SoLID SIDIS Physics Case

SoLID Collaboration Meeting
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Overview of SoLID

Solenoidal **L**arge **I**ntensity **D**evice

- **Full exploitation of JLab 12 GeV Upgrade**

A **Large Acceptance** Detector **AND** Can Handle **High Luminosity** (10^{37}-10^{39})

Take advantage of latest development in detectors and data acquisitions

- Reach ultimate precision for SIDIS (TMDs), providing three-dimensional imaging of nucleon in momentum space
- PVDIS in high-*x* region providing sensitivity to new physics at 10-20 TeV, and QCD
- Threshold J/ψ, probing strong color field in the nucleon, trace anomaly

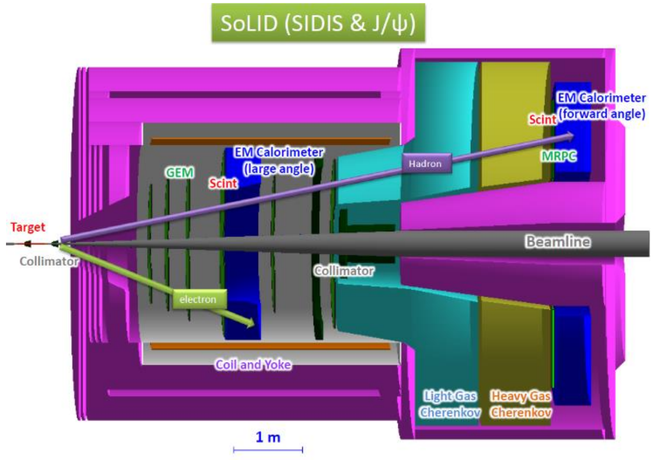
- **5 highly rated experiments approved**

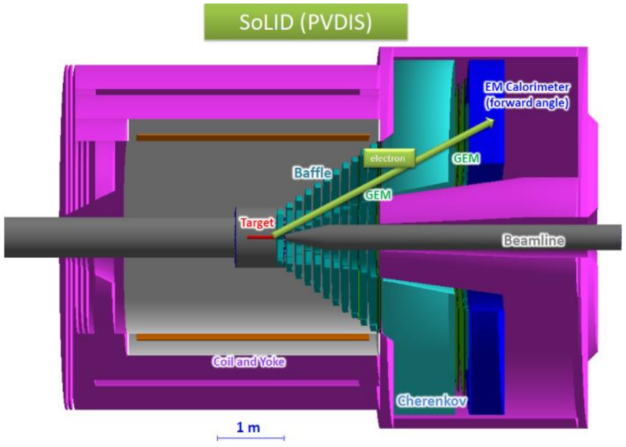
Three SIDIS experiments, one PVDIS, one J/ψ production

Run group experiments: di-hadron, Inclusive-SSA, and much more …

- **Strong collaboration** (250+ collaborators from 70+ institutes, 13 countries)

Significant international (Chinese) contributions and strong theoretical support





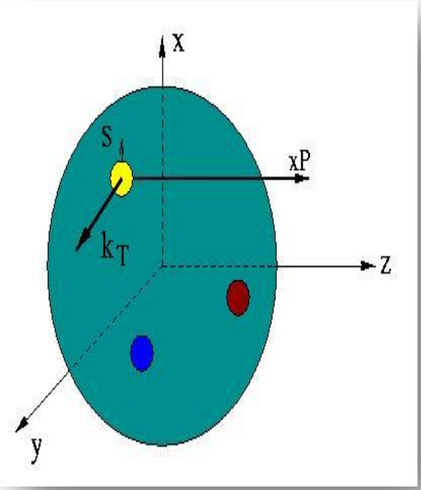
Unified View of Nucleon Structure

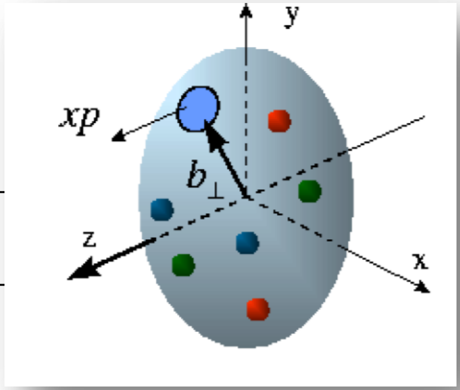
5D Dist.

$W_p^u(x,k_T,\boldsymbol{r_T})$ Wigner distributions

$d^2\boldsymbol{r_T}$ → TMD PDFs: $f_1^u(x,k_T)$, .. $h_1^u(x,k_T)$

d^2k_T → GPDs/IPDs





3D imaging

TMD PDFs $\xrightarrow{d^2k_T}$ PDFs

GPDs/IPDs $\xrightarrow{d^2r_T}$ PDFs

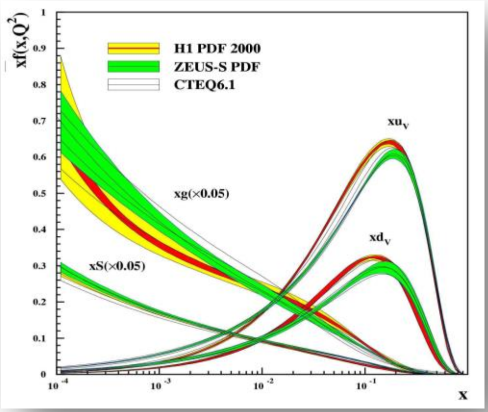
GPDs/IPDs $\xrightarrow{dx\ \&\ \text{Fourier Transformation}}$ Form Factors

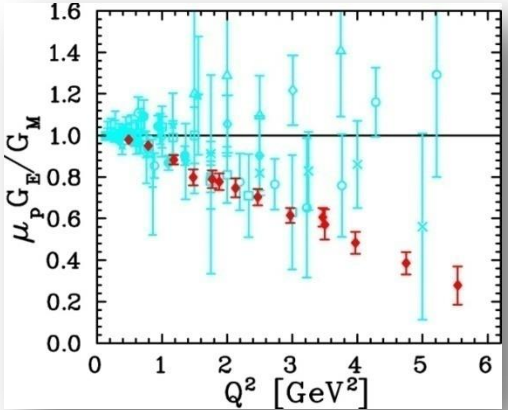
dx &
Fourier Transformation

1D

PDFs
$f_1^u(x)$, ..
$h_1^u(x)$

Form Factors
$G_E(Q^2)$,
$G_M(Q^2)$



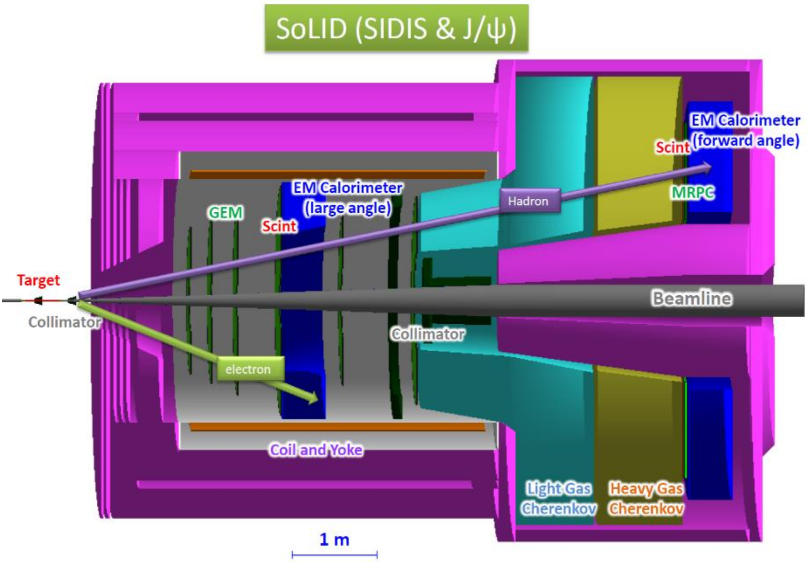


Leading Twist TMDs

→ Nucleon Spin
→ Quark Spin

		Quark polarization		
		Un-Polarized	Longitudinally Polarized	Transversely Polarized
Nucleon Polarization	U	$f_1 =$		$h_1^{\perp} =$ − Boer-Mulder
	L		$g_1 =$ − Helicity	$h_{1L}^{\perp} =$ −
	T	$f_{1T}^{\perp} =$ − Sivers	$g_{1T}^{\perp} =$ −	$h_{1T} =$ − Transversity $h_{1T}^{\perp} =$ − Pretzelosity

SoLID-Spin: SIDIS on ^{3}He/Proton @ 11 GeV

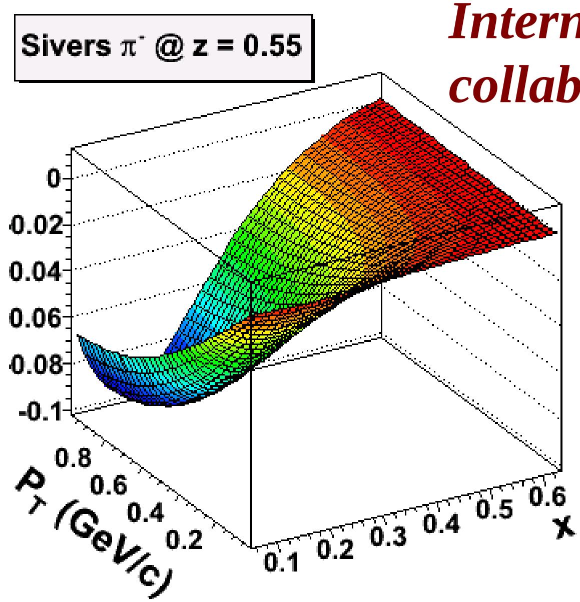


E12-10-006: Single Spin Asymmetry on Transverse ^{3}He @ 90 days, **rating A**

E12-11-007: Single and Double Spin Asymmetry on ^{3}He @ 35 days, **rating A**

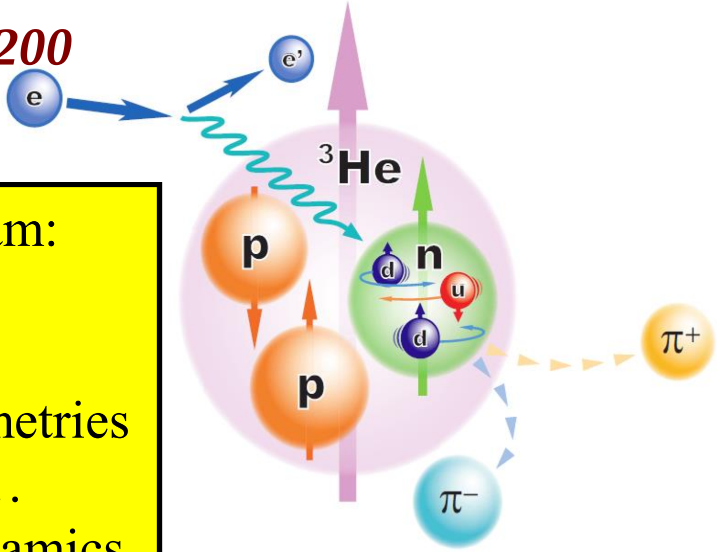
E12-11-108: Single and Double Spin Asymmetries on Transverse Proton @120 days, **rating A**

Two ``bonus" experiments approved



International collaboration with 200 collaborators from 11 countries

Key of SoLID-Spin program:
Large Acceptance
+ High Luminosity
→ **4-D** mapping of asymmetries
→ Tensor charge, TMDs …
→Lattice QCD, QCD Dynamics, Models.



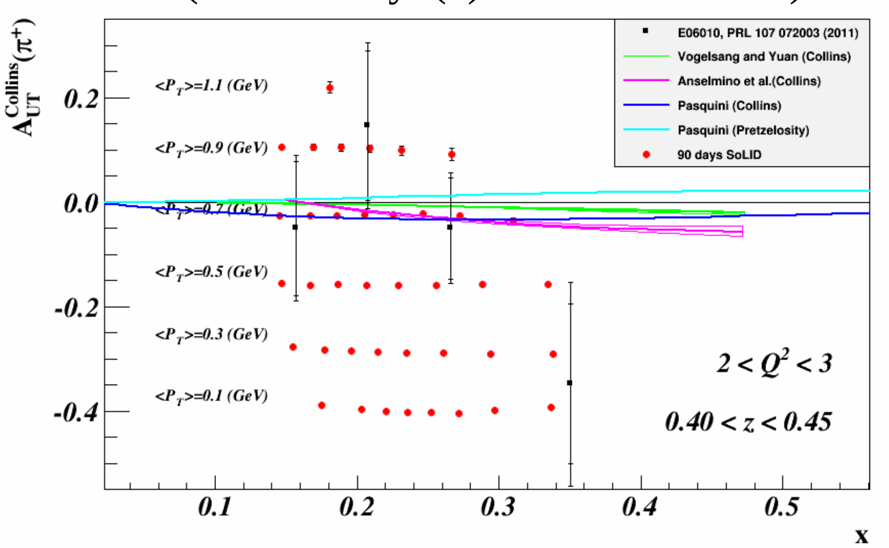
Transversity and Tensor Charge

- **Tensor charge (0th moment of transversity): intrinsic property (charge, magnetic moment), also input for beyond Standard Model physics searches**

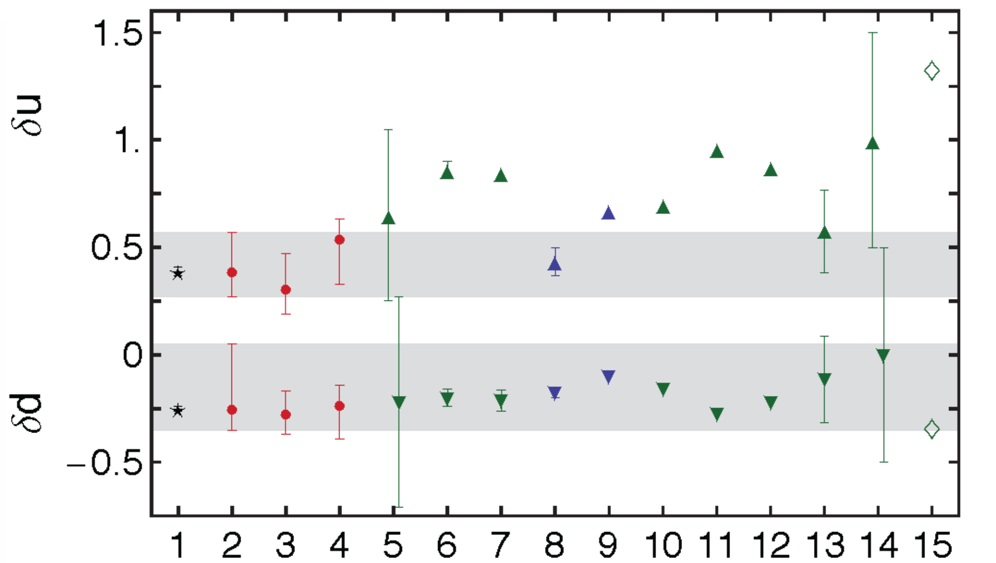
  Lattice QCD, Bound-State QCD (Dyson-Schwinger) , Light-cone Quark Models, …
- Global model fits to experiments (SIDIS and e+e-)
- **SoLID** with **trans. polarized n & p** → **determination of tensor charges for d & u**

Collins Asymmetries

(Transversity (x) Collins Function)



Tensor Charges



Total 1400 bins in x, Q^2, P_T and z for 11/8.8 GeV beam

X. Qian et al in PRL 107, 072003

12-GeV SoLID projections *together with existing extractions and predictions*

Transversity and Tensor Charge

- **Tensor charge (0th moment of transversity): intrinsic property (charge, magnetic moment), also input for beyond Standard Model physics searches (EDM)**

  Lattice QCD, Bound-State QCD (Dyson-Schwinger) , Light-cone Quark Models, …
- Global model fits to experiments (SIDIS and e+e-)
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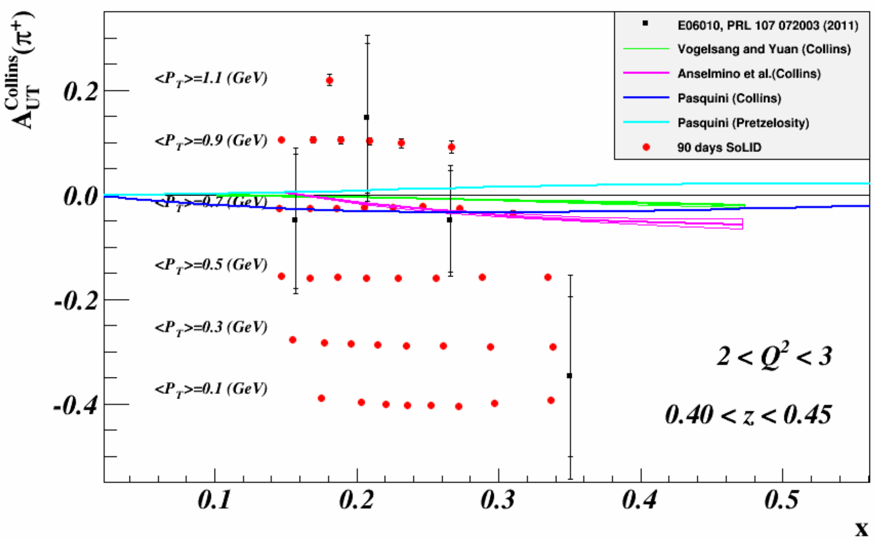

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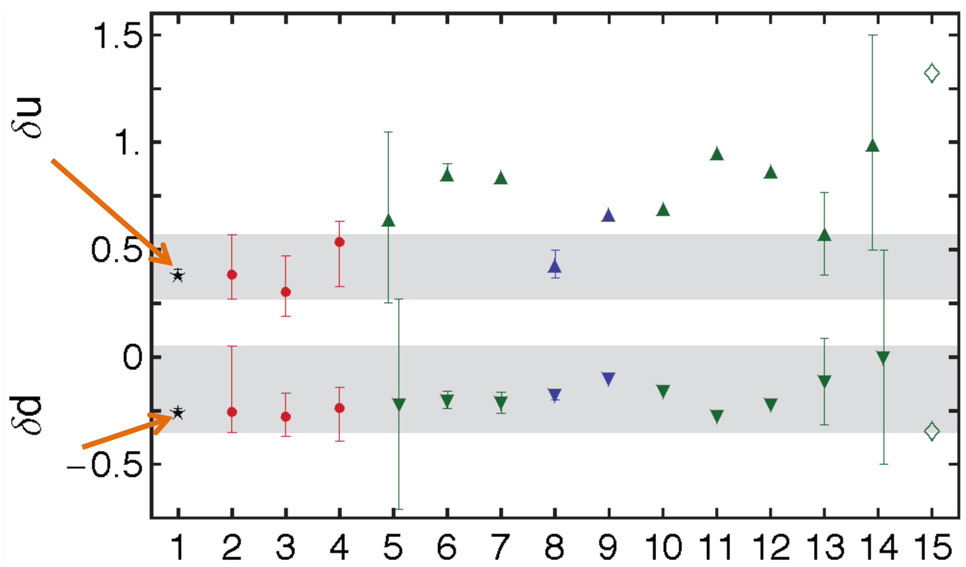
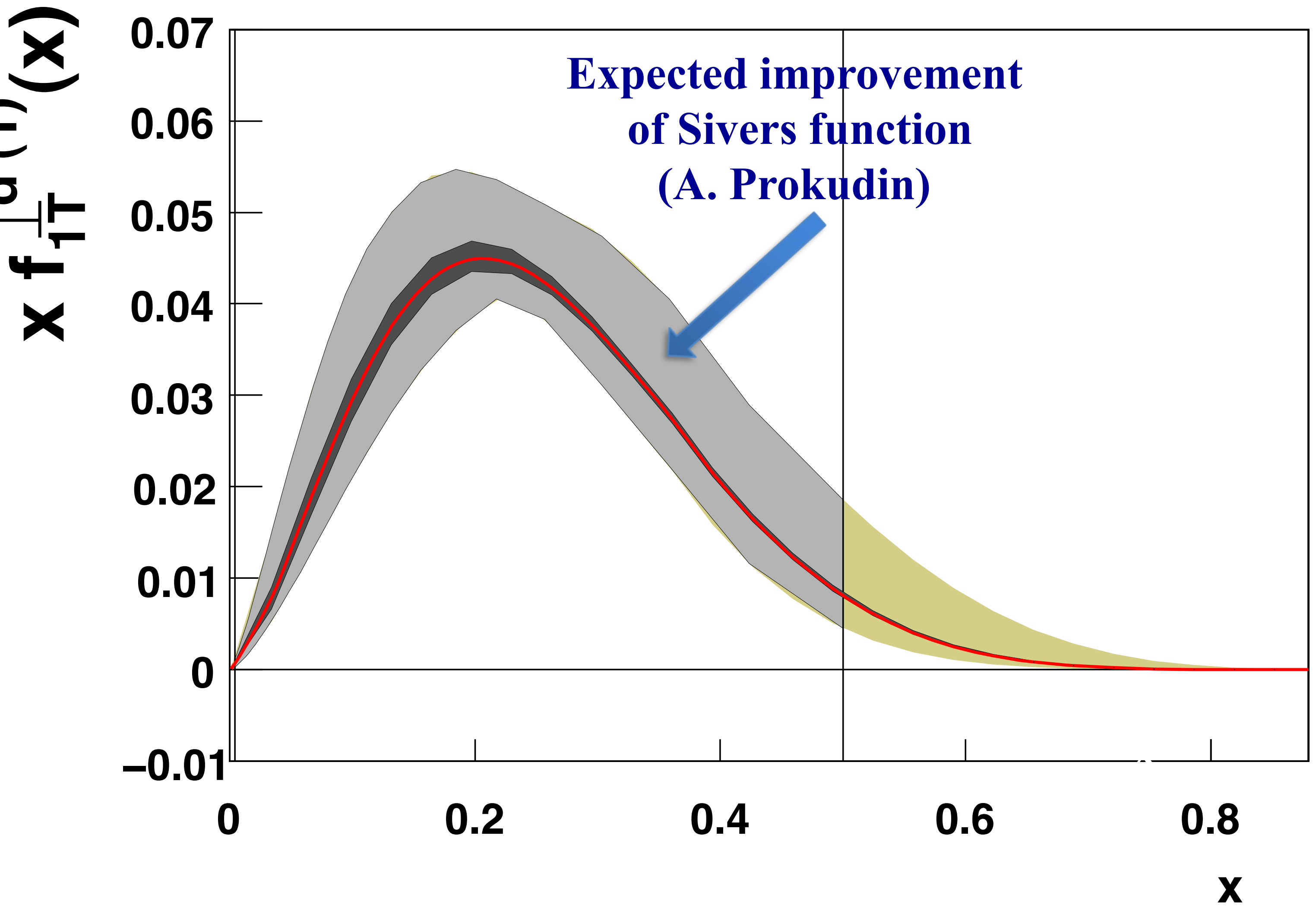
Tensor Charges

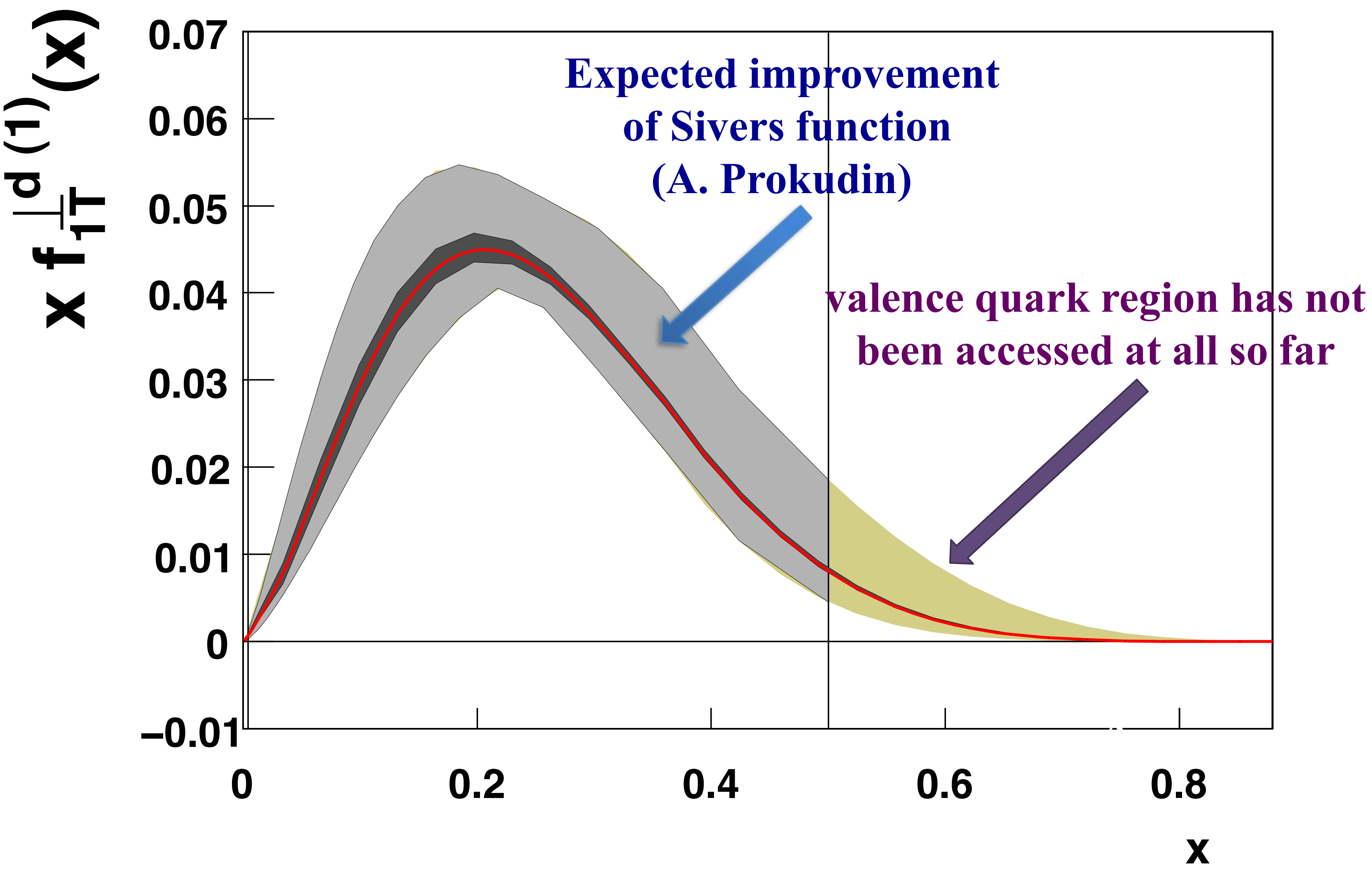


***12-GeV SoLID projections** together with existing extractions and predictions*

Projected measurements in 1-D (x)



Projected measurements in 1-D (x)



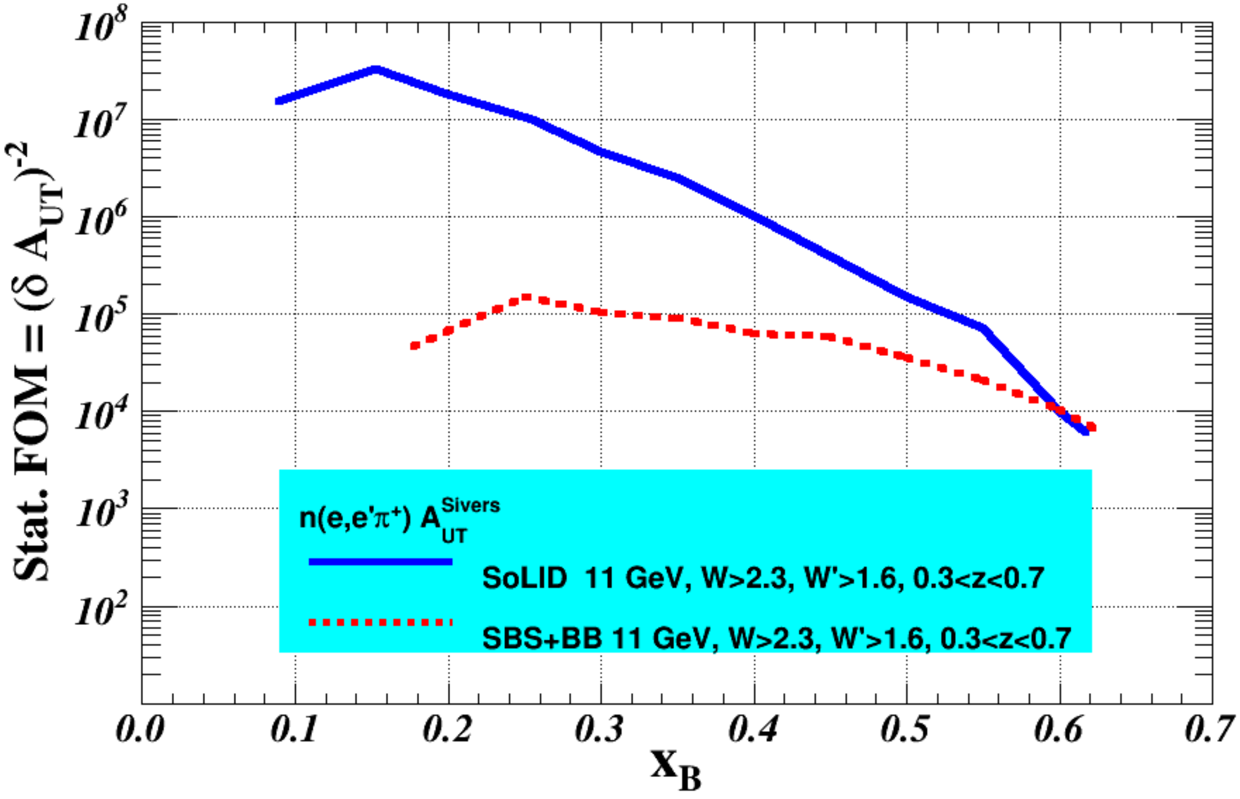
SoLID-SIDIS compared with SBS & CLAS12

Factor	SoLID E12-10-006 (A) (neutron)	SBS E12-09-018 (A-) (only neutron approved)	SoLID E12-11-108, A (proton)	CLAS12 C12-11-111 (only proton conditional approved)
Targets	He3 ("n")	He3 ("n")	NH3("p")	HDice ("p")
Polarization (P)	65% (60% in beam)	65% (<60% in beam)	70%	60%
Dilution-Factor (f)	0.15~0.3	0.15~0.3	0.13	0.33*80%
Polarized Lumonisity (L)	1.0×10^{36} $cm^{-2}s^{-1}$	2.7×10^{36} $cm^{-2}s^{-1}$	1.0×10^{35} $cm^{-2}s^{-1}$	1.4×10^{33} $cm^{-2}s^{-1}$ (quoted: 5.10^{33} $cm^{-2}s^{-1}$
Solid-Angle (Ω_e Ω_h)*	0.067 (e: θ→8°~25°, Φ→0°~360°. h: θ→8°~14.5°, Φ→ 0°~360°)	Quoted: 0.0026 (h-SBS: θ→26.5°~35°, Φ→-24°~24° e-BB: θ→10°~19.5°, Φ→ -30°~30°)	0.067 (e: θ→8°~25°, Φ→0°~360°. h: θ→8°~14.5°, Φ→ 0°~360°)	1.32sr (e: θ→6.5°~40°, Φ→0°~360° * 80%. h: θ→5°~40°, Φ→ 0°~360° * 80%)
*FOM in the same kine. (L*P2*f2*Omega)*	5.43×10^{32}	5.69×10^{31}	5.55×10^{31}	4.64×10^{31} (2.35×10^{30} with SoLID angular range)
SIDIS π^+ EventsP^2*f^2*	100M	0.21M	5.06M	3.07M (2.02M with SoLID acceptance)

Based on the 1-D Projection results

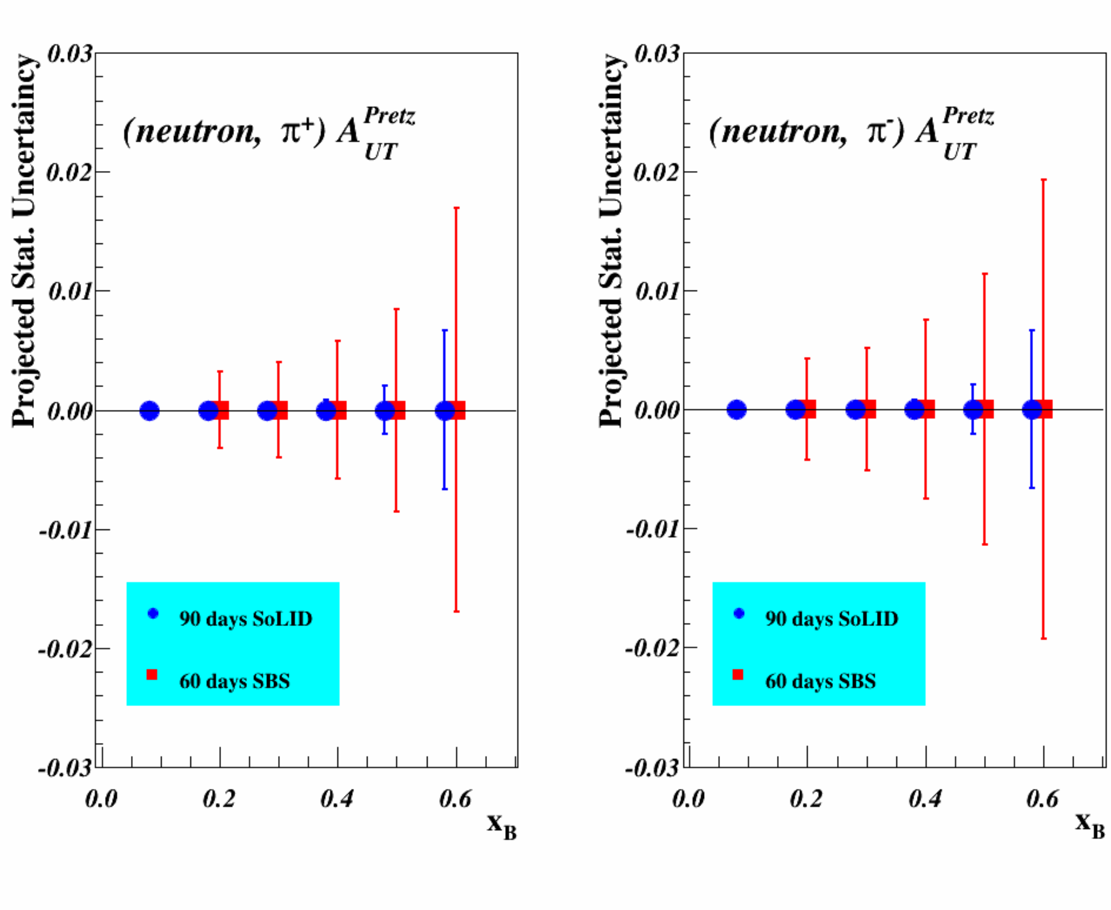
SoLID vs. SBS Neutron-SIDIS Comparison

- Figure of Merit comparison at the same kinematic setting with the same cuts.



SoLID vs. SBS Neutron-SIDIS Comparison

- SoLID bins are to match the SBS ones and thus are not optimized for SoLID kinematics



SoLID vs. SBS Neutron-SIDIS Comparison

SBS:

•3D binning: $0.1 < x < 0.7$, $0.2 < z < 0.7$, $0 < p_T$ (GeV) < 1.2

•Typically 120 bins, dependence on Q2 gives fully-differential analysis

SoLID:

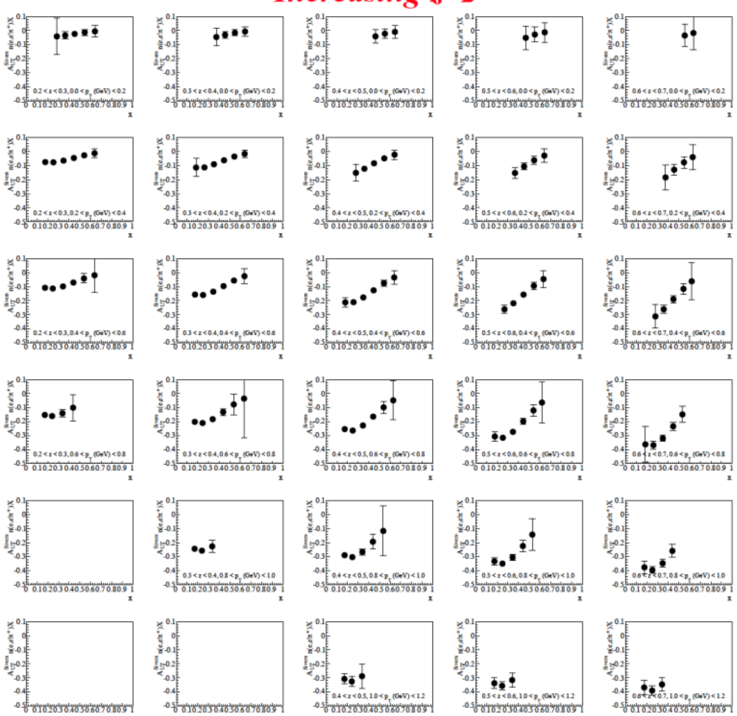
• 4D-MAPPING: $0.05 < x < 0.6$, $0.3 < z < 0.7$, $0 < p_T$ (GeV) < 1.0, $1.0 < Q^2 < 7.0$ GeV^2

•1400 bins

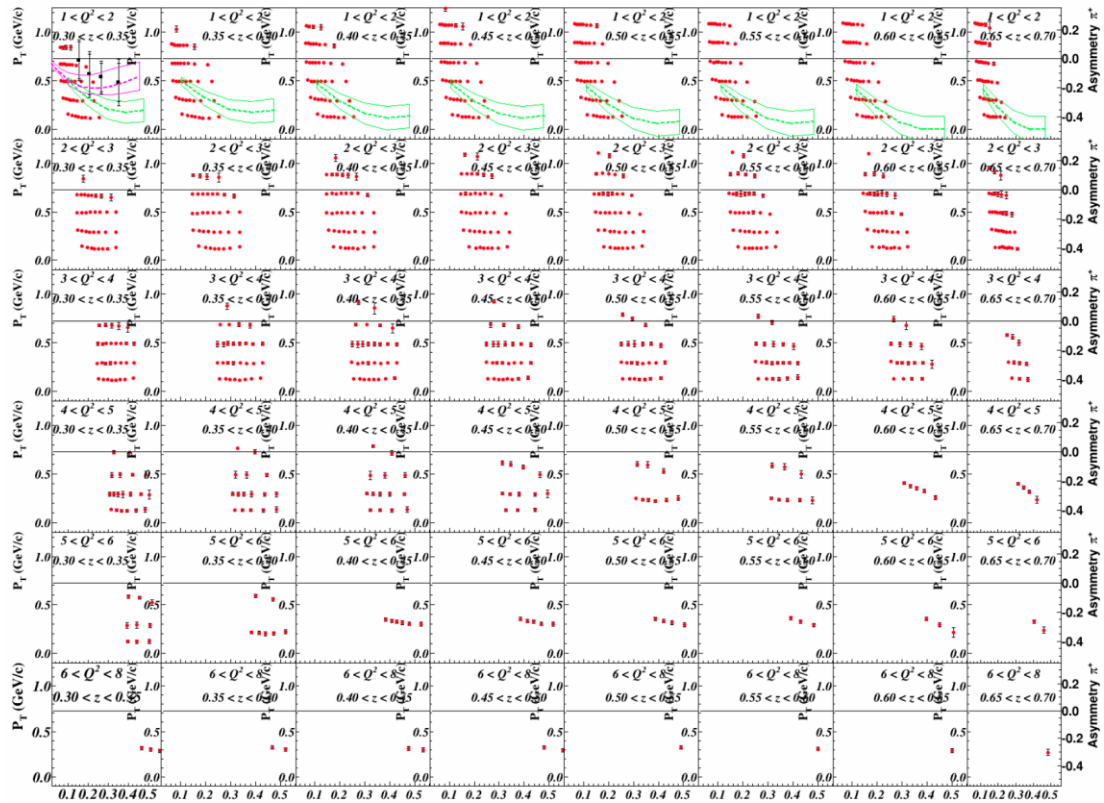
SBS 3D-Mapping

Increasing z →

← Increasing p_T



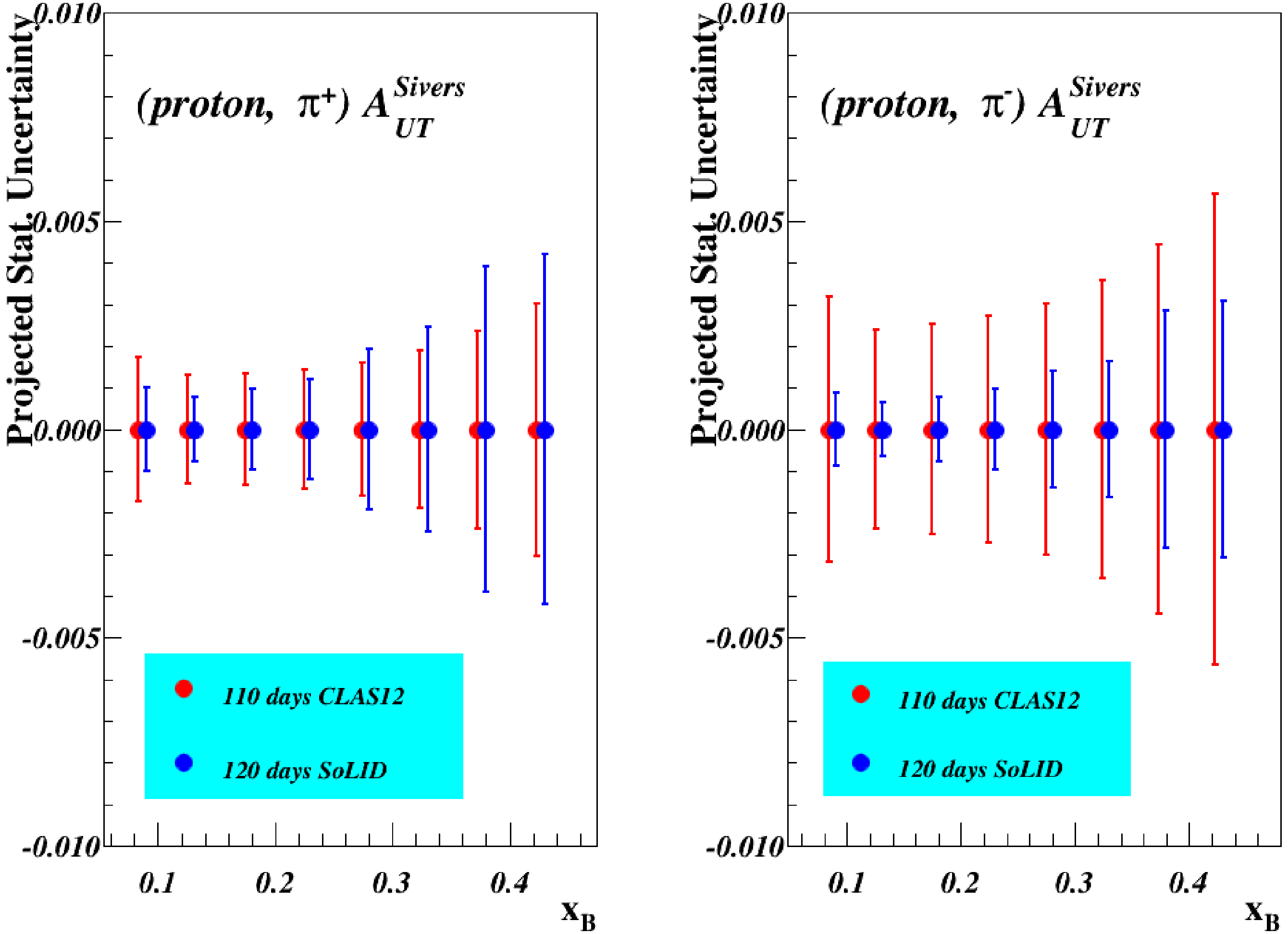
Sivers A_{UT}, $n(e,e'\pi^+)X$ vs. x, 40 days @ 11 GeV



Example of SoLID 4D-Mapping

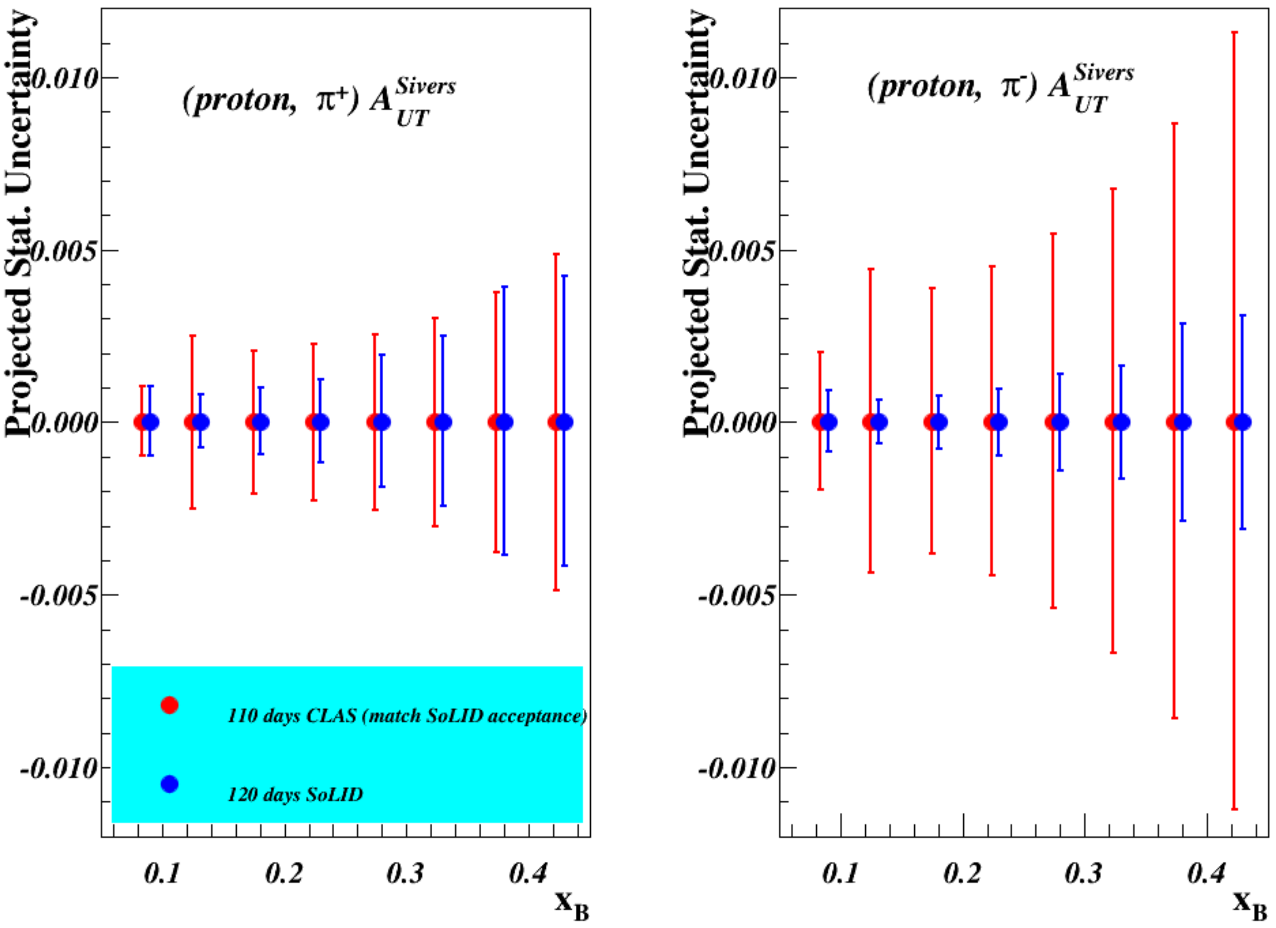
SoLID vs. CLAS12 Proton-SIDIS Comparison

- SoLID data were rebinned to match CLAS12's bins.



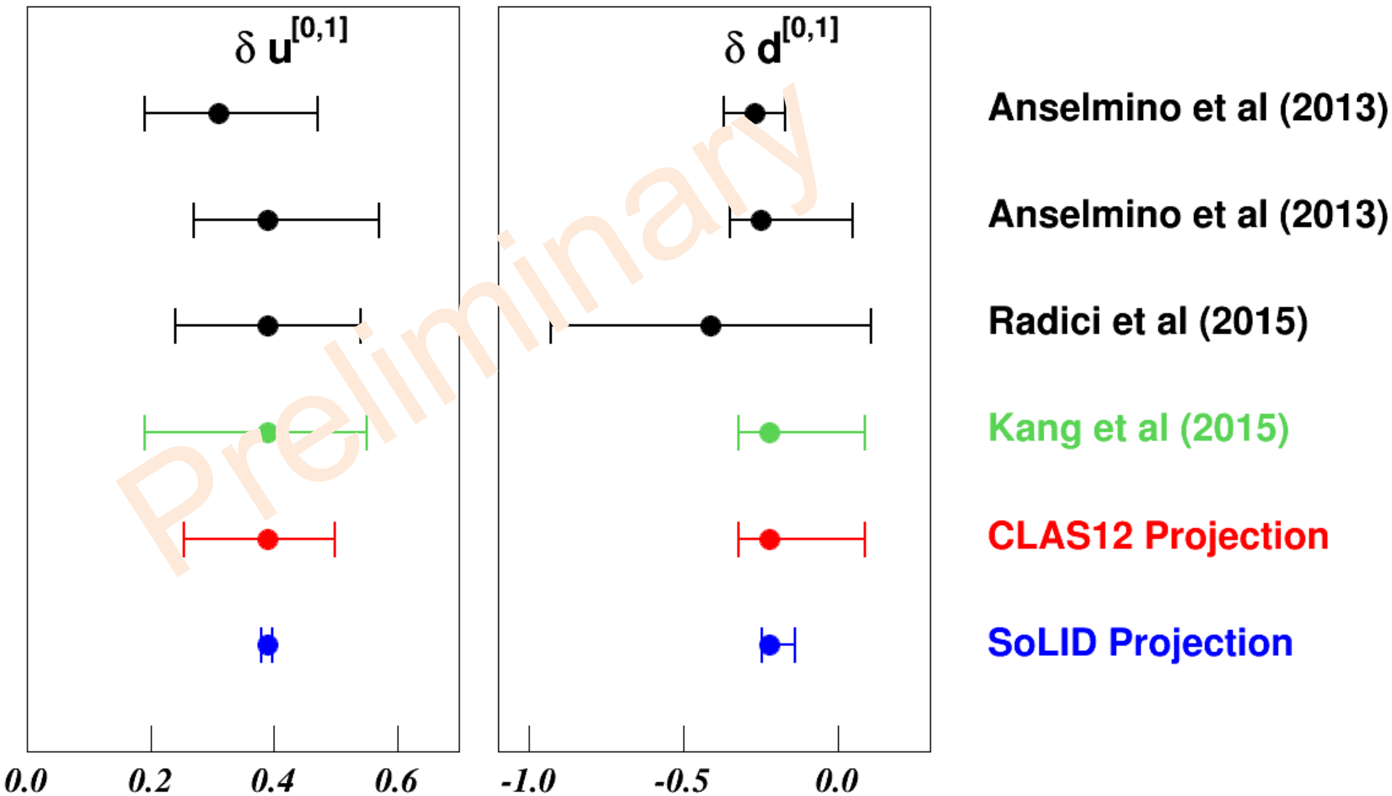
SoLID vs. CLAS12 on Proton-SIDIS Comparison

- SoLID data were rebinned to match CLAS12's bins.
- CLAS12 Projection was redone with SoLID's Acceptance and Kinematic cuts (Courtesy of Luciano Pappalardo).



Impact on Tensor Charge: SoLID vs. CLAS12

- A model dependent study (directly compare to Alexei's work data fit)
- Using multi-dimensional binning results from SoLID and CLAS12 (match SoLID's cuts)
- Only statistical errors are considered for the projected results.



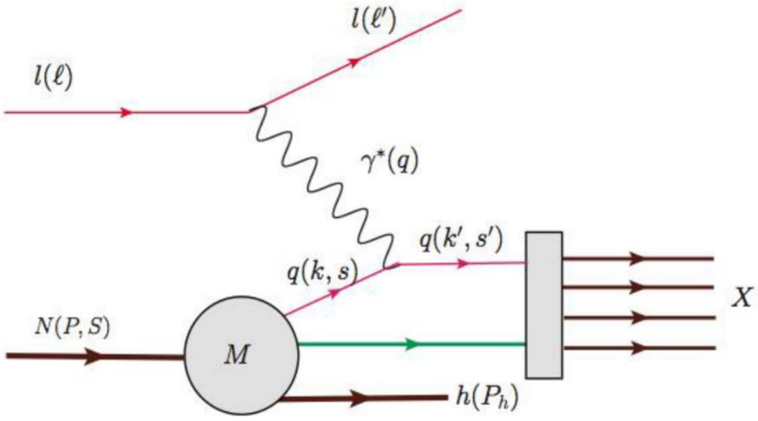
Ongoing work by Alexei Prokudin, Nobuo Sato, Kalyan Allada and Zhihong Ye

What else can we learn in SoLID?

- Test QCD and TMD factorization

$$f_{1T}^{\wedge q}|_{SIDIS} = -f_{1T}^{\wedge q}|_{DY} \qquad h_1^{\wedge q}|_{SIDIS} = -h_1^{\wedge q}|_{DY}$$

- Sea quark TMDs, esp BM $h_1^{\wedge q}$ and Sivers $f_{1T}^{\wedge q}$
  (Kaon capability)
- Twist-3 TMDs, e.g. $f_L^{\wedge q}$ h_L^q f_T^q h_T^q $h_T^{\wedge q}$ $f_T^{\wedge q}$ $g_L^{\wedge q}$ $g_T^{\wedge q}$
- Target fragmentations (fracture functions)



Tianbo Liu joined Duke group

Summary of SoLID SIDIS program

- SoLID: unique combination of large acceptance and high luminosity – truly utilize 12-GeV upgrade to its full potential, most precise data from spin-dependent SIDIS
- SoLID SIDIS: comprehensive program with both proton and ``neutron'' targets in the same setup allows for flavor separation with better control of systematics
- Multi-dimensional binning of the data with high precision help reduce theoretical uncertainties in extracting TMDs
- Apart from three approved experiments, two ``bonus'' experiments will accumulate data without additional beam time, providing complementary way to access transversity, and new information, and expect more such bonus

Backup

SBS Coverage

BigBite:

counter, a two-layer electromagnetic calorimeter and a scintillator hodoscope. The value of the solid angle for 60 cm long target was found to be of 45 msr.

$\Omega_{e\pi}$ = 0.0019 (0.0024sr)

SBS:

For the proposed SIDIS experiment, the magnet will be placed at the distance 245 cm from the target to the return yoke, providing a solid angle of 42(53) msr. The magnet inter-

From their kinematic coverage plot:

$\Theta_e \rightarrow$ 0.465~0.620 rad
(26.64°~35.52°)
$\Phi_e \rightarrow$ -0.42~0.42 rad
(-24° ~ 24°)

$\Theta_\pi \rightarrow$ 0.175~0.340 rad
(10°~19.5°)
$\Phi_\pi \rightarrow$ -0.52~0.52 rad
(-30°~30°)

$\Omega_{e\pi}$ = 0.0029sr

Distance from the target to the detector, cm	417
Central angle θ_c , degree	14
horizontal range: $\Delta\theta_h$, degree	± 3.6
vertical range: $\Delta\theta_v$, degree	± 12
angular resolution: σ_{θ_c}, degree	0.02
vertex resolution (along beam), cm	0.2
momentum resolution σ_p/p	0.001×p[GeV]

Table 3.1: The parameters of SBS in the SIDIS experiment.

???

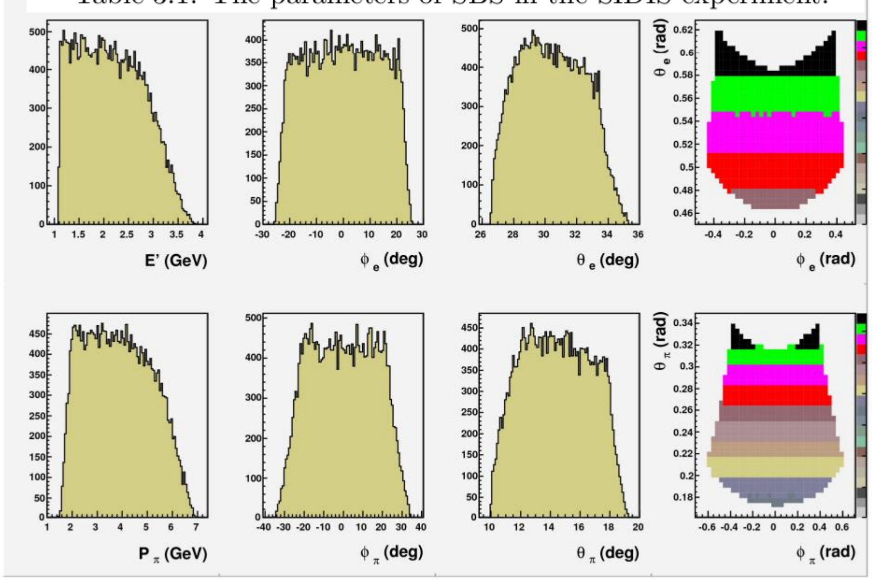


Figure 5.1: 11 GeV kinematics, phase space of the two detected particle momenta and angles, with the SIDIS cuts applied.

Table 5.1: DIS events selection, kinematical cuts and mai

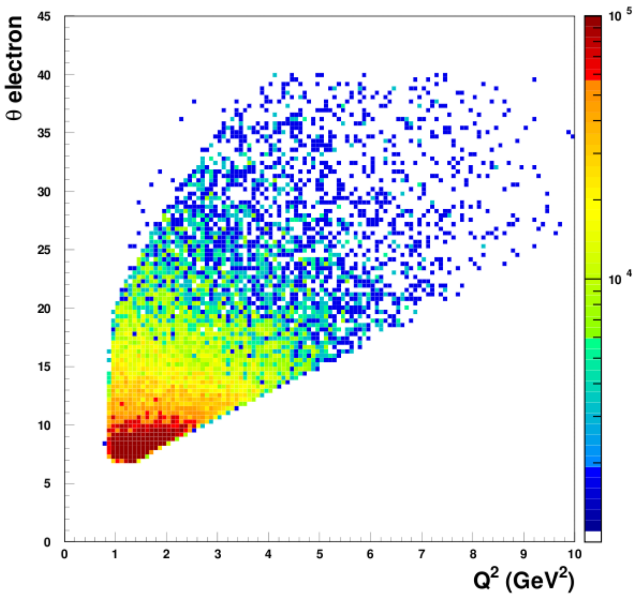
	Unit	Proposed Exp.	HERMES	HallA 6 GeV
Q^2	GeV^2	> 1	> 1	> 1.31
W	GeV	2.3	> 3	> 2.33
W'	GeV	> 1.5		> 1.5
y		< 0.9	< 0.95	
			≥ 0.1	
z		> 0.2	> 0.2	
		< 0.7	< 0.7	

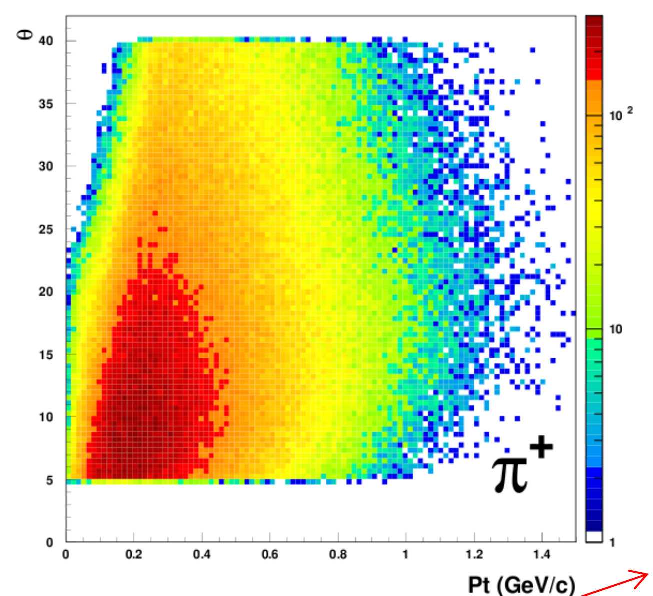
CLAS Coverage

$\Theta_\pi \rightarrow 5^o \sim 40^o$
$\Phi_\pi \rightarrow 360^o * 80\%$ (20%gaps)

$\Theta_e \rightarrow 6.5^o \sim 40^o$
$\Phi_e \rightarrow 360^o * 80\%$ (20%gaps)

$\Omega_{e\pi} = 1.32sr$





SoLID-SIDIS Cuts:
W>2.3GeV (W2>5.29GeV2)
+ Wp > 1.6GeV

accounting for calibration runs, empty target runs, and supportive tests). The expected number of SIDIS pions and kaons within the kinematic limits: $Q^2 > 1$ GeV^2 (corresponding to $x > 0.05$), $W^2 > 4$ GeV^2, $0.10 < y < 0.85$ and $0.3 < z < 0.7$ are:

17.6 M, 5.8 M and 3.9 M for π^+, π^-, and π^0, respectively, and 1.9 M and 0.4 M for K^+ and K^-, respectively. A squared missing mass greater than 2 GeV^2 was required

From their 1D projection stat. error bars: N(π+)=3.07M, N(π-)=0.87M;
The proposal didn't mention whether they are corrected by Pol&Dilution or not.

TMD Projection

- Global fit to the world data
- Obtain a set of parameters for each TMDs
- Use SoLID-SIDIS' kinematic variables and the fitted parameters to generate pseudo-data based on the current uncertainties
- Re-weight the pseudo-data with the projected statistical errors from SoLID

$$\chi_k^2 = \sum_{i=1}^{Bin} \left(\frac{A_i^{SoLID} - A_i^{Fit}}{A_i^{Fit}} \right)^2 \qquad w_k = e^{-\frac{1}{2}\chi_k^2} / \sum_{k=1}^{N} e^{-\frac{1}{2}\chi_k^2}$$

- Calculate the new expectation values and uncertainties with the new weights

$$< O >\Big|_{w/o-SoLID} = \sum_{k=1}^{N} \frac{1}{N} O_k \qquad \delta(O) = \sqrt{\sum_{k=1}^{N} \frac{1}{N} (O_k - < O >)^2}$$

$$< O >\Big|_{w/-SoLID} = \sum_{k=1}^{N} w_k O_k \qquad \delta(O) = \sqrt{\sum_{k=1}^{N} w_k (O_k - < O >)^2}$$

Other TMD programs at JLab

E12-09-018 at JLab Hall-A

Physics Goal: measure **transverse** target SSA (A_{UT}) in ^{3}**He**(**e**,e'h)X in the valence region
- SIDIS at 8.8 and 11 GeV, luminosity: 4.10^{36} cm^{-2} s^{-1}, 40 μA
- 3D binning: 6 ($0.1 < x < 0.7$) × 5 ($0.2 < z < 0.7$) × 6 ($0 < p_T$ (GeV) < 1.2)
- Typically 120 bins, dependence on Q2 gives fully-differential analysis

SoLID E12-10-006: 1400 bins, 4D-MAPPING.
$0.05 < x < 0.6$, $0.3 < z < 0.7$, $0 < p_T$ (GeV) $< \sim 1$, $1 < Q^2$ (GeV^2)<8 with $\Delta Q^2 = 2$ GeV^2

CLAS12 Program at 11GeV

Pol. NH_3 and ND_3 target (if pol. 10^{35} cm^2 s^{-1} at 10 nA)

- E12-09-007: long. pol. **Measures $x(\Delta\bar{u}-\Delta\bar{d})$**
  unpol. for **multiplicity and strange PDF measurements**
- E12-09-008: unpol. **Measures A_{UU}**(cos 2ϕ of charged kaons))
- E12-09-009, long pol.
- E12-07-107, long. pol. **NH_3** target,

} **Measure A_{UL} and A_{LL}** (sin2ϕ of charged pions)

Programs complimentary to SoLID, but no competition for precision