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ScienceDirect
Nuclear Physics B 762 (2007) 256–283
NUCLEAR PHYSICS B

Azimuthal asymmetries in DIS as a probe of intrinsic charm content of the proton

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Received 16 October 2006; accepted 6 November 2006

Available online 28 November 2006

Abstract

We calculate the azimuthal dependence of the heavy-quark-initiated $\mathcal{O}(\alpha_s)$ contributions to the lepton–nucleon deep inelastic scattering (DIS). It is shown that, contrary to the photon–gluon fusion (GF) component, the photon–quark scattering (QS) mechanism is practically $\cos 2\varphi$-independent. We investigate the possibility to discriminate experimentally between the GF and QS contributions using their strongly different azimuthal distributions. Our analysis shows that the GF and QS predictions for the azimuthal $\cos 2\varphi$ asymmetry are quantitatively well defined in the fixed flavor number scheme: They are stable, both parametrically and perturbatively. We conclude that measurements of the azimuthal distributions at large Bjorken x could directly probe the intrinsic charm content of the proton. As to the variable flavor number schemes, the charm densities of the recent CTEQ and MRST sets of parton distributions have a dramatic impact on the $\cos 2\varphi$ asymmetry in the whole region of x and, for this reason, can easily be measured.

PACS: 12.38.-t; 13.60.-r; 13.88.+e

Keywords: Perturbative QCD; Heavy flavor leptoproduction; Intrinsic charm; Azimuthal asymmetries

1. Introduction

The notion of the intrinsic charm (IC) content of the proton has been introduced over 25 years ago in Refs. [1,2]. It was shown that, in the light-cone Fock space picture [3,4], it is natural to expect a five-quark state contribution to the proton wave function. The probability to find in a

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doi:10.1016/j.nuclphysb.2006.11.008

nucleon the five-quark component $|uudc\bar{c}\rangle$ is of higher twist since it scales as $1/m^2$ where m is the c-quark mass [5]. This component can be generated by $gg \to c\bar{c}$ fluctuations inside the proton where the gluons are coupled to different valence quarks. Since all of the quarks tend to travel coherently at same rapidity in the $|uudc\bar{c}\rangle$ bound state, the heaviest constituents carry the largest momentum fraction. For this reason, one would expect that the intrinsic charm component to be dominate the c-quark production cross sections at sufficiently large Bjorken x. So, the original concept of the charm density in the proton [1,2] has nonperturbative nature and will be referred to in the present paper as nonperturbative IC.

A decade ago another point of view on the charm content of the proton has been proposed in the framework of the variable flavor number scheme (VFNS) [6,7]. The VFNS is an approach alternative to the traditional fixed flavor number scheme (FFNS) where only light degrees of freedom (u, d, s and g) are considered as active. It is well known that a heavy quark production cross section contains potentially large logarithms of the type $\alpha_s \ln(Q^2/m^2)$ whose contribution dominates at high energies, $Q^2 \to \infty$. Within the VFNS, these mass logarithms are resummed through the all orders into a heavy quark density which evolves with Q^2 according to the standard DGLAP [8–10] evolution equation. Hence the VFN schemes introduce the parton distribution functions (PDFs) for the heavy quarks and change the number of active flavors by one unit when a heavy quark threshold is crossed. We can say that the charm density arises within the VFNS perturbatively via the $g \to c\bar{c}$ evolution and will call it the perturbative IC.

Presently, both perturbative and nonperturbative IC are widely used for a phenomenological description of available data. (A recent review of the theory and experimental constraints on the charm quark distribution can be found in Refs. [11,12]. See also Appendix C in the present paper.) In particular, practically all the recent versions of the CTEQ [13] and MRST [14] sets of PDFs are based on the VFN schemes and contain a charm density. At the same time, the key question remains open: How to measure the intrinsic charm content of the proton? The basic theoretical problem is that radiative corrections to the fixed order predictions for the production cross sections are large. In particular, the next-to-leading order (NLO) corrections increase the leading order (LO) results for both charm and bottom production cross sections by approximately a factor of two at energies of the fixed target experiments. Moreover, soft gluon resummation of the threshold Sudakov logarithms indicates that higher-order contributions are also essential. (For a review see Refs. [15,16].) On the other hand, perturbative instability leads to a high sensitivity of the theoretical calculations to standard uncertainties in the input QCD parameters. For this reason, it is difficult to compare pQCD results for spin-averaged cross sections with experimental data directly, without additional assumptions. The total uncertainties associated with the unknown values of the heavy quark mass, m, the factorization and renormalization scales, μ_F and μ_R, Λ_{QCD} and the PDFs are so large that one can only estimate the order of magnitude of the pQCD predictions for production cross sections [17,18].

Since production cross sections are not perturbatively stable, it is of special interest to study those observables that are well-defined in pQCD. A nontrivial example of such an observable was proposed in Refs. [19–22] where the azimuthal $\cos 2\varphi$ asymmetry in heavy quark photo- and leptoproduction has been analyzed.[1] In particular, the Born level results have been considered [19] and the NLO soft-gluon corrections to the basic mechanism, photon–gluon fusion (GF), have been calculated [20,21]. It was shown that, contrary to the production cross sections, the

[1] The well-known examples are the shapes of differential cross sections of heavy flavor production which are sufficiently stable under radiative corrections.