Charm (and beauty) production in DIS at HERA

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Recent measurements of charm and beauty differential cross sections in the deep inelastic scattering regime are presented. The measurements are performed with the data collected by the H1 and ZEUS experiment at the HERA collider. Different experimental techniques are used for the charm and beauty signal extraction. The next-to-leading-order Quantum Chromodynamics predictions obtained with the HVQDIS program are compared to the H1 and ZEUS data.

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1. Introduction

Deep inelastic scattering (DIS) events kinematic is described in term of the virtuality of the exchanged photon, Q^2, of the fraction of the proton momentum taken by the parton in the hard subprocess, x, and of the fraction of the electron momentum taken by the exchanged virtual photon, y. The x and y definitions refer to the proton rest frame. Only two out of the three presented variables are independent. The DIS regime is characterized by the condition $Q^2 > 1$ GeV^2. At HERA heavy quark production in DIS is dominated by the photon-gluon fusion process. This process constitutes an important playground for perturbative QCD (pQCD) because the large heavy quark mass provides a hard scale that allows pQCD calculations to be made. At large Q^2 values at least two scales are present: the heavy quark mass and Q^2 itself. A comparison of theory with data allows to test simultaneously the calculations of the hard scattering matrix element and the predictions for the proton gluon density.

At HERA charm and beauty production can be identified using the large lifetime of the produced heavy hadrons or the semileptonic electron decay mode. Other techniques not presented here involve the semileptonic muon decay mode or the complete reconstruction of the heavy hadrons, mostly D mesons in the HERA case.

2. Charm and beauty jet selection in DIS events using the lifetime tag

In the analysis presented in [1], DIS events are selected requiring $Q^2 > 6$ GeV^2. Jets are reconstructed in the laboratory frame using the k_T jet algorithm in the rapidity range between -1 and 1.5 with a minimum transverse energy requirement set at 6 GeV. The jets flavor separation is achieved using the distance of closest approach, δ, of the jet tracks to the primary vertex. A sign is given to δ using the relative position between the jet axis and the segment connecting the primary vertex to the point corresponding to the distance of closest approach of the track. The significance, S, is defined as the ration between δ and its uncertainty. Light flavor jets have a symmetric S distribution, heavy flavor jets have a tail towards positive values of S, a consequence of the heavy hadrons large lifetime. A simultaneous fit is performed using MC templates for the light- (u, d and s) charm- and beauty-quarks contributions.

The H1 charm jet cross section measurements are shown in Fig. 1: jet transverse energy, upper left, jet rapidity, upper right, Q^2, lower left, and number of jest, lower right. Here and in the following the inner and outer error bars represent the statistical and the overall uncertainty of the measurements, respectively. The theoretical predictions are obtained from the HVQDIS next-to-leading order program convoluted with hadron level corrections. Two different choices of the hadronisation and factorisation scale are shown.

Fig. 1 shows that the variations due to the scale choice are as large as the uncertainties of the data. A very good description of the data is obtained setting the square of the scale to $Q^2 + 4\ m^2$, with the alternative scale the agreement is significantly worse.

The H1 beauty jet cross section measurements are shown in Fig. 2. The legends are as in Fig. 1. Comparing Fig. 1 and 2 the beauty cross sections are seen to be, on average, only 1/20 of the charm cross sections. Fig. 2 shows that the effect of the scale choice is now small so the large

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mass of the beauty quark plays an important role also at large Q^2 values. Clearly, pQCD provides a good description of the beauty measurements.

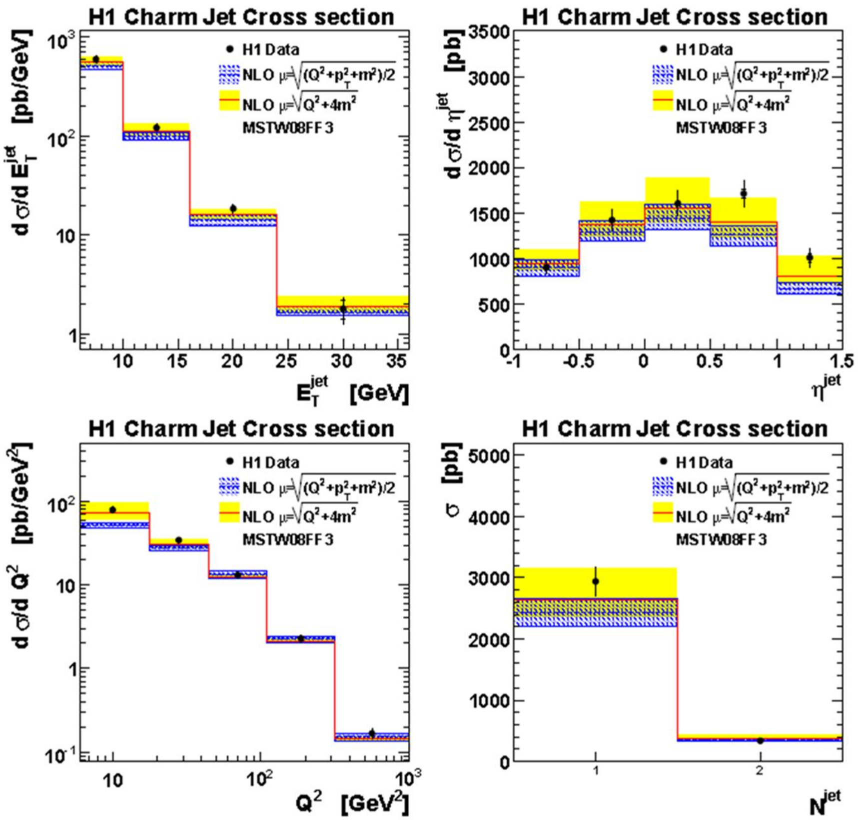

Figure 1: H1 charm-jet cross sections measurements. The HVQDIS NLO predictions are compared to the data. See text for further details.

3. Beauty tag using the electron decay mode

In the analysis presented in [2] DIS events are selected requiring $Q^2 > 10$ GeV^2. Jets are reconstructed in the laboratory frame as described in Sec. 2. The jet flavor separation is achieved using the identification of a semileptonic electron decay candidate. The electron candidate transverse momentum of is required to be in the range 0.9 to 8 GeV and the absolute value of the rapidity to be less than 1.5. The electron-jet association is performed using a cone of radius 1 in the η-ϕ space.

Beauty-jet tagging is achieved using an electron-from-beauty discriminating test-function variable. The method is based on a likelihood ratio technique. The test-function is using the most relevant electron observables: the dE/dx in the central tracker, the calorimeter energy to track momentum ratio, the transverse momentum with respect to the jet axis, the corresponding significance, as defined in Sec. 2, the azimuthal difference between the track and the missing transverse momentum and the deep of the calorimetric energy deposit. A fit to the test-function

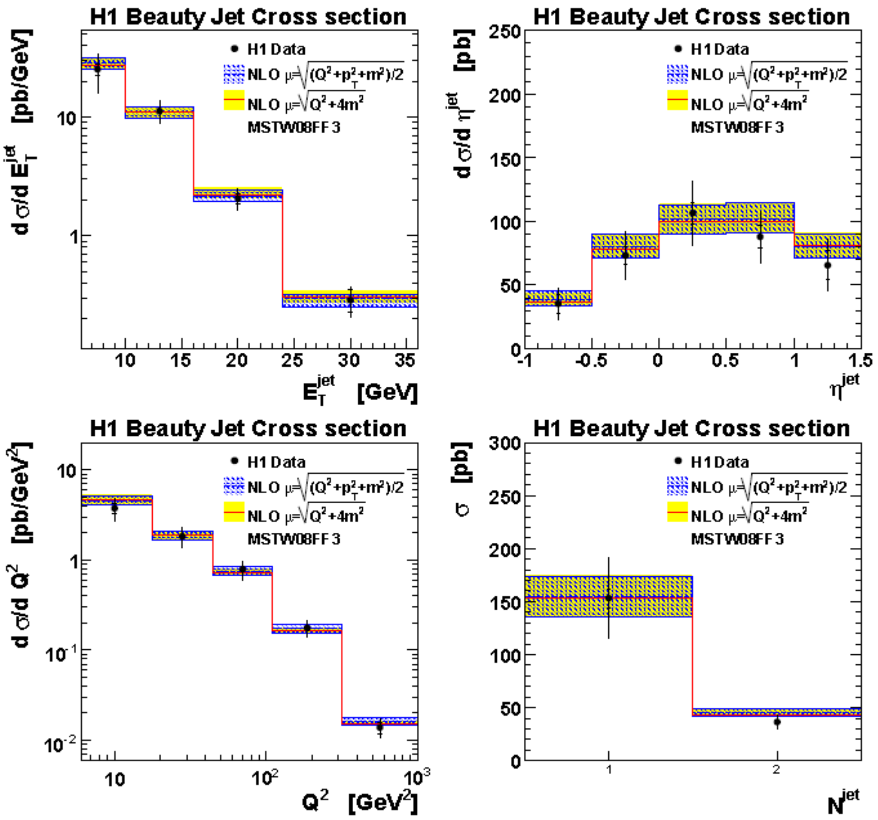

Figure 2: H1 beauty-jet cross section measurements. The HVQDIS NLO predictions are compared to the data. See text for further details.

variable is performed using MC templates for the light-, charm- and beauty-quarks contributions.

The ZEUS beauty jet cross section measurements are shown in Fig. 3: Q^2, upper left, x, upper right, electron transverse momentum, lower left, and rapidity, lower right. The HVQDIS NLO predictions are complemented with the hadronisation corrections obtained from the LO RAPGAP MC. Data and pQCD predictions have uncertainties of the same size, NLO QCD is providing a good description of the data. The LO RAPGAP MC predictions should be multiplied by a constant factor of 1.3 to reproduce the normalization of the measured beauty cross sections.

The outlined experimental procedure can also be used for a measurement of the beauty double differential cross section in bins of x and Q^2. This intermediate measurement allows the extraction of the beauty contribution to the inclusive structure function, F_2, using

$$F_2^{b\bar{b}}(x,Q^2) = \frac{\mathrm{d}^2\sigma_{b\to e}}{\mathrm{d}x\,\mathrm{d}Q^2} \cdot \frac{F_2^{b\bar{b},\mathrm{NLO}}(x,Q^2)}{\mathrm{d}^2\sigma_{b\to e}^{\mathrm{NLO}}/\mathrm{d}x\,\mathrm{d}Q^2}$$

in the above formula the appendix NLO indicates the predictions obtained with the HVQDIS program.

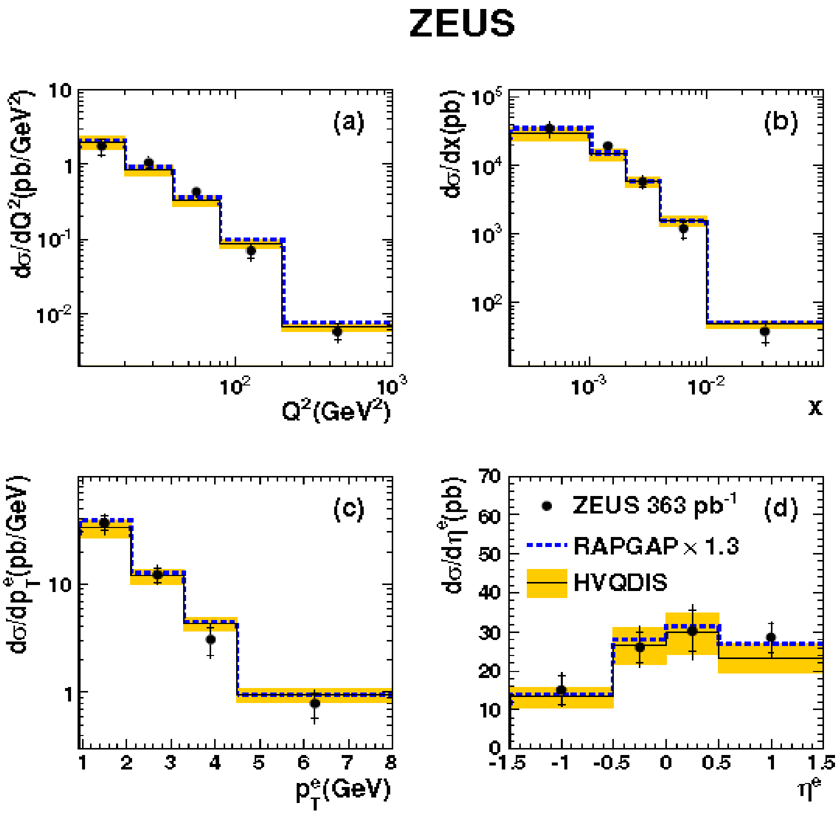

Figure 3: ZEUS beauty-jet cross section measurements. The HVQDIS NLO predictions are compared to the data. See text for further details.

The measured beauty contribution to the inclusive F_2 structure function, as obtained from the semileptonic electron decay, is shown in Fig. 4. The results of this analysis are compared to the ones obtained by H1 and ZEUS using different beauty tagging techniques, namely: using the semileptonic muon tag, refining the semileptonic muon tag with the distance of closest approach of the muon track and finally using inclusive secondary vertex techniques. Fig. 4 shows that different experimental methods are providing consistent results. NNLO and NLO predictions are compared to the data. All predictions are rather similar and provide a good description of the H1 and ZEUS measurements.

4. Conclusions

Accurate charm and beauty cross section measurements have been performed by the H1 and ZEUS collaborations. The measurements have been performed using different experimental techniques, each technique having specific advantages. Charm data are significantly more precise than the available NLO predictions which suffers from large scale uncertainties. NNLO predictions are needed for charm. Beauty NLO prediction and data have the same accuracy and are in good agreement: a fruitful consistency test for pQCD. To achieve the best accuracy the results obtained using different experimental techniques applied to the H1 and ZEUS data will be combined.

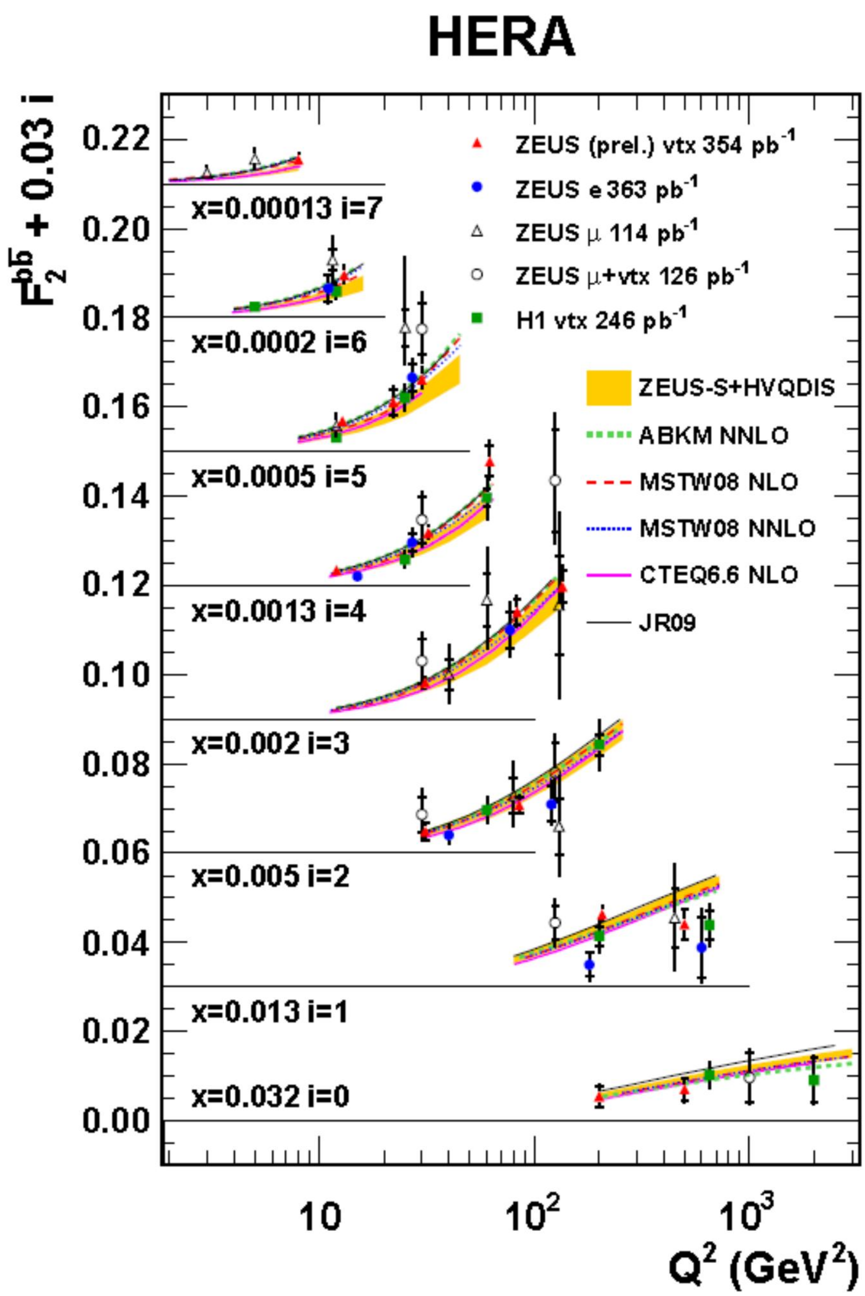

Figure 4: beauty contribution to the inclusive F_2 structure function. pQDC predictions are compared to the H1 and ZEUS measurements. See text for further details.

References

[1] H1 Coll., F. D. Aaron et al., Eur. Phys. J. C 71, 1509 (2011);

[2] ZEUS Coll., H. Abramowicz et al., Eur. Phys. J. C 71, 1573 (2011).