Measurements of Charm and Beauty in DIS via muon tags at ZEUS

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Charm and Beauty production were measured in deep inelastic scattering (DIS) with the ZEUS detector at HERA. Heavy quarks were reconstructed using their semi-leptonic decay into muons. The signal was separated from the background using lifetime information, the transverse momentum of the muon with respect to the axis of the associated jet and the missing transverse momentum parallel to the muon direction. Differential cross sections were measured and compared to next-to-leading order QCD predictions. The heavy quarks contribution to the proton structure function F_2, $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$, were extracted and compared with theoretical predictions using different parametrizations of the proton PDFs.

1 Introduction

The measurement of charm and beauty production in deep inelastic scattering (DIS) provides a stringent test of quantum chromodynamics (QCD) since the large quark masses and the square of the four momentum transfer, Q^2, provide hard scales that make perturbative calculations applicable. At leading order, heavy quarks (HQ) are produced in DIS via boson–gluon fusion (BGF) ($\gamma^* g \to q\bar{q}$). A precise measurement of HQ production in DIS therefore provides a direct constraint on the gluon parton density function (PDF) of the proton.

Charm production in DIS at HERA has been measured previously using reconstructed charmed mesons or inclusively by exploiting the long lifetime of charmed hadrons[1]. Beauty production in DIS has been studied in events with muons and jets and from lifetime information[1]. The existing data are generally in good agreement with next-to-leading-order(NLO) QCD predictions.

We present here a recent measurement[2] of HQ production using semi-leptonic (SL) decays into muons. It is the first time that leptonic tags are used for charm measurements at HERA.

2 Selection cuts, fits and cross sections measurement

The data used in this analysis have been collected with the ZEUS detector in the 2005 running period during which HERA collided electrons of energy $E_e = 27.5$ GeV with protons of energy $E_p = 920$ GeV corresponding to a centre-of-mass energy $\sqrt{s} = 318$ Gev. The corresponding integrated luminosity was $\mathcal{L} = 126.0 \pm 3.3\ pb^{-1}$.

A sample of muon in DIS was selected and the accessible inelasticity $y = Q^2/(xs)$ and Q^2 were restricted to $0.01 < y < 0.7$ and $Q^2 > 20$ GeV^2. To remove background events with isolated muons ($\gamma\gamma \to \mu^+\mu^-$, J/ψ and Υ decays) and residual cosmic muons, an anti-isolation

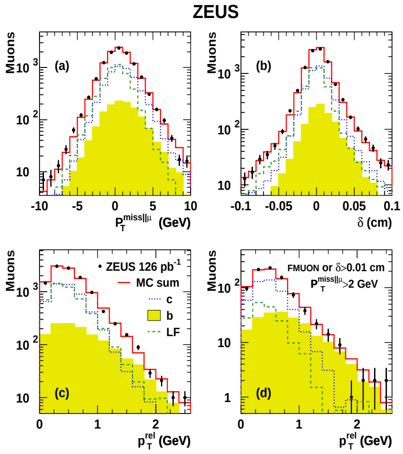

Figure 1: Distributions of (a) $p_T^{\text{miss}||\mu}$, (b) δ, (c) p_T^{rel} for the selected sample of muons in DIS, and of (d) p_T^{rel} for a signal-enriched subsample with $p_T^{\text{miss}||\mu} > 2$ GeV and either a muon in FMUON or $\delta > 0.01$ cm.

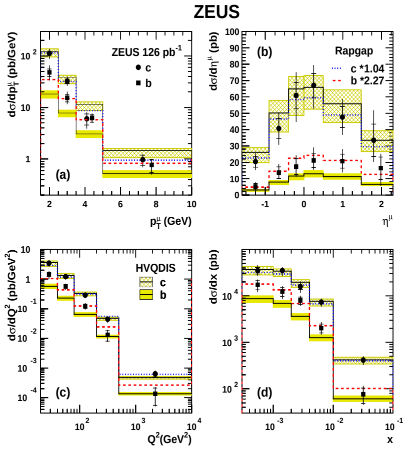

Figure 2: Differential muon cross sections for c and b as a function of (a) p_T^μ, (b) η^μ, (c) Q^2, and (d) x. The bands show the NLO QCD predictions (HVQDIS) and the corresponding uncertainties. The differential cross sections from RAPGAP are also shown.

cut was applied by requiring that the hadronic energy around the muon candidate was $E^{\text{iso}} > 0.5$ GeV. A jet associated to the muon was required with $P_T^{jet} > 2.5$ GeV. The fractions of muons originating from charm, beauty or LF events were determined by fitting a combination of MC distributions to the measured three-dimensional distribution of the following discriminating variables [2] that are sensitive to different aspects of HQ decays:

· p_T^{rel}, the muon momentum component transverse to the axis of the associated jet,

· δ, the distance of closest approach of the muon track to the interaction point in the X, Y plane,

· $p_T^{\text{miss}||\mu}$, the missing transverse momentum parallel to the muon direction, that has a distribution with a positive tail of events containing semileptonic HQ decays due to the presence of the neutrino.

A control sample of inclusive DIS data was used to test the quality of the simulation of these variables. The distributions of the three discriminating variables are shown in Fig. 1 (a-c) togheter with the distribution of p_T^{rel} for a signal-enriched subsample (Fig. 1 - d).

The global HQ fractions resulting from the fit are $f_c = 0.456 \pm 0.029$ (stat.) and $f_b = 0.122 \pm 0.013$ (stat.). The cross sections for muons from HQ decays were measured in the kinematic region $Q^2 > 20$ GeV^2, $0.01 < y < 0.7$, $p_T^\mu > 1.5$ GeV and pseudorapidities[1] $-1.6 < \eta^\mu < 2.3$ as a function of p_T^μ, η^μ, Q^2, and of the Bjorken scaling variable x and compared to QCD predictions. The differential cross sections as a function of p_T^μ, η^μ, Q^2, and x are compared in Fig.2 to the NLO QCD predictions based on HVQDIS.

[1]The ZEUS coordinate system is a right-handed Cartesian system, with the Z axis pointing in the proton beam direction, referred to as the "forward direction", and the X axis pointing towards the centre of HERA. The pseudorapidity is defined as $\eta = -\ln\left(\tan\frac{\theta}{2}\right)$, where θ is the polar angle.

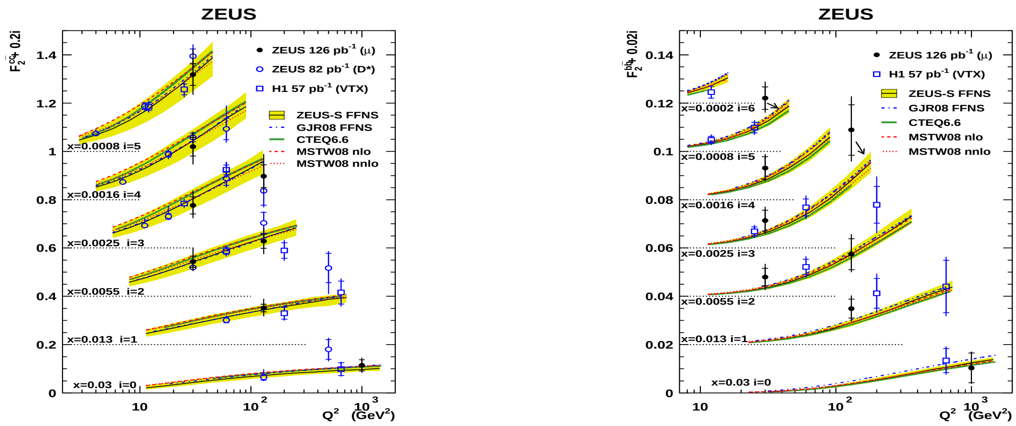

Figure 3: $F_2^{c\bar{c}}$(left) and $F_2^{b\bar{b}}$(right) extracted from the ZEUS muon[2](μ), and ZEUS charmed mesons [1](D^*) and from the H1 lifetime analysis[1](VTX). The data are shown as a function of Q^2 for fixed x values. The band represents the NLO FFNS calculation based on the ZEUS-S PDF fit and its uncertainty obtained from variations of the renormalisation and factorisation scales, of the HQ mass and of the PDFs. The different curves show the NLO FFNS calculation of GJR08 [3], the NLO and NNLO calculations in the GM-VFNS of MSTW08 [3] and the NLO GM-VFNS calculations of CTEQ6.6 [3] with $\mu_F^2 = Q^2 + m^2$.

3 Extraction of $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$

The muon cross sections, σ^q, measured in bins of x and Q^2, were used to extract $F_2^{q\bar{q}}$ at a reference points in the x, Q^2 plane by: $F_2^{q\bar{q}}(x, Q^2) = \sigma^q \frac{F_2^{q\bar{q},\text{th}}(x,Q^2)}{\sigma^{q,\text{th}}}$, where $F_2^{q\bar{q},\text{th}}(x, Q^2)$ and $\sigma^{q,\text{th}}$ were calculated at NLO in the FFNS using the HVQDIS program. The largest uncertainty is related to the extrapolation to the full muon phase space. The theoretical uncertainty in the extraction of $F_2^{q\bar{q}}$ was evaluated by varying the HVQDIS parameters and by using a different PDF set (CTEQ5F). Figure 3 shows the extracted $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ from this analysis, as functions of Q^2 for fixed values of x, compared to previous ZEUS and H1 results [1] corrected to the same reference x used in the present analysis. Different QCD calculation are also shown. For $Q^2 \geq 60$ GeV^2 the present results are of comparable or higher precision than those previously existing.

References

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