Global Analysis of SSAs and the Impact of the EIC on Tensor Charge Extractions

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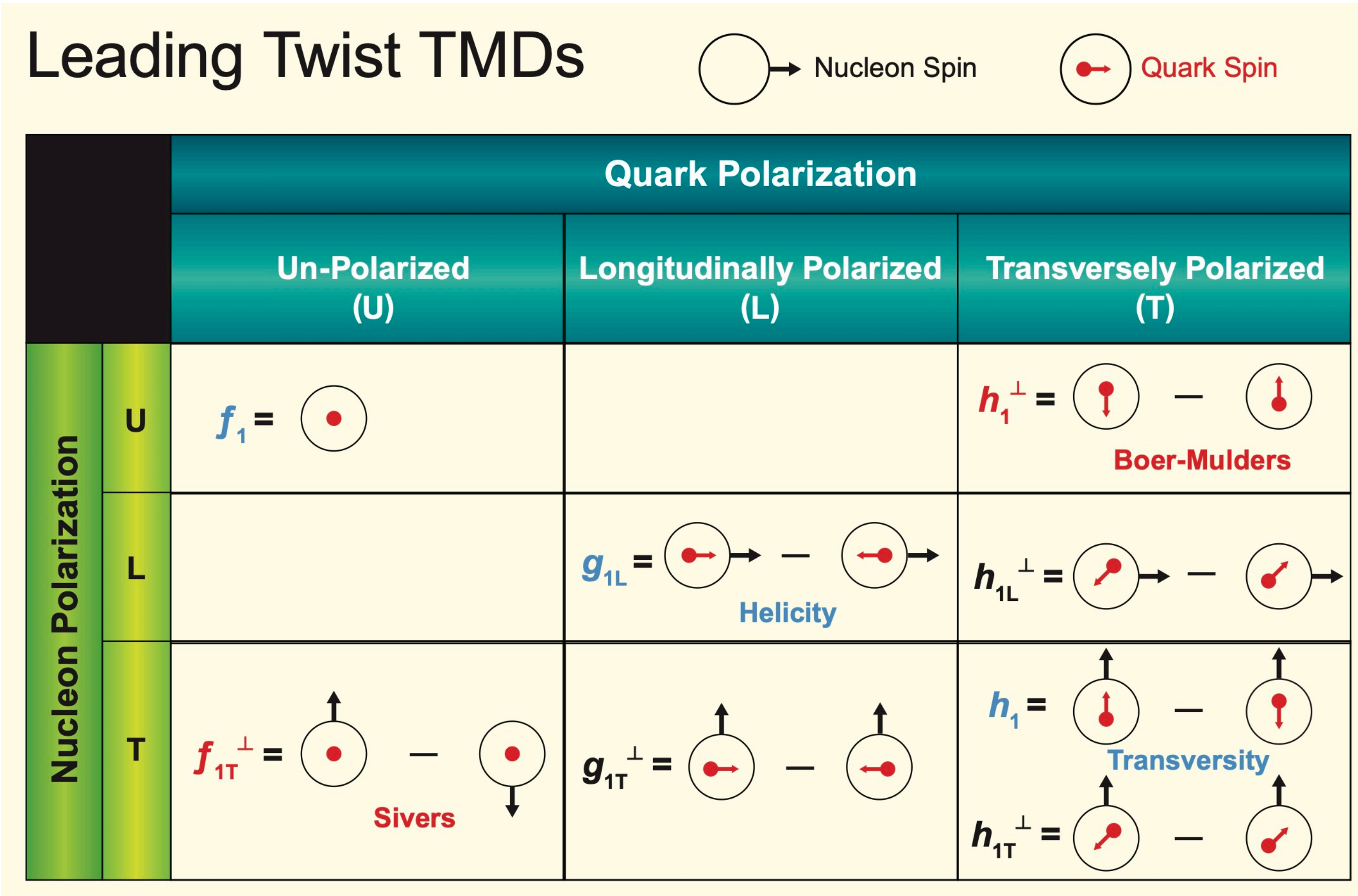
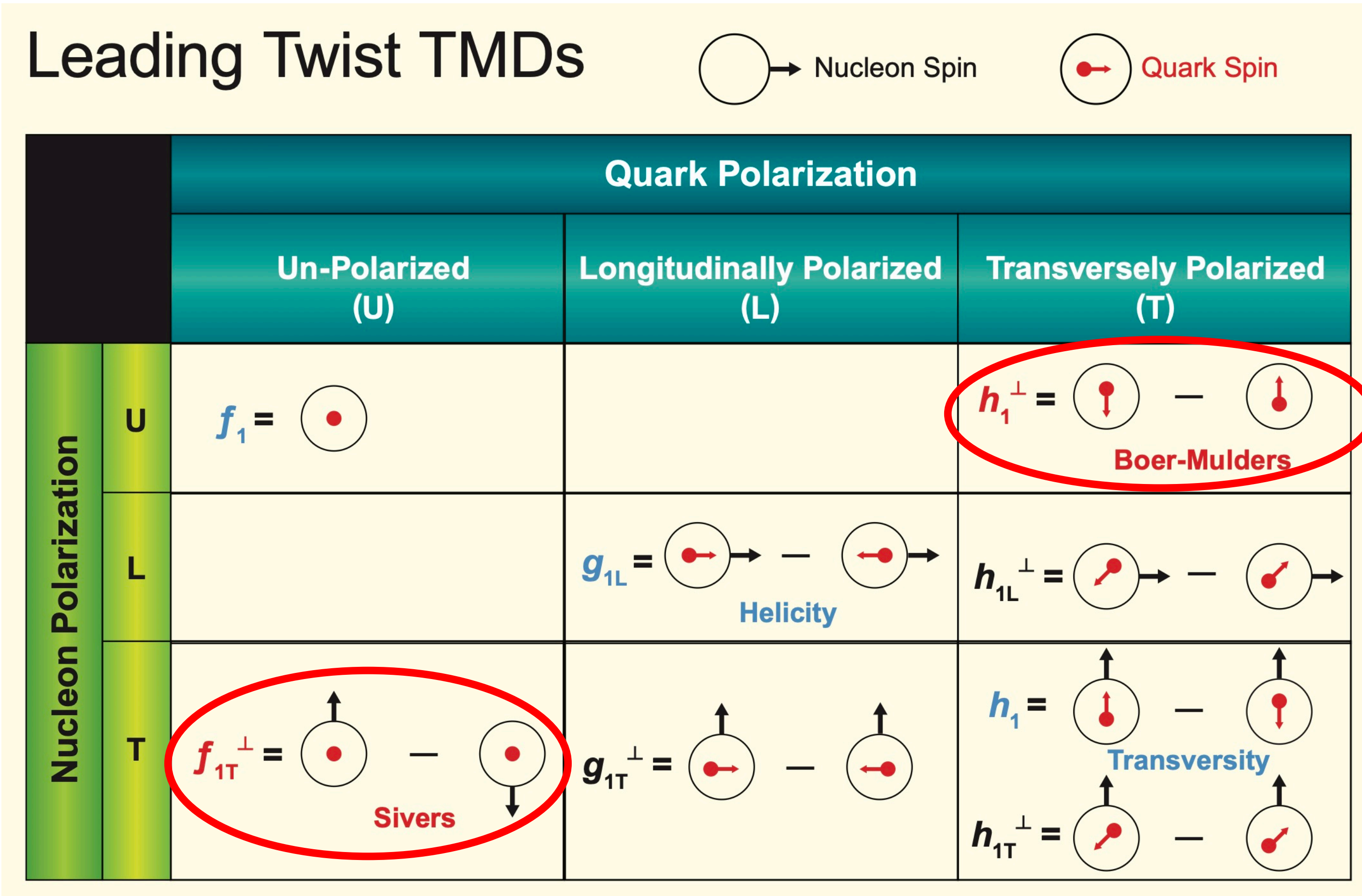
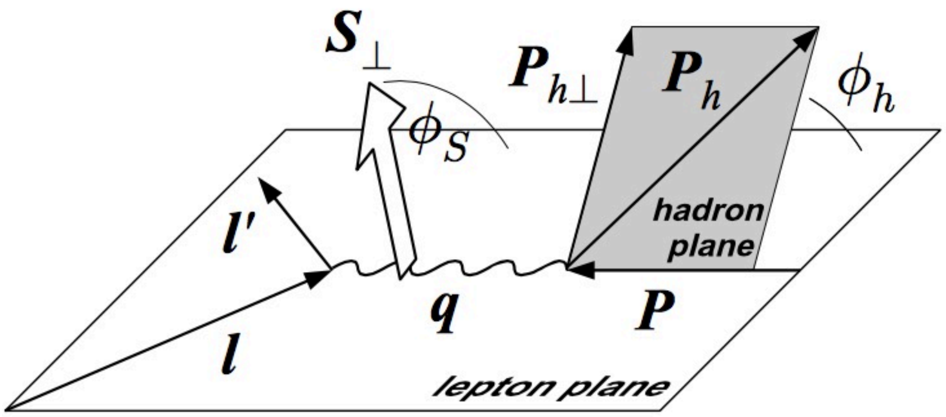

Leading Twist TMDs
Nucleon Spin
Quark Spin
Quark Polarization
Un-Polarized (U)
Longitudinally Polarized (L)
Transversely Polarized (T)
Nucleon Polarization
U
L
T
f_1 =
$h_1^\perp$ = −
Boer-Mulders
g_{1L} = −
Helicity
$h_{1L}^\perp$ = −
$f_{1T}^\perp$ = −
Sivers
$g_{1T}^\perp$ = −
h_1 = −
Transversity
$h_{1T}^\perp$ = −

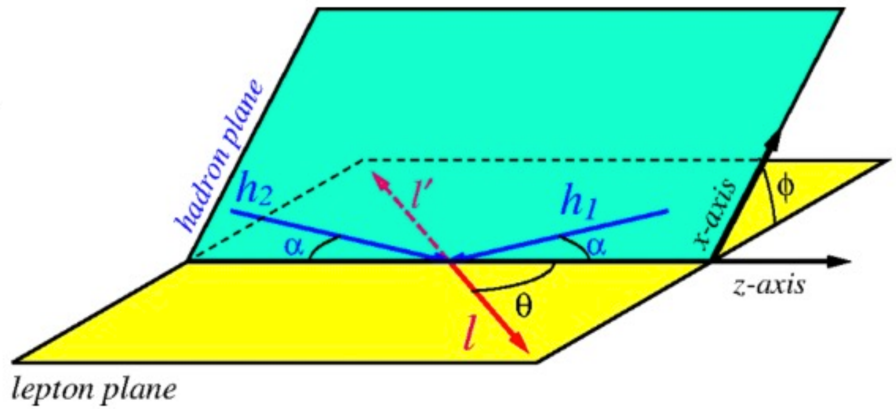


Naïve time-reversal odd (T-odd)

$$\ell p^{\uparrow} \to \ell h X$$



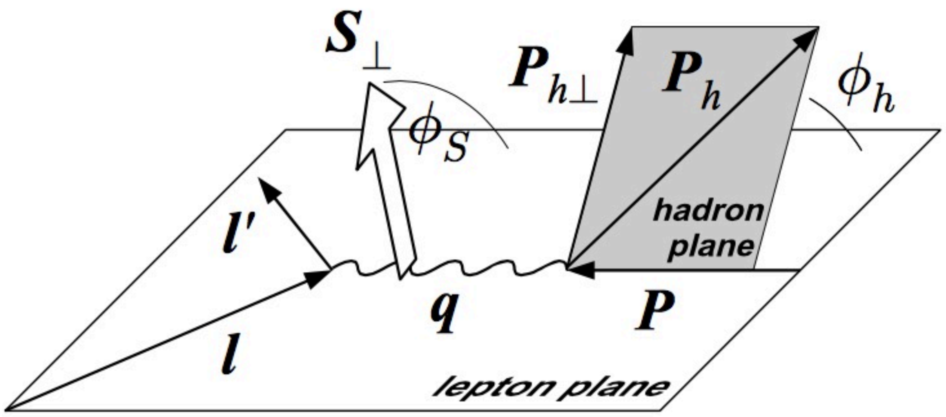
$$\{\pi, p\} p^{\uparrow} \to \{\ell^+\ell^-, W^{\pm}, Z\} X$$



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

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

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



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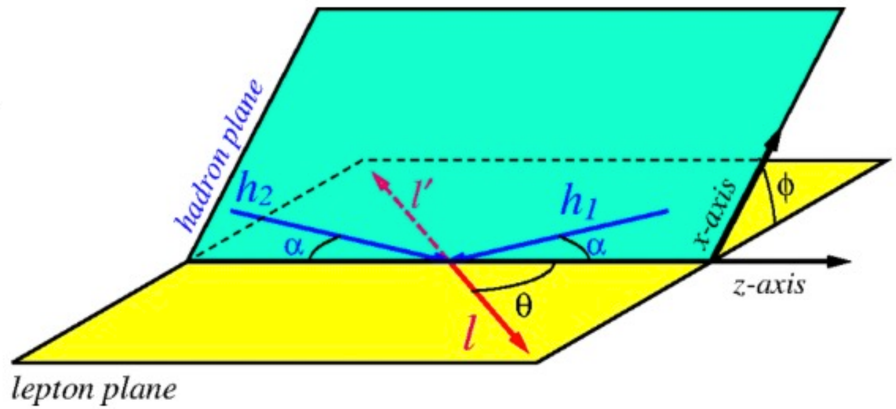


$$F_{UT}^{\sin(\phi_h - \phi_S)} = \mathcal{C}\left[-\frac{\hat{h}\cdot\vec{k}_T}{M} f_{1T}^{\perp} D_1\right]$$

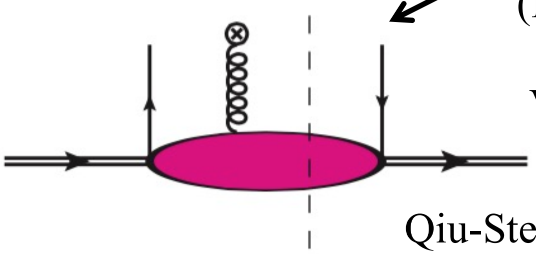
$$F_{TU}^{\sin\phi} = \mathcal{C}\left[-\frac{\hat{h}\cdot\vec{k}_{aT}}{M_a} f_{1T}^{\perp} \bar{f}_1\right]$$

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

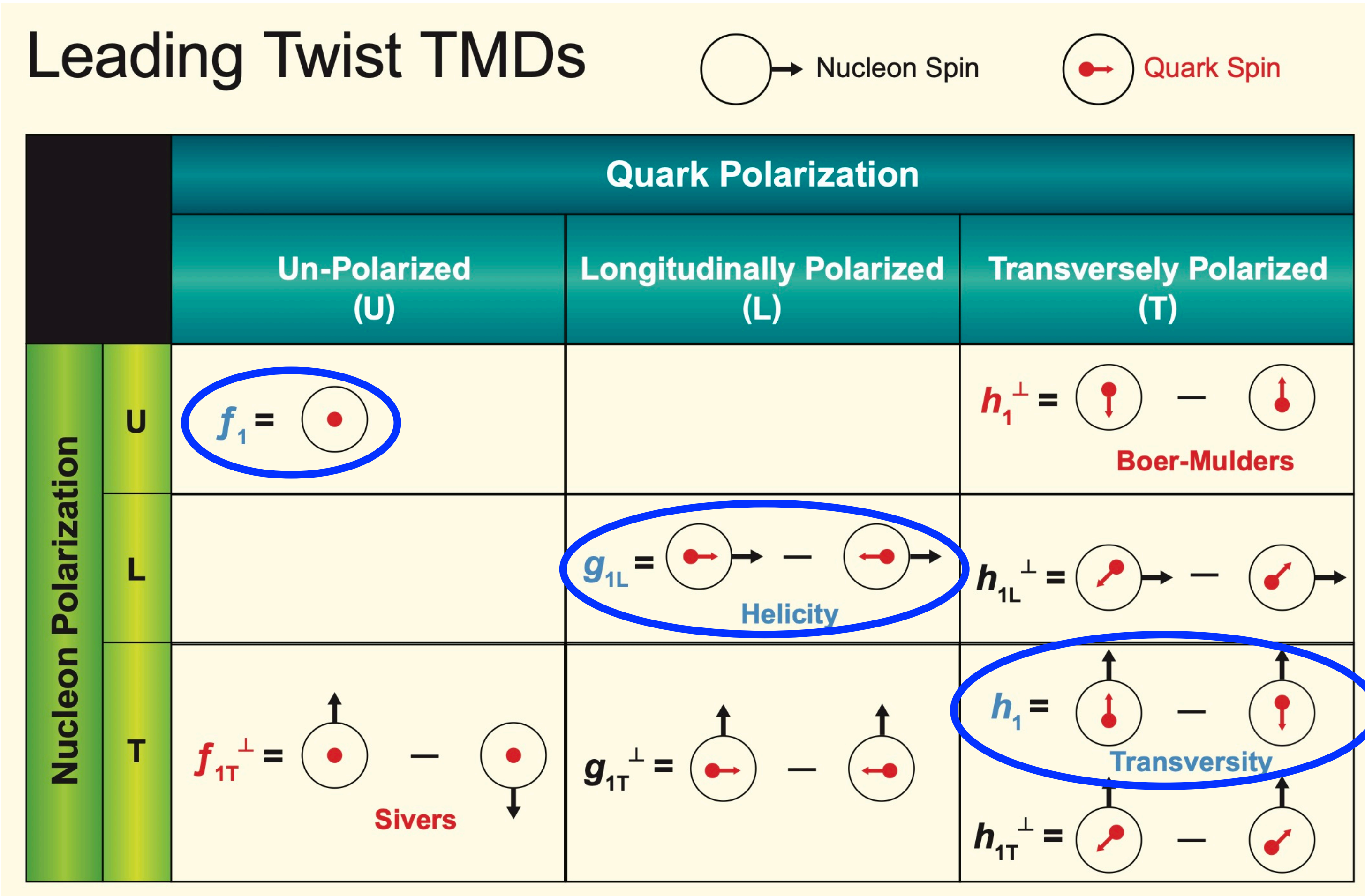
OPE
(NLO available from Scimemi, Tarasov, Vladimirov (2019))

$$g_{f_{1T}^\perp}(x, b_T) + g_K(b_T)\ln(Q/Q_0)$$

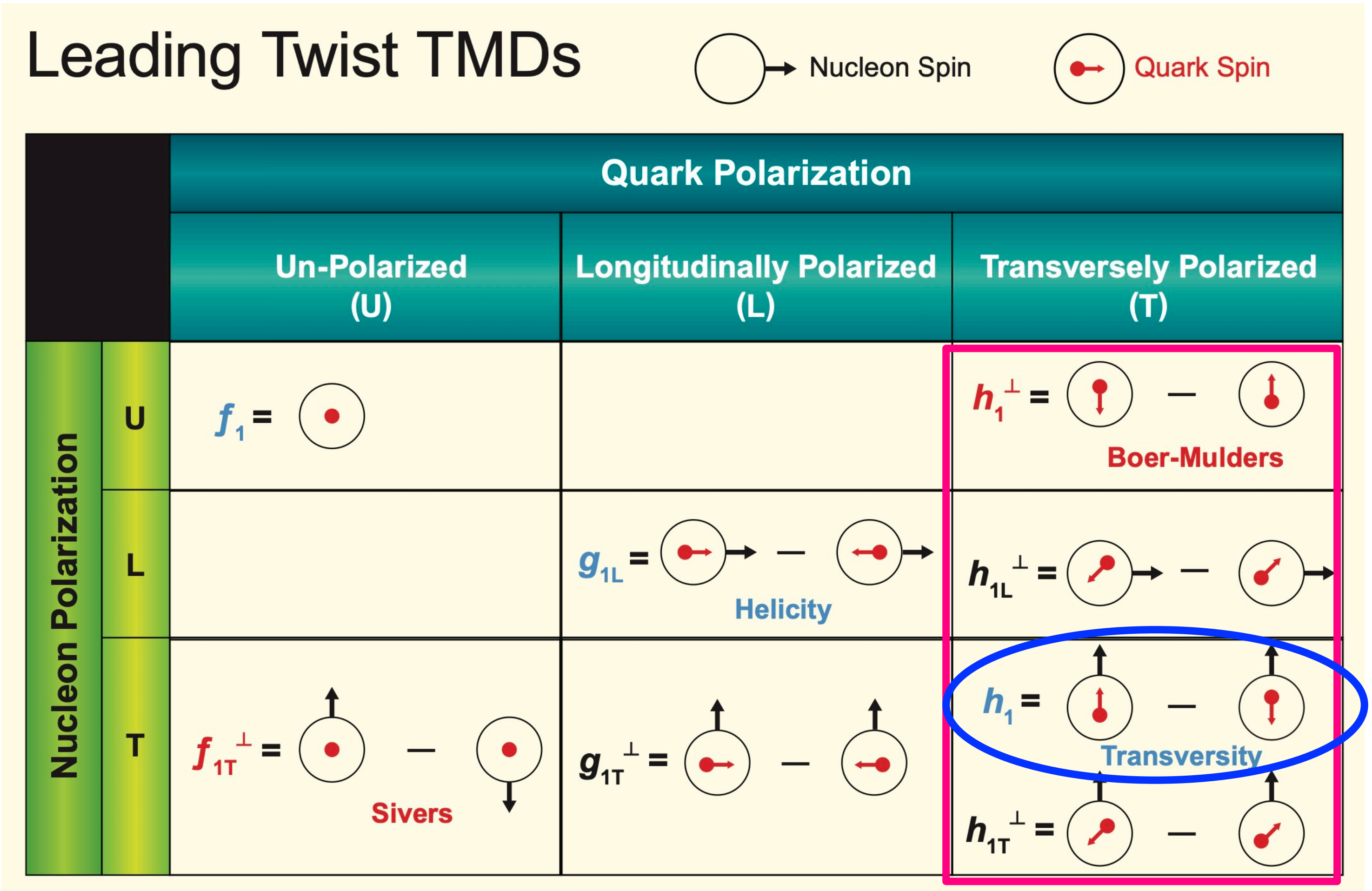
(Aybat, et al. (2012); Echevarria, et al. (2014))



Qiu-Sterman function



Survive integration over k_T



Chiral odd

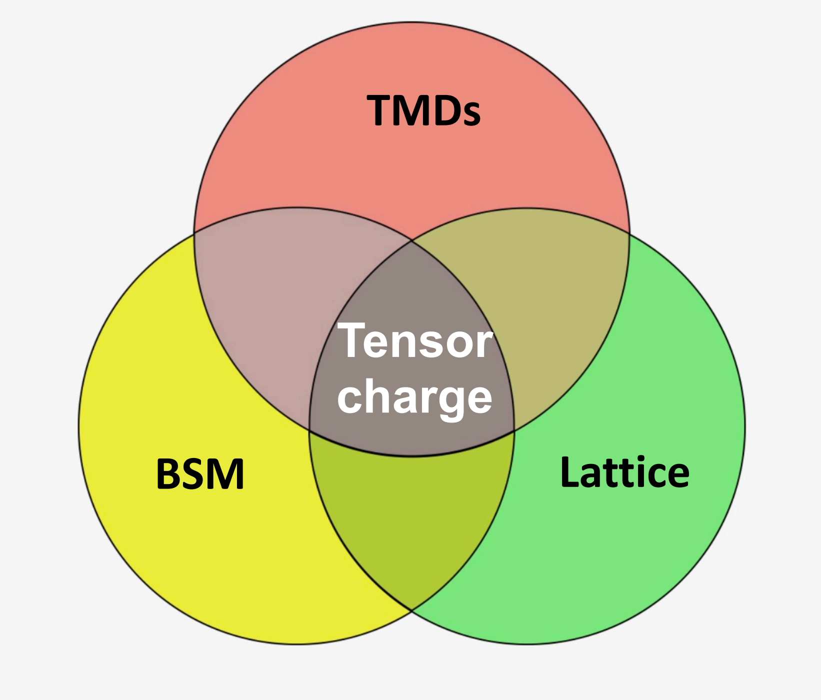
Survive integration over k_T

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

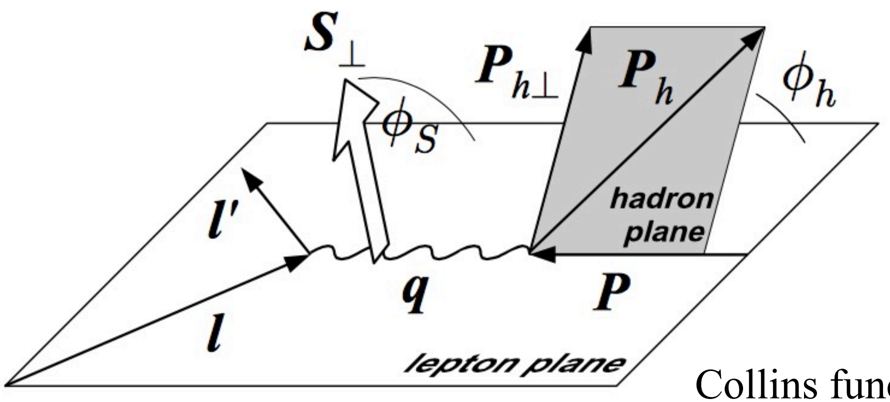
The tensor charge of the nucleon is one of its fundamental charges and is important for BSM studies in, e.g., beta decays (Gonzalez-Alonso, et al. (2018),…)

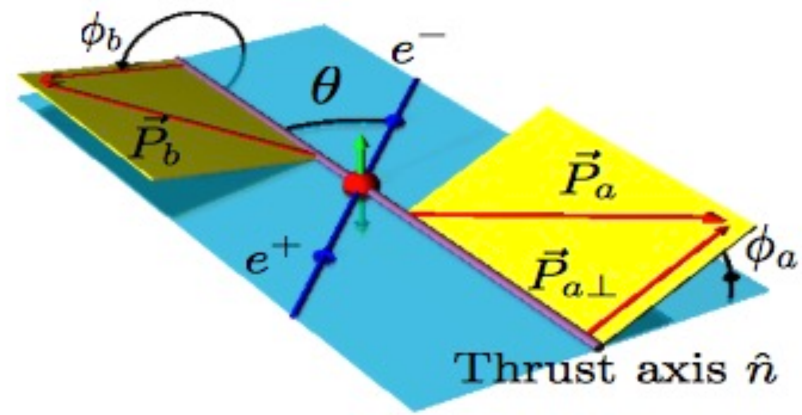
Processes sensitive to TMDs can play an important role in these efforts (Courtoy, et al. (2015); Yamanaka, et al. (2017), Liu, et al. (2018),…)

Lattice QCD has also calculated the tensor charges with great precision (Gupta, et al. (2018); Hasan, et al. (2019), Alexandrou, et. (2019),…)



$\ell p^\uparrow \to \ell h X$ $\qquad$ $e^+e^- \to h_1 h_2 X$





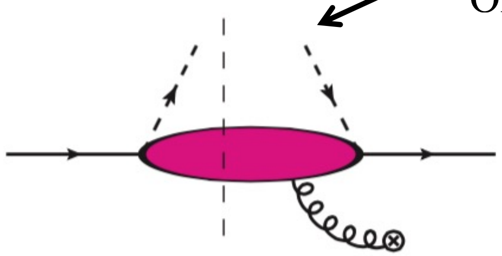
Collins function

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

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

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

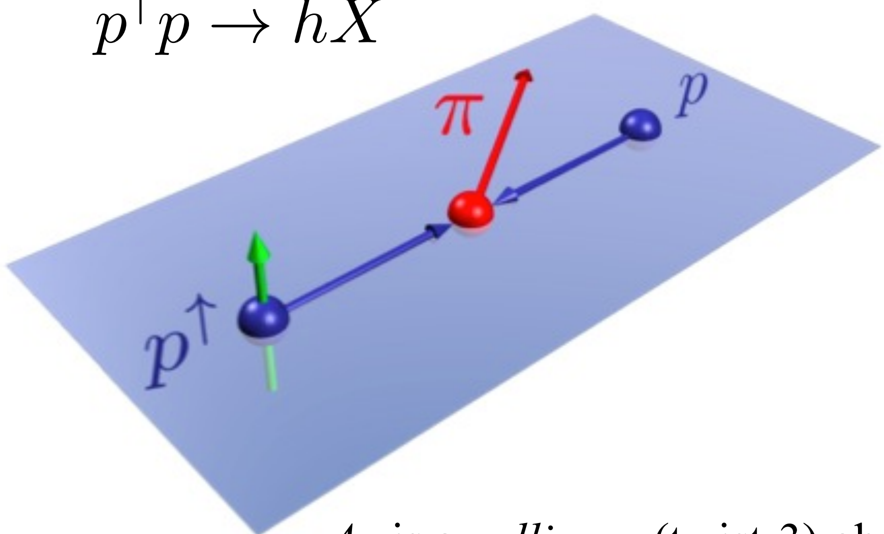
OPE



qgq
fragmentation
function

(Kang, et al. (2016))

$p^{\uparrow}p \to hX$

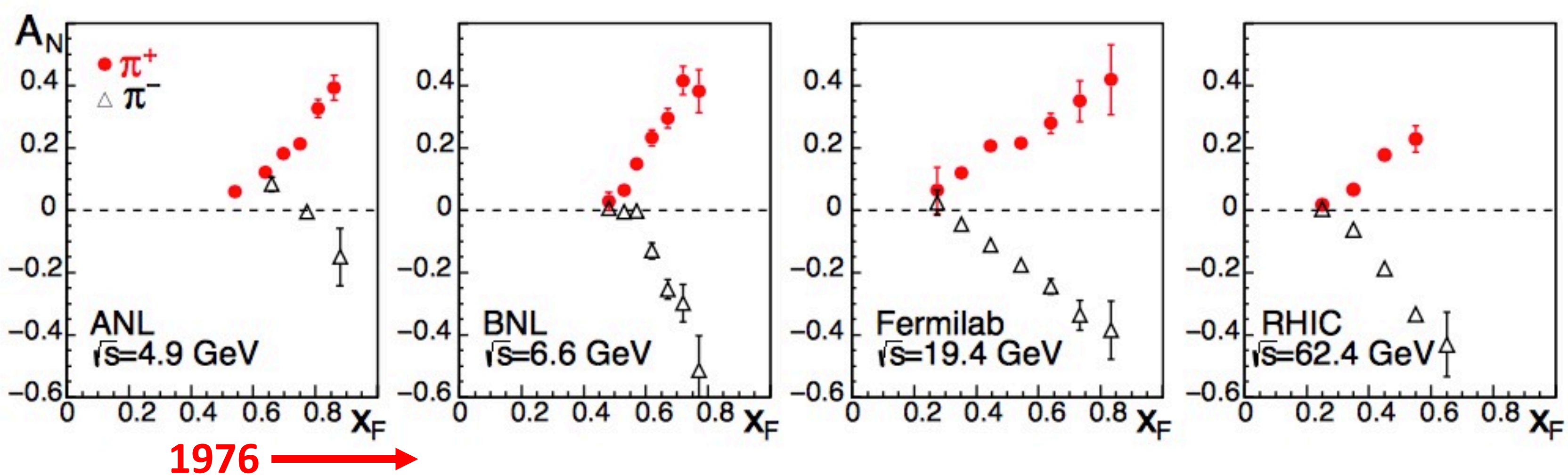


$$d\Delta\sigma(S_T) \sim \underbrace{H_{QS} \otimes f_1 \otimes \boldsymbol{F_{FT}} \otimes D_1}_{\text{Qiu-Sterman term}}$$

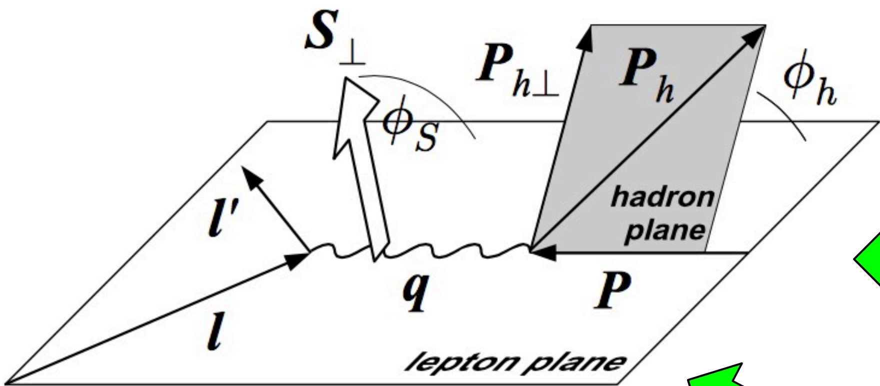
$$+ \underbrace{H_F \otimes f_1 \otimes \boldsymbol{h_1} \otimes \left(\boldsymbol{H_1^{\perp(1)}}, \boldsymbol{\tilde{H}}\right)}_{\text{Fragmentation term}}$$

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

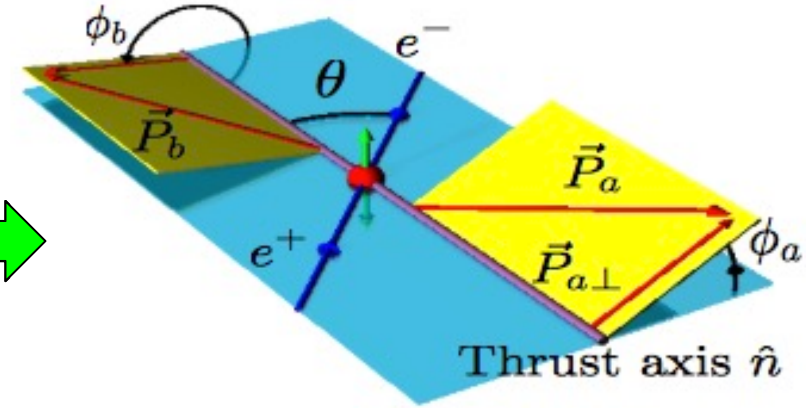
A_N is a *collinear* (twist-3) observable



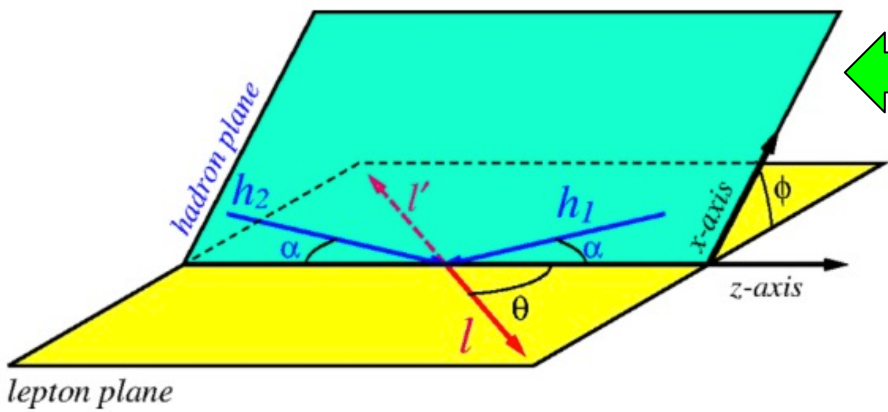
Cammarota, Gamberg, Kang, Miller, DP, Prokudin, Rogers, Sato, PRD **102** (2020)



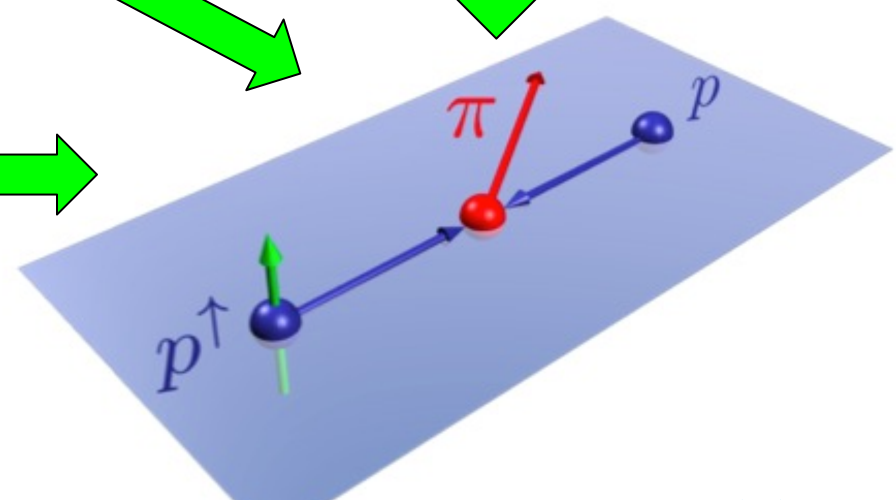
h_1, F_{FT}, $H_1^{\perp(1)}$



$H_1^{\perp(1)}$

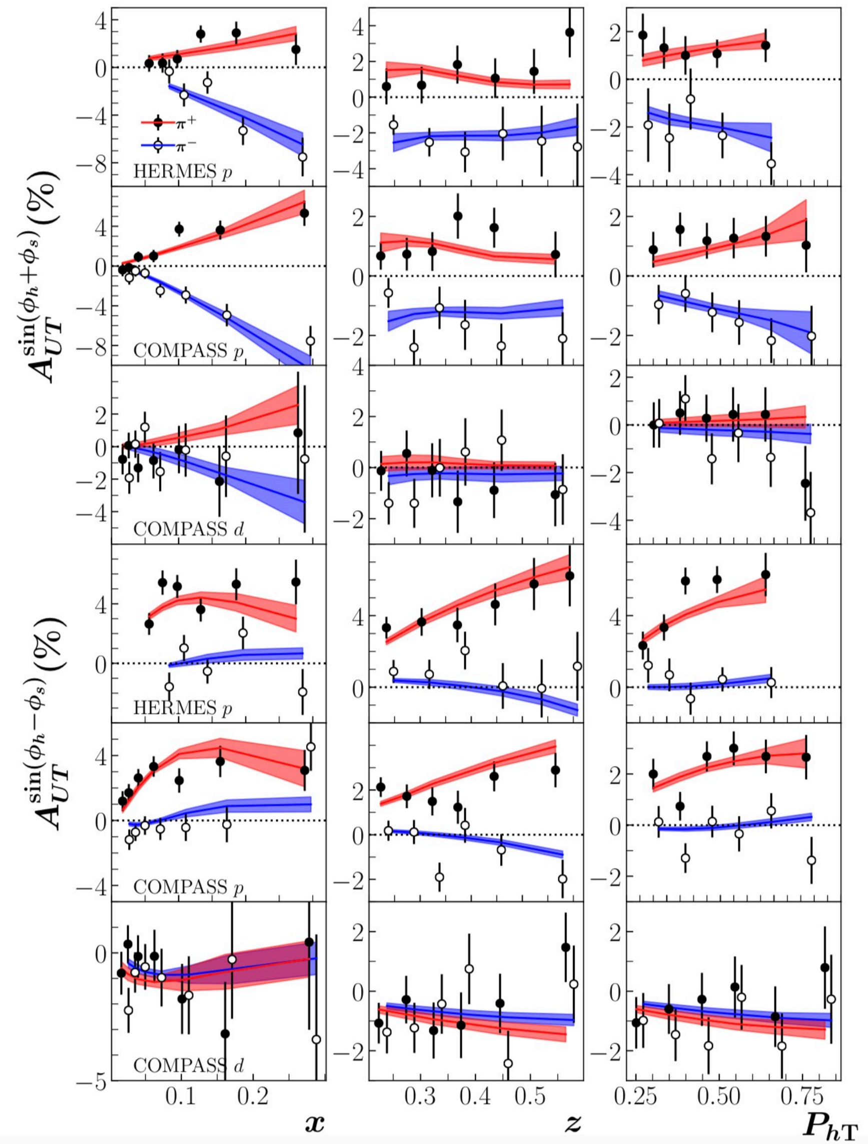


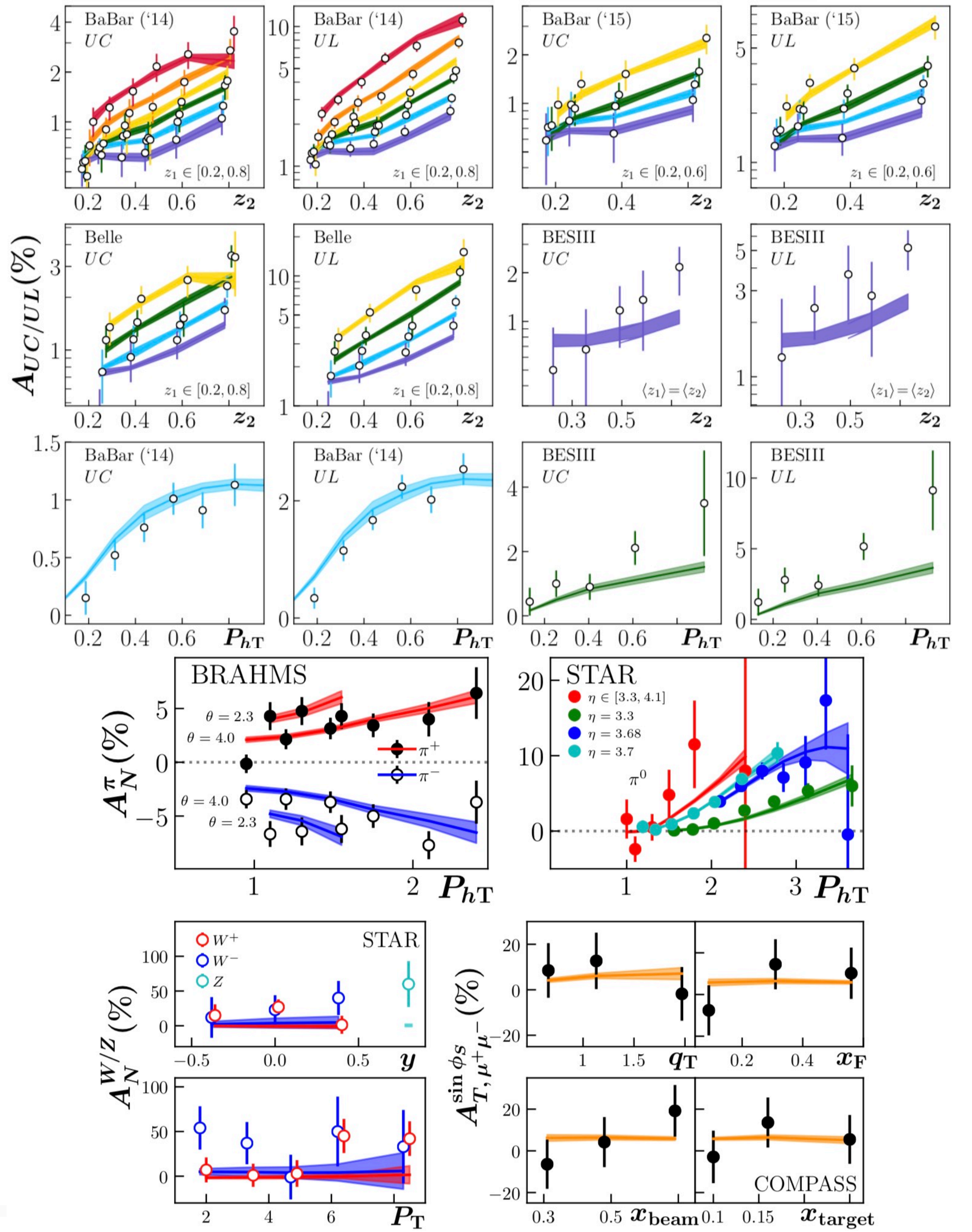
F_{FT}

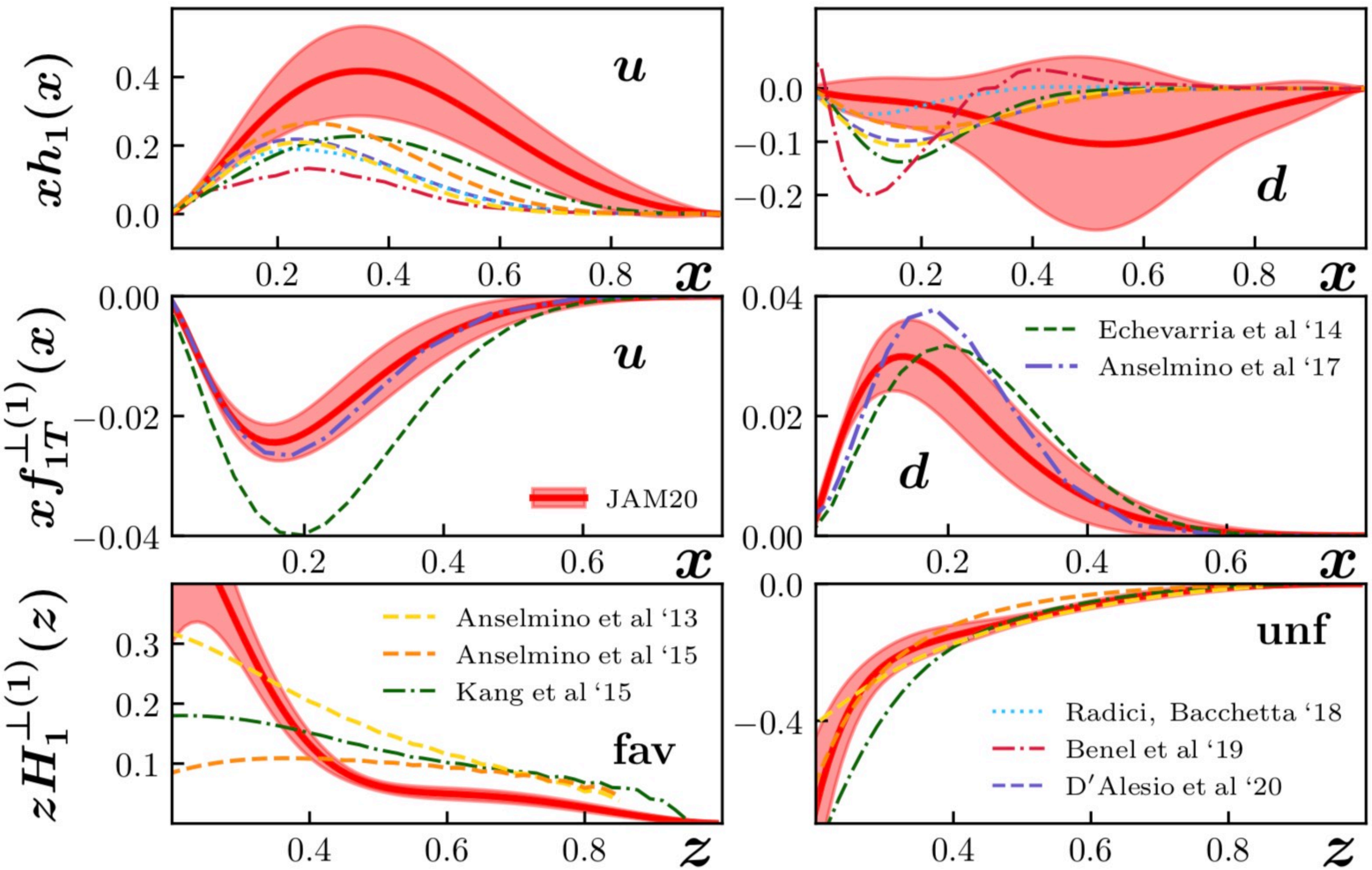


h_1, F_{FT}, $H_1^{\perp(1)}$

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





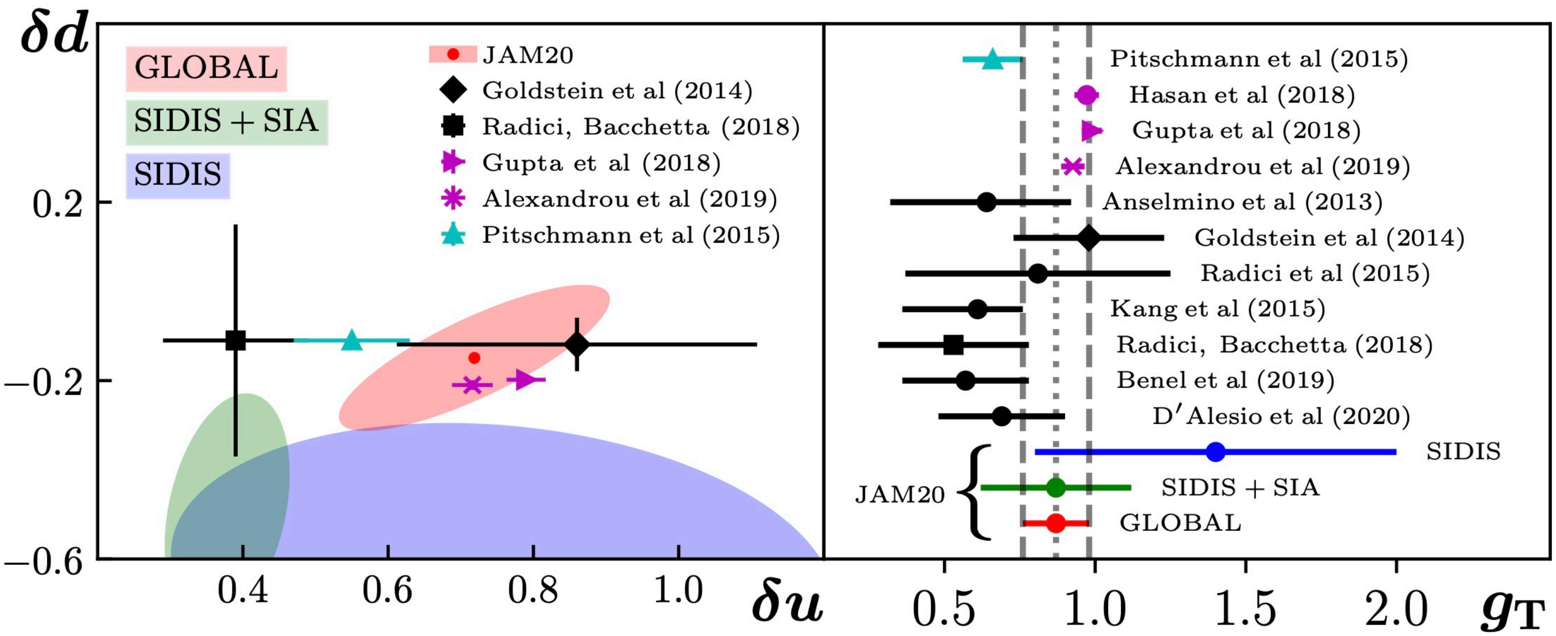


Transversity

Sivers first moment (QS function)

Collins first moment

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



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

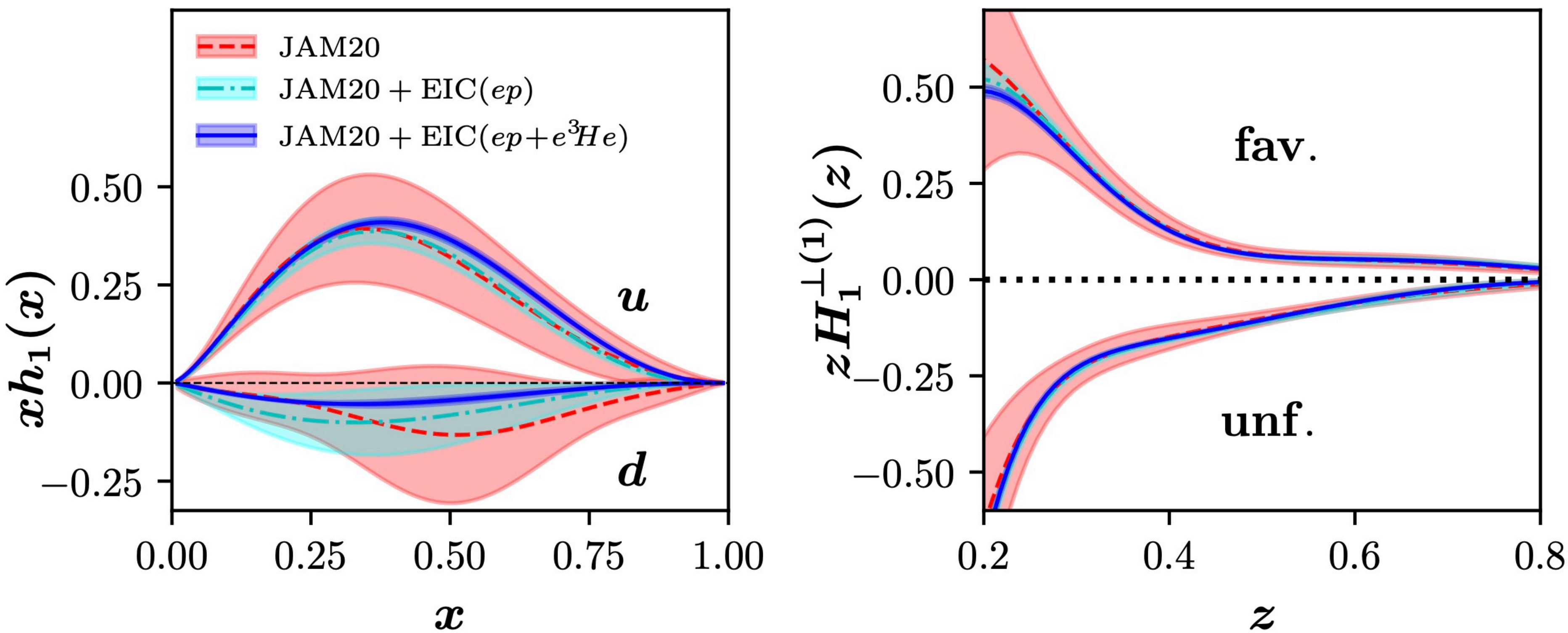
Only after a *simultaneous* QCD global analysis of SSAs does the phenomenological extraction of the tensor charges agree with lattice*, but still with large uncertainties*

Gamberg, Kang, DP, Prokudin, Sato, Seidl, arXiv:2101.06200, to be published in PLB

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**

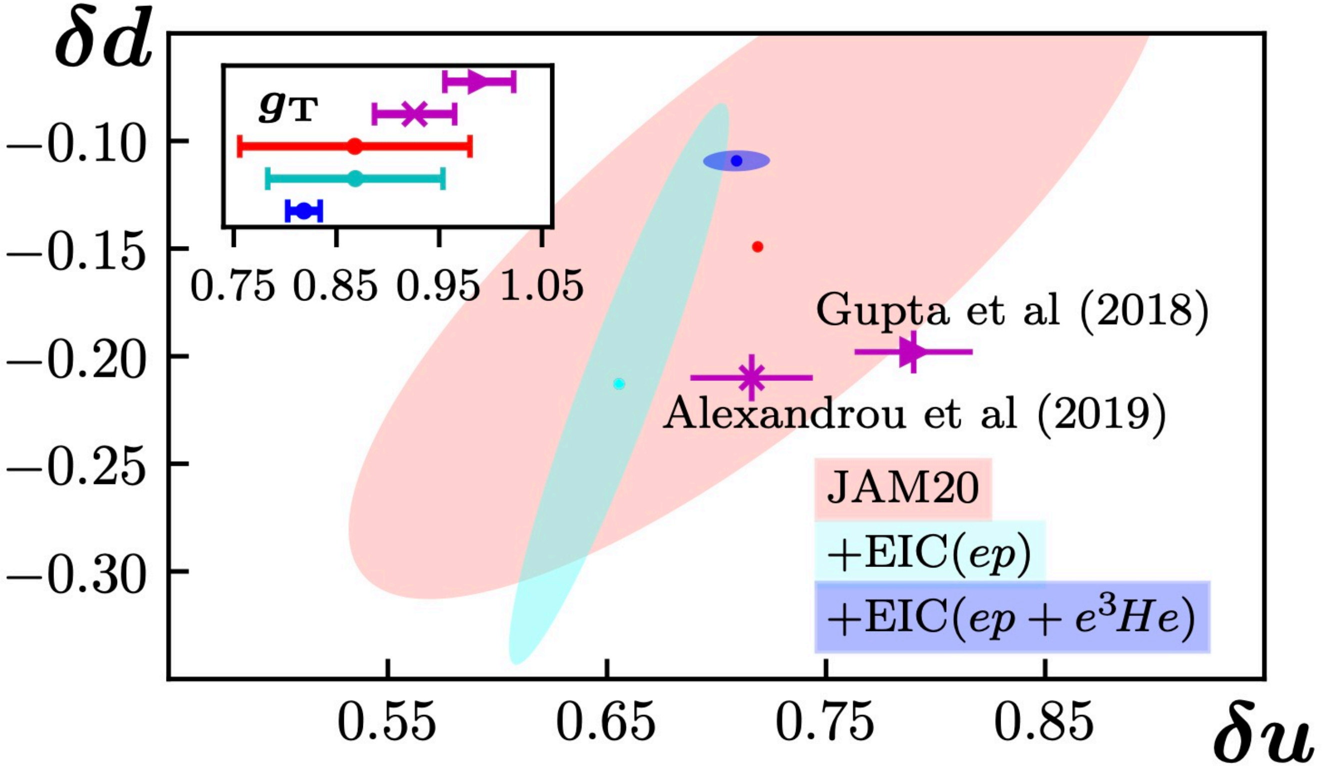
Assumed accumulated luminosities of 10 fb^{-1}, 70% polarization, conservatively accounted for detector smearing and acceptance effects

Gamberg, Kang, DP, Prokudin, Sato, Seidl, arXiv:2101.06200, to be published in PLB



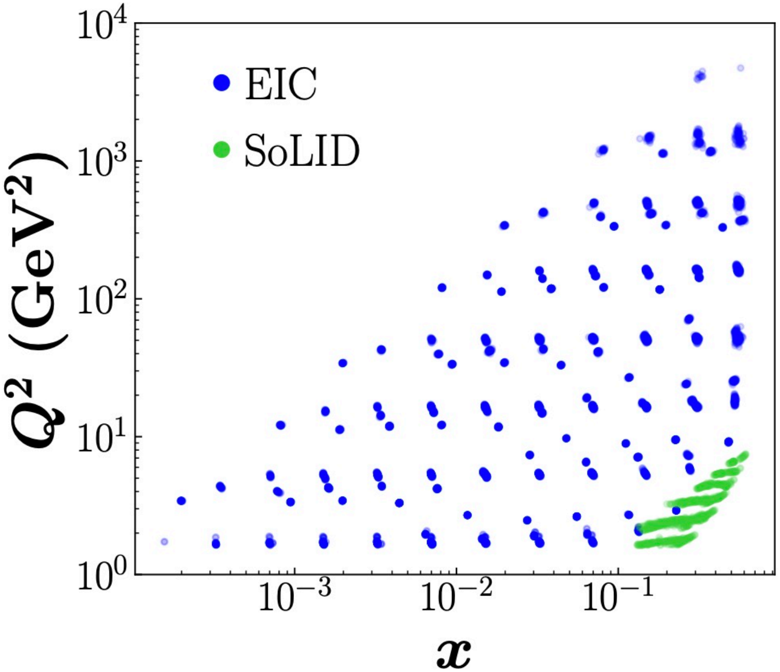
EIC data on the Collins effect will significantly reduce the uncertainties in extractions of the transversity PDF (as well as the Collins FF)

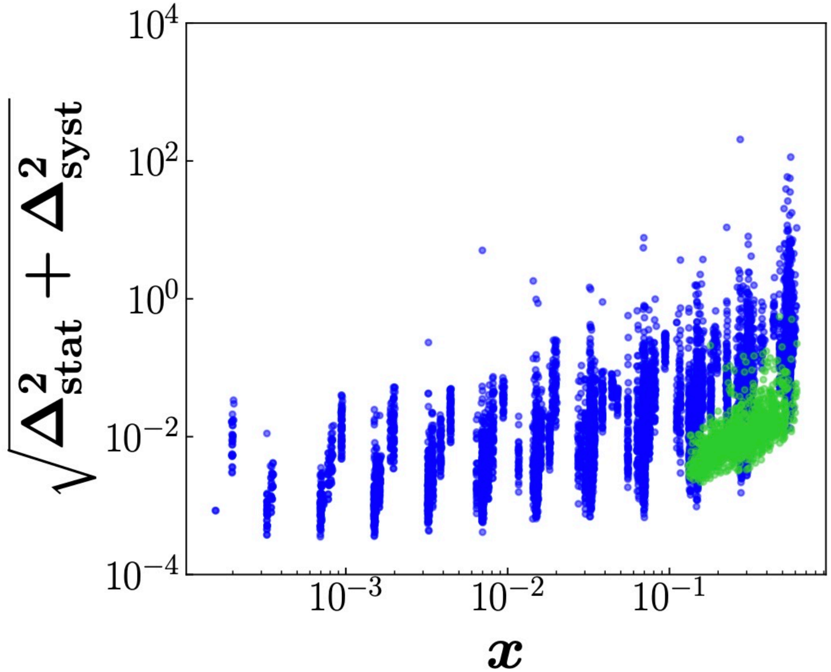
Gamberg, Kang, DP, Prokudin, Sato, Seidl, arXiv:2101.06200, to be published in PLB



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

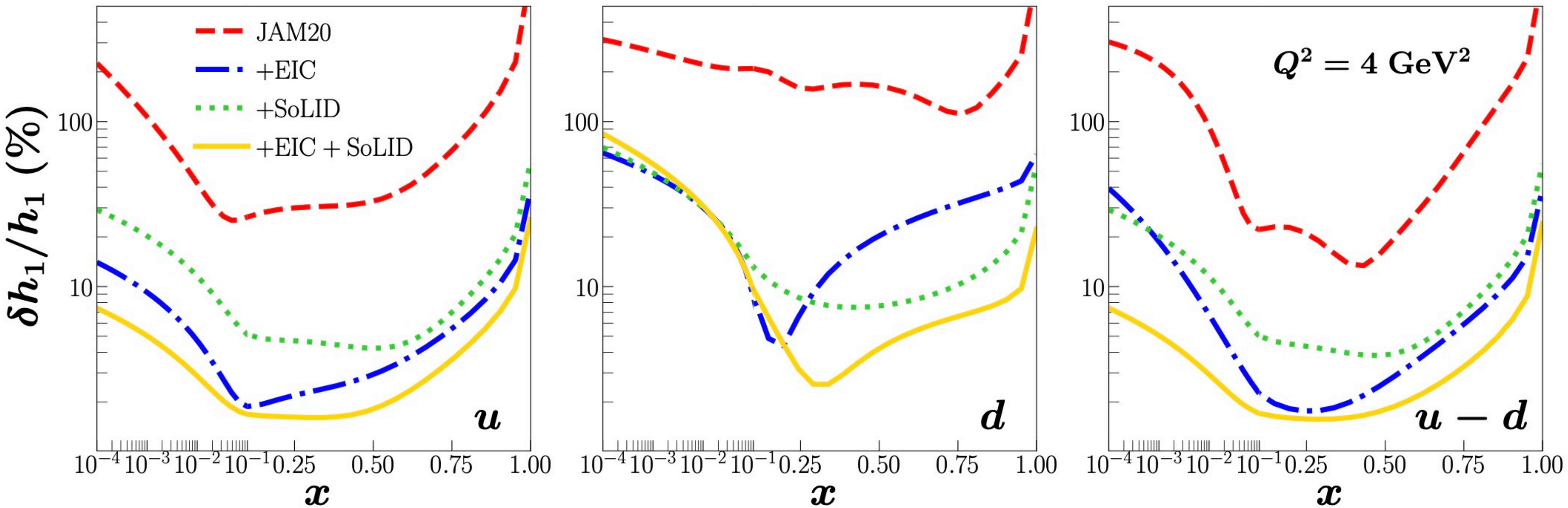
Gamberg, Kang, DP, Prokudin, Sato, Seidl, arXiv:2101.06200, to be published in PLB





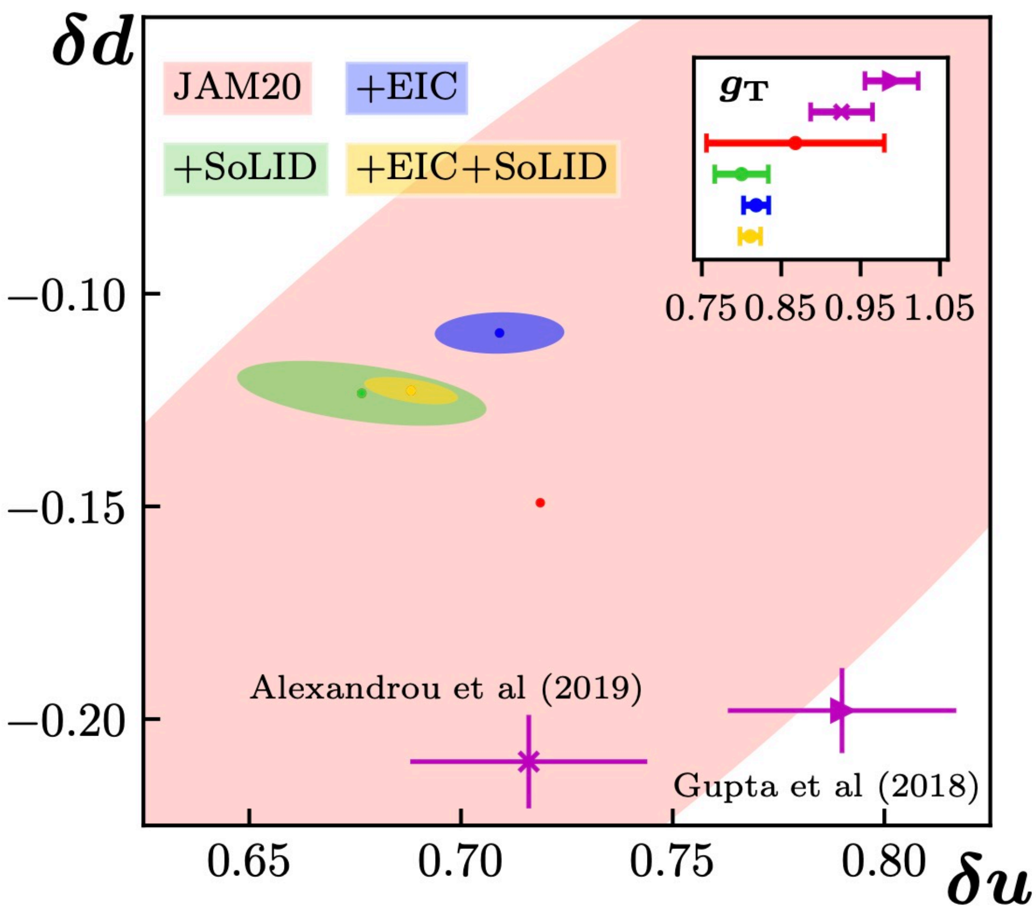
SoLID at JLab covers a complimentary region at higher x and lower Q^2 with much greater luminosity – important to explore the effect of multiple measurements in different kinematic regions

Gamberg, Kang, DP, Prokudin, Sato, Seidl, arXiv:2101.06200, to be published in PLB



SoLID reduces the relative uncertainty in the down quark h_1 at higher x more than the EIC, and overall the relative uncertainties improve the most when data sets from both facilities are included

Gamberg, Kang, DP, Prokudin, Sato, Seidl, arXiv:2101.06200, to be published in PLB



Accuracy vs. precision – a precise measurement cannot always guarantee a very accurate extraction of the distributions, and multiple experiments, such as EIC and SoLID, should be performed in a wide kinematical region in order to minimize bias and expose any potential tensions between data sets (also one reason to have IR2@EIC)

The combined fit that includes both EIC and SoLID pseudo-data provides the best constraint on transversity and the tensor charges, with the results more precise than current lattice calculations

- The tensor charge is arguable the least known of the fundamental charges of the nucleon
- The tensor charge is unique because of it sits at the intersection 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
- In order to reduce bias and obtain the most accurate extraction of the tensor charge, one must have data from multiple future facilities (e.g., EIC and SoLID) that give the most kinematic coverage possible in x and Q^2