T-even gluon TMDs of proton in light-cone spectator model

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Introduction

Lot of theoretical and experimental work has been done during recent years to reveal the partonic structure of hadrons. Theoretically, different distribution functions provide information about the partonic configuration of hadrons. Transverse momentum dependent parton distribution functions (TMDs) provide the three dimensional structure of hadron. TMDs gives information about the longitudinal momentum fraction x and transverse momentum $\mathbf{p}_T$ of parton inside a hadron. In this work, we study the T-even gluon TMDs of proton using light-front spectator model.

Gluon TMDs

The gluon containing minimal state of proton is $|qqqg\rangle$. Gluon has been considered as an active parton to study the gluon distributions of a proton. In the spectator model, a spin-1/2 proton of mass M can be viewed as a composite system of a spin-1 massless gluon (g) and a spin-1/2 spectator (qqq) of mass M_X. The light-front wave functions of this two-particle Fock state of proton with up helicity ($\Lambda = \uparrow$) are [1]:

$$\begin{aligned}
\psi^{\uparrow}_{+1+\frac{1}{2}}(x, \mathbf{p}_T) &= \sqrt{2}\frac{(p_x - \mathrm{i}p_y)}{x(1-x)}\,\varphi, \\
\psi^{\uparrow}_{+1-\frac{1}{2}}(x, \mathbf{p}_T) &= -\sqrt{2}\left(M - \frac{M_X}{(1-x)}\right)\varphi, \\
\psi^{\uparrow}_{-1+\frac{1}{2}}(x, \mathbf{p}_T) &= -\sqrt{2}\frac{(p_x + \mathrm{i}p_y)}{x}\,\varphi\ , \\
\psi^{\uparrow}_{-1-\frac{1}{2}}(x, \mathbf{p}_T) &= 0\ , \qquad (1)
\end{aligned}$$

where x and $\mathbf{p}_T$ are longitudinal momentum fraction and transverse momentum of gluon, respectively. The function $\varphi(x, \mathbf{p}_T)$ is:

$$\varphi(x, \mathbf{p}_T) = \frac{N_\lambda (1-x)\exp\left(-\frac{\mathbf{p}_T^2 + xM_X^2}{2\beta_1 x(1-x)}\right)}{M^2 x(1-x) - \mathbf{p}_T^2 - xM_X^2}.$$

Here N_λ provide the strength of proton-gluon-spectator vertex and β_1 is the cut off parameter.
Similarly for down helicity ($\Lambda = \downarrow$), we have

$$\begin{aligned}
\Psi^{\downarrow}_{+1+\frac{1}{2}}(x, \mathbf{p}_T) &= 0, \\
\Psi^{\downarrow}_{+1-\frac{1}{2}}(x, \mathbf{p}_T) &= \sqrt{2}\frac{p_x - \mathrm{i}p_y}{(1-x)}\varphi, \\
\Psi^{\downarrow}_{-1+\frac{1}{2}}(x, \mathbf{p}_T) &= -\sqrt{2}\Big(M - \frac{M_X}{x}\Big)\varphi, \\
\Psi^{\downarrow}_{-1-\frac{1}{2}}(x, \mathbf{p}_T) &= -\sqrt{2}\frac{p_x + \mathrm{i}p_y}{x(1-x)}\varphi. \qquad (2)
\end{aligned}$$

By omitting the gauge link, the gluon correlator can be defined as

$$\Phi^{g[ij]}(x, \mathbf{p}_T; S) = \frac{1}{xP^+}\int \frac{d\xi^-}{2\pi}\frac{d^2\boldsymbol{\xi}_\perp}{(2\pi)^2}\, e^{ip\cdot\xi} \times \big\langle P; S\big| F_a^{+j}(0)\, F_b^{+i}(\xi)\,\big|P; S\big\rangle\Big|_{\xi^+=0}. \quad (3)$$

The twist-2 T-even gluon TMDs through correlator can be defined as

$$\begin{aligned}
\delta_T^{ij}\Phi^{g[ij]}(x, \mathbf{p}_T; S) &= f_1^g(x, \mathbf{p}_T^2) + ... \quad , \\
i\epsilon_T^{ij}\Phi^{g[ij]}(x, \mathbf{p}_T; S) &= g_{1L}^g(x, \boldsymbol{p}_\perp^2 \mathbf{p}_T^2) + \frac{\mathbf{p}_T.\mathbf{S}_T}{M}\, g_{1T}^g(x, \mathbf{p}_T^2), \\
-\hat{\mathbf{S}}\Phi^{g[ij]}(x, \mathbf{p}_T; S) &= -\hat{\mathbf{S}}\frac{p_T^i p_T^j}{2M^2} h_1^{\perp g}(x, \mathbf{p}_T^2) + ...
\end{aligned}$$

The gluon TMDs can be calculated by the LFWF overlap representation given below:

$$\begin{aligned}
f_1^g(x, \mathbf{p}_T^2) &= \sum_{\lambda_\mathrm{g}\lambda_\mathrm{X}} \frac{1}{16\pi^3}\Big(\epsilon^{1*}_{\lambda_\mathrm{g}}\epsilon^{1}_{\lambda_\mathrm{g}} + \epsilon^{2*}_{\lambda_\mathrm{g}}\epsilon^{2}_{\lambda_\mathrm{g}}\Big) \\
&\times\ \psi^{\uparrow\star}_{\lambda_\mathrm{g}\lambda_\mathrm{X}}(x, \boldsymbol{p}_\perp)\psi^{\uparrow}_{\lambda_\mathrm{g}\lambda_\mathrm{X}}(x, \boldsymbol{p}_\perp), \\
g_{1L}^g(x, \mathbf{p}_T^2) &= i\sum_{\lambda_\mathrm{g}\lambda_\mathrm{X}} \frac{1}{16\pi^3}\Big(\epsilon^{2*}_{\lambda_\mathrm{g}}\epsilon^{1}_{\lambda_\mathrm{g}} - \epsilon^{1*}_{\lambda_\mathrm{g}}\epsilon^{2}_{\lambda_\mathrm{g}}\Big) \\
&\times\ \psi^{\uparrow\star}_{\lambda_\mathrm{g}\lambda_\mathrm{X}}(x, \boldsymbol{p}_\perp)\psi^{\uparrow}_{\lambda_\mathrm{g}\lambda_\mathrm{X}}(x, \boldsymbol{p}_\perp),
\end{aligned}$$

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$$\frac{\mathbf{p}_T\cdot\mathbf{S}_T}{M}g_{1T}(x,\mathbf{p}_T^2)=\sum_{\lambda_g\lambda_X}\frac{\left(\epsilon^{1*}_{\lambda_g}\epsilon^{2}_{\lambda_g}-\epsilon^{2*}_{\lambda_g}\epsilon^{1}_{\lambda_g}\right)}{16\pi^3}$$
$$\times\frac{i}{2}\Big[\psi^{\downarrow\star}_{\lambda_g\lambda_X}(x,\boldsymbol{p}_\perp)\psi^{\uparrow}_{\lambda_g\lambda_X}(x,\boldsymbol{p}_\perp)$$
$$+\psi^{\uparrow\star}_{\lambda_g\lambda_X}(x,\boldsymbol{p}_\perp)\psi^{\downarrow}_{\lambda_g\lambda_X}(x,\boldsymbol{p}_\perp)\Big],$$
$$\frac{\mathbf{p}_T\cdot\mathbf{p}_T}{2M^2}h_1^{\perp}(x,\mathbf{p}_T^2)=-\frac{1}{2}\sum_{\Lambda\,\lambda_X}\frac{1}{16\pi^3}$$
$$\times\Big[\psi^{\Lambda\,\star}_{+\,\lambda_X}(x,\boldsymbol{p}_\perp)\psi^{\Lambda}_{-\,\lambda_X}(x,\boldsymbol{p}_\perp)\epsilon^{j*}_{+}\epsilon^{i}_{-}$$
$$+\psi^{\Lambda\,\star}_{-\,\lambda_X}(x,\boldsymbol{p}_\perp)\psi^{\Lambda}_{+\,\lambda_X}(x,\boldsymbol{p}_\perp)\epsilon^{j*}_{-}\epsilon^{i}_{+}\Big].(4)$$

In above expressions, ϵ_{λ_g} is the gluon polarization vector. The letters f, g and h refer to the unpolarized, circularly polarized and linearly polarized gluon, respectively, while L and T refer to the longitudinally and transversely polarized proton.

Result and Discussion

We have obtained the following results for T-even gluon TMDs by substituting the LFWFs (given in Eq. (1) and Eq. (2)) in Eq. (4):

$$f_1^g(x,\mathbf{p}_T^2)=\frac{N_\lambda^2}{(2\pi)^3}\exp\Big(-\frac{\mathbf{p}_T^2+M_X^2x}{\beta_1^2x(1-x)}\Big)$$
$$\times\frac{\mathbf{p}_T^2(1+(1-x)^2)+x^2(M(1-x)-M_X)^2}{x[M^2x(1-x)-\mathbf{p}_T^2-M_X^2x]^2},$$
$$g_{1L}^g(x,\mathbf{p}_T^2)=\frac{N_\lambda^2}{(2\pi)^3}\exp\Big(-\frac{\mathbf{p}_T^2+M_X^2x}{\beta_1^2x(1-x)}\Big)$$
$$\times\frac{\mathbf{p}_T^2(2-x)+x(M(1-x)-M_X)^2}{[M^2x(1-x)-\mathbf{p}_T^2-M_X^2x]^2},$$
$$g_{1T}^g(x,\mathbf{p}_T^2)=\frac{2N_\lambda^2M}{(2\pi)^3}\exp\Big(-\frac{\mathbf{p}_T^2+M_X^2x}{\beta_1^2x(1-x)}\Big)$$
$$\times\frac{M(1-x)-M_X}{[M^2x(1-x)-\mathbf{p}_T^2-M_X^2x]^2},$$
$$h_1^{\perp g}(x,\mathbf{p}_T^2)=\frac{4N_\lambda^2M^2}{(2\pi)^3}\exp\Big(-\frac{\mathbf{p}_T^2+M_X^2x}{\beta_1^2x(1-x)}\Big)$$
$$\times\frac{1}{[M^2x(1-x)-\mathbf{p}_T^2-M_X^2x]^2}.$$

The distribution of linearly polarized gluon inside the unpolarized proton, $h_1^{\perp g}(x,\mathbf{p}_T^2)$, is

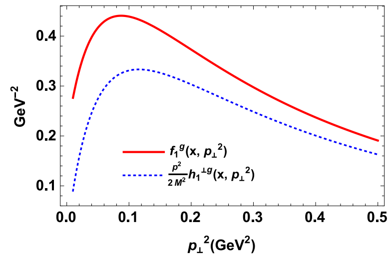

FIG. 1: The $\mathbf{p}_T$-dependence of $f_1^g(x,\mathbf{p}_T^2)$ and $\frac{\mathbf{p}_T^2}{2M^2}|h_1^{\perp g}(x,\mathbf{p}_T^2)|$ for fixed value of $x=0.4$.

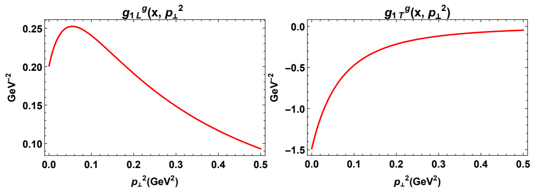

FIG. 2: The $\mathbf{p}_T$-dependence of $g_{1L}^g(x,\mathbf{p}_T^2)$ and $g_{1T}^g(x,\mathbf{p}_T^2)|$ for fixed value of $x=0.4$.

constrained by following model-independent postivity bound relation [3]:

$$\frac{\mathbf{p}_T^2}{2M^2}|h_1^{\perp g}(x,\mathbf{p}_T^2)|\le f_1^g(x,\mathbf{p}_T^2). \qquad (5)$$

To obtain numerical results for gluon TMDs, we have used the parameters $N_\lambda=5.026$, $M_X=0.943$ GeV, $\beta_1=2.092$ GeV [1]. In Fig. 1, we have shown the $\mathbf{p}_T$-dependence of $f_1^g(x,\mathbf{p}_T^2)$ and $\frac{\mathbf{p}_T^2}{2M^2}|h_1^{\perp g}(x,\mathbf{p}_T^2)|$ for fixed value of $x=0.4$. It can be clearly seen from Fig. 1 that the positivity bound relation given in Eq. 5 is satisfied in this model. For circularly polarized glouns, the $\mathbf{p}_T$-dependence of $g_{1L}^g(x,\mathbf{p}_T^2)$ and $g_{1T}^g(x,\mathbf{p}_T^2)$ for fixed value of $x=0.4$ is shown in Fig. 2. The integration of $g_{1L}^g(x,\mathbf{p}_T^2)$ over $\mathbf{p}_T$ provide the helicity distribution of gluon.

References

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