

HEAVY FLAVOR PRODUCTION AT HERA

O. BEHNKE

University of Heidelberg Philosophenweg 12 D-69120 Heidelberg, Germany

E-mail: behnke@physi.uni-heidelberg.de

On behalf of the H1 and ZEUS collaborations

Recent results of open charm and beauty production in electron proton scattering at HERA are presented. In photoproduction, the measured cross sections for charm exceed fixed order NLO QCD calculations. Experimental evidence supports the hypothesis that a significant fraction of photoproduction events with charm can be described by resolved photon processes, where the charm quark is a constituent of the resolved photon. In deep inelastic scattering the NLO calculations give in general a fairly reasonable description of the observed charm cross sections. The measurements of the structure function $F_2^{c\bar{c}}$ show that, at large photon virtualities and low x , the events with charm constitute a major part of the total ep cross section. The beauty cross sections both in photoproduction and in DIS exceed NLO predictions.

1 Introduction

Open heavy flavor production at HERA is understood as being mainly due to the photon gluon fusion reaction (see Figure 1a)), which is directly sensitive to the gluon density in the proton. In this process two hard scales are

a) Direct γg fusion

b) Resolved γ processes

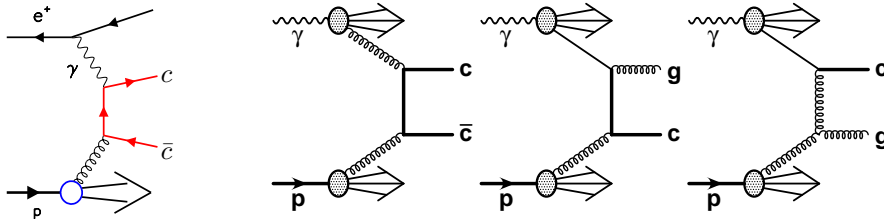


Figure 1. Leading order contributions to open heavy flavor production at HERA.

available facilitating the convergence of perturbative QCD. The first is the virtuality Q^2 of the exchanged photon, with accessible values at HERA ranging from zero (photoproduction) to larger values (deep inelastic scattering, DIS), reaching up to $Q^2 \approx 40000 \text{ GeV}^2$. The second is the mass of the heavy

quark, which allows the calculations to be extended to the photoproduction regime. Further significant contributions to heavy flavor production at HERA are expected from *resolved* processes (see Figure 1b), in which the photon initially fluctuates into hadronic objects whose partons enter into the hard scattering. These processes are expected to be strongly suppressed towards larger photon virtualities.

Within the framework of pQCD, two approaches are available to describe heavy flavor production at HERA. In the so-called *massive* or *fixed order* scheme¹, u, d and s are the only active flavors in the proton, and charm and beauty are dynamically produced in the hard scattering. It is expected that this approach works well at HERA for the important kinematic region $p_t \leq m_q$, where p_t (m_q) is the transverse momentum (mass) of the heavy quark. At higher transverse momenta, the so-called *massless* or *resummed* approach² should be applicable, where charm and beauty are regarded as active flavors (massless partons) in the proton and in the photon, and fragment only after the hard process into massive quarks. This ansatz incorporates diagrams such as the two most right shown in Figure 1 b), which are called charm (or beauty) excitation processes.

In the following we will “take a walk” through the scales, i.e. in Q^2 from photoproduction to DIS and in m_q from charm to beauty and compare the data for each case with QCD predictions. The results presented here are based on analyses exploiting partial or full statistics of the HERA I data from the years 1995-2000, while the HERA collider was operated with 820 or 920 GeV protons colliding on 27.5 GeV positrons or electrons.

2 Charm

The results on open charm production presented here rely almost entirely on analyses of the channel $D^{*+} \rightarrow D^0 \pi_s^+$ with $D^0 \rightarrow K^- \pi^+$ and the corresponding charge conjugated mode.

In **photoproduction**, inclusive and differential D^* -measurements³ significantly exceed the massive NLO calculations unless one uses theory parameters which are at their extreme limits, e.g. a charm quark mass of 1.2 GeV. To obtain more information, ZEUS has measured the D^* -yields in events with two identified hard central jets⁴. From the kinematics of the jets, the photon fractional momentum x_γ^{obs} entering into the hard interaction can be determined. Figure 2 (left) shows the observed x_γ^{obs} spectrum compared with predictions from massive NLO (bottom) and massless LO (top) QCD. For x_γ^{obs} values below 0.75, the domain of resolved photon processes, the massive NLO calculation is clearly below the data. A much better description is obtained by the

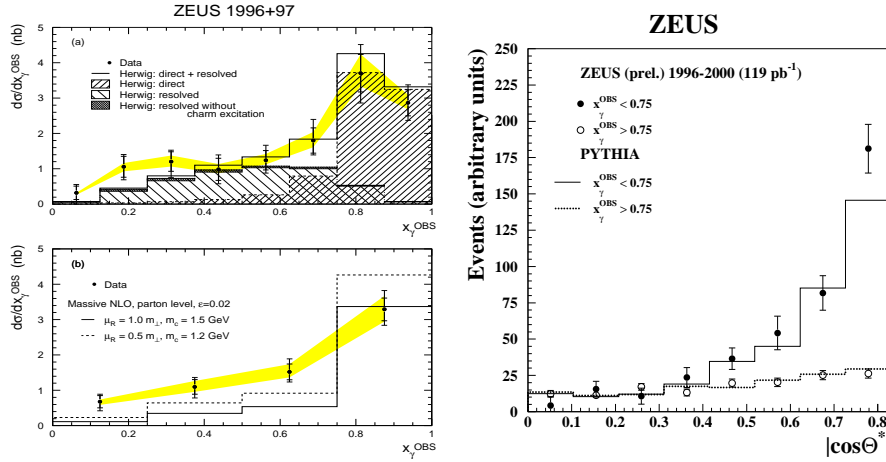


Figure 2. Left: Differential cross section $\frac{d\sigma}{dx_{\gamma}^{\text{OBS}}}$ in events with reconstructed D^* -mesons and two jets compared to LO massless (top) and NLO massive (bottom) QCD predictions. Right: Angular correlation between the jets and the beam axis (more details in the text).

massless LO prediction, where the bulk of the resolved events is due to charm excitation processes. In such processes, diagrams with a gluon propagator in the hard scattering box (see Figure 1b) most right) contribute. For these diagrams, the angle between the jets and the beam axis in the dijet center of mass system should peak more forward than for diagrams with a quark propagator. The angular distribution as measured by ZEUS⁵ (see Figure 2 right) is matched well by the overlaid LO massless MC prescription and exhibits, for the resolved part of the data ($x_{\gamma}^{\text{OBS}} < 0.75$), a stronger rise towards small angles, adding evidence to the charm excitation hypothesis.

In contrast to photoproduction the observed D^* -cross sections^{6,7} in *deep inelastic scattering* are in general fairly well described by the massive NLO calculations. Some excess of reconstructed D^* -mesons is found towards the forward region, which is especially sensitive to the quark fragmentation. A key interest in charm production in DIS is the contribution of charm events to the total ep scattering cross section, which can be expressed by the structure function $F_2^{cc}(Q^2, x)$. For this the D^* -measurements have to be extrapolated outside the accessible $p_t(D^*)$ and $\eta(D^*)$ regions. The F_2^{cc} measurements of H1 and ZEUS shown in Figure 3 agree within the errors with each other and with the overlaid massive NLO prediction. The structure function F_2^{cc} rises towards larger values of Q^2 and towards lower values of x , reflecting the behavior of the gluon density in the proton. At highest Q^2 and low x , the

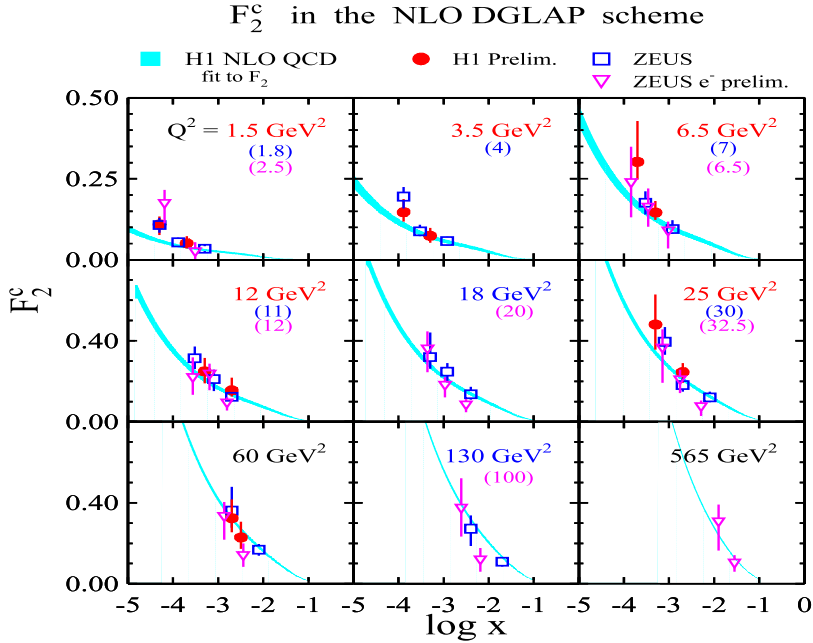


Figure 3. H1 and ZEUS measurements of the structure function $F_2^{cc}(Q^2, x)$ and comparison with NLO QCD theory.

charm contribution to the total cross section approaches the expected limit of 40%, when charm contributes to the proton structure effectively like an u quark.

3 Beauty

The expected beauty cross section at HERA is roughly two orders of magnitude smaller than for charm, due to the larger b-mass reducing the available phase space and the smaller b-quark charge. In order to find these rare processes, both H1 and ZEUS select dijet events with high p_t leptons (muons or electrons) from semileptonic heavy flavor decays. The beauty component in these events can be isolated from charm and light quark background by using the relative transverse momentum p_t^{rel} of the lepton to the associated jet, a quantity which is sensitive to the mass of the semileptonically decaying

quark. A second observable used by H1 with its central vertex detector is the signed impact parameter δ of muons with respect to the event vertex. This quantity is sensitive to the quark life time. Figure 4 shows the observed muon impact parameter spectrum in photoproduction events together with signal and background contributions. The relative fractions have been determined

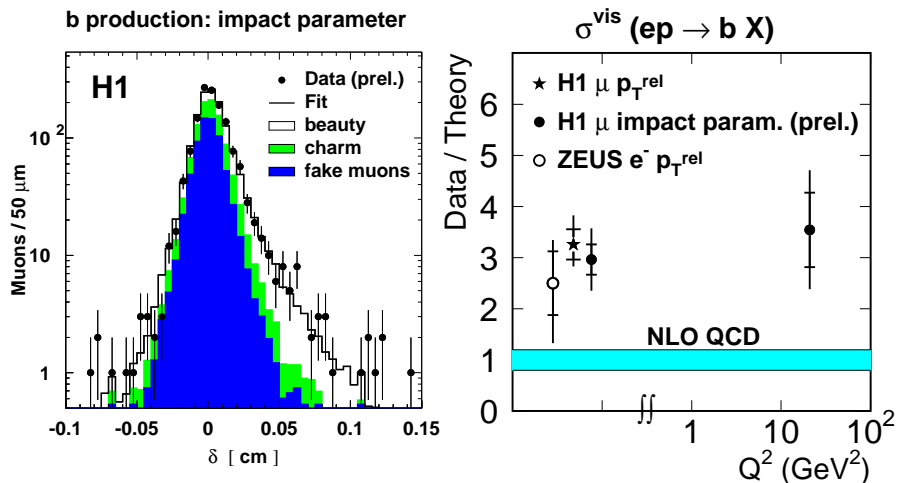


Figure 4. Left: H1 muon impact parameter spectrum and fitted signal and background contributions. Right: Comparison of H1 muon- and ZEUS electron-based measurements of the b cross section with massive NLO QCD.

from a likelihood fit to the two dimensional p_t^{rel} versus δ distribution, yielding a beauty component of about 27%. The same measurement technique has been used by H1 to determine for the first time the cross section for beauty production in the regime of deep inelastic scattering. H1 muon and ZEUS electron results^{8,9} have been compared with NLO calculations in the massive scheme as shown in Figure 4 (right). Three independent measurements in photoproduction and the measurement in DIS, with an average Q^2 of about 12 GeV² all exceed the NLO calculations.

4 Conclusions

An overview of recent results for open charm and beauty production in ep scattering at HERA has been presented. In photoproduction the measured charm cross sections overshoot the NLO QCD calculations in the massive scheme. Experimental evidence is found that a significant fraction of photoproduction

events with charm can be described by resolved photon processes, where the charm quarks are a part of the photon structure function. In deep inelastic scattering, the NLO QCD calculations give a fairly reasonable description of the observed charm cross sections. The measurements of the structure function F_2^{cc} show that, at large photon virtualities and low x , the events with charm constitute a major part of the total ep cross section. The beauty cross sections in photoproduction and in DIS, where it is measured for the first time, significantly exceed the NLO predictions in the massive scheme.

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