HEAVY FLAVOUR PRODUCTION AT HERA

Dipartimento di Fisica “G. Galilei”
via Marzolo 8, I-35131 Padova, Italy
e-mail: longhin@pd.infn.it
on behalf of H1 and ZEUS collaborations

A selection of topics on open heavy quark production at HERA are reviewed here. Measurements of charm fragmentation parameters will be presented together with developments in the study of $D^*$ di-jet angular distributions. Charm production in deep inelastic scattering (DIS) is also discussed. Finally we deal with recent measurements of $b$ cross sections using impact parameters in both DIS and photoproduction regimes.

1 Introduction

Colliding $ep$ at a center of mass energy of $\sqrt{s} = 296 - 318$ GeV HERA provides an interesting environment for testing QCD predictions on heavy quark production. The virtual photon emitted by the incoming lepton provides a clean probe which, interacting with quarks and gluons in the proton, can initiate hard processes. The scale of the QCD interaction spans over a wide range of values which are under direct experimental control. This report will concentrate on a selection of some recent measurements performed by the H1 and ZEUS collaborations with a focus in particular on open $c$ and $b$ quark production in both deep inelastic scattering (DIS: $Q^2 > 1$ GeV$^2$) and photoproduction ($Q^2 \sim 0$ GeV$^2$) regimes.

2 Charm production

2.1 Fragmentation tests

The luminosity accumulated in the first phase of HERA running (1992-00, $\sim 130$ pb$^{-1}$) allows the study of particular decay channels which provide measurements of some phenomenological parameters used to describe charm fragmentation. ZEUS recently presented measurements of the branching fraction $f(c \rightarrow D_s^+)$, the strangeness suppression factor $\gamma_s$ (a parameter of Lund string model which rules the relative production of strange and non strange $D$ mesons) and the $P_v = V/(V + PS)$ ratio relating the production of the vector (spin-1) to the pseudoscalar charmed mesons. The values shown in tab.1 give support to the hypothesis of charm fragmentation universality: the $c$ quark hadronizes in the same way in $e^+e^-$ and $ep$ interactions.

$^aD_s^+(2536)$ is one of the $L = 1$ states of the $cs$ system
2.2 Di-jet angular distributions in $D^*$ events

Di-jet angular distributions, depending on the spin of the exchanged propagator, are an interesting tool one can use to gain insight into parton dynamics. Charm is produced in direct processes essentially through the $q$-exchange diagram $\gamma g \rightarrow c\bar{c}$ (Boson Gluon Fusion) (fig.2, top right) while resolved production receives contributions also from $g$-exchange processes like the one shown in the bottom right part of fig.2 ($cg \rightarrow cg$). The distribution of the variable $\cos\theta^* = \tanh \frac{\eta_{\text{jet}1} - \eta_{\text{jet}2}}{2}$, $\theta^*$ being the angle between the beam axis and the di-jet axis in the di-jet rest frame, has been studied for two different samples enriched in direct or resolved processes. This separation is defined experimentally by cutting on the jet-based observable $x_{\gamma}^{\text{OBS}} \equiv \sum_{\text{jets}} E_{T} e^{-\eta}/2yE_{e}$ which is an estimator of the fraction of $\gamma$ momentum entering in the hard scattering. Preliminary results from ZEUS show a steep angular rise for the resolved enriched sample ($x_{\gamma}^{\text{OBS}} < 0.75$) towards high $|\cos\theta^*|$ in marked contrast to a gentler behaviour in the direct enriched sample ($x_{\gamma}^{\text{OBS}} > 0.75$). The solid histograms are obtained with the PYTHIA LO Monte Carlo.

The result is consistent with the fact that the direct processes proceed via $q$-exchange (spin 1/2 propagator $\sim (1 - |\cos\theta^*|)^{-1}$ is expected) while resolved processes are dominated by gluon exchange (spin 1 propagator $\sim (1 - |\cos\theta^*|)^{-2}$ Rutherford scattering). This observation is consistent with an important gluon exchange contribution which is directly associated to the presence of c-excitation processes in the quasi-real photon.

2.3 Open charm in DIS: contribution to the $F_2$ structure function

Both H1 and ZEUS measured $F_2^c$, the charm contribution to the $F_2$ proton structure function, as $\frac{dF_2^c}{dxQ^2} = \frac{2\pi^2}{xQ^2} (1 + (1 - y)^2) \cdot F_2(x, Q^2)$. Two procedures for tagging charm have been exploited: the presence of $D^{*\pm}$ mesons or electrons from c semi-leptonic decays. After the signal has been identified the numbers of events in bins of $x$ and $Q^2$ are converted into an inclusive charm cross section extrapolating to the full phase space by means of Monte Carlo generators. Theoretical models are then used to relate the measured cross section to $F_2^c$. The plot in fig.3a shows how $F_2^c$ exhibits evident scaling violations (i.e. $Q^2$ dependence).
of $F_2^c$ to the inclusive $F_2$ is presented in fig.3b as a function of $x$ in $Q^2$ bins. Charm contribution to DIS is definitely sizeable ranging from $\sim 10\%$ of the inclusive $F_2$ at low $Q^2$ up to $\sim 40\%$ at $Q^2 \sim 500$ GeV and $x \sim 0.01$. This asymptotic contribution at high $Q^2$ is consistent with the picture in which the $c$ quark can be treated as any other massless quark ($Q^2 >> m_c$), the relative contribution following just from a simple charge counting rule. The drop of $F_2^c/F_2$ at high $x$ is related to the steep decrease of the proton gluon density with $x$ leading to a suppression of gluon initiated processes. The HVQDIS program which is based on DGLAP evolution equations, evaluating the BGF diagram at NLO, provides an overall satisfactory description of $F_2^c$ data. In addition to HVQDIS HI uses the Monte Carlo program CASCADE which implements the so called CCFM evolution scheme. Using this approach the description of data improves at lower values of $x$ and $Q^2$ (not shown).

![F_2 in the NLO DGLAP scheme](image)

Figure 3: charm contribution to $F_2$

### 3 Beauty production

Both HI and ZEUS have published results on $b$ production. The basic sample used for this measurement consists of events with jets and moderately high momentum leptons. Due to the high $b$ quark mass, the lepton from $b$ semi-leptonic decay tends to emerge at higher transverse momenta with respect to the jet axis ($p_{T}^{\mu}$) than in the case of $c$ or light quarks decays. This feature allows signal extraction on a statistical basis by fitting data with Monte Carlo distributions. The latest HI results benefit also from the presence of a micro-vertex detector information. The impact parameter distribution of candidate $\mu$ tracks ($\delta$) is endowed with an asymmetric tail at positive values (i.e. vertex is downstream of the associated jet) coming from the presence of long living particles. This independent signature provides results which are in good agreement with those obtained using the $p_{T}^{\mu}$ method. The distributions of the two observables $\delta$ and $p_{T}^{\mu}$ for a DIS selection ($2 < Q^2 < 100$ GeV$^2$, $0.05 < y < 0.7$, $p_{T}^{\mu} > 2$ GeV/c, $30^\circ < \theta^\mu < 135^\circ$) are shown in fig.4. The measured cross section ($39 \pm 8 \pm 10$) pb$^6$ lies significantly above the value of HVQDIS NLO calculation ($11 \pm 2$) pb. The LO Monte Carlo AROMA gives a prediction of 9 pb and CASCADE expects 15 pb. The NLO theoretical error has been evaluated by varying the renormalization and factorization scales, $m_b$ and fragmentation parameters. Similarly HI measured the cross section at low $Q^2$. In the following kinematic

---

$^6$In the following first quoted error is statistical and the second systematic.
region: $Q^2 < 1 \text{ GeV}^2$, $0.1 < y < 0.8$, $p_T^{rel} > 2 \text{ GeV/c}$, $30^\circ < \theta^\mu < 135^\circ$ the measured cross section is $\sigma_{vis} = (160 \pm 16 \pm 29) \text{ pb}$. When combined to a previous measurement which used just the $p_T^{rel}$ variable the result becomes: $\sigma_{vis} = (170 \pm 25) \text{ pb}$ which is well in excess with respect to various expectations which amount to $38, 67, (54 \pm 9) \text{ pb}$ for the AROMA, CASCADE and NLO FMNR calculations respectively. The first measurement of $b$ differential cross sections has also been recently carried out by ZEUS. Visible cross sections in the muon transverse momentum and pseudo-rapidity have been calculated. The signal component was determined in each bin through a fit to the $p_T^{rel}$ distribution. In this case PYTHIA expectation is not far from data with some deficit at high $\mu$ pseudo-rapidities where excitation contribution is expected to be large. HERA results on $b$ cross sections are summarized in fig.5. The ratio of the measured cross sections to the predictions at NLO is plotted for different $Q^2$ regimes. The inner (outer) error bands represent the statistical (total) experimental error, the shaded band covers the theoretical uncertainty.

Acknowledgments

I would like to thank my ZEUS and H1 colleagues for the suggestions I had from them for the preparation of this talk.

References

1. ZEUS Coll., contributed paper 497 to EPS2001, Budapest 2001
2. J. Breitweg et al. [ZEUS Coll.], Phys. Lett. B481 (2000) 213
3. ZEUS Coll., contributed paper 501 to EPS2001, Budapest 2001
4. K. Ackerstaff et al. [OPAL Coll.], Z. Phys. C76 (1997) 425
   A. Heister et al. [ALEPH Coll.], Phys. Lett. B526 (2002) 34-49
5. K. Ackerstaff et al. [OPAL Coll.] Eur. Phys. J. C 5 (1998) 1
   R. Barate et al. [ALEPH Coll.], Eur. Phys. J. C 16 (2000) 597
6. ZEUS Coll., contributed paper 499 to EPS2001, Budapest 2001
7. C. Adloff et al [H1 Coll.], Phys. Lett. B528 (2002) 199
8. J. Breitweg et al. [ZEUS Coll.] Eur. Phys. J. C 12 (2000) 35-52
9. ZEUS Coll., contributed paper 853 to ICHEP2000, Osaka 2000
10. B.W. Harris and J.Smith, Phys. Rev. D57 (1998) 2806
11. H. Jung and G.Salam, Eur. Phys. J. C 19 (2001) 351
12. C. Adloff et al., [H1 Coll.], Phys. Lett. B467 (1999) 156-164
13. J. Breitweg et al. [ZEUS Coll.], Eur. Phys. J. C 18 (2001) 625
14. H1 Coll., contributed paper 979/982 to ICHEP2000, Osaka 2000
15. H1 Coll., contributed paper 807 to EPS2001, Budapest 2001
16. ZEUS collaboration, contributed paper 496 to EPS2001, Budapest 2001