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Review

Charm, beauty and top at HERA

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ABSTRACT

Results on open charm and beauty production and on the search for top production in high-energy electron–proton collisions at HERA are reviewed. This includes a discussion of relevant theoretical aspects, a summary of the available measurements and measurement techniques, and their impact on improved understanding of QCD and its parameters, such as parton density functions and charm- and beauty-quark masses. The impact of these results on measurements at the LHC and elsewhere is also addressed.

Contents

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1. Introduction

HERA was the first and so far only high energy electron[2]-proton collider. The production of heavy-quark final states in deeply inelastic scattering (DIS) and photoproduction (γp) from ep interactions at HERA (Fig. 1) originally was [1] and still is (this review) one of the main topics of interest of HERA-related physics, and of Quantum Chromodynamics (QCD) in general.

A quark is defined to be "heavy" if its mass is significantly larger than the QCD scale parameter $\Lambda_{QCD} \sim 250$ MeV. The heavy quarks kinematically accessible at HERA are the charm and beauty quarks, which are the main topic of this review. At the time of the proposal of the HERA collider and experiments in the 1980's [2], a search for the top quark was one of the major goals [3]. This influenced parts of the detector design: if at all, top quarks would be produced boosted into the proton direction, and top-quark mass reconstruction from hadronic final states would profit from an excellent hadronic energy resolution. As we know today, top-quark pair production was out of the kinematic reach of the HERA collider. Single top-quark production is kinematically possible, but strongly suppressed by Standard Model couplings. This allows the search for non-Standard Model top-production processes which will be covered in Section 5.

Charm production at HERA, in particular in deeply inelastic scattering, was realised from very early on to be of particular interest for the understanding of QCD [1,4]. Up to one third of the HERA cross section is expected to originate from processes with charm quarks in the final state: assuming "democratic" contributions from all quark flavours, which is a reasonable assumption at very high momentum transfers, this fraction $f(c)$ can be approximated by the ratio of photon couplings in Fig. 1, which are proportional to the square of the charges $Q_q,\ q = u, d, s, c, b$ of the kinematically accessible quark flavours:

$$f(c) \sim \frac{Q_c^2}{Q_d^2 + Q_u^2 + Q_s^2 + Q_c^2 + Q_b^2} = \frac{4}{11} \simeq 0.36, \qquad (1)$$

while a similar approximation for beauty yields $f(b) \sim \frac{1}{11} \simeq 0.09$. In general, the impact of beauty on inclusive cross sections at HERA is thus smaller than the impact of charm.

At momentum transfers large enough for these approximations to be meaningful, charm and beauty can be treated as an integral part of the "quark–antiquark sea" inside the proton (Fig. 2), similar to the light quarks in Fig. 1(b), originating from

[2] Throughout this document, the term "electron" includes positrons, unless explicitly stated otherwise.