

**INCLUSIVE HADRON ELECTROPRODUCTION AT HERA AT NLO
WITH AND WITHOUT TRANSVERSE-MOMENTUM CONSTRAINT**

B. A. KNIEHL

*II. Institut für Theoretische Physik, Universität Hamburg,
Luruper Chaussee 149, 22761 Hamburg, Germany
E-mail: kniehl@desy.de*

We study single-hadron inclusive electroproduction in ep scattering at DESY HERA at next-to-leading order in the parton model of quantum chromodynamics endowed with non-perturbative fragmentation functions. Specifically, we consider charged-hadron production, with unspecified transverse momentum p_T , in the Breit frame and $D^{*\pm}$ production as a function of p_T , and perform comparisons with recent data from the H1 Collaboration.

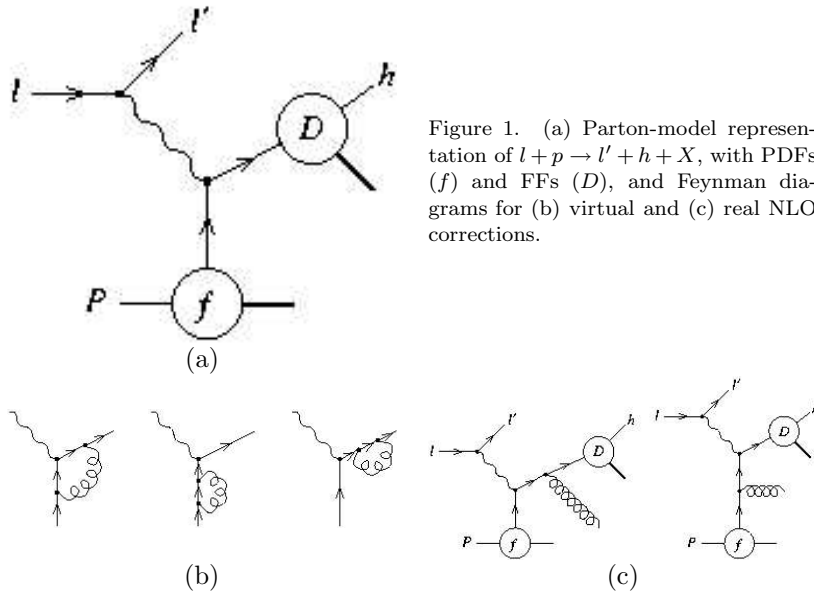
1. Introduction

In the framework of the parton model of quantum chromodynamics (QCD), the inclusive production of single hadrons is described by means of fragmentation functions (FFs) $D_a^h(x, \mu)$. At leading order (LO), the value of $D_a^h(x, \mu)$ corresponds to the probability for the parton a produced at short distance $1/\mu$ to form a jet that includes the hadron h carrying the fraction x of the longitudinal momentum of a . Analogously, incoming hadrons and resolved photons are represented by (non-perturbative) parton density functions (PDFs) $F_{a/h}(x, \mu)$. Unfortunately, it is not yet possible to calculate the FFs from first principles, in particular for hadrons with masses smaller than or comparable to the asymptotic scale parameter Λ . However, given their x dependence at some energy scale μ , the evolution with μ may be computed perturbatively in QCD using the time-like Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) equations. Moreover, the factorisation theorem guarantees that the $D_a^h(x, \mu)$ functions are independent of the process in which they have been determined and represent a universal property of h . This entitles us to transfer information on how a hadronises to h in a well-defined quantitative way from e^+e^- annihilation, where the measurements are usually most precise, to other kinds of experiments, such as photo-, lepto-, and hadroproduction. Recently, light-hadron FFs with complete quark flavour separation were determined¹ through a global fit to e^+e^- data from LEP, PEP, and SLC thereby improving previous analyses.^{2,3}

In the following, we extend our previous report⁴ on the electroproduction, through deep-inelastic scattering (DIS), of π^0 mesons and charged hadrons with finite transverse momentum p_T^* in the γ^*p c.m. frame at next-to-leading order (NLO)⁵ by discussing charged hadrons with unspecified values of p_T^* , including $p_T^* = 0$, and $D^{*\pm}$ mesons with $p_T^* > 0$.

2. Analytic Results

At LO, inclusive hadron electroproduction proceeds through the Feynman diagram shown in Fig. 1(a), so that $p_T^* = 0$. At NLO,⁶ virtual and real corrections, indicated in Figs. 1(b) and (c), respectively, contribute. In the latter case, p_T^* is integrated over. The NLO cross section is conveniently evaluated with the FORTRAN program CYCLOPS.⁶



The NLO analysis for the case that $p_T^* > 0$ already at LO involves one more external parton leg and may be found in Refs. 5, 7.

3. Numerical Results

3.1. Charged Hadrons in the Breit Frame

H1⁸ and ZEUS⁹ measured the normalised Q distribution $(1/\sigma_{\text{DIS}})d\sigma/dQ$ of charged hadrons in bins of $x_p = 2p^{\text{Breit}}/Q$, where $Q^2 = -q^2$ is the virtuality of γ^* and p^{Breit} is the projection of the three-momentum of h onto the flight direction of γ^* in the Breit frame. In this frame, γ^* is completely space-like, with four-momentum $q^\mu = (0, 0, 0, -Q)$. This frame provides a clear separation of current and remnant jets and is especially appropriate for comparisons with inclusive hadron production by e^+e^- annihilation.

In Fig. 2(a), preliminary H1 data⁸ are compared with NLO predictions evaluated with CTEQ6.1M¹⁰ proton PDFs and AKK¹ FFs; the renormalisation (r) and initial-state (i) and final-state (f) factorisation scales are taken to be $\mu_r = \mu_i = \mu_f = \xi Q$, where ξ is varied between 1/2 and 2 about its default value 1 to estimate the unphysical-scale uncertainty. The PDF and FF uncertainties are assessed in Figs. 2(b) and (c) by switching to the MRST2004¹¹ PDFs and to the KKP² and K³ FFs, respectively.

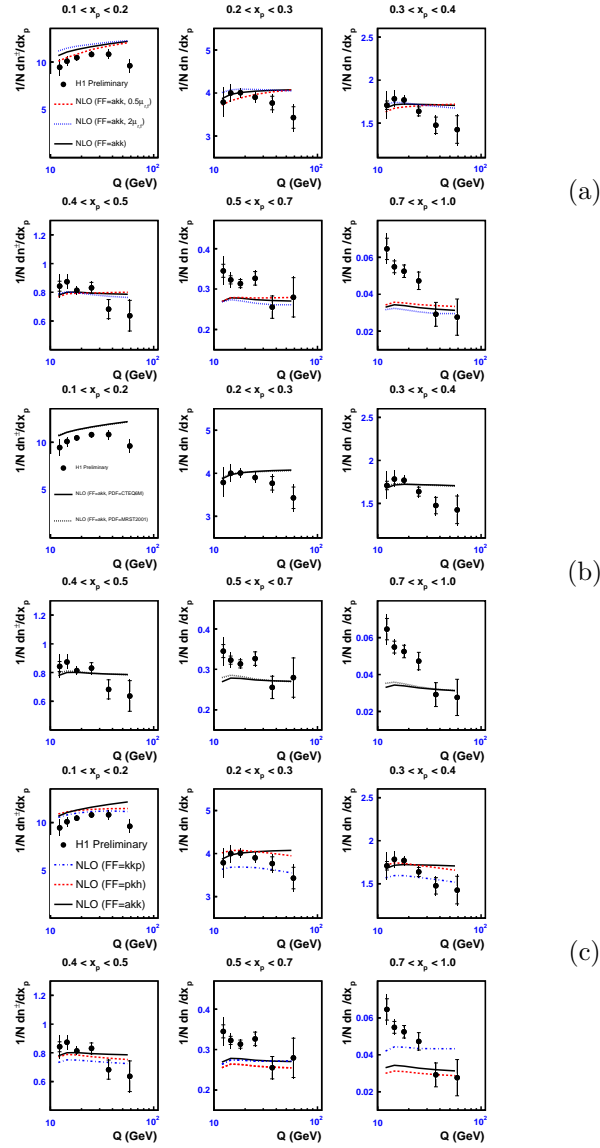


Figure 2. The normalised Q distribution $(1/\sigma_{\text{DIS}})d\sigma/dQ$ of charged hadrons measured by H1⁸ in bins of x_p is compared with our NLO predictions estimating the theoretical uncertainties from the freedom of choice of (a) unphysical scales, (b) PDFs, and (c) FFs.

3.2. $D^{*\pm}$ Mesons

Among other things, H1¹² measured the p_T^* distribution $d\sigma/dp_T^*$ of $D^{*\pm}$ mesons in the DIS range $2 < Q^2 < 100 \text{ GeV}^2$ and $0.05 < y < 0.7$ with the acceptance cuts $p_T > 1.5 \text{ GeV}$ and $|\eta| < 1.5$ in the laboratory frame, where y is the relative lepton energy loss in the proton rest frame and η is the $D^{*\pm}$ pseudorapidity.

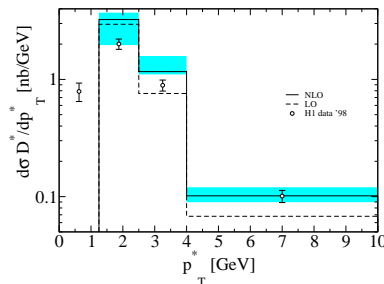


Figure 3. The p_T^* distribution $d\sigma/dp_T^*$ (in nb/GeV) of $D^{*\pm}$ mesons measured by H1¹² is compared with our LO and NLO predictions.

In Fig. 3, H1 data¹² are compared with LO and NLO predictions evaluated with CTEQ6¹⁰ proton PDFs, BKK¹³ FFs, and $\mu_r^2 = \mu_i^2 = \mu_f^2 = \xi [Q^2 + (p_T^*)^2] / 2$ for $\xi = 1$. The theoretical uncertainty at NLO is estimated by varying ξ between 1/2 and 2 about its default value 1.

4. Conclusions

We compared H1 data on the electroproduction of charged hadrons⁸ in the Breit frame and of $D^{*\pm}$ mesons¹² with $p_T^* > 0$ with up-to-date NLO predictions. In the first case, we found reasonable agreement, except for the region of $Q \lesssim 30 \text{ GeV}$ and $x_p \gtrsim 0.5$, where the FFs are generally less well constrained by e^+e^- data. In the second case, we found good agreement for $p_T^* \gtrsim 1.25 \text{ GeV}$. This nicely supports the scaling violations in the FFs encoded via the DGLAP evolution as well as their universality predicted by the factorisation theorem.

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