

HEAVY QUARK PRODUCTION AT HERA AND ITS RELEVANCE FOR THE LHC

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The import of HERA data on heavy quark production for LHC experiments is discussed. Knowledge of all aspects of the beauty and charm production process, viz. the parton density functions of colliding hadrons, the hard scatter, and the fragmentation of the quarks into hadrons, can aid LHC experimentation. This short write-up concentrates on possible influences HERA data can have and on the current status (and history) of beauty production from both HERA and Tevatron experiments. In general, next-to-leading order QCD gives a reasonable description of beauty production although some regions of phase space such as low p_T show indications of differences.

1. Why study heavy quark production?

The measurement of heavy quarks can give insights into many physical phenomena such as: new particles which are expected to decay predominantly to beauty (and charm); precise measurements of electroweak parameters; and, the subject of this paper, a deeper understanding of the strong force of nature. The strong force as described within perturbative Quantum Chromodynamics (QCD) should be able to give a precise description of heavy quark production. This postulate is tested here. The measurement of heavy quark production also yields valuable information on the structure of colliding hadrons. The production of a pair of heavy quarks in a generic hadron collision is directly sensitive to the gluon content of the hadron. Most information on the structure of a hadron comes from inclusive deep inelastic scattering where the gluon content is determined in the evolution of the QCD equations. Therefore measurement of such a process provides complimentary information to that from inclusive measurements.

As well as understanding for its own sake, knowledge of the structure of hadrons will be important at future colliders such as the LHC and International Linear Collider where hadronic photons will provide a large cross section in both e^+e^- and $\gamma\gamma$ modes. Heavy quarks will be copiously produced at future colliders as a background to the more exotic processes expected. Therefore a precise description of their production properties within QCD will aid in the discovery of physics beyond the Standard Model.

2. Information needed by the LHC experiments

Information needed by the LHC which can be provided by the HERA experiments is the following:

- the state of the description of heavy quark production data by theoretical predictions. The production of beauty in the hard scattering process is discussed here in detail. Information on heavy quarks produced in the splitting of a gluon outgoing from the hard sub-process is also important for the LHC, but the information from HERA is currently limited;
- the gluon and heavy quark proton parton density functions;
- details of fragmentation in a hadronic environment;
- the effect of the underlying event in heavy quark processes. This information is limited at HERA but may be studied in the future;
- HERA results can provide general information on event and jet topologies which will be useful for designing algorithms or triggers at the LHC experiments.

Designing effective triggers for b physics is particularly acute for the LHCb experiment¹. Large backgrounds are expected although event topologies should be different to the signal b physics. For example minimum bias events will have a smaller track multiplicity and a lower transverse momentum for the highest p_T track. Therefore using Monte Carlo simulation, cuts can be found to be able to reduce the rate of minimum bias whilst triggering efficiently on b events. Such trigger designs require reliable Monte Carlo simulation of the event topologies of both classes of events.

Measurements of the proton structure function at HERA will constrain the parton densities in a large region of the kinematic plane where B mesons will be produced within the acceptance of the LHCb detector. According to Monte Carlo simulations, these events are produced predominantly with a b quark in the proton. However, this is just a model (PYTHIA²) and at NLO

some of the events will be summed into the gluon distribution of the proton. Nevertheless, measuring all flavours in the proton at HERA is one of the goals of the experiments and recent results on the beauty contribution to the proton structure function³ shed some light on the issue.

3. Open beauty production

The production of open beauty and its description by QCD has been of great interest in the last 10–15 years. The difference between the rates observed by the Tevatron experiments⁴ and NLO QCD predictions led to a mini crisis with many explanations put forward. Several measurements were performed in different decay channels and then extrapolated to the quark level to facilitate a comparison with QCD and between themselves. The NLO QCD prediction was found to be a factor of 2–3 below the data for all measurements. These results were extrapolated to the b -quark level using Monte Carlo models which may or may not give a good estimate of this extrapolation. To facilitate a particular comparison, an extrapolation can be useful, but should always be treated with caution and the procedure clearly stated and values of extrapolation factors given. Initial measurements in terms of measured quantities should also always be given.

The CDF collaboration also published measurements of B meson cross sections. They were also found to be significantly above NLO calculations, but allowed for phenomenological study. Work on the fragmentation function was performed by Cacciari and Nason⁵ which in combination with updated parton density functions and a combined fixed-order and resummed calculation gave an increased prediction. New measurements at Run II have also been made by the CDF collaboration which probe down to very low transverse momenta. In combination with a measured cross section lower (but consistent) than the Run I data, and the above theoretical improvements, the data and theory now agree very well.

The first result from HERA⁶ also revealed a large discrepancy with NLO QCD predictions. This analysis presented an extrapolated quantity, whereas later measurements⁷ also presented measured quantities. The measurements in photoproduction are well described by the prediction from NLO QCD and the data from the two collaborations also agree well. The H1 data is somewhat higher than that from ZEUS; the difference is concentrated at low p_T^μ where the H1 data is also above the NLO calculation. The measurements in deep inelastic scattering are also generally described by NLO QCD although some differences at forward η^μ and low p_T^μ are observed

by both collaborations. However, inclusive measurements which lead to a measurement of the beauty contribution to the proton structure function³ are well described by QCD.

The situation for the QCD description of b production has recently changed significantly. In general, QCD provides a good description of the data with some hints (a few sigma) at differences in specific regions. Certainly, there is no longer a difference of a factor of 2–3 independent of p_T . The HERA experiments will produce several new measurements in the next few years of higher precision and covering a larger kinematic region at both low and high p_T and forward η . Allied with expected calculational and phenomenological improvements, a deep understanding of beauty production should be achieved by the turn-on of the LHC.

4. Charm production

Due to its larger cross section, more high-precision and detailed measurements of charm production at HERA have been made. However, due to length limitations, the reader is referred to a previous review⁸ which discusses open charm production, the contribution of charm to the proton structure function and universality of charm fragmentation.

References

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