Spin densities in impact parameter space

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Introduction

Many experiments are presently running worldwide and some have finished taking the data towards the study of hadronic structure. There has been an enormous interest to understand the partonic distribution and many models have been proposed to explain the hadronic properties theoretically. Last two decades have been dedicated towards the study of generalized parton distributions (GPDs) which contain 3-D structure information of the hadrons. Several experiments, for example, H1 collaboration, ZEUS collaboration and fixed target experiments at HERMES have completed taking data on deeply virtual Compton scattering (DVCS). Experiments are also running at JLAB, Hall A and B and COMPASS at CERN to access the GPDs. GPDs have been classified into two types: the chiral even GPDs (H,E, $\tilde{H}$, $\tilde{E}$) and the chiral odd GPDs $(H_T, E_T, \tilde{H}_T, \tilde{E}_T)$ [1]. Chiral even GPDs allow us to access partonic configurations not only with a given longitudinal momentum fraction but also at a specific (transverse) location inside the hadron. In the forward limit they reduce to usual parton densities and when integrated x, they reduce to the form factors which are the non-forward matrix elements of the current operator and describe how the forward matrix element (charge) is distributed in position space.
The chiral odd GPDs, in the forward limit, reduce to transversity $h_1(x)$. The fundamental term $2\tilde{H}_T + E_T$ is of great interest as it provides valuable information about the correlation between the spin and orbital angular momentum of the quarks inside the nucleon. There is however no direct interpretation for $\tilde{E}_T$ [1].
We have used the covariant model [2] to evaluate the quark-proton helicity amplitudes. The formalism is based upon the dissociation of the initial proton into a quark and a fixed mass system (diquark). To obtain the distinct predictions for the up and down quarks we have considered both the spin-0 (scalar) and spin-1 (axial-vector) configurations for the diquark. Further, we have obtained the results for the fundamental term $2\tilde{H}_T + E_T$, linked with the transverse momentum distributions (TMDs) and it's first moment providing the proton's transverse anomalous magnetic moment. We have also studied the spin densities for monopole, dipole and quadrupole contributions for different situations, for example, when the quarks and proton both are unpolarized, when the quarks are polarized but proton is unpolarized and finally when both the quarks and proton are polarized but in different directions.

Spin Densities

We define the three-dimensional density $\rho(x, b_\perp)$ which gives the probability to find a quark with momentum fraction x with transverse position $b_\perp$ and transverse spin $s_\perp$ in the proton with transverse spin $S_\perp$ [3]. We have

$$\begin{aligned}\rho(x, b_\perp) \;=\; & \frac{1}{2}[\mathcal{H}(x, b^2) + s^i S^i \Big(\mathcal{H}_T(x, b^2) \\ & - \frac{1}{4M^2}\Delta_b \tilde{\mathcal{H}}_T(x, b^2)\Big) + \frac{b^j \epsilon^{ji}}{M} \\ & \Big(S^i \mathcal{E}'(x, b^2) + s^i[\mathcal{E}'_T(x, b^2) \\ & + 2\tilde{\mathcal{H}}'_T(x, b^2)]\Big) + s^i(2b^i b^j - \\ & b^2\delta_{ij})\frac{S^j}{M^2}\tilde{\mathcal{H}}''_T(x, b^2)]. \qquad (1)\end{aligned}$$

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They depend on $b_\perp$ only via $b_\perp^2 = b^2$ due to rotational invariance and we can define

$$f' = \frac{\partial}{\partial b^2} f, \; f'' = \left(\frac{\partial}{\partial b^2}\right)^2 f,$$
$$\Delta_b f = 4 \frac{\partial}{\partial b^2}\left(b^2 \frac{\partial}{\partial b^2}\right) f, \qquad (2)$$

with two dimensional antisymmetric tensor ϵ^{ij}, $\epsilon^{12} = -\epsilon^{21} = 1$ and $\epsilon^{11} = \epsilon^{22} = 0$.

Calculations

The Fourier transform for different contributions discussed in Eq. (1) are expressed as

$$-\frac{1}{2}\frac{s_i b_j (\mathcal{E}'_T(x, b_\perp) \; + 2\tilde{\mathcal{H}}'_T(x, b_\perp))}{M} = \frac{s_i b_j}{2M}$$
$$\int \frac{\Delta^2 d\Delta}{2\pi} J_1(\Delta b)(E_T(x, 0, t) \; + 2\tilde{H}_T(x, 0, t)),$$

$$-\frac{1}{2} S_i b_j \frac{\mathcal{E}'(x, b_\perp)}{M} = \frac{1}{4\pi M} S_i b_j \times$$
$$\int \Delta^2 J_1(\Delta b) E(x, 0, t) d\Delta, \qquad (3)$$
$$\frac{1}{2} S_j b_i \mathcal{E}'(x, b_\perp) = -\frac{1}{4\pi} S_j b_i \times$$
$$\int \Delta^2 J_1(\Delta b) E(x, 0, t) d\Delta. \qquad (4)$$

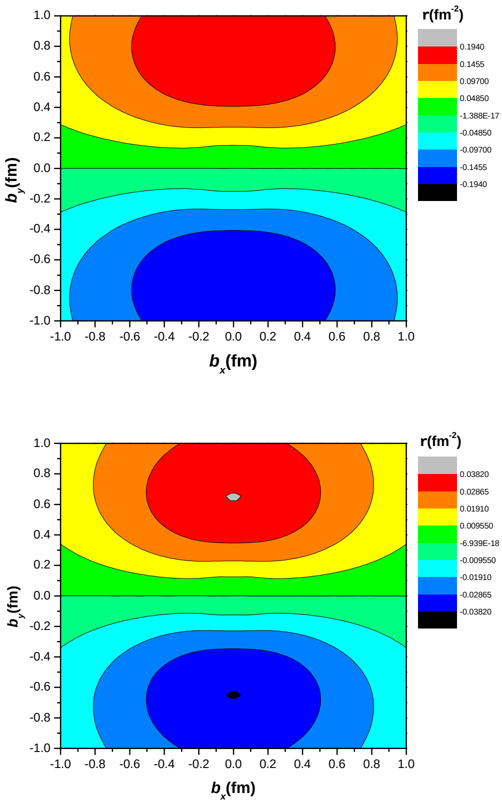

FIG. 1: The dipole contribution $-\frac{1}{2}s_i b_j(\mathcal{E}'_T + 2\tilde{\mathcal{H}}'_T)/M$ for the transversely polarized quarks in the unpolarized proton for the up (left panel) and down (right panel) quarks.

Summary and Conclusions

In the present work, we have studied the chiral odd GPDs in the impact parameter space. We have considered a model with the quark-proton scattering amplitudes at leading order with proton-quark-diquark vertices. In order to obtain the explicit contributions from up and down quarks, we have considered both the scalar (spin-0) and the axial-vector (spin-1) configurations for the diquark. We have also studied the spin densities for the up and down quarks for monopole, dipole and quadrupole contributions for unpolarized and polarized quarks in unpolarized and polarized proton. We have presented the results for the dipole contribution $-\frac{1}{2}s_i b_j(\mathcal{E}'_T + 2\tilde{\mathcal{H}}'_T)/M$ for $\hat{x}$ polarized quarks in an unpolarized proton. It is observed that the distribution has a reflection symmetry along the $\hat{y}$ direction and all orientations are equally probable in the positive and negative $\hat{y}$ direction. The density obtained for the up quark is however greater than the density obtained for the down quark. The spin densities provide a complete description of the spin structure of the nucleon and its relation with TMDs could be tested in future experiments.

References

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