Theory and Phenomenology of Helicity PDFs

Chris Cocuzza (Temple U.)
On behalf of:
Nobuo Sato (Jefferson Lab)

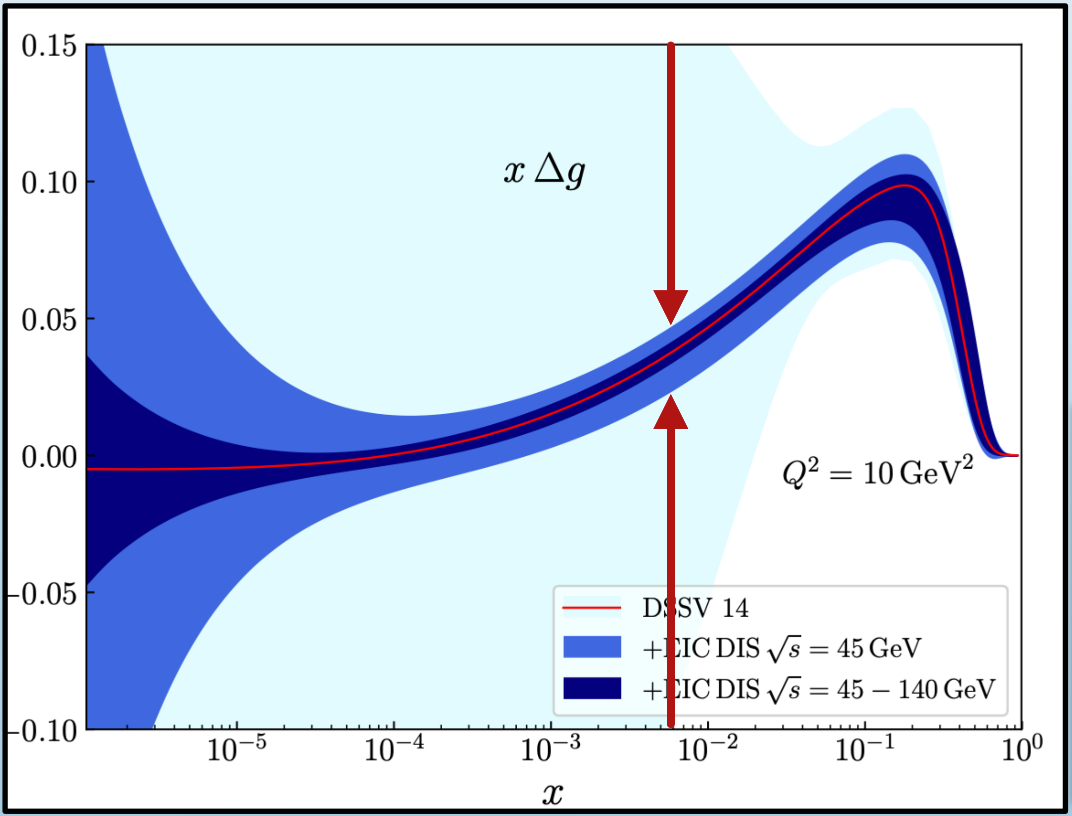
October 22, 2021

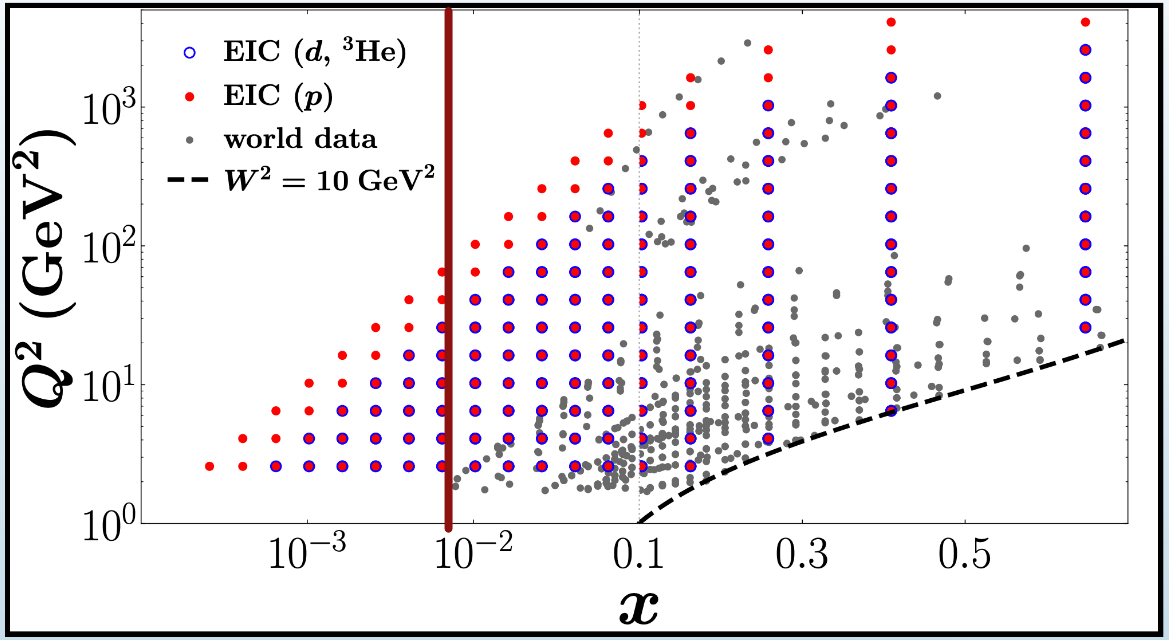
SPIN2021
Matsue, Japan

Current State of Helicity PDFs

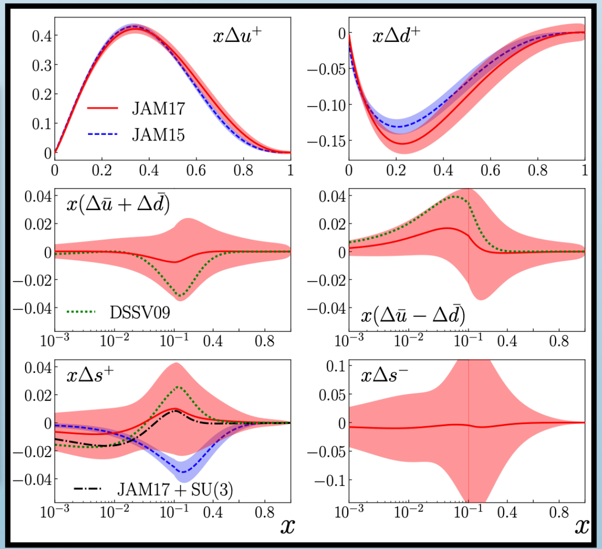
Proton spin puzzle:

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

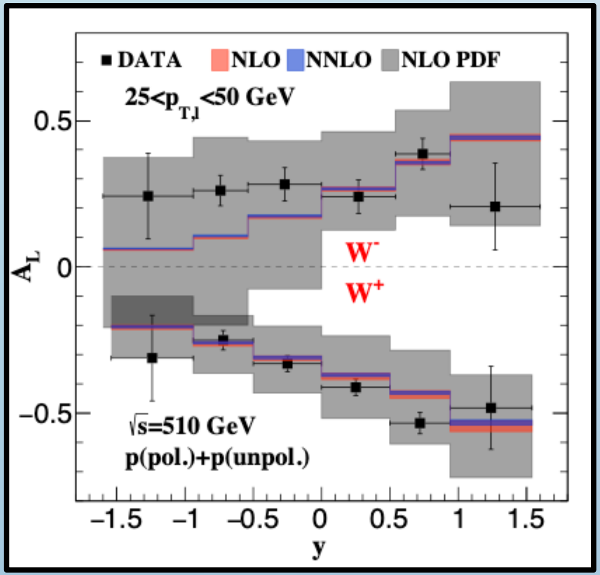


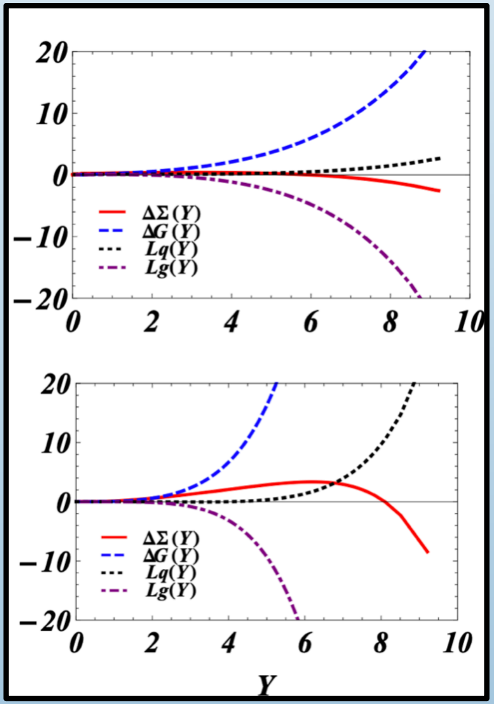


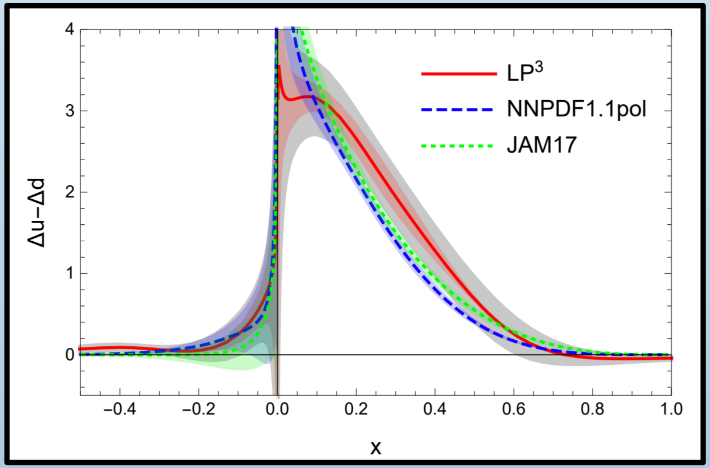
Still a lot to learn about helicity PDFs at low x and the helicity sea quark PDFs!



1. Recent Theory Highlights
2. Recent global analyses highlights
3. Opportunities at the EIC







Δg from Heavy Quarks in DIS (2021)

Differential Heavy Quark Distributions and Correlations in Longitudinally Polarized Deep-Inelastic Scattering

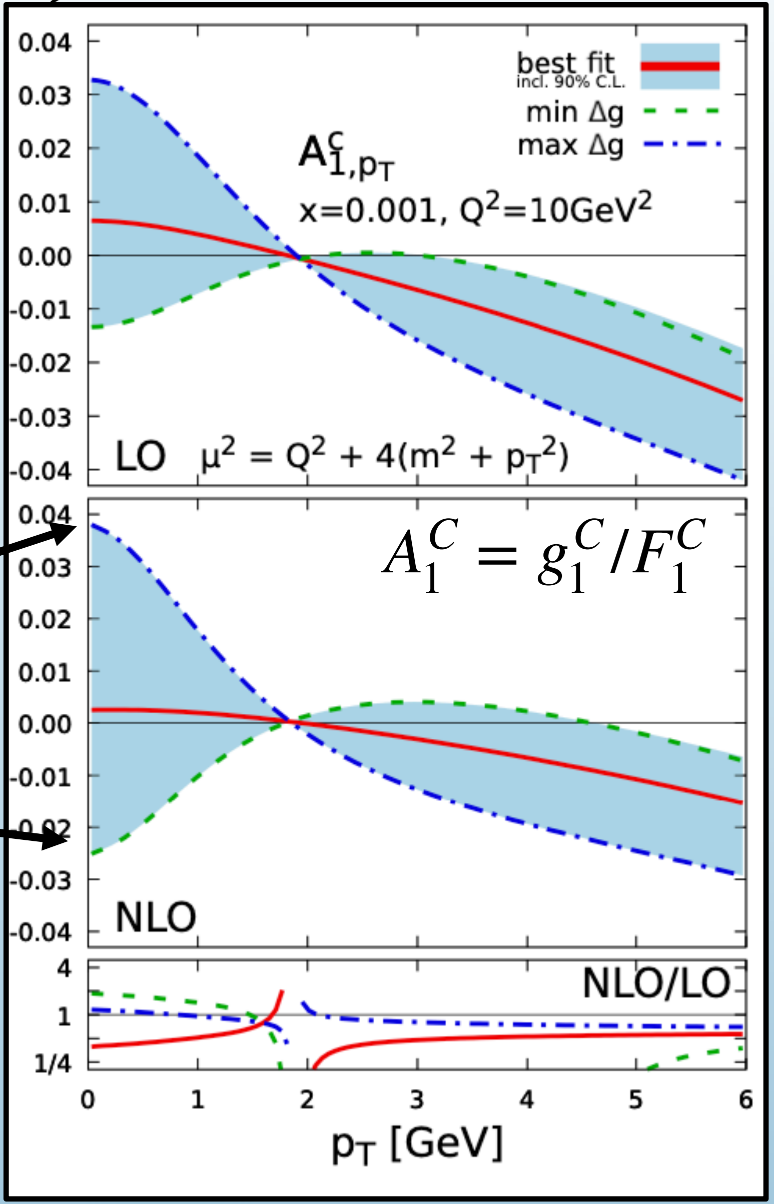
Felix Hekhorn[*]

Tif Lab, Dipartimento di Fisica, Università di Milano and INFN, Sezione di Milano, Via Celoria 16, I-20133 Milano, Italy

Marco Stratmann[†]

Institute for Theoretical Physics, University of Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

https://arxiv.org/abs/2105.13944



Strong sensitivity to Δg

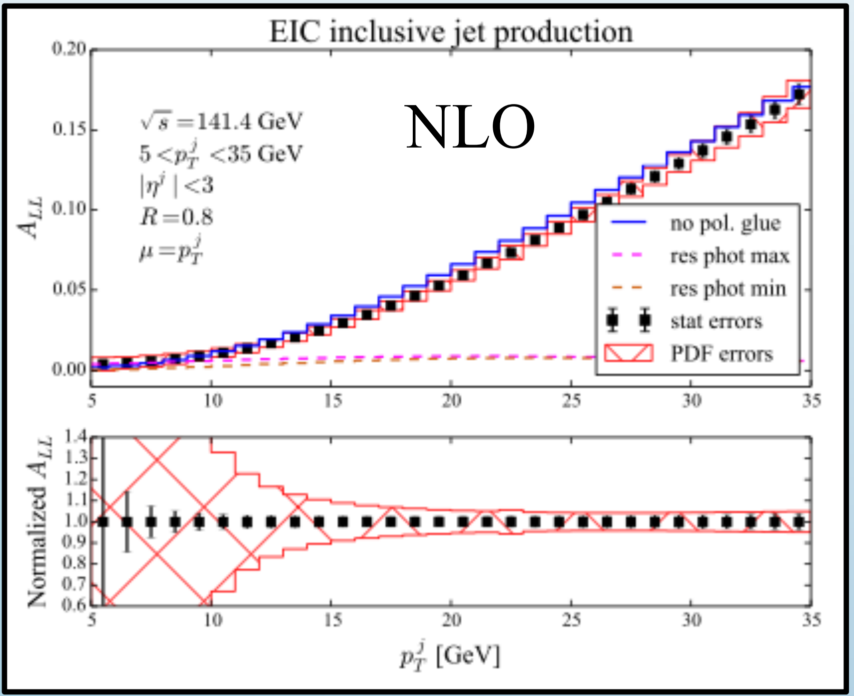
First calculation of the heavy flavor contribution to g_1^Q, performed at NLO accuracy

Jet Production in polarized DIS (2018-2021)

Inclusive jet production as a probe of polarized PDFs at a future EIC

Radja Boughezal,[1,*] Frank Petriello,[1,2,†] and Hongxi Xing[1,2,‡]

https://arxiv.org/abs/1806.07311

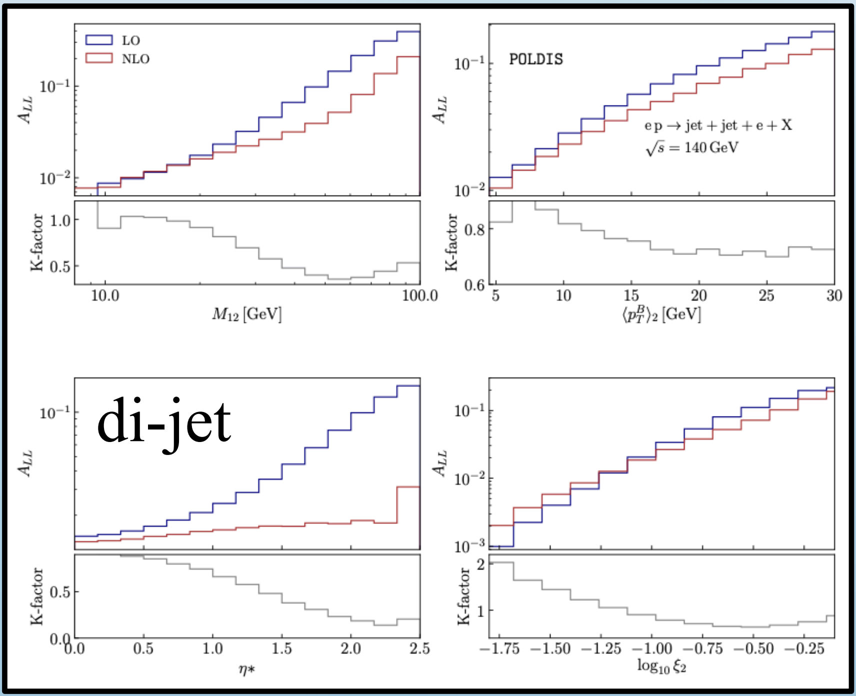


Inclusive-jet and Di-jet Production in Polarized Deep Inelastic Scattering

Ignacio Borsa*
Departamento de Física and IFIBA, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Ciudad Universitaria, Pabellón 1 (1428) Buenos Aires, Argentina

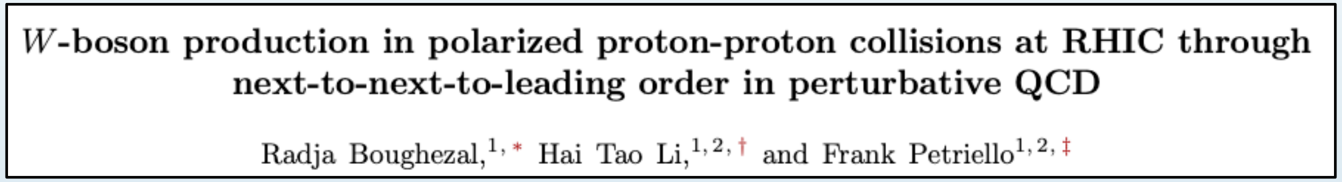
Daniel de Florian† and Iván Pedron‡
International Center for Advanced Studies (ICAS), ICIFI and ECyT-UNSAM, 25 de Mayo y Francia, (1650) Buenos Aires, Argentina

https://arxiv.org/abs/2010.07354



Provides sensitivity to both quark and gluon PDFs depending on kinematics

W Boson Production at RHIC (2021)

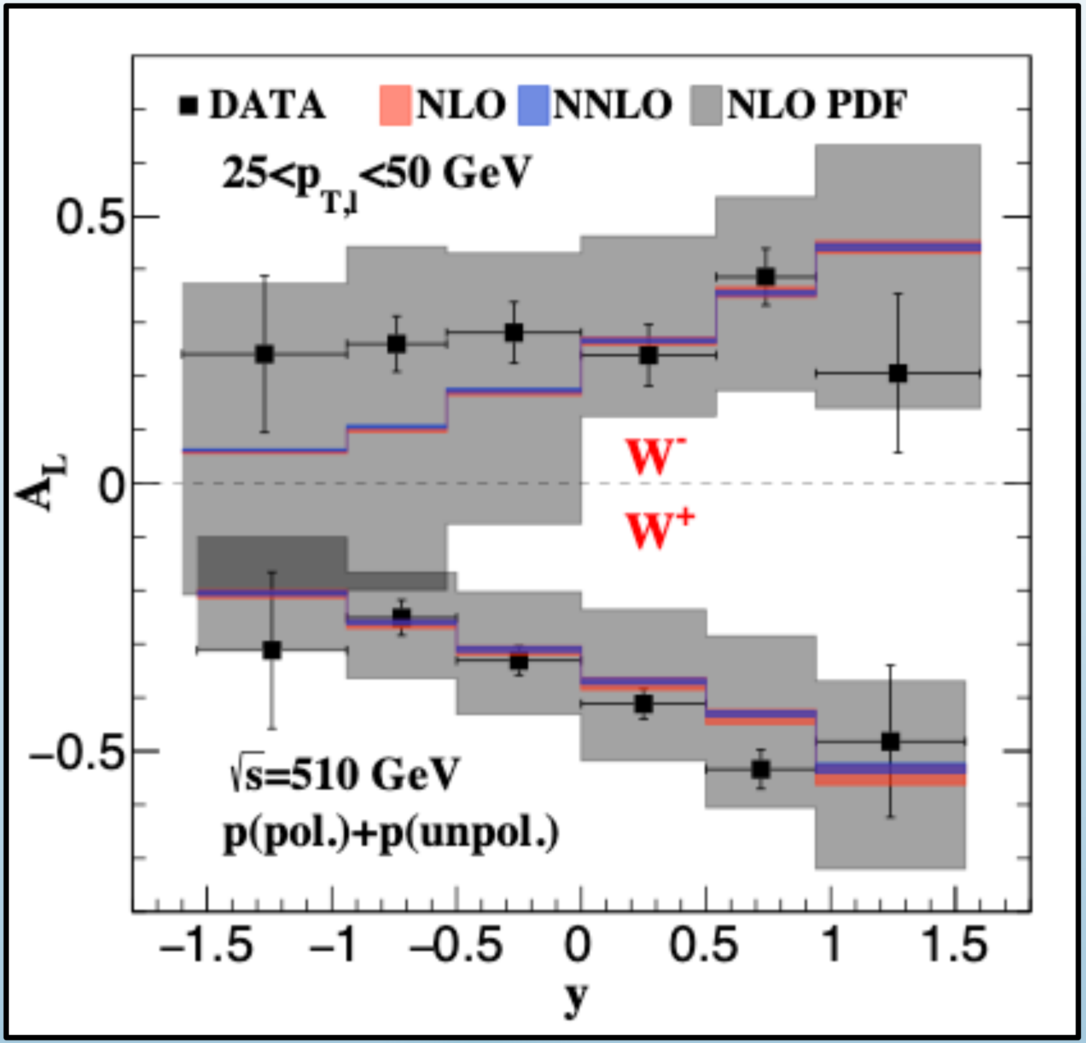

W-boson production in polarized proton-proton collisions at RHIC through next-to-next-to-leading order in perturbative QCD

Radja Boughezal,[1,*] Hai Tao Li,[1,2,†] and Frank Petriello[1,2,‡]

https://arxiv.org/abs/2101.02214

NNLO calculation for *W* production in $p\vec{p}$ collisions

Necessary to extend global helicity analyses to NNLO accuracy



Small x Helicity Evolution (2016)

Helicity Evolution at Small x: Flavor Singlet and Non-Singlet Observables

Yuri V. Kovchegov*
Department of Physics, The Ohio State University, Columbus, OH 43210, USA

Daniel Pitonyak†
Division of Science, Penn State University-Berks, Reading, PA 19610, USA and RIKEN BNL Research Center, Brookhaven National Laboratory, Upton, New York 11973, USA

Matthew D. Sievert‡
Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA and Physics Department, Brookhaven National Laboratory, Upton, NY 11973, USA

https://arxiv.org/abs/1610.06197

Could be used to predict spin structure below $x \approx 0.01$ in absence of experimental data

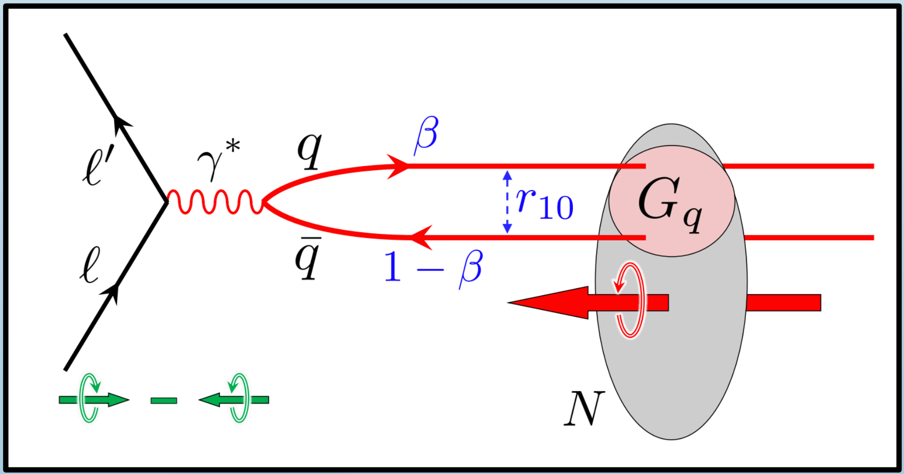
Derived small x behavior of singlet and non-singlet helicity PDFs in light-front perturbation theory

$$\Delta q(x, Q^2) \sim \left(\frac{1}{x}\right)^{\alpha_h^q}$$

$$\Delta G(x, Q^2) \sim \left(\frac{1}{x}\right)^{\alpha_h^G}$$

$$\alpha_h^q = \frac{4}{\sqrt{3}} \sqrt{\frac{\alpha_s N_c}{2\pi}} \approx 2.31 \sqrt{\frac{\alpha_s N_c}{2\pi}}$$

$$\alpha_h^G = \frac{13}{4\sqrt{3}} \sqrt{\frac{\alpha_s N_c}{2\pi}} \approx 1.88 \sqrt{\frac{\alpha_s N_c}{2\pi}}$$



Angular Momentum at Small x (2018)

On the small-x behavior of the orbital angular momentum distributions in QCD

Yoshitaka Hatta[1] and Dong-Jing Yang[2]

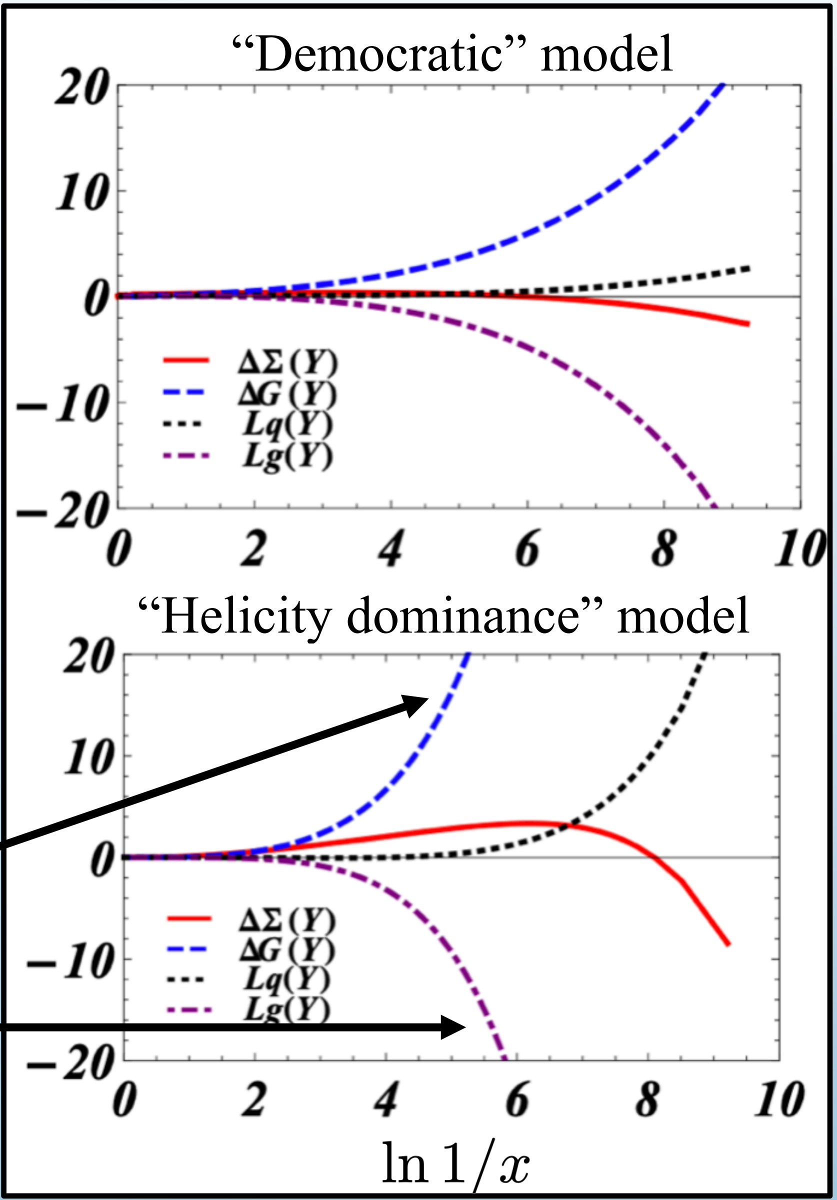
https://arxiv.org/abs/1802.02716

Examined gluon and quark orbital angular momentum at small x in two models

$$\frac{d}{d\ln Q^2}\begin{pmatrix} L_q(x) \\ L_g(x) \end{pmatrix} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{dz}{z}\begin{pmatrix} \hat{P}_{qq}(z) & \hat{P}_{qg}(z) & \Delta\hat{P}_{qq}(z) & \Delta\hat{P}_{qg}(z) \\ \hat{P}_{gq}(z) & \hat{P}_{gg}(z) & \Delta\hat{P}_{gq}(z) & \Delta\hat{P}_{gg}(z) \end{pmatrix}\begin{pmatrix} L_q(x/z) \\ L_g(x/z) \\ \Delta\Sigma(x/z) \\ \Delta G(x/z) \end{pmatrix}$$

Significant cancellation between gluon helicity and angular momentum

$$L_g(x) \approx -\Delta G(x) + \cdots$$



Moments from Lattice QCD (2020)

Complete flavor decomposition of the spin and momentum fraction of the proton using lattice QCD simulations at physical pion mass

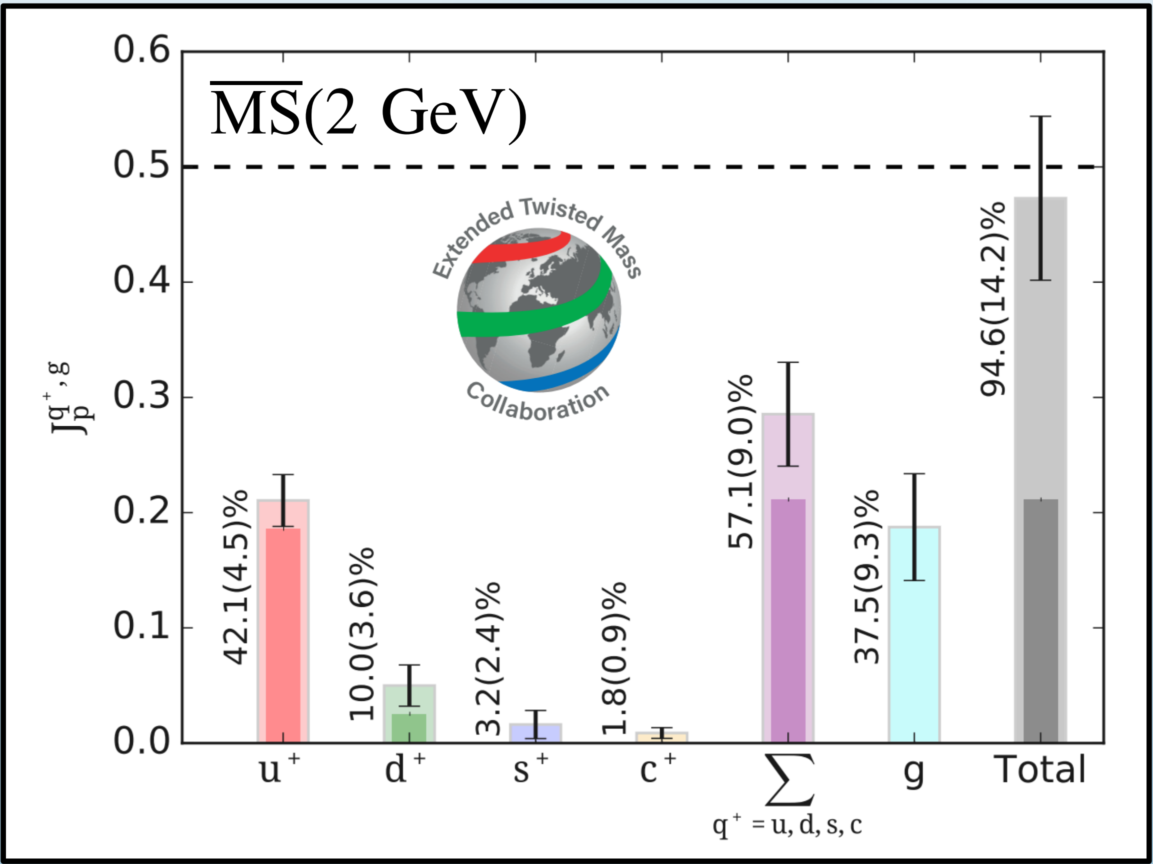
C. Alexandrou[1,2], S. Bacchio[2], M. Constantinou[3], J. Finkenrath[2], K. Hadjiyiannakou[1,2], K. Jansen[4], G. Koutsou[2], H. Panagopoulos[1], G. Spanoudes[1]
(Extended Twisted Mass Collaboration)[1]

https://arxiv.org/abs/2003.08486

$$\sum_q J_p^q + J_p^g = \frac{1}{2}$$

Calculated quark and gluon contributions to the spin of the proton

	$\langle x \rangle$	J	$\frac{1}{2}\Delta\Sigma$	L
u^+	0.359(30)	0.211(22)	0.432(8)	-0.221(26)
d^+	0.188(19)	0.050(18)	-0.213(8)	0.262(20)
s^+	0.052(12)	0.016(12)	-0.023(4)	0.039(13)
c^+	0.019(9)	0.009(5)	-0.005(2)	0.014(10)
g	0.427(92)	0.187(46)		
Tot.	1.045(118)	0.473(71)	0.191(15)	0.094(51)



Quasi-PDFs from Lattice QCD (2019-2021)

Flavor decomposition of the nucleon unpolarized, helicity and transversity parton distribution functions from lattice QCD simulations

Constantia Alexandrou,[1,2] Martha Constantinou,[3]
Kyriakos Hadjiyiannakou,[1,2] Karl Jansen,[4] and Floriano Manigrasso[1,5,6]

https://arxiv.org/abs/2106.16065

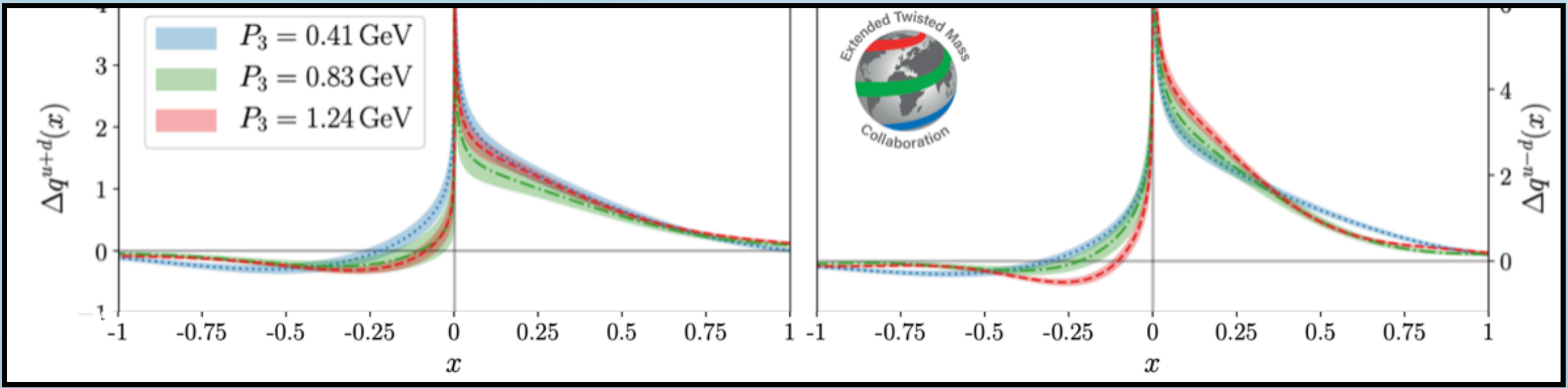
Proton Isovector Helicity Distribution on the Lattice at Physical Pion Mass
(LP^3 Collaboration)

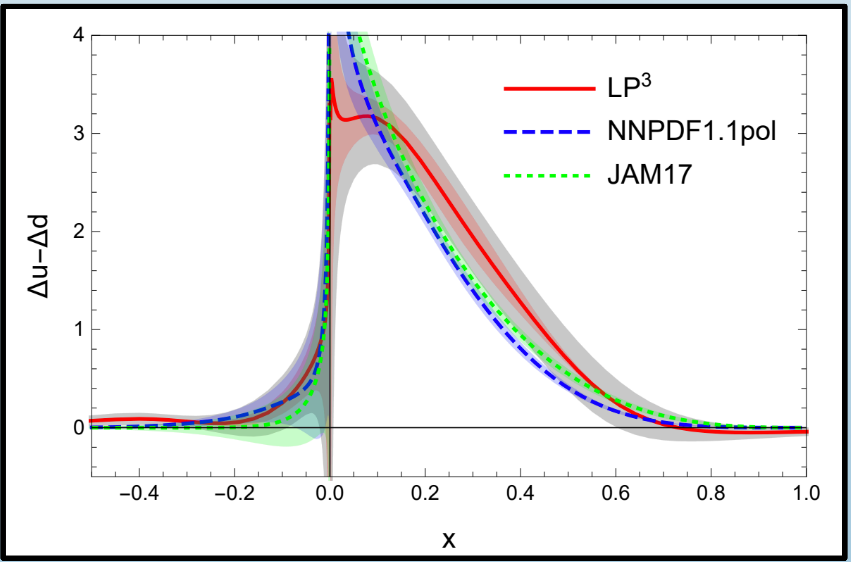
Huey-Wen Lin,[1,2] Jiunn-Wei Chen,[3,4] Xiangdong Ji,[5,6] Luchang Jin,[7,8] Ruizi Li,[1] Yu-Sheng Liu,[9,*] Yi-Bo Yang,[1,10,†] Jian-Hui Zhang,[11] and Yong Zhao[4]

https://arxiv.org/abs/1807.07431

Quasi-PDF approach allows calculation of isovector distributions

$$\Delta q(-x) = \Delta \bar{q}(x)$$





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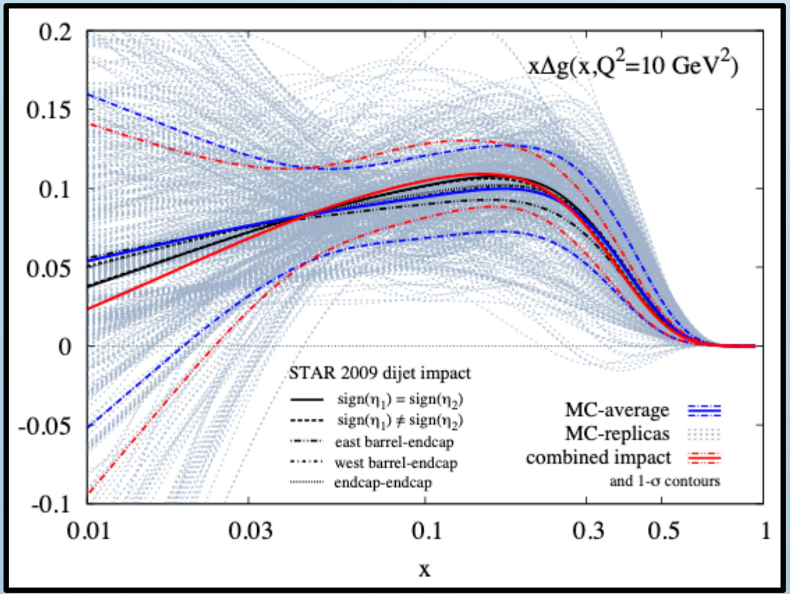
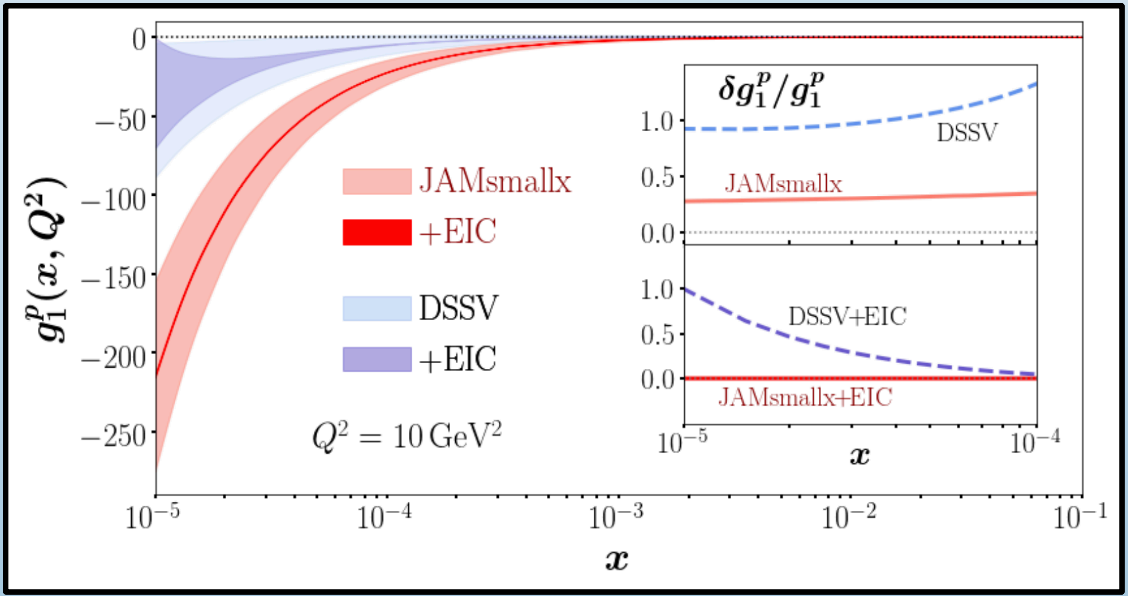
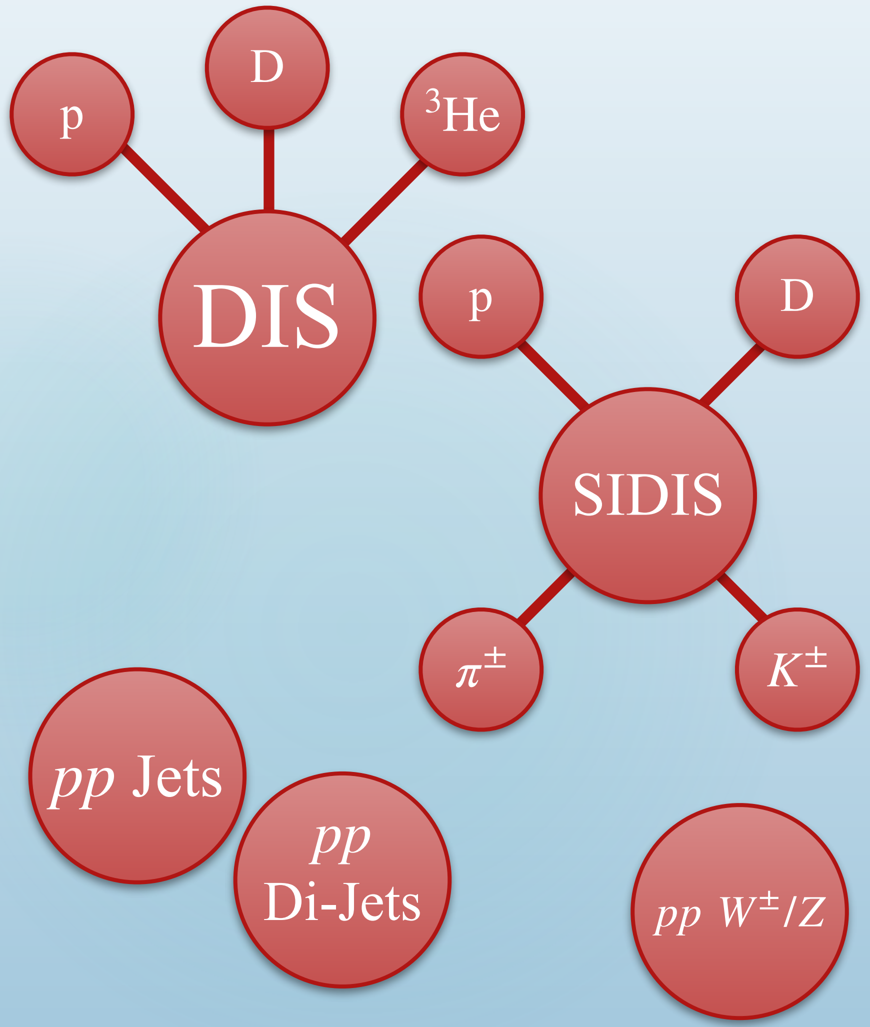


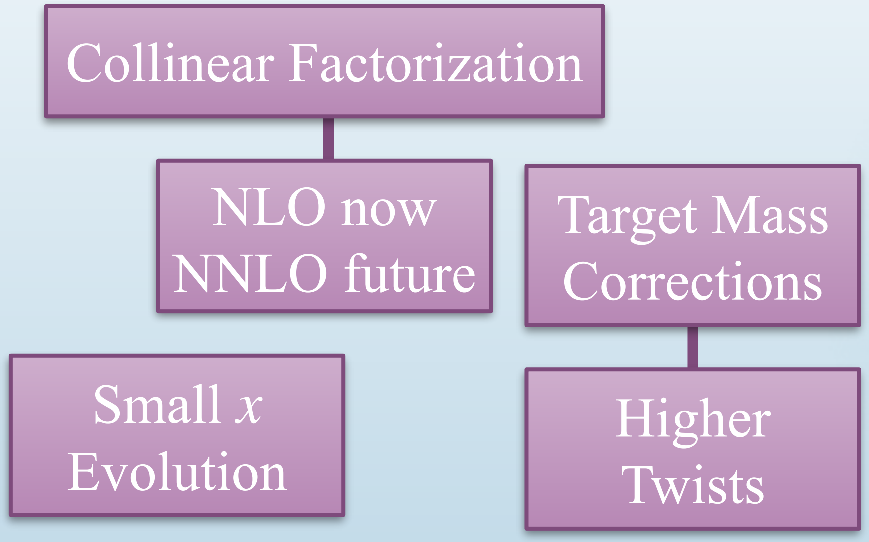


Current State of Helicity PDF Global Analyses

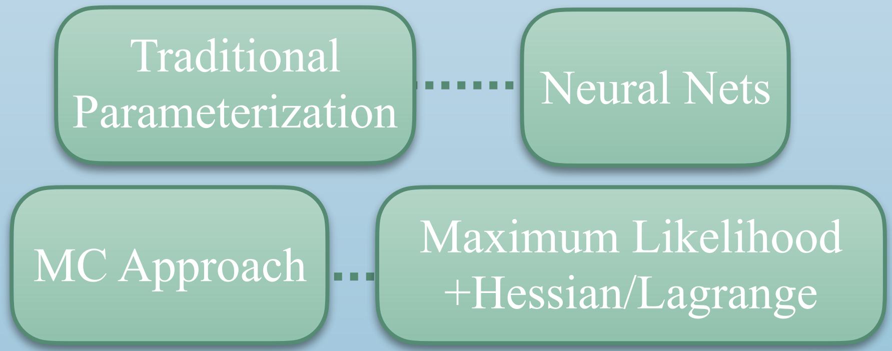
Data space



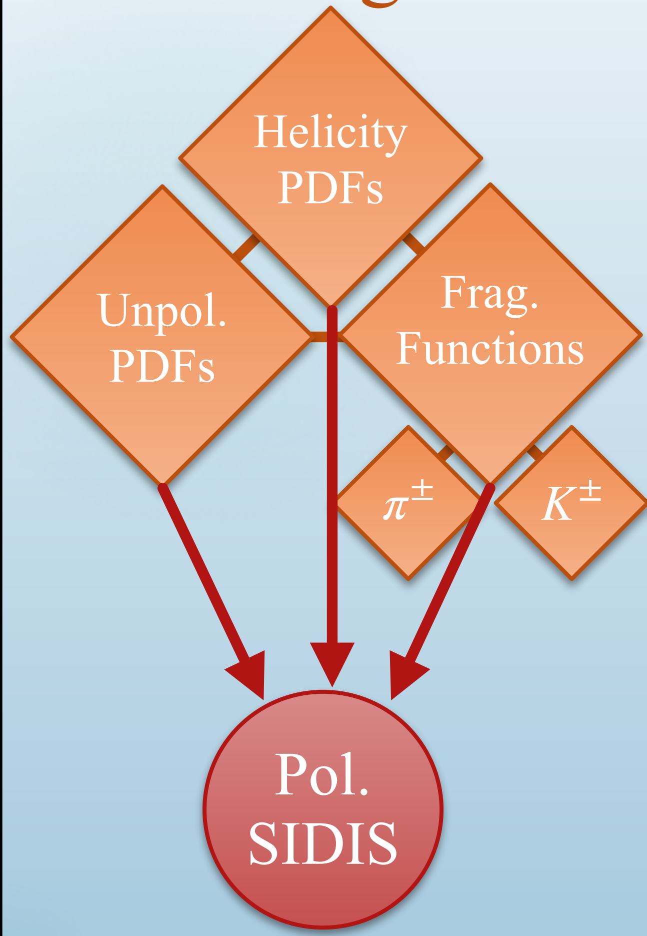
Theory



Methodology



Simultaneous Paradigm



Impact of COMPASS DIS data (2018)

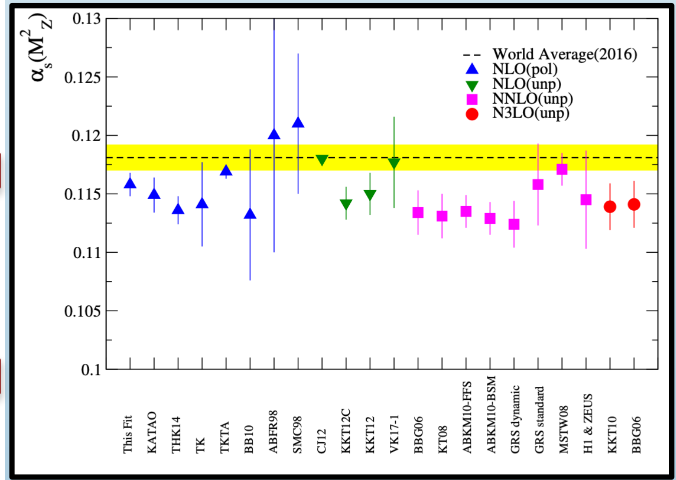
Impact of recent COMPASS data on polarized parton distributions and structure functions

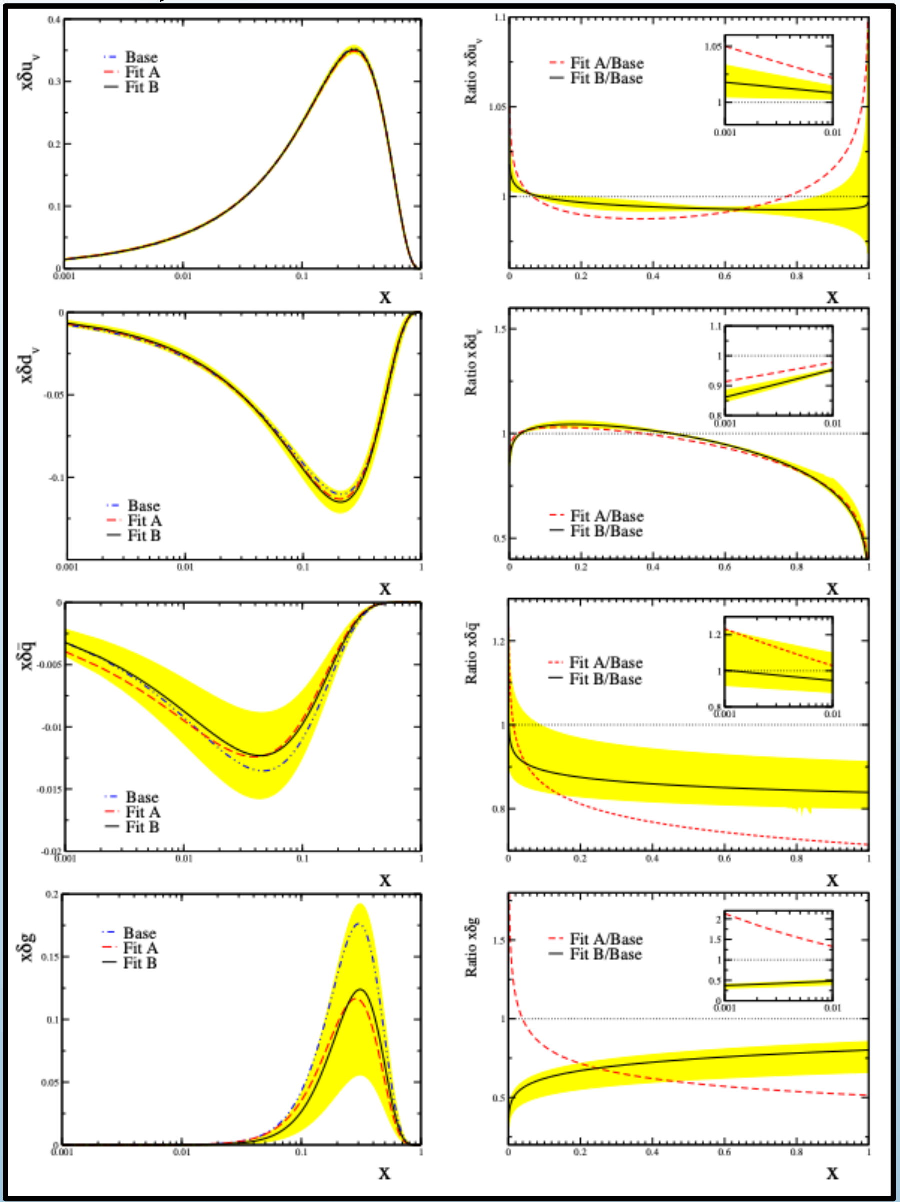
M. Salimi-Amiri,[*] A. Khorramian,[†] and H. Abdolmaleki[‡]
Faculty of Physics, Semnan University, 35131-19111, Semnan, Iran

F. I. Olness
Department of Physics, Southern Methodist University, Dallas, TX 75275-0175, USA[§]

https://arxiv.org/abs/1805.02613

Experiment	Reference	Data Type	# data points	x–Range	Q^2–Range (GeV^2)	$\mathcal{K}_i$
HERMES	[52, 53]	DIS (g_1^p)	39	0.028-0.66	1.01-7.36	1.000
HERMES06	[51]	DIS (g_1^p)	51	0.026-0.731	1.12-14.29	0.999
SLAC/E143	[57]	DIS (g_1^p)	28	0.031-0.749	1.27-9.52	0.999
SLAC/E155	[60]	DIS (g_1^p)	24	0.015-0.750	1.22-34.72	1.023
SMC	[62]	DIS (g_1^p)	12	0.005-0.480	1.30-58.0	1.000
EMC	[61]	DIS (g_1^p)	10	0.015-0.466	3.50-29.5	1.011
COMPASS10	[63]	DIS (g_1^p)	15	0.005-0.568	1.10-62.10	0.993
COMPASS16	[68]	DIS (g_1^p)	51	0.0035-0.575	1.03-96.1	1.000
Proton			**230**			
HERMES06	[51]	DIS (g_1^d)	51	0.026-0.731	1.12-14.29	0.997
SLAC/E143	[57]	DIS (g_1^d)	28	0.031-0.749	1.27-9.52	0.998
SLAC/E155	[58, 59]	DIS (g_1^d)	24	0.015-0.750	1.22-34.79	0.999
SMC	[62]	DIS (g_1^d)	12	0.005-0.479	1.30-54.80	0.999
COMPASS17	[69]	DIS (g_1^d)	43	0.0045-0.569	1.03-74.1	1.001
Deuteron			**158**			
HERMES	[52, 53]	DIS (g_1^n)	9	0.033-0.464	1.22-5.25	0.999
HERMES06	[51]	DIS (g_1^n)	51	0.026-0.731	1.12-14.29	1.000
SLAC/E142	[54]	DIS (g_1^n)	8	0.035-0.466	1.10-5.50	0.999
SLAC/E154	[56]	DIS (g_1^n)	17	0.017-0.564	1.20-15.00	0.999
Neutron			**85**			
Total			**473**			





Impact of STAR Di-Jet Data (2019)

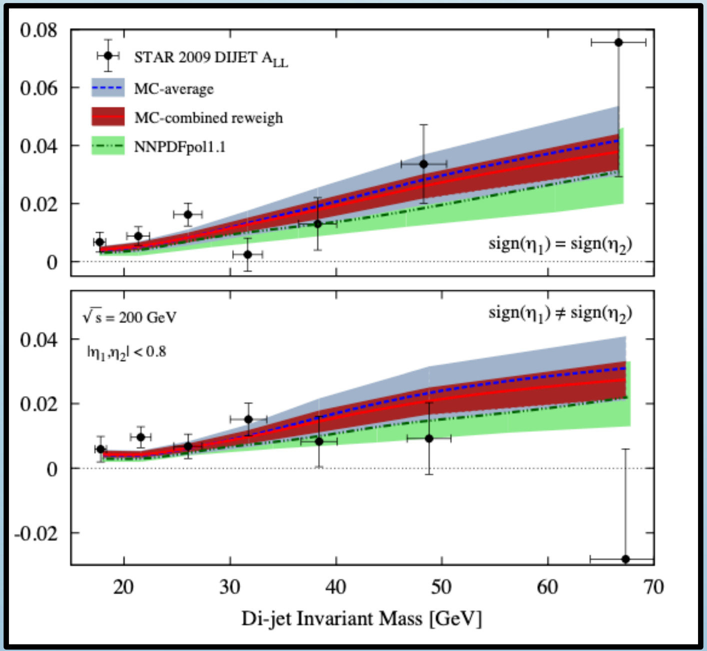
Monte Carlo sampling variant of the DSSV14 set of helicity parton densities

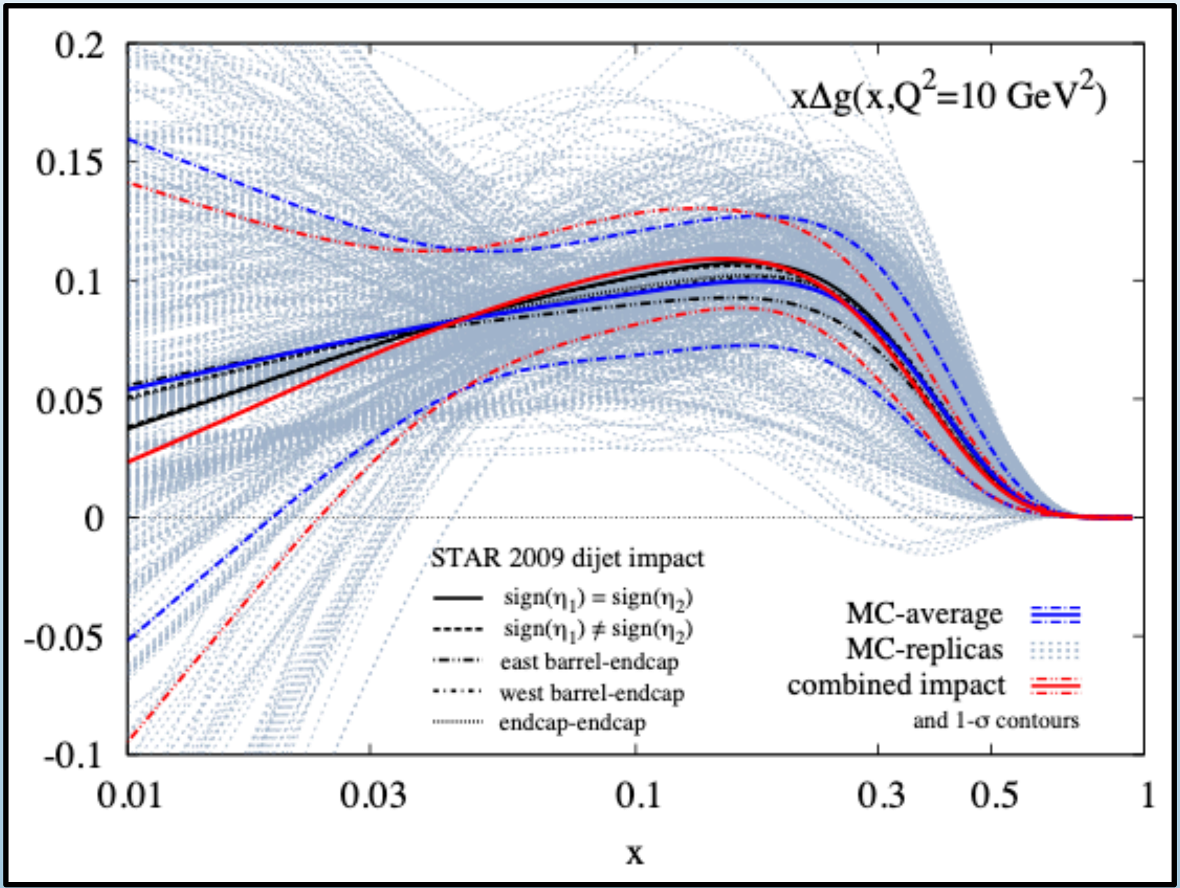
Daniel de Florian*
International Center for Advanced Studies (ICAS), UNSAM, Campus Miguelete, 25 de Mayo y Francia (1650) Buenos Aires, Argentina

Gonzalo Agustín Lucero† and Rodolfo Sassot‡
Departamento de Física and IFIBA, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Ciudad Universitaria, Pabellón 1 (1428) Buenos Aires, Argentina

Marco Stratmann§ and Werner Vogelsang¶
Institute for Theoretical Physics, University of Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

https://arxiv.org/abs/1902.10548



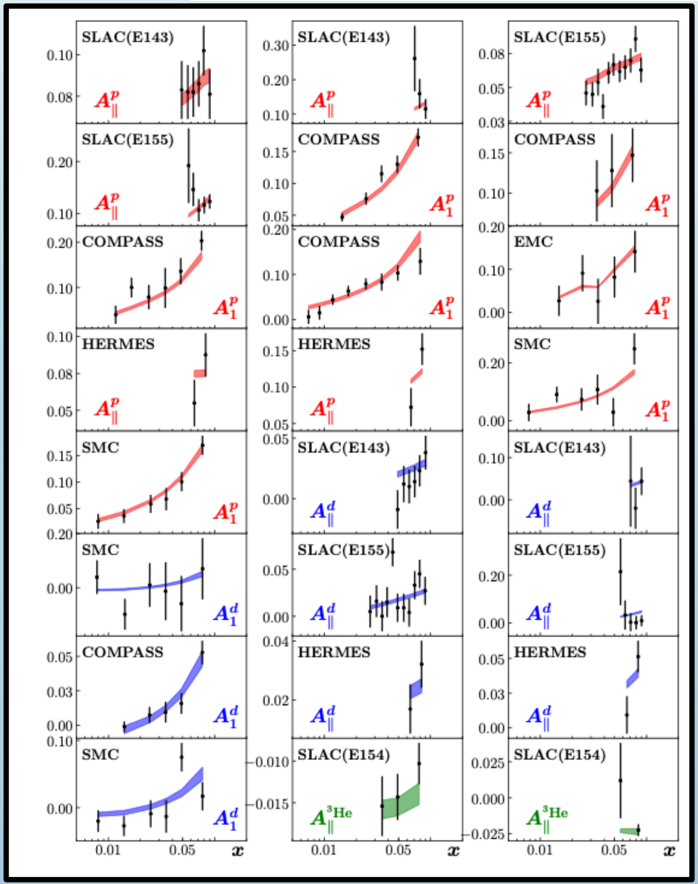


Small x Global Analysis (2021)

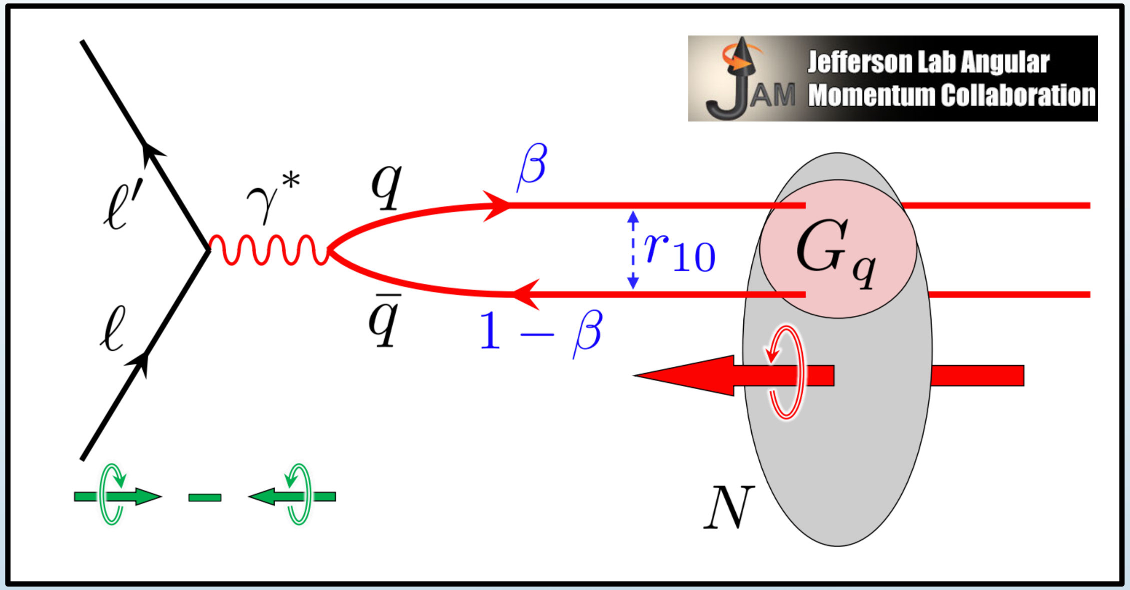
First analysis of world polarized DIS data with small-x helicity evolution

Daniel Adamiak,[1,*] Yuri V. Kovchegov,[1,†] W. Melnitchouk,[2]
Daniel Pitonyak,[3,‡] Nobuo Sato,[2,§] and Matthew D. Sievert[4,¶]

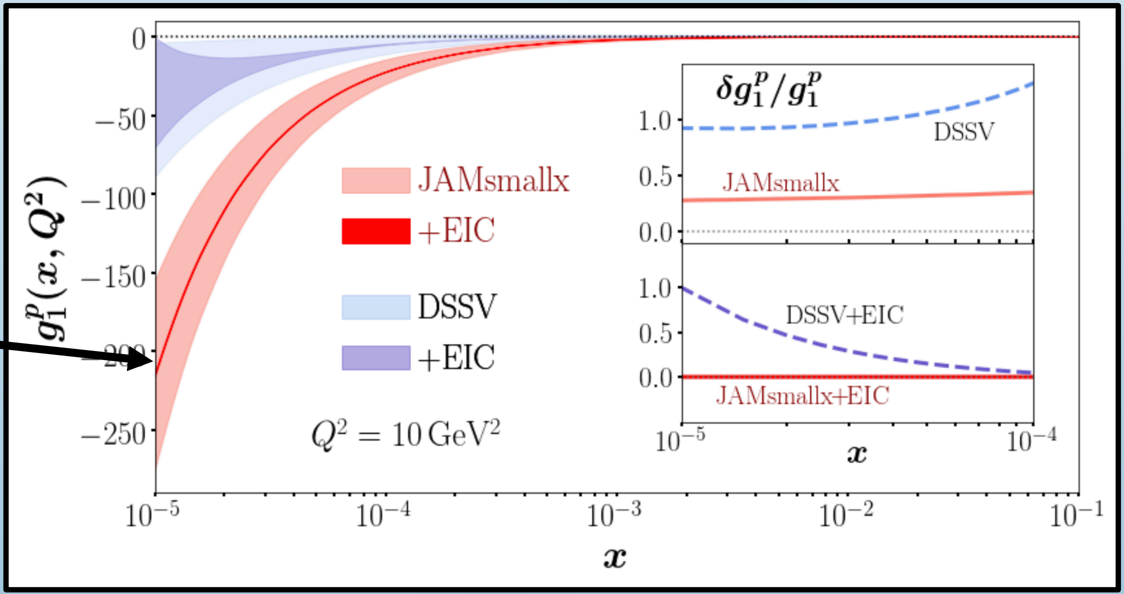
https://arxiv.org/abs/2102.06159



$x < 0.1$



Prediction, not extrapolation!



Combining Experiment with Lattice (2020)

Confronting lattice parton distributions with global QCD analysis

J. Bringewatt

Department of Physics, University of Maryland, College Park, Maryland 20742, USA

N. Sato, W. Melnitchouk, and Jian-Wei Qiu

Jefferson Lab, Newport News, Virginia 23606, USA

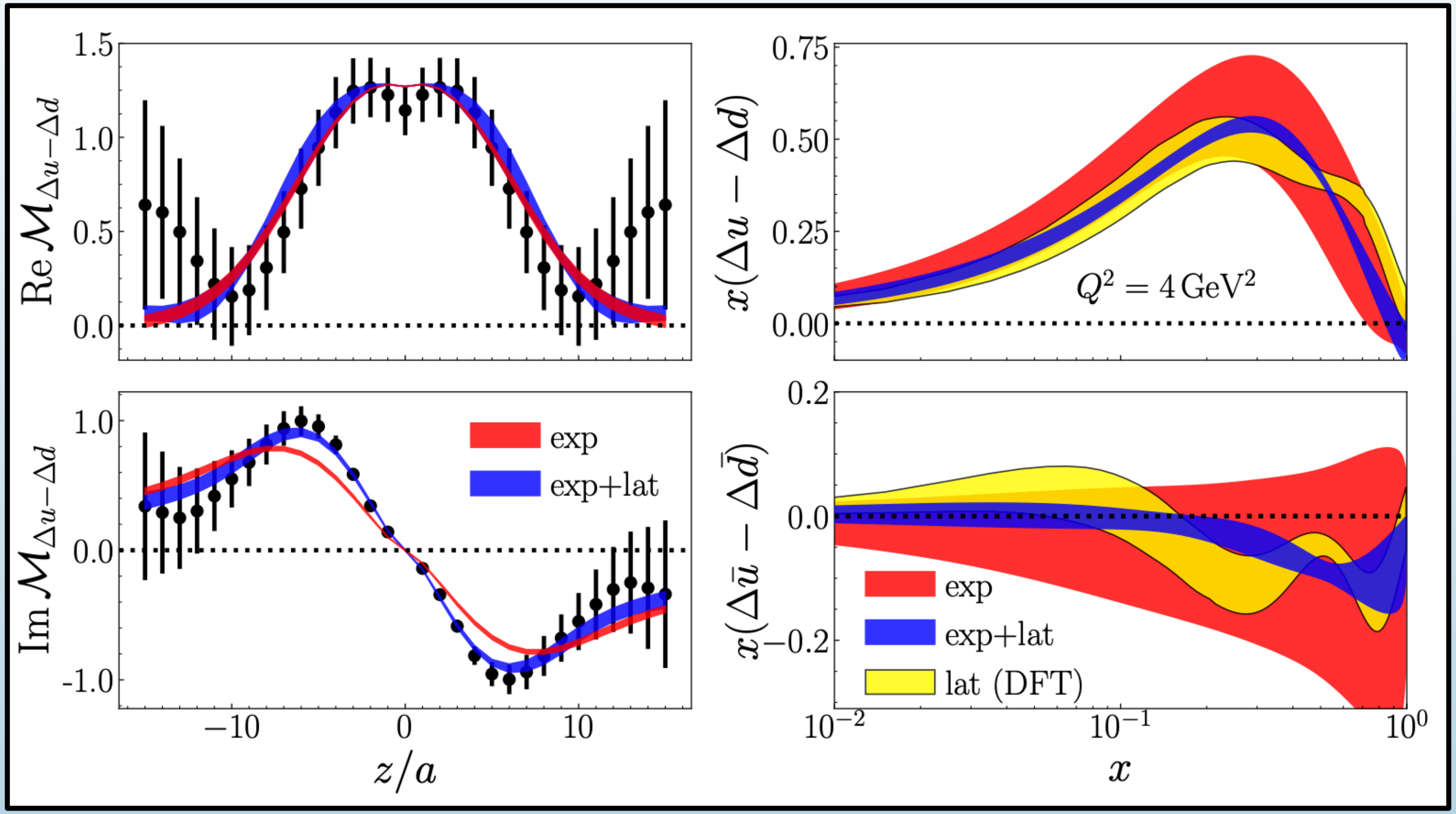
F. Steffens

Institüt für Strahlen- und Kernphysik, Universität Bonn, 53115 Bonn, Germany

M. Constantinou

Department of Physics, Temple University, Philadelphia, Pennsylvania 19122, USA

https://arxiv.org/abs/2010.00548



Combining experiment and lattice in a global QCD analysis is feasible!

Gluon Polarization (2021)

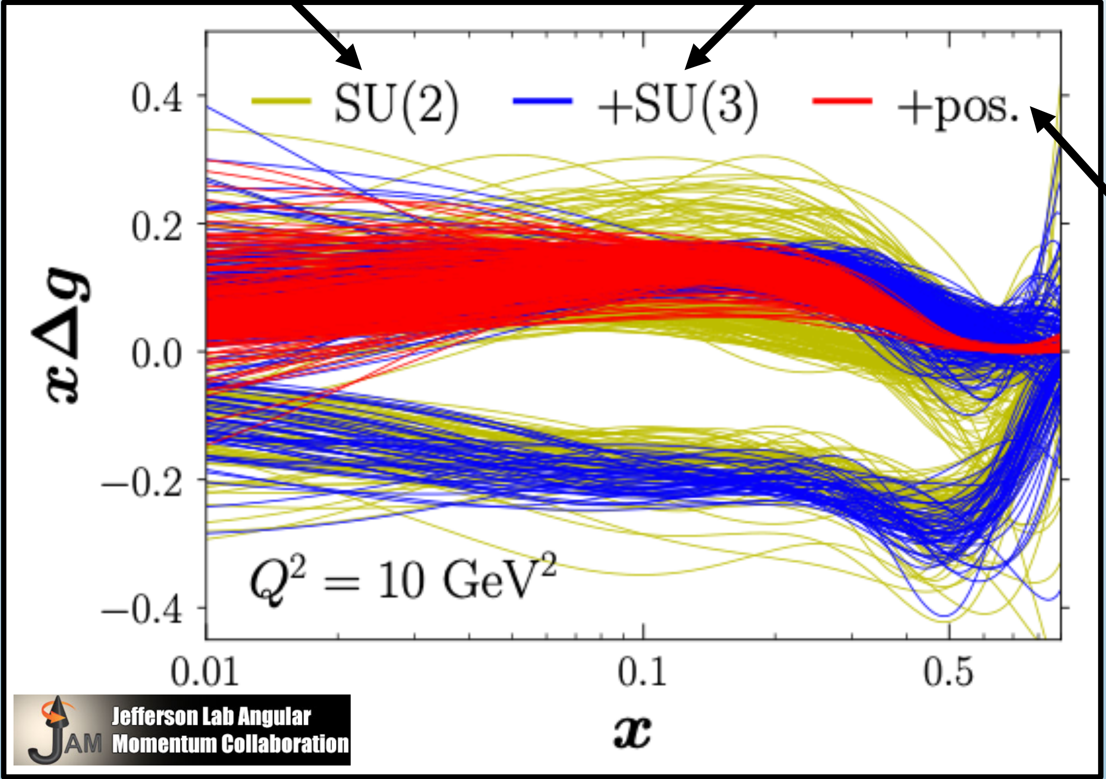
PRELIMINARY

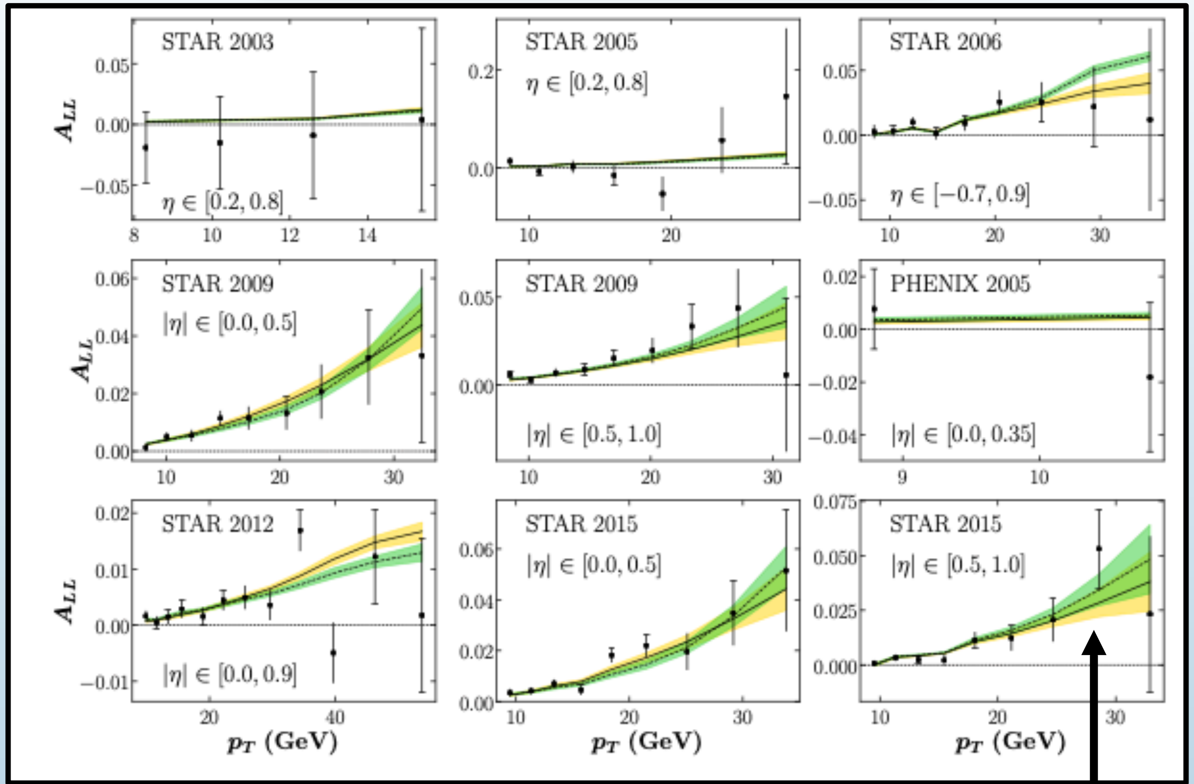
How well do we know the gluon polarization in the proton?

Y. Zhou,[1,2,*] N. Sato,[2] and W. Melnitchouk[2]

$$\int_0^1 dx\,[\Delta u^+ - \Delta d^+] = g_A$$

$$\int_0^1 dx\,[\Delta u^+ + \Delta d^+ - 2\Delta s^+] = a_8$$





$$|\Delta f(x, Q^2)| < f(x, Q^2)$$

Positive

Negative

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

Alessandro Candido, Stefano Forte and Felix Hekhorn

https://arxiv.org/abs/2006.07377

Helicity Sea Asymmetry (2021)

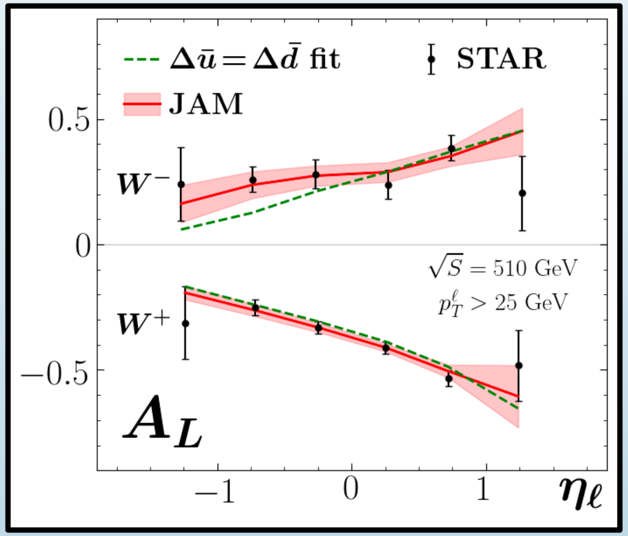
First Extraction of Polarized Sea Asymmetry from Weak Boson Production in Proton-Proton Collisions

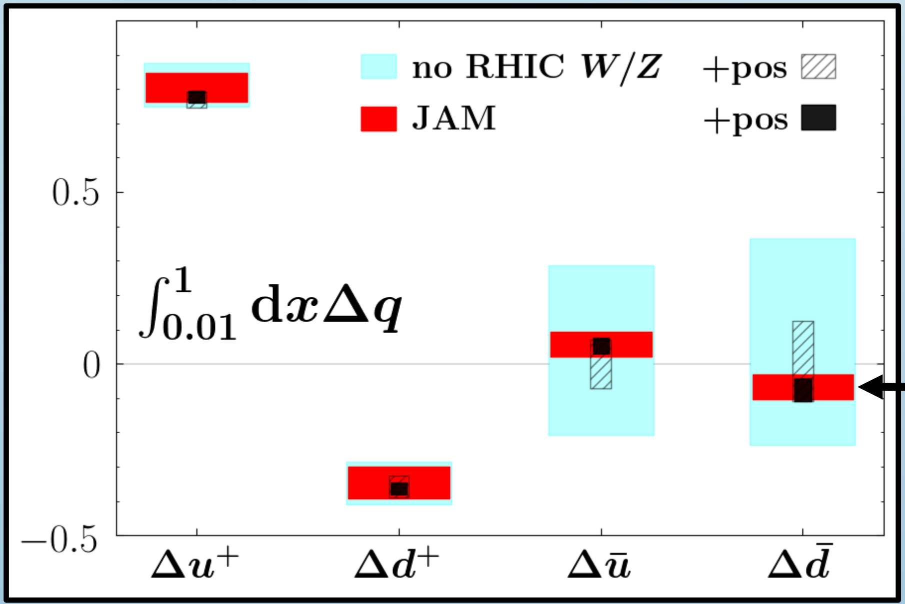
C. Cocuzza,[1] W. Melnitchouk,[2] A. Metz,[1] and N. Sato[2]

PRELIMINARY

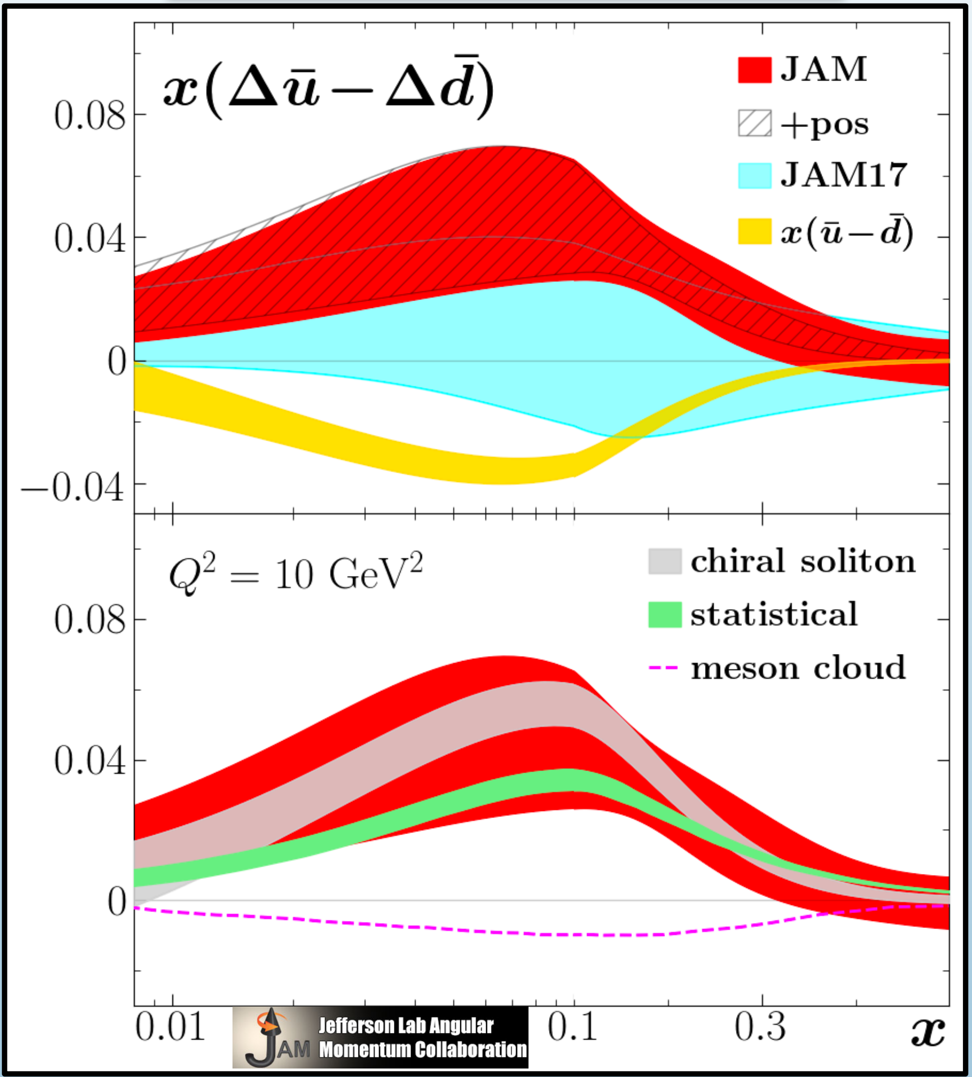
$$A_L^{W^+}(y_W) \propto \frac{\Delta\bar{d}(x_1)u(x_2) - \Delta u(x_1)\bar{d}(x_2)}{\bar{d}(x_1)u(x_2) + u(x_1)\bar{d}(x_2)}$$

$$A_L^{W^-}(y_W) \propto \frac{\Delta\bar{u}(x_1)d(x_2) - \Delta d(x_1)\bar{u}(x_2)}{\bar{u}(x_1)d(x_2) + d(x_1)\bar{u}(x_2)}$$





Impact of RHIC data



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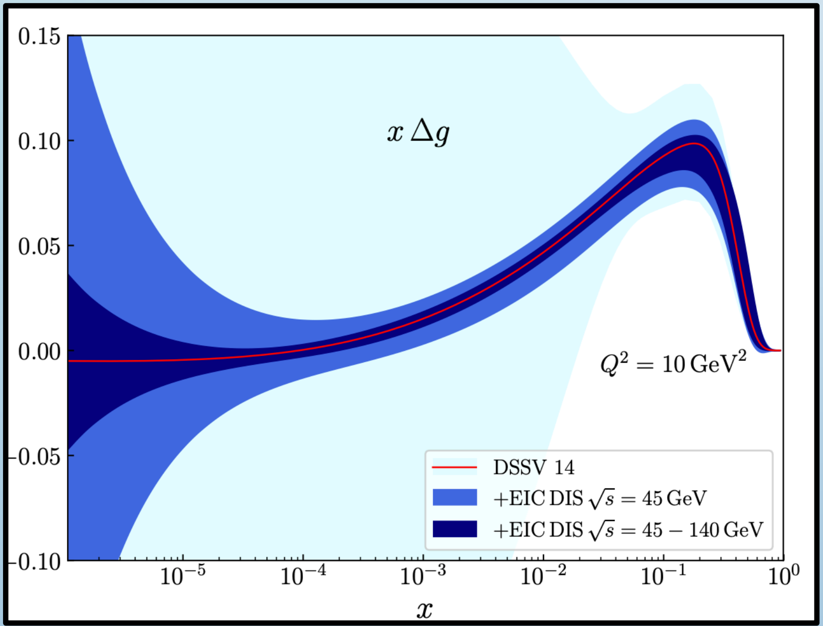
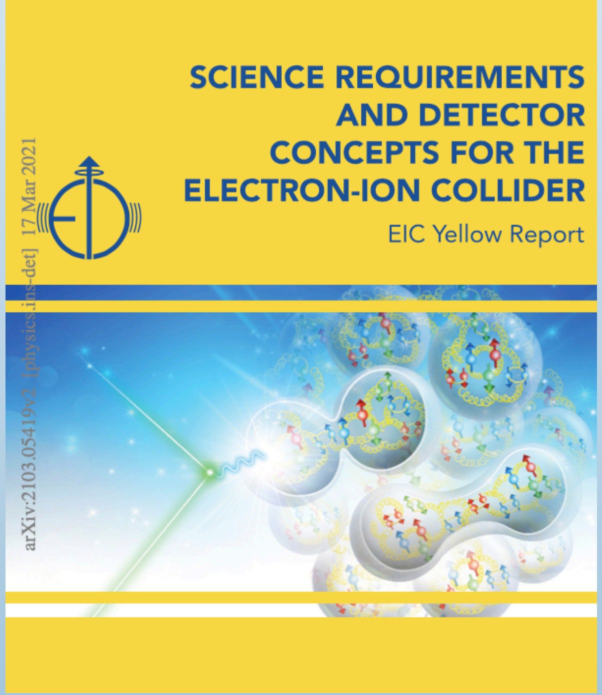
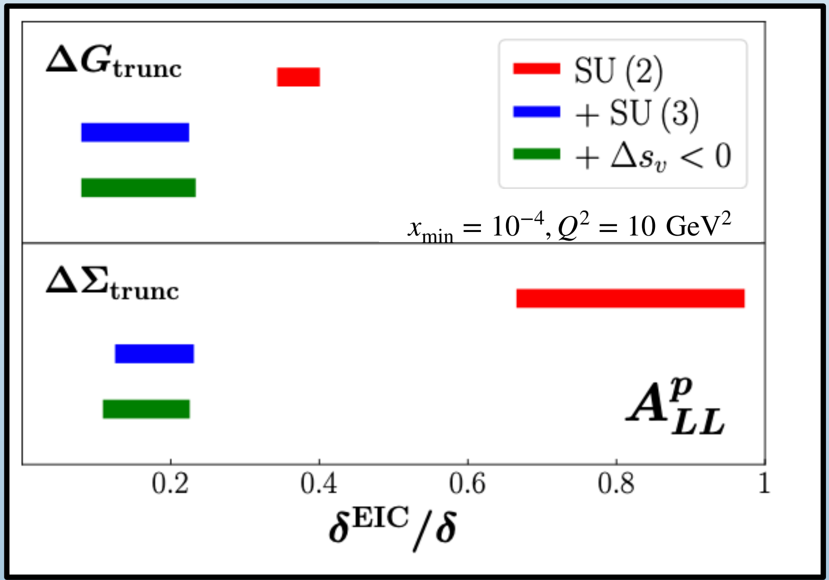






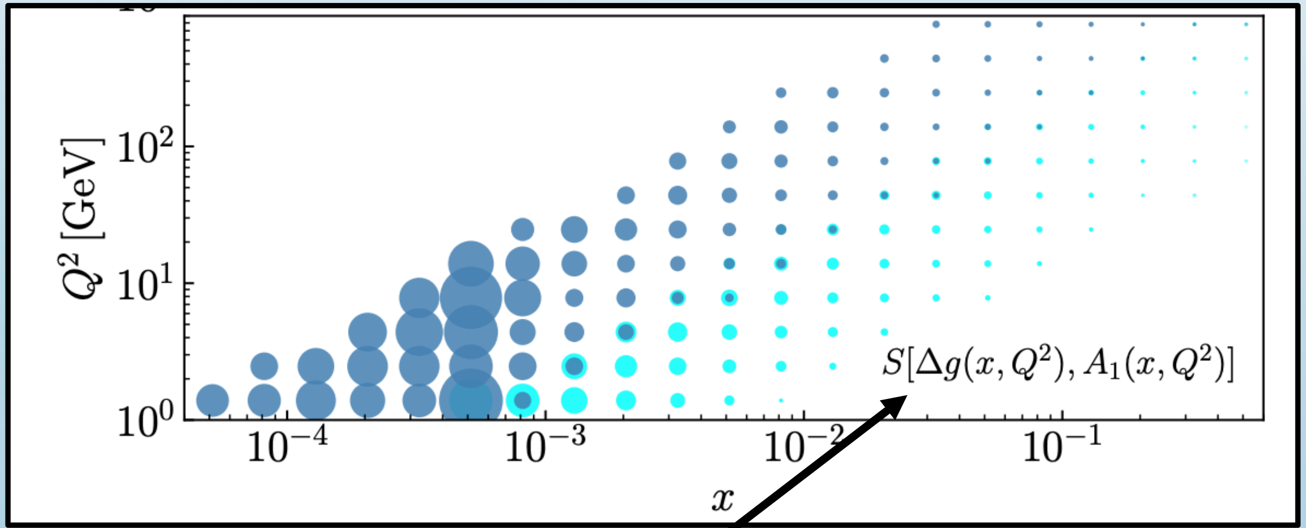
Impact of A_1 from EIC on Δg (2020)

Revisiting Helicity Parton Distributions at a Future Electron-Ion Collider

Ignacio Borsa,* Gonzalo Lucero,† and Rodolfo Sassot‡
Departamento de Física and IFIBA, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Ciudad Universitaria, Pabellón 1 (1428) Buenos Aires, Argentina

Elke C. Aschenauer§ and Ana S. Nunes¶
Physics Department, Brookhaven National Laboratory, Upton, NY 11973, USA

https://arxiv.org/abs/2007.08300

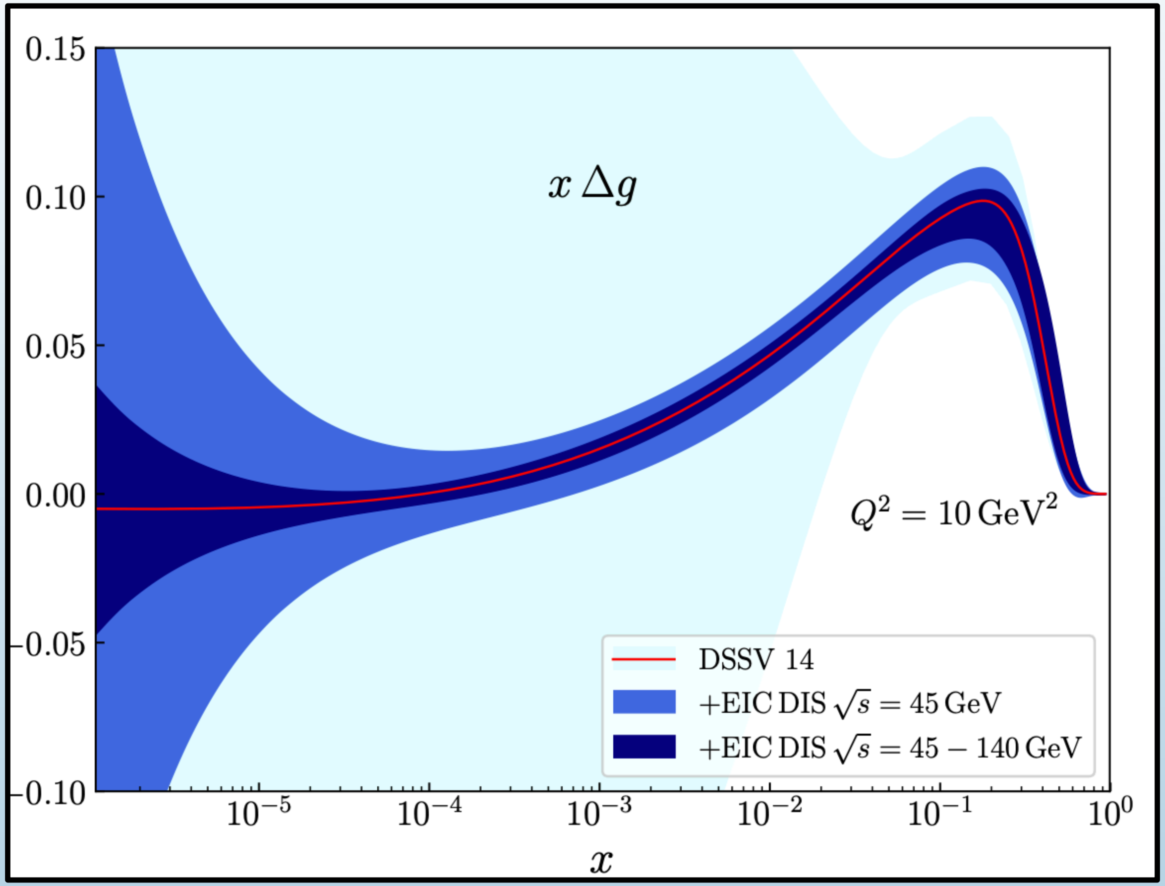


$$S[f_i,\mathcal{O}] = \frac{\langle \mathcal{O}\cdot f_i\rangle - \langle \mathcal{O}\rangle\langle f_i\rangle}{\xi\,\Delta\mathcal{O}\Delta f_i}$$

$$\xi \equiv \frac{\delta\mathcal{O}}{\Delta\mathcal{O}}$$

Experimental

Theoretical



Large impact on Δg predicted, especially below $x \approx 0.01$

Extrapolation and Theory Assumptions (2021)

Revisiting quark and gluon polarization in the proton at the EIC

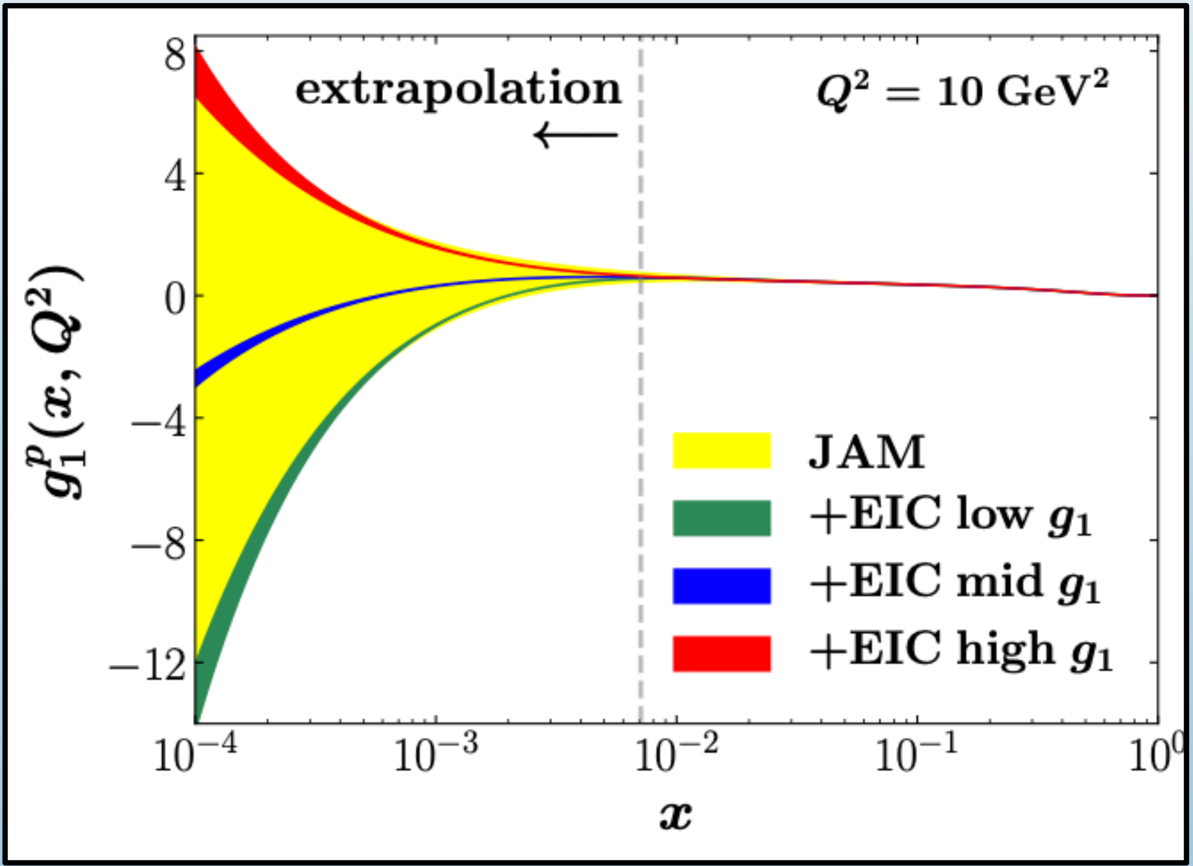
Y. Zhou,[1] C. Cocuzza,[2] F. Delcarro,[3] W. Melnitchouk,[3] A. Metz,[2] and N. Sato[3]

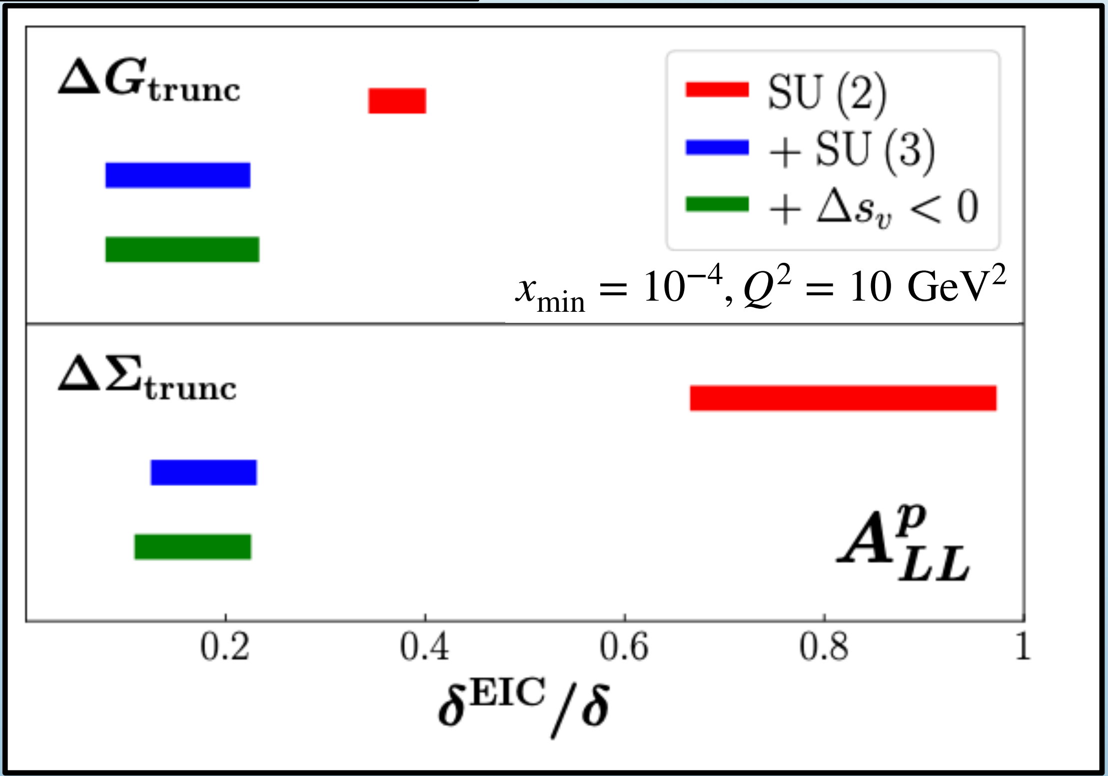
https://arxiv.org/abs/2105.04434

scenario	extrapolation	SU(2)	SU(3)
1	low	✓	
2	mid	✓	
3	high	✓	
4	low	✓	✓
5	mid	✓	✓
6	high	✓	✓

$$\Delta G_{\rm trunc}(Q^2) \equiv \int_{x_{\rm min}}^{1} dx\, \Delta g(x, Q^2),$$

$$\Delta\Sigma_{\rm trunc}(Q^2) \equiv \int_{x_{\rm min}}^{1} dx \sum_q \Delta q^+(x, Q^2)$$

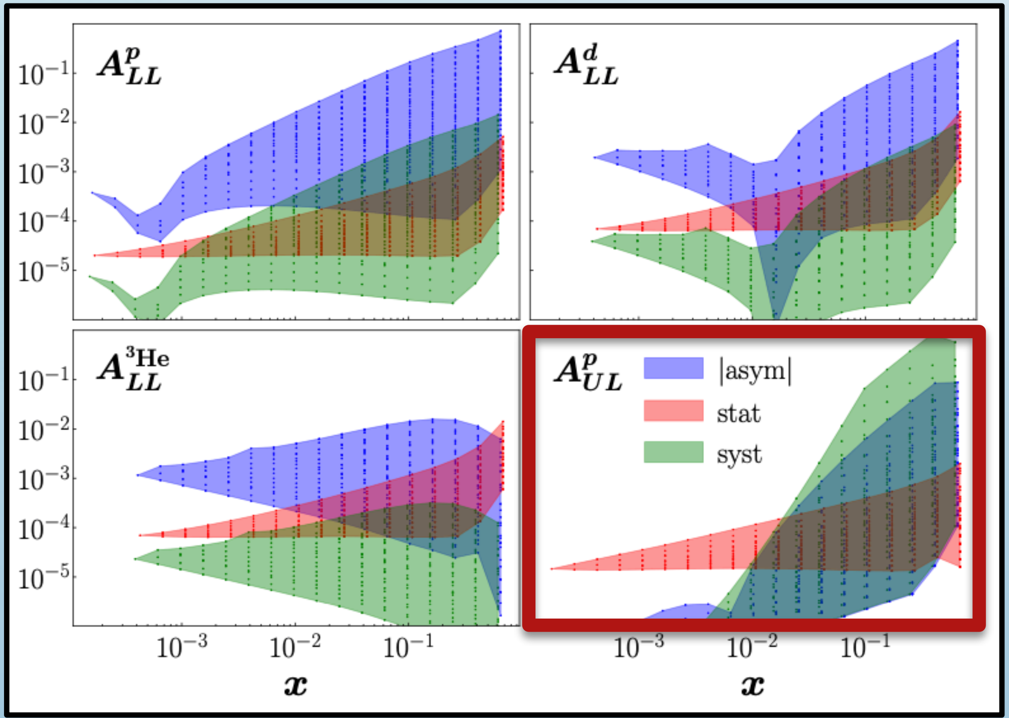


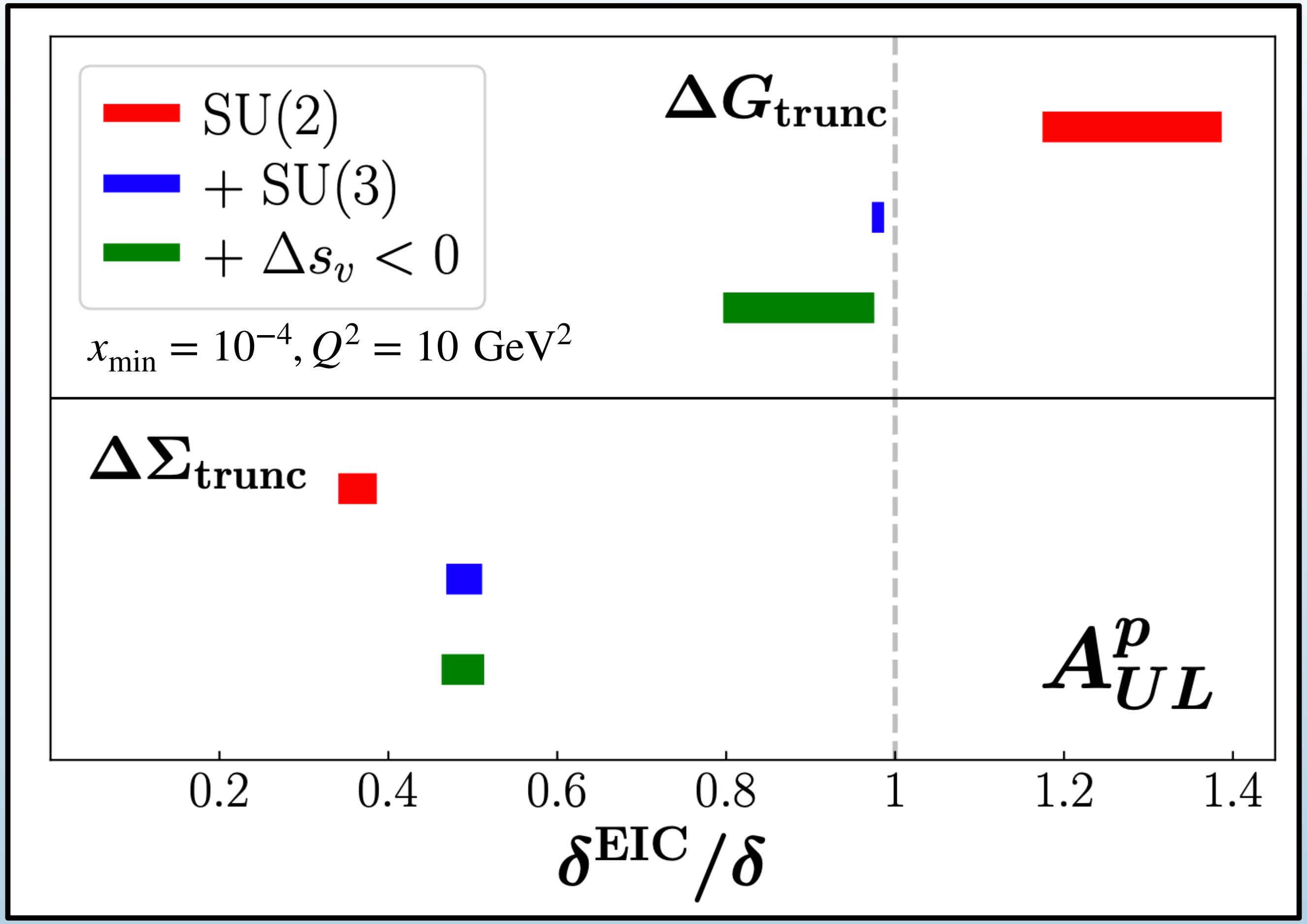


Impact of Parity Violating DIS (2021)

$$g_1^{\gamma Z} \approx \frac{1}{9}(\Delta u^+ + \Delta d^+ + \Delta s^+)$$

$$A_{UL} = \frac{G_F x Q^2}{2\sqrt{2}\pi\alpha}\left(\frac{g_A^e Y_- g_1^{\gamma Z} + g_V^e Y_+ g_5^{\gamma Z}}{xy^2 F_1 + (1-y)F_2}\right)$$





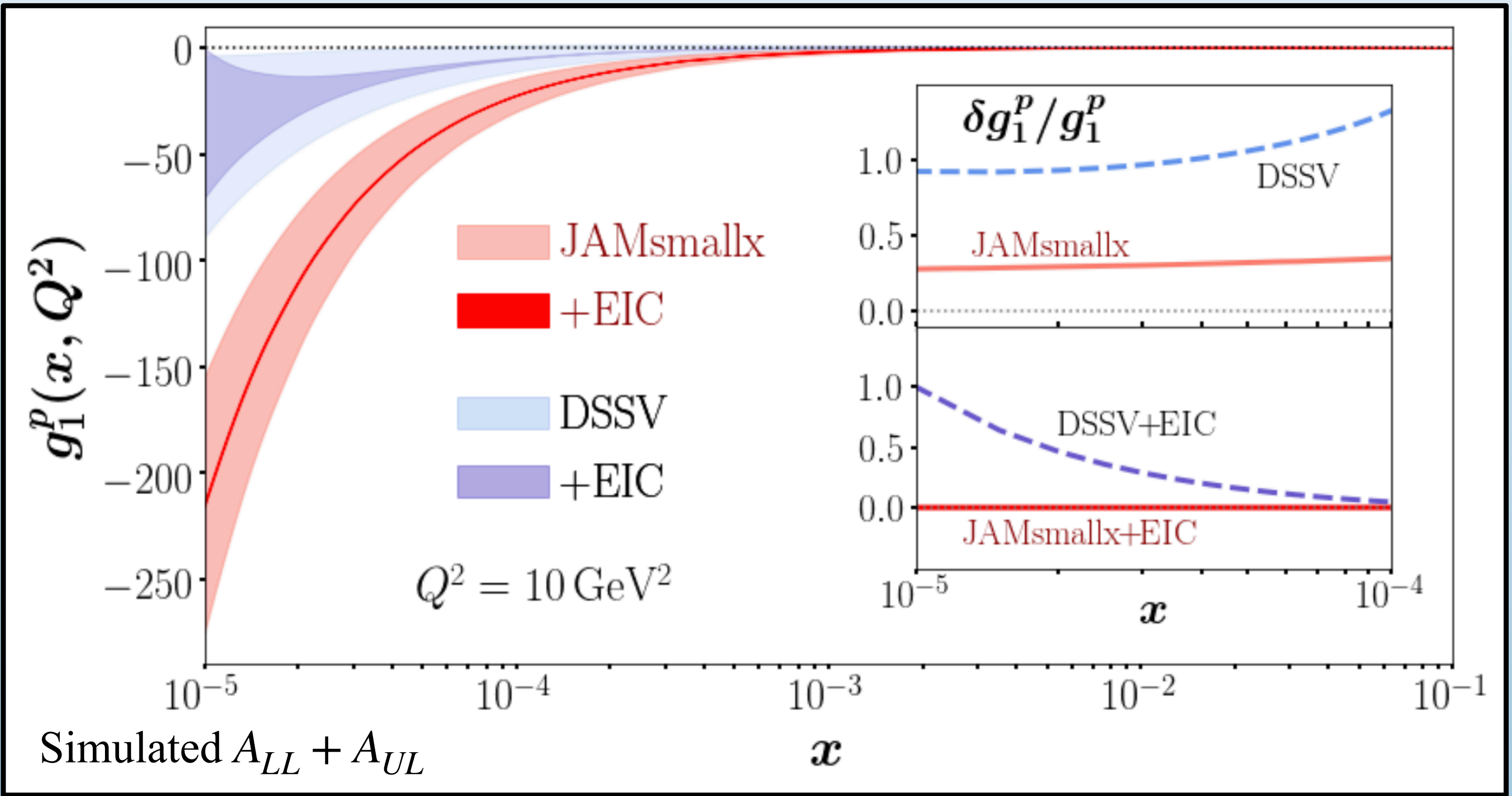
No impact on ΔG, but large impact on $\Delta\Sigma$ thanks to constraints on Δs^+

Impact of EIC at small x (2021)

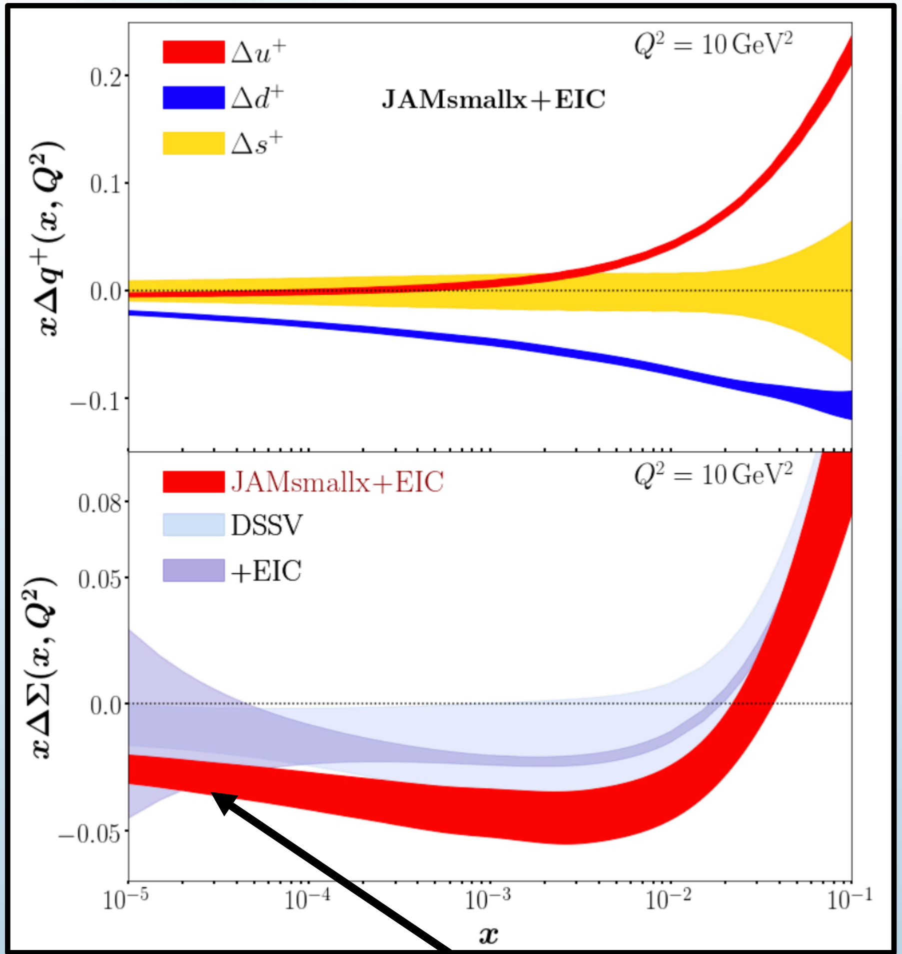
First analysis of world polarized DIS data with small-x helicity evolution

Daniel Adamiak,[1,*] Yuri V. Kovchegov,[1,†] W. Melnitchouk,[2]
Daniel Pitonyak,[3,‡] Nobuo Sato,[2,§] and Matthew D. Sievert[4,¶]

https://arxiv.org/abs/2102.06159



Simulated $A_{LL} + A_{UL}$



Uncertainties remain consistent even below EIC kinematics

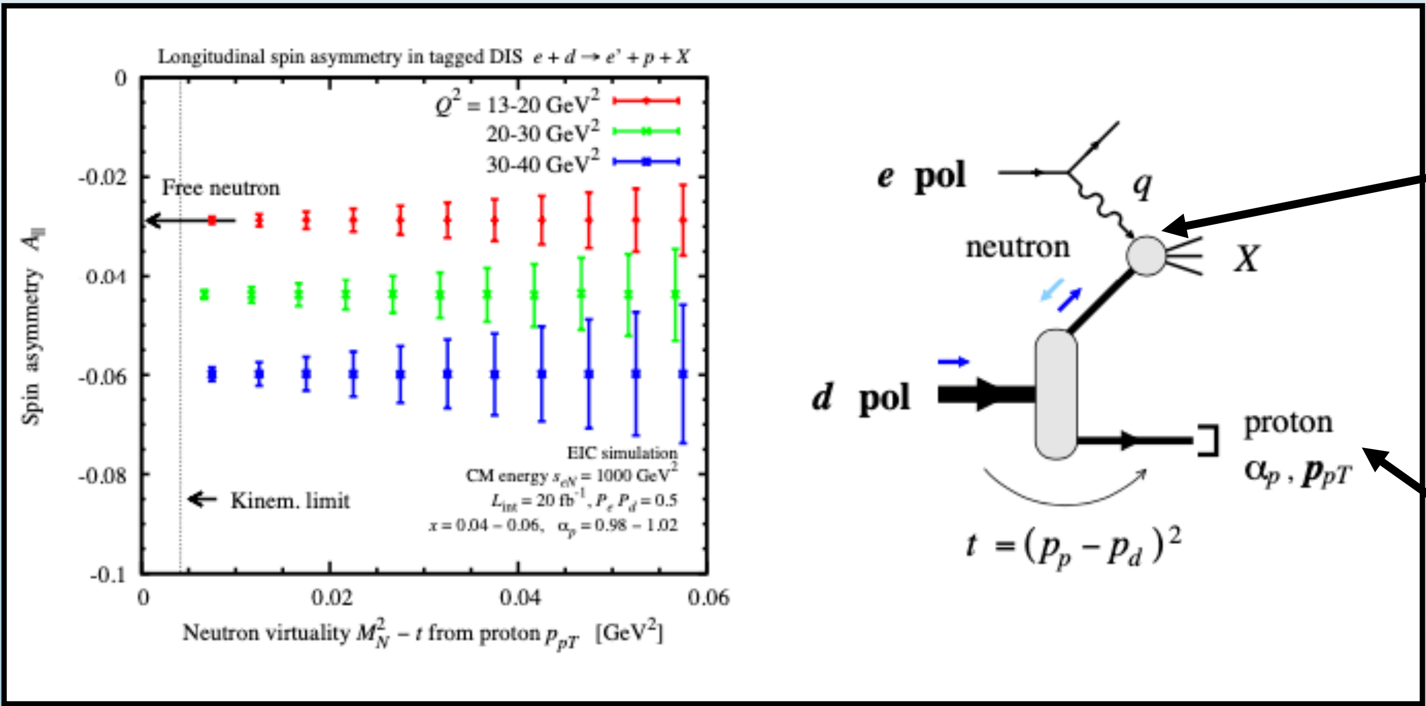
Tagged DIS and Neutron Spin Structure (2020)

Polarized electron-deuteron deep-inelastic scattering with spectator nucleon tagging

W. Cosyn[1,2,*] and C. Weiss[3,†]

https://arxiv.org/abs/2006.03033

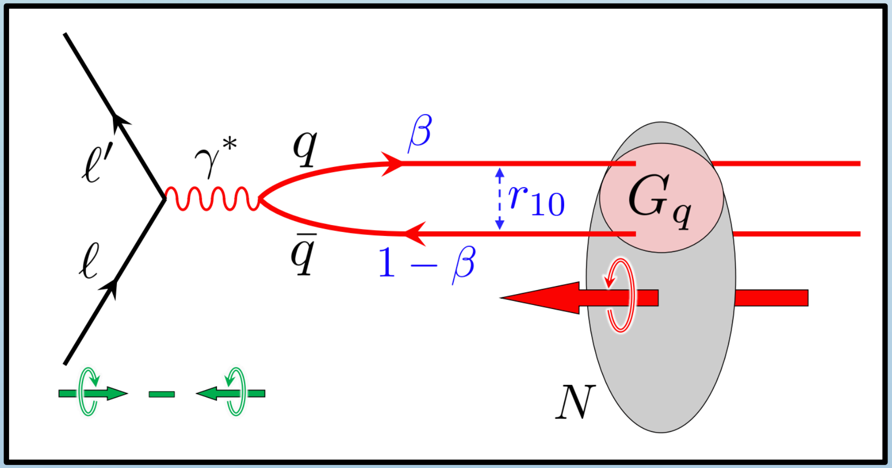
Allows access to spin structure of neutron



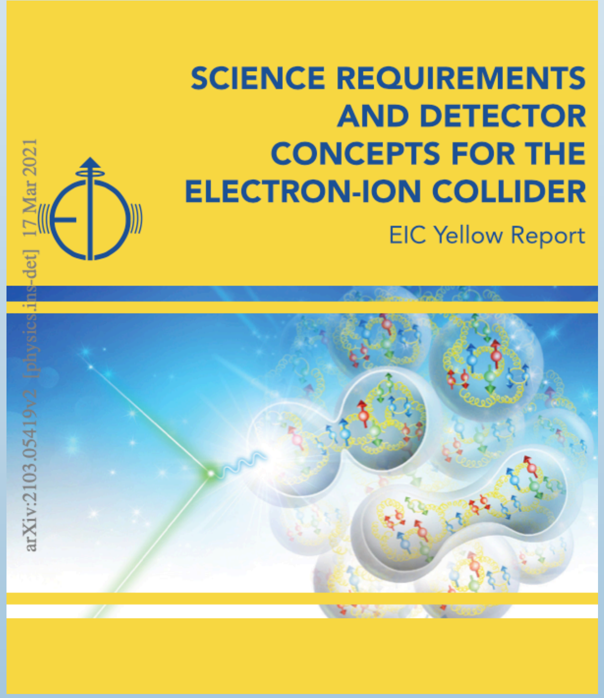
Study "free" neutron

Tag spectator proton in breakup region

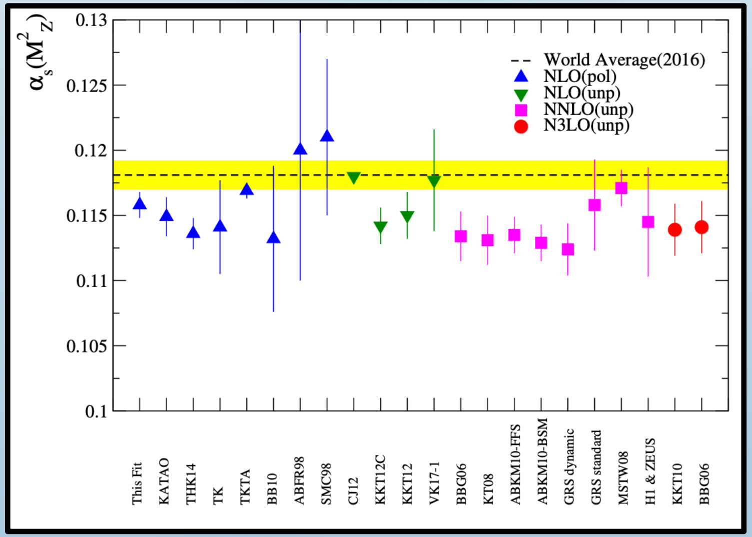
Summary



ℓ'
γ^*
q
β
r_{10}
G_q
ℓ
$\bar{q}$
$1-\beta$
N



SCIENCE REQUIREMENTS AND DETECTOR CONCEPTS FOR THE ELECTRON-ION COLLIDER
EIC Yellow Report
arXiv:2103.05419v2 [physics.ins-det] 17 Mar 2021



$\alpha_s(M_Z^2)$
0.13
0.125
0.12
0.115
0.11
0.105
0.1
World Average(2016)
NLO(pol)
NLO(unp)
NNLO(unp)
N3LO(unp)
This Fit
KATAO
THK14
TK
TKTA
BB10
ABFR98
SMC98
CJ12
KKT12C
KKT12
VK17-1
BBG06
KT08
ABKM10-FFS
ABKM10-BSM
GRS dynamic
GRS standard
MSTW08
H1 & ZEUS
KKT10
BBG06

Theory

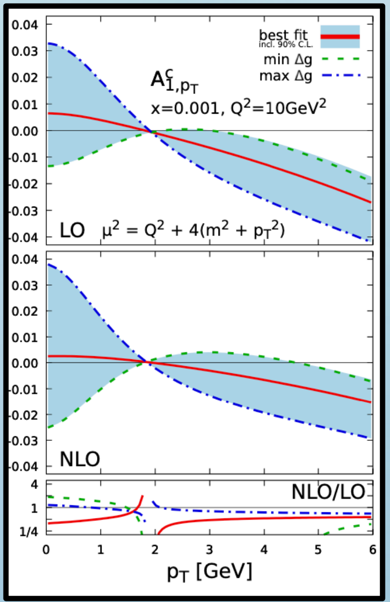
Differential Heavy Quark Distributions and Correlations in Longitudinally Polarized Deep-Inelastic Scattering

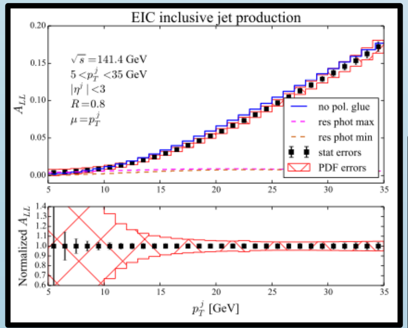
Inclusive jet production as a probe of polarized PDFs at a future EIC

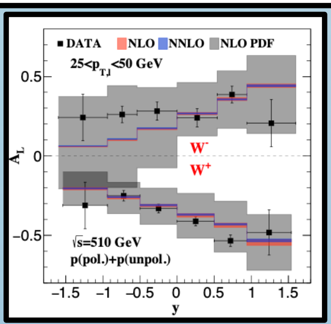
Inclusive-jet and Di-jet Production in Polarized Deep Inelastic Scattering

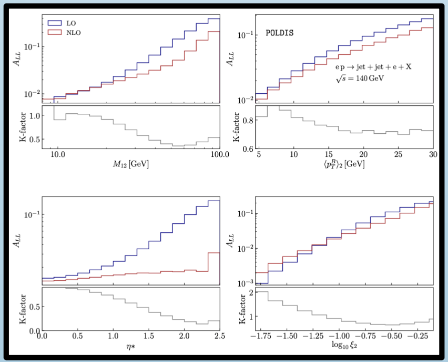
W-boson production in polarized proton-proton collisions at RHIC through next-to-next-to-leading order in perturbative QCD

New observables at the EIC + NNLO calculations





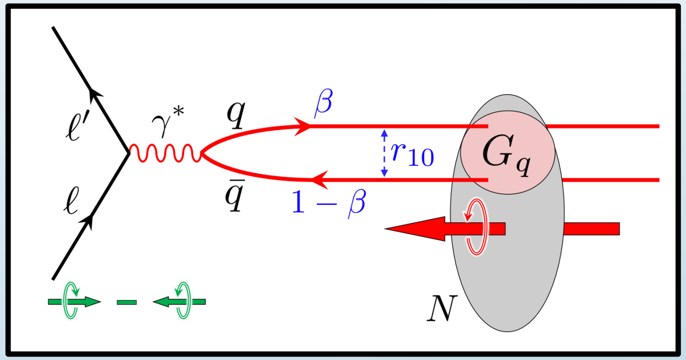


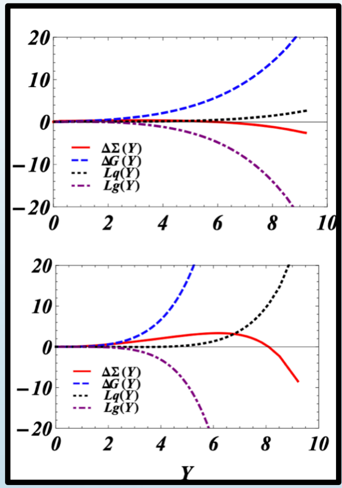


Helicity Evolution at Small x: Flavor Singlet and Non-Singlet Observables

On the small-x behavior of the orbital angular momentum distributions in QCD

Spin at small x



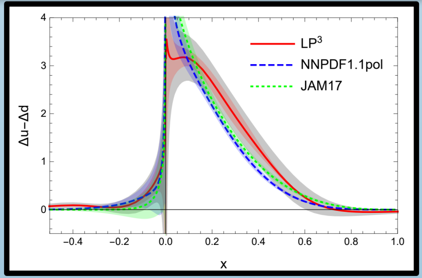


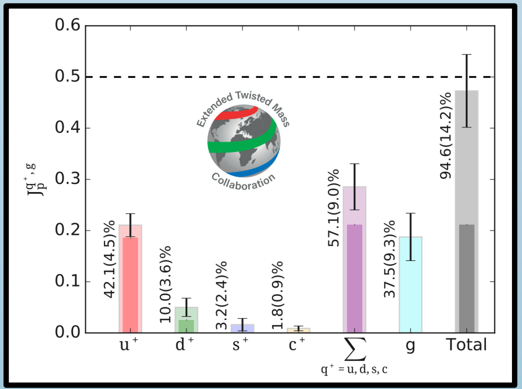
Complete flavor decomposition of the spin and momentum fraction of the proton using lattice QCD simulations at physical pion mass

Flavor decomposition of the nucleon unpolarized, helicity and transversity parton distribution functions from lattice QCD simulations

Proton Isovector Helicity Distribution on the Lattice at Physical Pion Mass (LP^3 Collaboration)

Lattice QCD



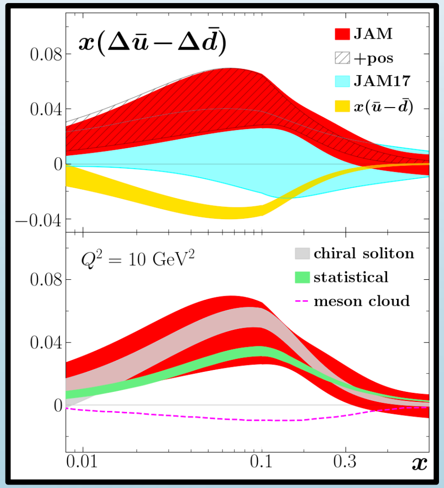


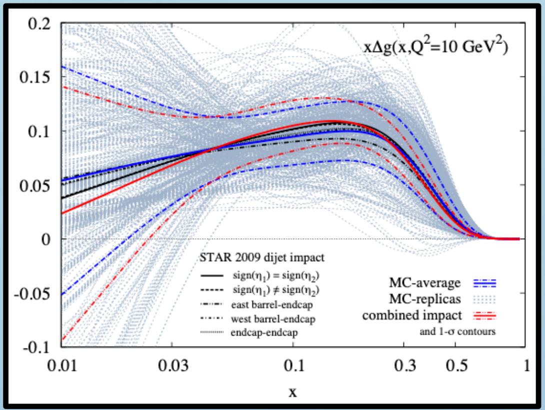
Global Analyses

Impact of recent COMPASS data on polarized parton distributions and structure functions

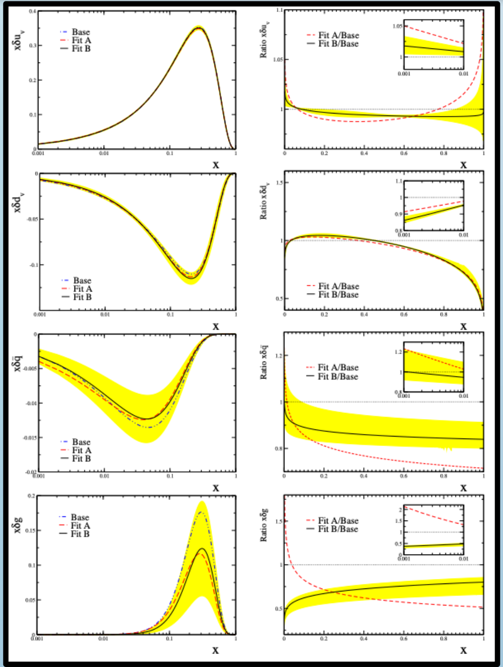
Monte Carlo sampling variant of the DSSV14 set of helicity parton densities

First Extraction of Polarized Sea Asymmetry from Weak Boson Production in Proton-Proton Collisions



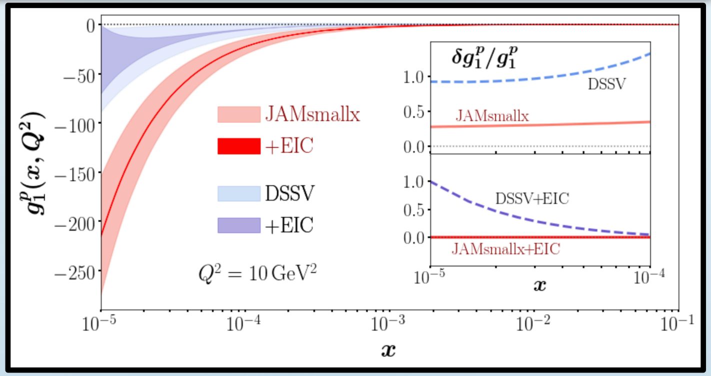


Impact of new RHIC + COMPASS data



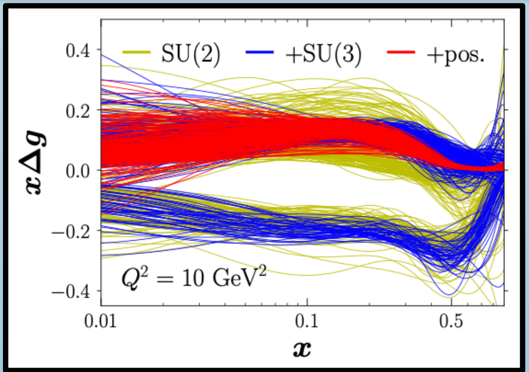
First analysis of world polarized DIS data with small-x helicity evolution

Small x global analysis



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

Theory assumptions and Δg



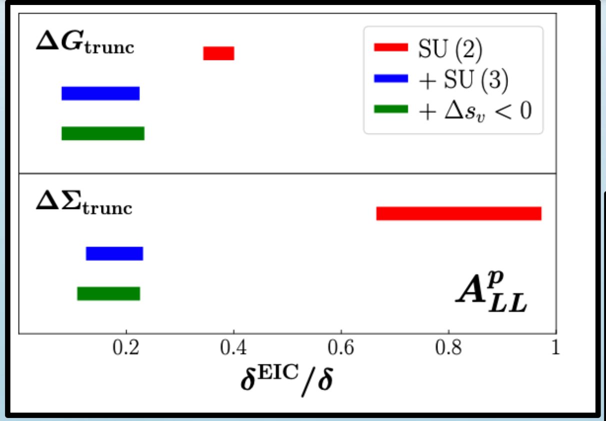
Opportunities at the EIC

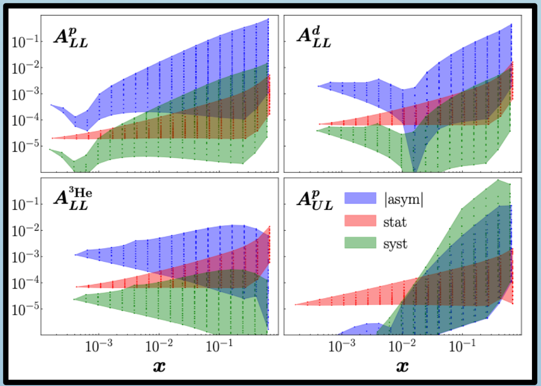
Revisiting Helicity Parton Distributions at a Future Electron-Ion Collider

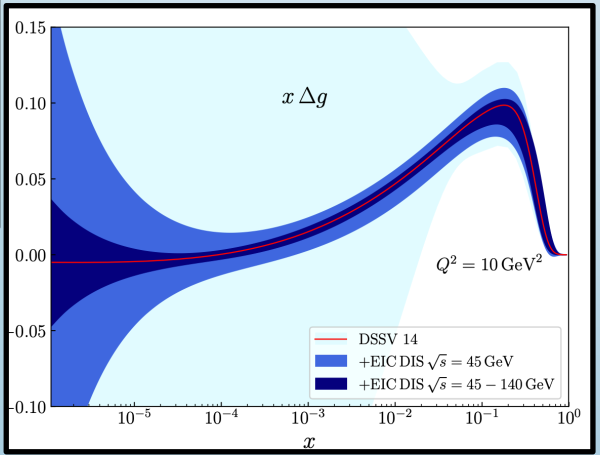
Revisiting quark and gluon polarization in the proton at the EIC

First analysis of world polarized DIS data with small-x helicity evolution

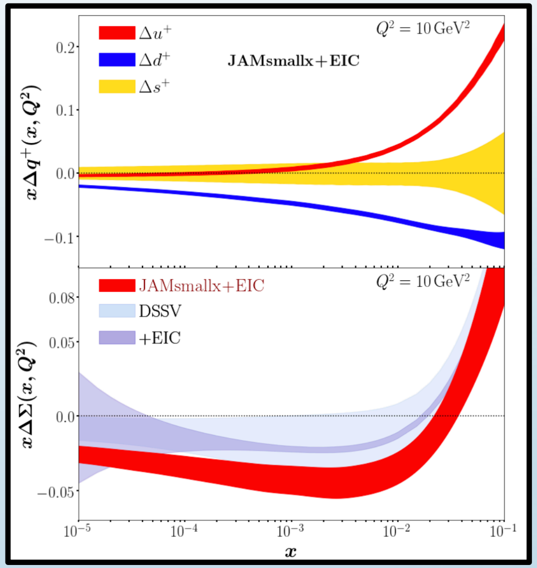
Impact of DIS spin asymmetries





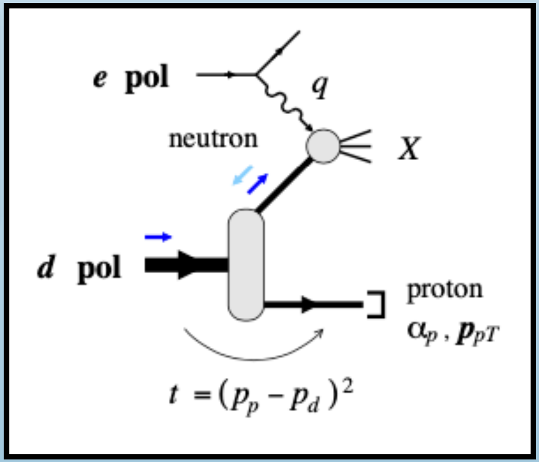


Small x EIC impact



Polarized electron-deuteron deep-inelastic scattering with spectator nucleon tagging

Tagged DIS and neutron spin structure



Related Talks (times are JST)

Progress on Lattice QCD studies on the spin physics

18 Oct 2021, 16:00
30m
Matsue, Shimane Prefecture, Japan

Plenary Presentation (... | Plenary presentations | Plenary Presentations

Speaker

Constantia Alexandrou (University of Cyprus...

Description

Resent results obtained using state-of-the-art lattice QCD simulations on the nucleon spin decomposition will be reviewed. The results include valence and sea quark and gluon contributions. Open issues in particular connected to the fixing and renormalisation will be discussed.

Small-x Helicity Evolution and the Proton Spin Puzzle

22 Oct 2021, 07:00
30m
Room 501 (Kunibiki Messe)

Parallel Session keynot... | Nucleon Helicity Str... | Nucleon Helicity Struct...

Speaker

Dr Daniel Pitonyak

Description

We report on the first phenomenological analysis of the world polarized deep-inelastic scattering (DIS) data incorporating small-x helicity (Kovchegov-Pitonyak-Sievert) evolution. This framework allows for one to predict the behavior of helicity parton distribution functions (PDFs) down to very low x. Consequently, one can control the uncertainties in these functions beyond the measured region and make precise calculations of the integrals needed to determine the contribution of quark and gluon spin to the proton spin. Therefore, the small-x helicity formalism will play a crucial role in using future Electron-Ion Collider data to resolve the proton spin puzzle.

First Extraction of Polarized Sea Asymmetry from Weak Boson Production in Proton-Proton Collisions

22 Oct 2021, 07:30
20m
Room 501 (Kunibiki Messe)

Parallel Session Prese... | Nucleon Helicity Str... | Nucleon Helicity Struct...

Speaker

Christopher Cocuzza (Temple University)

Description

We present the first global QCD analysis of helicity parton distribution functions (PDFs) to include the latest polarized W-lepton production data from the STAR collaboration at the Relativistic Heavy-Ion Collider. This data allows the first extraction of a nonzero helicity light quark sea asymmetry within a global QCD analysis. By performing a simultaneous extraction of the unpolarized and helicity PDFs, we are also able to extract for the first time in a self-consistent manner the polarizations of the light sea quarks $\Delta\bar{u}/\bar{u}$ and $\Delta\bar{d}/\bar{d}$.

Backup

Three-loop Splitting Functions

The three-loop unpolarized and polarized non-singlet anomalous dimensions from off shell operator matrix elements

J. Blümlein[a], P. Marquard[a], C. Schneider[b] and K. Schönwald[c]

https://arxiv.org/abs/2107.06267

Calculated non-singlet splitting functions at three-loops

First three-loop calculation for the non-singlet transversity splitting function

Chiral Anomaly in DIS

The role of the chiral anomaly in polarized deeply inelastic scattering I: Finding the triangle graph inside the box diagram in Bjorken and Regge asymptotics

Andrey Tarasov[1,2] and Raju Venugopalan[3]

The role of the chiral anomaly in polarized deeply inelastic scattering II: Topological screening and transitions from emergent axion-like dynamics

Andrey Tarasov[1,2] and Raju Venugopalan[3]

https://arxiv.org/abs/2008.08104

https://arxiv.org/abs/2109.10370

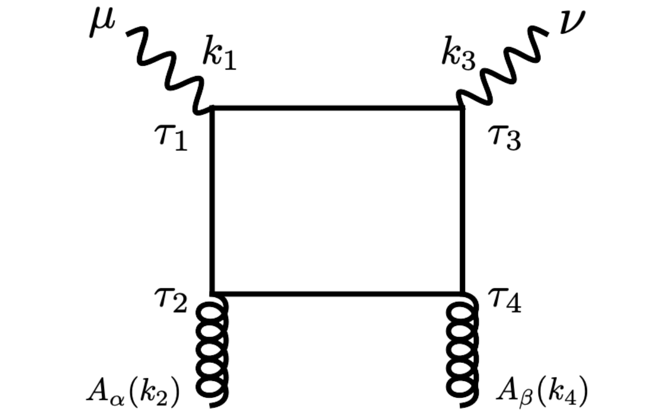


FIG. 1. The box diagram $\Gamma_A^{\mu\nu\alpha\beta}[k_1,k_3,k_2,k_4]$ for polarized DIS.

Bjorken limit

Regge limit

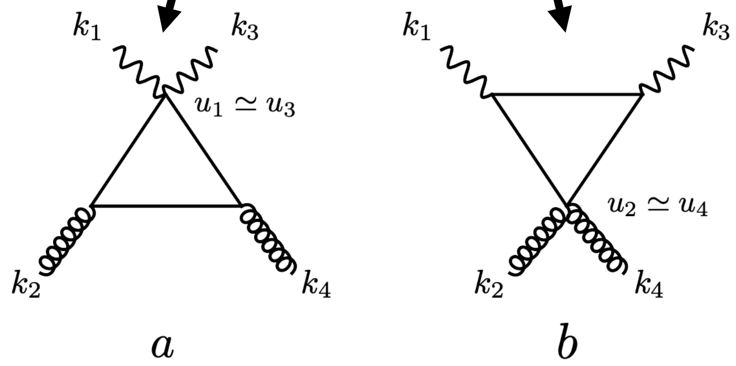


FIG. 2. Two "triangle" limits of the box diagram: a) the Bjorken limit, given by Eq. (39), b) the Regge limit given by Eq. (40).

Chiral anomaly provides dominant contribution to g_1 in the Bjorken ($Q^2 \to \infty$, x_{Bj} fixed) and Regge ($x_{\mathrm{Bj}} \to 0$, Q^2 fixed) limits.

g_T contribution in SIDIS (2021)

The $g_T(x)$ contribution to single spin asymmetries in SIDIS

Sanjin Benić,[1] Yoshitaka Hatta,[2,3] Abhiram Kaushik,[1] and Hsiang-nan Li[4]

https://arxiv.org/abs/2109.05440

$$\frac{d\Delta\sigma}{dP_{hT}} \sim g_T(x) \otimes H \otimes D_1(z) + \cdots ,$$

$$g_T(x) = \int_x^1 \frac{dx'}{x'} \Delta q(x') + (\text{genuine twist three}) ,$$

Deviations from predicted asymmetry can be contributed to twist-three effects