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Comparisons of electric charge and axial charge meson cloud distributions in the PCQM

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Abstract: The meson cloud distributions in r-space are extracted from the nucleon electromagnetic and axial form factors which are derived in the perturbative chiral quark model. The theoretical results indicate that the electric charge and axial charge distributions of the three-quark core are the same, the electric charge distributions of the meson cloud and three-quark core are more or less in the same region, but the axial charge meson cloud distributes mainly inside the three-quark core.

Keywords: PCQM, EM form factor, axial form factor, meson cloud

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Contents

1 Introduction

The meson cloud of the nucleon, undoubtedly, plays a relevant role in the study of low energy electroweak properties of the nucleon. The meson cloud model, where the nucleon is considered as a system of three valence quarks surrounded by a meson cloud [1–10], has recently been employed to study the generalized parton distribution [11, 12], nucleon electroweak form factors [13–17], nucleon strangeness [18, 19], etc. In [20–22], meson cloud contributions to the neutron charge form factor have been studied and discussed in the meson cloud model, while the effects of the meson cloud on electromagnetic transitions have been estimated in [23–25]. In our previous works [26, 27], the electromagnetic and axial form factors as well as electroweak properties of octet baryons have been studied in the perturbative chiral quark model (PCQM). The theoretical results in the PCQM with predetermined quark wave functions are in good agreement with experimental data and lattice QCD values. In addition, [27] reveals that the meson cloud plays an important role in the axial charge of octet baryons, contributing 30%–40% to the total values. In this work, we attempt to further study and compare the meson cloud distributions to the nucleon electromagnetic and axial form factors in the PCQM.

The paper is organized as follows. In section 2, we briefly describe the basic notions of the PCQM. The comparison and discussion between EM and axial form factors of nucleon are given in section 3.

2 Perturbative chiral quark model

In the framework of the PCQM, baryons are considered as the bound states of three relativistic valence quarks moving in a central Dirac field with $V_{\rm eff}(r) = S(r) + \gamma^0 V(r)$, while a cloud of pseudoscalar mesons, as the sea-quark excitations, is introduced for chiral symmetry requirements, and the interactions between quarks and mesons are achieved by the nonlinear σ model in the PCQM. The Weinberg-type Lagrangian of the PCQM under an unitary chiral rotation [14, 15] is derived as,

$$\mathcal{L}^W(x) = \mathcal{L}_0(x) + \mathcal{L}_I^W(x) + o(\vec{\pi}), \tag{2.1}$$

$$\mathcal{L}_0(x) = \bar{\psi}(x)\big[i\partial\!\!\!/ - \gamma^0 V(r) - S(r)\big]\psi(x) - \frac{1}{2}\Phi_i(x)\big(\Box + M_\Phi^2\big)\Phi^i(x), \tag{2.2}$$

$$\mathcal{L}_I^W(x) = \frac{1}{2F}\partial_\mu\Phi_i(x)\bar{\psi}(x)\gamma^\mu\gamma^5\lambda^i\psi(x) + \frac{f_{ijk}}{4F^2}\Phi_i(x)\partial_\mu\Phi_j(x)\bar{\psi}(x)\gamma^\mu\lambda_k\psi(x), \tag{2.3}$$

where f_{ijk} are the totally antisymmetric structure constant of $SU(3)$, the pion decay constant $F = 88$ MeV in the chiral limit, Φ_i are the octet meson fields, and $\psi(x)$ is the triplet of the u, d, and s quark fields taking the form

$$\psi(x) = \begin{pmatrix} u(x) \\ d(x) \\ s(x) \end{pmatrix}. \tag{2.4}$$

The quark field $\psi(x)$ could be expanded in

$$\psi(x) = \sum_{\alpha} \left(b_\alpha u_\alpha(\vec{x})\, e^{-i\mathcal{E}_\alpha t} + d_\alpha^\dagger \upsilon_\alpha(\vec{x}) e^{i\mathcal{E}_\alpha t} \right), \tag{2.5}$$

where b_α and $d_\alpha^\dagger$ are the single quark annihilation and antiquark creation operators. The ground state quark wave function $u_0(\vec{x})$ may, in general, be expressed as

$$u_0(\vec{x}) = \begin{pmatrix} g(r) \\ i\vec{\sigma}\cdot\hat{x} f(r) \end{pmatrix} \chi_s \chi_f \chi_c, \tag{2.6}$$

where χ_s, χ_f and χ_c are the spin, flavor and color quark wave functions, respectively.

In our previous works [26, 27], the ground state quark wave functions have been determined by fitting the PCQM theoretical result of the proton charge form factor $G_E^p(Q^2)$ to the experimental data [26], and the electromagnetic and axial form factors as well as electroweak properties of octet baryons in low energy region have been studied in the PCQM based on the predetermined quark wave functions. The PCQM theoretical results are in good agreement with experimental data and lattice QCD values. More details could be found in [26, 27].

3 Electric and axial charge distributions of meson cloud

Following our previous works [26, 27], we present in figure 1 the proton magnetic and nucleon axial form factors separately in leading order (LO) and loop Feymann diagram contributions. The PCQM results shown in figure 1 clearly reveal that the LO diagram results in a dipole-like form factor while the meson cloud leads to a flat contribution to the magnetic and axial form factors. The flat contribution may indicate that the meson cloud of the nucleon may distribute mainly in a very small region.

In general, the form factor $F(q^2)$ is the Fourier transformation of charge distribution in r-space and takes the form,

$$F(q^2) = \int \rho(\vec{r}) e^{iq\vec{r}} d^3\vec{r}, \tag{3.1}$$

where $\rho(\vec{r})$ is the charge density. If $F(q^2)$ has been determined, in principle, the charge distribution $\rho(r)$ could be obtained by the inverse Fourier transformation,

$$\rho(\vec{r}) = \frac{1}{(2\pi)^3} \int F(q^2) e^{i\vec{q}\cdot\vec{r}} d^3\vec{q}. \tag{3.2}$$

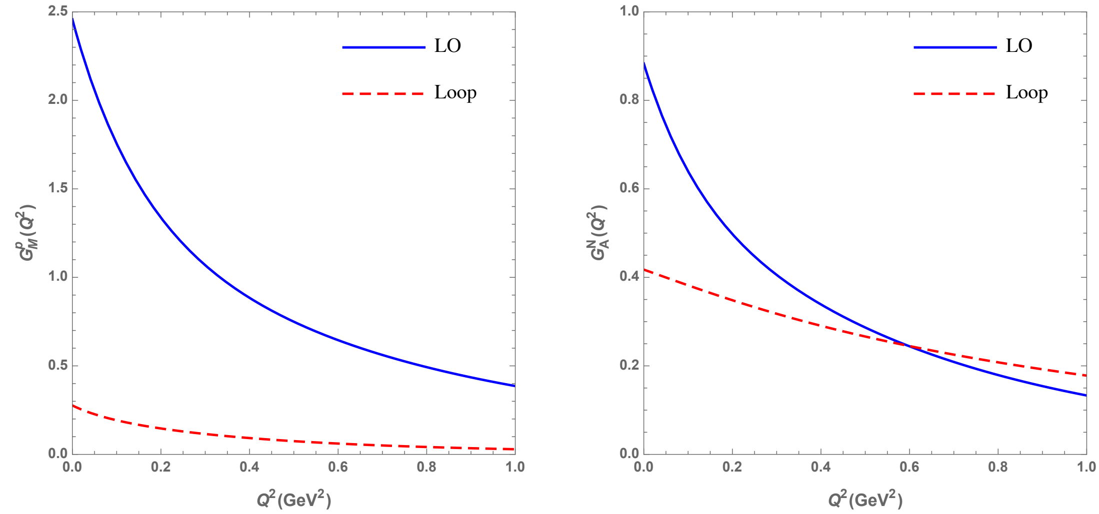

Figure 1. Leading order (solid) and loop (dashed) contributions to the proton magnetic (left panel) form factor and neutron axial (right panel) form factor.

In this work, we extract, based on the inverse Fourier transformation in equation (3.2), the electric charge and axial charge meson cloud distributions of the nucleon from the EM and axial form factors as shown in figure 1. Shown in figure 2 are the LO and meson cloud contributions to the proton magnetic form factor $G_M^p(Q^2)$ (left panel) and the nucleon axial form factor $G_A^N(Q^2)$ (right panel) in r-space. It is found in figure 2 that the electric charge distributions of the three-quark core and the meson cloud are almost in the same region, but the loop diagrams contribute to the $G_A^N(Q^2)$ in a clearly smaller region than the LO diagram, which may indicate that the axial charge meson cloud distributes mainly inside

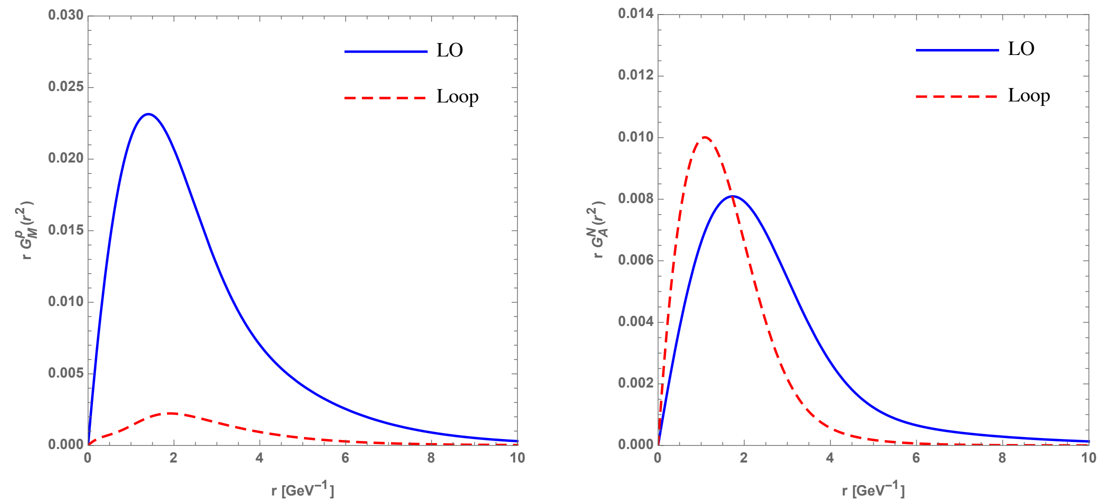

Figure 2. Comparisons between the LO and meson cloud distributions for proton magnetic (left panel) and axial (right panel) form factors in r-space.

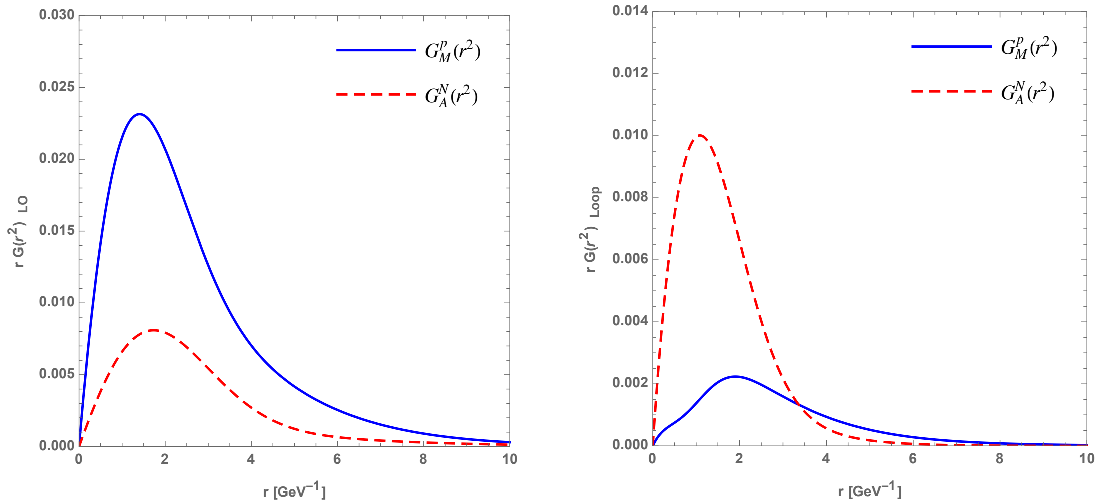

Figure 3. Comparisons between the magnetic and axial distributions in r-space for the LO (left panel) and loop (right panel) diagrams.

the three-quark core.

Furthermore, we also compare the LO contributions to the $G_M^p(Q^2)$ and $G_A^N(Q^2)$ in r-space, as presented in the left panel of figure 3. It is clear that the LO $G_M^p(r^2)$ and $G_A^N(r^2)$ show a similar r-dependence, which may indicate that the electric charge and axial charge distributions of the constituent quarks are the same. The meson cloud $G_M^p(r^2)$ and $G_A^N(r^2)$ in the right panel of figure 3 show that the axial charge distribution of the meson cloud is narrower and the peak is closer to the origin.

In summary, one may conclude that the similar r-dependence of the magnetic and axial form factors resulted from the LO diagrams may indicate that the electric charge and axial charge distributions of the constituent quarks are the same. The electric charge distributions of the meson cloud and three-quark core are more or less in the same region, but the axial charge meson cloud distributes mainly inside the three-quark core.

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