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Nuclear Physics B (Proc. Suppl.) 207–208 (2010) 383–386
NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS
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Production of heavy flavours at HERA

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(on behalf of the H1 and ZEUS collaborations)

Abstract

New results obtained by the HERA experiments H1 and ZEUS for charm and beauty production in $e^{\pm}p$ collisions based on different tagging techniques are described in comparison with perturbative QCD calculations. In general, QCD calculations at NLO describe the data well.

Keywords: Hadron-electron collisions; Heavy flavours; Deep inelastic scattering; Photoproduction; QCD; Perturbative QCD

1. Introduction

Heavy flavour production in $e^{\pm}p$ collisions at HERA provides a good testing of perturbative Quantum Chromodynamics (pQCD) as the high quark mass provides a hard scale that allows perturbative calculations. Furthermore, other hard scales such as Q^2, the virtuality of the exchanged boson, or p_t, the transverse momentum of the heavy quark, allow resummation techniques to be tested. The main process to produce c and b quarks is the Boson-Gluon Fusion (BGF) which provides a direct access to the gluon parton density in the proton (PDF).

The kinematic range of the analysed data can be separated in the two regimes: photoproduction (PHP) where the exchanged photon is almost real, and deep inelastic scattering (DIS), where the exchanged photon is virtual. Experimentally, PHP is defined by the scattered electron not being in the acceptance region of the detector, corresponding to a cut $Q^2 \lesssim 1$ GeV^2.

This paper describes new experimental results for heavy flavour production obtained by the H1 and ZEUS collaborations. They are based on different heavy quark tagging methods. Comparison with QCD calculations, either in a leading order (LO) plus parton showering (PS) or in the next-to-leading-order (NLO), were done.

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2. Theoretical approaches

In order to simulate colliding events all the applicable phenomenological models available are collected in computer programs called Monte Carlo (MC) event generators. The LO MC generators used are: PYTHIA [1], RAPGAP [2]. NLO calculations are based on several approaches: 1) Zero Mass Variable Flavour Number Scheme (ZM-VFNS) where heavy quarks are treated as massless; 2) Fixed Flavour Number Scheme (FFNS): FMNR [3], HVQDIS [4] where heavy quarks are treated as massive; 3) General Mass Variable Flavour Number Scheme (GM-VFNS) which is an interpolation between the massive FFNS at low Q^2 and the massless ZM-VFNS at high Q^2: MSTWxx [5], CTEQxx [6]; 4) MC@NLO which realize FFNS calculation with PS.

3. Charm in PHP

PHP of events containing a D^* meson and two jets were investigated with the H1 detector using the HERAII data sample [7]. The D^* mesons were reconstructed in the golden decay channel $D^* \to K\pi\pi_s$. PHP events were selected in the kinematic range $Q^2 < 2$ GeV^2 corresponding to $100 < W_{\gamma p} < 285$ GeV. The jets were reconstructed with the inclusive k_t algorithm in the laboratory frame and were selected if they have $p_t > 3.5$ GeV. An azimuthal correlation between 2 jets, $\Delta\Phi$, and a fraction of the photon energy entering hard interaction, x_γ^{obs}, were used to enrich resolved γp processes.

doi:10.1016/j.nuclphysbps.2010.10.100

Differential cross sections were measured in different variables and compared to QCD MC@NLO calculations (Fig. 1 and Fig. 2). MC@NLO undershoots data at low x_γ while the shape of the $\Delta\Phi$ distribution is described. This result is in good coincidence with the previous ZEUS result when NLO FMNR caclulation also undershoots experiment for small $\Delta\Phi$ [8].

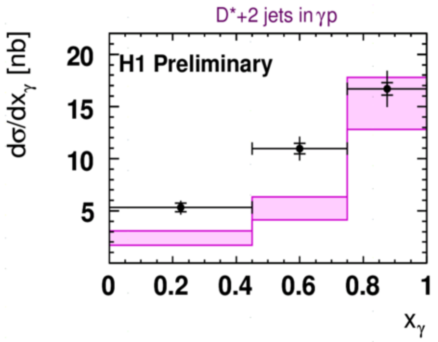

Figure 1: Differential cross section for D^* dijet PHP as a function of x_γ

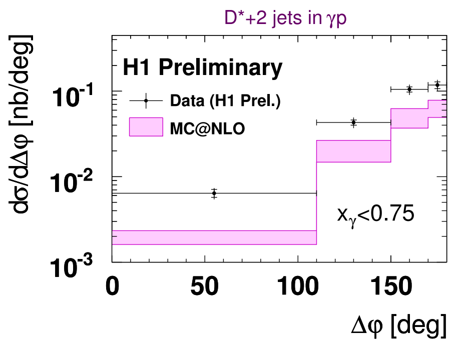

Figure 2: Differential cross section for D^* dijet PHP as a function of $\Delta\phi$

4. Beauty in PHP

PHP of b quarks in events with two jets has been measured with the ZEUS detector using an integrated luminosity of 128 pb^{-1} [9]. The beauty content has been extracted using the decay length significance, $S = \frac{DL}{\delta(DL)}$, of the B hadrons and the invariant mass of the decay vertices. A large secondary vertex mass gives almost pure beauty sample for large $S > 6$. This result is the most precise PHP beauty measurement at HERA so far.

Comparison of the differential cross sections in p_T^{jet} (Fig. 3) and η^{jet} (Fig. 4) with LO (PYTHIA [1]) and NLO (FMNR [3]) QCD calculations shows good agreement.

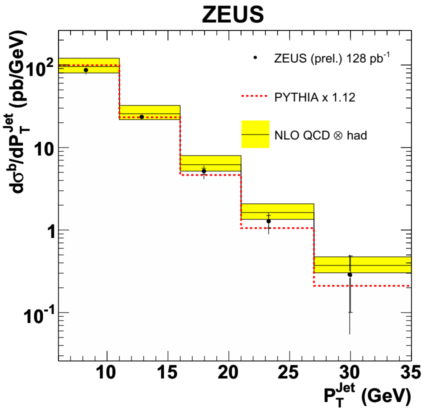

Figure 3: Differential cross section for beauty dijet PHP as a function of p_T^{Jet}

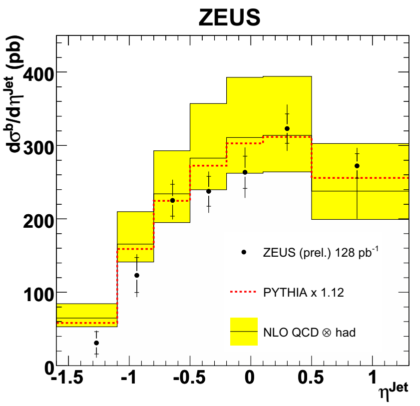

Figure 4: Differential cross section for beauty dijet PHP as a function of η^{Jet}

In Fig. 5 a summary of H1 and ZEUS measurements with different methods and systematics collected as a function of p_t^b generally shows good agreement with NLO QCD calculations.

5. Charm in DIS

Charm production in DIS has been measured with the ZEUS detector using the decay channels $D^+ \to K_S^0\pi^+, \Lambda_c^+ \to pK_S^0$ and $\Lambda_c^+ \to \Lambda\pi^+$ [10]. The presence of a neutral strange hadron in the final state reduces the combinatorial background and extends the measured sensitivity into the low transverse momentum region.

Inclusive and differential cross sections for the production of D^+ mesons were compared to NLO QCD predictions using HVQDIS program [4] (Fig. 6). From a comparison of the D^+ and Λ_c^+ cross sections the fraction of c quarks hadronising into Λ_c^+ baryons was extracted.

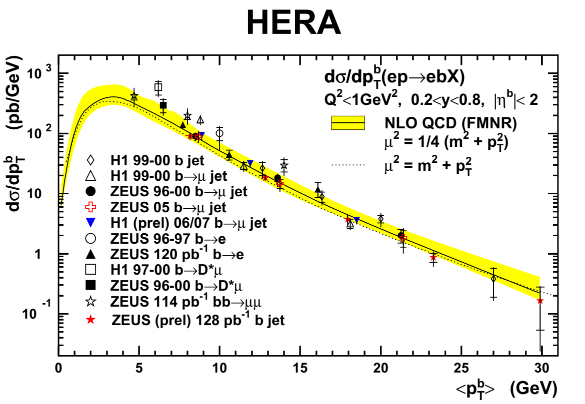

Figure 5: Cross section for beauty photoproduction as a function of p_T^{jet} from various H1 and ZEUS datasets

The measured value:

$$f(c \to \Lambda_c^+) = 0.117 \pm 0.033(stat.)^{+0.026}_{-0.022}(syst.) \pm 0.027(br.),$$

was compared with a previous ZEUS measurement in PHP regime [11] and with the e^+e^- average value.

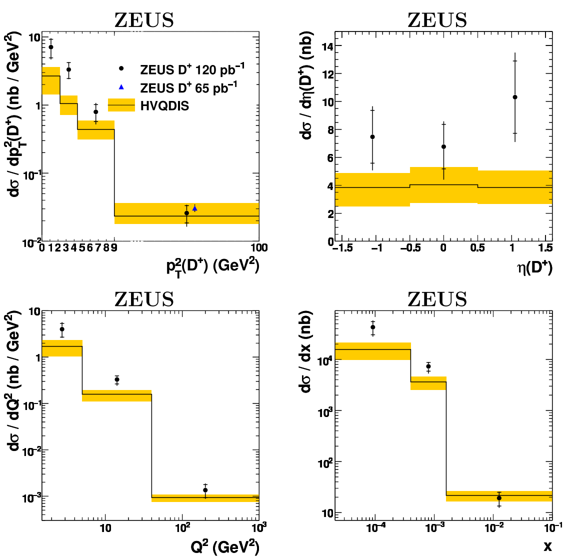

Figure 6: Differential D^+ cross sections in DIS as a function of $p_T^2(D^+)$, $\eta(D^+)$, Q^2 and x compared to the HVQDIS NLO calculations

6. Charm and beauty jets in DIS

Charm and beauty jets in DIS using a lifetime tag based on the track significance $S = \delta/\sigma(\delta)$ have been measured with the H1 detector in an extended region (high E_T^{jet}). The analysis was carried out in the Breit frame which is theoretically favorable and was used in previous heavy flavour analysis. The NLO QCD calculation (HVQDIS) gives a good data description for both scales (Fig. 7 and Fig. 8) [12].

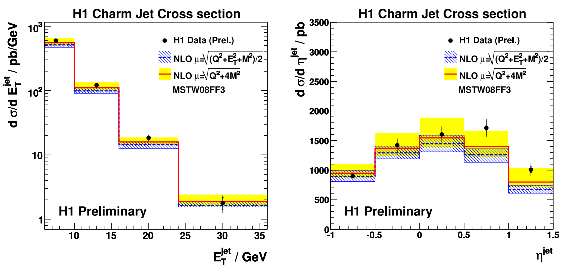

Figure 7: Differential charm jet production cross sections in DIS as a function of E_T^{jet} and η^{jet} compared to the HVQDIS NLO calculations [12]

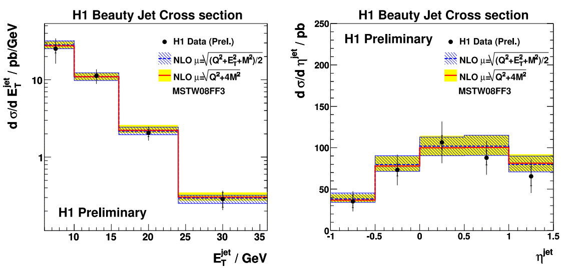

Figure 8: Differential beauty jet production cross sections in DIS as a function of E_T^{jet} and η^{jet} compared to the HVQDIS NLO calculations [12]

7. Charm contribution to the structure function $F_2^{c\bar{c}}$

The charm contribution $F_2^{c\bar{c}}$ to the proton structure F_2 was determined by the HERA Heavy Flavour Group [13, 14]. The results of the D meson production cross-section measurements were combined with the measurements using semi-leptonic decays into muons as well as the inclusive track measurements. The correlations of the systematic uncertainties between different measurements were taken into account. The data cover the kinematic range of photon virtuality $2 < Q^2 < 1000$ GeV^2 and Bjorken scaling variable $10^{-5} < x < 10^{-1}$. The data have decreased uncertainties and start to distinguish between theoretical predictions based on different PDFs/schemes. NLO calculation based on PDF extracted from HERA inclusive data (HERAPDF1.0) nicely fits experiment (Fig. 9).

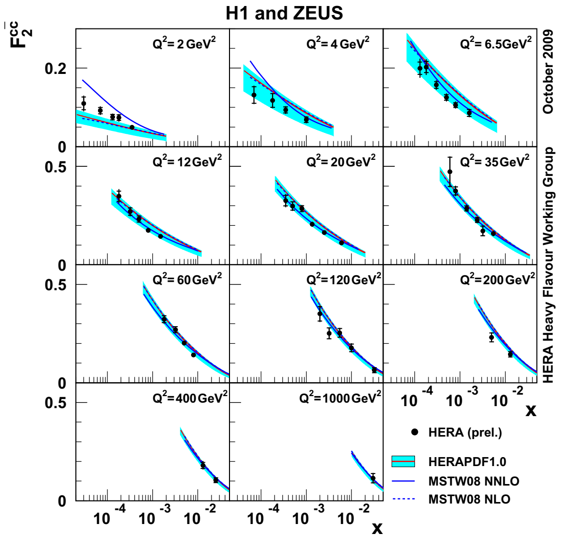

Figure 9: H1 and ZEUS combined charm structure function, $F_2^{c\bar{c}}(x, Q^2)$, in comparison with NLO calculation based on HERAPDF1.0 fit [13, 14]

8. Beauty contribution to the structure function $F_2^{b\bar{b}}$

The measurement of beauty production in DIS using the decay channel of semileptonic decays to electrons in the kinematic range $Q^2 > 10$ GeV^2 and for an inelasticity, $0.05 < y < 0.7$, with the ZEUS detector were done using an integrated luminosity of 363 pb^{-1} [15]. The beauty contribution to the proton structure function, $F_2^{b\bar{b}}$, was extracted from the double differential cross section as a function of Bjorken-x and Q^2 (Fig. 10). The HVQDIS NLO predictions were used for the extrapolation of the measured visible cross sections to $F_2^{b\bar{b}}$. For this step, uncertainties on the hadronisation corrections, the branching ratios and the shape variation due to the choice of PDF were also included. Similar analysis in the PHP regime, based on the data taken in 1996 - 2000 (120 pb^{-1}) have been done earlier [16].

The ZEUS and H1 data [17] using a completely different measurement technique are all compatible within uncertainties. At low x, the new measurements, in agreement with the previous ZEUS measurement, have a tendency to lie slightly above the H1 data. The largest difference is about 2 standard deviations. The predictions from different theoretical approaches agree fairly well with each other. The HVQDIS predictions are somewhat lower than the ZEUS data at low Q^2 and x, where the influence of the beauty-quark mass is highest, while at higher Q^2 the data are well described by all predictions.

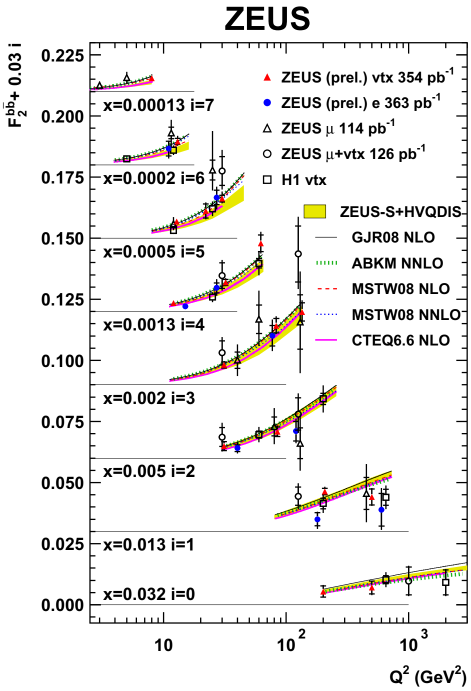

Figure 10: The beaty structure function, $F_2^{b\bar{b}}$, as a function of Q^2 for fixed values of x compared to previous results (open symbols) and to the NLO QCD predictions in the FFNS using the ZEUS-S PDF fit

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