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Dirac and Pauli form factors based on consideration of the gluon effect in light-cone wave functions

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Abstract

We discuss Dirac and Pauli form factors based on a generalized parton distribution framework in the range of high momentum transfers of $t < 30\ \text{GeV}^2$ and calculate the electromagnetic form factors, G_E and G_M, for the proton. In previous work, Gaussian parameterization has been used in wave functions for calculating electromagnetic form factors at intermediate-high momentum transfers of $1\ \text{GeV}^2 < t < 10\ \text{GeV}^2$; in this paper, by considering an improved Gaussian ansatz, we not only calculate the electromagnetic form factors at moderately high momentum transfers t but also can calculate these quantities at high momentum transfers, achieving reasonable agreement with experimental data and other previous work.

Keywords: Form factor; Momentum transfer; Generalized parton distribution

1. Introduction

One of the theories that can describe elastic form factors is that of generalized parton distributions (GPDs) [1–4]. The GPDs are the non-perturbative part of hard exclusive electro-production processes [5–9]. The GPDs contain information about the quark distributions in hadrons and are defined separately for each valence quark flavor (u, d, s). They are defined as transition matrix elements between states with different momentum fractions. The nucleon Dirac and Pauli form factors are described as sums of rules that link two GPD functions $(H(x, \xi, t),\ E(x, \xi, t))$ [7]. These functions in the light-cone frame depend on three parameters: x, the longitudinal quark

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momentum; t, the invariant momentum transfer; and ξ, the skewness, which is the longitudinal momentum transfer. The GPDs allow for the determination of the extent to which quarks with a specific momentum fraction x contribute to the form factor. By calculating these form factors, which are the non-forward matrix elements of the current operator, one can determine how the charge, which is the forward matrix element of the same operator, is distributed in position space [10]. By analogy between form factors and GPDs, one would expect that GPDs, the off-forward matrix elements of the operator [10], should contain information about how the quark distribution functions are distributed in position space [11–13]. In other work, the Dirac and Pauli form factors for the proton have been calculated by considering a Gaussian ansatz for the two-parton wave function [14]; however, this calculation yields reasonable agreement only in the range of $1\ \text{GeV}^2 < t < 10\ \text{GeV}^2$ by considering the soft part of the wave function (ψ_{soft}). Calculations presented in previous works have not considered the hard part for wave function; they merely present the results for form factors at moderately large t [14]. In this paper, we consider an improved Gaussian ansatz for $H(x,0,t) = q(x)\exp(\alpha t(1-x)\ln(\frac{1}{x}))$ [15], and by taking $\xi = 0$ in the generalized parton distributions, we calculate the Dirac and Pauli form factors and extend the electromagnetic form factors for the proton to cover the range of large momentum transfers, $t < 30\ \text{GeV}^2$. Additionally, we take the parton distribution, $q(x)$, from the MSTW 2008 parameterization in the NNLO approximation [16]. Taking $\alpha = -1.12\ \text{GeV}^{-2}$ for $H(x,0,t)$, our result spans the range of $1\ \text{GeV}^2 < t < 10\ \text{GeV}^2$, and taking $\alpha = -1.23\ \text{GeV}^{-2}$, our result spans the range of $t < 30\ \text{GeV}^2$; the results are in good agreement with the experimental data. Furthermore, we compare our results with those presented in another work [17].

2. Form factors in generalized parton distributions

The elastic helicity-conserving and helicity-flip form factors can be written as follows [15,17]:

$$F_1(t) = \sum_q e_q F_1^q(t), \tag{1}$$

$$F_2(t) = \sum_q e_q F_2^q(t), \tag{2}$$

where $F_1(t)$, and $F_2(t)$ are Dirac and Pauli form factors, which can be expressed in terms of the valence quark GPDs H and E by the following sum rules for quarks of the u and d flavors [17]:

$$F_1^q(t) = \int_{-1}^{1} dx\, H^q(x,\xi,t), \tag{3}$$

$$F_2^q(t) = \int_{-1}^{1} dx\, E^q(x,\xi,t). \tag{4}$$

If the momentum transfer $t = Q^2$ is transverse, then $\xi = 0$. The integration region can be reduced to the interval $0 < x < 1$; therefore, the non-forward parton densities are [17,18]

$$\mathcal{H}^q(x,t) = H^q(x,0,t) + H^q(-x,0,t), \tag{5}$$

$$\mathcal{E}^q(x,t) = E^q(x,0,t) + E^q(-x,0,t). \tag{6}$$

Then, Eqs. (3) and, (4) can be rewritten as: