0.0.1 Heavy quark production

ZEUS UK groups have been involved in many aspects of the programme to undertand heavy quark production, both in data analysis and hardware and software aspects. Analyses investigating the production rate and nature of beauty and charm quarks are making significant contributions in a field which is still poorly understood. The production of charm quarks in DIS and accompanied by jets in photoproduction are now being measured precisely. This is discussed below along with the first measurement of open beauty production at ZEUS. Details of the ongoing hardware and software projects which will aid in the detection of heavy quarks are discussed in Section **??**.

0.0.2 Charm production in DIS

Heavy quarks, particularly charm, are produced copiously in DIS, predominantly via the boson-gluon fusion process. This means that measurements of charm production allow, in principle, a direct determination of the gluon density in the proton. Charm has traditionally be identified by two decay chains, $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$ or $D^0 \to K^-\pi^-\pi^+\pi^+$ which have low backgrounds but also have small branching ratios. Using a luminosity of 37 pb^{-1}, ZEUS has published a measurement of charm production via these two decay channels [1]. Predictions of NLO QCD describe the data well over the full range in Q^2. The gluon distribution in the proton used was determined from fits to inclusive measurements of the proton struture function, F_2^p. The consistency of this prediction with the charm data demonstrates the universality of the gluon distribution in the proton, independent of the final state. Using all currently available ZEUS data along with other decay channels will greatly improve the precision of these measurements. UK physicists are taking a leading rôle in both of these directions. Very high-statistics measurements of heavy quark production in DIS will be a major goal with the new data to come with the upgraded HERA accelerator and ZEUS experiment.

0.0.3 Charm production with jets

With the larger statistical sample in the photoproduction regime ($Q^2 < 1$ GeV^2), charm production accompanied by jets, is providing a detailed picture of many aspects of QCD and, in particular, the charm content of the photon. The first measurement of charm quarks inside jets was published in 1999 [2], with UK physicists as principal authors. The results showed for the first time that charm is produced copiously in resolved-photon events. Building on these results, resolved-photon processes have been studied further in order to understand if the charm quark is an active parton in the photon or produced only in the hard scatter.

In charm events where two jets are produced, measurements of the angle, θ^*, between the jet-jet axis and beam direction in the dijet rest frame allow the dominant propagator in the hard scatter to be determined. Events in which the photon acts as a pointlike object (boson-gluon fusion) have a quark propagator; the cross section as a function of $|\cos\theta^*|$ is therefore $\propto (1 - |\cos\theta^*|)^{-1}$. In contrast events with a gluon propagator have a cross section which is $\propto (1 - |\cos\theta^*|)^{-2}$. If charm were not active in the photon, then charm in resolved-photon processes would be produced only via gluon-gluon fusion which has a quark as the propagator. Events enriched in direct- or resolved-photon processes can be selected by requiring $x_\gamma^{\rm obs} > 0.75$ and $x_\gamma^{\rm obs} < 0.75$, respectively; the variable $x_\gamma^{\rm obs}$ is the fraction of the photon's momentum taking part in the production of the two jets of highest transverse energy. Figure 1 shows the measured $\cos\theta^*$ distribution in the two regions of $x_\gamma^{\rm obs}$. The measurement is based on a luminosity 119 pb^{-1}, almost all of the avaliable pre-upgrade data. For $x_\gamma^{\rm obs} > 0.75$, the data show a shallow rise consistent with events having a quark propagator, whereas for $x_\gamma^{\rm obs} < 0.75$, the data show a more rapid rise to high $\cos\theta^*$, consistent with the dominance of a gluon propagator. Resolved-photon events with a gluon propagator can only arise if the charm is active in the photon ($Q_\gamma g_P \to Qg$). The data is adequately described by predictions from the PYTHIA MC simulation and provides the strongest evidence so far of a heavy quark density in the photon.

Also investigating the nature of the photon in charm events, the evolution of its structure with virtuality, Q^2, has been measured. The measurement is again using a luminosity of over 100 pb^{-1}. It has been observed in inclusive dijet events that the ratio, $\sigma(x_\gamma^{\rm obs} < 0.75)/\sigma(x_\gamma^{\rm obs} > 0.75)$ falls with Q^2, indicating the suppression of resolved-photon events with increasing photon virtuality. Figure 2 shows the ratio $\sigma(x_\gamma^{\rm obs} < 0.75)/\sigma(x_\gamma^{\rm obs} > 0.75)$ for dijet events accompanied by a charm quark tagged by reconstructing D^* mesons. The data is compared to various leading order Monte Carlo models. In Figure 2(a), models in which the partonic content of the photon is both suppressed and has no suppression as a function of Q^2 is compared to the data. Both models adequately describe the features of the measurement. Comparisons of models with no explicit resolved-photon component are made in Fig. 2(b). The AROMA model, which implements the DGLAP evolution scheme, lies below the data. The CASCADE model, which implements a version of the CCFM evolution scheme, gives a good description of the data.

The fact that the ratio does not change significantly with Q^2 in this range is in marked contrast to the case in which the charm requirement is not made, and suggests that the suppression of the low-$x_\gamma^{\rm obs}$ cross section due to charm and the suppression due to photon virtuality are not independent. This has been quantified by extrapolating the measurement to the full kinematic range of the $D^{*\pm}$ meson. The extrapolation is shown in Fig. 2(c) and demonstrates that the ratio falls off more slowly in the presence of charm than it does when charm is not required.

0.0.4 Beauty production

Heavy quarks can also be detected by identifying electrons from their decay. This is done by measuring the distinctive rate of energy loss of electrons in the CTD, as well as the way they interact in the calorimeter. Results by UK physicists from this method show a significant production rate for beauty quarks as can be seen in figure 3. The beauty component is identified by measuring the transverse momentum of the electron relative to the jet axis since electrons from beauty decays are expected to have a harder p_T^{rel} spectrum owing to the mass of the b. The beauty fraction has been extracted by fitting the data distribution with Monte Carlo. The measurements was published in 2001 [3]

Existing measurements of open beauty production from HERA, $\gamma\gamma$ collisions at LEP and $p\bar{p}$ colliders show cross sections that are high when compared to standard NLO QCD predictions. A direct comparison of the ZEUS result with an NLO QCD prediction is also possible by using the Monte Carlo to extrapolate to the $b\bar{b}$ cross section in a limited kinematic region. This extrapolated cross section is shown in Fig. 4; it also lies above the theoretical prediction.

Understanding such results is an important test of QCD and a necessary step towards understanding the new physics potential of future colliders. The results also represent a substantial technical triumph in the operation and understanding of the CTD dE/dx readout, a UK responsibility from the beginning of ZEUS.

The presence of heavy quarks in the evolution of the photon structure offers a promising window for understanding the development of QCD structure, splitting functions and threshold effects. The ability at HERA to select concurrently on jet transverse energy, $E_T^{\rm jet}$, photon virtuality and $x_\gamma^{\rm obs}$, as well as to compare heavy flavour jets with untagged jets, makes it uniquely suitable for detailed studies in this area. Thus heavy flavour jet production will be a growth area, and is a major driving force behind the UK's involvement in the MVD. The GTT will play a vital part in allowing these events to be saved at relatively low $E_T^{\rm jet}$ even after the upgrade, particularly if charm enrichment can be implemented.

Bibliography

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[3] ZEUS Collaboration, J. Breitweg et al., *Measurement of open beauty production in photoproduction at HERA*, The European Physical Journal C 18 (2001) 625

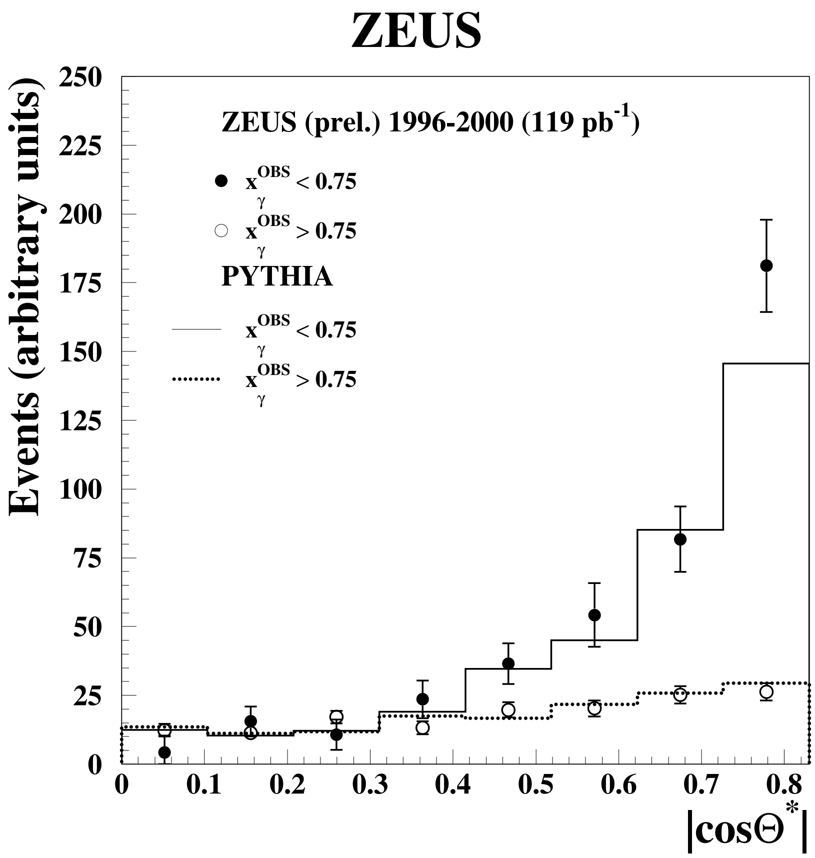

Figure 1: The $\cos\theta^*$ distribution in charm-tagged events for $x_\gamma^{\rm obs} > 0.75$ and $x_\gamma^{\rm obs} < 0.75$. Predictions from the PYTHIA MC are compared to the data.

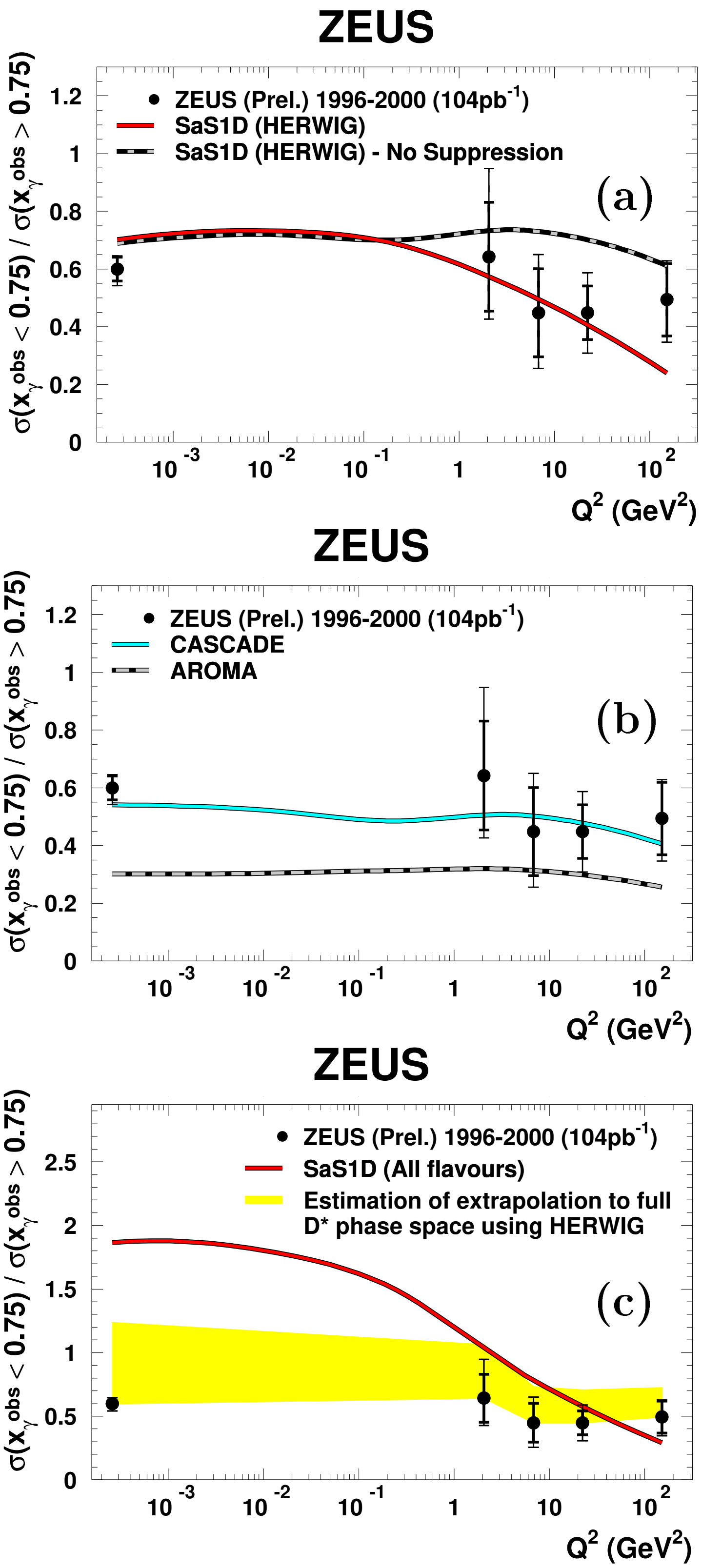

Figure 2: Ratio of low to high $x_\gamma^{\rm obs}$for events with a D^* meson comapred to (a) the SaS1D photon structure functions, (b) the AROMA and CASCADE MC models. In (c), the data is extrapolated to the full phase space of the D^* meson and compared to the SaS1D photon structure function.

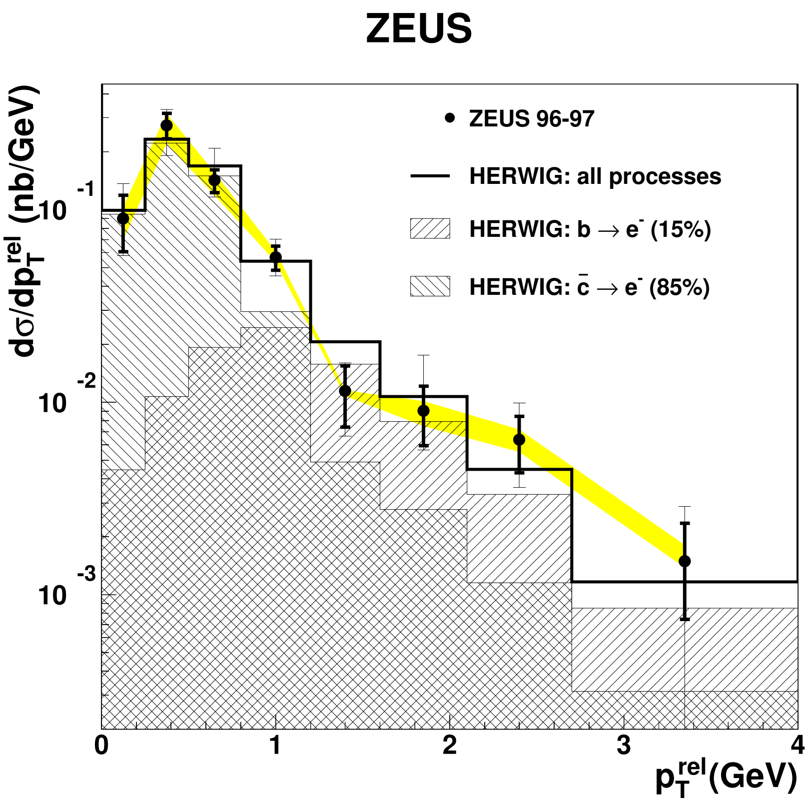

Figure 3: The transverse momentum of the electron relative to the jet axis, showing the presnece of beauty quarks

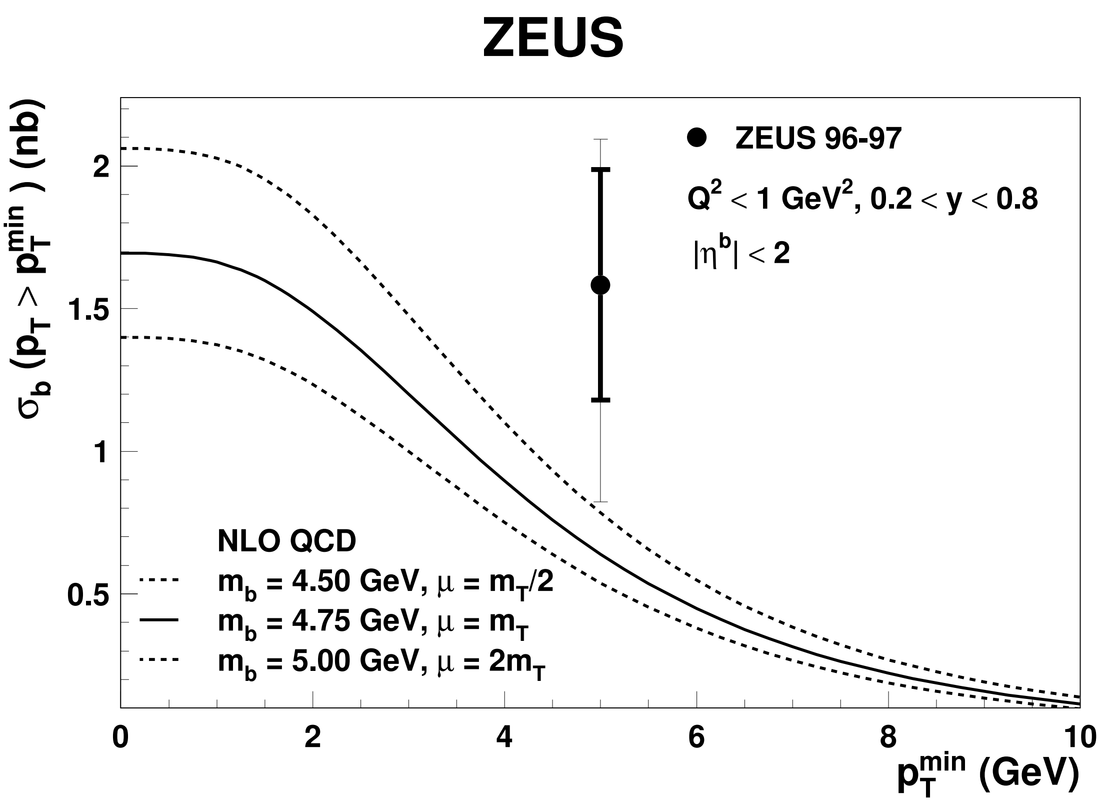

Figure 4: Extrapolated beauty quark cross section compared to NLO QCD predictions