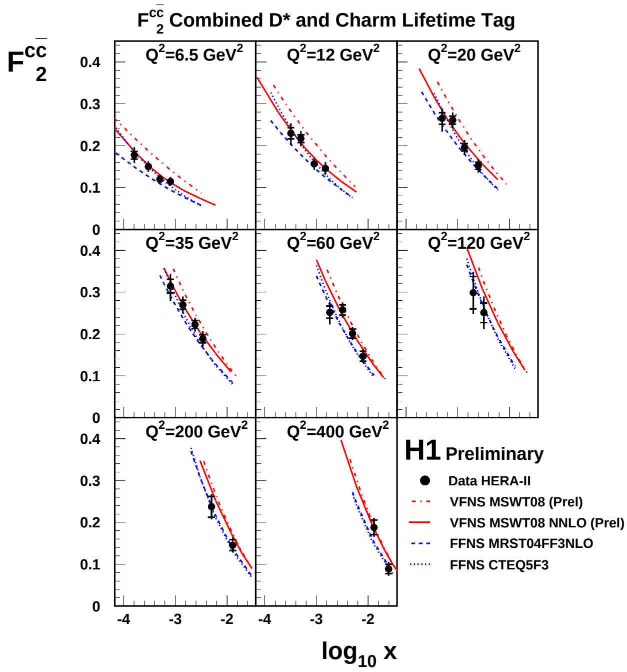

Figure 5: The H1 combined $F_2^{c\bar{c}}$ is compared to different NLO QCD calculations.

using different proton PDFs. The data are reasonably described by the different NLO QCD calculations in the FFNS scheme or the VFNS scheme [15] which implements a transition from the massive to the massless charm treatment. For the FFNS scheme the proton PDFs MRST2004FF3nlo and CTEQ5f3 are used, whereas for the VFNS scheme the MSTW08 at NLO and NNLO are used. Especially at low Q^2 the data are precise enough to distinguish between models.

4. Conclusions

New measurements using the full H1 HERAII data sample have been analyzed for charm quark production in ep scattering. Data in photoproduction are reasonable described by MC@NLO. The measurement in the DIS regime at medium Q^2 has been performed in the largest phase space at HERA for these kind of measurements. The data are reasonable described by the massive NLO QCD calculation. The massless NLO QCD calculation fails completely to describe the x slope. The data at high Q^2 show a reasonable description by the NLO QCD calculations except for the massless NLO calculation which again fails to describe the data. The charm contribution to the proton structure at high Q^2 has been presented and is reasonably well described by the H1 PDF fit H1PDF2009. Finally the combination of the $F_2^{c\bar{c}}$ measurements from the D^* results and the lifetime result was presented. The combined $F_2^{c\bar{c}}$ gives a more precise result and is reasonably described by different NLO QCD predictions. The data shows a sensitivity to the gluon density and at low Q^2 the data are precise enough to differentiate between models.

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