Accessing gluon polarization in large-P_T SIDIS

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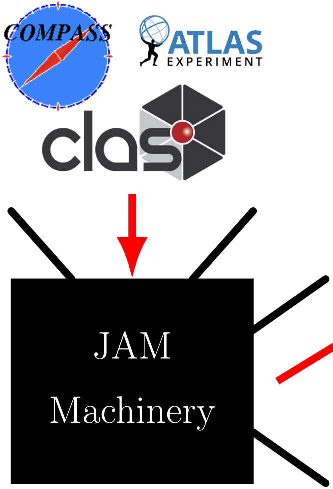
Jefferson Lab

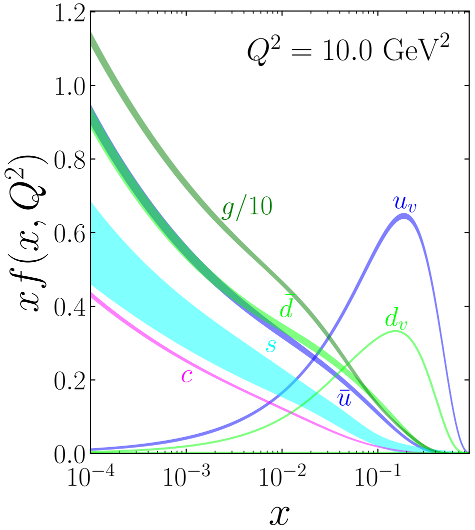
JAM Collaboration

The Jefferson Lab Angular Momentum (JAM) Collaboration is an enterprise involving theorists, experimentalists, and computer scientists from the Jefferson Lab community using QCD to study the internal quark and gluon structure of hadrons and nuclei. Experimental data from high-energy scattering processes are analyzed using modern Monte Carlo techniques and state-of-the-art uncertainty quantification to simultaneously extract various quantum correlation functions, such as parton distribution functions (PDFs), fragmentation functions (FFs), transverse momemtum dependent (TMD) distributions, and generalized parton distributions (GPDs). Inclusion of lattice QCD data and machine learning algorithms are being explored to potentially expand the reach and efficacy of JAM analyses and our understanding of hadron structure in QCD.

Summary: Understand partonic structure of hadrons and nucleons by studying and determining relevant quantum correlation functions

Global QCD Analysis





Recent results on Δg

Can $\overline{\text{MS}}$ parton distributions be negative?

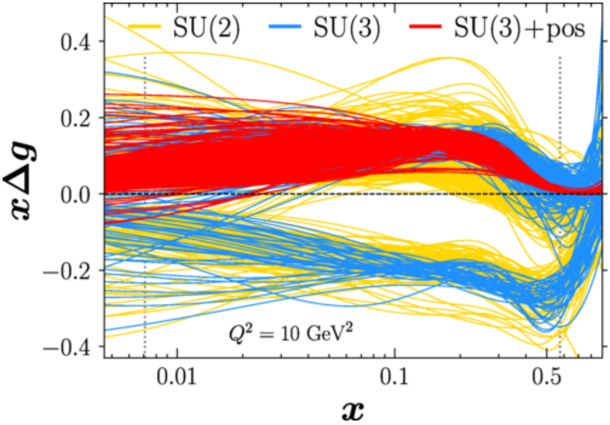
Alessandro Candido, Stefano Forte & Felix Hekhorn

Positivity and renormalization of parton densities

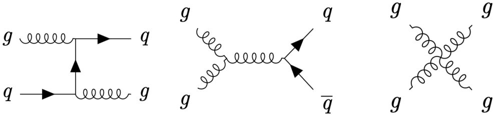
John Collins, Ted C. Rogers, and Nobuo Sato
Phys. Rev. D **105**, 076010 – Published 14 April 2022

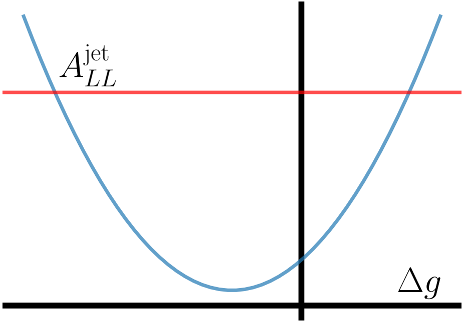
- Recent JAM global QCD analyses tested impact of assumptions on PDF results

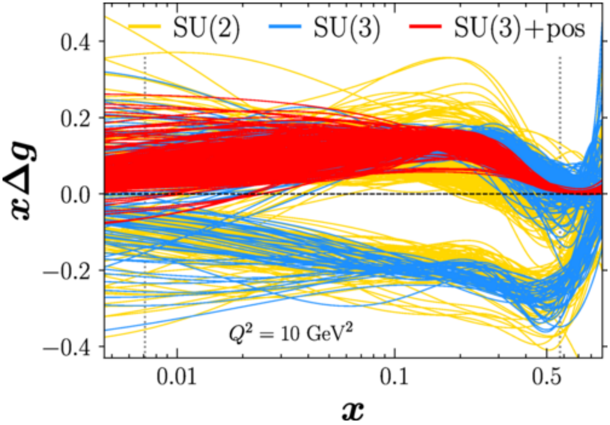
→ *Y. Zhou et al. Phys. Rev. D* ***105***, 074022



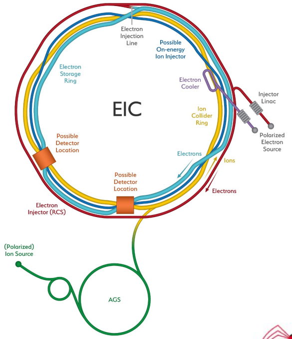
Recent results on Δg

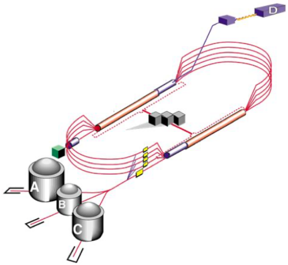


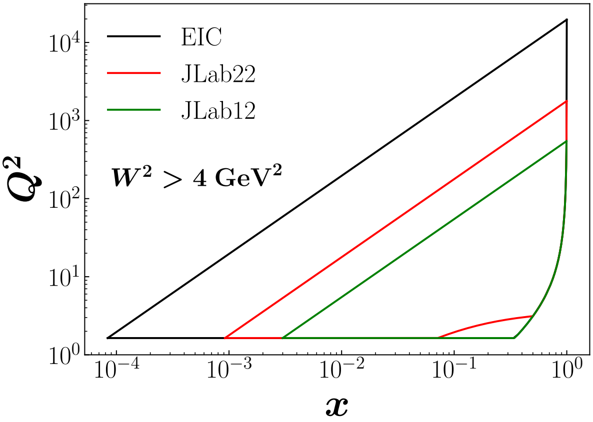




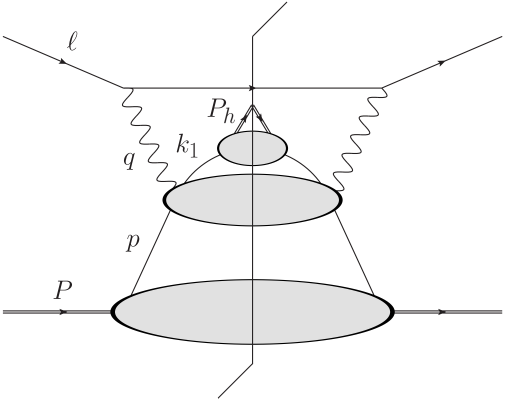
DIS facilities







Semi-inclusive DIS (SIDIS): $\ell P \to \ell' H X$



$$\frac{\mathrm{d}\boldsymbol{\sigma}}{\mathrm{d}\boldsymbol{x}\,\mathrm{d}\boldsymbol{Q}^2\,\mathrm{d}\boldsymbol{z}\,\mathrm{d}\boldsymbol{P}^2_{\mathbf{H,T}}} = \frac{\boldsymbol{\pi}^2\boldsymbol{\alpha}^2\boldsymbol{y}}{\mathbf{2}\boldsymbol{z}\boldsymbol{Q}^4}\boldsymbol{L}_{\mu\nu}\boldsymbol{W}^{\mu\nu}$$

$$Q^2 = -q^2 \quad x = \frac{Q^2}{2P\cdot q} \quad y = \frac{P\cdot q}{P\cdot \ell}$$

$$z = \frac{P\cdot P_H}{P\cdot q} \qquad q_T = \frac{P_{H,T}}{z}$$

Lepton and Hadron Tensors

Lepton tensor: $L_{\mu\nu} = 2(\ell_\mu \ell'_\nu + \ell'_\mu \ell_\nu - g_{\mu\nu} \ell \cdot \ell' - i\lambda_\ell \epsilon_{\mu\nu\alpha\beta} \ell^\alpha \ell'^\beta)$

Hadron tensor: Directly calculated at the parton level using collinear factorization

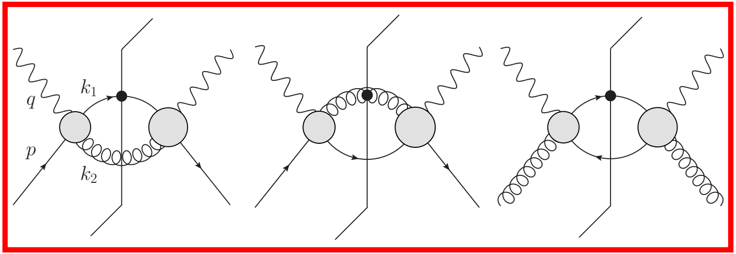
$$W^{\mu\nu} = \sum_{i,j} \int_x^1 \frac{\mathrm{d}\xi}{\xi} \int_z^1 \frac{\mathrm{d}\zeta}{\zeta^2} \widehat{W}_{ij}^{\mu\nu} f_{i/N}(\xi) D_{H/j}(\zeta)$$

- large Q^2 and $P_{\mathrm{H,T}}$
- $f_{i/N}$: PDF for parton of flavor i in nucleon N
- $D_{H/j}$: FF for parton of flavor j fragmenting into hadron H

Calculation at LO

$$W^{\mu\nu} = \int_x^1 \frac{\mathrm{d}\xi}{\xi} \int_z^1 \frac{\mathrm{d}\zeta}{\zeta^2} \widehat{W}^{\mu\nu} f_{i/P}(\xi) D_{H/j}(\zeta) \longleftarrow \mathcal{JAM}$$

$$\widehat{W}^{\mu\nu} = \sum \underbrace{\mathcal{M}^{\mu} \mathcal{M}^{\dagger\nu}}$$



Phase Space Constraints

Q^2:

- max: $Q^2 < (s - M^2)x$
- min: $Q^2 > m_c^2$, $\theta \gtrsim 5°$, and $W^2 > 4\,\text{GeV}^2$

x:

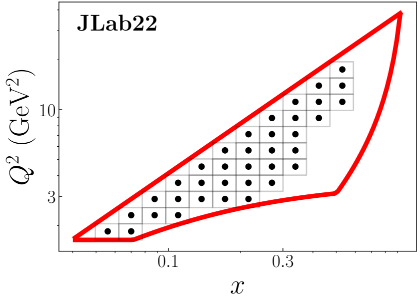
- within Q^2 contour boundaries

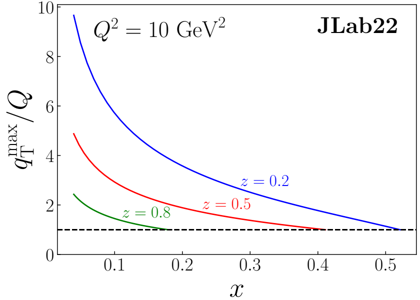
z:

- $z \in [0.2, 0.8]$ – where FFs describe data well

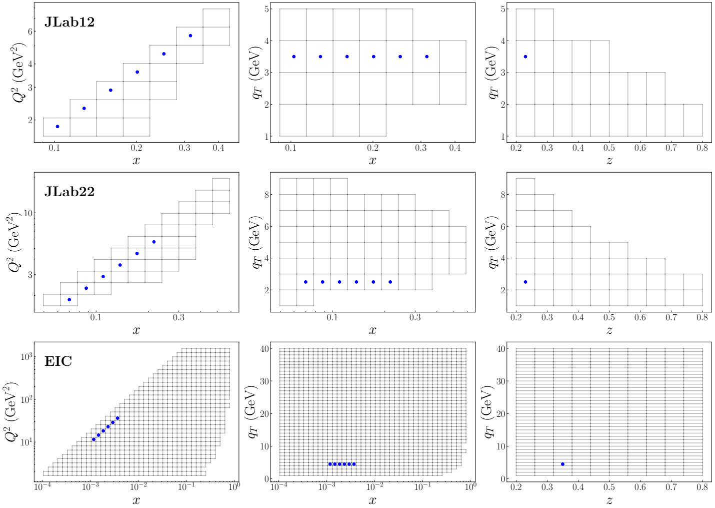
q_T:

- min: $q_T \gtrsim Q$
- max: $W_{\text{SIDIS}}^2 > M^2$





Kinematic Bins



Double Spin Asymmetry

$$\boldsymbol{A_{LL} = \frac{\mathrm{d}\Delta\sigma}{\mathrm{d}\sigma}}$$

Uncertainties:

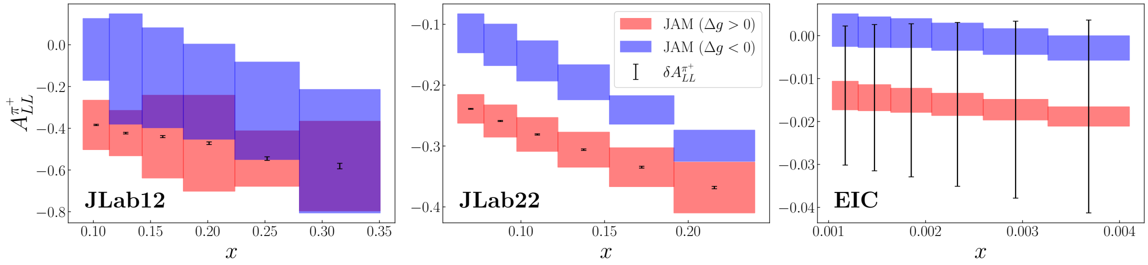
1. Statistical: $\delta A_{LL} = \sqrt{\dfrac{1 + A_{LL}^2}{N}} \approx \dfrac{1}{\sqrt{N}}$ when $A_{LL} \ll 1$

$\rightarrow$ Experiments are Poisson processes: $\delta N = \sqrt{N} = \sqrt{\mathcal{L}\sigma}$

$$\rightarrow \sigma = \int_{\text{bin}} \mathrm{d}x\,\mathrm{d}Q^2\,\mathrm{d}z\,\mathrm{d}P_{\mathrm{H,T}}^2 \frac{\mathrm{d}\sigma}{\mathrm{d}x\,\mathrm{d}Q^2\,\mathrm{d}z\,\mathrm{d}P_{\mathrm{H,T}}^2} \approx \Delta x\,\Delta Q^2\,\mathrm{d}z\,\Delta P_{\mathrm{H,T}}^2 \frac{\mathrm{d}\sigma(\text{center})}{\mathrm{d}x\,\mathrm{d}Q^2\,\mathrm{d}z\,\mathrm{d}P_{\mathrm{H,T}}^2}$$

2. PDF replicas: 1σ deviation of asymmetry values from the PDF & FF replicas

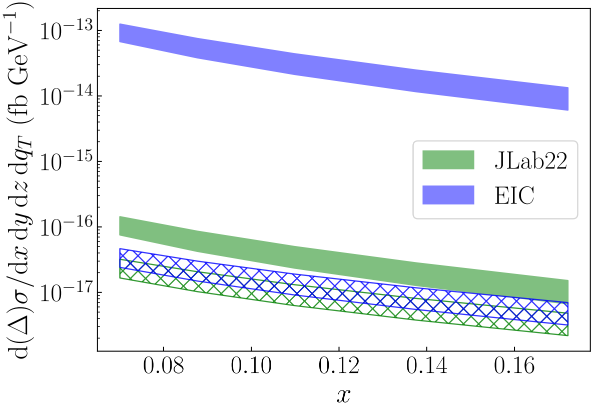
Results



$$\mathcal{L}_{\rm JLab} = 86\,{\rm fb}^{-1}\ \text{(10 days!)}, \quad \mathcal{L}_{\rm EIC} = 10\,{\rm fb}^{-1}$$

Scaling with $\sqrt{s}$

Overall A_{LL} pre-factor: $[(2-y)/y]/[1/y^2] = (2-y)y$



Note:

- Hatched bands = $\Delta\sigma$
- Solid bands = σ

$$\frac{\delta A_{LL}}{A_{LL}} = \frac{1}{\Delta\sigma}\sqrt{\frac{\sigma}{\mathcal{L}}}$$

Outlook

- Significant sensitivity to the gluon channel with A_{LL}
- JLab with $\approx 20\,\mathrm{GeV}$ beam is uniquely positioned to determine sign of Δg
- Strong scaling behavior with $\sqrt{s}$ makes further constraint of Δg implausible at small-x from this process

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