# Update on SIDIS Issue:

## Systematic uncertainties and physics impacts

SoLID Collaboration Meeting

*May 6-7, 2016*

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# Raw Asymmetry

## n ($^3$He)

Absolute uncertainties on raw asymmetries.

Spin flip every 20 minutes. 1% control on luminosity, detector efficiency.

| Absolute | $\pi^+$ | $\pi^-$ |
|---|---|---|
| 11 GeV (48 days) | 1.3E-3 | 1.0E-3 |
| 8.8 GeV (21 days) | 2.1E-3 | 1.5E-3 |

## p ($NH_3$)

Spin flip every 2 hours. 2% control on luminosity, detector efficiency.

| Absolute | $\pi^+$ | $\pi^-$ |
|---|---|---|
| 11 GeV (55 days) | 6.1E-3 | 7.1E-3 |
| 8.8 GeV (27.5 days) | 8.5E-3 | 9.9E-3 |

# Resolution

based on Weizhi's tracking results

## n ($^3$He)

Absolute uncertainties with three term separation.

$\varphi_h$

| Absolute | $\pi^+$ | | $\pi^-$ | |
|---|---|---|---|---|
| | Sivers | Collins/Pretzel. | Sivers | Collins/Pretzel. |
| 11 GeV | 4.0E-4 | 5.3E-4 | 1.4E-4 | 1.8E-4 |
| 8.8 GeV | 4.3E-4 | 5.8E-4 | 1.5E-4 | 1.9E-4 |

$\varphi_S$

| Absolute | $\pi^+$ | | $\pi^-$ | |
|---|---|---|---|---|
| | Sivers | Collins/Pretzel. | Sivers | Collins/Pretzel. |
| 11 GeV | 1.8E-4 | 2.6E-4 | 0.73E-4 | 0.80E-4 |
| 8.8 GeV | 1.6E-4 | 2.3E-4 | 0.66E-4 | 0.80E-4 |

## p ($NH_3$)

On-going tracking study by Weizhi.

# Background

## Random coincidence

Within 6 ns time window. Assume 20% uncertainty on this subtraction.

n ($^3$He)

| Relative | $\pi^+$ | $\pi^-$ |
|---|---|---|
| 11 GeV | 0.21 % | 0.21 % |
| 8.8 GeV | 0.24 % | 0.24 % |

p ($NH_3$)

| Relative | $\pi^+$ | $\pi^-$ |
|---|---|---|
| 11 GeV | 0.22 % | 0.22 % |
| 8.8 GeV | 0.23 % | 0.23 % |

## Other background

On-going simulation by Zhiwen/Tianbo.

# Nuclear Effect: $^3$He

## Sivers

| Relative | $\pi^+$ | $\pi^-$ |
|---|---|---|
| 11 GeV | 4.3 % | 4.2 % |
| 8.8 GeV | 4.3 % | 4.2 % |

## Collins

| Relative | $\pi^+$ | $\pi^-$ |
|---|---|---|
| 11 GeV | 4.7 % | 4.6 % |
| 8.8 GeV | 4.7 % | 4.6 % |

## Pretzelosity

| Relative | $\pi^+$ | $\pi^-$ |
|---|---|---|
| 11 GeV | 4.4 % | 4.4 % |
| 8.8 GeV | 4.4 % | 4.4 % |

# Dilution Factor: $NH_3$

Yield from LHe: empty and dummy target. 1.5 days (11/8.8 GeV)
Yield from N: carbon disk. 6 days (optics and detector calibration)
assume 1% uncertainty of the correction from C to N.

| Relative | $\pi^+$ | $\pi^-$ |
|---|---|---|
| 11 GeV | 3.8 % | 4.7 % |
| 8.8 GeV | 3.8 % | 4.7 % |

# Systematic Uncertainty: n ($^3$He)

| | 11 GeV | | 8.8 GeV | |
|---|---|---|---|---|
| | $\pi^+$ | $\pi^-$ | $\pi^+$ | $\pi^-$ |
| Raw asym. (abs.) | 1.3E-3 | 1.0E-3 | 2.1E-3 | 1.5E-3 |
| Resolution (abs.)* | 4.4/5.9 E-4 | 1.6/2.0 E-4 | 4.6/6.2 E-4 | 1.6/2.0 E-4 |
| Background (rel.)? | 0.21% | 0.21% | 0.24% | 0.24% |
| Target pol. (rel.) | 3% | 3% | 3% | 3% |
| Nuclear effect (rel.) | ~ 4.5% | ~ 4.5% | ~ 4.5% | ~ 4.5% |
| Diffractive meson (rel.) | 3% | 2% | 3% | 2% |
| Radiative (rel.) | 2% | 2% | 2% | 2% |
| Total (abs.+ rel.) | ~1.4E-3 + 6.5% | ~ 1.0E-3 + 6.1% | ~2.2E-3 + 6.5% | ~ 1.5E-3 + 6.1% |

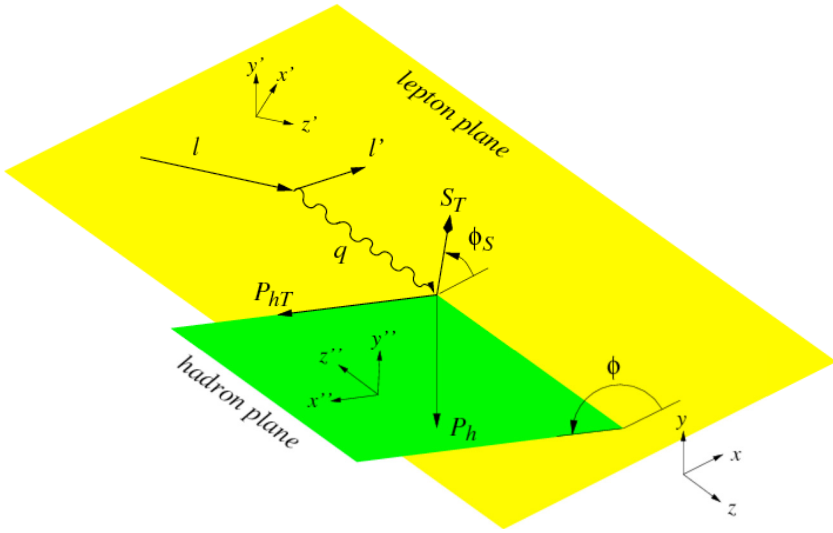
# Systematic Uncertainty: p ($NH_3$)

| | 11 GeV | | 8.8 GeV | |
|---|---|---|---|---|
| | $\pi^+$ | $\pi^-$ | $\pi^+$ | $\pi^-$ |
| Raw asym. (abs.) | 6.1E-3 | 7.1E-3 | 8.5E-3 | 9.9E-3 |
| Resolution (abs.) | ? | ? | ? | ? |
| Background (rel.)? | 0.22% | 0.22% | 0.23% | 0.23% |
| Target pol. (rel.) | 3% | 3% | 3% | 3% |
| Dilution (rel.) | ~ 3.8% | ~ 4.7% | ~ 3.8% | ~ 4.7% |
| Diffractive meson (rel.) | 3% | 2% | 3% | 2% |
| Radiative (rel.) | 2% | 2% | 2% | 2% |
| Total (abs.+ rel.) | ~ 6.1E-3 + 6.0% | ~ 7.1E-3 + 6.3% | ~ 8.5E-3 + 6.0% | ~ 9.9E-3 + 6.3% |

# Physics Impact

## SIDIS differential cross section

18 structure functions $F(x, z, Q^2, P_T)$, model independent. (one photon exchange approximation)



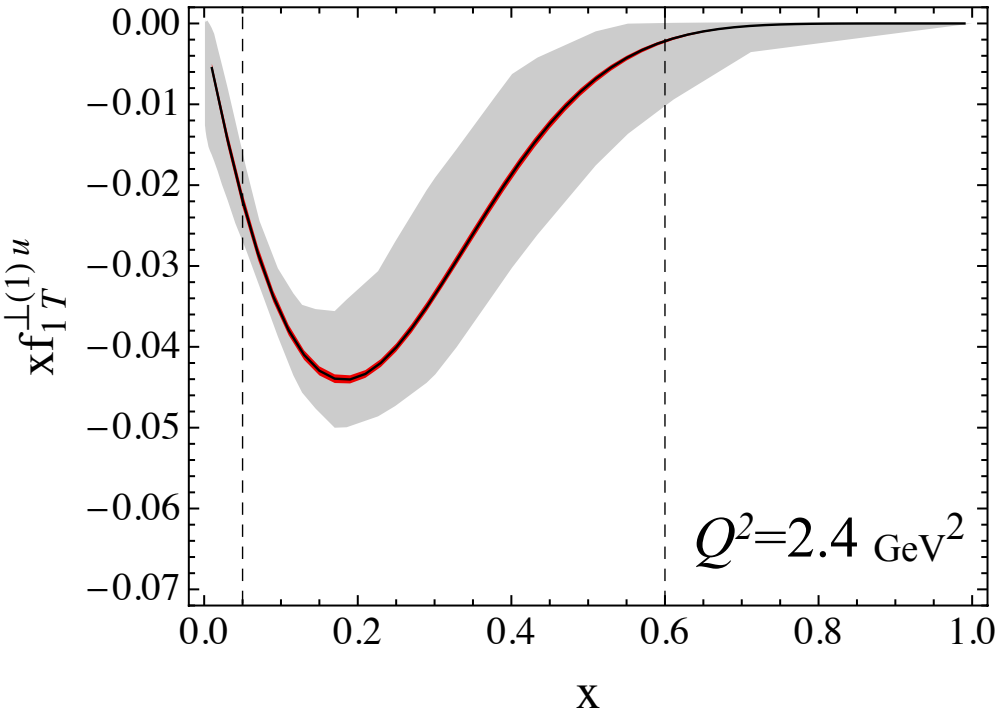

[Diehl&Sapeta EPJC2005]

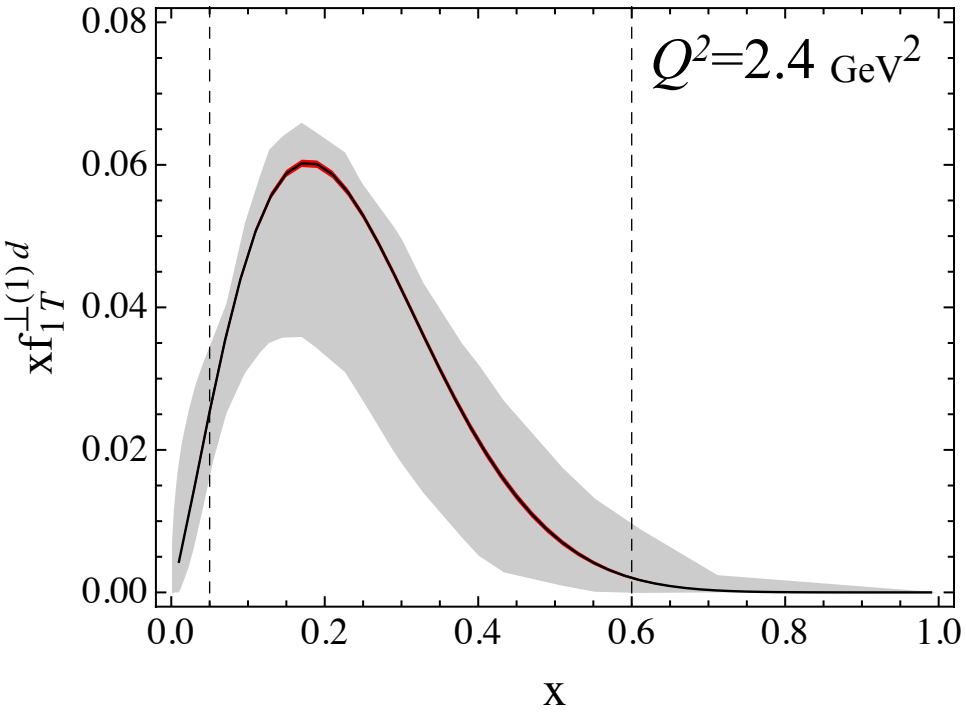
$$
\begin{aligned}
&\frac{d\sigma}{dxdydzdP_T^2 d\phi_h d\phi_S} \\
&= \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right) \\
&\times \Big\{ F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)} F_{UU}^{\cos\phi_h} \cos\phi_h + \epsilon F_{UU}^{\cos 2\phi_h} \cos 2\phi_h + \lambda_e \sqrt{2\epsilon(1-\epsilon)} F_{LU}^{\sin\phi_h} \sin\phi_h \\
&+ S_L \left[ \sqrt{2\epsilon(1+\epsilon)} F_{UL}^{\sin\phi_h} \sin\phi_h + \epsilon F_{UL}^{\sin 2\phi_h} \sin 2\phi_h \right] + \lambda_e S_L \left[ \sqrt{1-\epsilon^2} F_{LL} + \sqrt{2\epsilon(1-\epsilon)} F_{LL}^{\cos\phi_h} \cos\phi_h \right] \\
&+ S_T \left[ (F_{UT,T}^{\sin(\phi_h-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}) \sin(\phi_h-\phi_S) + \epsilon F_{UT}^{\sin(\phi_h+\phi_S)} \sin(\phi_h+\phi_S) + \epsilon F_{UT}^{\sin(3\phi_h-\phi_S)} \sin(3\phi_h-\phi_S) \right. \\
&\quad \left. + \sqrt{2\epsilon(1+\epsilon)} F_{UT}^{\sin\phi_S} \sin\phi_S + \sqrt{2\epsilon(1+\epsilon)} F_{UT}^{\sin(2\phi_h-\phi_S)} \sin(2\phi_h-\phi_S) \right] \\
&+ \lambda_e S_T \left[ \sqrt{1-\epsilon^2} F_{LT}^{\cos(\phi_h-\phi_S)} \cos(\phi_h-\phi_S) \right. \\
&\quad \left. + \sqrt{2\epsilon(1-\epsilon)} F_{LT}^{\cos\phi_S} \cos\phi_S + \sqrt{2\epsilon(1-\epsilon)} F_{LT}^{\cos(2\phi_h-\phi_S)} \cos(2\phi_h-\phi_S) \right] \Big\}
\end{aligned}
$$

SoLID:
*4D* bins in ($x$, $z$, $Q^2$, $P_T$)

# SoLID Impact on Sivers

$$f_{1T}^{\perp(1)}(x) = \int \mathrm{d}^2\mathbf{k}_\perp \frac{\mathbf{k}_\perp^2}{2M^2} f_{1T}^{\perp}(x, k_\perp)$$



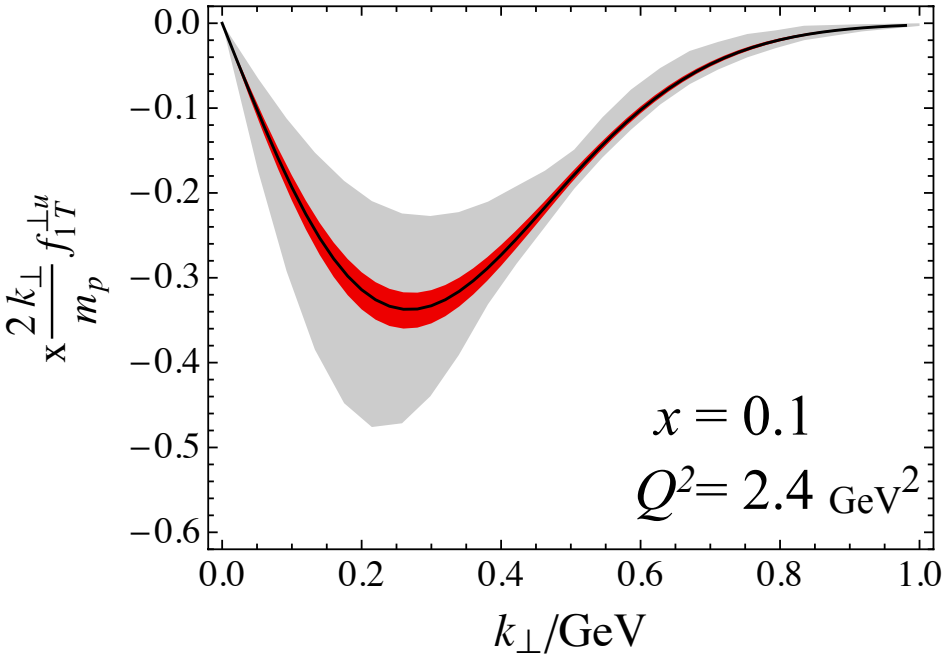



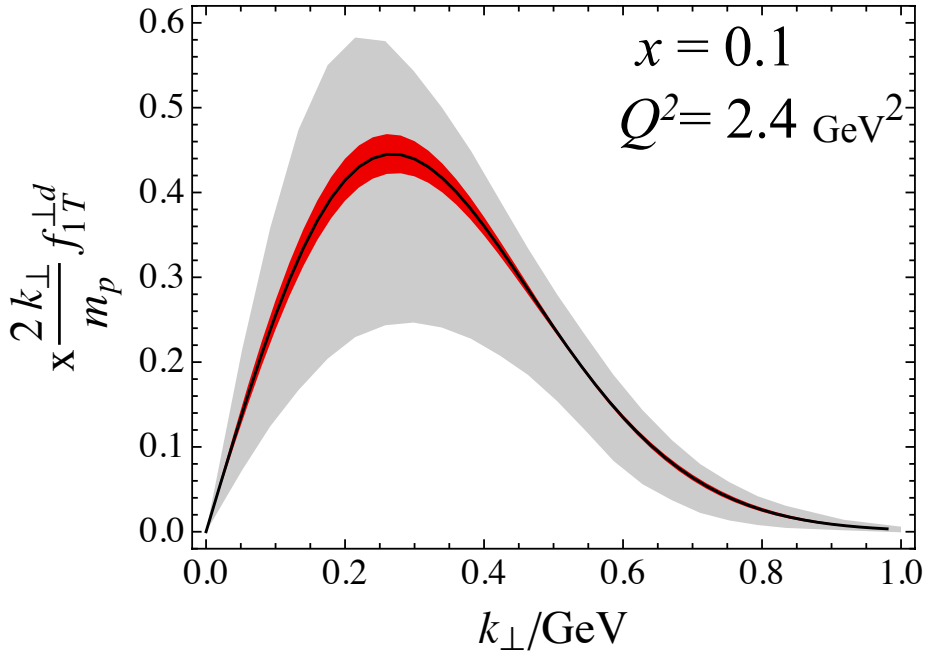

95% C.L.

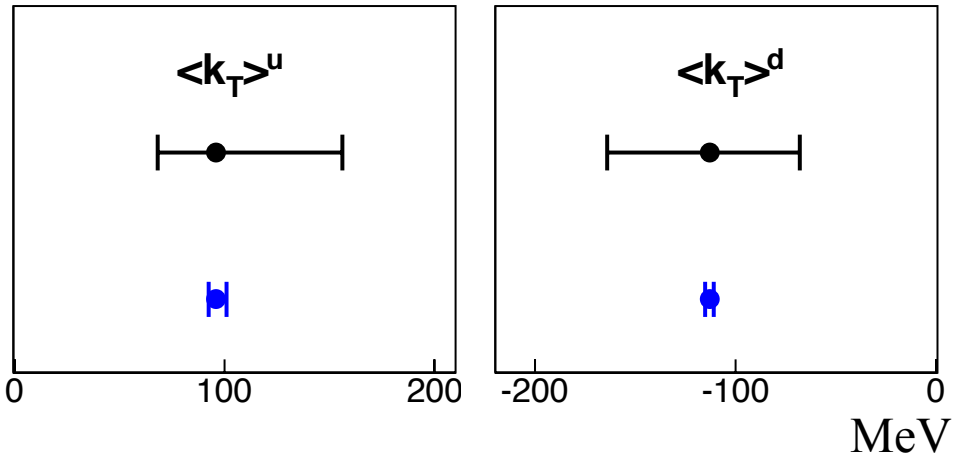
parametrization by M. Anselmino *et al.*, EPJ A 39, 89 (2009).

SoLID projection with transversely polarized neutron and proton data.

# Quark Transverse Momentum in $p\uparrow$



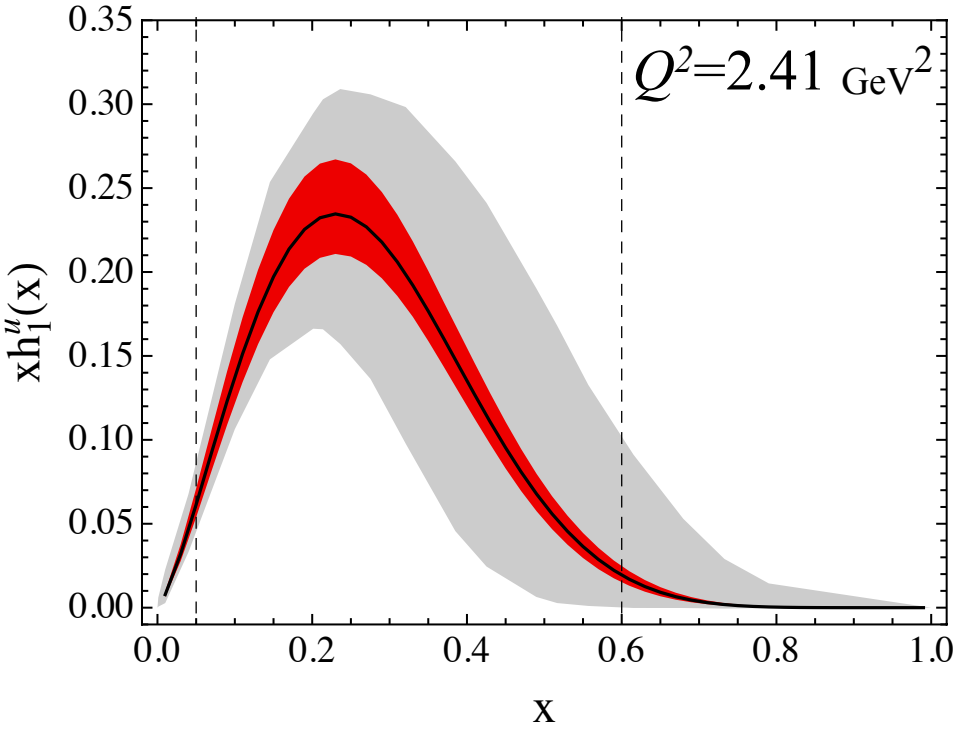



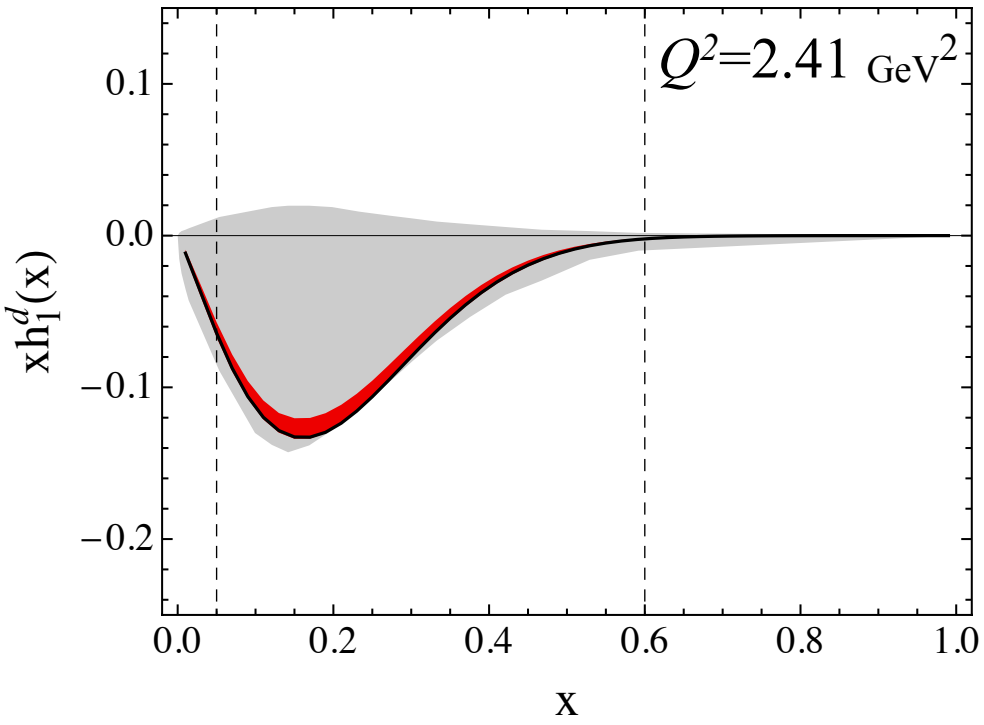

$$\langle \mathbf{k}_\perp \rangle = -M \int \mathrm{d}x f_{1T}^{\perp(1)}(x) \, (\mathbf{S} \times \hat{\mathbf{P}})$$

Anselmino et al. (2009)

SoLID

# SoLID Impact on Transversity



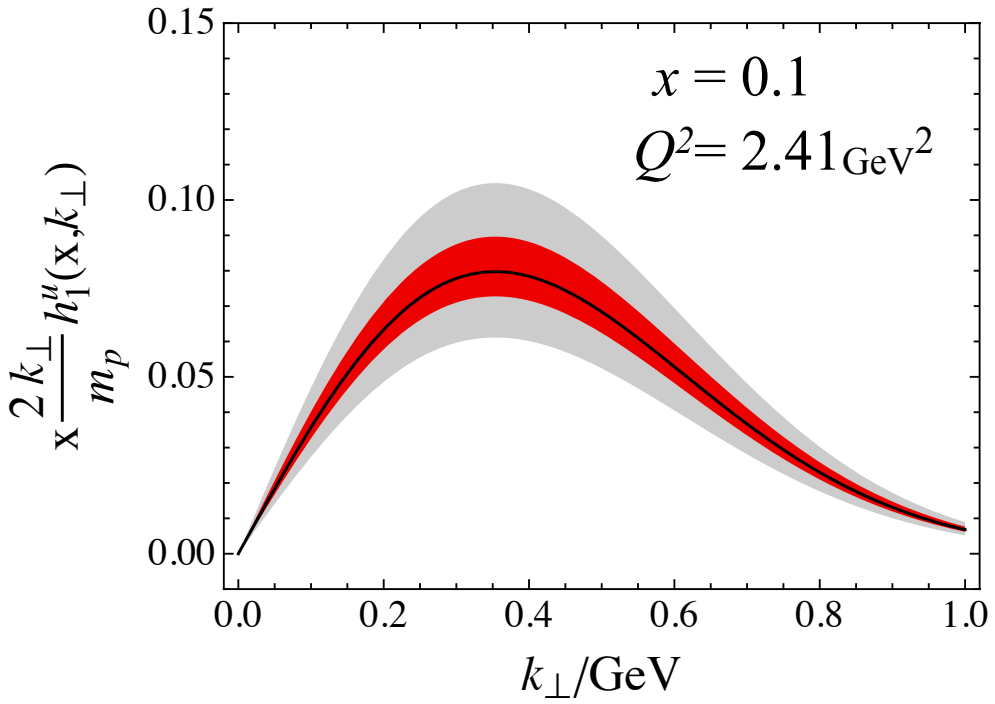



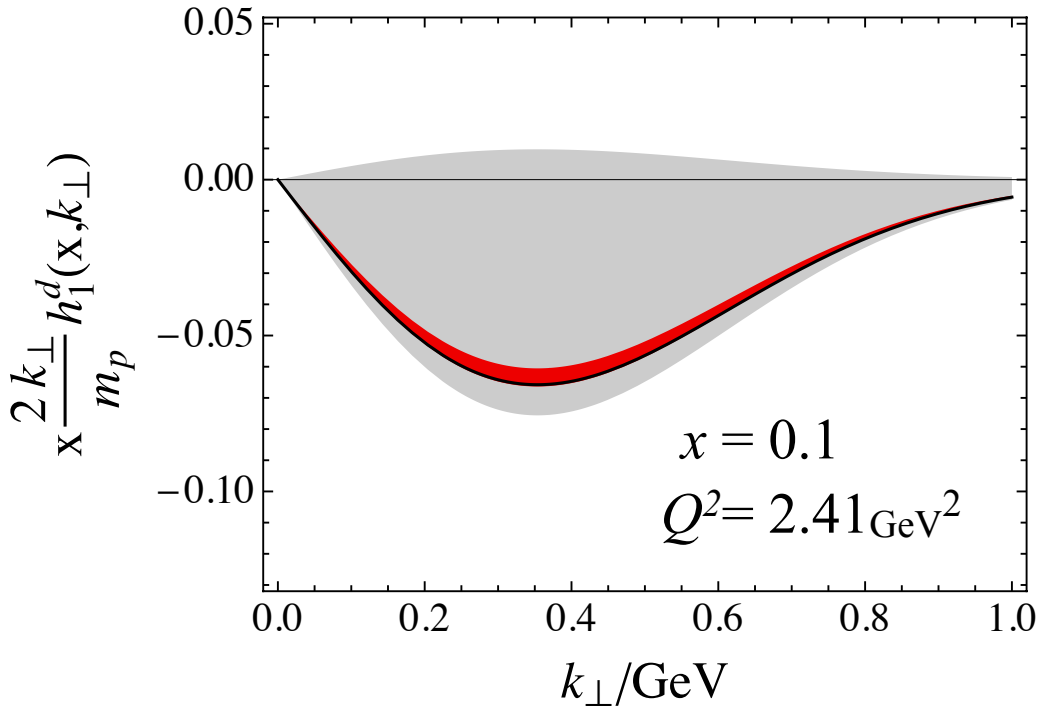

95% C.L.

parametrization by M. Anselmino *et al.*, PR D 87, 094019 (2013).

SoLID projection with transversely polarized neutron and proton data.

# SoLID Impact on Transversity TMD



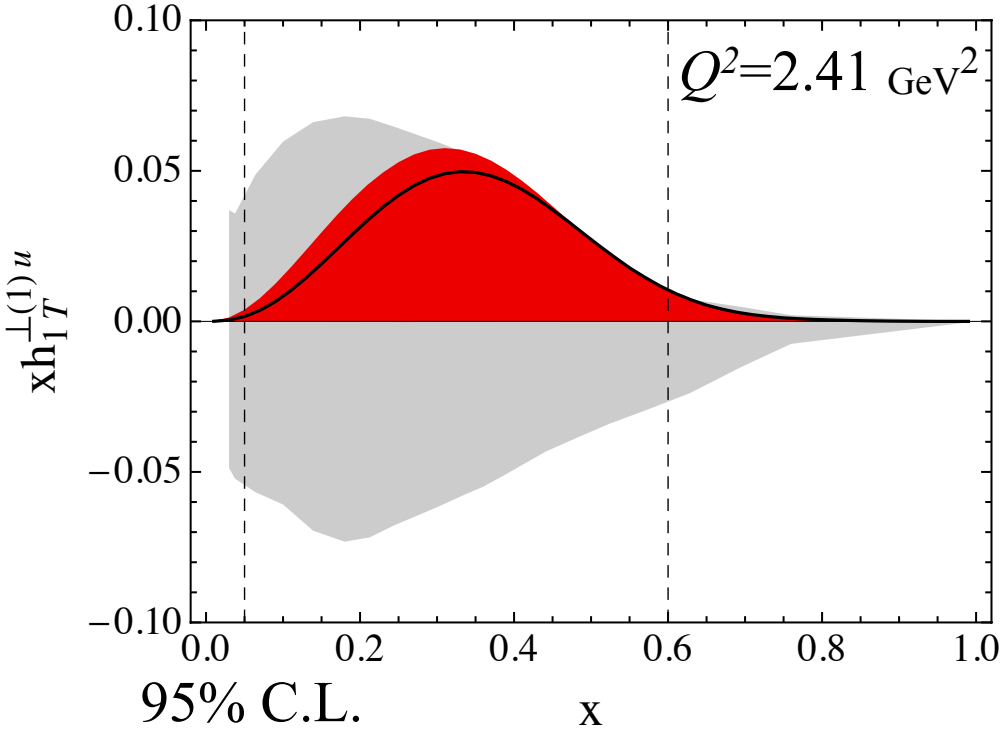



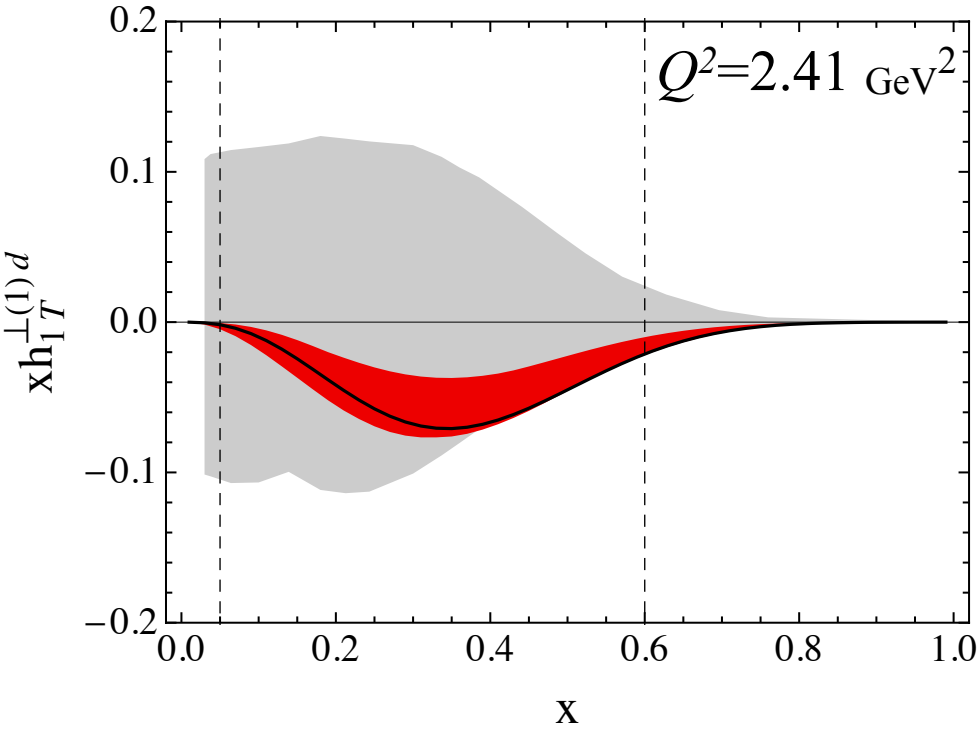

95% C.L.

parametrization by M. Anselmino *et al.*, PR D 87, 094019 (2013).

SoLID projection with transversely polarized neutron and proton data.

# SoLID Impact on Pretzelosity



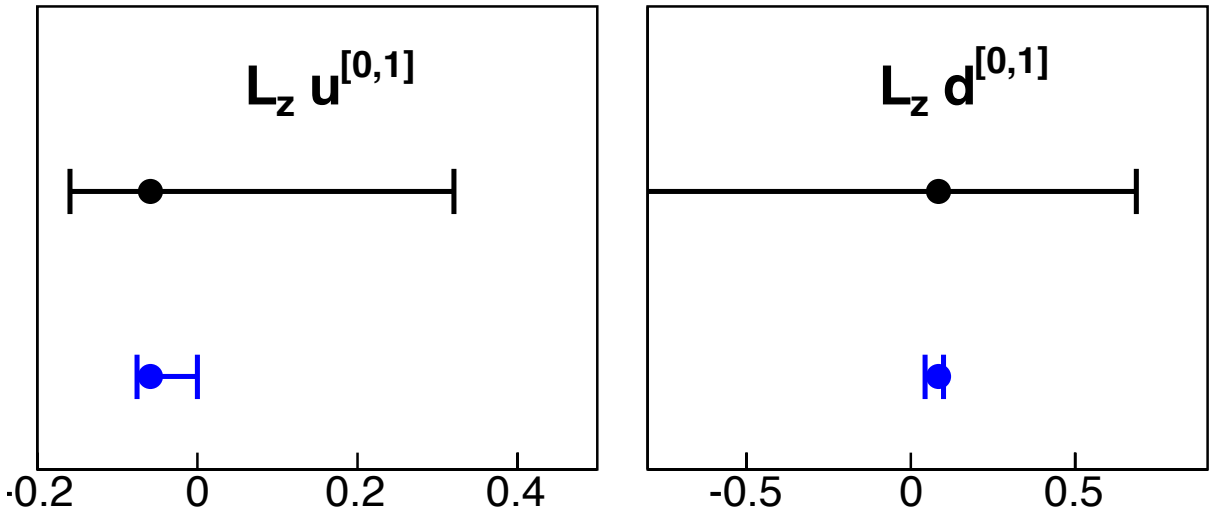




parametrization by C. Lefky *et al.*, PR D 91, 034010 (2015).

SoLID projection with transversely polarized neutron and proton data.

# Orbital Angular Momentum

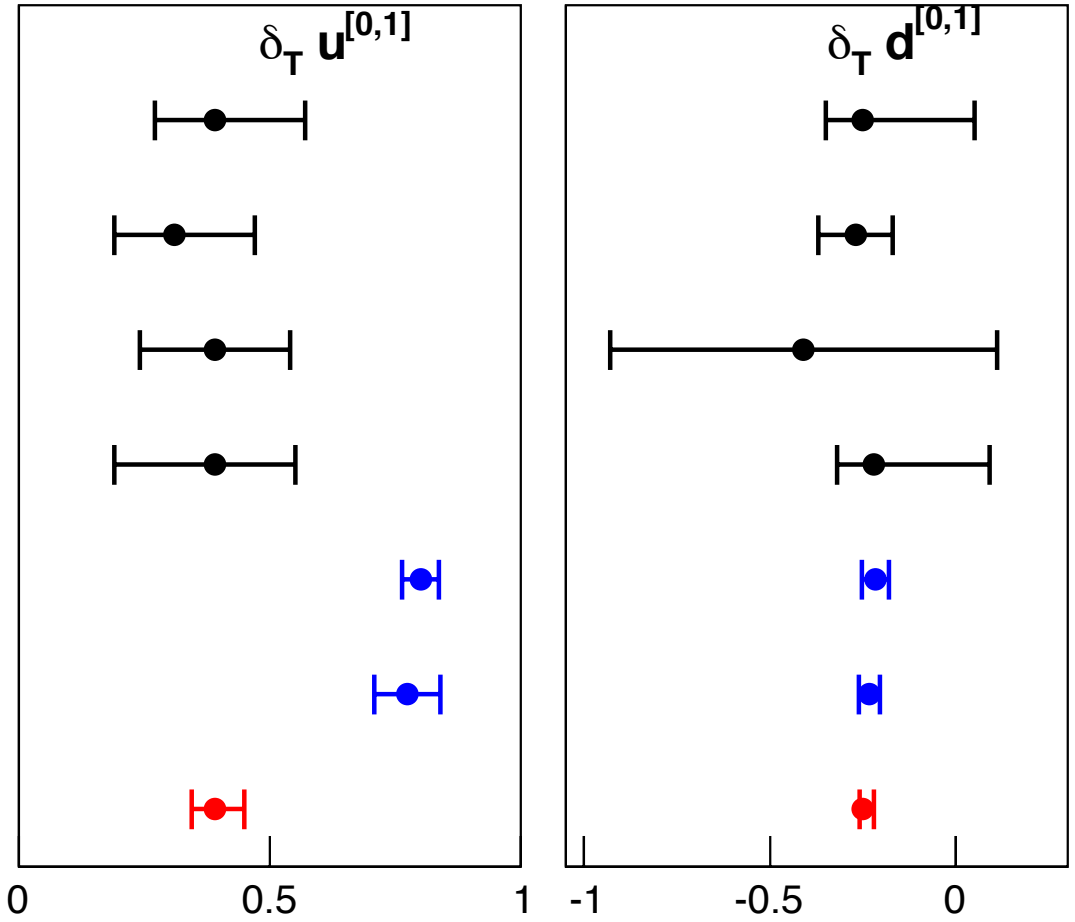
$$L_z^q = -\int \mathrm{d}x\mathrm{d}^2\mathbf{k}_\perp \frac{\mathbf{k}_\perp^2}{2M^2} h_{1T}^{\perp q}(x, k_\perp) = -\int \mathrm{d}x h_{1T}^{\perp(1)q}(x)$$




Lefky et al. (2015)

SoLID

# Tensor Charge




*Extraction from Experiments:*

Anselmino et al (2013a)

Anselmino et al (2013b)

Radici et al (2015)

Kang et al (2015)

*Lattice QCD:*

Alexandrou et al (2014)

Bhattacharya et al (2015)

SoLID Projection

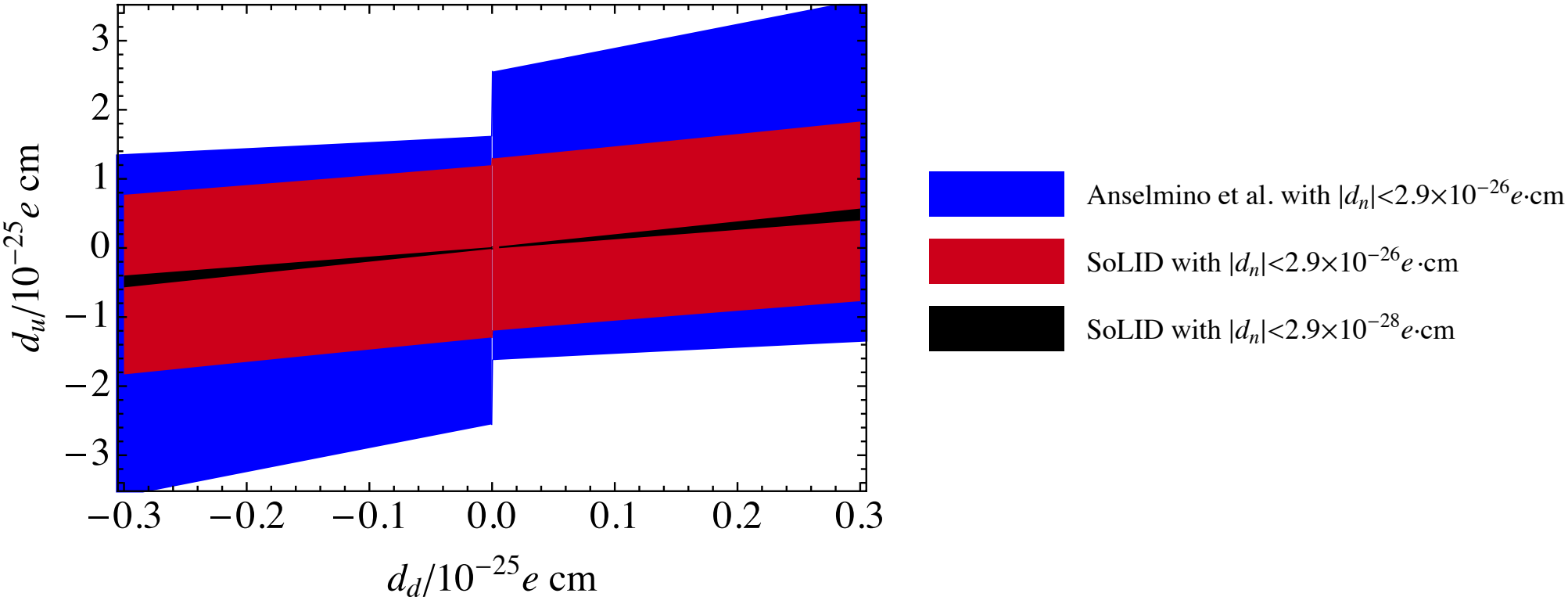
SoLID projection based on Anselmino et al 2013a parametrization.

# Tensor Charge and Neutron EDM

**E**lectric **D**ipole **M**oment

## Tensor charge and EDM

$$d_n = \delta_T u \, d_u + \delta_T d \, d_d + \delta_T s \, d_s$$




current neutron EDM limit $|d_n| < 2.9 \times 10^{-26}\, e \cdot \mathrm{cm}$

*Thanks!*