EIC impact study on the tensor charge from a QCD global analysis of SSAs

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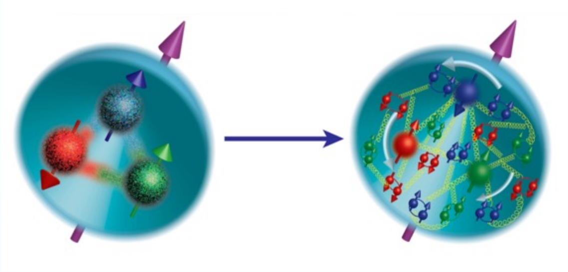
APS GHP 2021

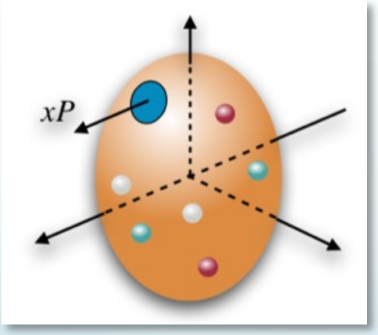
April 14, 2021

Imaging a proton

- Imagine of the proton

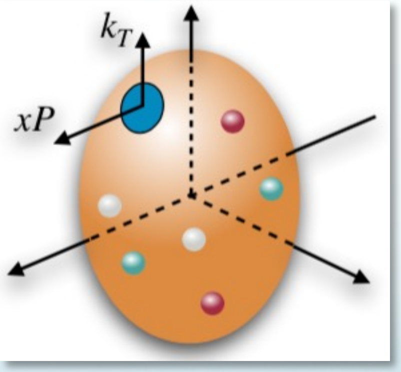


- Nucleon 1D and 3D imaging



$$f(x)$$

Collinear PDFs: Longitudinal motion

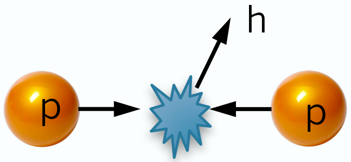


$$f(x, k_T)$$

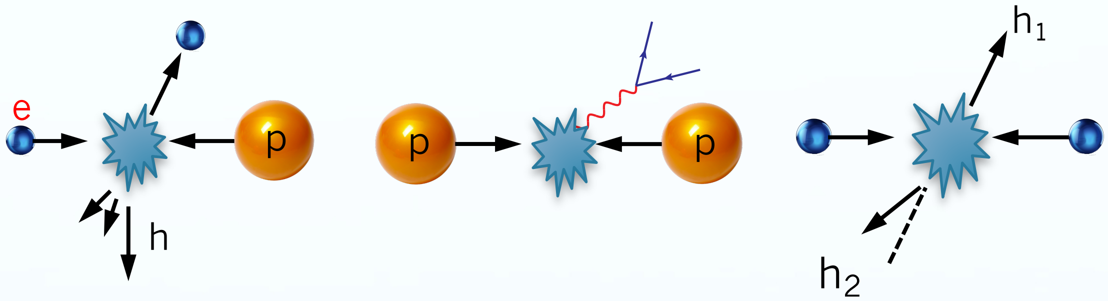
TMDs: Longitudinal + transverse motion

PDFs and TMDs

- They are usually probed in different QCD factorization framework
  - PDFs: process with single hard scale, e.g. $p + p \to h(p_T) + X$



  - TMDs: processes with two scales, e.g. SIDIS, Drell-Yan, and dihedron in e+e-



- However, they are closely related to each other
  - In parton model, related via naïve equation of motion

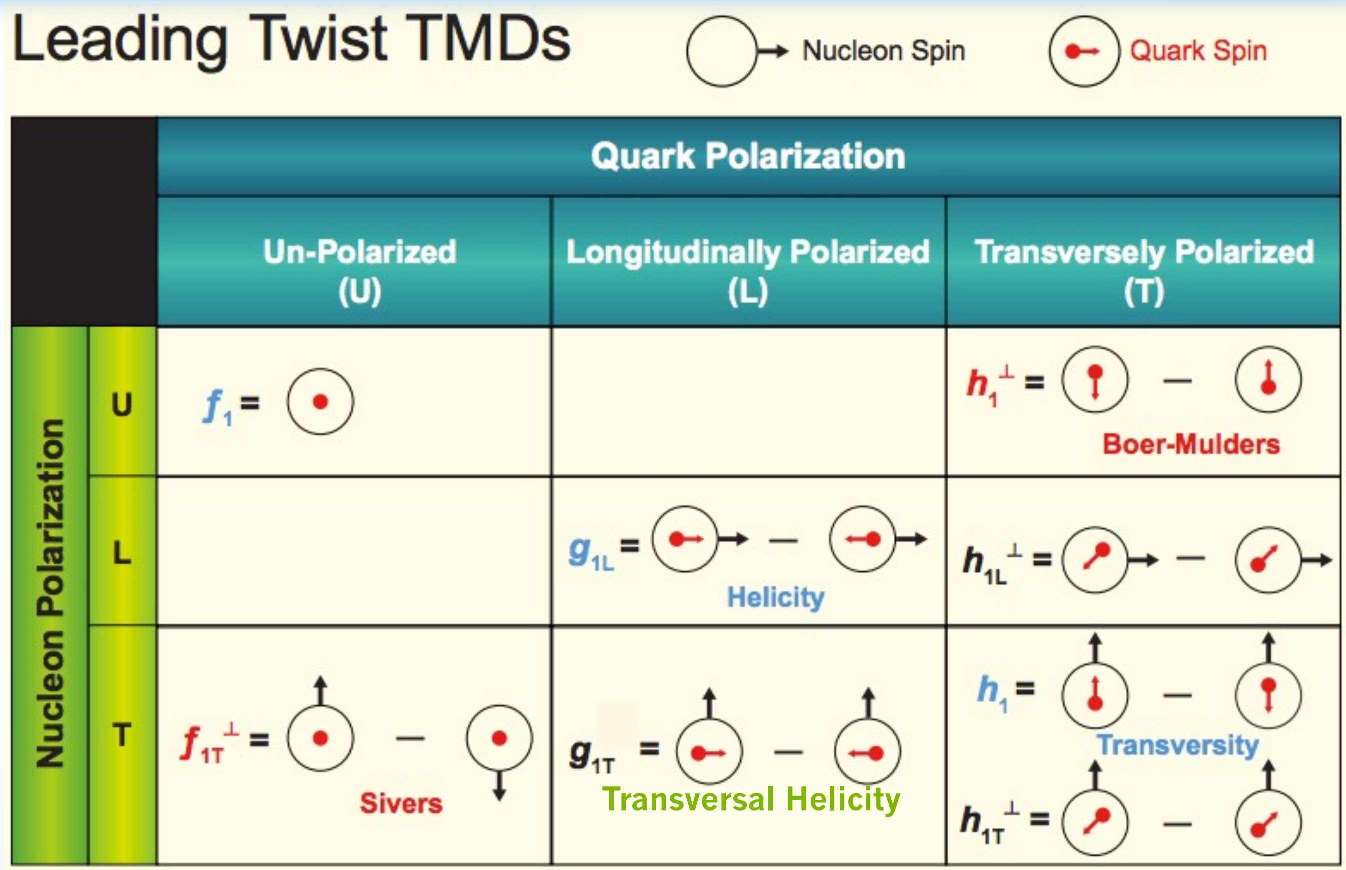
$$f(x) = \int d^2k_T\, f(x, k_T)$$

  - In pQCD, they are related via operator product expansion

$$f(x, k_T) \xrightarrow{k_T \gg \Lambda_{\rm QCD}} C(x, k_T) \otimes f(x)$$

Applying to all relevant TMDs and corresponding collinear functions

TMD parton distribution

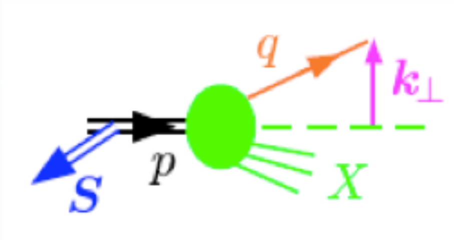


TMD fragmentation function

	Quark Polarization U	L	T
Pion	D_1		$H_1^\perp$ **Collins**

Examples: parton model

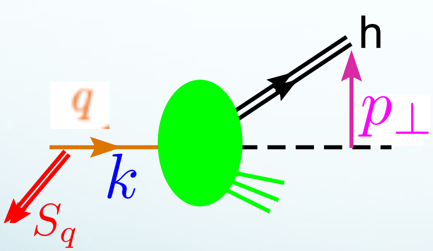
- Sivers function and Qiu-Sterman function (collinear twist-3)



$$f_{q/h^\uparrow}(x,\mathbf{k}_\perp,\vec{S}) \equiv f_{q/h}(x,k_\perp) - \frac{1}{M} f_{1T}^{\perp q}(x,k_\perp)\,\vec{S}\cdot(\hat{p}\times\mathbf{k}_\perp)$$

$$\pi F_{FT}(x,x) = \int d^2\vec{k}_T \,\frac{k_T^2}{2M^2} f_{1T}^{\perp}(x,k_T^2) \equiv f_{1T}^{\perp(1)}(x)$$

- Collins function and collinear twist-3 fragmentation function

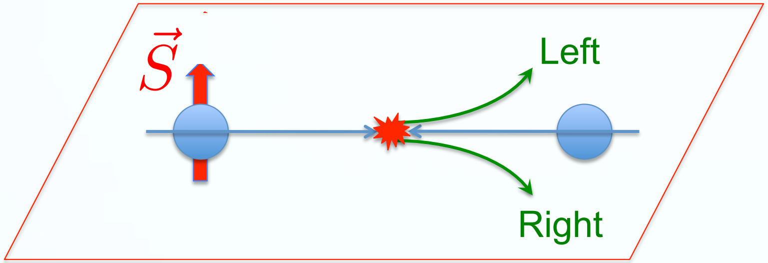


$$D_{h/q}(z,p_\perp) = D_1^q(z,p_\perp^2) + \frac{1}{zM_h} H_1^{\perp q}(z,p_\perp^2)\vec{S}_q\cdot\left(\hat{k}\times p_\perp\right)$$

$$H_1^{\perp(1)}(z) \equiv z^2\int d^2\vec{p}_\perp \,\frac{p_\perp^2}{2M_h^2} H_1^{\perp}(z,z^2p_\perp^2)$$

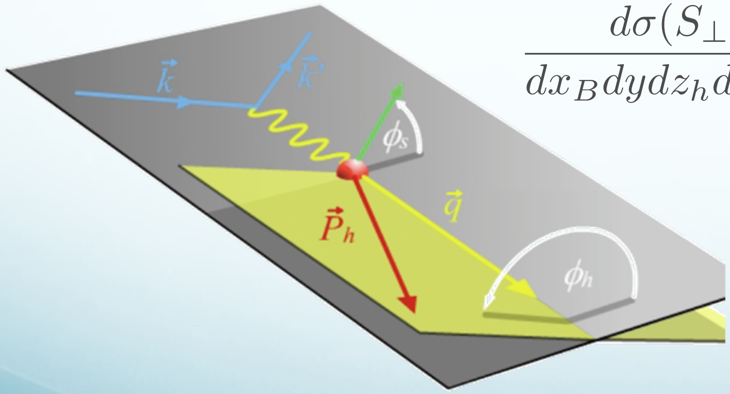
Early naïve test

- Extracting Qiu-Sterman function from $p + p \to h(p_T) + X$
  - Assuming A_N is fully generated from Qiu-Sterman mechanism



$$A_N \equiv \frac{L - R}{L + R} = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow}$$

- Extracting Sivers function from SIDIS process

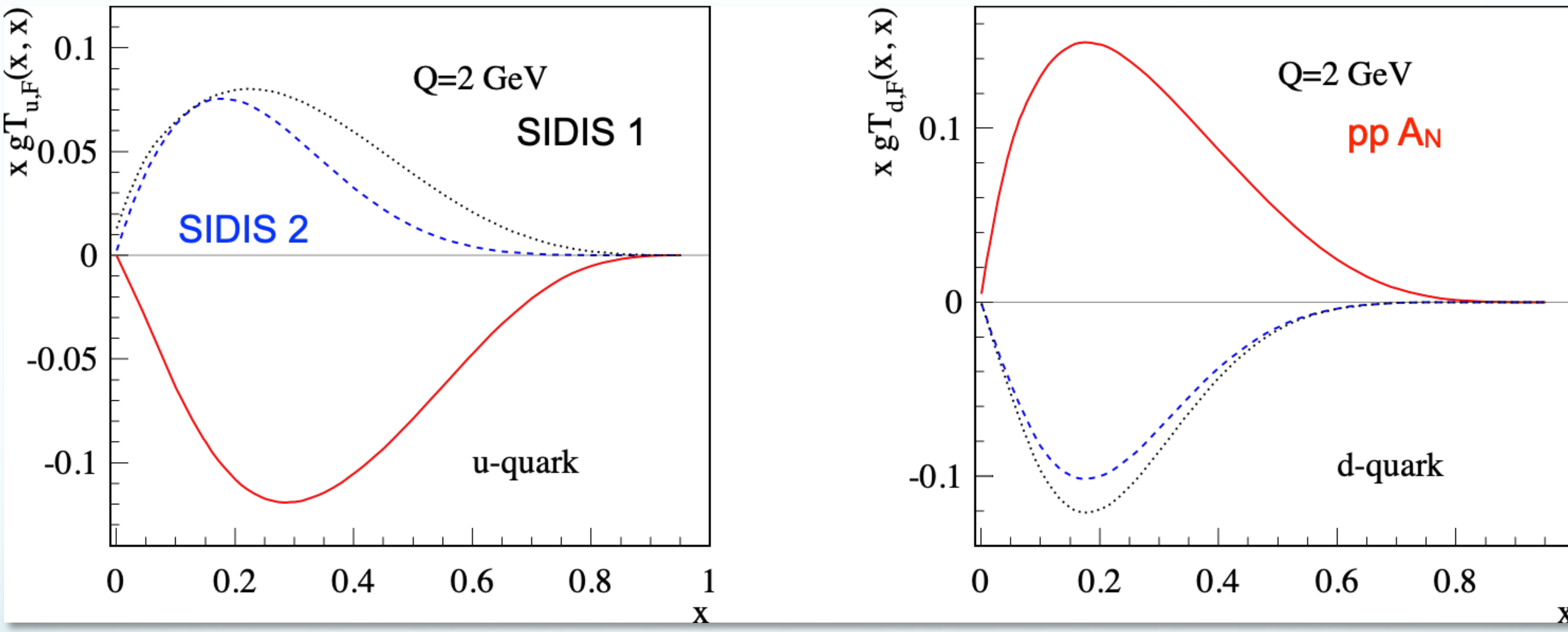


$$\frac{d\sigma(S_\perp)}{dx_B dy dz_h d^2 P_{h\perp}} = \sigma_0(x_B, y, Q^2) \left[F_{UU} + \sin(\phi_h - \phi_s)\, F_{UT}^{\sin(\phi_h - \phi_s)} + \ldots \right]$$

Sign mismatch

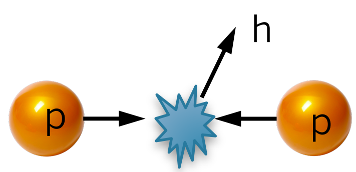
- Seems not being consistent with parton model relation

Kang, Qiu, Vogelsang, Yuan, 2010



Towards solving sign mismatch puzzle

- People quickly realized that twist-3 fragmentation functions also contribute to pp A_N (besides Qiu-Sterman contribution)
  - Early results by Kang, Yuan, Zhou, Koike, Metz, Pitonyak, Gamberg, Prokudin, ...
  - One always wonders if it is possible to perform a global analysis to include SIDS, Drell-Yan, e+e-, and pp A_N data
  - It took several years to get it done due to the hard work of Pitonyak, Sato, Prokduin, Gamberg, and others

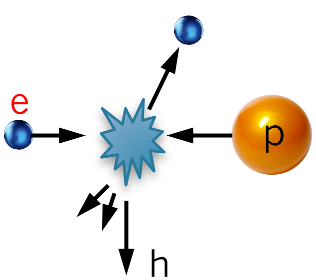


$f_{1T}^{\perp(1)}(x)$

$h_1(x) \otimes H_1^{\perp(1)}(z)$

Cammarota, Gamberg, Kang, Miller, Pitonyak, Prokudin, Rogers, Sato arXiv: 2002.08384, PRD

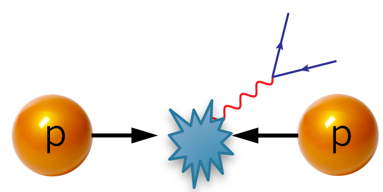
SIDIS Sivers, Collins



$f_{1T}^{\perp}(x, k_T)$

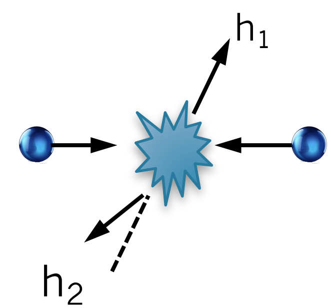
$h_1(x, k_T) \otimes H_1^{\perp}(z, p_T)$

DY Sivers



$f_{1T}^{\perp}(x, k_T)$

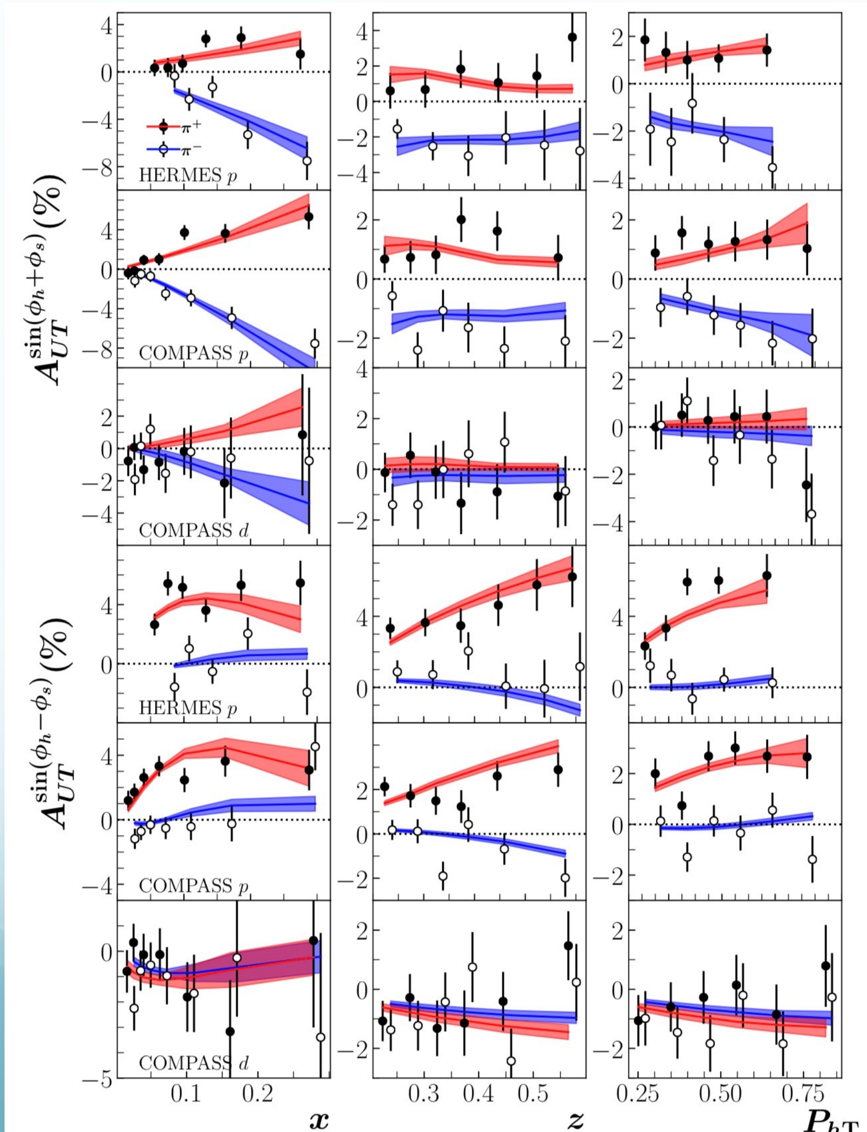
e+e- Collins

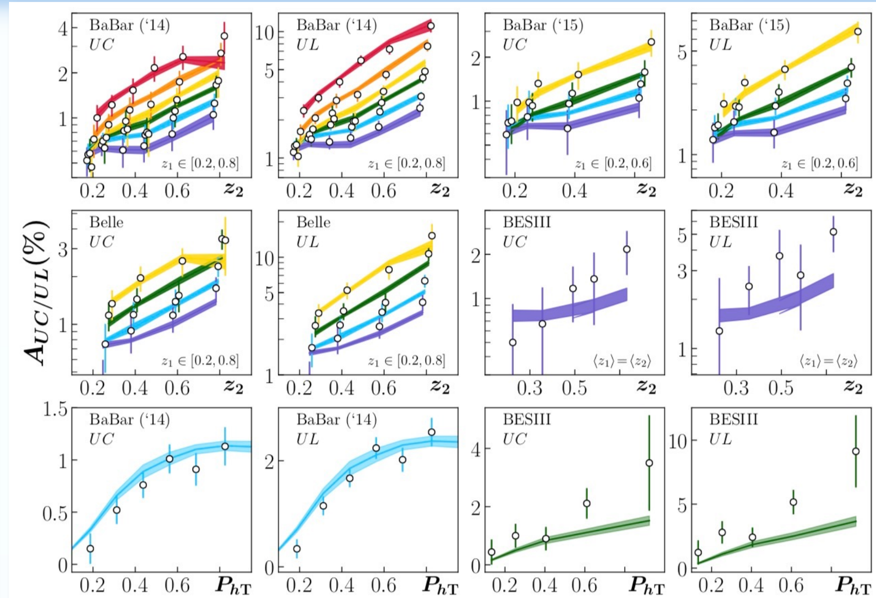


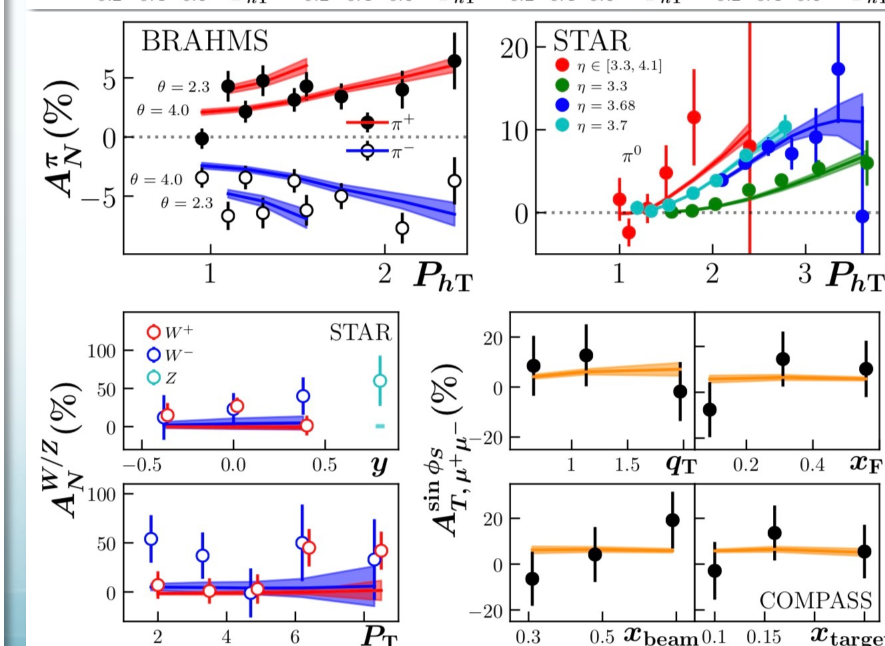
$H_1^{\perp}(z, p_T)$

Global fit

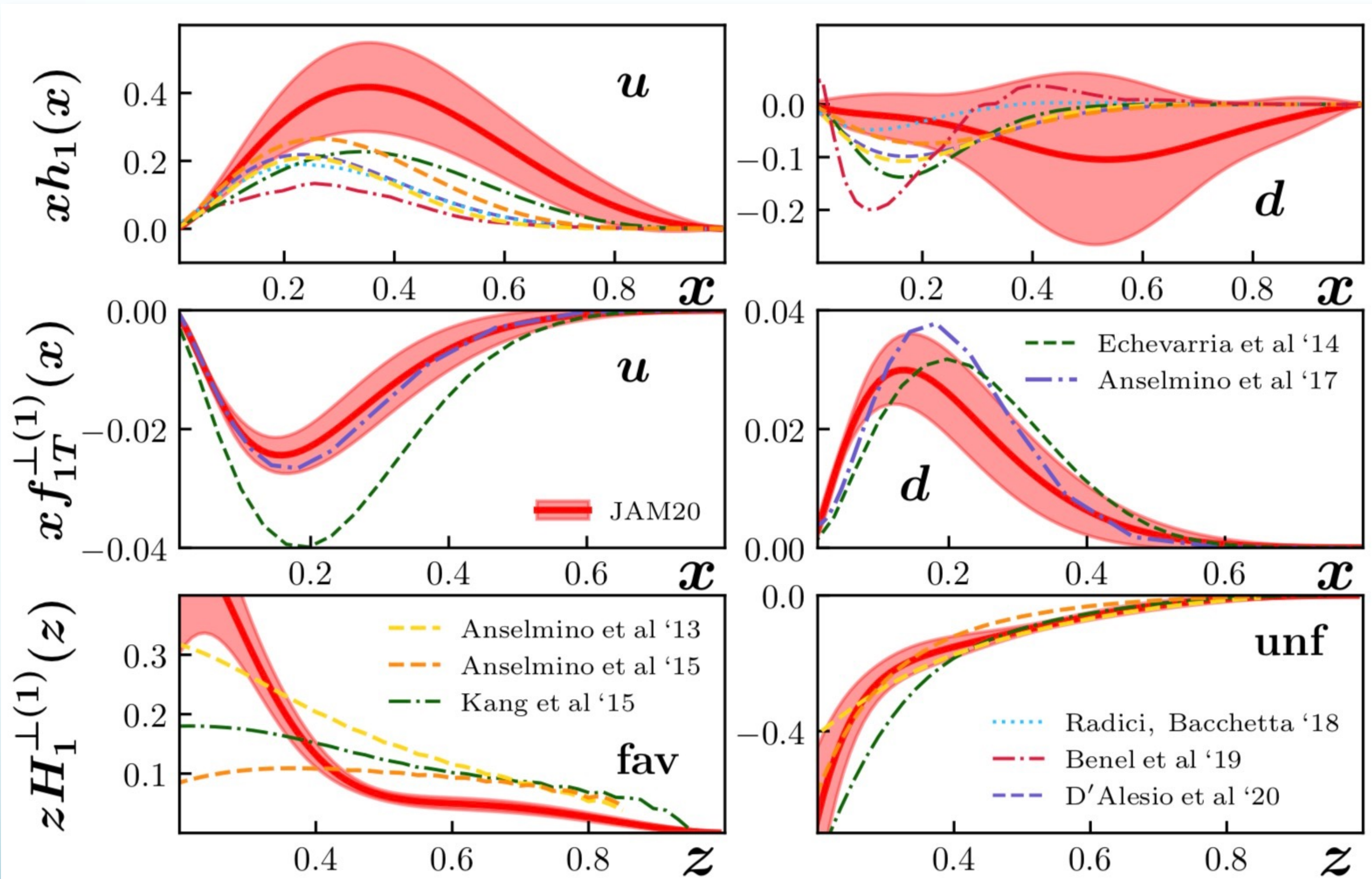
$$\chi^2/N_{\mathrm{pts.}} = 520/517 = 1.01$$







Extracted functions



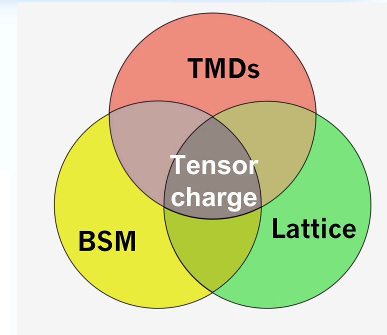
transversity

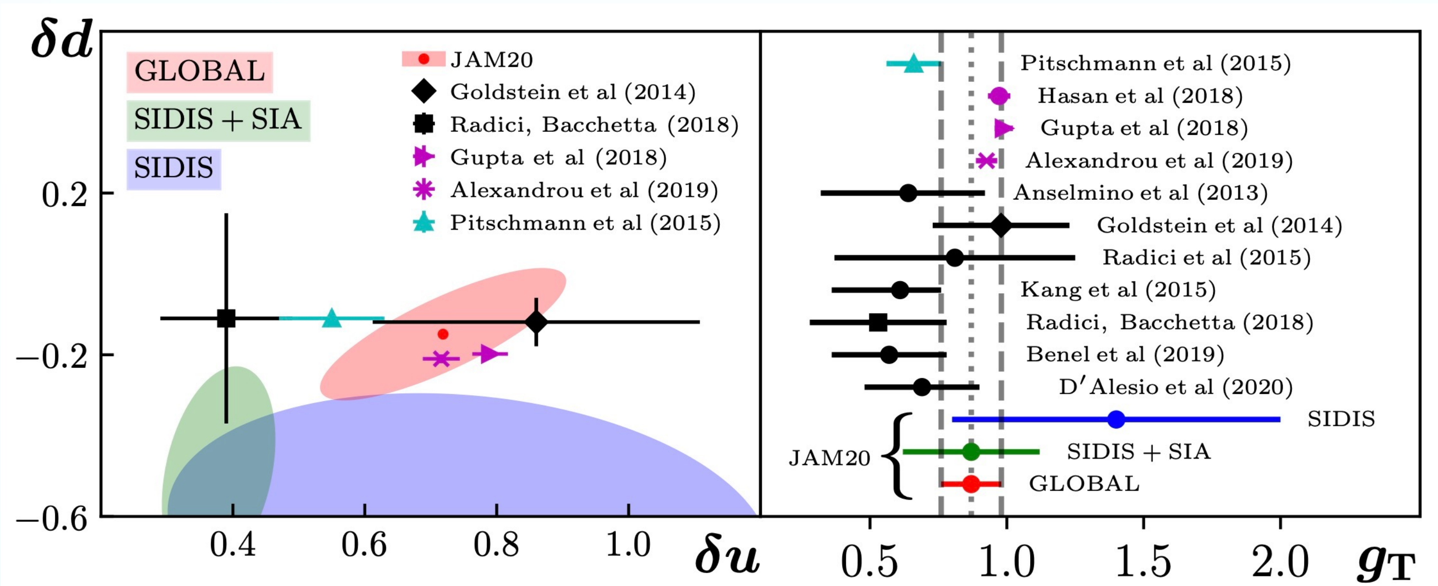
Qiu-Sterman function [Sivers first moment]

Twist-3 FFs [Collins first moment]

Tensor charge

$$\delta q = \int_0^1 dx\,\left[h_1^q(x) - h_1^{\bar{q}}(x)\right] \qquad g_T = \delta u - \delta d$$





$$\text{SIDIS} \rightarrow (\text{SIDIS} + \text{SIA}) \rightarrow \text{GLOBAL} : g_T = 1.4(6) \rightarrow 0.87(25) \rightarrow \mathbf{0.87(11)}$$

- Precision significantly improves by including A_N data
- Agreement with lattice, especially δu

$$\delta u = 0.72(19),\ \delta d = -0.15(16)$$

- Uncertainty still larger (*100% for d*) than lattice, can be further improved via EIC or SoLID@JLab

EIC impact study

- Pseudo-data generated by R. Seidl

Gamberg, Kang, Prokuin, Sato, Seidl, arXiv: 2101.06200, PLB in press

$$0.2 < z < 0.6, \quad Q^2 > 1.63\ \mathrm{GeV}^2, \quad 0.2 < P_{hT} < 0.9\ \mathrm{GeV}$$

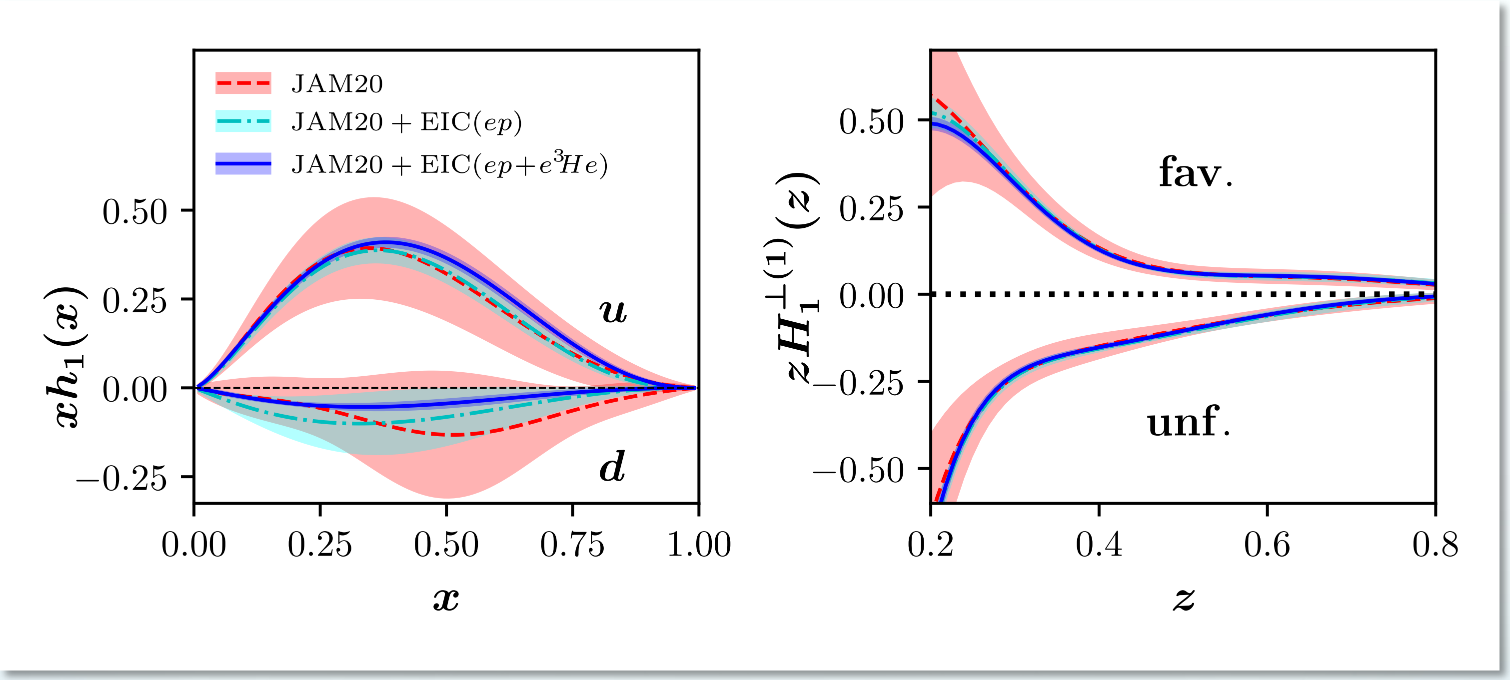
EIC Pseudo-data

Observable	**Reactions**	**CM Energy ($\sqrt{S}$)**	**$N_{\text{pts.}}$**
Collins (SIDIS)	$e + p^\uparrow \to e + \pi^\pm + X$	141 GeV	756 (π^+) 744 (π^-)
		63 GeV	634 (π^+) 619 (π^-)
		45 GeV	537 (π^+) 556 (π^-)
		29 GeV	464 (π^+) 453 (π^-)
	$e + {}^3He^\uparrow \to e + \pi^\pm + X$	85 GeV	647 (π^+) 650 (π^-)
		63 GeV	622 (π^+) 621 (π^-)
		29 GeV	461 (π^+) 459 (π^-)
		Total EIC $N_{\text{pts.}}$	**8223**

- Polarization 70%
- Each beam energy accumulated luminosity 10 fb^{-1}
- PythiaeRHIC, eic-smear package

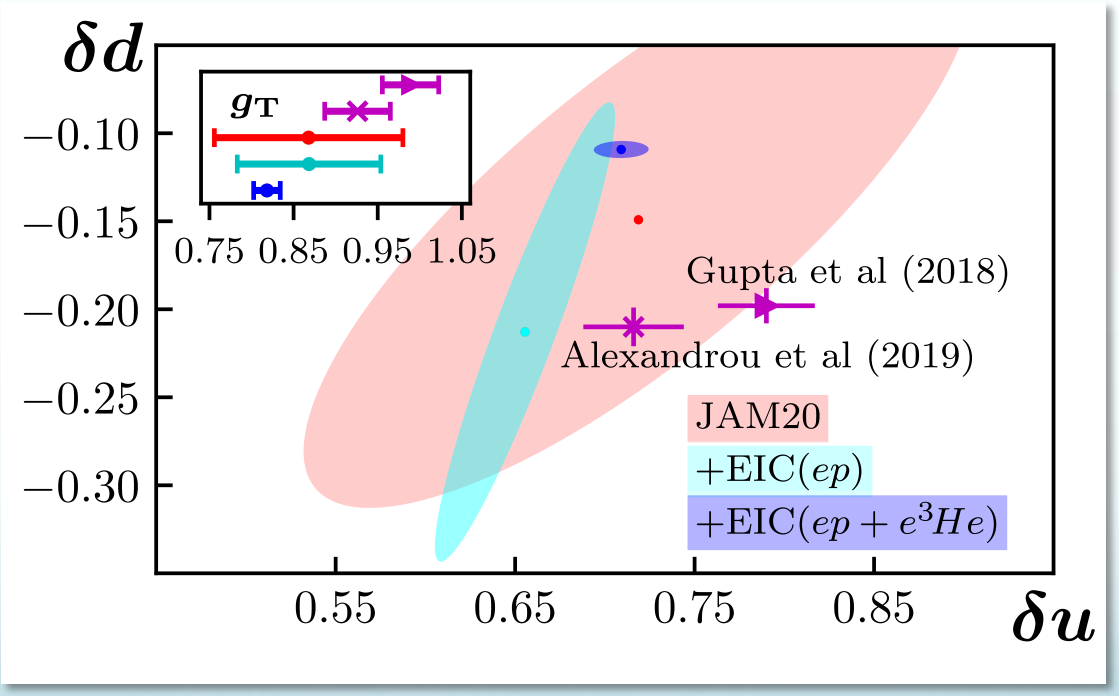
Impact of EIC data on TMDs

- EIC data will significantly reduce the uncertainties in the extracted transversity (and Collins function)



EIC impact on tensor charge

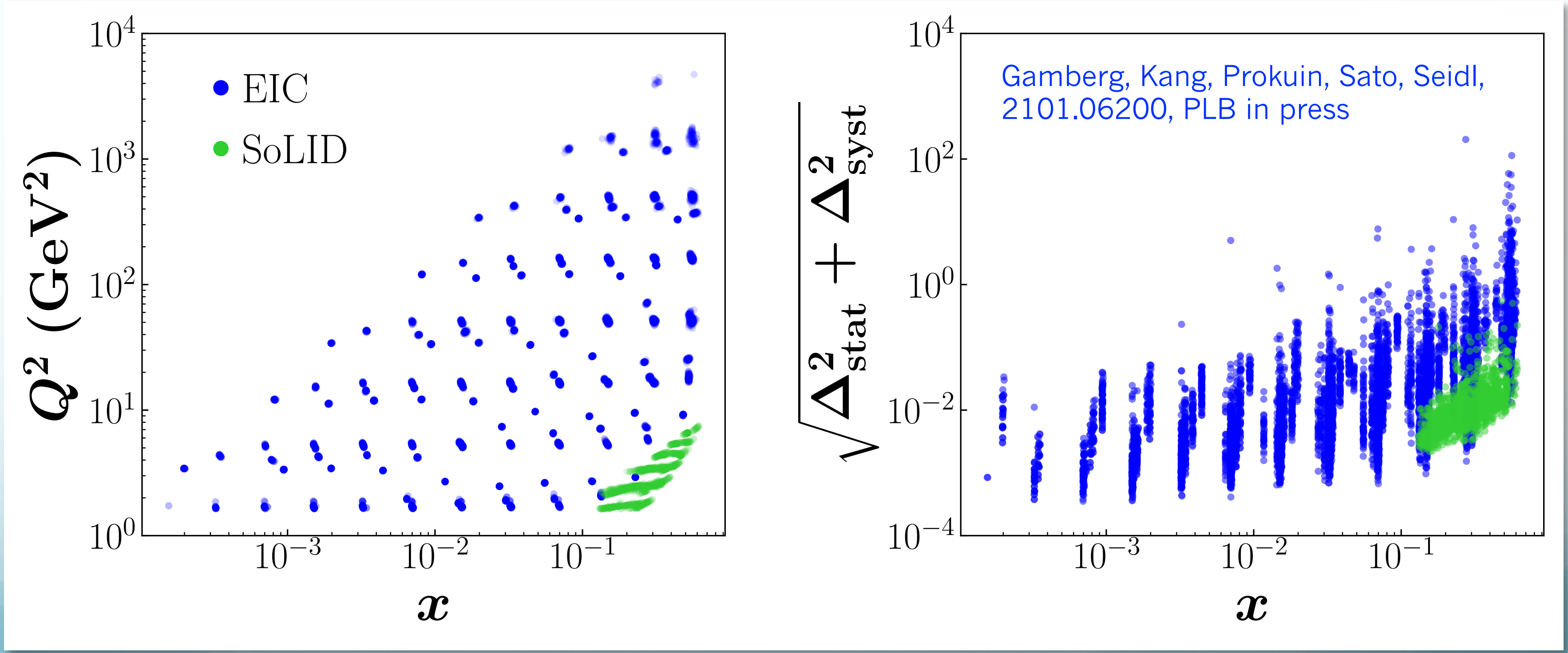
- EIC data would allow extraction of tensor charge to be on the similar precision as lattice results
  - With e+p would allow extraction of δu to be closer to lattice
  - With both e+p and e+He3, the phenomenological extraction of both u and d tensor charges are comparable to lattice



A few words on EIC + SoLID

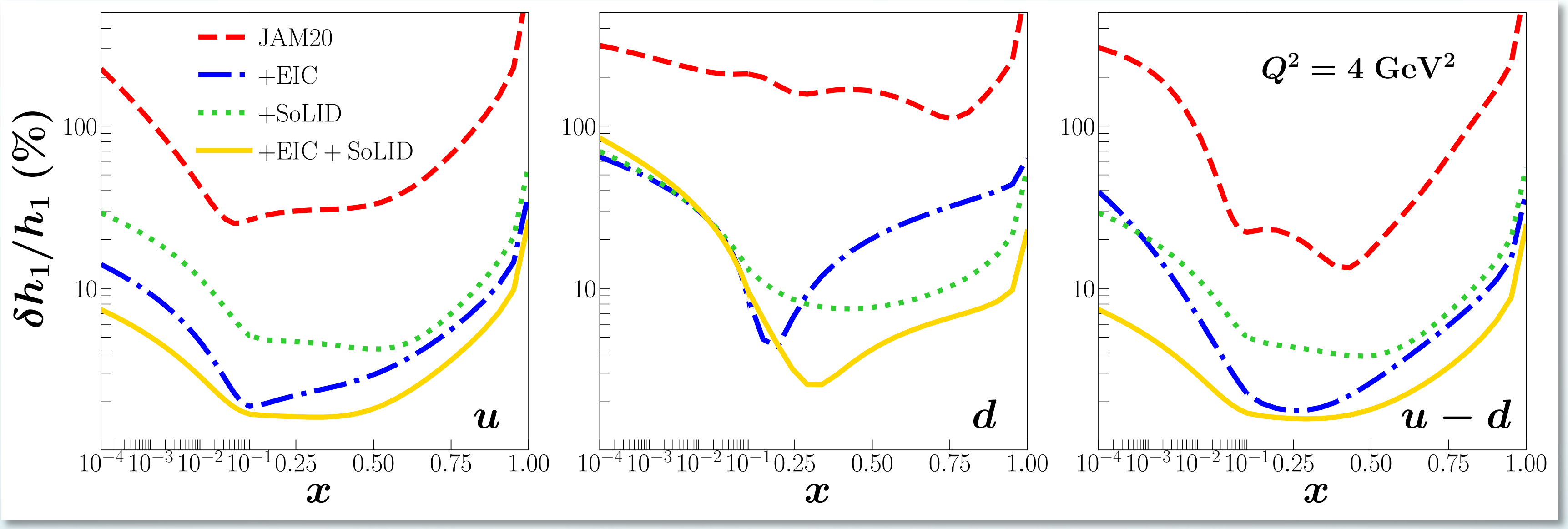
- Kinematic coverage
  - SoLID@Jlab sits in larger x and lower Q with much higher luminosity, thus explore TMD in the region complementary to EIC
  - Non-perturbative contribution in TMD evolution is much larger in such a region, thus could provide unique opportunities for TMD evolution

Grewal, Kang, Qiu, Signori, 2003.07453, PRD



Impact on the transversity

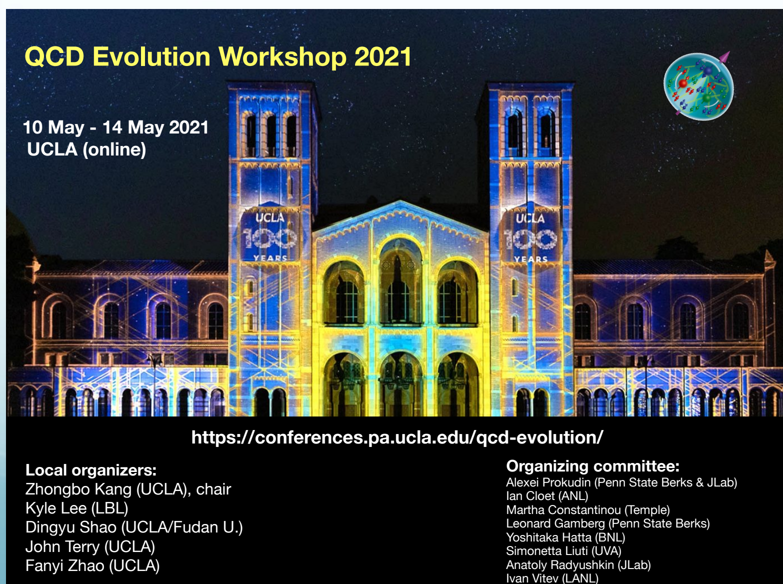
- SoLID can reduce the relative uncertainty of transversity at large x
- Overall, the uncertainty improves the most with EIC + SoLID



QCD Evolution 2021 ONLINE workshop

- Our announcement will be sent out later this week
  - May 10 – 14, 2021 (*canceled in 2020):* https://conferences.pa.ucla.edu/qcd-evolution/
  - Presentation (ZOOM) + Social/Coffee break (Wonder.me)

- Social medium (workshop official twitter, transfer to the next organizing chair)
  - Following us at twitter: https://twitter.com/qcd_evolution
  - Contact (Zhongbo Kang, Alexei Prokudin, Leonard Gamberg) if you want us to post/retweet something related, or if you want us to follow you



Thank you!