BEAUTY PRODUCTION AT HERA

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Recent results on beauty production in electron proton collisions at a center-of-mass energy of 318 GeV at HERA are presented. The data make use of the HERA-I data samples recorded between 1996 and 2000. The cross sections measured by the H1 and ZEUS experiments are compared with perturbative QCD calculations.

1 Introduction

The measurement of heavy flavour processes at the HERA *ep*-collider is a powerful means of exploring the dynamics of the strong interactions described by QCD. The kinematics at HERA spans a large range in the photon virtuality Q^2 and the Bjorken scaling variable x. While in photoproduction, $Q^2 \sim 0$ GeV^2, the photon is almost real, in deep inelastic scattering (DIS) Q^2 can reach values much higher than the squared b-quark mass m_b^2. Perturbative QCD (pQCD) has been seen to describe inclusive production cross sections wherever Q^2 or the transverse momenta of the outgoing partons are sufficiently large to provide an energy scale for expansions in orders of the strong coupling constant α_S. In heavy flavour production the largeness of the heavy quark mass provides an alternative energy scale for perturbative calculations, and it has been shown that pQCD provides a reasonable description of charm production[1]. The first measurements of beauty production at HERA[2,3] revealed excesses of the data over pQCD predictions. Similar findings were made in $p\bar{p}$ and $\gamma\gamma$ collisions at the Tevatron[4] and at LEP[5]. The most recent HERA results[6,7,8,9,10,11] are reported here.

2 Heavy Quark Production

The dominant mechanisms for beauty production in *ep*-collisions at HERA are the boson gluon fusion processes as shown in fig.1.

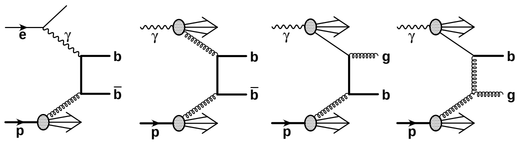

Figure 1. Beauty production processes in leading order pQCD.

At leading order the direct photon gluon fusion process (left diagram in fig.1) is distinguished from the resolved photon processes (right 3 diagrams), in which the photon fluctuates into a hadronic state which subsequently interacts with a parton coming from the proton.

Calculation tools are available in the massive scheme up to next-to-leading order (α_s^2, NLO) in form of Monte Carlo integration programs[12,13]. In the massive scheme[14], u, d and s are the only active flavours in the proton, and charm and beauty are dynamically produced in the hard scattering. This scheme is expected to work well in regions where the transverse momentum of the outgoing b-quark is of similar magnitude as the quark mass.

At higher transverse momenta or high photon virtualities the massless scheme[15] should be applicable, in which charm and beauty are regarded as active flavours (massless partons) in the proton and in the photon and are fragmented only after the hard process into massive quarks. The massless ansatz incorporates excitation processes (such as shown for leading order in the two right diagrams in fig.1). So-called variable

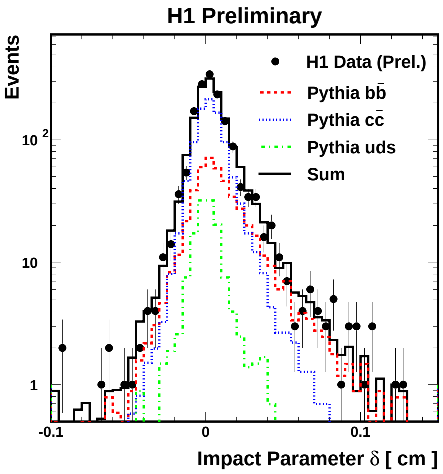

Figure 2. Muon impact parameter distribution as measured by H1 and estimated contributions from b (dashed), c (dotted) and light-quark (dashed-dotted).

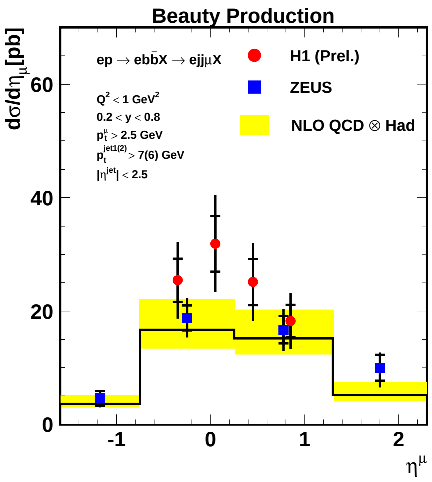

Figure 3. Differential beauty photoproduction cross sections from H1 and ZEUS as a function of pseudo-rapidity of the muon.

flavour number schemes (VFNS) have been developed[16] which provide a smooth transition from the massive scheme at $Q^2 \sim m_b$ to the massless scheme at $Q^2 \gg m_b^2$.

3 Jet-Muon Analyses

Both H1 and ZEUS have presented measurements in which the events containing beauty are identified using high p_T muons from semileptonic b-decays. The beauty signal events are distinguished from the charm and light quark background by means of two observables which exploit the large mass or the long lifetime of the b-quarks. The transverse momentum p_t^{rel} of the muon with respect to the axis of the associated jet exhibits a much harder spectrum for muons from b-decays than for the other sources. The signed impact parameter δ (fig.2) of the muon track with respect to the primary event vertex reflects the lifetime of the particle from which the muon decays.

Differential measurements from H1 and ZEUS are available for beauty production in photoproduction and DIS[6,7,8,9]. Figure3 shows the differential photoproduction cross-sections as a function of the muon pseudorapidity for the process $ep \rightarrow eb\bar{b}X \rightarrow e\,\mathrm{jet}\,\mathrm{jet}\,\mu$. The H1 and ZEUS data, which are in reasonable agreement, are compared to an NLO calculation in the massive scheme[12]. The errors of the theory prediction are dominated by the uncertainties of the renormalisation scale and the b-quark mass.

The results of beauty measurements with muons at HERA are summarized in fig.4 where the ratios between the measured beauty production cross sections and the corresponding next-to-leading order predictions in the massive scheme[12,13] are shown as a function of the photon virtuality Q^2. The data tend to be somewhat higher than the predictions but still in agreement.

4 Inclusive Lifetime Tag Analyses

The H1 Experiment reports new beauty and charm measurements in which the impact parameters of all tracks coming from secondary decay vertices are used to identify beauty and charm events[10,11]. The track se-

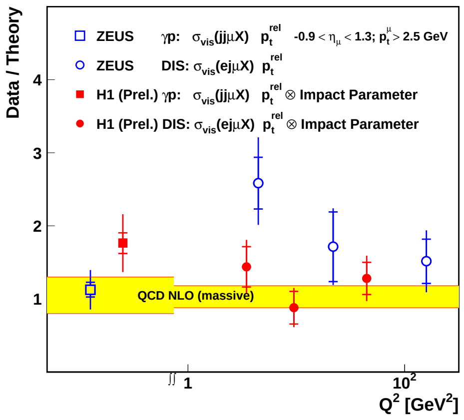

Figure 4. Data to theory comparison for the beauty cross section measurements with muons at HERA as a function of Q^2.

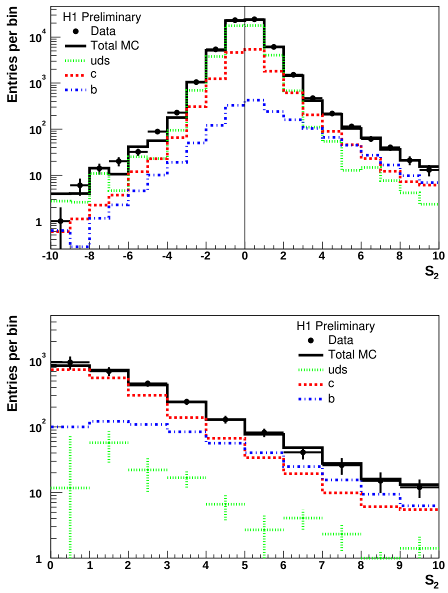

Figure 5. Significance distributions a) before subtraction and b) after subtraction (see text).

lection requires full silicon vertex detector information and imposes a transverse momentum cut $p_T > 500$ MeV. From the measured impact parameter δ a lifetime significance $S = \delta/\sigma_\delta$ is calculated[17]. Two independent distributions are constructed. S_1 is the significance distribution of tracks in events with exactly one selected track. The distribution S_2 (see fig.5) contains the significances of the tracks with the second highest significance for events with two or more selected tracks. Events in which the tracks with the first and second highest absolute significance have different signs are removed from the S_2 distribution. The subtracted significance distributions (see fig.5) are obtained by bin-wise subtraction of the numbers of entries on the negative side from those on the positive side. The subtraction method substantially reduces the systematic uncertainties due to track and vertex resolutions. The relative contributions from b, c and light quarks are determined from a fit to the subtracted S_1 and S_2 distributions and the total number of events, using the shapes of Monte Carlo b, c and light quark distributions as templates.

The dijet beauty photoproduction cross section is measured for events with two jets with $p_T > 11(8)$ GeV[10]. In fig.6 the differential cross section is presented as a function of the jet transverse momentum p_T. The data are found to be higher than predictions from the NLO QCD calculation[12] and from the Monte Carlo programs PYTHIA[18] and CASCADE[19] by roughly a factor of 2.

At large Q^2 the beauty and charm structure functions have been determined (see

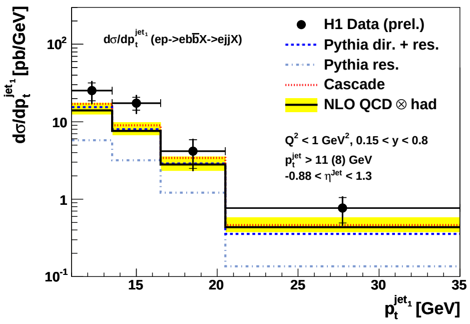

Figure 6. Differential beauty photoproduction cross section as a function of the jet transverse momentum.

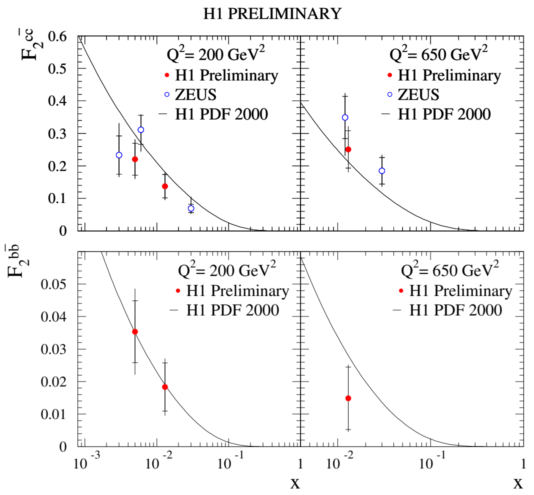

Figure 7. Structure functions $F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ as a function of x at two Q^2 values.

fig.7). In the kinematic range considered here the uncertainties due to model assumptions are negligible as the extrapolation from the measured sample to the full phase space is small. This is the first measurement of $F_2^{b\bar{b}}$. The results for $F_2^{c\bar{c}}$ are compared with the results of the ZEUS collaboration where the cross sections were obtained from the measurement of $D^{*\pm}$ mesons. The data are found compatible with the prediction from NLO QCD in which the c and b quarks are treated in the massless scheme, using the parton distributions from the H1 PDF 2000 fit[20].

5 Summary

Recent results on beauty production in *ep*-collisions have been presented. The measured cross sections based on event samples with muons and jets, are in agreement or somewhat above the QCD predictions. In new analyses inclusive lifetime tagging techniques are used to measure c and b cross sections. In photoproduction the dijet-beauty cross section is higher than the QCD calculations by roughly a factor of 2. At large Q^2 the charm and beauty structure functions have been determined and are found to be in agreement with the expectations.

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