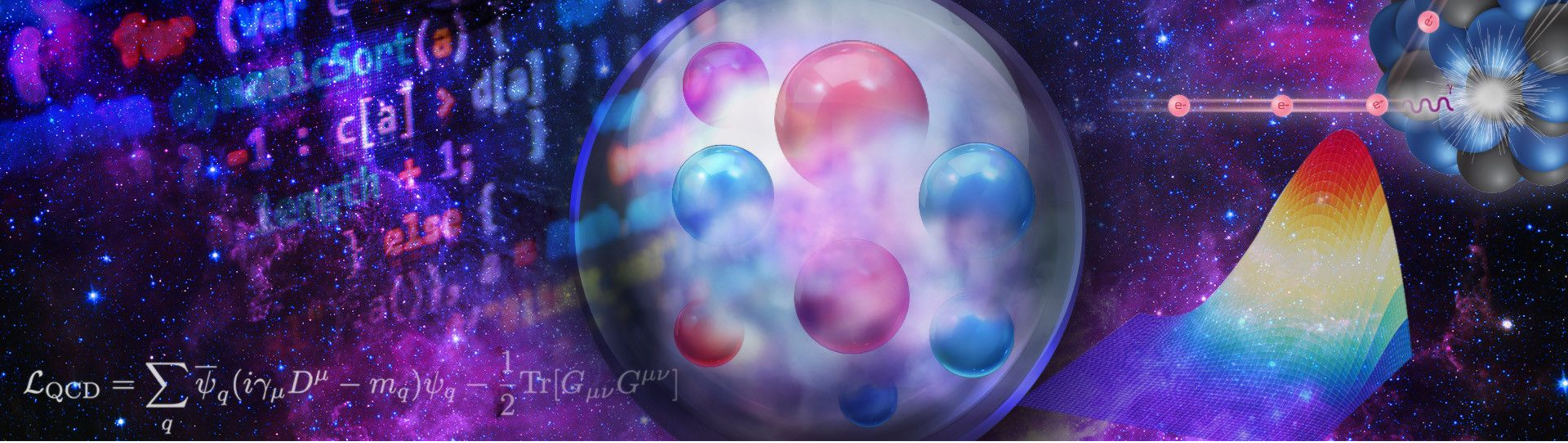
What can be done at 20+ GeV for SIDIS/TMDs

Nobuo Sato

The next generation of 3D imaging
July 7 2022

Jefferson Lab

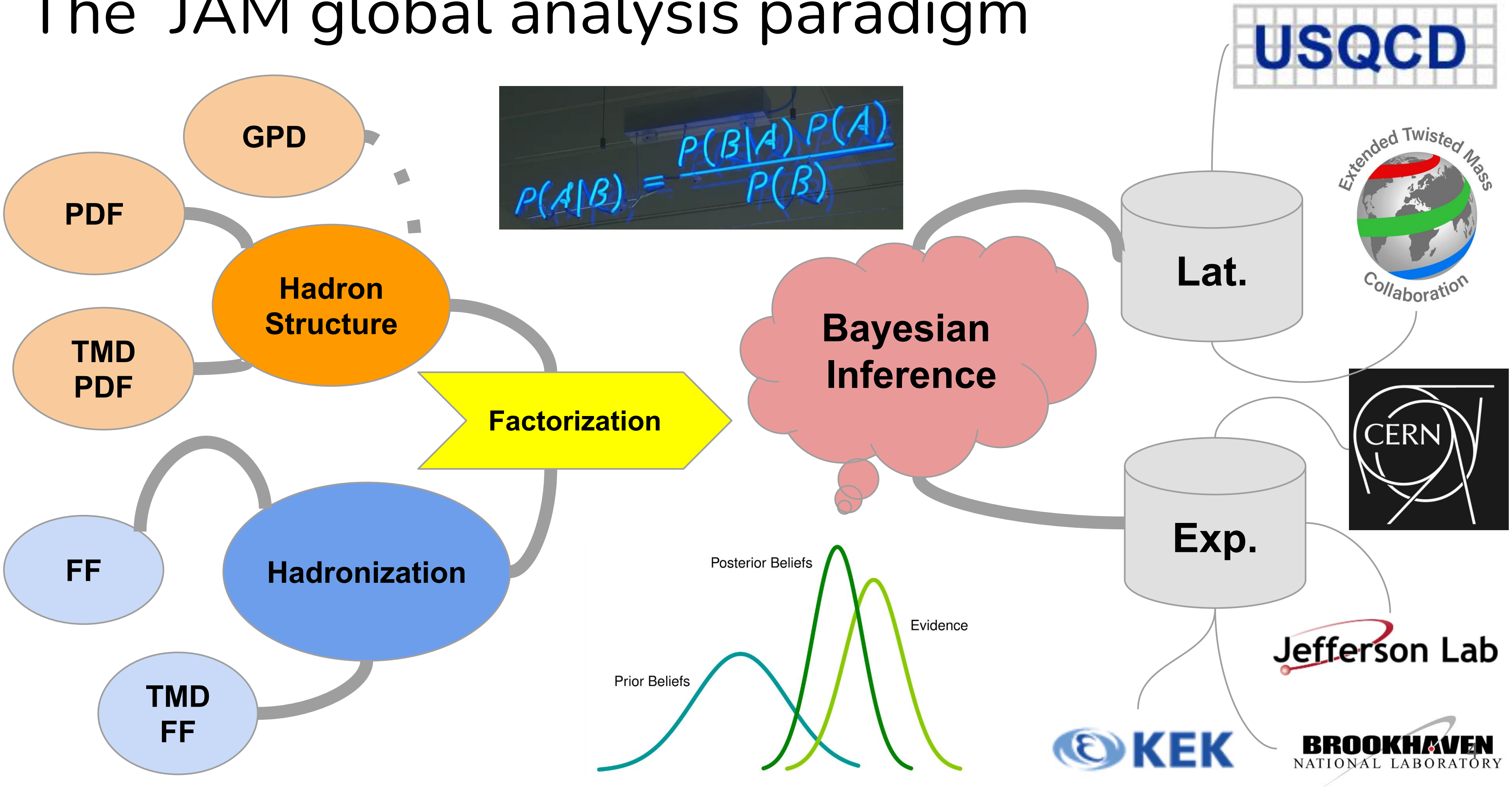
Motivations



JEFFERSON LAB ANGULAR MOMENTUM 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.

The JAM global analysis paradigm



f_1, d_1

Strange quark suppression from a simultaneous Monte Carlo analysis of parton distributions and fragmentation functions

JAM Collaboration • N. Sato (Old Dominion U. and Jefferson Lab) et al. (May 9, 2019)

Published in: *Phys.Rev.D* 101 (2020) 7, 074020 • e-Print: 1905.03788 [hep-ph]

f_1, d_1

Simultaneous Monte Carlo analysis of parton densities and fragmentation functions

Jefferson Lab Angular Momentum (JAM) Collaboration • Eric Moffat (Old Dominion U.) et al. (Jan 12, 2021)

Published in: *Phys.Rev.D* 104 (2021) 1, 016015 • e-Print: 2101.04664 [hep-ph]

$f_1, \Delta f_1$

How well do we know the gluon polarization in the proton?

Jefferson Lab Angular Momentum (JAM) Collaboration • Y. Zhou (South China Normal U. and Cape Town U., D
Math. and UCLA and William-Mary Coll. and Jefferson Lab) et al. (Jan 6, 2022)

Published in: *Phys.Rev.D* 105 (2022) 7, 074022 • e-Print: 2201.02075 [hep-ph]

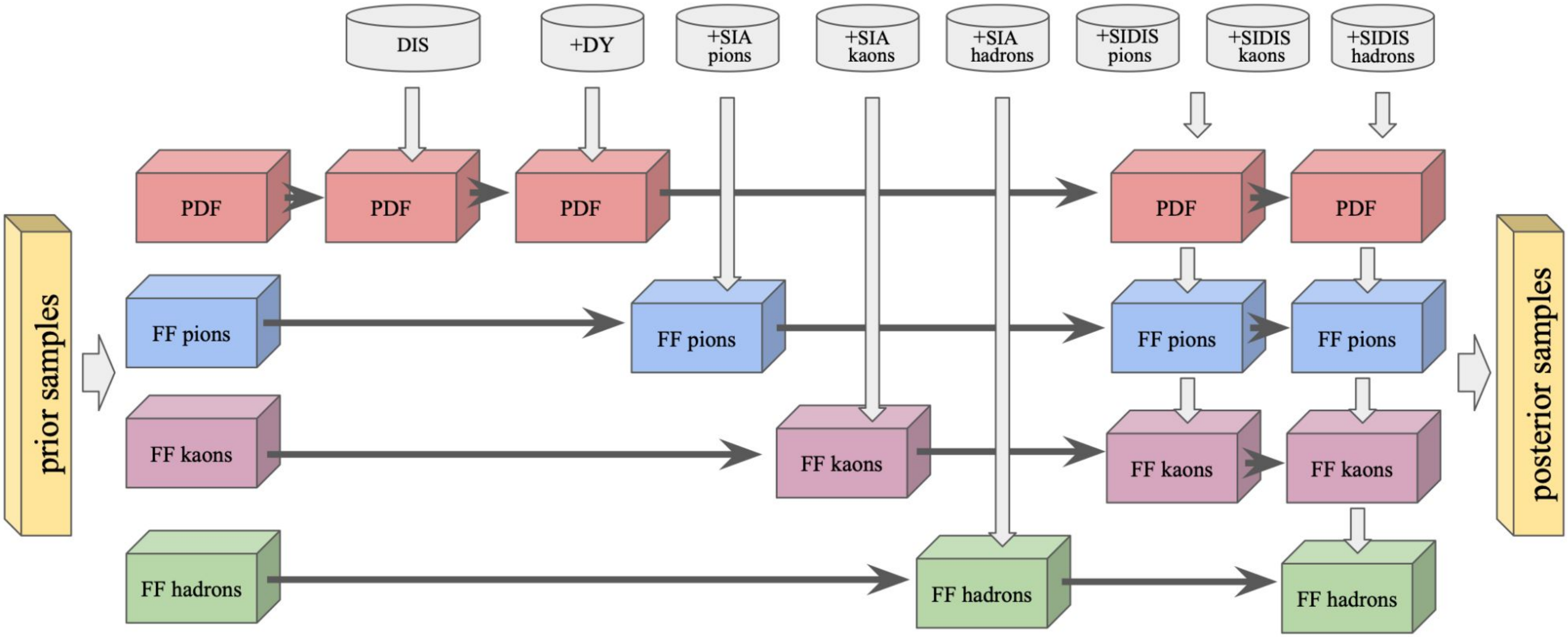
$f_1, \Delta f_1$
d_1

Polarized Antimatter in the Proton from Global QCD Analysis

Jefferson Lab Angular Momentum (JAM) Collaboration • C. Cocuzza (Temple U.) et al. (Feb 7, 2022)

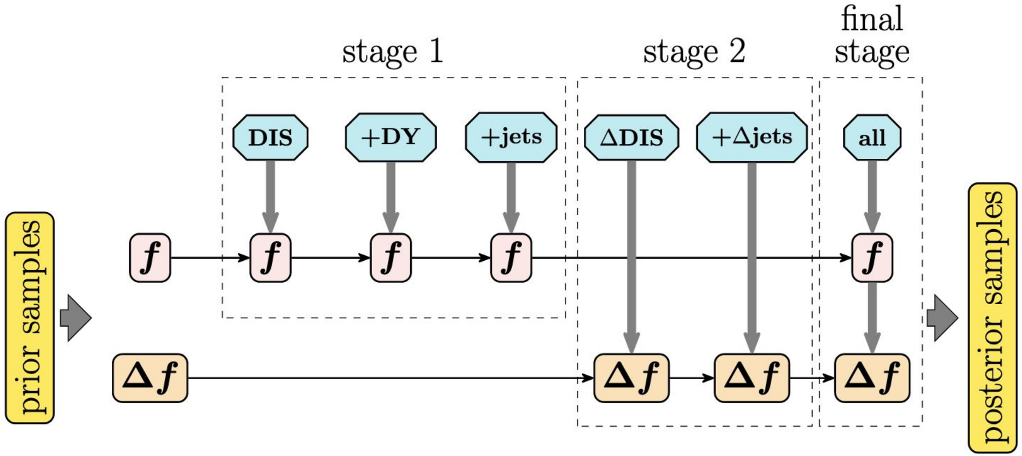
e-Print: 2202.03372 [hep-ph]

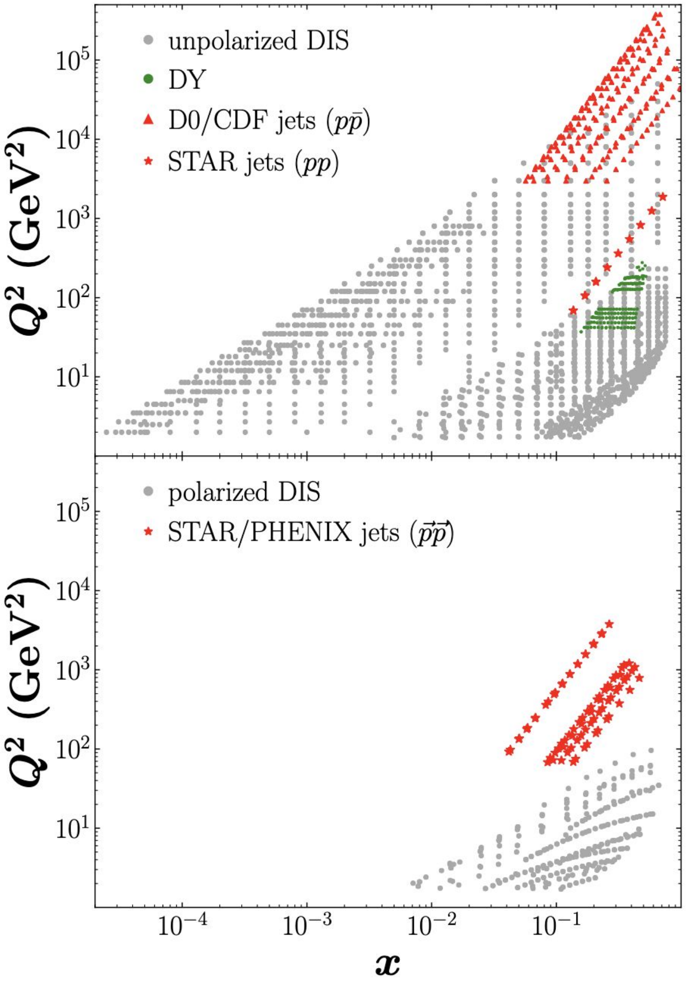
Multi-step strategy

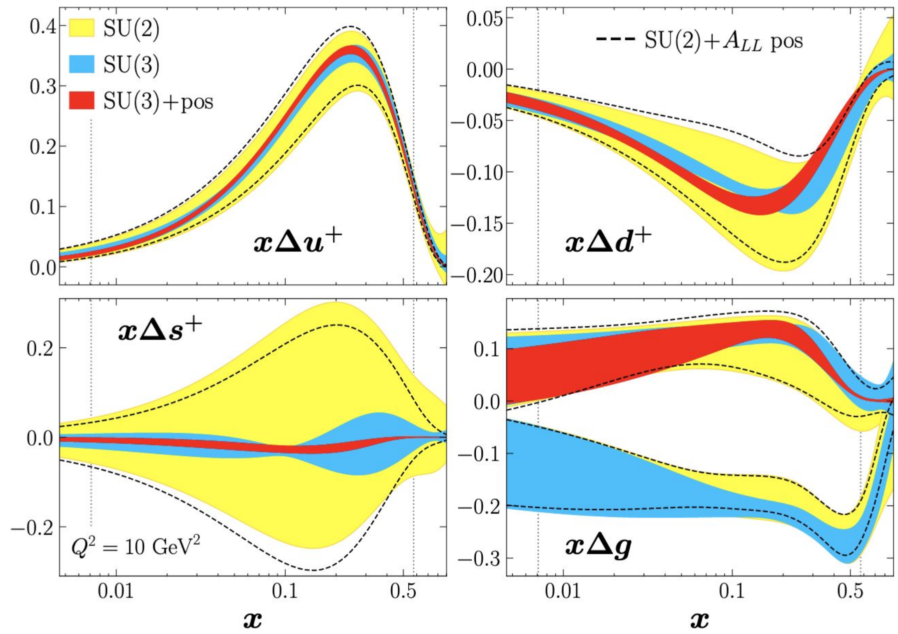


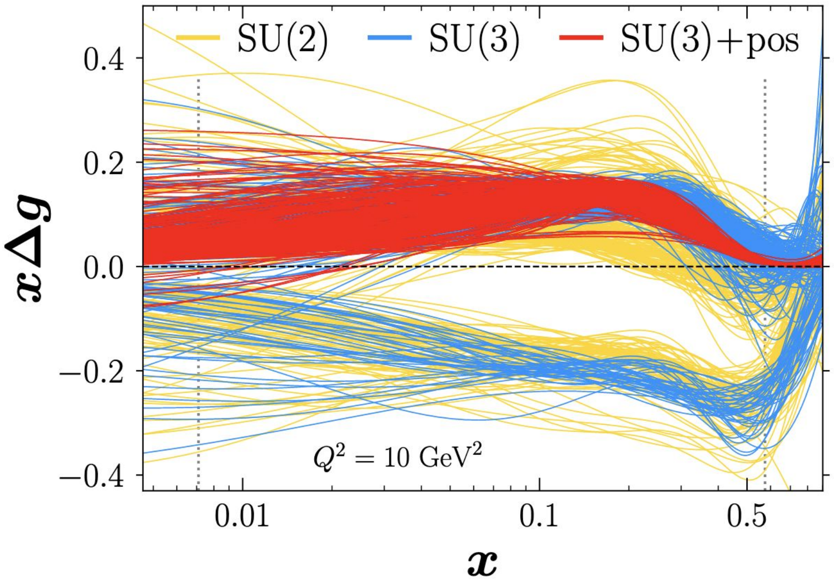
How well do we know the gluon polarization in the proton?

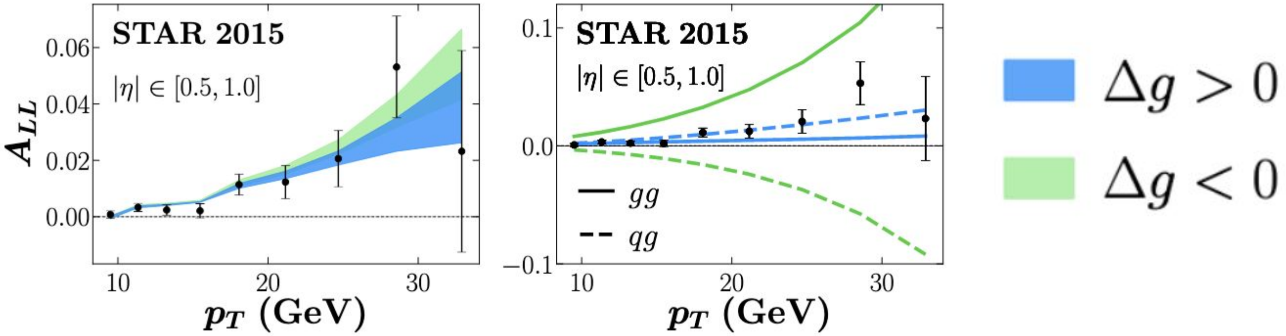
Y. Zhou, N. Sato, and W. Melnitchouk (Jefferson Lab Angular Momentum (JAM) Collaboration)
Phys. Rev. D **105**, 074022 – Published 25 April 2022





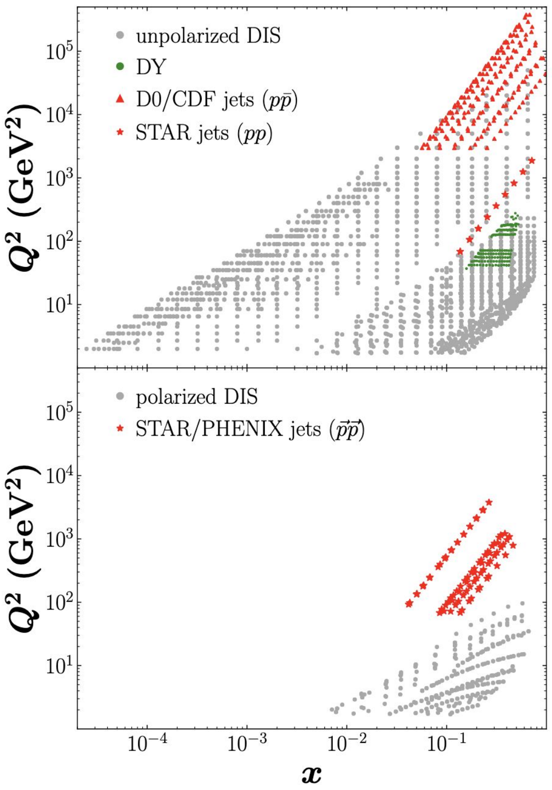


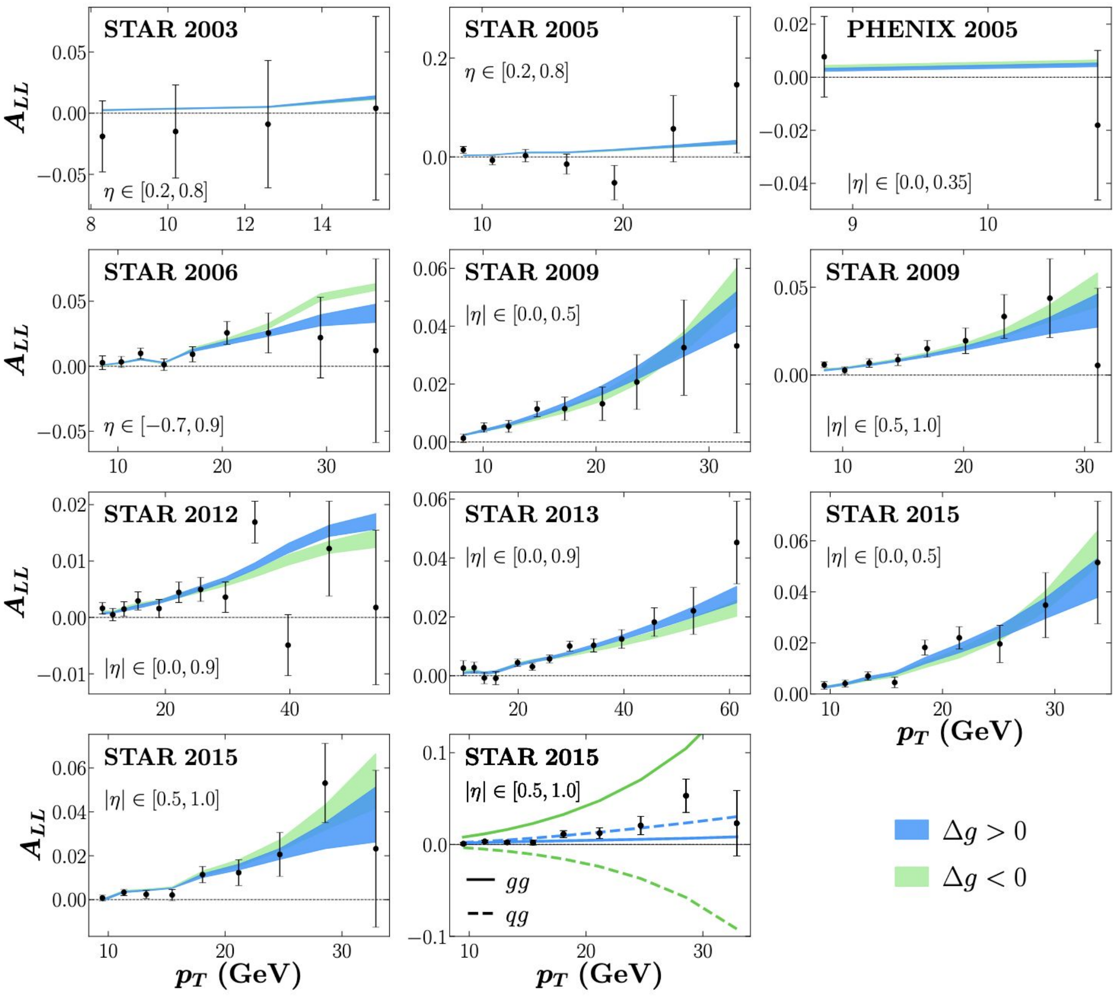




Polarized jet data
cannot discriminate
between positive
& negative solutions

Polarized Jets

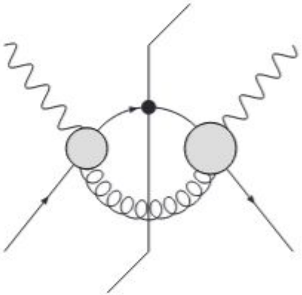




SIDIS @ JLab 20+

Accessing gluon polarization with high-P_T hadrons in SIDIS

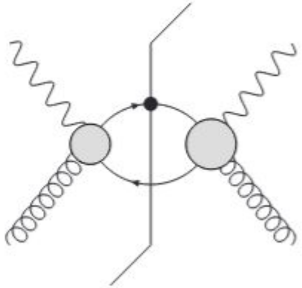
Richard Whitehill,[1] Yiyu Zhou,[2] N. Sato,[3] and W. Melnitchouk[3]



(a)

$$4P_H^0 E' \frac{\mathrm{d}(\Delta)\sigma_H}{\mathrm{d}^3\mathbf{l}'\mathrm{d}^3\mathbf{P}_H} = \sum_{i,j} \int_x^1 \frac{\mathrm{d}\xi}{\xi} \int_z^1 \frac{\mathrm{d}\zeta}{\zeta^2} \left(4k_1^0 E' \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}^3\mathbf{l}'\mathrm{d}^3\mathbf{k}_1}\right) (\Delta) f_{i/P}(\xi) D_{H/j}(\zeta).$$

At LO, all the flavors contributes including gluons!



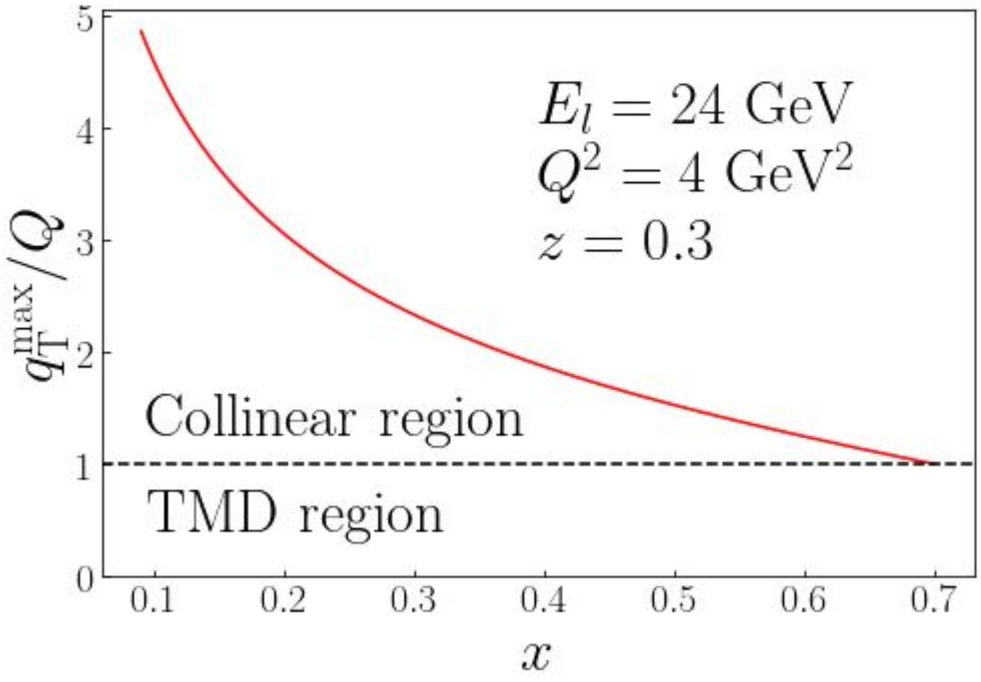
(c)

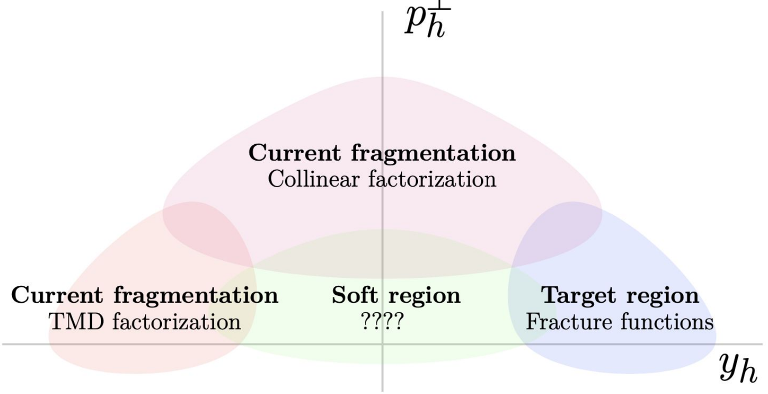
$$\frac{\mathrm{d}\Delta\hat{\sigma}_{\mathrm{q,q}}}{\mathrm{d}\hat{x}\,\mathrm{d}y\,\mathrm{d}\hat{z}\,\mathrm{d}P_{\mathrm{T}}^2} = -\frac{16\,(2-y)\,(Q^4\,(\hat{x}^2\hat{z}^2+1) - \hat{x}^2\hat{z}^2 q_T^4)}{3\hat{x}y\,(\hat{x}-1)\,(Q^2\hat{z} - Q^2 - \hat{z}q_T^2)}, \tag{A4}$$

$$\frac{\mathrm{d}\Delta\hat{\sigma}_{\mathrm{q,g}}}{\mathrm{d}\hat{x}\,\mathrm{d}y\,\mathrm{d}\hat{z}\,\mathrm{d}P_{\mathrm{T}}^2} = \frac{16\hat{x}\,(2-y)\,(Q^4\,(\hat{x}\hat{z}^2 - 2\hat{x}\hat{z} + 2) + 2Q^2\hat{z}q_T^2\,(1-\hat{x}) - \hat{x}\hat{z}^2 q_T^4)}{3y\,(\hat{x}-1)\,(Q^2\hat{x}\hat{z} - Q^2\hat{x} + Q^2 - \hat{x}\hat{z}q_T^2)}, \tag{A5}$$

$$\frac{\mathrm{d}\Delta\hat{\sigma}_{\mathrm{g,q}}}{\mathrm{d}\hat{x}\,\mathrm{d}y\,\mathrm{d}\hat{z}\,\mathrm{d}P_{\mathrm{T}}^2} = \frac{2Q^2\,(y-2)\,(Q^4\,(2\hat{x}^2\hat{z}^2 - 2\hat{x}^2\hat{z} + 2\hat{x} - 1) + 2Q^2\hat{x}\hat{z}q_T^2\,(1-\hat{x}) - 2\hat{x}^2\hat{z}^2 q_T^4)}{\hat{x}y\,(Q^2\,(\hat{z}-1) - \hat{z}q_T^2)\,(Q^2\hat{x}\hat{z} - Q^2\hat{x} + Q^2 - \hat{x}\hat{z}q_T^2)}. \tag{A6}$$

SIDIS phase space

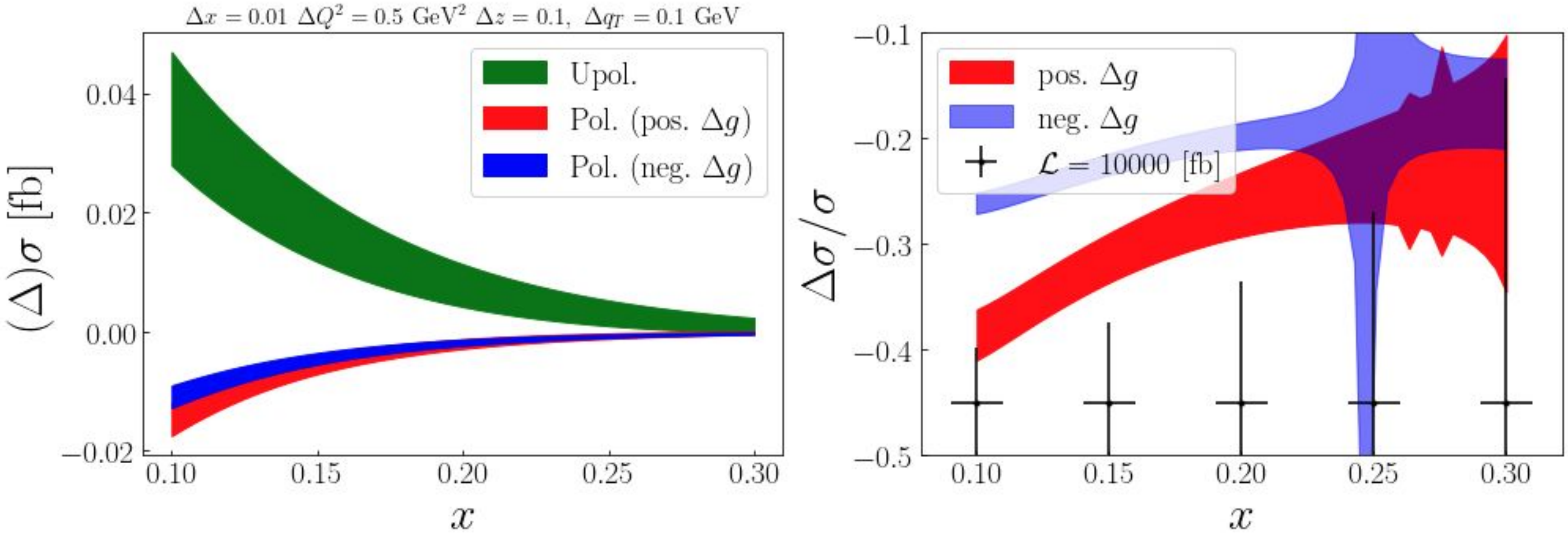




- For 0.1<x<0.3 there, there is phase space with large transverse momentum

SIDIS with pions

PRELIM



PDFs, PPDFs, FFS from

Polarized Antimatter in the Proton from Global QCD Analysis

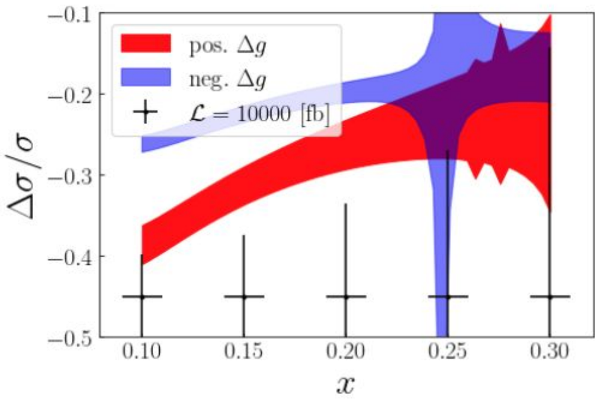
Jefferson Lab Angular Momentum (JAM) Collaboration • C. Cocuzza (Temple U.) Show All(4)

Feb 7, 2022

Summary/Outlook

- Gluon polarization is still elusive in the valence region.
- SIDIS with large pT can have direct access to gluon polarizations
- JLab 20+ can potentially provide high precision SIDIS measurements to discriminate gluon polarization
- Other hadron species such as Kaons can be used for flavor separation (more studies are needed)

PRELIM



$$\mathcal{L}_{\rm QCD} = \sum_q \overline{\psi}_q (i\gamma_\mu D^\mu - m_q)\psi_q - \frac{1}{2}\mathrm{Tr}[G_{\mu\nu}G^{\mu\nu}]$$