First Observation of Open b Production at HERA

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The first observation of open b production, in ep collisions is reported. The measurement was carried out using data taken by the H1 experiment at HERA at a centre of mass energy of $\sqrt{s} = 300$ GeV. Events containing muons and jets were used to select a data sample enriched in b events. The cross section was found to be a factor ~ 5 higher than calculations based on LO-QCD models.

1 Introduction

The study of heavy quark production in electron–proton scattering provides an important testing ground for QCD. At the electron–proton collider HERA with an ep centre of mass energy $\sqrt{s} = 300$ GeV, heavy quarks are produced predominantely by the photon gluon fusion process $\gamma g \rightarrow q\bar{q}$ ($q = c, b$), where a real or virtual photon emitted by the electron and a gluon from the proton generate a heavy quark pair.

The dominant contribution to heavy quark production is due to the exchange of an almost real photon (*photoproduction*), where the negative squared four-momentum transfer carried by the photon is $Q^2 \approx 0$. The heavy quarks hadronize and are then either detected as *"open charm (beauty)"*, i.e with charm(beauty) hadrons, or alternatively as *"hidden charm(beauty)"* states such as $J/\psi(\Upsilon)$.

The kinematics of the ep interactions are described by three independent variables, the centre of mass energy $\sqrt{s}$, the photon four momentum squared $q^2 = -Q^2$ and either one of the scaling variables $y = (q \cdot P / l \cdot P)$ the inelasticity of the ep-interaction, or the Bjorken-x $x = Q^2/(2P \cdot l)$, where P and l denote the four-momenta of the proton and the electron, respectively. The $\gamma - p$ centre of mass energy squared is given by $W_{\gamma p}^2 = W^2 \approx ys - Q^2$.

Heavy quark results at HERA are dominated by charm production. The cross section of open b production at HERA is expected to be suppressed by about two orders of magnitude compared to $\sigma(ep \rightarrow c\bar{c}X)$. The predictions for open b production at HERA for the NLO QCD calculations [1,2,3] are between 4.7 and 10 nb depending on the assumptions for the mass of the b quark and the parton density function (pdf) used. The expectation of AROMA [4] Monte Carlo event generator, which is based on LO-QCD matrix elements with parton showers, is 3.8 nb for a mass of the b quark, $m_b = 4.75\,\mathrm{GeV}/c^2$ and the MRS(G) pdf. The first observation of open b production at HERA is reported here.

2 Open Beauty Photoproduction

In the following, two methods used to identify b events in the H1 data sample are presented. For this purpose the data selected during the 1995–96 running periods are used, corresponding to an integrated luminosity of $\mathcal{L} = 8.3\,\mathrm{pb}^{-1}$.

2.1 Single Muon Analysis

To identify b events the semileptonic b decays into muons are used. Events are selected with the requirement of at least two jets with $E_T > 6\,\mathrm{GeV}$ and at least one muon in the central region of the detector with a transverse momentum $p_T^\mu > 2\,\mathrm{GeV}/c$. The muon has to be found within one of the jets. Beauty and charm events are separated on a statistical basis using the transverse momentum of the muon $p_{T,rel}^\mu$ relative to the thrust axis of the jet defined as the direction in which T is maximum,

$$T = \max \frac{\sum |p_i^L|}{\sum |p_i|} \quad i = \text{all the particles in the jet}$$

where p_i and p_i^L are the momentum and its longitudinal component respectively. Because the b quark is heavier than the c quark it is expected that the $p_{T,rel}^\mu$ distribution peaks at higher values for the former. The shapes of the $p_{T,rel}^\mu$ distributions for beauty and charm are taken from the Aroma Monte Carlo event generator.

The main problem is to identify the fake muon contribution in the event sample.The background consists of events with two jets and with one of the hadrons identified as a muon in the detector. To solve this problem it is essential to know the probability that a hadron h fakes a muon, $\mathcal{P}_h^\mu(p,\theta)$, where $h = \pi, K, p$. The probability functions $\mathcal{P}_h^\mu(p,\theta)$ are defined as a function of the momentum and the polar angle of the hadron.

One can find these probability functions directly from the data by studying K_S^0, ϕ and Λ decays as a clean source of pions, kaons and protons. However, the available data do not allow the determination of these functions to sufficient precision. Therefore, after it was checked that the detector simulation describes the data very well, big Monte Carlo samples with single pion, kaon and proton events were generated and passed through the full detector simulation.

To verify that the method works the sample of pions from the K^0S decays in the data is used. In this sample, the number of pions misidentified as muons is known. Then for each of the pions of the sample the probability that it fakes a muon is calculated and is used as weight to plot the θ, p distributions. As can be seen in figure 1, the agreement of the expected distributions with these fake muons actually found is excellent, both in shape and magnitude. Similar tests have been performed for the case of the kaons using events of elastic ϕ production.

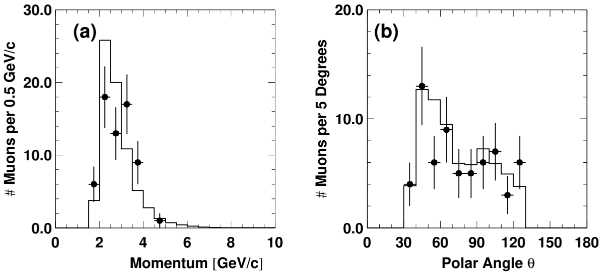

Figure 1: Momentum (a) and polar angle (b) distributions for fake muons due to a pion sample. The pions are identified via the decay $K_S^0 \to \pi^+\pi^-$. The filled points show the muon yield as measured in data. The solid histogram gives the estimate of the muon yield as obtained by assigning $P_\pi^\mu(p,\theta)$ as weight to every pion and summing the weights of the entire pion sample. The measured yield is 64 fake muons; the estimate amounts to 69.8.

Having the $\mathcal{P}_h^\mu(p,\theta)$ functions one can use the data event sample with two jets with $E_T > 6\,\mathrm{GeV}$and calculate the expected background in the $p^\mu_{T,rel}$ distribution in shape and absolute magnitude. The assignment of a hadron to a pion, kaon or proton was done according to the fractions of these particles as given by JETSET[5]. This hypothesis is supported by the measurements of the SLD[6] and DELPHI[7] collaborations.

After the contribution of the fake muons in the $p^\mu_{T,rel}$ spectrum is estimated both in shape and absolute magnitude, the components of beauty, charm are fitted to the measured $p^\mu_{T,rel}$ distribution. The result is shown in figure 2a.

The relative composition of the data sample is determined from the fit to the $p^\mu_{T,rel}$ distribution and amounts to $f_b = 51.4 \pm 4.4\%$ (beauty), $f_c = 23.5 \pm 4.3\%$ (charm), and $f_{fake} = 23.5\%$ (background, fixed). Other distributions, e.g. the muon transverse momentum and polar angle as well as the jet transverse energy and polar angle distributions, are very well described with this data composition. The pseudorapidity, η, distribution of the jet containing the muon is shown in figure 2b. The data are produced mainly in the forward direction.

The open beauty cross section is determined from the number of muons N_b^μ attributed by the fit to b decays which are in the visible range $Q^2 < 1\,\mathrm{GeV}^2$,

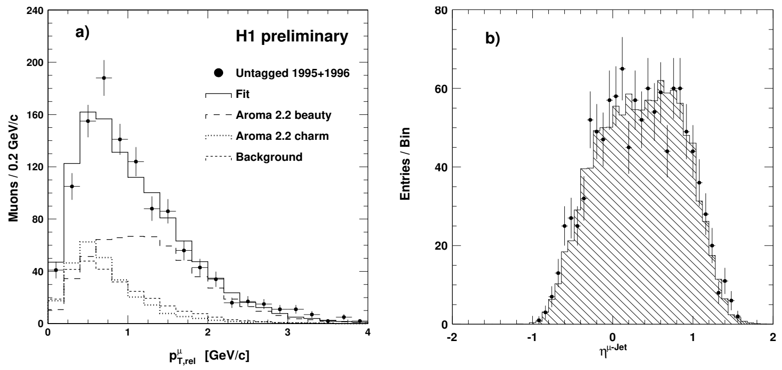

Figure 2: a) The measured $p^{\mu}_{T,rel}$ distribution and the result of the fit and the contribution of the different components. b) The pseudorapidity distribution of the jet containing the muon for the data (dots) and the sum of the different components (filled histogram) as given by the fit.

$0.1 < y_{JB} < 0.8$, $p^{\mu}_{T} > 2.0\,\mathrm{GeV}/c$, $35° < \theta^{\mu} < 130°$:

$$\sigma_{vis}(ep \to b\bar{b}X) = 0.93 \pm 0.08(stat.)\,^{+0.21}_{-0.12}(syst.)\,\mathrm{nb}, \qquad \text{(H1 preliminary)}$$

where the first uncertainty is statistical and the second systematic. The estimated visible beauty cross section of Aroma amounts to 0.19 nb, which is roughly a factor of five below the measured value. This measurement has been cross-checked using the Herwig 5.9 [8] Monte Carlo event generator. The difference from Aroma is of the order of 5% and is included in the systematic error.

The visible charm cross section has been measured with the same method and shows good agreement with the expectation. Using Aroma for the extrapolation to the full kinematic range, the total charm cross section is consistent with the value measured with the reconstruction of D^* mesons [9].

2.2 A Dimuon Analysis

An alternative method to search for b production is by using like-sign dimuon events. It has been noted that the only physics channel that can produce like-sign dimuons at HERA is b production. The number of like-sign dimuon events, $N_{\pm\pm}$, can be written as:

$$N_{\pm\pm} = N_{bb} + N_{bf} + N_{cf} + N_{ff}$$

where N_{bb} is the "real" number of dimuons both coming from b decays, N_{bf} (N_{cf}) the number of events where we have one $b(c)$ decaying via a semi-muonic channel and one like-sign hadron misidentified as muon, and N_{ff} is the number of events that both muon candidates are due to hadron misidentification. Note that $N_{bf} + N_{cf} + N_{ff}$ is nothing more than the data sample with the single muon candidates combined with a hadron faking a muon. Therefore, one can use the single muon event sample in combination with the $\mathcal{P}_h^{\mu}(p, \theta)$ to estimate the background. In the H1 data 9 events with like sign dimuons are found and the expected background is 3.0 ± 0.15 events. The cross section in the visible range ($0.1 < y_{JB} < 0.9$, $P^{\mu}_{T\ 1(2)} > 2.0\,\mathrm{GeV}/c$, $35° < \theta^{\mu} < 130°$) is found to be

$$\sigma_{vis}(ep \rightarrow b\bar{b}X) = 55 \pm 30(stat.) \pm 7(syst.)\,\mathrm{pb}, \qquad \text{(H1 preliminary)}$$

The expectation of Aroma is 17 pb.

3 Conclusion

The open b production cross section was observed for the first time at HERA with the H1 detector using semi-muonic decays of the b quarks. The cross section found to be ~ 5 higher than expectation using LO-QCD. The dimuon analysis shows a tendency of the data to be higher than the LO-QCD expectation but the statistical significance is still small.

Acknowledgments

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References

1. R.K. Ellis, and P. Nason, *Nucl. Phys.* B **312**, 551 (1989).
2. J. Smith and W. L. van Neerven, *Nucl. Phys.* B **374**, 36 (1992).
3. S. Frixione *et al*, *Phys. Lett.* B **348**, 633 (1994).
4. G. Ingelman, J. Rathsman and G. A. Schuler, *Comp. Phys. Com.* **101**, 135 (1997).
5. T. Sjöstrand and M. Bengtsson, *Comp. Phys. Com.* **43**, 367 (1987).
6. SLD Collab., "Production of $\pi^{\pm}$, $K^{\pm}$, K^0, K^{*0}, ϕ, p and Λ^0 in Hadronic Z decays", contributed paper # 287 to the International Europhysics Conference on HEP, Aug. 19-26, 1997, Jerusalem, Israel.
7. DELPHI Collab., "$\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ production in $Z^0 \rightarrow q\bar{q}$, $Z^0 \rightarrow b\bar{b}$ and $Z^0 \rightarrow u\bar{u}, d\bar{d}, s\bar{s}$" , contributed paper # 541 to the International Europhysics Conference on HEP, Aug. 19-26, 1997, Jerusalem, Israel.
8. G. Marchesini *et al*, *Comp. Phys. Com.* **67**, 465 (1992).
9. H1 Collaboration, *Nucl. Phys.* B **472**, 32 (1996).