H1 Measurements of Open $\boldsymbol{b}$ Production

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Two measurements of the visible cross section for open b production at HERA are reported. In the first analysis, events with jets containing muons are used to obtain a sample enriched in b events. In the second analysis, events with pairs of like-sign muons are studied. Both measurements suggest that the visible b cross section is significantly larger than that predicted by leading order QCD,

1. Introduction

The study of heavy quark production is an important aspect of the program of research into QCD and proton structure at HERA. The heavy quark masses provide a natural cut-off preventing infrared divergences in perturbative calculations. At leading order,the production mechanism is almost exclusively boson-gluon fusion ($\gamma^{(*)}g \to q\bar{q}$), such that heavy quark production is sensitive to the gluon distribution of the proton.

Open charm cross sections have already been measured at HERA [1]. The cross section for open beauty production is expected to be approximately two orders of magnitude smaller than that for open charm production. Next to leading order QCD predictions for the total b cross section vary between 4.7 nb and 10 nb [2], depending on the assumptions on the b quark mass m_b and the proton parton distributions. The leading order Monte Carlo generator, AROMA [3] predicts the smaller value of 3.8 nb for $m_b = 4.75$ GeV with the MRS(G) parton distributions.

The large luminosities provided by HERA in recent years have allowed the first measurements of open b production cross sections. Two such measurements are described here, based on data taken by the H1 experiment in 1995-6 corresponding to a luminosity of 8.3 pb^{-1}. In order to maximise statistics, data are used in which the final state electron is not observed in the main electromagnetic calorimeters. This implies that the angle through which the electron is scattered is less than 2.2° and $Q^2 < 1$ GeV^2. The Jacquet-Blondel method [4] is used to reconstruct y.

Both measurements require the identification of muons in the instrumented iron return yolk of the H1 solenoidal magnet. The most challenging experimental task is the evaluation of the probability for misidentifying a hadron as a muon in this detector. Section 2 of this document explains the method used to evaluate this misidentification probability. Sections 3 and 4 describe the two measurements themselves.

2. Muon Misidentification Background

In the instrumented iron detector, muons can be faked by hadronic particles either due to in-flight decay ($\pi^\pm$ or $K^\pm \to \mu^\pm \nu_\mu$) or due to leakage from the hadronic calorimeter. The probabilities $\mathcal{P}_h^\mu(p,\theta)$ that a hadron $h = \pi, K, p$ fakes a muon have been evaluated as a function of momentum (p) and polar angle (θ) using large samples of simulated hadrons, after checking carefully that the detector simulation describes the data very well. One demonstration that $\mathcal{P}_h^\mu$ as extracted from simulated data gives a good description of real data is shown in figure 2. Here, a clean sample of $\pi^\pm$ tracks is obtained from the data by selecting $K_s^0 \to \pi^+\pi^-$ decays. Those $\pi^\pm$ tracks that are associated with reconstructed tracks in the muon detector are shown as a function of p and θ, where $\theta = 0$ in the outgoing proton direction. The distributions of identified fake muons are compared to the predictions obtained by convoluting the p and θ distributions of all $\pi^\pm$ tracks from the K_s^0 sample with $\mathcal{P}_h^\mu$ as determined us-

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ing the simulation. The agreement between the number of fake muons obtained in the two approaches is good. This is also the case where a sample of $K^{\pm}$ from the decay $\phi \to K^+K^-$are tested in a similar way. The values of $\mathcal{P}_h^{\mu}(p,\theta)$ obtained from the simulated data do not exceed 0.02 at any value of p or θ for any of $h = \pi, K, p$.

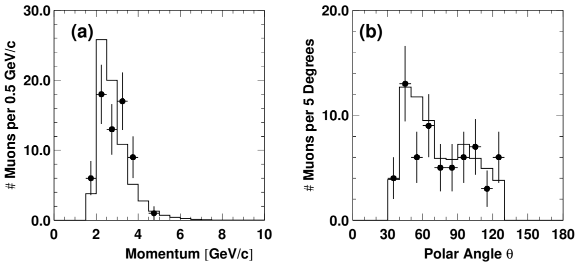

Figure 1. Distributions in p and θ of misidentified muons from $K_s^0 \to \pi^+\pi^-$ decays. There are 64 events in the sample as determined directly from the data (points). The simulated $\mathcal{P}_h^{\mu}(p,\theta)$ convoluted with the distributions from the full K_s^0 sample predicts 69.8 events (histograms).

3. Inclusive Muon Measurement

In the first analysis method, b quarks are identified through their semi-leptonic decay $b \to \mu\nu_\mu X$. A sample of events containing at least two jets is obtained, using a cone algorithm with cone radius $\sqrt{(\Delta\eta^2 + \Delta\phi^2)} = 1$, jet transverse momentum $p_t^{\rm jet} > 6$ GeV and jet pseudorapidity in the range $|\eta_{\rm lab}^{\rm jet}| < 2.5$. Heavy quark production is identified by requiring that at least one of the jets contains a muon with $p_t^{\mu} > 2$ GeV and $35 < \theta_\mu < 130°$. Beauty and charm events are separated on the basis of the transverse momentum $p_t^{\rm rel}$ of the μ relative to the thrust axis [2] of the jet. The heavier mass of the b than the c quark implies that the $p_t^{\rm rel}$ distribution is harder for the case of b production than for c.

Figure 3 shows the $p_t^{\rm rel}$ distribution of the selected events. To extract the contribution from b quarks, the data are subjected to a fit with three terms. The first term is the contribution from light quark initiated jets in which a muon is faked by a hadron. This term is fixed in the fits and is determined from the muon misidentification probabilities, $\mathcal{P}_h^{\mu}$ described in section 2. The ratio of $\pi : K : p$ contained in the jets is taken from the JETSET hadronisation model [5]. The second and third terms in the fit are the contributions from b quarks (via $b \to \mu\nu_\mu X$ or $b \to c \to \mu\nu_\mu X$) and from c quarks (via $c \to \mu\nu_\mu X$). The shapes of the distributions from these two sources are taken from the predictions of the AROMA Monte Carlo model. There is thus only one parameter in the fit, corresponding to the relative normalisation of the b and c contributions.

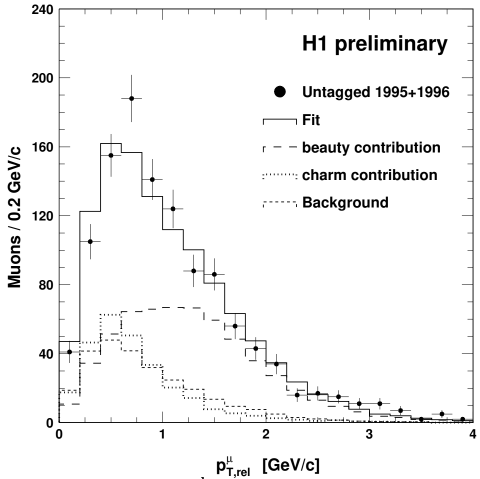

Figure 2. The $p_t^{\rm rel}$ distribution of events with two jets, at least one of which contains a muon. The decomposition of the data into c, b and background contributions is shown.

The fit results in a b contribution of 51.4 ± 4.4 (stat.)% and a c contribution of 23.5 ± 4.3 (stat.)% with a 23.5% contribution from misidentified hadrons. To check for uncontrolled systematic effects, the decomposition of the $p_t^{\rm rel}$ distribution extracted from the fit is used together with the AROMA model of b and c events to predict the p_t and θ distributions of the muons and jets used in the analysis. The results are in very good agreement with the data, as can be seen from figure 3.

The numbers of c and b quark initiated events extracted from the fit to the $p_t^{\rm rel}$ distribution are corrected for detector and trigger effects to ex-

[2] The thrust axis maximises the thrust $T = \sum_{i\neq\mu} |p_i^z| / \sum_{i\neq\mu} p_i$ of particles i comprising the jet.

tract the open charm and beauty cross sections in the visible region of phase space defined by the cuts on the p_t and θ of the μ and jet, with $Q^2 < 1$ GeV^2 and $0.1 < y_{JB} < 0.8$. The resulting charm cross section is consistent with that extracted directly in measurements of D^* mesons [1]. The visible beauty cross section is 0.93 ± 0.08 (stat.) $^{+0.21}_{-0.12}$ (syst.) nb. This is a factor of around five larger the leading order QCD prediction from the AROMA model (0.19 nb).

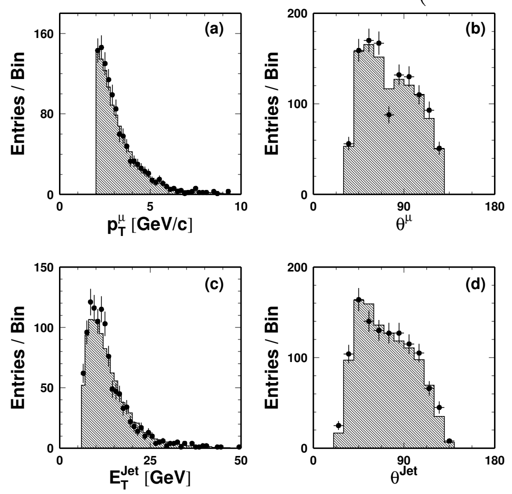

Figure 3. Control distributions in muon and jet p_t and θ. The data (points) are compared with the AROMA simulation (histograms) with b, c and background contributions determined by the fit to the p_t^{rel} distribution.

4. Di-muon Measurement

In the decays of heavy flavour quark-antiquark pairs, there are many ways of producing pairs of muons of unlike sign. One such example is $c \to s\mu^+\nu_\mu$; $\bar{c} \to \bar{s}\mu^-\bar{\nu}_\mu$. However, in the low orders of QCD, pairs of muons of the same sign can only be produced from a $b\bar{b}$ pair. This can occur for example in the decay chain $b \to c\mu^-\bar{\nu}_\mu$; $\bar{b} \to \bar{c}X \to \bar{s}\mu^-\bar{\nu}_\mu X$. It can also occur due to $b\bar{b}$ mixing.

In a second analysis of open b production, events containing pairs of like-sign muons with $p_t^\mu > 2$ GeV and $35 < \theta^\mu < 130°$ are selected. Nine such events are found. The principal background again arises from the misidentification of hadrons as muons. This background is estimated to be 3.0 ± 0.2 events, using the $\mathcal{P}_h^\mu(p,\theta)$ factors described in section 2. After subtracting the muon misidentification background, the remaining signal is corrected to yield a cross section in the kinematic region defined by the p_t^μ and θ^μ cuts, with $Q^2 < 1$ GeV^2 and $0.1 < y_{JB} < 0.9$. The resulting visible cross section is 55 ± 30 (stat.) $\pm\, 7$ (syst.) pb, which again is larger than the leading order AROMA prediction (17 pb).

5. Conclusions and Outlook

Open b production at HERA has been measured by two complementary methods. Particularly in the p_t^{rel} measurement, the resulting cross sections are found to be significantly larger than those predicted in leading order of QCD. It remains to be seen whether higher order QCD corrections can account entirely for the discrepancy, though next-to-leading terms increase the predictions by a factor of around 2. The prospects for more precise measurements in the future are very good. Several times more statistics are available for analysis from 1997 data and beyond. The H1 silicon micro-vertex detectors are also now fully commissioned. Further increases in statistics will be available after HERA is upgraded in 2000-2001.

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