A few highlights of Heavy flavor measurements at HERA

J. G. Contreras ^{a *}

^aDepartamento de Física Aplicada, Centro de Investigación y Estudios Avanzados IPN, 97310, Mérida, Yucatán; México.

Selected results from the H1 and Zeus Collaborations relating to heavy flavor physics in deep inelastic scattering are presented. Results from three different experimental techniques, reconstruction of charmed mesons, search for secondary vertices and inclusive search for displaced tracks are discussed. The high statistics sample of HERA II together with the different and complementary techniques used to analyze the data promise many beautiful and charming results to come in the near future.

1. Introduction

The HERA $e^\pm p$ collider operated from 1992 to 2007. The data collected during its second phase, called HERA II, comprises some 0.5 fb^{-1} for each of the two collider experiments: H1 and Zeus. Most of these data is being analyzed now and it is expected that many new and exciting results will be published in the next few years. Many of these papers will be devoted to the physics of heavy quarks.

As a comparison, HERA I data sets have an integrated luminosity of around 150 pb^{-1} . With these data, the H1 and Zeus collaborations have published in the leading journals of the field, more than 50 papers on heavy quarks (see the home pages of the Collaborations for links to each of these papers)

As it is impossible to discuss in a few minutes all these results, in the following I concentrated in presenting just a few highlights from deep inelastic scattering (DIS).

2. Heavy flavors in DIS

The dominant process in DIS at HERA to produce heavy flavors is Boson Gluon Fusion where the virtual photon emitted by the lepton interacts with a gluon from the proton through a $q\bar{q}$ pair. Interestingly, this process has several hard scales: (i) the virtuality of the photon, (ii) the masses and (iii) the transverse momenta of the

heavy quarks. The availability of the different scales gives a handle to test and extend perturbative approaches. The data itself is sensitive to the production, but also to the fragmentation of heavy quarks as well as to the gluon structure of the proton.

The most common approaches to describe the data are HVQDIS[1] which includes a full NLO computation at the parton level and the Rap-Gap[2] and Cascade[3] MC which combine a leading order matrix element, supplemented by parton showers with a hadronization prescription based on the Lund model. The main theoretical uncertainties come from the variation of the factorization and renormalization scales, the different PDFs and the value used for the charm mass.

3. Heavy flavor tagging

Here I will discuss examples of three techniques to tag processes with a heavy quark: (i) using the decay of a particle with heavy quark quantum numbers (ii) measuring the displaced vertices produced by long lived particles and (iii) the inclusive heavy flavor tagging.

3.1. Production of D^{*+} mesons

The D^{*+} mesons contain a charm quark. Furthermore, its main decay channel $D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow (K^- \pi^+) \pi_s^+$ has a very small phase space available due to the small mass difference $\Delta m = m_{D^{*+}} - m_{D^0} = 146 \text{ MeV}$. This produces a very clean experimental signature which per-

*Presented on behalf of the H1 and Zeus Collaborations

mits to extract reliably the corresponding cross sections as shown in figure 1, where it can be observed that the data is quite precise and that the theory is able to describe it albeit with somehow sizable scale uncertainties.

3.2. Displaced vertices

Particles containing heavy quarks are normally long lived and thus their decay vertices are separated from the collision point. Both the H1 and the Zeus Collaboration have installed very sophisticated and precise silicon detectors [4,5] to measure these displaced vertices. It has to be stressed that this is a very challenging measurement, because the vertices are outside the geometrical acceptance of the detectors and long extrapolations are needed.

Using these detectors [4,5] and the significance (the measurement divided by its error) of the radial decay length of the heavy flavored particle, both Collaborations were able to improve the signal to noise ratio to a point where it was possible to measure several charmed mesons and extract their production cross sections. An example, for the case of $D^\pm$ preliminary HERA II results from the Zeus Collaboration, is shown in figure 2. Here again the theory describes satisfactorily the data, although the theoretical uncertainty is not negligible.

Using these measurements along with similar ones from other charm mesons it is possible to compute different ratios and fragmentation functions and compare the results to those obtained at LEP in e^+e^- collisions and results from HERA in the photoproduction regime to test idea of the universality of charm fragmentation. Results for the isospin invariance ratio $R_{u/d}$, the vector to pseudo scalar ratio, the strangeness suppression factor and the universality of fragmentation can be found in [6].

3.3. Inclusive heavy flavor tagging

As mentioned before, particles containing heavy quarks are long lived and produce tracks displaced from the main vertex. One can then define the signed impact parameter with respect to the main vertex as the distance of closest approach of the track to the main vertex, where the

sign is given as positive if this distance points into the hemisphere of the struck quark and negative otherwise.

Using the distribution of the significance of this variable it is observed that it is symmetric for tracks produced from particles with light quarks, but asymmetric -a long tail in the positive side- for tracks produced from heavy quarks. The negative side of the distribution is given by the resolution of the tracking detectors while the positive side includes the contribution of the resolution and the signal. Subtracting the negative from the positive side produces a clean sample dominated by heavy flavors. Some variations of the analysis are possible, for example taking only the track with the biggest significance in the event, or the first and second most significant tracks (for more details see [7]).

With this sample the structure functions $F_2^{q\bar{q}}$ can be extracted using:

$$\frac{d^2\sigma^{ep\rightarrow c\bar{c}X}}{dx dQ^2} \approx \frac{2\pi\alpha^2}{Q^4x} (1 + (1-y)^2) F_2^{c\bar{c}}(x, Q^2),$$

where x is the Bjorken variable, Q^2 the virtuality of the photon, y the inelasticity of the collision and α the QED coupling constant.

A summary of the results for the charm and beauty $F_2^{q\bar{q}}$ structure functions extracted using all different techniques available to the H1 and Zeus Collaborations are shown in figure 3. One can notice the huge phase space covered, the good agreement among different techniques, data sets, experiments and data vs theory. Clear scaling violations are seen and these results are close to constraint the gluon in the proton. For the case of beauty there are differences among the theory predictions.

4. Summary and outlook

There are some 0.5 fb^{-1} of HERA II data per experiment available for analysis. Both Collaborations are very active analyzing these data and expect many new and exciting results to come. Regarding the heavy flavor sector it has been shown that the charm analyzes, due to the high statistic samples collected and the different complementary techniques used by the Collabora-

tions, are close to produce precision physics results. In particular they are close to constraint the gluon contribution to the structure of the proton. The data are in general well described by the different theoretical approaches but there are still sizable scale and PDF uncertainties. In Summary, stay tuned, there are many more beautiful and charming analysis to come from HERA II data and the H1 and Zeus Collaborations

Acknowledgments

It is a pleasure to thank the H1 and Zeus Collaboration on whose behalf I gave this talk, as well as the organizers of this wonderful meeting.

REFERENCES

1. B. W. Harris, J. Smith, Phys. Rev. D57 (1998) 2806.
2. H. Jung, Comput. Phys. Commun. 86 (1995) 147.
3. H. Jung, Comput. Phys. Commun. 143 (2002) 100.
4. D. Pitzl et al., Nucl. Instrum. Meth. A454 (2000) 334.
5. E. Koffeman et al., Nucl. Instrum. Meth. A473 (2001) 26.
6. Zeus Collab., S. Chekanov et al., JHEP07 (2007) 074.
7. H1 Collab., A. Aktas et al., Eur. Phys. J. C45 (2006) 23; H1 Collab., A. Aktas et al., Eur. Phys. J. C40 (2005) 349.

Figure 1. Preliminary results from the H1 Collaboration showing HERA II data on the production of D^* in DIS compared to different theoretical models.

Figure 2. Preliminary results from the Zeus Collaboration showing HERA II data on the production of $D^\pm$ in DIS compared to an NLO calculation.

Figure 3. A summary of the results for the charm and beauty F_2^{qq} structure functions extracted using all different techniques available to the H1 and Zeus Collaborations