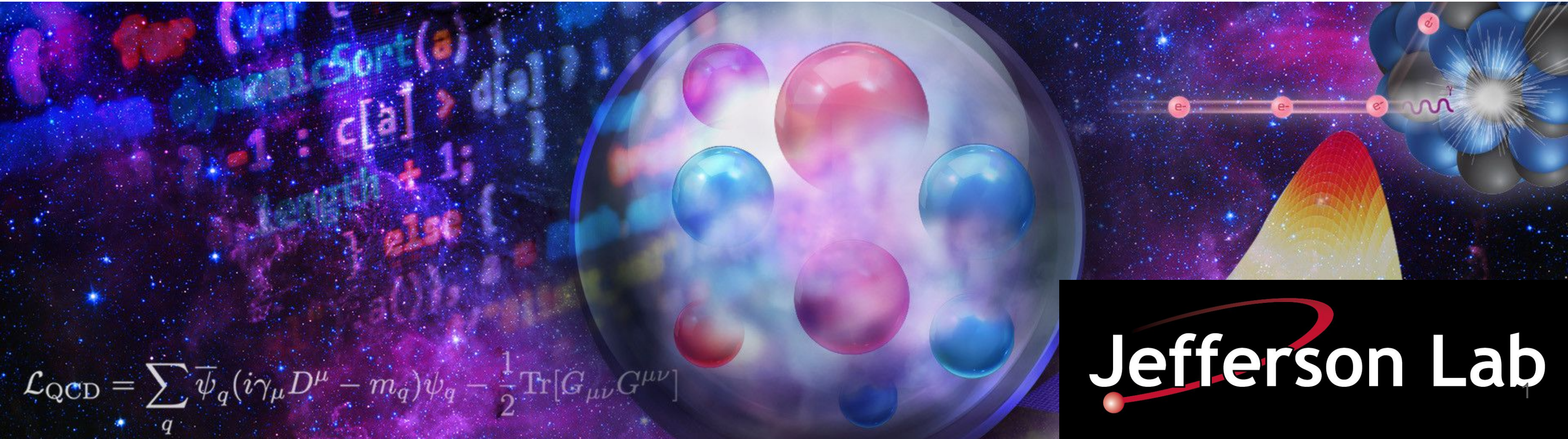
25TH INTERNATIONAL SPIN PHYSICS SYMPOSIUM

September 24 – 29, 2023
Durham Convention Center
Durham, NC, USA

Updates on phenomenology

Nobuo Sato

Sep. 27, 2023



Jefferson Lab

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JAM — Theory, Experiment, Computer Science

Updates on ~~phenomenology~~ Δg

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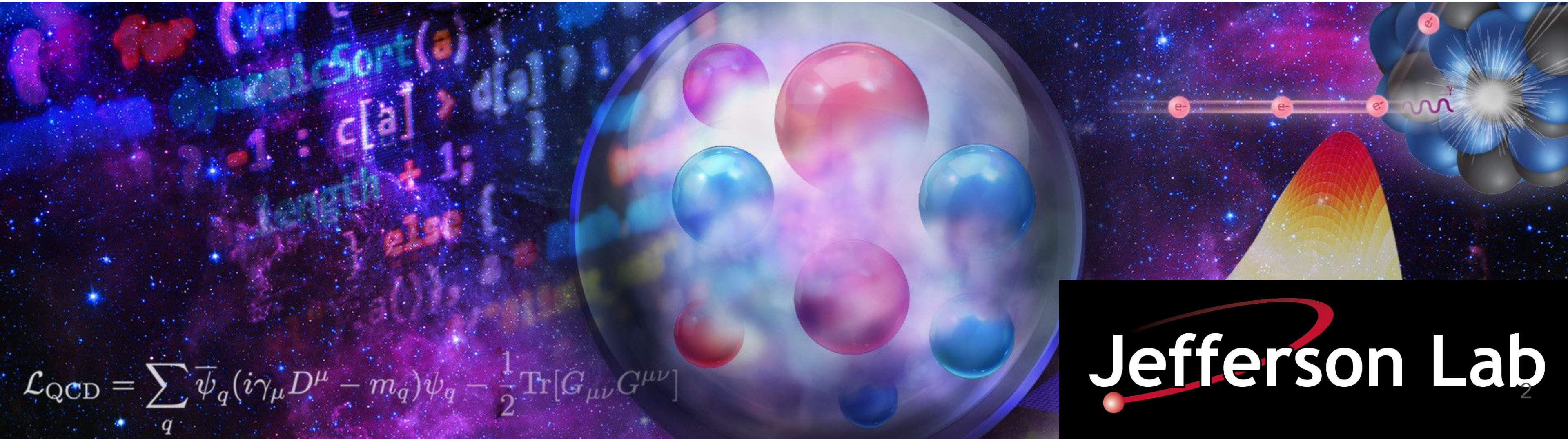
Sep. 27, 2023

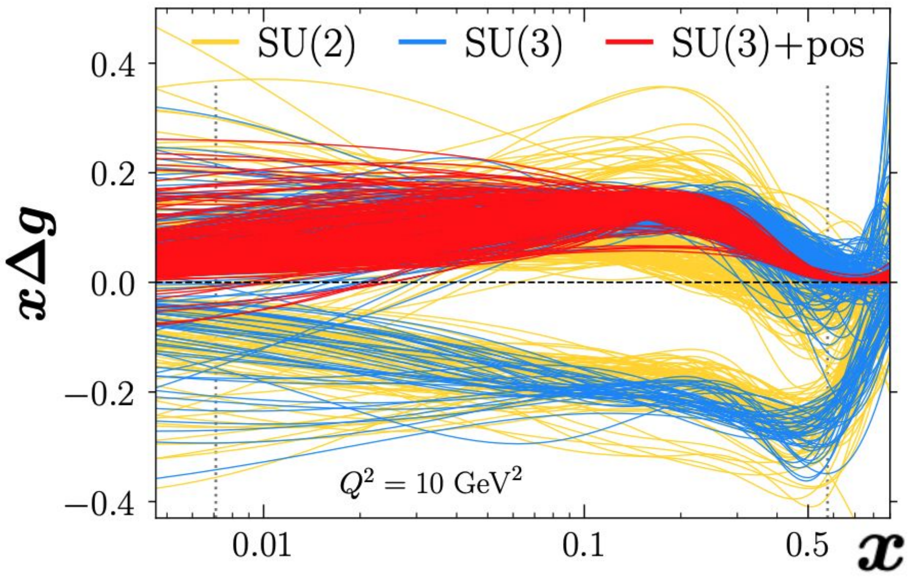
See also talk by M. Sievert (small x) and updates from DSSV (W. Vogelsang)



Jefferson Lab

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

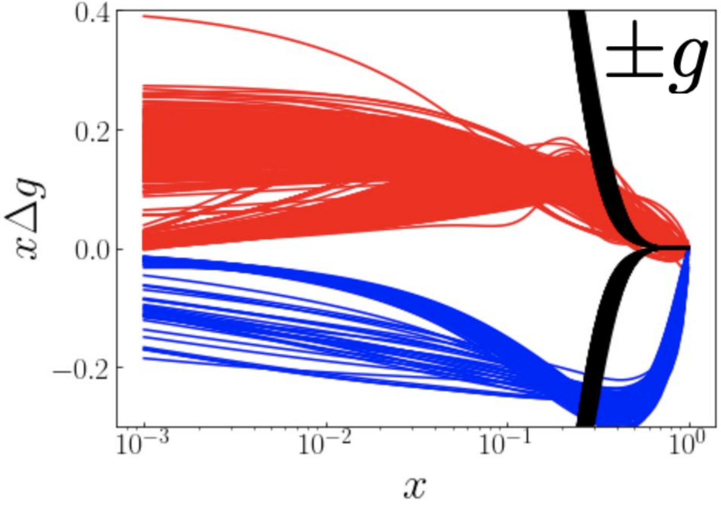
Y. Zhou, N. Sato, and W. Melnitchouk (Jefferson Lab Angular Momentum (JAM) Collaboration)
Phys. Rev. D **105**, 074022 – Published 25 April 2022

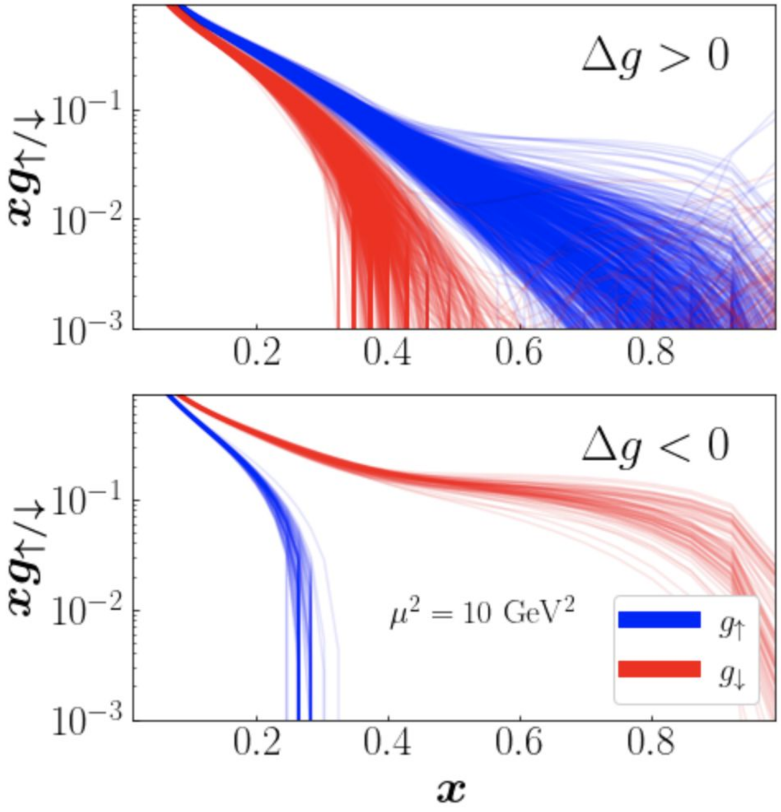


See also talk by M. Sievert (small x) and updates from DSSV (W. Vogelsang)

Updates on gluon helicity

What do we mean by positivity?





$$g_{\uparrow/\downarrow} = \frac{1}{2}(g \pm \Delta g)$$

Positivity condition $\Rightarrow$ $g_{\uparrow/\downarrow} > 0$

Are the negative solutions non-sense?

$$g_{\uparrow/\downarrow} \overset{?}{>} 0$$

Positivity and renormalization of parton densities

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

pdfs can be **negative** at low scales

- For BSM searches at LHC, negative pdfs leads to negative cross sections in some observables at extreme regions of phase
  - need positive pdfs
- For MCEGs, one needs to initiate the markov chain by sampling parton momentum fractions
  - need positive pdfs
- Exploration of origin of proton spin
  - do need positive pdfs?

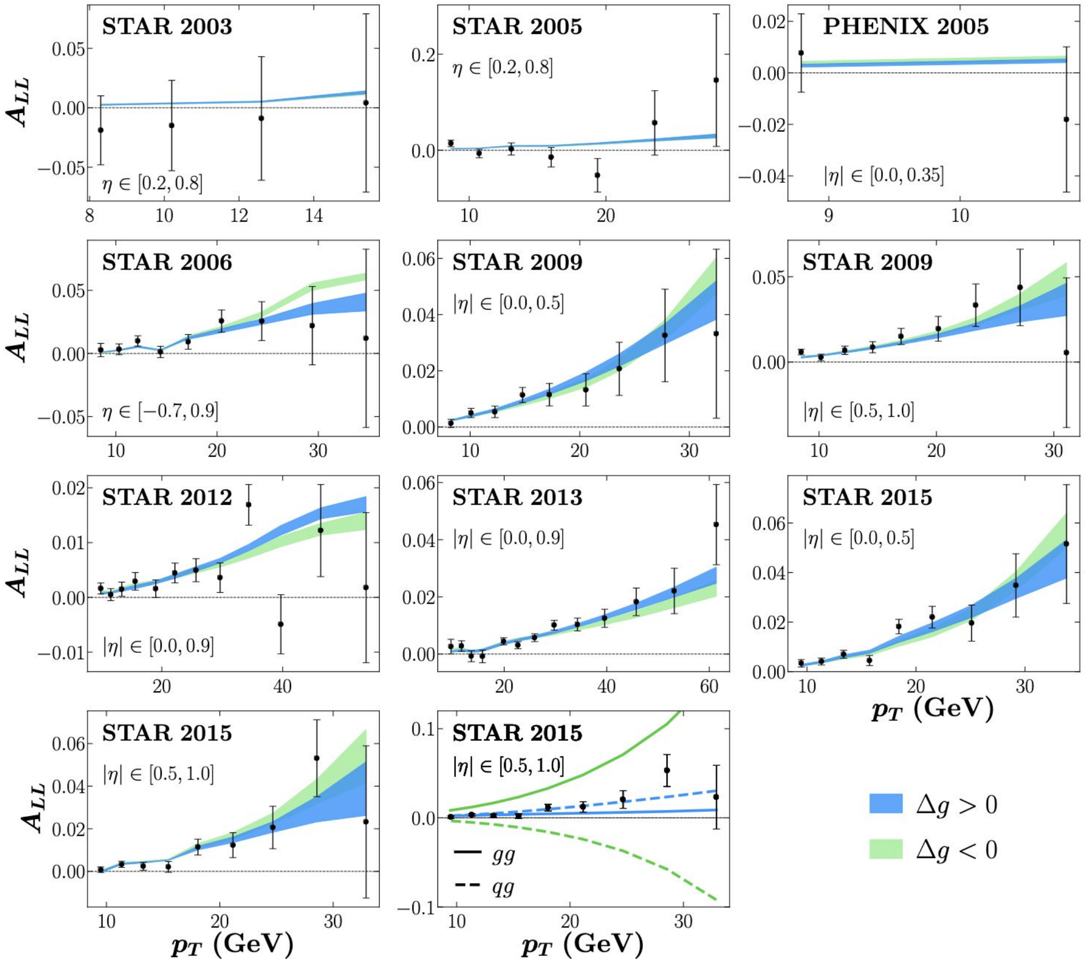
- Negative cross sections are non-sense
  - true for helicity dependent cross sections

$$A_{LL} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

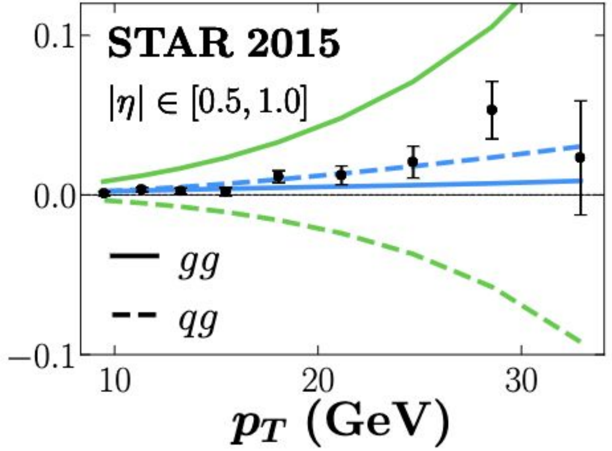
$$\sigma_\pm > 0$$

$$|A_{LL}| < 1$$

- Does negative gluon hpdf violate this?
  what does the data tell us?



$$|A_{LL}| < 1$$



- Negative qg subchannel is admissible by data
- The gg channel can be large and positive at the expense of negative qg

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

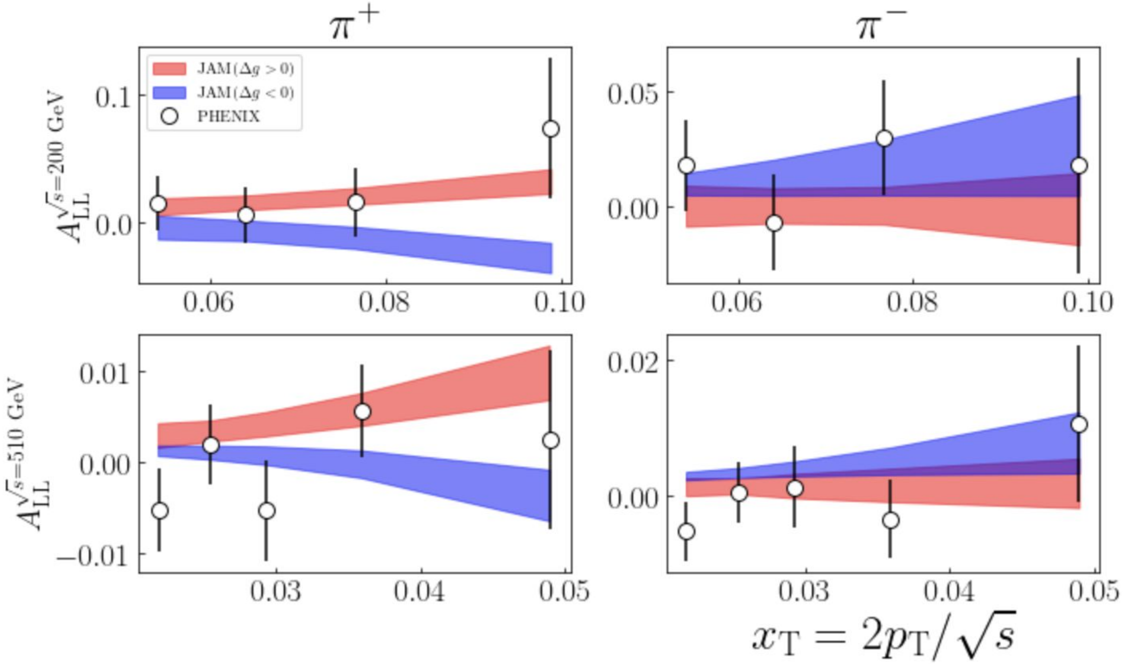
PHENIX Collaboration • U.A. Acharya (Georgia State U.) et al. (Apr 6, 2020)

Published in: *Phys.Rev.D* 102 (2020) 3, 032001 • e-Print: 2004.02681 [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 [hep-ex]

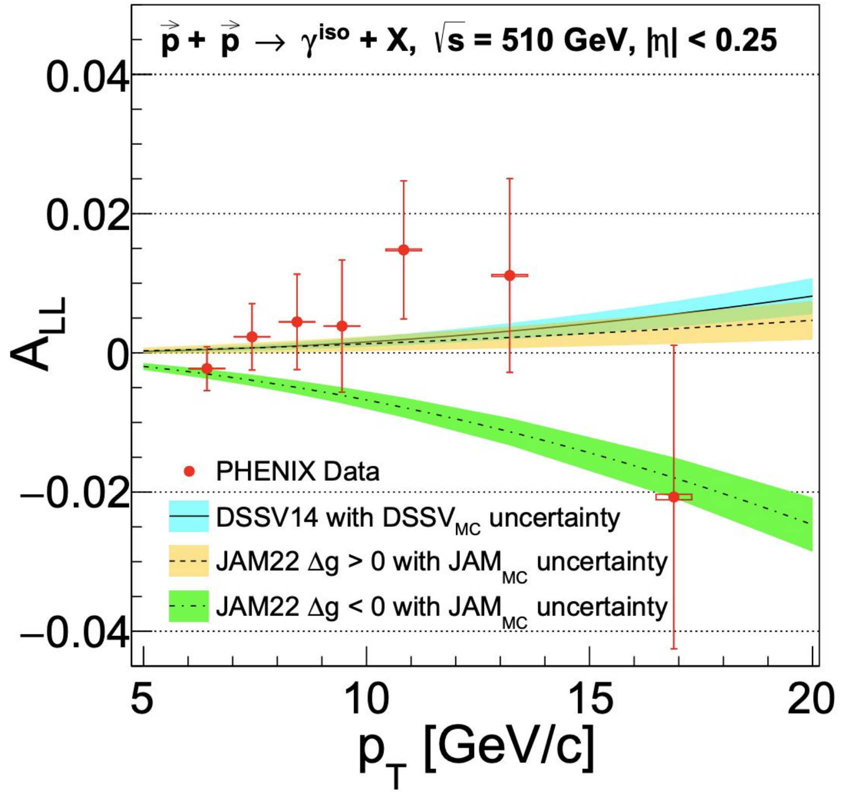


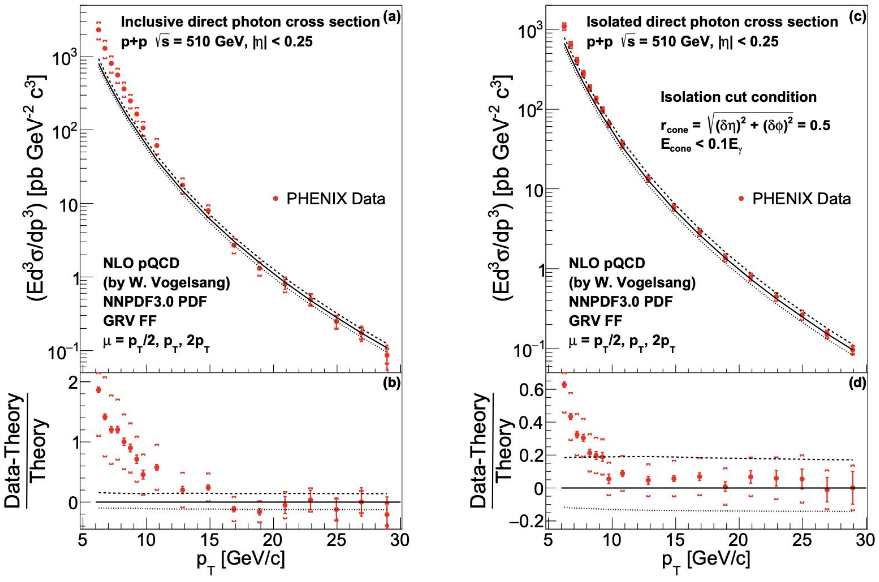
The PHENIX experiment at the Relativistic Heavy Ion Collider has measured the longitudinal double spin asymmetries, A_{LL}, for charged pions at midrapidity ($|\eta| < 0.35$) in longitudinally polarized p+p collisions at $\sqrt{s} = 510$ GeV. These measurements are sensitive to the gluon spin contribution 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.

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 [hep-ex]



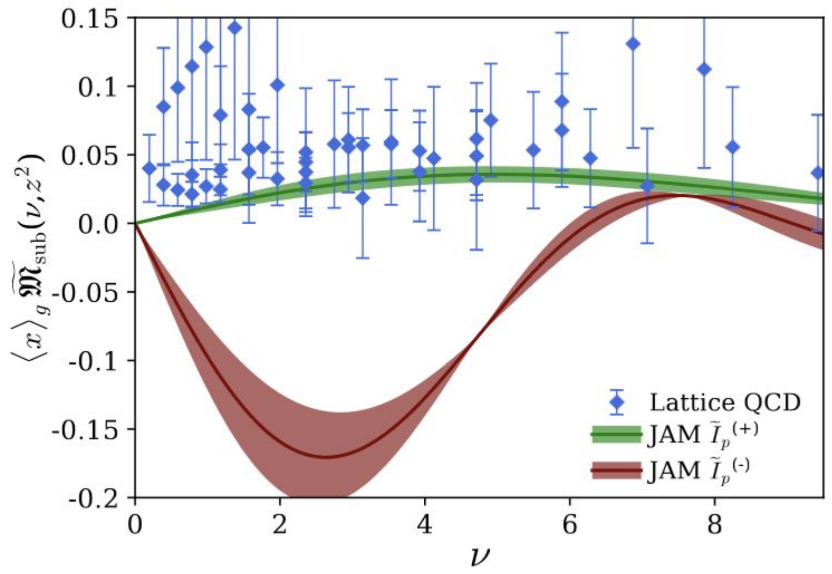


The two dashed curves in Fig. 2 come from the global analysis of the JAM Collaboration [15, 16]. They found there are two distinct sets of solutions for the polarized gluon PDF, Δg, which differ in sign. Even though the solutions with $\Delta g < 0$ violate the positivity assumption, $|\Delta g| < g$, all previous data cannot exclude those solutions due to the mixed contributions from quark-gluon and gluon-gluon interactions. However, the direct-photon A_{LL} comes mainly from the quark-gluon interactions and has $\chi^2 = 4.7$ and 12.6 for 7 data points for the $\Delta g > 0$ and $\Delta g < 0$ solutions, respectively, with the difference of 7.9 between χ^2 values implying that the negative solution is disfavored at more than 2.8σ level.

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 [hep-lat]



Negative delta g seems to be largely disfavored by LQCD

Constraints from LQCD

Constraints from LQCD

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

For space-like z

$$\begin{aligned}\widetilde{M}_{00}(p,z) &= p_0 p_3\left[\widetilde{M}^{ti;it}(p,z) + \widetilde{M}^{ij;ji}(p,z)\right] \\ &= \underbrace{\widetilde{\mathcal{M}}(\nu,z^2)}_{\text{LP matching}} + \underbrace{\frac{m^2 z^2}{\nu}\mathcal{M}_{pp}(\nu,z^2)\,.}_{\text{Beyond LP}}\end{aligned}$$

$$\nu = p \cdot z$$

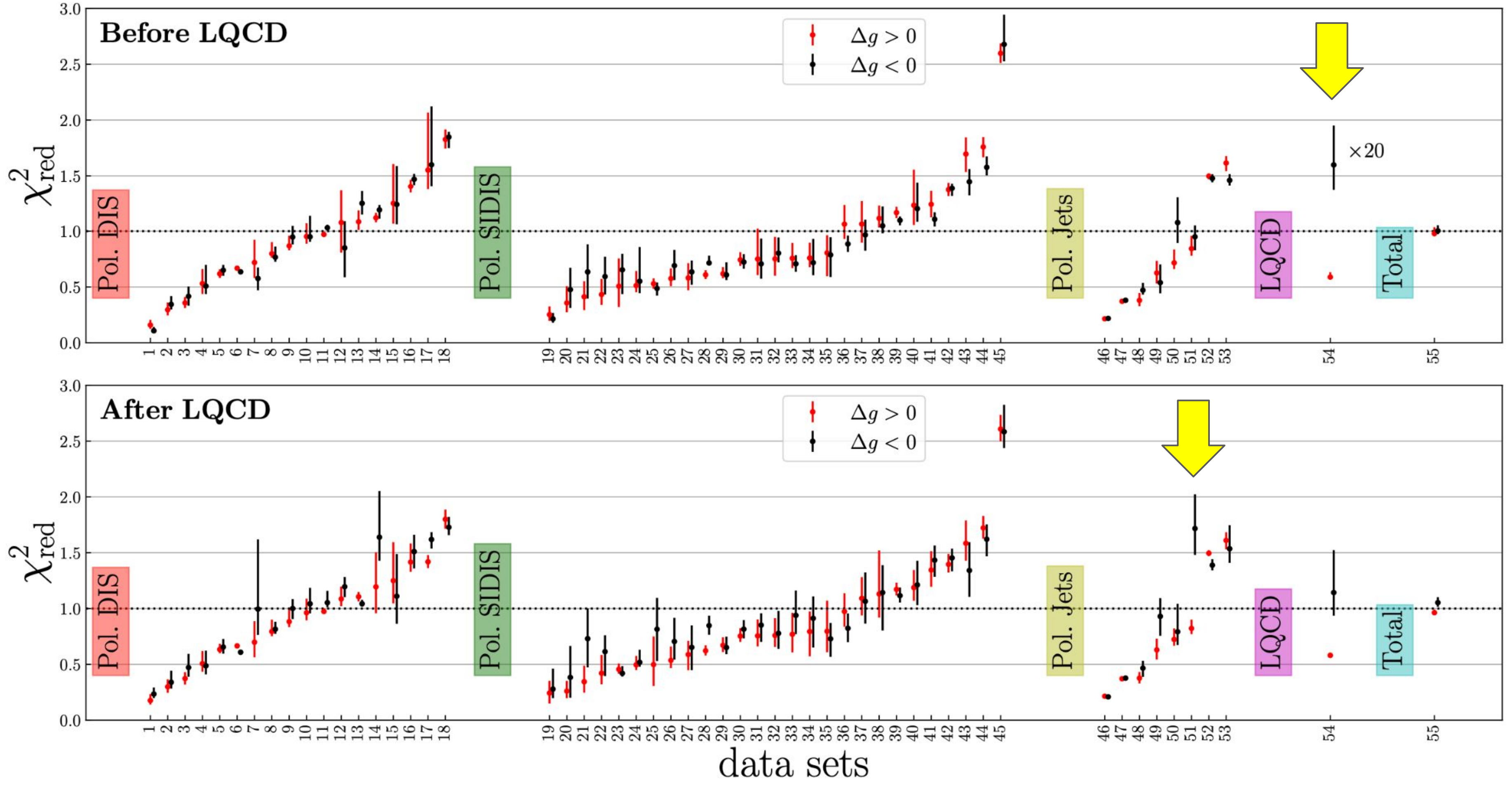
Constraints from LQCD

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

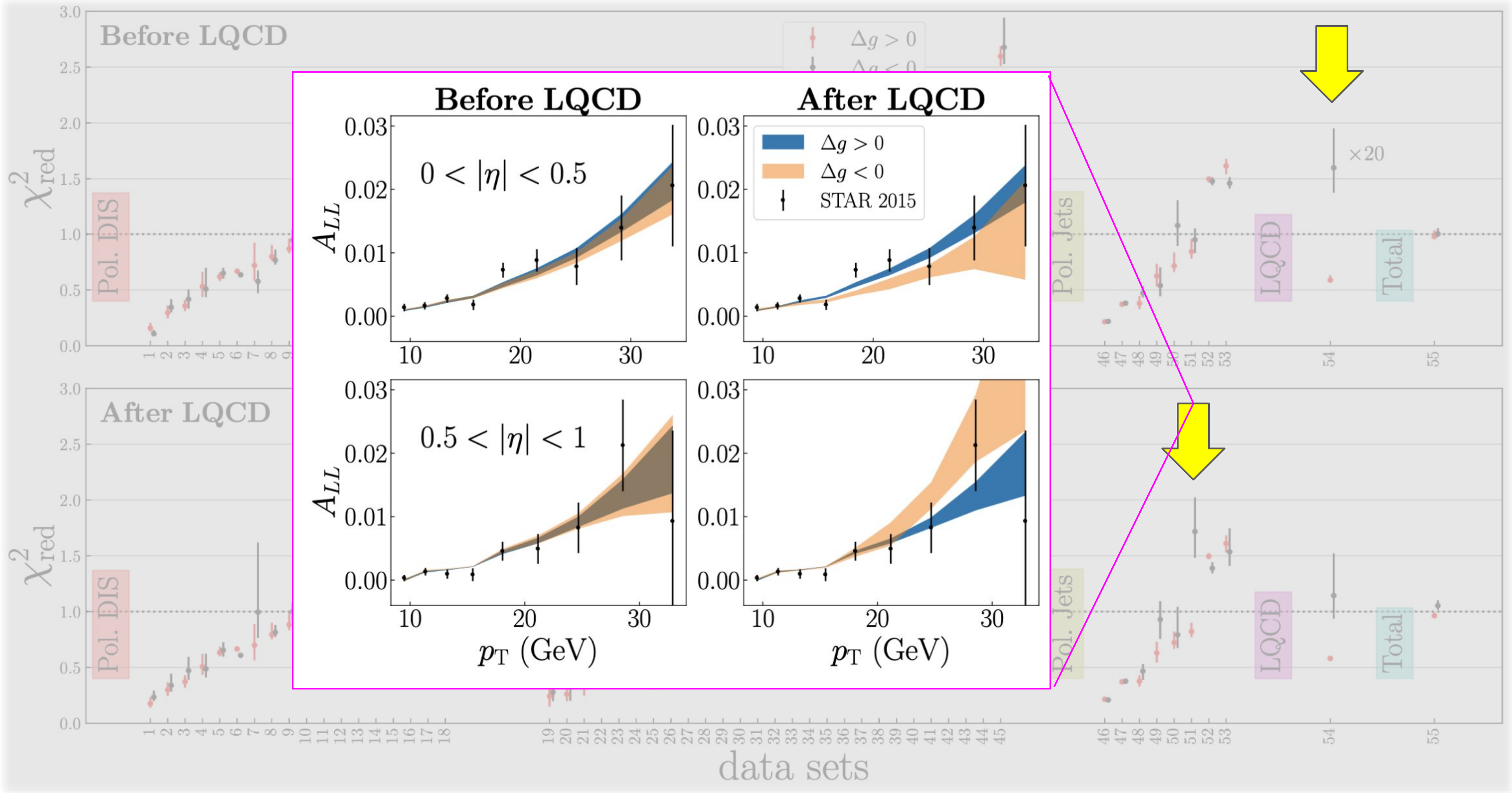
$$\begin{aligned}\widetilde{\mathfrak{M}}(\nu, z^2)\langle x_g\rangle_{\mu^2} = \boxed{\widetilde{\mathcal{I}}_p(\nu, \mu^2)} - \frac{\alpha_s N_c}{2\pi}\int_0^1 \mathrm{d}u\, \widetilde{\mathcal{I}}_p(u\nu, \mu^2)\Bigg\{ \ln\left(z^2\mu^2\frac{e^{2\gamma_E}}{4}\right) \\ \left(\left[\frac{2u^2}{\bar{u}}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

$$\boxed{\widetilde{\mathcal{I}}_p(\nu) = \frac{i}{2}\int_{-1}^1 \mathrm{d}x\, e^{-ix\nu}\, x\,\Delta g(x)\,.}$$

Balitsky, Morris, Radyushkin ‘22

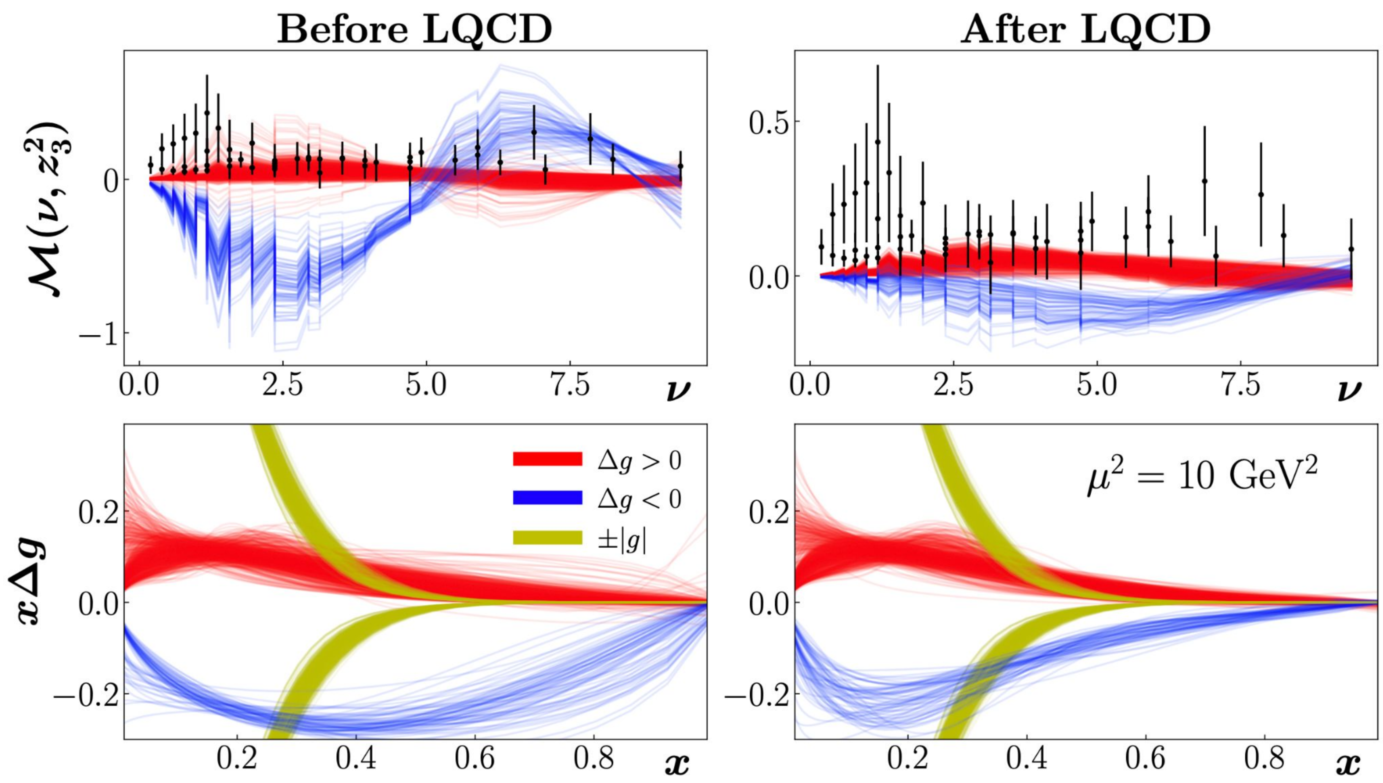


Before LQCD
After LQCD
$\Delta g > 0$
$\Delta g < 0$
$\times 20$
Pol. DIS
Pol. SIDIS
Pol. Jets
LQCD
Total
$\chi^2_{\rm red}$
data sets



Before LQCD
After LQCD
$0 < |\eta| < 0.5$
$0.5 < |\eta| < 1$
A_{LL}
p_T (GeV)
$\Delta g > 0$
$\Delta g < 0$
STAR 2015
$\chi^2_{\rm red}$
Pol. DIS
Pol. Jets
LQCD
Total
×20
data sets

Karpie et al, JAM+HadStruc (in preparation)



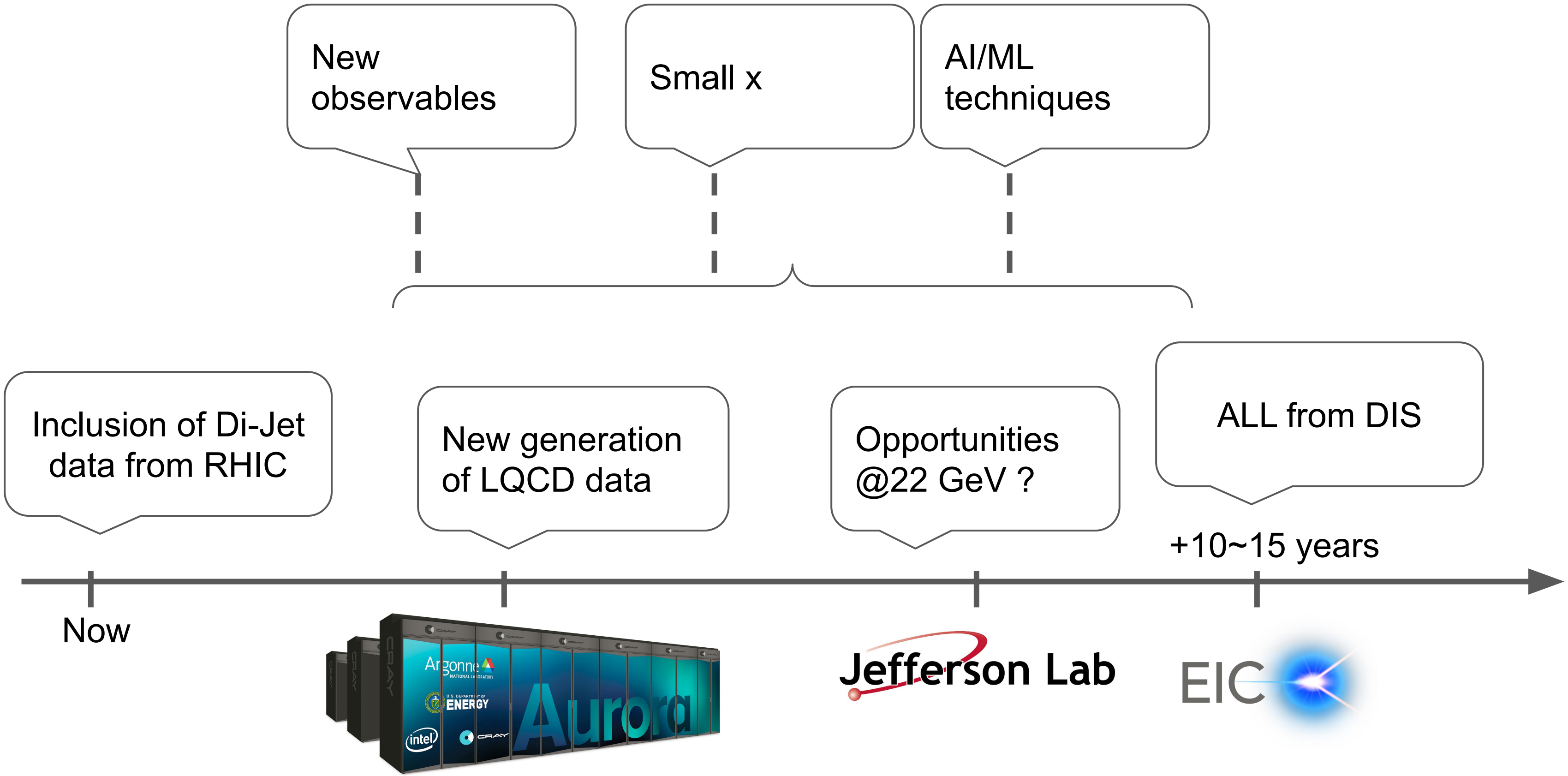
> The error bars only includ diagonal parts of cov matrix

> Offdiagonal entries weakens the constraints

> LQCD data does not remove entirely the negative solutions

> LQCD prefers to less violation of positivity

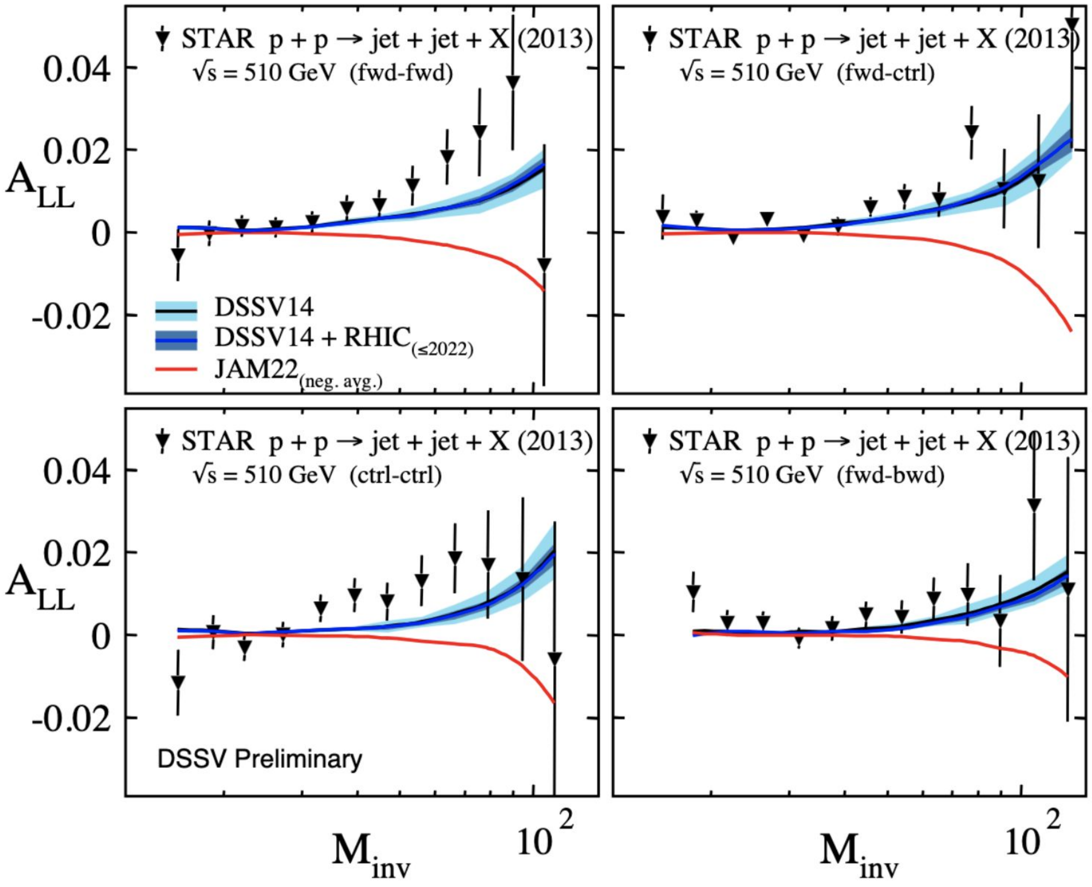
So, whats next?



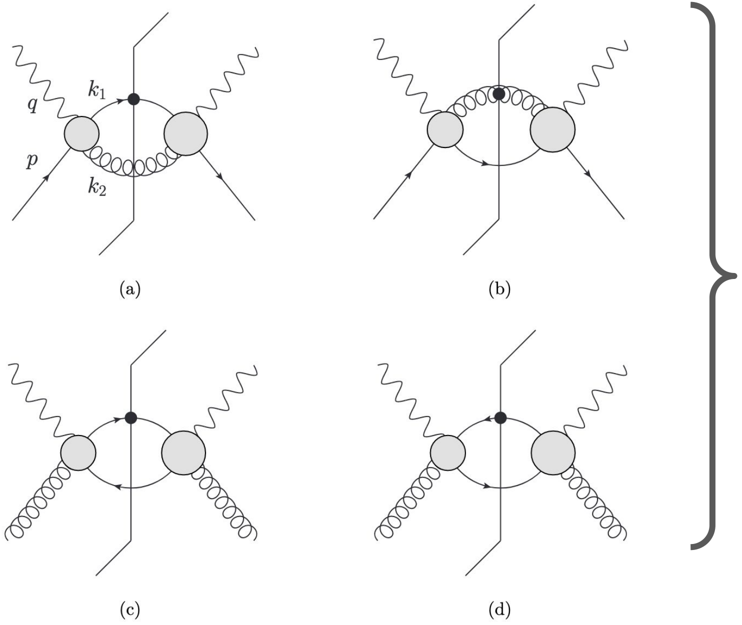
DSAs in dijets

- High Mjj probes high x
- Fwd-fwd data suggests new trends even for the positive solutions
- Need to include the data in global analysis

$$x_{a,b} = \frac{M_{jj}}{\sqrt{s}} e^{\pm Y_{jj}}$$



Pol. High pT SIDIS

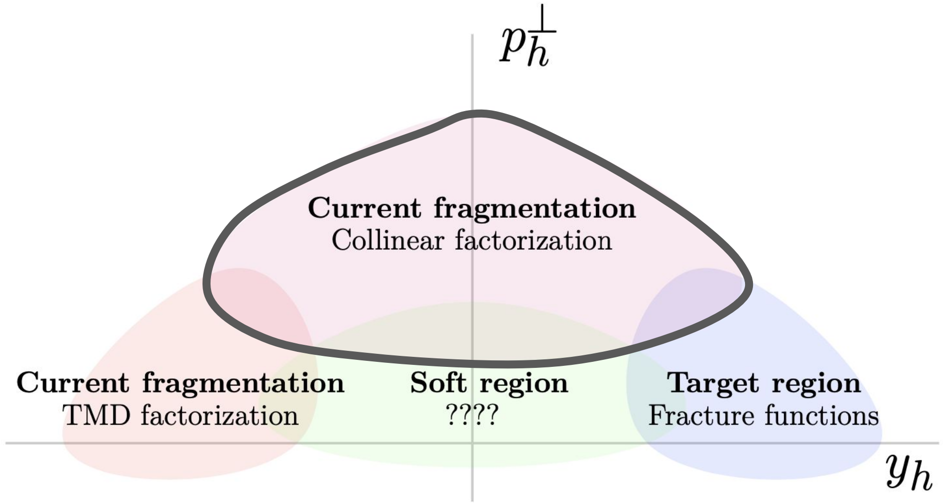


Gluon initiated subprocess appears at the same order as quarks in pQCD

Accessing gluon polarization with high-P_T hadrons in SIDIS

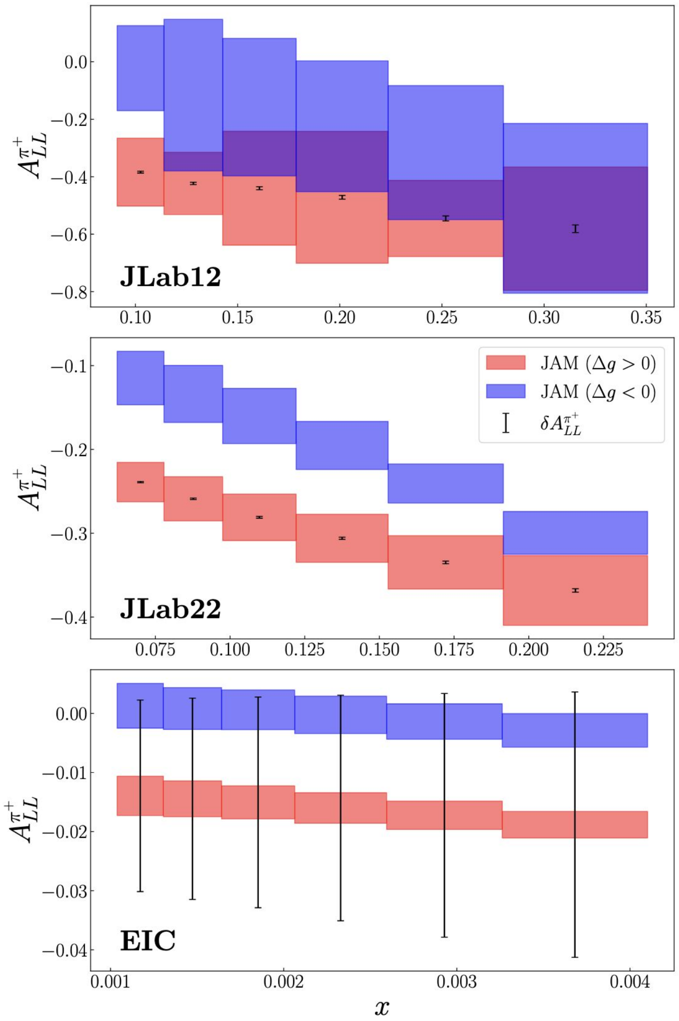
R.M. Whitehill (Wichita State U.), Yiyu Zhou (South China Normal U. and UCLA), N. Sato (Jefferson Lab), W. Melnitchouk (Jefferson Lab and Adelaide U., Sch. Chem. Phys.)

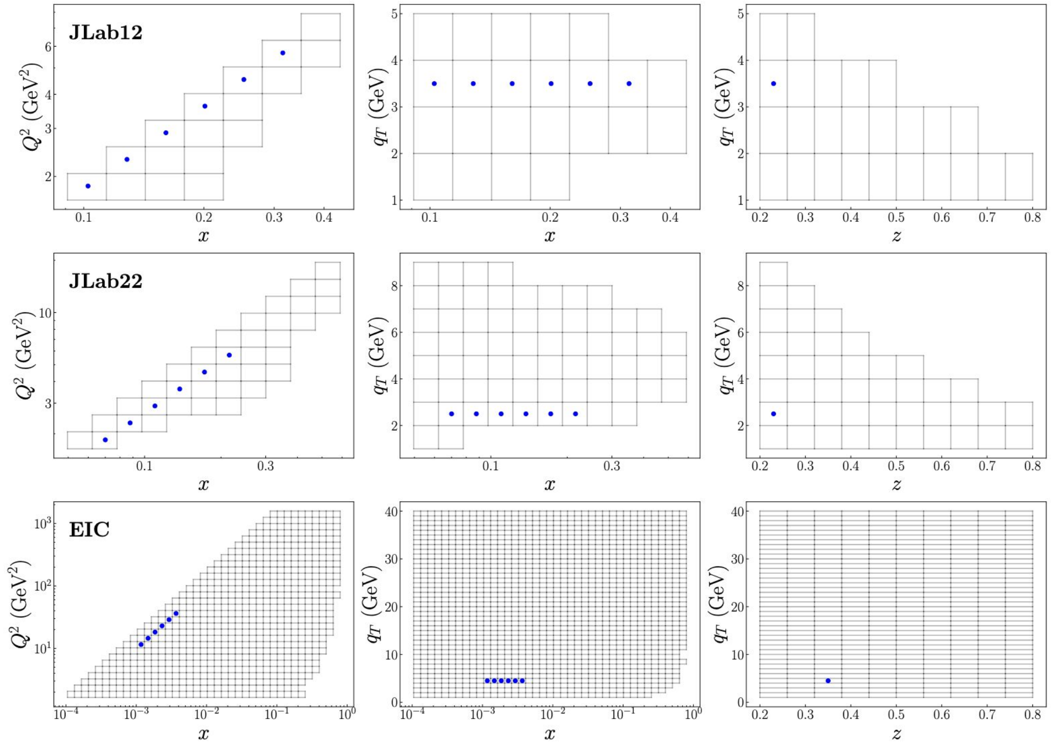
Oct 21, 2022



$$4P_h^0 E' \frac{d\sigma_h}{d^3\boldsymbol{\ell}' d^3\boldsymbol{P}_h} = \sum_{ij} \int_x^1 \frac{d\xi}{\xi} \int_z^1 \frac{d\zeta}{\zeta^2} \left(4k_1^0 E' \frac{d\hat{\sigma}_{ij}}{d^3\boldsymbol{\ell}' d^3\boldsymbol{k}_1} \right) f_{i/N}(\xi)\, D_{h/j}(\zeta),$$

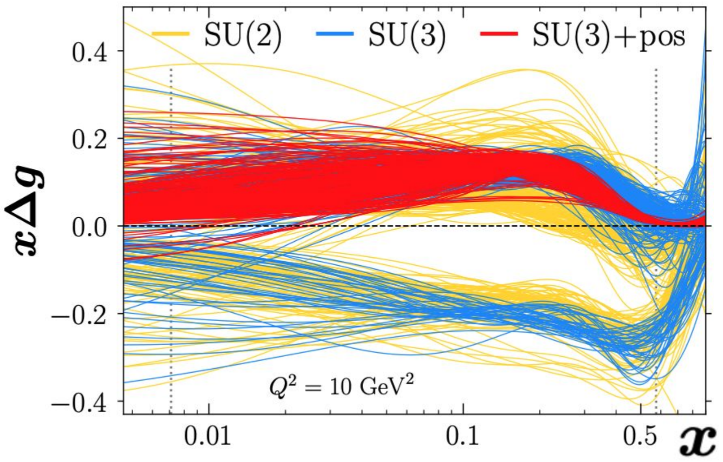
$$4P_h^0 E' \frac{d\Delta\sigma_h}{d^3\boldsymbol{\ell}' d^3\boldsymbol{P}_h} = \sum_{ij} \int_x^1 \frac{d\xi}{\xi} \int_z^1 \frac{d\zeta}{\zeta^2} \left(4k_1^0 E' \frac{d\Delta\hat{\sigma}_{ij}}{d^3\boldsymbol{\ell}' d^3\boldsymbol{k}_1} \right) \Delta f_{i/N}(\xi)\, D_{h/j}(\zeta),$$





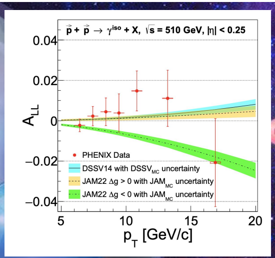
Bottom line: sign of gluon polarization might be resolved empirically with pol SIDIS

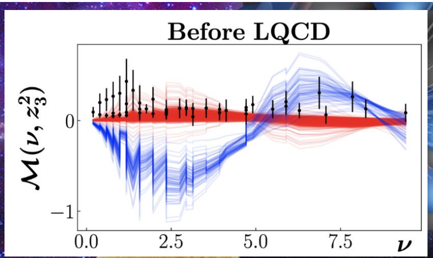
Summary

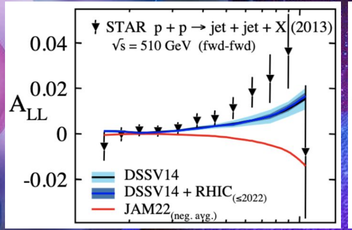


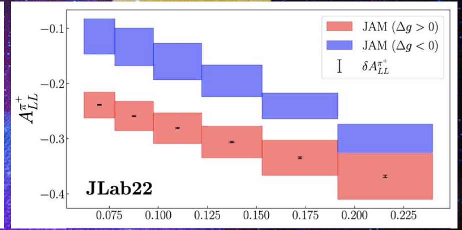
- Empirical determination of gluon polarization at high x is still evolving and more studies/more data is needed

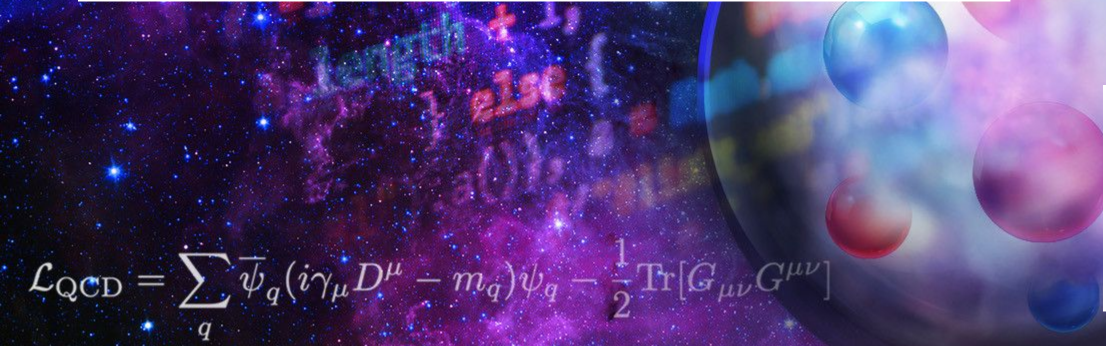
- Synergistic activities with LQCD is paving new opportunities for parton physics (eg. tensor charge, pion)



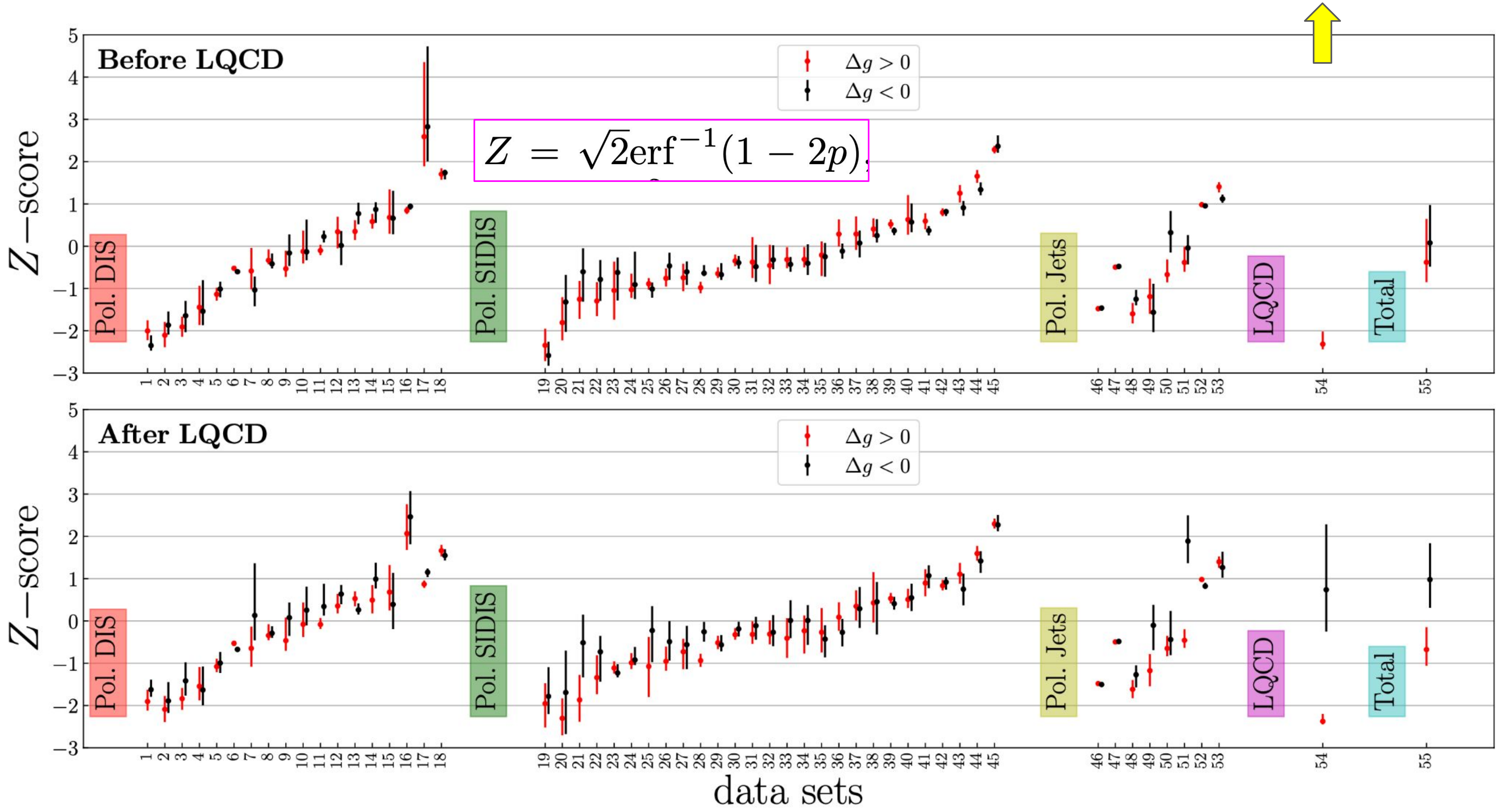








Backup slides



$$Z = \sqrt{2}\,\mathrm{erf}^{-1}(1 - 2p),$$