Longitudinal momentum distributions in transverse coordinate space

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Introduction

From the first principle of Quantum Chromodynamics (QCD), it is difficult to understand the hadronic structure and their properties due to their nonperturbative nature. In the last decade, there have been numerous attempts to gain insight into the hadronic structure by studying the QCD inspired models. The quark-diquark model is one of the most successful QCD inspired models to investigate various aspects of hardonic properties where the nucleon is considered to be a bound state of a single quark and a scalar or vector diquark state. Recently, a light-front scalar quark-diquark model for the nucleons inspired by soft-wall AdS/QCD has been proposed [1] and extensively used to investigate and reproduce many interesting properties of the nucleons [2]. The light-front wave functions (LFWFs) in this model are obtained by matching the electromagnetic form factors of the hadrons in the soft-wall model of AdS/QCD which has been successful in explaining various hadronic properties, for example, hadron mass spectrum, Parton Distribution Functions (PDFs), Generalized Parton Distributions (GPDs), meson and nucleon form factors, transverse densities, structure functions etc.
The AdS/CFT correspondence [3] between the string theories of gravity in the AdS space and conformal gauge field theories in the physical space-time provides a completely new set of tool for studying the dynamics of QCD. One can represent the strong interactions of quarks and gluons by a semi-classical gravity theory i.e., without quantum effects such as particle creation and annihilation in higher dimensions. Even though, a perfect string theory dual of QCD is not yet known, the AdS/CFT correspondence can still provide remarkable insight into various properties/features of QCD including color confinement, qualitative explanation for meson and baryon spectra and wave functions describing the hadron structure. In the present work, we study the longitudinal momentum distributions in the transverse coordinate space in a light-front quark-diquark model inspired by soft-wall AdS/QCD. We take the phenomenological light-front quark-diquark model proposed by Gutsche *et. al* [1]. In this model, the LFWFs for the proton are constructed from the two particle wave functions obtained in soft-wall AdS/QCD.

Light-front diquark AdS/QCD model

In this model, one can contemplate the three valence quarks of the nucleons as an effectively composite system composed of a fermion (quark) and a composite state of diquark (boson) based on one loop quantum fluctuations. The Dirac and Pauli form factors for quarks in this model can be evaluated in terms of overlap of the LFWFs as

$$\begin{aligned}
F_1^q(Q^2) &= \int \frac{dxd^2\mathbf{k}_\perp}{16\pi^3} \Big[\psi_{+q}^{+*}(x,\mathbf{k}'_\perp)\psi_{+q}^{+}(x,\mathbf{k}_\perp) \\
&\quad + \psi_{-q}^{+*}(x,\mathbf{k}'_\perp)\psi_{-q}^{+}(x,\mathbf{k}_\perp)\Big], \\
F_2^q(Q^2) &= -\frac{2M_n}{q^1 - iq^2}\int \frac{dxd^2\mathbf{k}_\perp}{16\pi^3}\Big[\psi_{+q}^{+*}(x,\mathbf{k}'_\perp) \\
&\quad \psi_{+q}^{-}(x,\mathbf{k}_\perp) + \psi_{-q}^{+*}(x,\mathbf{k}'_\perp)\psi_{-q}^{-}(x,\mathbf{k}_\perp)\Big],
\end{aligned} \quad (1)$$

*Electronic address: narinder.msc.phy@gmail.com with $\mathbf{k}'_\perp = \mathbf{k}_\perp + (1-x)\mathbf{q}_\perp$ for the struck quark. Here x is the light-cone momentum fraction and $\psi^{\lambda_N}_{\lambda_q q}(x, \mathbf{k}_\perp)$ are the LFWFs with nucleon helicities $\lambda_N = \pm$ and for the struck quark $\lambda_q = \pm$, where plus and minus correspond to $+\frac{1}{2}$ and $-\frac{1}{2}$ respectively.

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The gravitational form factors $A(Q^2)$ and $B(Q^2)$ can be obtained from the helicity conserving and helicity-flip matrix elements of the T^{++} tensor current. $A(Q^2)$ and $B(Q^2)$ are analogous to $F_1(Q^2)$ (Dirac) and $F_2(Q^2)$ (Pauli) form factors for the J^+ vector current. The helicity conserved form factor $A(Q^2)$ allows one to measure the momentum fractions carried by each constituent of a hadron. The gravitational form factors in the light-front quark-diquark model can be obtained in terms of the overlap of the wave functions as [2]. Using the LFWFs in transverse coordinate space we can now define the longitudinal momentum distribution in the transverse coordinate space for a struck flavor q (fermionic)

$$P^f_{Lq(flavor)}(r) = \int dx\ x[\tilde{\psi}^{+*}_{+q}(x, \mathbf{r}_\perp) \tilde{\psi}^{+}_{+q}(x, \mathbf{r}_\perp) + \tilde{\psi}^{+*}_{-q}(x, \mathbf{r}_\perp)\tilde{\psi}^{+}_{-q}(x, \mathbf{r}_\perp)], \quad (2)$$

and for the diquark (bosonic)

$$P^b_{Lq(flavor)}(r) = \int dx\ (1-x)[\tilde{\psi}^{+*}_{+q}(x, \mathbf{r}_\perp) \tilde{\psi}^{+}_{+q}(x, \mathbf{r}_\perp) + \tilde{\psi}^{+*}_{-q}(x, \mathbf{r}_\perp)\tilde{\psi}^{+}_{-q}(x, \mathbf{r}_\perp)]. \quad (3)$$

Results and Discussion

We have studied the longitudinal momentum distributions for proton and the individual distribution for quark (fermionic) and diquark (bosonic) in the transverse coordinate space from the gravitational form factors. We have used the light-front quark-diquark model where the wave functions are modeled from the solution of two particle wave function in the soft-wall AdS/QCD correspondence. It has been observed that the diquark distributions are larger than the quark distributions

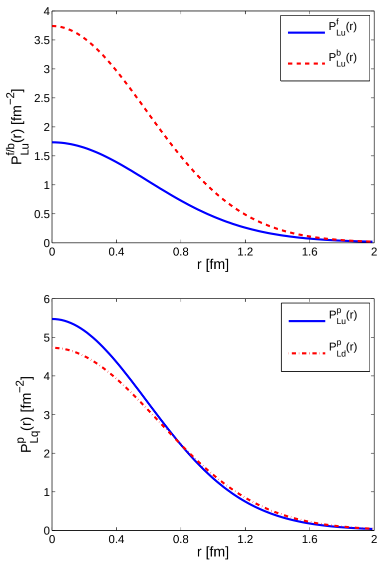

FIG. 1: Longitudinal momentum distributions $P^{f/b}_L$ for struck u quark with fermion and bosonic contributions and P^p_L for proton when struck quarks are u and d.

but when the quark and diquark contributions are added up, they provide more or less same proton distributions for different struck u and d quarks. It is observed that for u quark, fermionic contribution is much larger than bosonic contribution. The magnitude for $P^p_{Lq}(x, \mathbf{r}_\perp)$ is large when the struck is u as compared to d quark.

References

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