Photon 01

BOTTOM PRODUCTION AT HERA

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The production of bottom quarks, tagged by their semi-leptonic decay, has been studied in *ep* collisions at HERA with the ZEUS and H1 detectors. Results are reported from both experiments on the total and differential bottom cross-sections.

1 Introduction

The study of heavy quark production in positron–proton scattering provides an important testing ground for QCD, and helps in understanding the structure of the proton and photon. At the *ep* collider HERA with a centre of mass energy $\sqrt{s} = 300$ GeV, heavy quarks are produced predominantly in collisions between a photon, emitted by an incoming positron, and a proton. The main contribution to the cross section comes from the exchange of an almost real photon (*photoproduction*, PHP), i.e. when the four–momentum squared, Q^2, of the exchanged photon is $Q^2 \simeq 0$. If $Q^2 \gg 1$ GeV^2 (*deep inelastic scattering*, DIS) the cross-section is lower, but still measurable at HERA.

Two types of leading order (LO) processes can contribute to heavy quark production: in *direct* photon processes, the photon acts as a pointlike particle, coupling directly to a parton from the proton, while in *resolved* processes it fluctuates into a state of quarks and gluons, with one of these partons taking part in the hard interaction. Resolved photon processes, which include also flavour excitation processes where a heavy quark is extracted directly from the photon or from the proton, are expected to be more important for PHP than for DIS.

Here, the results obtained from ZEUS and H1 analyses on bottom production, based on events tagged by its semi–leptonic decay into muons or electrons, are reported, in both the DIS and PHP regimes, as total and differential cross sections. The results obtained are compared to Monte Carlo simulations implementing LO matrix elements and to NLO QCD calculations. The Monte Carlo models used in the analyses are PYTHIA [1] and HERWIG [2], which implement both direct and resolved photon processes, AROMA [3], which has no resolved photon component, and CASCADE [4], which contains only the direct photon component but implements the CCFM [5] gluon evolution in the proton.

2 H1 PHP analyses

The H1 collaboration has performed two measurements of bottom production in PHP, the first is published [6] using 1996 data ($\mathcal{L} = 6.6\ \text{pb}^{-1}$), while the latter is preliminary [7], and uses 1997 data ($\mathcal{L} = 14.7\ \text{pb}^{-1}$) when the vertex detector was fully commissioned. The two analyses are very similar in their methods, the main difference is the discrimination between signal and background. In the first, use was made of p_T^{rel}, the transverse momentum of the muon relative to the axis of the closest jet. In the second analysis, the impact parameter variable, δ, was also used: since a b particle has a longer mean life, the δ distribution is expected to show a tail for positive values, coming from bottom events.

A more detailed description of the first measurement of open bottom production by H1 can be found elsewhere [6], while here the second one is reported in detail.

The selection of the data was made by requiring the presence in the event of at least two jets with $E_T > 5$ GeV, reconstructed with the k_T–algorithm [8] and at least one muon with $p_T^\mu > 2$ GeV and $35^\circ < \theta^\mu < 130^\circ$, associated with one of the jets by the jet algorithm. The data sample was limited to the region $Q^2 < 1\ \text{GeV}^2$ (photoproduction regime) with an inelasticity $0.1 < y < 0.8$. For each muon candidate, the impact parameter δ in the plane transverse to the beam axis and the p_T^{rel} variable were calculated.

Both p_T^{rel} and δ (fig.1) distributions were plotted for the data and a likelihood fit [9] to the spectra was performed. The fits used the shapes of the distributions of b and c events from the AROMA Monte Carlo simulation, and those of fake muon events from a tagged photoproduction event sample fulfilling the same selection criteria as the signal sample, except that no muon identification was required. The results for the fractions f_i obtained from the δ distribution were $f_b = (26 \pm 5)\%$, $f_c = (24 \pm 12)\%$ and $f_{fake} = (50 \pm 5)\%$, while from the p_T^{rel} fit the fraction of bottom in the data was estimated to be $f_b = (27 \pm 3\%)$ (in this latter case the background from light quarks was kept fixed since charm and light quarks events could not be distinguished by the fit). Results from the two fits were in good agreement and were therefore combined in a likelihood fit to the two–dimensional distribution of these variables. The values found were then $f_b = (27 \pm 3\%)$, $f_c = (27 \pm 7)\%$ and $f_{fake} = (46 \pm 7)\%$, and were used to extract the visible cross section in the kinematic region defined by $Q^2 < 1\ \text{GeV}^2$, $0.1 < y < 0.8$, $p_T^\mu > 2$ GeV and $35^\circ < \theta^\mu < 130^\circ$ (the same as for the previous analysis [6]):

$$\sigma_{vis}(ep \to b\bar{b}X \to \mu X') = 160 \pm 16(stat.) \pm 29(syst.)\ \text{pb}. \qquad (1)$$

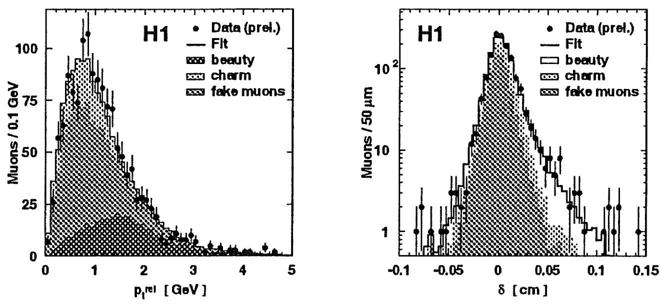

Figure 1. $p_T^{\rm rel}$ (left) and impact parameter (right) distributions and their decomposition from the likelihood fit. In the $p_T^{\rm rel}$ distribution, the normalisation for the fake muon contribution is fixed.

This value is in very good agreement with the published one:

$$\sigma_{vis}(ep \to b\bar{b}X \to \mu X') = 176 \pm 16(stat.)^{+26}_{-17}(syst.) \text{ pb.} \tag{2}$$

The two results are then combined to obtain:

$$\sigma_{vis}(ep \to b\bar{b}X \to \mu X') = 170 \pm 25 \text{ pb.} \tag{3}$$

The prediction from the AROMA Monte Carlo is 38 pb, while CASCADE gives a value of 67 pb. NLO calculations by Frixione et al. [10] give a value of (54 ± 9) pb, more than a factor 3 below the measured value.

3 H1 DIS analysis

A similar analysis was carried out by the H1 Collaboration [11] in the DIS regime. The kinematic region was defined by $2 < Q^2 < 100$ GeV^2, $0.05 < y < 0.7$, and the same cuts on the muon as in the previous analysis. The fraction of bottom in the data was extracted by a combined fit on $(\delta, p_T^{\rm rel})$, as in the PHP regime, and found to be $f_b = (43 \pm 8)\%$. The corresponding visible cross section is:

$$\sigma_{vis}(ep \to bX \to \mu X) = 39 \pm 8(stat.) \pm 10(syst.) \text{ pb.} \tag{4}$$

The result obtained is again well above the theoretical expectations, since NLO calculations by HVQDIS [12] predict (11 ± 2) pb, AROMA 9 pb and CASCADE 15 pb.

4 ZEUS $p_T^{\rm rel}$ analysis, electron channel

The ZEUS Collaboration has published [13] the results of an analysis on bottom photoproduction with events tagged by its semi–leptonic decay into electrons, using $\mathcal{L} = 38.5$ pb^{-1} of data collected in 1996–97. The events were selected by requiring the presence of at least two jets with $E_T^{\rm jet1(2)} > 7(6)$ GeV and $\eta^{\rm jet1(2)} < 2.4$, reconstructed with the k_T–algorithm [8], at least one electron with $p_T^{e^-} > 1.6$ GeV and $|\ \eta^{e^-}\ | < 1.1$, and $0.2 < y < 0.8$. Other cuts were imposed in order to limit the data sample to $Q^2 < 1$ GeV^2.

The bottom cross section was extracted by fitting the $p_T^{\rm rel}$ distribution of the data to the sum of contributions from bottom and charm. The fraction of bottom found was $f_b = (14.7 \pm 3.8)\%$, in good agreement with the predictions by HERWIG (16%) and PYTHIA (19%). By using that value of f_b, the cross section for bottom production in the restricted region previously defined is calculated to be:

$$\sigma^{b \to e^-}(e^+ p \to e^+ \text{ dijet } e^- \ X) = 24.9 \pm 6.4^{+4.2}_{-7.3} \text{ pb.} \qquad (5)$$

LO Monte Carlo predictions are 8 pb (HERWIG) and 18 pb (PYTHIA and CASCADE).

This cross section was then extrapolated to the parton level in a restricted range of the transverse momentum and pseudorapidity of the quark using HERWIG and PYTHIA Monte Carlo models. The value found for $p_T^b > p_T^{\rm min} = 5$ GeV, $|\ \eta^b\ | < 2$, $Q^2 < 1$ GeV^2 and $0.2 < y < 0.8$ was:

$$\sigma^{ext}(ep \to e^+ bX) = 1.6 \pm 0.4(stat.)^{+0.3}_{-0.5}(syst.)^{+0.2}_{-0.4}(ext.) \text{ nb,} \qquad (6)$$

where the central value was calculated by using HERWIG to extrapolate and the value obtained with PYTHIA was included in the extrapolation systematic uncertainty. The CASCADE prediction for this cross section is 0.88 nb, while NLO calculations by Frixione et al. [10] give a value of $(0.64^{+0.14}_{-0.10})$ nb; both predictions are below the experimental value.

5 ZEUS $p_T^{\rm rel}$ analysis, muon channel

The ZEUS Collaboration has also presented some preliminary results [14] on bottom photoproduction obtained with events tagged by its semi–leptonic decay into muons. Events were required to have at least two jets reconstructed by the k_T–algorithm with one of them containing a muon, associated with it by the jet algorithm. The kinematic region was defined to be $Q^2 < 1$ GeV^2, $0.2 < y < 0.8$, $E_T^{\rm jet1(2)} > 7(6)$ GeV, $\eta^{\rm jet1(2)} < 2.5$, $p^\mu > 3$ GeV and $-1.75 < \eta^\mu < 2.3$. The difference between this analysis and the previous

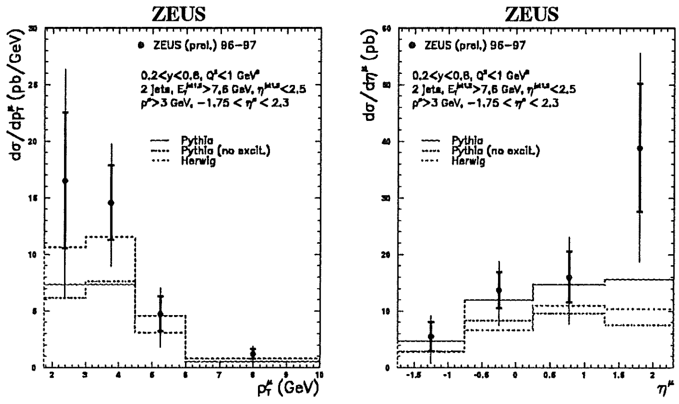

Figure 2. Differential bottom cross sections as functions of the muon transverse momentum (left) and pseudorapidity (right) for events with two jets and a muon, compared to the absolute predictions from PYTHIA 6.1 and HERWIG 5.9 Monte Carlo models.

one with the electron is that a more forward η^{μ}–region is now included, where resolved photon processes are expected to give a more sizeable contribution. The total cross section was determined, extrapolated to the electron analysis kinematic region, and the two values found to be in good agreement. In addition, differential cross sections as functions of the transverse momentum and pseudorapidity of the muon were calculated (fig.2). The PYTHIA predictions are in reasonable agreement with the measured cross sections but with a tendency to be too low in the most forward (proton) region, where the contribution from resolved photon processes is expected to be large. The HERWIG predictions are lower but still compatible with the data within the errors.

6 Conclusion

Bottom production has been observed at HERA,both in photoproduction and deep inelastic scattering processes,with the two detectors H1 and ZEUS.Total cross sections have been measured and compared to LO Monte Carlo models and NLO QCD predictions. The experimental value is systematically above NLO QCD predictions(fig.3).The CASCADE prediction is somewhat above the NLO calculations, but still undershoots the data.Differential cross sections as functions of the muon variables have been calculated including a more forward region,where resolved photon processes are expected to be more important.

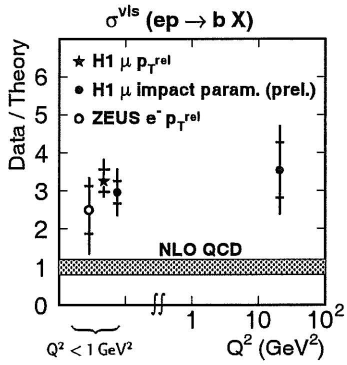

Figure 3. Ratio of measured b production cross sections at HERA over theoretical expectation, as a function of Q^2. The inner (outer) error bars represent the statistical (total experimental) error, the shaded band being the theoretical uncertainty.

References

1. T. Sjöstrand *et al*, *Comp. Phys. Comm.* **82**, 74 (1994); E. Norrbin and T. Sjöstrand, *Eur. Phys. J.* C **17**, 137, (2000).
2. G. Marchesini *et al*, *Comp. Phys. Comm.* **67**, 465 (1992).
3. G. Ingelman *et al.*, *Comp. Phys. Comm.* **101**, 135 (1997).
4. H. Jung and G.P. Salam, *Eur.Phys.J.* C **19**, 351 (2001).
5. M. Ciafaloni, *Nucl. Phys.* B **296**, 49, 1998; S. Catani *et al*, *Phys. Lett.* B **234**, 339 (1990); *Nucl. Phys.* B **336** (1990); G. Marchesini, *Nucl. Phys.* B **445**, 49, (1995).
6. H1 Coll., C. Adloff *et al*, *Phys. Lett.* B **467**, 156 (1999) and Erratum *Phys. Lett* B **518**, 331 (2001).
7. F. Sefkow, [H1 Coll.] contributed paper to ICHEP 2000, hep-ex/0011034.
8. S. Catani *et al*, *Nucl. Phys.* B **406**, 187, (1993).
9. R. Barlow and C. Beeston, *Comp. Phys. Comm.* **86**, 147 (1995).
10. S. Frixione *et al*, *Phys. Lett.* **348**, 633 (1995); S. Frixione *et al*, *Nucl. Phys.* B **454**, 3 (1995).
11. H1 Coll., C. Adloff *et al*, contributed paper 484 to EPS 2001.
12. B.W. Harris and J. Smith, *Nucl. Phys.* B **452**, 109 (1995); *Phys. Lett.* B **353**, 535 (1995); *Phys. Rev* D **57**, 2806 (1998).
13. ZEUS Coll., J. Breitweg *et al*, Eur. Phys. J. C **18**, 625 (2001).
14. ZEUS Coll., J. Breitweg *et al*, contributed paper 498 to EPS 1999; contributed paper 496 to EPS 2001.