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Geometrical scaling in charm structure function ratios

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Abstract

By using a Laplace-transform technique, we solve the next-to-leading-order master equation for charm production and derive a compact formula for the ratio $R^c = F_L^{c\bar{c}}/F_2^{c\bar{c}}$, which is useful for extracting the charm structure function from the reduced charm cross section, in particular, at DESY HERA, at small x. Our results show that this ratio is independent of x at small x. In this method of determining the ratios, we apply geometrical scaling in charm production in deep inelastic scattering (DIS). Our analysis shows that the renormalization scales have a sizable impact on the ratio R^c at high Q^2. Our results for the ratio of the charm structure functions are in a good agreement with some phenomenological models.

Keywords: Ratio of the charm structure functions; Laplace method; Geometric scaling; Low-x

1. Introduction

The *ep* collider at HERA has played a crucial role in furthering the understanding of the proton's structure. In the case of pure photon exchange, the totally inclusive cross section of deep-inelastic lepton–proton scattering (DIS) has the form

$$\frac{d^2\sigma}{dx dQ^2} = \frac{2\pi\alpha^2 Y_+}{Q^4 x}.\sigma_r, \tag{1}$$

where the reduced cross section can be defined by the structure functions $F_2(x, Q^2)$ and $F_L(x, Q^2)$ as

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$$\sigma_r \equiv F_2(x, Q^2) - \frac{y^2}{Y_+}.F_L(x, Q^2), \tag{2}$$

where $Y_+ = 1 + (1 - y)^2$. The structure functions F_2 and F_L are related to the cross sections σ_T and σ_L for the interaction of transversely and longitudinally polarized virtual photons with protons [1]. The quark parton model (QPM) predicts $\sigma_L = 0$, which leads to the so-called Callan–Gross relation $F_L = 0$, where it is further broken by QCD corrections. Thus, in QCD, the longitudinal structure function F_L becomes non-negligible, and its contribution should be properly taken into account when F_2 is extracted from the measured cross section. However, the contribution of the longitudinal structure function F_L to the cross section is sizeable only at large values of the inelasticity y, and in most of the kinematic range, the relation $\sigma_r \approx F_2$ holds to a very good approximation. The same is true for the contributions $F_2^{c\bar{c}}$ and $F_L^{c\bar{c}}$ to F_2 and F_L due to the charm quarks.

Therefore, precise measurements of the charm-inclusive scattering cross section at the *ep* collider are important for the understanding of charmed meson production. The charmed meson production in deeply inelastic *ep* scattering, in the one-photon-exchange approximation, is via the reaction

$$e^- + p \to e^- + c\bar{c} + X. \tag{3}$$

The reduced cross section is defined as

$$\begin{aligned} \sigma_r^{c\bar{c}} &= \frac{Q^4 x}{2\pi\alpha^2 Y_+}\frac{d^2\sigma^{c\bar{c}}}{dxdy} = F_2^{c\bar{c}}(x, Q^2, m^2) - \frac{y^2}{Y_+}F_L^{c\bar{c}}(x, Q^2, m^2) \\ &= F_2^{c\bar{c}}(x, Q^2, m^2)\left(1 - \frac{y^2}{Y_+}R^c\right). \end{aligned} \tag{4}$$

A measurement of the longitudinal charm structure function at small x at HERA is important because the $F_L^{c\bar{c}}$ contribution to the charm cross section can be sizeable. At small values of x, $F_L^{c\bar{c}}$ becomes non-negligible, and its contribution should be properly taken into account when $F_2^{c\bar{c}}$ is extracted from the measured charm cross section.

In perturbative QCD (pQCD) calculations, the production of heavy quarks at HERA proceeds dominantly via direct boson–gluon fusion (BGF), where the photon interacts with a gluon from the proton through the exchange of a heavy quark pair [2]. In recent years, both the H1 and ZEUS Collaborations have measured the charm component $F_2^{c\bar{c}}$ of the structure function at small x and have found it to be approximately ∼30% of the total at HERA [3].

For the treatment of the charm component of the structure function, there are basically two different prescriptions for charm production in the literature. The first is advocated in [4], where the charm quark is treated as a heavy quark, and its contribution is given by fixed-order perturbation theory. This involves the computation of the boson–gluon fusion process. In the other approach [5], the charm is treated similarly to a massless quark, and its contribution is described by a parton density in a hadron. Here, we consider the charm production via boson–gluon fusion, where the charm is treated as a heavy quark and not a parton. This scheme is usually called the fixed flavor number scheme (FFNS). In this scheme, by definition, only light partons (e.g. u, d, s and g) are included in the initial state for charm production and the number of parton flavors n_f is kept constant regardless of the energy scales involved. The boson–gluon fusion gives the correct description of F_2^c for $Q^2 < 4m_c^2$ and should remain a reasonable approximation to F_2^c for $Q^2 \geq 4m_c^2$. However, the boson–gluon fusion model will inevitably break down at larger Q^2 values because the charm can no longer be treated as a non-partonic heavy object, and begins