

Updates from JAM on gluon helicity PDF

Nobuo Sato



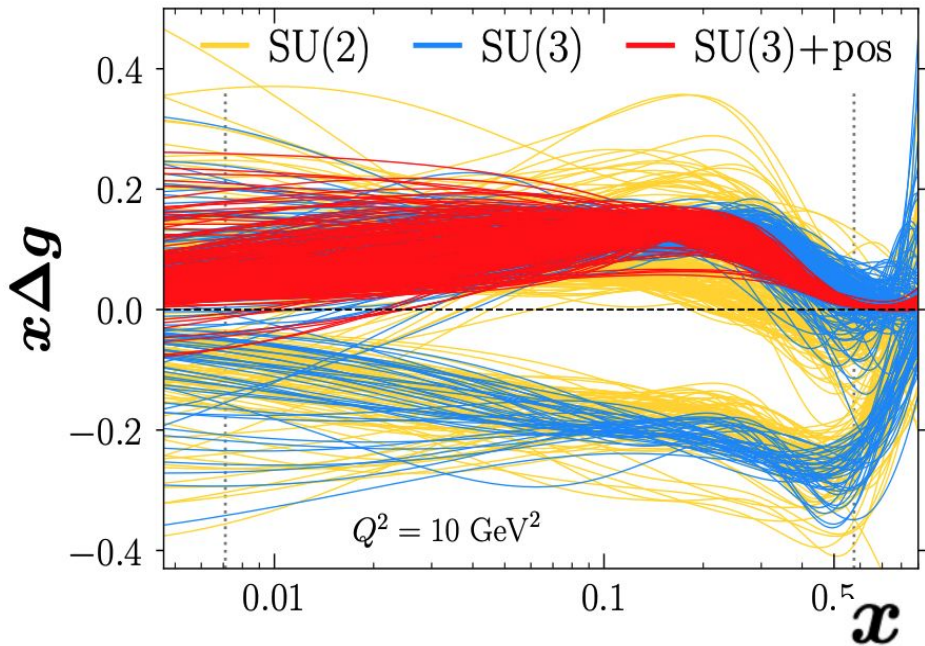
Zhou, NS, Melnitchouk '22
Karpie, Whitehill, Melnitchouk, Monahan, Orginos, Qiu, Richards, NS, Zafeiropoulos '23
Hunt-Smith, Cocuzza, Melnitchouk, NS, Thomas, White '24

QCD evolution,
Pavia IT May 24 2024

The Jefferson Lab logo consists of the text 'Jefferson Lab' in a white, sans-serif font. To the left of the text is a stylized red graphic element resembling an orbit or a particle path, with a small red sphere at its end.

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

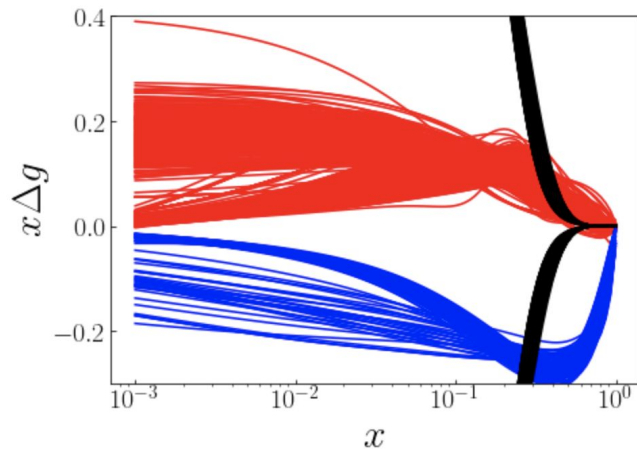
Y. Zhou, N. Sato, and W. Melnitchouk (Jefferson Lab Angular Momentum (JAM) Collaboration)
Phys. Rev. D **105**, 074022 – Published 25 April 2022

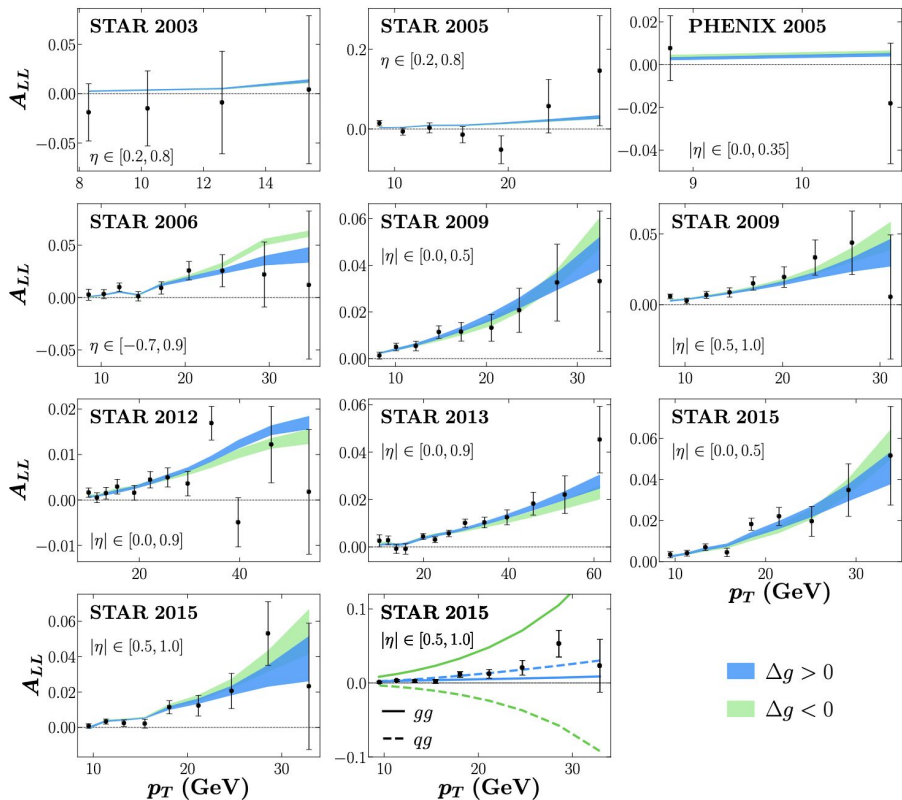


$$|\Delta g| < g$$

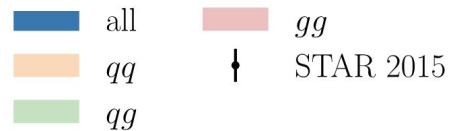
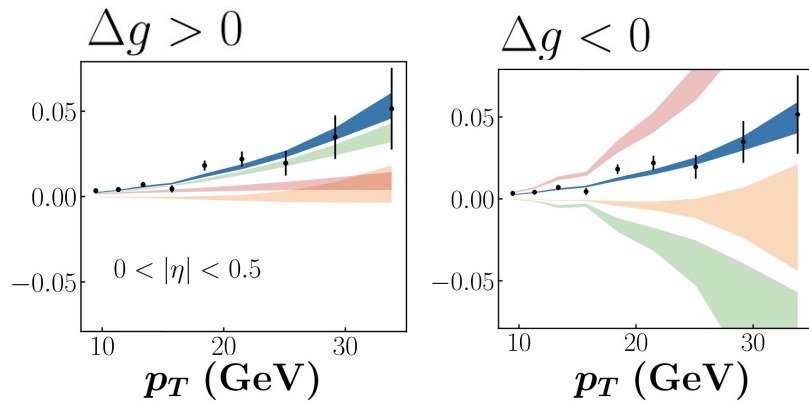
PDF positivity constraint

- Sign of gluon-hpdf is not uniquely determined by existing experimental data (DIS $W^2 > 10 \text{ GeV}^2$)
- PDF positivity constraints + data strongly disfavors negative g-hpdf
- Negative g-hpdf violates significantly pdf positivity constraint
- PDF positivity is not a strict requirement in QCD





$$|A_{LL}| < 1 \quad \checkmark$$



$$A_{LL}^{\text{jet}}(p_T, y) \propto a_{gg}[\Delta g \otimes \Delta g] + \sum_q a_{qg}[\Delta q \otimes \Delta g] + \sum_{q, q'} a_{qq'}[\Delta q \otimes \Delta q'] + \mathcal{O}(\alpha_s),$$

g-hpdf enters quadratically, and different subchannels contribute with different signs and strengths

Measurement of charged pion double spin asymmetries at midrapidity in longitudinally polarized $p + p$ collisions at $\sqrt{s} = 510$ GeV

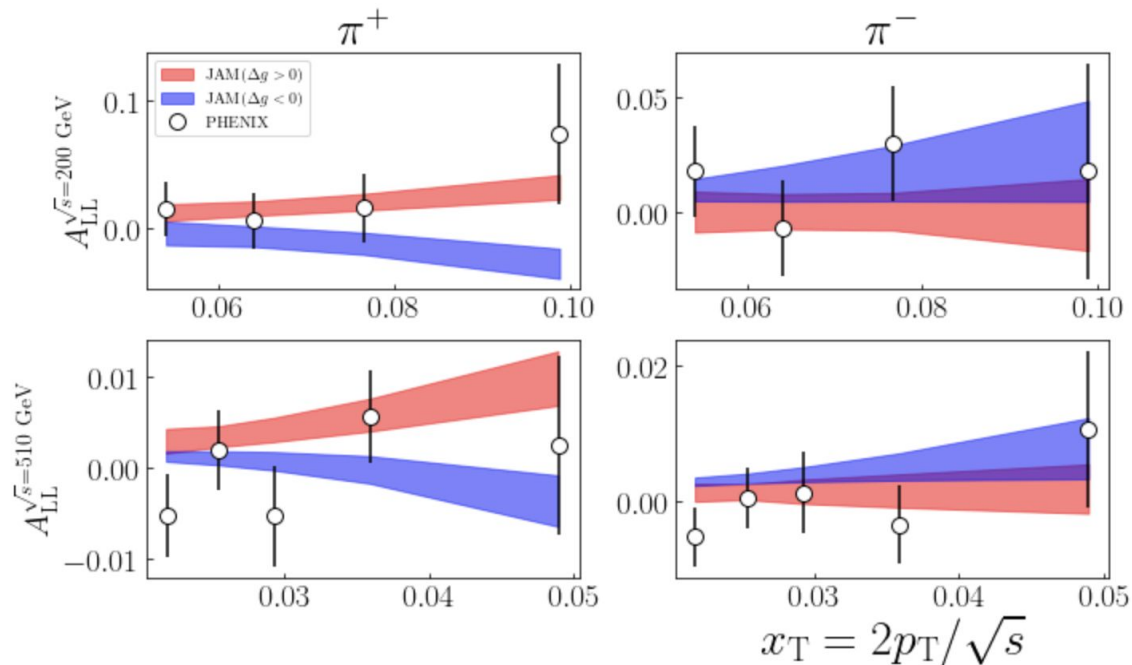
PHENIX Collaboration · U.A. Acharya (Georgia State U.) et al. (Apr 6, 2020)

Published in: *Phys.Rev.D* 102 (2020) 3, 032001 · e-Print: [2004.02681](https://arxiv.org/abs/2004.02681) [hep-ex]

Charged-pion cross sections and double-helicity asymmetries in polarized p+p collisions at $\sqrt{s}=200$ GeV

PHENIX Collaboration · A. Adare (Colorado U.) et al. (Sep 5, 2014)

Published in: *Phys.Rev.D* 91 (2015) 3, 032001 · e-Print: [1409.1907](https://arxiv.org/abs/1409.1907) [hep-ex]

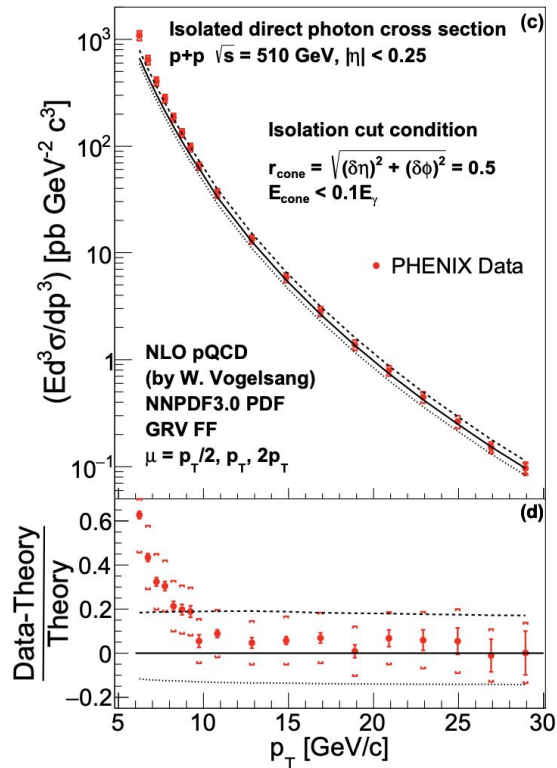
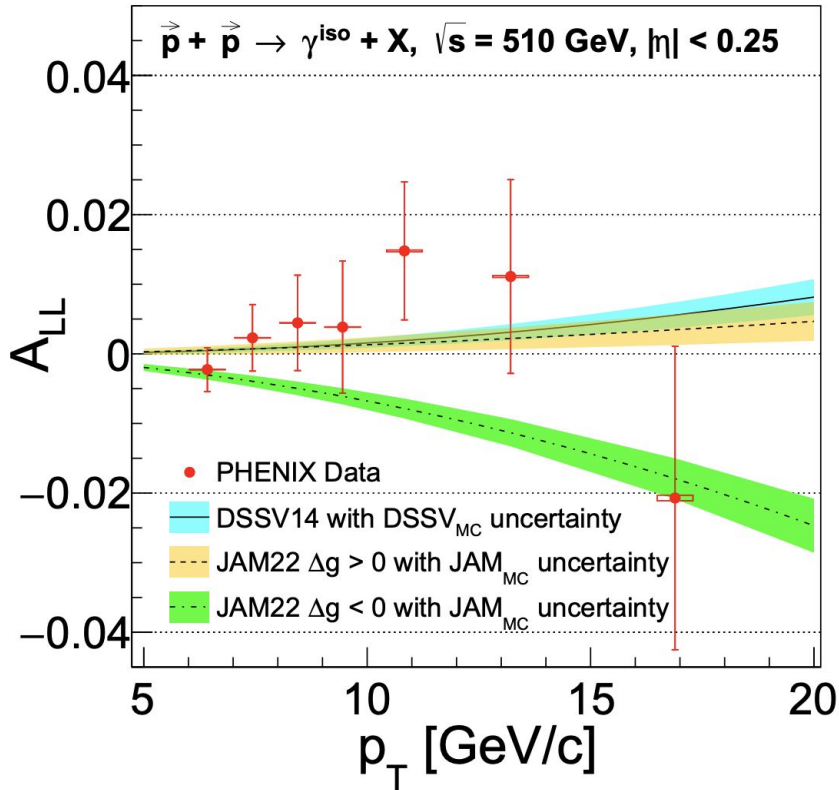


- PHENIX collaboration stated that the gluon spin contribution is positive
- The two solutions for g-hpdf found by JAM describe the data equally well

Measurement of Direct-Photon Cross Section and Double-Helicity Asymmetry at $\sqrt{s} = 510$ GeV in $\vec{p} + \vec{p}$ Collisions

PHENIX Collaboration • U. Acharya (Georgia State U., Atlanta) et al. (Feb 16, 2022)

e-Print: [2202.08158](https://arxiv.org/abs/2202.08158) [hep-ex]



- PHENIX collaboration stated that negative g-hpdf is disfavored by more than 2.8σ
- However, only last 3 high- p_T A_{LL} points are well described in pQCD (see denominator of A_{LL})

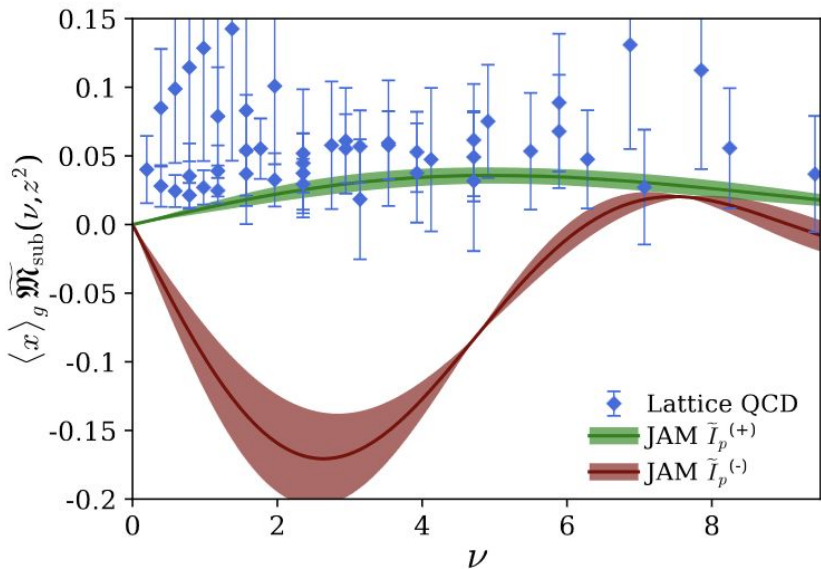
Gluon helicity from global analysis of experimental data and lattice QCD Ioffe time distributions

J. Karpie, R. M. Whitehill, W. Melnitchouk, C. Monahan, K. Orginos, J.-W. Qiu, D. G. Richards, N. Sato, and S. Zafeiropoulos (Jefferson Lab Angular Momentum and HadStruc Collaborations)
Phys. Rev. D **109**, 036031 – Published 27 February 2024

Toward the determination of the gluon helicity distribution in the nucleon from lattice quantum chromodynamics

HadStruc Collaboration · Colin Egerer (Jefferson Lab) et al. (Jul 18, 2022)

Published in: *Phys.Rev.D* 106 (2022) 9, 094511 · e-Print: [2207.08733](https://arxiv.org/abs/2207.08733) [hep-lat]

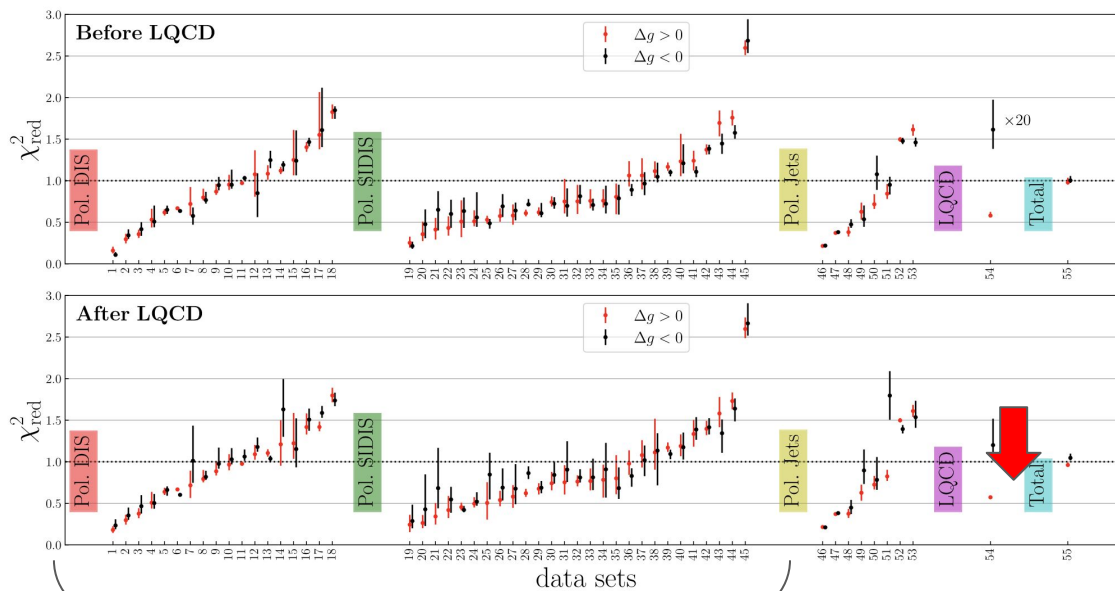


$$\widetilde{M}^{\mu\nu;\alpha\beta}(p, z) = \langle p | F^{\mu\nu}(0) W(0; z) \widetilde{F}^{\alpha\beta}(z) | p \rangle$$

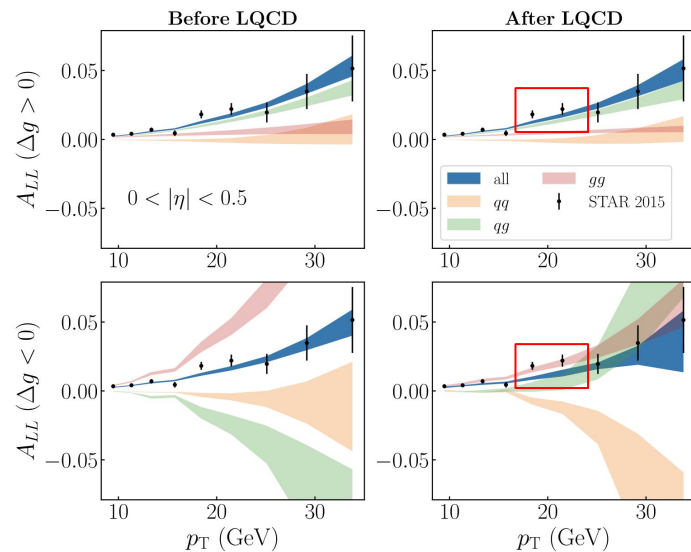
$$\widetilde{\mathfrak{M}}(\nu, z^2) = \frac{\widetilde{M}_{00}(p, z) / p_0 p_3 Z_L(z_3/a)}{M_{00}(p=0, z) / m^2}$$

$$\begin{aligned} \widetilde{\mathfrak{M}}(\nu, z^2) \langle x_g \rangle_{\mu^2} = & \tilde{\mathcal{I}}_p(\nu, \mu^2) - \frac{\alpha_s N_c}{2\pi} \int_0^1 du \tilde{\mathcal{I}}_p(u\nu, \mu^2) \left\{ \ln \left(z^2 \mu^2 \frac{e^{2\gamma_E}}{4} \right) \right. \\ & \left(\left[\frac{2u^2}{\bar{u}} + 4u\bar{u} \right]_+ - \left(\frac{1}{2} + \frac{4 \langle x_S \rangle_{\mu^2}}{3 \langle x_g \rangle_{\mu^2}} \right) \delta(\bar{u}) \right) \\ & + 4 \left[\frac{u + \ln(1-u)}{\bar{u}} \right]_+ - \left(\frac{1}{\bar{u}} - \bar{u} \right)_+ - \frac{1}{2} \delta(\bar{u}) + 2\bar{u}u \left. \right\} \\ & - \frac{\alpha_s C_F}{2\pi} \int_0^1 du \tilde{\mathcal{I}}_S(u\nu, \mu^2) \left\{ \ln \left(z^2 \mu^2 \frac{e^{2\gamma_E}}{4} \right) \tilde{\mathcal{B}}_{gq}(u) + 2\bar{u}u \right\} + \mathcal{O}(\Lambda_{\text{QCD}}^2 z^2), \end{aligned}$$

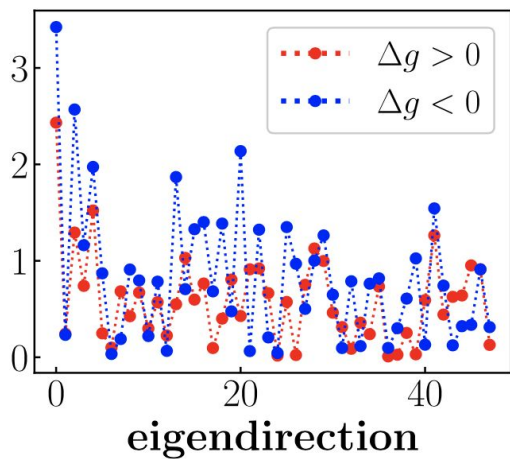
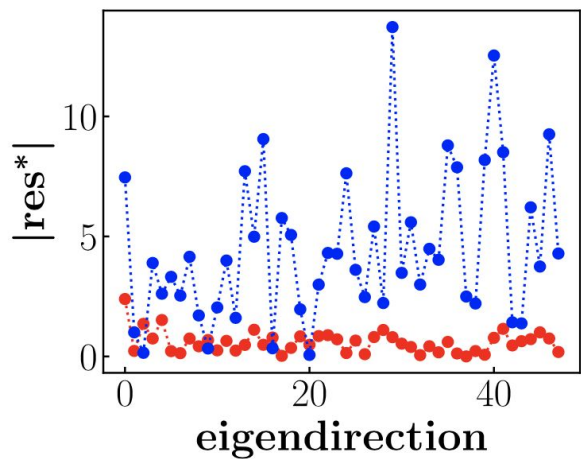
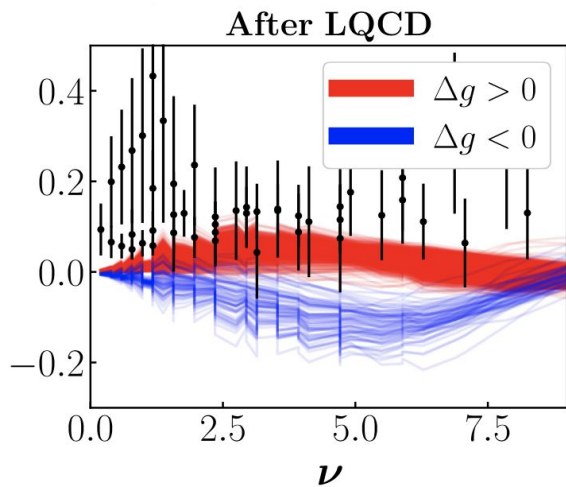
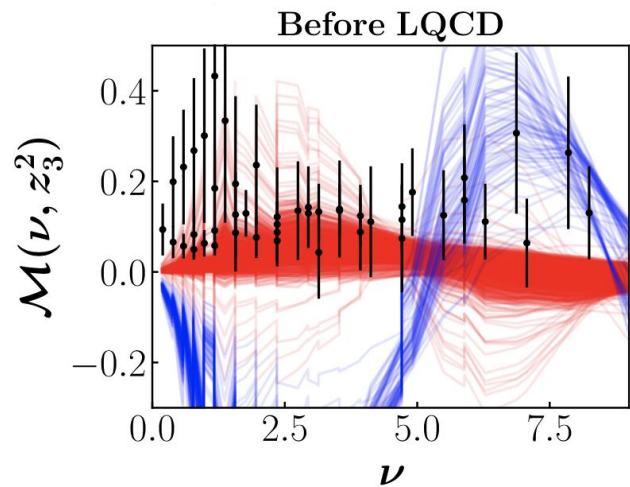
$$\tilde{\mathcal{I}}_p(\nu) = \frac{i}{2} \int_{-1}^1 dx e^{-ix\nu} x \Delta g(x).$$



DIS $W^2 > 10 \text{ GeV}^2$



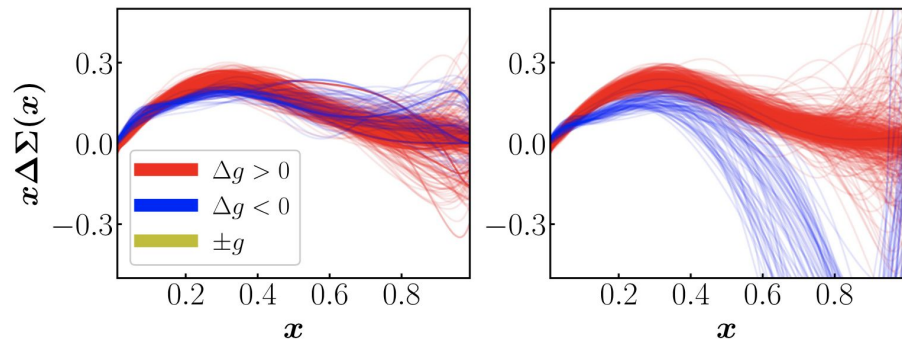
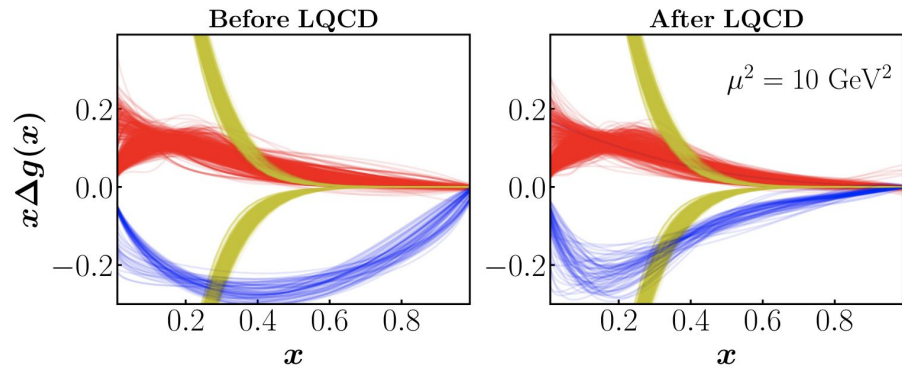
- Good description of global data after inclusion of LQCD for both solutions for g-hpdf
- On the basis of χ^2 , LQCD cannot discriminate fully the sign of g-hpdf



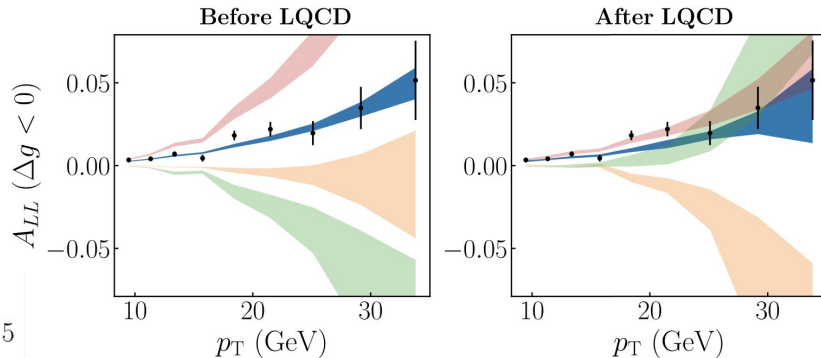
$$\begin{aligned}\chi^2 &= (\mathbf{d} - \mathbf{t})^T \boldsymbol{\Sigma}^{-1} (\mathbf{d} - \mathbf{t}) \\ &= (\mathbf{d} - \mathbf{t})^T \mathbf{U} \mathbf{D}^{-1} \mathbf{U}^T (\mathbf{d} - \mathbf{t}) \\ &= \sum_i \text{res}_i^{*2}.\end{aligned}$$



- PCA projections of residuals reveal strong correlations between LQCD data points
- The correlations prevent determination of g-hpdf sign



- LQCD distorts significantly the negative g-hpdf at higher $x > 0.3$
- Note that both solutions violate pdf positivity bounds for $x > 0.3$
- Before inclusion of LQCD data, singlet-hpdf were stable for both solutions
- Inclusion of LQCD data forces the quark singlet-hpdf to become negative at $x > 0.4$ for the negative g-hpdf



On the resolution of the sign of gluon polarization in the proton

N. T. Hunt-Smith,¹ C. Cocuzza,² W. Melnitchouk,³ N. Sato,³ A. W. Thomas,¹ and M. J. White¹

¹*CSSM and ARC Centre of Excellence for Dark Matter Particle Physics,
Department of Physics, University of Adelaide, Adelaide 5005, Australia*

²*Department of Physics, William and Mary, Williamsburg, Virginia 23185, USA*

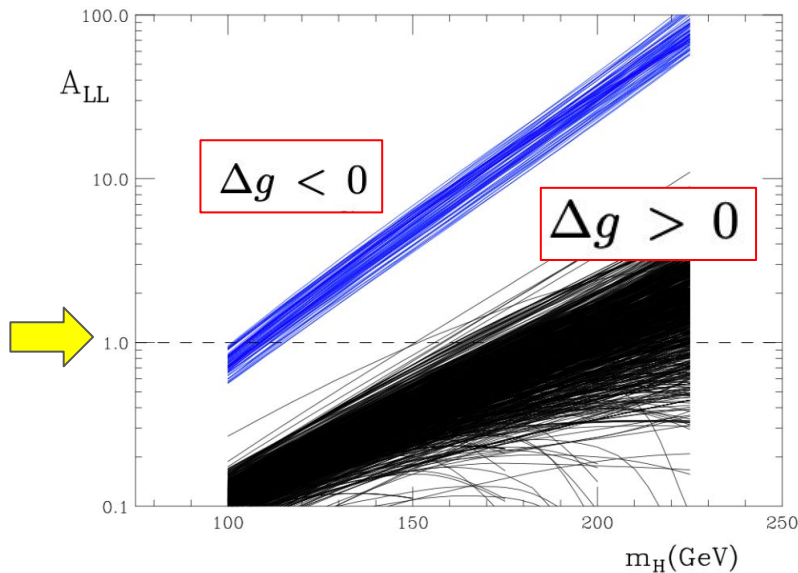
³*Jefferson Lab, Newport News, Virginia 23606, USA*

JAM Collaboration

(Dated: March 14, 2024)

Higgs production at RHIC and the positivity of the gluon helicity distribution

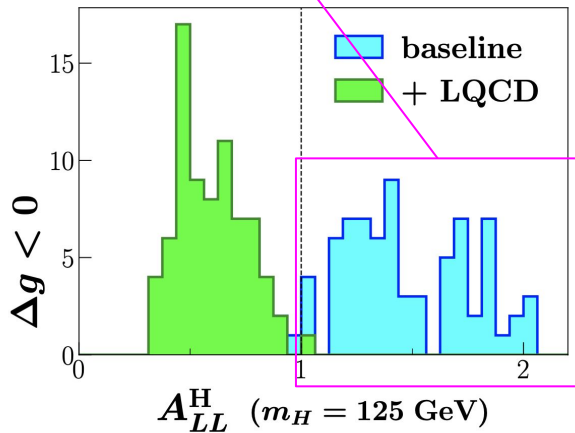
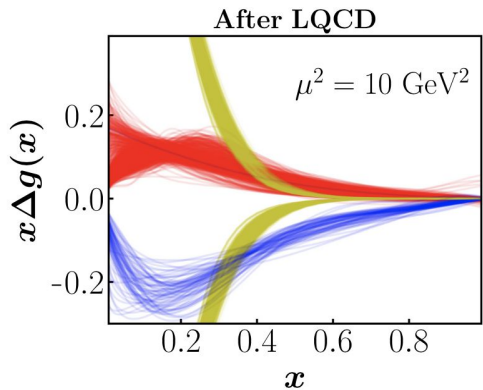
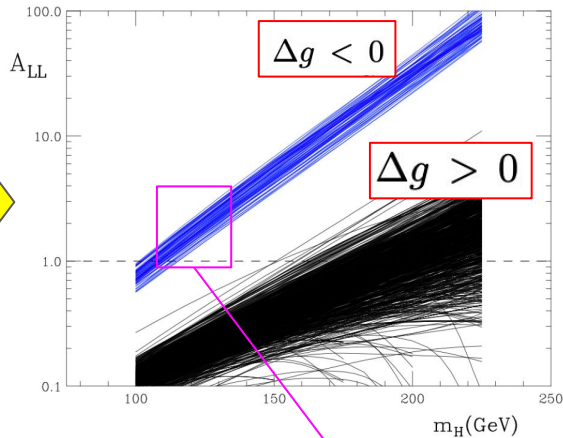
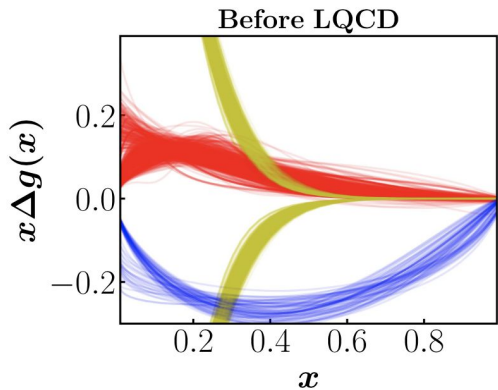
Daniel de Florian^a, Stefano Forte^b, Werner Vogelsang^c



- Higgs A_{LL} is directly sensitive to g-hpdf squared at LO
- Calculations of $A_{LL}(H)$ with negative g-hpdf can lead to unphysical results
(using non-LQCD based analysis)

$$A_{LL}^H(\tau) = \frac{[\Delta g \otimes \Delta g]}{[g \otimes g]} + \mathcal{O}(\alpha_s),$$

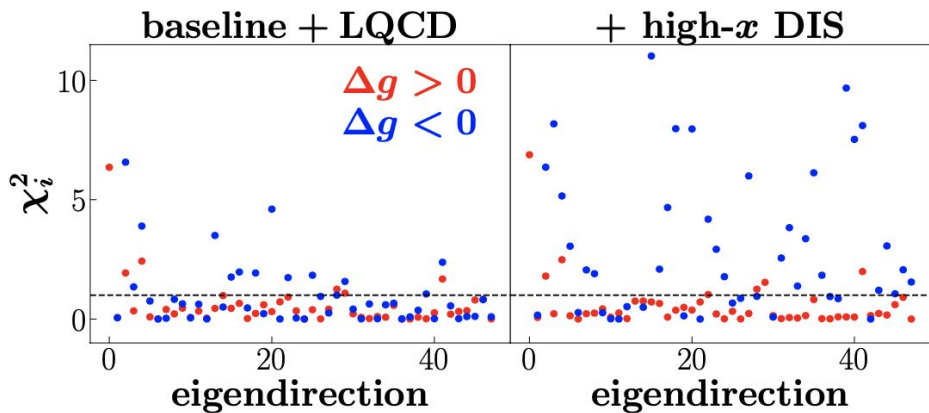
Can Higgs A_{LL} fully discriminate negative g -hpdf?



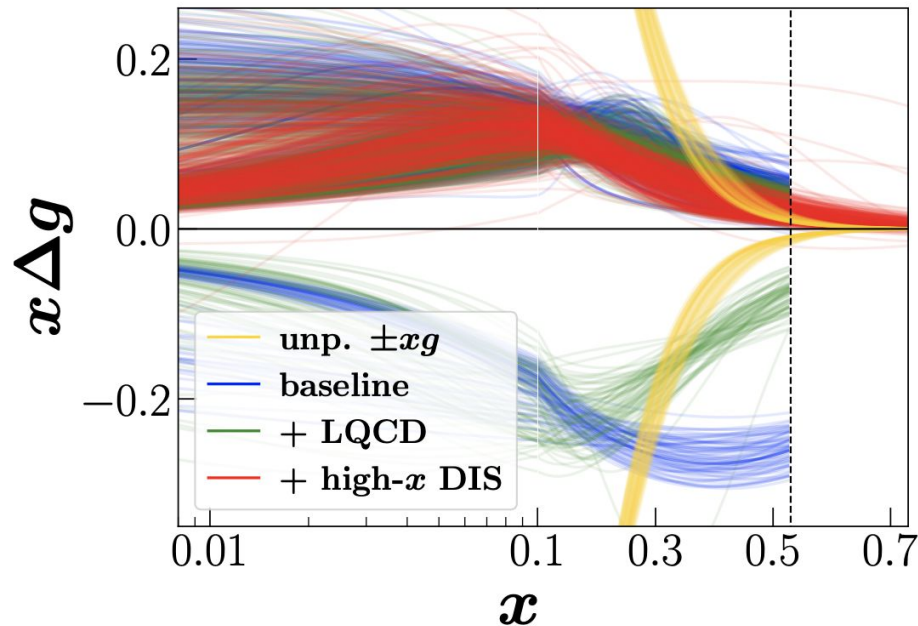
Negative g -hpdf with LQCD constraints still admits a physical Higgs A_{LL}

Reaction	$\chi^2_{\text{red}}(\Delta g > 0)$			$\chi^2_{\text{red}}(\Delta g < 0)$			N
	baseline	+ LQCD	+ high- x DIS	baseline	+ LQCD	+ high- x DIS	
<i>Polarized</i>							
Inclusive DIS	0.95	0.96	1.21	0.98	1.12	1.25	1735*
SIDIS	0.85	0.84	1.08	0.84	0.96	1.11	231
Inclusive jets	0.84	0.89	0.90	0.88	1.10	1.44	83
Inclusive W^\pm/Z	0.60	0.60	0.99	0.83	0.84	1.32	18
<i>Total</i>	0.89	0.90	1.18	0.92	1.06	1.24	2067
<i>Unpolarized</i>							
Inclusive DIS	1.17	1.17	1.17	1.18	1.18	1.19	3908
SIDIS	0.99	0.99	1.04	0.99	0.99	1.02	1490
Inclusive jets	1.28	1.28	1.30	1.29	1.29	1.30	198
Drell-Yan	1.21	1.21	1.21	1.24	1.24	1.24	205
Inclusive W^\pm/Z	1.01	1.01	1.01	1.03	1.03	1.04	153
<i>Total</i>	1.14	1.14	1.14	1.15	1.15	1.15	5954
SIA	0.86	0.86	0.89	0.90	0.90	0.92	564
LQCD	—	0.57	0.58	—	1.18	3.92	48
<i>Total</i>	1.08	1.10	1.13	1.10	1.12	1.17	8633

1370 additional data points for pol DIS (+ high- x DIS)

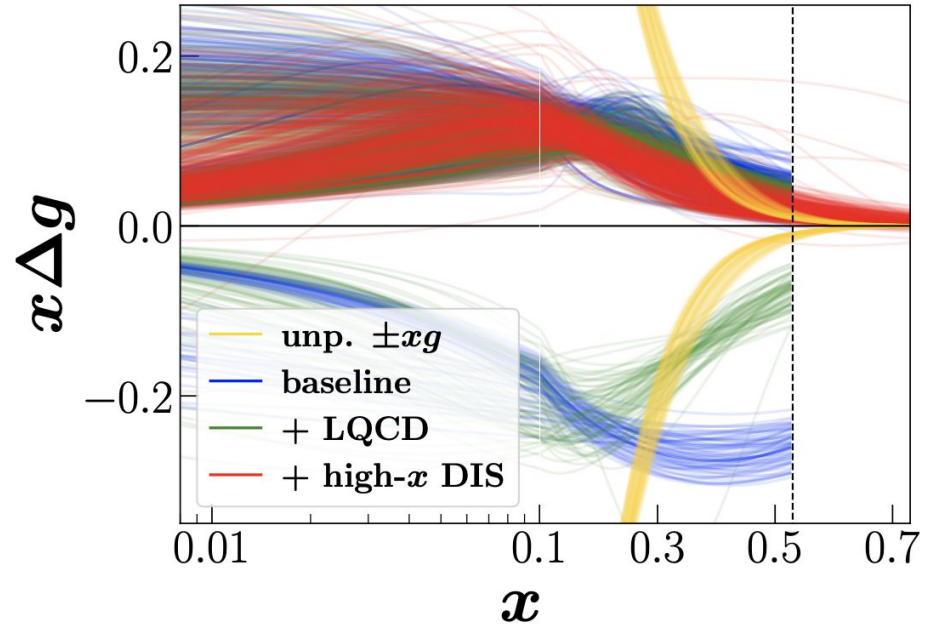


- With inclusion of high- x DIS DSAs, LQCD data strongly disfavor negative g -hpdf solution
- Combined DSA from jet and high- x DIS with LQCD allows us to discriminate the sign of g -hpdf for the first time!



Summary & outlook

- For the first time, we were able to discriminate the sign of g -hpdf using data-driven approach
- Constraints from LQCD along with DSAs from jets and DIS at large- x were crucial to achieve the resolution of g -hpdf sign
- Inclusion of LQCD is becoming increasingly important in global analysis
- Experimental constraints at large x on gluon - hpdf are still scarce, and more data needed to reach precision similar to unpolarized gluon density (EIC - small x , JLab12/22 - high x)



Backup

Measurement of charged pion double spin asymmetries at midrapidity in longitudinally polarized $p + p$ collisions at $\sqrt{s} = 510$ GeV

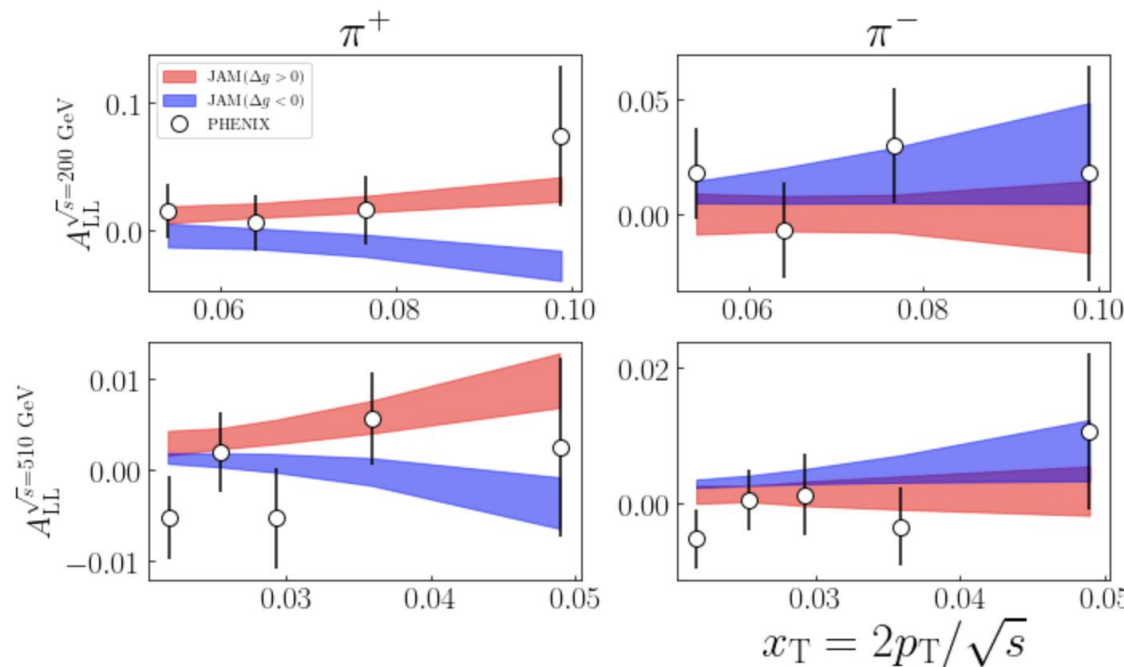
PHENIX Collaboration • U.A. Acharya (Georgia State U.) et al. (Apr 6, 2020)

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Charged-pion cross sections and double-helicity asymmetries in polarized $p+p$ collisions at $\sqrt{s}=200$ GeV

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The PHENIX experiment at the Relativistic Heavy Ion Collider has measured the longitudinal double spin asymmetries, A_{LL} , for charged pions at midrapidity ($|\eta| < 0.35$) in longitudinally polarized $p+p$ collisions at $\sqrt{s} = 510$ GeV. These measurements are sensitive to the gluon spin contribution to the total spin of the proton in the parton momentum fraction x range between 0.04 and 0.09. One can infer the sign of the gluon polarization from the ordering of pion asymmetries with charge alone. The asymmetries are found to be consistent with global quantum-chromodynamics fits of deep-inelastic scattering and data at $\sqrt{s} = 200$ GeV, which show a nonzero positive contribution of gluon spin to the proton spin.

