Address Recommendations: SIDIS

Tianbo Liu
Duke University and Duke Kunshan University

SoLID Collaboration Meeting
January 12-13, 2016

Recommendations from Director's Review

Related to SIDIS directly:

- Better comparisons with expected results on programs such as SBS and particularly CLAS12 are needed to clarify the need for the SoLID SIDIS program. Crisp demonstrations of the improvements possible with SoLID should be developed.
  -- Comparisons have been done. *SIDIS physics*, Haiyan (Sep.11-12, 2015)
  -- Update in this talk.

- The SoLID Collaboration should investigate the possibility of kaon identification, especially given their high luminosity.
- The collaboration is encouraged to explore the power of extended kaon identification (through Cherenkov or TOF).
  -- RICH approach, *heavy gas Cherenkov*. Zhiwen
  -- Fast TOF approach, *time of flight* and *MRPC*. Alexandre, Yi

Recommendations from Director's Review

Related to SIDIS and others in general:

- Acceptances, efficiencies, and systematic uncertainties should be simulated for each of the core measurements.
  -- Acceptance, *simulation*. Seamus
  -- Efficiencies, subsystems should update.
  -- Systematic uncertainties, update in this talk.

- End-to-end simulations with realistic subsystem responses and material budgets, and complete track finding and reconstruction should be developed.
  -- Simulation, GEM, HGC,MRPC,SPD,EC are in GEMC, LGC is onging.
  -- Track finding and reconstruction, *tracking*, Weizhi.
- The development of a simulation framework with realistic reconstruction and analysis should be pursued with high priority and increased resources.
  -- Reconstruction and analysis, *software*, Ole

Systematic Uncertainties

In proposal:

E12-10-006 ^{3}He 11GeV

	Sivers π^+	Sivers π^-	Collins π^+	Collins π^-
Raw asymmetry (absolute)	1.1E-3	1.1E-3	1.1E-3	1.1E-3
Background subtraction (rel.)	1.0%	1.0%	1.0%	1.0%
Detection resolution	negligible	negligible	negligible	negligible
Nuclear effects (rel.)	5%+1.2%	5%+1.2%	4%+1.2%	4%+1.2%
Diffractive vector meson (rel.)	3%	2%	3%	2%
Radiative correction (rel.)	2%	2%	2%	2%
^{3}He polarization (rel.)	3%+0.5%	3%+0.5%	3%+0.5%	3%+0.5%

Target Polarization

Asymmetry:

$$A = \frac{2}{P_1 + P_2} \frac{\sqrt{N_1(\phi_S)\, N_2(\phi_S+\pi)} - \sqrt{N_1(\phi_S+\pi)\, N_2(\phi_S)}}{\sqrt{N_1(\phi_S)\, N_2(\phi_S+\pi)} + \sqrt{N_1(\phi_S+\pi)\, N_2(\phi_S)}}$$

Knowledge on the target polarization: 3% (rel.)

Polarization direction: 0.0012% (rel.) assume 0.2° uncertainty of the direction

Second order effect (physics asym. related part.): relative

	Sivers		Collins		Pretzelosity	
11GeV π^+	~ 5.3E-4	< 4.0E-3	~ 1.3E-5	< 6.6E-5	~ 1.8E-7	< 4.2E-6
11GeV π^-	~ 7.3E-5	< 4.7E-4	~ 1.8E-5	< 1.1E-4	~ 1.4E-7	< 3.0E-6
8.8GeV π^+	~ 4.8E-4	< 3.4E-3	~ 1.2E-5	< 5.5E-5	~ 6.0E-8	< 1.1E-6
8.8GeV π^-	~ 6.6E-5	< 3.5E-4	~ 1.5E-5	< 6.6E-5	~ 4.0E-8	< 6.9E-7

Second order effect from luminosity and detector efficiencies.

Longitudinal polarization contamination.

Random Coincidence Background

Coincidence e and π:

Choice of the time window 6 ns.

$1 < Q^2 < 8$, $0.05 < x < 0.6$, $0.3 < z < 0.7$, $0 < P_T < 1.2$, $W > 2.3$, $W' > 1.6$

Signal to noise ratio:

before vertex cut

	11GeV π^+	11GeV π^-	8.8GeV π^+	8.8GeV π^-
Total	6.1	6.6	3.3	3.8
Every Bin	0.5 ~ 180	0.5 ~ 120	0.6 ~ 50	0.7 ~ 50

Preliminary

Background subtraction uncertainty:

Assume 20% uncertainty in the subtraction procedure.

after 3σ vertex cut

	11GeV π^+	11GeV π^-	8.8GeV π^+	8.8GeV π^-
Every Bin (rel.)	0.02~5.9%	0.03~5.7%	0.06~5.4%	0.06~4.6%
Average (rel.)	0.5%	0.5%	1.0%	0.9%

Preliminary

Background from $\pi^0 \rightarrow \gamma\gamma$.

Detection Resolution

Resolution of kinematic variables in "Trento" convention:

RMS.

11GeV ^{3}He π^+

	x	z	Q^2/GeV^2	P_T/GeV	φ_h /rad	φ_S /rad
Average	0.0026	0.0020	0.029	0.0039	0.012	0.0047
Range	< 0.011	< 0.006	< 0.10	< 0.010	< 0.055	< 0.0063

Based on Weizhi's preliminary tracking results.

Detection resolution uncertainty (relative)

	Sivers		Collins		Pretzelosity	
11GeV π^+	0.026%	< 0.18%	0.026%	< 0.18%	0.15%	< 0.94%
11GeV π^-	0.026%	< 0.18%	0.026%	< 0.19%	0.15%	< 0.95%
8.8GeV π^+	0.018%	< 0.10%	0.018%	< 0.10%	0.096%	< 0.49%
8.8GeV π^-	0.017%	< 0.10%	0.018%	< 0.10%	0.095%	< 0.49%

Remaining

Nuclear effects:

Combine the ^3He and NH_3 data to extract the effective physics asymmetry on neutron.
about 5% (in proposal).

Diffractive vector meson:

$\pi^{\pm}$ decayed from diffractive ρ meson is about 8% estimated based on Pythia.
Assuming 0 SSA for ρ, the uncertainty on physics asymmetry ~3% (in proposal).

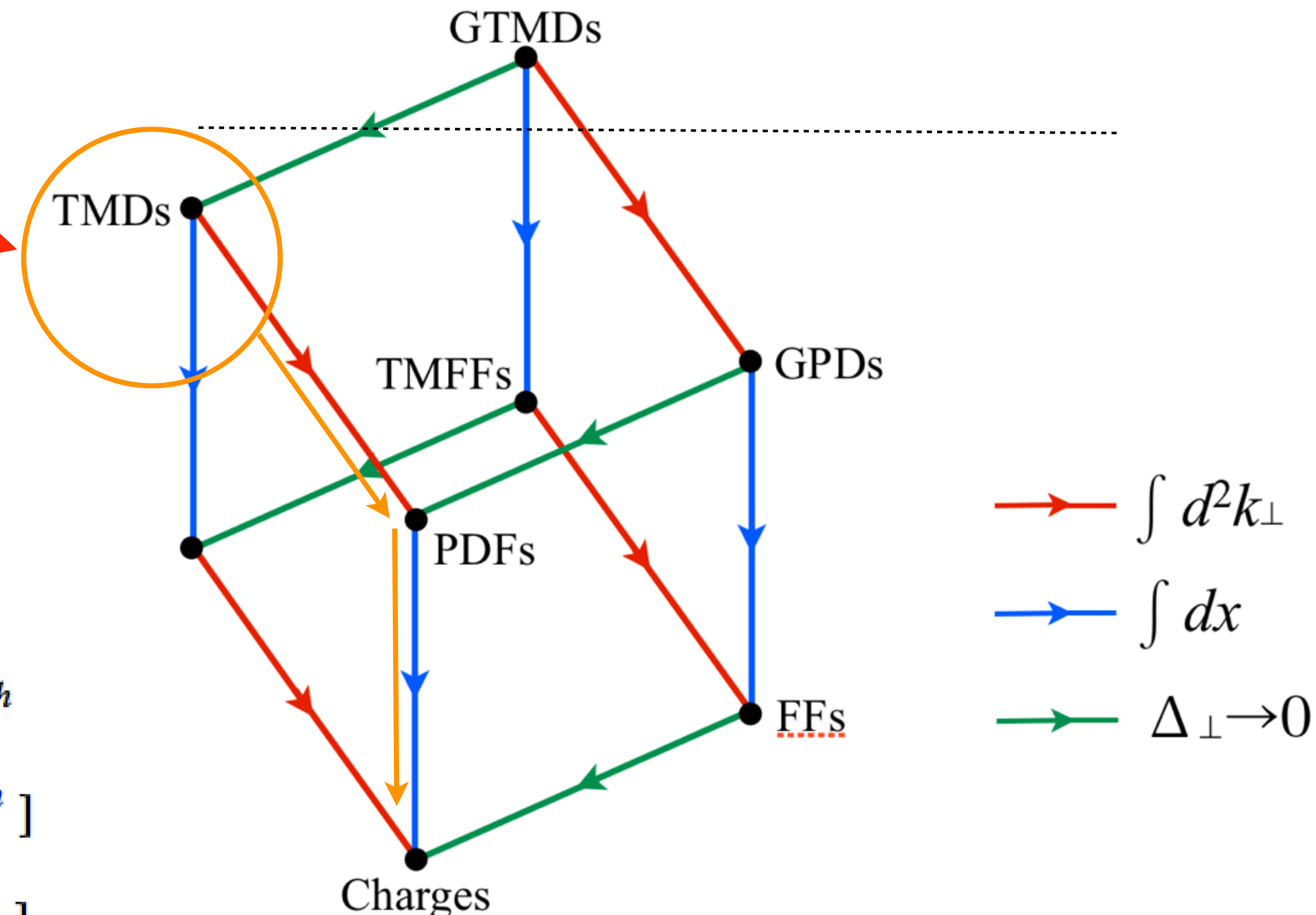
Radiative correction:

Estimated by the HERMES tuned Pythia.
The uncertainty on physics asymmetry ~2% (in proposal).

Zhiwen and Tianbo will update these.

Physics Impact

SoLID SIDIS



cross section:

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

18 structure functions
model independent

$F\,(\,x\,, z\,, P_T\,, Q^2\,)$

extracted from 4-dimensional bins at SoLID

Tensor Charge

Exp.	Target	Had.	Improvement (u)	Improvement (d)
CLAS	p	π^+	1.38E-2	3.23E-2 ?
CLAS	p	π^-	4.04E-2 ?	3.14E-2 ?
SoLID	p	π^+	7.45E-3	3.37E-2 ?
SoLID	p	π^-	2.60E-2	2.88E-2 ?
SoLID	^{3}He	π^+	2.68E-2	2.86E-2
SoLID	^{3}He	π^-	3.25E-2	3.05E-2

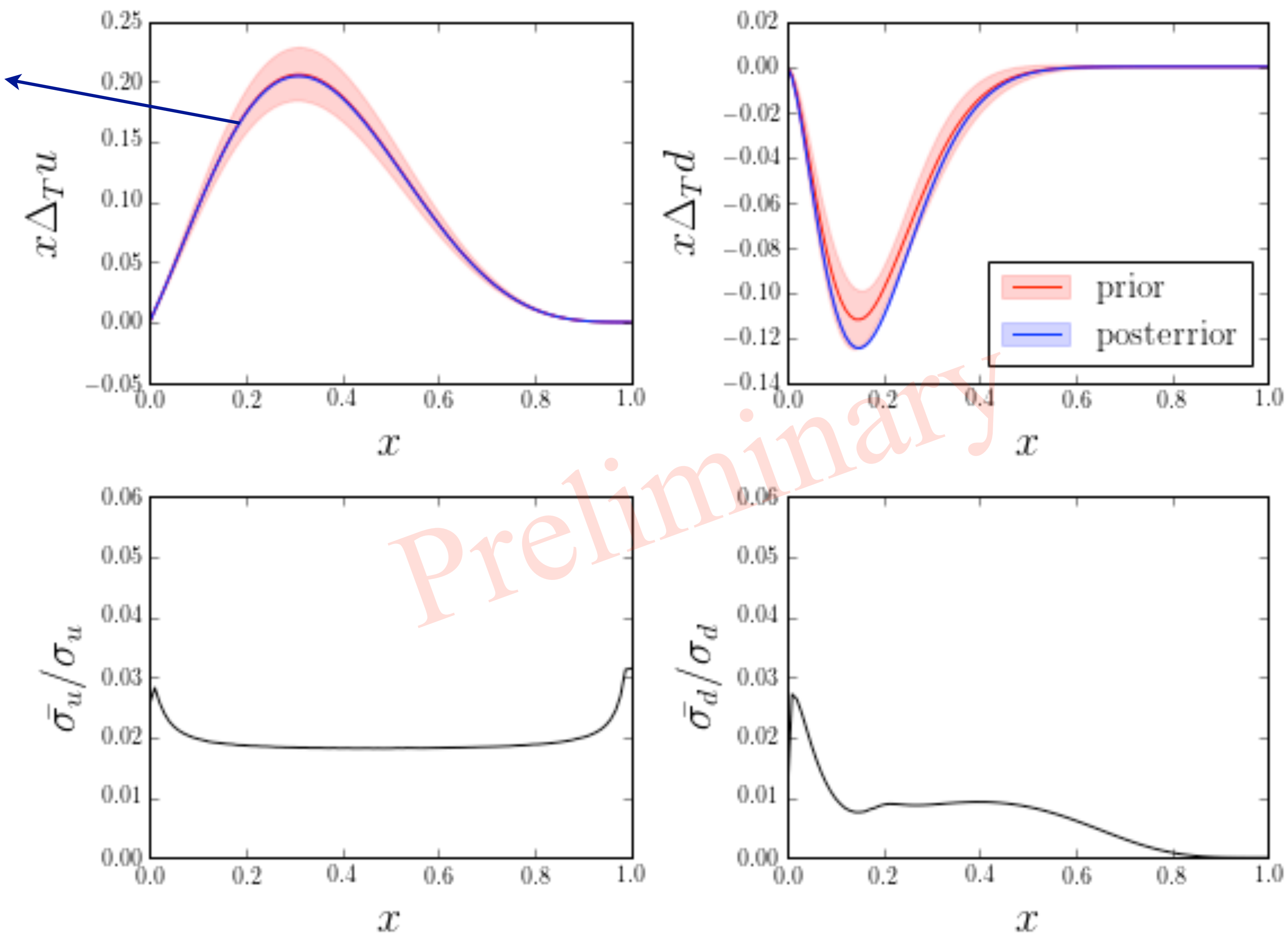
⋆ Improvement means the ratio between re-weighted uncertainty and current uncertainty.

ongoing work by Nobuo Sato, Alexei Prokudin, Kalyan Allada, and Zhihong Ye.

Transversity

It is a band.

SoLID $^3He\ \pi^+$



Similar work has been done for SoLID $^3He\ \pi^-$ and p $\pi^\pm$, not combined yet.

ongoing work by Nobuo Sato, Alexei Prokudin, Kalyan Allada, and Zhihong Ye.

Extractions of TMDs

$$F(x, z, P_T, Q^2) = \sum_q e_q^2 \, x \int d^2 k_\perp \, d^2 p_\perp \, \delta^2(P_T - p_\perp - z\, k_\perp) \, w(k_\perp, p_\perp) \, f(x, k_\perp, Q^2) \, D(z, p_\perp, Q^2)$$

Gaussian ansatz:

$$f(x, k_\perp, Q^2) = f(x, Q^2) \frac{\exp\left(-\frac{k_\perp{}^2}{<k_\perp^2>}\right)}{\pi <k_\perp^2>} \qquad D(z, p_\perp, Q^2) = D(z, Q^2) \frac{\exp\left(-\frac{p_\perp{}^2}{<p_\perp^2>}\right)}{\pi <p_\perp^2>}$$

Sivers:

$$f_{1T}^{\perp}(x, k_\perp, Q^2) = -N \, f_1(x, Q^2) \, x^\alpha \, (1-x)^\beta \sqrt{2e} \, \frac{(\alpha+\beta)^{\alpha+\beta}}{\alpha^\alpha \, \beta^\beta} \, \frac{M_S \, M_p}{M_S{}^2 + <k_\perp^2>} \, \frac{\exp\left(-\frac{k_\perp{}^2}{K^2}\right)}{\pi K^2} \qquad K^2 = \frac{M_S{}^2 <k_\perp^2>}{M_S{}^2 + <k_\perp^2>}$$

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

Transversity:

$$h_1(x, k_\perp, Q^2) = \frac{N}{2} \left(f_1(x, Q^2) + g_1(x, Q^2)\right) x^\alpha \, (1-x)^\beta \, \frac{(\alpha+\beta)^{\alpha+\beta}}{\alpha^\alpha \, \beta^\beta} \, \frac{\exp\left(-\frac{k_\perp{}^2}{<k_\perp^2>}\right)}{\pi <k_\perp^2>}$$

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

Pretzelosity:

$$h_{1T}^{\perp}(x, k_\perp, Q^2) = N \left(f_1(x, Q^2) - g_1(x, Q^2)\right) x^\alpha \, (1-x)^\beta \, e \, \frac{(\alpha+\beta)^{\alpha+\beta}}{\alpha^\alpha \, \beta^\beta} \, \frac{M_p^2}{M_T{}^2 + <k_\perp^2>} \, \frac{\exp\left(-\frac{k_\perp{}^2}{K^2}\right)}{\pi K^2} \qquad K^2 = \frac{M_T{}^2 <k_\perp^2>}{M_T{}^2 + <k_\perp^2>}$$

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

SoLID Impacts

Sivers:

95% C.L.

	N_u	N_d	N_s	N_{ubar}	N_{dbar}	N_{sbar}
Anselmino2009	$0.35^{+0.08}_{-0.08}$	$-0.90^{+0.43}_{-0.10}$	$-0.24^{+0.62}_{-0.50}$	$0.04^{+0.22}_{-0.24}$	$-0.04^{+0.33}_{-0.44}$	$1^{+0}_{-0.0001}$
SoLID	$0.35^{+0.13}_{-0.06}$	$-0.90^{+0.04}_{-0.04}$	$-0.24^{+1.21}_{-0.76}$	$0.04^{+0.96}_{-1.04}$	$-0.04^{+0.16}_{-0.21}$	$1^{+0}_{-1.44}$
	α_u	α_d	α_{sea}	β	M_S^2	
Anselmino2009	$0.73^{+0.72}_{-0.58}$	$1.08^{+0.82}_{-0.65}$	$0.79^{+0.56}_{-0.47}$	$3.46^{+4.87}_{-2.90}$	$0.34^{+0.30}_{-0.16}$	
SoLID	$0.73^{+0.35}_{-0.34}$	$1.08^{+0.16}_{-0.15}$	$0.79^{+0.09}_{-0.14}$	$3.46^{+0.37}_{-0.34}$	$0.34^{+0.03}_{-0.02}$	

Transversity:

95% C.L.

	N_u	N_d	α	β	$\langle k_T^2 \rangle$
Anselmino2013	$0.36^{+0.19}_{-0.12}$	$-1^{+0.40}_{-0}$	$1.06^{+0.87}_{-0.56}$	$3.66^{+5.87}_{-2.78}$	0.25 (fixed)
SoLID	$0.36^{+0.04}_{-0.03}$	$-1^{+0.08}_{-0}$	$1.06^{+0.06}_{-0.07}$	$3.66^{+0.29}_{-0.33}$	$0.25^{+0.02}_{-0.01}$

Pretzelosity:

95% C.L.

	N_u	N_d	α	β	M_T^2
Lefky2015	$1^{+0}_{-1.4}$	$-1^{+1.3}_{-0}$	$2.5^{+1.5}_{-1.5}$	2 (fixed)	$0.18^{+0.7}_{-0.7}$
SoLID	$1^{+0}_{-0.56}$	$-1^{+0.50}_{-0}$	$2.5^{+0.96}_{-0.33}$	$2^{+3.26}_{-0.70}$	$0.18^{+0.18}_{-0.08}$

Angular Momentum (1)

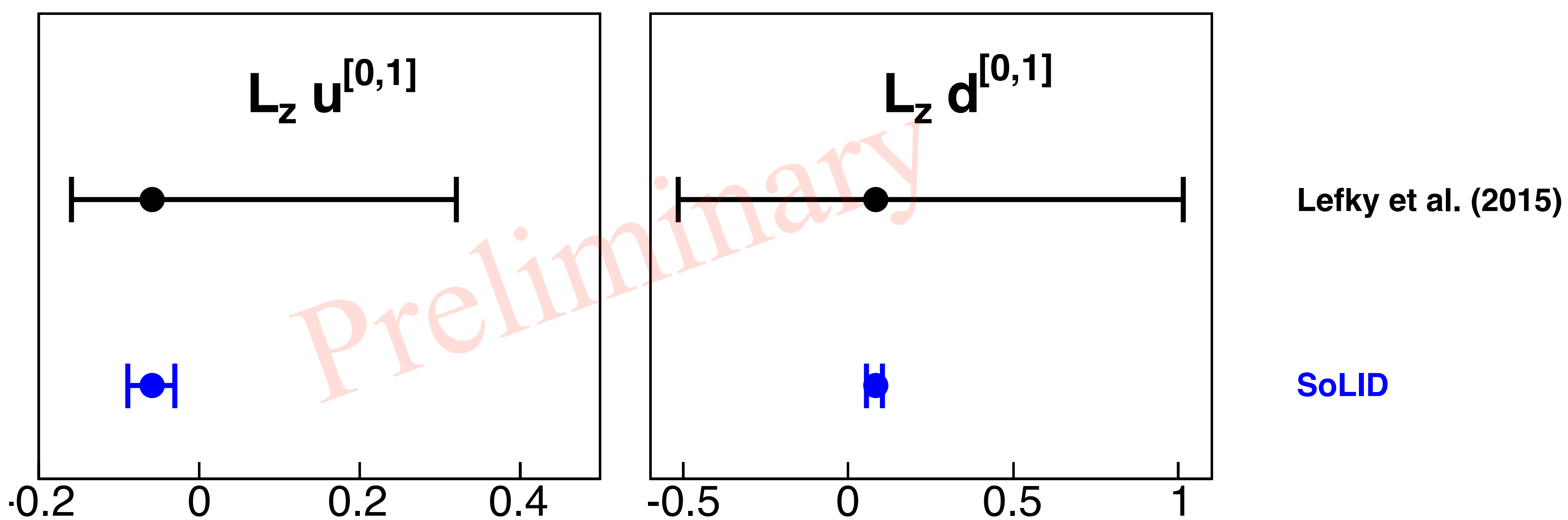
OAM and pretzelosity:

model dependent

$$L_z = -\int d\,x\,d^2\,k_\perp\,\frac{k_\perp{}^2}{2\,M_p^2}\,h_{1T}^{\perp}(x, k_\perp{}^2)$$

J. She *et al.*, PR D 79, 058008 (2009).

SoLID impact:



Angular Momentum (2)

Sivers and GPD *E*:

model dependent

$$f_{1T}^{\perp(0)}(x, Q_0^2) = -L(\mathrm{x})\, E\left(x, 0, 0, Q_0^2\right)$$

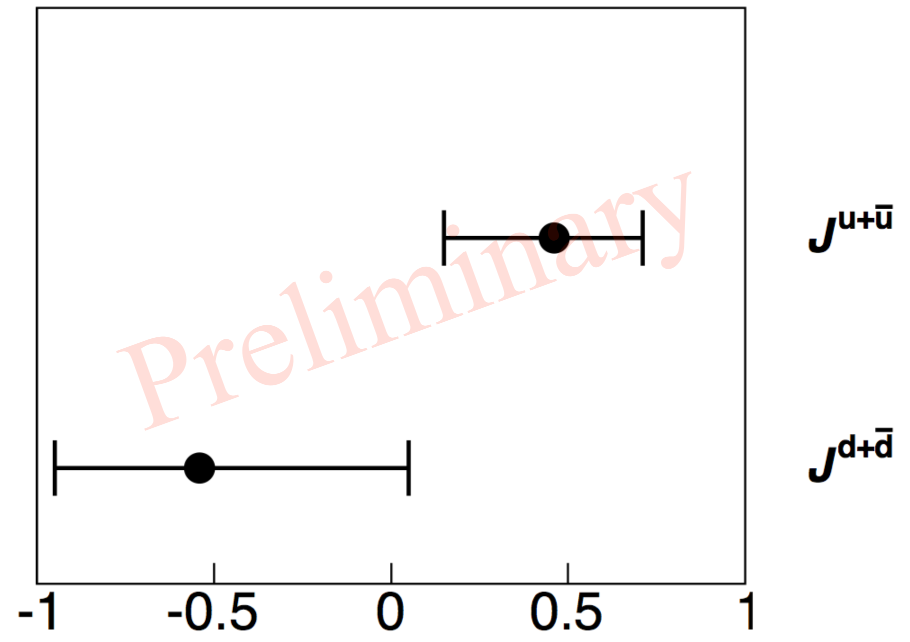
$$L(\mathrm{x}) = \frac{\mathrm{K}}{(1-x)^{\eta}}$$ lensing function

A. Bacchetta *et al.*, PR L 107, 212001 (2011).

K and η are fixed by anomalous magnetic moments κ^p and κ^n.

$$J = \frac{1}{2}\int d\,x\,x\,[\,H(x,0,0) + E(x,0,0)\,]$$

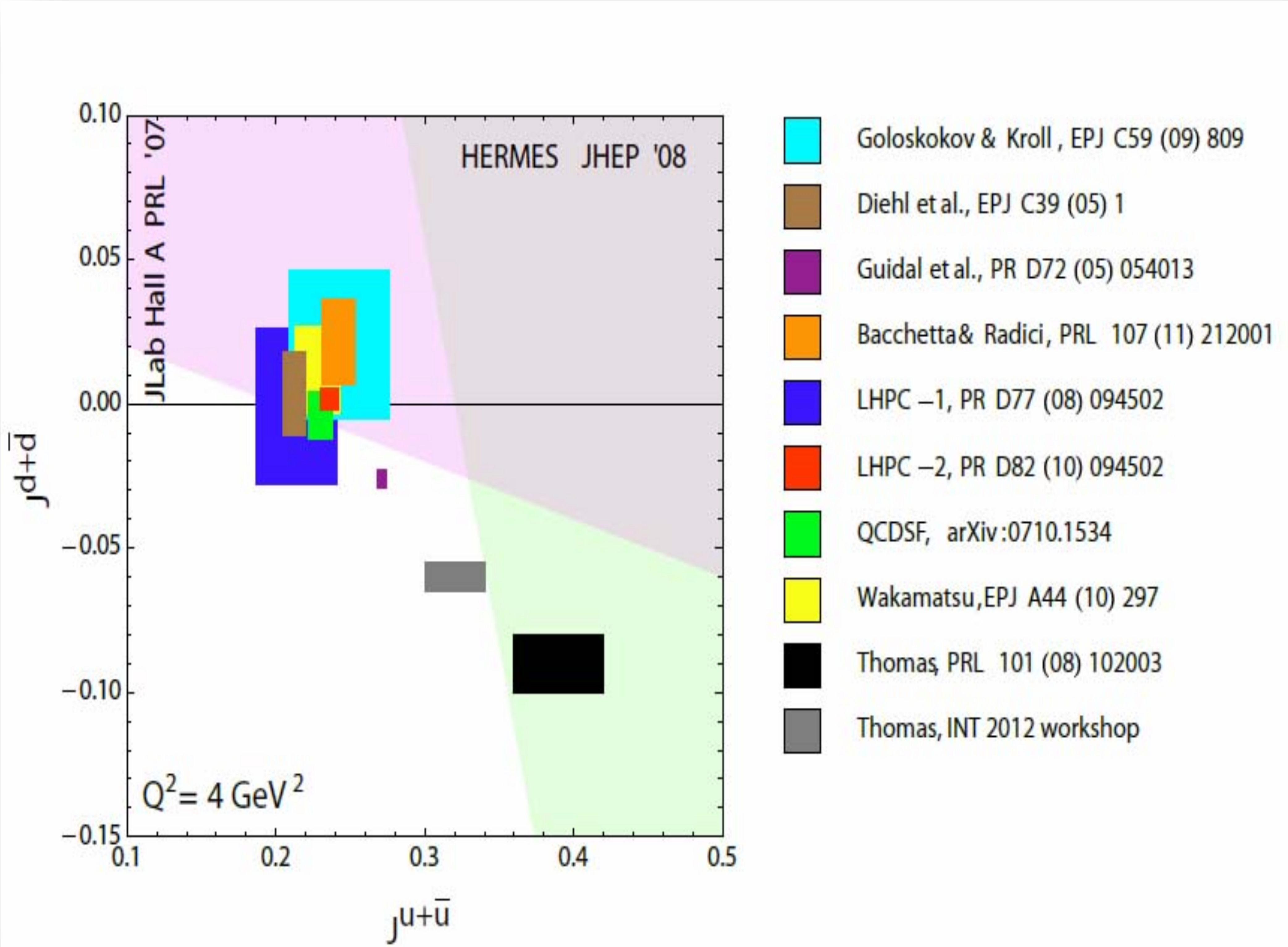
SoLID:



Based on the Anselmino *et al.* Sivers parametrization.
and CT10 leading order PDFs for H(x,0,0)

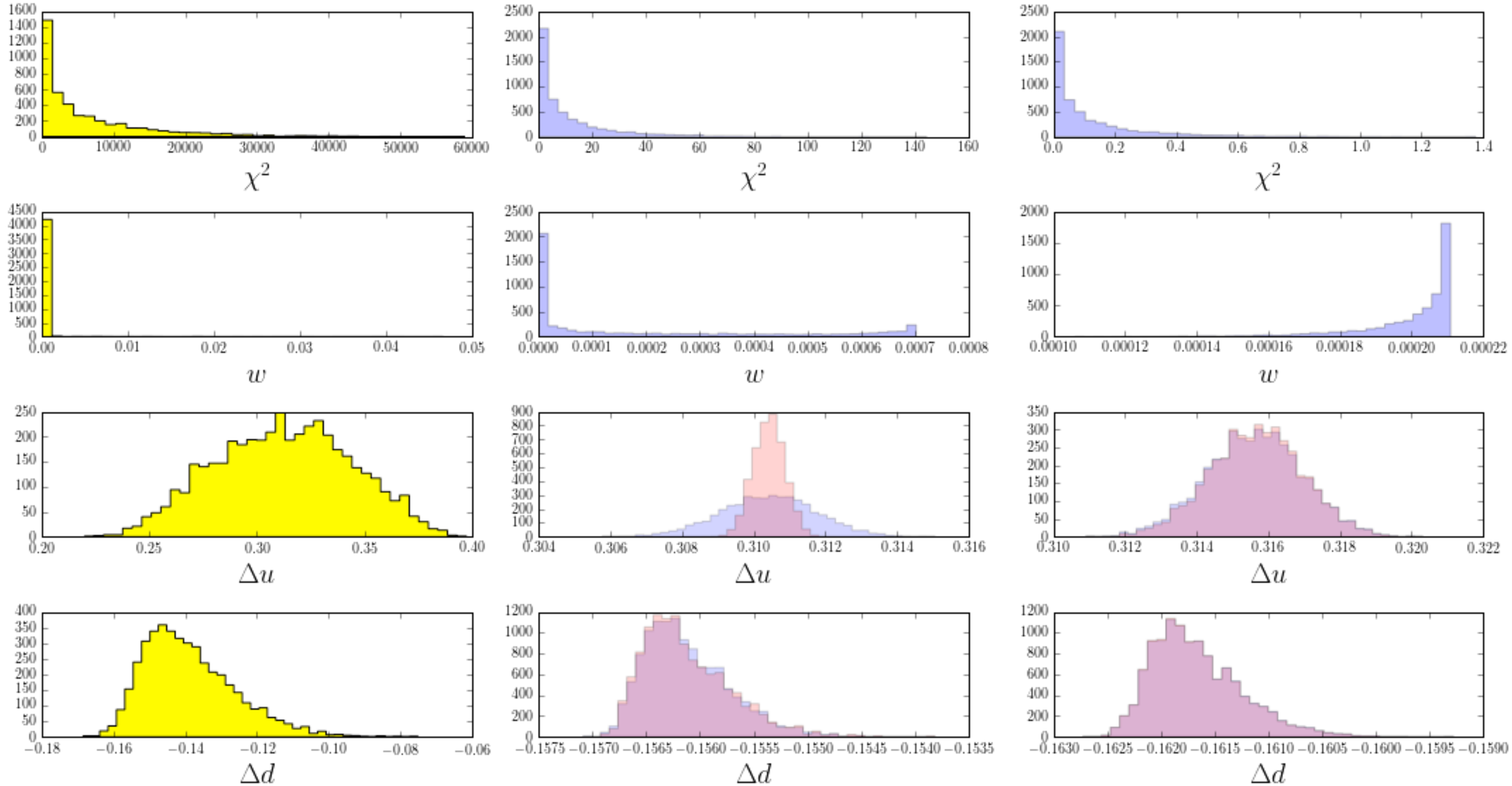
Backup

Quark Angular Momentum



Tensor Charge

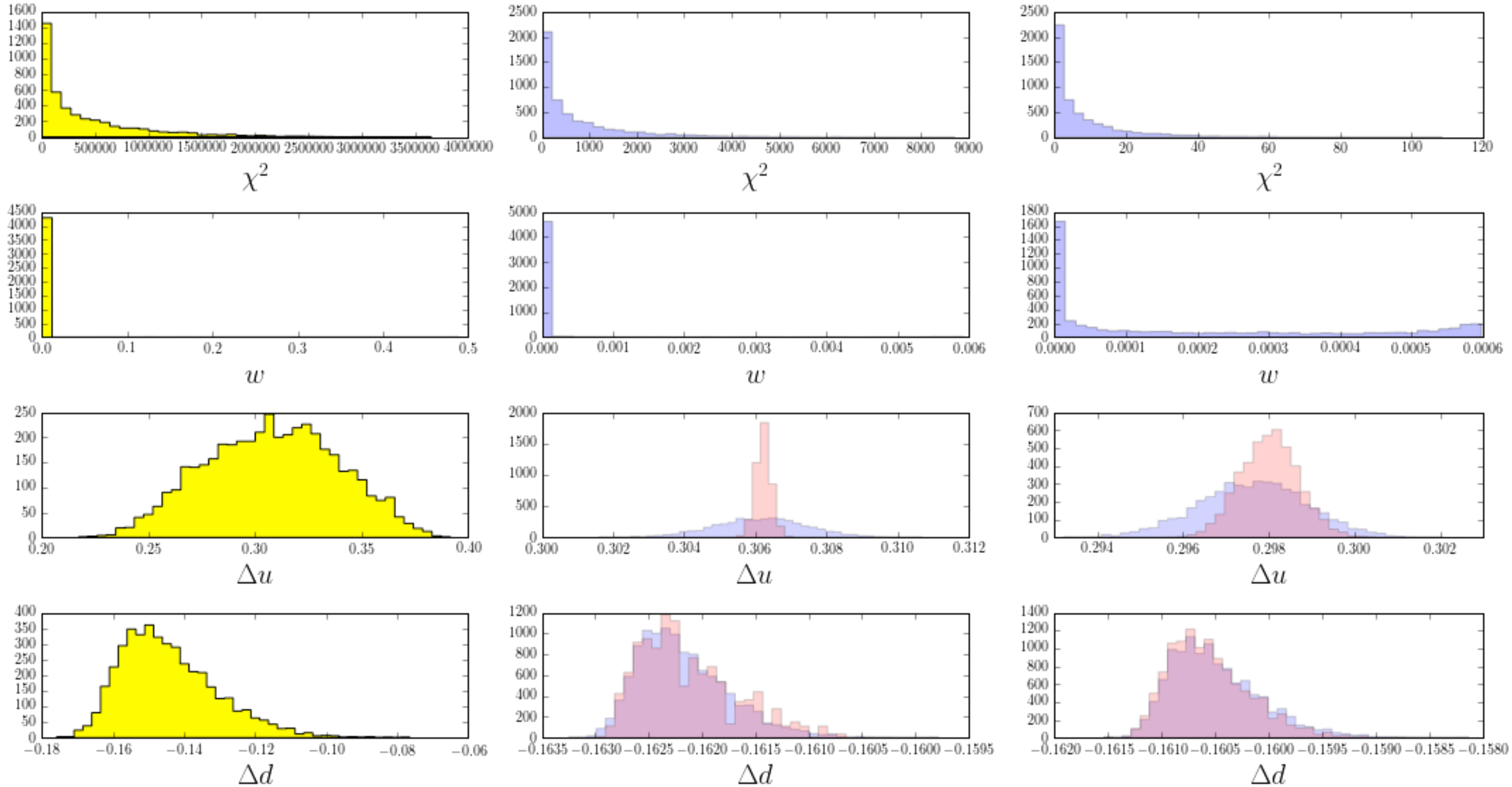
CLAS:



current π^+ π^-

Tensor Charge

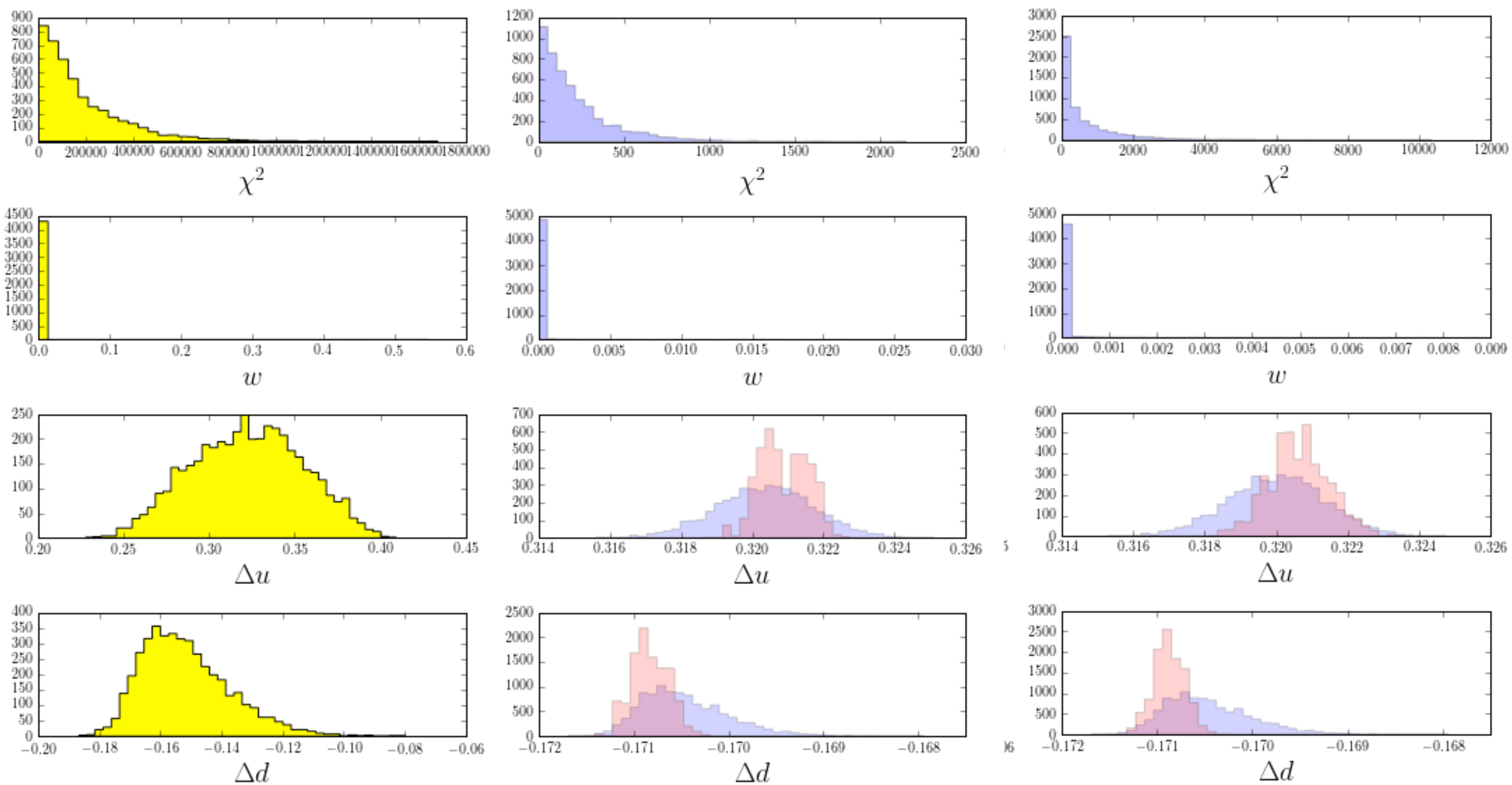
SoLID: p



current π^+ π^-

Tensor Charge

SoLID: ^3He



current π^+ π^-

Transversity

u quark

d quark