

# EIC Impact Study on the Tensor Charge using TMDs from a Global Analysis of SSAs



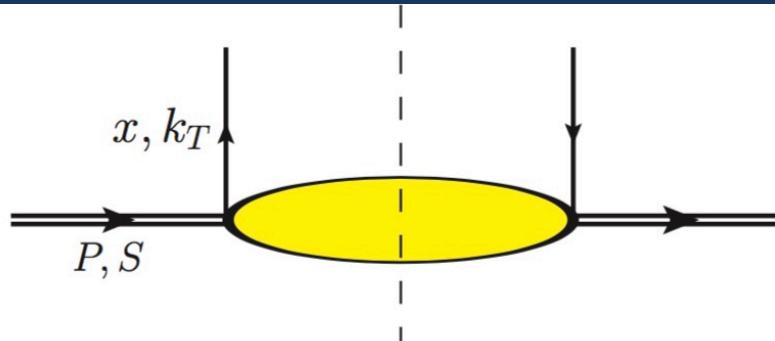
Daniel Pitonyak

*Lebanon Valley College, Annville, PA, USA*



Workshop on EIC Opportunities for Snowmass

January 26, 2021



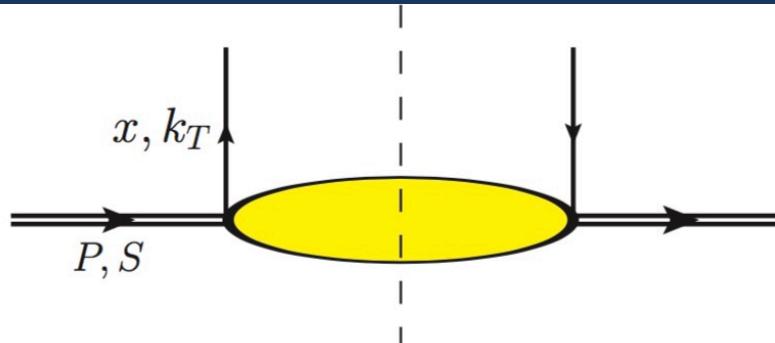
$$\mathcal{F}. \mathcal{T}. [\langle P, S | \bar{\psi}(0^-, 0_T) \mathcal{W}(0; \xi) \Gamma \psi(\xi^-, \xi_T) | P, S \rangle]$$

## Leading Twist TMDs

○ → Nucleon Spin

○ ↗ Quark Spin

		Quark Polarization		
		Un-Polarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Nucleon Polarization	U	$f_1 = \bullet$		$h_1^\perp = \bullet - \bullet$ Boer-Mulders
	L		$g_{1L} = \bullet \rightarrow - \bullet \rightarrow$ Helicity	$h_{1L}^\perp = \bullet \rightarrow - \bullet \rightarrow$
	T	$f_{1T}^\perp = \bullet \uparrow - \bullet \downarrow$ Sivers	$g_{1T}^\perp = \bullet \uparrow - \bullet \uparrow$	$h_1^\perp = \bullet \uparrow - \bullet \uparrow$ Transversity $h_{1T}^\perp = \bullet \uparrow \rightarrow - \bullet \uparrow \rightarrow$



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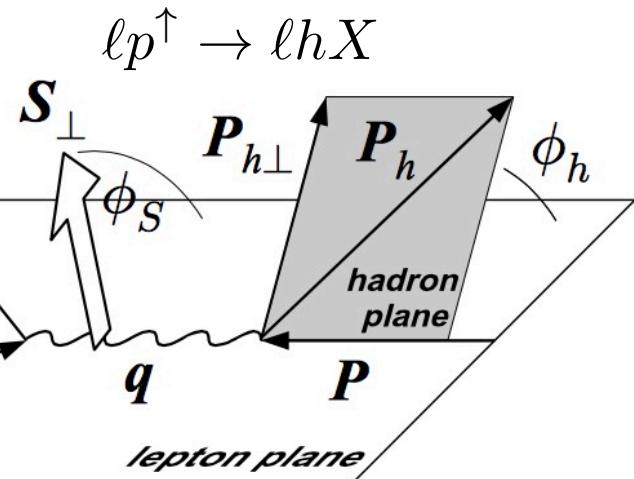
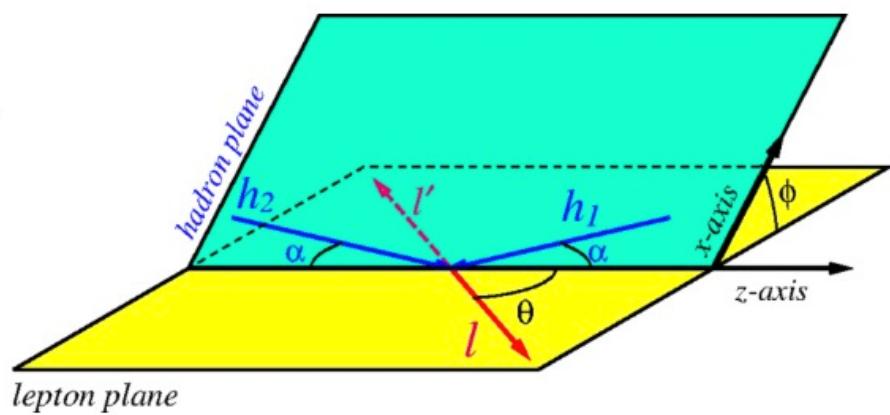
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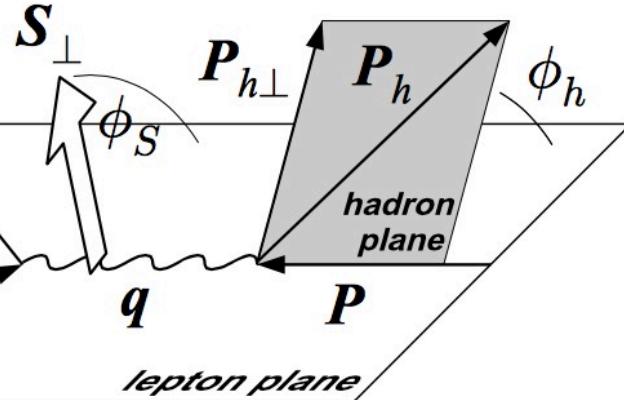
Naïve time-reversal odd (T-odd)

$\ell p^\uparrow \rightarrow \ell h X$ 

 $\{\pi, p\} p^\uparrow \rightarrow \{\ell^+ \ell^-, W^\pm, Z\} X$ 


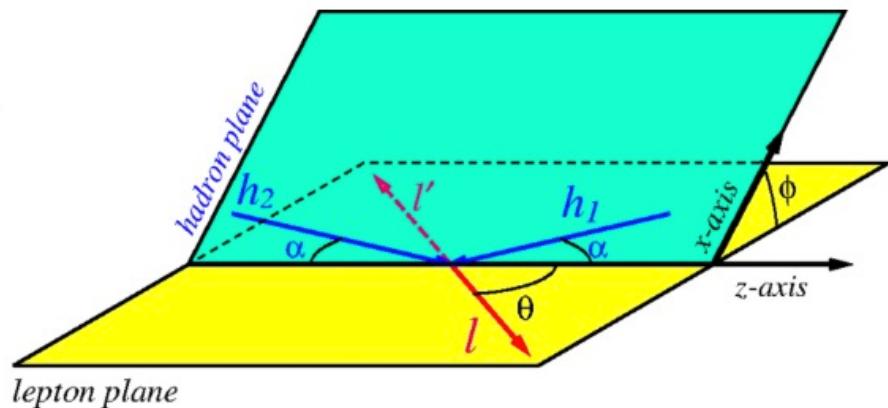
$$F_{UT}^{\sin(\phi_h - \phi_S)} = \mathcal{C} \left[ -\frac{\hat{h} \cdot \vec{k}_T}{M} \mathbf{f}_{1T}^\perp D_1 \right]$$

$$F_{TU}^{\sin \phi} = \mathcal{C} \left[ -\frac{\hat{h} \cdot \vec{k}_{aT}}{M_a} \mathbf{f}_{1T}^\perp \bar{f}_1 \right]$$

$$\ell p^\uparrow \rightarrow \ell h X$$



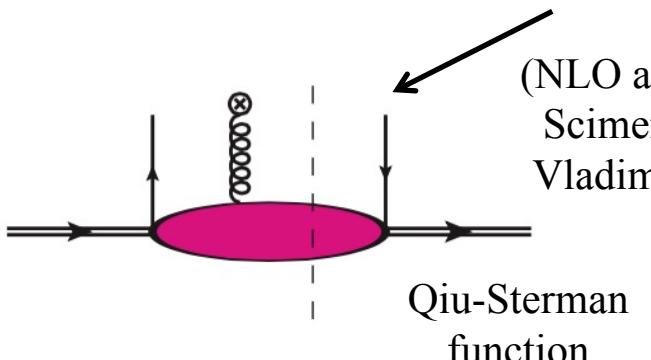
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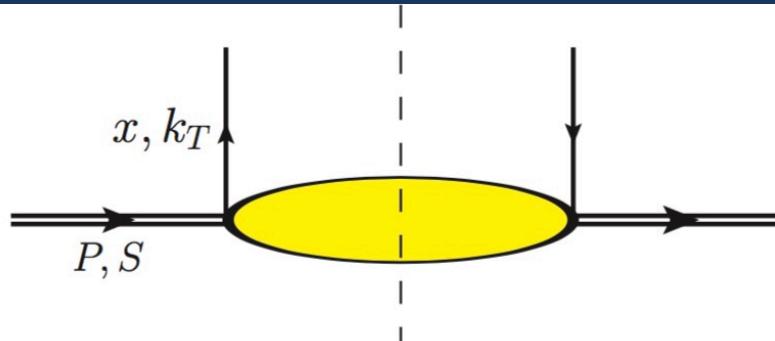
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$$\tilde{f}_{1T}^{\perp(1)}(x, b_T; Q^2, \mu_Q) \sim F_{FT}(x, x; \mu_{b_*}) \exp \left[ -S_{pert}(b_*(b_T); \mu_{b_*}, Q, \mu_Q) - S_{NP}^{f_{1T}^\perp}(b_T, Q) \right]$$



OPE  
(NLO available from  
Scimemi, Tarasov,  
Vladimirov (2019))

$g_{f_{1T}^\perp}(x, b_T) + g_K(b_T) \ln(Q/Q_0)$   
(Aybat, et al. (2012); Echevarria, et al. (2014))



$$\mathcal{F}. \mathcal{T}. [\langle P, S | \bar{\psi}(0^-, 0_T) \mathcal{W}(0; \xi) \Gamma \psi(\xi^-, \xi_T) | P, S \rangle]$$

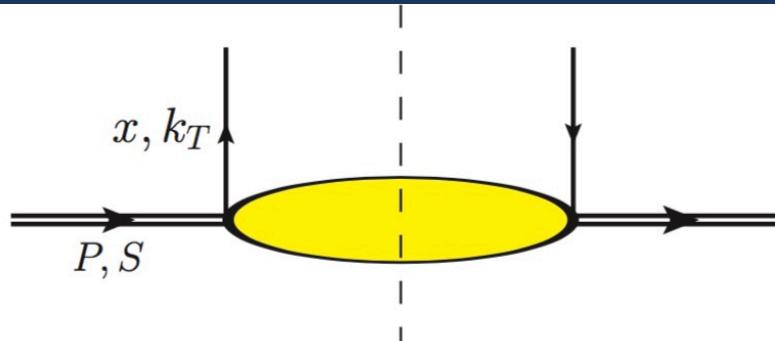
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Survive  
integration  
over  $k_T$



$$\mathcal{F}. \mathcal{T}. [\langle P, S | \bar{\psi}(0^-, 0_T) \mathcal{W}(0; \xi) \Gamma \psi(\xi^-, \xi_T) | P, S \rangle]$$

## Leading Twist TMDs

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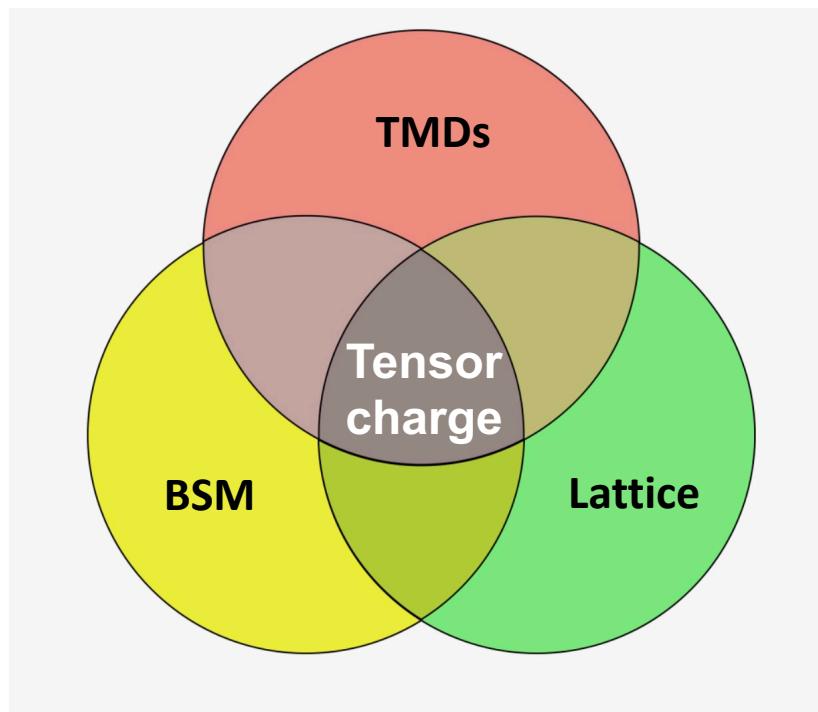
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Chiral odd

Survive  
integration  
over  $k_T$

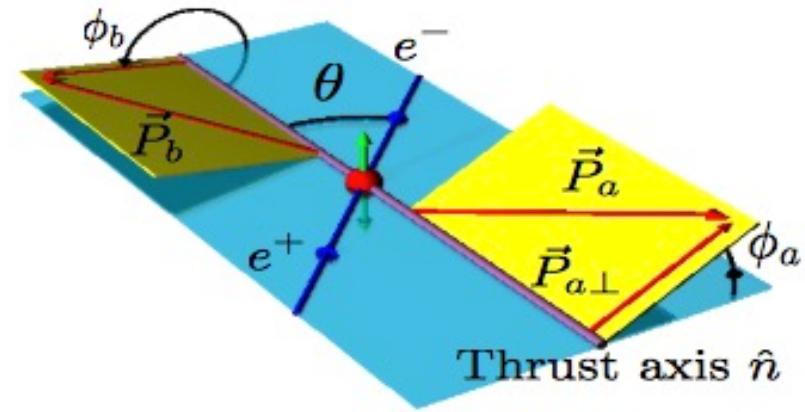
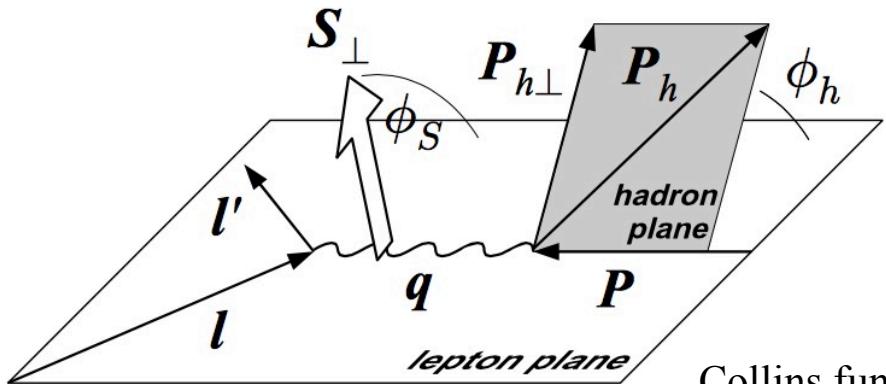
$$\delta q \equiv \int_0^1 dx [h_1^q(x) - h_1^{\bar{q}}(x)] \quad g_T \equiv \delta u - \delta d$$

The tensor charge of the nucleon is one of its fundamental charges and is important for BSM studies (beta decay, EDM). Processes sensitive to TMDs can play an important role in these efforts (Courtoy, et al. (2015); Yamanaka, et al. (2017), Liu, et al. (2018),...). Lattice QCD has also calculated the tensor charges with great precision (Gupta, et al. (2018); Hasan, et al. (2019), Alexandrou, et. (2019),...).



$$\ell p^\uparrow \rightarrow \ell h X$$

$$e^+ e^- \rightarrow h_1 h_2 X$$

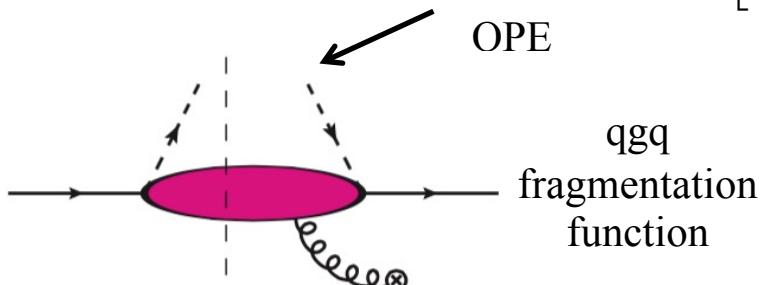


Collins function

$$F_{UT}^{\sin(\phi_h + \phi_S)} = \mathcal{C} \left[ -\frac{\hat{h} \cdot \vec{p}_\perp}{M_h} h_1 \textcolor{blue}{H_1^\perp} \right] \quad F_{UU}^{\cos(2\phi_0)} = \mathcal{C} \left[ \frac{2\hat{h} \cdot \vec{p}_{a\perp} \hat{h} \cdot \vec{p}_{b\perp} - \vec{p}_{a\perp} \cdot \vec{p}_{b\perp}}{M_a M_b} \textcolor{blue}{H_1^\perp} \bar{H}_1^\perp \right]$$

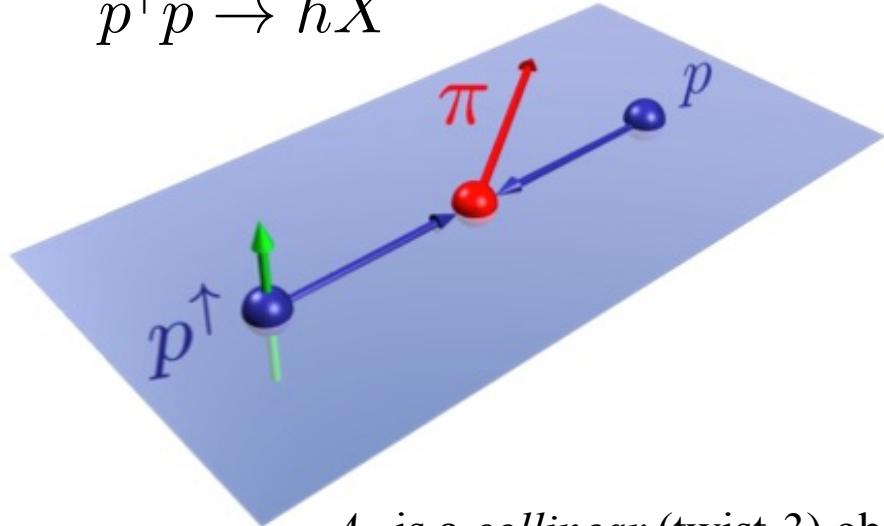
$$\tilde{h}_1(x, b_T; Q^2, \mu_Q) \sim h_1(x; \mu_{b_*}) \exp[-S_{pert}(b_*(b_T); \mu_{b_*}, Q, \mu_Q) - S_{NP}^{h_1}(b_T, Q)]$$

$$\tilde{H}_1^{\perp(1)}(z, b_T; Q^2, \mu_Q) \sim \textcolor{blue}{H_1^{\perp(1)}(z; \mu_{b_*})} \exp \left[ -S_{pert}(b_*(b_T); \mu_{b_*}, Q, \mu_Q) - S_{NP}^{H_1^\perp}(b_T, Q) \right]$$



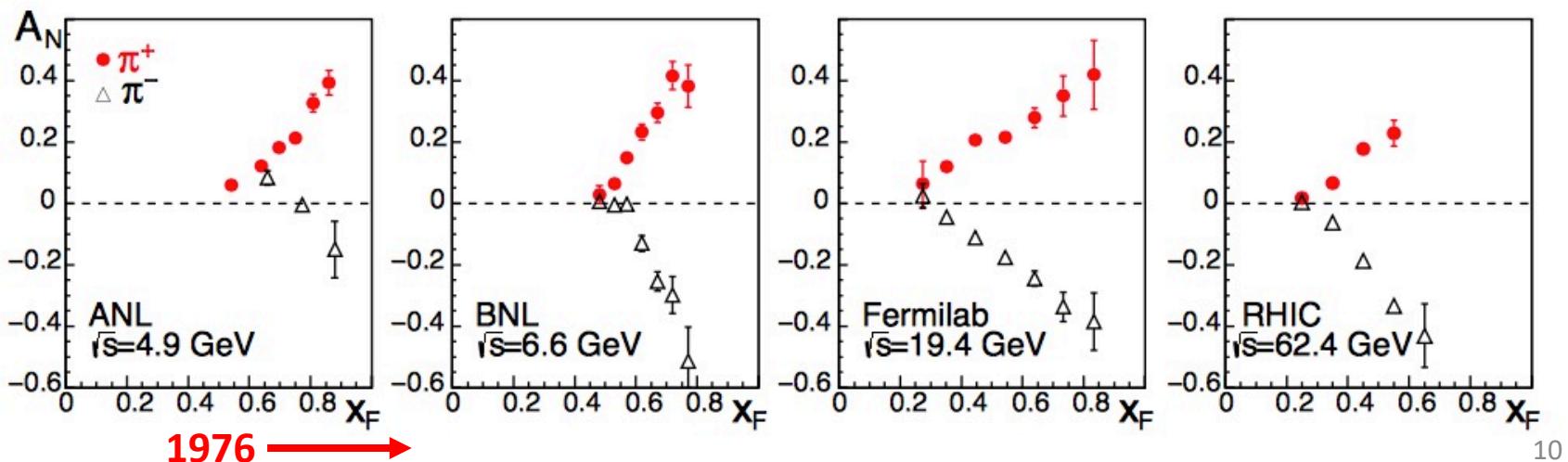
(Kang, et al. (2016))

$$p^\uparrow p \rightarrow hX$$

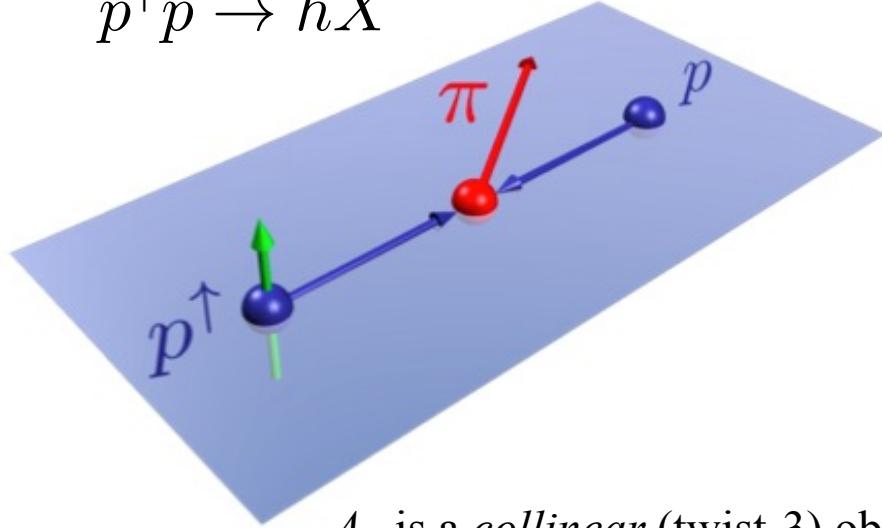


$A_N$  is a *collinear* (twist-3) observable

$$d\Delta\sigma(S_T) \sim \underbrace{H_{QS} \otimes f_1 \otimes \textcolor{magenta}{F}_{FFT} \otimes D_1}_{\text{Qiu-Sterman term}} + \underbrace{H_F \otimes f_1 \otimes \mathbf{h}_1 \otimes (\mathbf{H}_1^{\perp(1)}, \tilde{\mathbf{H}})}_{\text{Fragmentation term}}$$



$$p^\uparrow p \rightarrow hX$$

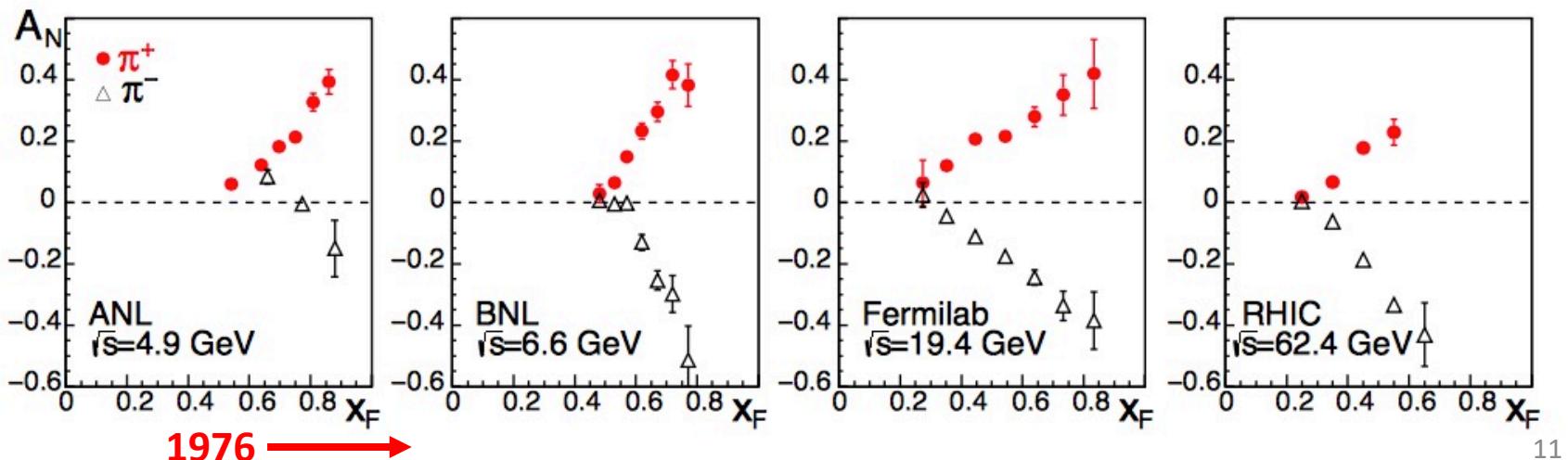


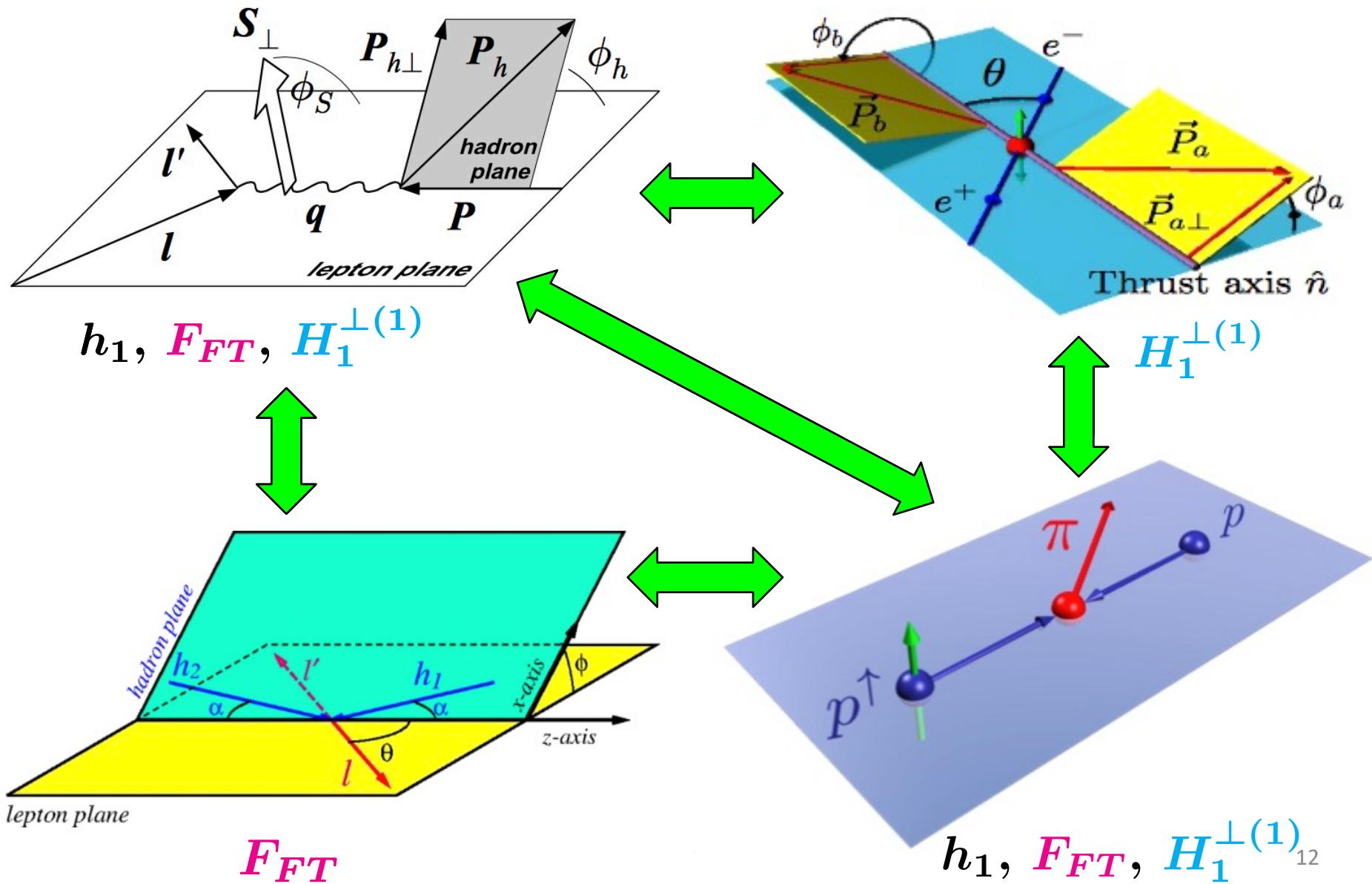
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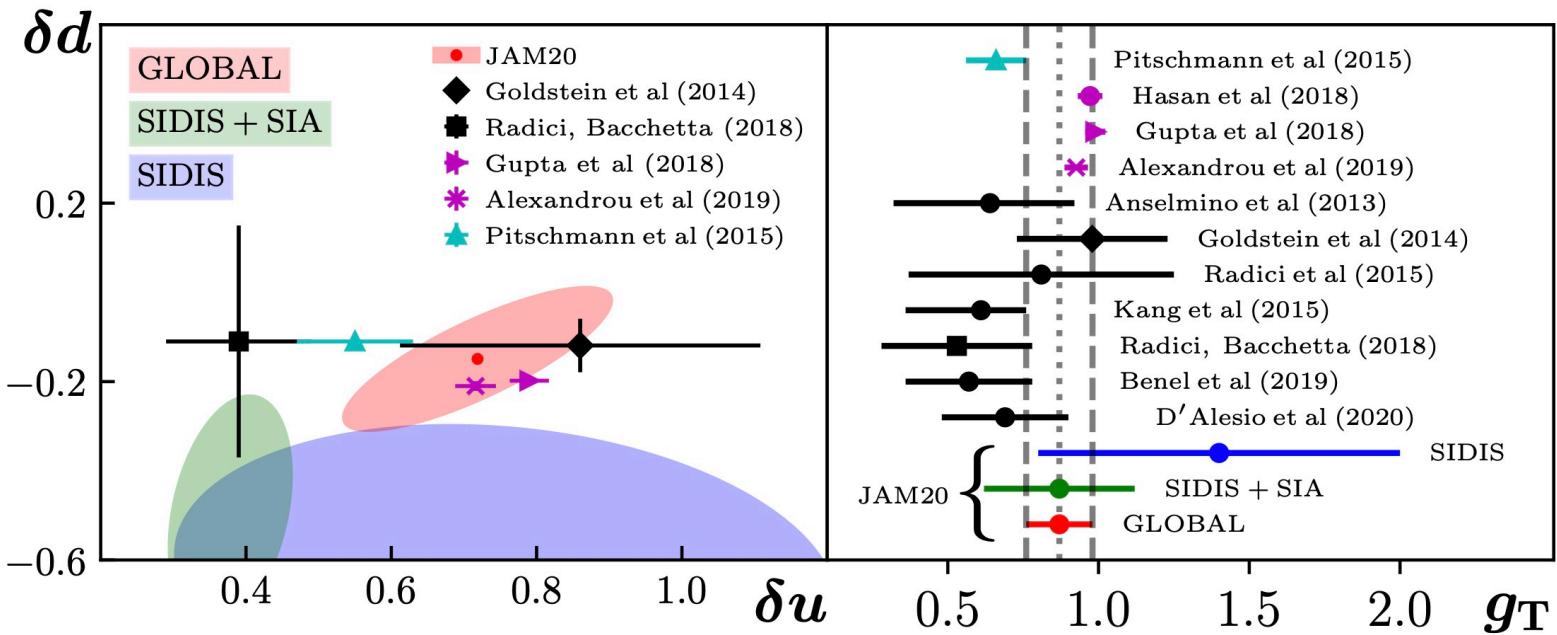
$$+ \underbrace{H_F \otimes f_1 \otimes \mathbf{h}_1 \otimes (\mathbf{H}_1^{\perp(1)}, \tilde{\mathbf{H}})}_{\text{Fragmentation term}}$$

(Metz, DP (2012); Kanazawa, et al. (2014); Gumberg, et al. (2017); Cammarota, et al. (2020))





Simultaneous fit of SSAs in SIDIS, Drell-Yan,  $e^+e^-$  annihilation, and proton-proton collisions (JAM20) using a Gaussian ansatz for the TMDs



Cammarota, Gamberg, Kang, Miller, DP, Prokudin, Rogers, Sato, PRD **102** (2020)

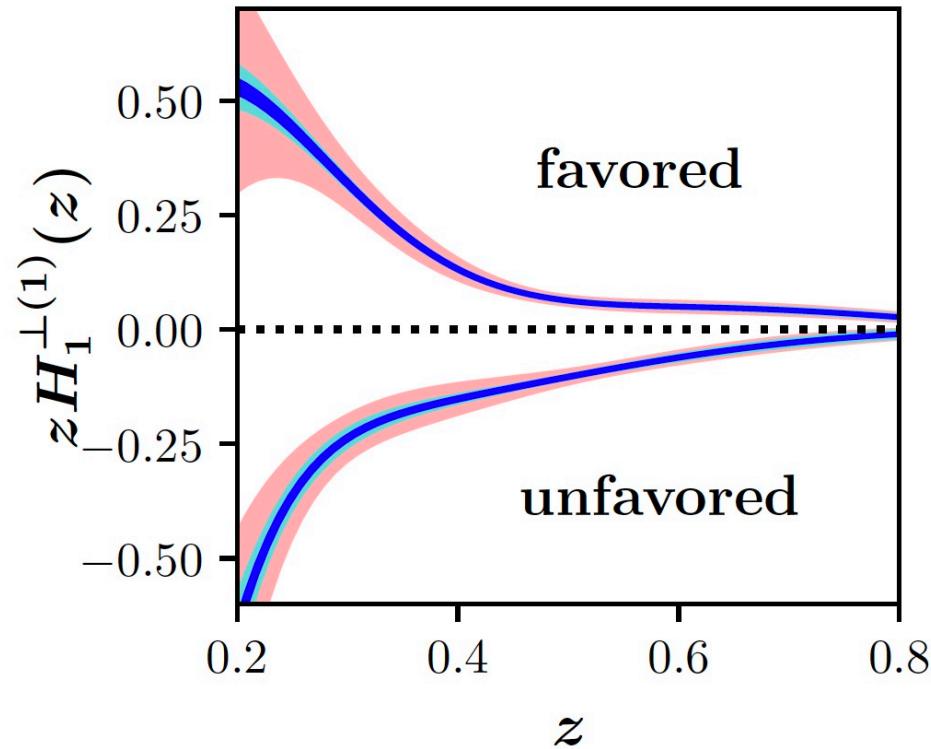
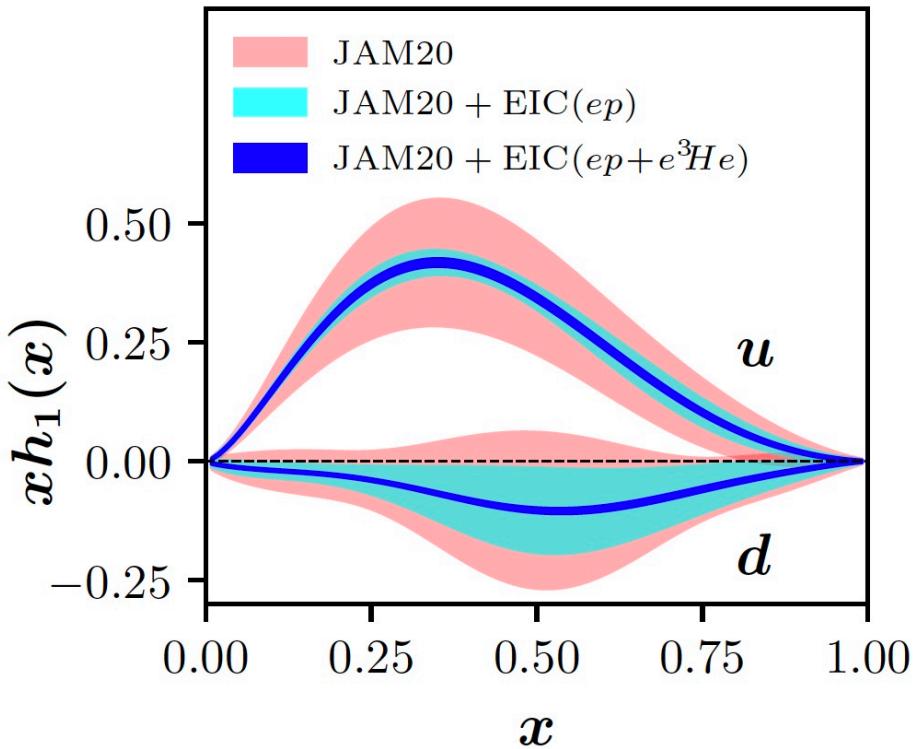
Only after a *simultaneous* QCD global analysis of SSAs does the phenomenological extraction of the tensor charges agree with lattice, *but still with large uncertainties*

Gamberg, Kang, DP, Prokudin, Sato, Seidl, arXiv:2101.06200, submitted to PLB

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

Assumed accumulated luminosities of  $10 \text{ fb}^{-1}$ , 70% polarization, conservatively accounted for detector smearing and acceptance effects

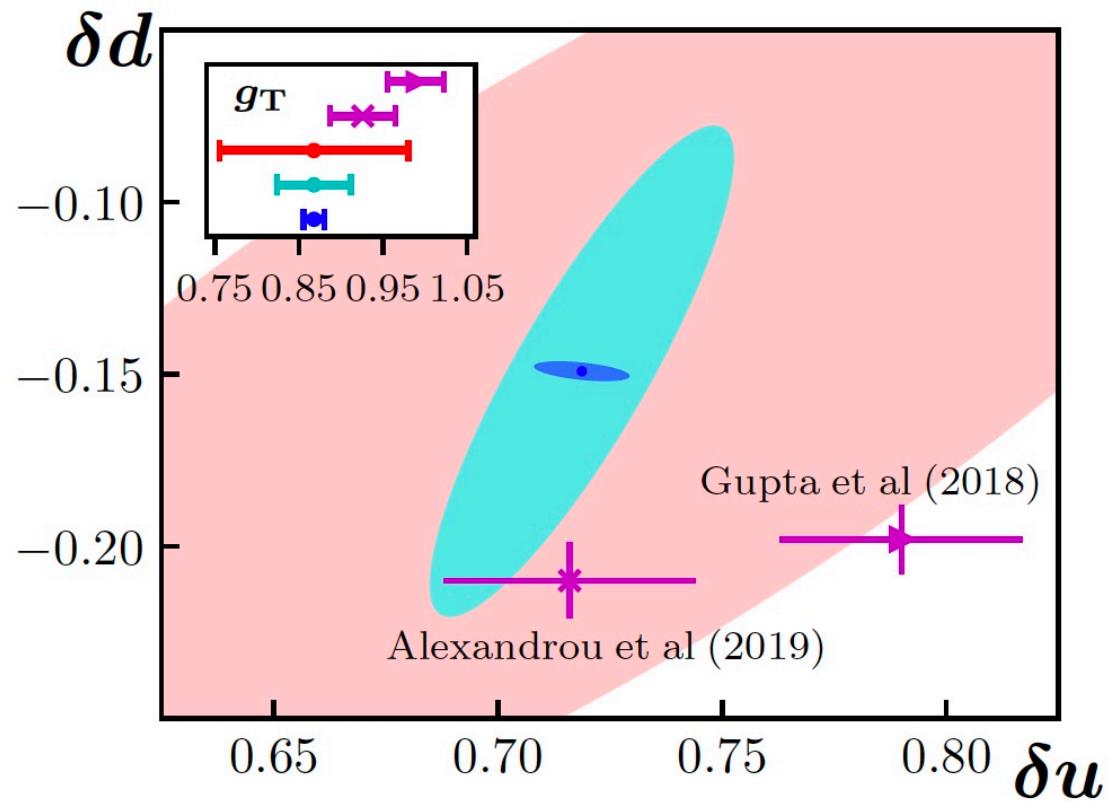
Gamberg, Kang, DP, Prokudin, Sato, Seidl, arXiv:2101.06200, submitted to PLB



EIC data on the Collins effect will significantly reduce the uncertainties in extractions of the transversity PDF (as well as the Collins FF)

Gamberg, Kang, DP, Prokudin, Sato, Seidl, arXiv:2101.06200, submitted to PLB

- █ JAM20
- █ JAM20 + EIC( $ep$ )
- █ JAM20 + EIC( $ep+e^3He$ )

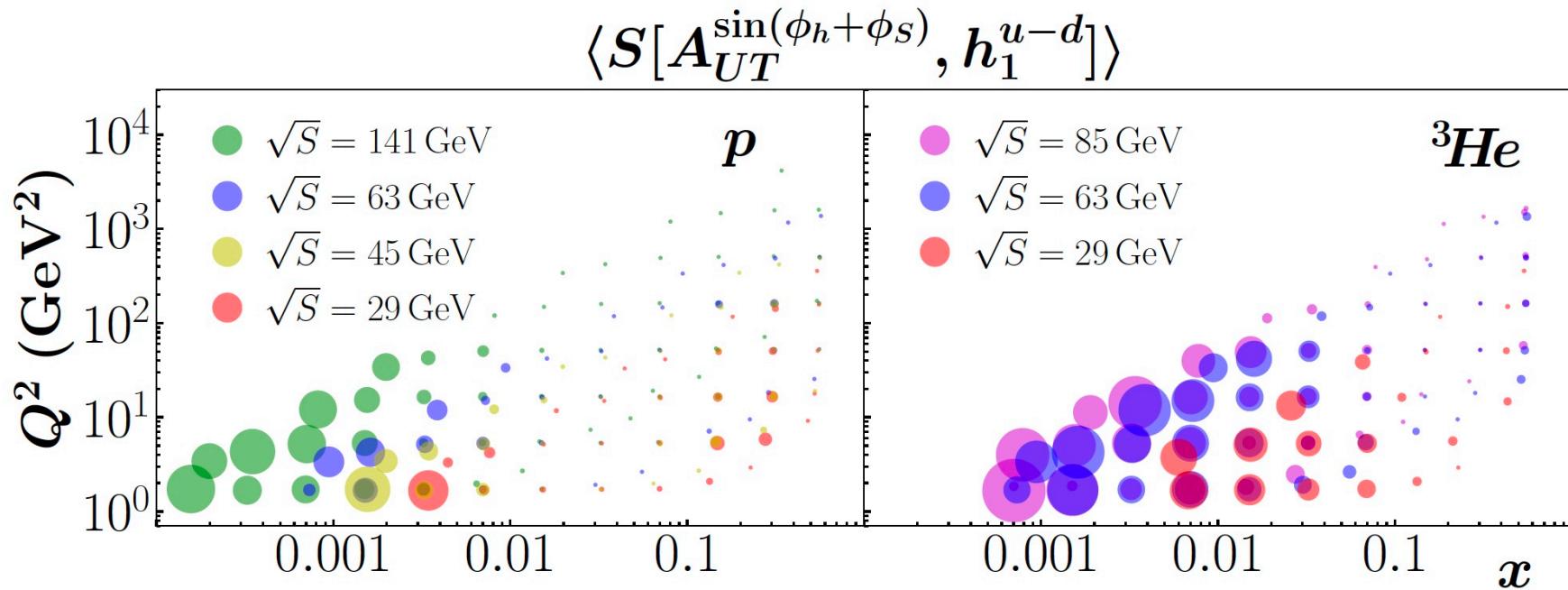


EIC data will allow phenomenological extractions of the tensor charge to become as precise as current lattice calculations

Gamberg, Kang, DP, Prokudin, Sato, Seidl, arXiv:2101.06200, submitted to PLB

$$S[O, f] \equiv \frac{\langle O \cdot f \rangle - \langle O \rangle \langle f \rangle}{(\Delta O)_{\text{EIC}} (\Delta f)_{\text{JAM20}}} \rightarrow \left\langle S[A_{UT}^{\sin(\phi_h + \phi_s)}, h_1^{u-d}] \right\rangle \equiv \frac{1}{N_{\text{bin}}} \sum_i \left| S_i[A_{UT}^{\sin(\phi_h + \phi_s)}, h_1^{u-d}] \right|$$

Wang, et al. (2018); Borsa, et al. (2020) where  $h_1^{u-d} \equiv h_1^u(x) - h_1^d(x)$



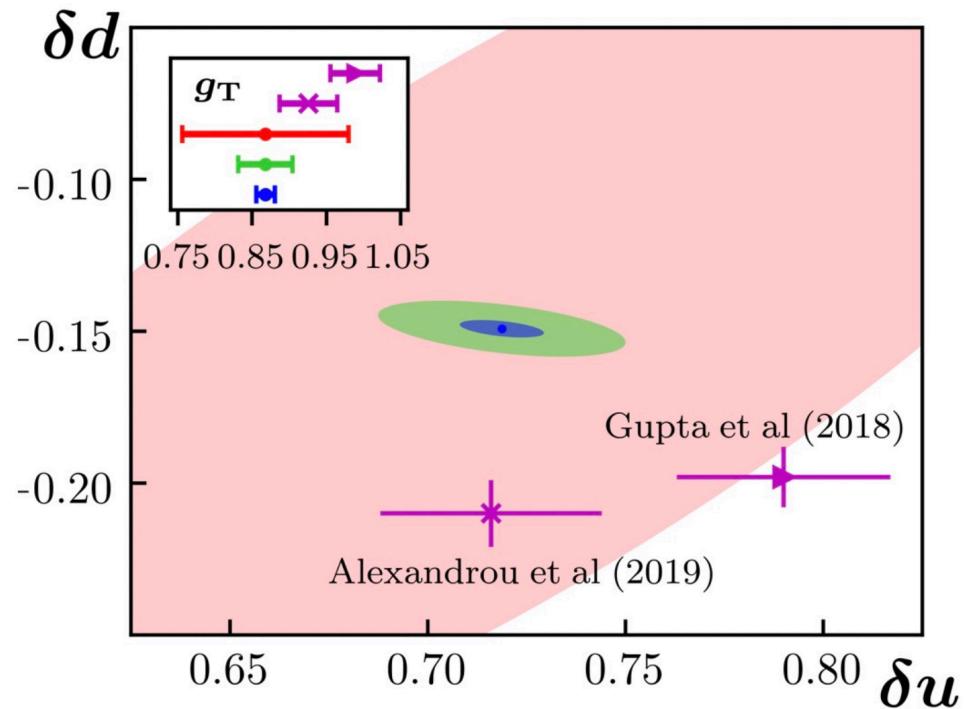
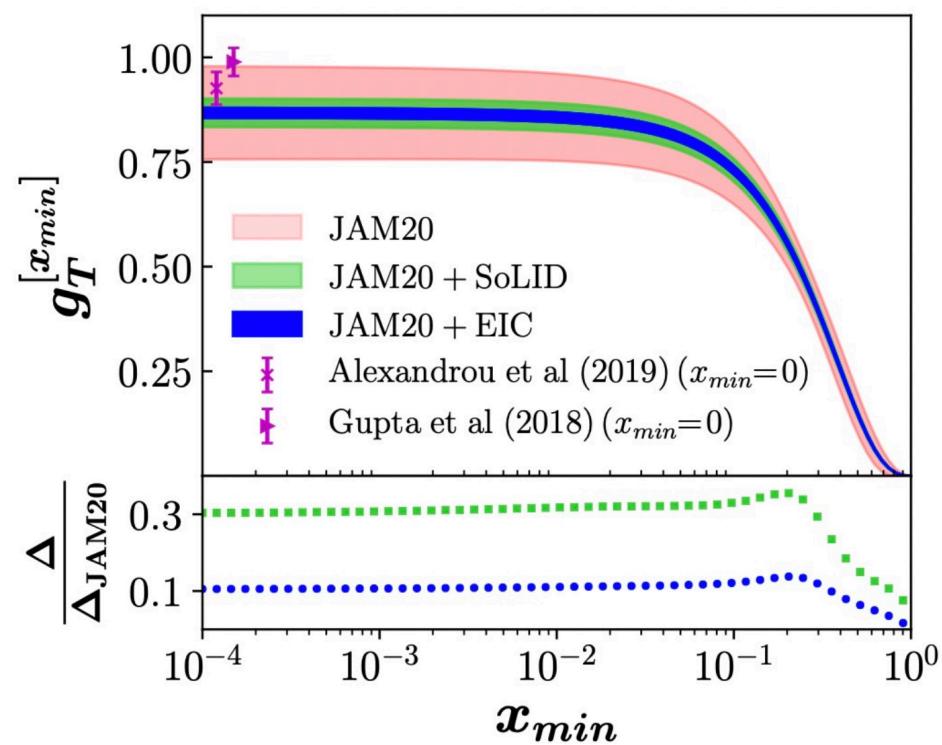
Most impact will be in the low  $x$ , low  $Q^2$  region, and the  ${}^3\text{He}$  program will play a very important role

- The tensor charge is arguably the least known of the fundamental charges of the nucleon
- The tensor charge is unique because of its role in the interaction of 3D nucleon tomography (TMDs), BSM physics, and lattice QCD
- Including as much data as possible that is sensitive to the transversity PDF allows for the most precise extraction of the tensor charge (JAM20 QCD global analysis)
- EIC data on the Collins effect will allow for phenomenological extractions of the tensor charge to be as precise as current lattice calculations

Studies of TMDs involving transverse polarization will continue to play a crucial role in exploring aspects of factorization and evolution as well as making connections to BSM and lattice QCD

# Backup Slides

Gamberg, Kang, DP, Prokudin, Sato, Seidl, arXiv:2101.06200, submitted to PLB



SoLID (at Jefferson Lab) will offer needed complementary measurements to the EIC in order to test that a consistent picture emerges across multiple experiments on the extracted value of the tensor charge