Gluon Parton Distributions in a spectataor model

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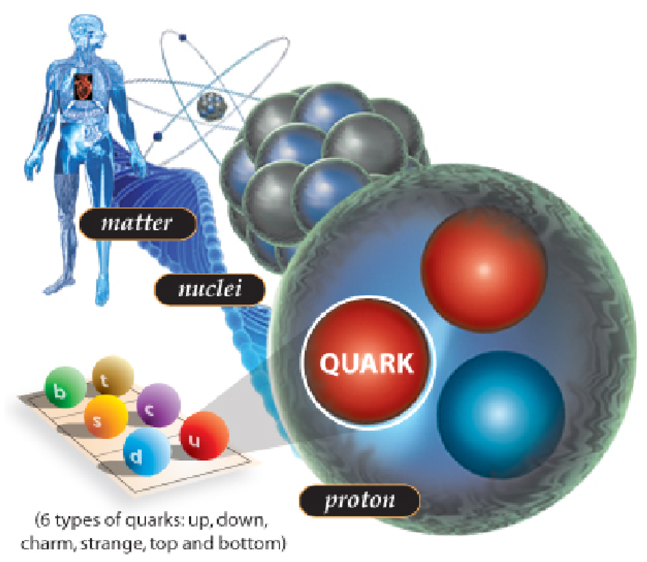
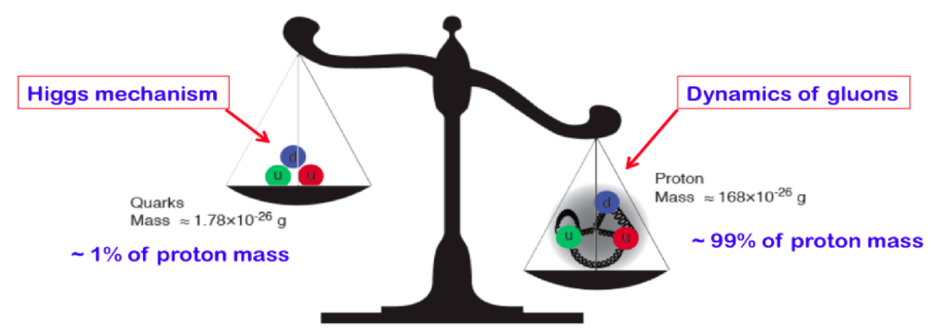
Introduction

Gluon transverse momentum dependent parton distribution functions (TMDPDFs) are important quantities used in high-energy physics to describe the distribution of gluons inside a proton.

- PDFs describe the probability of finding a particular parton carrying a certain fraction of the hadron's momentum.
- TMDPDFs go beyond the traditional collinear PDFs by incorporating the transverse momentum of the partons. This additional information allows for a more detailed understanding of the proton structure.

Proton Mass puzzle



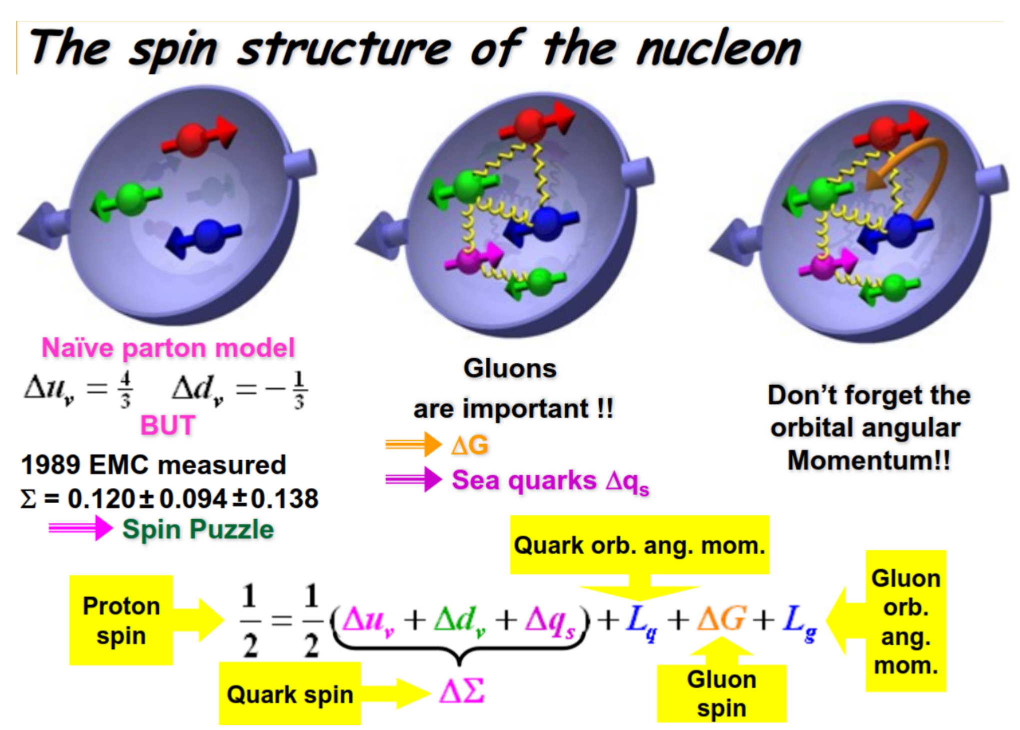


- Proton mass decomposition: Traceless kinetic energy and trace anomaly part of EMT.

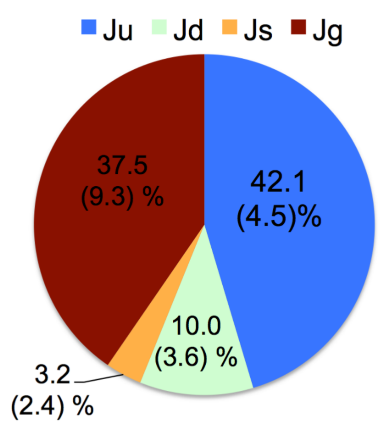
$$T^{\mu\nu} = \left(T^{\mu\nu} - \frac{\eta^{\mu\nu}}{d}T^{\alpha}_{\alpha}\right) + \frac{\eta^{\mu\nu}}{d}T^{\alpha}_{\alpha}$$

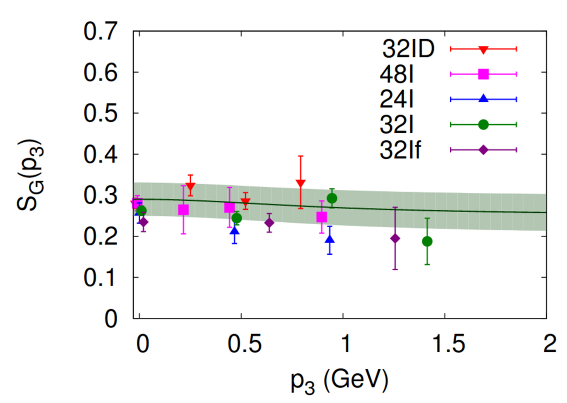
- Total proton mass: $M = M_q^{kin} + M_g^{kin} + M_a + M_m$.

Proton spin puzzle



- State-of-the-art lattice study on the proton spin.





Background and Motivation

- The two-particle Fock state for a proton with $J_z = \pm 1/2$.

$$|P;\uparrow(\downarrow)\rangle = \int \frac{d^2\mathbf{p}_\perp dx}{16\pi^3\sqrt{x(1-x)}} \sum_{\lambda_g,\lambda_X} \psi^{\uparrow(\downarrow)}_{\lambda_g,\lambda_X}(x,\mathbf{p}_\perp)\left|\lambda_g,\lambda_g; xP^+,\mathbf{p}_\perp\right\rangle$$

$$\begin{aligned}
\psi^{\uparrow}_{+1+\frac{1}{2}}(x,\mathbf{p}_\perp) &= -\sqrt{2}\frac{(-p^1_\perp + ip^2_\perp)}{x(1-x)}\varphi(x,\mathbf{p}^2_\perp), \\
\psi^{\uparrow}_{+1-\frac{1}{2}}(x,\mathbf{p}_\perp) &= -\sqrt{2}\left(M - \frac{M_X}{(1-x)}\right)\varphi(x,\mathbf{p}^2_\perp), \\
\psi^{\uparrow}_{-1+\frac{1}{2}}(x,\mathbf{p}_\perp) &= -\sqrt{2}\frac{(p^1_\perp + ip^2_\perp)}{x}\varphi(x,\mathbf{p}^2_\perp), \\
\psi^{\uparrow}_{-1-\frac{1}{2}}(x,\mathbf{p}_\perp) &= 0,
\end{aligned}
\qquad
\begin{aligned}
\psi^{\downarrow}_{+1+\frac{1}{2}}(x,\mathbf{p}_\perp) &= 0, \\
\psi^{\downarrow}_{+1-\frac{1}{2}}(x,\mathbf{p}_\perp) &= -\sqrt{2}\frac{(-p^1_\perp + ip^2_\perp)}{x}\varphi(x,\mathbf{p}^2_\perp), \\
\psi^{\downarrow}_{-1+\frac{1}{2}}(x,\mathbf{p}_\perp) &= -\sqrt{2}\left(M - \frac{M_X}{(1-x)}\right)\varphi(x,\mathbf{p}^2_\perp), \\
\psi^{\downarrow}_{-1-\frac{1}{2}}(x,\mathbf{p}_\perp) &= -\sqrt{2}\frac{(p^1_\perp + ip^2_\perp)}{x(1-x)}\varphi(x,\mathbf{p}^2_\perp).
\end{aligned}$$

- Modified soft-wall AdS/QCD wave function:

$$\varphi(x,\mathbf{p}_\perp{}^2) = N_g\frac{4\pi}{\kappa}\sqrt{\frac{\log[1/(1-x)]}{x}}x^a(1-x)^b \exp\left[-\frac{\log[1/(1-x)]}{2\kappa^2x^2}\mathbf{p}_\perp{}^2\right]$$

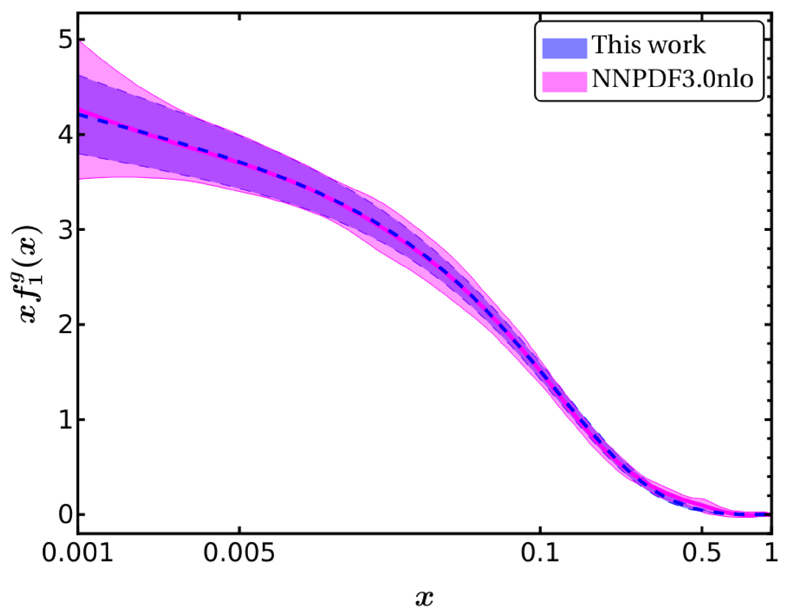
- Model parameters a, b, and Ng are fixed by fitting the $f_1^g(x)$ at $Q_0 = 2$ GeV with NNPDF3.0 data with $M_X > M$ condition.

Gluon parton distributions

- In SIDIS at the leading twist the unintegrated gluon TMD correlation function:

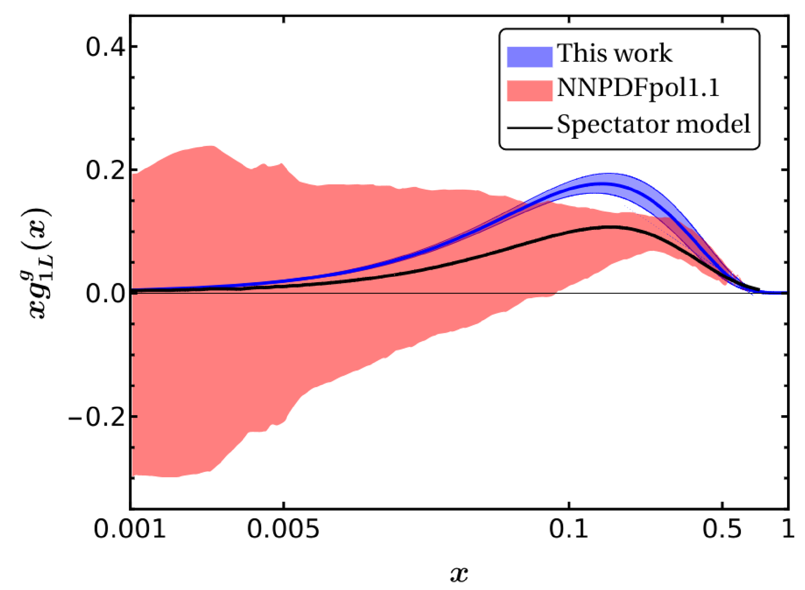
$$\Phi^{g[ij]}(x,\mathbf{p}_\perp;S) = \frac{1}{xP^+}\int \frac{d\xi^-}{2\pi}\frac{d^2\xi_\perp}{(2\pi)^2}e^{ik\cdot\xi}\langle P;S\left|\Gamma^{ij}F_a^{+j}(0)\mathcal{W}_{+\infty,ab}(0;\xi)F_b^{+i}(\xi)\right|P;S\rangle\Big|_{\xi^+=0^+}$$

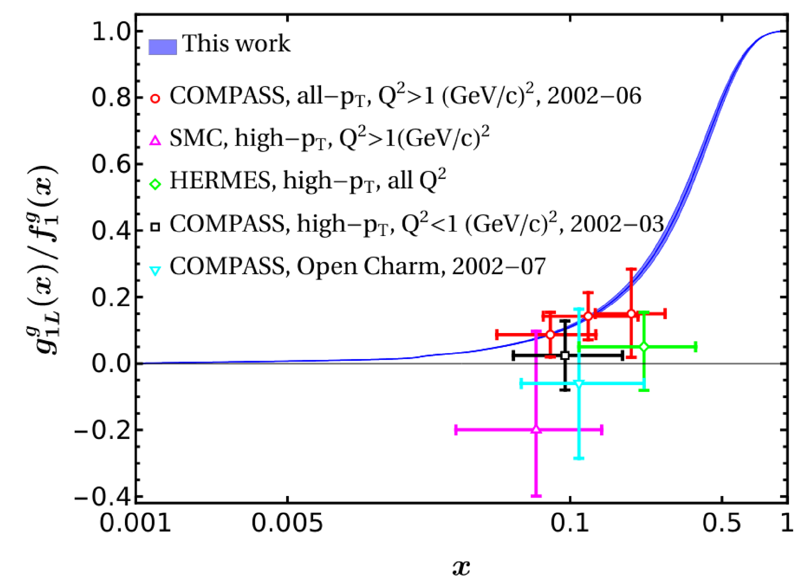
- At leading twist there are eight gluon TMDs f_1^g, g_{1L}^g, g_{1T}^g, $h_1^{\perp g}$ are T-even and $f_{1T}^{\perp g}$, $h_{1L}^{\perp g}$, h_{1T}^g, $h_{1T}^{\perp g}$ are T-odd>



- The average gluon longitudinal momentum: Second Mellin's moment of unpolarized gluon PDF, $\langle x\rangle_g = \int_{0.001}^1 dx x f_1^g(x) = 0.416 \pm 0.045$ is close to the recent lattice predictions $\langle x\rangle_g = 0.427(92)$ as well as other theoretical models.
- Gluon spin: First Mellin's moment of the gluon helicity PDF, $\Delta G = \int dx g_{1L}^g(x) = 0.326 \pm 0.058$ is larger than large-momentum effective theory $\Delta G = 0.251(47)(16)$ and DSSV19 $\Delta G = 0.309 \pm 0.109$.
- The gluon helicity asymmetry satisfy the pQCD constarints at the endpoints, i.e.,

$$\lim_{x\to 0}\frac{g_{1L}^g(x)}{f_1^g(x)} = 0, \quad \& \quad \lim_{x\to 1}\frac{g_{1L}^g(x)}{f_1^g(x)} = 1.$$





Gluon orbital angular momentum

- GPDs are experimentally accessible through the hard exclusive processes like deep virtual Compton scattering(DVCS) and deep virtual meson production(DVMP).
- The kinetic OAM for the gluons can be calculated using the sum rule for the gluon GPDs.

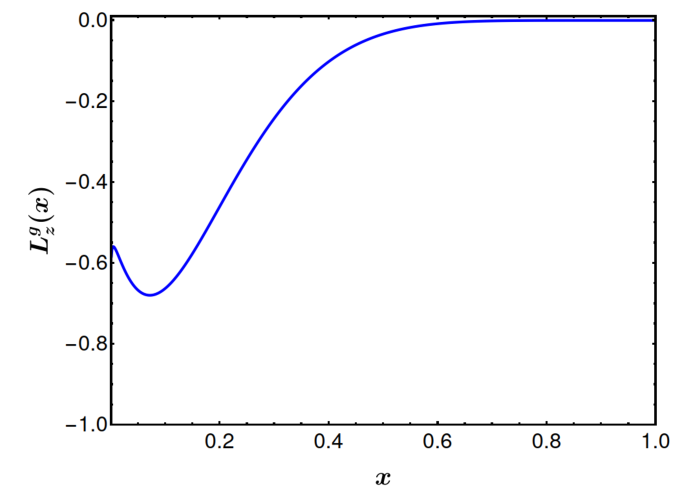
$$L_z^g = \frac{1}{2}\int dx\left\{x[H_g(x,0,0) + E^g(x,0,0)] - \tilde{H}^g(x,0,0)\right\}$$

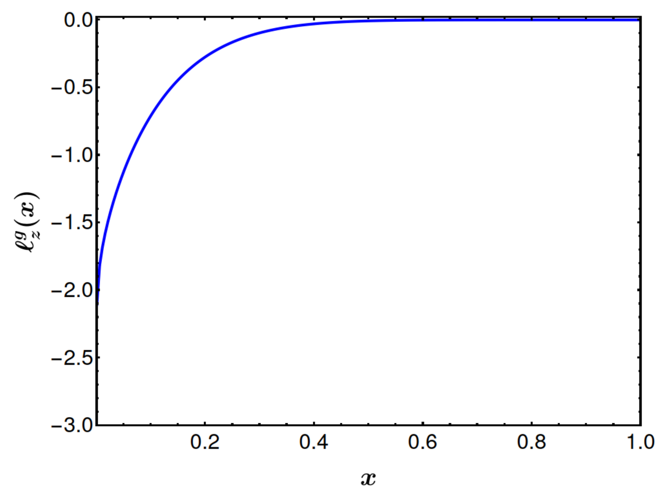
The gluon kinetic OAM is negative: $L_z^g = \int dx L_z^g = -0.18$.

- The gluon canonical OAM is related to the GTMD $F_{1,4}$ as follows:

$$\ell_z^g = -\int dx d^2\mathbf{p}_\perp \frac{\mathbf{p}_\perp^2}{M^2}F_{1,4}^g$$

The gluon canonical OAM is also negative: $\ell_z^g = \int dx \ell_z^g = -0.19$.



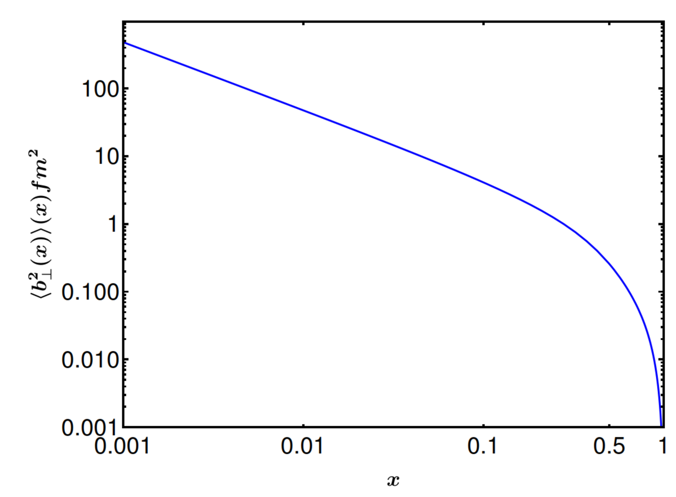


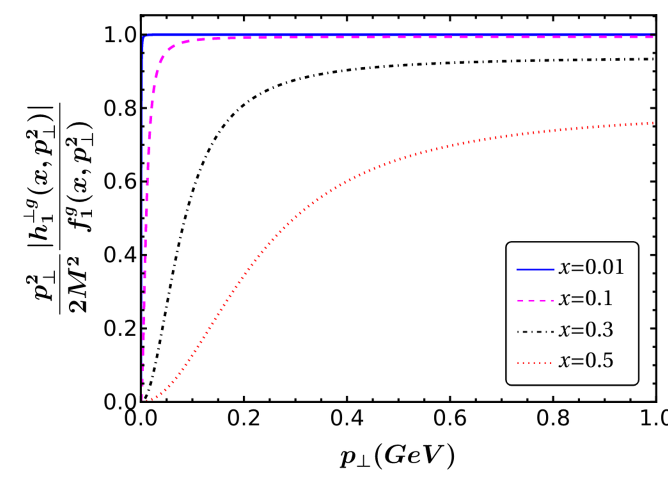
- According to the Ji's sum rule, the gluon contribution to the nucleon spin J_g:

$$J_g = \int dx\frac{1}{2}x\left[H_g(x,0,0) + E_g(x,0,0)\right] = 0.186, \quad \text{[PRD 101, 094513 (2020)]}$$

- x-Dependent Squared Radius & Model independent Positivity bound:

$$\langle b_\perp^2\rangle^g(x) = \frac{\int d^2b_\perp b_\perp^2 H^g(x,b_\perp)}{\int d^2b_\perp H^g(x,b_\perp)}, \qquad f_1^g(x,\mathbf{p}_\perp^2) \geq \frac{|\mathbf{p}_\perp|^2}{2M^2}|h_1^{\perp g}(x,\mathbf{p}_\perp^2)|.$$





Conclusions

Future Prospects: Gluon TMDPDFs continue to be an active area of research in hadronic physics. Ongoing and upcoming experiments, such as those at the LHC and future Electron-Ion Collider (EIC), aim to provide more precise measurements of TMDPDFs, which will enhance our understanding of the partonic structure of hadrons and QCD dynamics.

References

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Acknowledgments

I would like to thank all the co-authors for their insightful contributions to this work. Also, I would appreciate to the organizers of HUGS 2023 and Jefferson Lab.

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