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A Flavour of Heavy Flavour Physics at HERA [1]

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Abstract

A short overview of heavy flavour production in *ep* collisions at HERA is given. Using a model based on boson-gluon fusion into a heavy quark-antiquark pair, followed by gluon emission and string hadronization, the main production characteristics of charm, bottom and top are predicted.

[1] Talk at the XXIIIrd Rencontres de Moriond 'Current Issues in Hadron Physics', Les Arcs, France, March 1988, to be published in the proceedings.

The phenomenology of heavy flavour production in ep collisions has recently been investigated in detail[1] based on a Monte Carlo model[2] simulating complete events. In the leading order quark-parton model (QPM) heavy quark production occurs through mixing in the charged current process $e+q \to \nu + Q$. The cross-section $\sigma(Q) = \sum_q V_{Qq}^2 \sigma_q$ is, however, very small due to the suppressed mixing V_{Qq}^2 between heavy and light quark flavours. In fact, it is negligable compared to the next-to-leading order boson-gluon fusion (BGF) mechanism: $V+g \to Q+\bar{Q}'$ where $V=\gamma/Z^0$ or $W^\pm$ for neutral (NC) and charged (CC) current processes, respectively. The cross-section is in first order QCD given by

$$\sigma(e^\pm p \to Q\bar{Q}'X) = \int dy \int dQ^2 \int dx_g \int dz \int d\Phi \; g(x_g, M_g^2)\, h(y, Q^2, x_g, z, \Phi) \qquad (1)$$

as a convolution of the gluon density $g(x_g, M_g^2)$ and a QCD part h for the subprocess. The latter[3] depends on the heavy quark masses, the electroweak charged/neutral current structure including γ/Z^0 interference and polarization of the $e^\pm$ beam. In addition to the normal deep inelastic variables (y, Q^2), three new independent variables enter: the gluon momentum fraction x_g, $z = P\cdot p_Q / P\cdot q$ related to the angle between the $Q\bar{Q}$-axis and the boson-gluon axis in this subsystem cms, and the azimuthal angle Φ between the lepton and hadron planes.

The inclusive heavy quark cross-section, $\sigma_Q = 2\sigma(ep \to eQ\bar{Q}X) + \sum_{Q'} \sigma(ep \to \nu Q\bar{Q}'X)$, is given in Fig. 1a in terms of the ep (or μp) cms energy $\sqrt{s}$. The quark masses are taken as $m_c = 1.5\,\mathrm{GeV}$, $m_b = 5\,\mathrm{GeV}$ and the top quark mass varied between $m_t = 50$ and 100 GeV. Concentrating on the HERA configuration of 30 GeV electrons on 820 GeV protons, the charm and bottom cross-sections are comparable to (or larger than) those expected at SLC/LEP. With an integrated luminosity of 200 pb^{-1}, corresponding to ~1 year of running at HERA, one would produce about 10^8 charm and a million bottom particles — making HERA a potential bottom factory! The large cross-sections are provided by neutral current processes

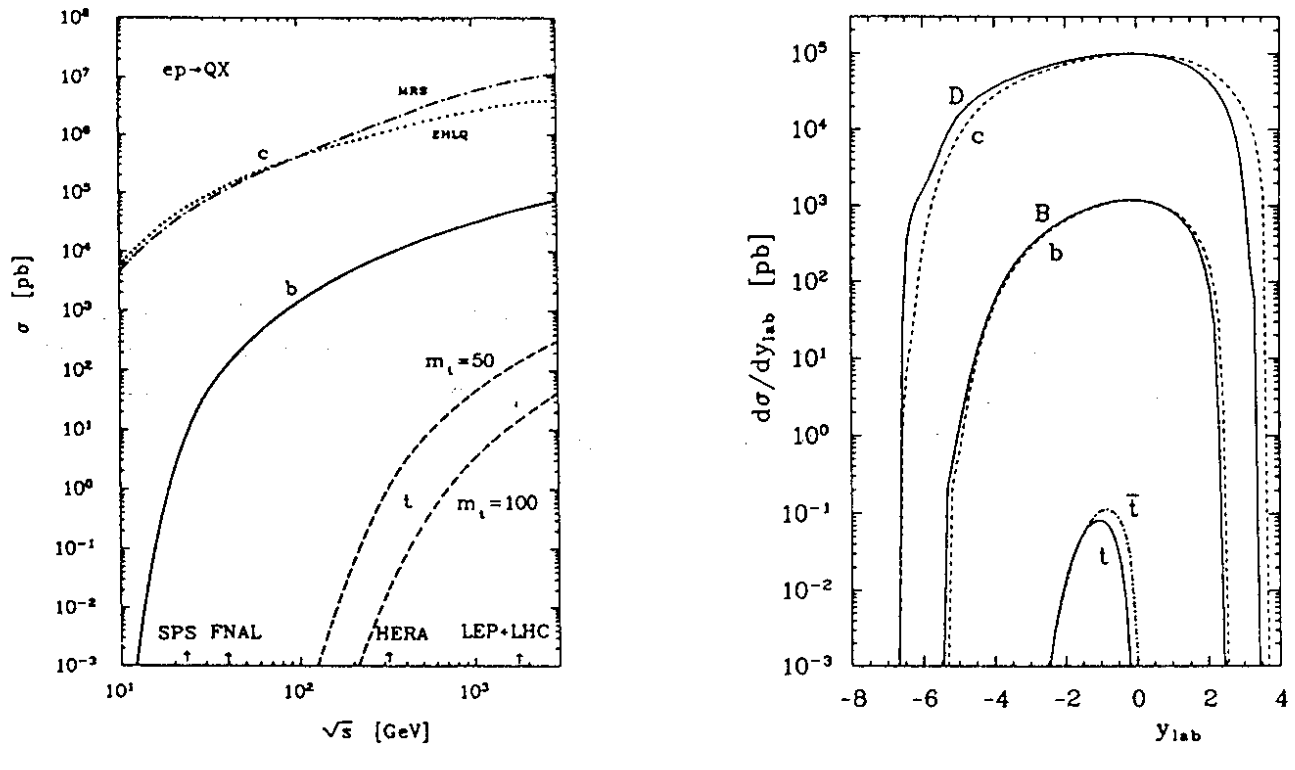

Figure 1: *(a) Inclusive heavy flavour cross-section. (EHLQ[4] gluon density, for charm also the softer MRS[5] alternative.) (b) Rapidity of heavy quarks and hadrons for $c\bar{c}, b\bar{b}, t\bar{t}$ and $\bar{t}b$ production in the HERA lab frame; $m_t = 60$ GeV.*

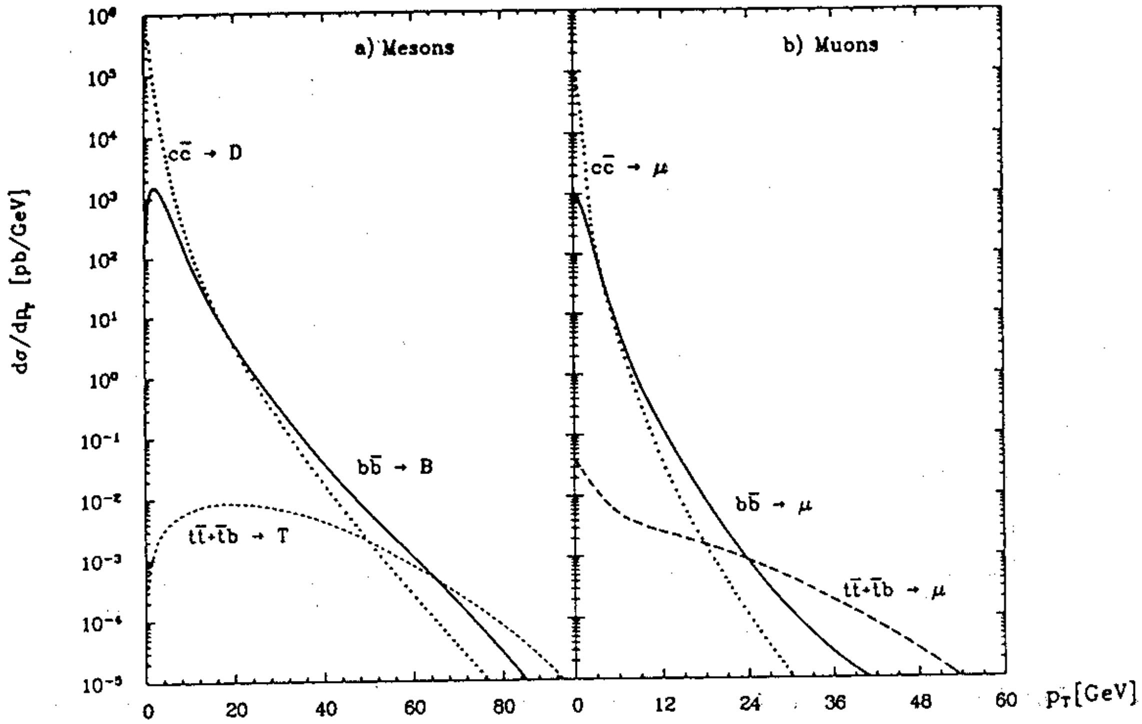

Figure 2: *Transverse momentum of heavy mesons and decay muons for charm, bottom and top production in the HERA lab frame. ($m_t = 60$ GeV)*

at very low Q^2, i.e. γ exchange giving essentially real photoproduction. As a consequence, the electron is usually scattered to very small angles and thus very hard to measure; hence the kinematics must be reconstructed from the hadronic system.

Top production via the CC process is larger than NC production for $m_t > 55$ GeV due to the lower threshold for $\bar{t}b$ compared to $t\bar{t}$ in the NC case. For masses above ~85 GeV the top production rate is expected to be below observability at HERA, i.e. less than ~ 10 events for an integrated luminosity of 200 pb^{-1}. With present limits[6] $m_t \gtrsim 50$ GeV, together with increasing background problems for collider searches at higher top masses there may be a 'window' of 55–85 GeV for top quark discovery at HERA!

Higher order gluon radiation effects from the $Q\bar{Q}$ system as described by a leading log parton cascade model[7] and finally hadronization using the Lund string model[8] are also included in our model[1,2] to give a realistic description of the complete final state. The additional gluon radiation has noticable effects on the charm events, but with increasing quark mass their effect is reduced due to a smaller phase space for radiation. The heavy flavours are dominantly produced in the central rapidity region covered by the HERA experiments, Fig 1b. The transverse momentum distributions, Fig. 2, are strongly suppressed only for values above the corresponding quark mass, since only then is $\hat{s}$ significantly increased above the threshold value where the cross-sections is strongly peaked. There are, however, important long tails to large $p_\perp$ also for the lighter flavours due to the normal power dependence in the hard $Vg \to Q\bar{Q}$ process. A cut in $p_\perp$ of the decay muons, Fig. 2b, can be used to get a useful bottom sample whereas for top a non-vanishing sample cannot be very clean based on such a cut alone and other signatures has to be exploited also.

There are several event characteristics which depend on the produced flavour. From the increasing transverse momenta with increasing quark mass together with the larger energy release in their decays one expects an increasing transverse energy and more spherical events for heavier flavours. This is clearly shown in Fig. 3 by the total transverse energy, $\sum E_\perp$, and

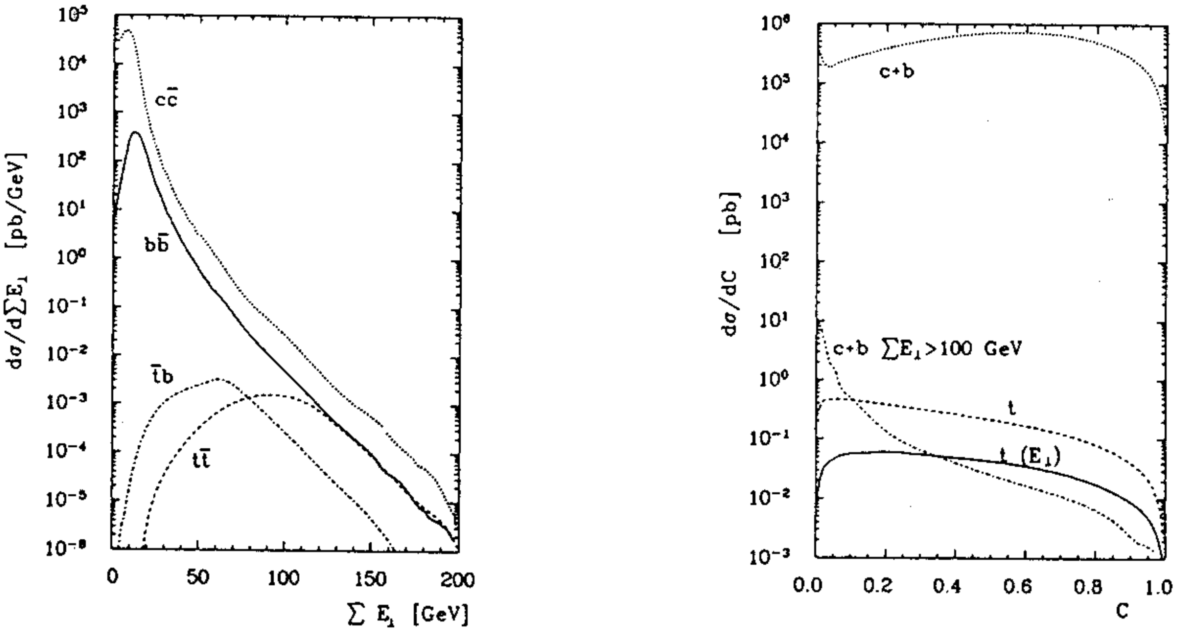

Figure 3: *Total transverse energy and 'circularity' for inclusive heavy flavour event samples and with a cut $\sum E_\perp > 100$ GeV. ($m_t = 60$ GeV)*

the 'circularity' measure (sphericity in the transverse plane to suppress the target remnant jet). Charm and bottom events are typically quite 'circular' due to the dominant production at threshold with only limited $p_\perp$, but with a cut in $\sum E_\perp$ their rate is reduced by several orders of magnitude and the remaining events are much less 'circular' such that most of them can be separated off from the top sample which has only been moderately reduced by this cut. In Fig. 3b, the top signal for $C > 0.35$ has $\sigma = 1.8 \times 10^{-2}$ pb and the background is half as large. Although useful, cuts in such inclusive variables cannot give clean top samples of the desired statistics. For a dedicated top search[9] one would also use signatures like isolated leptons and multijets that preferentially selects top decay topologies. The semileptonic decay will typically give cleaner signatures, but are disfavoured by statistics.

Beside the important top search possibilities, the large charm and bottom rates will provide interesting tests of the QCD boson-gluon fusion mechanism and possibly lead to a measurement of the gluon structure function which enters at the Born level in this process. In addition, the field of heavy flavour decay physics, including branching ratios, life times and $B\bar{B}$ mixing has the potential to yield a rich harvest.

I am grateful to G. Schuler for interesting collaboration on this study.

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