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Heavy flavour physics at HERA

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Abstract

Recent results in the production of heavy quark flavours in the H1 and ZEUS experiments at HERA are reviewed, and compared with the predictions of theory.

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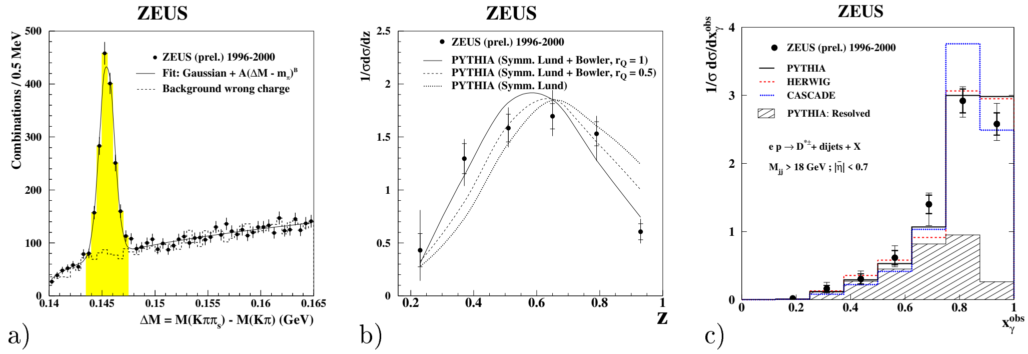

Figure 1. a) Mass difference plot in $D^* \to D$ decay via soft pion emission; b) distribution of $z = (E + p_{||})_{D^*}/(E + p_{||})_{\mathrm{jet}}$ for D^* production, compared with several PYTHIA-based fragmentation models; c) distribution in x_γ = fraction of incoming photon energy taken by dijet system. The resolved contribution is shaded.

1 INTRODUCTION

In recent years, the H1 and ZEUS experiments have made extensive studies of processes in which heavy-flavour quarks are produced, namely charm (c) and beauty (b). Like all parton interactions, such processes should be governed by QCD within the framework of the standard model; however they merit special study because the production of a heavy object means that the methods of perturbative QCD should be more widely applicable than in light-quark processes. On the other hand, in hard photoproduction and in deep inelastic scattering (DIS), more than one momentum-transfer scale becomes involved in the process, making the perturbative calculation potentially more complex. The HERA collider, in which an exchanged photon of virtuality Q^2 interacts with a proton in ep collisions, provides an excellent facility to investigate this area of physics. In addition to the understanding of the parton dynamics, the topics of study opened up include the mass of the c quark, the properties of fragmentation (hadronisation) of heavy quarks into jets, production mechanisms of heavy quarkonia such as the J/ψ meson, and the size of the b-production cross section. The last of these presents a particular challenge to theory.

2 OPEN CHARM PRODUCTION

The most straightforward way to identify open charm production is through the $D^* \to D$ decay via emission of a soft pion, where a narrow signal is seen on a usually manageable background (Fig. 1a). Fragmentation of the c quark into jets has been studied by determining the z parameter, which is a measure of the fraction of the c quark energy taken by the charmed particle (Fig. 1b). ZEUS have obtained best fits using PYTHIA (JETSET) fragmentation with a Peterson parameter of $\epsilon = 0.064$; some alternative possibilities are illustrated here. The shape of the x_γ distribution in the production of charm in dijet events through direct and resolved photoproduction (i.e. $Q^2 \approx 0$) is well described overall by PYTHIA and HERWIG and slightly less well by CASCADE (Fig. 1c), but it should be noted that the theory distributions have been normalised to the data. However ZEUS find an indifferent fit (Fig. 2a) to the NLO calculations of Frixione et al. (histogram) and Cacciari et al. (shaded band), even allowing for uncertainties on the renormalisation scale and c-quark mass in the range 1.3 - 1.7 GeV, lighter masses giving higher predictions. In DIS, measuring the $D^+ \to K^-\pi^+\pi^+$ channel for the first time at HERA, H1 obtain agreement with distributions predicted by the AROMA program (Ingelman et al., Fig. 2b).

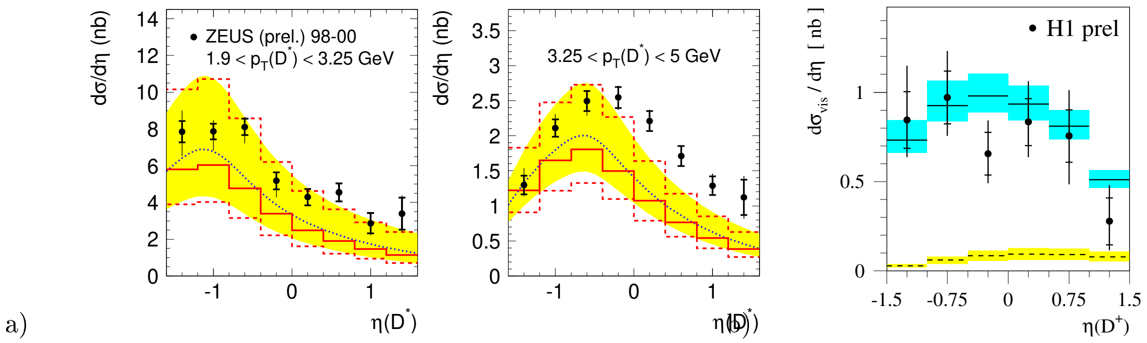

Figure 2. Distributions in pseudorapidity η of D^* mesons at HERA, in various ranges of transverse momentum a) in photoproduction b) in DIS, compared with theoretical predictions.

3 J/ψ PRODUCTION

Elastic production of J/ψ at HERA is a diffractive process. Here we consider inclusive production, which may be modelled theoretically by allowing the $c\bar{c}$ quark pair to be produced in a colour singlet (CS) or colour octet (CO) state, which then hadronises with a certain matrix element for J/ψ formation. Both H1 and ZEUS have studied this process. In photoproduction, there is no conclusive evidence for the CO term, although LO QCD + CS alone is too low. Either LO + CS + CO or NLO + CS (Krämer) will fit the data (Fig. 3a). In DIS, H1 find that CS + CO is excessive at low transverse momentum p_t, but at higher p_t more than just CS is needed in an LO model (Fig. 3b). Clearly a full NLO calculation is wanted here.

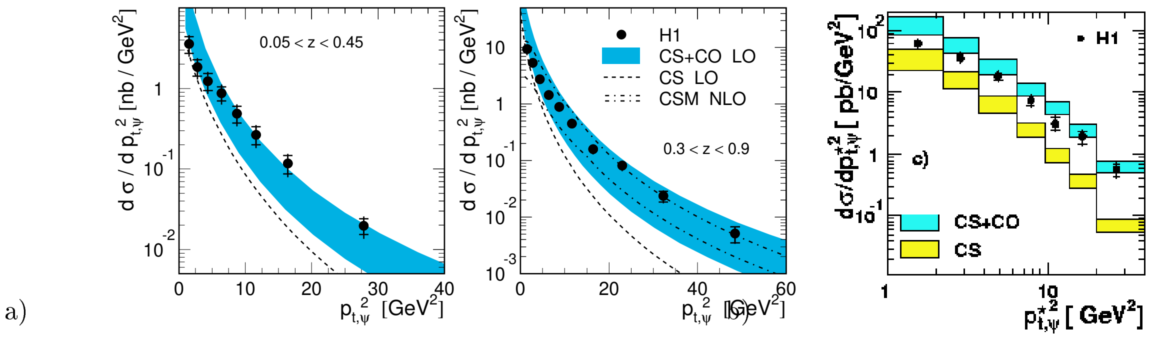

Figure 3. Inclusive J/ψ distributions a) in photoproduction for different kinematic ranges, b) in DIS, compared with NRQCD model of Kniehl and Zwirner.

4 BEAUTY PRODUCTION

The presence of a B meson is often detected in its semileptonic decay though a high-energy electron or muon which has either a large impact parameter at the event vertex or a large transverse momentum relative to the axis of a jet. In either case, a substantial charm background must be subtracted. There is considerable disagreement between the different HERA measurements of beauty production, and between these and existing theory. In photoproduction, the shape of the x_γ distribution is described well by the NLO calculation of Frixione (Fig. 4a), but this lies consistently lower than the data. Figure 4b summarises the overall situation. The recent ZEUS DIS cross section agrees with NLO QCD, but the corresponding photoproduction result, as noted, is higher than the theory, as are the other photoproduction measurements at HERA. The H1 DIS measurement is in poor agreement both with ZEUS and with theory. The ZEUS DIS measurement also agrees with the CASCADE model prediction, but is consistently higher than the LO calculation from RAPGAP.

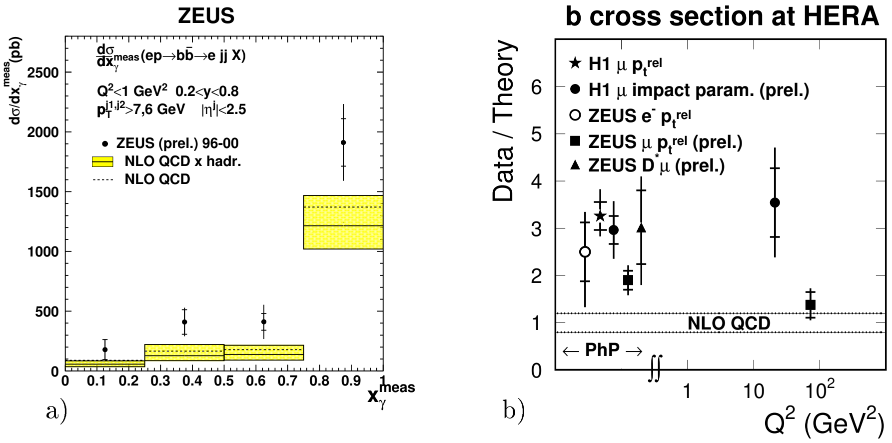

Figure 4. a) Distribution in x_γ of photoproduced dijet events containing a B meson, compared with NLO QCD theory; b) summary of B cross sections in photoproduction (PhP) and DIS, divided by the NLO QCD predictions.

5 CONCLUSIONS

Many aspects of charm and beauty production have been studied at HERA, but an assortment of experimental and theoretical questions remain. A light value of the effective c quark mass may be favoured, but a good theoretical description of the extensive D^* photoproduction data is still lacking; the theoretical situation in DIS appears better. In the area of inclusive J/ψ production, more developments in NLO theory are desirable. A theoretical breakthrough in understanding beauty photoproduction seems long overdue, but the experimental situation also needs clarification. Further details of the results may be found on the H1 and ZEUS experimental web pages, and a more extensive discussion has been given by the present author [1]. All the heavy flavour measurements will benefit substantially from more precise data, which should become available with the operation of high quality vertex detectors with the higher luminosities promised by HERA.

6 REFERENCES

1. P. J. Bussey, *Heavy flavour physics at HERA – a survey,* Int. J. Mod. Phys. A 17 (2002) 1065.