Summary for SIDIS Working Group

The 8th EicC CDR Workshop
Aug. 17th-20th, 2024 @ Qingdao, Shandong

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On behalf of the EicC semi-inclusive working group

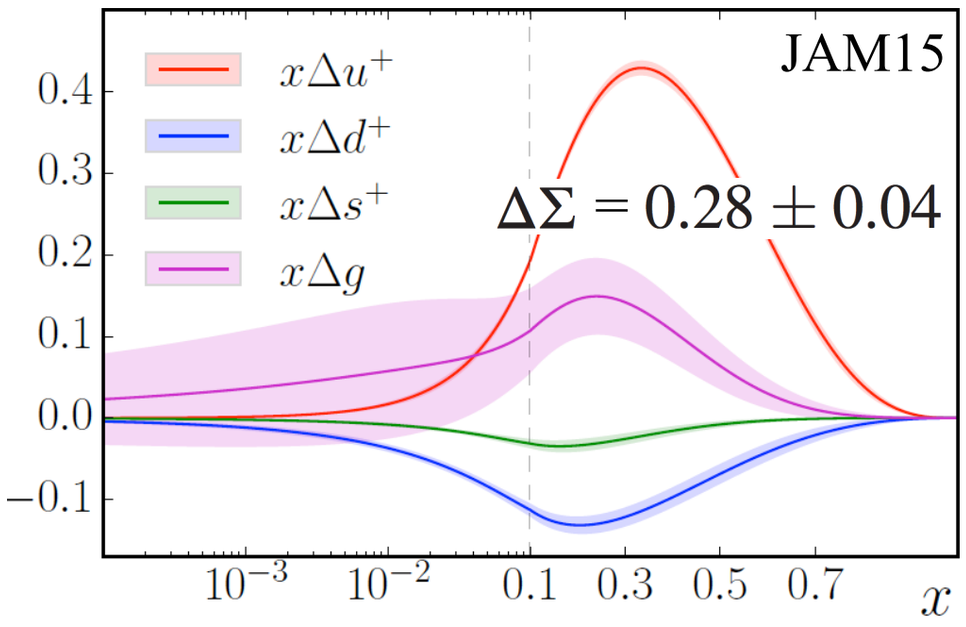
Nucleon Spin Structure

Proton spin puzzle

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s \sim 0.3$$

Spin decomposition

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



JAM Collaboration, PR D 93, 074005 (2016).

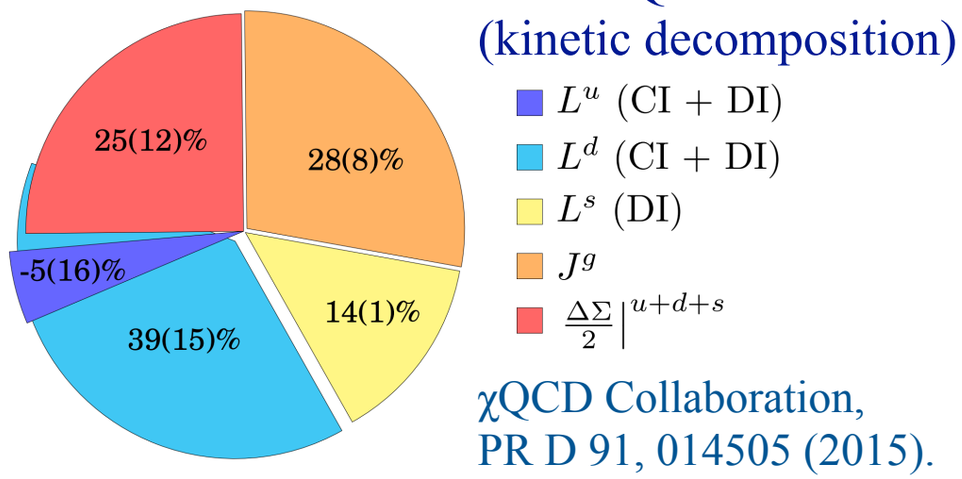
JAM17: $\Delta\Sigma = 0.36 \pm 0.09$

JAM Collaboration, PRL 119, 132001 (2017).

Quark spin only contributes a small fraction to the nucleon spin.

J. Ashman *et al.*, PLB 206, 364 (1988); NP B328, 1 (1989).

Lattice QCD
(kinetic decomposition)

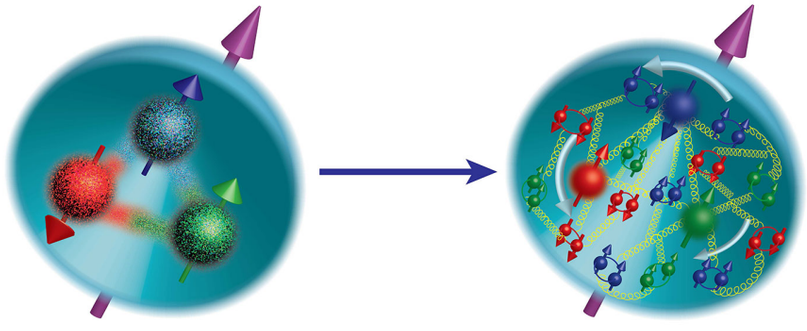


χQCD Collaboration,
PR D 91, 014505 (2015).

Gluon spin from LQCD: $S_g = 0.251(47)(16)$

50% of total proton spin

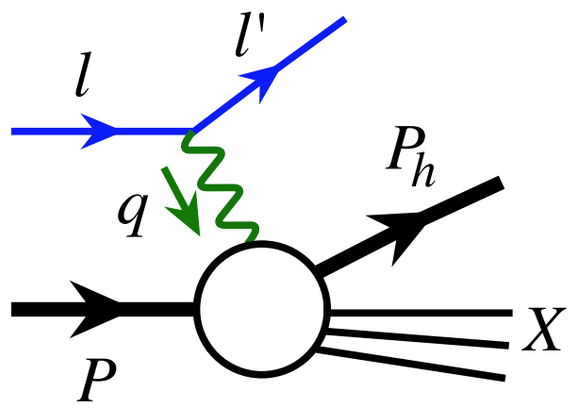
Y.-B. Yang *et al.* (χQCD Collaboration), PRL 118, 102001 (2017).

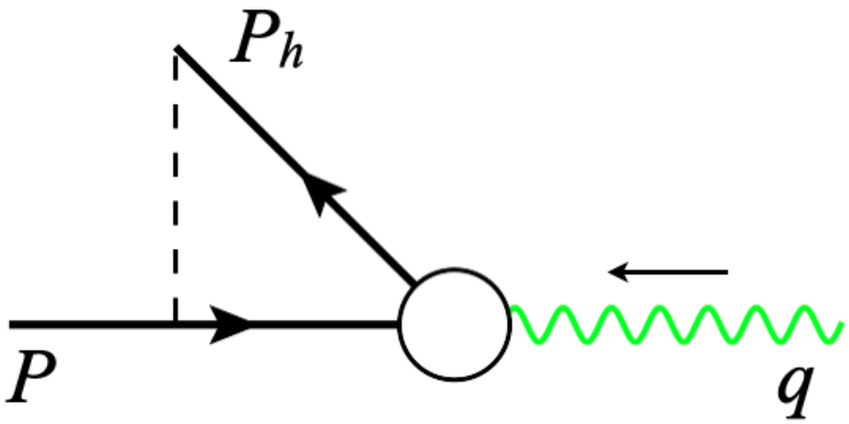


Semi-inclusive Deep Inelastic Scattering

Semi-inclusive DIS: a final state hadron (P_h) is identified

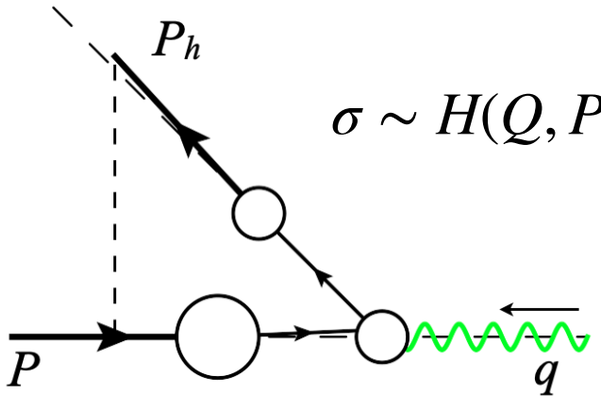
- enable us to explore the emergence of color neutral hadrons from colored quarks/gluons
- flavor dependence by selecting different types of observed hadrons: pions, kaons, …
- a large momentum transfer Q provides a short-distance probe
- an additional and adjustable momentum scale P_{hT}
- cold nuclear effects via eA SIDIS





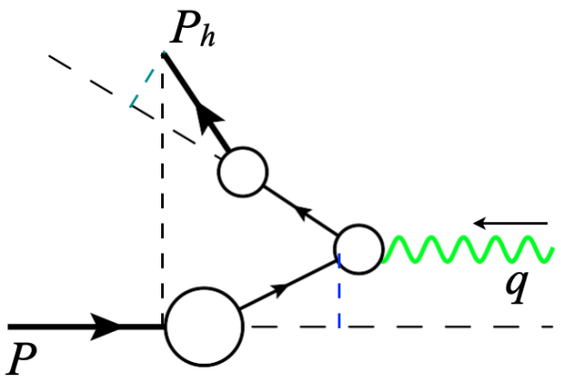
SIDIS Kinematic Regions

Sketch of kinematic regions of the produced hadron



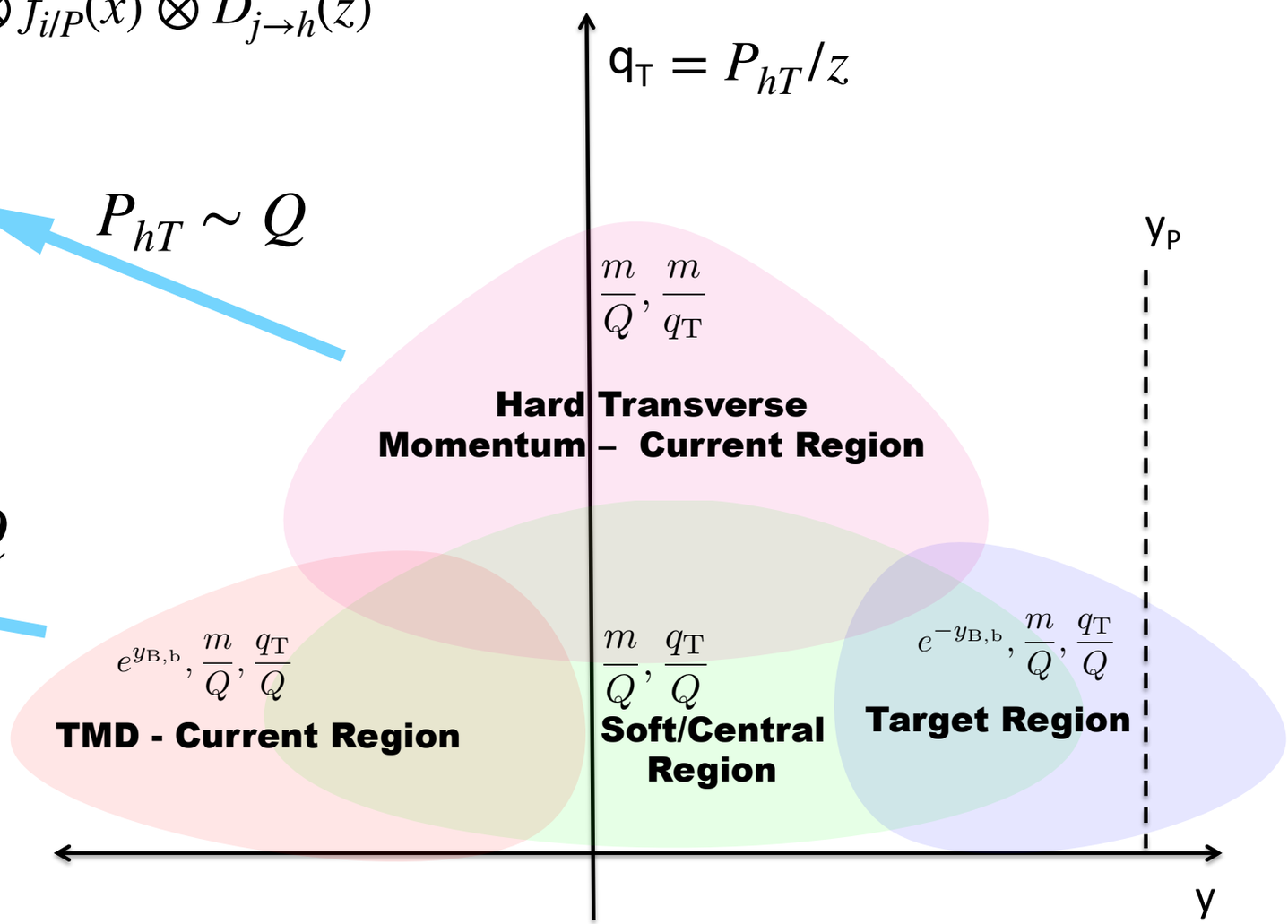
$$\sigma \sim H(Q, P_{hT}) \otimes f_{i/P}(x) \otimes D_{j\to h}(z)$$

$P_{hT} \sim Q$



$P_{hT} \ll Q$

$$\sigma \sim H(Q) \otimes f_{i/P}(x, k_T) \otimes D_{j\to h}(z, p_T)$$



P_{hT} is defined in the photon-hadron frame

[Figure from JHEP10(2019)122]

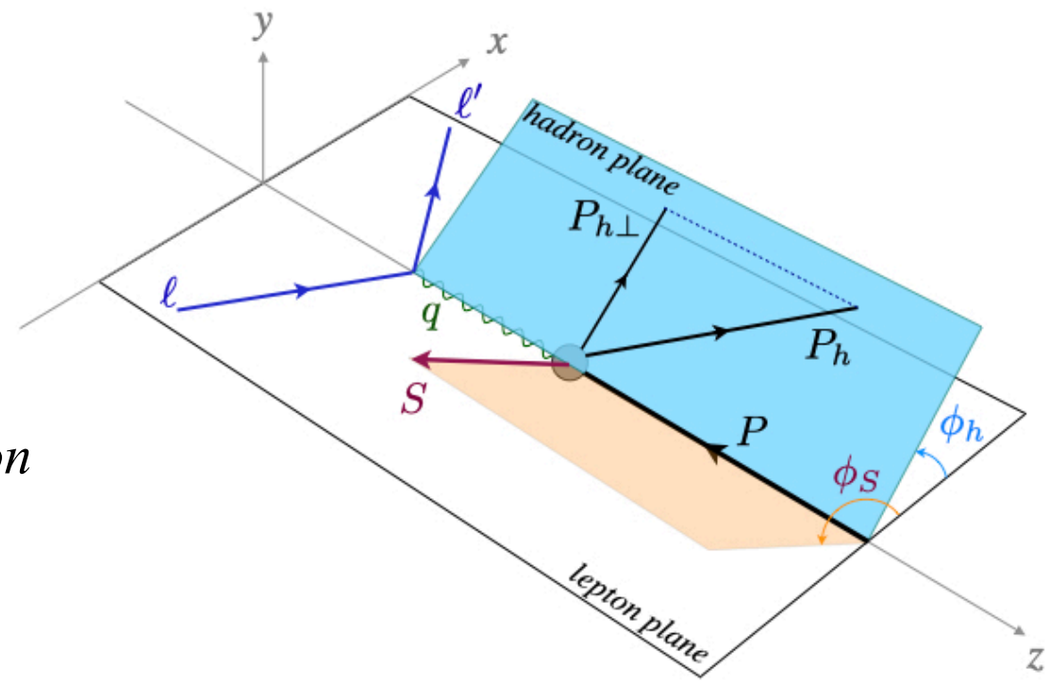
Structure Functions

SIDIS differential cross section

in terms of 18 structure functions

$$F_{AB,C}(x_B, z, P_{hT}^2, Q^2)$$

A: lepton polarization
B: nucleon polarization
C: virtual photon polarization



$$\frac{\mathrm{d}\sigma}{\mathrm{d}x_B\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}P_{hT}^2\,\mathrm{d}\phi_h\,\mathrm{d}\phi_S}$$

$$= \frac{\alpha^2}{x_B y Q^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x_B}\right)$$

$$\times\Big\{F_{UU,T}+\epsilon F_{UU,L}+\sqrt{2\epsilon(1+\epsilon)}F_{UU}^{\cos\phi_h}\cos\phi_h+\epsilon F_{UU}^{\cos 2\phi_h}\cos 2\phi_h+\lambda_e\sqrt{2\epsilon(1-\epsilon)}F_{LU}^{\sin\phi_h}\sin\phi_h$$

$$+S_L\left[\sqrt{2\epsilon(1+\epsilon)}F_{UL}^{\sin\phi_h}\sin\phi_h+\epsilon F_{UL}^{\sin 2\phi_h}\sin 2\phi_h\right]+\lambda_e S_L\left[\sqrt{1-\epsilon^2}F_{LL}+\sqrt{2\epsilon(1-\epsilon)}F_{LL}^{\cos\phi_h}\cos\phi_h\right]$$

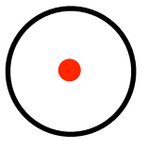
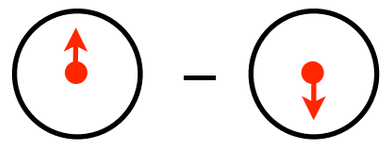
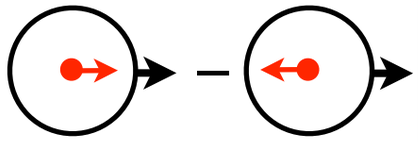
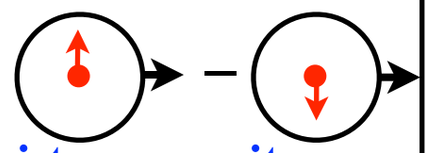
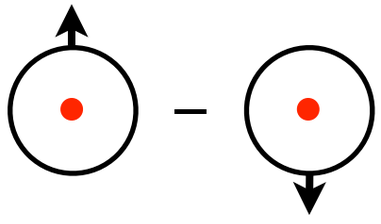
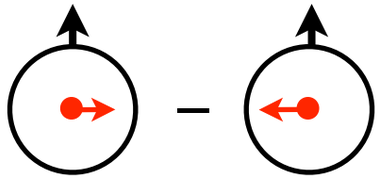
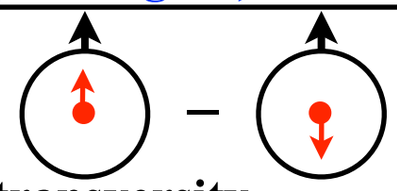
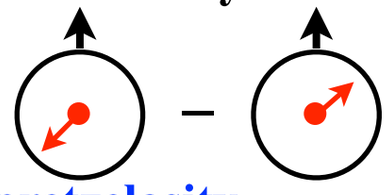
$$+S_T\left[\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\epsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)\sin(\phi_h-\phi_S)+\epsilon F_{UT}^{\sin(\phi_h+\phi_S)}\sin(\phi_h+\phi_S)\right.$$

$$\left.+\epsilon F_{UT}^{\sin(3\phi_h-\phi_S)}\sin(3\phi_h-\phi_S)\quad+\sqrt{2\epsilon(1+\epsilon)}F_{UT}^{\sin\phi_S}\sin\phi_S+\sqrt{2\epsilon(1+\epsilon)}F_{UT}^{\sin(2\phi_h-\phi_S)}\sin(2\phi_h-\phi_S)\right]$$

$$+\lambda_e S_T\left[\sqrt{1-\epsilon^2}F_{LT}^{\cos(\phi_h-\phi_S)}\cos(\phi_h-\phi_S)\right.$$

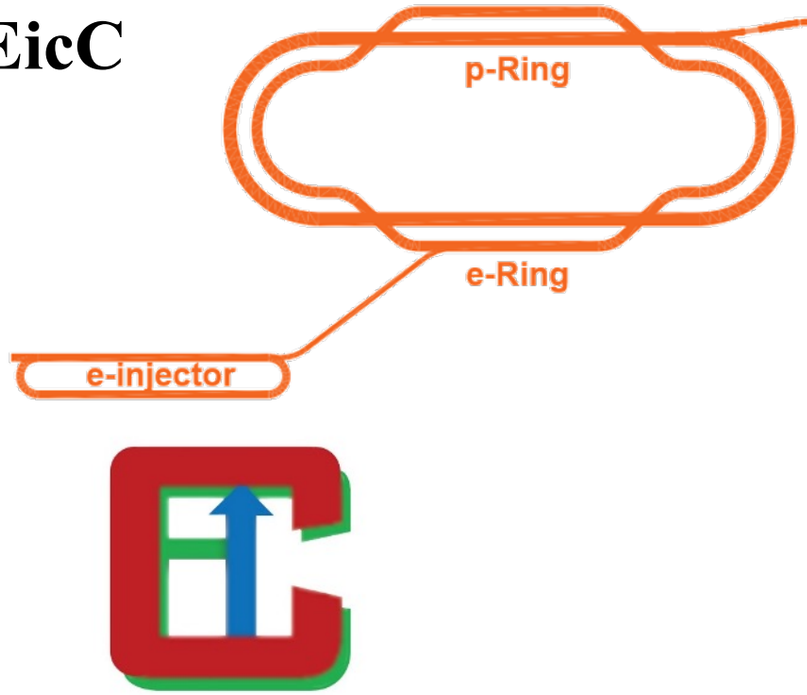
$$\left.+\sqrt{2\epsilon(1-\epsilon)}F_{LT}^{\cos\phi_S}\cos\phi_S+\sqrt{2\epsilon(1-\epsilon)}F_{LT}^{\cos(2\phi_h-\phi_S)}\cos(2\phi_h-\phi_S)\right]\Big\}$$

Leading Twist TMDs

Nucleon Polarization	Quark Polarization: U	Quark Polarization: L	Quark Polarization: T
U	f_1  **unpolarized**		$h_1^\perp$  **Boer-Mulders**
L		g_{1L}  **helicity**	$h_{1L}^\perp$  **longi-transversity (worm-gear)**
T	$f_{1T}^\perp$  **Sivers**	g_{1T}  **trans-helicity (worm-gear)**	h_1  **transversity** $h_{1T}^\perp$  **pretzelosity**

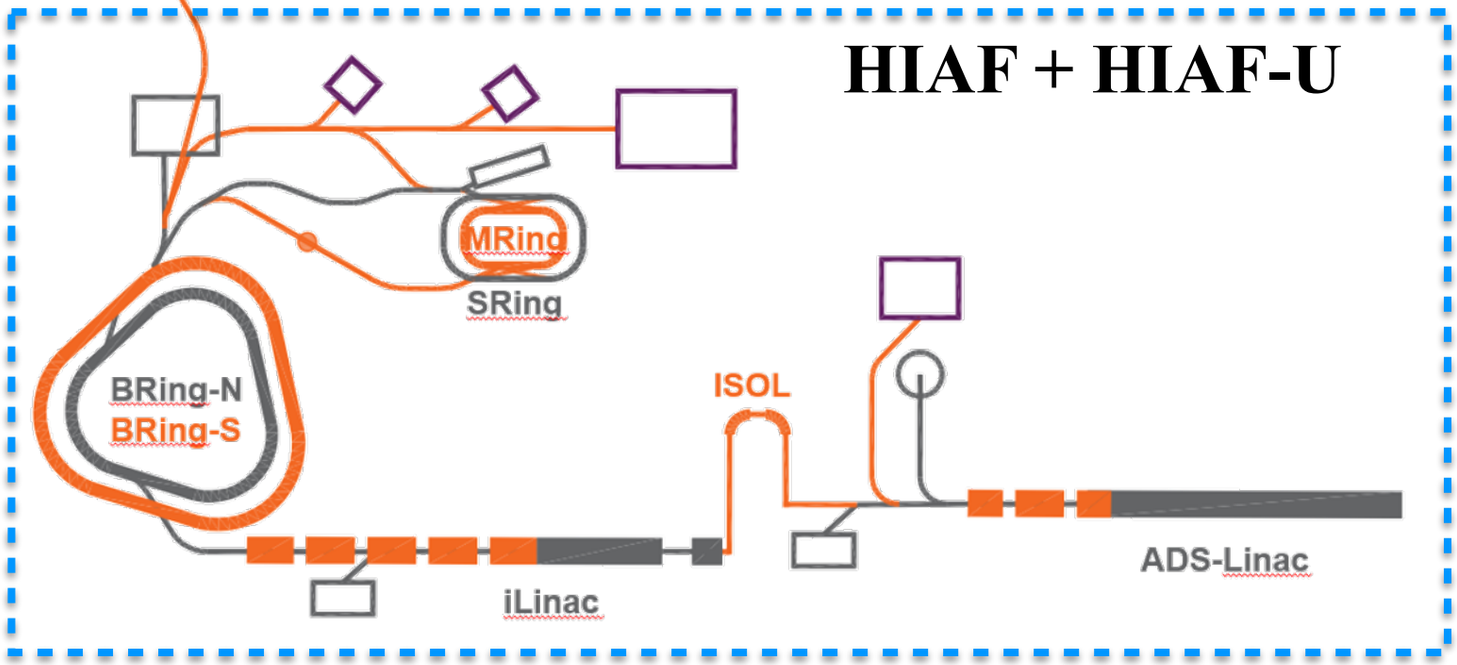
Electron-ion Collider in China

EicC



Electron Ion Collider in China

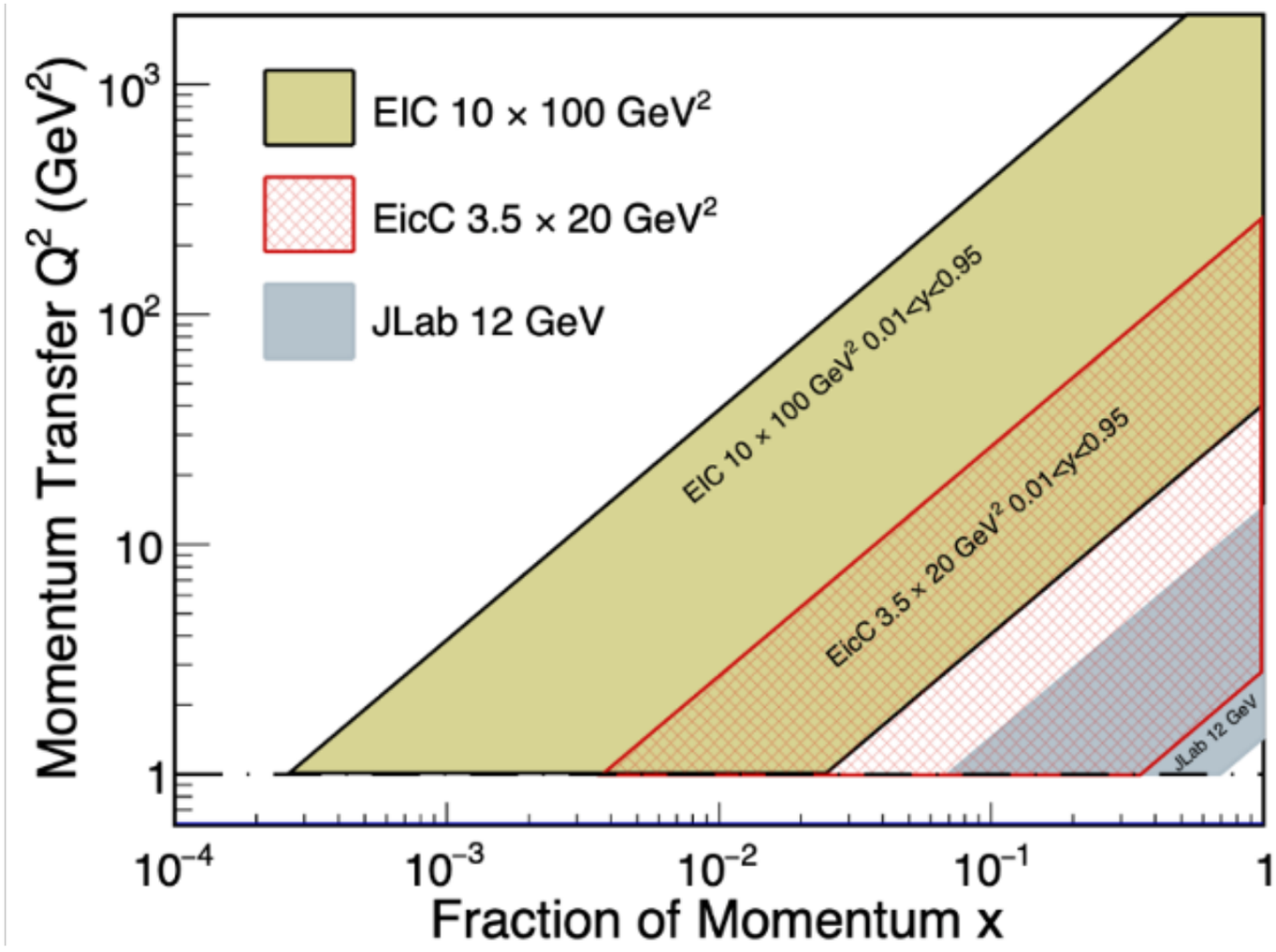
- Based on HIAF



[Figure by EicC Accelerator WG]

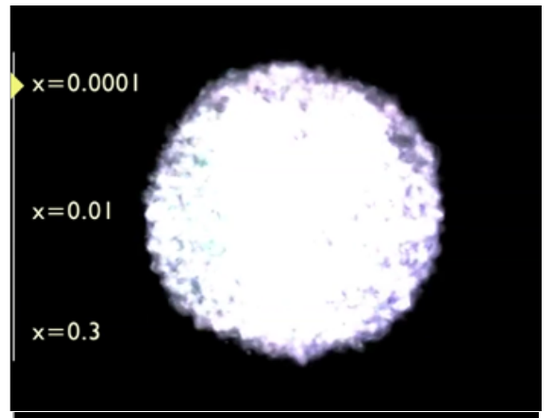
- energy in c.m.: 15 ~ 20 GeV
- luminosity: ≳ 2×10^{33} $cm^{-2} \cdot s^{-1}$
- electron beam: 3.5 GeV, polarization ~ 80%
- proton beam: 20 GeV, polarization ~ 70%
- other available polarized ion beams: d, $^{3}He^{++}$
- available unpolarized ion beams: $^{7}Li^{3+}$, $^{12}C^{6+}$, $^{40}Ca^{20+}$, $^{197}Au^{79+}$, $^{208}Pb^{82+}$, $^{238}U^{92+}$

Complementary Kinematic Coverage

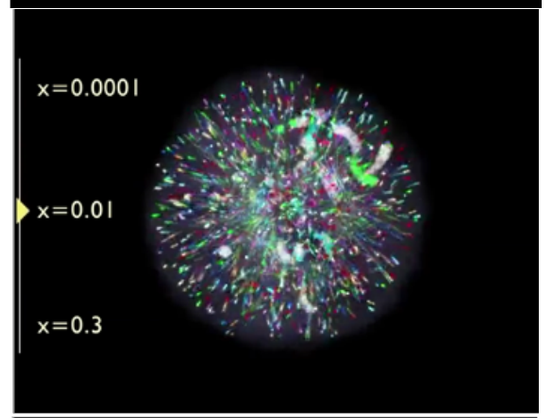


[Figure from EicC White paper]

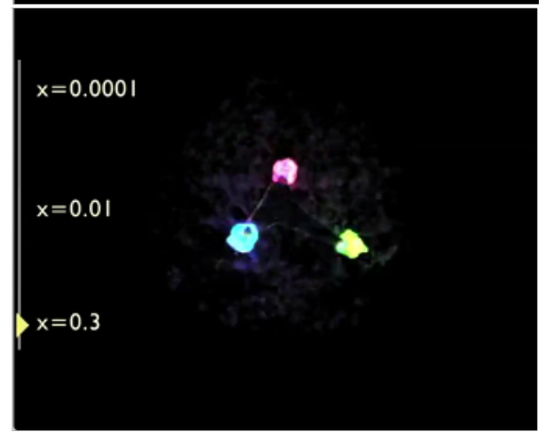
gluon dominates



sea quarks + gluons



valence dominates

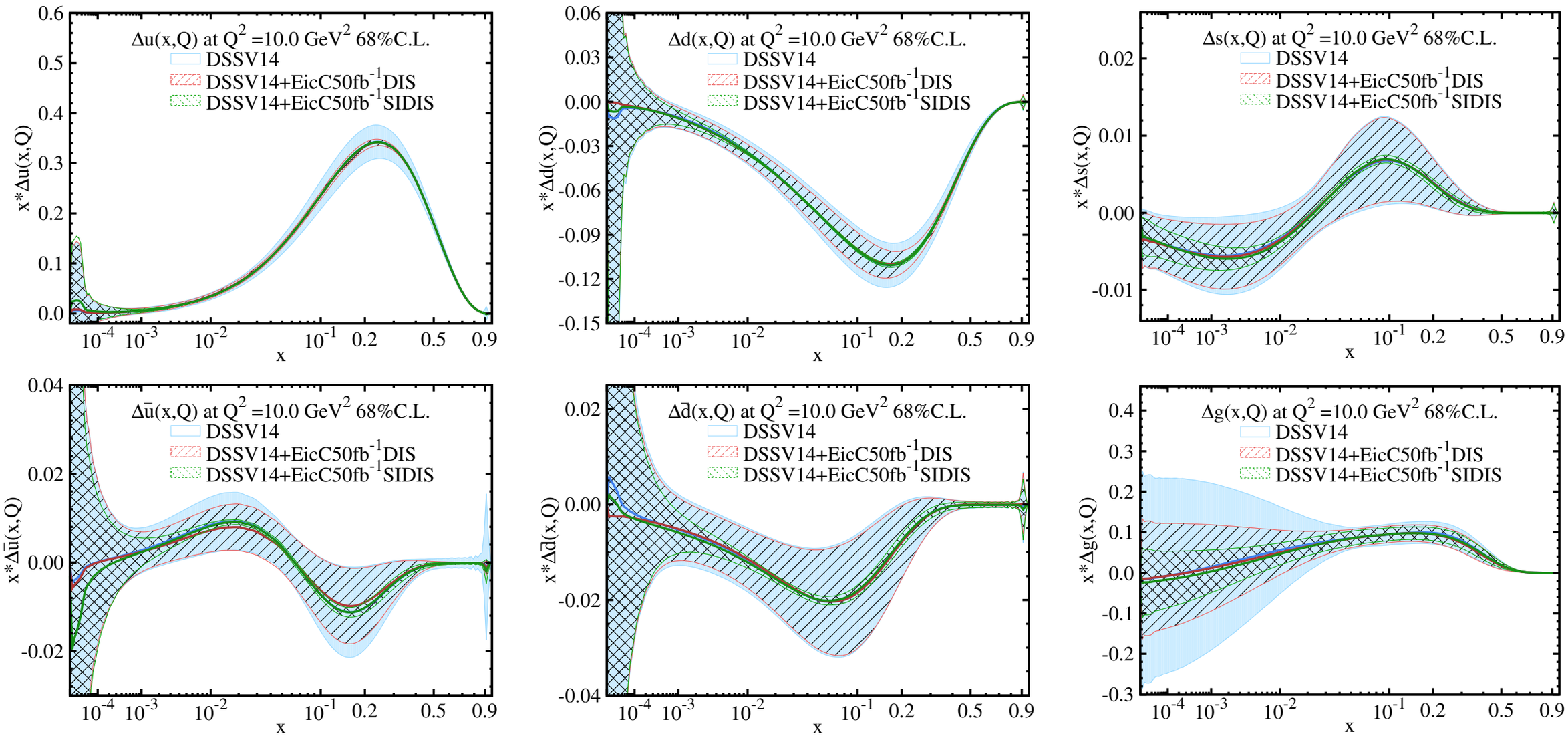


R.G. Milner and R. Ent, *Visualizing the proton* 2022

EicC is optimized to systematically explore the gluon and sea quarks in moderate x regime
At a crucial place between JLab and EIC-US

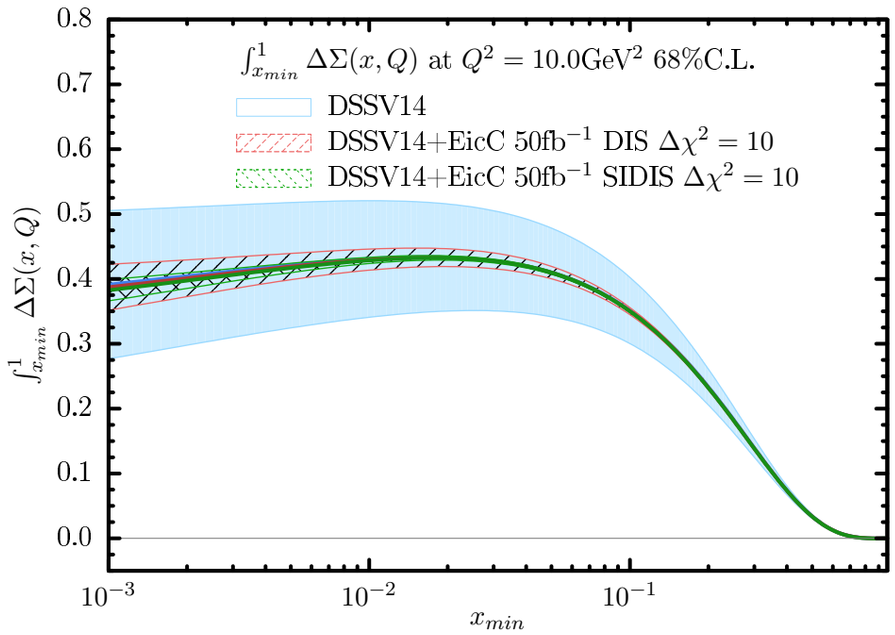
Impact Study: Helicity Distributions

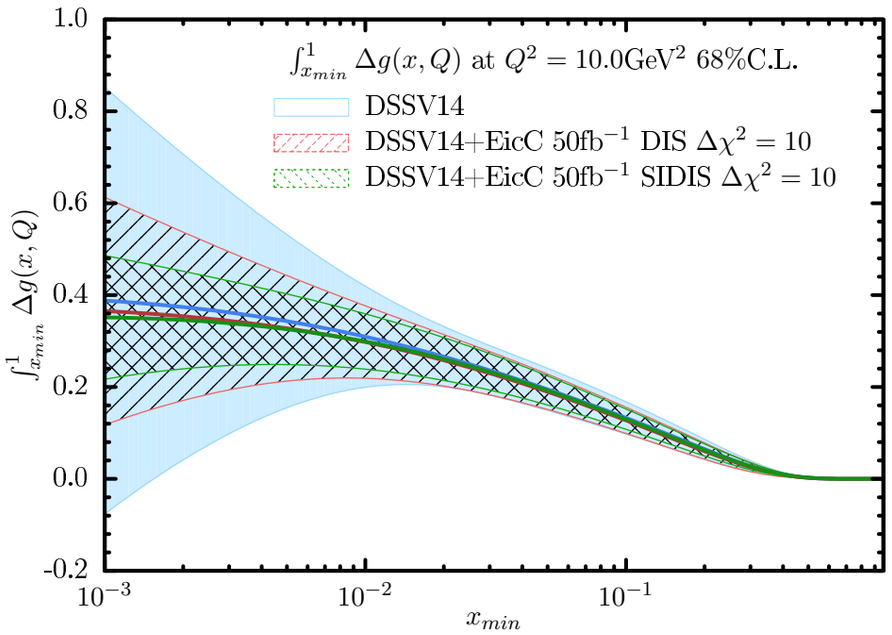
P_{hT}-integrated double spin asymmetry: $A_{LL} \sim \Delta q(x) \otimes D(z)$

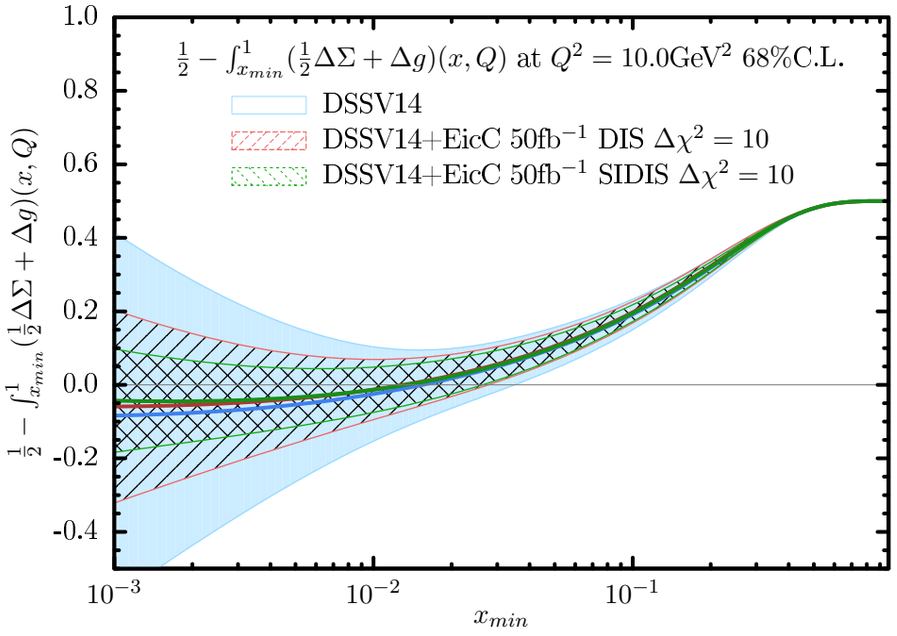


D.P. Anderle, T.J. Hou, H. Xing, M. Yan, C.-P. Yuan and Y. Zhao, JHEP 08 (2021) 034.

Impact Study: Helicity Distributions



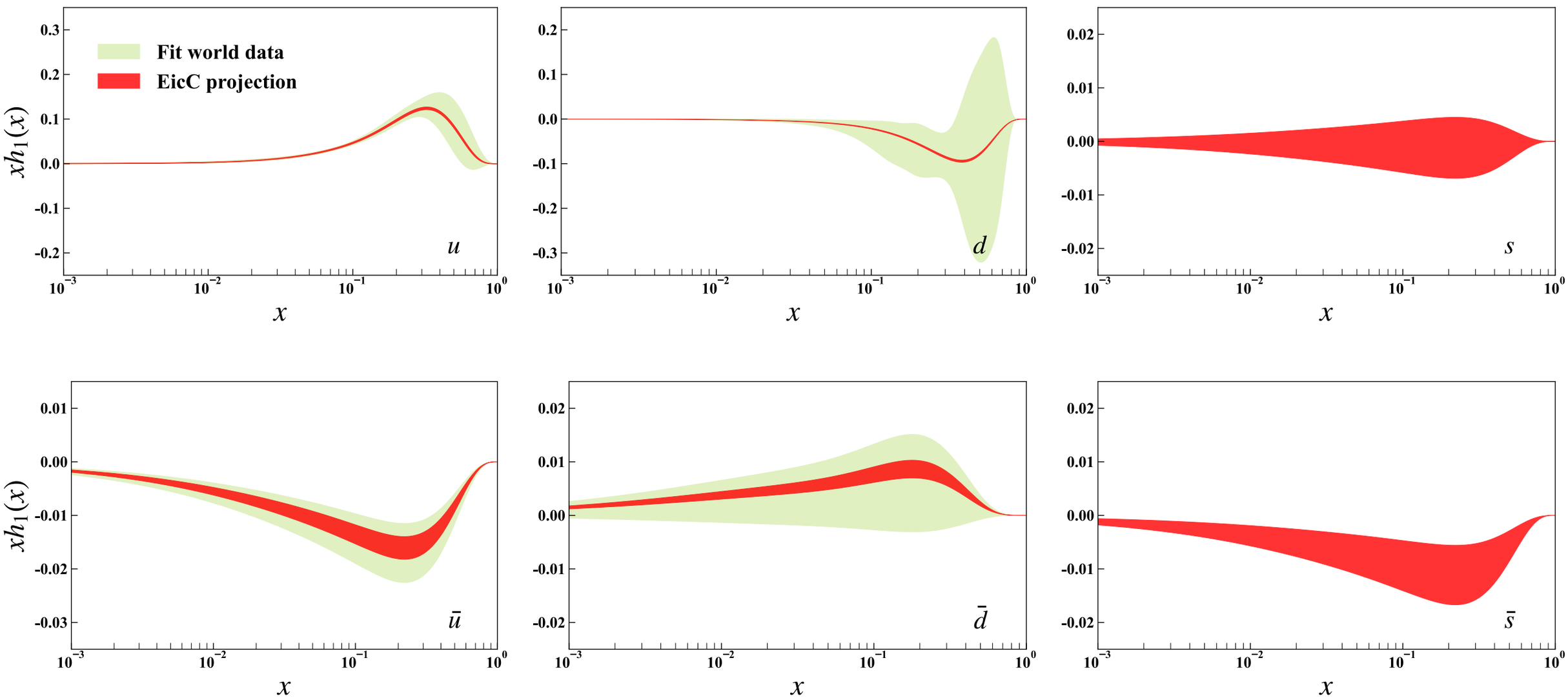




D.P. Anderle, T.J. Hou, H. Xing, M. Yan, C.-P. Yuan and Y. Zhao, JHEP 08 (2021) 034.

Impact Study: Transversity Distributions

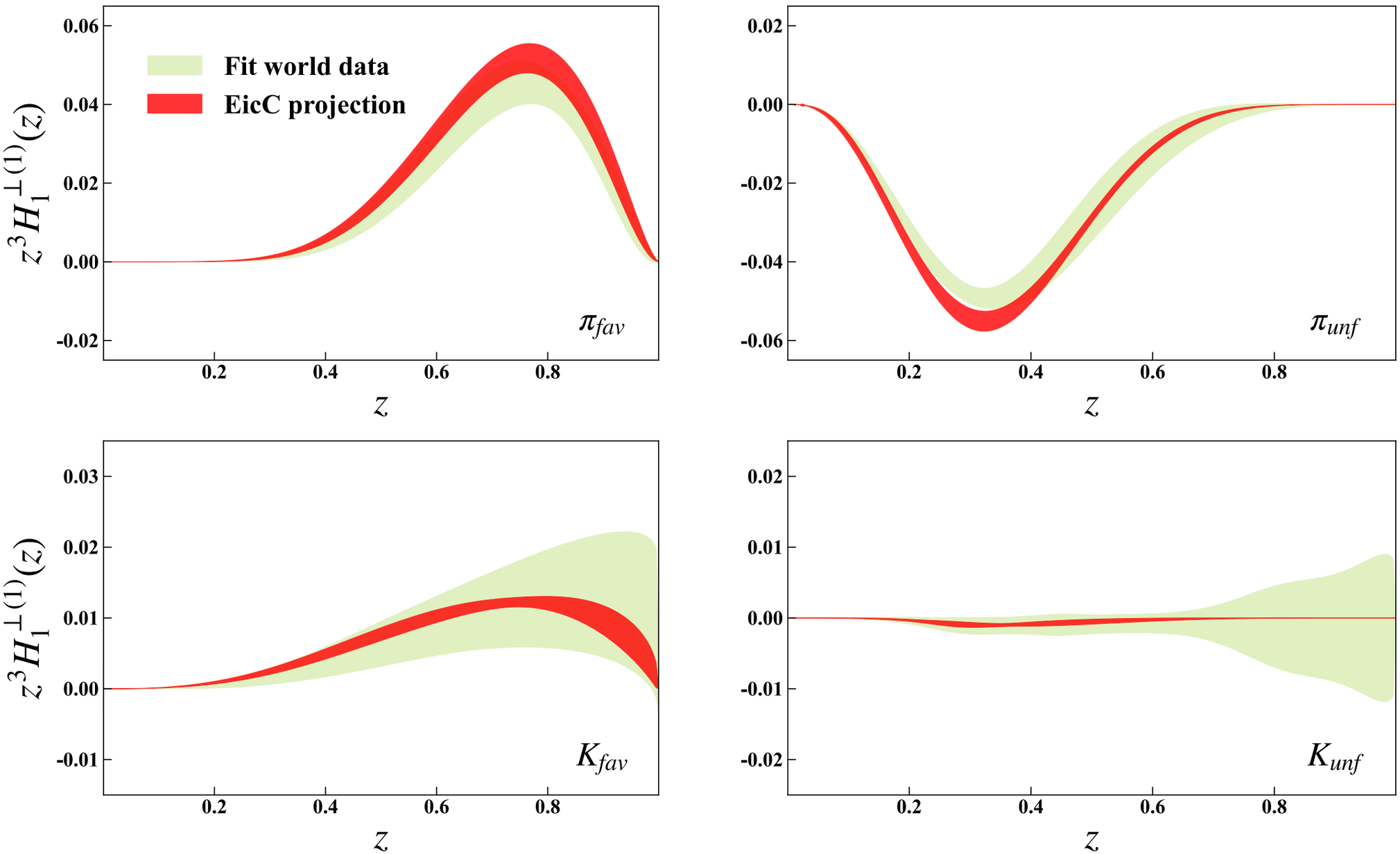
Transverse single spin asymmetry (Collins asymmetry): $A_{UT}^{\sin(\phi_h+\phi_S)} \sim h_1(x,k_T) \otimes H_1(z,p_T)$



C. Zeng, H. Dong, T. Liu, P. Sun, Y. Zhao, PRD 109 (2024) 056002.

Impact Study: Collins Fragmentation

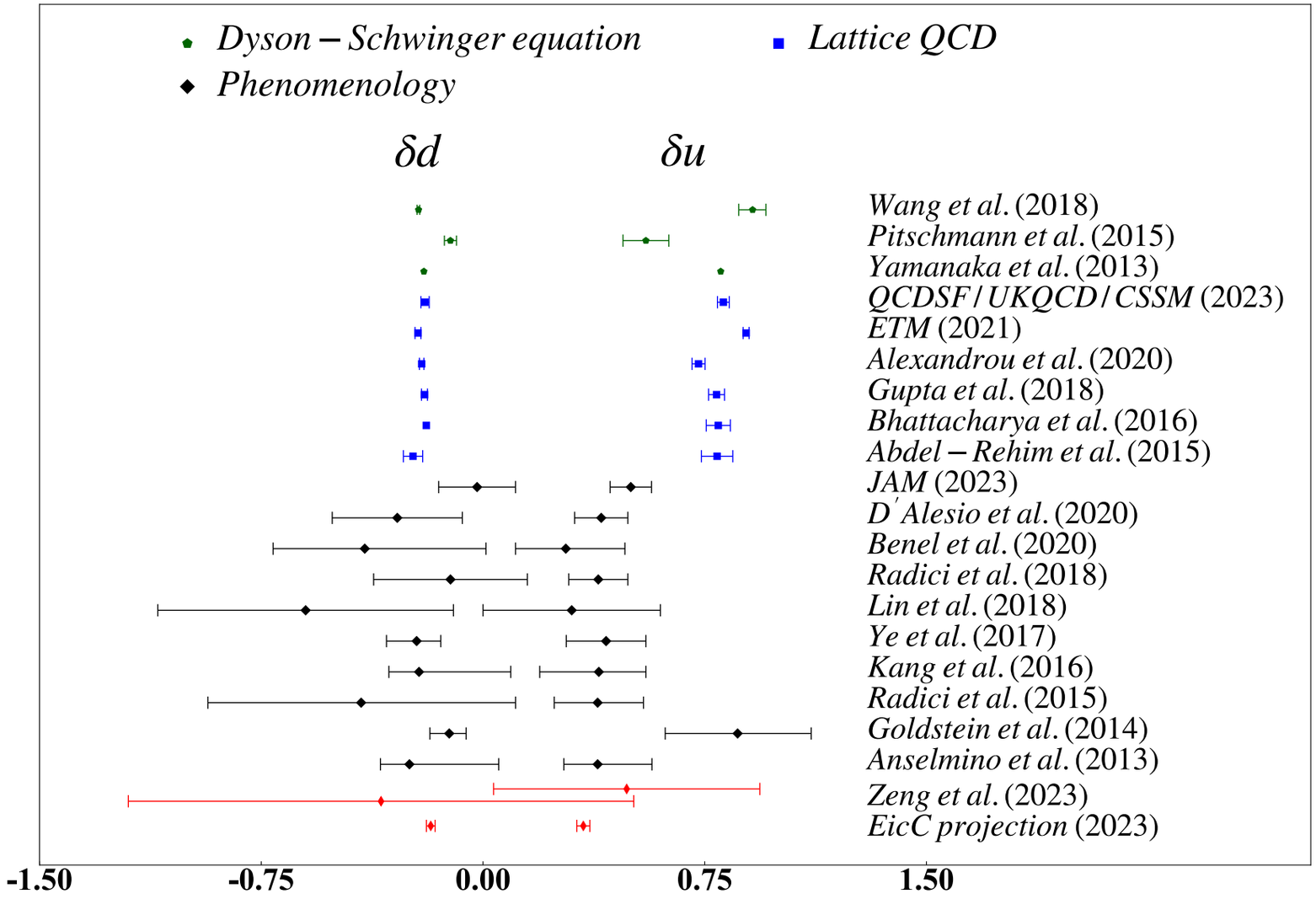
Transverse single spin asymmetry (Collins asymmetry): $A_{UT}^{\sin(\phi_h+\phi_S)} \sim h_1(x,k_T) \otimes H_1(z,p_T)$



C. Zeng, H. Dong, T. Liu, T. Sun, Y. Zhao, PRD 109 (2024) 036002.

Impact Study: Tensor Charge

$$\langle P,S|\bar{\psi}^q i\sigma^{\mu\nu}\gamma_5\psi^q|P,S\rangle = g_T^q \bar{u}(P,S) i\sigma^{\mu\nu}\gamma_5 u(P,S) \qquad g_T^q = \int_0^1 [h_1^q(x) - h_1^{\bar{q}}(x)]\,dx$$



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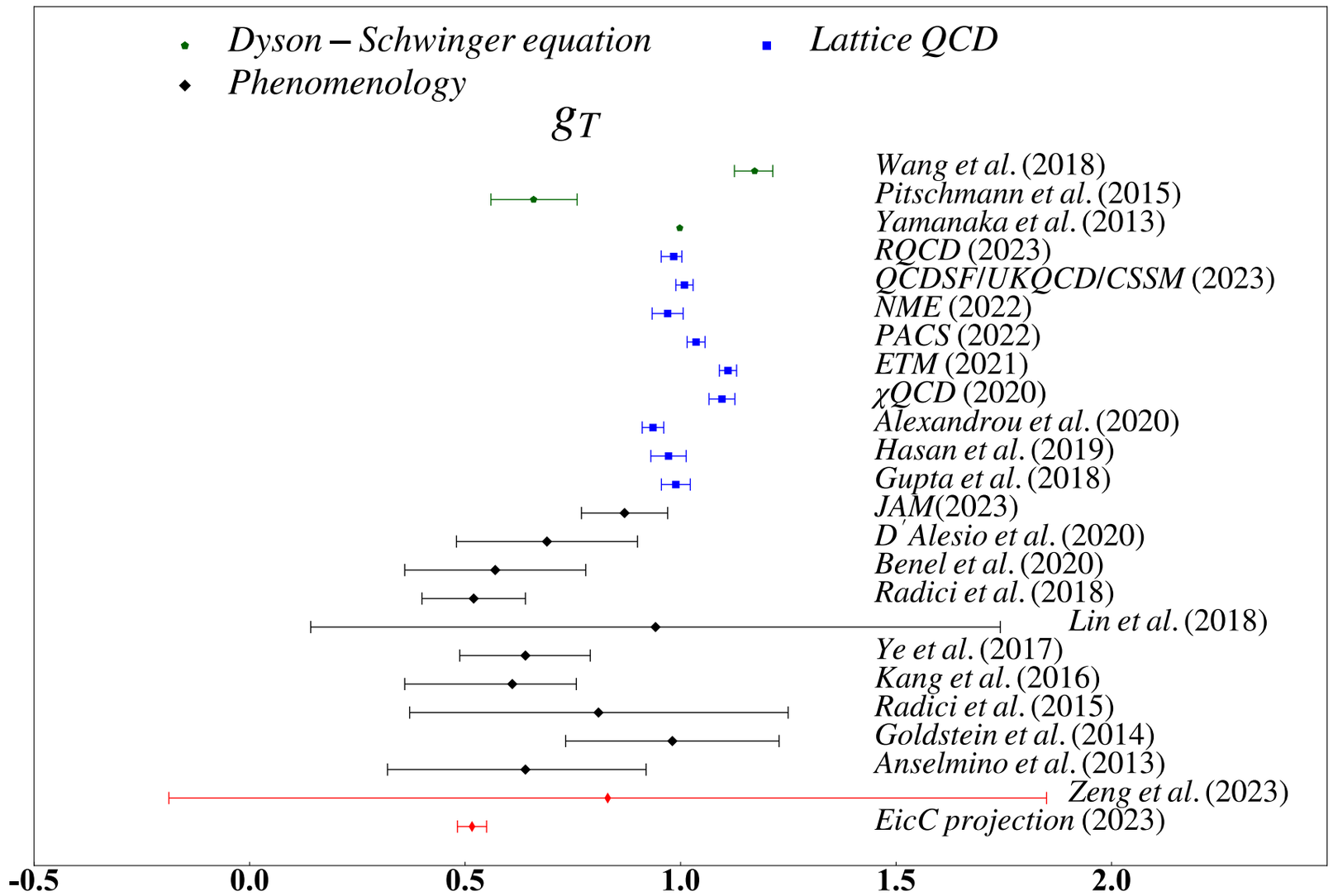
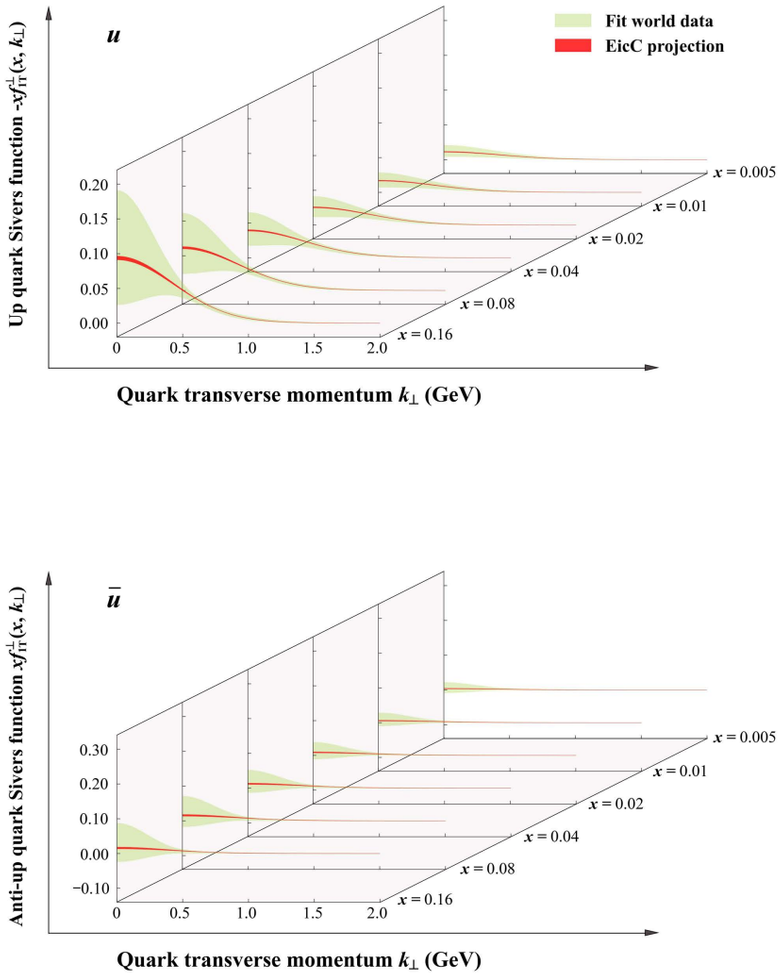
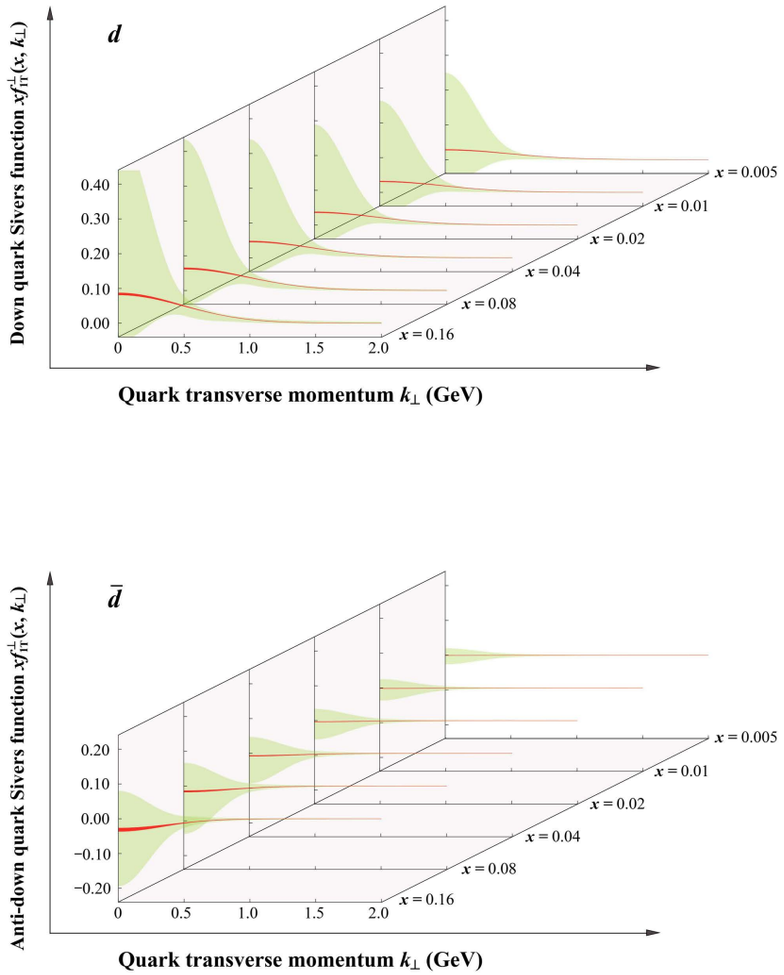


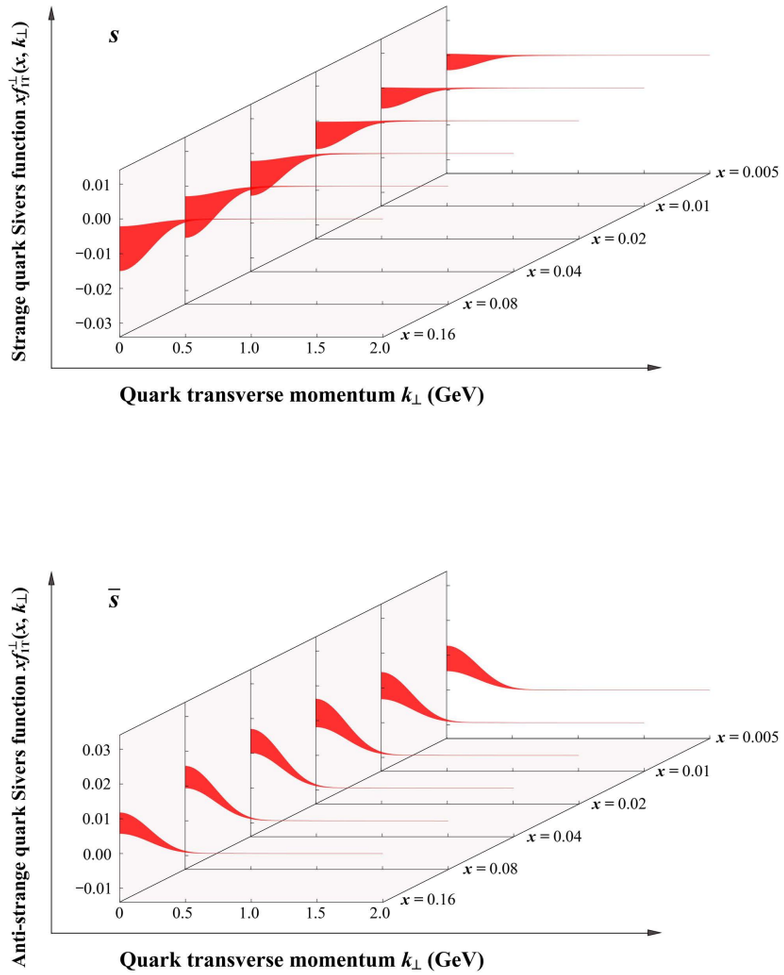
C. Zeng, H. Dong, T. Liu, P. Sun, Y. Zhao, PRD 109 (2024) 056002.

Impact Study: Sivers Function

Transverse single spin asymmetry (Sivers asymmetry): $A_{UT}^{\sin(\phi_h-\phi_S)} \sim f_{1T}^{\perp}(x, k_T) \otimes D_1(z, p_T)$



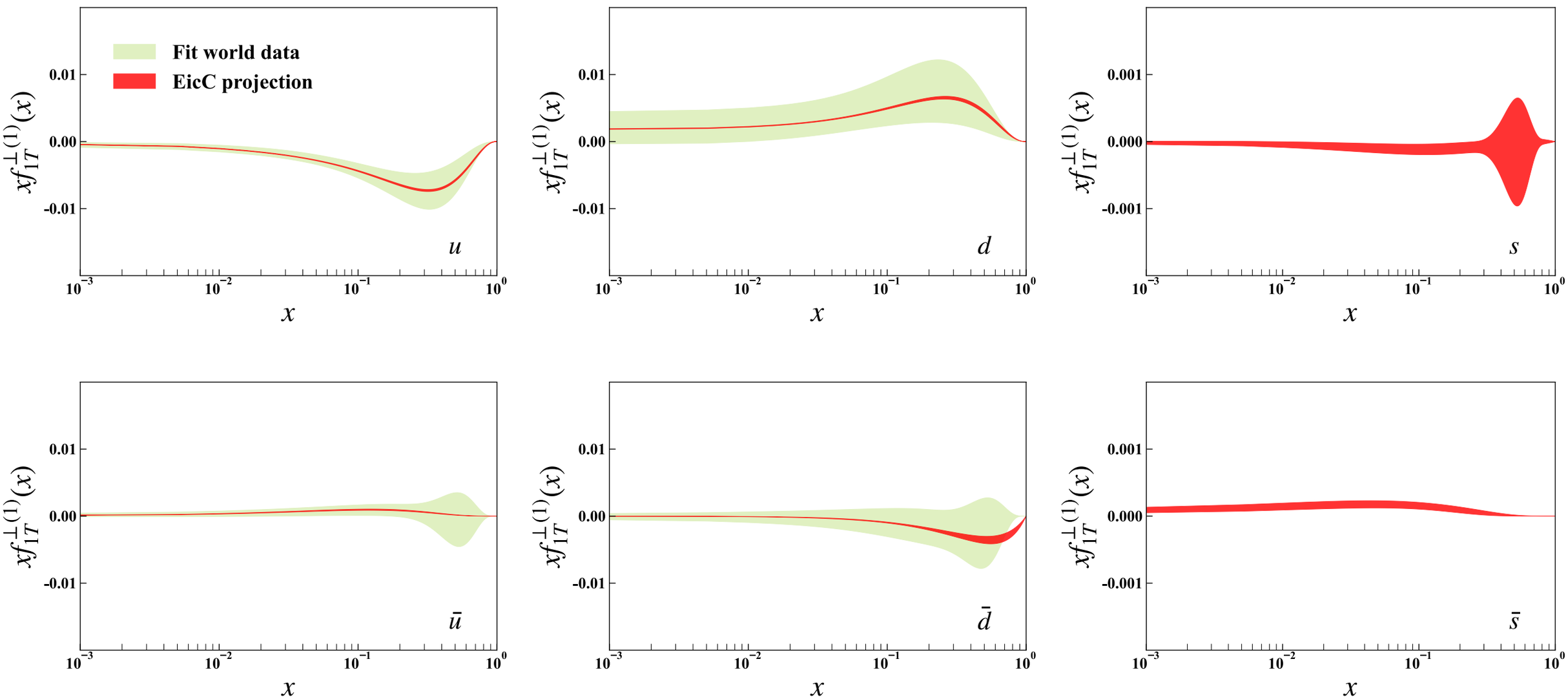




C. Zeng, T. Liu, P. Sun, Y. Zhao, Phys. Rev. D 106 (2022) 094039.

Impact Study: Sivers Function

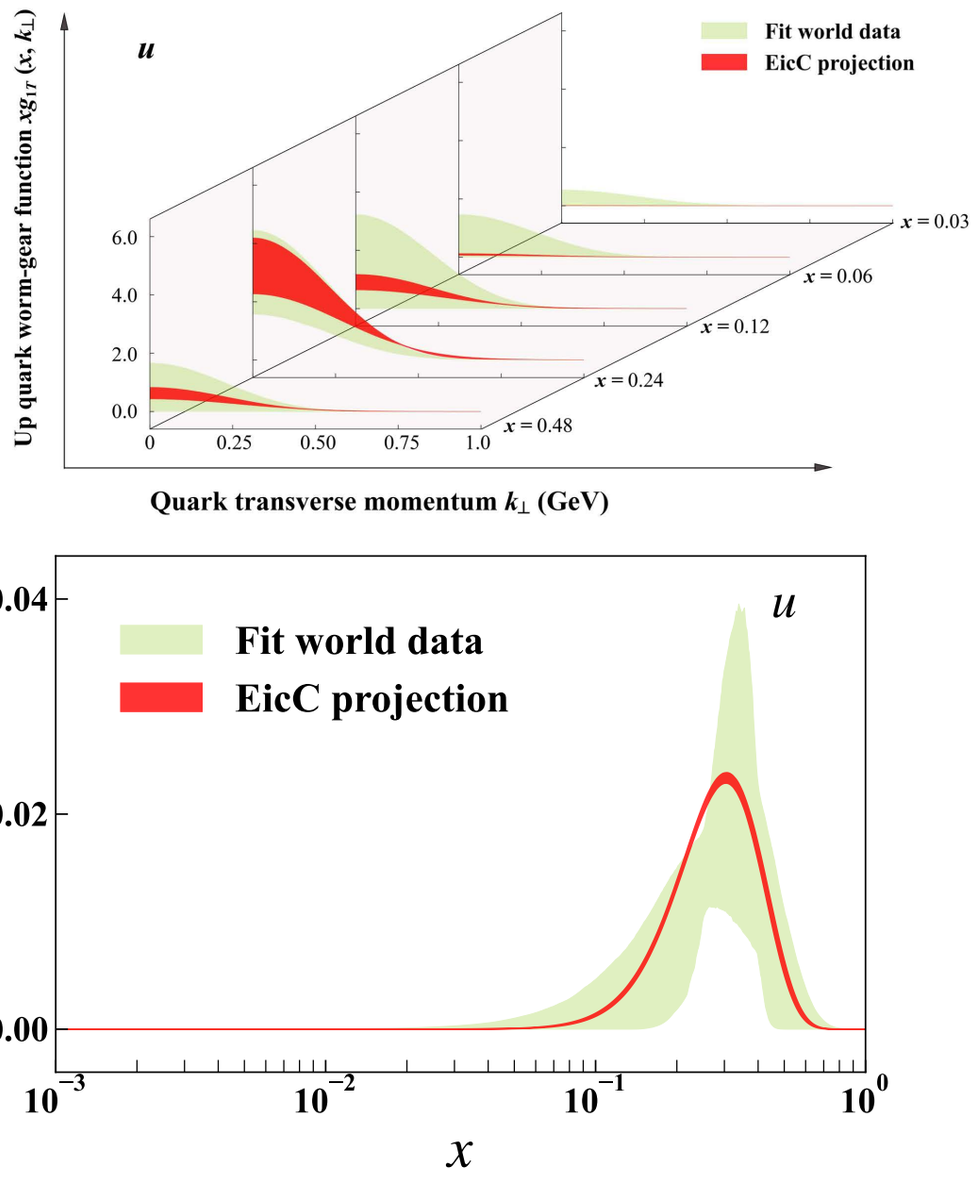
Transverse single spin asymmetry (Sivers asymmetry): $A_{UT}^{\sin(\phi_h-\phi_S)} \sim f_{1T}^{\perp}(x,k_T) \otimes D_1(z,p_T)$

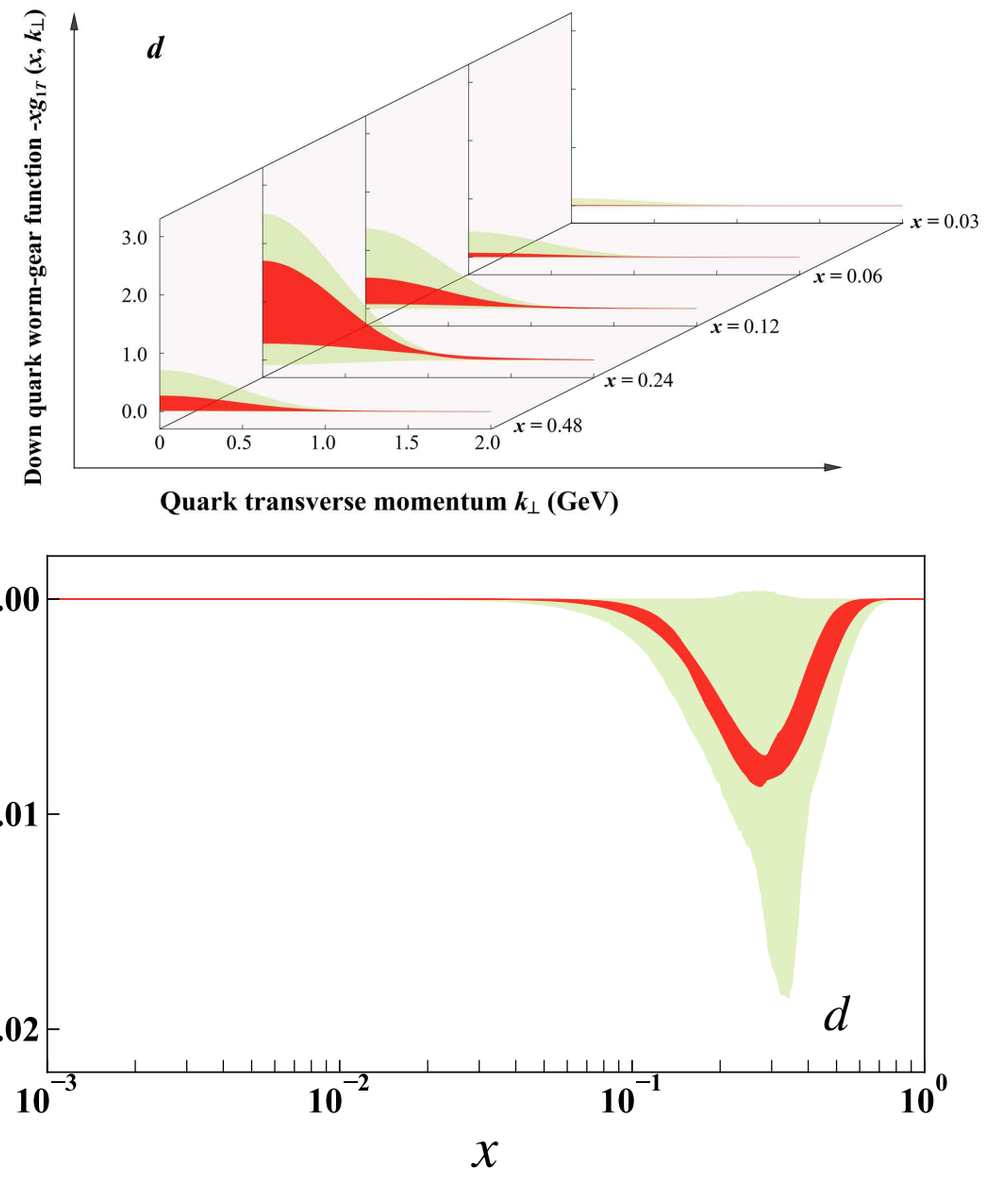


C. Zeng, T. Liu, P. Sun, Y. Zhao, Phys. Rev. D 106 (2022) 094039.

Impact Study: Trans-helicity Distribution

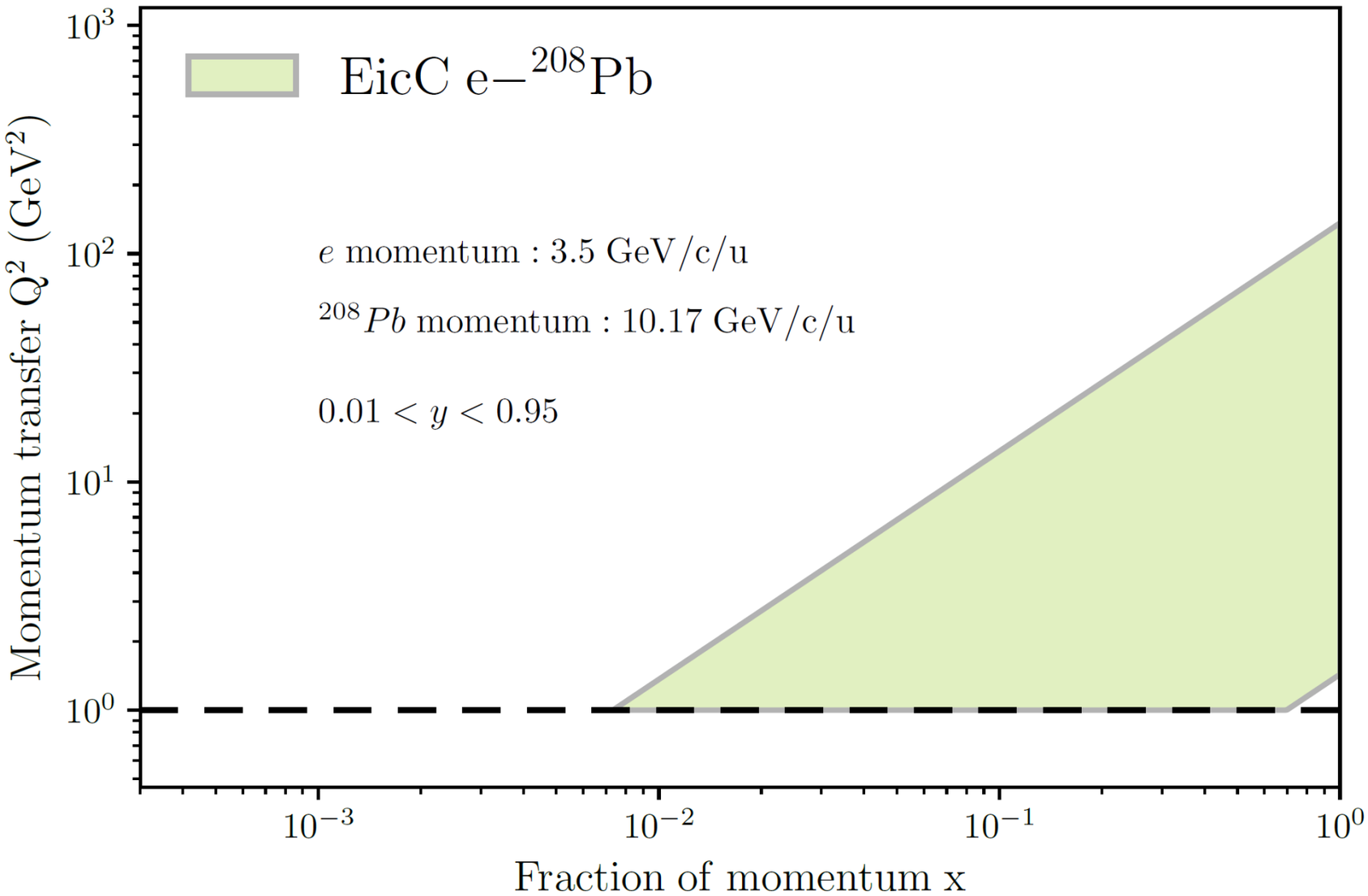
Longitudinal transverse double spin asymmetry: $A_{LT}^{\cos(\phi_h-\phi_S)} \sim g_{1T}^{\perp}(x,k_T) \otimes D_1(z,p_T)$



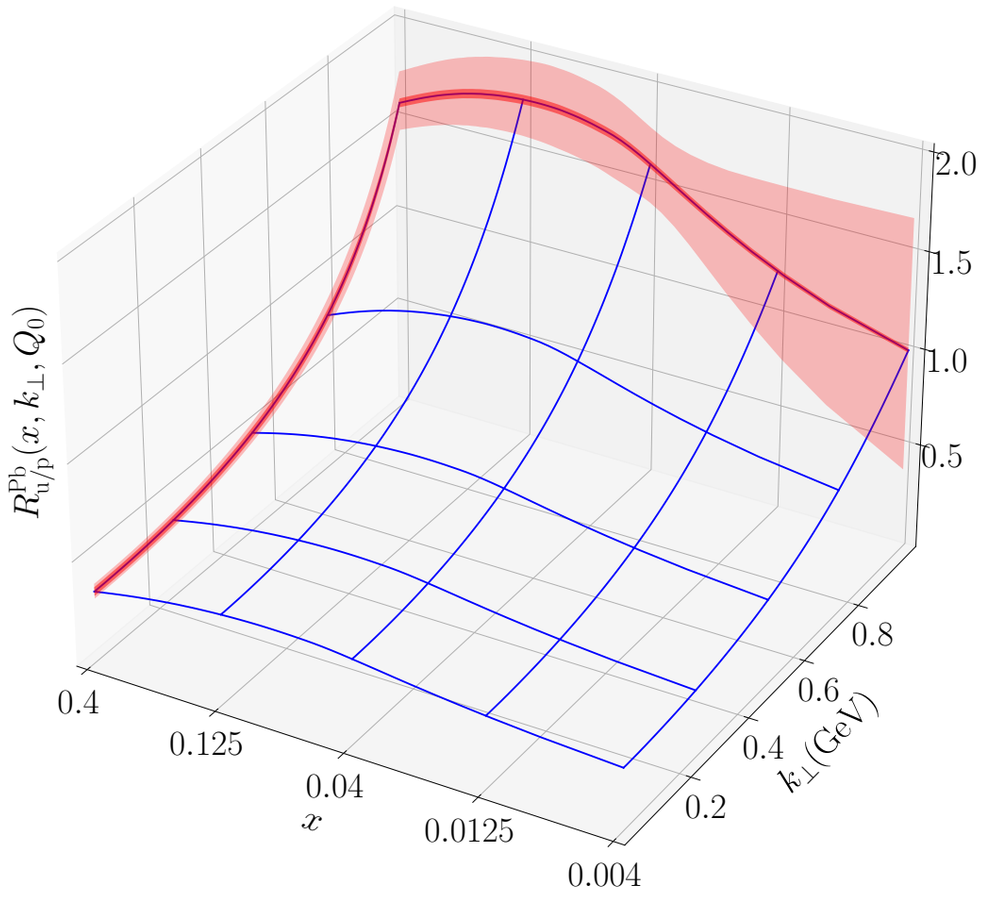


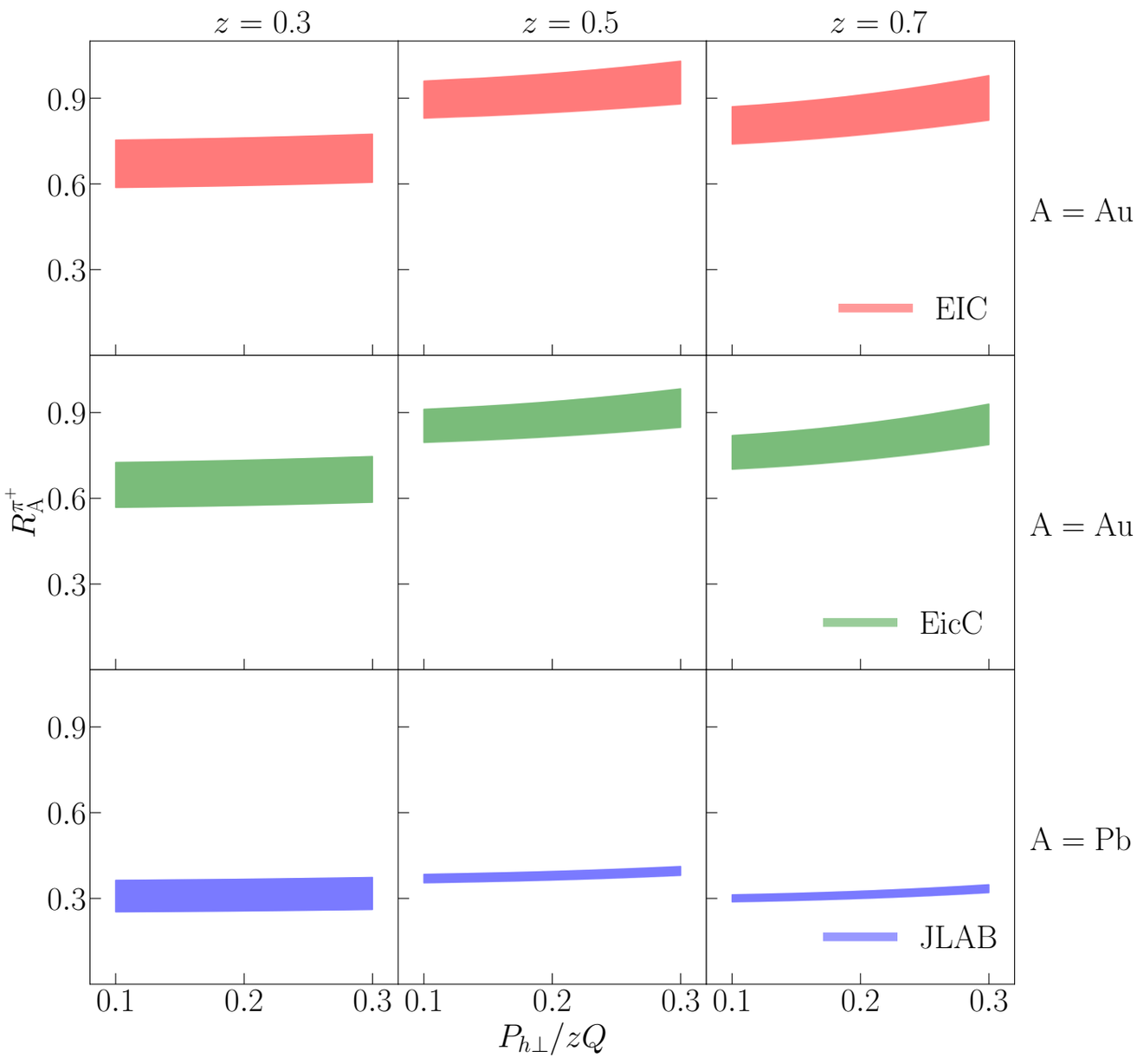
K. Yang, T. Liu, P. Sun, Y. Zhao, B.-Q. Ma, Phys. Rev. D (2024).

eA Collision at EicC



Nuclear TMD PDF



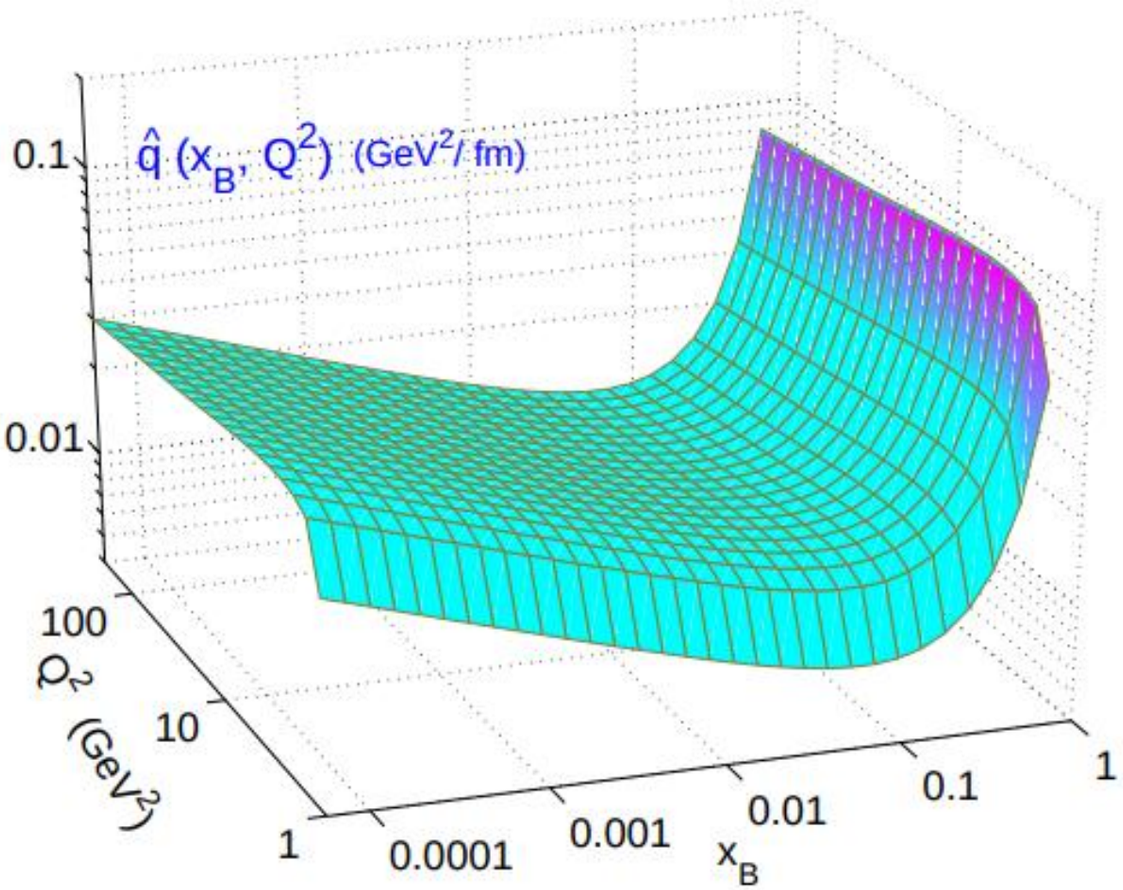


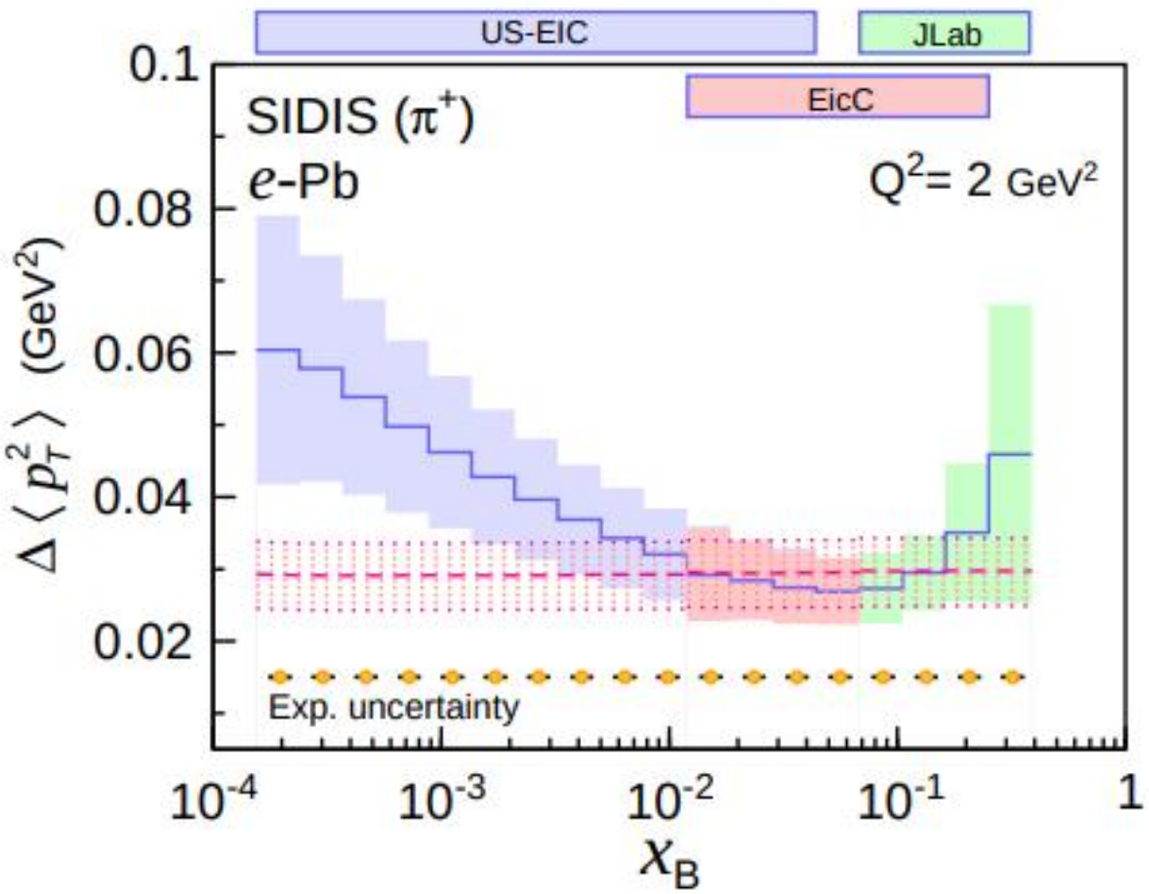
$$R_A^h(x, z, P_{h\perp}) = \frac{M_A^h(x, z, P_{h\perp})}{M_p^h(x, z, P_{h\perp})}$$

M. Alrashed, Z.-B. Kang, J. Terry, H. Xing, C. Zhang, axXiv:2312.09226.

Jet Transport in Nuclear Medium

Jet transport parameter

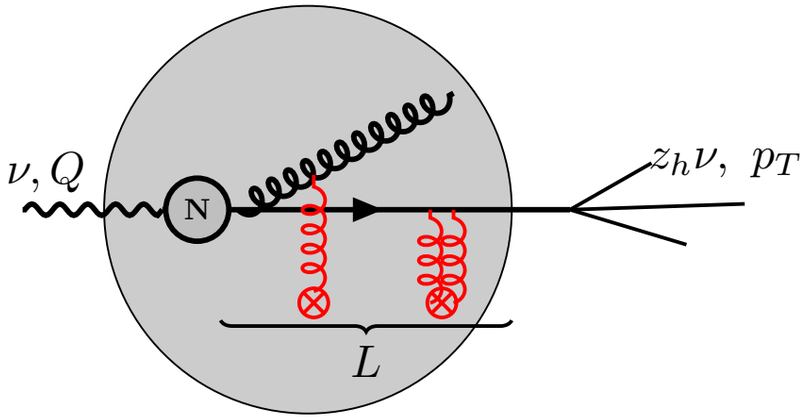


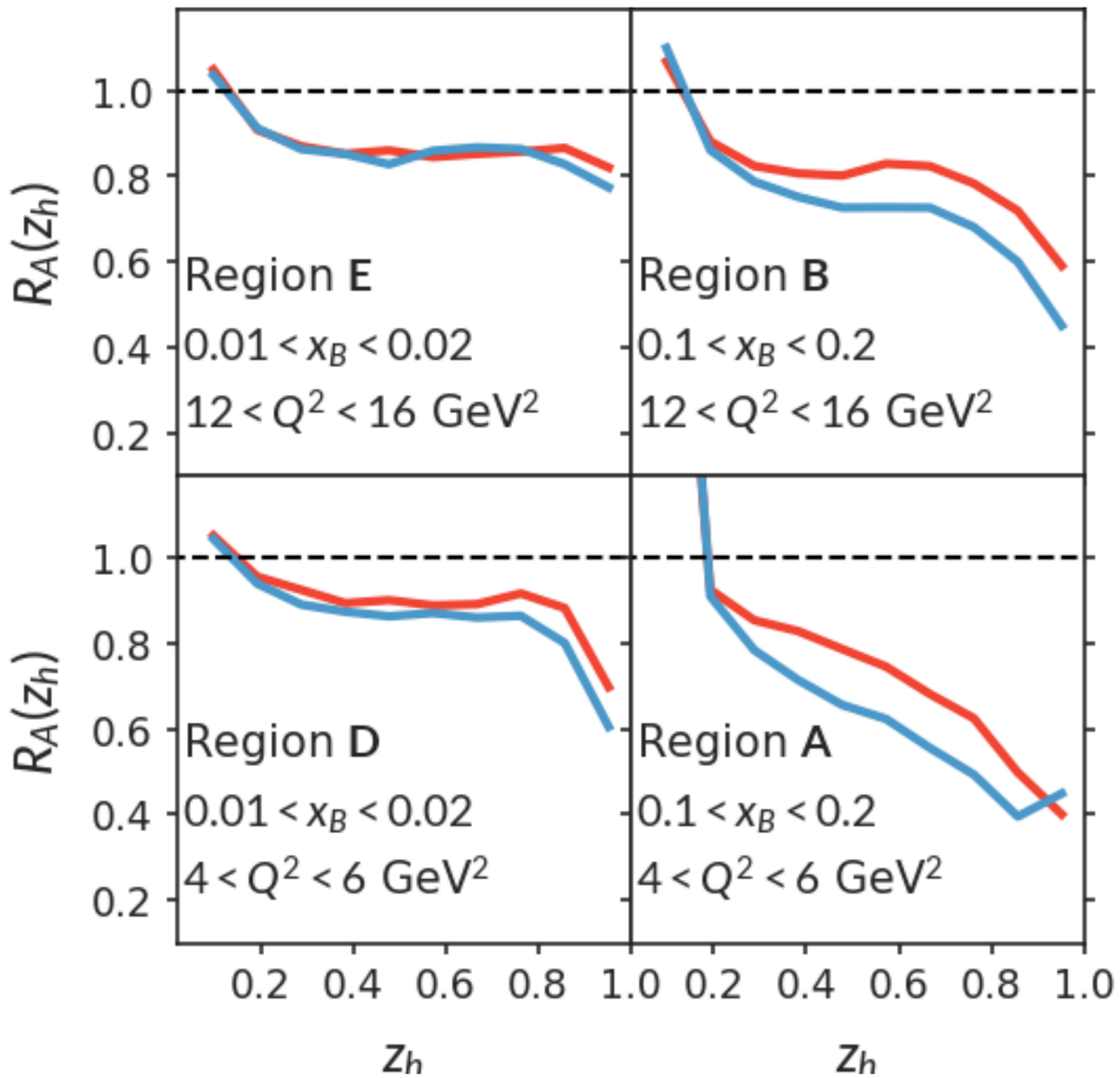


P. Ru, Z.-B. Kang, E. Wang, H. Xing, B.-W. Zhang,
Phys. Rev. D 103 (2021) L031901; arXiv:2302.02329.

Jet Transport in Nuclear Medium

z dependent nuclear medium modification

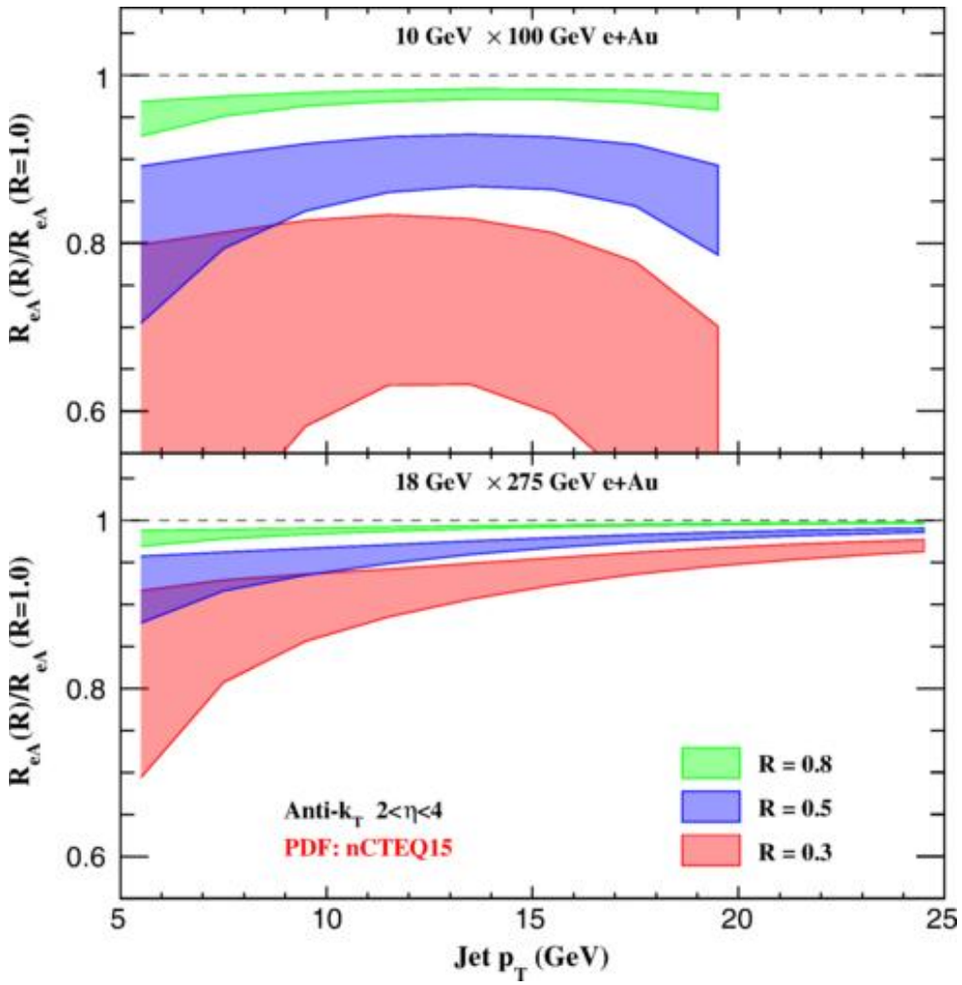




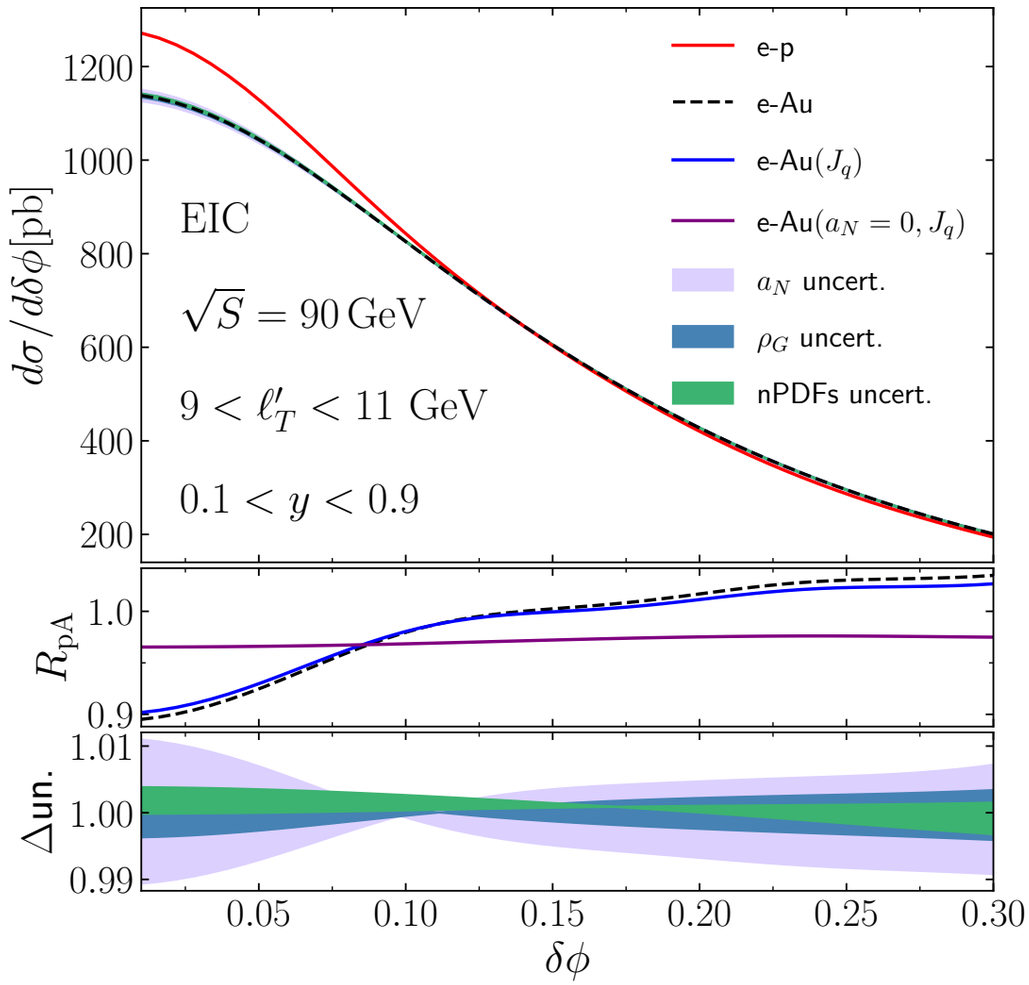
W. Ke, Y.-Y. Zhang, H. Xing, X.-N. Wang, Phys. Rev. D 110 (2024) 034001.

Jet Transport in Nuclear Medium

Nuclear modified jet function



Nuclear modified lepton jet correlation



H. T. Li, I. Vitev, Phys. Rev. Lett. 126 (2021) 252001.

S. Fang, W. Ke, D.Y. Shao, J. Terry, JHEP 05 (2024) 066.

Summary

- Nucleon spin structures:
  - helicity distributions
  - transversity distributions, tensor charges, and Collins fragmentation functions
  - Sivers distribution functions,
  - trans-helicity worm-gear distribution functions
- Cold nuclear effects
  - nuclear PDFs and TMDs
  - jet transport parameter
  - z dependent p_T broadening
  - energy loss

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