Gluon Helicity and Parton Orbital Angular Momentum Contribution to the Proton Spin

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Letter of Interest

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Naive sum rule for proton spin

- Free-field expansion of the QCD angular momentum:

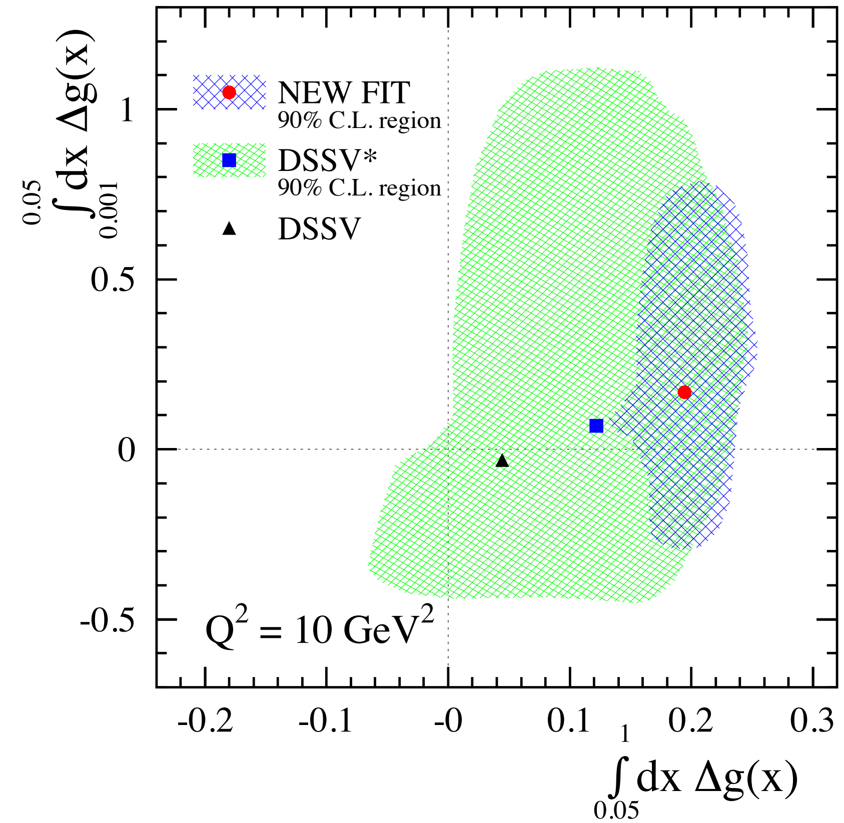
$$\vec{J} = \int d^3\xi\ \psi^\dagger \frac{\vec{\Sigma}}{2}\psi + \int d^3\xi\ \psi^\dagger \left[\vec{\xi}\times(-i\vec{\nabla})\right]\psi$$

$$+ \int d^3\xi\ \vec{E}\times\vec{A} + \int d^3\xi\ E^i \left(\vec{\xi}\times\vec{\nabla}\right) A^i\,, \qquad A^+ = 0$$

- Jaffe-Manohar sum rule:

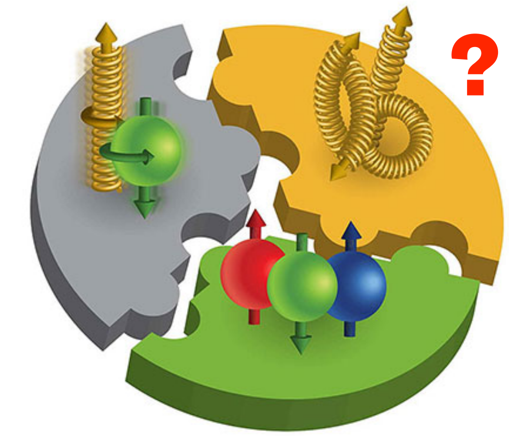
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma(\mu) + l_q^z(\mu) + \Delta G(\mu) + l_g^z(\mu)$$

- Gauge dependent but with simple parton picture;
- ΔG: Best constraints given by RHIC polarized *pp* scattering data for 0.05<x<0.2;
- $l_q^z(\mu)$ and $l_g^z(\mu)$: twist-3 observables, no experimental result so far.



De Florian, Sassot, Stratmann and Vogelsang, Phys.Rev.Lett. 113 (2014)

The gluon helicity ΔG



- Method to calculate in large-momentum effective theory (LaMET):

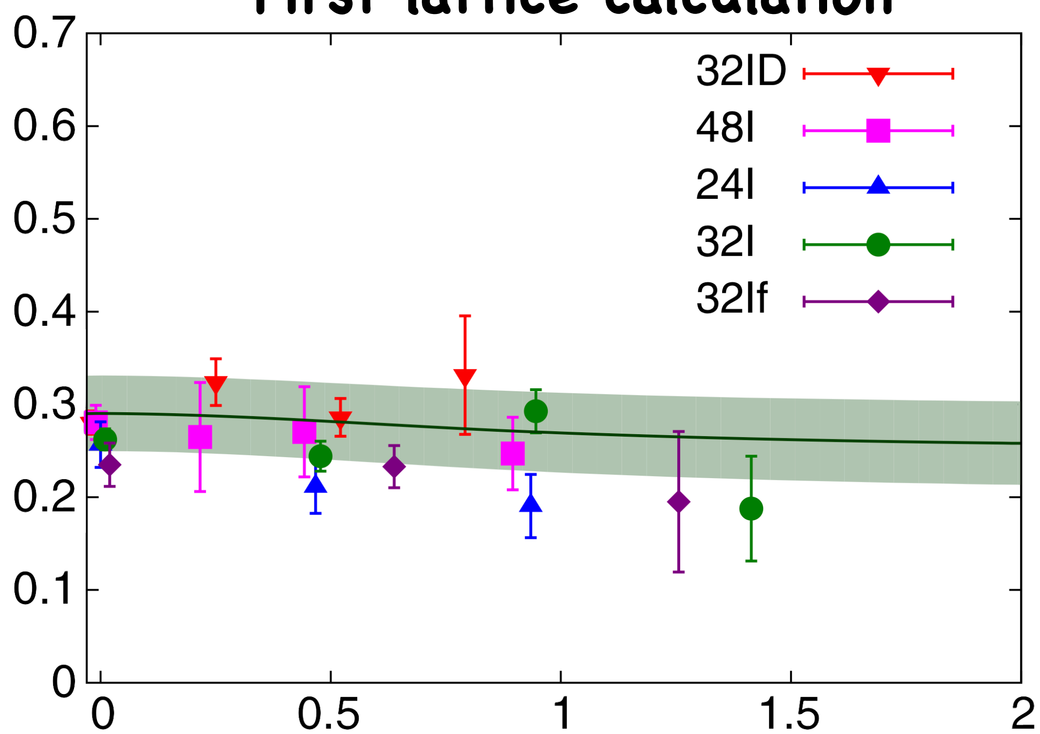
X. Ji, J.-H. Zhang, and YZ, Phys. Rev. Lett. 111 (2013);
Y. Hatta, Ji and YZ, Phys.Rev.D 89 (2014).

$$\Delta\tilde{G}(P^z,\mu) = \langle PS|\,\vec{E}\times\vec{A}\,|PS\rangle\Big|_{\vec{\nabla}\cdot\vec{A}=0}$$

Other choices: $A^z=0, A^0=0$

$$\Delta\tilde{G}(P^z,\mu) = Z_{gg}(P^z/\mu)\Delta G(\mu) + Z_{gq}(P^z/\mu)\Delta\Sigma(\mu) + \ldots,$$

First lattice calculation



Y.-B. Yang, K.-F. Liu, YZ, et al. (χQCD Collaboration), Phys. Rev. Lett. 118 (2017)

$$\Delta G(Q^2=10\ \text{GeV}^2) = 0.251(47)(16)$$

Agrees with truncated first moment of $\Delta g(x)$ within $[0.05,\ 0.2]$

Outlook:

- Lattice renormalization;
- Higher-order perturbative matching;
- Exploration of other operator choices to seek faster convergence to ;
- Calculating $\Delta g(x)$ and obtain its first moment.

Parton Orbital Angular Momentum

- Methods have been proposed to calculate with LaMET:

$$\tilde{l}_q^z(2S^z) = \lim_{\Delta\to 0} \epsilon^{ij} \frac{\partial}{\partial i \Delta^i} \langle P'S \,|\, \psi^\dagger(0) i\partial^j \psi(0) \,|\, PS \rangle \Big|_{\vec{\nabla}\cdot\vec{A}=0}$$

- Perturbative matching:

YZ, Liu and Yang, Phys.Rev.D 93 (2016);
Ji, Zhang and YZ, Phys.Lett.B 743 (2015).

$$\tilde{l}_q^z(P^z, \mu) = P_{qq} l_q^z(\mu) + P_{gq} l_g^z(\mu) + p_{qq} \Delta\Sigma(\mu) + p_{gq} \Delta G(\mu)$$

$$\tilde{l}_g^z(P^z, \mu) = P_{qg} l_q^z(\mu) + P_{gg} l_g^z(\mu) + p_{qg} \Delta\Sigma(\mu) + p_{gg} \Delta G(\mu)$$

- Systematic corrections in lattice calculations:
  - Lattice renormalization;
  - Mixing with other twist-3 observables in renormalization and matching;
  - Comparison with the derivative method that starts from staple-shaped Wilson-line quark bilinear correlators (for Wigner distribution) (M. Engelhardt, Phys.Rev.D 95 (2017)).

Parton Orbital Angular Momentum

- Comparison with the orbital angular momentum in the gauge-invariant, frame-independent sum rule (Ji, Phys.Rev.Lett. 78 (1997)):

  Related to the moment of twist-2 GPDs.

- Experimental measurement from twist-3 GPD or Wigner distributions:
  - Identify the experimental observables in hard exclusive processes; Ji, Yuan and YZ, PRL 118 (2017); Hatta, Yuan, YZ et al., PRD 95 (2017); Bhattacharya, Metz and Zhou et al., Phys.Lett.B 771 (2017), 1802.10550.
  - Evolution of and higher-order corrections to the cross section; Hatta and Yao, Phys.Lett.B 798 (2019).
  - Extraction from the cross section data.